Under the waves, above the clouds.

A history of the pressure suit.

Vom Fachbereich Gesellschafts- und Geschichtswissenschaften
der Technischen Universität Darmstadt
zur Erlangung des Grades eines Doktors der Philosophie (Dr. phil.)
genehmigte Dissertation
von
Alexander von Lünen
Dipl.-Inform.
geb. am 17.02.1971
in Bad Marienberg

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Einreichung: 25.10.2007
Prüfung: 24.04.2008

D 17

Darmstadt
2010

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Preliminaries

0.1 Copyright Declaration

0.2 Foreword

This is the abridged version of my doctoral thesis submitted to the History department of the *Technische Universität* Darmstadt (TUD), Germany. The thesis was submitted in October 2007 and defended in April 2008, receiving the mark "magna cum laude".

As it is compulsory in Germany to publish one's thesis to get the actual degree, this abridged online version is part of this process. The submitted version is not available online, but through the faculty office (Fachbereich 2: Gesellschafts- und Geschichtswissenschaften) of the TUD. In comparison to the submitted version, two chapters have been excluded from this publication: firstly, the chapter on methodology as this would have been superficial to most readers; secondly the chapter on the history of space conceptions was taken out. I had deemed it necessary to ground my investigations in the common nature of underwater and space exploration (in terms of medicine and technology) through a lengthy discussion of the intellectual history of how space was conceived over the centuries. Well, killing two birds with one stone doesn't always do. For the sake of clarity and conciseness this topic was completely dropped for this publication version.

Furthermore, some footnotes and minor remarks have been added to clarify some of my propositions. These clarifications include references to literature not available at the time I submitted my thesis, but I found it worthwhile to add them at this later stage to provide a clearer picture. Obviously, in the light of the new structure and re-written parts, the introduction and the conclusions differ heavily from the submitted thesis.

The thesis was the result of nearly four years of research. It is needless to say that its original designation and topic changed significantly over those years. "Plan your dive, dive your plan", as diving students learn in their first course sessions. However, this does not work too well for a topic that has not yet been well researched and that does not experience much popularity anyway. A broad study of the development of pressure suits and cabins in the Interwar Years has not been undertaken so far. I had therefore little groundwork to base my thesis on and have had to spread the topics considerably.

This thesis therefore not only got its inspiration from personal affection, but also from many inputs and comments from colleagues, friends, scholarly and non-scholarly work. It is a dynamic "work in progress", a continuing story so to speak. I beg the reader to bear this in mind when going through the chapters, especially when some of the ideas displayed therein seem confusing. I had little preceding work to base my thesis on, and tried to trespass through new ground. This is not meant as an excuse, but rather as a guideline for following my approach to tackling the topic.

0.3 Acknowledgments

No work can flourish without the support and guidance of many people. My thesis is no exception to that and I am highly indebted to a number of people. Murphy's Law has it that usually someone gets forgotten in such *Acknowledgments*, and even if I have no such intention to forget to mention anybody in the next paragraphs, I nonetheless apologize well in advance in case I did.

First of all, I have to thank my supervisor, Prof. Dr. Mikael Hård, who holds the chair for the History of Technology in the History Department of the TUD. His guidance and counseling were of utmost help to my thesis. My warmest thanks also go to Dr. Noyan Dinçkal, Dr. Detlev Mares and Mr. Wolfgang Moschek of the History Department in Darmstadt (by now "Dr. Moschek"). Their comments and our discussions, respectively, was a source of inspiration for me and my work. I am also especially grateful to Mrs. Iris Ohlrogge, secretary to Prof. Hård, who helped me a great deal with bureaucratic issues etc.

During my six months in 2006 when I was a research fellow at the Deutsche Museum, Munich, Germany, I also made good use of discussions with the staff there. In particular, I would like to thank Prof. Dr. Helmuth Trischler, director of the research institution of the Deutsche Museum for his kind assistance. Also the staff of the archive, first and foremost Dr. Eva

Mayring and Mr. Wolfgang Schinhahn, and the assistants in the library who were most generous in offering their help. I would also like to express my gratitude to the two other research fellows who were around at the same time as I was: Mr. Benjamin Steininger and Dr. Ellen Harliszius-Klück. I regard the exchange of ideas with them as most fruitful to my work.

Certainly my greatest and warmest thanks must go to Dr. Steven Sturdy, from the Science Studies Unit of University of Edinburgh, UK, who helped me a great deal when I was there as a visiting postgraduate student in 2004.

It goes without saying that I owe much to the work and assistance of the staff of the archives I visited or otherwise contacted. The number of persons to list here are too numerous, and most contact has been on a rather anonymous basis anyway. My appreciation goes to them nonetheless. I would like to particularly thank those people who helped me out, even when their regular job was not in the line of general archival supervision. My special thanks are due to Prof. Dr. Andrew Parker, professor of physiology at University of Oxford, UK, for giving me access to the manuscript collections of the Physiological Laboratory at Oxford. I would also wish to thank Mr. Brian Riddle, librarian of the Royal Aeronautical Society, London, UK, who was very helpful when I contacted him and when I used the library.

A special thanks for this online publication must go to the copyright holders of the many images I am using. These images are vital for the publication and all the archives granted permission (or had respective policies in place) to use it free of charge for this freely available PDF publication. In particular, I would like to thank the Trustees of the National Library of Scotland, the Royal London Hospital Archives and Dr. Wilhelm Füßl (Head of the archive of the Deutsche Museum, Munich, Germany) for granting special permissions to use the images from their respective institutions free of charge.[1]

I largely funded my PhD studies myself, aside from the six months in Munich. To do part-time work when conducting research was not always an easy task to carry out. I am also grateful to those who supported and encouraged me during this time. In particular, I am indebted to imcos Gmbh, Neu-Isenburg, Germany, a company where I worked for over eight years, and which always bore with me when I had to go abroad for conferences or archive visits. Hence I would like to thank my former 'boss' Dipl.-Ing. Uwe Bannow and my former colleague Dipl.-Ing. Frank Weisenberger, who provided a comfortable working environment and many hours of fun.

Last, but not least, I would like to thank my current colleague, Miss Paula Aucott for proof-reading the manuscript. While I am not a native speaker of English and expected some errors, it was still quite embarrassing to see how one could get carried away and distracted by his research to a degree where even the skills one believed to possess would falter.

[1] The copyrights are listed with the figures on page 269.

No, we'll both be wearing gloves.

Heavyweight boxer Joe Louis to a reporter prior to his second bout against Max Schmeling in 1938, when asked whether the chilly weather in the Yankee stadium wouldn't bother the two fighters.

1 Introduction

"What is it", Tom Wolfe asked in his introduction to *The Right Stuff* "that makes a man sit on top of a rocket?" While Wolfe (1979) explained this phenomenon as "something beyond courage", as the "Right Stuff", he neglected and even disrespected other actors such as physiologists, divers, or simply: all non-test-pilots. What he defined as the *Right Stuff*, which he attributed solely to pilots, is perhaps more frequently available in historical actors than he insinuated.

What Wolfe described so picturesquely in his novel – the narcissism of the pilots and the public hype over the first manned space flights in America –, is implicit in all emerging technology in Western societies. The *daredevil* attitude typically inherent in young men combined with contemplated publicity stunts of technocrats brought about a daring feat that may sit well with the public. Though at first sight it seems strange that society cheers such acts, since they mean danger to traditionally well-coddled members (young men, the only son, etc.) of that society.

This issue, the cheering of dangerous acts on the one hand, and the will to contemplate such acts as a test of one's manhood on the other, may be deduced from a constant anthropological desire for both *thrills* and *heroism*.[1]

In ancient times heroes were often "great warriors", kings and generals. Due to the anonymization of warfare in modern times, however, these models diminished. Eventually, the mass-wars of the 20^{th} century created no more heroes, in spite of some reminiscences in the public. More and more scientists and engineers competed with the archetypal definition of a *hero*. They tried

[1] Balint (1959) and Campbell (1973), respectively, for the psycho-social fundamentals of these terms. Both works will be discussed later in the thesis.

to convince the public that their accomplishments were to the greater benefit for society, and therefore more *heroic*.

Society, on the other hand, managed to incorporate both characters into the plot of utilizing the potential of its creative, productive members. The *dare-devils* found new ways to approve their status, last but not least by *appropriating* the new technology, like aeroplanes, rockets or diving apparatuses. It seems science and technology acted as the binding-glue for this plot, bringing together potential heroes from all sides – scientists, engineers, pilots, etc. – to combine their efforts.[2]

This thesis will not deal with the question and individual structure of heroism. My former colleague, Christian Kehrt, deals with the *habitus* of military pilots in detail and I will therefore refrain from this issue. My story is a quite different one: Acknowledging the existence of a drive and desire for acts of heroism in society, I will inquire into the *social embeddedness* of it, and give numerous examples. These examples serve as an illustration of the (partial) irrationality of modern technology, or should I better say: of modern administration of science and technology?

In the course of my thesis I will therefore show how the diverse and multi-faceted aspects of the topic needed to coincide with each other to constitute the implementation of said technology. Why, for instance, does the General Surgeon of the Royal Air Force (RAF) state in a paper from the Summer of 1933 that pressure suits are not a desirable technology, when in the Fall of 1933 the RAF issues a research contract with private companies to manufacture such a suit? Why was the development of such suits often exclusively in the hands of private researchers and engineers, despite the costs involved and the unsure prospect of commercial success? Why, then, was the military interested only after details of these suits had been published in the press? The French government even refused to sponsor any high-altitude research[3] at all in the 1930s, in spite of the high positions French pilots (both male and female) held in the international aviation community.

On closer inspection, the motivation for high-altitude research was not always obvious. The pioneering research lay in the hands of single individuals, and their networks, respectively. When examining these networks of early 20^{th} century physiology, one will find surprising connections. Who would have thought, for example, that the early American aviation physiology was heavily influenced by a two month stay in the Rocky Mountains by British and American physiologists in 1911? And that this research trip took place only because one of the British researchers found the European Alps too uncomfortable, despite his peculiar sense of heroism – in the form of dangerous and sometimes bizarre self-experiments –, and upon sitting at the coffee table of a Vienna café during a physiologic conference was invited by

[2]On *appropriation*: Cf. Hård and Jamison (1998).

[3]The research field out of which the idea for pressure suits was born.

an American physiologist to come over to the United States, since he would find there the "nice, comfortable mountain" he was looking for. And that this event led to the *take-off* of American aviation medicine, and a life-long devotion by an eminent British scientist, who couldn't get a professorship at home due to his own form of *hubris*.[4]

What made this scientist – who had already written in 1922 about pressure suits, and that they were not used "due to ignorance" – believe a pressure suit would be desirable for commercial air traffic? Did he really believe every passenger on an aeroplane would put on such a suit and turn it it just for a minute, sacrificing all comfort during flight? Why did he believe that his scientific theory concerning pressure suits was superior and that all other "ignorants" would favor pressure cabins instead, when other suit projects in other countries were deployed, but abandoned simply due to engineering problems?

Stories like these could – and will – be told in length in this publication, bringing to life what was claimed above: the evolution of the technology in question was driven not only by economical, political, military or scientific needs, but also by personal desire – whether you'd like to call it "hubris", the "Right Stuff" or "primary narcissism" is a matter of taste.

In terms of other literature on the topic (history of pressure suits) there is actually little to no work this publication can relate to. While works on the history of pressure suits as artifacts (e.g. Abramov et al., 2003; Kozloski, 1994) are very impressive and informative, they do not give much background and context to the development of the suits in question. First of all, they are on the history of *space suits*, with pressure suits simply being regarded as a preliminary and anecdotal episode, rather than being the history of the pressure suit in its own right. Secondly, they are quite often related to an institutional history, i.e. the history of an organization that facilitated the production of pressure/space suits such as NASA. This approach is wholly legitimate, but leaves much to be desired. As will be shown in this publication, the history of pressure suit development before World War II was missing exactly this institutional frame and the debate and the actual development was often made *because* of this missing frame, and not *despite* it.

In chapter 4, for example, it will be outlined that the initial incentive to devise pressure suits in the 1930s was entirely irrational. Several experts

[4]This concept of hubris in connection with technoscience – as the topic in question (pressure suit development) is a case *par exellence* – is discussed by Hård and Jamison (2005). This concept applies the modern usage of the term "hubris" (i.e. overconfident pride and arrogance, as compared to the classic Greek term "hubris" that referred to actions that shamed and humiliated a victim for the fun of its abuser, cf. entry "hubris" in Encyclopedia Britannica (2004)) to technological and scientific research and identifies hubris as a driving force of engineers and scientists going about their business. While I would object to such a general claim, it is certainly the case in the field of pressure suit development in the Interwar Years, the topic of this publication.

spoke out against suits in favor of cabins, just to find a bit later that their air forces were pursuing suits rather than cabins for short-term aviation records. The incentive to have such a pressure suit was therefore entirely based on national prestige (or hubris), and not its feasibility or its economic merits. Despite great efforts by some nations to develop pressure suits, both before and during the war, it is outlined why some failed although there were comparable infrastructures in place. The failure – as much as the incentive outlined above – was due to misguided and misplaced rationalism, i.e. technical rationalism as part of an overarching irrational political agenda, and was often influenced by personal motives.

This inherent irrationality in modern science and technology will be discussed on a general level in this study as well. The focus, however, will be on smaller structures. It will be detailed how individuals and individual organizations got involved in pressure suit design and how they "interfaced" with larger structures like government agencies. The difference between pressure suit and pressure cabin development was chiefly the infrastructures required and the degree of rationality found in them. Suits were meant for short-term success and *ad hoc* approaches, and therefore fitted nicely with individualistic setups and agendas, i.e. they would fit well into highly individualized setups and notions of hubris, whereas cabins required a much more professionalized and anonymous structure.

1.1 Methodology

It has become somewhat of an obsession in the humanities, and in Science and Technology Studies (STS) in particular, to outlines one's methodological framework and to situate oneself in a methodological "school". One of the juxtapositions encountered in this debate is the often heard "postmodernism vs positivism" controversy. It is certainly beyond the scope of this publication to detail the history and nature of this debate, so I will leave it to a few remarks. First of all, this work does not situate itself in a particular school at all. Rather, a position of eclecticism is assumed. While this move could be interpreted as a "weasel" tactic, trying to dodge any methodological stance, it is indeed a stance in itself to strike a middle-ground between extreme positions and simply a tribute to actual scholarly practice.[5]

[5] On closer inspection a lot of the criticism uttered from one school against the other appears grossly exaggerated. The attack by Windschuttle (1997) for example, is not entirely without substance. Its vehemence, however, is. The alleged absence of any factual argument in historical scholarship, as Windschuttle (1997) insinuates, is not observable with the great majority of works in the field of academic history. While it may be arguable about whether the degree of literature/discourse/social theory is to be appreciated for a number of these works, it is beyond doubt that almost all of these scholars properly use the tools of the trade, i.e. proper use of archive material, literature, etc. Any survey of recent historical studies will surely fail to produce any evidence to the claims that all

In many publications on theory one will obviously encounter strong arguments for and against certain "schools". Jenkins (2007) for example stresses the importance of postmodernism and the "linguistic turn" as vital for academic history, dismissing older textbooks such as that of Carr (1990) and complaining about student's disinterest on the "theory" of history. Perhaps the cause for that is Jenkins' own narrow approach to history? Looking at Carr (1990) one would not necessarily come to the conclusion that this work is as flawed and old-fashioned as Jenkins (2007, xvi) would want to make the reader believe. Or maybe it is Jenkins' (and other postmodern scholars) fixation on history as a power-struggle that fails to attract student's appreciation?

The almost always encountered implicit or openly expressed critique of modernity in postmodern history (cf. Iggers, 1997, 69), however, is as biased as the positivist school. Its chief agenda is to make ends meet, i.e. to make one's research coincide with one's own preferred world-view. It is this bias I am questioning, and not any particular school. It is the preoccupation in statements like "History is about power" (Alan Munslow in his introduction to Jenkins, 2007) that is ultimately rendering any debate futile, as the outcome is known before the actual research.

On the other hand the often met publications in history that claim to solely rest on "proof" rather than discourse fall short in many respects as well. These proof-fixated views are prevalent especially in quantitative and internalistic studies. While the scholars from these schools are quite good at gathering all kinds of evidence (however "evidence" is defined in this context), almost all of these studies fail to make any satisfactory conclusions from it, if they draw conclusions at all. This lack of context often brings studies to a point where they fail to make sense, as they can only explain the "how" but not the "why" of their effort.

It is these two antipodes that are the focus of Carlo Ginzburg's call for a middle-ground, a middle-ground between "objective" history and discourse oriented studies. As Ginzburg (1999) points out (by referring to Aristotle's classic work on Rhetoric) a good rhetoric (something the postmodernists are concerned with) must be based on proof, no matter how the latter is defined. Aristotle, according to Ginzburg (1999, 39), "detect[ed] a rational core within rhetoric: proof, or rather, proofs". Ginzburg then further elaborates that history, like other scholarly and scientific activities, works with *clues* and *traces*, i.e. the "facts", and uses rhetoric to embed these clues into a wider context (Ginzburg, 1999, 46). Ginzburg (1999) tries to thus amend the two diverging philosophies of history: the one school that regards history as a text, a "linguistic concept" (Jenkins, 2007, 9), and the other school that

of history is "postmodern" (which often is a synonym for "writing papers without doing any actual research" to its opponents), whereas claims to the supposed prevalence of "this unreflexive attitude" in history, as made by Jenkins (2007, xvi) and others, are also out of place.

strives for an “objective” and “provable” history.

This publication will by and large comply with Ginzburg’s notion of history as clues and traces (cf. also Ginzburg, 2002) as a foundation for inferences, i.e. rhetoric. The (supposed) facts that will be presented are embedded into, and used as point of departure for, wider-reaching debates, i.e. the context of the development of pressure suits. The approach taken is an eclectic one, not only by Ginzburg’s approach as outlined above, but also by liberally picking methods from the different schools of history. Rather internalistic views will be employed, as well deconstructionist ones. I.e. I will use the concept of critical analysis, but I do not endorse the implied critique of modernity so often encountered in other works. The concept of “deconstruction” will be used throughout this study (cf. Munslow, 1997), but its implied political agenda is not pursued. While many aspect of modernity – namely science and technology, its public reception and its propaganda value – are dealt with in a very critical way, I will not make deconstruction into destruction or derision.

1.2 Layout

I have chosen separate parts for *culture* and *technology* in my thesis, although I firmly believe they belong closely together. From an organizational point of view, however, it proved quite difficult to maintain a good structure. I have drawn from a variety of topics to make my case and these various topics are initially not obviously linked with each other. Hence, to provide a background for my technology study in Part II, I need to rehearse and outline several important cultural influences in Part I.

The layout of my thesis is consequently as follows: Chapter 3 will investigate the scientific side of reaching alien spaces (“alien” meaning “not meant for humans to live in” here), focusing on medical research. The networks in late 19^{th} and early 20^{th} century diving and aviation physiology will be reconstructed to outline the structural and scientific conditions of pressure suit development. As I will show in this chapter, important structural foundations for aviation medicine were laid down in those days, chiefly through personal contacts and networks.

Chapter 4 will shortly discuss the cultural and political setup in the 1920s/30s, when pressure suits development was actually pursued for height records. The significance of the medical debates and persons introduced the chapter before will then become clearer. Also, it becomes apparent that the development of pressure suits had comparably little political backing, other than for reasons of national prestige.

Chapter 5 will then give detailed accounts of the pressure suits produced in the 1930s, mainly in Western European countries. Here, the actors of chapters 3 and 4 will show up again and their actual technical work in connection with their political and social embedding will be specified. The focus will be on rather *internalistic* issues though.

Finally, chapter 6 will bring it all together again, drawing the overall conclusions of my inquiry and bundling the diverse nature of the single chapters into a more concise form.

There are also some appendices to this publication. The appendix on page 269 lists up the abbreviations commonly used in this publication, followed by a list of the photographs and illustrations used in this publication, with the respective copyright holders specified. The appendix on page 275 details and discusses the sources used for the research and write-up of this publication. This publication is then concluded with the bibliography.

Those automatic toys [...] which once amused the vulgar, are now employed in extending the power and promoting the civilization of our species.

David Brewster, *Letters on Natural Magic*, 1832

2 Fictional high altitude equipment

In STS, the term "co-construction" usually describes the process of scientific and technological developments as a kind of feedback loop between, say, a technical artifact and its users. This is not meant in terms of an actual development, as it is for instance in software engineering, where "co-construction" refers to the user feedback that influences the development decisions and gives the technology in question its actual eventual shape (Oudshorn and Pinch, 2003). More generally, *co-construction* is used in various disciplines, such as linguistics, and refers to "the joint creation of a form, interpretation, stance, action, activity, identity, institution, skill, ideology, emotion, or other culturally meaningful reality" (Jacoby and Ochs, 1995, 171).

The co-construction I will describe throughout the publication, and specifically in this chapter, is more along the lines software engineers would employ for the term. I.e. I am referring to an ongoing bounce of feedback forth and back and information exchange between scientists and engineers, engineers/scientists and administrators, engineers/scientists and popularizers, etc. As I will outline, technical advancements of one particular artifact led popularizers (novelists, science journalists, etc) to think about new applications of this particular technology. This in turn may sit well with administrators picking up these reasonings, or may even lead scientists and engineers to indulge in these reasonings and use them as inspiration or even as a guideline for research desiderata.

As this publication is about the history of the pressure suit and the pressure cabin, which – as I am going to show – is a bastardized diving suit and submarine, respectively, I am going to show early ideas of pressure suits and cabins in 19^{th} century *scientific romances*, the precursor to science fiction (SF).

2.1 First ideas of pressure cabins

Edgar Allen Poe (1809–1849) gave the first literary account of a resemblance of a pressure cabin in his story "The Adventures of one Hans Pfaall" from 1835 (Poe, 1966, 1–35). In it, he describes the story of one citizen of the Dutch town of Rotterdam, who fled from creditors in a balloon to the moon. The short-story is a very neglected piece of literature, and therefore little information is available on its background. It is most likely Poe used it as a satire against several popularizations of moon travels, published in contemporary newspapers (cf. Cohan, 1986).

It is also likely that Poe used a story by Dutch romanticist Willem Bilderdijk (1756–1831) of a journey to the moon as a model, and hence chose the Dutch town as the place of the action (cf. Bilderdijk, 1813).

Poe employed a very satiric use of language, naming the mayor of Rotterdam "Superbus Von Underduk" and the "Vice-President of the Rotterdam College of Astronomy" as "Professor Rubadub" (Poe, 1966, 3). Both names appear as a scoff, as do many passages of the short story. The narrative is written as a letter from Pfaall, which a moon dweller drops from "within a hundred feet of the earth" over Rotterdam (Poe, 1966, 2). In this letter Pfaall tells of his escape from Rotterdam in his balloon and his adventurous travel to the moon.

Poe let his protagonist Pfaall describe the conditions of the journey, including the problem of respiration. Poe alleged that there was no such thing as a vacuum in the space between earth and moon (Poe, 1966, 12):

> "[...] ascend as high as we may, we cannot, literally speaking, arrive at a limit beyond which *no* atmosphere is to be found. It *must exist*, I argued; although it *may* exist in a state of infinite rarefaction."

Poe reflected here the state of knowledge about the atmosphere in his time quite accurately. The discovery of oxygen by Joseph Priestly in 1779 and its importance for sustaining life, also the formulation of the law that the pressure of a gas mixture (such as air) is the sum of the partial pressures of the gases composing it by John Dalton in 1801, was taken into account by Poe (cf. Phillips, 1998).

The conclusion Poe reached to keep Pfaall from choking was somewhat quirky, however. Poe continued his account by stating that the "medium" between earth and moon is "essentially what we denominate atmospheric air" and that "it could make comparatively little difference at what extreme state of rarefaction I should discover it" (Poe, 1966, 13). I.e. Poe alleged that the atmosphere as found on earth is essentially the same in the space between earth and moon, only smaller in respect to barometric pressure. It would therefore not require a genuine oxygen apparatus, but simply a compressor (Poe, 1966, 13):

> "Granting that on my passage I should meet with atmosphere *essentially* the same as at the surface of the earth, I conceived that by means of the very same ingenious apparatus of M. Grimm, I should readily be enabled to condense it in sufficient quantity for the purposes of respiration. This would remove the chief obstacle in a journey to the moon."

As already mentioned, there's little to no information available on the background to this story. Considering Poe mentioned of a compressor adds some evidence to the idea that he learned about this technique from diving. Diving bells and helmets were still in their infancy, but the growing success of these devices were owed to the introduction of compressor machines in that field. Where hand-pushed bellows were formerly used in diving devices, machine compressors provided steady and more powerful means of delivering air to divers (including diving bell workers). It was due to this introduction of compressors that Triger's invention of the *caisson* was made possible, and that something like *decompression illness* (DCI) could evolve at all.[1]

Poe in fact gave a rough description of the symptoms of DCI on the next page, based upon the little knowledge that was in circulation at the time:[2]

> "It has been observed, that, in balloon ascensions to any considerable height, besides the pain attending respiration, great uneasiness is experienced about the head and body, often accompanied with bleeding of the nose, and other symptoms of an alarming kind [. . .]
>
> Their origin was to be looked for in the progressive removal of the *customary* atmospheric pressure upon the surface of the body, and consequent distension of the superficial blood-vessels [. . .]"

As for the cure of this bodily disorder, Poe had a somewhat peculiar strategy by solely relying on his physical "iron hardihood" (Poe, 1966, 14).

The symptoms Poe described are astoundingly accurate and reflect those experienced when traveling to high altitudes Poe (1966, 16). What is even more interesting is Poe's technical setup. Beside the already mentioned "condenser", he let Pfaall describe the rudiments of a pressure cabin Poe (1966, 18):

> "[M]y object, in the first place, was to surround myself and car entirely with a barricade against the highly rarefied atmosphere in which I was existing, with the intention of introducing within this barricade, by means of my condenser, a quantity of this same atmosphere sufficiently condensed for the purposes of respiration. With this object in view I had prepared a very strong, perfectly air-tight, but flexible gum-elastic bag. In this bag, which was of sufficient dimensions, the entire car was

[1] Phillips (1998, 47ff.), see also section 3.2.1.

[2] Poe (1966, 14). Remarkably, this account on DCI refers to ballooning, and not diving. As discussed in chapter 3, DCI in aviation was long deemed as unlikely or even impossible up to the Second World War.

> in a manner placed. That is to say, it (the bag) was drawn over the whole bottom of the car, up its sides, and so on, along the outside of the ropes, to the upper rim or hoop where the net-work is attached."

Whereas Poe's description of the "barricade" is somewhat implausible, since hardly any rubber-based material could be employed to maintain the pressure inside, his ideas – if they were his own or if he just picked them up somewhere else is not known – on the medical implications are incredibly informed. Pfaal's statement on DCI is especially remarkable: "I was also agreeably surprised to find myself, in a great measure, relieved from the violent pains which had hitherto tormented me." (Poe, 1966, 20) If Poe really referred to DCI by this and the above mentioned statement, he is extremely well-informed. According to Phillips (1998), it was not before Pol and Watelle's investigations in the 1840's and 1850's that the symptoms of DCI were related to the decompression from increased ambient pressure, and they were the first to propose a *re-compression* of the caisson workers suffering from DCI. They also suggested the addition of a second chamber on top of the caisson to serve as a re-compression chamber (Phillips, 1998, 56). This chamber might be regarded as an ancestor of the pressure cabin. What Poe describes in *Hans Pfaall* as a "barricade", as given above, implies something else. Even though Poe was apparently aware of the medical, technical, and scientific discussions of his time, it is not likely that he was too deeply involved in the issue.[3] That he gave a sketch of a counter-measure to the effects and disorders as experienced in decompression, seemingly long before any scientific investigation was conducted in the field, is mysterious. As mentioned before, little is known of the backgrounds of this short-story, so it is unclear where Poe got the idea from.

Furthermore, Poe's application of rubber to construct the "barricade" is even more remarkable. India-Rubber, as it is called, was long known to indigenous cultures of the Amazon region. The "Rubber Boom", however, was ignited by Charles Goodyear with his invention of the process called "vulcanization" in 1839 – i.e. four years after Poe's story – and it was not before 1900 that rubber became a big industrial product, as it is now (Frank and Musacchio, 2002). A first thought on uses of india-rubber for purposes relevant to this publication were published in Sci.Amer. (1861): a diving suit made entirely of india-rubber (beside the helmet made out of copper, see figure 2.1). Another remarkable idea, considering that it took another hundred years before rubber products (neopren) were introduced into diving suit production at full scale.

Poe's story had a tremendous influence on the formation of the *scientific romances* that began to blossom in the following years. Renowned French

[3]He received training in mechanical engineering at West Point Academy and certainly had a good scientific understanding (Tresch, 2002, 118). It is also visible from his stories that he had an excellent understanding of the scientific debates of his time, supposedly from scientific journals.

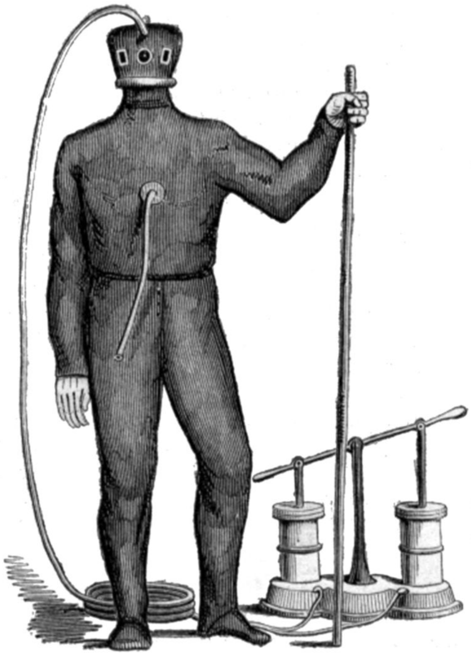


Figure 2.1: Diving suit made of india-rubber. Taken from Sci.Amer. (1861).

author Jules Verne (1828–1905), inspired by *Hans Pfaall* in his novel *From earth to moon* (1865)[4] also gave an astoundingly informed sketch of a sealed cabin used for his moon-capsule. While the physical details of the spacecraft were not realistic, his idea and design of the technical features for the interior at least show a good amount of scientific background. While the mere interior design of the capsule appeared more like a Victorian lounge, the description of the breathing system was not very far-fetched (Verne, 2005, 208–209):

> "[T]he next [question] to be considered was how to obtain a supply of air. [...] Air, as is well known, consists principally of two gases, oxygen and nitrogen, in the proportion of about twenty of the former to eighty of the latter, or as one is to four.[...] The nitrogen question presenting no difficulty, two things were clearly to be done: 1. to renew the absorbed oxygen; 2. to destroy the exhaled carbonic acid. Both these objects could be readily attained by means of potassium chlorate and caustic potash."

The breathing system is exactly the method that has been used (and is still in use) in so-called *rebreathers* in diving and other fields where breathing devices are applied. These kinds of systems were in use in submarines and diving apparatuses from the early 20^{th} century.[5]

[4] Tresch (2002, 117). Verne (2005, 16–17), through one of his protagonists, indeed makes an explicit reference to Poe's story, giving him credit.

[5] The principle of absorbing certain gases with the help of different chemical agents was

2.2 First ideas of pressure suits

This makes up for a common ancestry of space- and underwater-technology, as far as human factor engineering is concerned. When it became clear that humans cannot go out into space without special equipment, imagination resorted to the already established technology. That was diving technology, which was introduced a century before space-related equipment, in the form of diving bells and suits, and submarines.

In literature, Faure and Graffigny (1889a) published for the first time a reference to a "scaphandre" (see below for an explanation of the term) for space, which the French space farer in the novel attributed to the (fictional) French inventors Fricoulet and Flammermont. They discuss the notion of the physiologist Ossipoff, who claims that the moon (to which the two Frenchmen wanted to travel) would provide sufficient amounts of oxygen in its atmosphere. Flammermont is "a man of precaution" and has constructed six kits just in case. The suit is briefly referred to as a rubber diving suit (scaphandre) with an air tank, without detailing any technical features. It was thereby suggested by the authors that the Moon's physical conditions were comparable to Earth, aside from the rarefied air.

The book was published in four large volumes (each c. 450 pages), and after the first volume mentions the suit with a short simple sentence, the second one (Faure and Graffigny, 1889b) provides a few more lines, but also only rehearses the contemporary knowledge from diving regarding breathing apparatuses and transferring that to walking on the Moon. In the capsule, carbon dioxide would be absorbed by potash, just as other authors had mentioned before (see above).

The illustrations in the book show more or less a contemporary diving suit (see figure 2.2); consequently the skeptical crowd attending a preparatory meeting for the trip into space were assured that the conditions in space and under water are the same, and hence a diving suit could be used.

The whole four volumes outline a quite ambitious scope, in which not only travel to the moon is narrated, but a journey through the entire solar system. Both Georges Le Faure and Henry de Graffigny were dedicated rocket enthusiasts themselves. The latter especially – being an engineer – participated in various activities by rocket societies, e.g. by flying a rocket-powered model airplane in 1904. In 1915 Graffigny proposed to catapult a vessel into the earth's orbit, by centrifugal force alone (Lofficier and Lofficier, 2000, 341).

A few years after Le Faure's and Graffigny's novel, Harry Putnam Serviss (1851–1929) was likewise envisioning a space suit. In his sequel to Well's

also used in the *Haldane Gas Analysis Apparatus* (1895), where gases in an air sample were absorbed one by one, and the amount of each measured by reading off the displacement this absorption caused in a connected burette filled with mercury (Haldane, 1912). See also section 3.2.5.

War of the Worlds, *Edison's Conquest of Mars* from 1898, American inventor Thomas A. Edison is supposed to have invented a variety of technical devices like a spaceship, a ray gun, etc. to carry out a preemptive strike against the Martians before they can attack the Earth again, like they did previously in Well's novel. The ray gun was installed in the spaceship so that the crew would not need to leave the ship. In case of emergency, however, a suit was devised (Serviss, 2005, 49):

> "[...] Mr. Edison had provided for [...] emergency by inventing an air-tight dress constructed somewhat after the manner of a diver's suit, but of much lighter material. Each ship was provided with several of these suits, by wearing which one could venture outside the ship even when it was beyond the atmosphere of the earth."

Provisions were also made for meeting the "terrific cold" in space and telephone devices were installed in the suits for communication purposes.[6] The reference to a diving suit as the ancestor of the space suit is what literary science denominates by *catachresis*: well-established technical metaphors are employed to popularize new technology.[7]

Rocket pioneers Hermann Oberth (1894–1989) and Konstatin Tsiolkovsky (1857–1935) also deliberated space suits in their early writings on space exploration. Tsiolkovsky (1960), written before 1917, is an imaginative journey into space and Tsiolkovsky expresses his ideas about space travel in it. This included a *space walk* in a space suit,[8] even though the technical description is quite scarce, and the physiological details given are not really accurate. The features this suit is supposed to have resembled those of modern space suits and go beyond those found in contemporary diving suits.[9]

Oberth (1923) also mentions a "diving suit" for EVA in his book (Oberth, 1923, 85), which is regarded as a milestone of rocket science, together with the works of Tsiolkovsky and the American Robert Goddard (1882–1945). Oberth had studied medicine before World War I, and served as paramedic in it. His earliest medical studies date back to his high-school days, where

[6] Serviss (2005, 49). Curiously, Serviss (2005) envisioned all sort of technical gadgets that were later to become common in SF folklore. But he had not thought of radio communication, a technology still in its very infancy at this time, but rather employed telephone wire communication for his astronauts.

[7] In literary science, "trope" denotes a rhetorical figure which deliberately deviates from a linguistic norm. Perhaps the best known trope is the *metaphor*, which replaces one term with another that has a semantic relation with the original term (cf. Baldick, 2004). A "catachresis" is an "implied" or "extravagant, far-fetched metaphor" (Lanham, 1991, 189). This concept is usually employed to define a term that does not yet exist by introducing a metaphor that refers to a semantically similar term.

[8] Space Walks are called "Extra Vehicular Activity" (EVA) in technical literature (Dasch, 2005).

[9] Tsiolkovsky (1960, 222). Unfortunately, I haven't had access to the Russian original of this story to check whether the suit is dubbed "skafandr" there, the common term for both diving, pressure and space suits in the Russian language (see below).

he was intrigued by the writings of Jules Verne. Besides experiments in rocketry, he also went to the local swimming pool to study the effects of acceleration by jumping from the tower, and the effects of weightlessness as experienced underwater (cf. Rauschenbach, 1995).

A few years after Oberth (1923), German rocket enthusiast Max Valier (1895 – 1930) introduced a space-farer with a diving suit (see fig. 2.3) in space. Valier (1924) said in the text, that he got the idea from Oberth (Valier, 1924, 80). Valier wrote in the picture's caption that the person would do EVA during full throttle of the rocket, which seems somewhat obscure, only promoting the negative attitude other German rocket enthusiasts like Hermann Oberth had towards him.[10]

In a later edition Valier (1928) proposed to use a "modified diving-suit" upon consultation with the Dräger company.[11] Valier reported on the experiments done in the decompression chamber by aviation physiologist Dr. Wilhelm Kaiser of the DVL in 1928 (in which no suit was used). From this short summary he concluded that an air-tight diving suit or capsule must be employed for safe travel into space, with at least one-third of atmospheric pressure inside the apparatus and a device for filtering out the carbon dioxide (Valier, 1928, 69).

Albeit Valier did not possess the same level of technical expertise as other German rocket enthusiasts of his time, but he very well elucidates the trouble of manufacturing a diving suit for space:[12]

> "Obviously, regular diving suits (designed for external overpressure) can't be employed, not even if one wraps them – to prevent bursting – in a fine steel mesh, because the internal overpressure would stretch the sleeves and trouser legs with such force that movement of the arms and knees would be impossible with human muscular force. One would therefore have to choose models comparable to armored diving suits, which essentially represent an air-tight, rigid harness, which supports itself and does not come in contact with the human body, with the limbs movable through ball-joints."

It is quite unlikely that Valier conceived this idea by himself, but rather from the discussions with Dräger engineers, who faced exactly these problems a few years later when contemplating pressure suit production (see 5.2.3).

[10] As can best be judged by a letter from Ernst Wurm, chairman of the *Verein für Raumschiffahrt* office in Berlin, to Johannes Winkler on Dec 9, 1929 in which Wurm reports on a speech by Valier he attended: "My general judgment tends in the direction that Valier appeared like a complete charlatan [...] Valier's advantage is his appearance, since his speech was very smooth. I only wish Prof. Oberth would have the same talent for presentations." DM, NL 097/009, translation mine.

[11] Valier (1928, 70), translation mine. Unfortunately, Valier did not mention the name of the Däger engineer. It might be safely said though, that this was unlikely to have been anyone else but Hermann Stelzner, who was always fond of these rather offside topics, besides being chief engineer of Dräger and himself a popularizer of technical feats.

[12] Valier (1928, 69), translation mine.

Valier then discussed the weight-issue if a pressure-cabin was built into the rocket. He discussed the question of a space suit not under the EVA aspect, but rather as a general means to venture into space. In his outline of the cabin approach, Valier discusses Dräger's oxygen systems as they were installed in submarines (Valier, 1928, 70).

Space suits were not uncommon among the thinkers in the German speaking rocket scene. In a notable publication on space travel from 1929, Hermann Potočnic (1892–1929) from Slovenia, but then living in Vienna, under the pseudonym Hermann Noordung, designed the first space station, the *Wohnrad* (engl: living-wheel). Also he discussed the nature of a "space suit".[13] He dealt with the problem of life-support systems in space in his book, oxygen supply chief among them. Diving appliances are the primary source on which engineers of space suits and the like would have to rely on:[14]

> "To live outside closed rooms in interstellar space, one has to use airtight suits, which are supplied with air from the inside: i.e. devices that are quite similar to the well-known underwater-diving-suits. We want to call them 'space suits'. [...] As one can see, we have something very similar to a stay underwater, i.e. as in submarine technology or diving. Upon the rich expertise gathered in these in respect to artificial air supply, we can say that this question can also be solved when it comes to a stay in open space."

He took up that discussion in a later chapter in the book, discussing the technical issues and features in more detail. He recognized that despite the principal similarity of diving and space suits, the two are technically different, particularly when it comes to tear-proofness and thermal protection. Since the internal pressure is higher than the external one,[15] the material must be extremely durable. Also, to shield the wearer against cosmic rays that would heat up the suit to extreme temperature, it should be made of polished metal or at least covered with metal.[16] The suit should also be coated with aluminum foil from the inside to prevent convection of the body heat. If this would not suffice, the sunrays could be utilized to keep the wearer warm. Noordung proposed that these features (metal, rigidness, air supply) are

[13]German: "Raumanzug" (Noordung, 1929, 119). This is perhaps the first time a space suit is explicitly referred to as a "space suit", and not a "diving suit for space" etc. As far as the discussions of the structure of the German rocket societies is concerned, refer to Neufeldt (1990) or Winter (1992).

[14]Noordung (1929, 119), translation mine.

[15]He supposed the space suit shall have one atmosphere of internal pressure (Noordung, 1929, 150), which is not quite what scientists (Noordung had a degree in engineering) had in mind. See Haldane's statement below.

[16]Radiation was a major issue in the discussion among many engineers of such suits. The first actual space suits for the US Mercury project were shielded with a silver garment to protect from the rays. Later it was found out that this issue is not as serious as it was supposed to be. Hence, suits from later projects had other fabrics to protect from sun rays. Cf. Wilson (1985).

all met in the armored diving suits, and these could therefore be taken as a model (Noordung, 1929, 150–151). Furthermore, the suit should be equipped with a radio as a means to communicate with the space ship, and for moving freely in space, a hand-held mini-recoil apparatus should be included in the package. The general ideas of the suit, especially concerning the utilization of the sun rays to heat up the wearer, and shielding the suit from too intense radiation, has some resemblance to the concept of a space suit from the British Interplanetary Society (BIS) at the end of the 1940s (see below). Since the BIS activists were well aware of, and familiar with the German literature, it can be speculated on whether Smith and Ross, the designers of the BIS suit, were inspired by Noordung.[17] What is apparent, though, is that Noordung, albeit demarcating the domain of diving and space suits, repeatedly had to fall back to the world of diving suits to model his space suit. Both Valier's and Noordung's accounts of space suits as ancestors or even equivalent of diving suits, were not taken out of the blue, but followed the real-world technical discussion.

2.3 First technical debates

As a matter of fact, diving suits were *the* model for pressure suits, as is visible in the first patent on a pressure suit by the American Fred Sample, filed March 1917, granted July 1918 (see fig. 2.5).[18]

[17] I have no sources to support such a conclusion, considering that the BIS was not very keen to provide much information on whether they have any materials in their archives, when I inquired.

[18] Mallan (1971) refers to Sample's patent as the first being issued in respect to pressure suits and I could not find any evidence to the contrary, doing an extensive patent search of the online patent databases of the US Patent Office (`http://www.uspto.gov/patft/index.html`, last access: January 17, 2006), on the British patents in the database of the European Patent Office (`http://gb.espacenet.com/`, last access: May 19, 2006) and the German Patent Office's online patent database (`http://www.dpma.de/`, last access: June 03, 2006). Unfortunately I have no background information on Sample, and Mallan (1971) does not provide any. Shayler (1990, 417) specifies that there was a French patent from 1910 on a pressure suit, but does not provide any name or details. I was not able to track down such a patent just by the year.

Figure 2.2: Spacesuit from Faure and Graffigny (1889a).

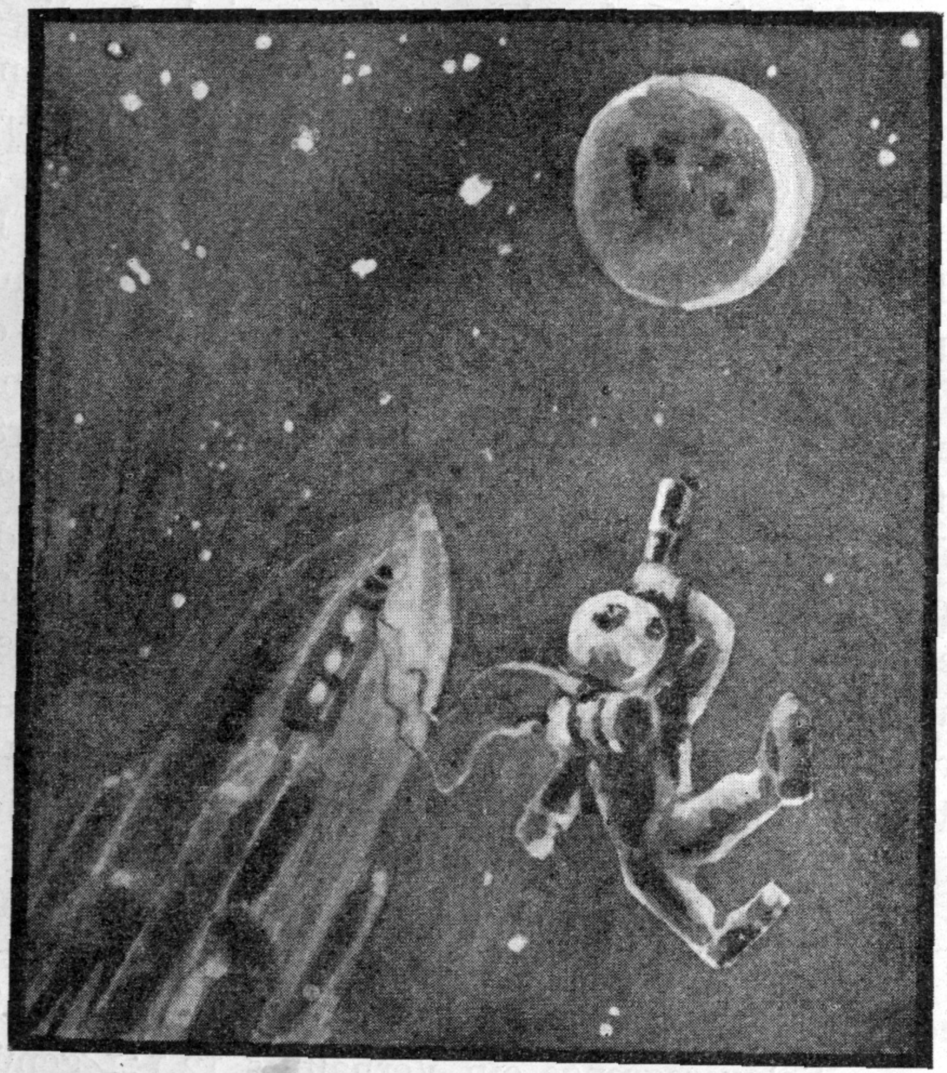


Abb. 32. Der Beobachter im Taucheranzug im freien Weltenraum, nur durch Kabel mit dem Raketenschiffe verbunden, während der Fahrt zum Mond.

Figure 2.3: Valier's space suit. The original caption translates as "The observer in his diving suit in open space, only connected by wires to the rocketship, during his flight to the moon". Taken from Valier (1924).

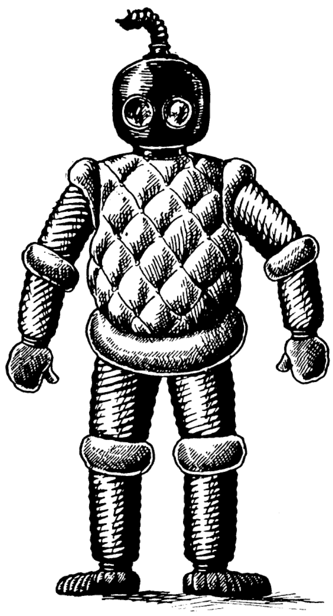
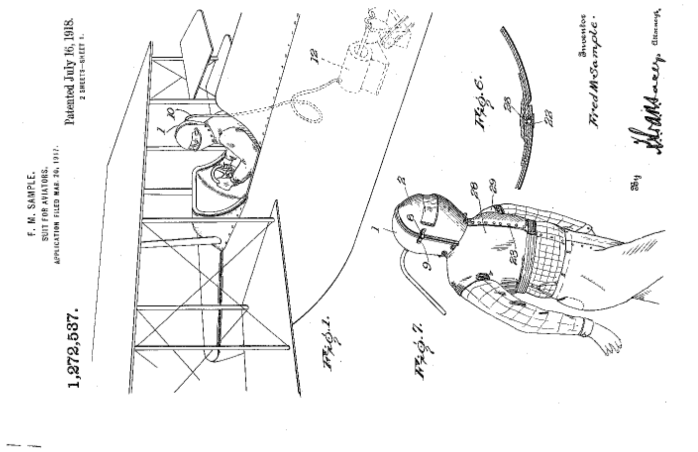
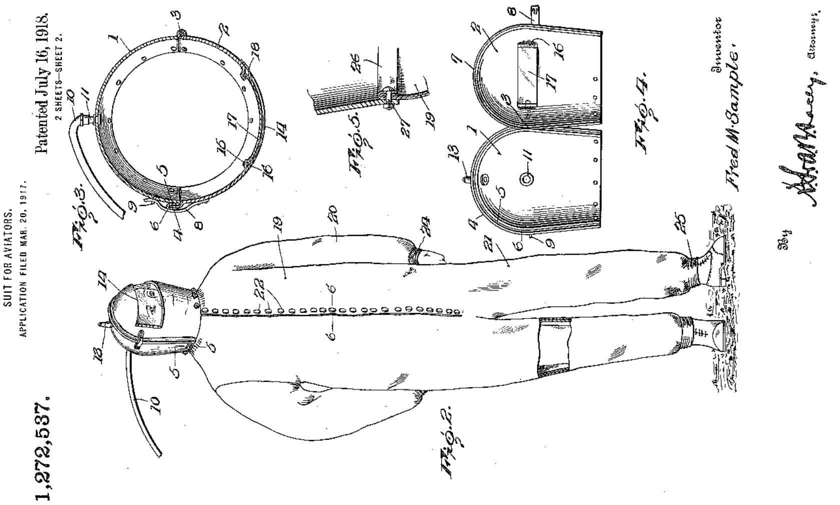


Figure 2.4: Valier's second space suit. Taken from Valier (1928).



(a) Page 1 of the patent.



(b) Page 2 of the patent.

Figure 2.5: Fred Sample's patent for an "aviator suit". Courtesy USPTO.

John Scott Haldane was the first scientific person to mention the idea of a pressure suit and making a reference to a diving suit, owing to his involvement in the design of diving equipment, as shown in section 3.2.5. In 1922 he published (Haldane, 1922, 380–381):

> "If it were required to go to much above 40,000 feet, and to a barometric pressure below 130 mm. [Hg], it would be necessary to inclose the airman in an air-tight dress, somewhat similar to a diving dress, but capable of resisting an internal pressure of say 130 mm. of mercury. This dress would be so arranged that even in a complete vacuum the contained oxygen would still have a pressure of 130 mm [Hg]. There would then be no physiological limit to the height attainable."

That book by Haldane (1922) was the product of the *Silliman-Lectures* given at Yale in 1916, yet there is no evidence that the above quote was already present in the lecture's manuscript in 1916. This book (Haldane, 1922) is an extended version of the lectures, as is stated in the introduction. A shorter publication of the lectures was released in 1917 (Haldane, 1917). There, the foreword mentions that the war entry of the USA hindered the publication of the full lectures, and that only the philosophical lectures were picked from it. To what degree the manuscript for Haldane (1922) was altered prior to the print is not quite obvious. So it remains unclear whether Sample was aware of Haldane's idea, or if Haldane might have been inspired by Sample's patent. More likely, however, the idea seemed to have lingered around, and perhaps Haldane grabbed up the principle idea somewhere else.

Haldane's approach and involvement, as well as those of other people in other countries, signifies that the conception of pressure/space suits as modified diving suits was not an idea borne out of science-fiction novels and depictions. How far SF and science have inspired each other is debatable. Should one accept the thesis of the study of the *European Space Agency* (Raitt et al., 2003) that SF literature would yield innovative technical concepts, referring to Hugo Gernsback, founder of several pulp magazines before World War II, who "noted that science fiction was socially useful precisely because it inspired research and inventions"? (Raitt et al., 2003, 3)

It might as well be concluded that the depiction of space suits, stemming from diving suits, in popular publications was an intellectual appropriation of technology, since diving suits existed before those publications in the first place. So the question of who inspired whom remains one of the proverbial *chicken-and-egg* problems.

This issue gets further complicated by the fact that rocket and space enthusiasts who met in the rocket societies were usually extremely wary of SF literature, seeing those publications as derision and trivialization of their higher motives. Those members of the rocket societies in the 1920s and beyond were usually themselves engineers and had a more romantic sentiment towards space travel, and despised the sensationalist SF stories as "vulgar".

Rocket and space enthusiasts resorted to technical and scientific publications – last but not least to justify their cause as a serious one. Technical literature inspired them, not pulp.

2.3.1 The BIS suit

For example, upon the publication of Davis (1947), in which he described the making of the *Haldane-Davis-Suit* (see chap. 5) for the first time, Harry Ernest Ross (1904–1978), a member of the *British Interplanetary Society* (BIS, founded 1933), wrote a review of it, frenetically describing the account of the suit in Davis' book (Ross, 1949, 40):

> "Again, the pages devoted to a description of the original Haldane-Davis stratosphere flying suit should not be overlooked. For here, more clearly delineated than in any other type of dress, we begin to discern the lines of evolution of a spacesuit."

In fact, a few months later the Journal of the BIS published a paper from Ross presenting a space suit inspired by Davis' account.[19]

Ross (1950a) heavily utilizes Davis (1947) account of the *Haldane-Davis-Suit* to come up with a space suit design of his own. Ross' (correctly) stated that "the spacesuit which is to do duty on the Moon will differ in detail from one that has to operate in the presence of an *irrespirable atmosphere*". His specification for the said spacesuit consequently was more or less Davis' design with some additional thoughts on thermal protection.

Neither Ross nor Smith were experts in the field of physiology or diving/pressure suit manufacture. Harry Ross went to work as a lab assistant at London Zoo after school, then went to work in the Department of Helminthology at the London School of Tropical Medicine and Hygiene.[20] In 1920–21 Ross studied radio engineering, went to sea in 1924 and in 1941 he became controller for a radio valve company. In 1937 he joined the BIS and published several papers on the feasibility of a travel to the Moon together with R. A. Smith, including ideas on rocket design and mission planning (Parkinson, 2008, 27).

Ralph Andrew Smith (1905–1959) on the other hand, became a spaceflight enthusiast in his early years. After he had to abort an apprenticeship as an aircraft engineer due to the company's financial trouble, he used his skills in technical drawing to work in architectural decoration. Besides this he made money as a free-lance draughtsman for the aircraft industry. Before

[19]The idea of that suit was published as Ross (1950a), on which some discussion followed by Cross (1950), answered by Ross (1950b), again being commented on by Cross (1951). A footnote of Ross (1950a) mentions that the article was a paper held at the *Symposium of Medical Problems Associated with Space-Flight*. This symposium was held on 19 November 1949 and had three papers (Parkinson, 2008, 34).

[20]Helminthology is the study of parasitic worms and the effect on their hosts (Encyclopedia Britannica, 2004).

World War II he took a post in a radio production engineering company and became designer-draughtsman at a rocket propulsion research company after WWII (Parkinson, 2008, 30).

So while both Ross and Smith had modest knowledge of rocket design and engineering and other technical issues,[21] neither of them had proficient knowledge of the medico-technical issues required to design a space suit. It is thus remarkable that the suit proposed by them resembled to a large degree the design of actual spacesuits as used by astronauts ten years later.

Seeing the need to have a "self-sufficient as regards to oxygen supply" type of suit (Ross, 1950a, 25) a backpack was designed to carry oxygen tanks to meet this purpose. Since "on the Moon the weight of all things is reduced to one-sixth of the terrestrial weight" it would be no problem to carry tanks "for 12 hours service [...] with comparative ease" in the EVA (Ross, 1950a, 31). The breathing apparatus should be a closed-circuit device, preferably using compressed, pure oxygen, since normal air would impose "some risk of the 'bends' [...] which might occur if the pressure inside the suit fell suddenly through any reason, as in the case of a bad leak" (Ross, 1950a, 30).

So far these are all features borrowed from the *Haldane-Davis-Suit* and there was not much dispute about the technical implementations of them. However Davis' suit was not so much concerned with thermal and radiation protection, since this was not in the scope of its designated purpose. Hence Ross started to think about the best possibilities for insulating the wearer from both extreme heat and cold, as experienced in the lunar day and during the lunar night, respectively.

The suit should consist of "four distinct layers" with one of the layers specifically destined to work as insulation against the cold (Ross, 1950a, 27). For the heat insulation of the boots, Ross picked up the fire-fighter suit from Davis (1947), which used asbestos. The cape is used as a "temperature regulator by color".[22] while the suit "with the exception of the chest-area" would be "silvered" just like the cape. The chest would be matte-black. The temperature would then be regulated "by exposing more or less of the black chest-area, the reflecting properties of the *cape* being effective in preventing the escape of calories" (Ross, 1950a, 34).

This account generally signifies one thing: Ross surely had a good technical understanding of the requirements of a space suit, and his mentioning of features like closed-circuit breathing and thermal protection assure this, even though his genuine skills in this field were severely limited. In terms of a garment and a breathing device he completely adopts Davis' design, whereas in terms of thermal protection by a special fabric – where he cannot count on somebody's else expertise – he apparently runs into uncertainty.

[21] In 1948 they proposed a lunar rocket, based on the V2. (Smith, 1948).

[22] Ross (1950a, 34). Ross assumed that the lunar ground will be heated up to 120° C during the lunar day hence the fire-proof boots (Ross, 1950a, 27).

The design exited a discussion among the BIS members, not only directly after the meeting as it was published as supplement to the paper by Ross (1950a), but also via several letters to the editor by one C.A. Cross, which all were published as full-fledged articles in the journal of the BIS. Cross wrote to the Journal to correct one or two of Ross' assumptions about heat convection, stating that "the aluminum foil multilayer type, with dry air in the interstices to insulate refrigerated vehicles" would make a better insulation for the suit than Ross' "cellular design". Cross elucidates "that a space suit working in a vacuum may readily be converted into an extremely efficient flexible thermos flask." (Cross, 1950, 258). Ross is grateful for the constructive criticism, admitting that "Mr. Cross rightly points out that a cellular structure does not provide ideal thermal insulation[...]" (Ross, 1950b, 300). He then invites Cross for further comments on insulation and garment issues, which Cross happily provides (Cross, 1951).

Just like other rocket societies in other countries, Ross and Smith are quite optimistic and embracing towards their proposals. Just like their brethren of the German *Verein für Raumschiffahrt* or the *American Rocket Society* they are a peculiar mixture of "educated laymen", i.e. people with a technical background, though not experts in the respective fields. Their visions were therefore astoundingly informed and generally on the right track, but nonetheless insufficient and *naïve*.

Those involved in actual research on suits and breathing devices were thus not so impressed:[23]

> "The Interplanetary Society (of Madman I think) have designed a suit for a visit to the Moon on a rocket ???.
>
> My view is that supposing exposure to temperature low & high is over come & oxygen under pressure provided & CO2 absorbed & all very efficient, there is still the difficulty of gravity lowered to 1/5. This would disturb heart & respiratory & skeletal muscles & make life impossible. Moreover the lowering of gravity may disturb injector apparatus for circulating oxygen, & alter chemical reactions possibly. What do you think of the gravity problem? There does not seem to be any way of testing it on earth."

A.V. Hill's reply to L. Hill also did not show much respect to the BIS, but admitted a certain social value:[24]

> "I can think of a great variety of good reasons why I should not go to the moon but the absence of gravity, or rather its relative absence, would not disturb me. I have never noticed any disability as the result of swimming in the sea, a condition under which gravity is effectively eliminated. But I am afraid it would be terribly hot on the moon during the lunar day which lasts fourteen of ours and terribly cold in

[23] Leonard Hill in a letter from March 16, 1949, to A.V. Hill; CCAC, AVHL II 4/35.
[24] CCAC, AVHL II 4/35, letter from March 18, 1949.

> the lunar night. One would have to live in a vacuum flask, well silvered, to have much chance of survival.
>
> In fact, I should like to live in a place where gravity was reduced to 1/5th: it would be fun to be able to jump over the top of a house.
>
> The Interplanetary Society of Lunatics, the flat-earth merchants, the Society for the Prevention of Premature Burial, and all such things ought to be encouraged: otherwise, people are apt to take Fascism or anti-vivisection or other more harmful pranks."

Just like other scientists, Hill and Hill were not fans of SF which was often regarded as trivial and vulgar, rather than being beneficial to humanity. In the eyes of serious scientists SF would not ameliorate the condition of humanity and serve only lower purposes. The BIS surely regarded itself as not falling in this category. Rather, it differentiated between "serious" and "trivial" SF and welcomed the former. Nothing could epitomize that stronger than Arthur C. Clarke's presidency of the BIS (Parkinson, 2008, 14).

This venture into the literary and SF conception of pressure- and space-suits should only elucidate the far-reaching influence of technical discussions as made by Haldane and others. It also shows the contempt scientists usually had for SF style writings. Gernsback's statement from above, that SF furthered technical development, is questionable . In the field of investigation for this publication especially – diving-, pressure- and space suits – the only exchange of ideas was a one-way appropriation of well-established technology by SF authors, i.e. diving-suits as models for space-suits. No genuine contribution to the technical process of designing such suits was made by the SF community.

2.3.2 Diving Suits as a discursive framework

As will be shown throughout this publication, the use of the word "diving suit" for pressure and space suits was wide-spread in the debate. This was due to the medical and technical models physiologists and engineers used, and not only due to the personal continuities in the business (e.g. Haldane's long standing contributions to the development of diving- and breathing devices). Furthermore it permeated the public picture of these suits. As a matter of fact the introduction of the term "diving suit" into the discussion was entirely a *rhetorical accomplishment*.[25]

[25] Historian of Science Nicolas Jardine coined the term "rhetorical accomplishment" to question the often heard notion that medical research became scientific only after it had embraced laboratory work. Jardine (1992) argues that there was a large school of medical researchers who insisted on field studies (with complementary laboratory studies) and that the common conception of scientific research occurring solely in the laboratory was the *rhetorical accomplishment* of the proponents of laboratory studies. The sense in that I will use this term is similar. As I will point out, the usage of the concept of diving suits as pressure/space suits was such *rhetorical accomplishment*, as it abstracted the technical

Whereas the first technical descriptions simply named the suits as "aviator suits" or even "pressure suits", it was necessary to define a term better suited for the less technically inclined. Since early science fiction literature (see above) already popularized the idea of a space suit as a diving suit, it seemed natural to appropriate the term. Technicians themselves rarely referred to these devices as "diving suits", but to propagate its use to the layman, the term fitted nicely.

It is noteworthy, however, that the usage of the term did not last for very long in the Anglo-American and the German linguistic sphere. The English term "diving suit" or the German "Taucheranzug" is occasionally used in popular publications and almost given up at the end of the 1930s. In Romance languages, however, an equivalent term is still in use today, although less frequent. In French the term "scaphandre" is used for *diving suit* and *space suit* (scaphandre des astronauts). In Italian the corresponding term "scafandro" is used, in Spanish "escafandra" whereas in Russian "skafandr" (скафандр) is employed.[26]

This term, *scaphandre*, is worth examining in more detail. Its widespread use in the Romance language sphere for diving, pressure and space suit is remarkable. According to Gamillscheg (1928), the term is etymological derived from two Greek words: 1) "skaph" ($\sigma\kappa\alpha\phi\eta$), and 2) "andros" ($\alpha\nu\delta\rho o\varsigma$) (Gamillscheg, 1928, 789). The first term means "light boat" or "skiff", the second means "man" or "human" (like in *andro*id).[27] The term "scaphandre" would therefore roughly translate as "human boat".

The term dates back to 18^{th} century France: Jean-Baptiste de la Chapelle (1710–1792) introduced the concept of a swimming aid in 1775. He described a vest made of leather with pieces of cork in it. The wearer would be thus enabled to "walk" through the water (Jung, 1999, 64). The "swimming belt" as Chapelle also called his device, can be roughly regarded as a precursor of today's life jackets, even though its practicability is questionable.

Jung (1999) attributes the invention to Chapelle (1775), but Bry (1722) had already given an account of a similar device. Bry is similarly enthusiastic about his invention: the "air trousers, with which one can walk across the greatest waters" and a "swimming belt".[28]

Chapelle's term "scaphandre", however, inspired others to adopt it for their inventions. The Frenchman Joseph-Martin Cabirol (1799–1874) produced a diving apparatus which soon became the standard in France, and even when he could no longer dominate the market, the name of his device continues to this day.

concept. Diving suits and pressure suits have only the general principle in common, but are rather different in the technical details.

[26]F: Brick (2002, 926), I: Reynolds (1975, 233), E: Smith (1996, 303), Russ: Ryan and Norman (1995, 125).

[27]Liddel et al. (1958, 275,1605)

[28]From the table of contents on the title page from Bry (1722). Translation mine.

Cabirol started to produce diving helmets in the 1840s and presented his *Scaphandre Cabirol* at the exhibition *Exposition Universelle* in Paris in 1855. English producers like Augustus Siebe (1788–1872) were also around at that fair, and they were quite upset that Cabirol's device resembled pretty much their own – and that he offered it for half the price the Englishmen did. This was one reason why the French Navy switched supplies, from Siebe to Cabirol.[29] Cabirol's only notable innovation was a fourth window above the position of the front window, an improvement that allowed divers to look up without the risk of tilting the helmet, which would run the risk of water entering it. Aside from that, there was no difference to the devices of Siebe and others (Jung, 1999, 132).

Cabirol's market share was so large that another, more innovative invention needed several years to take over. The French engineers Benoît Rouqayrol (1826–1875) and Auguste Denayrouze (1837–1883) invented the *demand-regulator* in 1860. This device was originally designed to be used in mining, therefore no helmet was provided, only a clamp for the nose. Diving masks were not invented at this point, so diving in salty or muddy water was extremely uncomfortable, a circumstance that contributed to the low popularity of the device. It was not until 1867 that a helmet was introduced.[30]

What was most remarkable with Rouqayrol's and Denayrouze's device though, was that it could be supplied with air both via a hose from the surface and via an autonomous reservoir, worn as "backpack". Even though the air tank could only be pressurized to 30bar, which does not allow for lengthy underwater walks, it can be legitimately called the birth of the modern SCUBA diving apparatus, and also served as a model for EVA suits for space.

2.4 Outlook

This treatise on the discussion of diving appliances for space travel should suffice to outline the discursive framework for early 20^{th} century engineers and scientists when it came to pressure suits for aviation.[31] Apparently div-

[29]Siebe himself profited much from other's work. He took over a device from John (1800-1884) and Charles Deane (1796–1848), who asked him to work his "smoke helmet" into a diving device in 1834. As Jung (1999, 126–130) outlines, Siebe "adopted" not only Deane's concept, but also that from George Edwards (1804–1893) to produce "his" diving apparatus.

[30]Cf. Denayrouze (1866) for an original account, or Rouqayrol (1866) for the US patent; also Jung (1999, 209ff.) for the history of this device, or Bremen (1873) for a contemporary appraisal.

[31]The term "discursive framework", upon which many works (e.g. Hård and Jamison, 1998) rest is based on well-established concepts from discourse theory. Most prominent in this is perhaps the work by Frenchman Michel Foucault who argued that "discourse constructs the topic". The common technical and linguistic concept in the debate on pressure/space suits as diving suits is, as I will argue, what Foucault called "discursive

ing appliances served as a role-model for personal equipment to venture into the fringes of earth's atmosphere and ideally beyond. From the early 19^{th} century on, diving equipment inspired writers to apply this technology were humans to travel into the upper air or even outer space, although such early references were rather crude and vague. It is thus questionable that the stories by Poe, Verne and others actually inspired any scientists or engineers to any particular technology. On the other hand, it is safe to say that the above mentioned stories both created an incentive and sparked a general discussion about the technology required to go into the stratosphere. The stories therefore served as a *cultural resource* engineers could draw upon. They provided a source of inspiration, a rhetorical aid to convey scientific issues in connection with high-altitude or space travel, and they led people to believe that such ventures were feasible, as all it seemed to take to let humans safely endure them would be an application of some well-known technology. The public and scientific debate over pressure suits represents the concept of "co-construction" I mentioned earlier by constituting a collaborative effort. This effort may not have been affiliative, i.e. the parties involved may not have asserted support to each other (as in the case of popularizers and engineers), but this is not contradictive to the term "co-construction", since even a disagreement in an argument is still an interaction (Jacoby and Ochs, 1995, 171). This paradox is characteristic for the debate over pressure suits, and this publication will outline this debate by looking at the different stakeholders and their interaction.

formation": discursive events referring to the same object, sharing a similar style and supporting a common strategy (Hall, 2001, 73, see also Foucault, 1972, 32). More fundamentally a "frame" in discourse theory refers to the boundaries of a discourse that act as an "advance organizer" or "scaffolding" for the discourse in general and the participants in that discourse in particular (Tomlin et al., 1997, 90).

If fishes could reason, how could they believe that creatures can live in comfort in that element which is death to them?

R. A. Proctor, *Other Worlds than Ours*, 1872

3

History of Diving & Aviation Medicine

The undersea is tantamount to the upper air (and outer space), as far as cultural and technical metaphors are concerned, be it with Torricelli's "ocean of air" or the notion of the cosmic aether as fluidum. Originally instigated in the context of cosmology, it soon comprised the medical body of knowledge, last but not least because of the growing influence of modern chemistry and physics on medical research and practice. While the medical link might be quite apparent, and is as such acknowledged by both physiologists and historians of medicine,[1] it is nonetheless not very well examined, particularly when it comes to contextualizing the medical research with cultural and political events.

These cultural and political investigations are crucial for a correct historical account, and not simply some sort of intellectual hedonism. The problem with most literature on the history of medicine, and with the history of aerospace medicine in particular, is its internalistic notion, mistakingly displaying a single event in medical research or single actors isolated from their environment. This attitude usually makes it appear that the event or actor in question is some kind of genius, since it appears as if he (rarely "she") made his contribution to science all on his own. Even if there was something like an "isolated genius", working alone in his laboratory separated from the rest of the world, he would still be embedded in his social, political and

[1] As one introductory speech to a conference on hyperbaric medicine in Germany in 1993 indicated: "A common issue of both aviation and space medicine, as well as diving and hyperbaric medicine, is the impact of changes in ambient pressure on the human organism." Hampe et al. (1993, 11), translation mine. The (internalistic) connection of mountaineering and aviation medicine is elaborated by Cüppers (1994).

cultural environment which determines much of his scientific outcome.

This chapter takes a *prosopographic* approach, outlining the biographies of some of the important figures in aviation and diving medicine. This approach is somewhat problematic, as biographies quite often turn out to be *hagiographies*, i.e. inaccurate or even apologetic glorifications.[2] By showing some interesting and yet unreported (or at least yet unexplored) connections, light will be shed not only on personal links not so apparent to most historians, but also on the structure of research in the respective fields at large. An internalistic historiography would fail to see these links and would therefore deliver an incomplete and even inaccurate account. It is thus not one of the usual STS fads of seeing everything in the history of science as "socially constructed", but rather an empirical study of the complex intertwining of scientific research, without "degrad[ing] persons to mere carriers of social functions".[3]

3.1 The beginning

It is difficult to exactly define the beginnings of diving and aviation medicine, largely because there's no definition as to what exactly comprises these fields. It would be therefore appropriate to start with Paul Bert's work in the 1870's, since he was the first to nominate the pressure differentials as the common cause to medical problems in both diving and altitude.

Picking this period as the starting point also makes sense in terms of the technological environment. In the early days of diving technology most fatalities occurred due to failures in the diving appliances, primarily in the breathing devices. In the middle of the 19^{th} century however, it was realized that more scientific investigations had to be introduced into engineering, since many of the failures were rooted in insufficient knowledge of physics, chemistry and medicine.

Also, more physiological knowledge of the human metabolism was required to fully understand the causes and factors involved in *decompression illness* (DCI) and *hypoxia*, the chief problems met in diving and high-altitude respectively. These causes and factors were recognized not before the end of the 19^{th} century, despite first glimpses made by Boyle, Lavoisier or Priestly (cf. Proctor, 1995).

At the same time engineering posed some serious hygienic issues to workers, divers and finally aeronauts. Improved pumps and valves allowed for longer and deeper dives (both "wet" dives as well as caisson work, see below), and made possible balloon ascents to higher altitudes. The more humanity started to leave its predestined living space (that is, generally the regions at sea-level and slightly above and below), the more medical issues were en-

[2] Cf. Kragh (1991, 169). "Hagio" is the Greek word for "hero".

[3] Trischler (1998, 47), translation mine.

countered, requiring more medical and technical research to make such an endeavor secure.

The branch of *applied medicine* had its cradle right in the midst of this interplay, and it epitomizes two key features of social and cultural change in the 19^{th} century in the occident: the scientification and technification across all intellectual – and eventually social – disciplines. Physiologists cooperated with engineers to construct "safer" engineering appliances. Physiologists also started to become engineers themselves, by constructing all sorts of laboratory equipment necessary for their research, but not readily available on the market.

3.2 Pioneers

Although the term "pioneer" as a *leitmotif* for a historical inquiry is almost always troublesome, it is nonetheless given space to describe such legacy making here. Often enough, the term "pioneer" in the history of science, technology or medicine (or other historical branches as well) is misused to introduce hagiographic accounts of actors important for their authors, rather than giving a quantifiable and reproducible representation of the status of the actor amongst his contemporaries.

As difficult as this may be to come up with, this approach is taken by analyzing contemporary literature, like papers in scientific journals, contemporary bibliographies and – where available – from archives. The "eminence" of one scientist is obviously hard to measure, but contextualizing the biography of the respective actors with enough statements from their contemporaries should ensure the integrity of statements being made about the influence of the respective actor.

Some actors were handpicked, where others were omitted in spite of their contributions to the field and the reverberations they created among their contemporary colleagues. This reflects the focus on physiologists who exerted some influence on other social groups like engineers and politicians. Therefore, a preference was given to physiologists who gained some kind of "normative power".[4]

[4] Mitchell and Agle (1997, 865): "coercive power, based on the physical resources of force, violence, or restraint; utilitarian power, based on material or financial resources; and normative power, based on symbolic resources". In this context, "Definitionsmacht" or "normative power" is a successful attempt of a person or group to achieve the power to define the way topics are regarded by the recipients, i.e. the public. The term "Definitionsmacht" is often biased negatively in debates in Germany, since it implies – often rightfully – the intention of those striving for it to conceal something from the peers, usually the sober details of the topic in question revealing a differing reality than that presented. Here, the application of the term "normative power" is used in a rather neutral and narrative fashion to describe the dissemination of terms, metaphors and concepts to further a specific view. The intention behind such a process need not be *evil* but is mostly simply narcissistic, or a sign of *hubris*. This notion of normative power corresponds with

3.2.1 Paul Bert

The French physiologist and politician Paul Bert (1833–1886) remains as one of the most influential figures both in general and in diving and high-altitude physiology, and this is not simply a retrospective impression defined by historians of science. All physiologists in the early 20^{th} century referred to Bert as *the father* of these topics. While during his lifetime his findings in Bert (1878) were contested by some contemporary scientists, they were widely accepted shortly after.

Bert was an eminent scientist and a politician at a time when there was much unrest in France (the German-French War of 1870/71, ending with France's defeat and political upheaval in the government). Biographies are not hard to find; Encyclopedia Britannica (2004) features an entry on him, and so does the *Dictionary of National Biography of France* (Prevost and d'Amat, 1954). Also many historic accounts such as West (1998a), Phillips (1998), Colin (1992) or Dejours and Dejours (1992) provide information on his life and work. Unfortunately, all of the latter inhibit diverse shortcomings in terms of historiography, usually being *internalistic* or *hagiographic*. However, since Bert's life and work is only of interest for this publication when it comes to his defining of a legacy, these publications sufficiently serve this purpose.

Diving Medicine before Bert

Bert was neither the first to investigate nor to report on DCI or hypoxia. Actually, the first to report – though quite unintentionally – on DCI was Robert Boyle in mid-17^{th}. After the construction of his air-pump, he conducted a series of experiments on animals with it. In one series he took a rather small glass cylinder and evacuated it with the pump to see the reaction of the animals put in the cylinder. Upon "decompressing" a snake this way, he observed a bubble in the eye of that animal. After having treated various animals this way, he noted (Boyle, 1966, 241):

> "Another suspicion we should have entertained concerning the death of our animals, namely that upon sudden removal of the wanted pressure of the ambient air, the warm blood of those animals was brought to an effervescence or ebullition, or at least so vehemently expanded as to disturb the circulation of the blood, and so disorder the whole economy of the body."

Boyle was not aware of the causes of these disorders. He simply wrote it down and did not inquire into the issue further. The first actual investigation into DCI was made by the French physicians Pol and Watelle (Phillips,

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the concept of *Social Influence Agents*, which is discussed in this chapter's conclusions.

1998, 52–59). The French engineer J. Triger (1800–1868)[5] had invented the *Caisson* – a steel shaft let into the water – in 1841 and used it to lay the foundations of bridges in rivers etc. The *caisson* was designed to let workers do their job without getting their feet wet by keeping the water out of the shaft with pressurized air (see fig. 3.1).

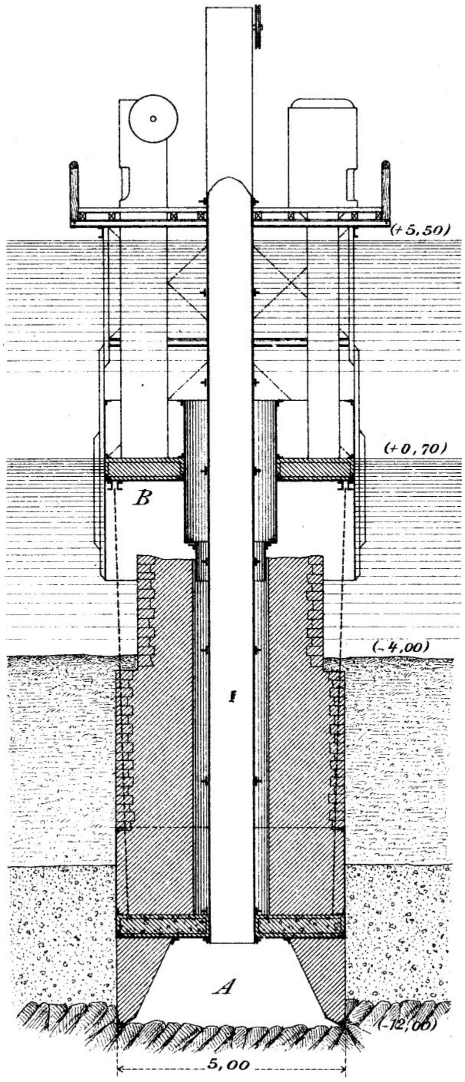

Figure 3.1: Caisson at the end of the 19^{th} century. Taken from Zschokke (1896).

[5]Neither Triger's christian name nor his exact living dates are assured, as Phillips (1998, 223–224) discusses. Several contemporary obituaries, apparently dealing with the same person, date his life from 1861–1867, or 1860–1868, some name him "Jules", some "Charles-Jean".

Soon there were incidents of some mysterious sickness the caisson workers suffered from, resulting in nausea, paralysis or even death. The symptoms were so diverse and the only common cause was the previous work in the caisson, that it was named *caisson disease* or *caisson sickness*, a name that is occasionally used until today, especially in French speaking countries. Another "popular" term to describe this disease was the *bends*, since often the workers suffered from joint necrosis, leading to a "bended" posture when the person in question writhed in pain.

Triger soon hired the two physicians Pol and Watelle to investigate the disease and to find measures against it. They started their research at the work sites and closely monitored the workers, leading to report in 1854 that they could not state much more than the mechanics of DCI: "On ne paie qu'en sortent".[6] I.e. they observed that the trouble of DCI only arises when leaving the caisson, upon decompression. The phase of compression, they were convinced, was without symptoms. They developed a theory of "congestion of the blood", i.e. a mechanical theory of DCI in which the force of the pressure modifies the consistency of the blood (just as Boyle had stated, see above), which then after decompression would not flow steady through the veins anymore. The theory remained popular among scientists until Bert contested it in the 1870s, and still then it took some time until Bert's hypothesis was widely accepted.

High-Altitude Medicine before Bert

As outlined in section 4.2, there was virtually no *scientific* researches in high-altitude physiology before Bert. Boyle's and Hooke's experiments, and Glaisher's and Coxwell's (and other) accounts on the effects of decreased barometric pressure can hardly be called *scientific* investigations into physiology.

When in 1874 a French team with Sivel, Croce-Spinelli and Tissandier was formed to beat the altitude record by Coxwell and Glaisher, Paul Bert supported this expedition in order to gain physiological data from the balloonists. The balloon was unintentionally taken up to 8000m, leading to the deaths of Sivel and Spinelli, and to severe injuries to Tissandier.[7]

Bert was shocked by this tragedy and felt guilty about this outcome. From then on he restricted himself to sole indoor experiments, i.e. experiments carried out in a controlled environment in the laboratory, using animals and himself as test subjects (Phillips, 1998, 112). Laboratories were well-established as primary places of scientific research by the middle of the 19^{th} century (cf. Cunningham, 1992). The research needed for diving

[6] Engl: "One only pays on leaving", Pol and Watelle (1854, 261), translation mine.

[7] Phillips (1998, 112). See also section 5.3. The incident also furthered the notion that such heights were not attainable and that Glaisher and Coxwell did not reach it also. See Coxwell's *Letter to the Editor* to the The Times on page 101.

and high-altitude physiology could hardly be done in a laboratory, though. To have a reliable pressure chamber available for experiments would have required a large amount of resources. Since the fields of diving and high-altitude studies were still in their very infancy, no interest group in the government arose to request such studies. Pol and Watelle, and those that came after them in the 19^{th} century, were usually contracted by private companies, in this case by Triger. Research was not particularly thorough and was geared at finding *ad hoc* solutions rather than foundational scientific theories.

Bert, on the other hand, equipped with a modest wealth and political influence, terrified by the risks of *in-field* studies, originated and established the methodology for future research. Before delving into his experiments further, a short sketch of his life is appropriate.

Short biography

Paul Bert was born in the French city of Auxerre on October 19, 1833, and died on November 11, 1886 in Hanoi (Vietnam). He moved to Paris to study law and medicine, studying physiology under the eminent physiologist Claude Bernard (1813–1878). In 1863, he finished his MD and in 1866 he earned his PhD, both these works dealt with animal physiology. After becoming a lecturer for zoology and physiology at Bordeaux, he was elected as successor to Gustave Flourens (1838–1871) as the chair of physiology of the Natural History Museum of Paris in 1867. In 1869 he became successor of Claude Bernard at the Sorbonne.

In 1870 began his long-lasting and wide-reaching ventures into politics, becoming Secretary General of the prefecture of the city of Yonne. After he failed to get elected for parliament in 1871 he turned to his scientific offices again. However, he remained with the administration by becoming elected to the municipal council of Auxerre. His fields of interest were politics of education and religion. Bert, being a radical French republican, opposed the catholic church with vigor and did everything he could to push back its influence, demanding that the Republic should be based on three principles: income tax, general military service and obligatory primary education (free of charge and secular). When he became the member of parliament for Yonne in 1872 he joined the faction of minister Leon Gambetta (1838–1882) and furthered the implementation of these principles, struggling against any concessions being made to the catholics. He was re-elected to the parliament several times, eventually becoming Minister of Religion and Education under then prime minister Gambetta in 1881. After the death of Gambetta the next year Bert was re-elected into parliament, becoming leader of Gambetta's party and finally his bill on primary education passed legislation in 1886. In the parliamentary elections of 1885 he was actually elected twice: once as deputy for Paris where he held office, and once for Yonne, where he still held residence; he decided to become deputy for the latter. He was also a supporter of colonial expansion of France, eventually becoming governor of the provinces Annam and Tonkin in French-Indochina in 1886. He left France for Vietnam in February to take his office with many programmes for commerce, education and public hygiene on his mind. In November, however, he died in Hanoi from an infection.[8]

It is remarkable to see that despite Bert's political involvement he still had the time to publish numerous scientific articles and undertake various influential physiological investigations.

Bert's research

It is no hagiography nor other exaggeration to call Bert's research in diving and high-altitude physiology as *path-breaking*. While there were others like Pol, Watelle, Jaminet or Smith who investigated the physiological effects of changes in barometric pressure, it was Bert who set the scene for the years to come. He defined his own legacy by setting up the methodology for these researchers, to which his successors adhere even today.

As mentioned above, Robert Boyle had undertaken experiments with animals in evacuated glass jars to study their reaction to rarefied air. Robert Hooke (1635–1703), collaborator of Boyle, also made the first experiments in an evacuated chamber on himself to study the effects (Phillips, 1998, 24). The intention and the outcome were quite questionable though. Around 1700, various people all over Europe experimented with little glass vacuum chambers. Following the trend of the time some of these "experiments" were staged as public lectures, creating some kind of *thrill* for the masses to display suffocating birds or other small animals.

Bert, however, shocked by the deaths of Sivel and Spinelli, not only exposed animals to pressure differences, but also subjected himself to such tests. Bert undertook a wealth of experiments in the 1870s, eventually leading to his seminal work in 1878 (cf. Bert, 1878). In this voluminous (c. 1200 pages) monograph he gave detailed information on the previous work done in the field, his experiments and his conclusions.

Bert not only specified the mechanics of DCI for the first time, he also recognized the nitrogen in the air as the primary source of bubble formation, based on *Henry's law* of physical chemistry, which relates the amount of solved gas in a liquid to the pressure of the gas above that liquid (Jones and Childers, 1993, 91). He championed *Dalton's law* by showing that the partial pressure of nitrogen is relevant for the DCI, whereas the partial pressure of oxygen leads to other effects like *hypoxia* or *hyperoxia*.[9]

[8] All information from Prevost and d'Amat (1954), unless otherwise indicated.

[9] The latter being the effect of oxygen on the human physiology when breathed under overtly pressure. Bert found out that above a partial oxygen pressure of 1.6bar, oxygen becomes toxic (Bert, 1878, 594ff). *Hyperoxia* is also often referred to as *Paul-Bert-*

As already mentioned, Bert preferred a controllable laboratory environment over studies in the field, i.e. he favored *in vivo* over *in situ*. In both diving or high-altitude physiology, studies *in situ* are hard to carry out without destroying the data gained by the experiments. High-altitude physiologists in the 1920s like Barcroft, for example, albeit experimenting in mountain huts, were keen to have "comfortable" conditions there, not so much because they were squeamish over subjecting themselves to harsh environments, but rather because they realized that cold, muscular exertion, etc. influenced the production of data, and hence knowledge (West, 1998a, 99). If conditions were to be changed this had to be done deliberately and in a reproducible manner to record the effects of the changed parameters.

The kind of experiments conducted by Bert were also highly influenced by his former teacher's methodology. Claude Bernard not only furthered the systematic "employment" of animals in experiments, he also called for the experiment on the living being, i.e. *in vivo* (cf. LaFolette and Shanks, 1994). These animals were often anesthetized in order to have said controlled conditions. Bert's introduction of a pressure chamber into the laboratory was in concord with the trend of 19^{th} century physiology to evolve a canon of reproducible and robust methodology. The laboratory equipment designed, like Kymographs and Plethysmographs, signify this notion. Whereas medicine before the early 19^{th} century was still loaded with philosophical sentiments in the tradition of Galen, the work in the newly erected and introduced laboratories required a new sort of *self-discipline* for experimentation, mechanizing physiologists rather than physiology.[10]

It is this therefore not my intention to discuss these philosophical struggles any further, but rather display the scientific influence of Bert to later physiologists of diving and aviation. One of these "disciples" became the Austrian Hermann von Schrötter.

3.2.2 Hermann von Schrötter

Hermann von Schrötter (1870–1928),[11] an Austrian physician with a PhD in *otolaryngology*[12] just like his father Leopold von Schrötter (1837–1908),[13] became one of Europe's most influential researchers in diving and high-altitude

Effect (Clark, 1993).

[10]Cf. Chadarevian (1993). I have argued in Lünen (2006b) that the *mechanistic* approach to physiology was an *habituation* by young physiologists, who "grew up" in the laboratory with these working conditions, rather than a well-defined, deliberate philosophy. In retrospect, the *mechanism-vitalism*-controversy in 19^{th} century (and beyond) physiology appears more as a generational conflict than a true ideological struggle.

[11]His actual name was "Hermann Anton Ritter Schrötter von Kristelli", indicating his aristocracy by the word "Ritter", the German word for "knight", beside the word "von" which in the German language always indicates nobility.

[12]I.e. head-neck-surgery. This medical sub-discipline was, together with respiration physiology, the primary "supplier" of aviation physiologists (cf. Alford, 1998).

[13]For biographical information on both Schrötters, see Csendes (1999).

physiology, not so much through his own findings, but through his authorship of seminal monographs and collaboration with several other important European physiologists.[14]

The only sources on biographical data is Csendes (1999) plus Gunga's biography on Nathan Zuntz which provides some information on Schrötter, since he and Zuntz were good friends and collaboratored in joint projects, especially in ballooning (cf. Gunga, 1989). At this point, however, I am only interested in Schrötter's influence in both physiological and technical terms, as he designed significant apparatuses for aviation. His reception by the international community, by physiologists like Leonard Hill or JS Haldane speaks for itself and signifies the eminence of his publications. These were first and foremost Heller et al. (1900), a voluminous monograph on the history and medical implications of barometric pressure; Schrötter (1904), a book on the use of oxygen as therapeutic; and Schrötter (1907a), the first book on aviation medicine worldwide.

Hermann von Schrötter studied medicine and natural science in Vienna, Austria, and Strasbourg, France.[15] He attained his PhD in medicine in 1894 and one in the humanities in 1895. After that he worked for two years at the *Chirurgische Klinik* and then at the *III. Medizinischen Klinik* until 1908 (both were in Vienna), of which his father was director. In 1920 he assumed the directorship of the *Lungenheilstätte Alland*, a clinic for lung-diseases founded by his father in Lower Austria, despite his own suffering from a lung disease. The clinic was transferred into private ownership the next year (it had been temporarily nationalized after his father's death), and Schrötter was given a post in the *Office for Public Health* in the Austrian *Ministry of Social Administration*. He achieved his *habilitation* in 1925, retiring the same year from his office.[16]

Schrötter did his military service in 1891, and was promoted to *Regimentsarzt* (regimental doctor) of the reserve in 1913. In the First World War he served as medic officer, promoted to surgeon major in 1916, and was finally discharged from service in 1919. In 1900 there was a dispute over the original authorship of an earlier work on DCI. Not much detailed information is available, but according to Csendes (1999), Schrötter claimed the sole authorship of said publication, but was turned down by the court and found guilty of violating intellectual rights. Upon this conviction, he was expelled

[14]In one of the obituaries on Schrötter (written by his friend Adolph Loewy, another eminent European high-altitude physiologist; Loewy, 1928) it is mentioned that he also had a keen interest in geography, ethnography and anthropology, on which he spent some of his time. Loewy (1928) indicates that by this frittering away of his energies Schrötter's recognition as a scientist was severely hindered.

[15]As a matter of fact the province of Alsace-Lorraine, of which Strasbourg is the capital, was occupied by Germany after the French-German war in 1870/71, and fell back to France after the First World War in 1918. So during Schrötter's time in Strasbourg 1890/91, the city and the area were under German reign.

[16]All information from Schrötter's entry in Csendes (1999).

from the military, but rehabilitated in 1906.

Beside his investigation in otolaryngology, he started to inquire into the effects of barometric pressure on the human organism from 1897 on. His first publications dealt with the pathology of mountain sickness and caisson sickness.[17] Both these works did not contribute much towards original findings, but served as very complete review of the state-of-the-art in the respective fields, serving as standard references for the scientific community.

Technology

Schrötter, very much like other physiologists of his time, was keen to invent technology for or from his work. Physiologists often had to invent technology for recording of their experiments, and they also often had ideas for technically overcoming physiological problems of the human organism. Particularly in the field of diving and aviation the cooperation with engineers was very close and fruitful.

Schrötter, for instance, collaborated a lot with the Drägerwerke (or short: Dräger) in Lübeck, Germany, to produce breathing devices. Schrötter also proposed a special breathing mask, instead of the pipe-stem system, which nonetheless prevailed for a good time, since the mask-principle introduced its own problems which needed some working-out before being ready to apply (see section 5.3).

Also, Hermann von Schrötter proposed a sealed gondola for ballooning (see figure 3.2 and chapter 5) and discussed this principle with different engineers. He also discussed diving technology with engineers and even filed a patent for mixed-gas diving. In 1907 he proposed a system for breathing a mixture of oxygen-hydrogen (or, alternatively, oxygen-methane) to speed up decompression (Schrötter, 1907b). He correctly assumed that when the nitrogen in the inspired air is replaced by another gas, the off-gassing of nitrogen is accelerated. Pure oxygen would actually be better, but as Bert had shown, pure oxygen becomes toxic at a partial pressure of 1.6bar, hence with 100% oxygen one can not go deeper than 6m.[18]

This idea, in a modified form applied later on, could furthermore be employed in an autonomous system, in which the partial pressure of the gases is regulated by pistons that react to the ambient (i.e. hydrostatic) pressure. As a matter of fact this idea is discussed by a number of contemporary diving physiologists, but Schrötter might be one of the first to make an actual technical proposal. His principle has two flaws however: 1) Any gas inspired that is not processed by the human metabolism acts as *inert gas*. Every inert gas contributes to the DCI problem, even though gases with a lower

[17] Cf. Schrötter (1899) and Heller et al. (1900).

[18] At sea-level the atmospheric pressure is already c. 1bar, and for each 10m water depth, there is one additional bar. Hence, the critical pressure of 1.6bar is reached at 6m depth.

atomic number[19] than nitrogen diffuse much faster and thus allow shorter decompression times, but they do not eliminate the need for decompression, as Schrötter (1907b) insinuates. It would be much more appropriate – and as practiced today – to use the gas mixture throughout the dive, and not only for the ascend. 2) The use of oxygen-hydrogen mixtures were extensively researched in the 1960s. Hydrogen seems most attractive, since it has the lowest atomic number, i.e. it would diffuse from the tissues fastest. However, it was given up in favor for helium (ranking second in the periodic table), since a oxygen-hydrogen mixture is extremely combustible (cf. Bennet and Elliot, 1993).

Notwithstanding these shortcomings, Schrötter (1907b) displays a good understanding of mechanics and technology, and it hints at Schrötter's inclination to discuss technical issues with engineers like Hermann Stelzner from Dräger. The idea of having a system that automatically mixes the gases depending on the ambient pressure is quite advanced and not realized even today (divers use pre-mixed bottles, which they have to change when reaching a certain depth). Further efforts of Schrötter to collaboratively develop breathing and diving equipment are shown in section 5.3.

Ballooning

As noted above, Schrötter became interested in aviation around 1900, obtaining a license as balloonist from the Berlin *Aëro Club*. He undertook his first ascents in 1896/97 up to 3500m. At this height, however, only slight symptoms of hypoxia and other phenomenons connected with low barometric pressure can be observed, so he strove for higher flights. Finding no such opportunity in Vienna, he moved to Berlin for some time, befriending a number of balloonists and physiologists, which – as pointed out above – were often one and the same persons.

Thus, in 1901, he accompanied R. Assmann in several ascents in Berlin, leading him to flights between 7000 and 8000m, for a total of 12 flights (Schrötter, 1912, 2). He made several experiments in the lab with Berson and Süring and worked out the guidelines for their stratosphere flights (Süring, 1909, 55). On June 24, 1903, he also traveled with A. Berson to 8770m.[20] Furthermore, in 1903 Schrötter proposed a sealed gondola for high-altitude ascends.[21]

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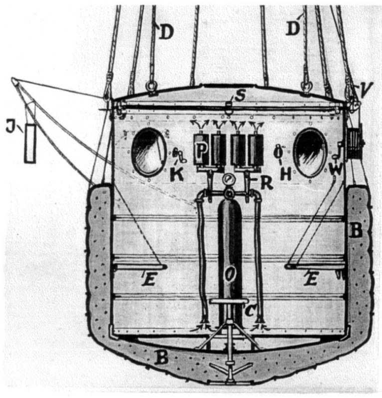
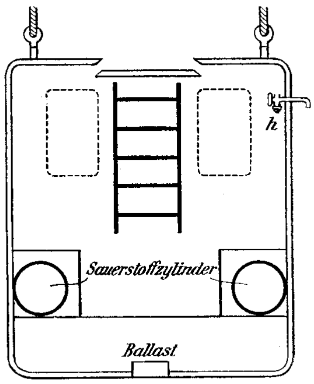
[19] Cf. "periodic table" in Encyclopedia Britannica (2004).

[20] Cf. Süring (1909, 58) and Schrötter (1912, 6). His travels and his research with Zuntz will be displayed below, see also section 4.2 for Assmann and Berson.

[21] Cf. Schrötter (1903). See also fig. 3.2 for a sketch made by Stelzner in 1910, and a sketch from Schrötter (1912). Unfortunately, not much information of Stelzner's source is available. The folder in the archive of the *Deutsches Museum* contains (beside the sketch itself) only a small note on the sketch, specifying its creation date to 1910 and Stelzner as its creator. Whether Stelzner really got the idea from Schrötter is not clear, but considering that both had cooperated in the design of the Dräger high-altitude breather, it is very likely (cf. Dräger, 1904). Ruff (1989, 37) alleges that Dräger/Stelzner had the



(a) Drawing by Stelzner in 1910, after Schrötter. Reproduced by permission from the Deutsches Museum.



(b) Drawing in Schrötter (1912).

Figure 3.2: Sealed gondola, after Schrötter.

He then made numerous experiments on the effects of low barometric pressure, resulting in the monograph Schrötter (1912), of which Csendes (1999) states that an earlier, shorter first edition was published in 1908. Schrötter (1912), however, cites Schrötter (1907a) as this earlier edition, which has been extended considerably in his words.[22] The monograph is rather a survey of the state-of-the-art in the subject than a piece of original work in the field. His physiological "investigations" are at large an appraisal of Bert's findings and many other physiologists, including Zuntz, Haldane, Douglas, Barcroft etc. This is an observation that can be made in many of his publications on diving and high-altitude physiology, and is not meant derogatively. On the one hand he provided nearly the only complete references on these subjects[23] at that time, leading to a great popularity of his publications among physiologists,[24] and on the other hand he could thereby "assemble" the distributed and scattered knowledge and garnish it with findings of his own (many of them on the applied side of science), defining his publications

idea independent from Schrötter. Furthermore, the information that the design of such a gondola was devised by Schrötter in 1903 is taken from Csendes (1999). In Schrötter (1912, 33), however, he describes the design as "proposed in a presentation in Berlin six years ago" (translation mine). Whether this refers to 1906, or to 1902, is not clear. Süring (1909) and Zuntz (1912) both report of Schrötter's idea of a sealed gondola.

[22] Schrötter (1912) in his foreword states that Schrötter (1907a) has been extended with information on the hygiene of the flying machine (i.e. an aeroplane), a device not readily available in 1907, but in 1912.

[23] Like Heller et al. (1900) for diving and Schrötter (1912) for aviation, or Schrötter (1904) on oxygen as treatment in DCI.

[24] His publications are widely and often cited by eminent physiologists in the field like Leonard Hill, J.S. Haldane, Joseph Barcroft, etc.

as *standard reference* for a while and thus furthering his scientific reputation.

For instance, he was the first to mention that above a height of 5000m pure oxygen shall be breathed (Schrötter, 1907a, 15; the principal idea coming from Bert) and specified the parameters for the flow rates for oxygen apparatuses (Schrötter, 1912, 28). He also gave for the first time the threshold values for oxygen depletion at high-altitude, providing a table with the physiological values of oxygen tension in the inspired air at various heights and the resulting oxygen tension of the alveolar air up to 12000m, and how breathing of oxygen shifts these parameters to allow for greater heights (values up to 17000m are given).[25]

Hermann von Schrötter therefore remains an important actor in the history of diving and high-altitude physiology, not through his genuine work, but through his dissemination of knowledge of the field and his cooperation with other physiologists and with engineers, which will be considered in the next chapter.

3.2.3 Nathan Zuntz

Nathan Zuntz (1847–1920) was one of the champions of German science. He was one of the most reputed physiologists of his time, visible by many references made to him in international publications. Haldane, Hill, Barcroft, and many others regularly cite his fundamental work around 1900. He was also the master mind behind the Anglo-German mountain expedition to Teneriffe in 1910 and he was the greatest authority on mountain or high-altitude sickness at the end of the nineteenth century.

Together with his former student Hermann von Schrötter he investigated high-altitude sickness in ballooning (e.g. Zuntz and Schrötter, 1902) cooperating with the meteorologists Berson and Süring in Berlin. He did not, however, ventured into designing technology like von Schrötter. In this light, von Schrötter left much more impression in the field of aviation medicine, since he devised many devices like the sealed gondola or the oxygen mask. Even though Zuntz was certainly the more able man in terms of scientific achievements, von Schrötter was more influential in the long run.

Biographical details have been extensively given by Gunga (1989), and Gunga and Kirsch (1995a,b) for summaries in English. Zuntz came from a tradition of physiologists, his father Leopold Zuntz (1814–1874) being an eminent scientist in his time. Even though Nathan Zuntz must be regarded as "father" of aviation medicine in Germany, he was not commemorated by later aviation physiologists, especially in the Nazi period, since he was of Jewish religion and only rediscovered as an important figure in recent years.

Zuntz, as mentioned, investigated more into fundamental – often dubbed "pure" – science. Especially concerning the question of oxygen, in which

[25] Schrötter (1912, 16), this height is not correct, though, as Zuntz elaborated the same year (see below).

he conducted numerous studies. The use of oxygen to avoid high-altitude sickness was debated among physiologists and others until the 1920s (see below), and Zuntz adamantly argued in favor of it. In the discussion session of Anonymous (1903), e.g., he vigorously stated, that "all objections to the life-saving effect of oxygen are decrepit".[26]

In Zuntz (1912) he calculated the height limit attainable by breathing pure oxygen. *Dalton's law* from physics, which states that the pressure of a gas mixture is the sum of the partial pressures of the gases that compose the mixture, is the basis for such calculations, and Zuntz made full use of it.

Zuntz assumed that the contemporary form of oxygen in tanks will never be totally pure, but rather has three to four percent nitrogen in it, and even seven to eight percent have been encountered by him in some tanks. Zuntz therefore recommended that the oxygen in the tanks had to be analyzed prior to a flight and that more than three percent impurity should not be tolerated (Zuntz, 1912, 62).

He then continued to calculate the minimum barometric pressure to sustain life. Assuming that the water vapor pressure in the lungs is at 46mm Hg, plus, the pressure of CO_2 inside the lungs is at 60mm Hg, and the nitrogen from the oxygen tank amounts to 4mm Hg. A sufficient oxygen partial pressure would, according to Zuntz (1912), level at 40mm Hg, and thus the minimum barometric pressure of the inspired gas must be 150mm Hg, which is equivalent to 13km height Zuntz (1912, 63).

Zuntz stated that the value for carbon dioxide is extremely conservative and that Arnold Durig (1872–1961) has specified a lower value of 36mm Hg, resulting in a net maximum height of 14300m that could be attained when breathing pure oxygen. Zuntz, however, makes sure that this maximum would be only achievable when breathing through a mouth-piece, which he does not favor for other reasons (see section 5.3). Rather, he recommends the use of oxygen masks, like that of Schrötter. These masks, however, have a so-called "dead space", i.e. part of the expired air accumulates in the mask and is inspired again. Zuntz set this volume to 140ccm, and 150ccm with a safety-margin for calculations. This would increase the carbon dioxide in the inspired air, and after some calculations on air circulation in the mask, Zuntz sets the CO_2 value to 64.5mm Hg, resulting in a maximum height of 12705m. Zuntz (1912) thus evinces that the benefit of oxygen to extend the height limit depends heavily on the technology employed, and demands that equipment and tanks must be thoroughly checked prior to any ascend (Zuntz, 1912, 64).

Zuntz (1912) also discusses technology, like masks and liquid oxygen, but he chiefly refers to other people's work, despite his cooperation with them (Schrötter, Berson, Süring). His fundamental researches and personal participation surely have inspired a good number of technical projects, but

[26] Anonymous (1903, 47), translation mine.

he himself was not too technically inclined. So even though he was part of a techno-social network, he is not central to my investigation of diving and aviation related personal equipment. His influence on other relevant scientists, however, is indisputable. One such case would be the British physiologist Leonard Hill.

3.2.4 Leonard Hill

Particularly in the case of Leonard Hill, sources were hard to find. There is no dedicated Hill-Archive, nor are there institutional archives that would host considerable collections on him. The only documents available were some letters in the NLS, the CCAC, the RGS and the RI.[27] This correspondence was illuminative, but not sufficient to trace Hill's involvement with the relevant fields. This gap could be closed by using contemporary publications, as well as the obituaries on him (Douglas, 1953; Partin, 2001). Surely, obituaries are a problematic source. In the case of Douglas (1953), it gets even more troublesome, since Douglas was a close friend of J.S. Haldane and also wrote the obituary on him (Douglas, 1936). Haldane and Hill, although the latter always spoke highly of the former, had a dispute in the field of decompression research (see below), which was pretty much suppressed and euphemized by Douglas (1953).

Thus, care must be taken when outlining Hill's biography. Since, however, his general biography is not of utmost relevance to this publication, but rather single aspects of his career, the archivals together with the contemporary publications suffice to integrate his work into the history of diving and aviation medicine.

Short biographical sketch

Leonard Erskine Hill was born in Tottenham (UK) in 1866. There he attended the *Hazelwood School*, which was purchased by his great-grandfather in 1820. Hill's father presided over the school until 1877 and soon dictated his son's career, as he wanted him to become a physician, despite Leonard's desire to become a farmer (Partin, 2001, 169). He was then sent to *Haileybury College* to study the *Classics*, his father being apparently unaware that to become a physician a different education would be required. Thus, when Leonard Hill entered the medical school of *University College* in London (UCL) in 1885, he had troubles to master the new curriculum. After some work, he could nonetheless catch up and even win distinctions like the Bruce Medal and finally receive his M.B. in 1890. After attending a lecture of John Burdon Sanderson, he decided to strive for a research career. He received a scholarship at UCL, briefly taught at Oxford, held a post as as-

[27]See Appendix A.

sistant professor at UCL, and he finally became lecturer in physiology at the *London Hospital* (LH) in 1895 (Partin, 2001, 170).

His first researches and publications dealt with the circulation and the pressure of blood. Together with H. L. Barnard, he developed the armlet method of blood pressure measurement. The paper on that gauge was rejected by the *Royal Society*, since it was "only on [...] an instrument".[28] Nonetheless, Hill was elected a fellow of that society in 1900.

After leaving LH in 1914 he became director of the Department of Applied Physiology in the National Institute of Medical Research. There he carried out investigations on a field that occupied the major part of his scientific life: the health of workers.[29] His researches included studies on diet issues, gas warfare, ventilation in dug-outs or the influence of humidity, heat and ventilation on health and working capacity of humans.

He became one of Britain's vigorous advocates of the therapeutic use of oxygen. He was, for instance, the inventor of the *oxygen tent*. The use of oxygen in the treatment of sick persons was still disputed in the 1930s, and Hill emphasized his position in the *TIMES*:[30]

> "The letter of Sir Robert Davis (The Times, August 18) gains the support of physiologists. [...] The breathing apparatus designed for resuscitation by Sir Robert is excellent and should be available everywhere. [...] Many years ago Sir Robert Davis constructed for me an oxygen bed.[...] This invention was used by me with success, but met with neglect. In America it has been reinvented, and there are now several oxygen tents on the market."

Hill was also, like numerous other physiologists of his time, involved in topics outside the scientific world. He was, for example, a passionated painter and lover of the fine arts, including music.[31] In 1935, he founded the *Medical Art Society*. Being a painter himself, Hill managed to exhibit his works in numerous galleries. After befriending a Japanese visitor in London, a total of three exhibitions of some of his paintings was staged in Japan, which were

[28] Partin (2001, 170). This notion of that society is very interesting, since historians of medicine are still somewhat reluctant to deal with the applied and technological side of medical research and rather focus on the development in pure science and on biographies.

[29] A very similar field of investigation that Haldane was occupied with, who made a number of achievements in industrial hygiene, as well as diving and high-altitude physiology. Thus the researches of the two often "collided", as I will outline below.

[30] *Letter to Editor* in the TIMES, titled "TREATMENT OF GAS POISONING. OXYGEN AND CARBON DIOXIDE. USES IN PNEUMONIA", August 23, 1932, p. 11, col E. Right before Hill's letter, there is one by J.S. Haldane, also referring to Davis' letter a few days before and supporting the widespread use of his *resuscitation apparatus*. Both Hill and Haldane mentioned the "pioneering" role of Yandell Henderson in the USA in their letters.

[31] He noted that a singer could sustain a tone longer after inhaling oxygen. He deliberated that it might be possible to compose music specifically for vocalists who inhaled oxygen prior to their singing (Partin, 2001, 170).

well-received there.[32]

Hill also participated vigorously in public debates, chiefly in the hygiene of workers and the general public. A query on the *Times Digital Archives* yielded nearly 50 hits in the database, the vast majority being *Letters to the Editor*, in which Hill elucidated his position on health issues or his involvement in research projects. Also, he contributed much to the popular magazine *Nature*, either in the form of articles or again in *Letters to the Editor*. He died in the year 1952 in London, UK.

Diving Physiology

In 1900 Hill delved into decompression research in diving. His first investigations were carried out together with J. Macleod (cf. Hill and Macleod, 1903a,c,b) and later together with M. Greenwood (cf. Hill and Greenwood, 1906, 1907a,b). Eventually, Hill published a monograph on the subject (cf. Hill, 1912). Hill took up the then common form of *uniform decompression*, as devised by Paul Bert. He felt that this form would provide a sufficiently safe form of decompression. Together with his colleagues, they tried the decompression strategies on themselves in the decompression chamber of the *Lister Institute* in London.

Hill, who started his scientific career on issues of circulation, soon conceived that certain tissues of the body have different saturation rates than Bert, Zuntz, Haldane and others had assumed. In Hill and Greenwood (1907a) he showed that the human urine is saturated with nitrogen in a very short time, but the evidence did not suffice to conclude from this that the kidney cells itself saturated faster than other tissues. Only years later, did Hill together with Campbell manage to provide an experimental proof.[33]

Nonetheless, Hill championed *uniform decompression* and still remained skeptical of Haldane's *stage decompression*. He also doubted whether experiments on goats (as carried out by Haldane *et al.*) delivered any reliable data, having himself experimented on pigs which, as he evinced, showed different results (Hill, 1912, 214). He had discovered that Haldane's threshold values for safe decompression were not conservative enough, and his skepticism arose from this circumstance, and not from a general deficiency of Haldane's principle.

Hill and Greenwood in their early studies were able to safely decompress themselves after short exposure to 6atm, taking 20min decompression time for each atm thereafter. Their strategy, just as had been the case with *uniform decompression* strategies of others, was quite fuzzy though, and it was hard to define a general scheme for decompression. This shortcoming was

[32] Douglas (1953, 483). Partin remarks, that particularly Hill's painting of a turkey achieved some sensation among the visitors in the galleries in Japan.

[33] Cf. Hill and Campbell (1933a,b,c). Also, Hill's letter to Haldane from July 15, 1906, discusses urine saturation. NLS, MS 20510, F192–195.

eliminated by *stage decompression*, making decompression a comparable deterministic procedure, despite shortcomings with early decompression tables calculated by this procedure.

Hill and Haldane

Haldane approached Hill to get access to the decompression chamber at the Lister, since Hill had occupied it for his and Greenwoods experiments. Hill misunderstood this as an invitation for a cooperation. Haldane's letters to Hill have not survived, Hill's letters to Haldane as found in the NLS provide a clear picture of the misunderstanding, though. In the first letter from Hill to Haldane, the former made all kinds of suggestions how to organize the experiments, what kind of experiments should be conducted, etc. The whole letter epitomizes Hill's delight and willingness to do research with Haldane, and getting involved in the research for the Admiralty.[34] The second letter then displays his disappointment:[35]

> "Many thanks for your letter. I only wanted matters cleaned up, for I was under the impression we had slanted in a joint research. Greenwood and I will now confine ourselves to our own experiments and their interpretation. I leave you and Boycott to the Goats. Same misunderstanding was bound to arise since I supposed you had asked me to carry on the research, while Boycott and Damant evidently knew nothing of this, you yourself became interested and took over the complete control. I am not the least afraid of your "cutting in" to my work. It's all an open field, and so long as the bulk comes out of the tangle, I don't care whether you or I straighten it out a bit further."

Hill was convinced of his strategies and tried to demonstrate to Haldane their feasibility. He failed, however, to demonstrate the superiority of his findings, i.e. his supposed advantage of uniform decompression over stage decompression.

This rivalry in the field of decompression research is not the issue here. Hill fully acknowledged Haldane's principle of *stage decompression* as the better one some years later, as well as he always spoke highly of Haldane. What is more interesting here, is Hill's capability to cooperate with engineers, namely Robert Davis of Siebe & Gorman, and to deliberate himself technical apparatuses that are not primarily medical devices – just like J. S. Haldane.

In the first letter to Haldane, Hill not only outlined the various kind of experiments he would like to carry out, he also sketched his idea of a *submersible decompression chamber* (see figure 3.4).

Despite Haldane's rejection of Hill's decompression strategy, this idea of a submersible chamber was acknowledged as a viable improvement in

[34]Letter from Hill to Haldane, July 15, 1906. NLS, MS 20510, F192–195.
[35]Letter from Hill to Haldane, July 24, 1906. NLS, MS 20510, F198.

decompression procedures:[36]

> ”Dr. Leonard Hill has proposed the plan of lowering to the bottom a steel chamber, into which a diver could get on the completion of his work and close the door. The chamber could then be hauled to the surface, the pressure inside being lowered very gradually by allowing the air to leak out at a perfectly safe value. In this way the danger of decompression could be completely obviated.”

The idea of a submersible decompression chamber already bears the idea of the pressurized airplane cabin in its back. The idea of Hill, to restore – and more important: to control – the ambient pressure the diver is exposed to is vital for both the concept of a pressure suit or cabin. The idea behind such devices is to maintain an ambient pressure at a level were the aviator can work efficiently and comfortably. Such is the idea behind the submersible chamber for divers: to control the decompression process and to decouple it from uncomfortable or even dangerous environmental factors like tides, currents, cold, dehydration, etc.

The chamber was soon constructed and put into use by Siebe & Gorman (Davis, 1935). Leonard Hill's role as inventor of the concept is usually omitted from historical accounts, which usually specify Davis as the inventor.[37]

The submersible chamber, though perhaps Hill's most important contribution to diving technology, remains not his only one. Just like Haldane, he jointly developed diving gear with Robert Davis, filing several patents with the latter.[38]

Hill could never gain much support for his diving researches from official sources. Most of his investigations into the physiology of diving were conducted during his time at UCL. Also, Robert Davis let him use the testing facilities at Siebe & Gorman. Only in 1930 when the Second Committee on Deep-Diving was formed by the Admiralty, was Hill made the scientific member of it, with A.E. Boycott (Douglas, 1953, 434). Haldane was not involved in this second committee. Boycott, however, kept in touch and occasionally discussed matters with him.[39] The task of the committee was to revise and

[36]Haldane et al. (1907, 54–55), also see the manuscript of the report, NLS, MS 20514, F17.

[37]Even in more or less contemporary accounts, as in Stelzner (1931), who in other cases correctly references Davis' cooperation with Hill or Haldane. On the other hand, he usually does such references on the ground of jointly held patents by Davis and either Hill or Haldane. So most likely, Hill never made any claims on the patent level, leaving the sole credit to Davis.

[38]E.g. Davis (1907). This patent describes an improvement in Davis' former design of a *rebreather*, in the form of a reduction valve which controls the injection of oxygen into the circuit. The flow of oxygen was too rapid in the old design and the valve through which is was injected too small, thereby imposing a risk to its user.

[39]See e.g. a manuscript from Boycott that he sent Haldane for comments. This paper summarizes the findings of the second committee compared to the first. NLS, MS 20513, F141–144.

refine the findings of the first committee, namely the Haldane-Tables, to allow for shorter decompression times and also to extend the tables to deeper dive profiles.

Since Haldane's researches, diving equipment had been improved and regular dives to greater depth were made. As it turned out, Haldane's tables were proximal to safety thresholds. Hill and Boycott found that to allow ascends from these greater depths safely, Haldane's 2:1 ratio had to be modified to 1.75:1. As a result, the second committee presented tables for dives up to a depth of 91.35m (300ft), and even greater depths had been reached in the experiments. The committee's report was published in 1933.[40]

Aviation Physiology

Though not having any seminal publications to his credit, or having any significant post within civil or military aviation, Leonard Hill became nonetheless one of UK's eminent scientists in regard to aviation medicine. Besides designing oxygen devices for the British expeditions to Mount Everest (see below), and having devised important work on high-altitude physiology, he was also the professor in charge of training Martin Flack (1882–1931), who later became director of medical research at the RAF. Together, they undertook various studies in the 1910s, all on general physiology and sports medicine. During the First World War, Hill and Flack investigated oxygen apparatuses for aviators. In 1919 they published a textbook on physiology, which also included a chapter on aviation medicine by Dreyer.[41]

Sources on the nature of their experiments are rare. Neither manuscripts nor publications from this time are available. One of the few links between Hill and Flack are found in the introduction by the chairman of the *Royal Aeronautical Society* (RAeS), when Flack held a lecture at their third meeting in 1920 (Flack, 1920, 650):

> "The Chairman in introducing the Lecturer, Wing-Com. Martin Flack, said there were two kinds of physiologists or investigators into the normal functions or activities of living bodies, both of whom did extremely valuable work: (1) Those who attacked problems from a purely scientific standpoint, for the love of truth and without any utilitarian thought; often their results were eventually found to be of great practical value; (2) those who attacked and solved questions with an obvious bearing on health, industry or preventive medicine; this was applied physiology, and Dr. Leonard Hill was its apostle. Wing-Commander Martin Flack was his disciple and had devoted himself to elucidation of practical problems in connection with the selection and testing of airmen."

[40] Douglas (1953, 434)

[41] Hill and Flack (1919). For minor information on Dreyer and Hill's and Flack's WWI oxygen equipment research, see section 5.3.2.

Hill apparently remained in touch with Flack to discuss physiological issues, but how far their cooperation, if any, continued is not visible – the only exception being the oxygen equipment tests for the Everest expedition in 1921 (see section 5.3.2). It is also hard to evaluate if Hill had any official cooperation to the RAF in his 1920s studies on mountain physiology and breathing apparatuses, in which RAF officers participated. His most important and influential researches were surely made during World War I which had great influence on Martin Flack. At the time of their cooperation (and thereafter), however, they could not publish on it much as their work was considered confidential.[42]

In the 1930s Hill conducted experiments on physiology at great altitudes in the decompression chamber at the Siebe & Gorman facilities in London, cooperating with Robert Davis to design altitude breathers. In 1931 Hill cooperated with Joseph Barcroft, another eminent physiologist in the field of high-altitude studies, to check the breathing of oxygen as a means of extending the height limit for humans. Using Eric Taylor from the Siebe & Gorman staff as the test subject and the company's *Salvus* apparatus for breathing pure oxygen, they made tests at various pressures. These tests consisted of taking notes of his condition on a piece of paper by Taylor. Above 12180m (40000ft) Taylor found it very hard to write down his impressions and to control his senses. A report of these 1931 experiments was published (Barcroft et al., 1931), but Hill does not appear as author, despite speaking of his cooperation in the experiments (Hill, 1934, 299).

In Hill (1932a), however, he gave a short report on his findings, picking on Schrötter (1904) to elucidate the height limits a person could reach with and without oxygen. In it, Hill corrects the values of water vapor pressure and carbon-dioxide in the lungs that Schrötter and Haldane have specified. He thus comes to a different conclusion than Zuntz (1912), who had outlined a limit of 12000m. Hill argued that 11000m would constitute the maximum height that can be safely reached when breathing pure oxygen. He also notes that the symptoms of hypoxia – tested on small animals and goats – are notably improved when breathing oxygen prior to the decompression (Hill, 1932a, 397):

> "These animal experiments show that, given an efficient oxygen breathing apparatus and an hour, say, spent in breathing oxygen before the climb in order to wash out nitrogen from the body, a pilot might attain certainly to 50,000 and perhaps even to 55,000 ft."

In this statement Hill speaks of nothing but *denitrogenation*, a practice now commonly employed in preparing astronauts for EVA, and used for instance by US and Italian pilots shortly before WWII.

[42] Cf. a letter (1917) from W. M. Fletcher from the Medical Research Committee of the Royal Army to James Dewar, in which the former indicates that Hill's and Flack's research (and Dewar's support to this) were officially regarded as "confidential". RI, DEWAR/DVIIc/61.

In 1933 Hill collaborated with G.S. Marshall, director of the Medical Service of the RAF. Again they were testing Eric Taylor at Siebe & Gorman for the safe limit of extending the maximum height attainable by a human by breathing pure oxygen. Marshall (1933) reports on his insights, including his experiments with Hill, referring to him as his source of knowledge in a great variety of topics in aviation medicine. This time, they took Taylor to 13925m (43660ft), but he fell unconscious, so the pressure was dropped to 12789m (42000ft) again, where he slightly recovered (Hill, 1934, 300).

Summarizing and discussing the experiments done previously, taking into account the height record of C. F. Uwins from 1932 (13398m, 44000ft), Hill concludes (Hill, 1934, 306): "When breathing oxygen loss of consciousness occurs in monkeys and men when the barometric pressure falls to about 115mm Hg."

This limit of 115mm Hg is very close to the limit nowadays accepted as threshold value of 0.16bar for hypoxia (Beers et al., 2006). Hill then refers to Haldane (1922) and Haldane's experiments with Davis and Mark Ridge to evince that breaking the limit of 115mm Hg would require a pressure suit (see section 4.4.2).

Even though Leonard Hill did substantial work on aviation and high-altitude physiology, he is scarcely commemorated for his researches in this field. The main reason for this might be that he never published anything substantial on it, besides some rather informal articles in scientific and semi-scientific journals (e.g. Hill, 1932a, 1934). His affiliation with Flack is hardly mentioned[43] and their joint papers deal with general physiology.[44] Hill's work with and for the Everest Expedition or at Siebe & Gorman on questions on high-altitude physiology is not documented by historians of medicine. This is even more astounding, since, for example, Hill in comparison to John Scott Haldane was socially and scientifically more well-accepted. But where Haldane did not publish much on aviation medicine, the *Haldane-Davis pressure suit* helped to sustain his name in this field.

[43]Gibson and Harrison (1984) don't mention Hill at all.

[44]Douglas (1953), in its appended bibliography lists up ten papers and one book (Hill and Flack, 1919) authored jointly by Hill and Flack between 1909 and 1919.

3.2.5 John Scott Haldane

John Scott Haldane (1860–1936)[45] is a controversial figure in 19^{th} and 20^{th} century science. Honored and respected for his scientific achievements and the humanitarian value of his work in industrial hygiene, he exacerbated many of his contemporaries with his philosophical sermons. Or, to put it more precisely: It was not that he published many philosophical pamphlets and engaged in many discussions that would turn other scientists off – philosophical and popular writings were expected from the Victorian scientists, anyway –, but the way he vigorously defended his ideas, and attacked other scientists who did not share his point of view, led to negative attitudes toward his person by other scientists.[46]

The controversies he provoked were not restricted to philosophical issues, however. Whereas philosophy was concerned, he vigorously opposed the *mechanistic* conception of physiology, or materialism in general. Sturdy (1987, 1988) has discussed Haldane's philosophy in great detail, and I have myself published a short paper on the topic (Lünen, 2006b). It is therefore neither necessary nor within the scope of this publication to discuss Haldane's philosophy. It will therefore only be discussed where it matters for the context of the publication's topics.

Historians of Science and Technology have much neglected Haldane, usually picking up his much more famous son JBS, while Historians of Medicine deal with Haldane in a rather limited and hagiographic fashion. Publications on the history of mountaineering or the history of diving use some single aspects of his work, not contextualizing it with Haldane's social network, which plays an important role in his life. Books on diving, e.g. Phillips (1998), or on mountain sickness, e.g. West (1998a), – as they nonetheless are excellent works – focus on very narrow and special topics, leaving much to be desired

[45] John Scott (JS) Haldane is often mixed up (in both contemporary and historian accounts on the Haldanes) with his son John Burdon Sanderson (JBS) Haldane (1892–1964), who gained a reputation as both pioneer in genetics and biometry, and popularizer of science. This confusion was predicted by JS Haldane when he wrote to his mother on November 26, 1892: "We have fixed on the name John Burdon Sanderson for Spawks, & to call him Jack, which will distinguish him from various Johns." NLS, MS20659, F254. In this publication, when I refer to "Haldane", I mean JS Haldane, and not JBS, unless noted otherwise.

[46] The eminent physiologist Archibald Vivian Hill (1886–1977), Nobel prize winner of 1922 and for a time secretary of the Royal Society, wrote a small note in his later years when he sorted his personal papers and correspondence from the past: "John Haldane (not J.B.S.!) A very great scientist who had a great influence. Often wrong and stupid. But discounting that I proposed him for the Copley Medal – which was awarded." CCAC, AVHL 3/29. The Copley Medal is awarded by the Royal Society for outstanding scientific achievement, Albert Einstein or Max Planck (and in 1948 Hill himself) among the winners. JS Haldane received the Copley Medal in 1934, after his friends A.V. Hill and C.G. Douglas have proposed him for this distinction. Douglas, former student, close friend and colleague of Haldane, has authored the proposal and eulogy for Hill, as can be seen from various letters between Douglas and Hill in the Hill-Archive (CCAC, AVHL).

as far as social and historical context is concerned.

This shortcoming, or, rather, the neglect of JS Haldane in historians' accounts, is partly owed to the controversies Haldane created. While many contemporaries regarded him as a genial, but stubborn, scientist, there were many amongst his friends – mostly former students and colleagues – who had the highest regard for him. These friends – first and foremost Claude Gordon Douglas (1882–1963) – tried to "disarm" the controversies and retain his reputation. This is especially true of the obituaries on Haldane which were more or less all authored by Douglas: the obituary of the Royal Society (Douglas, 1936), which served as model for many obituaries in daily newspapers like *The Times*, was copied into the *Oxford Dictionary of National Biography* (Smith, 1949), and was copied in large parts by Yandell Henderson as obituary for the *Journal of Industrial Hygiene*.[47] Plus, the proceedings of the centennial symposium on JS Haldane, held in 1962 in Oxford, contains a reprint of Douglas' obituary. Thus, most, if not all, biographies were in one form or another the obituary authored by Douglas.[48] Much of his philosophical and scientific controversies were not mentioned in Douglas' obituary, or put very euphemistically.

Among the many controversies, the most devastating for Haldane's reputation was his denial of the *Second Law of Thermodynamics* in the 1920s. Haldane published several books on his conception of heat energy and how this fitted into his philosophical framework – which he called "coordinated activity" or "coordinated whole", later he adopted J.C. Smut's "holistic biology" (cf. Sturdy, 1987). He regarded the *Second Law* as philosophical and scientific mischief.[49] His books, papers and talks on this topic created a considerable stir among scientists. His friend Douglas started to worry considerably and tried to counter-act his mentor's aberrations:[50]

> "Your letter worries me a great deal. I have the greatest personal regard for Haldane; I regard him as the greatest physiologist that this country has produced, and I think that there are others who would agree with me. But when it comes to thermodynamics I can see that he is asking for trouble."

Haldane, however, stoutly insisted on his views and would make no concession to a plausible argument. Just as in the case of *Oxygen Secretion*, he

[47]The latest edition of the Oxford Dictionary of National Biography has the biography on JS Haldane written by Steve Sturdy.

[48]Letter from Henderson to Douglas, dated April 7, 1936; OPL C.11. See also Cunningham and Lloyd (1963). JS' daughter Naomi Mitchison (1896–1999), noted novelist, was the second most noted source of biographies, e.g. Mitchison (1974). JBS, too, occasionally gave biographical notes upon his father, e.g. Haldane (1960). Even though he always spoke highly of his father, there's a somewhat aloof position to be observed in his notes, mostly due to his peculiar sense for heroism of his father under which he had to suffer as child.

[49]Science and Philosophy were two sides of the same coin to him, anyway.

[50]Letter from Douglas to A.V. Hill, dated July 8, 1925.; CCAC, AVHL II 4/21.

could not be persuaded of his errors. His philosophy was to him not simply some kind of amusement for his spare-time, rather, he saw himself on a mission against mechanism.[51]

Summarized in short, Haldane's concept of *holistic biology* postulates that contrary to both the mechanistic and the vitalistic concept of physiology, the organ could not be examined out of the context of the whole organism. The activity of the single organs would follow a "coordinated activity" to constitute the organism, which then becomes the "coordinated whole" (Sturdy, 1988). While it was not uncommon for scientists to participate in philosophical debates, the vehemency with which Haldane indulged in it was far beyond the normal measures, and particularly his vigor in this respect was a nuisance to many of his contemporary physiologists.

The stance towards him by many contemporaries is perhaps illustrated best by Needham (1932). In his review on one of Haldane's philosophical pamphlets, Needham exposes the duality of Haldane's character (Needham, 1932, 525):

> "Prof. Haldane is assured of an honourable place in the history of biology in the late nineteenth and early twentieth centuries. But this will always be in spite of, and not because of, his presentation of his case. It will be said of him that he took biological organisation seriously when no other biologist would, but perhaps this recalcitrance on the part of his colleagues was partly due to his own inability to distinguish between the conflicting claims of science and philosophy, and, we may add, of religion also."

Due to his nature, Haldane could never gain a regular professorship in his life, despite his undisputed scientific credibility.[52] While this adds to Haldane pronounced attitude of hubris, this yields an interesting issue for this publication: because Haldane could not rely on the financial security provided by a professorship, he had to resort to many industry-based funding to finance both his living and research. Through this intense contact with the industry, which also can be observed in other British scientists, we get an excellent example of the successful interaction of scientists and engineers, and compare this to cooperations less fertile.

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[51] Hill, upon Douglas above recited request, wrote to Haldane on the issue. Haldane's answer is partially quoted in footnote 52. In another retrospective note in his archive, Hill stated: "JSH was convinced the second law of thermodynamics was wrong! This was due to an elementary mistake in drawing a figure. But it hung over him for years!"; CCAC, AVHL 3/29.

[52] He received an honorary professorship from the University of Birmingham in 1921. Cf. Douglas (1936). Haldane wrote to A.V. Hill on this matter: "You really mustn't worry about my reputation. I've been a heretic in science all my life, but long enough to see the world gradually coming round to my heresies, or something very like them, and I am quite confident that I am right in the conclusions of the paper I sent you." Letter to Hill, dated July 16, 1925. CCAC, AVHL 3/29.

Short biographical sketch

John Scott Haldane was born on May 2, 1860 in Edinburgh (UK). His family held high ranks in British society and politics. His father Robert Haldane was a lawyer and baptist preacher, and was married to Mary Elizabeth Burdon Sanderson (1825–1925) in his second marriage.

Mary Burdon Sanderson was great-niece of Lord Chancellor John Scott (Lord Eldon, 1751–1838) and sister of one of Britain's highest reputed physiologists in the 19^{th} century, John Scott Burdon Sanderson (1828–1905). Robert and Mary Haldane had four children: John Scott, Richard Burdon (1856–1928), Elizabeth (1862–1937), William Scott (1864–1951).[53]

William Scott Haldane became Crown Agent for Scotland from 1905 to 1917, besides other local political offices, e.g. Scottish Commissioner under the Development Fund Act in 1910.[54] Elizabeth Haldane became involved in various social societies, the *Carnegie-Trust* and the *British Red Cross* being among them, and was awarded the *Companion of Honour* in 1918 for her work in several military nursing services during World War I.[55] Richard Haldane studied law in Edinburgh and philosophy in Göttingen (Germany). He became a lawyer and local politician in the 1880s and *Member of Parliament* (MP) for the Liberal Party in 1895. In 1905 he became *War Secretary* under the government of Henry Campbell-Bannermann (1836–1908), and then under Herbert Asquith (1852–1928). In 1912 he became *Lord Chancellor* after the officeholder Lord Loreburn retired due to health reasons. In the summer of 1915, Richard Haldane retired from his office, after the conservative press – first and foremost the *Daily Mail* under Alfred Harmsworth – attacked him as being too German-friendly. Richard had always a high esteem of German philosophy and upheld many of the contacts he made during his time in Göttingen, even during the war.[56]

JS Haldane profited in many ways from his brother's political offices, as will be discussed below. Since JS Haldane not only worked for private companies, but also for a number of government commissions, his brother's position helped him raising his status with those agencies at the time.

JS Haldane received an MD in medicine from Edinburgh University in 1886, after he received an MA in *General Arts* from Edinburgh Academy

[53] Two more children died at young age. Robert Haldane, at the time of their marriage in 1853, was a widower with four children. See obituary on Mary Elizabeth Haldane in *The Times*, London, May 21, 1925, p. 11, col. E. Also see her autobiography, Haldane (1925).

[54] See obituary on W.S. Haldane in *The Times*, London, Nov 11, 1951, p. 8, col. D.

[55] See the entry for Elizabeth Haldane in Smith (1949). The *Order of the Companions of Honour* was a British and Commonwealth society installed by King George V in June 1917 that awarded the *Companion of Honour* (CH) to men and women who excelled in social and cultural activities (cf. Encyclopedia Britannica, 2004).

[56] See the obituary on Richard Haldane in *The Times*, London, August 20, 1928, p. 13, col. B–D, and his autobiography, Haldane (1929).

two years before. After he finished his studies in *General Arts*, he published a pamphlet together with his brother, that can be regarded as a manifest of Scottish Idealism. In it Richard and John Haldane laid out their opposition to the rising materialism in science and social issues.[57]

Early work

After receiving his MD in 1886, JS Haldane became *Demonstrator* for Professor Andrew Carnelly at Dundee University. One of his first research projects was the examination of sewage gases and the "foul" air found in worker slums. In the middle of the 19th century, several epidemics (primarily cholera) had shaken Scottish towns, so the government urged scientists to investigate the hygienic conditions found in living and industry quarters (Nicolson, 1993, 339).

Haldane and his colleagues took many air samples in the sewers and workers housing in Dundee. The social prejudices that the foul air found in the worker slums would spread diseases could not be assured. Rather, as Haldane found out, the general poor hygienic conditions found in the slums and with their inhabitants furthered the outbreak of epidemics.

This early project shaped much of his later researches and became a prototype of future projects: the hygienic problems in connection with breathing. After Haldane spent some months in Berlin for laboratory studies, he became Demonstrator in his uncle's lab in Oxford in 1887. His uncle, John Burdon Sanderson, held the Waynflete chair for physiology at that time, before becoming Regius Professor in 1901.

Since his payment as demonstrator was not too opulent,[58] JS Haldane had to resort to assignments from the industry. Soon he came into contact with a field he devoted much of his remaining (scientific) life to: the hygiene in mining. In 1887, the *Doncaster Coal Owners* asked him to examine the so-called "after damp" found after colliery explosions in mines, which were responsible for the majority of deaths occurring at such disasters.

Upon researching the nature of "after damp", mostly by self-experiments, he found out that this gas is nothing else but carbon monoxide, which results from the explosion. Further research revealed that carbon monoxide leads to

[57]Haldane and Haldane (1883). Cf. Sturdy (1988, 317). As Richard elucidates in his autobiography: "In that essay [Relation of Philosophy to Science] we sought to demonstrate, from our respective points of view, that the phenomena of life were unintelligible unless there entered into the constitution of biological experience relations of a wholly different order from those of mechanism. He [John] has pursued this theme undeviatingly since then from the standpoint of experimental science, while I have been occupied with it from that of the theory of knowledge." (Haldane, 1929, 28)

[58]His wife noted in her autobiography: "I think his uncle paid him about a hundred a year." (Haldane, 1961, 156) According to the UK National Archive's "currency calculator", £100 in 1890 would have the same spending worth of today's £5989; `www.nationalarchives.gov.uk/currency`, accessed 02 April 2010.

anoxemia (oxygen deficiency in the blood) through the much higher binding power of carbon monoxide over oxygen to hemoglobin. As a counter-measure, Haldane proposed to place birds and mice in the mining tunnels. These animals were equally vulnerable to this gas, their faster metabolism caused them to be troubled much sooner than humans, though, so they served as formidable detection tools. Also, Haldane developed the Mine Rescue Apparatus together with Robert Davis from Siebe & Gorman Ltd., London (see figure 3.5).

This research yielded some fundamental insights into the physiology of breathing. The positive effects of oxygen as both therapeutic and means to survive in toxic or rarefied atmospheres was evidenced by Haldane (1895). The experiments with canaries and mice as an early detection mechanism in mines were continued and Haldane proved that a mouse could be kept alive despite exposure to carbon monoxide, when the animal was exposed to hyperbaric oxygen (i.e. oxygen with higher pressure than the normal atmospheric one). This set the scene for both hyperbaric oxygen treatment, as Haldane's oxygen therapy for gas warfare victims in World War I, or employing supplemental oxygen in mountaineering or aviation.

Haldane's work was much appreciated by both the mining industry and workers. JS Haldane henceforth became an important figure in the world of mining, not only by contributing to hygienic research, but also by assuming responsibility in government commissions. In 1906 he became member in the *Royal Commission on Mines*, in 1911 in the *Royal Commission on Metalliferous Mines* and in 1921 in the *Safety in Mines Research Board*, of which he became chairman of the *Spontaneous Combustion Committee* (cf. Douglas, 1936). In 1912, the *Doncaster Coal Owners* erected a research laboratory and made him director of it. The lab was transferred to Birmingham University as part of the Institute of Metallurgy and Mining in 1921. In 1915, Haldane received the gold medal of the *Institution of Mining Engineers*, finally becoming their president from 1924 to 1927, surely the clearest sign of admiration, since he was not an engineer himself.[59]

[59] His involvement in mining research was again not without controversies, though, as McIvor and Johnston (2007, 69–73) discuss. Just as with *oxygen secretion* he made some great misjudgment, this time about the role of dust in the many deaths especially among older miners, which he attributed solely to bronchitis caused by poor ventilation in the mines. The inhalation of coal dust over many years by these persons he not only neglected as source of the deaths, but even worse, he regarded it as beneficiary. He even went so far as to suggest that smoker's lungs were healthier, as they had been hardened by the "educat[ion of] their lung epithelium to deal with really harmful foreign bodies." (From an article in *The Scotsman*, 9 June 1916, quoted from McIvor and Johnston (2007, 69)). At this time, Haldane did not have many critics, as he was regarded as the eminence in respiration issues. Later, in the early 1930s, he would still cling to the notion of coal dust being protective against lung diseases and he downplayed the danger of particles in both coal and silica dust, but the amounting evidence against his case would at least exact some concessions from him. While his prestige as expert on respiration could still silence a number of critics, his views on the matter got under considerable pressure and were

These were just the first steps into his involvement with the industry and government commissions. He served as the scientific member of many of those commissions e.g. in 1920 he became *Gas Referee* in the Board of Trade. His industrial expert opinions included reports for the ventilation of tunnels, e.g. in the Mersey and in the Dartford Tunnel. Also, his expertise was requested by the Army, especially during the time of his brother's office. This included diet plans for infantry soldiers, ventilation in submarines, diving tables (see below), and research on gas victims and gas masks in World War I (cf. Donald, 1963).

The kind of practically induced research and his collaboration with individuals from different social groups in this context became typical for Haldane. Even though complicated in his character, and vigorous and often schoolmasterly to his scientific colleagues when it came to the "right" kind of epistemology in physiological research, he could work well together with people coming from different backgrounds. This property of his personality played an important role in his involvement in the pressure suit design in the 1930s among other things.

Respiration Physiology

The abnormalities in breathing as met so often in diseases and hygiene led Haldane to reason about and inquire into questions of general physiology. Upon finding out the nature of "after-damp" in mining, he started to research into the binding powers of gases to hemoglobin in the 1890s. Together with John Lorraine Smith (1862–1931), one of his students in Oxford, he experimented with the effects of various gases on the human organism, including carbon monoxide and carbon dioxide. The papers published by them explained in great detail the methodology used and the results obtained in the experiments, providing not only some new insights into the topic, but also inspiring instrument design. While some of the recording instruments by Haldane were based on other physiologists paradigms, he gained quite some reputation with the design of his *Air Analysis Apparatus* in 1892. The apparatus prevailed Haldane's name much longer than his scientific findings, the principle still being discussed up to the 1950s (cf. Lünen, 2006b). The apparatus, though far from accommodating industry-level status, i.e. looking rather prototypical, became widely used in laboratories world-wide.[60]

By employing his apparatuses and "intertwining" his research projects in pure with those in applied science, he gained more and more knowledge of the foundations of an important issue in respiratory physiology: the regulation of breathing. The experiments and results from the 1890s served as a basis

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eventually dismantled after his death.

[60] As Haldane reported in a letter to his mother, during his travels in the USA in 1916: "I found my own analysis apparatus etc. in use in all the laboratories." Letter from Nov 2, 1916; NLS, MS20512, F27–28. Quoted from F27.

for the research in the next decade that resulted in what is generally regarded as his most important single paper in 1905, in which he and John Priestly showed the interdependency of the level of carbon dioxide in the blood and the breathing reflex. The model Haldane developed corresponded largely to his philosophy, even though among historians of science there is dispute about this question (Haldane and Priestly, 1905).

An early paper by Garland Allen purports that Haldane developed his theory of "coordinated activity" upon his physiological findings, evidencing that he never produced a genuine form of philosophy before 1909; whereas Sturdy (1988) argues against Allen (1967), that Haldane's philosophy, as expressed by his early publications like Haldane and Haldane (1883), formed the basis for later physiological research: "[...] his philosophical inclinations were highly influential in determining the kinds of experimental studies he undertook." (Sturdy, 1988, 316)

It has been discussed how far Haldane's early philosophical underpinnings shaped his later research.[61] Allen, however, simply noted that Haldane had not used the term "coordinated activity" before 1909, and that this model was a consequence of his scientific research. It is beyond doubt, as Sturdy argues, that Haldane's philosophy influenced his scientific work from early on. The degree of influence, however, that his philosophy really had on his scientific experiments is debatable. Much of Haldane's own account on the eminence of his philosophical on his physiological seem to have been authored in his later years, i.e. in hindsight.[62] Rather, Haldane's son JBS was much more accurate in his later assessment: "Even if (as I [...] believe) his point of view is fundamentally false, it has great heuristic value" (Haldane, 1960, 104).

This "heuristics" (i.e. his physiologic methodology) became quite influential. Ironically, despite his vigorous opposition to mechanism, his apparatuses furthered it considerably. He himself saw this coming and tried to ensure that his apparatus must be regarded in the light of his philosophy of biology. He stressed the point that biology is not simply applied physics and chemistry, but rather incorporates methods from these two sciences to form its own epistemology eventually.[63]

[61]Needham (1932) also impinges on that notion by stating: "It seems profitless to criticise this point of view, for scarcely any modification has taken place in Prof. Haldane's opinions since the days of his paper in Andrew Seth's collaborative 'Essays in Philosophical Criticism' (1883)." (Needham, 1932, 524)

[62]Haldane's early writings on philosophy just manifested his rejection of mechanism, only in later writings (after the inception of his "own" philosophy in biology) he rejected vitalism to the same degree. This led many contemporaries to confuse his philosophy with vitalism, as he himself conceded in his *Autobiographical Notes*: "It has always been difficult for me to prevent confusion between the ideas which I had adopted and the old fashioned vitalism." Quoted from Sturdy (1988, 324).

[63]Letter to A.V. Hill, dated Oct 25, 1920. CCAC, AVHL 3/29.

Diving Physiology

In 1905 John Scott Haldane was asked by the Admiralty to conduct research upon medical problems related to respiration experienced in diving. Haldane's reputation as Britain's expert on all hygienic matters concerned with breathing, together with his extensive experience in work funded by the government or private institutions, made him a premier candidate for this job. Obviously, his brother's position as War Secretary helped his assignment in this project too.

When the project was finished in 1907, a report to the Admiralty was published, detailing diving procedures and so-called *decompression tables* (Haldane et al., 1907). A year later, a voluminous paper was published by Haldane and his collaborators (Haldane et al., 1908).

Haldane never claimed that he was the genuine discoverer of most of the points made in these publications. In both the report and the paper, he referred to the research of others and made clear that his results are obtained as a result of frequent consultation of these works. He referred to the work of Bert, Zuntz, Hill and others, and improved and corrected their findings where he and his colleagues have found inaccuracies. The paper in the *Journal of Hygiene* gives a good account on the focus of the work. In it, almost one-third deals with the theory of decompression illness (DCI), whereas the rest explains the experiments conducted by Haldane, Boycott and Damant. As a matter of fact, no genuine theory was developed by Haldane et al, other than the so-called "2:1-ratio", and even that was inspired by a remark by Bert (1878).[64]

Haldane's research led to safer decompression procedures and shorter decompression times. It is thus not surprising that divers and diving companies welcomed Haldane's diving tables and honored his name for this development. Even more so because, besides the Royal Navy, private companies also sponsored the research, chief among them Siebe & Gorman Ltd. and S. Pearson & Son, both from London. While Siebe & Gorman, represented through their managing director and chief engineer Robert Davis, provided much of the infrastructure, like decompression chambers and diving appliances, Ernest W. Moir (1862–1933) from S. Pearson & Son (inventor of the recompression chamber) discussed many physiological details with Haldane.

S. Pearson & Son Ltd. was a company involved in engineering projects concerned with excavation work, for instance tunneling or harbor basins. Both these fields required work under compressed air and the company's president Weetman Pearson (1856–1927) hired Moir because of his prior experience with decompression issues. Moir, however, developed the recompression chamber solely from guessing, without any scientific investigations grounding it. While this worked all right for a certain span of time, it be-

[64] For the "2:1-ratio see below. I have published a short article on Haldane's diving research lately, pointing out what Haldane invented and what not (Lünen, 2006a).

came evident during the Hudson River Tunnel project of Pearson's in 1895 that more scientific expertise had to be sought. When Pearson signed the contracts for the East River Tunnels with the Pennsylvania Railroad Company in 1904, they looked out for such expertise and finally found it with the Admiralty Committee, which they duly supported henceforth.[65]

Siebe & Gorman Ltd. had a somewhat immediate interests in Haldane's involvement. His earlier cooperation with Robert Davis on the Mine Rescue Apparatus was of utmost importance on the first topic of research mentioned in Haldane et al. (1907): Divers had reported breathing problems with the Siebe & Gorman diving apparatus. Hence, Haldane first was assigned to inquire into this issue (Haldane et al., 1907, 10ff.). Haldane found out that the ventilation in the helmet was insufficient, leading to an increased level of carbon dioxide in the helmet, causing nausea and even unconsciousness with the diver. Haldane defined the threshold values for carbon dioxide acceptable in the helmet, i.e. at which rate the air delivered by the air-pump had to flow in and out of the helmet. Haldane identified the position of the air-valve as the technical source of the problem. In the contemporary diving dress, the hose coming from the surface was attached to the back of the helmet. This was due to practical purposes, preventing the hose from getting over-bended and keeping it out of the diver's feet. Because of the lack of proper ventilation, however, a certain amount of expired air remained in the helmet, accumulating to the aforementioned dangerous level of CO_2. Also, the pressure regulator, which was placed at the helmet inlet, was not at the same ambient pressure as the chest of the diver. Thus, the mechanical force necessary to breathe was slightly increased.

Haldane proposed that the perfect position of the valve would be the breast plate, or at least to place the valve near the mouth of the diver, so the expired air would be displaced with fresh air instantly (Haldane et al., 1907, 14). This was technically difficult, however, for the reasons mentioned above. The mechanical strain put on the hose and valve would be greater; also, the degree of freedom in the diver's motions would be hindered by having the hose hanging right in front of him.

Davis consequently designed a diving helmet with an extra breathing mask inside. The mask, however, only had a direct connection with outlet valve, drawing the inspirational air from inside the helmet. The design's priority lay thus in venting-off the expired air, i.e. the carbon dioxide (see fig. 3.6 and Davis, 1917).

[65]Cf. Young (1966, 43–57) for a summary of the tunnel projects of Pearson's. For the contracts between S. Pearson & Son and the Pennsylvania Railroad Company, which made provisions for medical screening and facilities for workers among others (and also other documents related to the East River Tunnel project), see SML, PEA8. Haldane also became councilor on another Pearson project, the Mersey tunnel, in which he gave counsel on carbon monoxide levels to be expected in the tunnel from car traffic. SML, PEA46.

While the introduction of these improvements in diving helmet ventilation took some years to materialize, Haldane and Davis deliberated another, somewhat more practical, patent. In a situation of emergency, the diver may find it apt to drop his weights in order to do an emergency ascent with the help of the positive buoyancy created by the air in the helmet and dress. For the sake of stability when working underwater, i.e. for the provision of an upright and stable standing position, much of the weight is situated at the lower half of the diver's body, e.g. in the shoes. Once these weights are dropped, the helmet is the heaviest part of the equipment, and is only lifted by the air in the helmet. A diver might ascent upside-down when the air gathers in the legs of the suit, and no weight is present to counter-act this buoyant force. Thus, to prevent the legs from inflation, Haldane proposed to Davis a set of "gaiters" to restrain the suit legs (see fig. 3.7). Even though this design did not gain much popularity among divers, it shows two points which will become more interesting in Haldane's and Davis' cooperation on pressure suits later: 1) Haldane's understanding of non-medical technical issues, and 2) the idea of restraining the inflation of a suit, an issue of utmost importance in pressure suits, as we will see later. As a matter of fact, Russel Colley's pressure suit for Wiley Post uses a comparable approach for the legs (see next chapter).[66]

Stage Decompression

The principle of *stage decompression*, so often attributed to Haldane, was deliberated and described by Bert (1878) already. Bert simply considered this mode of ascent too impracticable:[67]

> "I have remarked no great difference between the cases in which decompression was effected continuously at the rate of eight or ten minutes per atmosphere and those in which it was carried out by means of sudden jumps, with intervals of repose. The facts are not, however, sufficiently numerous to permit of deciding in favour of one or other of these methods."

"Stage Decompression" refers to the principle of introducing stops into the ascent at the end of a dive. The idea behind this principle is to give the human body ample time to give off the surplus of nitrogen, which was resolved in the tissues upon the increased ambient pressure during the descent and the bottom time.

[66] Davis (1907). That this patent is based on Haldane's idea is stated in Stelzner (1931, 88), Davis (1935, 171) and Haldane (1922, 336).

[67] Quoted from the English translation of Bert's book, Bert (1943). Original quote (Bert, 1878, 975). I did not have the English translation available, since most libraries in Germany carry only the French original. Therefore, I used the French version as reference. The quote from the English version of was found in Schilling (1981) (at the entry for the English version of Bert's book), a commented bibliography on historical diving medicine literature.

"Uniform Decompression", on the other hand, coins a different ascent scheme in which the diver slowly and continually ascends to the surface. The speed of the ascend is tuned according to the gas-uptake that took place during the dive, i.e. the longer the actual dive was, the slower the ascend would be. This was the established method prior to Haldane's research. Many contemporaries, however, especially the diving engineers and divers, noted an increased risk of DCI incidents. The speed rates given in the literature on diving were extremely fuzzy, and the diving gear of those days – heavy and clumsy – did not further fine-tune ascend modes much. Haldane therefore noted in the report to the Admiralty (Haldane et al., 1907, 41):

> "It seems evident that with uniform decompression a great part of the time spent in the process is time lost, for during the greater part of the time [. . .] the difference in pressure between the nitrogen in the tissues and that in the air is much less than it might safely be made; and as a consequence the nitrogen is given off from the lungs much more slowly than would be safely possible."

This statement is not one of mere economic advantage, it also eased the diver's life considerably. Spending less time in the water meant a tremendous increase in comfort and security. As parenthetical as this statement may seem, it can be regarded as the answer to an ongoing dispute: mechanical vs. gas theory of decompression. As Heller et al. (1900, 737) alleged,[68] the gas theory of DCI had followers in France, Germany and Russia, whereas the British and American physiologists rejected it and favored the mechanical theory. If this notion is true, Haldane's work in diving physiology might be seen as a "breakthrough" in a controversial topic. I doubt the correctness of the Heller et al. (1900) sentiment, though. Publications in physiology in the late nineteenth century often carried a somewhat nationalistic bias, despite the internationality of the discipline. The Franco-German "faction", however, often had a little scoffing for their British colleagues. Great Britain could not easily compete with "giants" of the discipline from the continent, like Zuntz, Du Bois-Reymond, Pflüger, Helmholtz, etc. The temporary decline in science in Great Britain in the middle of the 19^{th} century was subject to many critical domestic pamphlets, and continental authors somehow could not hide their *Schadenfreude*, considering the long reign of British science and engineering in the 17^{th} and 18^{th} century.[69]

[68]"Alleged", because I have no proof how the majority of physiologists in the mentioned countries really regarded the issue, I have only Heller et al.'s notion of it.

[69]For example, Kronecker (1881) gives a survey of the European physiology scene in the introduction, naturally claiming that the German research was leading, calling in a speech from Helmholtz of 1869 as advocate: "While in the inquiry into the inorganic nature the diverse countries in Europe advanced at the same level, it was Germany which took the lead in the recent development in physiology and medicine. There are excellent researchers in England and France, who can put any effort in employing the right kind of scientific method, but who were almost always hindered by social and clerical prejudices, and could

The statement of Heller et al. (1900) can therefore be seen in this light. Given the circumstance that only two seminal monographs existed at Haldane's time, Heller et al. (1900) and Bert (1878), and that Haldane et al. (1908) refers to them very often (beside Zuntz, 1882), it can be safely said that the authors did not assume a controversial position. The correspondence with Moir and Keays rather points to discussions about the right set of parameters than on principal differences of opinion. For example, Moir wrote to Haldane on January 9, 1907:[70]

> "Dear Professor Haldane,
>
> Your letter of the 5th. inst. has been duly received. I gather from your blood experiments and our own that your view is that the pressure was not as I thought due to decomposition but due to the blood actually giving up some absorbed gas.
>
> I think the gas remains in the human systems a good deal longer that at present you seem to think.
>
> [...]
>
> I tried stage decompression on myself when I was in New York last time but as I never suffered in the past it was difficult for me to say whether I was any better or not."

Contrary to Moir's doubts on stage decompression expressed in that letter, the Haldane-Tables became the standard of their time. The Royal Navy naturally adopted them for their divers, so did the British Institution of Civil Engineers.[71] But also in other countries, Haldane's tables were introduced as the official standard, including the USA and Germany.[72]

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only speak their mind openly by damaging their social influence and impetus." Kronecker (1881, 587–588), translation mine.

[70]NLS, MS20510, F256.

[71]For the latter, see NLS, MS20514, F282ff: "The Institution of Civil Engineers. Report of the Comittee on Regulations for the Guidance of Engineers and Contractors for work carried out under Compressed Air. (1935/1936)". Haldane was the consultant for this committee.

[72]For the USA: The US Navy Diving Manual from 1916 (USN, 1916, 83–84) produced modified Haldane tables, i.e. tables employing the method of *stage decompression*, but with slightly different stopping times. Haldane's (or any other person's) work is not mentioned, something not too unusual for a manual. On pp. 22–23, however, the method of stage decompression and its advantages over uniform decompression is explained, and Haldane's "2:1"-ratio is set to "2.3:1" as maximum. The line of argument is exactly the same as made by Haldane et al. (1907), as quoted above: "It has been determined that decompression in this manner [stage decompression] is far more safe after short exposures than a gradual decompression; i.e. going slowly to a low pressure. With uniform decompression the diver, instead of desaturating, continues to saturate with nitrogen at the higher pressures." Even though Haldane did not invent *stage decompression*, as pointed out above, he brought the term into wide-spread use. Hence, the US Navy Manual apparently refers to his work. For Gemany: Stelzner (1931) includes an appendix with the Haldane-Tables, whereas pp. 154–159 discusses the Haldane decompression strategy. Stelzner (1931), and its second edition (Stelzner, 1943), became the *de facto* standard book on diving tech-

Diving experiments

When the research project on diving was started, much work on the principal physiology of diving was conducted by other scientists, as already mentioned. The blood-gas-exchange (diffusion from the blood vessels to the tissues), the uneven gas uptake in the various tissues due to their number of capillaries, or the bubble formation in the tissues – all of these foundations of decompression theory were well laid out by Bert (1878), Heller et al. (1900) or the work of Leonard Hill or Nathan Zuntz. Hence, Haldane et al. (1907, 1908) did not inquire into these topics much. In the first part of Haldane et al. (1908) (which is about one-third of the entire report), a brief overview on the physiological foundations is given, crediting the respective authors, and adjusting their parameters on diffusion and perfusion, according to Haldane's recent research on blood circulation and respiration.

The major part of Haldane et al. (1908) deals with the experiments conducted on goats and – to a smaller part – on humans. The use of animal testing in scientific research was heavily restricted in the UK, after the inception of the *Cruelty on Animals Act* in 1878.[73] Therefore, it was purported that goats have been chosen for the experiments, not only "as they were the largest animals which could be conveniently used", but also they are "definitely insensitive to pain" (Haldane et al., 1908, 350,379).

This, however, was only a minor point. First, as a matter of fact, the section in the paper dealing with the experiments, elucidates that the animals have suffered from pain caused by DCI (Haldane et al., 1908, 387). Then, Haldane et al. (1908, 378) made clear that the choice of the animals was rather a trade-off in terms of size and handling. It is explained that the size of the goats, was most convenient, because it closely resembled the fat-blood-distribution of a human, considering the restriction in size of contemporary pressure chambers. Where other scientists had used smaller animals before, Haldane et al. (1908, 379) evinced that this would lead to insufficient results. The faster metabolism of smaller animals would produce symptoms of DCI much later – or not at all.

Thus, the selection of goats was not a decision of the heart, but rather a practical concession; Haldane et al. (1908, 379) themselves stated that goats

nology and education in Germany and the German-speaking countries. Excerpts of it (including the tables) were published as manuals for the German Association of Commercial Divers, cf. BG (1937) or BG (1948). As Seemann (1967) evinces, the tables of 1935 in civil engineering in Germany were revised just at the end of the 1960s, discounting that diving in civil engineering in Germany was completely restricted to rivers and lakes or coastal shores, thus an extension was not regarded necessary for a long stretch of time, since off-shore diving was not really an option. The situation with British diving was not much different, as Walder (1967) elucidates. Only after the British government became interested in off-shore diving in the face of oil exploitation in the North Sea, was a revision deemed desirable.

[73]For a good overview on the issue, see Richards (1986).

"are not perhaps such delicate indicators as monkeys or dogs", while Davis (1934, 1079) asserted that Haldane would have actually preferred pigs or baboons. Their higher intelligence, however, rendered this enterprise futile, since the animals would not enter the decompression chamber without producing much trouble, sensing or remembering the uncomfortable nature of the experiments.[74]

As it was conceived, that *uniform decompression* – or rather the guide lines given by its proponents – were too fuzzy to be of much practical value, Haldane considered a different approach. Bert (1878, 975) had remarked that in his experiments, no symptoms of DCI were produced when the dive was shallower in depth than 10m, regardless of the duration of the dive. From this, Haldane elaborated the thesis that – since ascending from 10m to the surface means halving the ambient pressure – in any instance, a halving of the ambient pressure would not produce DCI (Haldane et al., 1908, 374). Together with Bert's concept of introducing stops for decompression into the ascend, Haldane developed "his" concept of *stage decompression*: The diver could always ascend to half of his current depth, then make a stop of pre-calculated duration to give off excessive amounts of nitrogen (liberated by the decrease in pressure), then ascend to the next stop, which is at half of the depth of the previous stop, and so forth. The Haldane-Tables are so calculated to specify both the depth and the duration of the stops. The principle of halving the pressure was called the "2:1-ratio" of decompression.

Taking this hypothesis as point of departure, Haldane et al. started to validate this concept in the experiments with goats. Since these have different rates of metabolism, the tables were modified to cope with the different times for taking up and giving off gas from the tissues. A total of 85 animals were used for the experiments (Haldane et al., 1908, 379). Some of the goats were deliberately exposed to rapid decompression in order to observe the pathology of DCI, and how it might be counter-acted. The account of the experiments described in Haldane et al. (1908) reads somewhat macabre to modern eyes, detailing both the experiments carried out on the goats and the symptoms produced. Haldane was never too keen on animal testing, though, primarily for scientific reasons. According to his philosophy, the organism has to be examined in its environment. He ardently criticized his colleagues for using anesthetized or even vivisected animals, for this setup would not produce authentic results.[75]

[74] Davis actually tried these animals at the facilities of Siebe & Gorman in London, resulting in discomfort: "He [the donkey tested] was the silliest ass of them all. The best of carrots failed to lure him into the steel chamber; even oats were tried in vain. At last the services of a donkey merchant from a local market-place were enlisted and, using appropriate measures and language, he succeeded in a few minutes where we had failed. If Neddy was the most obstinate, the baboons were the most vicious." (Davis, 1934, 1079)

[75] Allen (1967, 404). His laboratory instruments were designed to observe the animal in question as a whole, e.g. Haldane (1892).

Instead, Haldane's affection for self-testing was extremely pronounced. The reason was to a large part owed to his belief in authentic experiments. Animals could not tell much of their feelings, so experiments on humans were favored, usually on Haldane and his colleagues. For example, when conducting experiments to research into carbon monoxide in the 1890's with John Lorrain Smith, a large sealable tank was constructed, which served as a "gas chamber". Haldane often sat himself into the tank to test the degrees of carbon monoxide poisoning on himself, leading to somewhat disturbing effects:[76]

> "[...] if he had been badly gassed, he would send off a series of telegrams, saying he was all right, the carbon monoxide poisoning having left him, as he thought, perfectly all right, but with curious gaps in his memory."

When researching into the effects of vitiated air in the 1890s, he used the sealed chamber to see how long the air in it would be breathable. He and John Lorrain Smith made tests on themselves accordingly, to sometimes drastic degrees:[77]

> "After $1\frac{1}{2}$ minutes getting blue. 1.40 sec getting uncomfortable. Stopped after 2 minutes face pretty blue, & cleaned up again at once."

This attitude could be found with many other physiologists in that period, too, e.g. Pettenkofer's self-infection with cholera to find a cure,[78] or Barcroft's infamous experiment with gas.[79] Self-testing was therefore nothing extraordinary at the time. Haldane, however, made some kind of conviction out of it. In his eyes, cowardice in the face of scientific experiment was not an option. The research was to the benefit of mankind, and everything that would stand in the way of his research would therefore hinder mankind's welfare.[80] This attitude of heroism also influenced the education

[76] From an undated manuscript authored by Naomi Mitchison, apparently an obituary speech on her father. NLS, MS20235, F247.

[77] From a *Lab Notebook* of J.S. Haldane, the quote is headlined "Apnoea of J.L.S. 6/11/90". NLS, MS20522, F4. The results of that research were published as Haldane and Smith (1893).

[78] Pettenkofer (1873)

[79] Joseph Barcroft, like Haldane, researched on Gas Warfare in WWI. Whereas Haldane's and Douglas' experiments were geared to find protective measures like gas masks – the functionality tested on themselves by testing the masks in gas chambers –, Barcroft was asked to join a committee to develop gas for the British. After a dispute with another committee member over the feasibility of hydro cyanide, Barcroft entered the gas chamber filled with that gas together with a dog. After a while, he left the chamber with the dead dog on his arms to show that the gas was sufficient to kill a dog, but ineffective to kill a human. Source: Article "Freezing & Stiffling", TIME-Magazine, October 19, 1936.

[80] As Douglas (1936, 136) asserted: "He drew no sharp distinction between pure and applied science, for they were to him but two aspects of the same thing, acting and reacting one on the other; to him the welfare of mankind was the fulfilment of the growth of knowledge."

of his children, not always to their pleasure, especially in the case of his son JBS.[81]

Networks in Diving Physiology

Before the Second World War, diving had not much actual military value, i.e. it wasn't applied to actual military combat operations.[82] The Royal Navy and other navies, on the other hand, were vitally interested to employ the service of divers. After centuries of colonial rule, in which goods of all sorts were transported across the oceans, many wrecks were inhabiting the coastal stretches. According to the maritime right, these treasures belonged to those who could recover it, thus the government had much interest to secure their sunken treasures, hence they had a number of divers under their command.

Augustus Siebe, co-founder of Siebe & Gorman, developed his first diving apparatus in the 1830s. The Royal Navy immediately showed interest and ordered some copies and tried them in the salvage of the *Alphonso XII*. The employed divers developed DCI, however, so it became clear that further research had to be conducted to exploit the deeper wrecks.[83]

The interest from the Royal Navy in the development in diving tables and the formation of the committee for deep-diving in 1906, therefore, were heavily influenced by the desire to salvage the wreck of the *Laurentic*. The salvage took seven years altogether, due to harsh weather and marine conditions. The tables, however, proved worthwhile, since not one incidence of DCI occurred, with 99 percent of the sunken gold recovered, at the cost of 24 percent of the gold retrieved (cf. Damant, 1925).

The interest in diving from both governments and adventurers was therefore the salvage of sunken treasures, whereas engineering companies were usually more interested in applications more mundane. Diving, and more important Caisson work, were and are crucial in tunnel work and for laying foundations for bridge pillars. Engineering companies involved in such enterprises thus signed up their own physicians for screening and treatment of caisson workers and divers (cf. Phillips, 1998).

Taking the committee from 1906 as an example, we see this structure

[81] As Naomi Mitchison pointed out in the aforementioned obituary speech: "He couldn't realize that 'hardening' doesn't always do." NLS, MS20235, F247.

[82] J.S. Haldane's son, JBS Haldane, together with Helen Spurway, who later became his second wife, conducted numerous experiments and test series between 1942 and 1944 for the RN to investigate into diving with *enriched air*, i.e. air with an increased amount of oxygen. This should alleviate the decompression time, or even completely circumvent it. There are a number of manuscripts and records in the NLS from JBS, all of them unpublished, e.g. NLS, MS 20569, MS 20573.

[83] See the article "DEEP-SEA DIVING. SALVAGE OPERATIONS ON THE LAURENTIC", reporting of a lecture by G.C.C. Damant. The Times, London, Jan 7, 1937, p. 15, col E.

of interest quite clearly. The involved companies S. Pearson & Son Ltd., London, and Siebe & Gorman, Ltd., London, both had an interest in the results of the investigations by the committee. S. Pearson & Son was a company providing services for the construction of tunnels and bridges, employing numerous caisson workers, as specified above. Siebe & Gorman, as one of the leading manufacturers of diving equipment, obviously hoped to gain improvements to their apparatuses and procedures – which in fact happened, as elaborated above, e.g. in the case of the ventilation deficiencies of their helmets. Hence, both companies cooperated to the fullest to make the committee a success, providing financial and structural support, as well as diving and accident data.

The Royal Navy provided the testing facilities for the open water dives, e.g. the vessel from which the dives were conducted. Also, Navy divers were employed for the test dives, and G.C.C. Damant, Navy surgeon (holding the rank of a captain), actively participated in the physiological researches. Since the nature of the diving experiments and their results were not considered as confidential from a military viewpoint, the investigations and their outcome (i.e. the diving tables) could be openly published, furthering both discussion in the medical community and the establishment of the tables as standard tables in Navies worldwide.[84]

The situation in Germany was not much different. Germany's leading diving equipment company, the *Drägerwerke* from Lübeck had a setup comparable to Siebe & Gorman. Their chief engineer Hermann Stelzner (1884–1942) was the *alter ego* of Robert Davis as far as position and prominence were concerned. Just as Davis (1935) became the standard reference in diving technology and history, Stelzner (1931) was the equivalent for the German speaking countries (and beyond).

The role of Dräger and Stelzner in terms of developments in diving technology will be elucidated in the next chapter. At this point, it is of interest to illuminate the topology of companies and government. Naturally, Dräger became the main supplier of diving and breathing equipment for the German government. This, obviously, changed with the end of World War I, when the *Treaty of Versailles* prohibited the existence of a Navy and Air Force in Germany. Since the military was only one, and not the largest, client to Dräger, however, they could continue their business without too much trouble.

[84]Contrary, for instance, to JBS' researches in WWII, which were declared *Secret* and consequently no publications are available. Even though the medical researches have been de-classified, military historians still don't have much chance to publish on the actual operations. As one editorial of the *Historical Diving Times*, the magazine of the *Historical Diving Society* (UK), complained in 2005 (issue no. 36), the British *Official Secrets Act* still forbids combat divers of WWII to speak about their operations.

3.2.6 Pike's Peak

Haldane's role in the famous expedition to *Pike's Peak* in the Rocky Mountains in 1911 is extensively elaborated on in West (1998a) or Nye and Reeves (2001); also, Haldane *et al.* published a voluminous report themselves after the expedition (Douglas et al., 1913). So, in short, there's no need to review their experiments and findings in greater detail, but only to give a short summary.

Haldane, his friend and former student Claude Gordon Douglas, Yandell Henderson from Yale University and Edward Schneider from the University of Colorado Springs spent six weeks on the summit of *Pike's Peak*. Their main goal was to study the effects of acclimatization of the human organism to high altitude, both under rest and physical exertion. Their studies were widely acclaimed among physiologists, not only for the quality of their findings, but also for the quantity of data documented in their report. Haldane, as the architect behind the experiments, could build a reputation based on this study as *the* expert for high altitude physiology. And in fact, most – if not all – contemporary bibliographies of aviation medicine etc. list his monograph (Haldane (1922); Haldane and Priestly (1935), published some years later and including a lengthy chapter on high altitude physiology) among the most influential and important publications,[85] and most – if not all – publications on aviation medicine in the 1920s and 1930s – and beyond – refer to Haldane's book.[86]

Even more important was the direct influence on Henderson and Schneider, who both became eminent figures in American aviation medicine shortly after. Both men were deeply impressed by Haldane's methodology, and at least Henderson remained an ardent admirer of Haldane.

Haldane's methodology had a somewhat more lasting echo than his actual researches or his philosophy (Lünen, 2006b). This surely is true in regard to his high altitude studies. His method of recording the metabolism at higher elevation – first and foremost by employing his *Gas Analyzer Apparatus* and the *Douglas Bag*[87] – was extensively used by aviation physiologists in the years to come.[88] So, although Haldane never had much actual connection to aviation medicine, he was one of its most important actors.

It must also be noted that Haldane had a quite romantic stance, not only towards science, but also towards nature, being an avid mountaineer himself. But he never let that transcend much into his publications, and one can find only scarce hints in his papers. In 1888, for example, he spent

[85]E.g. Fulton and Hoff (1942), Hoff and Fulton (1942), Schmidt (1938, 1943).

[86]E.g. Jongbloed (1929), Bauer (1926), Schnell (1935), Ruff and Strughold (1939), Benzinger and Hornberger (1941).

[87]A bag for collecting expired air invented by C. G. Douglas, which proved very effective when collecting samples from humans under physical exertion. Cf. Douglas (1911).

[88]E.g. Jongbloed (1929), Bauer (1926), Ruff and Strughold (1939) or Gross and Romberg (1943).

some weeks in Freiburg im Breisgau, on the fringes of the Black Forrest in Germany. What exactly he did there is not quite clear, since in his letters to his mother, he talked much about his walks in the Black Forrest, rather than anything scientific.[89] That he admired nature was also testified by his daughter:[90]

> "[...] he loved natural beauty, and would walk miles for a 'view', but he couldn't express himself much about it, and aesthetically he was never, I thought, developed – never adult."

This statement might also explain why he never included any romantic accounts of the mountains in his publications. Like other scientists involved in mountain research, anyway, he had quite a personal affection for this subject of study.

3.2.7 Americans

It is beyond the scope of my inquiry to venture into a full-fledged history of American Aviation Medicine. Credible literature is scarce though, and most of it leaves a lot to be desired, or is limited in scope. Weitekamp (2004) focuses on post-WWII aerospace medicine and gender issues, but delivers some interesting information on Randolph Lovelace, physiologists in charge of the oxygen masks for the US Air Force in World War II, for example (see section 5.3).

Mackowski (2002), and the abridged published version (Mackowski, 2006), respectively, deals with the role of German aviation physiologists in American space medicine after WWII, via *Operation Paperclip*. Where pre-WWII aviation medicine is concerned, these works are inherently inaccurate, besides being methodologically weak. As far as the Interwar Years are concerned, no American physiologists beside Harry Armstrong are discussed in detail.

Robinson (1973), albeit being a standard reference for most historians of aviation, suffers a bit from an internalistic viewpoint, but must be regarded as the best reference available. Works like West (1998a) or Colin (1992) are not very helpful in this respect, too. The former focuses on mountaineering, the latter displays a rather anecdotic outline of the subject from its early beginnings and certainly could not serve as frame of reference.

So, when it comes to American aviation medicine before the Second World War, Noë (1989) is the only secondary literature available that deserves credit. Her account on the topic is an outstanding example of a thorough but non-internalistic investigation in the field of aviation medicine. Although the thesis has its shortcomings (e.g. the neglect of Henderson's

[89] Letter to his mother, April 24, 1888, out of Freiburg. NLS, MS20659, F244.

[90] Manuscript of an obituary speech, not dated, by Naomi Mitchinson. NLS, MS20235, F249.

role, see below), it is baffling that it has not been published.[91]

Besides Noë (1989), first-hand accounts will be utilized, i.e. contemporary accounts by persons involved in the research in question, like Wilmer (1935). Since the topic – aviation medicine in the Interwar Years – has been somewhat neglected, these publications are often the best sources at hand. The general history of American aviation medicine before WWII, is not in in the scope of this book, as pointed out above. Rather, it will be outlined how the early American aviation medicine was influenced by international physiological research, and how important international networks were. Attention is given to two persons who were heavily influenced by JS Haldane and his methodology and work – and his person also.

Yandell Henderson

As so often it is difficult to find reliable accounts and sources on a physiologist. This is also the case with Yandell Henderson (1873–1944). Next to no secondary literature exists. West (1998b) is an obituary on Henderson, but doesn't use any sources at all, only Henderson's own autobiographical scientific account (Henderson, 1938) and the Pike's Peak report (Douglas et al., 1913).[92] Also, there is C.G. Douglas' obituary, which somewhat falls in the same (hagiographic) category (Douglas, 1944). As a matter of fact, if it wasn't for Pauly (1999), it would be hard to find out that Henderson's life and work was quite controversial, just like Haldane's.[93]

In 1891 Henderson enrolled at Yale College, and from 1895 to 1898, he completed his PhD at Yale's Sheffield Scientific School with Russel Chittenden, working on the metabolism of a food supplement called "peptone". After that he spent two years in Germany for additional training at the University of Marburg with Albrecht Kossel (1853–1927), and Carl von Voit (1831–1908) at the University of Munich, both renowned experts in medical chemistry.[94]

When Henderson returned to the US, he was hired by the Yale Medical School, becoming an assistant professor in 1903 and professor in 1911. In the 1910s, he also ventured into a political career, campaigning for his election as congressman in both 1912 and 1914, as a member of the *Progressive Party* of Conneticut. He initiated and championed various medical and social reforms. As a consultant to both government and industry, he urged the

[91] One might argue, that it is exactly *because* her work is non-internalistic that it has not found a publisher, considering that the date of creation falls in a period where the history of aviation medicine was usually done by MD's, and not *real* historians (no pun intended).

[92] Personal communication with John West, Dec 4, 2005.

[93] And in Haldane's case it was only possible to get a picture of the controversies he spawned not from the Haldane-Archive (NLS), but e.g. from A.V. Hill's archive (CCAC).

[94] Pauly (1999, 579), also Encyclopedia Britannica (2004) for names and life dates; see also West (1998b, 145).

implementation of measures to improve social and industrial hygiene – just like Haldane. He developed breathing apparatuses for the mining industry, invented an apparatus for resuscitating victims of carbon monoxide poisoning and tried to push social reform, since "[...] we must cut into social problems in order to apply preventive medicine."[95] He also mandated that science and politics must stand together to hold down "selfish businessmen" (Pauly, 1999, 579). As he himself stated in a paper (Henderson, 1919, 441):

> "One of these lessons is that scientific men need to develop the capacity to become the heads of large enterprises without ceasing to be scientific, without degenerating, as is too often the case, into the super-clerk, who seems to be the American ideal of the high executive official. It is not enough for the scientific man to become the expert adviser to the unscientific administrator. [...] The path of science must lead to the top, and at the top must still be science."

It is striking how many parallels there were in the lives of J.S. Haldane and Yandell Henderson. The fields of applied research (breathing apparatuses, etc.), the vigor when it came to social reform and its connection to science, and the opposition they encouraged by either questionable scientific theories – like Haldane's *oxygen secretion* – or their style of defending their political and philosophical stances. Where Haldane had to wrestle with his contemporaries largely through his philosophical inclinations, but was acknowledged as an eminent scientist, Henderson was not so fortunate to at least have this discount. As Pauly (1999) remarks:[96]

> "Henderson was a self-confident and dogmatic scientist. His ideas were often poorly grounded and sharply criticized by scientific colleagues [...] Most of Henderson's American colleagues believed that his theories were overstated, if not entirely wrong. He gained confidence, however, from the support of the prominent British physiologist John Scott Haldane."

Nonetheless – and here again he turned out to be Haldane's *alter ego* –, he gained much influence in industrial hygienic practice. In 1920, when Yale's funds were stocked-up by the Rockefeller Foundation, Henderson was left behind by the administration. He made himself so unpopular among many of his colleagues that his leave from his chair of physiology was inevitable. Remaining professor at Yale, he was given no duties nor funds. As a consequence, Henderson took up contract research for the industry and the government (Pauly, 1999, 580).

Henderson finally retired from his (then rather nominal) position as professor at Yale in 1938, publishing his autobiographical defense of his scientific

[95] Henderson in a paper for the *Journal of the American Medical Association* in 1916, quoted from Pauly (1999, 579).

[96] Pauly (1999, 579). This evaluation of Henderson's work is the only critical position found among the biographies and obituaries, as outlined above.

ideas the same year (Henderson, 1938). The book was dedicated to J.S. Haldane and much of his memories of their time on Pikes Peak (see above) went into it.[97]

Besides his close affiliation to Haldane and his apparent affection for the latter, Henderson's pioneering role in American aviation medicine – at least institutionally – is most remarkable for this publication. Even though Henderson sympathized with Germany, which he regarded as a "progressive nation", after the US' entry into World War I, he fully supported the (scientific) war effort of his country (Pauly, 1999, 579).

He served as chief of the medical section of the *U.S. War Gas Investigations*, which later became the research department of the *Chemical Warfare Service*. In this function, he went to France to improve the gas masks in use by the Allied Forces – yet another parallel to Haldane (West, 1998b, 151).

In 1917, before the war entry, military aviation in the USA was imposed by the Air Service of the US Army Signal Corps. At that time, there was no dedicated medical service for aviators, matters were handled by the General Surgeon of the Army. With the US' entry into the First World War, the General Surgeon decided to introduce a medical officer specifically for aviation matters and to put him under the auspices of the Chief of the Signal Corps. Col. Theodore Charles Lyster (1875–1933) was appointed for this post, who established examining units in the larger American cities to select pilot candidates in the summer of 1917, a number that was greatly increased over the next months (Wilmer, 1935, 116).

Two issues became visible in this course, however: 1) There were not enough medical officers who had appropriate training in the specifics of aviation, 2) medical knowledge pertaining to aviation was scarce and a special research unit had to be established to gather such knowledge. To overcome both issues, Lyster incepted the *Medical Research Board* (MRB) on October 18, 1917. However, organizational meetings took place earlier that year. The MRB consisted of four officers and one civilian member: Maj. W. H. Wilmer, Maj. E. G. Seibert, Maj. J. B. Watson, Maj. E. R. Lewis – and Yandell Henderson, the latter serving as chairman of the board.[98]

The MRB met from September 1917 on to discuss and establish guidelines for pilot selection and training, clothing and protection devices, nutrition and physiological research to be conducted. On October 2, 1917, the MRB met at Hazelhurst Field, Mineola, Long Island, to scout the place for the erection of a laboratory. On this day, it was also discussed and agreed how research should be organized and which were the priority topics. To cover

[97]See also his letter to C.G. Douglas, in which he discusses some of the topics in the book and on Haldane briefly. SL, A.20

[98]Wilmer (1935, 117). Strangely, Noë (1989, 44ff.) mentions Henderson's importance as far as research equipment is concerned (see below), and also the different sections of the MRB are detailed, but she doesn't mention that Henderson was the chairman of the MRB.

the most important research fields, several departments of the MRB were sanctioned (Wilmer, 1935, 117):

1. Physiology: Maj. E. C. Schneider,
2. Cardiology: Maj. J. F. Whitney,
3. Psychology: Maj. K. Dunlap,
4. Otology: Maj. E. R. Lewis,
5. Ophthalmology: Maj. W. H. Wilmer.

One of Henderson's first tasks – besides working out the guidelines for the research to be carried out by the MRB (Henderson and Seibert, 1989) – was to devise an apparatus for the testing of aviator candidates: the *rebreather*, typically named the *Henderson-Pierce-Rebreather*. Henderson had designed this apparatus as early as 1906, when he was working for the US Mining Bureau. It was Capt. Harold F. Pierce who introduced and established the device at Mineola, hence the reference to both persons (Noë, 1989, 45).

This device should not be mixed up with the *closed-circuit-rebreather* (CCR) used in diving. The basic principle is the same and Henderson most likely has been inspired by his earlier work on breathing apparatuses for mining. The *rebreather* is a device with a mouthpiece for its user, connected to one inlet and one outlet valve. The expired air is cleaned from the carbon dioxide produced by the human metabolism. The remaining oxygen in the expired air (not all of the inspired oxygen is actually taken up by the alveoli in the lungs, but simply exhaled again), is then returned into the circuit and the user breathes this reduced concentration of oxygen, whereas a CCR replenishes this expired oxygen with supplemental oxygen from a tank. The idea behind the *rebreather* is to simulate the depletion of the inspired air with oxygen as experienced at high-altitudes. E.C. Schneider had devised the "Schneider-Test" to test a pilot candidate's susceptibility to hypoxia by using a *rebreather*, since he conceived during his experiments on Pikes Peak that the individual disposition toward hypoxia varies significantly with different people.[99]

In the first weeks the team at Mineola did not have sufficient equipment for experiments to hand, thus part of the research activities were relocated to

[99] Wilmer (1935, 118), see also Scott (1920); Ellis (1923); Larsen (1923) for contemporary accounts of the *rebreather*, besides Henderson's own account in Henderson (1919, 439). Also Noë (1989, 45ff.). Zuntz (1912) had devised a similar procedure: To test the potential aviator's tolerance to hypoxia, the person should breathe air with constantly 12% oxygen. If after some minutes the person would not feel uncomfortable, he was considered "fit for flying".

the American University in Washington D.C.[100] The laboratory in Mineola was newly erected and had therefore not been equipped with all the technology required to do serious research. One such device was a decompression chamber which had to be constructed out of town and transported to Mineola, a task that turned out to be quite cumbersome since it weighed 4 tons and the streets and bridges between Lancaster (Pennsylvania), where it was constructed, and Long Island were not prepared to endure such transport, hence the installation of the chamber took until January 1918 (Wilmer, 1935, 118–119).

Paul Bert had already employed such a chamber for his path-breaking work on aviation medicine in the 1870s, but many of the contemporary aviation physiologists did not see its ultimate necessity. Henderson, on the other hand, was well aware of Haldane's use of a sealed chamber for various research projects, including carbon-monoxide poisoning, testing of gas-masks, decompression in diving, etc. He therefore reflected (Henderson, 1919, 439):

> "To control and test the accuracy of the results with the rebreathing apparatus we installed in our laboratory at Mineola a steel chamber, in which six or eight men together can sit comfortably, and from which the air can be exhausted by a power driven pump down to any desired barometric pressure."

The officer in charge of operating the chamber, one of Henderson's assistants at Mineola, noted a few years later (O'Bear, 1923, 75):

> "During the early days of the Medical Research Laboratory when it was situated in the American University at Washington the need was felt for some apparatus which would simulate high-altitude conditions and lend itself to greater variety of application than the Henderson rebreathing apparatus already in use. [...] Dr. Yandell Henderson first suggested the plan. He and his colleagues took the matter in hand and in due course of time the chamber arrived at Hazelhurst Field, Mineola, the new station of the laboratory."

Just like Haldane, Henderson believed in the necessity of close cooperation between physiologists and engineers when it came to aviator equipment. And also just like Haldane, he was in a way forced to such cooperation by his exclusion from the academia – provoked by his controversial political stances, as discussed above – and the need to take up contract work for the industry. Even though both Haldane and Henderson regarded science and practice as two sides of the same coin, it is striking that both had no choice but to

[100]Wilmer (1935, 118), also, as Henderson and Seibert (1989, 469) pointed out, that in the first weeks while the laboratory at Mineola was erected, experiments were done in the War Gas Experimental Laboratory, then under the U.S. Bureau of Mines. This cooperation was surely made possible by Henderson's previous posts at these institutions. In fact, it appears that Henderson's work in the MRB was more organizational, rather than scientific.

seek collaboration of practitioners due to their industry work. Designing breathing devices were no exception to that (Henderson, 1919, 440):

> ”In fact the devising of such [oxygen] apparatus and its adaption to the peculiar requirements of the human wearer are a problem which can be solved only by the close cooperation of a physiologist and a mechanical engineer.”

The MRB and its laboratory in Mineola remained very active after the war, being at Hazelhurst Field until 1918, before it was transfered to Mitchel Field the next year. The laboratory was the birthplace of American aviation medicine and later the “School for Flight Surgeons”, from which the “School of Aviation Medicine” evolved (Robinson, 1943, 1640–1641).

In 1918, the results of the war-time research was published in the series “Medical Studies in Aviation” in the *Journal of the American Medical Association*, in which each section director published a paper on his respective work and Henderson on the general task of the board.[101] Furthermore, papers were published in special issues of the *Air Service Information Circular*.[102]

While the MRB had a strong position in the American aviation medicine, they certainly did not have the monopoly on it. Other researchers like E.S. Sundstroem, biochemist from the University of Berkeley also published papers that achieved seminal status and were listed in the bibliographies like that of Fulton and Hoff (1942).[103] However, most research activities established few distinct facilities. Laboratories run by the US Army Air Corps, like Mineola, and later Wright Field and Brooks dominated the scene, notwithstanding close collaboration with private institutions like Yale University or the Mayo Clinic.

Henderson was the only member of the MRB who did not attain a military rank, as the section directors did. He carried out much important work for the war effort as chairman of the MRB and as chief of the medical section of the U.S. War Gas Investigations. However, Henderson, as the politically inclined person that he was, declined to take military insignias (Henderson, 1919, 441):

> ”It is a wise provision of our government by which the Secretary and Assistant Secretaries of War are always civilians. It would also be wise for the general staff in any future war to keep scientific men on a scientific status instead of practically forcing them into uniform.”

That he garnished supposedly scientific articles like Henderson (1919) with such political statements might explain his somewhat neglected status in the history of American aviation medicine. As has been pointed out

[101] E.g. Henderson and Seibert (1989); Schneider (1989); Whitney (1989).
[102] E.g. Johnson and Paschal (1921); Howard (1923).
[103] Among Sundstroem’s early work, Sundstroem (1919); Sundstroem and Bloor (1920) are the most important.

above, most of the history of aviation medicine is authored by aviation physiologists themselves.[104] Henderson, just like Haldane, was an outsider both in the academia and in the military. These "historians" tend not to commemorate such people, usually attributing the pioneering work to someone from their ranks. Something that is also true when it comes to evaluating the significance of scientists from one's own country. Hence, persons like Harry Armstrong are favored, and even historians who have no background in medicine or military cling to these accounts (Mohler, 1999a,b).

Edward Schneider

Edward Christian Schneider was born in 1874 and entered Tabor College in 1895. He graduated in 1897 and began teaching courses in chemistry for two years. He then went to Yale University to study biochemistry with Mendel and physiology with Yandell Henderson, receiving his PhD in 1901. After receiving a chair for biology and physiological chemistry at Tabor College, he attained the position of professor for biology at Colorado College in Colorado Springs in 1903, where he remained for 15 years (Goodrich, 1955, 412).

Through the proximity to the Rocky Mountains, he became interested in high-altitude physiology, starting expeditions to Pike's Peak in 1904. When his former supervisor Henderson, with whom he stayed in touch over all the years, contacted him to undertake an international expedition to Pike's Peak, he happily agreed.

Schneider then ventured further into the physiological conditions at lower barometric pressure, and became one of America's most cited authors in this field. Upon the American entry into World War I he was called by Henderson to work as director of the physiological section of the MRB (see above). Schneider devised a cardio-vascular test, named the *Schneider-Test*, to test the fitness of pilot candidates. The test remained in service until the end of World War II. When the *School for Flight Surgeons* was installed in March 1918 Schneider designed the first curriculum and thereby shaped the subject in America in its infancy.[105] In July 1918 he went to Europe for six months with other flight surgeons to support American aviators at the front and to conduct and supervise field work. Discharged from service in January 1919, he remained director of the *School of Aviation Medicine* as a civilian from 1919 to 1925 (Goodrich, 1955, 413).

Schneider also accepted a chair for biology at Wesleyan University and for a time fulfilled all positions concurrently, but Wesleyan then became his focus until he retired. And even after that he was affiliated with that institution until his death in 1954.

[104] E.g. Dille (1990) or the various publications of Stanley Mohler, which I repeatedly cite in this book.

[105] The first American book on aviation medicine (Bauer, 1926) is consequently dedicated to Schneider.

Schneider's work on the physiology of aviators was not much different from his mountain studies. Actually, in his publications there is little to no difference noticeable between both fields (aviation and mountaineering), since he is solely dealing with the effects of low pressure environments on the metabolism of the heart and circulation. All of these papers, including those on his *Schneider-Test*, were published after WWI.[106]

The already mentioned *Schneider-Test* was an early attempt to normalize the criteria for pilot selection by developing a measure of fitness for the candidates. Schneider's first concern was to "eliminate the 'personal equation"' from screening candidates, i.e. methods that would rely on the expertise of the medical personnel. Both the bias of the examiner and the chance to cheat from the candidate should be avoided by introducing a standardized and neutral test (Schneider, 1990, 277).

The test resembles today's fitness checks and seems from a current viewpoint self-evident. At the time when Schneider devised the test, however, not much measurable criteria for such fitness had been defined. Schneider lists up such criteria and had to draw them together from a variety of sources, all representing the newest research of his time. One such criterion was the pulse rate at certain conditions, i.e at rest and after exercise. Also, the arterial blood pressure for these conditions was recorded and evaluated as a measure of fitness. Both the two criteria (pulse rate, blood pressure) Schneider had learned during the *Pike's Peak* expedition of 1911. Haldane, Douglas, Schneider and Henderson had made numerous such tests to measure the metabolism at high altitudes, both at rest and after exercise (see figure 3.8).

To evaluate the six criteria of physical fitness (a: pulse rate at rest, b: pulse rate while standing, c: pulse rate during exercise, d: pulse rate after exertion, e: normal arterial pressures, f: postural changes in arterial pressure), Schneider defined a points system to have the proper weighing of these criteria. He also defined a standard procedure on how to carry out the tests (Schneider, 1990).

During his time at the MRB, Schneider also made self-experiments in the decompression chamber. In March 1918 he and an assistant exposed themselves to a pressure equivalent to c. 10000m for 23min breathing pure oxygen and experiencing no problems (Wilmer, 1935, 119). Schneider never ventured into the development of technical measures against the dangers of hypoxia. Schneider's methodology shaped American aviation medicine, as it influenced first Louis Bauer and then Harry Armstrong; Bauer as student of Schneider and Armstrong as student of Bauer. Schneider, on the other hand, learned a great deal of methodology from Haldane on Pike's Peak. While it would not be fair to state that American aviation medicine was a British off-spring (since physiology was always an international discipline, Haldane

[106]See eg. Schneider and Lutz (1923); Schneider (1989, 1990).

learning a lot from other European physiologists before he developed his own genuine canon of methods), the influence of JS Haldane on its early champions is hard to deny.

3.3 Mountaineering

Mountaineering expeditions for the sake of high-altitude medicine, and consequently for aviation medicine, was a widely practiced enterprise around 1900. Bert's methodical heritage says that for the sake of the safety for the test-persons, experiments with low barometric pressure should only be conducted in a controllable environment, i.e. a pressure chamber. Those chambers, however, were not capable of simulating all environmental conditions met in the mountains. As Schrötter (1899, 7) remarks, the common mechanism (i.e. hypoxia) of mountain sickness and high-altitude sickness as experienced in ballooning was widely accepted among physiologists, but the causes and the stages of the disorder were not clear.

Zuntz and Zuntz (1897, 5) remark – by referring to Bert – that the physical exertion introduced by climbing would impose a great difference as to the development of hypoxia in mountain climbers and balloon pilots. This statement somehow hints at the overstated value of mountain expeditions for aviation physiology, since the results from mountain expeditions are not fully transferable to aviation.

The international aviation medicine community nonetheless sought participation in mountain expeditions, but when pressure chamber technology improved and became widely available in the 1930s, these expeditions were no longer desirable.

3.3.1 Mount Everest

In the 1920s British mountaineers tried to tackle the ascent to the summit of Mount Everest in the Himalayas. Several bodies and persons competed for the access, which had to be granted by the Nepal office of the British government. The expeditions gained interest from RAF officials as well, be it for the medical value, or simply personal interest.

For instance, O.E. Simmonds, Honorary Secretary of the RAE Technical Society contacted the *Royal Geographical Society* (RGS) on October 28, 1922, to invite mountaineers for lectures at the RAE:[107]

> "We are now arranging our lectures for the Spring Session & should be very grateful if you could prevail on one of the members of the Mount Everest Expedition to come down here in the New Year & talk to our members.

[107] RGS, EE 13/3/12.

> As perhaps you are aware in our high altitude flying here we are up against similar problems to those encountered by the expedition & if this lecture could be arranged I have no doubt we could make it of mutual usefulness."

Also, Marshall (1933, 399) refers to Air Commodore Fellowes, "leader of the Mt. Everest Expedition" who was among the audience. Fellowes and his team had flown over Everest with an open cockpit biplane in April 1933, two Bristol experimental airplanes dubbed "Westland PV3" and "Westland Wallace", both with an Bristol Pegasus IS3 supercharged engine, were used for the flight.[108] Preparations for this flight commenced in 1931, after word spread that both French and German teams had the same idea in mind. Britain, being short of notable aviation records in the 1920s, therefore decided "to make an important contribution to geography, and to its allied sciences" and to "carry out these feats with purely British personnel and therefore give a stimulus to enterprise" (Fellowes et al., 1934, 24).

While the desire to reach (or overfly) the summit of Mt. Everest was the driving force in the 1920s and 1930s, it furthered many interesting debates. Most climbers consulted physiologists to learn of hypoxia and preventive measures. John Scott Haldane, for example, conducted various experiments with his close friend Alexander Mitchell Kellas (1868–1921), who also attempted to reach Mt. Everest. Haldane and Kellas made numerous experiments in the former's decompression chamber in Oxford in 1919.[109]

Kellas' death furthered the debate over supplemental oxygen and other safety aspects of a projected Everest climb. As a matter of fact the use of oxygen was heavily debated by climbers, even though most physiologists agreed on its necessity for high-altitude mission, either to mountains or in airplanes.[110] British mountaineering icon Mallory also rejected the use of oxygen since he considered it as "unsportsmanlike", even though he later had to admit that there was no way of getting to the summit of Everest without extra oxygen.

In the years 1931 and 1932 the debate reached the magazines. Several persons who were involved in mountaineering and its physiological aspects outlined their respective viewpoints, leading to controversy. Greene (1931), for a start, summarized the different positions, that of the "no oxygen" and

[108] The expedition became known as the "Houston-Westland expedition", or simply "Houston Mt. Everest expedition", for it was funded by Lady Lucy Houston (1857–1936). Cf. Fellowes et al. (1934).

[109] See Haldane's lab notebook on the experiments with Kellas, NLS, MS20529. See also article "Mechanisms of life", *The Scotsman*, Dec 27, 1921, which reports of a lecture of Haldane, in which he comments on Kellas' accident on Everest. Furthermore, see Blakeney (1970) for Kellas' role in the Himalyan expeditions.

[110] E.g. Schrötter (1919, 732–733) postulates: "The sometimes heard notion that artificial respiration is superfluous, must be considered overcome today. The aspects under consideration have been laid out so clearly like no other question in physiology". Translation mine.

the "oxygen school", as he called them.[111] The confusion among climbers over the benefits of oxygen is mostly due to malfunctions of the oxygen systems, rather than general obstacles. The "oxygen school" were largely physiologists and climbers like Finch that had made good experience in chambers and on climbs with oxygen, whereas persons like Bruce or Odell quoted from bad experience made with faulty equipment.

Consequently, Odell (1931) objected in a Letter to the Editor of Greene's assessment.[112] Odell actually did not object to the use of oxygen in general, but reiterated Barcroft's statement, that "the problem [...] of climbing Everest was deemed one less for the mountaineer than for the engineer" (Odell, 1931, 1038). He then hinted at the contradicting experiences of Finch et al. and Mallory, the latter having reached a greater altitude solely by acclimatization whereas the former had relied on supplemental oxygen only. Furthermore, he alleged that the death of Mallory was not due "to a breakdown of the oxygen apparatus" (Odell, 1931, 1038). He also pointed out that the extra weight of oxygen tanks would actually cause more trouble to the mountaineers than bring about benefits. Despite the obvious advantages of a light emergency oxygen apparatus he repeated Mallory's sentiment (Odell, 1931, 1038):

> "But both the engineer and physiologist may be reminded that among many mountaineers the opinion prevails that if Mount Everest and other high Himalayan peaks are worth climbing at all, they should be ascended without such artificial aids as may reduce a sport to a mere laboratory experiment."

Hill (1932b) vigorously opposed Odell's view. From his researches with Argyll Campbell at the National Institute of Medical Research carried out in the 1920s, and experiments in Siebe & Gorman's decompression chamber, he concluded that acclimatization is not the final solution to mountaineering, as Odell (1931) had suggested, and that oxygen could be used only for the final stage of the climb. Hill (1932b) reported from his experiments that deterioration at high altitudes is "rapid and excessive, and no acclimatization prevents this." (Hill, 1932b, 93) He therefore recommends the sole use of supplemental oxygen and postpone any climb to Everest until an apparatus light enough has been devised.

Greene (1932), in his response to Odell (1931) also questions the possibility of acclimatization to such a height required for Everest. As far as Odell's statement on the "sport" aspect is concerned, Greene replies: "Others believe that such aids may raise a mere sport to the dignity of a laboratory experiment" (Greene, 1932, 94). This controversy over whether the use of oxygen

[111] Raymond Greene (1901–1982), Oxford educated physician, became senior doctor of the RGS Everest expedition of 1933.

[112] Both Greene's and Odell's statements were made posterior to Barcroft's paper "The Limits placed by Altitude to Physical Exercise" before the annual meeting of the British Association in 1931.

was a *dignity* or not, seems once more the clash of pilot/mountaineer and scientist, as Wolfe (1979) placed so prominently in the center of his story.

Odell (1932) consequently replied to both Hill (1932b) and Greene (1932), rejecting or playing down Hill's arguments on acclimatization or deterioration. Aiming at Greene's statement from above he insisted (Odell, 1932, 244–245):

> "Whatever analogies, however, on a physical basis may be drawn, such experiments on animals entirely leave out of account the psychological factor so germane to all man's higher activities: the will to climb higher, the exhilaration of possible success, apart from the accompanying stimulating effects of environment in this case."

Scientists, however, clung to their theoretical approach and claimed that inefficient breathing apparatuses would be the problem, not the general use of oxygen. As Margaria (1932), who experimented in Oxford together with C.G. Douglas and others, pointed out following the discussion of the above actors, the *pipe-stem* system (see section 5.3) did not deliver sufficient amounts of oxygen. Hence (Margaria, 1932, 397):

> "In this way we can explain why in the last Everest expedition climbers did not get any advantage from the oxygen, but that is not due to the oxygen being of no value, but because the principle of the oxygen apparatus was wrong and did not increase the oxygen tension in the inspired air to an appreciable extent. Such an experiment cannot form the basis for a 'no oxygen school'."

To this debate, Henderson (1932) added some interesting thoughts. He outlined that acclimatization and use of oxygen actually limit each other. Carbon dioxide production increases in acclimatized men and therefore would induce hypernoea in them. Whatever the scientific or practical reasons for or against oxygen might be, Henderson (1932) pointed out that both sides of the controversy were biased by their personal experience. In a letter to the editor of *Nature*, Henderson outlines that the dispute over oxygen or no-oxygen chiefly rests on individual physiological dispositions. It had been established that certain individuals react rather well to acclimatisation, whereas for others it simply did not work out as desired. The question whether acclimatisation is the superior scientific theory or not would therefore not be governed by evidence, but personal experience: "Those who disagree with [Haldane] on such matters as acclimatisation, do so, not so much because they think differently, as because they breathe differently." (Henderson, 1932, 650)

Besides these debates over technology, physiology and "sportsmanship", there was also a sort of political controversy involved in the Everest expeditions, as West (2003) reports. To combine forces, the RGS and the *Alpine Club* (AC) of Great Britain founded the *Everest Committee* (EC) in 1920. It was decided to conduct survey missions to find the best path to the summit of Everest and then to conduct expeditionary missions.

The AC and RGS had different personal structures, however, and these determined some of the EC's decisions. The AC consisted of Oxford and Cambridge educated persons, often having a military background, adding some "elitist character" to the club (West, 2003, 1706).

The members of the RGS on the other hand, and especially its Secretary Arthur Hinks (1873–1945), regarded themselves as scientists and were not too keen on publicity and "sportsmanship". So when George I. Finch (1888–1970) was considered as expedition leader for the 1922 trip, there were many objections to this by EC members. From the RGS and Hinks, Finch's self-display in the press did not sit well with their scientific attitude, while the AC regarded the Australian-born who was educated at European schools as not "fit[ting] with the English climbing establishment" (West, 2003, 1702).

Finch, however, became an advocate of the use of supplemental oxygen at high altitude. He went to Oxford in 1921 to see Georges Dreyer, professor of pathology, who had devised the oxygen apparatus for the RFC in the First World War (see section 5.3). Their experiments in the pressure chamber both supported the benefit of oxygen and attested for Finch's good physical condition (West, 2003, 1705).

Finch and Dreyer modified the standard aviator oxygen mask and set up the oxygen apparatus for the climbers, based on the Siebe & Gorman equipment made for aviators (West, 2003, 1709). With this equipment, Finch and Geoffrey Bruce reached a height of 8320m on Mt. Everest in 1922, 500m short of the summit, but had to return because of trouble with the equipment and harsh weather. Nonetheless, this was the greatest height hitherto attained by climbers (West, 2003, 1710).

Finch, however, was not selected a member of the next expedition in 1924, for the reasons outlined above. Opposition against his nomination even went so far to fix the medical reports on his physical conditions, to have reasons to exclude him from all further activities in the EC. Thus, persons like Mallory, who ridiculed the use of oxygen, could dominate the expeditions to come and make it harder for the "oxygen school" to establish their viewpoint. The circumstance remains that Finch was expelled from the EC for his unconventional views and his role as an "outsider" in the British climber community (West, 2003, 1702). This sort of attitude, the need to be part of an established community to conduct mountain expeditions, is likewise encountered in other circles where record breaking was sought.[113]

West (2003) outlines that the decision to take oxygen aloft, the controversy between the "oxygen school" versus the "no-oxygen school", was not merely driven by scientific or technical arguments. The controversy between Greene, Odell or Hill would suggest something like this, but West (2003)

[113]This sort of elitism is also encountered with German climbers in that time. Mierau (2006, 98ff.), for instance, outlines the attempts of early 1930s mountaineers organized in the "Deutscher Alpenverein" (DAV, German Alps Club) to appeal to law-makers to ban "wild" climbing, i.e. by climbers not members of the DAV.

hints at the political/personal conflicts in a networked community that hindered certain technological breakthroughs.

That the elitist spirit of a national alpine club sat well among a society that declared its sportsmen (and mountaineers and aviators striving for records can well be counted as such) as *national heroes* seems to be self-evident. As Gilchrist (2006) elucidates, Victorian and Edwardian Britain cultivated the "British sporting hero" as signifier of national greatness, and the "Conquest of Everest", as conquest of the Earth's highest mountain seemed to be all natural for the British Empire, which in its self-image had excelled in so many areas, that this mountain appeared as the *final frontier*. Gilchrist (2006) makes his case with Sherpa Tenzing Norgay, who climbed Everest with Hillary in 1953, making it to the summit for the first time. He evinces that the neglect toward Norgay, who is said to have actually reached the summit before Hillary, is due to the nationalist bias of British press accounts on the event. The same might hold true as well with Finch in the 1920s, who – as an outsider – was not wished to reach the summit as the first person. And his "almost-success" in 1922 certainly had alerted and disturbed the EC members, who wished one of their fellows to reach the summit first. The ridiculing of oxygen for mountaineering, which was nonsense from the contemporary physiologic knowledge, is therefore more of a political struggle than anything else.

3.3.2 Mountaineering and Aviation

When going to heights, the physiological problems that occur seem to be unrelated to the way one chose to reach that altitude. On the physical level, the decrease in ambient pressure, i.e. the deprivation of the inspired air with oxygen, is the same on a mountain top or in a balloon or aeroplane flying at the same height. It therefore seems natural to investigate both in the same context.

This conception falls short, however, for various reasons, and physiologists had already recognized that at the start of the 20^{th} century. Zuntz and Zuntz (1897) conjure up Bert's statement on the relation of mountaineering and aviation:[114]

> "Paul Bert himself at the end of his work [Bert (1878)] calls attention to this circumstance, that with mountaineers the mountain sickness occurs at much lower altitudes as with aeronauts, because the former require a surplus of oxygen for the strenuous physical work in the ascent, which can not be taken up from the thin air by their already exerted lungs."

This is the reason why J.S. Haldane, as an attentive reader of Schrötter and Zuntz, argued in 1910, that mountains like Monte Rosa or the Scottish

[114] Zuntz and Zuntz (1897, 5), translation mine.

mountains are not optimal for investigations in high-altitude. He wanted a "nice, comfortable mountain" (West, 1998b, 148), not because he dreaded the long and strenuous ascent necessary for getting to the summit of Monte Rosa etc, but because of the corruption of the physiological data this would bring about in terms of height acclimatization. To reach the summit of Monte Rosa, for example, a multi-hour climb over rocky and icy footpaths would be required, limiting both the amount of laboratory equipment that could be taken up, and the value of the resulting data.

Haldane, on the other hand, was convinced that the full scale of altitude acclimatization would require a relaxed human that needed to be brought to the relevant height as fast as possible. Thus, Pike's Peak was chosen, since you can get up to the summit with a cog railway in no time, a situation comparable to an ascent in an aeroplane, even though at that time Haldane might have not been paying much attention to aviation.

While mountain expeditions in the early 20^{th} century surely were a good opportunity to study the effects of high altitudes on the human body, their value should not be overestimated in terms of physiological findings. In the first years these expeditions provided the only framework for long-term high altitude study, where balloon ascents could be made only for short durations and aeroplanes would not get high enough to relevant levels.

The German expeditions in the 1930s were conducted at a time when most other aviation physiologists had established their own canon of methodology, usually discarding mountain expeditions. Rather, the pressure chamber had taken over and the Germans also used it widely. Their 1937 expedition to the Nanga Parba mountain shows in fact how far behind the Germans were in the field. Hence, Simmond's statement from above, that high altitude flying and mountaineering have much in common should not lead one to the conclusion that this defined a long-lasting agenda, but rather a episodic, contemporary point of view, which was revised later on. That the Germans would not recognize this in the 1930s is not an indication of their superiority, as Mackowski (2002, 16ff.) insinuates, but quite the opposite. On the other hand, it shows how much dynamics there was in the field of aviation medicine, and how long some agendas can endure in the public understanding of the field.

3.4 Chapter conclusions

The venture into a rather prosopographic approach to the scientific side of aviator equipment was made in order to further outline how personal *hubris* is responsible for the development of particular technology, such as pressure suits. As was shown in this chapter, almost all of the most influential actors in diving- and aviation medicine had some rather romantic and idealistic notions of their discipline that went beyond the idealism usually connected with medicine.

In this vein it comes as no surprise that most physiologists were quite vigorous about their respective field, even though not all of them were at such extremes as JS Haldane, who regarded opponents to his theories (both scientific and philosophical) as misanthropes. It was also shown that those scientists considered pioneers in diving and aviation medicine had interests far beyond medicine. Paul Bert was a politician, Yandell Henderson tried to be one, Hermann von Schrötter was an avid balloonist, John Scott Haldane a vigorous philosopher, and Leonard Hill a producer of fine art, who also got involved in social debates. It seems that those actors had a broad range of non-scientific interests that actually comprised their genuine approach to science and its applications.

This becomes even more significant when one considers their status of being important *agents of social influence*.[115] Haldane, despite being left behind in academia, had quite some influence on scientific heuristics and also was the scientific member of many government commissions. His views were quite influential in the fields of diving, tunnel work, mining and other issues of industrial hygiene – not only in the UK, but also abroad. Hill, too, made many influential studies in industrial hygiene and applied physiology and set his landmarks in the respective areas, first and foremost by advocating the application of oxygen to respiratory problems. Schrötter had quite the same standing among the German-speaking audience. Also consulted by government bodies in Austria, he also did much – if not the most – applied research on oxygen masks in Germany before the First World War, closely cooperating with the Dräger company, Germany's largest producer of such technology, that also had a good market share in other countries. Henderson and Schneider laid the foundations of American aviation medicine and shaped the field for years to come.

From this it could be inferred that it is actually required to have interests beyond science to make scientists excel in their discipline, simply because it opens up their minds to issues in *applied science*, such as diving or aviation medicine. In recent years much attention was paid by historians of technology to the connection of technology and play. One could actually sort the scientists depicted in this chapter into this sort of category, by concluding that it requires this *joyful* and *vigorous* encounter with science to become a champion in a particular scientific field. It also denotes the notion of *hubris* mentioned already, and that Hård and Jamison (2005) put in their focus of

[115] McGinn (1991, 214ff.) discusses "Societal Influence Agents" as agents having influence on the proliferation of technology. His categories differentiate between groups of people, rather than individuals. One such category being the regulatory branch of government, of which Haldane (or the other scientists in question) was a member in more than one case. Since he had quite some influence there, often being the sole scientific member of a government commission, I deem it appropriate to attribute the status of "social influence agent" to him.

investigation. The hubris involved in the attempt to *conquer the elements* mingles with the *philobatic*,[116] joyful side of science. Nearly all scientists in this chapter had some kind of emotional reward from their studies – an emotion of joy, especially when facing dangers, like balloon ascents (Schrötter and others) or self-experiments (Haldane). Psycho-analysts would argue that this is due to some kind of *primary narcissism*, as sign of desired *self-sufficiency*. At the social level it satisfied a complex network of thrills and political incentives, as will be outlined in the next chapter.

[116]Balint (1959, 25) has coined the term "philobatic to describe one who enjoys such thrills", in contrast to an "ocnophil" person "who prefers to clutch at something firm when his security is in danger". While Balint defined these terms in the context of funfairs, the joy with which Haldane seemed to have enjoyed dangerous and sometimes painful experiments on himself could be well applied to this as well.

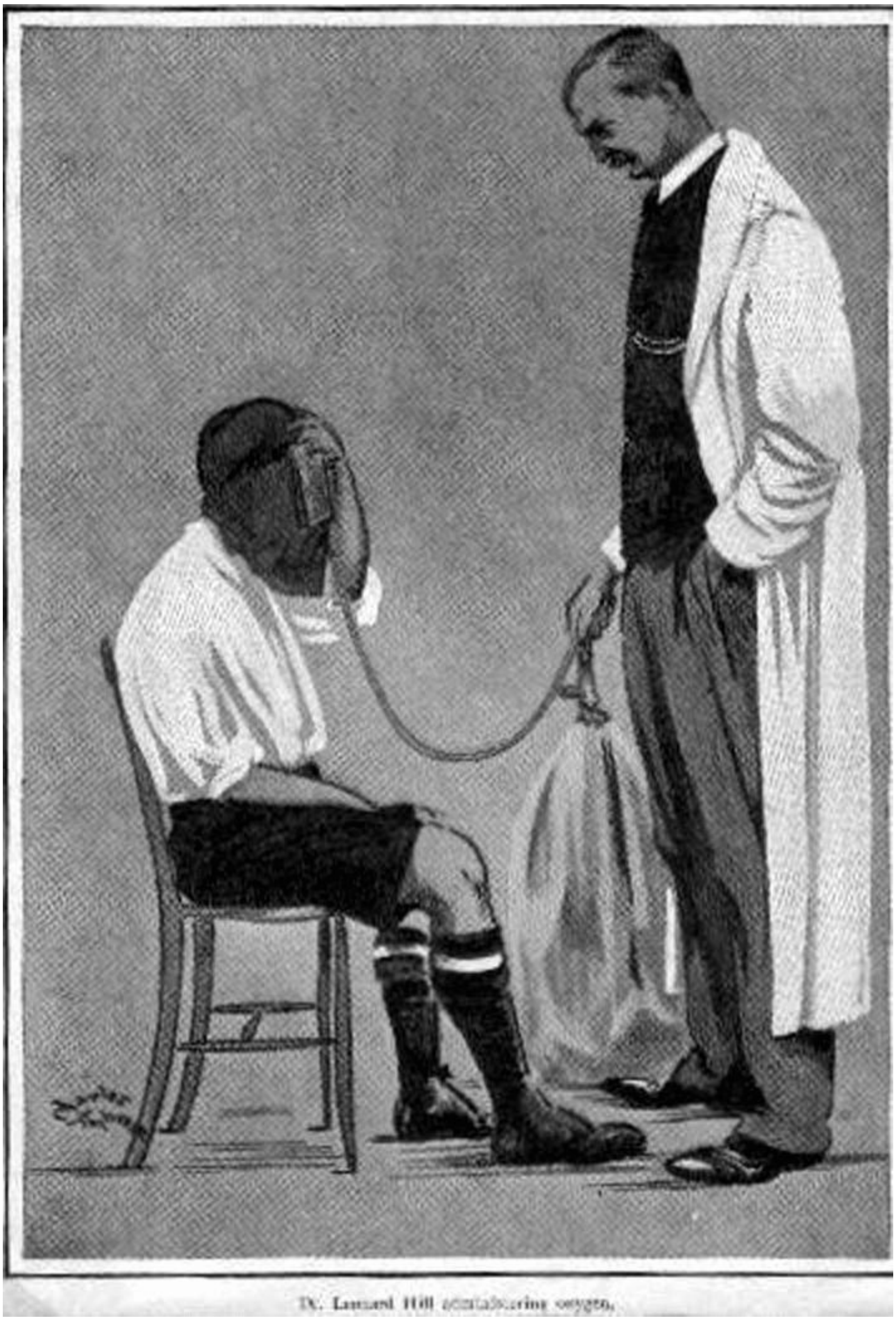

Figure 3.3: Cartoon of Hill administering oxygen. Courtesy of The Royal London Hospital Archives.

(a) Sketch from Hill

(b) Illustration from Davis

Figure 3.4: Hill's submersible decompression chamber. Reproduced by permission from the National Library of Scotland.

Figure 3.5: Rescue Apparatus by Siebe & Gorman Ltd. Reproduced by permission from the National Library of Scotland.

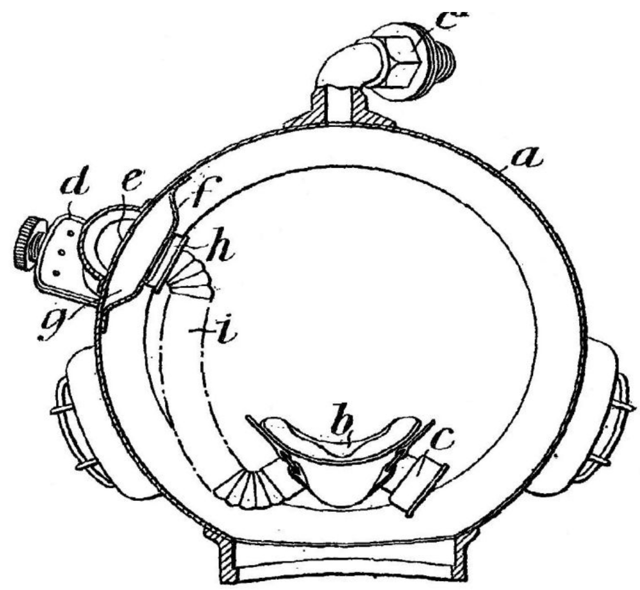

Figure 3.6: Drawing from Davis (1917). Courtesy EPO.

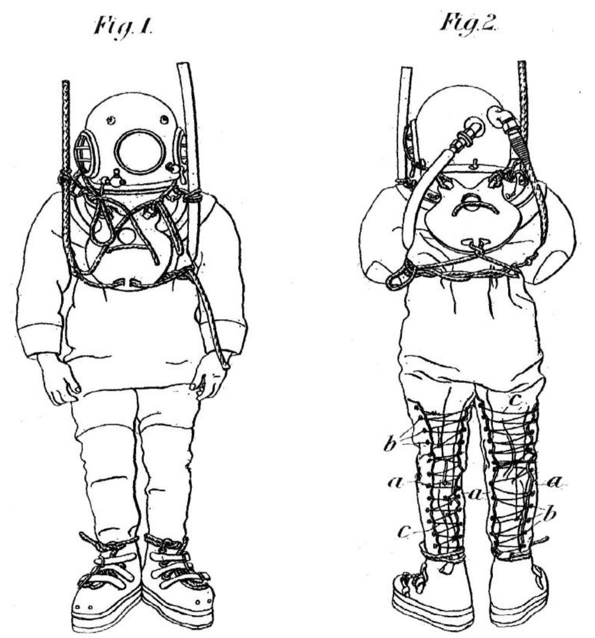

Figure 3.7: Haldane's idea for an improvement in the Siebe & Gorman diving dress. Drawings from Davis (1907). Courtesy EPO.

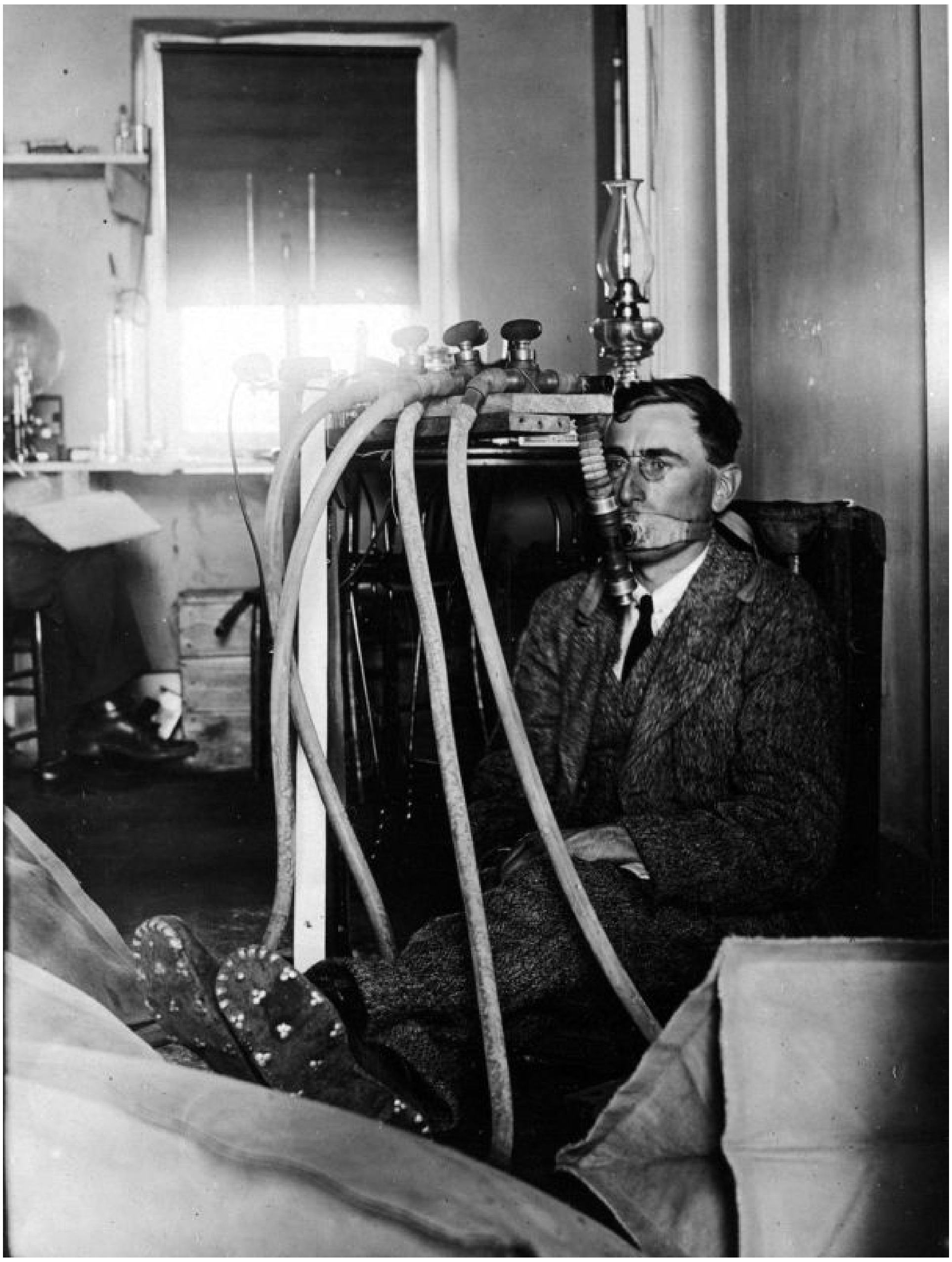

Figure 3.8: E.C. Schneider being tested for his metabolism during rest on Pike's Peak, 1911. Reproduced by permission from the National Library of Scotland.

Young barbarians still marveling at our new toys – that is what we are. Why else should we race our planes, give prizes to those who fly highest, or fastest? We take no heed to ask ourselves why we race: the race itself is more important than the object.

Antoine Saint-Exupery, *Wind, Sand, and Stars*, 1939

4 Aviation Records

AVIATION, as its precursors ballooning and airshipping did, immediately became a popular icon of modern technology. Its' feats became national epics, the reckless aviator and the stunt symbols for the self-image of the nation they represented.[1]

4.1 Aviation and Popular Culture

The flight shows of the Wright Brothers, which were actually nothing more than a showcase for their first airplane, exemplify the public arousal aviation created. The "flying shows" that soon emerged all over the industrial world became a phenomenon of modern mass culture, attracting thousands of spectators. For example Fritzsche (2007, 95) reports 60000 spectators attending the stunt flying of former World War I ace Ernst Udet on April 25, 1926 in the city of Bamberg. In the summer of 1931 up to 100000 people amassed at shows which the tobacco company Bergmann organized all over the country.

This phenomenon falls into the same category that Balint (1959) has coined "thrill". Actually aimed at *funfairs*, his observations holds true to aviation shows too (Balint, 1959, 19):

> "Funfairs mean a break in the daily routine, in the exacting discipline

[1] I will only briefly discuss female aviators, usually dubbed "aviatrix" (singl.) or "aviatrices" (pl.). Even though it would be interesting to see why aviatrices have been somewhat neglected, despite many remarkable record flights, this would be beyond the scope of this publication. Also, there have been a number of publications out there that deal with this issue in great detail, e.g. Rieger (2005), Zegenhagen (2007) or Weitekamp (2004).

> of working life. They bring about an easing-off of the strict rules governing the life of society. In this sense they offer something akin to all other 'holidays'."

While at first sight this might only hint at the motivation of the single aviator, but not at the public reception, one must consider that also the act of watching the daring feats inhibits a sort of *participative dramaturgy.* This dramaturgy explains to a good degree the different attitude of the public towards aviation records. Not only could the public participate with the aviator's fate by reading newspaper accounts, the public also could participate live at flight shows and had a certain visual contact with their object of admiration. Diving was in a less favorable position, simply because it could not provide for such publicity paraphernalia. In the early 20^{th} century culture had transformed into mass culture already. "A mass-market of culture emerged, supplied by specialized corporations [...]" as Maase (2001) has analyzed.[2] A good number of popular magazines concerned with aviation – and technology in general – developed that delivered the newest thrills to their audience. Whereas 19^{th} century scientific popularization efforts were supposed to be educating the public, in this period the efforts were solely geared at maximizing financial gain (Maase, 2001, 17).

In his classic study on the *hero* topos of ancient mythology, Campbell (1973) identifies this topos as a means for a social initiation rite, i.e. as a test for manhood, these daring feats are part of a social process. According to Campbell the hero topos persists in European writing and imposes some kind of *longue dureé* – or "nuclear unit of the monomyth" as he termed it – in occidental culture. Many modern stories still derive from the trilogy detailed in Campbell's book. First, a young adventurer leaves his town/community to gain fame and glory (Departure). Then he proves his skills and valor during the voyage (Initiation), and eventually returns home later to contribute his gained experience to his hometown's well-being (Return) (Campbell, 1973, 30).

It is thus not very surprising that aviation in the early days were full of references to youth or that aviation was regarded as the personification of youth – "although some pilots were actually in their thirties and forties" (Rieger, 2005, 124–125).

In the Interwar Years especially, i.e. the 1920s and 1930s, this attitude towards aviation became increasingly pronounced – for a variety of reasons. German right-wing philosopher and author Ernst Jünger (1895–1998) developed a philosophy of aviation as "character building" and that aviation would summarize all properties the valiant German should cultivate. Jünger (1928) wrote a pamphlet published by the German Aviation Association emphasized those nationalistic and *völkisch* attitudes: "vigor, self-control, strong nerves, and youthful vitality" (Rieger, 2005, 125).

[2]Maase (2001, 17), translation mine.

This public image of the valiant aviators furthered a thrill experienced by the audience that assumed national dimensions. In those feats, not only the fate of the pilot was at stake, but also the fate and self-esteem of the nation.

Ergo, the record lists as sanctioned by the *Fédération Aéronautique Internationale* (FAI) became best-sellers. The FAI itself published their lists in large batches in ever shorter periods, which were eagerly awaited by aviation enthusiasts, and the growing number of aviation journals quickly reprinted the newest lists in their issues.[3]

Beside some obvious nationalistic impetus that was particularly dominant in Germany, the *dramaturgy of pity*[4] was evidently employed in the many emerging stories on aviators, displaying the blood-toll humanity had to pay to master the elements. Within 10 months in the years 1928 and 1929, nine persons alone lost their lives in the attempt to cross the Atlantic. Each of those tragedies was covered in great detail in the press, declaring all of those people as "heroes", showing much compassion for them (Crouch, 2003, 277).

In the course of this chapter a good number of examples of this mix of personal hubris, national thrill and dramatic accounts will be listed. The focus is on height records, since those – any more than other forms of aviation records – furthered a concerted effort to manufacture special personal equipment, that would have otherwise been not much more than thought experiments: pressure suits. As chapter 5 in respect to the technology employed evinces, the observations and conclusions made in this chapter will contribute to the notion of pressure suits as hybrid technology.

4.2 Ballooning and Aviation Records

In the second half of the 19^{th} century meteorologic societies emerged in all European countries, e.g. 1850 in Great Britain, 1865 in Austria and 1883 in the newly inaugurated German empire (Bernhardt, 2004, 105). Their primary goal was the exploration and investigation of the upper atmosphere, and the balloon was conceived as the primary tool for this purpose. While it was occasionally debated whether these ascents had to be manned or unmanned, meteorologic instruments were not automated enough to do recording without supervision.

British science, and Victorian science in particular, was mandated to incorporate the public in both the self-image of the scientists and the public expectation, and what could serve this purpose better than public balloon

[3]For some German examples of these reprints see Anonymous (1936d, 1937c, 1939), which will be referred to later.

[4]As James Joyce specified in *A Portrait of the Artist as a Young Man*: "Pity is the feeling which arrests the mind in the presence of whatever is grave and constant in human sufferings and unites it with the human sufferer." Quoted from Campbell (1973, 26).

ascents? Whereas the emerging scientific societies of the era were designated to "educate" the public (Finnegan, 2005) and the scientist – like the churchman – was considered to participate in public discussions and publish semi-scientific articles (Gunn, 2000), ballooning – and later aviation – was somewhat different.

Publicity became an elementary feature of the ascents of James Glashier (1809–1903) and Henry Coxwell (1819–1900) in the 1860s, which went as far as offering balloon trips for paying passengers. The Royal Society had refused to sponsor the flights because they feared the promotion of "ballomania" (Tucker, 1996, 146), so Glaisher and Coxwell had to look for other sources of income. Only after Glaisher could ascertain that their balloon flights were for scientific achievements and not simply "stunts", did scientific societies start to support their efforts financially. Glaisher *et al.* nonetheless published numerous popular accounts of their "travels through the air".[5]

In the 1860s and 1870s balloon flights were still spectacular enough to create public interest, a notion that started to diminish through the incoming familiarization. Newer technology, like the airship and later the airplane, soon followed overtaking the balloon in the role as icon of modernity. Thus ballooning receded to a solely scientific feat, and only occasionally gained public attention.

In Berlin the "German Association for the Promotion of Airshipping"[6] was founded in 1881. Its major proponent became physicist Richard Assmann (1845–1918), who served as director of the "Department for Thunderstorms and Exceptional Phenomena" – which was later renamed the "Aeronautics Department" in 1899 – at the Prussian Meteorologic Institute from 1886. Between 1888 and 1899 65 manned balloon flights were made which had comparably long distances and great heights. On Dec. 4, 1894 the physicist Arthur Berson (1859–1942) made a solo flight up to 9155m, then the world's height record (Bernhardt, 2000, 53).

While the great majority of flights were done at altitudes between three and five kilometers, later flights were pushed to altitudes even higher, leading to the height record (10500m) of Berson and his colleague Reinhard Süring (1866–1950) on July 31, 1901 (Bernhardt, 2000, 53–54).

Attaining accurate measurements of the height was difficult though. As seen in Glaisher's case, the height of 11000m he had claimed to have reached, and which he published in his book (Glaisher et al., 1870), was not acknowledged by the greater part of the community. Assmann argued in a publication from 1899 that the height reached by Glaisher and Coxwell could have been no more than 8700m, and most likely was not even more than 8500m.

As a matter of fact, there soon were rumors after the mentioned ascent that the height specified by Glaisher could not be realistic. Glaisher and

[5]Cf. Tucker (1996, 153); Glaisher et al. (1870).

[6]German: "Verein zur Förderung der Luftschiffahrt".

Coxwell both fell unconscious at a height of c. 8000m, and the fact that they had reached 11000m was only testified by the recording instruments on board, which were deemed unreliable by most contemporaries. After newspapers had published the doubts about the height attained, Coxwell had to defend himself and Glaisher:[7]

> "I always found Mr. Glaisher very careful to understate rather than exceed the limits of our own travels in the air. I have known that gentleman, with his well-known exactness, to quibble over a foot, and I am sure he never gave out to the scientific world or to the public what was not true. I beg, therefore, at least in my own name, to protest, and to state that, if there is any doubt upon the subject, I am ready, if our veracity is at stake, or if the interests of science require it[.]"

Another hindrance of public recognition of altitude records attained in a balloon was due to their scientific character. Somehow, particularly with the advent of dirigible air vessels like Zepplins and then airplanes, balloons quickly lost their appeal, and them being *scientific* ascents contributed to that.[8] So, while Glaisher had to struggle to get credit from the scientific societies for his balloon flights, since he garnered them with much publicity and made them appear as vulgar amusements, around 1900 the public ceased to care about ballooning records. Still, they did have with official blessings, like the visit of the German emperor before the start of Berson and Sühring's record flight. This gave it the aura of an outstanding mission, vital to Germany's self-image as a world-power which would take the lead in all fields, including science. Since both scientists were no publicity experts – contrary to persons like Glaisher before or Piccard after them – the public hardly noticed the feat. The gathered ballooning aficionados at Berlin in 1902, however, could not help themselves but praised Berson and Süring for their altitude record (stressing that it was German balloonists that had broken Glaisher and Coxwell's record) and raised a "hip-hip-hooray" three-times during the meeting (Anonymous, 1903, 48).

Therefore ballooning around 1900 was in a somewhat contradicting situation: on the one hand it had established itself as *sport* and therefore became common and unspectacular, i.e. despicable to scientists; on the other hand as a scientific endeavor, it suffered from its fuzzy definition. *Scientific* ballooning thus had a difficult standing among the scientific community; it was regarded as too popular, while the public regarded it as too scientific.[9] Being

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[7] The Times, London, April 29, 1875, pg. 6, col. F.

[8] As the Austrian satirist Karl Kraus (1874–1936) noted: "The regression from Montogolfier to Zeppelin becomes apparent by the fact that the ascends of the Montogolfière were described by Jean Paul, whereas the air ship 'Sachsen' only had Paul Zifferer". Paul Zifferer (1879–1922) was an arts critic and feuilleton writer for the newspaper *Neue Freie Presse*, Vienna. Quoted from Riha (1992, 41), translation mine.

[9] On the German scientific ballooning around 1900, see Höhler (2001, 2007). For the American scientific ballooning with a focus on pre-WWII, see DeVorkin (1989).

jammed between these two poles, only occasionally could a balloonist gain wider public attention, like the Swiss physicist Auguste Piccard.

The technical features of Piccard's balloon will be outlined in the next chapter. The whole balloon was actually a multi-national effort. Piccard, born in Basel, Switzerland, received the position as a professor of physics at Brussels, Belgium, in 1922. The Belgian *Fonds National de la Recherche Scientifique* (FRNS) sponsored the construction of the balloon from 1929 on. The German company Riedinger in Augsburg, Europe's largest balloon manufacturer at this time, constructed the hull to Piccard's specifications. The Belgian company G. L'Hoir in Liège, the biggest aluminum producer in Belgium at the time, constructed the gondola also on Piccard's plans (Sponsel, 1955, 53).

Piccard and and his assistant Kipfer attained a height of 15785m on May 27, 1931, the new absolute altitude record. The ascent was made from Augsburg and the balloon landed in in the Alps in Austria – as the balloon has drifted away due to strong winds. The Belgian people were wary before, since the public asked why Piccard did not make his ascent from Belgian soil, when the Belgian tax-payer sponsored the whole thing. And when Piccard had to cancel his ascent in the fall of 1930 due to bad weather and postpone the flight to the spring of 1931, public opinion in Belgium got even worse. Many newspapers called for a stop to the expedition to prevent a catastrophe, not for Piccard, but for the nation (Sponsel, 1955, 56ff.).

But when the flight succeeded public opinion turned upside down. Piccard became sort of a *pop star*, but while Auguste despised any publicity, his twin brother Jean in the USA was not so shy. Doing balloon ascents to the stratosphere himself in the years after his brother's records, Jean knew how to use the public for his plans. Even though Jean was also a man of science, being a professor for chemistry, he had no trouble dealing with reporters and exploiting his feats as *records* rather than deeds of science, like Auguste had always done.

Jean Piccard (1884–1963) had immigrated to the USA in 1916 and made balloon ascends of his own, following in the footsteps of his brother, together with his wife Jeanette (1895–1981). In 1935 they reached c. 18000m in a balloon, constructed according to Auguste's design and sponsored by Henry Ford (Sponsel, 1955, 90). Contrary to his brother, Jean had no aversion to publicity, and Jean and Jeanette toured the States to report of their ascensions, and published on it (Piccard and Piccard, 1935).

Auguste Piccard, however, after his ascend of 1931, was the more famous brother for a time. Unsatisfied with the few experiments he could carry out because his equipment had crashed during the transport in the preparation for the 1931 ascent, he asked the FRNS for sponsorship of another ascension, which they happily granted, surely not only for scientific reasons, but also for the fame of their organization (Piccard had baptized the balloon of 1931 "FRNS"). When Piccard announced he would make another balloon flight the next year, the crowd cheered at the whole event this time.

On August 18, 1932 Piccard and his assistant Max Cosyns started from Zurich, Switzerland, and rose to a height of 16200m, experiencing no trouble this time. He landed safely near Monzambano in northern Italy, and all nations involved (Belgium and Germany for the balloon, Switzerland for Piccard and the take-off site, Italy for the landing place) declared Piccard as their national hero. Cigarettes and sweets were named after him, and he was requested for interviews by many journals. Piccard, however, according to his biographers, disliked this publicity. Asked to break another height-record, he refused to make any more flights himself, instead counseling others, in order to set up his new plans for the deep sea. He had heard of Beebe's deep sea exploration with a diving sphere and had devised plans to construct an independent deep-sea vessel.

For the "A century of progress" exhibition in Chicago 1933, the organizers were keen to exhibit Piccard's gondola together with Beebe's *bathysphere*. With the help of the American embassy in Brussels, the Belgian government were convinced to lend the gondola to the exhibition. The Belgian government was urged to participate in the exhibition to show the "internationality" of it and also "symbolizing the fact that science recognizes no geographical boundaries".[10]

In 1937 Jean Piccard, in a presentation at the University of Minnesota, introduced his new plans to break once again the general height record.[11] In this speech before the Institute of Aeronautics, he revealed that he wanted to reach an altitude of 32km, this time not by employing one large balloon, but by bundling several smaller "weather" balloons together. These balloons had a diameter of only 30cm, but according to Piccard they could be expanded to 4.8m, and he proposed to bundle 2000 of these. The advantage of his approach, he elucidated, would be that the small balloons altogether had a lighter weight than one large balloon, thereby allowing for greater heights. To make an emergency descent, Piccard furthermore suggests that a small explosive charge should be attached to each balloon, so that individual balloons could be destroyed to stop the ascent.[12]

Jean made several such presentations and gained much publicity for his projects through this. After he lost his position as professor at the MIT in 1929, he worked for a company in New Jersey as an engineer, while his brother achieved world-fame, though against his will. In 1932 he even lost his engineering job and had trouble finding a new employer, in both the academic

[10] Correspondence between the organizers and officials, quoted from DeVorkin (1989, 10).

[11] Jean Piccard was given the position of *special professor* for the "study of problems pertaining to the stratosphere" in spring 1936 at the University of Minnesota. Cf. Akerman (1938).

[12] Article in the German newspaper *Stuttgarter N.S.-Kurier*, Feb 15, 1937. DM, LRD 00701. The balloons are dubbed "children balloons", because of their size.

and in the industrial world. Auguste Piccard's balloon flights revived the "balloomania" in the US, which had nearly come to an end with the tragedy of Gray's death in 1927 (see below) and Auguste Piccard was eagerly awaited to lecture in America. Here, Jean found himself in an excellent position, both to organize a lecture tour through the States for his brother, and to exploit his brother's fame to gain publicity for himself (DeVorkin, 1989, 42ff.).

The role of both Piccards in high-altitude ballooning is superbly outlined in DeVorkin (1989), which is still the best and most credible literature available. It gives a detailed account of the scientific discussions and the public reverberations of these balloon ascents. Also, there exist numerous contemporary accounts on the same by Piccard, especially when he initiated his *bathyscaph* project after the Second World War, showing the public interest and arousal Piccard created with his scientific expeditions. Most of these publications also give a report on the patriotic connotation of the record-flights by Piccard, who never conceived them as such, but could not prevent the public reception he evoked.[13]

4.3 Aviation Records and National Pride

When the very first aviators, the Wright Brothers, came over to Europe to showcase their flying machines, Europe became painfully aware that the New World was not as backward as had been supposed (Behringer and Ott-Koptschaijski, 1991, 399ff.). Although their show flights were cheered, honored and admired all over Europe, it spurred a notion of competition among European aviation enthusiasts – and others.

Aviation was henceforth seen as competition of both man and machine. It was a "knightly" battle for the air, as Junkers called it in 1930 with regard to aviation records. Facing the atrocities of the trench warfare in the First World War, the "knights in the air" were literally above these bloody and dull affairs. After the war, in the midst of economic crises and political turmoil in many European nations, "Aviators became heroic exemplars for their nations" (Crouch, 2003, 278).

Whereas in the winner nation's self-esteem, aviation was a sign of their superior culture, the loosing nations, first and foremost Germany, saw it as a symbol of their humiliation Fritzsche (2007, 89–90). Germany, stripped off its air force by the Treaty of Versailles and severely restricted in the civilian aviation sector, set the struggle for aviation records as a "struggle for survival", as in Jünger's case (see above). All record attempts were characterized as a "fight" or "struggle"[14] and therefore named as such – not only in aviation but also in other fields as well, e.g. mountaineering. Also the

[13]See, e.g. Tilgenkamp (1959), Sponsel (1955), Piccard (1950), Piccard (1954) for contemporary popular publications.

[14]The German word for both is "Kampf", like in Römer (1929).

attempts to penetrate the higher and lower regions (i.e. air and undersea) of the earth were stylized as a "conquest" in this period in German publications, something that had little or no counterpart in other languages and nations.[15] Consequently aviation in Germany had a pronounced nationalistic bias, stronger than in other countries. The "airmindedness" therefore transformed into a "desperate search for the means of regeneration for a smitten nation", as Fritzsche (2007) summarizes.[16]

Furthermore, upon the advent of the dictatorships in Europe, "[...] aviation feats meant to demonstrate their national strength and technological prowess" (Crouch, 2003, 278). Germany, Italy and the Soviet Union all intensified their efforts to achieve aviation records in the 1930s, whether this had any military value or not.

Conversely, in the USA it took a little longer for the aviation enthusiasm to catch on. According to Gibbs-Smith (2003) it was not before Lindbergh's transatlantic flight (1927), that the "air fever" in the US was evoked (Gibbs-Smith, 2003, 227). However, aviation was regarded as much a spectacle in the USA as in any other part of the world. It just seems that America took a little longer before it had its national hero that made the field attractive to the public. Nonetheless, it was already regarded as "the next big thing", and even among scientists there was a certain patriotic stance towards it. One of the first American aviation physiologists wrote in 1917 (Schurmeier, 1989, 182):

> "Many of these intrepid pioneers of the air have lost their lives in this most hazardous but most fascinating of all sports. [...] The American is a composite and should lead in aviation; in him is combined the daring of the French with the ultraconservatism of the English and German, and there are certainly times when both of these factors are needed."

Despite the nationalistic and at times even social-darwinistic impetus of aviation in the Interwar Years, promoters of aviation always strove for a "sporty" aspect to the struggle. The Junkers aircraft company of Germany, which afforded itself a whole propaganda department, went to great pains to display their aviation records, and the records achieved in their crafts, respectively.[17] When Italian aviators Maddalena and Ceccioni broke the *continual flight* record in 1930 previously held by Germans Risztics and Zimmermann (in a Junkers airplane), Junkers issued several press releases, one titled "Fair Play", to assure the world that they saw this competition as a sportive one. In the press release it is stated that Junkers immediately sent off telegrams to Italian air secretary Italo Balbo to congratulate not only the

[15] Cf. Günther (1928) or Schuster (1924).

[16] Fritzsche (2007, 90), translation mine.

[17] See e.g. a datasheet in DM, LRD 05612, in which the figures of records flown with Junkers' airplanes are compared for the year 1927. Needless to say that the diagrams are carefully selected to augment Junkers' significance in the aviation market.

aviators in question, but also the Italian nation for its achievement. One telegram states that "the knightly contest, [...] in which the pilots of the nations involved in aviation are comparing their power and the products of their aviation industry, is to the best benefit to progress in aviation". Balbo's response was an equivalent to this statement.[18]

It was also in a Junkers W33 airplane – baptized "Bremen" – that German Hermann Köhl and his Irish navigator James C. Fitzmaurice started their East-West transatlantic flight in April 1928 (actually, the first East-West transition ever), from Ireland to Newfoundland (Gibbs-Smith, 2003, 227). This flight had everything dear to the audience of the 1920s. Transatlantic flights, especially on the East-West course, were an extraordinary thrill for their dangers. The technical achievement alone surely would have not created much exaltation, as "the media showed little or no enthusiasm for such purely technical 'facts'" Rieger (2005, 116). The long voyage, on the other hand, more than any other form of aviation record, holds the same fascination as the long sea-voyages in mythology as specified by Campbell (1973): Departure – Initiation – Return.

So it is no surprise that the German public (and elsewhere) were sympathetic with the fliers. Köhl successfully made it to an island in Newfoundland, off the Canadian coast. But his original destination was New York. Due to bad weather, transfer to the continental shore was delayed for several days, with no communication equipment available or functional on the island. Spectators in Germany thus thought Köhl was dead, and newspapers had already started publishing obituaries, making a "hero of aviation" out of him (Rieger, 2005, 133–134), when the news of his rescue came across. His flight nonetheless acknowledged as a record flight, since he had in fact reached the American continent. Köhl was awarded the *Flying Cross* of the USA and went to a ticker tape parade through New York, but that was nothing compared to the cheers in Germany. The whole nation regarded this as a triumph. Only the left-wing, which hailed Köhl's achievements as an individual, could not help but scoff about the national allure of aviation feats. As left-wing satirist Kurt Tucholsky mocked:[19]

> "By every gazette we have been told:
> if to contemplate a flight one is so bold,
> then even the dumbest reader's self-esteem
> will soar to regions aloft and supreme.
> – "'Cos, we, my countrymen, are tarred with the same brush,
> and so I, too, do become a cheering celebrity crush."
>
> Tell me what's on your mind,
> and I'll tell you how to kiss my behind.
> Our airmen! Our airmen!

[18] Junkers press release Nr. 44/116/611, DM, LRD 05615.

[19] Excerpt from Tucholsky (1928), translation mine.

> Did it again! Did it again!
> Your pilots surely are no match,
> for our outstanding batch!"

This notion, however, was that of a minority. Aviation in the Interwar Years was a spectacle for a wide audience, and served nationalistic, conservative stances as well as technocratic and progressive ones. Height records, in this respect, also fueled the notions of both of these groups.

4.4 Height Records in the Interwar Years

Height records, more than any other type of aviation records, were special, not only since they required the manufacture of special aviator equipment (like oxygen masks and later pressure suits), but also because they literally touched new ground. In speed or long-distance records, the ultimate task was to optimize a feat already known. There aviators did not venture into new, yet undiscovered landmarks, but sought to get faster over a well-known stretch of land, or manage to travel a distance not yet within the reach of contemporary aircrafts.

Height records, on the other hand, pushed into regions that were neither yet fully explored nor understood. The knowledge of the upper layers of the atmosphere was closely tied to the speed of progress made in recording and aviation technology. Height records thus not only had a morale value to the public, but also were of great scientific value. As was evinced in the case of scientific ballooning above, the mixture of science and adventure had to be thoroughly balanced to make those ascents attractive to the public, while at the same time remaining reputable among scientific societies and government agencies.

In airplane height records, however, the scientific side played almost no role. In high-altitude flying, technical issues dominated. First and foremost, the engines were a major concern. Other than in speed records, simply increasing the power of the engine is not sufficient. Just like humans at high-altitude suffer from insufficient oxygen in the air, so does an engine. Superchargers had to be developed that would compress the air to maintain the ignition point. Coming up with a proper engine for high-altitude purposes therefore was the main obstacle on the way to the stratosphere. As a matter of fact, often enough insufficient engines posed about the only problem to achieving a height record.

Another issue, of course, was the maintenance of the functions of the human organism. Besides hypoxia, hypothermia and fatigue had to be taken into account. While hypoxia could be countered by an oxygen mask, or with a pressure suit above a certain height where breathing oxygen would be hindered by insufficient pressure, the other two are harder to overcome in a suit. Furthermore, vision and motion was restricted in a suit. Thus, pressure cabins were regarded as the only feasible solution. In them, oxygen gauges, heating, usability, better vision, etc., could be more easily achieved.

Unfortunately, cabins introduced some considerable extra weight. As the engines for high-altitude flying in the 1920s and early 1930s were not too powerful, the weight of a cabin made its use prohibitive. So, to save such weight and keep the plane as light as possible, pressure suits, albeit regarded as inferior technology by contemporary scientists, were developed (Wilson, 1985, 51).

Since some of the single European nations put so much effort into furthering height records, a comparative study of these efforts would be appropriate at this stage. The discussions and setups are most interesting and serve as a point of departure for further studies in regard to rational frameworks of technology in general.

4.4.1 German Height Records

German aviation in the Interwar Years was certainly not in a position to attain records. The Treaty of Versailles prohibited any military aviation, making sponsorship and recruitment for such records difficult. Whereas the governments and air forces of other countries could openly cooperate with the aviation industry to strive for new achievements – primarily for reasons of prestige –, the Germans had to stick with private initiatives – at least officially.

Thus, the aviation-ardent crowd had to rely on companies like Junkers or on non-restricted activities like gliding, the latter gaining much popularity as a sport (Gibbs-Smith, 2003, 225). However, even though the Germans achieved much fame to their credit in gliding, just like ballooning it did not attract as much public attention as motorized flight. Albeit that there was much coverage in the aviation magazines on gliding activities in 1920/30s Germany, gliding could not supersede the fascination of the symbiosis of machine and man power.

This circumstance is quite remarkable and deserves a closer look. In the first years after the Nazis seized power especially, gliding was promoted as popular sport, including young women. The popular, semi-scientific aviation journal *Luftwelt*, incepted 1934, in its first volumes was full of accounts on the activities of gliding clubs, and the *Hitler-Youth* arranged for model-making events and older members could take up gliding lessons. Also, the international reputation that German gliders like Hannah Reitsch or Peter Riedel gained was exploited as a publicity stunt. Gliding, of course, was in a way paramilitary pilot training to circumvent the Treaty of Versailles, and the issues of *Luftwelt* for the year 1937 and later became increasingly decorated by *Luftwaffe* ads addressing the youngsters to join (cf. Lünen, 2008).

So, despite aviation interest, and several aviation records to the credit of Junkers airplanes, height records for motor flight was not in the line of German aviators – while height records for gliders were continuously being broken. The only general height record in aviation was achieved in 1929 by Willy Neuenhofen (1891–1936), a Junkers test pilot (see figure 4.1).[20]

Neuenhofen, a former World War I ace, flew a Junkers W34 with an English Bristol Pegasus engine. The Pegasus was a special double-charged engine for high altitude flying. It was the best engine available for this purpose, hence around 1930 most aviators used it for their record flights. This was actually the reason why Germany could not gather many height records in the first place. Being both short of appropriate engines for high-altitude flying, or the funds to buy them on the international market, they simply did not have the motor power to seek out great altitudes. Even though BMW, Daimler and Junkers tried hard to come up with specific high-altitude engines, they largely failed to produce anything competitive, an aggravation that lasted until the end of World War II (see below).[21]

Germany nonetheless collected a number of aviation records, especially in speed and distance,[22] and they were frenetically applauded in aviation magazines and daily newspapers alike. Besides height records in gliding, the records in airplanes with weight are most interesting. While they could not achieve any general height record, i.e. in the FAI subclass C-1 (Landplanes, height record with no payload), German planes broke records in the subclasses *with* payload, something that should have alerted other European nations that the Germans planned to take something heavy (like bombs and troops) up into the air. In early 1939, for example, German aviators held the height-record for airplanes with 5t (9312m) and 10t (7242m) payload.[23] Apparently, these records were not celebrated so loudly, since the public was more interested in general height records, and the German officials most likely wanted to keep the matter quiet.

4.4.2 British Height Records

Great Britain threw her hat into the ring at a rather late point. The Bristol company had produced the engines for airplanes of other nations before, but Britain could not profit from the expertise in regard to a genuine height record.

Only on September 16, 1932, could Cyril F. Uwins, a Bristol test pilot

[20]He died in an airplane crash in 1936. For a contemporary obituary, see Anonymous (1936b).

[21]See also the contemporary article in the *Deutsche Bergwerkzeitung* (DBZ) in 1938, where the author emphasized: “The question of high altitude flight is primarily a question of the engine”. DM, LRD 00691, translation mine.

[22]Interestingly enough, as the Second World War approached, the number of records they broke increased. Cf. the record list of the FAI of 1939 (Anonymous, 1939).

[23]Anonymous (1939, 211). In 1936 these records were held by Italy (Anonymous, 1936d, 133), in 1937 they were held by the Soviet Union (Anonymous, 1937c, 192).

fly a Vickers Vespa biplane with an open cockpit to a height of 13404m and thereby secure the height record for the UK for the first time in aviation, i.e. in motorized heavier-than-air aviation. Uwins only wore protective clothes (including an electrically heated garment under his coat) and an oxygen mask, and the latter he reported caused much distress due to its unreliability (Gibson and Harrison, 1984, 51).

The biggest problem British aviation had to deal with was the rather conservative nature of its aviation engineering companies, both in military and civil aviation. Even though the nation was obsessed with aviation records like all the other industrial countries, few of the companies in the 1920s and early 1930s had the will to push the limits of construction technology (Gibbs-Smith, 2003, 218).

Only the Bristol Aeroplane Company developed a desire to construct competitive aircrafts of its own. The company was well established as a producer of powerful engines, especially for high-altitude flight, but was originally not an airplane producing company. Since the models of the British airplane manufacturers did not prove to be any serious threat to the then dominating French planes, Bristol concluded it needed to construct an airplane of its own in the early 1930s. It was designed to be made of plywood and of monoplane type. The *Experimental Flying Section* of the *Royal Aircraft Establishment* (RAE) at Farnborough was contacted and specifications were drawn together to secure official support. It soon became clear though, that despite G. S. Marshall's stance toward pressure suits (see section 5.2), the extra weight introduced by a pressure cabin was prohibitive to gain a height record.

For the master minds of the project it became evident that a pressure suit had to be utilized. But no expertise with this technology was available in the UK – or in any other country for that matter. Even though John Scott Haldane had proposed such a suit as early as 1922, no actual suit was ever produced so far. An illustrious individual from abroad came to the rescue.

Mark Ridge

In 1933 a letter by the American Mark Ridge from Boston (Ma.) reached the noted physiologist John Scott Haldane in Oxford, who had championed both high-altitude and diving medicine, besides general respiration physiology (see section 3.2.5). In the letter, which was written in a rather quirky linguistic style, Ridge reports of his contemplated balloon ascent to the stratosphere, stating that he had conducted "years of exhaustive research" and had co-operated with a number of notable scientists in this endeavor, among them physiologist Phillip Drinker from Harvard and physicist Robert A. Millikan from the California Institute of Technology.[24]

[24]Letter from July 7, 1933 from Ridge to Haldane, NLS, MS 20513, F109–111.

This, however, was a blatant lie. As Mallan (1971) splendidly outlines, Ridge had neither support from US officials, nor had Drinker or Millikan agreed to cooperate. Nearly all of the mentioned scientists denied support for Ridge when asked by US officials, to whom Ridge had applied for government support for his plans, about their opinion on the matter (Mallan, 1971, 2ff.).

Millikan, an expert on cosmic rays, had send several unmanned balloons into the stratosphere to survey for radiation in the upper layers of the atmosphere. He was not in favor of manned ascensions though:[25]

> "In December 1932 he noted to a correspondent who was a manned flight buff: 'At the moment I cannot see that more is to be learned by going up in manned balloons than in any unmanned so far as cosmic rays are concerned.'"

Ridge had been turned down by various government agencies like the US Navy when approaching them to gain support. The main reason for this was because Ridge appeared as a publicity-seeker rather than a serious scientist or engineer. In fact, Ridge's only credentials in aviation was his short-lived career as a stunt pilot, and he was on the run from the police for a time in 1931 for violating a Boston law against exiting a cockpit other than for emergency reasons, i.e. he had done a stunt parachute jump over Boston which was prohibited by local law (Mallan, 1971, 2–3). According to Mallan (1971), after hearing of Piccard's record flights (see above) he became obsessed by the plan to do an ascent in an open basket balloon with a pressure suit.

Getting a hint from the local Boston coroner – about the only medical person supporting Ridge in the US – that Haldane had conceived the idea of a pressure suit years before, he contacted the British physiologist. After Haldane received Ridge's letter, he went to see Robert Davis to discuss the issue with him (Davis, 1947, 104). Haldane (1922) had stated that pressure suits were not in use or even contemplated because of "ignorance", which is not true, but such was the way of Haldane. When Ridge referred to this statement in his letter to Haldane, the latter seemed to have been struck to show the world once again the superiority of his theories, as he had failed to do so in the case of thermodynamics or oxygen secretion (see section 3.2.5).

Davis, always happy to cooperate with other individuals to create and test new equipment, according to his own account, manufactured the suit within one month (see section 5.2.1). Ridge then came over to the UK in November of 1933 to test the suit in the decompression chamber of Siebe

[25] DeVorkin (1989, 69), who refers to the Millikan archive at the California Institute of Technology. The "manned flight buff" is Mark Ridge, as DeVorkin points out in the corresponding footnote. Millikan had also criticized – and to a certain degree had even tried to ridicule – Piccard's ascent from 1931 by questioning the ascent in general and Piccard's scientific motives in particular. Cf. article "Little Information Expected From Ascent" in the *LA Times*, May 28, 1931, p. 2, which gives respective statements from Millikan.

& Gorman in London. His final test was made at a pressure of 20mm Hg, equivalent to a height of 27406m "with perfectly satisfactory results" (Davis, 1947, 105).

Besides the technical issues involved, which are discussed in section 5.2.1, the most remarkable circumstance of the suit fabrication was the press coverage attained by Ridge and Haldane. Having an exclusive deal with the *Daily Mail*, numerous articles were published therein to cover the whole event.[26] Ridge had always displayed US official's refusal to support him as act of cowardice, alleging that the officials were afraid to let him conduct the "dangerous" experiments. The *Daily Mail*, a quite conservative British tabloid, ventilated this notion unquestioned and even Davis (1947) and other persons involved reiterated this (false) statement by Ridge. The *Daily Mail* happily used this occasion to scoff about the USA and to highlight the British boldness, which would not hesitate to advance science and technology, even if it proved fatal. This becomes quite evident when looking at the sub-headings of the article where the *Daily Mail* makes a juxtaposition: " 'Certain Death' – U.S. Scientists" vs. " 'We can do it' – Prof. Haldane" (see figure 4.2).

The *Daily Mail* also published statements by Haldane on the supposed excellence and prospect of his suit, giving him the space to outline his "superior" theory.[27] Furthermore, the *Daily Mail* published a number of "Home Stories" about Ridge, making the whole event into a true yellow press arrangement. They also stressed the fact that his mother was first-generation and his father a second-generation immigrant from the UK, declaring Ridge as actual Brit.[28] The *Daily Mail* exposed the whole event as extremely dangerous and therefore glorious, calling Ridge a "dare-devil" – with no pun intended (see figure 4.3).

After Ridge returned to the US in December of 1933 he tried to find persons or organizations to sponsor the balloon for his ascent, now that he had the suit. He contacted a variety of organizations and persons, like the *National Geographical Society*.[29] All but some rather illustrious individuals agreed to support Ridge, mostly for their own selfish reasons, like publicity or for using Ridge as guinea-pig for their experiments. E.g. Ridge proudly reports to Haldane that Dr. Joseph Daily, his dentist, made experiments with him to test his reaction to Nitrous Oxide (N_2O) in order to see his resilience towards artificial respiration – certainly a dubious claim.[30] Furthermore, Ridge reports to Haldane of having the support of "Manhattan publicity man" (TIME magazine) Fice Mork and (supposed) Texan oil tycoon Harry

[26] Between November 1933 and April 1934 there were 15 articles in the *Daily Mail*, with only a few in other papers.

[27] Article "Prof. Haldane on Air Suit Test", Daily Mail, Nov 30, 1933.

[28] Article "Mother's Faith in Stratosphere Explorer", Daily Mail, Dec 11, 1933.

[29] See NGS' response in a letter from October 23, 1934; NLS, MS 20235, F107.

[30] Letters from Ridge to Haldane, Jan 20, 1936, and Feb 14, 1936; NLS, MS 20235, F116–117, and F118–122, respectively.

Doherty.[31] The connection to Doherty seemed to have been effectless, while Mork seemed to have had a long-lasting (for whatever reasons), but likewise inconclusive interest in Ridge. In short, Ridge could gain no funds for his project in the US, first and foremost for his unprofessional appearance, which was manifested by an article in the TIME magazine, which took delight in Ridge's mishap during a presentation of his thermal protection suit at the *Liquid Carbonic Corporation* (LCC) in Boston.

Ridge had rightly assumed that hypoxia is only one issue at high altitudes, hypothermia being the second one. He therefore devised an overall suit which was coated with aluminum foil from the inside, which he manufactured with the Boston-based aluminum dealer Samuel Ring. Ridge convinced the managers of LCC, a company producing frozen carbon, to construct a chamber with liquefied carbon for him to let him test his suit. Ridge wore an oxygen apparatus constructed by Ring and him from an old gas-mask. The valve failed and Ridge had to wave for help as soon as he entered the chamber and the door was closed. The local press regaled themselves and their readers with the apparent demise of Ridge's plans, and after TIME magazine published (and scoffed at) it on March 19, 1934, the whole nation regarded Ridge as a dare-devil, who would foolishly doom himself with his contemplated ascent. From then on Ridge could gain no further assistance nor funding for his cause. American publications mocked his amateurish appearance, and rather cheered "winners" like Wiley Post or the *Explorer* crew, the pulp magazine *Science and Mechanics* being the only notable exception, publishing a two-page article on Ridge's project in May 1934 and devoting the title page of the same issue to him (see figure 4.4).[32]

Haldane also tried to gain funding from British offices to show off to the world his enduring suit. However, the RAF had gotten their hands on the suit (see below) and did not wish to have the suit disclosed to the world before they could utilize it. Consequently Haldane failed to gain resources from the Treasury department or the Royal Society.[33]

Haldane also contacted balloon makers in England, and used his name to give credit to Ridge's enterprise, e.g. in a letter to the American ambassador in the UK.[34] All these attempts proved futile, however, for Ridge's and Haldane's lack of funds and Ridge's lack of credibility. After Haldane got involved in the British height record attempts of the RAF, he no longer actively pursued Ridge's cause, albeit giving him credit in the second edition of *Respiration* (cf. Haldane and Priestly, 1935), an act that extremely

[31] Letter from Ridge to Haldane, Oct 9, 1934; NLS, MS 20235, F85–86.

[32] See also article "22 Miles Up", pp. 282 and 285, *Science and Mechanics*, May 1934.

[33] Davis (1947, 105), see also NLS, MS 20235, F92, for a letter from the Royal Society to Haldane, Jan 28, 1935, explaining the delay of their answer to his proposal; and F137–138 for Haldane's proposal.

[34] See NLS, MS 20235, F82–F84.

delighted Ridge:[35]

> "Imagine my surprise and happiness when the Postman delivered to me the autographed copy of the book you recently sent me. I want you to know how delighted I am to get it.
>
> I understand that no American is Knighted, but to have received the distinction of being mentioned in your work is in itself an equal honor."

Ridge, especially after Haldane's death in 1936, becomes ever more obsessed with his plan and contacts various public persons in order to secure their support, Albert Einstein among them.[36] Despite having convinced MIT president Karl Compton for a time, Ridge completely failed to gain any considerable support. Ridge became more and more detached from reality and was eventually sent to an insane asylum in 1942 after continually addressing and annoying various congressmen, senators and even the president. The *Boston Globe* showed some remaining interest, publishing an article on his contemplated enterprise in 1941,[37] and making a telephone interview with him in 1946, in which he offered to put himself in a captured V2-rocket to have himself rocketed to a height of 75km.[38] In April 1962 Ridge died in the asylum, having spent the rest of his life there, aside from short-lived escapes.

Royal Air Force

Alerted by the press coverage of Ridge's ventures, the RAF became interested in the suit. As mentioned above, Bristol Co. and the RAF were about to make plans for a height record flight. They were, however, not really interested in making this project public before the actual record flight succeeded. Hence, the RAF evaded official channels, fearing that some information might leak out, and contacted Davis and Haldane via persons outside the Air Ministry, but affiliated with it. Some news of this enterprise did get out to the public, but the RAF kept the affair quiet for the rest of the time.[39]

In November 1933, K. R. Park from the *Oxford University Air Squadron* (OUAS) had already contacted Haldane and confidentially told him of the Air Force plans.[40] At this time engineers were still struggling with the engine and the air screw, and the team was happy to have the problem of pressurized equipment solved by others. Park was thus the mediator between Haldane

[35] Letter from Ridge to Haldane, March 7, 1935; NLS, MS 20235, F105.

[36] Ridge asks Haldane to write him an introductory letter for Einstein. Whether Haldane complied is untraceable. Letter from Ridge to Haldane, Nov 26, 1934; NLS, MS 20235, F89–90.

[37] Article "17 miles up in the air", Boston Sunday Globe, July 6, 1941, p. 5.

[38] From Mallan (1971, 20), I was not able to find the article in the LOC newspaper archive, nor was I able to find the obituary on Ridge in the Boston Globe from April 16, 1962, as Mallan (1971) specified.

[39] See article "R.A.F. to test Mr. Ridge's flying kit", *Daily Mail*, Jan 04, 1934.

[40] Letter from Park to Haldane, Nov 24, 1933; NLS, MS 20235, F51.

and the Air Ministry. The OUAS was a paramilitary corps, like many found in the UK at that time. Having no conscription program, voluntary corps of high-school and university students were formed, having also the Officers' Training Corps (OTC) in service to scout and train for potential officers.[41] The OUAS was founded in 1925 to train students in flying, as a sort of silent reserve for the RAF. Even though the OUAS was part of Oxford University, it was subordinate to the Air Ministry. The training, which took two years, was cost-free and the number of members limited to 75.[42] The OUAS was the ideal platform for the RAF to communicate in an unofficial manner with Haldane.

The number of records by British aviators had declined considerably in the early 1930s (not that there were many of them before, anyway). The Editorial of the aviation magazine *Flight* on September 28^{th}, 1936 therefore complained:[43]

> "A few weeks ago *Flight* called attention to the somewhat lamentable fact that at the present time not a single worth-while world's record stands to the credit of Great Britain."

As mentioned above, aviation records meant great fame and pride for a nation in the eyes of the public. Having no such record therefore meant great disdain for the British patriots. Ironically, only one day after this call-to-arms, Squadron Leader F.R.D. Swain achieved the absolute height record in aviation with the Bristol airplane and the Haldane-Davis-Suit, setting the record to 15223m.

Needless to say the crowd cheered about this feat. Aviation magazines like *Flight* or *Aeroplane* featured articles over several issues, boasting: "Britain's Highest!"[44] Even the honorable *Times* could not help but to cheer over the event, calling the Haldane-Davis-Suit an "Ingenious Apparatus".[45] The article remained one of the few accounts made on the suit. Most, if not all, other articles in magazines and newspapers focused on the *heroic* Swain and the Bristol airplane.

Of course the Bristol company exploited this record to brag about its airplane and engine. An article in the company's magazine pointed to the fact that recent non-British height records had been attained with Bristol engines, but that this time "all-British" equipment had gained the fame in the world of aviation (Anonymous, 1936a). Other companies involved in the flight, like the Shell company which provided the fuel and the lubricants, also

[41] The OTC was comparably old, but in its modern form it existed only through Richard Haldane's military reform in 1908.

[42] All information from Minkowski (1935, 11).

[43] Section "Let's have a record", p. 285.

[44] Title of the first article in *Flight* on Swain's record flight on October 1, 1936, pp. 338–348.

[45] Subtitle of the article "Height Record Aeroplane", Times (London), Sep 30, 1936, p. 12

used this publicity stunt to show off the supposed quality of their products (see figure 4.5).

Italy acquired the height record the next year (see below), but Flt. Lt. M. J. Adam regained it in the summer of 1937, making *Flight* boast again: "Height Record Home Again" (Anonymous, 1937a). The Brits regarded it as national humiliation that the record had been taken off their hands, and thus famed Adam for retaking it. It is noteworthy, however, that the public reaction was less enthusiastic than it was for the previous record. As so often during the course of publicly acclaimed feats, the public awareness wore off quickly. Also, the growing fear of an upcoming war in Europe occupied the public discussion to a large degree. When Italy regained the height record in 1938, little public interest was aroused in Britain to get it back anytime soon. Aviation now became a serious concern for RAF officials and politicians. Where the 1920s and early 1930s saw relatively little investment in new aircrafts – as many conservative politicians and publishers have complained[46] –, the officials became increasingly aware that conflicts were about to begin. The technology as employed for the British height records, however, did not play a crucial role (see below).

Whose suit?

The RAF had installed a high altitude flying group at the *Royal Aeronautical Establishment* (RAE) at Farnborough. This group coordinated all activities regarding the height records of the RAF. Most research, however, was conducted by private companies like Bristol for the engines and aircraft, and Siebe & Gorman Ltd. for the pressure suit. The suit was the one Davis had designed for Mark Ridge, and further modified in cooperation with RAE engineers (Davis, 1947, 106).

Turnhill and Reed (1980), on the other hand, make it appear as if RAE engineers had solely designed the suit, naming Dr. Helen Grimshaw and R.C. London as its creators, saying "two [suits] were made by SiebeGorman" (Turnhill and Reed, 1980, 47). Robert Davis himself simply states that the suit has been modified during the flight tests and that M.J. Adam in 1937 flew "with a suit and apparatus similar to those used by Swain" in 1936 (Davis, 1947, 107).

Contemporary articles in aviation magazines, however, scarcely published anything vital on the suit, but always refer to Haldane and Davis as the creators of the suit.[47] That Davis was further involved in the making of the suits is indicated by a lecture manuscript of J.S. Haldane after the tests with Mark Ridge:[48]

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[46]See contemporary articles in the *Daily Mail*.
[47]See e.g. Anonymous (1937a) or Anonymous (1936c).
[48]NLS, MS.20235, F100.

> "Easy applicability to high altitude aeroplanes [...]. Examination by Air Force representatives. Not at liberty to say anything I know of Air Force plans, or to show the apparatus, which has meanwhile been greatly improved by Sir Robert Davis, who naturally does not wish the design to be prematurely disclosed."

Furthermore, Leonard Hill's *Letter to the Editor* to the TIMES points in that direction, too. Hill himself conducted numerous experiments in S&G's decompression chamber at that time with the assistance of Davis (see section 3.2.4), so he had a good insight into the works going on there:[49]

> "Attempts have been made to design cabins which will remain pressure-tight under the severe conditions of high flight at great speed, but so far these have not been very successful. The future may, however, see them so. In the meantime, a suit and respiratory apparatus have been produced which have given the British Empire the lead in high flying, and credit should be given for this.
>
> Haldane was very enthusiastic over the preliminary experiments, and predicted that very rapid stratosphere flying would soon be in general use. I wish he were here to see this first consummation."

Also, Robert Davis continually participated in the meetings organized by Bristol at their facilities or at the RAE, e.g. to discuss engineering aspects in regard to the oxygen system and its placement in the cockpit.[50]

Gibson and Harrison (1984) pointed out that Haldane and Davis went to the RAE to cooperate with the director of the Physiological Laboratory Lt. Col. Gerald Struan Marshall in 1935 (Gibson and Harrison, 1984, 53ff.). RAE personell only participated in the engineering and testing process.

Finally Marshall himself indicated that Davis was the sole creator of the suit, with Haldane taking care of the theoretical side (Marshall, 1936, 1006).

4.4.3 French Height Records

The 1920s saw a lot of pioneering feats in aviation by French pilots. A number of records had been broken, actually too much to list them all here.[51]

In the 1930s this domination deteriorated significantly. In the first half of that decade, with the *Potez* aircraft company being the driving force behind it, they could – at least for short moments – achieve a number of height records.

On September 28, 1933 for example, Gustave Lemoine flew his Potez airplane to 13661m, beating the height record, which lasted only a few months, while George Detré broke it on August 14, 1936 at 14836m.

[49] *TIMES*, London, July 12, 1937, p. 13, col. E.
[50] Cf. RAeS, Bristol-Collection.
[51] Refer to the FAI list as found in DM, LRD 05612.

But France also was a shangri-la for the aviatrices. Being quite liberal about women in aviation,[52] the *Grande Nation* had a number of records in female aviation to its credit. While other countries also had numerous female pilots, who could also gain some glory with their aviation records, France at that time gave their aviatrices nearly the same recognition as their male counterparts.[53]

Hélène Boucher (1908–1934), for example, who held the female speed and height record in her time, died in an airplane crash in November 1934. She was given the honor of being the first woman laid out in the dome *Les Invalides* in Paris, the place where persons like Napoleon were buried, an honor usually only given to significant statesmen.[54]

Another female pilot gaining a good reputation in the 1930s was Maryse Hilsz (1901–1946), who held the female height record for a while, providing close competition to Italian aviatrix Carina Negrone (see below). Even though Hilsz never broke the absolute height record – as a matter of fact no female pilot ever achieved that – she flew well above the height of the average male pilot, having set the female height record to 14310m in 1936 – not too far from the absolute height record (Chazeaux, 1999, 171).

The government support for aviation, however, and high-altitude flying in particular, was in a heavy decline in the 1930s. In a press release dated March 03, 1937, the French Secretary of the Air Ministry is indirectly quoted, saying that "the French government refuses to financially support stratosphere researches, because it sees no value for the national defense in it. Only private funding is acceptable in this field."[55] Even though this might seem implausible at first sight, actually no nation had high-altitude flying for military purposes on their mind in the 1930s.

In the British efforts, as outlined above, albeit that the high-altitude aircraft were designed to carry a machine gun, or a photo-camera (useful for military reconnaissance), no actual military plans were made to utilize such crafts. From this angle, France was no different from Italy, Britain, Germany or the USA.

On the other hand, most of these other nations, especially Britain and Italy, invested heavily into high-altitude flight. This was, however, for matters of prestige, as outlined above, and not for the military benefits of it. Germany seemed to be more interested in speed records, rather than height records.

[52] First African-American female pilot Bessie Coleman (1892–1926) went to France in 1920 to get her pilot training, since she found no one to train her in the USA. See Hart (2001) for details.

[53] For an overview, albeit quite hagiographic, on French female pilots, see Nicolau and Mismes-Thomas (2004).

[54] Cf. the contemporary article in the German *Luftwelt*, Toggenburg (1935), whose author was quite amazed over this ceremony, and also Nicolau and Mismes-Thomas (2004) for a biography on her.

[55] DM, LRD 00701, Press release from *DT Paris*, translation mine.

In short, the decline in French aviation was tightly related to the decline of state support. Development of new airplanes, engines and related equipment not only required good amounts of funding, but also a good deal of infrastructure. While the commercial aviation industry could provide for the expertise and the incentive, it needed state support to implement above-average aircrafts. Germany and Italy were good examples to that sentiment, while France proved to be the other way round.

4.4.4 Italian Height Records

Whereas commercial companies were involved with record flying in most countries, Italy took the concept one step further. In 1934 fascist air secretary Italo Balbo (1896–1940) installed the *Reparto d'Alta Quota* (RAQ, high altitude flying section) of the *Regia Aeronautica* (RA, Royal Air Force) at the RA base of Guidonia Montecelio (short: Guidonia), near Rome, making Col. Mario Pezzi (1898–1967) its commander.[56]

The aviation industry was naturally interested in these activities too. The Italian company *Caproni* delivered the airplane for the height records, and *Piaggio* the engines. The first Italian height records however, prior to the installation of the RAQ, were made with foreign engines. Renato Donati, for example, made his record flight to 14433m on April 11, 1934 in a Caproni Ca 114 open biplane equipped with a Bristol Pegasus engine.[57] Bristol's engines were at this time superior to any other brand, so they were used by Caproni in Italy and Junkers in Germany for height records. Donati wore only an oxygen mask and a heatable garment.

In the early 1930s the aristocratic aviatrix Carina Negrone (1911–1991), née Massone, also gained fame in breaking height records in the women's category. Even though fascist leader Mussolini himself wished that women should only "pilot numerous children" (Gori, 2000, 246), she used her aristocratic background and her wealthy husband to secure for herself the glory of flying. On May 5, 1934 she reached the female height record in the "Seaplane C" category with an altitude of 5544m reached. Italo Balbo, also a renowned Italian aviator of the fascist era,[58] became interested in her talents and arranged for her training at the air force base in Guidonia (Gori, 2000, 246).

On June 20, 1935 Negrone reached an altitude of 12043m, beating the female height record of French aviatrix Maryse Hilsz. Like Donati, she only wore a electrically heatable suit and an oxygen mask. She reported numerous difficulties of breathing through the oxygen system, mostly due to the

[56] Cf. Pezzi (1937), Süßbrich (1938), Lomonaco (1967), and various paper clippings in DM, LRD 00690, LRD 00691.

[57] See FAI record list from 1939, DM, LRD 05612.

[58] He became Air Secretary in 1929. In 1930 and 1933 he led transatlantic flights with flying boats. In 1940, he was shot down by *friendly fire* in Lybia. Cf. Taylor (1996).

extreme cold.

Henceforth the RAQ assessed that high altitude flying was no longer feasible without special protection in regard to extreme cold and hypoxia. The records sought by the RAQ in the following years therefore developed a number of technical means to maintain the physical abilities for their aviators (see section 5.2.4).

On the evening of May 7, 1937, Pezzi flew his plane to a height of 15665m in a pressure suit, breaking the British record of Swain from 1936 (see above). The standard Caproni Ca 161 double-decker served as basis for a specially constructed model Ca 161a, powered by a Piaggio XI R.C. 70 radial engine, maximum power 1800HP. The airplane had a span of 14.25m and a height of 3.55m.

On October 22, 1938, Pezzi flew from Guidonia to an altitude of 17083m.[59] His Caproni 161 was modified to host a pressure cabin (see section 5.2.4), and the engine was a Piaggio XI R.C. model.

Another contemporary newspaper quoted the undersecretary in the Italian Air Ministry, General Galle, who is said to have stated that the RAQ would work on airplanes to break the 20000m line and that would attain a speed of 1000km/h.[60]

Height records were not tracked by the FAI during the war, and after WWII height records were achieved with jet airplanes. Thus, Pezzi's record from 1938 is still the valid height record for piston-engined airplanes.[61]

4.4.5 American Height Records

The USA was an "air-minded" nation, just like any other industrialized country, and aviation, perhaps more than anywhere else, was a big popular spectacle. In Europe, as outlined above, a sort of *Cold War* dominated aviation records and trophies, in order to ascertain who was the leading country in Europe. In the USA the majority of the audience did not care much for other nations simply because they were out of reach.

Air races and aviation records in the USA therefore did not inhibit the same degree of nationalistic bias. Since the USA provided enough space, long distance and speed records were more at the heart of American aviators, even more so since the audience could participate and observe these feats better than a height record, with an airplane lofting above the clouds and landing some time later at the same spot. In Europe long-distance records could involve the crossing of a dozen of national borders, something that

[59] See FAI database query below. The contemporary article in the German *Münchener Neueste Nachrichten*, Oct 24, 1938, specified 17074m. An article in the *Berliner Morgenpost* from the same day gives the same value. DM, LRD 00690.

[60] Article in the *Münchener Neueste Nachrichten*, Oct 24, 1938. DM, LRD 00690.

[61] His record is listed in the class C-1 (Landplanes), Group 1 (Piston Engines), "Altitude without payload" category. Query on the F.A.I. database (`www.fai.org`), March 27, 2006. Database ID 11713.

could prove troublesome in those unsteady days. Thus height records were actually easier to strive for than any other type of record. Plus commercial companies in the US had a vital interest in fast connections over the the whole country, e.g. for mail carriage.

In America record attempts were often done within trophy races, and a number of aviators achieved celebrity status by touring from one air circus to another. One of these persons was Wiley Post (1899–1935), former oil-worker and prison inmate. Post, born in Texas and raised in Ohio, worked for the oil industry and became a parachute jumper for stunt flying shows after that. He soon realized that he needed his own airplane and returned to the oil industry in 1925 to gain the money for his plans. On his first day back, he got severely injured in an on-site accident and lost his left eye. Through this blessing in disguise, he got a $1800 compensation and could thus make his dream come true with one day's work. From the compensation money, he spent $530 on a Canuk airplane, which he used for flying shows and charter flights (Norris, 1999, 734).

In early 1928 Post was offered employment by the Briscoe oil drilling company and its manger F.C. Hall, and was given a Lockheed Vega airplane baptized *Winnie Mae* after Hall's daughter. Post had to leave the company when they got into trouble the next year, but was able to return to Hall in 1930 when things cleared up again. He was assigned to supervise the construction of a new, customized *Winnie Mae*, which Hall designated was to achieve record-flights with (Norris, 1999, 734).

Post won the *Bendix-Trophy* the same year (non-stop race from Los Angeles to Chicago, 2816km) and then started to plan a round-the-world-flight. On June 23, 1931 Post and Australian Harold Gatty departed from Long Island for this enterprise. Their circumnavigation led them via New Foundland, England, continental Europe, the Soviet Union, Alaska, Canada, Ohio to New York; it took them eight days, fifteen hours and fifty-five minutes to achieve this feat. In July 1933 Post finally secured world-fame when he did the same tour solo with the help of an auto-pilot in seven days, eighteen hours and fifty-five minutes (Norris, 1999, 734).

In 1933 Post had achieved all the fame and glory in aviation one could hope for. Being a celebrity in America and Europe, having won significant trophies and made a fortune out of that, it looked like there was nothing left to gain for him. British millionaire Macpherson Robertson, however, offered a big challenge (and prize) the next year: the MacRobertson race. This race was supposed to start on October 20, 1934 and would lead the participants from the UK to Australia, promising £10000 to the pilot who would reach the destination first. "This race had everything dear to Post's heart: [...] first class competition [...and] a widely publicized event" (Mohler and Johnson, 1971, 71).

Post knew that his *Winnie Mae* was outdated technology, and could not catch up with newer airplanes. To win a long-distance race was therefore illusory. Aware that recent technological advances had rendered his plane obsolete, Post conceived the plan to utilize the powerful winds that he knew were present in the stratosphere.[62] If he could get his *Winnie Mae* up into those heights, his travel speed might be greatly accelerated. So actually Post sought not a height- but a speed-record, seeking out the height merely to thrust his vintage airplane to victory in the MacRobertson race (Post, 1934, 492).

This is a quite remarkable approach. Height records were usually "artificial flights" (Mohler and Johnson, 1971, 71), i.e. made locally from one airport, ascending straight to the desired height, and landing shortly after on the same spot, with no horizontal distance accomplished worth mentioning. So, while most record-hunters strove for one single feat, Post tried to kill two birds with one stone.

Even though conceived for a mere publicity stunt (and some desire of more fame and money), Post started to appeal to a variety of people and the general public to convince somebody that his plan might work and was reasonable. The parlance employed by him was quite visionary, calling for nothing else but the future of commercial aviation.

The visions of regular commercial air travel through the stratosphere (which was conceived by European authors as well at that time, see below) made some impression on his contemporaries. Due to his prior work for the oil industry, Post could utilize his old contacts to gain support from Frank Phillips from the Phillips Petroleum Company, who funded Post's further experiments (Mohler and Johnson, 1971, 86).

Some time later, the *Transcontinental and Western Airlines* (TWA) also supplied funds. In 1935 however, TWA started its own stratospheric flying program, with D.W. Tomlinson in charge of it (Mohler and Johnson, 1971, 97).

Post then did his first test flight in the summer of 1934 from Burbank, California, to Cleveland, Ohio; flying at an average height of 10km. The flight took eight hours and four minutes, making up for an average speed of 402km/h. To spare the weight of the landing gear (which was not retractable in the Lockheed Vega), the *Winnie Mae* was modified to dispose of its landing gear after take-off and to land on its belly afterward. It had a double-charged Pratt & Whitney *Warp C* engine (Römer and Römer, 1937, 491). The pressure suit employed is described in chapter 5.

Post did not live long enough to see the future coming to terms with his predictions. He died in a plane crash the next year, having never achieved an officially acknowledged height record. To his credit were nonetheless a number of other aviation feats, and he was given a number of distinctions, some made posthumously. Post was awarded the *Distinguished Flying Cross* (1932), the *Collier Trophy* (1932) for outstanding contributions to aviation,

[62] Mohler and Johnson (1971, 71). Nowadays called "jet-stream".

the *Gold Medal* of Belgium, the *Harmon Trophy* and the *International Gold Medal* of the FAI, beside the public praise of his achievements (Norris, 1999, 735).

4.5 Commercial and Military Aviation

One can think whatever one wants about the hagiographies on Post. However, it cannot be denied that it was through his popularity that the idea of high altitudes for commercial aviation was considerably furthered. As outlined above, he did not seek out the stratosphere for achieving a height record, but for faster travel, something at the heart of commercial aviation companies. After Post initiated the discussion by disseminating his idea of stratospheric travel from early on, the ground work was laid for the industry to plunge in and start research of their own.

In his popularization effort Post (1934) suggests that "all flying will be done at altitudes of 50,000 feet", cutting down travel-times of transcontinental flights to half the duration (Post, 1934, 495). In the *Oklahoma City Times* of July 24, 1933, Post remarked: "The next development for long-distance flying [. . .] will be high altitude flying, flying in the stratosphere".[63]

Post simply approached the industry, not so much because of his good contacts with it, but rather because of the incapability of the governmental agencies, including the US Army Air Corps (USAAC). Despite the latter's participation in various stratosphere projects, before Post's project the Air Corps could not display any outstanding achievements. Most of its airplanes were wooden biplanes, years behind civil aircrafts (Mohler and Johnson, 1971, 83). In the early 1930s it was the civil sector that had the steepest progress curve in aviation technology – at least in the USA (Gibbs-Smith, 2003, 222).

Obviously the industry was keen to have its name associated with aviation feats to promote its products. The already mentioned propaganda from the manufacturers are a telling example of that.[64]

However, the conglomeration of interests, as became visible in the XC-35 joint project of USAAC and companies like Lockheed and others are most likely the birthplace of the *military-industrial complex.*[65] Here, more than anything else, it became apparent that the government and its armed forces did not have the drive, the personnel, nor the infrastructure to deploy genuine aircrafts, while the industry was eager to get government support and hoped for good business deals in terms of government contracts. The industry also did not have so much access to medical laboratories, physiologists and aviators as test subjects. The aeromedical branch of the US Army Air Corps

[63] Quoted from Mohler and Johnson (1971, 71)
[64] See also Anonymous (1936a); Swan (1937) for some more examples.
[65] See next chapter for an short account of the XC-35 project.

could fill the gap, and Harry Armstrong was the person in charge of defining physiological parameters for all pressure cabin airplanes in the 1930s (e.g. Armstrong, 1938).

As for the US Army Air Corps, the deal was simply the most convenient form of venturing into a technology whose outcome was uncertain. Whether pressure cabins for military flight would ever become significant was irrelevant at this point. The industry cooperation guaranteed a steady interest in the technology and provided for a wide technical and medical debate. The Air Corps could therefore conduct research and gain expertise in a field that otherwise would have been hard to push through in Congress for funding.

4.5.1 The military uses of high altitude flights

The development of high-altitude flying technology in the 1930s, although pushed further by the Air Forces, had little to no influence on airplane design for the war. Nations with advanced and dedicated high-altitude aircrafts were not necessarily ahead of their opponents in the war, and the technology developed over the years for height records had no impact on tactics and war technology, other than contributing to a general advancement of aviation technology.

Even though the military forces were involved in the attempts at height records, either directly or indirectly, the idea of the military value of flying at high altitude was questioned. Few or no proponents could be named that attributed a direct military value to the height records of the 1930s, other than achieving fame and glory for their Air Force.

This might be explained in the first run by a general uncertainty over the value of aerial warfare. After all, the political and economical struggle of the Interwar Years left little room for investments into modernizations within the Armed Forces, and most nations did not bother to deploy new tactics with an yet emerging technology like the airplane.[66]

Despite H.G. Well's early dramatic accounts on urban bombings by warplanes, e.g. *The war in the air* (1907), which furthered the public fear before aerial warfare, a real-world debate on military tactics regarding the airplane, especially bombers, did not take place. The already mentioned airmindedness did not leave place for a critical survey of the dangers of aviation. For example, the editor of the British *Flight* magazine, in his feature from the October 1, 1936 issue mocked the paratroopers employed by the Red Army in rehearsal combat, calling it of military value only "against an uncivilised enemy".[67] JBS Haldane's emergency call over the threat of aerial bombings, *Air Raid Precautions* (1938), which proposed among other things to use

[66]For a comparison of the debate in various countries over the 'war of the future', see Förster (2002).

[67]Feature "The Outlook", *Flight*, October 1, 1936, pg. 331.

London's underground tunnels as bomb shelters, was also met with much skepticism.

The *Bristol* airplane used in the 1936/37 height records was specified to have mounting sites for either a machine gun (Vickers .303, later the specification was changed to a Browning .303) or a electrically-operated camera (F.24 type) for reconnaissance.[68] It does not appear, however, that these features had too much influence on the discussions in the Air Ministry. The airplane was in fact entirely regarded as a show case.

Pezzi (1937) also speaks of the value of his high-altitude flights, like meteorology or photogrammetry, which could be judged on military value. However, as will be outline below, the Italian Air Force was more a way for Fascist dictator Mussolini to brag about his glory, rather than a serious military threat. Whether Pezzi's height records were really discussed as military research within the Italian Air Force is unclear. If it were the case, however, it was astoundingly ineffective, given the circumstance that vast resources were dedicated to high-altitude flying in Italy in the 1930s, and the performance the Italian Air Force delivered later (cf. Morrow, 2006).

4.5.2 Commercial Airlines

What is most remarkable with the American height record attempt of Wiley Post, as outlined above, was that it was for the sake of speed that Post sought to reach the stratosphere. As already mentioned, the airline TWA soon got involved in Post's project to get the first glimpse of the benefits of stratospheric flying.

In 1935 however, TWA started their own program to research these features, and D.W. Tomlinson from Boeing was nominated to supervise it. For the test flights Tomlinson utilized a Northrop Gamma airplane in 1936 and 1937. Based upon the Boeing B-17 bomber design, the company then came up with the *Stratoliner*, the first commercial passenger airplane with a pressurized cabin (see fig. 5.9).[69]

Just as with the Lockheed XC-35, the USAAC participated in the project. The Air Corps, together with commercial airlines and Boeing cooperated to research into substratospheric conditions,[70] and Harry Armstrong from the Air Medical Service of the Air Corps defined the physiological parameters for pressure cabin design. This degree of cooperation in both the XC-35 and the Stratoliner project between USAAC, commercial companies and universities is truly remarkable. Whereas European nations also developed joint programs between industry and Air Forces, they failed to create the

[68] Air Ministry, Directorate of Scientific Research, Spec. No. 2/34, from April 28, 1934; Minutes of the meeting at the Bristol company at Filton, June 14, 1936. RAeS, BC.

[69] Mohler and Johnson (1971, 97), see also Tomlinson (1938a); Anonymous (1938). For the technical features, see section 5.1.

[70] Cf. a Boeing press release from March 13, 1938, p. 3, DM, LRD 05627.

vision of the utilization of stratospheric flying for commercial flying.

One reason for this might be found in the circumstance that most European airlines were nationalized and therefore did not opt for too creative solutions, since they were more in the role of executioners of the administration than self-relying managers. On the other hand, the great distances in America might as well have inspired people to deliberate economical measures to speed up flights. As far as Europe was concerned, only intercontinental flights were seen as benefiting from high-altitude flight. And few European countries had actually any interest in settting up such intercontinental connections. Nonetheless, Munich-based illustrator von Römer drafted his vision of intercontinental stratospheric flight in 1930 (see fig. 4.6).

One must keep in mind though, that the state of the US Army Air Corps in the early 1930s was lamentable. It consisted of nothing more than some outdated biplanes, which were years behind those aircrafts in the private sector. Mail carrying was actually a duty of the Air Corps, but due to its shortcomings several accidents occurred, resulting in the deaths of many airmen, and US president Roosevelt therefore withdrew the Air Corps' license to carry mail and gave it to private companies. This event, more than anything else, demonstrated to Air Corps officials the need to catch up in aircraft technology. Hence projects like the *Explorer* balloons, the XC-35 or the Stratoliner were sponsored. This mingling of interests of scientists, engineers, businessmen and military at this time was unique and explains a good deal why America was so pragmatic about its air efforts, a stance that contributed much to the dominance of American war planes in the coming war.

Another remarkable issue is the willingness with which all participants published their research. Tomlinson for the Stratoliner, Younger for the XC-35, Armstrong on pressure cabin design and others openly published and presented accounts of their work in international journals and conferences, respectively.[71] This might be rightly seen as a typical Anglo-American stance, where the trenches between science and commerce are not so deep as in Europe. In Britain a number of persons also lectured on the commercial aspects of stratospheric flying, but the scarcity of resources hindered a break-through.[72]

Of course, in Britain before World War II the vastness of the Empire would have given way to the idea of intercontinental air travel. And John Scott Haldane stated just that to a reporter during his time with Mark Ridge:[73]

"'Stratosphere flying in heavier-than-air machines will be practicable

[71] I have cited a number of such accounts already, with more to follow in the respective sections. For the commercial prospects, one might refer to Younger (1938b) or Klemperer (1938).

[72] See e.g. Millar (1937).

[73] Article "Stratosphere Flying in a Year", *Daily Mail*, Jan 03, 1934.

> within 12 months. Man can now go to such high altitudes – it only remains to build a machine capable of carrying him there.'
>
> This was the remarkable presentation made yesterday to a *Daily Mail* reporter by Professor J. S. Haldane, Fellow of New College, Oxford, the expert on respiration. [...]
>
> 'There is the immediate prospect of mail carrying. Machines can be built to carry mails through the stratosphere to India in three hours and to Australia in a few more hours.
>
> 'The Atlantic crossing will be equally speedy, for at that altitude the rarefied air would make phenomenal speeds possible in view of the power of aero-engines nowadays. [...]'"

Even though the Americans were not the first to venture into these topics, as Younger (1938b) admitted in the discussion session after his speech before the Royal Aeronautical Society, it was them who exploited them for commercial applications and thus championed pressurized high-altitude flight in a remarkably short time. Nonetheless, inspired by the reports on German pressurized airplanes like the Ju49, German illustrator von Römer soon conceived the concept of a pressurized airplane for commercial flight. See figure 4.7, which appeared for example in Römer and Römer (1935).

Despite this early design of a high-altitude airplane with pressure cabin, which was inspired by the respective Junkers' airplanes, the Junkers company saw itself at the loosing end in this development. Whereas the broad cooperation in the USA led to the realization of a commercial airplane,[74] Junkers could not come up with more than prototypes. Commercial airlines like the Deutsche Lufthansa showed no interest in participating or sponsoring pressurized airplanes. The propaganda department of Junkers (Junkers having been nationalized in 1934) therefore put some effort into debunking Boeing's project:[75]

> "Ever more often we hear in recent times – originating from America – that aviation will take place at high altitude in the near future. Since this typical American propaganda, we feel obliged to veto against this sentiment and have therefore shed some light on this topic in this fundamental paper."

While this apparent attempt to cloak their own failure to produce a feasible high-altitude airplane by debunking foreign achievements might be

[74]An improved version of the prototype of the Boeing 307 "Stratoliner", the 307B, was put into service in April 1940 by TWA and PAA. A total of 20 airplanes was bought by these companies and used for regular flights between New York and Los Angeles.(Gibbs-Smith, 2003, 239)

[75]Letter from Junkers propaganda department to the editor of the *Völkischer Beobachter*, Sept. 23, 1938; DM, LRD 05627. Translation mine. The manuscript attached was not only published in Germany, but also translated by the propaganda ministry and published in other European countries, meaning to deceive the public over Germany's shortcomings and American "propaganda".

disposed of as merely part of a "propaganda war", the usefulness of pressure cabins for commercial aviation was questioned in Germany before. Engineer Hermann Röder from Dresden wrote an article for the German *Berliner Börsen Zeitung* in 1928 arguing against the economy of stratospheric flight by calculating that the gain in speed would inevitably introduce higher ticket prices (and mean fewer passengers), since the technology required for such flights would be much more expensive than a regular airplane. Furthermore, he dreaded the potential of accidents in case of failures of the pressure cabin or the oxygen system.[76]

Röder, however, supposed that commercial high-altitude flight would be conducted no lower than 10km, while the Boeing Stratoliner only flew at c. 5km. This height already shortened the travel time between California and New York considerably, while allowing for feasible security mechanisms, e.g. supplemental emergency oxygen or bringing the airplane down instantly to safer heights. On July 8, 1940 TWA took up regular passenger transport from New York to Los Angeles. On the East-West trip, duration took 14h09min; from West to East, it took 12h13min, at an average traveling height of 5500m. Whereas previous trips of that distance with standard airplanes had to make interruptions in Kansas City, Albuquerque and Chicago, the Stratoliner needed only one break in Kansas City to refuel.[77]

4.5.3 High Altitude Flight in WWII

That successful high altitude flying in times of peace and successful air campaigns in the war did not necessarily go hand in hand is perhaps demonstrated best by the Italian Air Force. Having achieved height and speed records in the 1930s, with an extra *high altitude flying section* in Guidonia, it degenerated into a sports club rather than an impressive military force. Rather than developing a competitive force to be reckoned with, hunting records for the political system was the dominating attitude – as it was with so many admirers of aviation in the 1930s (cf. Morrow, 2006).

As a matter of fact, Italian air marshal Italo Balbo installed a whole range of aeronautical research departments, chiefly to pursue aviation records. The research institution for high speed flight at Desenzano near Lake Garda, for example, was founded as early as 1928. Its mission, on the other hand, was not to further general advances in aircraft design, but "to pursue the Schneider Cup with greater method", and the navigation school at Orbetello was first and foremost "to train crews for the Atlantic cruises" (Segrè, 1987, 180). Italian aviators excelled at the respective competitions and records, but there were never any provision made for conveying these successes into commercial or military applications. When Balbo was transferred to Lybia

[76] DM, LRD 05627.
[77] *interavia* press release, July 22, 1940, DM, LRD 05627.

in 1934, most special programmes and department were dismantled during the following years.

The Italian case might provide an example of where a research agenda driven by the state only fails to proliferate technology, yet it would be rash to dismiss the Italian efforts so light-heartedly. While the interfacing between state and industry was a bit more intense in other countries, this did not guarantee success either.

Germany

The German Junkers aircraft company played a vital role in the secret armament plot of the German government in the Weimar Republic. After World War I, the *Treaty of Versailles* prohibited a German air force. Nonetheless, Germany secretly researched and developed military airplanes, disguised under several international treaties. Junkers, for example, erected two aircraft factories in the USSR in the 1920s. They also produced prototypes of bombers, devising the civilian airplane Ju35 as a bomber in 1928 for instance.[78]

In 1930 Junkers engineer Zindel authored a memo on the military value of high-altitude flying. This memo is remarkable insofar as later administrators in both the civilian and the military sector of aviation in Germany completely neglected the ideas Zindel outlined in this memo as far as high-altitude-flight is concerned. Whether this ignorance was political or simply for technical reasons remains unclear. Zindel, anyway, speaks of the vast increase in speed and saving of gasoline for commercial aviation when traveling at above 10km.

However, the greater benefit from high-altitude flying would be for military purposes, especially in the case of reconnaissance and bombing airplanes. In a side note, he furthermore made a comparison between a submarine and the high-altitude bomber, since they both have to be sealed off from their environment, and when dropping their torpedoes or bombs, respectively, the same mechanism would take action. Zindel then continued to discuss the technical difficulties of protecting a high-altitude bomber against fighter airplanes, and discussed installation of machine-gun domes at the rear of the plane as a counter-measure.[79]

Apparently this memo, as visionary as it was, did not have much influence on the war planning activities in Nazi Germany. The *Luftwaffe* tactics concentrated on dive bombers, rather than long-range or high-altitude bombers.

[78]Cf. reports in BA-MA, RL 3/491. For the German-Soviet cooperation in the 1920s, cf. Fischer (2003), Sobolew (2000), Zeidler (1994). In a nutshell: Junkers was requested to erect an airplane factory in the USSR by the German War Ministry in 1923. The Ministry promised to compensate for financial losses; but due to the economical crisis in the 1920s, it failed to hold onto this promise. In 1926, Junkers, frustrated by the affair, made it public, causing much distress to the German government. The Nazis then regarded him as untrustworthy and nationalized the Junkers company when they seized power in 1933.

[79]Zindel memo, DM, LRD 00700.

The *Blitzkrieg* doctrine with its combined fast tank sweeps into enemy territories, supported by dive bombers that would neutralize the enemy Air Force while still on the ground – or dog-fighting in case those enemies did make it up into the sky soon enough–, left not much room for considering high-altitude bombings. This issue was therefore completely discarded from the military discussions in the 1930s.

The discussion on high-altitude flying became ever more bizzare during the war. While official propaganda tried to denounce the value of military high-altitude flying as enemy propaganda, German Air Force HQ became more and more obsessed by exactly this feature.[80]

When it became clear during the *Battle of Britain* that the Germans could not outperform Allied fighters, and that the *Blitzkrieg* tactics with *Stuka* dive bombers could not work on a geographically separated entity like the British Isles, and that, furthermore, German fighters had not enough reach to provide protection for long-range bombers, Air Ministry officials became obsessively convinced that high-altitude bombers could even out the odds of aerial warfare. Furthermore, rumors spread that Allied forces would introduce high-altitude warplanes themselves, so high-altitude fighter planes were also sought as counter-measure (Wagner, 1991, 175–192).

Air Secretary Hermann Göring (1893–1946) demanded from German aviation industrialists (at a meeting with them in the summer of 1942) "high-altitude fighters that operate at 14, 15km height, where we expect the bombers in the future, to shoot down those bombers".[81] Later he demanded a high-altitude bomber, that would also operate at a height of 14 to 15km, with greater heights "obviously in sight".[82]

Technical director of the German Air Ministry Erhard Milch (1892–1972), World War I ace and manager at Junkers in the 1920s, saw the whole issue a bit more pragmatically. Göring had been put under pressure in the Nazi government since he could not keep up to his big-mouthed promises made at the start of World War II, that the *Luftwaffe* would win the war for Hitler. Göring, to save his own career, therefore pushed technical development in the hope to keep up to his promise.

The bombings of German towns especially bothered Göring, and when the Germans came to realize that Allied airplanes had technically caught up in no time, he became very irated. When the *Mosquito* bomber, a wooden airplane used as a bombing and reconnaissance craft flying at 9km with a speed of c. 500km/h which was too fast for the German interceptor airplanes

[80] E.g. Bley (1941, 232): "Why are the British airplanes flying so high? Because our flaks drive 'em there!" The whole article tries to debunk the British high-altitude flying program as propaganda, turning the technical issues upside down, and nonchalantly concealing that the German Air Ministry believed this "propaganda" most.

[81] Minutes of the meeting of Göring with German aviation industry managers at Göring's residence Karinhall, Sep 13, 1942; BA-MA, RL 3/60, F122. Translation mine.

[82] *ibid.*, F138. Translation mine.

and too high for German anti-aircraft guns, Göring blamed German aircraft manufacturers:[83]

> "The Mosquito, which has photographed Linz, has according to our own calculation, not according to the English one, reached a traveling speed of 530km/h – as a bomber! You should take a leaf out of their book! That's a machine every piano-factory can build over there!"

Milch, on the other hand, viewed it from a more realistic angle. He stated that at the moment (1943), the English airplanes fly at 8 to 9km height, and would probably come in at 10 to 11km in the future. Technical features of German warplanes would have to adapt to this.[84] Similar statements were made earlier by an aircraft engineer named Reinicke, who indicated in a presentation in 1942, that only medium heights were relevant for fighters and reconnaissance airplanes, since the usual cloudy weather in Europe would render greater heights useless.[85]

Nonetheless, Göring insisted on the high-altitude warplanes, using them as last resort for his career and the grace of his *Führer*. Allied success, first with the *Mosquito*, then with the *Flying Fortress*, promoted Göring's obsessive belief in a victory through superior technology. After Göring demanded a fast bomber like the *Mosquito* from the German aviation industry, he then switched to a B-17 equivalent: the Junkers Ju288. Consequently one Junkers engineer presented the Ju288 prototype as a *Flying Fortress* equivalent, even though he was not sure whether the Ju288 could hold this promise. The plans were made much too late anyway. Prototypes were not presented before 1943, with mass production scheduled to start in 1946.[86]

The biggest issue, however, was not whether pressure cabins or pressure suits should be employed. No such discussions took place at the meetings of Air Ministry officials. Pressure cabins were clearly given preference. In the next chapter, however, it will be detailed that German officials were convinced that an *emergency* pressure suit was absolutely necessary should the cabin break.

The biggest technical problem with high-altitude flying for the Germans was the lack of competitive engines. The only company having experience with special high-altitude engines in Germany was the Junkers company, and they lost touch with the performance of international producers in the 1930s. Later when Junkers could present capable engines, like the Jumo222 or the Jumo207 series, the lack of resources, especially metals, hindered the large-scale production of these types. Only a few prototypes were produced

[83] Minutes of the meeting of Göring with German aviation industry managers, March 18, 1943; BA-MA, RL 3/60, F344. Translation mine.

[84] Minutes of the meeting at Milch's office, June 15, 1943; BA-MA, RL 3/37, F13.

[85] Presentation of Reinicke before the Air Ministry officials, Oct 15, 1942; BA-MA, RL 3/1901, p. 2.

[86] Minutes of the meeting at Göring's office, Feb 22, 1943; BA-MA, RL 3/60, F202 & F212.

between 1941 and 1944, with many modification being necessary to qualify them for field use (Müller, 2006, 180–192,207–209).

The minutes of the meeting in the Air Ministry reveal that the struggle for the proper engine was not really a technical matter though. Just like Willy Messerschmitt (1898–1978) tried to use his standing to sell his airplanes to the *Luftwaffe*, so did managers from *Daimler-Benz* or *BMW* try to employ their influence for their own ends. It came as no surprise therefore that the Air Ministry ordered the *Daimler-Benz* DB603 engine as its official high-altitude work horse in the October of 1941, a decision regarded as "prematurely made" by Junkers engineers. Only apparent technical problems with the DB603, as well as with the alternative BMW 801, kept the Jumo test series running (Müller, 2006, 188).

Whether or how the Germans could have won the war is highly speculative and ahistorical. There are a number of publications out there debunking the *Wunderwaffen* (engl: wonder weapons) myth (e.g. Schabel, 1994), even though historians of aviation still employ that reverential bias in their accounts on the *Luftwaffe* achievements. The point in question is that this discussion produces a telling example of the irrationality of the technical debate both before and during the war. Where the Germans often mocked the pressure suits of other countries in the 1930s and praised their cabin designs, during the war they could not come up with a feasible solution for both. Pressurized flight, be it in the form of cabins or suits, was not an issue among Allied considerations, however.

Allies

In Schwerdtfeger and Luft (1944), results of the interrogation of Allied pilots who were held as POW in Germany are summarized. While most of the report concerned hygienic matters, also a survey on the state-of-the-art in high-altitude flying, medicine, equipment and training is given. It is questionable how reliable the data given by the POWs is, and the authors of the report themselves have considerable doubts in that regard. The hints toward pressure cabins and high-altitude flying are at least in concord with my observations: Pressure cabins did not really play any important role in World War II air combat.

According to the statements gathered from POWs, in the RAF only the *Spitfire 6* and the *Spitfire 7* and in the USAF only the *Thunderbolt* airplanes were equipped with pressure cabins, but all of these were not or only scarcely in use when it came to fighter planes (Schwerdtfeger and Luft, 1944, 6).

As far as bombers were concerned, the then newly planned *Boeing B-29* supposedly had pressurized compartments and in the RAF, a new version of the *Moskito* was also intended to have a pressure cabin (Schwerdtfeger and Luft, 1944, 6–7). The account on the B-29 is comparably long, and since it is stated by the authors that the B-29 was "in preparation", I wonder if the interrogated POWs really had enough knowledge to provide the details in question. Also, matters of high-altitude training and oxygen masks were well-explained. The report, issued on October 31, 1944, is based on “interrogations, bagged documents and foreign press releases”, and despite its informed character it spreads not much more than trivia. The information compiled in the report simply reflects what at this stage of the war was apparent to everyone: Pressure cabins were not decisive for the war effort, hence only experimental aircrafts or prototypes were equipped with it, the crews were depending on oxygen breathing, and last but not least: The Germans were in no sector of aviation medicine ahead of their Allied counter-parts.[87]

As a matter of fact the Germans themselves had come to realize that in spite of Göring’s belief (see above), the Allies were not flying at extreme altitudes (at least not at such heights that would require pressurized equipment). In a report from November 2 of 1944 to the German Air Ministry, the author reveals that only the Boeing B-29 and the Spitfire XIV were flying above 10km, and they were not in service before 1944.[88] The statement from Gibbs-Smith (2003) that military flying in World War II was done up to c. 12.5km was certainly not the regular standard operational height of the average warplane, but an extreme situation (Gibbs-Smith, 2003, 245).

The account of Shelton (1999) on oxygen equipment used by the US Air Force in World War II in Europe is much closer to the truth: “Boeing B-17 and Consolidated B-24 [...] were designed to fight at altitudes above 20,000 feet” (Shelton, 1999, 284). Shelton (1999) also outlines that in the Pacific Theater, airborne operations were never carried out as high as in the European war, but gives no detailed explanation of why this was the case. On both scenes, oxygen masks were the focus of physiologists and engineers concerned with high-altitude flying.

Neither pressure cabins nor pressure suits were really sought by the Allies. Some prototypes of combat airplanes were tested, but the issue turned out to not be as significant as had been originally assessed. At the beginning of the war the USA also considered the use of pressurized equipment for high-altitude flight. But the constructional difficulties imposed by both suits and cabins were too severe, hence progress was made on a comparably small scale (Poppen, 1941, 60–61):

> ”Pressure cabins for single or two-place aircraft are not being used or contemplated. The additional handicap of weight and elaborate instrument installation militates against the use of this procedure in small combat airplanes. For the larger patrol and bombing planes, designed to continue at high altitude, very serious consideration is given to pressurizing. [...]

[87] Despite the statement to the contrary of Mackowski (2002, 4).

[88] Report published Jan 15, 1945; BA-MA, RL 39/476.

> The use of pressure suits has not been entirely abandoned. There are distinct advantages in this type of installation. The greatest difficulties encountered in those models tried so far, is the fact that, inflated, they have constituted a splint against all movement. It would appear that this mechanical engineering difficulty can be overcome."

This kind of optimism towards mere engineering problems faded away in the course of the war. As it turned out, the problems were not so easy to solve as assumed by Poppen.

4.6 Chapter Conclusion

As outlined at the beginning of the chapter, the development of pressure cabins and pressure suits in the 1930s was more driven by reasons of prestige rather than their military value. Pressurized apparatuses would have had much value in the war, but there were numerous other factors (primarily the lack of proper high-altitude engines) that contributed to the insignificance of such technology during the Second World War.

This leads directly to the conclusions to be made for this chapter. In this chapter it was argued that the incentive for or against a technology is not simply set by technological options or political desires, but rather by a complex social and political setup.

The question whether a pressure suit *or* pressure cabin should be sought was not the real issue. Most, if not all, experts in the field (beside Haldane, who regarded it as kind of personal crusade), opted against the suit, because of engineering problems and the general benefits of cabins in terms of human factors. However, those cabins introduced engineering problems themselves. For the military or commercial context that was not really an issue as the general value of high-altitude flight for military purposes was still a topic under debate, and for commercial uses a suit was not an option at all.

The reason why suits were devised anyway were pointed out in this chapter. The political situation in the 1920s and 1930s, as well as the general public interest in aviation records furthered the demand for instant high-altitude flight. New records were sought and the cabins to achieve them were not readily available in the first half of the 1930s, so pressure suits remained the only viable option.

This technical quest sheltered a rather *irrational* component. The special social and political situation in the Interwar Years created an irrational demand on all sides in the Western world. Germany, for example, tried to recover its smitten status and humiliated national feelings. Other countries also regarded it as a national agenda not to fall behind other nations in terms of aviation, as the cited Editorial from British *Flight* magazine showed. For the dictatorships like Italy, Germany, or the Soviet Union, it became an important propaganda issue to show off in aviation, even though the military and the commercial benefits of it might have been unclear.

For the general public the Interwar Years often meant dreadful times, shaken by economic and political crises. Aviation records with their *dramaturgy of pity* and their patriotic bias basically acted as a distraction. While the dictatorships used the aviation feats to show off their superiority, the other nations in turn were intrigued to resist that claim. For the public of the democratic nations, the aviation records of Italy or the Soviet Union added to the unease those dictatorships provoked among the other nations. Furthermore, it was regarded as vital to stay competitive in order to manage the economic crises.

Aviation feats were thus seen as signpost of one's nation vitality – both politically and economically. They became, in a manner of speaking, that "meaning-giving function" German philosopher Jürgen Habermas referred to. Habermas (1976) used this term to describe the role of religion in the pre-modern world. By making references to Max Weber's seminal studies of modern society he analyses that "dominant elements of the cultural tradition are losing the character of world-views, that is of interpretations of the world, nature, and history as a whole." The changing surrogates, like nationalism, technocracy or other ideologies, that have staggered the societies of the 19^{th} and 20^{th} century, he identifies as a "motivation crisis resulting from a systematic scarcity of the resource meaning" (Habermas, 1976, 78,80,97).

The hype over aviation records and the orchestrating nationalism in the Interwar Years are no exception to that. The thrill of aviation and its daring feats, the pity and propaganda over those who failed to survive a feat and the general hubris involved, created a relieving alternative reality to what most contemporaries experienced as dreary times. The Interwar Years were the years of the *pulp* magazines. In Germany, magazines like *Koralle* or *Daheim*, or *Science and Mechanics* and *Popular Mechanics* in the USA, as well as the numerous popular aviation magazine all over the world, all provided for the fantastic worlds that science and technology would open up and explore. Most readers certainly would have never bothered visiting these places themselves, but were rather intrigued by the bright glare these accounts produced.

It were not only dare-devils, though, who produced those fantastic accounts. Serious scientists were also involved, deliberately or not: Piccard with his balloon ascents, Beebe with his deep-sea expeditions, or Mallory and others in the mountains. Each of them served a romantic *wanderlust* by supplying colorful samples of alternative realities, either from the world of science or remote places, ideally from both.

The critics of the expenses of aviation records therefore remained a minority. But the public is only one side of the affair. One has to ask why armed forces and commercial companies gave support, as small as it may was.

As became evident in this chapter, the military had comparably little impetus on the development of both pressure suits or cabins. The prospect of pressure suits – both in terms of military and commercial outcome – were just too unsure; especially in times of peace when the military had little use for it, while commercial companies did not consider it as option at all. Pressure cabins had such prospects, for both parties. In Europe, however, the benefits of commercial air transport at high altitudes were not really apparent due to the many national borders that would restrict international travels. Furthermore, most airline companies in Europe were nationalized, a circumstance that also contributed to a lag in innovation.

So, in short, there was no such thing in Europe as the *market pull*, to follow the nomenclature of Schmookler (1966) or Rosenberg (1974, 1985), despite the visions of von Römer or Haldane, as given above. Travel restrictions in Europe made the issue just too unwieldy, hence a *pull* did not really develop. Consequently, both von Römer and Haldane envisioned stratospheric travel overseas. The *technology push* was there, however, as the inventions of pressure suits and cabins in Europe proof. But there simply was no affection on the receiving end, thus, the technology did not emerge at a larger scale and remained prototypical.

In the USA on the other hand, such demand was there. Air travel in America could benefit from high-altitude flight tremendously and was therefore a strong incentive. The interest was nurtured by a variety of parties: scientists, engineers, aviation enthusiasts, the military and cooperations. Even though this led to a successful introduction of the pressure cabin into the commercial market, the wider success in both military and commercial application was postponed by the Second World War. In the war both cabins and suits were disregarded because they had little military value at that time.

Only in Germany during World War II was the administration convinced that this technology could even out the odds of aerial warfare. The irrational attitude towards aviation in the Interwar Years somehow transcended into the military sphere. The quasi supernatural properties that were attributed to aviation so often in propaganda seemed to have blurred the *Luftwaffe* leaders sense of reality. Göring and others were truly convinced of the benefits of high-altitude fighters as *Wunderwaffen*. It might be argued though, how strong the influence of the aviation myths on political decisions really were, or whether the desire for such technology was only the last resort of a regime under pressure.

The point to make here is that the technology assessments made in regard to high-altitude flying in the Interwar Years had little to no influence. Although the armed forces in America and Europe were involved in a number of joint research projects with universities and private companies, there was rarely a clear agenda where this research eventually would end up. The Interwar Years were full of discussions and uncertainties in respect to military tactics and new technology (Förster, 2002). As Hughes (1989, 99ff.) points out, early cooperation with inventors in the US Army often proved disappointing. The organization of cooperation with outsiders had yet to emerge and the organized employment of engineers and scientists in the armed forces was also still under development.

In short, as mentioned before, the development in high-altitude flying in the Interwar Years was chiefly driven by motives of hubris, both on the personal and the national level. While personal hubris explains the willingness to risk one's life in a record flight attempt, the propaganda value explains the political interest, as well the thrill and provides for an explanation of the public cheer concerning the attempt in question. To what length individuals went to implement the unwieldy technology will be revealed in the next chapter.

Figure 4.1: Photo of Willy Neuenhofen, posing with a Dräger high-altitude breather, after his record flight 1929. Reproduced by permission from the Deutsches Museum.

TO-DAY'S WEATHER: Fair (See Page 13) WEDNESDAY. The Daily Mail NOVEMBER 29, 1933. LIGHTS OUT, 7.12 a.m.; LIGHTING UP, 4.24 p.m.

25 MILES UP IN OPEN BASKET OF BALLOON

Thrills of High Scientific Adventure Bid From English Soil

TO DOUBLE RECORD HEIGHT

BRITISH EXPERTS AND YOUNG AMERICAN

WONDER SUIT DESIGNED

Certain Death —*U.S. Scientists*

We Can Do It —*Prof. Haldane*

Edward Ridge at the door of the chamber in which he was … a lack of atmospheric pressure representing a height of 90,000ft., or more than 17 miles.

SPECIAL "DAILY MAIL" NEWS

WORLD COPYRIGHT RESERVED

By W. F. HARTIN

A MAN IS TO ASCEND NEXT SPRING FROM ENGLISH SOIL 20 TO 25 MILES INTO THE STRATOSPHERE IN THE OPEN BASKET OF A BALLOON—MORE THAN TWICE THE HEIGHT OF ANY EXISTING RECORD.

This amazing project, the full details of which *The Daily Mail* …

Figure 4.2: First article on Ridge in the Daily Mail, from Nov 29, 1933.

TUESDAY, The Daily Mail DECEMBER 5, 1933.

My Talk with

THE BALLOON MAN who MAY NEVER COME BACK

By MARGARET LANE

¶ *The Daily Mail* has exclusively announced the forthcoming stratosphere balloon flight to be made by Mr. Mark Ridge, a young American airman. Mr. Ridge contemplates rising to a height of twenty or more miles—a feat which, if accomplished, will be largely the result of scientific investigations now being made by Professor J. S. Haldane and Sir Robert Davis.

EARLY next spring a young man is going to leave England for a region where man has never been before, and where he can only breathe and live. He is unknown now — a serious young American of 28—but in a few months' time, Mark Ridge may be as famous in his own strange sphere of exploration as Captain Scott in his. As famous: that is, if he returns alive.

The region Mark Ridge is going to alone is difficult to imagine. The word "stratosphere" conveys little to most of us, going about on the earth's surface where air to breathe is taken for granted, and where there is wind and rain, and things to see and hear, and the solid earth always beneath our feet.

The earth itself may vanish from sight in that unimaginable upper air where young Mark Ridge is going. It is far, far colder than the lowest temperature at the Poles. There is nothing to see, nothing to hear, nothing to breathe.

There may even, he thinks, be a kind of perpetual twilight there, for there is not so much as a grain of dust to catch and reflect the sun. Or there may be a blaze of solar brightness beyond anything we can imagine.

He does not know yet. If he returns alive he will know things that no one else knows about that silent, worldless space.

He is a highly serious young man, not interested in breaking records. He is not very tall, has a lean face and blue eyes, and a tough, closely knit body that he is glad of because it stands unnatural strain without complaining.

By trade he is a stunt flyer in an air

and up into the sky. Once there, something told him he had found his element. Since that day ten years ago Mark Ridge has—metaphorically speaking—never come down to earth. Only now he has the idea of going right up through the skin of the sky and out on

THEY WENT UP 10¼ MILES—and came down feeling ill: Professor Picoard and his fellow adventurer after their descent near Lake Garda in 1932.

MARK RIDGE

of 25 miles from the earth meant certain death, no matter what kind of protective apparatus he wore.

Mark Ridge was determined to explore that region where there is not only no air to breathe, but where the pressure is so low that the blood is incapable of absorbing oxygen, even if you had a dozen cylinders of it. So he came to England and to Professor J. S. Haldane for encouragement.

Professor Haldane is the world's greatest authority on respiration, and believes that what young Ridge means to do is possible. With Professor Haldane's knowledge behind him Ridge says he will make the ascent without fear.

✣ ✣ ✣ ✣

NIGHT and day he thinks of that strange place he is going to, wondering what it will be like.

There will be nothing to see above him, around him, or perhaps below him. When he peers over the edge of his basket he may see sky as limitless and empty as when he looks up.

tastic touch of all, he is taking ordinary umbrella. "I've got to ha something to shade myself with," says; "the sun's rays will strike absolutely unimpeded, for I shall the only object in the heavens."

The only object in the heavens!

He says these phrases without a intention of effect, just trying to pict to himself what it will be like when drifts like some monstrous demon the upper air, carrying a black brella.

Mark Ridge has the same kind modesty that some astronomers ha Dealing with stars and space, it is h to convince them that an individua big enough to matter. Flying alon five miles high, he says, one's troubles and concerns look singul small.

✣ ✣ ✣ ✣

WHAT he will feel like when the earth has shrunk and va from his sight no one can say. Ar he should die up there in the sphere no one will ever know.

He has a marked objection to pe who "go around with their heads air." He is not even interested record his ascent will establish successful. For this reason he to follow Professor Haldane and make the 25-miles ascent a series of preliminary shor tances, to increase his cha getting there alive.

Recorded knowledge of the tions of the stratosphere will be value to science that he mea no unnecessary risks by making ascent, though the months of tion make him impatient of de will take a wireless telephone so that he can speak with the can perhaps no longer see.

✣ ✣ ✣ ✣

OLD people are fond there is no taste for in young people nowadays. be because there is little in explore the earth; it is hard spot where no one has been

But the stratosphere Mark dreams of is unseen and unkn possibilities are endless — travel that will bring Americ three hours' flying of Englan of the developments it may it can only be reached by would have looked fanta

Figure 4.3: Article on Ridge in the Daily Mail, from Dec 5, 1933.

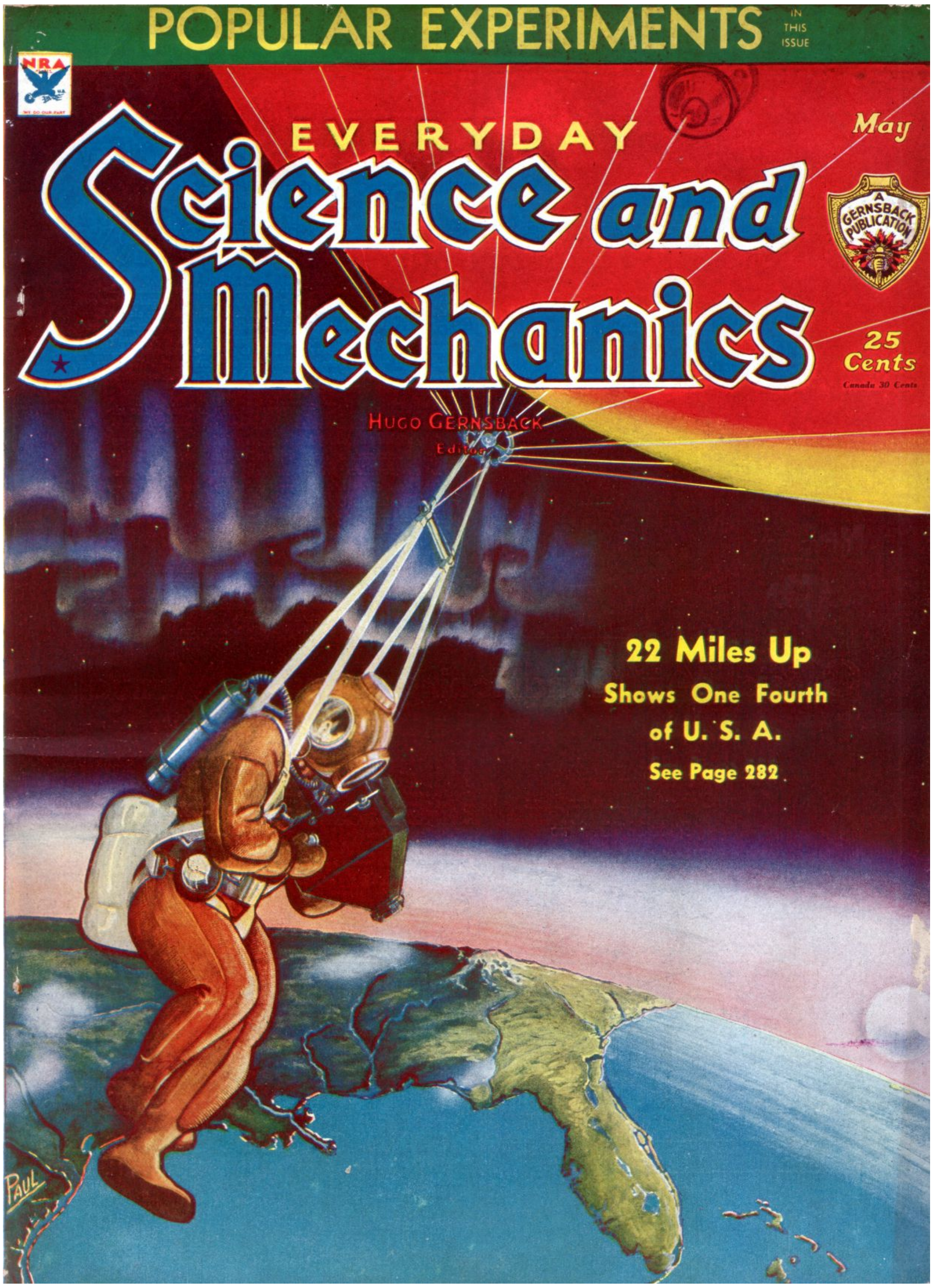


Figure 4.4: Mark Ridge on the cover of the pulp magazine Science & Mechanics, May 1934.

Figure 4.5: Various advertisements from 1936's British newspapers, orchestrating Swain's height record.

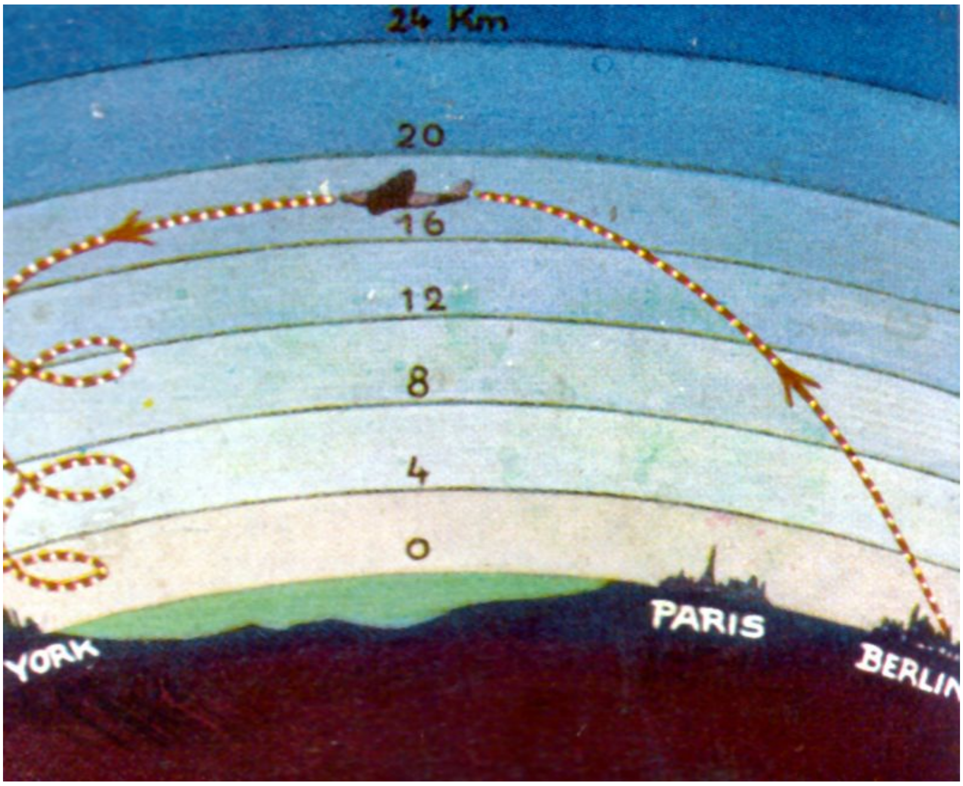


Figure 4.6: Von Römer's vision of transatlantic stratosphere flights. Taken from Römer and Römer (1930).

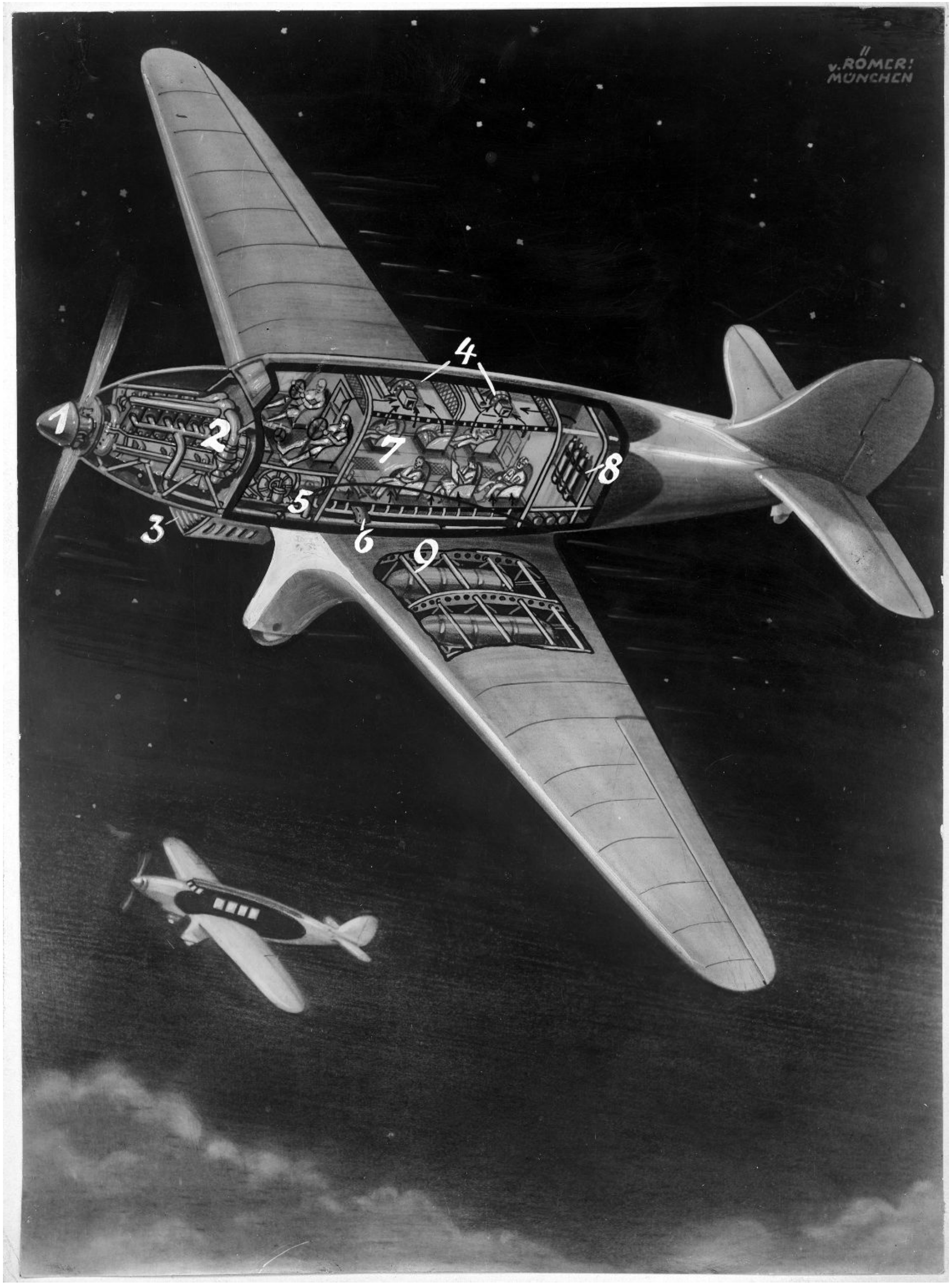


Figure 4.7: Illustration of a commercial airliner with pressurized cabin, c. 1935, by Hans von Römer. Reproduced by permission from the Deutsches Museum.

I say, beware of all enterprises that require new clothes [...]

Henry Thoreau, *Walden. Or, Life in the Woods.*

5 Technology for Height Records

Despite the habitus of military pilots (and other pilots as well) of being "tough guys", of having the "right stuff", pilots and engineers were concerned with making flying comfortable for pilots (cf. Kehrt, 2005). Not the kind of comfort a passenger of a commercial airline would demand, but still comfortable enough to make flying secure and endurable. Foiling the neo-romantic notion of the ardent zeal of the aviator struggling with and defying the laws of nature, this desire for comfort derives its virtue from the basic human psyche: the human being sheltered from the harsh environmental conditions.

Argelander (1972) puts this issue in the focus of his psycho-analytical investigation of pilots. Böhme and Böhme (1996) refer to this study in analyzing the relation of humans to the elements in general, calling it the "heroism of alienation": a heroism which sole glory stems from facing environments which were not designed to accommodate humans (Böhme and Böhme, 1996, 296). Böhme and Böhme (1996) also refer to Antoine de Saint-Exupéry for his romanticizing of aviation. One such romantic account resembles much of the notion of German geographer Carl Ritter (1779–1859) with nature as "God's reformatory" for humanity:[1]

[1] Saint-Exupéry (1948, 9), translation mine. This is the German edition of the French original Saint-Exupéry (1939), delivering the same paragraph on the same page number, providing an accurate translation. For some strange reason, this paragraph (actually, nearly an entire page) is missing from all the English editions I found, Saint-Exupéry (2002) which I used as reference for other quotes, and an earlier translation, Saint-Exupéry (1942). Both editions do not include the said paragraph, Saint-Exupéry (2002) appearing as a re-publishing of "Wind, Sand, and Stars", as included in Saint-Exupéry (1942). Why more than a complete page was dropped from the French original in the English edition

> "Earth grants us more self-knowledge than any book, because it offers us resistance. And only in struggling does man find the path to himself. But he needs a tool for this purpose, a planer, a plow. The farmer wrests the secrets from the Earth with hard labor, and the truths he unravels are universally valid. So does the aeroplane, the tool of aviation, let humans face the old riddles of the world, and it thereby becomes a tool of knowledge and self-knowledge to us."

Psychoanalysis offers a less romantic view on this subject. As Argelander (1972) evinces the fascination from aviation does not come from the direct contact with the element, as the above quote from Saint-Exupéry suggests, but from the *encapsulation* that prevents this direct contact. Argelander (1972), traced the behavior of pilots back to childhood traumas and identified a pronounced primary narcissism as the result (Symington, 1993, 97), and deemed the comfort and emotion of superiority of a pilot in his cockpit as "intra-uterine state", i.e. the pilots feels sheltered within the cockpit like in his mother's uterus. As soon as this "constant environment" is disturbed, as soon as the "nutritive unity" is disrupted, man's existence seems to be in danger (Argelander, 1972, 24). According to Argelander (1972) primary narcissism in this context is characterized by the patient's desire to choose a *diffuse* elemental object (i.e. the air) as place of struggle, rather than some concrete place or person, because the cockpit imparts an emotion of secureness and controllability, causing an "oceanic emotion".[2]

Campbell (1973) also uses the notion of an *intra-uterine state*. In his book Campbell also draws heavily on psycho-analysis, identifying human culture as a culture of finding measures against unfriendly environmental conditions (Campbell, 1973, 6):

> "Human beings are born too soon; they are unfinished, unready as yet to meet the world. Consequently their whole defense from a universe of dangers is the mother, under whose protection the intra-uterine period is prolonged."

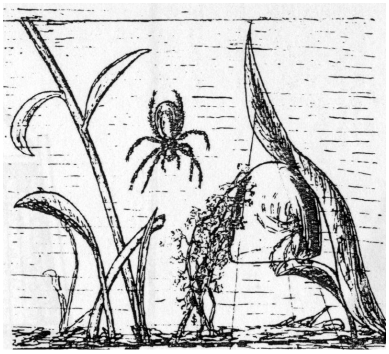
Psychoanalysis in historical research is a bit problematic; however, this characterization of a cockpit as "womb" indeed yields an interesting picture.[3] Engineers also referred to some kind of encapsulation in order to retain normal environmental conditions for the aviator/diver. Stelzner (1931) for instance uses the waterspider *Agyroneta Aquatica*, which weaves a bubble underwater to breathe and to survive, as a model for modern diving devices like diving bells. Davis (1935) makes a reference to the larvae of the dronefly *Eristalis*, which use "snorkels" to live underwater (see figure 5.1). All these

is beyond me, since it is included in the German editions.

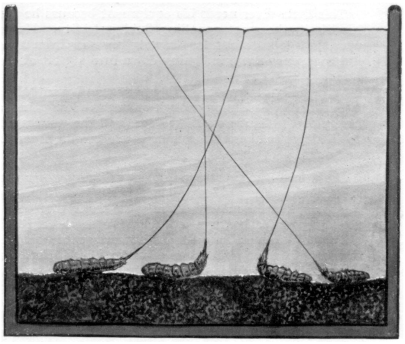
[2]Argelander (1972, 26). "Oceanic Emotion" is a term used by Freud to describe a person's "oneness" with his environment (cf. Vitz, 1988). Argelander (1972) applies this term to aviation. Freud characterized "Oceanic Emotion" as "a sensation of 'eternity', a feeling as of something limitless, unbounded, something 'oceanic'." (Balint, 1959, 73)

[3]I thank Dr. Ellen Harliszius-Klück for pointing me to this *womb*-analogue.

models from nature used for technical devices bear this womb and umbilical cord motif.



(a) From Stelzner (1931).



(b) From Davis (1935).

Figure 5.1: References to nature by diving engineers.

It was thus the ambition of engineers to shield the aviator, the diver and the astronaut from his hostile environment. The job of physiologists in this respect was to provide the physiological parameters that would make these artificial environments work, i.e. to determine by experiment how to sustain the "nutritive unity" between divers, aviators and astronauts and their respective personal equipment. "Man fashions his own environment to take with him" McDougall (1985, 3) summarizes.

That being said, it is the purpose of this chapter to show the attempts of engineers and physiologists to fashion such environments. It must be noticed that this approach, to fabricate an artificial environment, was the only actual approach to tackle the problem of surviving in a hostile environment. Spectacular medical experiments, e.g. Kylstra's *liquid breathing* with dogs (cf. Kylstra et al., 1966), furthered the idea of *adapting* humans to those environments, rather than constructing a protective hull. This was the entry point of the original authors of the now so popular and infamous *cyborg-concept*. Clynes and Kline (1995) coined this term by delineating the innovation of their concept with an analogy of a fish traveling on land with an "aquarium on wheels" rather than modifying its organism to cope with the different environmental conditions.

This, however, was not in the line of the early physiologists, who regarded Human-Factor-Engineering as an *interface* problem of humans and technology, not in the sense of making humans bio-technical hybrids, but rather in defining the physiological limits of the human organism when exposed to an altered environment, and setting the parameters for the engineers. In fact, as will be outlined in this chapter, the process of enabling humans to survive in environments that are not suitable for them, was more or less an engineering problem, rather than a medical problem. Early physiologists like

Schrötter, Zuntz, Haldane, Barcroft, Hill and others already elaborated on a sufficient knowledge to define the physiological limits, and their successors were to a large part occupied in fine-tuning these parameters and inquiring into the intricate and complex interplays of different environmental factors. "Equipment characterized work" as Noë (1989, 13) so markedly summarizes.

New laboratory equipment allowed for a finer granulation of the experimental research, new technology allowed humans to fly higher, fly faster, and dive deeper; the limits were continually pushed, the parameters hitherto regarded as sufficient to sustain life contested. Thus the research in aviation physiology in the 1930s and later was in most cases about extending the parameters and collaborating with engineers to improve the equipment, hence the term "human-factor engineering". Surely the investigations by aviation physiologists into pure science furthered insights into general physiology, in terms of metabolism and respiration and others, but most of their work was geared towards *applied* physiology.

Therefore the interaction of physiologists and engineers becomes the target for investigation in this chapter. The main fields of this interaction in the 1930s (and beyond) was in the design and construction of aviator equipment. All of these early attempts were inspired – directly and indirectly – by diving appliances.

5.1 Pressure Cabins

As mentioned in 3.2.2, Hermann von Schrötter was most likely the first physiologist elaborating the design of a pressure cabin for ballooning.[4] The principle idea as of Poe's *Hans Pfaall* would not seem to have played a big role in this development. Rather, the discussion and introduction of recompression chambers in diving might have had a major influence. Schrötter, going into great details of diving technology in publications like Heller et al. (1900), certainly was aware of that technology. Furthermore in Heller et al. (1900), a large chapter is dedicated to the caisson workers during the construction of a sluice in the Austrian town Nussdorf. Schrötter was appointed as supervising surgeon, and in that chapter the workers are used as case-studies to discuss the recompression chamber of E.W. Moir (Heller et al., 1900, 439). When in May 1895 the first cases of DCI were observed at Nussdorf, Schrötter urged the engineering company in charge to install such a chamber. Heller et al. (1900) not only provided photographs, but also technical drawings of the chamber, which was constructed by the company Redlich & Berger of Prague.

How far this influenced Schrötter's idea of a sealed gondola for balloon-

[4] Actually Bert (1878) also gave hints at such a device, but did not go into many details. Furthermore, when he learned of Verne's description, he found the idea a "mystification" and refused to discuss it. (Gibson, 1962, 90)

ing is not clear from the given sources. Csendes (1999) mentions the year 1903 as the year of its origin, but there are no sources at hand to confirm that. Schrötter (1912) on the other hand gives a rough sketch of such a gondola (see fig. 3.2),[5] discussing the placing of the oxygen tanks and the right alloying of aluminum in the construction.

Süring (1909) however, made clear that the advent of the pressurized gondola in ballooning would be inevitable:[6]

> "In case one wants to break the current height record, von Schrötter suggests a hermetically closed basket, comparable to a diving bell."

Haldane also proposed a sealed chamber to avoid the dangers imposed by high altitude, though in a narrower context. On the Pike's Peak expedition (see section 3.2.5) it was observed (and verified by checking with reports from other mountainous regions) that pneumonia proves fatal at high altitudes in most instances. In the Pike's Peak region mining workers suffering from pneumonia were put on a train and sent to Colorado Springs, i.e. to a lower elevation, to keep these people safe. It is then stated (Douglas et al., 1913, 307):

> "This danger might be averted by the use of chambers containing air with an increased oxygen percentage, or at increased pressure. In air with increased oxygen percentage the danger from fire would, of course, need to be carefully guarded against [...]"

Even though this is not a proposal for a sealed balloon gondola or even a pressure cabin for aircrafts, the discussion as observed in Schrötter and Haldane on sealing the patient/pilot from the hazardous environmental effects (in this case: low barometric pressure and the resulting hypoxia) by engineering efforts is clearly outlined: Rather than adapting the human organism to the hostile environment, the human is canned in an artificial environment that resembles those he or she normally lives in, i.e. at or nearly at sea-level. Even though Douglas et al. (1913) speak on the same page of acclimatization (which can, in a way, be regarded as adaption) for mountaineering, it is also pointed out that this is a time-consuming process,[7] and that, for example, a climb on Mt. Everest would still be a dangerous thing to do. Schrötter (1899) discusses the option of "training" climbers by regularly putting them into pressure chambers, but admits that this strategy needs considerable research efforts before it can be employed, since experiences are "vague" and "training" as a "prophylactic measure" is limited in its effects (Schrötter, 1899, 49, 52–53):

[5] Schrötter (1912, 33) comparing it with a submarine, and also gives an interesting endnote, in which he evinces that he had spoken with an engineer of the company Griesheim on questions of realizing such a cabin (Schrötter, 1912, 182). No details of the company nor the engineer is given.

[6] Süring (1909, 64), translation mine.

[7] After all, the Pike's Peak expedition was designed to record and evaluate the acclimatization process.

5.1.1 Ballooning

The problem of ascents in open basket balloons became evident in the 1920s and 1930s. Where early balloonists like Glashier in the UK or Berson in Germany only occasionally reached extreme altitudes (above 10000m), in the 1920s the envelope of heights attained was continually pushed higher, ascents above 10000m became the norm.

On May 13, 1934 the two German meteorologists Schrenk and Masuch died of hypoxia during a balloon ascent. The balloon, named *Bartsch von Sigsfeld*, after the German airship and ballooning pioneer Rudolf Hans Bartsch von Sigsfeld (1861–1902) who died in a ballooning accident, had a volume of 9500 cubic meters and was Germany's largest ever constructed balloon. It made its maiden flight in 1927 and reached a new height record of 11300m in 1933, but that was not acknowledged as such because the mission was a scientific one and not declared as a record attempt to the FAI. Nonetheless, it is the greatest height ever attained in an open basket balloon even today.

Even though it was used for meteorological investigations, the balloon was also used for medical studies, since problems of hypoxia soon became apparent. Thomas (1928) reported on problems with hypoxia during an ascent on July 11, 1928. One of the mission's goals, which was designated to reach 9000m, was to examine and observe the usage of high-altitude breathers by the balloonists and their handling of the equipment at greater altitudes. On the flight, a breather system by the *Hanseatischen Apparate-Bau-Gesellschaft mbH*[8] was tested. This was quite remarkable, since Dräger had the largest market share with its high-altitude breather, and on later ascents of the *Bartsch von Sigsfeld* this device was used. Whether this was due to the problems the crew experienced on said ascent in 1928 is not clear from the report. Insufficient training of some of the participants with the oxygen system (or high-altitude flights at all) led to the abolition of the flight at 6000m after two balloonist fell unconscious.

The meteorologists Schrenk and Masuch, on their flight in 1934, died of hypoxia well before the landing, as a contemporary investigation found out (Diringshofen, 1935a). For breathing equipment, the Dräger high-altitude breather was used, with a demand valve and no mask, but a *pipe-stem* system with no nose cap (see below). This system was regarded as the actual source of the trouble, since the open nose led to the inhalation of the rarefied environmental air and eventually to reduced consciousness. Bodily functions were thus hampered so much that the inspirational force was too weak to adequately work with a demand valve. Diringshofen (1935a) therefore recommended that constant flow oxygen (10l/min) systems shall be used on high-altitude missions, with CO_2 added (5%) to the oxygen to stimulate the

[8] Predecessor of the Hagenuk, successor of Neufeldt & Kuhnke, who among other things manufactured diving apparatuses.

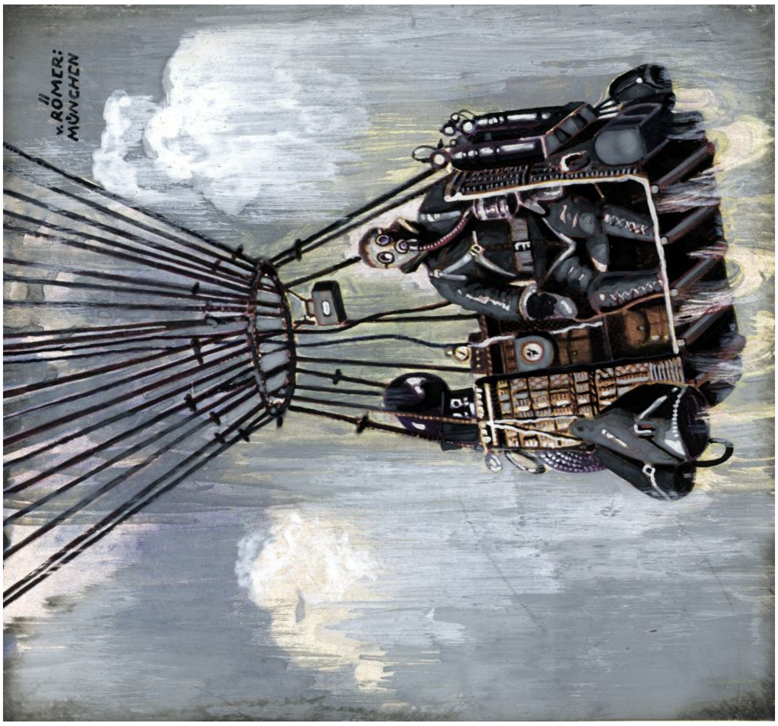
breathing reflex. Furthermore, if a pipe-stem system is used, a nose clamp must be employed, but a breathing mask would be the best option (Diringshofen, 1935a, 7–8).

Another incident from 1927 contributed to the negative stance toward open basket balloons, and furthered the demand for closed gondolas. The American Hawthorn Charles Gray (1889—1927), captain of the US Army Air Corps, tried to break Berson's and Sühring's altitude record from 1901. Equipped with compressed oxygen from a pipe-stem system, he made several attempts in 1927 to set a new record height.

As Robinson (1973) evinces, Gray and his supporters were most likely not aware of the physiological investigations Schrötter conducted for Berson and Sühring to define the height limit reachable with supplemental oxygen. Gray therefore pushed the limit without knowing that this might prove fatal (Robinson, 1973, 28).

On March 09, 1927, he reached 8690m in his US Army balloon. Dissatisfied with this height, he made a further attempt on May 04, this time reaching 12875m. The FAI did not acknowledge this as a record, though, since he had to jump out by parachute due to a malfunction of the balloon, which eventually crashed into the ground. FAI requires full control of the balloon until landing to claim a record flight, thus Gray had to start another ascent.[9]

[9] Cf. Robinson (1973, 28) and Crouch (1983, 15).



(a) Illustration by von Römer. Reproduced by permission from the Deutsches Museum

(b) Basket in the NASM

Figure 5.2: USAAC Cpt. Hawthorne Gray reached 13km on his ascend in 1927, but died due to hypoxia.

On November 04 the same year, Gray made his next ascent. He supposedly reached 12945m, but was dead when he arrived on the ground again. Post-mortem investigations could not deliver clear evidence on what had failed Gray, only that he died of hypoxia. Whether there was a malfunction in the oxygen system, a leakage in the mask, or if he simply ran out of oxygen is still not known now. All things considered, it became more and more obvious that such high regions of the sky could not be penetrated without further technology. Gray's final attempt again failed to achieve FAI's approval as a record flight, since he again was not in control of his balloon when he landed (Crouch, 1983, 18).

The experiences made in open-basket balloons were, as shown above, not very encouraging, to say the least. It was generally conceived by the engineering and scientific community that only a closed, pressurized gondola would bring about a feasible solution to the problems introduced by ever greater heights. Just as Schrötter and Stelzner had specified, a metal sealed encasement was therefore deliberated by Swiss physicist Auguste Piccard (1884–1962) for his ascent in the late 1920s (see figure 5.3).

Piccard contacted the Riedinger company in Augsburg, Germany, one of the largest companies on the continent for balloon construction. Reminded of Stelzner's earlier design, he also contacted the Dräger company to arrange for the breathing equipment for the gondola, and got a modified submarine breathing and ventilation system, working at 2l/min flow of oxygen and a ventilation of 75l/min (Sponsel, 1955, 60).

While the balloon hull was the largest ever produced, the gondola was actually the really demanding technical challenge. It was understood that the gondola's walls must be extremely durable, without too much weight to make the ascent possible. Aluminum was considered, but knowledge of alloying this material was scarce. Cooperating with the Belgian L'Hoir company, they produced an aluminum sphere of 2.1m diameter and walls of 3.5mm thickness (DeVorkin, 1989, 17).

The gondola also had several bulls-eye windows for observation and was entered through a sealable hatch. The interior pressure remained at ground level (c. 1 bar) during the ascent, and during the descent, at a height of 4500m, the hatch was opened to equalize the pressure (Schnell, 1935, 51).

To regulate the temperature inside the gondola, the hull was painted half black, half white. The gondola was then turned to the sun with its black side in case heating was required, or the white side, respectively, in case the interior needed cooling (Schnell, 1935, 52).

As far as the ventilation was concerned Dräger could fall back on two approaches they had implemented for the ventilation of submarines already, and which resembled to a large degree the concept as described by Jules Verne above. The first concept is based on compressed oxygen, while the second relies on liquid oxygen.

With the first principle tanks with 10l volume store oxygen at a pressure of 150bar, i.e. they contain 1500l of oxygen. With the help of a gauge the pressure for the cabin was adjusted. The valve through which the oxygen flow is driven goes through an alkali reservoir. The flow of the pressurized oxygen causes a stream near the valves that provides a circulation of air, and the drive through the alkali reservoir filters out the waste carbon dioxide. Since the gas within the gondola is evenly circulated, the system manages to keep the level of carbon dioxide in the air below 2%. The oxygen was consumed at a rate of c. 2l/min, but the flow could be adjusted. As Piccard and his assistent Kipfer barely moved during the balloon flight, they could reduce the oxygen consumption to a minimum (Schnell, 1935, 52–53).

The second principle, the liquid oxygen system, was already used by German warplane pilots in World War I. In such a system, which also was already discussed by Schrötter (1902), the oxygen was cooled down to its freezing point (-218,75°C). The storage for the liquid oxygen is then coupled to a carburetor to bring it back to its gaseous condition. Since this process is constant, a regulator is required to control the flow. This flow, just like the compressed oxygen system, caused a circulation, sucking in air from the gondola at the one end, and blowing out filtered air and new oxygen on the other (Schnell, 1935, 53–54).

Piccard used both systems on his ascents in 1931 and 1932 and seemed satisfied with both of them. However, this principle was not easily applicable to airplanes. First the spherical form of the gondola, ideal for a balloon would be prohibitive for airplanes because it hampered aerodynamics. Second, airplanes require through-holes for the control and steering mechanism etc. With sealed balloon gondolas this was not the case. Where samples of the outside air were required, the probing devices were simply attached to the outer hull, while other experiments were conducted inside the gondola. Therefore the principle of those sealed gondolas was closer to a submarine than to an airplane. Consequently Piccard's son Jacques used a similar spherical design for his record submarine dive in 1960.

As a matter of fact, the usefulness of a spherical design for a capsule reaching both extreme heights and extreme depths was seen by contemporaries too. Apparently, spheres offer the smallest surface while having the greatest volume. I.e. when it comes to withstanding extreme pressure differences, such a shape would be the first choice.

The American *Explorer* gondolas used an identical approach. Being a joint project between the US Army Air Corps and the *National Geographical Society* (NGS), they had a very good research infrastructure available, including experts from all the fields involved: physics, meteorology, physiology and engineering. The design of the gondola followed Piccard's, with modifications applied where they were regarded as necessary.[10] While the technical accounts on the first *Explorer* mission were a bit thin, the successor

[10] DeVorkin (1989) describes it in full detail.

Explorer II was covered in all its details and all it aspects, with the NGS publishing a thorough report (cf. Briggs, 1936). Therein, chapters on the medical aspects of the gondola's life-support systems were included (Winston, 1936), and other physiologists published on its medical aspects (E.g. Armstrong, 1936a).

The USSR also constructed a sealed gondola for balloon ascents into the stratosphere (see figure 5.5). In it, Soviet crews undertook ascents to 18482m in 1933, and 21978m in 1934 (Crouch, 2003, 279). On the latter flight, however, the gondola broke from its rigging and crashed into the ground, killing all its crew members. Analysis by Soviet scientists revealed that there would have actually been enough time to escape from the gondola by parachute (which were given to the crew), but the escape hatch was tightened with bolts and nuts and the crew was not able to loose the nuts in time. This accident curiously furthered the debate in the USSR to abolish sealed gondolas and use pressure suits in open baskets instead (Abramov et al., 2003, 5).

5.1.2 First Pressure Cabins in Aviation

Piccard's gondola, although not the first being deliberated, nonetheless paved the way for sealed, pressurized compartments when traveling to the stratosphere. While the spherical form was optimal for stationary ascents in a balloon, it was not very compatible when it came to the demands of aerodynamics in aviation. The spherical gondola could serve as a testbed for life-support systems in pressure cabins in aviation, but its construction issues for airplanes were different.

The weight introduced by a specially sealed cabin made its use in aviation prohibitive for many years. Engines and construction simply did not provide enough lift to carry the extra-weight of such a cabin. So, even though first attempts to utilize cabins were made in the 1920s, it took until the end of the 1930s until they came in use, and then still only scarcely.

France

In France the conditions for high-altitude flight were promising in the 1920s, but this changed entirely in the 1930s.

In 1936, France nationalized its airlines, bundling all authority on new developments into official hands. High-altitude research was given no credit by the government and commercial companies had little impetus to venture into this costly affair without partners from airlines or the military. Efforts therefore remained minor.

Aviation pioneer Louis Bréguet (1880–1955) supposedly filed a patent on a pressure chamber in 1908, but never constructed one himself.[11] Another

[11] This information was taken from discussion session in the account of Younger's paper

French aviation pioneer, Henri Farman (1874–1958), constructed an airplane with a pressure chamber in the 1920s, the Farman F1000, which flew up to 9135m,[12] but the project was given up after several fatal crashes. The cabin was far from being perfect. A mechanism to seal an entire operational airplane cockpit cabin could not be created, hence, the pilot had to start and land the plane from an attached cockpit with windows and then climb into the actual cabin, which had no windows, to fly on instruments only (Anonymous, 1941b, 98).

In 1938 Farman presented the F2234 airplane with a pressure cabin. However, as in the case of the F1000, the cabin could not be attached to the cockpit. The actual pressure cabin functioned only as panorama cockpit and "recreational room"; the pilot had to sit in an unpressurized cockpit and breathe supplemental oxygen to fly the plane. Not surprisingly, this airplane did not achieve anything significant and was soon abandoned (Anonymous, 1941b, 98).

As had become clear by then, France could produce neither a feasible pressure cabin or pressure suit. The authorities simply lacked the desire to achieve such, and individuals lacked the proper funding.

Belgian aircraft manufacturing company Renard, run by the brothers Georges and Alfred Renard, produced the R-35 prototype in 1938. This pressure-cabin airplane, however, crashed on its maiden flight on April 1, 1938, with pilot Yvon van Damme being killed, and no further development was sought.[13]

Germany

In Germany the Junkers company started to produce an airplane with a pressure cabin in 1928: the Junkers Ju49. Junkers did not have much experience with this type of craft (neither did any other company), and even though Schrötter and Stelzner had already devised principal pressure cabin designs, they were not sufficient for airplane plans.

Company founder and president Hugo Junkers (1859–1935) acquired the rights for two patents in 1930. In 1926, engineer Carl Klose from Berlin had filed a patent for the construction of a pressurized cabin for high-altitude airplanes. Klose (1926) admited that the basic principle of a sealed cabin was not new, but that it had not been implemented yet, because of fears

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before the *Royal Aeronautical Society*, where Younger stated: "Actually Monsieur Breguet had been granted patents in 1908 which covered all the points in the paper" (Younger, 1938b, 513). I was not able to track down this patent from 1908, the only patent in this direction was a patent filed in Germany by the Bréguet company in 1963 on a pressure chamber (German patent 1214091).

[12] For the height, refer to Younger (1938b, 513).

[13] Anonymous (1941b, 98). There are several photos of the crashed R-35 in the CEGES/SOMA archive, see appendix 6.3.

over the leakage in the cabin and death of the crew upon such rapid decompression. Klose (1926) proposed a two-layer hull of the cabin. The first layer should be made of an "airtight skin", with the second being a "cage-like partial hull", e.g. an iron grid. The grid should hold back the inner layer and prevent it from further ripping, once it was penetrated and broken, to give the crew enough time to repair the layer. Junkers became aware of the patent and bought the exploitation right in 1930.[14]

In 1927 engineer Asmus Hansen, also from Berlin, was granted a patent from the *Reichspatentamt* (German Patent Office) for a "closed, airtight cabin, particularly for high-altitude airplanes". Hansen (1927) proposed a cabin made of two metal hulls, leaving space between them for insulation against cold and radiation. The interior pressure could be raised to 1atm, and the pressure difference could be mitigated by varying the pressure of the gas between the inner and outer hull. The valves to regulate the pressure between the hulls should be controlled by levers from the cockpit. Junkers also bought the exploitation rights for this patent.[15]

The Junkers company, led by their chief engineer J. Muttray, then commenced the development of the Ju49 in 1928 (Seeler, 1950b, 532). Hugo Junkers himself kept himself involved in the design process and filed a number of patents in the following years, chiefly concerned with emergency devices.[16]

While these early patents on emergency devices were not taken into consideration for the Ju49, other patents were. Junkers (1931b) contained the construction principle of the Ju49 cabin (see figure 5.6). Junkers grabbed up the idea by Hansen (1927) to use a double-wall structure to protect the crew from a possible damage to the cabin. The patent (Junkers, 1931b) chiefly deals with construction issues, e.g. how bolts could be placed between the two hulls, and how the structure can be improved to withstand the drag in certain parts. This principle was in fact used in the Ju49 (see figure 5.7).

The next issue was the windows the cabin should have to allow for visibility. Junkers (1931a) outlined the principle employed in the Ju49. Small circular holes should be cut into the hull and plexiglas windows being set into the holes. The holes are then to be sealed through a large O-ring on the frame of the hole. The larger interior pressure on the cabin should push the window against the O-ring to seal the hole, a principle also used for bulls-eyes in ship construction.[17]

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[14]For a list of patents filed and acquired by Junkers in respect to pressure cabins, see the list in DM, LRD 00701. For the correspondence between Klose and the Junkers company, see DM, Junkers-Archiv, 0303-T22.

[15]See the list in DM, LRD 00701.

[16]Junkers (1930b) proposed an emergency shutdown mechanism for the engine, in case the pressure in the cabin drops to a dangerous level. Junkers (1930a) is a patent on an engine construction where the engine is placed on top of the cockpit so that when the propeller breaks, the chips would shoot over the cabin, and not pierce the hull.

[17]Just that the greater outer pressure is utilized there, i.e. in an airplane the windows

The windows, however, remained the largest problem in the construction. Because the Junkers company had no facilities to test the best material and construction, the *Deutsche Versuchsanstalt für Luftfahrt* (DVL, German Experimental Establishment for Aviation) was asked for help.[18] Their engineers tested various forms (plane and convex) and materials for the windows. The main issue under investigation was the pressure resistance and chipping of the windows. It was certified that two layers of convex-shaped special security glass, compounded with a layer of plexiglas between them, had the most desirable properties and would meet the requirements of the specification.[19]

The biggest peculiarity of the construction was that the cabin was made separable, i.e. it was a rather autonomous chamber that had to be attached to the rest of the airplane (see figure 5.7 and 5.8). The reason is not quite clear, but it seems that the pressure cabin was developed independently from the rest of the airplane, in case modifications to the cabin were necessary.

On October 02, 1931, the Ju49 made its first test flight (Anonymous, 1955, 134), and in 1933 it made its official maiden flight, where it flew to a height of 10000m. It reached its peak at 12500m in 1936.[20] The advent of the Ju49 was anticipated eagerly by aviation enthusiasts, and of course, Junkers had every reason to advertise its maiden flight as path breaking achievement, since this was the first airplane in the world with a pressure cabin that proved practicable.[21]

The cabin, designed for two people sitting single file, was pressurized with normal air instead of pure oxygen. It was considered that the extra weight of the oxygen tanks would have a negative effect on the airplane's performance, and that the CCR system required would not prove reliable enough to be installed in the vibrating environment of the cabin. The pressure inside the cabin was maintained at a height equivalent of 2000–2500m, and the crew was equipped with oxygen apparatuses for emergencies.[22] During the test flights, no fatal accidents were reported and the tests were a rich experience for future plans for pressure cabins.

After the successful tests with the Ju49, however, the Germans did not invest into pressure cabins too much. The greatest drawback of the Ju49 was its small bulls-eye windows, which did not allow for a good vision. In

must push from the inside, and therefore attached from the inside also, whereas in ships the windows must be attached from outside the hull.

[18]As a matter of fact, the DVL was the driving force behind the Ju49 development and actually ordered its construction, according to Ruff et al. (1989, 40).

[19]DVL report Vf 25/3, June 10, 1932. BA-MA, RL39/630.

[20]Seeler (1950b, 532). Anonymous (1955, 134) states that in 1933 not more than 9300m had been attained by the Ju49, whereas the 12500m altitude was reached in 1935 already.

[21]See e.g. a paper clipping from the *Anhaltinische Tageszeitung* from May 26, 1932, on the intended maiden flight. DM, LRD 00701.

[22]Ruff et al. (1989, 41). The air was compressed by an additional compressor installed in the aircraft. In other designs, the regular airplane engine was also used for this purpose, but this was considered unsafe in case the engine jammed. (Seeler, 1950b, 534)

1935 Muttray started the development of the Junkers EF-61 high-altitude airplane that had a plexiglass "dome" cockpit. This material did not turn out as reliable, however, breaking very frequently, so the project was soon abandoned.[23]

Development at Junkers then stalled, owed to the death of Hugo Junkers in 1935 and the preceding trouble he had with the Nazis and the Weimar government before.[24] The DVL, nonetheless, remained the driving force behind the development of high-altitude airplanes. It was soon conceived that the main issue in constructing such a plane was not the medical side, like pressure cabins, but having a powerful engine available (Ruff et al., 1989, 42). The Junkers L 88a engine used in the Ju49 would not suffice for bigger crafts, hence, alternatives were sought.

In the following years, the Henschel company from Berlin became the premium partner for the DVL to construct prototypes of high-altitude planes. The crafts, the Hs 128, Hs 129 and the Hs 130, were promising steps toward military high-altitude airplanes, and used engines from Daimler-Benz and BMW, respectively. The development process with the DVL resulted in some patents and the prototypes were regarded as satisfactory.[25]

Even though the Hs 128 was tested from 1937/38 on at the DVL (Anonymous, 1955, 135), and the Henschel prototypes (Hs 128, Hs 129, and Hs 130) were all designed for military purposes like reconnaissance or bombers, neither the DVL nor Henschel had the right standing with the Air Ministry to provoke enough interest, just like the prototype of the Arado Ar340, which was designed as a "high-altitude destroyer" and, according to its specification from April 1940, should fly at a ceiling of 8900m with a Junkers Jumo222 engine, or at 9700m with a Daimler-Benz DB604.[26]

Before the war not much interest in military applications of the pressure cabin was displayed by German Air Force officials anyway. A session of the *Lilienthal*-Society at their annual meeting in April 1939 featured a presentation of Muttray on the Ju49 and the EF-61 (Muttray, 1939), but the following discussion with Germany's leading aviation physiologists were all on rather technical and theoretical issues, rather than on practical ones. Construction issues, like double-walls for the cabin, windows, etc. were also at the heart of Muttray's presentation. Presentation by physiologists at that meeting also dealt with rather technical questions, e.g. mask design.

Benzinger (1939), as another pre-war study on cabin issues, also exposes a good deal of uncertainty in the debate, and that the Germans had not put too much thought into it before the war. He discussed the principal question

[23] Cf. Seeler (1950b, 532) and Anonymous (1955, 134)

[24] See section 4.5.3.

[25] For patents, see Neuber (1940) or Nicolaus (1939). DVL engineers also filed patents: Pfau (1939) or Ide and Grünert (1939).

[26] Cf. Kranzhoff (2001). See also Nes et al. (1939) for a patent on a regulation valve held by Arado.

of whether oxygen masks or pressure cabins were more feasible at heights of 6000 to 8000m, based on Pezzi's experience in Italy (see below). The Italians had favored pressure cabins from 1938 on for their height records, after Pezzi experienced difficulties with his breathing equipment. Benzinger (1939), on the other hand, was not able to reproduce these issues Pezzi had reported of. While Benzinger (1939) made it clear that at heights over 12000m a pressure cabin is mandatory, he had to admit that below that height the question is not so easy to decide. He therefore demanded test-flights to see which technology offers the most benefits in terms of warfare.[27]

Pressure cabin development in the early war years remained at a low level. All in all, little to no resources were spent on such questions and technical specifications remained at the pre-war level (e.g. Voigt, 1940). When the Air Ministry became obsessively interested in high-altitude flight in 1941 (see section 4.5.3) it was Junkers and Messerschmidt (and in part Focke-Wulff) that were asked to produce high-altitude warplanes. Companies like Henschel, Heinkel and Arado, which had all conducted studies on high-altitude flying previously, did not get much involved in the production, but nonetheless contributed their expertise, as can be seen by a look in the *Table of Contents* of the report from *Lilienthal*-Society's special meeting on pressure cabins from January 1941 (cf. Anonymous, 1941a). At this meeting physiologists and engineers accumulated all their knowledge on contemporary pressure cabin design, including the architecture of the Boeing 307 presented by DVL engineer H. Ide.

While this meeting had only the synopsis of recent developments of pressure cabins on its agenda, the increased interest by Air Force officials in high-altitude warplanes led to a greater number of research projects, with Muttray of Junkers being at the center of cabin construction issues. Also the Testing Facility of the German Air Force at Rechlin[28] contributed in eliminating technical difficulties found in construction issues and in authoring technical and physiological specifications for such cabins (e.g. Kaufmann, 1941).

It soon became evident that the Ju49, the EF-61 or the Hs128 provided for a good operational experience in terms of the general feasibility of the pressurized cabin, but that a lot needed to be done to make them fit for applications in war. Junkers therefore came up with several versions of high-altitude airplanes: the Ju188, Ju288, and the Ju388. Construction and resource issues posed the greatest trouble to Junkers, and the Air Ministry could not decide which model would best meet their needs, resulting in heated discussions at the meetings in the Ministry.[29] The biggest problem

[27] The report (Benzinger, 1939) was issued November 20, 1939. Experiences with oxygen equipment in the war was therefore scarce.

[28] "Erprobungsstelle der Luftwaffe Rechlin"

[29] See BA-MA, RL 3, boxes 21, 24, 37, 60, for the minutes of the meetings, or Vernaleken and Handig (2003) for a summary.

were the engines supplied by Daimler, BMW and Junkers. Most of them were not powerful enough to carry the specified load to high-altitudes, or they simply were not maintainance-friendly enough for using them at the front. Thus, only a few prototypes of these planes were produced, and the Air Ministry fell back on a modified version of the pre-war Junkers Ju86, the Ju86P, which also was only produced in small batches.

Physiological issues remained the same throughout all these designs, which could meet the requirements sufficiently. Further research thus concentrated on more mundane problems, such as fogging of the windows or keeping the cabin air-tight with less effort, i.e production costs (cf. Dessau, 1943; Muttray, 1944).

Messerschmitt, with its Bf109 (later named Me109) fighter used as the standard fighter plane of the *Luftwaffe*, was also supposed to deliver an improved version during the war. Since the German Air Ministry was so obsessed in obtaining a high-altitude fighter, and Willy Messerschmitt himself had a great influence in the Air Ministry,[30] the company was first addressed to provide a high-altitude fighter. Messerschmitt produced a number of prototypes, like the *Bf 109 V55*, but they failed to be competitive to the Focke-Wulff airplanes. A successor of the Bf 109, the Me209, was supposed to overcome this deficiency, but the high-altitude version also could not prove its feasibility, as General of the *Luftwaffe* Adolf Galland (1912–1996) angrily commented on Messerschmitt's excuses: "Not one pressure cabin is working!"[31]

The chief engineer of Focke-Wulff, Kurt Tank (1898–1983), designed a number of high-altitude fighter planes, first under the standard abbreviation *Fw* for Focke-Wulff airplanes, then under his own acronym *Ta*. The Fw190 for instance was projected as an alternative to the Messerschmidt Me109,[32] and Tank designed c. 15 prototypes of the Fw190, all for different purposes. One of these models was the *Fw190 D-12*, a high-altitude fighter with a Junkers Jumo 213 E-1 engine, although the design did not include a pressure cabin. Tank presented three prototypes of it in October and November 1944. The model, which was supposed to operate at a ceiling of 12.5km, was considered for mass production in early 1945 – but this never happened (Wagner, 1991, 173–174).

Tank also designed the *Ta152A*, a high-powered fighter airplane, which never got off the drafting board. The main reason was the lack of engines, the major obstacle to plans on high-altitude airplanes in that time. The *Ta153*, for instance, also remained only a sketch, since the DB603A with a Hirth

[30] Messerschmitt participated in most of the meetings held by Technical Director Milch.

[31] See minutes of the meeting at Milch's office, August 17, 1943. BA-MA, RL 3/24, F366–367. Translation mine. See Kosin (1990) for German fighter planes, also Jane's Publishing Company (1995).

[32] For the political discussion over high-altitude flight in the Second World War, see section 4.5.3.

turbocharger was not available. 15 prototypes of the high-altitude fighter *Ta152C*, on the other hand, were constructed altogether. It was supposed to operate at a ceiling of 12300m, and the first batch of prototypes (sub series C-0) came without a pressure cabin, whereas a later sub series (C-3) had one. Later sub series were projected, but never implemented, even though the *Ta152* was designated as the standard fighter plane of the Germans by Göring in July 1944. The lack of resources prevented this scenario from becoming a reality. Furthermore, Tank designed the *Ta152 H* series for reconnaissance, and the sub type H-10 was designed to fly at a ceiling of 14200m. Production of the plane did not start before December 1944 and mass production was intended to start in March 1945 (Wagner, 1991, 175–192).

During the war it soon became obvious that the standard fighter airplane, the Messerschmidt Bf109, which was designed in the mid-1930s and accepted as the *Luftwaffe* standard fighter in 1938, had to be replaced with a modernized version. While Messerschmitt did not have much competition in the fighter segment before 1939, Tank and Focke-Wulff soon became serious rivals. Messerschmitt failed to convince the officials with his Me309 model, and fell back to the intermediate version Me209, which had more promising features. The Ta153 was supposed to fly at a ceiling of 11.5km, while the Me209 should have had a ceiling of 11.7km, and both airplanes were designed with a pressure cabin (Hermann, 2004).

Even though Focke-Wulff could place Tank's design in pole position with the decision-makers in the Air Ministry, Willy Messerschmitt had much influence there and could hinder the final decision. Eventually the Ta153 was dropped completely in favor of the Me209, and Tank resorted to the Ta152, which never made it into regular use, as discussed above. Political struggles in this respect are beyond the scope of this book, but are shortly discussed in section 4.5.3.

USA

In 1920 the US Army Air Corps (USAAC) at McCook Field started the development of a pressurized airplane in the form of a steel tank attached to a DeHavilland biplane. On its test flight on June 8, 1921, a severe fault in the pressure equalizer of the cabin nearly led to the death of the crew. Upon this accident the project was completely abandoned (Armstrong, 1939, 366–67). One is tempted to think that the technological progress being made in aeronautics was not advanced enough at this time. King and Carroll (1924), albeit having a focus on breathing equipment, complained about an insufficient communication between physiologists and engineers, seeing this as the actual shortcoming in aircraft R&D. The proposition of Younger (1938b), that "in the United States they now have the result of nearly 20 years' research" is quite an exaggeration in this respect (Younger, 1938b, 511).

Harry Armstrong (1899–1983), US aviation physiologists for the USAAC at Wright Field, started studies in the 1930s on pressurized cabins. Armstrong, being Captain in the USAAC, had a pilot's license himself and therefore a good understanding of aeronautical issues. His first studies were conducted in the *Explorer* balloon projects, a joint operation of USAAC and National Geographic Society.[33]

In 1935 the USAAC at Wright Field under Major Carl F. Greene started research for a pressure-cabin airplane, which was finished in mid-1936. The Lockheed airplane company then constructed the experimental Lockheed XC-35, the basis for all later pressurized airplanes in the US, in early 1937 (Gibbs-Smith, 2003, 233).

As a prerequisite, extensive tests had been made in decompression chambers. Also a discarded pressure cabin from the prototype was taken into a refrigerated room to test for temperature insulation. The scientific research was conducted by Professor for engineering John E. Younger from the University of California at Berkeley. Younger did most of the work as far as scientific engineering studies were concerned, and he took every occasion to publish his findings. This, in fact, is the remarkable difference between US and European efforts in devising an airplane with a pressure cabin.

Both Younger and Tomlinson (see below) published extensively and held public speeches before aeronautical societies around the world, e.g. Great Britain and Germany.[34] While most European projects on pressurized airplanes were handled with a lot of marketing talk, with little or no technical information specified, the American *openness* furthered a wide debate on the feasibility of such projects.

To investigate this feasibility various forces joined each other in the USA. For the XC-35 project, chiefly Lockheed, the University of California and the US Army Air Corps combined their respective powers to develop a prototype of an airplane with a pressure cabin. All groups involved had their specific interests and cooperated seamlessly to achieve them. In the parallel running *Stratoliner* project, the Boeing company, the US Army Air Corps and airline companies collaborated to investigate sub-stratospheric flying (see below). Furthermore, the US Army Air Corps and the National Geographic Society cooperated to conduct the *Explorer* projects, manned stratosphere balloons with sealed, pressurized gondolas. All of these developments were published in great detail and spun a series of discussions at conferences and lectures. The XC-35 project was the center of joint efforts tackling the problem of regular (compared to exceptional record flights) high-altitude flight, and the persons involved published in their respective fields of elaboration, which were often presented in joint conferences.[35]

[33]Cf. Armstrong (1936c,b); Noë (1989).

[34]Cf. Younger (1938b) or Tomlinson (1938a).

[35]E.g. a special issue of *Journal of the Aeronautical Sciences* in 1938, with contributions

Nonetheless, American authors like Armstrong (1939) who alleged that the XC-35 was "the first successful pressure cabin airplane to be flown anywhere in the world" were not correct (Armstrong, 1939, 377). The Ju49 was flown before the XC-35, but the success achieved in a comparably short time with it is far more remarkable than Junkers' feats.

The parallel running Boeing Stratoliner project eventually led to the introduction of the first pressurized passenger airplane in April 1940 (see figure 5.9). The Stratoliner was "derived from the Boeing B-17 bomber" (Gibbs-Smith, 2003, 239), and was a monoplane with four Wright GR engines. It provided enough space for 33 passengers and a six man crew.[36] Its regular ceiling was 5.2km, at which it reached a speed of 350km/h with a 69.4% power load (Cooper, 1941, 5).

The airplane had all the conveniences possible at that time. It had nine recliner seats on the right side of the cabin, while the left side was partitioned into four compartments with 2 rows of triple seats each. If required for sleeping, the triple seats could be turned into beds. Washing rooms, toilets and a panorama turret at the rear end were available (Cooper, 1941, 5).

The windows, which were the most troublesome part in the early Junkers pressurized cabins, were made of compound glass and plexiglass. The front window consisted of six windows of that compound glass, each 16mm thick, and eight windows of plexiglass, each 9.5mm thick. The windows in the passenger cabin were made of 9.5mm thick plexiglass. The doors could be opened only swinging to the inside, and large rubber rings on their frames sealed the cabin with the help of the internal pressure (Cooper, 1941, 5). The same principle is used in today's passenger airplanes, and was derived from submarine technology, where the hatches are usually swung to the outside and the external pressure helps to seal off the interior.

Two General Electric superchargers provided a cabin pressure equivalent to 2400m height, with a tolerable threshold of up to 3600m (Cooper, 1941, 5–6). The Stratoliner was usually flown in heights between 5000 and 5500m.[37] After Boeing introduced the Stratoliner in 1940, other companies like Curtiss (CW-20) or Douglas (DC-4a) followed suit with their products (Anonymous, 1941b, 98). However, the US entry into the Second World hindered the breakthrough of this cabin technology for civilian flight at this time.

Boeing installed a pressurized chamber, the *Strato-Chamber*, in its laboratories in Seattle, to test and develop the pressure chamber and to simulate

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of various persons, like Younger (1938a), Tomlinson (1938b), Klemperer (1938), Heim (1938), and Armstrong (1938); all of these articles dealt with findings of either the XC-35 or the Stratoliner project (or both). See Chapin (1991) for an account of the collaboration of engineers and physiologists in the XC-35 project, although it is a bit internalistic, and fails to outline the intertwining on a more social and cultural level.

[36]Because of its technical features, i.e. the pressure cabin, the Boeing 307 Stratoliner was the first commercial airplane that required an engineer as a crew member.

[37]For more technical details and accounts on the Boeing 307, see Gerresheim (2001) or Smith (1991).

all environmental conditions that the airplane could meet at the intented traveling height. This pressure chamber could simulate heights of up to 12km, with projected heights of up to 18km.[38]

UK

In the UK, prior to World War II, no attempts had been made to construct an airplane with a pressurized cabin. Whether this was due to a conservative stance among the British aviation industry, as Gibbs-Smith (2003) alleged, or due to the superiority of the Haldane-Davis suit, as Hill (1934) proclaimed, is not easy to decide here, and is beyond the scope of this publication.

However, Younger (1938b) gives a remarkable comment from the first user of the Haldane-Davis suit, F.R.D. Swain, who states in the discussion appended to Younger (1938b), that the Bristol directors would have actually preferred a pressure-cabin to be built into the Bristol 138 airplane that was used for the height-records in the 1930s, but the weight issue prohibited this. The airplane was made of plywood to minimize the overall weight and to attain greater heights. A pressure-cabin would have counter-acted this intention.

During the war plans were devised to introduce both bombers and fighters with pressure cabins, since the High Command of Britain feared that the Germans might use high-altitude warplanes themselves. After the *Battle of Britain* was won by the RAF and the *Mosquito* proved to be versatile enough (see section 4.5.3), plans for high-altitude versions of the *Spitfire* fighter and the *Welkin* bomber, both with pressure cabins, were given up, and only prototypes were ever built.[39]

5.2 Pressure Suits

Most representatives of aviation industry and administration, as well as aviation physiologists, favored pressure cabins as the solution to overcome physiological limits. G.S. Marshall, as the general surgeon of the RAF stated in his already mentioned and cited speech before the RAeS (Marshall, 1933, 395):

> "It would no doubt be mechanically possible, instead of seating the pilot in a sealed cockpit at relatively high pressure, to enclose his whole body in an impermeable suit, or his head and neck in a sort of diver's helmet. The helmet has the virtue of not requiring a special type of cockpit, but it has many disadvantages. It would be most unwieldy, it would inevitably interfere with the pilot's free movement to an undesirable degree, it would increase the respiratory problem of dead space, it

[38] *Bilder* press release, July 22, 1940, DM, LRD 00701.

[39] For the development of the Spitfire, see Morgan and Shacklady (2000); see Jane's Publishing Company (1995) for info on the Welkin and the Mosquito.

> would subject the pilot to different pressures inside and outside his thorax, so that resistance to inspiration would be reduced, and to expiration increased, and it would be very difficult to devise a fastening for it about the chest and shoulders which would be both airtight and readily detachable without excessive weight."

Here, Marshall expressed, what most contemporaries felt: The technical progress being made in suit manufacture was not advanced enough to provide a feasible solution, and therefore cabins should be employed. In a cabin, so it was conceived, the control of the environmental conditions were easier to maintain than in a fragile suit. Besides, and this might not be underestimated, the cabin manufacture was a process done by the aircraft industry, which had quite a good lobby with the government etc. Whereas suit manufacturers (i.e. diving suit manufacturers) did not rely on pressure suit manufacture for their financial well-being. On the contrary: Pressure-suit manufacture was a costly process, with a product yet not ready for the market, and with only a handful customers, to whom the suits had to be customized. Whereas cabins could be produced from one design in large numbers, suits were intrinsically hard to produce, with many obstacles to overcome. It is therefore not too surprising that even though suits were deliberated from early on, cabins were given priority from the viewpoint of aircraft industrialists as well as from administrative personnel.

For the average military and commercial purposes, cabins were superior. No passenger would have donned a pressure suit prior to the commencement of his or her travel, as they would have been unable to sip a cocktail in the air. For record flights, however, one was willing to make trade-offs in comfort. And since high-altitude aircrafts required a minimum amount of weight, cabins were counter-productive to that end. To topple the contemporary height-records thus involved serious dealings with pressure suits.

5.2.1 British Pressure Suits

The development and evolution of the British Pressure Suit, the Haldane-Davis-Suit, is extremely interesting for its circumstances of creation, as outlined in section 4.4.2. Whereas a plethora of information on the social and political background are available, documents on the technical side of the suit are much more scarce.

As a matter of fact, documents found in the Haldane-Archive do not deal with technical issues at all. Only Davis (1947) and Gibson and Harrison (1984) provide some information. On the other hand, much of the suit was a re-use of Davis' earlier projects in diving- and breathing-devices, and these are well-covered e.g. in the books of Davis and Stelzner.

From this it becomes quite visible that the Haldane-Davis-Suit evolved from two major Siebe & Gorman products: the Fleuss-Davis CCR diving apparatus,[40] and the *Proto*, a breathing device Haldane had proposed in 1917 as protection against war-gas.[41]

Gibson and Harrison (1984) specify that the pressure suit manufactured by Davis was nothing but a modification of a standard Siebe & Gorman diving dress (Gibson and Harrison, 1984, 54). The design – which Gibson and Harrison (1984) actually detail – suggests otherwise, however. The pressure suit was made of rubberized fabric – comparable to the MacIntosh raincoats that were quite popular in Britain –, presumably making it rather stiff, as a Soviet contemporary author evinced (see below).

A major difference was, however, that the pressure suit was made as two piece suit, contrary to the standard diving dress, which was a one piece type. The two pieces were connected with a metal waist belt, conspicuously resembling a Dräger design.[42] The helmet, on the other hand, had a totally different setup than any known diving helmet, and actually was the part of the pressure suit deserving credit for an innovative design. While most of the helmet was also made of rubberized fabric, the large visor was made of double-layered celluloid (Gibson and Harrison, 1984, 55).

The CCR-system was thus coupled to the helmet, setting the pressure to 0.17bar inside the suit. The oxygen reservoir was stored in the airplane, but a single bottle was available in case of an emergency.

The most detailed account on the suit was published by Marshall (1936), the director of the medical service of the RAF, who coordinated the medical efforts for the high-altitude flying group at Farnborough. In his paper, however, nothing really new is disseminated. The suit, as outlined above, is composed of laminated fabric and the breathing device is a closed-circuit rebreather using pure oxygen. The suit is pressurized to 0.17329bar, and the exhaled carbon-dioxide and the moisture are extracted from the expired air with soda-lime (Marshall, 1936, 1001–1002). No actual details about the suit construction is given, only the parameters are rehearsed. Most of the account deals with the setup at Farnborough, e.g. the decompression chamber, yet another indicator that Marshall had not much to do with the suit fabrication or design, but only with some executive work at the RAE.

The suit was produced in a short time by Davis in October 1933 and tested on Mark Ridge in the decompression chamber at Siebe & Gorman in London, taking Ridge up to a pressure equivalent of 27405m with no trouble reported.[43]

Shortly after the RAF became interested in the pressure suit, a group was formed at the RAE to issue design specifications to meet the projected

[40] Davis (1947, 102); for Davis appropriation of Fleuss' technology, see Foregger (1974).

[41] Davis (1947, 103) relates Haldane's reference to the Mine-Rescue-Apparatus in his quote on the pressure suit (see above) to the *Proto*. See also section 5.3.

[42] See figure 5.26.

[43] Cf. the various paper clippings in the *Daily Mail*, Davis (1947, 52), Hill (1934) or Haldane and Priestly (1935, 325–326).

high-altitude airplane. The Bristol Aeroplane company, actually in charge of coordinating all the engineering efforts of the project, set a number of requirements, most of them owing to the different environment of an airplane, compared to the open basket of a balloon. Davis and other personnel from Siebe & Gorman participated in various meetings to discuss issues in the airplane's design, particularly the oxgen gauge on the cockpit's dashboard, which directly affected the design and engineering process of the plane.[44]

Furthermore, Davis produced a number of modified suits for the pilots at the RAE, to meet their feedback on design flaws. It was found that when the electrically heatable underwear was turned off, the visor would become foggy, while when the heating was turned on, condensating water accumulated on the visor and also rendered vision futile.[45]

Ventilation issues therefore had to be taken care of, especially when it came to separating the helmet from the suit internally. If the pilot became prone to flatulent processes, and the oxygen system had no mouthpiece but was directly attached to the helmet. Since helmet and suit composed one connected entity, gas from the suit therefore reached the helmet and was injected in the CCR system, leading to a "contamination" of the oxygen being breathed. As a consequence, the suit was modified to have a diaphragm at the neck, that "decoupled" suit and helmet (Hawkins, 1995).

Also, in a later revision of the suit, a knife was attached to the sleeve with which the pilot could cut open the visor in case the oxygen system failed, so the pilot could try to survive on the air in the cockpit. As a matter of fact, that was what happened on Swain's record-flight. For some reason, Swain felt like he was choking on his descent, even though there was no evidence for a fault in the oxygen system. He nonetheless cut open the visor of his helmet to circumvent the CCR and breathe the air from the cockpit, luckily finding himself at an altitude where this action did not cause any problems.

The cooperation of Davis with Haldane in this project – after many preceding fruitful joint projects – is badly documented, since the RAF demanded a high level of secrecy for the project. The RAF wanted no information on the whole height record project disclosed prematurely,[46] and when the press releases were issued, not much room was given to the suit, but rather they focused on the heroic effort of pilot and airplane engineers.

Haldane's cooperation with Davis – as well as Davis' other cooperations, e.g. with Leonard Hill and later with JBS Haldane – would be worthwhile to examine more closely. Sources on or from Davis are hard to come by, though. Few documents besides printed material is available. While his publications had much impact on his contemporaries as well as historians of diving, they gave a rather idealized picture of this man. His most famous

[44]See RAeS, BC.
[45]RAeS, BC, Test report by Adams.
[46]Cf. correspondence in the RAeS, BC.

book, Davis (1935), reprinted several times, is one of the most often cited source on diving history and technology. Biographical works, however, were not in Davis' line (Young, 1963, 20):

> "The preceding chapter contained a brief epitome of an immensely long and successful career. In general, said Macaulay, there is nothing less attractive than an epitome. Sir Robert Davis, however, holds that the interest in a life such as his lies in his work. Having boggled for ten years at the very idea of a biography, he insists that this book be as far as possible impersonal. What matters, he says, is not the individual but the achievement."

Thus, a few letters from Davis to Haldane in the Haldane-Archive and letters to the editor of *The Times* and his publications are the only sources available. But these already show the ability of Davis to cooperate with persons like Haldane or Hill. As a matter of fact, Davis, in his position as managing director of the Siebe & Gorman company, provided both Haldane and Hill and their colleagues access to their test installations, like a decompression chamber and a cold chamber to conduct experiments they otherwise could not have made, due to lack of funding. Both Hill's and Haldane's ventures in aviation medicine were made possible this way, since other institutions neither had the interest nor the infrastructure to provide either physiologist with the proper research environment. Hill and Haldane, both very open and keen on the practical side of physiology, could furthermore convey their theoretical knowledge directly to the engineers, and discuss matters with them instantly. Both groups, scientists on the one side, engineers on the other, could therefore learn from each other a good deal and became acquainted with each other's way of thinking.

Through this comparably long tradition of close cooperation of Davis with Haldane (and Hill), it most likely was not bragging, when Davis publicly stated that it took him only one month to produce the suit for Mark Ridge in October 1933.

5.2.2 French Pressure Suits

As already mentioned the French government, namely the Air Secretary Pierre Cot, refused to support any high-altitude research since he saw no military value in it. Only private sponsorship would be acceptable.[47] Therefore, the eminent aviation physiologist Paul Garsaux (1882–1970), then head of the "Civil Center of Examinations for the Navigation Personnel" which was located at *La Bourget* airport near Paris, the airport where Charles Lindberg landed after his transatlantic flight, organized such studies at his facility. Garsaux, who had designed the oxygen masks of the French Air Force in World War I (see below), changed to the civil aviation branch after

[47] Press release DT Paris, Mar 03, 1937. DM, LRD 00701.

the war and took office at *La Bourget*, erecting a pressure chamber there in 1923 (Lomonaco, 1970).

In the middle of the 1930s several studies were conducted on the effects of hypoxia, and how to circumvent them. Drs. Richou and Artola, for instance, made several tests to see the effects of breathing oxygen as a measure against hypoxia. Their research, not surprisingly, lagged behind their European and American colleagues tremendously. With the few resources at their fingertips, no reasonable advances could have been made.[48]

From this point of departure, i.e. insufficient or no funding for high-altitude studies, it is not surprising that activities in this sector were little to zero, with only the *Potez* aircraft company sponsoring efforts at high altitude flying. Nonetheless, a most interesting pressure suit was demonstrated in a public event at the airport *La Bourget* on June 20, 1935. The suit was designed and constructed by Garsaux, with the help of the Navy Surgeon Rosenstiel.[49]

[48] See itav press releases from Aug 25, 1938, and Oct 11, 1938, respectively, for some information on the research of Richou and Artola. DM, LRD 00701.

[49] So far, I have not been able to find any further information on Rosenstiel, other than three publications in the journal *La Presse Medicale*. I could not track down any biographical information, not even his first name. Garsaux (1963) also does not provide for any further information. Only two pages in it are devoted to the pressure suit, Garsaux apparently was disappointed by the technical problems with it.

Figure 5.3: Piccard's gondola, illustration by Hans von Römer. Reproduced by permission from the Deutsches Museum.

Figure 5.4: Sealed gondola of "Explorer II" on display in the NASM.

Figure 5.5: Sealed gondola of the Soviet balloon “USSR”, taken from the magazine “Luftwelt”, 1934.

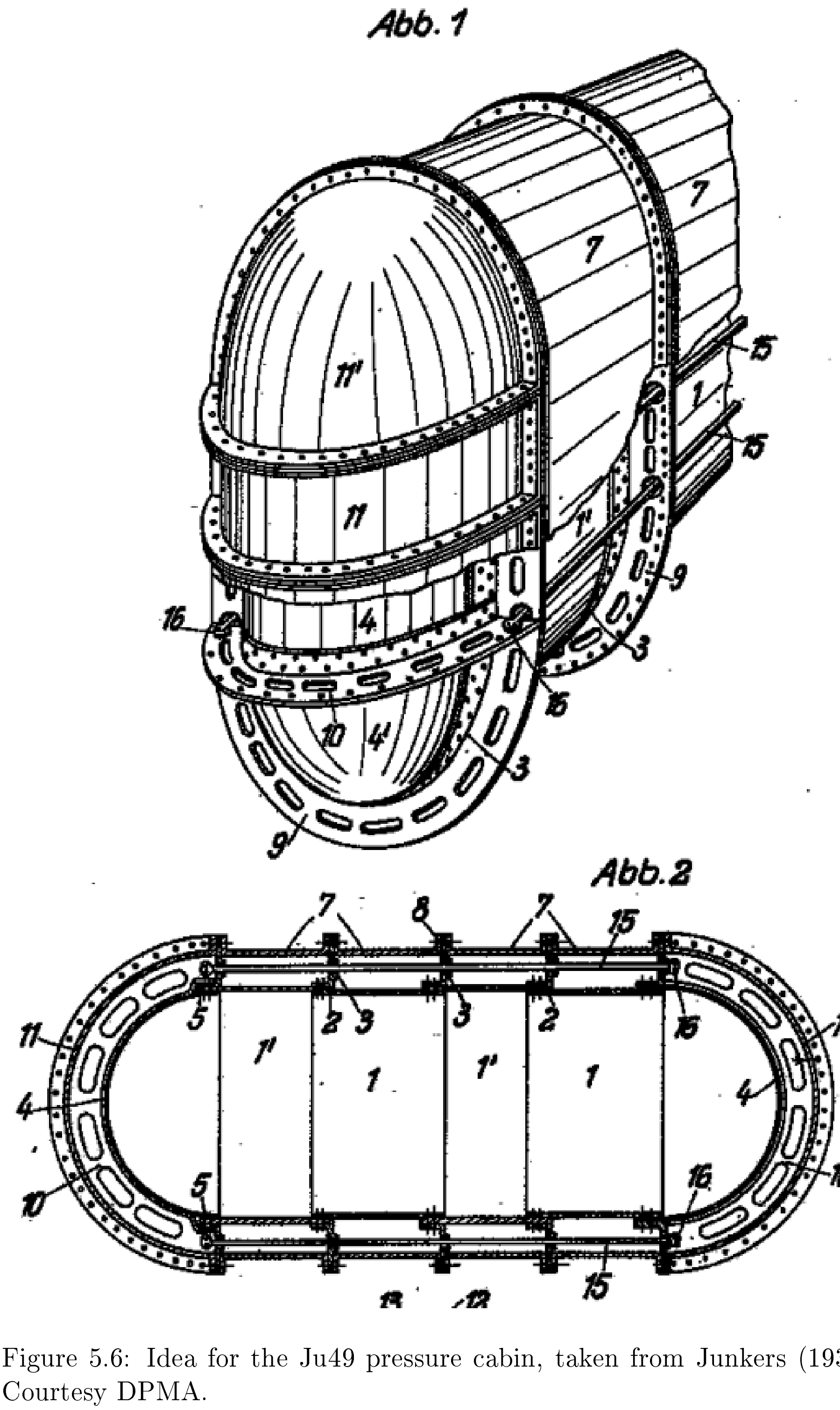

Figure 5.6: Idea for the Ju49 pressure cabin, taken from Junkers (1931b). Courtesy DPMA.

Figure 5.7: Pressure cabin of the Junkers Ju49, uncoated. Reproduced by permission from the Deutsches Museum.

Die erste Höhenkammer

Den vielen Rätseln des Höhenfluges suchte man zuerst durch geheizte, mit künstlicher Sauerstoffzufuhr versehene Anzüge für den Flieger beizukommen. Grundsätzlich sind sie jedoch nur durch Anwendung einer Druck- oder Höhenkammer für die Besatzung zu lösen. Im Jahre 1931 startete die Ju 49, ein neu entwickeltes Höhenflugzeug mit Höhenkammer und 800 PS-Höhenmotor Junkers L 88a, zum ersten Versuchsflug. Mit dieser Pionierleistung hat die deutsche Luftfahrt die Klärung der Fragen des Höhenfluges für Besatzung und Motor grundlegend ermöglicht.

Die Höhenkammer der Ju 49, eine geheizte, doppelwandige Druckkabine für zwei Mann, im Querschnitt der Körperform der Insassen angepaßt. Sie ermöglicht innerhalb des Flugzeugs ähnliche Lebensbedingungen, wie sie der Mensch vom Boden her gewöhnt ist. Viele weitere Fragen waren jedoch für den Höhenflug des Motors zu klären. Die Kammer enthielt daher ein fliegendes Laboratorium an Instrumenten und Geräten. Wie es in ihrem Inneren aussieht, zeigen die folgenden Seiten.

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Figure 5.8: The Junkers Ju49, with coated pressure cabin. Taken from "ADAC-Motorwelt", 1935.

Figure 5.9: Boeing 307 “Stratoliner”. Reproduced by permission from the Deutsches Museum.

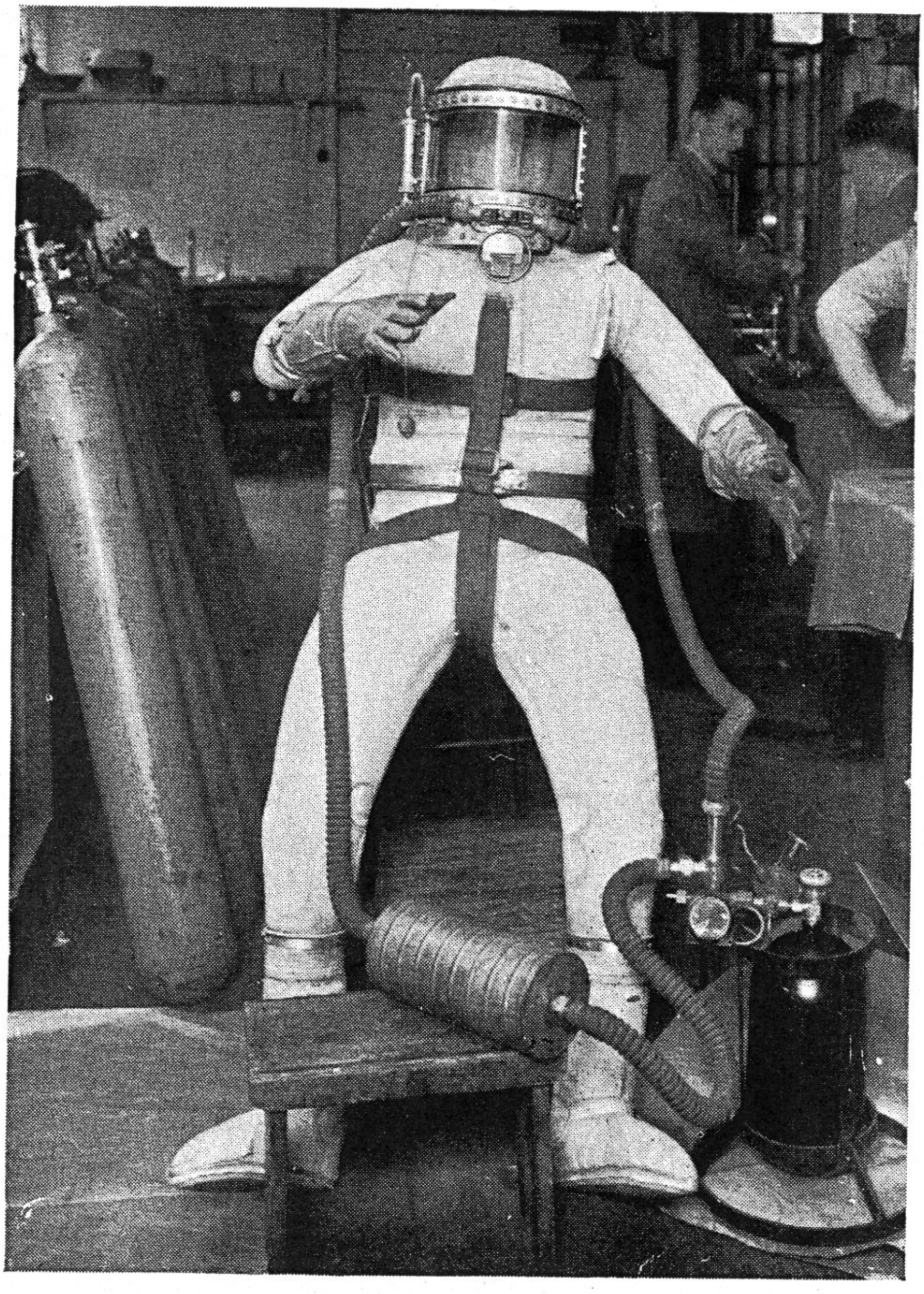
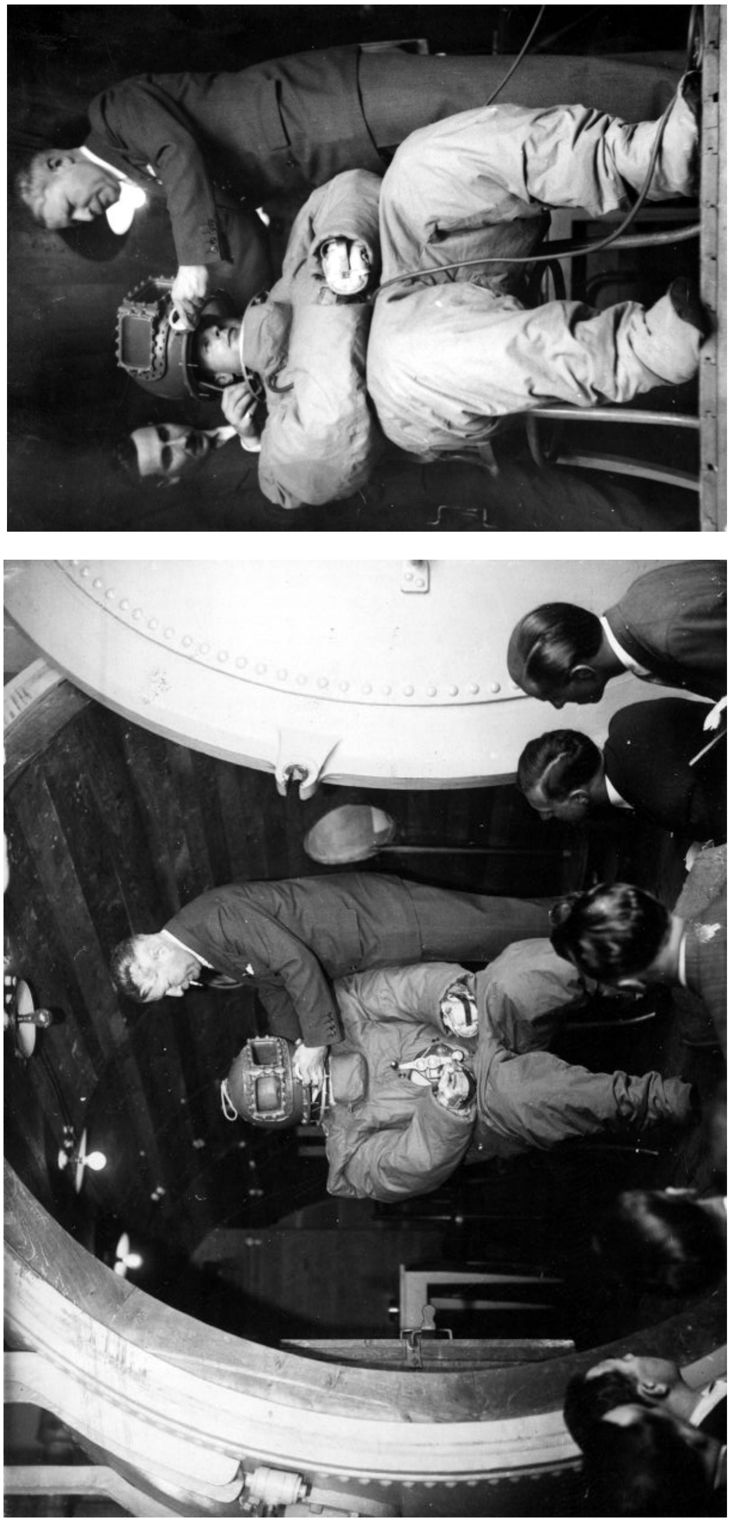


Figure 5.10: Photo of an earlier prototype of the Haldane-Davis Suit, taken from Davis (1947).

Figure 5.11: Photo of F.R.D. Swain exiting the plane after his height record flight in 1936. Reproduced by permission from the Deutsches Museum.



(a) (b)

Figure 5.12: Photos from June 20, 1935. Garsaux putting the suit on Rosenstiel at La Bourget. Reproduced by permission from CEGES/SOMA.

Rosenstiel published a description in a French medical journal the same year (Rosenstiel, 1935). He had discussed the issue of sufficient partial pressure of oxygen before,[50] and had already hinted at the insufficient partial pressure attained at great heights with oxygen masks. Rosenstiel (1933a, 941) postulates that the physiological issues of flights to high altitude and in deep-sea diving are two aspects of the same problem. Breathing supplemental oxygen at high altitudes would not suffice from certain heights on, and thus only encapsulation of the aviator in the form a diving-suit or sealed cabin are feasible options. Since he dreads the dangers of rapid decompression should the cabin be ruptured, only a suit would provide for sufficient personal safety (Rosenstiel, 1933a, 942).

Rosenstiel (1935) attributed the problems met in high-altitude flying with respect to insufficient oxygen supply to the osmosis, concluding that the oxygen consumption in pulmonary ventilation follows simple patterns to maintain the threshold of the required amount of oxygen by the organism. This pattern usually consisted of deeper breathing, but with lower frequency. He also considered the construction of a partial apparatus to increase the pressure of the inspired gas, but he gave up on this idea because of the problems incurred by the pressure differential in- and outside the chest, i.e. the greater pressure inside the lungs would exert the lungs and considerable hamper breathing, since the lower pressure from the outside would circumvent the exhalation (Rosenstiel, 1935, 1477). He thus concluded:[51]

> "Only apparatuses wrapping the whole man in an enclosure with constant pressure or slightly variable are usable; two solutions: the airtight cabin and the individual diving-suit."

In the next paragraph, he alleged that the cabins constructed by Farnham or Junkers were not satisfying to their creators, whereas "the diving-suit proved reliable". This is a somewhat quirky statement, since most contemporaries felt differently about the issue. Junkers Ju-49, of course, was not the best solution to the problem of high-altitude flying, despite the 1936 Nazi-propaganda that claimed otherwise. The technology was still in its infancy, a major problem being the small bulls-eye windows that severely restricted vision, something much more dangerous in an aeroplane than a balloon. That's one reason why aircraft engineers still clung to pressure suits in the early 1930s, whereas balloonists didn't bother with the uncomfort of an open basket and a unwieldy suit.[52]

Rosenstiel then continued by discussing the engineering problems. He correctly observed a paradoxic problem: On the ground, the suit should be

[50] Rosenstiel (1933a). He refers to that paper in Rosenstiel (1935) as being from 1935. I checked the issues of said journal, however, and only found Rosenstiel (1933a), so this seems to be an error in the paper.

[51] Rosenstiel (1935, 1477), translation mine.

[52] More on this debate below.

smooth and flexible to allow the pilot ease of donning of the suit and entering of the aircraft. At greater altitude, however, the material must be robust enough to withstand the pressure difference and it should not grow too large in volume to allow free movement of the limbs (Rosenstiel, 1935, 1477).

Rosenstiel and Garsaux, like other manufacturers of such suits, had therefore to find the right fabric, which would have to be gas-tight, and also smooth enough to create flexible joints to allow free movement. Also they constructed a "stabilizer" for their suit to maintain a constant pressure inside of it. Furthermore, as Rosenstiel reported, he needed "three months of studies in the chamber of La Bourget",[53] to counter the severe technical problems introduced by the extreme cold that would be met at high altitudes. He described in detail what these problems were, but not what exactly his solution was.

He also briefly mentioned that the suit had been made "mobile" by allocating an oxygen bottle and a parachute for an emergency, when the pilot has to bail out. Eventually Rosenstiel (1935) pointed out that during the testing phase, the suit was worn out so that it was no longer usable. He expressed his hope that a new suit could be produced in the near future to continue the research. The breakdown of the suit prevented him from reaching the desired "altitude" of 17000m in the pressure chamber, so the greatest height achieved was an equivalent of 14600m.

It seems as though a second suit was never produced, most likely due to the stance of the French administration, exemplified at the beginning of this section. Thus Rosenstiel's hope that: "It will require nothing more but to find the plane able to reach this altitude, for the greatest glory of the French aviation", did not come true.[54] Lomonaco (1970) furthermore points out that: "This suit did not turn out as a solution to the problems as hoped due to mechanical difficulties."[55]

The suit was to the largest part designed by Rosenstiel, who had much expertise in this field as a Navy Surgeon,[56] whereas Garsaux was the expert on breathing apparatuses. He designed the oxygen system as a *constant flow* device, with the flow rate adjustable by a lever on the belly (see figure 5.12). Even though this sounds a bit inconvenient, the handling of this device – at least in the pressure chamber – seems to have worked.

The Garsaux-Rosenstiel-Suit thus added one more anecdote to the period of suit manufacture in the 1930s, without leaving too much impression on later engineers.

[53] Rosenstiel (1935, 1477), translation mine.

[54] Rosenstiel (1935, 1478), translation mine.

[55] Translation mine.

[56] Rosenstiel (1933b) gave a short summary of the problems of decompression in diving and submarine escape.

5.2.3 German Pressure Suits

Even though the same holds true for the German suits of that time, there were some extremely interesting designs devised at the end of World War II. Though they did not have any use in the war effort, the Germans nonetheless strove for the implementation of different forms of suits throughout the 1930s and the early 1940s, for a variety of reasons. The sometimes amusing, sometimes impressive designs are specified in greater detail in this section.

As a preliminary remark it must be said that Germany, just like France, did not play a major role in height records in the 1930s. The main reason for this can be easily comprehended when looking at the influence of persons/companies like Messerschmitt and Junkers. Both companies, together with their engine-subcontractors BMW and Daimler weren't able to produce a competitive engine for high altitudes, so they had to resort to foreign providers like Bristol.

As a matter of fact, the last height record achieved by Germans was made in 1929 by Willy Neuenhofen with a Junkers aeroplane that was powered by a Bristol "Pegasus" engine. As means of protection from hypoxia, Neuenhofen used a Dräger high-altitude breather with the pipe-stem mouthpiece (see figure 4.1 on page 138), and the aircraft had a peculiar "emergency system". It was known that despite the use of an oxygen system, pilots could fall unconscious during a flight at great heights. Even though Hermann von Schrötter had elucidated that these "accidents" were a result of insufficient breathing masks and inadequate use of the breathing devices (usually they were used too late when symptoms of hypoxia had already set in), it still took considerable time until sufficiently working breathing masks were available.

Junkers *ad-hoc* solution to this was an "attention button":[57] A large button was placed on the middle of the steering wheel, connected to the ignition mechanism of the engine. The button had to be pushed in to keep the engine running, i.e. once the button was left gone, the engine would immediately stop. The aircraft had very good gliding capabilities, so the idea behind that mechanism was that as soon as the pilot fell unconscious due to hypoxia, the engine would stop and the plane glide to lower altitudes, where the pilot had sufficient oxygen again and would awaken and recover, eventually being able to take control of the aircraft and land it safely. That was exactly what happened to Neuenhofen on a test flight. He fell unconscious at a height of 9000m, since he accidently let go of his pipe-stem mouthpiece, then he loosened the button which stopped the engine, glided down to 4000m, recovered and safely landed his craft.[58]

In the years from 1928–1933 the German aircraft industry got into hefty

[57]Term mine.

[58]Cf. article "Vom Sinn der Rekorde" in the German newspaper *Anhaltiner Anzeiger*, May 26, 1939. DM, LRD 05612. Diringshofen (1935a, 6) reports that Neuenhofen fell unconscious at 11000m, and woke up at 6000m again.

financial trouble. Record flights were henceforth no longer in the scope of the companies. After the Nazis came to power they granted considerable amounts of money to them. The strategy of dive bomber tactics did not have high-altitude flying on its agenda, though. Therefore, together with inferior engines, pressure suits and cabins were only a minor issue in political/military debates in the 1930s.

The Klanke-Suit

The first German pressure suit hence was to be constructed by a private initiative. In the years 1936 and 1937 several popular technology magazines published photographs and reports on a "Diving Suit for the Stratosphere" by a Dr. Gerhard Klanke (see figure 5.13).[59]

Gerhard Klanke (1902–1993) attained his PhD in meteorology in 1931 at the University of Hamburg and entered the *Reichswetterdienst* (RWD, National Weather Service) the same year.[60] His PhD thesis dealt with measuring techniques in flights for aerology (Klanke, 1931). Before 1935 the RWD was the *Reichsamt für Flugsicherheit* (RfF, National Office for Flight Safety), an autonomous department under the Ministry for Transport and Traffic. In 1935 the RfF was re-named to RWD, after the RfF became part of the newly arranged German Air Ministry in 1934. Issues of Flight Safety were then handled by another department of the Air Ministry and the RWD was solely responsible for weather forecasting.[61]

Klanke also attained his pilot's license in 1929, being trained at the Flight Academy of World War I ace Ernst Udet (1896–1941) in Schleißheim near Munich.[62] After joining the RWD as a *weather pilot*, he soon developed a strong interest in technological issues, striving for various patents.[63]

Weather pilots, at a time when no satellite surveys could be utilized for weather forecasting, flew to considerable heights on a regular basis, usually between 5000 and 6000m. They used aircrafts – chiefly Focke-Wulf A47 and Heinkel He46 – which had open cockpits and required special garments for protection against the cold and equipment for preventing hypoxia.[64]

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[59] See e.g. Römer and Römer (1936, 1937).

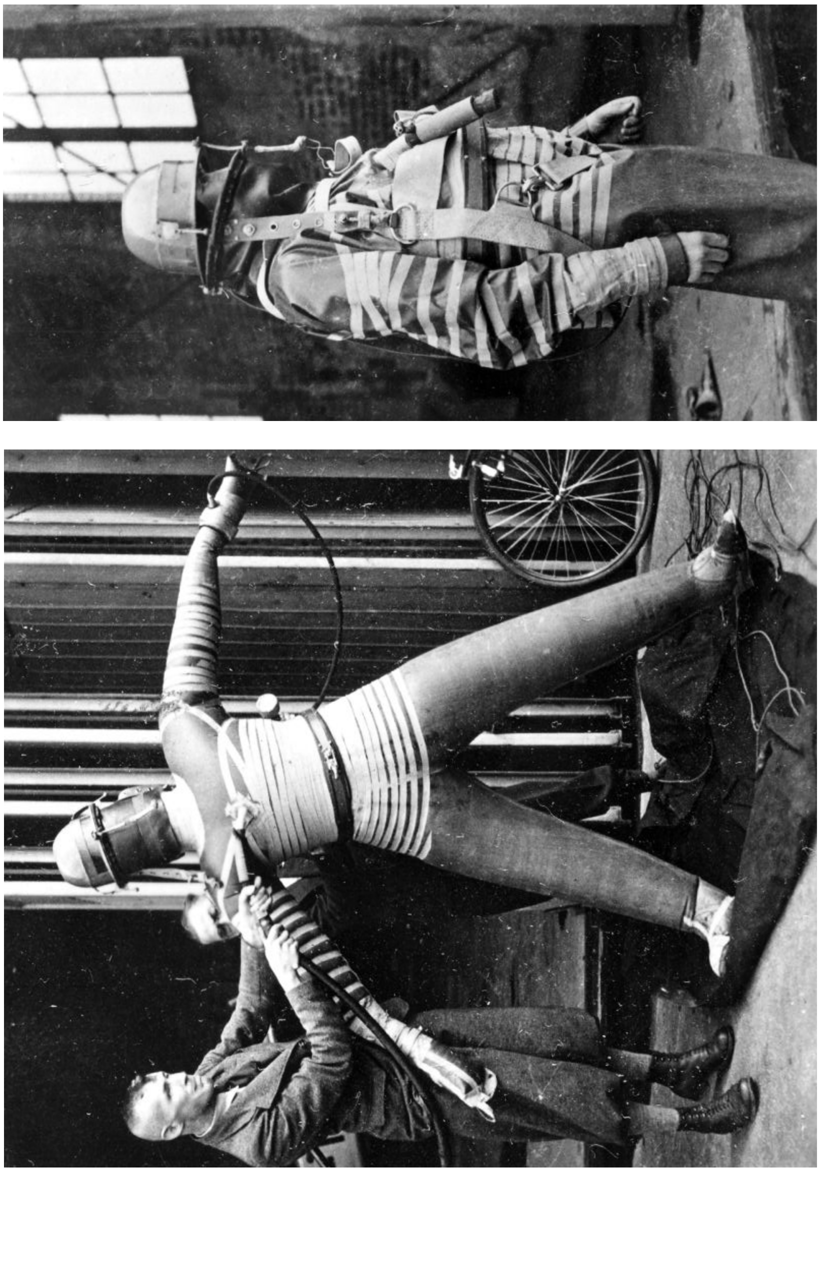
[60] See the roster in BA-MA, RL 6, F186.

[61] Cf. a short note in *Luftwelt*, 1935, 2(1):35.

[62] Telephone interview with Manfred Klanke, August 14, 2006.

[63] A quick search on the database of the German Patent Office resulted in 18 patents granted to Klanke, the earliest dating from 1925: a speed indicator for bicycles.(Klanke, 1925)

[64] Vocke (2002, 145). See below for garment and other personal equipment.



(a) Inflated suit, unmanned, Klanke on the left.

(b) Non-inflated suit, Klanke inside.

Figure 5.13: Photos of Klanke's pressure suit, c. 1936.Reproduced by permission from the Deutsches Museum.

As already discussed, reliable breathing masks were not readily available and prone to errors, i.e. leaking. Hypoxia therefore remained a continuing threat to aviators going to great altitudes. Klanke, having no funds or other support by the RWD, started to construct a "diving-suit" to overcome these troubles in 1933, according to his own account (Römer and Römer, 1937, 492).

Klanke was based at the *Wetterflugstelle* (Weather Pilot's Office) in Cologne, Germany, after he entered the RWD. His work on the suit took place in the backyard of their office at the airport *Butzweiler Hof*, located at the border of Cologne (Mayer, 2001). The suit consisted of two parts and a helmet; the jacket was fabricated out of a rubber-cotton cloth by the *Klepper* company (sewn together by Klanke's wife),[65] and the trousers were a standard Dräger gas-protection trouser.[66] The helmet was made out of brass, held together by two *stove-rings*.[67] Locks from suitcases were used as fasteners for the helmet. The visor was made of unbreakable plexi-glass (Römer and Römer, 1937, 492). The two parts (jacket and trousers) were compounded and sealed by a gas-tight belt at the waist (see next section).

As so often with the pressure suits of those days, the major technical problem was introduced by the fabric of the suit. As Rosenstiel (1935) had pointed out, the suit needed to be both flexible and inelastic, something that was hard to achieve. As can be seen in figure 5.13 (subfigure a), once the suit was inflated, i.e. set under pressure, the expansion of the fabric became serious, severely restricting movement of the pilot. In the cockpit only the arms needed to be moved freely, hence Klanke used rubber bands for the chest and arms to limit the expansion of these respective parts of his suit. One serious issue remained: through the expansion of the suit, the helmet was lifted above the pilot's head, rendering vision next to nothing. In order to prevent this scenario, Klanke attached the helmet to leather belts, similar to braces (see figure 5.13).

While the matters concerning fabric were the same as found with other suits, the approach in terms of air supply taken by Klanke was different and most peculiar. Since Zuntz (1912) had calculated that breathing pure oxygen would only extent the limit to 12000m (see section 3.2.3), physiologists and engineers tried to maintain a constant pressure in a pressure suit, using pure oxygen as the breathing gas (see Haldane's statement from above). This approach was based on the principle that with pure oxygen, the internal pressure could be chosen at a rather small degree. Since Zuntz had set the limit to c. 12000m, and Leonard Hill corrected it slightly to 10000m, the minimum pressure inside a pressure suit should not fall below an equivalent

[65] *Klepper* produced water-proof suits and coats for motor-bike riders, and other purposes.

[66] See various brochures of Dräger in DM-FS.

[67] German, singl.: *Herdring*. Such a metal ring was used to customize the area of the cooking plate.

pressure of these heights. The pressure difference between the inside and the outside could thus be minimized, enormously limiting the stretch of the fabric, because the expansion of the suit would be much less severe. With normal air (i.e. 21% of oxygen), the height limit is c. 5000m. So if one would want to rise to 10000m with normal air as breathing gas, the pressure ratio inside/outside the suit would be roughly 2:1, incurring a considerable stress on the fabric of the suit, whereas with 100% oxygen as breathing gas the ratio could be theoretically 1:1, thus virtually no stretching of the suit would occur at all.

Gerhard Klanke, however, chose to use normal air inside his suit, at a pressure equivalent to 3000–4000m. The airstream outside the aircraft was used for ventilation and compression. This seemed natural since Klanke usually conducted his weather flights at heights between 5000 and 5500m. The excess pressure thus was only $\frac{1}{8}$atm (Klanke, 1938, 182, 187). Pressure differences of $\frac{1}{3}$ or even $\frac{2}{3}$atm were supposedly aspired to by Klanke, in order to attain heights of 10000m or more (Römer and Römer, 1937, 492). Klanke reports nearly 300 flights done with his suit between 1935 and 1938 (Klanke, 1938, 187). His speech (Klanke, 1938) before German aviation physiologists was received with much interest.[68] Klanke also gave hints and suggestions regarding diets and procedures for regular high-altitude flying. The suit and Klanke's remarks did not seem to have any influence on either the pressure suit development or aero-medical matters though. So Klanke's presentation before the physiologists did not result in any cooperation on this side.

The *Luftwaffe* claimed the *Butzweiler Hof* for military uses in 1936. It was used until 1939 when balloon barricades were installed in the nearby city of Leverkusen to protect the *Bayer* factories from air attacks, and usage of the airport was not possible anymore. The *Wetterflugstelle* was re-located to the city of Münster. In 1938, the Cologne office had already been restructured and Klanke moved to the *Wetterflugstelle* at Darmstadt, which was located at the suburban airport *Griesheimer Sand* (Vocke, 2002, 99, 105). Klanke worked there for some months, but quit the RWD the next year. In 1939, the year his son Manfred was born, he accepted a post at the *Deutsche Forschungsanstalt für Segelflug* (DFS, German Research Establishment for Gliding) in Darmstadt, led by Prof. Walter Georgii (1888–1968), one of the three most eminent persons in German aeronautical research, besides Ludwig Prandtl (1875–1953) and Adolf Bäumker (1891–1976). Klanke gave up flying that year, restricting himself to research at the DFS and some flying of gliders.[69] His research dealt with de-icing of cockpit windows amongst other things.

In 1939 upon the outbreak of the Second World War, the airport in

[68] Judging from some short discussion that was appended to the report.(Klanke, 1938, 189)

[69] Telephone interview with Manfred Klanke, August 14, 2006.

Darmstadt-Griesheim, used by RWD, DFS and civilian air lines, came under the auspices of the *Luftwaffe*. The DFS was first re-located to Braunschweig, and finally to Ainring in Bavaria in 1940.[70] Klanke moved with the DFS both times, but quit the DFS in 1942/1943 to work at the *Walter* company in Kiel in the very north of Germany.[71]

After the war he started to work for *Askania* in Berlin, a company producing aircraft instruments, chiefly as patent attorney. Vocke (2002, 145) alleges that Klanke never strove for a patent for the suit, because the Air Ministry had declared it *secret*. This does not seem very plausible, however. Pressure suits were no black art in those days and commonly known, as articles like Römer and Römer (1937) evince. Dräger had already started pressure suit development at the request of the Air Ministry in 1936. Furthermore, Klanke's design was in no way superior to other designs. Actually it was rather *inferior*. Striving for an excess pressure of $\frac{2}{3}$atm when the suit had apparent trouble even to withstand the probed excess pressure of $\frac{1}{8}$atm would not suffice as an argument to keep the design secret. As a matter of fact, Klanke attained a patent, not on the suit, but on the technique to suck in the airstream to put the suit under pressure.[72] Simply put, the officers of the Air Ministry did not seem too impressed by Klanke's suit, also taking into account that Dräger's efforts of 1936 also proved futile and that the Air Ministry did not pursue pressure suits after that for a while.

The Dräger Suits

Even though the Germans did not seek high-altitude flying for their war purposes, and commercial companies like Junkers pushed their pressure cabins, the Air Ministry asked the *Drägerwerke* (or short: *Dräger*, after their founder Heinrich Dräger (1847–1917)) in Lübeck, Germany's leading manufacturer of diving and breathing equipment to deliberate a pressure suit

[70] Information on the history and structure of German aviation research can be gathered from Trischler (1992), or the contemporary CIOS report (O'Hara, 1945). The DFS started to produce a number of astounding prototypes at Ainring, e.g. "rocket-gliders", for which Dräger had to construct pressure suits (see below), but Klanke does not seem to have been involved in any of these activities. In a discussion at the end of Muttray (1939), Klanke reports of heart problems following an accidental explosive decompression, so it seems he still participated in discussions. But there is no sign of him participating in pressure suit or cabin development.

[71] Walter produced engines for submarines. What exactly Klanke did there is unknown. Telephone interview with Manfred Klanke, August 14, 2006. He could not remember the exact year. The Walter-Werke also produced rocket engines for the experimental aircrafts of the DFS (see below), perhaps that's how Klanke came into contact with them when he worked at the DFS in Ainring.

[72] Klanke (1933). The patent specification was not published before 1941, but that was nothing unusual at the time. Many of Dräger's patents for breathing and diving appliances of the 1930s were published ten years after they had been accepted. German engineer H. Ide tried a similar mechanism for the Dräger pressure suits in 1943. Whether Klanke's idea/patent was exploited is not mentioned. BA-MA, RL 3/70.

for aviators in the fall of 1935. Hermann Stelzner (1884–1942) had already retired from the company so Dr. Hermann Tietze, chief engineer for diving apparatuses (Lovelace et al., 1945), was given the task to design a suit. The specifications by the Air Ministry were as follows:[73]

1. Internal pressure: 0.8atm, safety margin three times as much.
2. Shape and size for a person 1.8m tall.
3. Suit should be partitioned to simplify the donning.
4. Use of hands and sight shall not be hampered to allow easy landing and take-off.
5. Suit shall be electrically heated or the heat of the exhaustion pipe should be utilized.
6. Closed-Circuit-Rebreather system.
7. Fogging of the visor must be prevented.
8. Freedom of movement.
9. Rescue-exit with parachute must be possible.
10. Fail-safe system.
11. Radio communication inside the suit must be available.
12. Domestic components should be used, i.e. production independent of foreign currency.
13. Light weight.

Tietze started to incorporate the specifications, but these were hard to meet. Tietze concluded that the maximum pressure resistance must be 2.4atm, leading to a stress of 220kg on a 5cm wide piece of fabric. From that it follows that the fabric "must be extremely heavy and would be hard to tailor, since it is not the tearproofness that counts, but the expandability".[74]

The Air Ministry provided silk cloth to begin with, and Dräger engineers vulcanized it with a double layer of rubber, resulting in a 5mm thick fabric.[75] This gave a tearproofness of 180kg on a 5.4cm wide piece of fabric and a tolerable expansion of 18%.[76] Since these thresholds were insufficient,

[73]Report by Tietze to CIOS team, p. 1–2. BA-MA, RL 3/70. All quotes from it are my translations.
[74]*ibid.*, p. 3.
[75]*ibid.*
[76]Test protocol Nr. 1386. Appendix to the report of Tietze, BA-MA RL 3/70.

according to the specification, silk strings were weaved to a net and strapped over the fabric, the silk strings having a maximum tear of 140kg and maximum expansion of 50%.[77]

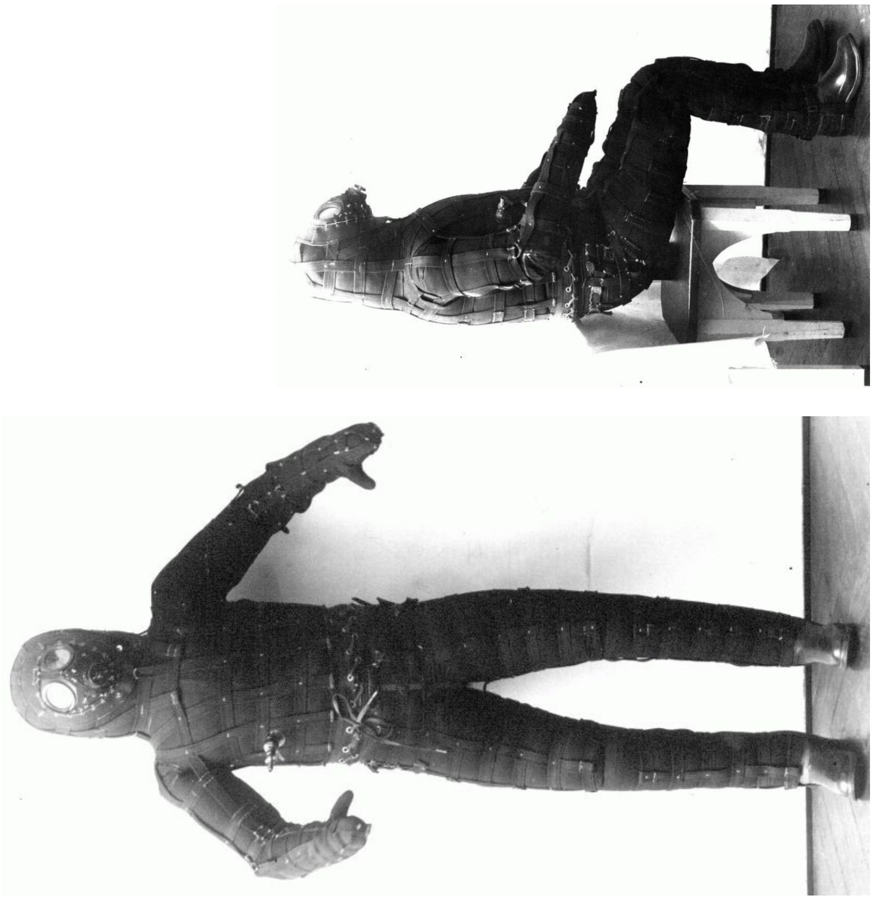
Engineering problems with the incorporation of the helmet in the first prototype led to the omission of the silk net, and the introduction of straps (see figure 5.14). However, the overt expansion of the suit when set under pressure could still not be circumvented.

Hence tests were made with a net of steel-wire, instead of silk-cord. The production of the wire-net turned out to be even more complicated and the danger of getting caught in the wire when moving inside the suit rendered this approach useless. It was thus conceived to embed the soft-suit within a hard shell to prevent the suit from excessive expansion. The delicate question of a feasible ball-joint for the knees and elbows posed a serious design-issue, however.[78] Tietze tried to implement this with a corrugated tube, applying longitudinal straps to limit the expansion. It turned out, however, that under pressure the joints had a tendency to block, and it required considerable physical force to move the joints. Since the results of the development were rather frustrating, the project was stopped in 1936.[79]

At the end of 1940 the Air Ministry requested the continuation of the project. German aviation physiologists had urged the officials that although pressure cabins existed in the designated high-altitude bombers of Junkers, emergency pressure suits had to be handed out to the pilots.[80]

Several German scientists had come to the conclusion that once the pressure cabin had been damaged there would not be enough time to descend to a safe height, in terms of hypoxia. They considered that German aircrafts would fly at altitudes of 17km, whereas with oxygen masks heights of 12km could be safely reached. Hence, once the pressure cabin broke one must quickly descend to 12km to prevent unconsciousness (Ruff, 1942, 4).

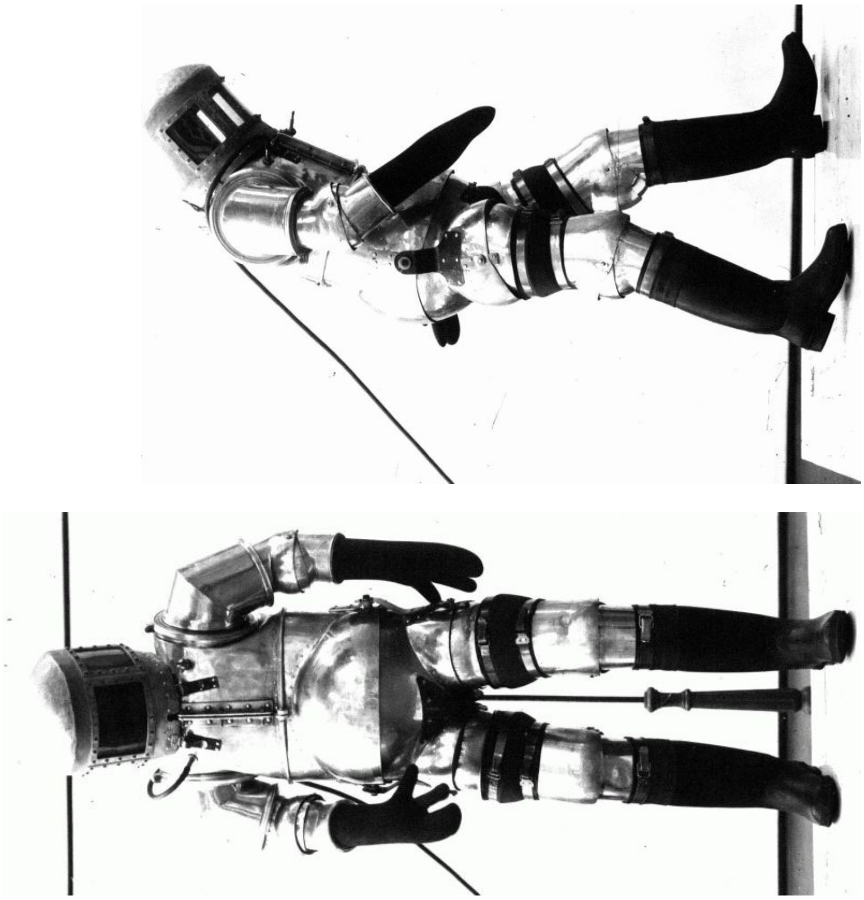
[77] Test protocol Nr. 1258. Appendix to the report of Tietze, BA-MA, RL 3/70.
[78] Report by Tietze to CIOS, p. 4. BA-MA, RL 3/70.
[79] *ibid.*, p. 5
[80] Ruff (1942, 5). See also preceding chapter.



(a) Front

(b) Side

Figure 5.14: Dräger soft-suit from 1936. Reproduced by permission from the Bundesarchiv.



(a) Front

(b) Side

Figure 5.15: Dräger hard-suit from 1940 (first design). Reproduced by permission from the Bundesarchiv.

Among German aviation physiologists the concept of *Zeitreserve* (time reserve) became somewhat of an obsession in the 1940s. This concept was nothing else but the threshold of the hypoxic reaction, i.e. the time from when a human is exposed to a situation of hypoxia until he or she falls unconscious. Since Hornberger (1942) had evinced that the *Zeitreserve* at an altitude of 17km would be only 9sec. (Hornberger, 1942, 8), and Ruff (1942) assumed it would take at least 6sec. to initiate an emergency descendt (Ruff, 1942, 4) the only chance of survival for the pilot was seen in an *emergency pressure suit*.[81]

This emergency suit should be worn all the time throughout the flight, and only be closed and used when a leak in the cabin occurs. It should have an autonomous oxygen bottle for inflating the suit and for breathing. The pilot was supposed to exit the plane by parachute, so the volume of oxygen in the bottle needn't be very large, and last only for the parachute descent.[82] The pressure suit therefore needed only work for a very limited amount of time.

The contact between Tietze and the aviation physiologists left much to be desired.[83] As it was customary in Nazi Germany, the cooperation between different departments was highly regulated. Whereas Stelzner from Dräger and persons like Hermann von Schrötter could go for a direct cooperation to develop the high-altitude breather around 1900, Tietze and persons like Ruff never met personally or even discussed issues with each other. Consequently no debates in wider circles could evolve that would bear a larger influence

[81] German: "Rettungsdruckanzug".

[82] This goes back to an idea of Wilhelm Lutz, a physiologist from the University of Munich. Cf. Lutz (1941) and Lutz (1942). The whole presentation (Ruff, 1942) is a patch-work of the work of others, like Lutz, Hornberger or Benzinger, and garned it with some of his and Strughold's older researches. Ruff summarizes their work and adds the the results of experiments his assistant Romberg and SS-physician Siegfried Rascher had conducted on inmates of the concentration camp Dachau. In these experiments Rascher exposed humans to hypoxic conditions, not only risking their death, but deliberately killing some of them to see the final stages of hypoxia, and finding the most extreme threshold values (Zeitreserve) possible. Since Rascher was not a member of the *Deutsche Akademie der Luftfahrtforschung* (DAL, German Academy of Aeronautic Research), he was not allowed to present his results at their meetings, a job carried out by Ruff (1942). Ruff and Romberg were tried at Nuremberg for these experiments, but were not sentenced for lack of evidence (cf. Mitscherlich and Mielke, 1978). These experiments were the topic of many scholarly debates, especially on the question of how much Ruff, Strughold and others knew of and profited from Rascher's experiments. The discussion of this issue is beyond the scope of this publication. Mackowski (2006) discusses this topic, but is quite conciliatory toward Strughold and others. Neumann (2007) has elaborated in how far the German aviation physiologists were informed and what their stance was. He, for example, has shown that physiologist Heinz von Diringshofen even visited Rascher in Dachau to keep himself informed about the experiments.

[83] In the discussion section, on the question of the developmental status of such suits, Ruff said: "I am not sure. I know that Lutz' proposal has been taken up by Dräger. I have no idea in regard of how far this development has advanced hitherto". Ruff (1942, 17), translation mine.

on the discussion of pressure suits, as was so evidently the case in pre-war pressure suit development, in Britain or Italy for example.

Tietze, on the other hand, made good progress in assessing the technical issues in suit engineering. He reached the conclusion that pressure suits did not need be made entirely of an elastic material, but only the joints.[84] Through this, he was convinced that overt expansion of the suit could be avoided, making the suit tearproof and ensuring no blockage of the joints would occur. This would only work for pivotal joints, however, like knee and elbow, but not for ball-joints like the shoulders. Since the arms of a pilot in a cockpit needed only to move back- and forward, this appeared negligible in his eyes, however.[85] Tietze thus used pivot-joints to achieve a high degree of manoeuverability (see figure 5.15).

The suit was put to an internal pressure of 0.75atm, allowing for smooth motions of the wearer. A later design used a plexi-glass helmet for better vision and had a diagonal partition in the chest to meet the requirement that the pilot should be able to don the suit without assistance (see figure 5.16). This suit was presented to the officials at the Air Ministry in June 1942.[86]

Parallel to that, on the aforementioned idea by Lutz, the Air Ministry asked for light-weight emergency pressure suit, which only needed to be inflated in case of a damaged pressure cabin. The hard-suit surely couldn't fullfil this purpose, so Tietze implemented a new design, named *Rettungsanzug Modell 1* (engl: emergency suit model 1). The Air Ministry demanded that the suit should remain unpressurized during the flight, and only in case of emergency it should be inflated instantly. An internal pressure of 0.15bar was desired. Several prototypes were produced in 1942. It had four "bulls-eye" windows in the helmet and a large sealed zipper in the front to enter it.[87]

The *Rettungsanzug Modell 1*, was not satisfying to its engineers. It was considered that a completely transparent helmet with a quick-connector would be required to allow sufficient vision. Furthermore, it turned out that from the engineer's point of view, there was no technical difference in a regular pressure suit and an emergency suit, with the problem of the joints as top priority.[88] From the expertise gathered in the construction of the hard-suit, Tietze started to develop a suit with flexible joints. In 1943, after several intermediate models, he could present a first design: the *Leichter Druckanzug, Modell 8* (see figure 5.17).

The design proved to be feasible, but it was considered desirable to have a sliding window in the helmet, to insert the breathing mask from the outside,

[84]Report of Tietze to CIOS, p. 5. BA-MA, RL 3/70.

[85]*ibid.*

[86]*ibid.*, p. 6.

[87]*ibid.* The photos are not given here, since they were too small and would not reproduce nicely when magnified. Cf. the list of photographs compiled by Tietze, BA-MA, RL 3/70.

[88]Report of Tietze for CIOS, p. 7. BA-MA, RL 3/70.

if necessary. Then, it was requested to enlarge the helmet to have better manoeuvering of the hose of the breathing apparatus inside. Several helmet designs were tried, and it testing was done to see how best to achieve a partition of the suit in two parts to allow easy donning.[89] These considerations resulted in the *Leichter Druckanzug, Modell 115 & 118* (see figure 5.18).

The design was modified in several instances, testing various materials and approaches to the gloves (see figure 5.19).

The gloves were further modified to allow a greater degree of freedom. Some of the test-subjects had complained about squeezing in the fingers when the suit was inflated and the pilot still had to grip the steering wheel closely. Thus, a more flexible material was sought, together with modified joints for the fingers in the gloves (see figure 5.20).

As these designs became increasingly sophisticated, but no suits were put to use, the German administration continued to expose their abundant irrationality. While the phantasmagoria of "Wonder Weapons" haunted the German administration later in the war,[90] many ideas sought then were borne by experiments devised earlier.

In the 1930s the Germans, like most other countries with ambitions in aviation, pushed research in the field of the effects of high acceleration, i.e. the tolerance of high G-Forces. Beside researches on hypoxia, high-speed flying was the most debated topic in aviation medicine.[91]

Leading among the German research institutions involved in investigating of the effects of high-speed flying was the Aero-Medical Department of the DVL, under its director Siegfried Ruff (1907–1989). Ruff and his assistants started a number of studies in 1936. While G-Force research is not within the scope of this publication, one conclusion drawn by Ruff et al. is most interesting in terms of pressure suit development.

The results of the research at the DVL led to the belief that forces of 6g could be tolerated for a short period in a sitting position, but up to 17g in a lying one.[92] This idea, that a pilot lying on his belly in a cockpit would endure higher G-Forces, permeated into the minds of the officials at

[89] *ibid.*, p. 8

[90] Cf. section 4.5.3.

[91] As can be seen from contemporary bibliographies, like the German Schmidt (1938, 1943) or the American Hoff and Fulton (1942) or Poppen (1941). Also, for Lünen (2009), I did an analysis of the reports of the *Zentralstelle für Wissenschaftliches Berichtswesen* (ZWB) of the German Air Ministry 1934–1944, and there were a number of research reports from aviation physiologists dealing with this topic. For the ZWB, see FIAT (1945).

[92] Wiesehöfer (1939, 135). Results were, as was often the case in German aviation medicine in that time, redundantly published by the participating physiologists. So, Gauer and Ruff (1939); Ruff (1939); Wiesehöfer (1939) pretty much are reflecting the same ideas. It was actually Diringshofen (1935b, 38) who was the first to speak in Germany about the greater tolerance toward high g-forces when not sitting upright, but he only gives a short hint at that.

the German Air Ministry.[93] Thus, several projects were started to construct airplanes with cockpits allowing the pilot to lie down. The first of such prototypes was the glider FS17 constructed by the *Flugtechnische Fachgruppe* (FFG, Aero-Technical Specialist Group) in Stuttgart (see fig. 5.22).[94] The design phase was started in 1936, construction started in 1937 and the prototype completed in 1938. A glider was chosen for budget reasons (Wiesehöfer, 1939, 138).

Whilst the pre-war experiments with pilots lying down suffered from insufficient funds, in 1942/43 the efforts became a bit more serious. Aeronautical engineer Felix Kracht (1912–2002) of the DFS in Ainring started to construct prototypes of *rocket-gliders*: the DFS 228 in 1942 and its successor DFS 346 in 1943/44. The DFS 228 was supposed to be carried up to 10000m piggy-back on a Dornier Do217 K-3 bomber airplane, and from there it should launch its engine to fly to a ceiling of 25000m at a speed of 900km/h. The DFS 228 was designed to work as a reconnaissance craft, equipped with two cameras. It should have a metal pressure cabin that could, in case of emergency, be blasted off and drop down with a parachute. At lower heights the pilot could then bail out with his own parachute. Tests revealed many problems, including issues with the original cabin. Another prototype was completed, but never made it into the air, just like the other ones (Lommel, 2000).

Kracht then designed the DFS 346 with an intended ceiling of 35000m. It was also supposed to be carried aloft by a bomber plane, this time hanging under its wing like a bomb. The experimental Walter engine made 900km/h, Kracht's design pursued a maximum speed of 2765km/h. The plane was never fully constructed during the war. The rudimentaries were bagged by Soviet troops at the end of WWII and served as testbed for Soviet jet-aircrafts until the 1950s (Lommel, 2000).

In 1943 the FFG of the Technical University of Berlin was asked by the DVL to develop another prototype. The FFG delivered the *Berlin B9* the same year, a power glider capable of reaching a height of 4000m and flying at 250km/h. It was designed and constructed purely for testing purposes, i.e. testing whether piloting an airplane in a lying position was feasible. It had a twin piston-engine and the aircraft could withstand an acceleration of 22g. In the same year commercial companies also tested prototypes of airplanes for pilots lying down, e.g. Blohm & Voss BV 40, Horten Ho IV and Ho VI

[93] Actually as can be seen in figure 5.21 the highest G-Forces were tolerated by a pilot lying on his back. This posture was considered undesirable, though, in regard to the cumbersome way of controlling the aircraft from this position. Ruff (1939) includes photographs of a specially constructed seat with springs that switches the pilot from a sitting position to a back-lying one at G-Forces greater than 6g.

[94] The FFG were Special Interest Groups for Aviation in engineering departments at German Technical Universities. They were closely affiliated with the Aeronautical Research Institutions, like the DVL, DFS or AVA. (Cf. Trischler, 1992)

or Heinkel "Projekt Julia" (Pawlas, 1975).

Just like the obsession with high-altitude bombers and fighters to even out the odds of aerial warfare in the German Command, the Air Ministry took its assessment seriously. While the DFS prototypes were considered to blast off their cabin and let the pilot drop to safe heights, a special *Emergency Pressure Suit* was deemed necessary, just as in the case of bombers (see above). Thus, Tietze of Dräger was also asked in the summer of 1944 to design a suit for lying down pilots, in case the cabin was pierced by bullets and leaked (see figure 5.24). The suit should have been pressurized by an autonomous bottle attached to the suit, which the pilot triggered by pulling a lever. The maximum overpressure should not have exceeded 210cm WS.[95]

The pressure suits that were produced by Tietze were tested at the Experimental Flying Establishment of the German Air Force (*Erprobungsstelle der Luftwaffe*) at Rechlin near Berlin, where aviation physiologist Theodor Benzinger (1905–1999) was in charge of the medical department from 1937–1944, which was a sub-department of the equipment testing department under the supervision of Dr. Wendroth.[96]

Benzinger's team, Walter Hornberger and Dr. König, started research of their own in respect to pressure suits. Again, the team at Rechlin did not have much contact with Tietze. The suits were handed over and tested in a pressure chamber and later in airplanes at Rechlin, the results were mediated to Tietze and Dräger in the form of research reports.

Benzinger and Hornberger used these experiments to gather some expertise in questions of *explosive decompression* (e.g. Hornberger, 1942; Hornberger and Benzinger, 1942). and they also started some genuine research on pressure suits and related issues. Hornberger and König (1942) examined the question of whether emergency pressure suits needed to enclose the human body completely or could be partial. Since the production of gloves for pressure suits was such a delicate hindrance (as Tietze had already struggled with), but vital for the handling of an airplane, the Dornier aeroplane company asked the Rechlin team if there was a chance of having a suit without gloves (Hornberger and König, 1942, 2). Benzinger *et al.* made experiments with a partial pressure suit, i.e excluding arms and hands, they had ordered to be constructed for them by Rechlin engineers. After a number of experiments they found out that the circulation of the blood is affected by such local pressure differences, i.e. the venous blood-flow was hindered when exposing single body parts to a lower barometric pressure. After having tried

[95] BA-MA, RL 3/70, Report from Tietze for the CIOS team, 1945, p. 8. "WS" stands for "Wassersäule" (engl: water column), an old pressure unit, with 1mm WS = 10Pa, i.e. 210cm WS = 21000Pa = 0.21 bar. (Cf. Cardarelli, 2003)

[96] See Beuvaix et al. (1998, 121,324–325). Benzinger (1942) doesn't mention the testing of pressure suits at all, just the evaluation of pressure cabins – contrary to Tietze's statements from above. This might indicate that Benzinger himself was not involved in the testing and that the suits were not a top priority at Rechlin.

both legs and arms at lower ambient pressures, and leaving only the torso under normal pressure, it became clear that the blood-flow was too severely hampered. Also, the sensitivity of the limbs became too great, causing pain to the experimentee after longer exposures and large pressure differentials. Thus Hornberger and König (1942) concluded that only the hands and arms can be excluded from a pressure suit, only at a pressure of 100mm Hg below the level in the suit, and only for a time frame of 20min (Hornberger and König, 1942, 1). Such a partial pressure suit was never constructed by Dräger or any other company in Germany though.

Even though the designs of Tietze, particularly the final ones in 1944, were all quite sophisticated, they were in no instance ahead of their Allied counterparts. Russel Colley in the US in 1934 and Robert Davis in the UK in 1933 had proven that they were capable of producing feasible, yet imperfect, pressure suits in a rather short time. As outlined below, there were numerous ideas deliberated in the USA during the war which followed pretty much the same pattern Tietze did, in terms of constructing ball joints. That no such suits were actually produced in the war time in the US or UK was, as was discussed in the preceding chapter, owed to the greater pragmatism on their side. While the Germans were somewhat obsessed with the rapid decompression a damaged cabin would impose, the Allied side considered this issue as not so vital and simply mandated the pilots to wear oxygen masks, which would suffice to counter-act the problems encountered in such a case.[97]

Hence, when the CIOS team inspected Dräger in 1945 they were not overtly impressed by the pressure suits they found (Lovelace et al., 1945, 20):

> "Development of this item has not progressed as far as had been hoped. However, consideration of the ball bearing joint may be of some value to allied agencies."

There were only remnants of the suits present at Dräger, the majority having been handed over to Rechlin in the wartime, apparently. The CIOS team therefore only could acquire one complete and one incomplete pressure suit, which they brought over to the USA (Lovelace et al., 1945, 44). Even though the latest suits (particularly the suit in figure 5.20) resemble a rudimentary form of the later space suits, it is doubtable whether the suits bagged by the CIOS team had any influence on the development of the American post-war suits. Russel Colley from B.F. Goodrich, who was in charge of suit designs and others already had a number of solutions up their sleeve during the 1940s (see below).

[97] A few years after the war, Demetriades (1954) computed the degree of decompression that would occur in the event of a damaged cabin. The results clearly show that for just some holes in the cabin, there would be ample time to respond for the crew (i.e by descending or putting on oxygen masks). For larger holes, the airplane would be so damaged already that decompression was the least thing to worry about.

Pressure suits played no role in the war, but the Germans were deeply convinced that such a suit was needed. Ruff (1942), as stated above, laid out the necessity to have such suit. His statement made later, that "There was no imperative to have such a device – particularly during the war" (Ruff, 1989, 37), is therefore a rather ridiculous one in the face of his ambitions in 1942.[98] A post-war statement by Seeler (1950b) gave some more pointers in that direction Seeler (1950b, 526–527):

> "However, it [the pressure suit] is unsuitable for military high altitude flight. [...] Since these pressure suits were not perfected sufficiently to permit the *Luftwaffe* to accept them for general use, no more suits were made than were required for testing."

Seeler's account is not too informed, though. On the same page, for example, he states that the French and Italian authorities "also began to develop pressure suits" – which is not true.[99]

Tietze, as Ruff (1989, 35) nonetheless correctly remarks, must be regarded as the first person to introduce ball bearing joints into pressure suit design. American designers, as shown below, had also tackled the problem of flexible elbow joints, but none had come up with a ball joint. Rather, similar to Herrera's design, they used the "harmonica" approach.

Tietze, as director of Dräger's diving apparatus department, albeit being on the wrong track with the soft and hard suits in the beginning, quickly acquainted himself with the problem of pressure suit development. The references to diving suits, although the later design did not have much resemblance to diving suit designs, is striking. The ball bearing joints were most likely inspired by those found in armored diving suits. Both Stelzner (1931) and Davis (1935) refer to the armored suit constructed by Gall in cooperation with the company Neufeldt & Kuhnke, as the most feasible one. With these suits, which maintained an internal pressure of 1atm, depths of 100m and more had been reached in the 1920s, furthering the hope that within the near future any depth might be attained with these apparatus. The ball joints, however, became hard to move under the extreme pressure met in those depths.[100] For aviation, on the other hand, the pressure differences were not so extreme, so the idea was revived for pressure suits.[101]

[98] The "Preliminary Instruction to Maintain High-Altitude Airplanes", issued by the Air Ministry on Aug 23, 1944, does not mention any pressure suit (emergency or normal), just a parachute with integrated high-altitude breather. BA-MA, RL 3/2516. This indicates that pressure suits were never actually used in the war by the Germans, other than for test flights.

[99] France was occupied from 1940 on and could have hardly manufactured any suits, and as I have outlined above, before the war French authorities were not interested in high-altitude flight.

[100] With todays armored diving suits, depths of c. 300m are achieved.

[101] Hard suits were also deemed desirable since it is easier to maintain normal atmospheric pressure inside, provided the suit is completely sealed. Hence, the concept of armored

Hermann Stelzner, chief engineer of Dräger for so many years and developer of the high-altitude breather among other important things, did not participate in the design of the pressure suits. While he was still active when the first soft suit was produced in 1936,[102] he doesn't seem to have been involved in the design process.

Without being aware of it, Dräger had already constructed a pressure suit in 1915 (see figure 5.25). As a means to conduct emergency recompression of a diver suffering from acute DCI, Ernest Moir (1862–1933) had invented the recompression chamber in 1889–90 (Phillips, 1998, 104). Dräger wanted to have a mobile recompression chamber to take aboard the diving vessels, so divers showing symptoms of DCI could be recompressed on the spot. As a first design, Hermann Stelzner of Dräger devised a modified standard diving suit to be put under pressure, employing ropes to limit overt expansion. This design proved to be flawed, however, and was replaced with a tube-like construction. It is questionable that the recompression suit as shown in figure 5.25 had any impact on the development of later pressure suits, other than that diving suits in general were taken as models for pressure suits.

That Stelzner and Dräger actually had the principle of a pressure suit invented as early as 1915, but that it took until the 1940s before Dräger's engineer Tietze could come up with a feasible design, after failing to do so in 1936, hints very much on the actual issues with pressure suits. It was not the scientific side that failed, or insufficient physiological research, but more mundane *engineering problems*. The trouble with pressure suit construction was dictated first and foremost by the lack of the right fabrics, as signified by Dräger's efforts. The lack of feasibility and comfort of the suits led to the abolition of most such efforts, as is best exemplified by the Italian design process.

5.2.4 The Italian Pressure Suit

In June 1934 the Italian government installed the *High Altitude Flying Group* at the Aircraft Establishment in Guidonia, near Rome. Its purpose was to carry out a combined effort to tackle all issues in regard to flying at high altitudes, like engineering or navigation. A great deal was spent on the development on both pressure suits and cabins.[103]

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pressure suits has likewise been sought over recent decades, with NASA still testing hard suits for EVA. Cf. Grossmann (1989)

[102]In the 1930s the German government made a survey of companies relevant for war efforts. Dräger, as manufacturer of gas masks, high altitude breather, etc. was obviously checked. When the inspectors visited Dräger in July 1936, Stelzner was still listed as "director". Report ("Werkbericht") on Dräger in BA-MA, RL 3/418.

[103]Pezzi (1937, 52). Unfortunately, not much published material on technical details of both the suit and the cabin are available. Most contemporary newspaper articles are quite shortspoken when it comes to the technology, and next to no information is contained in newer literature. Therefore, only sparse information on both suit and cabin will be given

Col. Mario Pezzi (1898–1967) became director of the High Altitude Group at Guidonia when this group was installed. He became a military pilot in 1926 after serving in the infantry in World War I. The flight surgeon in charge of the group was Tomaso Lomonaco, who wrote the obituary on Pezzi (Lomonaco, 1967, 415). Also the renowned physiologist Amedeo Herlitzka (1872–1944) was consulted for scientific guidance.

Furthermore, a large pressure chamber was installed at Guidonia to conduct experiments in order to study the effects of low barometric pressures on the human organism. Pezzi's reaction to various "heights" was tested and monitored, striving for the intended 15000m for the projected height record flight (Lomonaco, 1967, 417).

The notion that with pure oxygen and oxygen masks heights of 14000m would be attainable had been established at Guidonia, at least for short durations (Pezzi, 1937, 62). For weight issues, a pressure suit – which was called a "diving suit"[104] – was first sought to break that limit. Just like the other suit manufacturers around the world, the engineers at Guidonia had to struggle with the expansion of the suit when put under pressure. The first approach, as Mallan (1971) shows, was to put the pilot in a "suit" that resembled a knight's armor, taking the armored suits from diving as a model. Obviously, this design did not prove viable when it came to freedom of motion for the pilot.

Another setup was tried subsequently, combining two layers of fabric with different degrees of rigidity and a torso made of light metal (see figure 5.27): first, a electrically heatable garment was put on, then an air-tight rubber suit was donned on top of that. To restrict the expansion of the rubber suit when put under pressure, a linen suit covered the rubber layer. As a further restriction, and to mount the helmet, a vest made of light-metal was worn as an outer layer. The helmet was made of metal with several windows, which were electrically heated to prevent fogging.[105]

Helitzka had proposed to use a mixture of oxygen and carbon-dioxide (at 7%). In this he followed Mosso's *acapnia* theory that explained high altitude sickness with a lack of carbon-dioxide rather than a lack of oxygen. This theory, however, was continually contested after its formulation in 1898 (West, 1998a, 87). Angelo Mosso (1846–1910) noted physiologists from Torino, who had erected a laboratory on top of the *Monte Rosa* mountain in the Italian alps, had spoken out against Bert's theory of hypoxia as the cause of mountain sickness. Joseph Barcroft, however, finally refuted this

here.

[104]Ital: scafandri

[105]Anonymous (1937b). Unfortunately I could find no information or photographs of the helmet, and I have no information on the breathing apparatus being used with the suit. Süßbrich (1938, 274) reports on Pezzi's presentation at the *Lilienthal-Gesellschaft* (cf. Pezzi, 1937), and that the helmet had several windows which were heatable to prevent fogging.

theory in 1925, after several other authors like Adolph Loewy (1862–1936), a student of Nathan Zuntz, had expressed doubts about it before.[106] In 1908 Ronald Ward (1877–1938), a student of John Scott Haldane, took one of Haldane's gas analyzers to Monte Rosa and checked the partial pressures of CO_2 to evaluate Mosso's theory. He couldn't find any evidence supporting Mosso's acapnia theory.[107] That Herlitzka nonetheless proposed the usage of said mixture might have something to do with several factors. First of all, the role of carbon-dioxide as a stimulans for respiration was well-known.[108] Therefore it was used in resuscitation apparatuses, e.g. by Leonard Hill or in Dräger's *Pulmotor*.[109] The effect of the *Pulmotor* and other equipment might have led some contemporaries to believe, that the addition of CO_2 to the breathing gas had positive effects in regard to withstand the effects of high altitude. More important for the prevailing of the acapnia theory, however, was the national sentiment in most physiologists, a notion that was prevalent in many physiology circles in the 19^{th} and early 20^{th} century. Especially in an overtly nationalistic time as met in Italian Fascism, it is not surprising to find both Lomonaco (1967) and Pezzi (1937) clinging to this fallacy, with Lomonaco (1967) obviously being less euphemistic about it.

Notwithstanding the acapnia issue, the group at Guidonia realized that with breathing masks the heights reachable would not come close to the desired ones. Hence, pressure suits were designed. After the hard suit failed to deliver a solution, the soft suit was constructed.

As Pezzi (1937) reports, technical difficulties with the suit were enormous, primarily in regard to the expansion of the suit. As he describes, the expansion made the suit extremely rigid and hampered the pilot's mobility severely. The suit was supposed to work under a normal atmospheric pressure, i.e. 1atm, although this was not explicitly specified.[110] "Only the reduction of the pressure could solve the problems" he pointed out. The internal pressure was thus reduced to 0.3atm, using pure oxygen as breathing gas. As thermal protection, a electrically heated suit was worn underneath the pressure suit.[111]

Pezzi explained that for using a suit the pilots had to undergo a special training, so the suits were only for experts, and when stratosphere flying had to be employed in commercial air travel, a pressure cabin would be the only choice (Pezzi, 1937, 62).

As a matter of fact, the discomfort experienced with the pressure suit,

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[106] See Barcroft (1925, 89) for Barcroft's refutation.

[107] Cf. West (1998a, 88) and Ward (1908).

[108] Thanks to Haldane and Priestly (1905).

[109] For the Pulmotor, see e.g. *Drägerhefte*, no. 99, 1924, pp. 1022–1023. Also, see various Dräger brochures from 1917 in DM, FS 931. Yandell Henderson had also applied this principle in the USA, introducing an apparatus of his own. Cf. Henderson (1938).

[110] Lomonaco (1967, 419), however, affirms this desire to have 1atm in the suit.

[111] Pezzi (1937, 62). See also article in the *L'Echo Des Ailes*, May 20, 1937, DM, LRD 00691.

albeit the successful record flight in 1937, led to a concerted effort to come up with a pressure cabin that would be light enough to attain great heights. Astoundingly, this was achieved shortly after. The cabin had a shoe form to allow a sitting position, while minimizing size (see figure 5.28).

The cabin maintained a pressure of c. 1atm, and circulated pure oxygen from bottles, having a filter with silica-gel and potash to deduct moisture and carbon-dioxide, respectively, from the circulating air (Lomonaco, 1967, 420). Remarkably, Lomonaco (1967) pointed out, in case of emergency (i.e. leakage of the cabin) an oxygen mask would suffice, combined with an emergency descent (Lomonaco, 1967, 421–422). This contradicted the stance of German aviation physiologists, as outlined above.

Unfortunately, from the given sources, no statement in regard to the cooperation of engineers and physiologists can be made, or who was in charge of constructing the suit and cabin, as far as engineering was concerned. Pezzi (1937, 52) makes it appear as if all required personnel were gathered at Guidonia, i.e. no external companies were involved. Furthermore, a French article from 1937 states that the suit was manufactured at Guidonia by the Technical Service of Italian Aeronautics.[112] A short statement in the *Berliner Morgenpost* also points in that direction.[113]

5.2.5 The Spanish Pressure Suit

Spain's first venture into pressure suit development never left the drawing board, and is mentioned only for the sake of completeness and to exemplify the general popularity of the idea at the time.

Raoul Pateras Pescara (1890–1966) was born in Argentina, but ventured over to Europe and became a Spanish resident.[114] Pescara became a pioneer of helicopter flight and engineering, flying a helicopter on April 18, 1924 for a distance of 736m in 4min 11sec, then the world record. The work on helicopters was sponsored by the French government from 1921–24. After those years, he struggled to find financial support, and temporarily had to give up his company due to financial trouble.[115]

In 1923 he filed a patent in France for a "diving suit for the air".[116] In it, he argued that sealed cabins are not useful for military aircrafts, since

[112] Fr: *Services Techniques de l'Aéronautique Italienne de Guidonia*, DM, LRD 00691, article from *L'Echo Des Ailes*, May 20, 1937.

[113] Article in the *Berliner Morgenpost*, Oct 24, 1938. It states that the Piaggio-engine of the airplane and the cabin were engineered and tested at Guidonia.

[114] At least in the patent in question, Pateras-Pescara (1923), mentions him as a "resident of Spain". He retained his Argentine citizenship, although he lived in France for the majority of his life. His mother was French and his father Italian, and Raoul was raised by his grandparents in France. Before and during World War I, Pescara constructed airplanes and after the war he became interested in helicopter design. (Goldbeck, 1960, 481)

[115] He is also regarded as the inventor of the *free-piston engine*. (Goldbeck, 1960, 481–82)

[116] French: *Scaphandre aérien* (Pateras-Pescara, 1923).

bullets might pierce the hull and render the cabin dysfunctional. As a feasible alternative he proposed using an airtight diving-suit that had the strength to withstand the difference of internal and external pressure. Also, it should have a device to replenish the air in the suit. The helmet should be made of a light-metal, e.g. aluminum. It should also bear facilities for communication and the connector for the breathing apparatus. To prevent the suit from overt inflation, "bracelets" should be employed to restrict the expansion (see figure 5.29). Furthermore, for military uses, a body armor for the chest made of steel could be attached (Pateras-Pescara, 1923, 1–2).

It appears Pescara never bothered to construct such suit and his invention apparently did not become known to others. It shows, however, that the idea of pressure suits as modified diving suits permeated into technical discussions and deliberation very early. Pescara's connection to Spanish aviation is not quite apparent, though, and it is questionable wether he ever made contact with anyone who actually constructed pressure suits.

Another suit, however, displayed more potential and – contrary to Pescara's – was actually constructed, though never used in real flight. Emilio Herrera Linares (1879–1967) of Spain became interested in aerostats in 1901 while attending the Military Engineering School at Guadalajara, Spain. Being born into a family with many members in the military, and being vitally interested in science and technology, Herrera began a career in science after finishing at the said school. He ventured into ballooning to study the physics of the atmospheric layers, also participating in numerous record and competition flights in those years.[117] For example, he (then Lieutenant of the Spanish Army Aerostat Corps) participated in the first *Gordon Bennet Cup*,[118] a balloon-race in Paris, in 1906, ranking number 8, with his co-pilot Col. Echagüre in their balloon *AyAyAy*. Departing from the general starting point in the *Jardin des Tuileries*, Paris, France on September 30, 1906, they traveled a distance of 184km over a time of 6:23h, coming down 800m before the Channel coast.[119] Then he again participated in the 3^{rd} Bennet Cup in 1908 in Germany.[120] This time he finished it ranked 17 (out of 23 teams), traveling 121.5km.[121]

[117] The web-page of the *Herrera-Foundation* provides a biography in Spanish: `http://eherrera.aero.upm.es/`, last access: Feb 28, 2007.

[118] French: *Coupe Aéronautique Gordon Bennett.*

[119] Source: `http://www.coupegordonbennett.org/results/1906.asp`, last access: Feb 28, 2007. Winner was the American Frank P. Lahm (Lieutenant in the US Army Signal Corps, a pre-cursor of the US Army Air Corps), traveling 647.1km, landing in Flying Dales (Yorkshire, UK).

[120] It was ruled in the Cup's regulations that the winning country had to organize next year's race. In 1907 few balloonists had the funds to go over to the USA to participate. Source: `http://www.coupegordonbennett.org/results/1907.asp`, last access: Feb 28, 2007.

[121] Source: `http://www.coupegordonbennett.org/results/1908.asp`, last access: Feb 28, 2007.

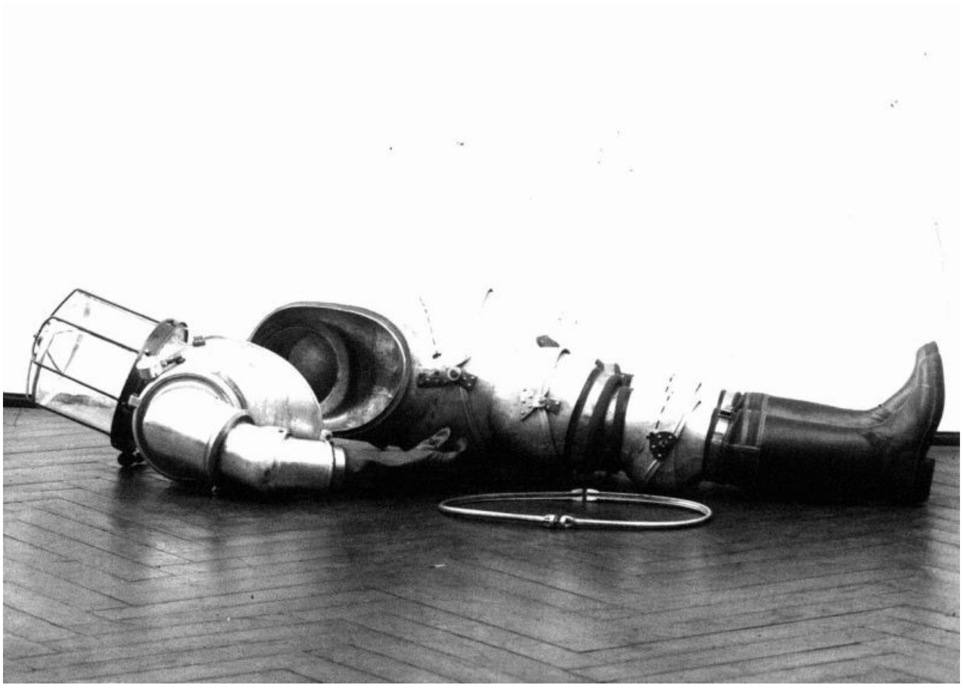
Herrera became involved in pilot's programmes once the Spanish Government had established an Air Force in 1910, becoming a professor at the Aviation School at Cuatro Vientas. In the years 1913–14 he participated in the Moroccon War as a pilot. During this time he was the first to cross the Strait of Gibraltar in an airplane, a feat which earned him a promotion to the rank of Commander and several other distinctions. From 1915 on, he devoted his flying practices to more scientific causes, getting involved more in physics, venturing into cosmology and relativism, becoming a member of several scientific societies. His military affiliation, however, let him frequently investigate military uses of aviation. For instance, he visited the war fields of World War I, studying air warfare tactics of the Allies.

After being involved in various scientific and political projects in regard to aviation, Herrera became director of the Aerodynamical Research Laboratory at Cuarto Vientas in 1928. In 1929 he was nominated as director of the College of Aeronautics, which educated engineers of aeronautics.[122]

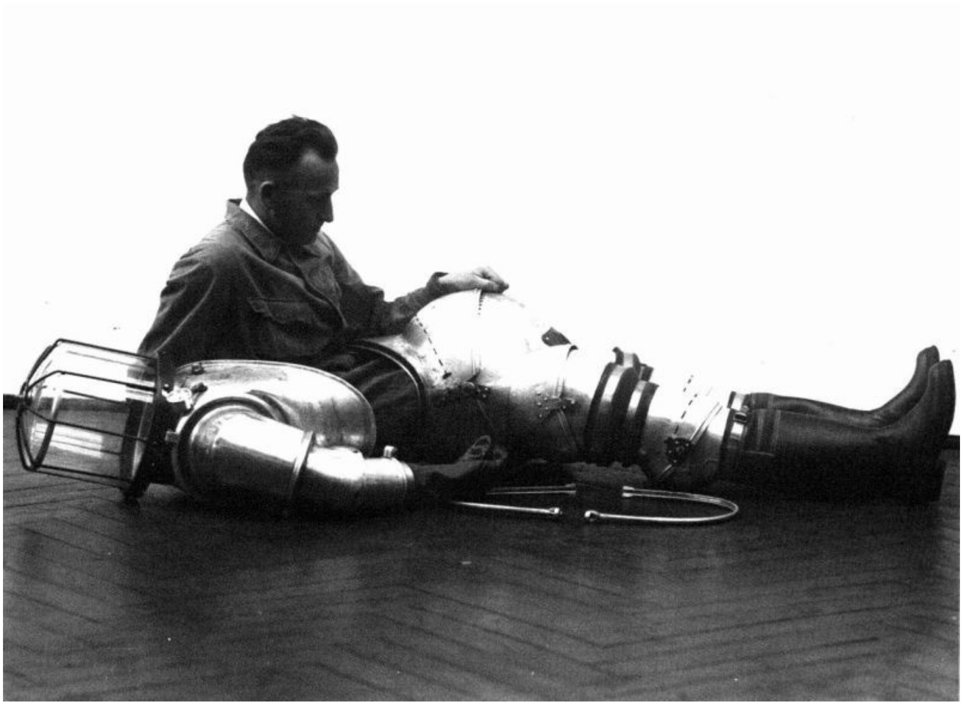
The uprise of the Second Republic led to a split in the aviator scene, with many former Army pilots taking their leave in a sense of discord with the new government. Herrera, however, despite being a monarchist, remained loyal to the Republic while upholding his personal relations with former comrades, seeing himself as a scientist. He argued that the army should always follow the legitimate government. This notion was not popular among other military pilots, leading to the rise of the *Nationalist Air Force* in the Spanish Civil War (1936–39). The nationalists, however, gained the smaller number of planes and pilots (Cortada, 1982, 11).

The events of the Civil War also affected Herrera's activities. In 1933 he started a research project to study the higher layers of the atmosphere with a balloon, comparable to the ones taking place in the USA (Explorer II) or Germany (Piccard) (cf. Herrera Linares, 1935a,b). For this, he designed and constructed a pressure suit (see figure 5.30), that provided some interesting features. The project ceased with the outbreak of the Civil War in 1936, though.

[122] `http://eherrera.aero.upm.es/`, last access: Feb 28, 2007.



(a)



(b)

Figure 5.16: Dräger hard-suit (second design) from 1942. Reproduced by permission from the Bundesarchiv.

Figure 5.17: Dräger pressure-suit “Leichter Druckanzug, Modell 8” from 1943. Reproduced by permission from the Bundesarchiv.

Figure 5.18: Dräger pressure-suit “Leichter Druckanzug, Modell 118” from 1943. Reproduced by permission from the Bundesarchiv.

Figure 5.19: Dräger pressure-suit "Leichter Druckanzug, Modell 223" from 1943. Reproduced by permission from the Bundesarchiv.

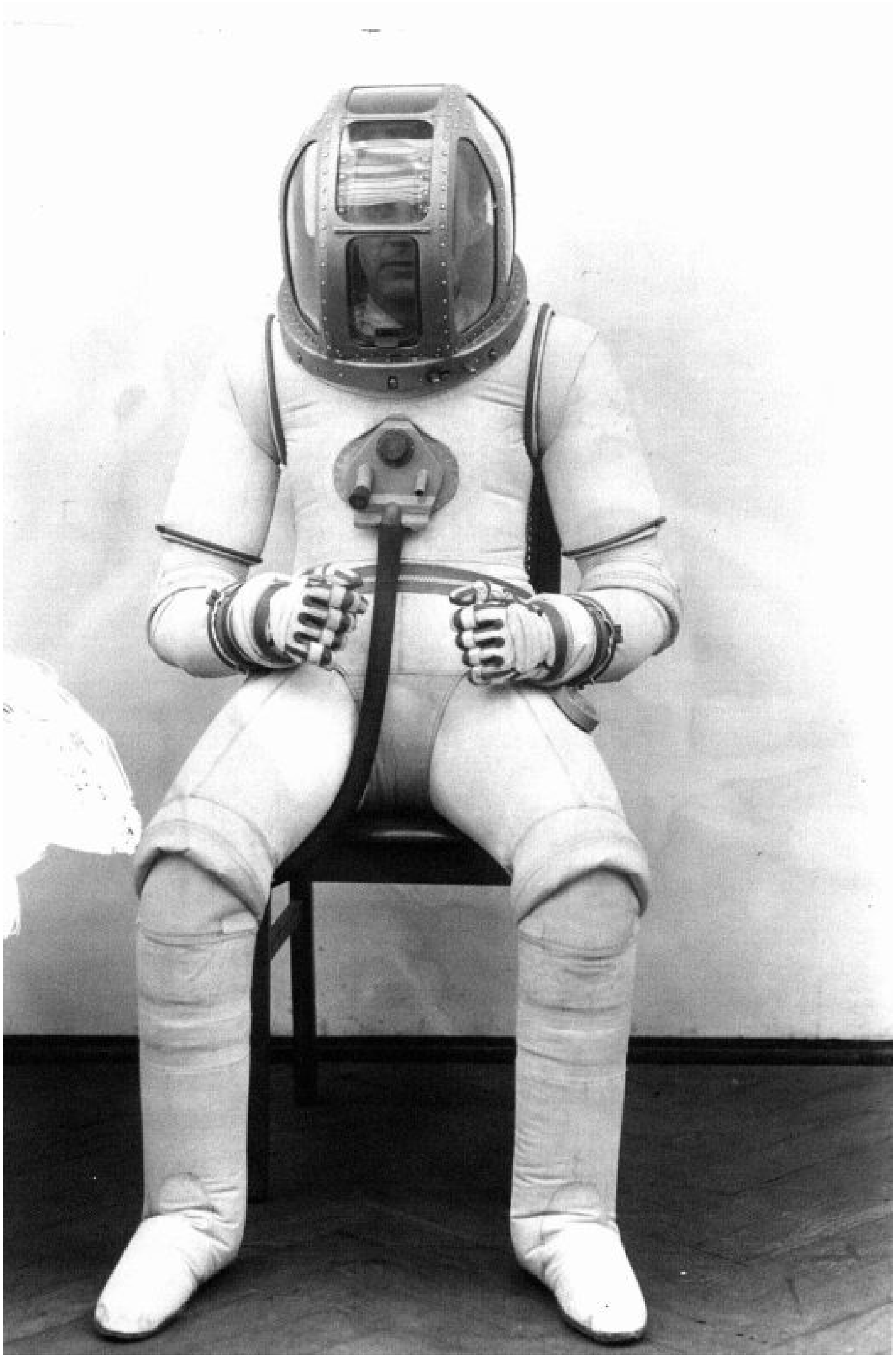


Figure 5.20: Dräger pressure-suit “Leichter Druckanzug, Modell 229” from 1944. Reproduced by permission from the Bundesarchiv.

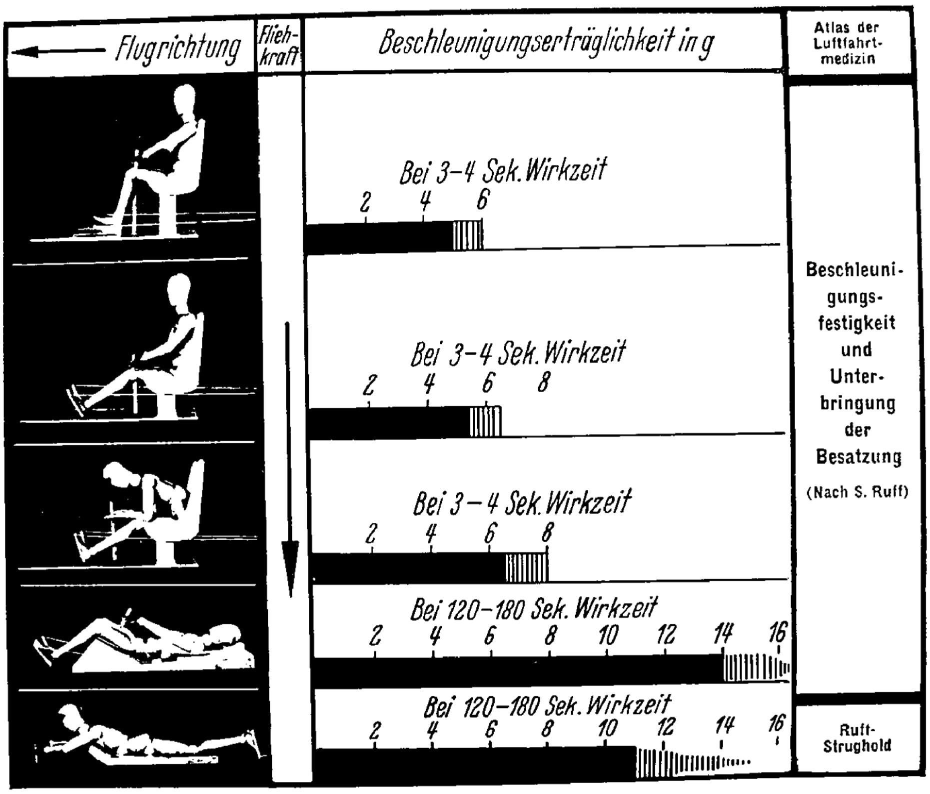


Figure 5.21: The tolerance toward G-Forces in varying postures, according to Ruff and Strughold (1942).

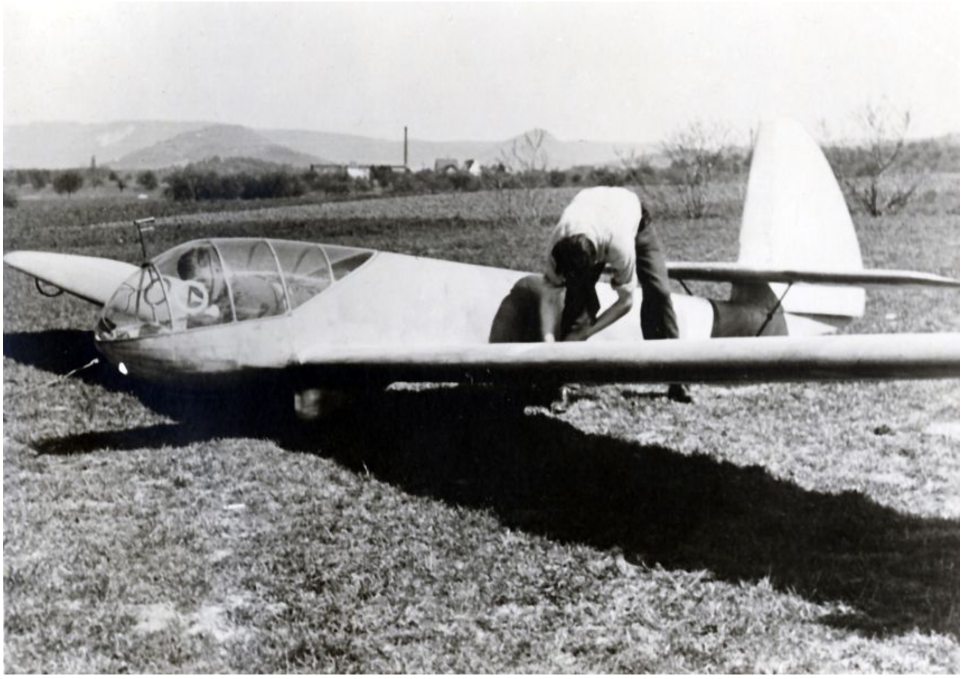


Figure 5.22: The FS17 by the FFG Stuttgart. Courtesy DLR.

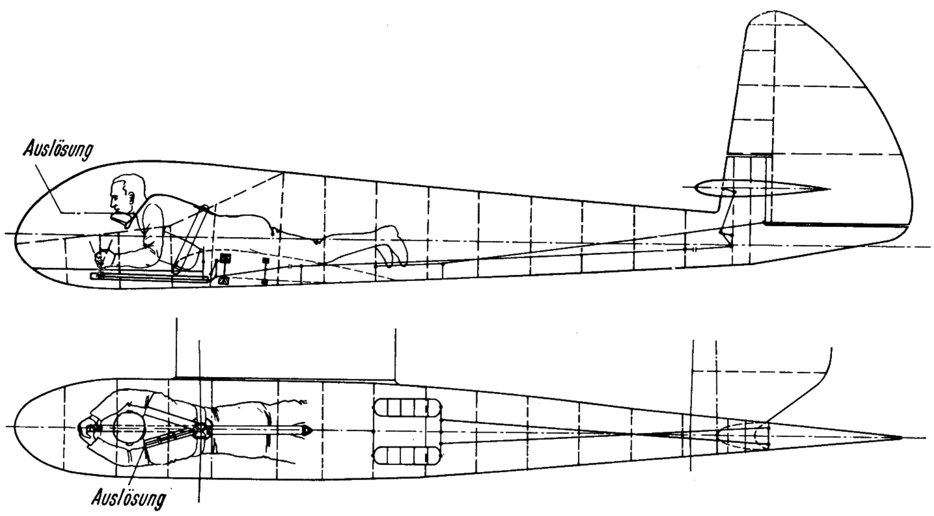


Figure 5.23: Sketch of a pilot in a lying position. Taken from Ruff (1939).

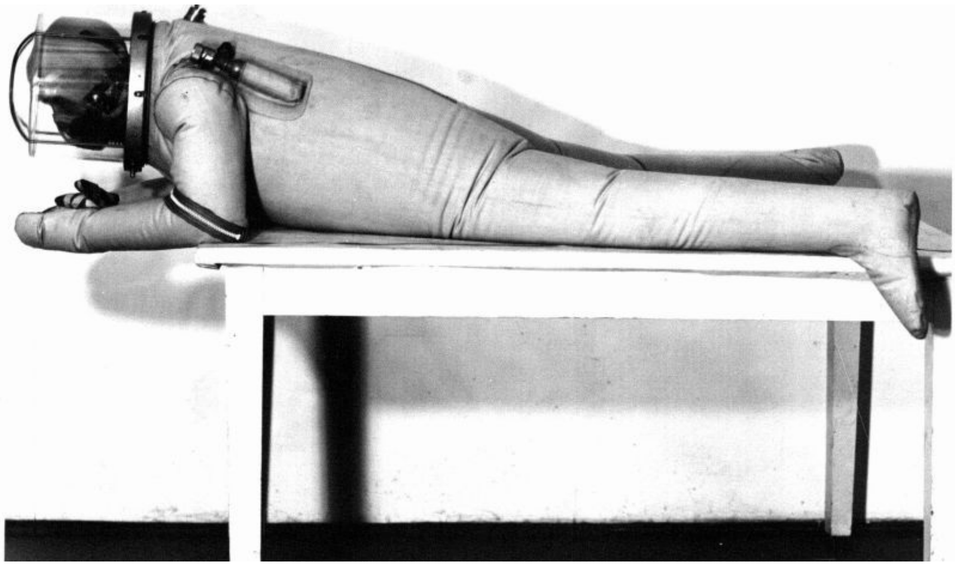


Figure 5.24: Dräger's "Rettungsanzug No. 230" from 1944. Reproduced by permission from the Bundesarchiv.

Figure 5.25: Dräger Recompression Suit from 1915, illustration from Umschau (1918).

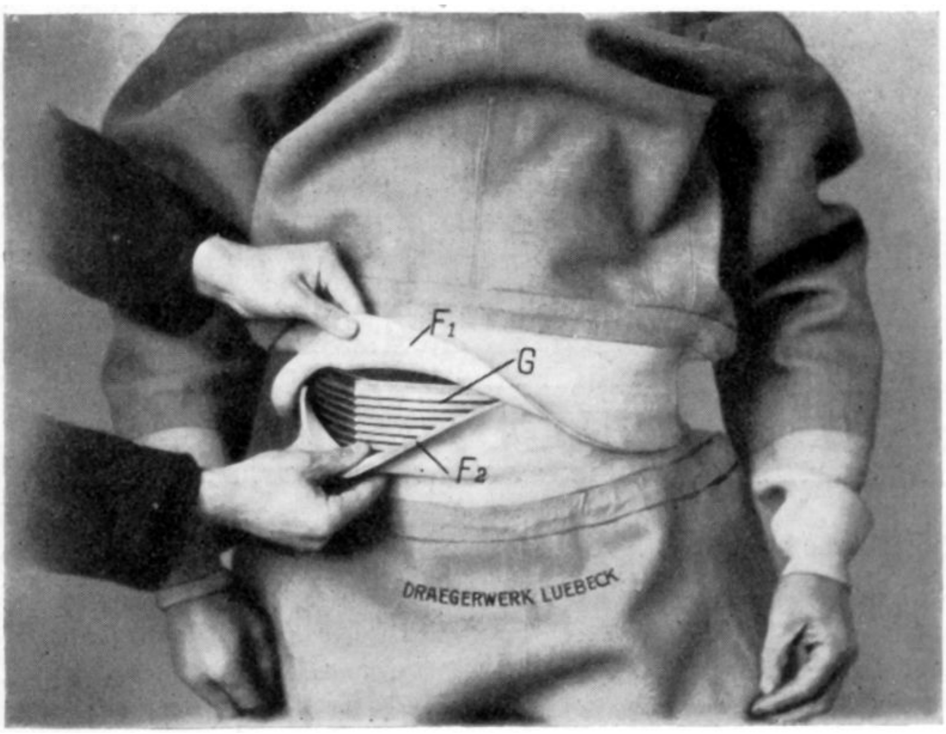


Figure 5.26: Dräger waist seal for diving suits, taken from *Drägerhefte*, 1914.

Figure 5.27: Photo (outlines augmented by Botho von Römer) of Mario Pezzi in his pressure suit in 1937. Reproduced by permission from the Deutsches Museum.

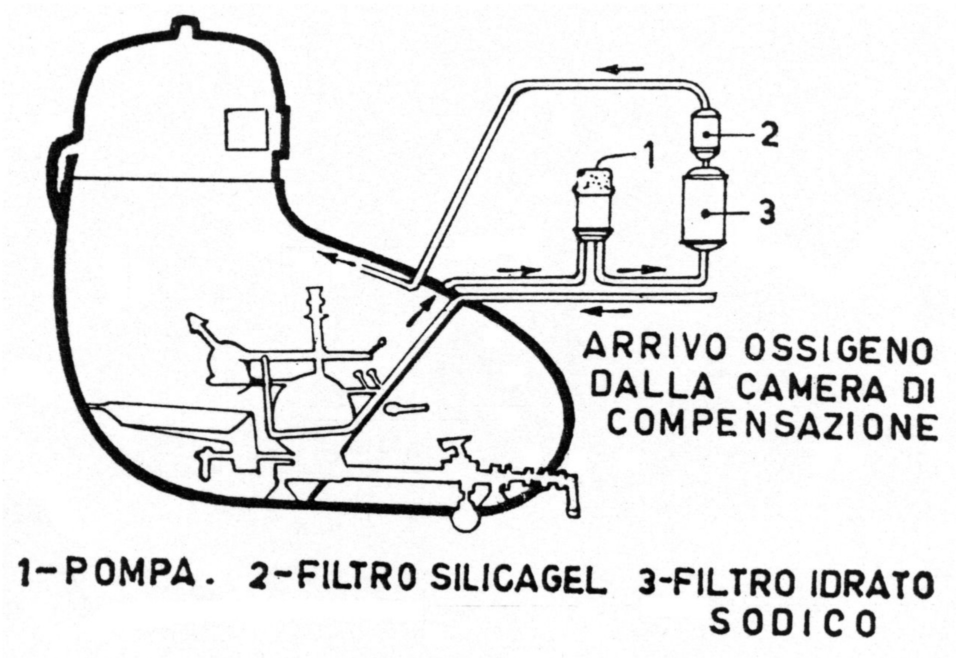


Figure 5.28: Drawing of the Italian pressure cabin, from Lomonaco (1967).

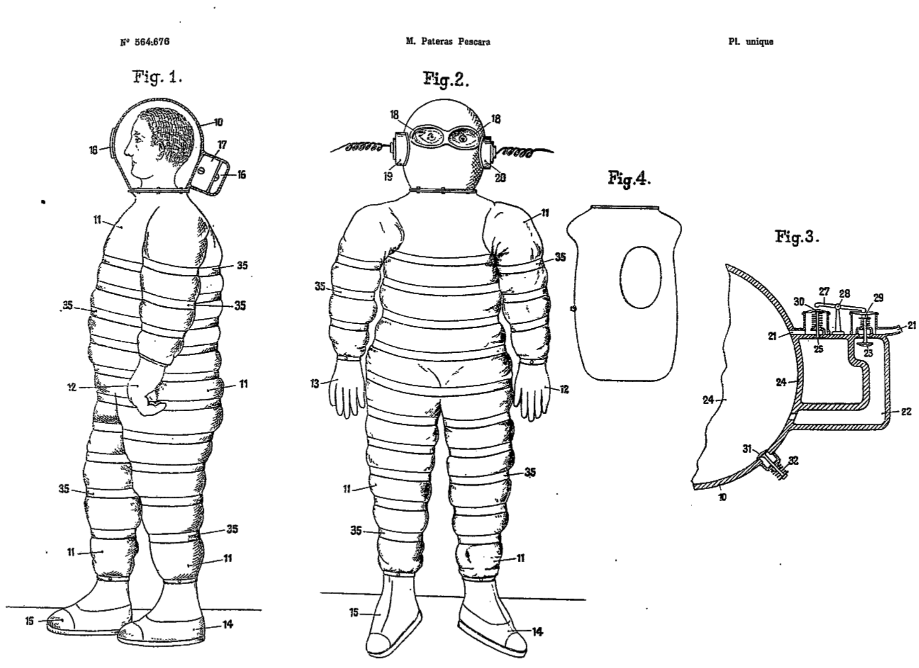
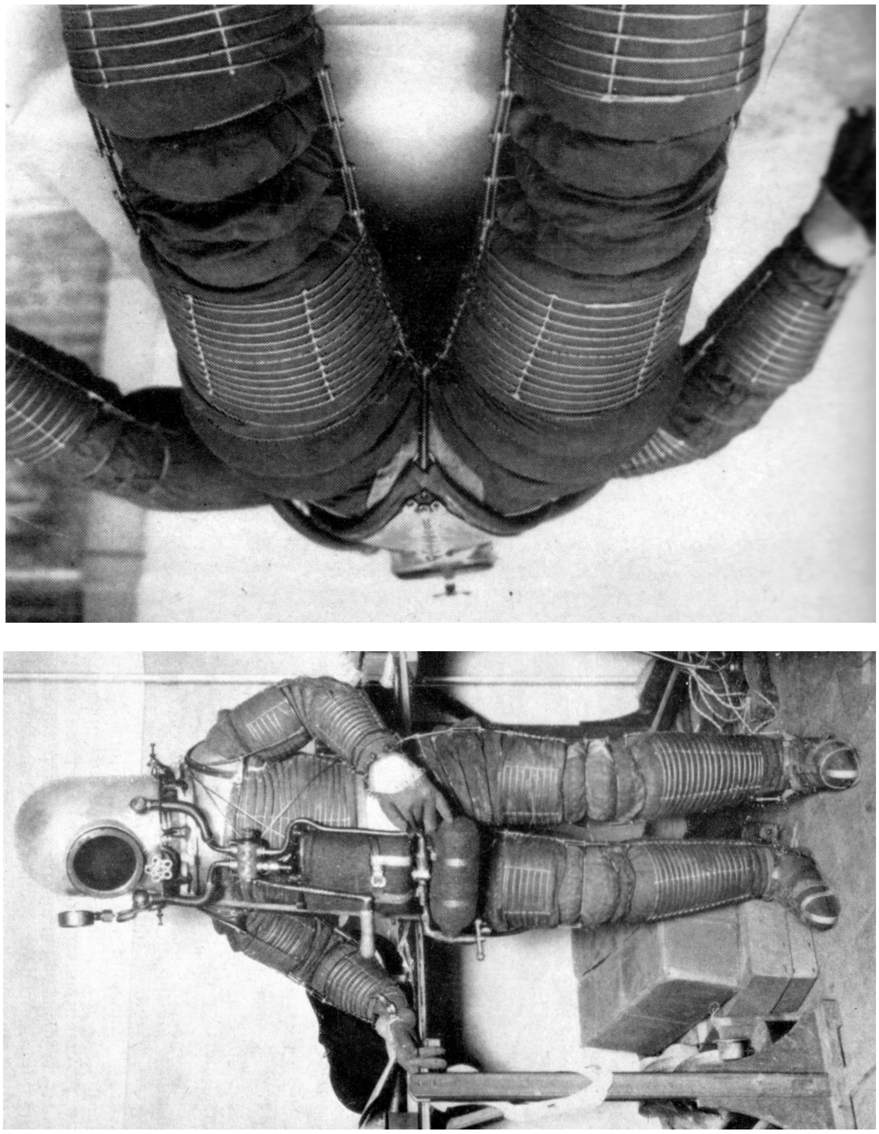


Figure 5.29: Drawings from Pescara's patent (Pateras-Pescara, 1923). Courtesy DPMA.



(a) (b)

Figure 5.30: Pressure suit by Emilio Herrera, Spain, 1936. Photos from Herrera (1965).

Herrera remained loyal to the Republican government, becoming the Technical Chief of the Republican Air Force in 1936 and being promoted to the rank of General in 1938. In November the same year he traveled to Chile on behalf of the Republican government. Upon his return the next year the Republican government had fled to Paris. Herrera remained with it, in exile for the rest of his life, whilst hoping to return to a liberated Spain. He died in Geneva, Switzerland (where he had fled to upon the German occupation of France in 1940) in 1967.[123]

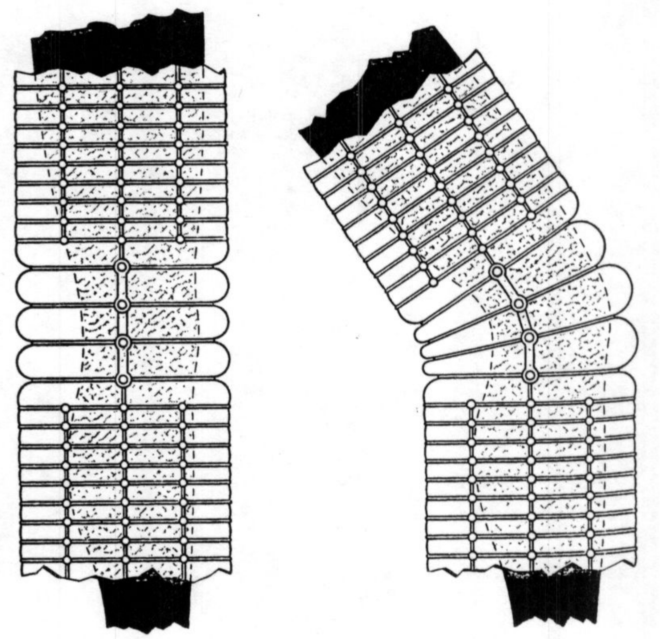


Figure 5.31: Drawing of the knee joint of Herrera's suit. Taken from Herrera (1965).

In 1936 the *Spanish Academy of Sciences* (SAoS), of which Herrera was a member, decided to support an ascension to the stratosphere with a balloon. Following the initiative of Emilio Herrera, the SAoS patronized the manufacture of a pressure suit. The ascent was destined to take place in October 1936, but, as mentioned above, the Spanish Civil War interfered with this intention (Herrera, 1965, 44).

Herrera faced the same kind of trouble that other manufacturers like Klanke, Dräger, etc. did. A need to restrain overt expansion caused by a higher internal pressure compared to the outer pressure, meant a material or construction method had to be found to make the suit both rigid and flexible at the same time. Testing his design at the Aeronautical Establishments at

[123] `http://eherrera.aero.upm.es/`, last access: Feb 28, 2007.

Guadalajara and Cuatro Vientos, Herrera came up with a design that both looked promising and strange at the same time.

He correctly identified (like others) the knee, elbow and shoulder joints as the critical spots of a feasible pressure suit. To restrain the expansion of the limbs, he enclosed the suit in wire compartments (see figure 5.30 (b)). To solve the joint issue, he proposed a form of corrugated tube that resembles the "shape of an accordion".[124] This should allow for greater flexibility of the joint, forming a "series of lobes" to impose an "unexpandable belt" with the help of small steel pivotal joints (see figure 5.31).

The fabric of the pressure suit consisted of three layers: 1) a woolen suit to cover the whole body, 2) an india-rubber suit over that to hermetically seal the body, and 3) a suit made of tear-proof cloth as outer layer, that supposedly resists an expansion force of three metric tons per meter. Also, the suit is electrically heatable (Herrera, 1965, 45).

The helmet was made of polished aluminum and connected to a Dräger closed circuit rebreather. The oxygen flow could be controlled via a small gear in the front of the helmet. The possibility of communication was also taken care of by incorporating a telephone into the helmet, just as was commonly found in diving helmets at the start of the 20^{th} century.

According to Herrera, the suit was tested twice in a pressure chamber. The first test ran over one hour and 25 minutes, the second over two hours and eleven minutes. During both tests the pressure in the chamber was lowered to 66mm Hg and the temperature lowered to -75°C (by frozen carbon-dioxide). The internal temperature of the suit was at 31°C and free movement of the limbs was possible (Herrera, 1965, 46). Since Herrera feared that the radiation in the stratosphere might cause thermal problems to the wearer, a cape with a reflective surface was designed.

The suit of Herrera had some very interesting and promising features. Especially the "accordion" joints resemble design principles of later suits, like Russel's "tomato worm" principle (see below). Unfortunately, there are no accounts on the Herrera-suit available, other than some short articles, like Herrera (1965). It is not really clear what happened to the suit after the Spanish Civil War broke out. Since Herrera was on leave in Chile, and could not enter Spain when he returned, it is likely that the suit remained with the Aeronautical Establishment in Gualdalajara. Whether is was immediately destroyed or explored by the Spanish Facists, or others, is not visible from the given sources.

5.2.6 Suits from other countries

Obviously the development did not stop at the gates of the technologically prowess countries, the Soviet Union (SU) and the USA. However, the devel-

[124] Herrera (1965, 44), translation mine.

opment of pressure suits will be only summarized. Since they both became prominent competitors in both jet aircrafts and space travel (incl. EVA), a good deal of literature is available, e.g. Mallan (1971), Kozloski (1994) or Abramov et al. (2003). Delving into SU and USA pressure suit design in the 1930s is therefore not necessary, as sufficient literature is available. The general design lines encountered in these nations, on the other hand, exposes the pervasiveness of the technical concept of pressure suits in the 1930s and 1940s.

USA

In 1934 aviation idol Wiley Post from the USA wanted to speed up his vintage customized Lockheed Vega for a race from England to Australia (see chapter 4). He concluded that his airplane was too old and slow to stand any viable chance, and thus conceived the idea to travel in the stratosphere to utilize the strong tail-winds there. Actually, he would have preferred to install a pressure cabin into *Winnie Mae*, his airplane. But its plywood shell did not allow for such action to be taken (Mohler and Johnson, 1971, 71). Also, the weight of such a cabin would be prohibitive, since his airplane could hardly get high enough with such extra ballast, as Post noted in an article by him (Post, 1934, 492).

Post approached the Los Angeles department of the B.F. Goodrich company, a manufacturer of rubber products, in April 1934. The engineer for his first prototype suit was William Bucks, and he made the pressure suit from a double-ply rubberized parachute cloth, and the helmet from aluminum with a double plexiglass visor. The suit, however, was ripped apart during the first test in the decompression chamber.[125] The suit was principally designed to have an internal pressure of 0.83bar, at the designated height of 8222m, it would thus have to withstand a pressure difference of 0.48265bar, the partial oxygen pressure would be equivalent to 1675m (Mohler, 1998, 803).

A second design was devised by Goodrich engineer Russel Colley, who later designed the *Tomato Worm* suit (see below) and the space suit of the NASA *Mercury* program. Post had turned to the department of B.F. Goodrich at Akron, Ohio, having being disappointed with the support given to him in Los Angeles, and being closer to his home. In June 1934 Colley designed the suit as a two-piece version, with a belt at the belly and metal rings at knees and elbows to allow for free movement of the limbs. This approach proved to be much more worthwhile. However, during testing Post became entrapped inside the suit and had to be freed from it by knife. Rumors were that Post had gained weight during the design process and the suit did not fit anymore when tested. Anyway, the second suit was also history and a new one had to be manufactured.[126]

[125]Cf. Wilson (1985, 51) and Mohler (1998, 803).
[126]Cf. Wilson (1985, 51) and Mohler and Johnson (1971, 77).

Thus, Colley came up with a third version in August of 1934, not simply by copying the second one, but also with improvements that were regarded as necessary. The helmet now looked much more like a diving helmet, and the visor was screw-mounted on the front, just like the standard diving helmet at that time.[127] The suit, on the other hand, was made of two layers: the inner layer was a "rubber bag" to make the suit air-tight; the outer layer was made from three-ply cloth to restrict the expansion of the suit when set under pressure (see figure 5.32).[128]

As Mohler and Johnson (1971, 84) report, this third suit was tested on August 27, 1934 for the first time. Post left the visor open until a height of 5481m, then he screwed tight the glass window and inflated the suit "in less than 30 seconds" to a maximum height of 6395m. The time of the flight amounted to 27min and Post reported trouble with the oxygen system, as Mohler and Johnson (1971) referred to in a report from Wright Field Airbase, Dayton, OH.

The decompression chamber once installed at Minneola by Yandell Henderson (see chapter 3) was brought to the medical facility in Ohio, when the whole laboratory was transferred there from Long Island. The oxygen system used was the standard UAAC "liquid oxygen container and converter" (Mohler, 1998, 804).

According to Wilson (1985, 52), the suit was tested and used successfully on ten occasions, i.e. flights, but "did not break the altitude record". This was allegedly due to the malfunction of the barographs on board. Trouble with the oxygen system persisted in the tests. Furthermore, the helmet had to be tied down, otherwise it would lift above the pilot's head (Mohler, 1998, 804).

Post's pressure suit (the third version) was the first pressure suit used in actual flight. The Haldane-Davis-Suit was produced in October 1933, but it was never used outside the decompression chamber until Swain's record flight in October 1936. The first Soviet suits were produced even as early as 1931, but also only used in pressure chambers (see below). Post's suit was produced and flown in August 1934, and therefore was the first suit ever used in real-world flights. It is more interesting, though, that it gained a broad public recognition as such, and furthered the debate on pressure suits world-wide. The RAF, who got their hands on the Haldane-Davis-Suit in Winter 1933, did not want to disclose any information on their height record attempt prematurely, and thus restricted all publicity.[129] Hence Haldane and Davis never gave too many details of their suit in their press interviews, and no photos. Their achievement was thus not received so enthusiastically as Post's feat.

[127]Post (1934, 493) compared the suit to a diver's suit.

[128]Wilson (1985, 51), Mohler (1998, 804), Mohler and Johnson (1971, 81). For pictures of the first two suits, see Benford (1979).

[129]Cf. letter from Puit to Tinson, Sept. 10, 1936, RAeS, BC.

In the USA, furthermore, Russel Colley and B.F. Goodrich remained in pole position for a time when it came to pressure suit design, despite some serious competition from the David Clark Company. In the 1940s Colley developed the *Tomato Worm* suit: the limbs of the suit had a ring-structure like that of worms, and could therefore easily bend without hindering movement (see figure 5.33 and 5.36). Actually, Herrera from Spain had a similar idea some years before (see above), but it does not seem Herrera made much of it public before the war, so it is not likely Colley had the idea from him.[130]

Ideas for pressure suits came from a number of people during World War II. The discussion on high altitude warplanes stimulated the development of protective measures. Beall (1940), for example filed a patent on a suit in 1940 (see figure 5.34).

John D. Akerman (1897–1972), professor for aeronautical engineering at the University of Minnesota, also filed a patent on a pressure suit during the war (see figure 5.35; Clark, 1989a, 624). His department had investigated high-altitude flight in the years before (see Akerman's statement in section 5.1). Akerman's design looks a bit like a Dräger suit from the same era, but since Dräger's suits were not disclosed before the end of the war, it is rather a proof for common thinking than intellectual theft (cf. Akerman, 1943).

What was peculiar with Akerman's suit design was its feature of a *two-gas* solution. Most suits delivered the pressurized oxygen into the entire suit, from which the pilot breathed it. Akerman (1943), however, introduced a breathing mask (Boothby type, see below) in the helmet, from which the wearer breathed pure, pressurized oxygen, whereas the suit was inflated with an inert gas. Through this, oxygen could be saved for the breathing process. Furthermore, if the suit broke, the wearer would still be connected to the oxygen mask and the fatal condition would set in much later, giving the wearer more time to take protective measures.

The suit was made of two layers, interior and exterior, and the helmet was devised as a double-walled plexiglas dome to allow for better vision. In case of emergency, a small oxygen bottle could be attached to the breathing system to allow a parachute drop exit for the pilot. Akerman (1943) states that he tested the suit in a decompression chamber to "altitudes exceeding 50,000ft".[131] Later tests also exhibited the same shortcoming that so many of the other pressure suits around the world struggled with: when put under pressure the arms became inflexible and control of airplane instruments was severely hampered.[132]

[130] See Colley (1942) for the patent. Also, in a Russian book on pressure suits from c. 1939 I found in the BA-MA (see below), there is a photo of Herrera's suit. So news seem to have been spread.

[131] Akerman (1943, 11), equals 15225m.

[132] Cf. Kozloski (1994, 20), which also gives a photograph of Akerman's suit on the same page.

Pressure suits for war purposes were not on the agenda of the Americans anyway. Dave Clark, founder of the company bearing his name, developed so-called "Anti-G suits", suits against the effects of high acceleration, from 1941 onwards. James P. Henry from the University of California then conceived the idea of a *partial pressure suit* (PPS; Clark, 1989a, 624) something the Germans had also thought of during that time (see above).

Dave Clark developed his Anti-G suits at the Mayo Clinic, where Randolph Lovelace was director and Walter Boothby was also around. Together with Dr. Bulbulian and Ohio Chemical, they were "developing protection for pilots at high altitudes". Clark recalled that "a few weeks later, Dr. Henry asked me to work with him on developing a new type of altitude suit". However, Clark declined the offer, since he was busy with his work on Anti-G suits already. "Late in 1945 or early 1946", Henry presented the "compact altitude suit" to the US Air Force at the University of California, giving a demo in the decompression chamber. The suit operated to a maximum height of 27405m, and the demo was made at an average height of 19793m for 30min. The breathing system used pure oxygen at a constant pressure (0.2bar; Clark, 1989a, 624).

All in all, 29 experimental suits (most of them were improved models of previous designs) were fabricated in World War II by American researchers and engineers, involving such companies as B.F. Goodrich Co., Goodyear and Bell Aircraft Co. (Kozloski, 1994, 16). From Clark's quasi-autobiographical sketch (cf. Clark, 1989a,b), and Kozloski (1994) it is evident that the Americans stopped the full pressure suit programme in 1943 because of disappointing tests. They had no operational partial pressure suit before 1946, well after the end of the Second World War. Even then the PPS were emergency suits with small high-pressure bottles, which lasted for only 3min (Clark, 1989b, 727).

One remarkable anecdote on the discussion of pressure suits in the USA is worth noting here. In 1941 aviation physiologist John R. Poppen, then Captain of the Medical Corps of the US Navy, published a paper, outlining the seven most burning issues in aviation medicine that would require the attention of physiologists in the years to come, "oxygen supply" was ranked on number three (Poppen, 1941).

In July 1941 movie company Warner Brothers released the motion picture *Dive Bomber*, a biopic starring Hollywood celebrities Fred McMurray as test pilot and Errol Flynn as flight surgeon, which dealt with all of these seven topics. Apparently Poppen (1941) was used as a blueprint for the script of the movie.[133] The movie was one of the most successful pictures at the box office in that year (Shindler, 1979, 27).

[133] Cf. with David Kirby's presentation at a conference in Manchester (UK) on December 5, 2005. A short report on the conference can be found in West (2006). For information on the movie, see its entry on the IMDb, `www.imdb.com`, last access: Feb 10, 2006, and its entry in Morella et al. (1973).

Poppen (1941) discussed pressure suits as the preferable alternative over pressure cabins, the latter he considered too vulnerable for combat airplanes. The movie exactly reflects that in one scene, when a General of the US Naval Air Force states that cabins could be pierced by bullets and doom the pilot. Errol Flynn, as Lt. Douglas S. Lee, together with Fred McMurray, as Lt. Cmdr. Joe Black, then jointly come to the idea of a suit "based on the principle of a diving suit" as the solution. The suit would also be as flexible as a regular diving suit, since the General said "you can't put a pilot in armor".[134] The movie, above all, signifies the American effort to catch up with the rest of the world in aviation. The US Navy not only provided the USS Enterprise aircraft carrier for outdoor shots and some of the brand-new Douglas dive bombers,[135] it also sponsored the extra-cost of shooting the movie in Technicolor, an expensive and therefore rarely employed technique in those days. The US Navy was keen for the US public to familiarize itself with the markings of its airplanes, to distinguish them from foreign (i.e. enemy) ones.[136] As West (2006) remarks:

> "This was an early example showing work done on the physiological problems of flight with an eye to propaganda value just prior to the entry of the United States into World War II."

This "propaganda value", however, was not desired by part of the political establishment. While US president Roosevelt thanked the film industry in early 1941 for their "splendid cooperation with all who are directing the expansion of our defense forces" and encouraged further efforts (quoted from Koppes and Black, 1987, 36), the US Senate filed a resolution (no. 152) to create a sub-committee to prevent "any propaganda disseminated by motion pictures ... to influence sentiment in the direction of participation by the United States in the ... European War" (quoted from Shindler, 1979, 31). Warner Brothers in particular was condemned to have produced several movies ("Dive Bomber" among them) that fell within that category.

However, the film shows again the *diving suit* analogy as *catachresis* for pressure suits. The reference to *diving suits* is made several times in the movie, all in an educative style, i.e. in a way to inform the layman of the nature of the apparatus shown.

Soviet Union

Abramov et al. (2003) is most likely the best and most complete reference when it comes to Soviet pressure suits. It devotes an entire chapter to the

[134] Unfortunately the license fees for using stills imposed by Warner Bros. were too high, therefore no picture of the suit in the film can be shown here.

[135] They also provided some of those bombers to display them before the theaters when the movie was shown, together with recruitment booths.

[136] Cf. Kirby's presentation.

early pressure suits in the 1930s, including a good deal of photographs of the suits and the testing facilities.

Furthermore, there is a manuscript with the translation of a Soviet book on stratospheric flying in the archives, supposedly from 1939.[137] It gives an excellent account on the stance of Soviet aviation medicine toward pressure suits and cabins in the 1930s. These three sources will suffice to give a synopsis of the development of pressure suits in the SU.

The development of pressure suits in the 1930s and into the Second World War in the USSR was surprisingly advanced and sophisticated. The SU never managed to construct engines competitive enough to attack height records, but it is interesting to note that suit development was instigated upon the achievement of balloon height records in the early 1930s.

As frequently found in other countries at this time, pressure suit and cabin development was initiated on the grounds of competing in height records. After Piccard's ascent in 1931, SU officials at the War Ministry and scientists geared themselves towards topping his height by constructing the balloon "USSR".[138] The gondola was made of riveted aluminum sheets (Crouch, 2003, 279).

In 1934 another balloon, the "Osaviakhim-I" made its maiden flight on January 10th. It was supposed to break the height record and achieve over 21km of altitude (Crouch, 2003, 279). The flight, however, ended in disaster. The gondola broke loose from its suspension and fell down to earth. Even though the crew members were all equipped with parachutes, they were unable to open the hatch in time, since it was tightened with 24 bolts. All of the crew died in the crash (Abramov et al., 2003, 5).

This furthered a debate among Soviet scientists, whether personal equipment in the form of pressure suits should be fashioned for balloon crews in open gondolas, instead of entrapping them in a sealed gondola. This appeared as the mirrored discussion of the one that took place in the US a few years earlier after Gray had died of hypoxia in an open basket balloon (see above).

Development of pressure suits had already been underway in the SU with the suit *Ch-1* introduced in 1931 by engineer E. E. Chertovsky in Leningrad. However, lacking integral joints it suffered the same fate as the suit by Klanke or the early Dräger suits. When set under pressure the expansion and inflexibility rendered usage futile (Abramov et al., 2003, 5).

Chertovsky then (1932–1934) manufactured the *Ch-2* with joints which provided for more flexibility. Between 1935–1937 the *Ch-3* was constructed with the help of physiologists Spassky and Apollonov, (from the Pavlov Red Army Institute of Aviation Medicine, Gippenreiter and West (1996) and "had all the basic elements of future full pressure suits" (Abramov et al., 2003,

[137] BA-MA, RL3/1898.

[138] See figure 5.5. Also chapter 4.

6). It was made of "rubberized fabric" and had an internal pressure between 0.1 and 0.15 bar. It was tested in a chamber at a pressure equivalent of 12km altitude. In 1938 the *Ch-4*, in 1939 the *Ch-5* and in 1940 the *Ch-6* and the *Ch-7* were produced with further improvements in the design (Abramov et al., 2003, 6).

The *Central Institute of Aerohydrodynamics* also started the development of pressure suits in 1936. Again the most effort was put in to constructing flexible joints, and mock-up models were used to systematically test various fabrics. The first suit, the *SK-TsAI-1* was completed in 1937. It was made of two parts, trousers and torso, and connected with a waist belt, like the German and the British suits.[139] Whether the Soviet engineers copied that approach from these is unknown. Dräger, however, had introduced this sealable waist interface years before for diving suits (see figure 5.26).

Between 1937 and 1940, eight pressure suits from the *SK-TsAI* series were produced and tested. They were constructed to meet the specification of 0.3bar pressure difference and the option to wear a electrically heated suit underneath the pressure suit. Development was halted upon the outbreak of the war (Abramov et al., 2003, 8–9).

What is remarkable in regard to the Soviet efforts to produce a pressure suit is the broad approach they took, in terms of organizations involved. Involved were the *Aviation Medicine Department of the Civil Air Institute of Scientific Research* in Leningrad, the *Kirilov Military Medical Academy* in Leningrad, and the *All Union Institute of Experimental Medicine* in Moscow. Furthermore, the *Pavlov Red Army Institute of Aviation Medicine* in Moscow developed life support equipment and authored many specifications for such devices, upon basic research on physiological thresholds.[140] All of the suits produced in the 1930s were tested almost exclusively in pressure chambers and only occasionally in actual flight. Development of the suits, as outlined above, were furthered by the high altitude balloon expeditions in the early 1930s. When these ambitions by the Soviets cooled down, the pressure on the development process diminished. Even more so with the involvement of the SU in the Second World War. The programme came to a near complete

[139] Abramov et al. (2003, 8). Shayler (1990, 418) alleges that the Soviets were not aware of the German development: "Pressure suit development in Germany is not mentioned by the Soviets in their literature until well after WWII, despite German research into the subject since the early 1930s." This is a bit inaccurate. One might be tempted to think that a) the Germans undertook fully fledged research efforts, which they b) published openly and widely – which they didn't. Besides Klanke's suit and the one from Dräger in 1936, no suits were produced in Germany in the 1930s. Dräger's suits (that from 1936 and those from the 1940s) were never published before the end of WWII, only Klanke's suit being published in popular magazines (see above) – as Klanke's design was surely no model for any serious engineer. So there was not much the Soviets (or any other nation) could appropriate before investigating teams at the end of WWII found some remnants of the Dräger pressure suits.

[140] Shayler (1990, 418). See also BA-MA, RL3/1898.

halt, indicating that the Soviet military strategy did not have pressure suits as military technology on their minds (Shayler, 1990, 481).

On the other hand, the design and manufacture of pressure suits seemed to be a top priority in times of peace, as can be seen from the systematic approach with which the development of such suits was tackled. Not only were the prototypes systematically tested, evaluated and continually improved, also the theoretical work was taken seriously. As the book on stratospheric flying evinced, it was tried to compile state-of-the-art medical knowledge in regard to the subject.[141]

The book mentioned the work and results of Jongbloed (1929), Bert (1878), Schubert (1935), some Soviet physiologists (Dijbovsky, Appolonov, Mirojubov) , Pettenkofer, and (as already mentioned) the suits of Garsaux-Rosenstiel, Haldane-Davis, Herrera and Pezzi. What is remarkable, though, is that neither German nor American works are cited. I.e., Bauer (1926), Ruff and Strughold (1939) and Schnell (1935) are not mentioned, to name but a few. This is even more surprising, since a CIOS report clearly states (Andrews, 1945, 5):

> "Russian visitors to the aviation medical laboratories were frequent and the German workers were instructed to cooperate completely and to show their work in all details. These Russians were disliked and the German personnel made their efforts at cooperation more apparent than real."

Even though the Soviets might have been "disliked", they should have been at least able to gather some of the latest literature, something that actually doesn't require a visit to a foreign lab to achieve. Not even such standard books like those of Haldane and Priestly (1935) or Barcroft (1925) are referred to when it comes to the respiratory values. Rather than these works, the authors refer to Pettenkofer to measure the carbon dioxide production in human respiration, a work that at this time was already c. 70 years old.

So, it is not the expertise in the field, but the effort to gain it, that makes the book remarkable. It attempted to compile all the medical knowledge to define the thresholds for ascents into high altitude, but it apparently fails to include the most important contemporary works. Whether this was due to a general lack of access to these sources, or simply a communication problem between different institutes or departments, is hard to judge. Considering the general setup of the development efforts in regard to pressure suits in the SU in the 1930s, the latter appears plausible. The book – for which no author is given – displays a good deal of dedication to the subject and a pronounced competitiveness in terms of resources, personnel and knowledge. The institutions involved, as outlined above, surely had the capacity to venture into the medical issues of stratospheric flying.

[141]BA-MA, RL3/1898.

Notwithstanding this, the book does not hesitate to define a number of parameters for engineers and physiologists alike. It specifies that an internal partial pressure of oxygen (either in a pressure cabin or a suit) should not fall below 125mm Hg, an equivalent of 2000m altitude.[142] When using normal air, the pressure inside a chamber must therefore be between 0.8 and 1atm, to maintain an oxygen pressure of 125–160mm Hg. Also, it is correctly assessed that the minimization of the pressure difference of internal and external pressure is desirable, in terms of keeping suits flexible and technical requirements feasible.[143]

Furthermore, it is mandated that the carbon dioxide concentration in the air in the cabin/suit shall not exceed 2%.[144] It is then calculated how much air is consumed by a person and how much carbon dioxide produced, and how much air the breathing apparatus must therefore deliver. To supply the pilot with enough fresh air, either a closed or open system could be used to replenish the air.[145]

Contrary to the abolition of pressure suit development during the war, the author supposes:[146]

> "The pressure suit can be used for test flights of high-altitude airplanes in times of peace, but its main application will be in times of war. Here the stratosphere pressure suit will be used mainly on bomber planes with large crews."

With this statement the author somehow retorts to the common notion, that pressure cabins are too vulnerable and therefore useless in aerial combat. Unlike the German aviation physiologists, who could convince the authorities to produce *emergency pressure suits* (see above), the high command of the Red Army Air Force apparently did not follow this advice.

Much closer to reality is the author's evaluation of the feasibility of pressure suits that have been produced so far:[147]

> "Therefore, the first and foremost problem that awaits a solution is the construction of flexible joints for the pressure suit, for arms, legs and the chest. This question is handled differently. Some solve it by fabricating metal joints, others by manufacturing harmonica-like structures which are then located at the natural joints of the human body. The degree of flexibility in these construction varies: from the less flexible pressure suit of Haldane and Davis to the significantly more flexible Soviet ones by the engineer Chertovsky. All in all, one must say that the problem of flexibility is intrinsically difficult, and even seemed to be insolvable for a time. Albeit the great success of engineers in this direction, current pressure suits are very far from perfect. [Photographs

[142] BA-MA, RL3/1898, 18.
[143] *ibid.*
[144] *ibid.*, 29.
[145] *ibid.*, p. 39ff.
[146] *ibid.*, p. 97. Translation mine.
[147] *ibid.*, p. 99. Translation mine.

> from the suits of Post, Garsaux/Rosenstiel, Herrera and Pezzi are then displayed. (p. 99ff.)]"

This statement illustrates that the Soviet engineers had a good overview of contemporary pressure suit development, albeit with the absence of any German products (Klanke or Dräger) in this account. However, from this book it becomes clear that the Soviets faced the same problems as everyone else, and the photographs in Abramov et al. (2003) also show that their approach to the problem was not much different to their international colleagues, despite their bragging in the above quote.

5.3 Breathing Equipment

The use of supplemental oxygen was recommended soon after Paul Bert's discovery of *hypoxia* as the primary cause of the troubles experienced on high altitudes. French balloonists Sivel, Croce-Spinelli and Tissandier wanted to break Glashier's and Coxwell's height record in 1875 and asked Bert for his advise in regard to oxygen breathing. Unfortunately, when the decision on the amount of oxygen being used was made, Bert was not around and could not prevent the fatal decision that had been made. When Bert received the letter from the balloonists in which they specified their projected oxygen supply and the flow rate, Bert immediately wrote back that these figures were completely insufficient. But the flight had already commenced, ending with the death of Sivel and Croce-Spinelli (Gibson, 1962, 89).

5.3.1 German Breathing Devices

It was, however, not merely a matter of ignoring physiological advise. Schrötter (1899) discussed that it was not due to Bert's calculations etc. that those balloonists died, but rather the crude technology employed and that the gas was breathed too late, i.e. when the symptoms of hypoxia were already severe (Schrötter, 1899, 30). The breathing gas was carried in leather bags with no dedicated mouth-pieces, but simple nozzles. As became evident in the case of the three balloonists and Bert, closer cooperation between aviators, physiologists and engineers was necessary to prevent further disasters.

One of Schrötter's remarkable properties was this kind of cooperation with these different groups (see section 3.2.2). Schrötter, and soon other physiologists, began to investigate better means of supplying aviators going to high altitude with oxygen. The first approach was to replace the crude nozzles with pipes made of glass and wrapped in leather and cloth to make breathing from the bag easier.

It was Hermann von Schrötter who first proposed steel tanks for the storage of compressed oxygen and who first came up with a design of an oxygen mask, c. 1900. He soon started to cooperate with the Dräger company to get this mask manufactured, and to try it on his own balloon ascents (see figure 5.38). Berson and Sühring had already used oxygen equipment in the 1890s during their flights (Bernhardt, 2000, 54), and the physiologist Schrötter, who had obtained a license as balloonist, was the right person to help improve this equipment.

Dräger soon included dedicated oxygen masks for aviators and balloonists in their program, and Dräger's chief engineer Hermann Stelzner devoted much of his energy to this topic.[148] Besides the oxygen masks (see below), he also proposed making use of the Dräger submarine escape apparatus, the *Tauchretter*, for aviation, particularly for waterplanes.[149]

In a chapter titled "Altitude Divers"[150] in his seminal publication, Stelzner (1931) surveys the physiological knowledge on breathing at high altitudes to define the parameters for the Dräger altitude breather.

He proposed breathing pure oxygen rather than compressed air, to make pressure regulation and the errors that might be introduced by the latter method obsolete. He furthermore suggested using the CCR principle in altitude breathers to use the oxygen most economically.

Stelzner praised the benefits of altitude breathers without hinting at the weight these devices would have (16kg according to his design), rendering it next to useless in mountaineering, where the oxygen supply would not last longer than two hours anyway. In his design the device would include four oxygen tanks (see figure 5.14), each pressurized at 120bar and having a volume of 10l. Thus the supply would be 1200l of oxygen, the constant flow being 5l/min.

[148] See e.g. Stelzner (1926), for his account on high-altitude breathers.

[149] See Stelzner (1913, 1915).

[150] German. "Höhen-Taucher". Cf. Stelzner (1931, 206–210). Stelzner had the tendency to relate all of his equipment to diving and divers. One of the chapters on breathing devices for irrespirable atmospheres, e.g. for fire fighters or mining workers, he entitled "Gas Divers".

Figure 5.32: Photo of Wiley Post (right) and the pressure suit manufactured for him by Russel Colley (middle) from B.F. Goodrich Co. in 1934. Reproduced by permission from the Deutsches Museum.

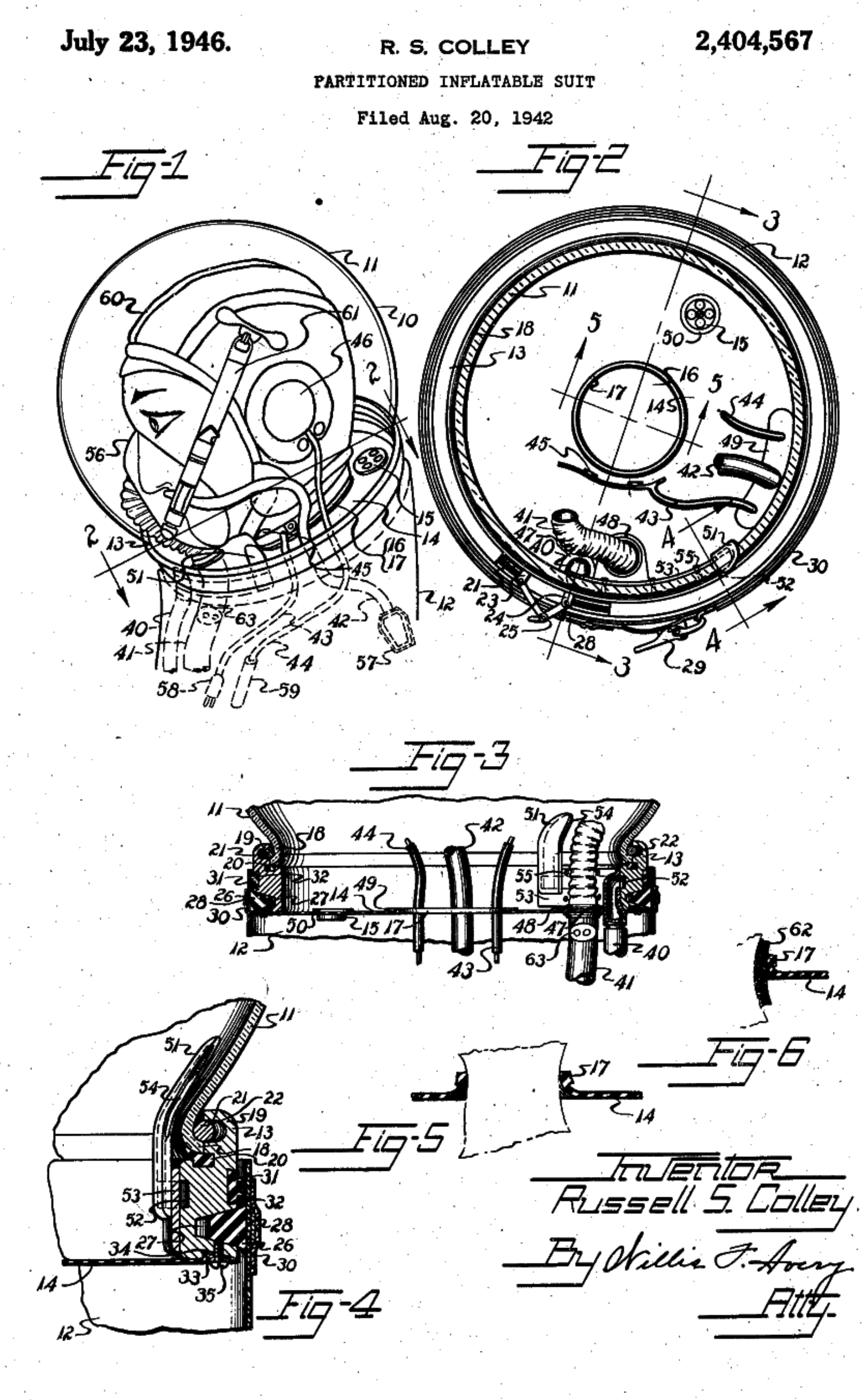


Figure 5.33: Drawing from Colley's patent (Colley, 1942). Courtesy USPTO.

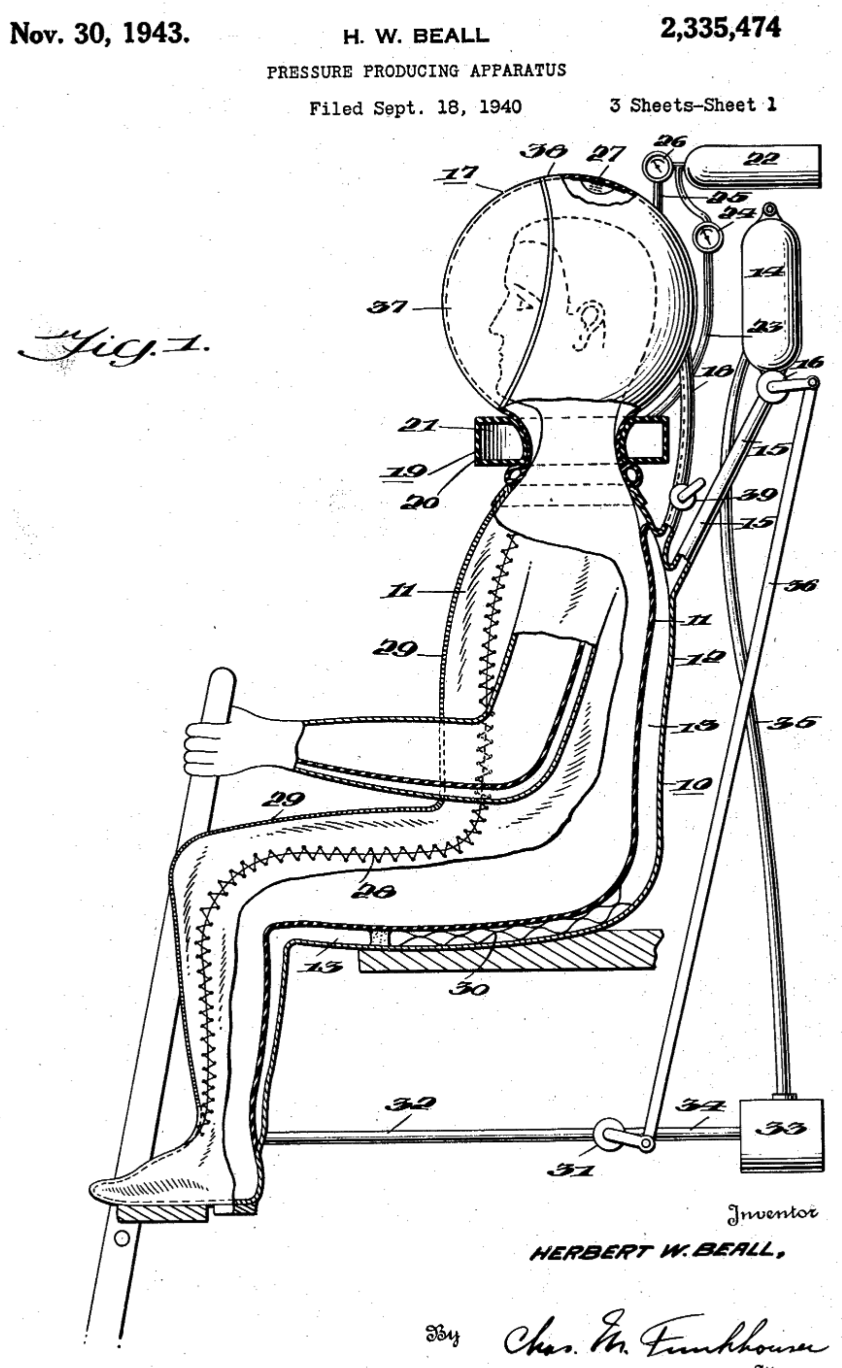


Figure 5.34: Drawing from Beall's patent (Beall, 1940). Courtesy USPTO.

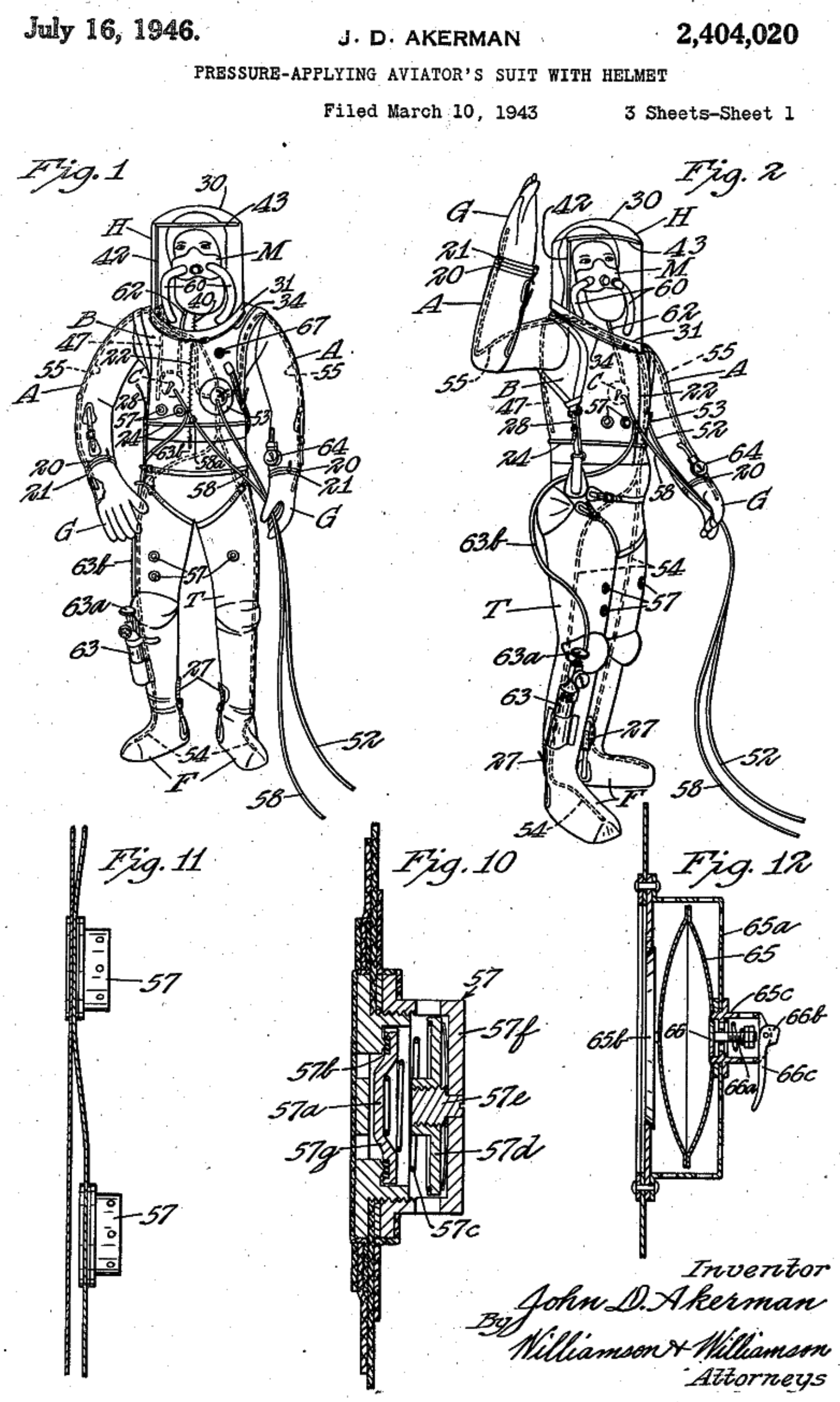
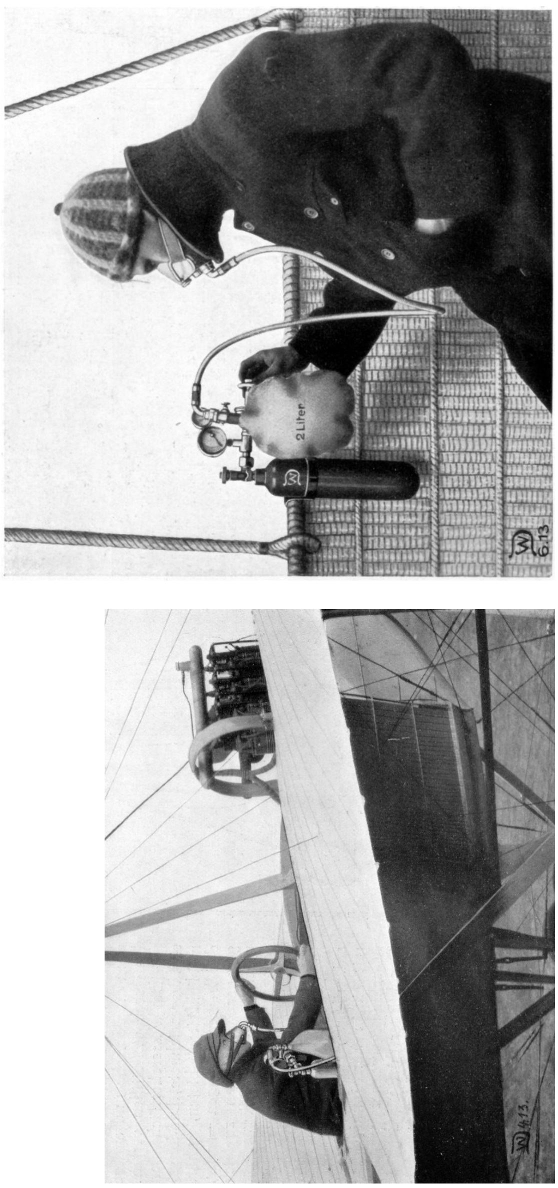


Figure 5.35: Drawing from Akerman's patent (Akerman, 1943). Courtesy USPTO.

Figure 5.36: Photo of Russel Colley's "Tomato Worm Suit" from 1950. Reproduced by permission from the Deutsches Museum.

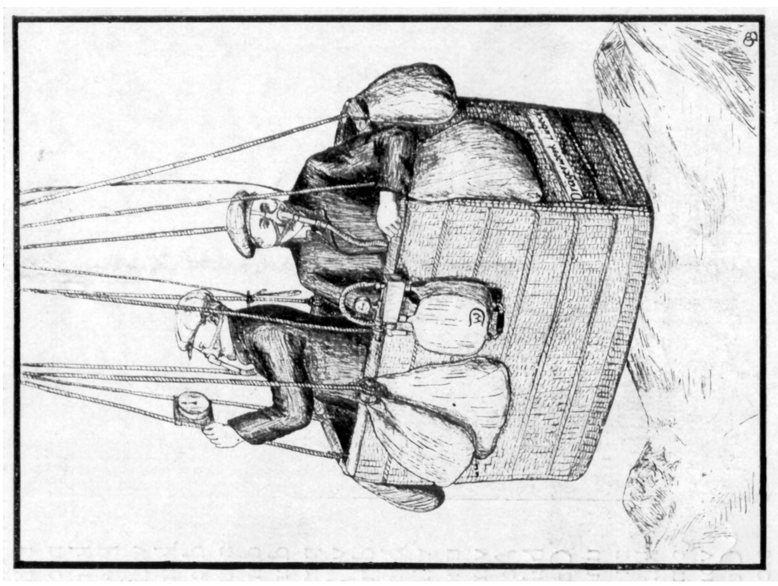
Figure 5.37: Photograph from the 1937 German Himalaya expedition, climbers using Dräger high-altitude breather to counter-act hypoxia. Reproduced by permission from the Deutsches Museum.



(a) (b)

Figure 5.38: Dräger's high-altitude breathing masks for aviators, 1913. Taken from Dräger-Hefte.

(a)



(b)

Figure 5.39: Dräger's high-altitude breathing masks for aviators, 1913. Taken from Dräger-Hefte.

Due to the physical strain of the activity, the climbers would use up 10l/min, thus the two hours time limit for when the air supply runs out. He therefore proposed not to use a constant flow system, but one with a breathing regulator (Stelzner, 1931, 209). Such a device was designed and constructed by Dräger and used throughout Germany and beyond (see figure 5.41). Neuenhofen used it for his height record in 1929 (see figure 4.1), also, Herrera used it for his pressure suit (see above).

As can be seen from figure 4.1 with Neuenhofen, the *pipe stem* mouthpiece was still popular in 1929. Even though breathing masks were on the market earlier, their design was flawed and caused many blackouts. Their designers did not take into account the *dead space*, i.e. the volume inside the mask in which CO_2 would gather and be breathed in again, a phenomenon similar to that found in diving helmets that Haldane had examined in 1907 (see section 3.2.5). Hence mask design became a major issue for aviation medicine in the 1930s. Another issue was the freezing of the moist expired air, which blocked valves and tubes (Gibson and Harrison, 1984, 39).

Therefore oxygen masks were rather unpopular and the pipe-stem system remained in service until the 1930s. The pipe-stem was regarded as flawed, actually, but the masks were considered uncomfortable and even dangerous. The chief problems with the pipe-stem system, on the other hand, was the discomfort introduced by breathing through the mouth, and also onto the pipe with the teeth which was fatiguing and in some cases severely hindered by the cold, leading some aviators to unwillingly drop the pipe due to shivering (Gibson and Harrison, 1984, 39).

The problems with the pipe-stem system led Hermann von Schrötter to conceive other methods of supplying oxygen to the aviator.[151] The problem of the unfamiliar concept of breathing through the mouth led many aviators to breathe accidently through the nose, and thus fall into hypoxia. Dräger released high-altitude breathers with nose-pieces, which were supposed to overcome this problem (see figure 5.39, b). This principle did not prove feasible, though. It turned out that aviators were more fallible to accidently breathe through the mouth when wearing the nose-mask than vice-versa. The concept was given up soon, only in the USA did it remain in some use until the end of the 1930s (see figure 5.45, a).

It was thus a great desire for aviators, physiologists and engineers to find a decent breathing mask. Part of the desire came from the need to protect the face from the extreme cold found at the altitudes that were reached in the 1920s. After scarfs and ski-masks (still with a pipe-stem system) were employed as an *ad hoc* approach to this issue (see figure 5.43), a more comfortable and safe solution was striven for. First, special face-masks (see

[151] Schrötter, for instance, devised the first oxygen masks with Stelzner, as seen in figure 5.38 and 5.39. See also Robinson (1973, 25ff.) for a short account on Schrötter's work.

figure 5.44) were devised, or the pipe-stem was simply combined with a standard gas-mask to give face protection (see figure 5.41).

After these first steps, more sophisticated approaches were taken, although engineering problems remained severe. Dräger's principle of using a standard gas-mask as a face-mask was regarded as promising, so it was sought with more intensity. In a first step, the pipe-stem was simply attached to a connector that was originally designed to hold the air-filter of the gas-mask (see figure 5.40, b). Modifications of this principle were employed by German pilots in World War II (see figure 5.42).

Dräger was the main supplier of oxygen equipment and breathing masks for the Germans, a stand that prevailed from pre-WWI times to the present day. Their only competitor from the early 20^{th} century to World War II was the *Auer* company from Berlin, which produced gas-masks and other protective devices for the German Army in the First World War and beyond. Their market share was minor though, compared to Dräger. The latter company simply had more resources to research and develop new systems and had a broader product bandwidth, outrunning Auer by providing complete solutions rather than just single devices.[152]

Even though Dräger could look back on a long tradition of producing masks and breathing systems, they were not ahead of their British and American counterparts. While it is debatable as to how far their products influenced other manufacturers abroad (see below), they had nothing advanced to offer, especially during the Second World War, when these devices were most needed.

When CIOS and BIOS teams inspected the Drägerwerk facilities and bagged breathing apparatuses, like high altitude breathers (Lovelace et al., 1945, 46), they were not too impressed with the equipment being found (Steadman et al., 1945, 7–8):

> "Any expectations of finding outstanding advancements in development of defensive equipment were, to a large extent, disappointed. Although some interesting developments were found, the main trend of the wartime work had been determined by shortage of materials with a result that, as regards service and civilian facepieces, for example, the latest design coming into production were inferior to those in service when the war commenced."

Hence the assessment of Seeler (1950a), being an account of an engineer once working for the Aviation Medical Institute of the German Air Minstry during the war, is much tainted by apologistics and simply does not take into account the *distributed* nature of technological developments, either by simple plagiats or active discussions (see below).

[152] For Auer's high-altitude breather see Smolczyk (1938). For Auer products see their company's brochures and catalogues in DM, FS 214.

5.3.2 Great Britain

The Britons devised a system based on the Siebe & Gorman *Proto* for aviators. The *Proto* was Davis' modification of Fleuss' breathing apparatus. Robert Davis and Leonard Hill started this modification in 1906, and this time – contrary to Fleuss' first design in 1879 – the system was a CCR with a rebreather bag (Davis and Hill, 1906). This device then became the *Proto* mine rescue apparatus of Siebe & Gorman. Again Fleuss' role in the development was neglected, even though his apparatus paved the way for all the different applications.[153]

At the end of the 19^{th} century, when breathing apparatuses for diving became more sophisticated, it was soon conceived that this gear would also be useful for aviation, as Richardson noted in *Nature* in 1879:[154]

> "Lastly, in wells charged with foul air, or in mines charged with choke-damp and other poisonous gases, the Fleuss apparatus will, I feel certain, prove of the greatest practical service and it is equally probable that the aeronaut may be able to rise much higher than he has done."

The *Proto* (see figure 3.5) became a standard device of Siebe & Gorman. In World War I, following the first German gas attacks in Ypres in Belgium, in April 1915, Haldane was called to investigate protective measures. He immediately traveled to France to examine the gas victims and advised the administration of oxygen as therapy.[155]

Haldane wasted no time and after he took samples of the gas on the field and conducted autopsies on the gas victims, he returned to Oxford to study the gas in his private laboratory, which hosted a pressure chamber amongst other things. The work was quite *ad hoc*:[156]

> "There was no time to work on animals, but he had himself and several assistants, one of whom was Ivon Graham, who worked with him afterwards until the end. They filled the big air-tight steel chamber in the laboratory with dilute gas and tried out one after another kind of gas-mask; everything woolen in the house – my mother's stockings and muffler, for instance – was comandeered for soaking in one thing or another. And for a time, one after the other, my father and his assistants were driven out of the gas, vomiting and coughing; I don't think my father's lungs ever quite recovered from that."

[153] John Scott Haldane had cooperated with Davis already in the 1890s to produce a mine rescue apparatus, and their first steps – also based on Fleuss' work – resembled later features, namely the pipe-stem system.

[154] Cf. Richardson (1879), quoted after Foregger (1974, 321).

[155] Haldane's daughter, Naomi Mitchison, summarized his involvement by quoting from her father's unpublished memoirs as follows: "When the war came and the Germans suddenly began to use poison gas, Lord Kitchener, who had been advised in this by my brother [Richard Haldane], telegraphed to me at Oxford to ask me to come and see him about defence against poison gas." (Mitchison, 1974, 10)

[156] From an obituary speech by Naomi Mitchison, NLS, MS 20235, F250.

The temporary gas-mask, the *bottle respirator*, was used as first protection against gas-attacks. A bottle was filled with cotton wool at the top and bottom, with damp earth in between. The bottom cap was cut off, and the soldier would have to breathe through the bottle in case of a gas attack. Haldane presented his first report on the question of gas-protection in May 1915,[157] in which he analyzed the nature of the gas (chlorine) and presented the temporary counter-measures (bottle-respirator). He also could make some conclusions on protection from German respirators that were bagged in Belgium.

Haldane furthermore proposed the use of the *Proto* as gas protection, but had to admit:[158]

> "Rescue Apparatus is of no practical use for troops in the case of a Gas Attack by the Germans.
>
> The Apparatus is too heavy and clumsy, the supply of Oxygen will not last longer than an hour or two, and in addition it would afford no protection to the eyes."

Haldane, as can be seen from the archive files, dominated the committee that was formed in 1915 in terms of scientific expertise, and because of his vigorous nature. He attacked everything and everybody that he deemed standing in his way, a way he conceived as beneficial for the lives of the soldiers. Upon the publication of some premature protection mask in the *Daily Mail* on April 29, 1915, which did not find Haldane's approval, he attacked Prime Minister Kitchener himself asking for the masks to be removed from the troops.

When the British government formed a new committee on gas warfare in late 1915 Haldane was not made a member of it, something he traced back to his brother's demission as Lord Chancellor in the summer of the same year.[159]

In fact, Claude Gordon Douglas remained with the committee and discussed many of the issues with Haldane. Haldane was also continually asked for advise on matters of breathing apparatuses and respiration matters during the war.[160] One such advise matter was the study of bagged German Dräger breathing equipment.[161]

[157] NLS, MS 20233.

[158] From a manuscript of Haldane, NLS, MS 20515, F106–107.

[159] Mitchison (1974, 13). His brother, Richard Haldane, retired from his post in the summer of 1915 since he was attacked by the English press – first and foremost the conservative *Daily Mail* – as "Friend of the Germans". Richard had studied philosophy in Göttingen, Germany, and remained a great admirer of Germany ever after, notwithstanding his contempt for the German war efforts. Cf. Haldane (1928).

[160] He also participated with Douglas in the two big Interallied Conferences on Gas Warfare in Paris in 1917, and 1918, respectively. See archivals in OPL for the conferences, and several manuscripts and letter in the NLS for Haldane's involvement in gas warfare researches.

[161] E.g. NLS, MS 20234.

It was during this time that Haldane cooperated with Davis of Siebe & Gorman to make modifications to the *Proto* to help gas victims.[162] Up until this time oxygen systems were largely *constant flow* systems, i.e. the oxygen was delivered in a constant stream rather than on demand, as Frenchmen Denayrouze and Rouquayrol had devised in 1886 (see above) – but which did not prevail until after WWI. Haldane noticed the waste of oxygen in the *constant flow* system, as during expiration the gas was blown off with no use. Eventually, in 1917, he designed a system with constant flow, but with a rubber mask and a rubber bag attached to the valve. The bag acted as a container for the oxygen during expiration, where the oxygen collected in the bag, held back by a valve, and the expired air was pushed out through another valve. On inspiration, the oxygen then was taken from the bag, minimizing the amount of oxygen being wasted.[163]

Stelzner and Dräger, on the other hand, had already devised something similar before World War I, as can be seen in figure 5.38. Whether these devices were actually constructed so early, is not clear, since there were only illustrations, but not actual devices printed in the *Dräger-Hefte*.

Haldane's design was modified by Davis to suit aviator's needs, chiefly by altering the size and position of the bag. These modified breathers were then delivered to the *Royal Flying Corps* (RFC), the predecessor of the RAF. They were, however, too complicated and prone to faults, so the valve design of British Major George Dreyer (1873–1934) was used instead by the RFC for some time. Only later could Siebe & Gorman produce oxygen regulators that were of more practical use. These regulators were, as before, usually modifications or adoptions of regulators used in diving, and Haldane tested them together with his colleague and former student Joseph Priestly.[164]

Dreyer's design was much more popular than both Siebe & Gorman's or that of French physiologist Paul Garsaux (see below). The Dreyer apparatus was produced from April to December 1917,[165] and the c. 50 devices produced were used by the RFC pilots, even though it was not the official device of the RFC. Dreyer's valve automatically regulated the flow of oxygen according to the height, whereas many other systems of the time had to be manually adjusted (Robinson, 1973, 97). Dreyer had devised his apparatus during his service as RFC flight surgeon in the field in France. To prepare his prototype he had cooperated with the Paris-based company De Lestang, which received the patent for the apparatus and produced the devices sent

[162] Haldane was never involved in developing British war gas, though he was asked for his opinion from time to time, as letters in the NLS indicate.

[163] Gibson and Harrison (1984, 39), also NLS, MS 20234, F68–69, F108.

[164] Cf. a letter from Haldane to his sister, which briefly mentions "high flying" experiments with "RFC men", without going into details. NLS, MS 20660, F297.

[165] With some assistance from Martin Flack, who was officially in charge by the RAMC to devise an oxygen apparatus. Since no feasible apparatus could be produced at the time, the RFC officially sanctioned the Dreyer device for the time being. RI, DEWAR/DVIIb/65.

to the front.

James Dewar (1842–1923), then Fullerian Professor of Chemistry at the Royal Institution (RI) in London, had researched and developed a liquid oxygen apparatus for which he held various patents some years before the First World War. Dewar was a specialist on the question of the liquifidation of gases and inventor of what nowadays is termed the "thermos flask".

During World War I he advised Leonard Hill and Martin Flack on the development of a liquid oxygen apparatus.[166] Before the war the Germans had obtained a license on Dewar's patent to produce a vacuum in flasks and then apparently used them for their high-altitude breathing systems.[167] The Britons consequently evaluated the German breathing apparatuses – which both Hill and Flack referred to as the "Hun instrument" in their correspondence with Dewar – and used them for improvements to their own systems.[168] Dewar especially worked on these improvements, as the German device was found to be superior to the British one.[169]

The liquid oxygen breather in those days worked on an evaporation principle: The liquid gas is streamed from the thermos flask into a metal evaporation chamber in which, under the ambient temperature, the oxygen became gaseous again. This implied the danger of freezing of the valves and gauges and other shortcomings. Dewar then devised an electrical system in 1917, having an electric heater in the evaporation chamber. The amount of oxygen flowing out could thus be regulated by regulating the electricity in the heater. First tests, however, showed no improvement compared to the "Hun apparatus".[170]

Hill, involved in the high-altitude breather research (and gas masks), urged Dewar to continue working on the system and gave guidance to the Air Board's engineers, who had trouble constructing Dewar's flasks from his schematics.[171] Robert Davis came up with an improved model of his breather later, although Hill suspected that this was copied from Dewar's ideas.[172] Dewar's breather never made it into field use. In the spring of 1918 the Air Board was still discussing tests of his apparatus and felt no need to make haste over the decision.[173]

Dreyer, on the other hand, was also in charge of devising the oxygen apparatus for the Everest Committee in 1921. He used the standard equipment of the RAF (2 liter steel bottles, which were usually pressurized at 150atm), and set a maximum pressure of 120atm for climbing for security reasons,.

[166]See RI, DEWAR/DVIIb, f. 27, 33, 59, and DEWAR/DVIIc, f. 58, for official recognition of Dewar's work in this respect.
[167]RI, DEWAR/DVIIb/113
[168]RI, DEWAR/DVIIb, f. 24, 61
[169]RI, DEWAR/DVIIb/65.
[170]*ibid.*
[171]RI, DEWAR/DVIIb, f. 112 and 113.
[172]*ibid.*, and RI, DEWAR/DVIIb/42.
[173]RI, DEWAR/DVIIb, f. 96 and 117.

The regulator in question was the Siebe & Gorman regulator designed for aviators in World War I, and two type of masks were issued: the *standard* mask and the *economizer* model. Dreyer recommended oxygen usage above 7000m at a flow of 2l/min to 2.4l/min at the Everest summit.[174]

Leonard Hill and Martin Flack were called in to evaluate and test the oxygen equipment, and give their ideas for how to lay out the bottles.[175] Hill had also championed the *oxylithe* apparatus and gave instructions about its use to the committee.[176] Siebe & Gorman had devised an *oxylithe* breathing apparatus for its submarine escape device in 1904. *Oxylithe*, a sodium peroxide mixture, was originally invented by French chemist George Jaubert, and Siebe & Gorman obtained the license rights that year.

Claude Gordon Douglas had also employed *oxylithe* as an oxygen provider on the expedition to Tenerife in 1910, which Zuntz (1912) reported on. He even went so far as to regard this technique as the future of artificial oxygen supply. At this time most other forms of supply had proven to be unsafe or unwieldy. *Oxylithe* on the other hand, is dehydrated as cubes and only has to be dissolved in water to gas-off the oxygen. All the user had to do was take a bag of water with him and throw the *oxylithe* into it. It also produces sodium hydrogen, which absorbs the expired carbon dioxide, thereby prolonging the use of the produced oxygen. The only obstacle Zuntz (1912) sees is the low temperature at high altitudes, and proposes to use a saline solution as a solvent (Zuntz, 1912, 66).

Even though *oxylithe* sounds like the best solution to the oxygen question, it was exactly the latter reason why it could not establish itself as the standard. Temperatures at high altitudes are so low that even saline solutions would freeze, and during the gassing-off phase, temperatures need to be considerably higher than those found at these heights.

5.3.3 USA

When the United States entered the war in 1917 they had no oxygen system at their fingertips, despite Henderson's expertise with this technology. Being short of time the US Army Air Corps thus simply modified the Dreyer apparatus. Modification was done by the A.C. Clark Company, henceforth the device was dubbed the *Clark-Dreyer-Apparatus* (it was later baptized the *Type A1-Regulator*). In 1923 the bagged Dräger systems were used as a model for new oxygen devices (Robinson, 1973, 96). T.C. Prouten, with the Van Sicklen & Company in Illinois, also produced a breathing device, which eventually became the official *Type A2-Regulator* of the US Army Air Corps in 1922.

[174] West (2003, 1709). See also "Everest Equipment. Memorandum", RGS, EE/30/5/1.
[175] See RGS, EE/30/5/1.
[176] *ibid.*

In the war, however, the use of oxygen systems on the allied side were rather rare. Henderson said:[177]

> "[...] the simplest way to solve the problem of lofty ascents would be by means of oxygen apparatus. The Germans evidently made use of such apparatus, for it was found in the wreck of one of the German planes shot down over London."

In the Interwar Years development of oxygen devices nearly came to a halt in the US, new masks and breathing apparatuses were designed and tested by the Medical Sections of the Air Corps at Minneola, but the development was on a rather low level. Knowledge of physiological issues was meager and not disseminated to engineers to take it into consideration in airplane design, as engineers from Langley Aeronautical Laboratory noted:[178]

> "As our experience developed, we were further surprised to find that even this fragmentary information was unreliable; that it was apparently collected rather for its news value than for its value as scientific data."

Only shortly before the Second World War, development of new, genuine systems commenced. The first designs consequently imparted flaws other nations had already passed, e.g. the question of an adequate mask. Astoundingly the Americans caught up in a very short time (see figure 5.45).

The Americans, too, had assessed that the *pipe stem* system was prone to failure: "Lost pipe stems on oxygen breathing apparatus have accounted for not a few fatalities" (Poppen, 1941, 63). For times of war it was completely inadequate, since the slogan for military aviation oxygen equipment was "Put it on, turn it on, and forget it" (Poppen, 1941, 62). Once again, breathing equipment design became "essentially a responsibility of the designing engineers and manufacturers" (Poppen, 1941, 62). Of course, new designs were apt to testing, and physiologists had to provide engineers with the right set of parameters for the breathing apparatuses. Hence close collaboration of physiologists and engineers was mandatory. The chief design task remained with the physiologists, whereas engineers were in charge of producing the right materials and construction processes. This required technically inclined physiologists, of course and luckily, aviation physiologists were usually of that kind. On the American side, Randolph Lovelace was one of the protagonists in mask design.

[177] Henderson (1919, 440). Schrötter (1919, 733) also ascertains that the Germans had oxygen apparatuses in their airplanes, since they "could not have carried out their systematic reconnaissance work at 6000m without" and that the German attacks on London in World War I would have been impossible without such devices, "which have been normalized upon our earlier work". Translation mine.

[178] King and Carroll (1924, 1). They refer to the development of altitude engines at Langley and notice that not much knowledge of physiological conditions for high-altitude flying was available for engineers.

Randolph William Lovelace (1907–1965) became chief of the oxygen branch of the Aeromedical Laboratory at Wright Field in Dayton, Ohio, in February 1942 (cf. Nelson, 1999). He had started the design of an oxygen mask earlier in 1938 in the Mayo Clinic and had devised the *Boothby-Lovelace-Bulbian* (BLB) mask with his two assistants. The modified BLB mask, then dubbed "A-8 mask" was issued to all airplane crews in 1941 by the US Army Air Corps (see figure 5.45).[179] The BLB mask had been constantly modified, first versions only had a nose mask, primarily to allow radio communication. Later revisions had nose-mouth masks that incorporated radio devices (see figure 5.45).

The Americans were soon challenged with a question the Germans had also considered. The oxygen system was installed in the airplane's cockpit and was stationary. What if a pilot had to bail out of the plane with a parachute in case of damage to the plane? Should he open the parachute immediately and breathe oxygen from a bottle or fall through to safe heights and open the chute there? At great altitudes, so both the Germans and the Americans conceived, hypoxia would soon knock the pilot out, making him unable to open the parachute, whereas the descent from great altitudes with an opened parachute would take considerable time and the mobile oxygen tank would not have enough gas in store to sustain life for such a long time.

Lovelace conceived that this issue could not be solved by pressure chamber tests alone and thus decided to try a jump himself from an airplane, although he had never trained as a paratrooper. On June 24, 1943, he jumped from a B-17 from 12253m, directly opening his chute. He underestimated the physical drag of the parachute, which knocked him out. The hypoxia, however, did not set in immediately. It was thus realized that a fall-through to safe heights could be made without risk. Thus, the Air Corps ordered all its pilots to drop to safe heights before opening the chute.[180]

The enumeration patterns of the breathing devices were applied in a confusing manner, for masks and oxygen delivery systems were developed separately, but with the same ordering numbers, i.e. the A-8 mask was something different than the A-8 regulator. The standard American oxygen mask A-8 was used in conjunction with the A-8 or A-9 constant-flow regulator. These regulators had a flaw that became apparent especially in combat:

[179] Cf. Weitekamp (2004, 28) and Shelton (1999, 284).

[180] Weitekamp (2004, 27–29), and Robinson (1973, 196–198). As a matter of fact, the Germans came up with the same strategy, despite their idea of an *emergency pressure suit*. The successful implementation of this strategy was hindered by the habit of fighter pilots of letting themselves be dragged out of the opened cockpit by the open chute, i.e. they opened the chute while still sitting in the pilot's seat. This made sense when the pilot was wounded and could not exit the cockpit easily, but it prolonged the time in the rarefied air thus causing trouble, especially by breaking the chute's belts which were not designed to withstand such heavy drag. German *Luftwaffe* command thus ordered that this "dragging-out" shall be refrained from. See minutes of the meetings in the RLM, June 15, 1943. BA-MA, RL3/37, F26–27.

The pressure of the oxygen had to be adjusted manually, i.e. whenever the height of the airplane changed significantly, the pilot had to instruct the other crew members via intercom to adjust the oxygen pressure of their regulator. In the stress of combat, this obviously became hard to manage. Thus, many causalities due to hypoxia resulted from insufficient opportunities to conduct this procedure, or simply from poorly instructed crew members. Furthermore, the A-8 mask was reported to be apt to freeze at higher altitudes. Redundancy was introduced as an *ad hoc* solution, i.e. crew members had to take a second mask aboard as emergency backup. Thereafter, until late 1943, the mask design underwent constant revision, with the A-14 mask being the final product issued to fighter pilots. As circumstances in bombers were different to those in fighter planes, another mask type A-15 was designed shortly after. The regulators were also revised, leading to the A-14 regulator, a demand-valve pressurizer oxygen system (Shelton, 1999, 285–286).

The events of war demanded this sort of constant modification, as new airplane technology created new situations for the crew. As Shelton (1999) evinces, both sides in World War II "learned" from each others' design, the Allied side learned from bagged Dräger apparatuses, while the Germans also adopted features of the oxygen masks found in shot down enemy airplanes.

5.3.4 France

Cailletet (1903) was one of the first French scientists to develop an oxygen system. He championed the use of *liquid oxygen* to allow smaller oxygen tanks, since oxygen in its liquid form has a higher density and requires therefore less storage space for the same amount of oxygen than in its gaseous form. To make the oxygen breathable, a system with a *condenser* was devised. The oxygen, having a very low melting point, then became quickly gaseous again. The process was not fool-proof though, and some aeronauts and physiologists like Schrötter (1902) were not too fond of it, despite seeing its economical value.

The French oxygen apparatus for aviators in the First World War was designed by Paul Garsaux, who later designed the French pressure suit (see above). The apparatus came in two versions: a 5.2kg one-person apparatus and a 9kg two-person apparatus. Both versions delivered oxygen for c. 2.5 hours, but there were no indicators, no gauge to see how much was left in the tank, or the level of the flow-rate. The device was therefore heavily criticized by the authorities. Furthermore, the device had several engineering flaws, which rendered its use nearly futile. The rubber parts cracked easily, causing leakages; the metal parts of the mask touched the face and caused frostbite; springs in the regulator were not invulnerable to the cold and warped and rusted, causing a variable flow of the gas (Robinson, 1973, 97).

There is little reliable information on the popularity of the Garsaux apparatus among aviators, other than Robinson (1973). Garsaux's own accounts published shortly after WWI do not deal with this issue at all, only describing the apparatus itself.[181] Benford (1979) gives a photograph and some short comments on the apparatus. An interesting feature of the mask, although it proved fault-prone in reality, was the self-sealing bladder. The mask was made of metal for the most part. However, inside it there was an inflatable bladder made of rubber which would seal the mask to the face, so the mask supposedly fitted perfectly on the wearer's face. In practice, however, the bladder ballooned out, since its designer had not kept in mind that at greater altitudes the air inside the bladder would expand.[182]

The first oxygen system by Garsaux was presented in 1917, after he tested the device in the pressure chamber of the research facility at Saint Cyr, France (Lomonaco, 1970). A second design was made in 1918 to overcome the flaws of the first type, but was never used during the war.

Just as was the case in the debate over pressure suits and cabins, the issue at stake was rather a matter of engineering problems, rather than any kind of ideological struggle. There were contemporary discussions over the supposed superiority of the liquid oxygen approach, but the latter was simply not developed enough to provide a reliable source of breathing gas, despite its theoretical advantage. There simply was no technical system available on the market which would actually exploit this advantage, but rather, the systems available caused more trouble due to their technical infancy than they did any good to their users. Other than what one might believe from the contemporary scientific or technical accounts, it was often simply *engineering problems* that hindered a theoretically superior idea from making its breakthrough.

5.4 Chapter Conclusion

In this chapter the technology of the pressure suits devised and developed in the 1920s and 1930s has been detailed, alongside pressure cabin development and breathing equipment. The focus of the investigation was on events chiefly outside government bodies. In fact most pressure suit development was done by private companies on the behalf of individuals. Two issues stand out in this context: The debate over suits vs. cabins; and why the former were sought notwithstanding the expert's preference for the latter.

5.4.1 Pressure Cabins vs. Pressure Suits

The major argument against cabins in the 1930s were their extra weight, even though most proponents of suits argued in favor of cabins, the contemporary

[181] Garsaux (1919a,b). Garsaux's scientific autobiography also does not shed much light on this issue, cf. Garsaux (1963).

[182] A problem comparable to pressure suit issues, as outlined in several examples above.

aircraft could not cope with that weight in terms of reaching a sufficient altitude, e.g. a height record.[183]

Also, usually in respect to local accidents, each technology was regarded as too unsafe at times. When the Soviet sealed gondola crashed in 1934, the Russians sought suits as a safer alternative, whereas the Americans reached out for sealed gondolas after Gray's death in 1928 (see the respective sections).

Often enough, however, the national communities fancied the technology they could handle best. When Däger in Germany failed to produce a feasible pressure suit, German cabin manufacturers like Junkers boasted about their achievements in pressure cabin design. With no pressure cabin at hand, but a viable suit, English scientist Leonard Hill bragged (Hill, 1934, 302):

> "By this simple means [the Haldane-Davis pressure suit] the possible height of flying has been doubled; there is no need for expensive and heavy observation chambers used at ordinary air pressure by Piccard, and others, for their balloon observations at great heights."

This signifies that the debate over the right kind of technology was not entirely a rational one that solely relied on technical issues, but also on national hubris. It seems at times that the superiority of one concept (cabin vs. suit) was not so much conceived by their technical merits, but rather whether the nation of a commentator had it at their disposal or not.

Only a few voices were raised to bring the debate back to a more reasonable level. German aviation physiologist Schnell discussed the benefits of suits and cabins in his textbook from 1935. He outlined the technical difficulty of the breathing system required for a truly autonomous system. Potash and oxygen supply need to be held in very large amount to allow for lengthy flights, something unachievable with transportable tanks. The tanks therefore had to be integrated into the cockpit. However, the hoses from the tanks to the suit would hinder movement severely. This shortcoming, together with its fault-proneness, thus rendered pressure suits unsafe in the eyes of Schnell (1935, 51). Cabins, on the other hand, offer better safety mechanisms, and if they failed, an emergency oxygen bottle would be sufficient to bail out by parachute. This became the notion of most airfaring nations by the end of the 1930s, hence breathing equipment was given more attention than suit fabric.

5.4.2 Glory and Failure

As outlined, in most cases private companies were successful at creating suits, to such a degree that the military actually had to resort to their expertise, since within their ranks no such knowledge has been established. The most

[183] Cf. a French article in DM, LRD 00691, in which it is argued that cabins would allow for more space to move for the pilot, but had too much weight.

extreme example might be the UK, with the medical director of the RAF, G.S. Marshall waving off the viability of pressure suits in favor of pressure cabins in the summer of 1933. In the fall of 1933, the same RAF had to contact individuals like Haldane and Davis to get their hands on exactly such a suit, since a cabin would not do for their height record attempt.

Also, as a comparing study, one might compare the efforts in the UK to those in Germany at the same time. The personal setup was quite comparable. Dräger and Siebe & Gorman had much in common as far as structure and the companies' agendas were concerned. Both companies represented what Radkau (1999, 115) has termed "entrepreneurial engineer". Even though Hermann Stelzner was not the president of Dräger, his influence on the company's decisions was tremendous. Basically, all that Dräger was between 1910–1930s was due to Stelzner's work. His cooperation with balloonists, pilots, divers and physiologists led to a wide acceptance of Dräger technology and was part of the company's success. The same holds true for Siebe & Gorman, with the exception that Davis had even more influence there, being also managing director of the company.

Furthermore, the successful application of pressure suit technology by Wiley Post and Russel Colley in the USA also hints at the *hacker culture* that was so closely associated with pressure suits in the 1930s. It seems that government institutions like the armed forces, as well as large airline companies like TWA, were not keen to venture into this kind of technology, and that successful implementation and application required some *hubris* and the will to solve technical problems in a rather unorthodox fashion.

Why then did Dräger fail to come up with a viable pressure suit in 1936, while backyard engineer Klanke did? Not that Klanke's suit would deserve the attribute "viable", but his suit – as crude as it was – was used in actual flight, while Dräger's suit from 1936 never left the testing facility. Also, the Italians could produce a working pressure suit and use it in actual flight, regardless of its likewise crude nature, although the Italian infrastructure was quite different from the *hacker* attitude to which Klanke or Davis were exposed.

One of the protagonists of the hacker spirit, Eric Raymond, elucidates that hacking has nothing to do with breaking into computer systems, but rather with "technical adeptness and a delight in solving problems and overcoming limits" (Raymond, 1991, 232). A *hack*, according to Raymond, is: "Originally, a quick job that produces what is needed, but not well", but nowadays first and foremost is an interaction with technology "in a playful and exploratory rather than goal directed way." A person acting in this spirit, a *hacker*, is consequently "[o]ne who enjoys the intellectual challenge of creatively overcoming or circumventing limitations." (Raymond, 1991, 189,191)

Raymond developed this concept further by propagating what he called the "Cathedral vs. the Bazaar" taxonomy of software development. Whereas in the "cathedral" (i.e. big, monolithic companies with strict hierarchies) engineers were just following orders and were limited in their creativity, the "bazaar" approach would profit from the enthusiasm of many individuals collaborating on a project without an absolute end (cf. Raymond, 2001). Himanen (2001) regards this as a challenge to what Max Weber has coined "protestant working ethics". Weber characterized Western capitalism as guided by the Protestant spirit of hard labor as a spiritual "calling". To Himanen "the radical nature of general hackerism consists of its proposing an alternative spirit [...] that finally questions the dominant Protestant ethic" (Himanen, 2001, 12–13). In a nutshell, the *hacker culture* epitomizes the playful and joyful side of engineering (but is not restricted to engineering alone), in which codes and rules of working patterns are explicitly defied.

In this sense the Italian high-altitude flying group falls into the same category. Even though the infrastructure was highly rationalized – a circumstance that does not contradict *hacker culture* – the incentive was rather irrational. Furthermore, the working culture within the group was rather personal. Although embedded in a military hierarchy, the structure within the group was comparably "flat". Pezzi, for example, was both the commander of the group and its chief test pilot, i.e. he could make decisions more oriented towards actual problems, rather than dealing with military and bureaucratic procedures. The group at Guidonia was thus organized more like the "bazzaar" than the "cathedral", with engineers, scientists and others working enthusiastically on the project – or: *hacking* together a height record. The same spirit could be found in the British equivalent at Farnborough.

The agenda for Dräger was less irrational in a way. Albeit the German government's idea of having a pressure suit manufactured was certainly driven by motives comparable to those of other nations. However, in Germany the government simply *ordered* Dräger to produce such a suit. Dräger, with Stelzner no longer in charge, had no incentive on their own to delve into the topic, and felt personally not committed to dedicate its resources to this issue beyond ordinary measures. In the case of Dräger and Germany, one could say that they failed to come up with a feasible pressure suit, *because* of the highly rationalized environment. As Schimank (2005) mentioned, rationalized production processes lead to "rationalized acting": "ready-made programs of actions that releases the actor from time-consuming reflexion".[184] This also expresses what Schimank coined as the *fiction of rationality*. In rationalized working environments, the worker is more and more alienated from his or her work, since his or her only task is to follow patterns. Thus, identification with the work is decreased and leads to irrational behavior, since the worker no longer actively pursues a common goal, but just follows orders. Hence the German setup in the 1930s was such an *actorless social*

[184]Schimank (2005, 47), translation mine.

body Schimank spoke about.[185] With no actor involved in the design-process of a pressure suit – like Davis and Haldane in the UK, Pezzi in Italy, Post in the USA, Garsaux and Rosenstiel in France – who had a high personal interest in the matter, the whole enterprise of producing a suit in Germany degraded into a "socially pre-configured script":[186] The design of the Dräger pressure suit in 1936 became just one project among others, with not much commercial prospect attached to it. The situation in the 1940s changed quite a bit, with Tietze in a more decisive position within the company and being personally responsible for the design. Also, they were times of war, which imposed a stronger incentive for the persons involved. Furthermore, during the war the Dräger company was not involved in much research, but rather confined to produce breathing apparatuses. For Tietze the pressure suit project was therefore the only chance to get away from dull business work.

Another point in regard of hindering "hacker power" in aviation in Germany in the 1930s, obviously, was the highly regulated setup in civil aviation. Where individuals like Wiley Post in the USA had the freedom to pursue high-altitude flying from their own purse, regulations in Nazi Germany rendered such an option almost impossible. Aviation became a major concern of the regime, and it would not allow any uncontrolled attempts to develop aviation technology. All efforts in aeronautical engineering were directed towards a future war effort, and where developments would not fit into that, they were strictly prohibited. For private aviators, opportunities to pursue their own agenda were rooted out. The newly created Sport Aviation Association of Germany (Deutscher Luftsportverband, DLV) regulated all activities of non-commercial or non-military aviation and had a keen eye on individual aspirations.[187] In this light, Klanke's suit appears even more remarkable, as he had apparently managed to evade this monitoring by the authorities. As a pilot for a government agency he could utilize the comparably small niche that was open to him.

When comparing the production of suits to the development of pressure cabins, the picture of engineering cultures becomes a bit more obvious. Pressure suits were sought to achieve height records in the first place. Such an endeavor was surely of interest to most companies in aviation, for the good opportunities of marketing propaganda that it provided. However, for the greater commercial interest, suits were only a marginal market. For commercial air transport, pressure cabins were indispensable.

Whereas suits could be manufactured rather quickly, and its users were willing to sacrifice comfort and even security for achieving a daring feat, this

[185] Schimank defined organizations in which not much use is made of individuals and their ideas, but in which decisions are rather based on pre-configured, formalized procedures as an "actorless social body". Schimank (2002, 53).

[186] Schimank (2005, 52), translation mine.

[187] Cf. Lünen (2008), where this policy is outlined for the case of gliding flight.

was neither technically nor economically an option for airline companies with cabins. Contrary to suit development, cabin integration required a close and wide cooperation between a wide variety of persons and institutions. The engineering effort to design and construct an airplane with a pressurized cabin was enormous and made communication protocols and organization between the various professional groups necessary to devise. This required concerted efforts in terms of research and development, and was surely not so easy to achieve as a *hacker* approach to pressure suit employment.

The pressure suit was a short-term project which could be sought rather independently from the aircraft, as it usually required not much more than *interface* discussions. Robert Davis, for example, only participated in the Bristol company meetings to discuss the interface of the oxygen system within the airplane. He did not discuss the general design of the craft. This was not the case in pressure cabins. Design issues with the cabin affected the overall design of the plane tremendously. Junkers attempt to decouple the cabin manufacture from the actual airplane construction, as can be observed with the Ju-49 and its attachable cockpit, was of limited use and soon given up. Projects that involved pressure cabins therefore were always large-scale projects that required greater amounts of resources.

To conclude, it is obvious that for quick, short-term successes the *hacker* approach works quite well, especially as it overcomes the oddities of the *fiction of rationality.* Usually this *hacker power* is a sign of a high personal affection and motivation for the project in question. With the pressure suits in the 1930s, we almost always encounter such high personal motivation in the form of some kind of hubris, or at least some kind of joyful affection with technology.

For long-term, normative projects, such as defining the standards for commercial air transport with pressurized cabins, such *hacking power* falls literally short. Since pressure cabins are not about short-term successes or daring feats, but rather defining a legacy in aircraft technology, a longer lasting agenda than record-seeking is required, such as the commercial prospect of flying at greater altitudes. The technical and organizational infrastructure required for this enterprise is much larger, and consequently, individual motives become less significant. The period of height records in the 1930s therefore marks a transition from aviation as individual, acrobatic thrill to an everyday, rational commercial activity.

Figure 5.40: Dräger's high-altitude breathing systems for aviators. On display in the Deutsches Museum.

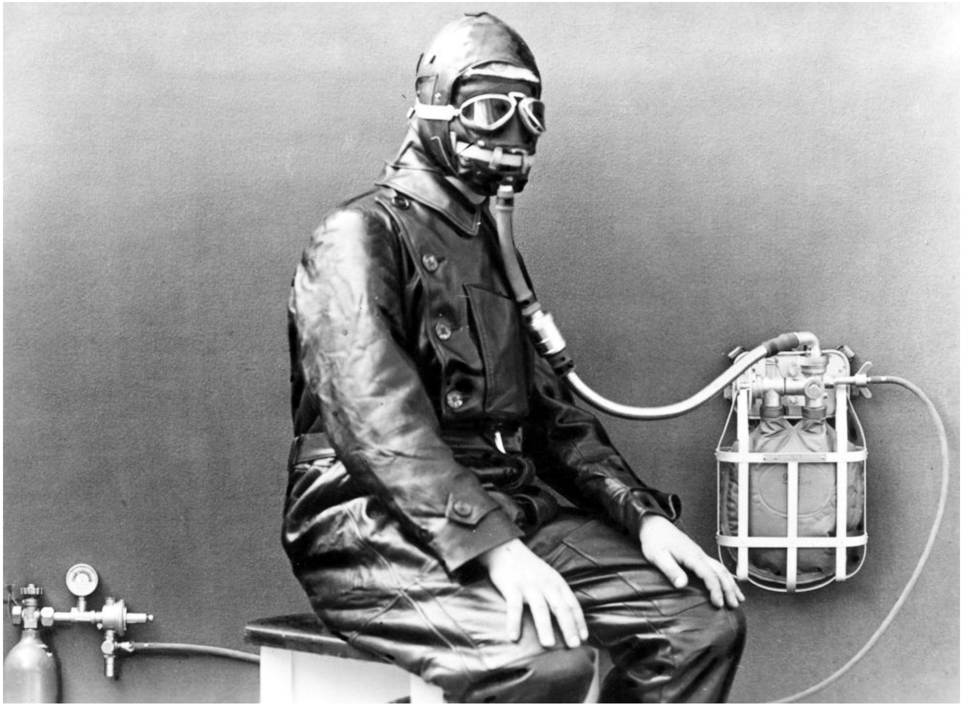


Figure 5.41: Pilot's garment and high altitude breather, c. 1929. Reproduced by permission from the Deutsches Museum.

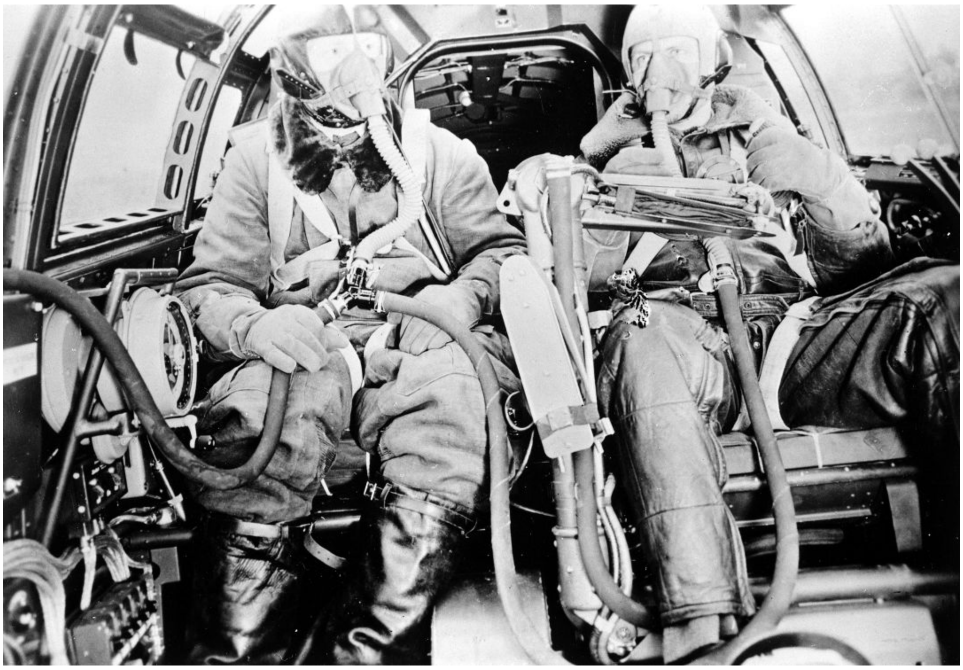


Figure 5.42: German bomber pilots in a Heinkel He111 in 1941, using Dräger high-altitude breathers. Reproduced by permission from the Deutsches Museum.

Figure 5.43: Dräger high-altitude breather with pipe-stem and face mask. Taken from Dräger-Hefte, 1922.

Figure 5.44: Pipestem system with face mask, USA, c. 1920s/30s, on display in the NASM.

(a) Mask Type A-7B, 1938. (b) Mask Type A-8B, 1940.

Figure 5.45: American oxygen masks 1930s/40s, on display in the NASM.

Man has climbed Mount Everest. Gone to the bottom of the ocean. He has fired rockets at the Moon. Split the atom. Achieved miracles in every field of human endeavor ... except crime!

Ian Fleming, *Goldfinger*

6 Conclusions

In this publication I told the story of the development of the pressure suit out of diving technology. I have outlined the scientific debates among physiologists in the late 19^{th} and early 20^{th} century, the political debates arising from the hype over aviation records in the Interwar Years and the technical debates in the 1930s when pressure suits were actually constructed. I have furthermore shown the paradoxes involved in these debates and how these paradoxes hint at the underlying notion of technological developments in general.

Over the course of this publication I have argued that the creation of conceptual models for pressure suits was rooted in diving technology. I have made the point that the introduction of terms like "scaphandre" or "diving suit for the air" are the epitomy of discursive frameworks in science and engineering, where established technology is quite often used as a model for new applications.

Scientific and technical models were shaped by the linguistic concepts previously made in regard to the undersea world. The undersea, consequently, provided the discursive framework for the debate on stratosphere and outer space exploration. I referred to Cassirer (1946) when I explained this prefiguration of *mental* constructions (Cassirer, 1946, 44–45):

> "The original bond between the linguistic and the mythico-religious consciousness is primarily expressed in the fact that all verbal structures appear as *also* mythical entities, endowed with certain mythical powers, that the Word, in fact, becomes sort of primary force, in which all being and doing originate."

A linguistic convention, using a "diving suit for upper air" or "scaphandre", which I have outlined on several occasions in this publication therefore reflect ideational conventions. Take the diving suit as a protective device for example. Over the centuries divers used but minimal protective measures, most of them extremely crude and useless. With the advent of modernity science and technology provided ever improving methods to conduct safe dives, i.e. technology like the air pump, the diving suit and helmet, and breathing devices helped humans to literally immerse themselves in a hostile environment and survive. The technical concept to achieve that is based on *shielding* or *encapsulating* the user from his environment, i.e. to minimize any actual physical contact between the user of that technology and the environment. Such *shielding-technology* thus becomes the model for *all* future shielding-technology, i.e. since diving suits and diving bells were the first technologies to allow a human to survive in potentially lethal environmental conditions, all later protective equipment was compared to it and served as a model for other applications. It is for this reason Drägerwerk engineer Hermann Stelzner dubbed his garment to protect against poisonous gases as a "gas diver" (or his high-altitude breather as an "altitude diver").

The ideational and linguistic technical domain of aviation and spacefaring is thus determined and shaped by its "ancestor": diving. *Diving* became a *cultural resource* for scientists and engineers, since this convention is transported through culture, predominantly by language. "Language" as prefiguring force, as Cassirer (1946) put it, becomes an actor in a socio-technical network.

Assuming the debates and culture represents a distributed act, in a way that engineers and scientists debate technology and science to arrive at new ideas, language not only becomes an active component in terms of communication, but also because of its inherent cultural load. As Cassirer (1946) outlined, all mental concepts were prefigured in language. Language therefore becomes the shaper of ideas and all new ideas are derived from a well-established linguistic pattern, like the "diving suit for upper air".

To use the concept of *Actor-Network-Theory* (ANT), language thus becomes an *actant* in a network of science and technology (cf. Latour, 2005). The process of *catarechsis* of "scaphandre" or "diving suit for the air" is therefore not merely a *rhetorical accomplishment* in the sense of propaganda, but an active component in the development of science and technology. All cultural achievements and social debates leave their mark and traces in language, so that language becomes the product of such social and intellectual debates. All contemporary debates consequently rest on the linguistic patterns evolved up to that particular point. Language – as cultural practice – therefore becomes a *cultural storage* and through this serves as resource for science and engineering.

6.1 Rhetorical Accomplishments

The linguistic patterns established also served for marketing propaganda of course. In the late 19^{th} century especially, metaphors in the form of reverences to mythology blossomed in engineering propaganda. For example electrical inventions were often depicted as mythical acts, and depicted with classic deities like Athena, as the Goddess of wisdom (who also brought the light to humans by showing Prometheus where to get it). In general inventors and engineers used this approach making a rhetorical connection between mythology and technology.[1]

This usage of metaphors partly stems from the *hubris* of the inventors. They firmly believed that they were some kind of mythical force, or that they were able to deliver what mythology had always promised. On the other hand, these metaphors were also designed to disseminate their inventions and findings. From the rhetorical viewpoint there was usually no other chance to introduce a new piece of technology, or a new scientific insight, other than by comparing it to well-known concepts – no matter how remote the comparison may have been.

The introduction of terms like "diving suit for upper air" must therefore be seen as *rhetorical accomplishment*, rather than a true affair of the heart.[2] Engineers and physiologists rarely called these suits "diving suits" in technical discussions between themselves, but used it solely to convey their idea to the outside world. The term sat well with the public, which would have experienced trouble in understanding terms like "pressure suit". By using a reference to a well-established piece of technology – a diving suit – which nearly everyone knew about, misunderstandings were circumvented.

As I have discussed terms like "diving suits for upper air", "scaphandre", etc. were never detailed at any time in popular publications (and often were not used in scientific and technical accounts). No introducing definition, no explanation why a pressure suit would qualify as a "diving suit" was ever given. The proponents of such metaphors were apparently fully confident that these terms spoke for themselves and needed no further details. So, even though the model-giving function of diving for aviator equipment and such might have been rather subtle, i.e. those drawing from this cultural resource might not have been fully aware of it, the application of those terms for dissemination were made in the broad awareness of the common nature of diving and space travel. The references to diving in aviation and space-faring were made to focus on a certain aspect of these enterprises: the

[1] Cf. Hughes (1989, 75ff.). References to mythology were a general feature of Enlightenment, resulting from the admiration of Enlightenment thinkers for classical Greece and its philosophers. Mythical figures like Prometheus or Daedalus were especially popular models for the human genius, as they defied the laws of the gods, who were identified with the feudal and unscientific societies of 18^{th} century Europe. Cf. Yolton et al. (1991).

[2] The term *rhetorical accomplishment* was borrowed from Jardine (1992).

technical means to reach such places and to survive in them.

This was a kind of *re-assurance* act. While pre-20^{th} century space propaganda could live on fantastic accounts, new technology gave a concise understanding of the intricate nature of space exploration in terms of technology and medicine. The employment of diving terminology for aviation and space exploration in 20^{th} century techno-propaganda was therefore not geared at the conceptual framework of space, but at the technical and medical obstacles. The linguistic patterns derived from diving were thus primarily an *assurance* policy: By referring to diving technology, it was assured that aviation or space-exploration would be safe. Everybody knew that it was possible to safely dive with the help of a diving suit, although only by certain trained and enduring individuals. So why would anyone believe that going to the stratosphere – as yet another hostile environment – would not be safe, now that a "diving suit" for it had been manufactured? The rhetoric for high-altitude equipment boiled down to this one and only aspect. Ernst Cassirer said (Cassirer, 1946, 37):

> "[...] the primary function of linguistic concepts does not consist in the comparison of experiences and the selection of certain common attributes, but in the concentration of such experiences, so to speak, in distilling them down to one point."

It was therefore not the object to arrive at a full-fledged common concept of diving and stratospheric flying/space travel, but to focus on a small number of common features that would help to dissipate anticipated opposition. That popular publications happily picked up this notion of pressure suits as a "diving suit" is a *rhetorical accomplishment*. That in reality the pressure suits of the 1930s were rather a risk than a safety measure did not provoke much public reflection.

That administrators and decision-makers did not really approve for such suits, but allowed them for reasons of national prestige displays the degree of irrationality under which pressure suits in the 1930s were developed.

6.2 The rationality of pressure suits

That the story behind the development of pressure suits appears as a rather irrational one may seem trivial. As a matter of fact, postmodern historical and social science assessments deal with exactly this issue. From the eminent work of Adorno and Horkheimer (*The Dialectic of Enlightenment*, 1947) to newer work like that of Schimank (2005), the nature and dichotomy of modernity in general, and science and technology in particular, has been *the* topic under debate.

At its center stood the *myth-making* with regard to science and technology. With the statement of Adorno and Horkheimer (1997) as the point of departure that reason became myth and myth became reason (Adorno and Horkheimer, 1997, 11–12):

> "Just as the myths already realize enlightenment, so enlightenment with every step becomes more deeply engulfed in mythology. It receives all its matter from the myths in order to destroy them; and even as a judge it comes under the mythic curse."

To conduct any further studies on myths and technology at this point would not be of any particular value, even more so since I have dealt with the mythopoesis in science and technology over the whole course of this thesis. Rather than rehearsing the position of Adorno and Horkheimer (1997) and others, I want to summarize the special kind of irrationality found in the Interwar Years' hysteria over aviation records, with a special focus on height records and pressure suits.

As I outlined in chapter 4, aviation records electrified the masses in the 1920s and 1930s, both in democratic and in totalitarian states in Europe and America. Maase (2001) notes in his study of mass culture that things like mass media were products of democratization, although they did not prevent dictatorships and were even exploited by the latter (Maase, 2001, 17–18).

I do not think, however, that this differentiation of *free vs. totalitarian* regimes helps to explain the irrationality involved in height records and pressure suits. Even though I pointed to the different stances held towards these records, I fail to see much difference between the involvement of totalitarian and democratic nations. The connotation of aviation records were nationalistic in both, and contrary to the Space Hype in the Cold War, these records did not display much of a struggle between the systems (fascist vs. communist, democracies vs. dictatorships), but rather of a struggle between the nations. Of course, totalitarian systems tried to exploit the feats as a signpost for their general superiority as I discussed in chapter 4.

On the other hand their propaganda departments did not really stress this circumstance. After all, aviation records were stylized as a *knightly* competition between nations, rather than a darwinistic fight between systems. The sentiment of German author Ernst Jünger, for example, displayed a social-darwinism in respect to aviation that was more directed to domestic rather than international people. For him aviation was a medium to strengthen the virility of one's nation and the competitors remained rather fuzzy in the debate.

This is yet another metaphor of Enlightenment that turned irrational. *Flying* became a "metaphor for freedom", and "the art of flying was a triumph of Enlightenment".[3] Like Daedalus in Greek mythology who defied the laws of nature and of the Gods by flying like a bird, science and technology should bring about this triumph of the human genius. In the quest to implement the kind of liberty that the Enlightenment movement had on its early agenda,

[3] Behringer and Ott-Koptschaijski (1991, 336), translation mine.

aviation epitomized this struggle as a sign of the rebellion against the laws – either against the laws of tradition or the laws of nature.

The stance of Jünger and other right-wing thinkers in Weimar's Germany on the other hand, epitomizes the mutation of Enlightenment's original ideas. For him and the others, aviation meant Germany's liberation from the "manacles of Versailles", i.e. aviation as a sign of human liberty perverted into ideas of national liberty. This symbolizes the transformation of Enlightenment's originally rational agenda into something irrational, as Adorno and Horkheimer (1997) have pointed out.

On a more individual level, the *hubris* involved in an aviator's self-image is also a result of Enlightenment's transformation. A popular topos in Enlightenment was the transformation of the individual to a higher spiritual level by reason. Aviation, and its technology, was seen as a transformation tool to achieve this dream of a *new human* in the late nineteenth century. Just as Schaffer (1999) noted in respect to automata, the airplane epitomized "what Enlightenment might achieve". However, contrary to the automata, the airplane was not just a fake like Kempelen's chess-player, but it was – in the eyes of its propagandists – really a "triumph of Enlightenment".

That the development of the pressure suit in the 1920s and 1930s was consequently irrationally guided is therefore no surprise. The pressure suit became the totem for the hopes and delusions of a society looking for *meaning* and provides an example of the hybrid nature of modern science and technology. As I have outlined the modern form of *hubris* that comprised the *hybrids* of science and technology, could draw from a pool of cultural and social resources. This pool provided the binding-glue for a variety of individual actors and organizations for which no common agenda had been defined. Culture therefore provides a strong influential agent in both scientific and technical innovation.

I outlined in the conclusions of chapter 5 that to achieve short-term fads (such as height records) this irrationality was essential for success. Long-term success, such as defining a technological legacy like pressurized cabins in commercial passenger flights, required a highly rational environment. These two approaches to high-altitude flight were not a juxtaposition of antipodes though, but complemented and interfaced with each other. The scientific research for both was very similar. Physiological issues for both suits and cabins were the same and so were issues in engine design.

The technologies of both pressure suits and pressure cabins are therefore hybrid technologies, comprising a network of research, commercial and political agendas and personal affections.

6.3 Outlook

That the notion of common concepts for both undersea and outer space were not a single event phenomenon is evidenced by the *Inner Space* term of the 1960s. In the 1950s the undersea was an often seen topic in popular movies and literature, be it in monster/SF movies such as *Creature from the Black Lagoon* or underwater documentaries like those from Jacques Cousteau. Through the *Sputnik-Shock* in 1957 all public attention shifted towards outer space. To stem this tide and participate in the surge in public funding for space related research, underwater scientists and engineers coined the term *Inner Space* as a synonym for the undersea.[4]

Throughout the 1960s and early 1970s the term was used in many popular science journals and books, but also made its way into official US Navy research reports. Underwater stations were cooperatively built and used by US Navy and NASA (with similar projects in other nations) to train astronauts to move in restricted spaces (as they would later experience in a space capsule) and to gain physiological knowledge about the human organism in such artificial environments. Colonies in Inner and Outer Space were discussed not only by pulp magazines, but also by scientific societies in their meetings. Former aviation engineer Edwin Link proclaimed the "Man-In-Sea" project, as opposed to J.F. Kennedy's "Man-In-Space" program to land a man on the moon. Inner and Outer Space were regarded as brothers in arms and synergies were sought by amateurs and professionals alike.[5]

Obviously the underwater activists wanted to ride piggy-back on the popularity of anything spacey, but as I have shown in this publication: diving served as model for space travel and not the other way around. My discussion of the relation of diving to aviation and space technology links to a wider and bigger phenomenon. Both pressure suits – which were only used in the 1930s to break records, but were otherwise dismissed as inferior technology – and pressure cabins were picked up and further developed for space suits and capsules, respectively. The debate over diving suits for space that was started in the 19^{th} century by the likes of Poe, Verne, Serviss, etc. consequently carried on and only ceased after the hysteria over space exploration had faded away in the 1970s. This episode of the technical debate over pressure suits however, is a telling example of how technology is conceived, both in the scientific and the public sphere in general.

[4] Simpson and Weiner (1989) reports that this term was first used in this sense in 1958 after a record dive by an US submarine.

[5] As mentioned in the foreword my thesis originally had a discussion of the common space conception in it, which also dealt with the notion of *Inner Space*. It became clear that this was too much material for one thesis, and should be better left out. That story will be told another time ...

Abbreviations

BA-MA	Bundesarchiv-Militärarchiv (Federal Archive - Military Section), Freiburg im Breisgau, Germany
DLR	Deutsches Luft- und Raumfahrtzentrum, Cologne, Germany (German Center for Aviation and Space, successor of DVL and other institutions)
DM	Deutsches Museum, Munich, Germany
DPMA	Deutsches Patent- und Markenamt (German Patent and Trademark Office)
DVL	Deutsche Versuchsanstalt für Luftfahrt (German Experimental Aviation Establishment)
EPO	European Patent Office
FAI	Fédération Aéronautique Internationale
NASM	National Air & Space Museum, Washington DC, USA
NLS	National Library of Scotland, Edinburgh, UK
NGS	National Geographical Society, USA
OTC	Officers' Training Corps of the UK
RAE	Royal Aircraft Establishment
RAF	Royal Air Force
RFC	Royal Flying Corps
RGS	Royal Geographical Society, UK
SL	Sherrington-Library, Physiological Laboratory, University of Oxford, UK
RLM	Reichsluftfahrtministerium (German Air Ministry in the Nazi era)
USAAC	United States Army Air Corps
USN	United States Navy

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[6] Cf. `http://commons.wikimedia.org/wiki/Commons:Bundesarchiv` and `http://creativecommons.org/licenses/by-sa/3.0/de/deed.en_GB`

Sources

Deutsches Museum

The *Deutsches Museum* (DM) in Munich (Germany) is Germany's largest and oldest museum of the history of science and technology. The museum has a large aviation section, including items from aviation medicine and suits. The DM, as an institution, also has an archive, a library and a research institution. The documents used for this publication will be listed and detailed here.

Luft- und Raumfahrtdokumentation

The *Luft- und Raumfahrtdokumentation* (LRD, Air and Space Documentation) of the archive of the DM is a large collection of material on all aspects of human flight. Most of the material is printed and published matter, like contemporary newspaper clippings or brochures, but since the collection is organized in categories (like "Medicine" or "Height-Records"), it is an excellent reference for these respective fields. It would be quite difficult to collect the clippings etc. yourself. To have so much material compiled in folders and boxes on specific topics is both a rich reference and an excellent entry point for further research.

A good deal of the LRD are remnants of formerly private archives, like the space collection of the German science journalist Werner Büdeler (1928–2004). One of the most interesting collection are the items deposited by the Römer-brothers. Hans (1896–1970) and Botho von Römer (1896–1980) collected thousands of aviation and space related materials, besides their own extensive collection of self-produced photographs and illustrations.[7]

LRD 00079

- Article Cooper (1941).

LRD 00086

- Article Bley (1941).

[7] Cf. the DM archive's monthly publication *Archiv-Info*, vol. 6, no. 1, 2005, pp. 3–5.

LRD 05612

- FAI record list in French from 1939, although no exact date given. The list not only specifies the contemporary records, but also lists the officially acknowledged records from the very beginning, e.g. for the height records it starts with Latham's record from 1909, the first height recorded in aviation history.

- Junkers press release "Weltrekorde und ihre Bedeutung", July 1927. In it: Diagram of the distribution of aviation records according to their nations, based on the data of July 15, 1927. Signed by "Junkers-Flugzeugwerk A.-G."

- Article "Vom Sinn der Rekorde" in the German newspaper *Anhaltiner Anzeiger*, May 26, 1939.

LRD 05615

- Junkers press release Nr. 44/116/611 "Fair Play", June 11, 1930. Hugo Junkers congratulates Italian Air Secretary Balbo and the aviators who have broken a previous Junkers aviation record in continual flying.

- Article "In luftdicht abgeschlossener Kabine" from the *Berliner Morgenpost*, Oct 24, 1938. Points out that for the first time a pressure cabin was used for a height record.

- Junkers press release Nr. 39/36/611 "Höchstleistungen der Luftfahrt", June 3, 1930. Same content as Nr. 44/116/611 but with more details.

LRD 05627

- Pamphlet written by a Junkers propaganda officer (name not specified) to the editor of the Nazi paper *Völkischer Beobachter* (VB) in 1938 arguing against commercial high altitude flight, which – according to the author – is "American propaganda". Includes letters from Junkers to VB editor Ernst Kredel and from the *Aufklärungs-Ausschuß Hamburg-Bremen* (AAHB) to Junkers about publications of the article in Belgian and Dutch papers (including copies of these articles). The AAHB was originally founded in 1923 by the chamber of commerce in Hamburg in the wake of the occupation of the *Ruhrgebiet* by French and Belgian troops. Its purpose was to agitate for German views in the European foreign press. In July 1933 it was taken over by the Nazi propaganda ministry and tried to influence journalism in foreign countries by releasing German propaganda. (Cf. Bohrmann and Bartels, 1999)

- Article "Die Frage des Höhenfluges im Luftverkehr" by Hermann Röder in the *Berliner Börsen-Zeitung* from Dec 6, 1928.
- Boeing press release in German about the Stratoliner, issued by the Boeing press office in Seattle. The subtitle says "For the Sunday issue, March 13, 1938". This might hint that the translation was not made by Boeing itself, but rather by some German newspaper which wanted to publish on this topic.
- *interavia* press release, July 22, 1940. It reports on the maiden flight of the Boeing 307 Stratoliner for TWA on July 08, for the flight New York-Los Angeles.

LRD 00690

- Paper clipping "Mit dem Flugzeug 17074 Meter hoch" from the *Münchner Neuesten Nachrichten*, Oct 24, 1938. Article on Pezzi's height record and the pressue cabin being used.
- Paper clipping "In luftdicht abgeschlossener Kabine" from the *Berliner Morgenpost*, Oct 24, 1938. Article on Pezzi's height record and the pressure cabin.

LRD 00691

- Paper clipping "Georges Détré a battu le record mondial d'altitude" from the *Les Ailes*, Aug 20, 1936. Article on the height record of Détré.
- Paper clipping "Ueber 15000 Meter hoch im Flugzeug" from the *Deutsche Allgemeine Zeitung*, Oct 1, 1936. Article on Swain's height record, which speaks of a "near death" situation for Swain.
- Paper clipping "Grâce à un nouveau compresseur à deux étages le chef d'escadrille Swain monte à 15.230 mètres" from the *Les Ailes*, Oct 8, 1936. Article on Swain's height record, with a short paragraph on the Haldane-Davis suit ("La scaphandre du R.A.F."), it is pretty much the same information as in the British papers, so this seems to have been the standard RAF press release.
- Paper clipping "La conquête du record d'altitude par l'Italie" from the *L'Echo Des Ailes*, May 20, 1937. Article on Pezzi's first height record (with the suit).
- Paper clipping "Der Kampf um die Stratosphäre" from the *Deutsche Bergwerk Zeitung*, Oct 27, 1938. Article on height records, with a focus on Pezzi.

LRD 00700

- Memorandum of Zindel (Junkers airplane design office) on high altitude flying, "Zur Frage des Höhenflugzeuges im allgemeinen und des militärischen Höhenflugzeuges im Besonderen", April 23, 1930. Together with an introductory letter from Junkers employees Merkatz and Saldern (Junkers administration).

LRD 00701

- Article in the *Stuttgarter N.S.-Kurier*, Abendausgabe, Feb 15, 1937, on Piccard's new plans to ascend to 32km height with "children balloons", as the paper called them.

- Article Swan (1937).

- Article Anonymous (1955), including a photocopy of the original manuscript.

- Paper clipping "Vor den ersten Stratosphären-Flügen" from the *Anhaltinische Tageszeitung*, May 26, 1932.

- List of Junkers patents on pressure cabins, compiled by a department of Junkers (T.W.B.-Hsn./se.), dated June 28, 1938. Two pages with six patents listed on them.

- *Bilder* press release from July 22, 1940, on the Boeing "Strato Chamber".

- *DT Paris* press release from March 03, 1937. The French Air Secretary Pierre Cot is indirectly quoted as saying that the state will not sponsor high-altitude research, because it is considered unimportant for the defense of the country.

- *itav* press release no. 547 from Aug 25, 1938. Experiments by Drs. Richou and Artola are detailed. A pressure equivalent of a height of 7000m was simulated in the pressure chamber at *La Bourget*, whilst breathing oxygen at a pressure equivalent to 4000m. No physical or psychical distress is experienced. Two canaries in the pressure chamber became 'height sick' and three fish died of hypoxia.

- *itav* press release (no number given) from Oct 11, 1938. Richou and Artola were situated in the pressure chamber at *La Bourget* at a height equivalent of 10000m, breathing oxygen at 500l/h. After two hours severe pain in the joints was experienced, the oxygen having little to no effect. Richou concluded that for flights above 10000m either a pressure suit or pressure cabin would be required.

Junkers-Archiv

The archive of the DM also has the remnants of the archives of the companies Junkers, Messerschmitt and Heinkel in its possession, Germany's biggest and most influential aircraft producers. There was not much material on the development of pressure cabins in the archive though. This somewhat indicates the low priority that this topic had among those manufacturers.

So the only actual archive material from the Junkers-collection are letters between Junkers and the engineer Klose, who had attained a patent on a pressure chamber in 1926 (cf. Klose, 1926). In the letters Klose and Junkers negotiate the royalties Klose wanted for licensing the patent to Junkers.

0303-T22

- Letter with a copy of a contract between Klose and the Junkers company, Jan 9, 1930. Conditions and terms of use of the patent Klose held are outlined.

- Letter from the Junkers company to Klose from Jan 20, 1930, with further details on the payment.

- Letter from Klose to Junkers, Jan 20, 1930, acknowledging the letters of Jan 9 and 20, and agreeing to the conditions in question, again stating that he is the sole patent-holder.

- Letter to Klose from Junkers, April 23, 1930, giving approval of all the conditions negotiated in earlier correspondence.

Wissenschaftliche Berichte

The archive of the DM also has a large amount of scientific reports in its collection. This concerns both the ZWB and the CIOS / BIOS / FIAT reports. The ZWB (Zentrale für Wissenschaftliches Berichtswesen in der Luftfahrtforschung) was installed by the German Air Ministry in 1934 and was published under the auspices of the *Generalluftzeugmeister* (Technical Director). The ZWB had an index of all scientific and technical reports published by German aeronautical establishments and research institutions. (Cf. FIAT, 1945).

The CIOS/BIOS/FIAT reports were authored by Western Allied intelligence teams and were directed at outlining the structure of German industry and science. The purpose of this effort was to find out about war crimes etc. for the Nuremberg trials (and others), to analyze the intertwining of German industry, science and the state, to *de-nazify* the German industry and science, and last but not least to survey whether technical or scientific achievements were made by the Germans that could be of use to the Allies.

The archive of the DM possesses a good number of ZWB and CIOS / BIOS / FIAT reports. While the collection is not complete, the volume is impressive. All ZWB and CIOS / BIOS / FIAT reports referred to in this publication were found in the archive of the DM.

Firmenschriften

The archive of the DM also hosts a good number of historic publications of German (and other nations) industrial companies (*Firmenschriften*, FS). The ones that were of major interest to me were those from Dräger and Auer:

- FS 928: Various price lists and brochures of Dräger.
- FS 929:
  - Manual for the Oxygen Rescue Apparatus (Dräger-Sauerstoff-Rettungsapparat), Modell 1910/11, from October 1915.
  - Field instruction HSS, Army Oxygen Protection Apparatus (Dräger Heeres-Sauerstoff-Schutzgerät), issued July 1918.
  - Manual for the Dräger T20 diving apparatus, May 1917.
- FS 930: Dräger catalog "Diving Appliances" from September 1919.
- FS 931: Reports of rescue operations with the Dräger *Pulmotor* and Breathing Apparatus.
- FS 932: Brochure "Dräger-Gürtel-Taucher-Apparat" (Dräger Belt Diving Apparatus), 1917.
- FS 933: Brochure "Der Retter Sauerstoff" (Oxygen as savior), 1909.
- Also: various catalogs from 1906, 1910, 1930 and brochures and catalogs after 1945 from Dräger.
- FS 214: Various brochures and manuals for gas masks from the *Auergesellschaft GmbH*, Berlin.

National Library of Scotland

The *National Library of Scotland* (NLS) in Edinburgh (UK) – among other things – is host to a huge archive collection (in the Manuscript Section of the NLS) on the Haldane family. The material on John Scott Haldane and JBS Haldane is very voluminous and includes notebooks, correspondence and manuscripts (some unpublished). Listed will be only those quoted directly and indirectly in this publication.

Box MS 20233

- F158–161: Haldane's first report on gas warfare: "MEMORANDUM. ON ASPHYXIATING GASES. AND VAPOURS, USED BY GERMAN TROOPS AND ON MEANS OF PROTECTION AGAINST THEM.", May 3rd, 1915.
- F162–164: Letter (handwritten) from C.G. Douglas to JSH, Date: May 10 [1915, added by archivist], detailing progress with the distribution of the respirators in the Army.
- F191: Letter from John Cadman to JSH from July 8, 1915. Cadman was asking Haldane for his opinion on a certain war gas.
- F221–222: Report of Capt. F.C. Vincent (T.W.R.5), Sep 30, 1916: "Confidential. SALVUS AND OTHER BREATHING APPARATUS. Two sets of Captured German Breathing Apparatus."
- F223–F232: Letter from Douglas to Haldane, Nov 13, 1916, describing Davis' prototypes for gas masks and oxygen apparatuses and other issues.
- F233–235: Typewritten Report from John Cadman on captured small German breathing apparatuses. The apparatuses (Dräger) were tested for 1.5h and still had enough gas left for another 30min, something that impressed the Britons and encouraged them to find out the mechanism of the device.
- F236–240: Typewritten Report, no author, no date (ca. 1916?), with handdrawn figures: "REPORT ON GERMAN APPARATUS. (non-regenerative type. Helmet pattern)."
- F241–242: Report on a comparative study of German and British breathing apparatuses by F.C. Vincent, Staff Captain, dated 06/12/1916, with the answer from Cadman appended, who disagrees with Vincent, calling the British *Salvator* and *Proto* superior to the German equipment.

Box MS 20234

- F45: Letter from Alex Richardson (Dept. of Scientific and Industrial Research, London) to JSH from Nov 12, 1917, presenting the following reports.
- F46–51: Report "Confidential. German Mine Rescue Apparatus found in the Captured Mine Systems after the Battles of the Somme, Anere, Vimy, Arras and Messines.", no date or author specified, but apparently not from Haldane.

- F68–69: Report from C.G. Douglas, R.A.M.C., dated Feb 27, 1918: "EXAMPLES OF CASES OF GAS POISINING TREATED BY OXYGEN ADMINISTRATION BY HALDANE APPARATUS".
- F108: Manuscript by Haldane: "SECRET. Apparatus for Continuous Administration of Oxygen.", not dated.

Box MS 20235

- F51: Letter from K.R. Park, Oxford University Air Squadron to JSH, Nov 24, 1933. Refers to a conversation Park and JSH had had a few days before. Tells Haldane he spoke to the Research Dept. of the Air Ministry, which has given him permission to tell JSH confidentially about RAF plans to construct a plane for a height record attempt.
- F61–62: Letter from Alfred Dehenden, Wembley Park to JSH, Feb 17, 1934. Speaks of plans to construct a pressure-cabin airplane. Discusses physiological parameters.
- F82: Letter from Hiram Bingham Jr. (Third Secretary of the Embassy, Embassy of the United States, London) to JSH, June 14, 1934. Asks JSH to compensate them for the telegram the embassy sent to Rufus Dawes in Chicago. This telegram was supposed to gain support from Dawes for the contemplated ascent of Ridge.
- F83: Copy of the telegram sent to Dawes.
- F84: Letter from Eva Spencer of Spencer Brother Ltd., Aeronauts and Balloon Manufacturers, London, Sep 07, 1934, to JSH. Short notice that the plans for a balloon could be carried out once her brother was back from hospital and had recovered.
- F85–86: Letter from Ridge to JSH, Oct 09, 1934. Reports that Monk said that Jean Piccard agreed to loan his balloon for 5000 US$. Says he asked NGS for funding.
- F87–88: Letter from Ridge to JSH, Nov 10, 1934. Reports that the newly elected Governor of Massachusetts is a relative by marriage of Ridge and is willing to support Ridge's cause. Also speaks of other persons like Piccard and Monk.
- F89–90: Letter from Ridge to JSH, Nov 26, 1934. Reports that Piccard hasn't answered Ridge's letters yet. Ridge proposes to write to Albert Einstein to get his support for the balloon flight so that the public interest might rise. Asks whether Haldane could write to Einstein.
- F92: Letter from F.J. Smith of the Royal Society to JSH, Jan 28, 1935. Explains to JSH why his grant application has not been considered yet.

- F123: Letter from Ridge to JSH. Only one leaf of the letter has remained, the one with the date missing. Ridge reports on cold chamber tests.

- F137–138: Project outline of JSH's grant application to the Royal Society: "Suggested Report to the Council of the Committee as to the desirability of instituting British Stratosphere Explorations by Balloons."

- F212–217: Obituary from Yandell Henderson on JSH for the *Journal of Industrial Hygiene*, not dated.

- F218–219: Obituary on JSH in *The Times*, authored by C.G. Douglas. Mar 16, 1936.

- F220–221: Obituary on JSH in *The Scotsman*, Mar 17, 1936.

- F239–246: Obituary on JSH by JBS Haldane, not dated.

- F247–252: Obituary on JSH by Naomi Mitchison, not dated.

Box MS 20510

- F192–195: Letter from Leonard Hill to JS Haldane, July 16, 1906. Many proposals by Hill on how to conduct joint experiments, also a sketch and an account on the submersible decompression chamber.

- F198: Letter from Hill to JS Haldane, July 24, 1906. Hill expresses his disappointment about Haldane's rejection, albeit trying to take it easy.

Box MS 20513

- F38–39: Letter from Damant to JSH, Sep 29, 1930. Discussing the work on the Haldane tables that Damant is doing for the Second Admiralty committee. Also sends a copy of an article of his in "Nature" to let JSH comment on.

- F40–41: Copy of the article in "Nature" mentioned above. Has written comments by JSH in the margins.

- F109–111: First letter from Ridge to JSH, July 07, 1933. Details his project and asks JSH for his assistance in regard to the pressure suit. Proclaims to have support from Drinker, Millikan, and Compton, and that student's of Drinker had already designed a pressure suit, but that the US Navy refused to let him test it in their pressure chamber because they considered it too dangerous.

- F116: Letter from Leslie W. Orton, "honorary president" of the "Anglo-American Radio & Television Society", to JSH, Jan 03, 1934. Has read the articles on Ridge and Haldane in the Daily Mail and offers radio equipment to JSH so that he could stay in contact when Ridge ascends into the stratosphere.
- F141–144: Manuscript from Boycott "Copy of Notes for Discussion on Paper Read January 8th, 1935, at the Institution of Civil Engineers on the Construction of the Silent Valley Reservoir, Belfast". Boycott discusses the times in Haldane's diving table and arrives at shorter decompression times.
- F147: Letter from "Mr. Malcolm, Auto. & Mech. Consulting Engineer" to JSH, Jan 29, 1935. Heard of the pressure suit from the newspapers and offers his help. Also reports of some of his inventions, which seem rather crude.
- F164: Letter from Ridge to JSH, July 08, 1935. Ridge reports that a Lester Yardner had shown interest in the suit, and wanted to license it to have it manufactured in the USA. No further information on that person is given (Ridge refers to the "last letter", in which he wrote about Yardner already; this letter does not seem to be in the NLS).
- F165: Letter from David Anderson of "Mott, Hay & Anderson, Chartered Civil Engineer, London" to JSH, July 12, 1935. Discusses JSH's counseling work done on the "COMPRESSED AIR COMITTEE".
- F217–218: Letter from Leonard Hill to JSH, not dated. Discusses decompression issues, also mentions the submersible decompression chamber and that he has not published anything on it, but that Siebe & Gorman attained a patent on it.
- F221-225: Handwritten manuscript, not dated, by JSH: "The Institition of Civil Engineers. The precautions needed to prevent illness due to work in Compressed Air."

Box MS 20514

In this box are stored Haldane's manuscripts connected to the "Admiralty Committee on Deep Diving".

- F2–109; Manuscript of Haldane et al. (1907).

Box MS 20515

- F106–107: Typewritten memo by Haldane on protection from gas, not dated, but since he refers to the committee from which he was removed in 1916, it must be from 1915/16.

Box 20659

Letters to his mother, 1888–1895.

- F23–25: Letter from JSH from Apr 24, 1888, when residing in Freiburg, Germany. Writes about his walks in the Black Forrest and that he took German grammar classes from a German student living in the same house in Freiburg as he does.

- F244: Letter from JSH from Nov 26, 1892. Writes that they (JSH and his wife) have decided to name their son "John Burdon Sanderson" and call him "Jack" for the sake of simplicity.

Box 20660

Letters to his mother and his sister, 1895–1936.

- F297: Letter to his sister, not dated, "1915" added by archivist. Refers to high flying of "R.F.C. men", and JSH and Priestly being in charge of "testing apparatus" for such purposes.

Churchill College Archives Center

The *Churchill College Archives Center* (CCAC) in Cambridge (UK) hosts, among other material, the archive collection of Archibald Vivian Hill. A noted physiologist he spent most of his time teaching and researching at the University College London, and later in Cambridge. Among the archival items concerned with Hill there are two boxes with correspondence with or regarding John Scott Haldane. The items used in thesis were (items not paginated):

Box AVHL II 4/21

- Letter from Claude Gordon Douglas to Hill, dated July 8, 1925. Handwritten on paper. Douglas worried about Haldane's pamphlets against thermodynamics, asks Hill for help.

- Letter from Claude Gordon Douglas to Hill, dated July 15, 1934. Discussing Haldane's nomination for the Copley Medal, and lists Haldane's achievements. Offers to write the proposal.

- Letter from Claude Gordon Douglas to Hill, dated November 2, 1934. Expresses his delight that Haldane was awarded the Copley Medal.

Box AVHL 3/29

- Letter from Haldane to Hill, dated October 25, 1920. Handwritten on a letter card, imprint "Cherwell, Oxford". Haldane lays out his philosophy of biology.

- Letter from Haldane to Hill, dated July 16, 1925. Handwritten on a letter card (with black frame). Haldane defends and outlines his view on thermodynamics.

- Letter from Hardy to Hill, not dated. However, Douglas (in his letter from July8, 1925, see above) has asked Hill to talk Hardy into writing a letter to Haldane in order to hold him back from publishing his pamphlets against thermodynamics. Hardy refuses to do so in this letter, commenting on it very sarcastically.

- Letter from Haldane to Hill, dated January 19, 1930. Handwritten on a letter card, imprint "Cherwell, Oxford". Haldane vigorously attacks Hill as "mechanist": "[You] make life into machinery!"

- Handwritten note (on Haldane's misconception of thermodynamics) by Hill, apparently as a retrospective remark. The note is on the torn out margin of a newspaper (Cambridge University Reporter, 27 May 1970).

- Another note by Hill (on Haldane's rank as a scientist), written on a small piece of paper, which appears to be the backside of an advertisement letter from a life insurance company. Judging from the quality of the paper and the font style this piece of paper is from c. 1970.

- Typed manuscript of the proposal to the Royal Society for the Copley Medal, some corrections and strikeouts. Apparently authored by Douglas for Hill (see letter above).

Box AVHL 4/35

- Letter from Yandell Henderson, dated May 1, 1925. Reply to Henderson's invitation to a meeting of the British Association. Discussion of Henderson's and Haggard's ideas on muscular work compared to Hill's ideas.

- Letter from Leonard Hill to A.V. Hill, dated March 16, 1949. Discussion of the space suit proposed by the British Interplanetary Society.

- Letter from A.V. Hill to Leonard Hill, dated March 18, 1949. Reply from A.V. Hill to Leonard Hill's letter from March 16.

Also in the Archive, there is a small collection on Thomas Graeme Nelson Haldane, nephew of John Scott Haldane (son of JS' brother William). Most of it concerns Thomas' work as an engineer though, besides some correspondence with his father William. There are two letters from Naomi Mitchison to Thomas discussing Naomi's paper to the Royal Institution (a biography on JS and JBS Haldane). Furthermore there is correspondence with the NLS discussing how and which material should be given to the NLS for the Haldane-Archive, besides copyright issues.

Royal Geographical Society

The *Royal Geographical Society* (RGS), London (UK), has in its possession material from the *Joint Himalayan Committee*, the *Mount Everest Committee* and the *Mount Everest Foundation* from the 1920s on the Himalaya expedition of Mallory et al. Some very interesting material could be found in the archives:

- File ref. EE/13/3/12; Letter from Hon. Secretary O. E. Simmons from the Royal Aircraft Establishment Technical Society (RAETS) to the Secretary of the RGS, dated October 28, 1922. Simmons asks for lectures by RGS people at the RAETS, since high altitude flying and mountaineering share common physiological issues.
- File ref. EE/29/8; no date and author given, but catalog says could be from 1925 and from Leonard Hill; Meteorology
- File ref. EE/29/8/12; Copy of typed memorandum by Leonard Hill entitled "Mt. Everest Expedition. Tests of fitness to be carried out at various altitudes" (2p., no date)
- File ref. EE/30/5/1; various manuscripts between 1922–1926; Typed letter from Capt. Farrar, Alpine Club to Hinks of 28 Feb. 1922 enclosing circulars on oxygen and oxygen apparatus sent to all climbers involved in the 1922 expedition. The circulars include notes by Professor Leonard Hill on the generator inhaler; Flack's breathing exercises, Prof. Hill's suggestions for fitness tests carried out at various altitudes; a memorandum on the oxygen equipment, laying out the bottles etc. 20p.

Royal Institution of Great Britain

The *Royal Institution of Great Britain* (RI), London (UK), hosts various collections on British scientists. Among them are James Dewar and William Bragg who both had contact with Leonard Hill. The Bragg collection, which includes correspondence with Hill (File e - ref. W.H. Bragg/27E - date: 1933-1939) was on topics not too interesting for this publication (chiefly discussions on resuscitation apparatuses like Hill's *pulsator*, the *Drinker Lung* and the Dräger *pulmotor*.

More interesting was the correspondence with Dewar, who counseled Hill and Flack on breathing apparatuses for aviation and gas protection in World War I. Dewar had developed a liquid oxygen system in which the oxygen was stored in a thermos flask and was brought back to gaseous form with electric heaters inside the system, and with which the amount of oxygen coming out of it was electrically regulated, i.e. by regulating the electricity applied. Dewar also developed a means of producing charcoal with a very high rate of absorptive capacity for various gases. He willingly shared his knowledge with various government bodies like the Gas Warfare Committee and with Hill and Flack.

File b: War work - ref. DEWAR/DVIIb - date: 1917-18

- Leonard Hill to James Dewar - ref. DEWAR/DVIIb/20 - date: 19 Aug. 1917; Hill informs Dewar that he is heading to Skye for government work, namely for interrogating German POWs, supposedly pilots who had been carrying high-altitude breathers with them.

- James Dewar to Martin Flack- ref. DEWAR/DVIIb/21 - date: 20 Aug. 1917; Dewar wishes to know from Flack whether his apparatus is actually being used in aeroplanes. Mentions that his idea of the metallic flask was first detailed in a paper by Dewar from 1912; and he wants to see his liquid oxygen apparatus in use in hospitals after the war.

- James Dewar - ref. DEWAR/DVIIb/24 - date: 02 Sept. 1917; General points brought forward in interviews with Dewar, given personally by Major Filon, Dr Leonard Hill and Capt Finch at the Royal Institution, with experimental illustrations, liquid oxygen apparatus etc. Discusses metallic vacuum vessels and suggests improvements to the German apparatus, commenting on the supply of liquid oxygen in Germany and on the German molecular pump for high exhaustion.

- Secretary of the Air Board, Healy, to Derwar, ref. DEWAR/DVIIb/27 - date: 07 Sept. 1917; Healy officially expresses the Air Board's thanks to James Dewar "for the advice and assistance [...] in connection with investigations of liquid oxygen apparatus".

- Martin Flack to James Dewar - ref. DEWAR/DVIIb/31 - date: 12 Sept. 1917; Flack mentions that he is collaborating with Dreyer to get the latter's oxygen apparatus ready for field use.

- Capt. Heald to James Dewar - ref. DEWAR/DVIIb/33 - date: 17 Sept. 1917; Heald, secretary of the RAMC, informs Dewar that the “Air Board Research Committee (Medical)” has officially expressed their gratitude at their last meeting for Dewar’s advice on liquid oxygen apparatus.

- Martin Flack to James Dewar - ref. DEWAR/DVIIb/35 - date: 18 Sept. 1917; Flack mentions that he tested a reconstructed German breathing apparatus (the “Hun apparatus”), but had trouble with it.

- Martin Flack to James Dewar - ref. DEWAR/DVIIb/37 - date: 19 Sept. 1917; Flack managed to get the “Hun apparatus” working.

- Leonard Hill to James Dewar - ref. DEWAR/DVIIb/42 - date: 25 Sept. 1917; Hill tells Dewar that JS Haldane and others are developing a liquid oxygen system. Hill fears that this might breach Dewar’s patents, and urges him to sort out issues with his system and have Siebe & Gorman produce it.

- James Dewar to Martin Flack - ref. DEWAR/DVIIb/44 - date: 27 Sept. 1917; Comments on information which Flack should have obtained easily from the Liquid Air Rescue Stations. When Levick produces vessels, would be pleased to see them. Comments on pressure gauges and valves he wants. Has been engaged in Leonard Hill’s problem; comments on this.

- Leonard Hill to James Dewar - ref. DEWAR/DVIIb/48 - date: 02 Oct. 1917; Hill mentions that the new mining rescue apparatus from Siebe & Gorman on which Hill has collaborated, should be named the “James Dewar” dress.

- Leonard Hill to James Dewar - ref. DEWAR/DVIIb/49 - date: 05 Oct. 1917; Hill compares the mining breathing apparatus to the high-altitude breather. The former must totally enclose the user (because of the carbon-monoxide), whereas for pilots the surrounding air could be sucked in and enriched with oxygen.

- Leonard Hill to James Dewar - ref. DEWAR/DVIIb/50 - date: 05 Oct. 1917; Hill outlines that the oxygen flow must be higher for the mining breathing apparatus because they have to escape the mine, which is more strenuous than flying.

- Martin Flack to James Dewar - ref. DEWAR/DVIIb/58 - date: 02 Nov. 1917; Hill reports that Dewar’s oxygen apparatus has been demonstrated to Royal Navy personnel, who were impressed. The National Physical Laboratory however, has developed a very similar device.

- Capt. Heald to James Dewar - ref. DEWAR/DVIIb/59 - date: 09 Nov. 1917; Heald forwards a resolution by the "Flying Services Medical Advisory Committee" from their last meeting, in which they officially express their gratitude for Dewar's advise given to Martin Flack on the Liquid Oxygen Apparatus.

- Leonard Hill to James Dewar - ref. DEWAR/DVIIb/61 - date: 05 Dec. 1917; Hill proposes to give Dewar's improvement of the German oxygen apparatus to the Gas Warfare Committee, as the Air Board seems not be able to get it produced. Dewar should collaborate with Robert Davis to manufacture it on a larger scale.

- Leonard Hill to James Dewar - ref. DEWAR/DVIIb/62 - date: 20 Dec. 1917; Hill proposes to Dewar that he should license his patents on the oxygen apparatus to the Medical Research Board and have the royalties invested into medical research. As the German device is so similar he is concerned that "The patent must be taken out by somebody to prevent the Hun exploiting it after the war."

- Copy of a report by Martin Flack: "Report to the Air Force Medical Advisory Committee on the present position in regard to Oxygen Apparatus. By Captain Martin Flack, RAMC", - ref. DEWAR/DVIIb/65 - no date. Reports that at present a Siebe & Gorman apparatus is used by RFC pilots. Dreyer is currently preparing his device in Paris. German apparatuses are evaluated and compared to the British ones, incl. Dewar's one. The German device and Dewar's are nearly equivalent in oxygen delivery at high altitude.

- James Dewar to Leonard Hill - ref. DEWAR/DVIIb/91 - date: 7 Feb. 1918; Dewar is frustrated with technical incompetence in the Air Board and its engineers.

- Leonard Hill to James Dewar - ref. DEWAR/DVIIb/92 - date: 14 Feb. 1918; Hill begs to give advice to the Air Board on how to produce the oxygen containers.

- Alex Peddler, chairman of the "Committee No. 5 (Medical Supplies)" of the "Department of the Surveyor General of Supply", to James Dewar - ref. DEWAR/DVIIb/96 - date: 12 Apr. 1918; Peddler hopes to consult Dewar on his "suggested scheme for a practical trial in the Field of the Oxygen Apparatus" in the next days.

- Report "The Department of the Surveyour-General of Supply. Committee No. 5 (Medical Supplies). Minutes of the 28th Meeting." - ref. DEWAR/DVIIb/117 - date: 02 May 1918; Among other things liquid oxygen containers are discussed. German apparatus is evaluated which has oxygen for "five hours". Proposes to produce 100 Dewar containers and try them in France.

- James Dewar to Briggs from Mining Dept., Herriot College, Edinburgh - ref. DEWAR/DVIIb/113 - date: 09 May 1918; Dewar answers a letter from Briggs (DEWAR/DVIIb/112). Says that Briggs method to create a vacuum is not novel, and that the Germans gained the rights to Dewar's patent to produce a vacuum though absorption with charcoal before the war, and used it throughout it.

File c: Admiralty Board of Invention & Research & others - ref. DEWAR/DVIIc - date: 1915-18

- Heald to James Dewar - ref. DEWAR/DVIIc/57 - date: 16 Nov. 1917; Heald asks about the amounts of oxygen required at various heights.

- James Dewar to Heald - ref. DEWAR/DVIIc/58 - date: 17 Nov. 1917; Dewar replies that he is only a chemist and physicist, and therefore not qualified to give advise on physiological issues. Refers to a conversation he had with Flack about this topic.

- Medical Research Committee (W.M.Fletcher) to James Dewar - ref. DEWAR/DVIIc/61 - date: 1 Dec. 1917; Is sending copy of Committee's Annual Report. In this the Committee has thanked Dewar for his assistance to Leonard Hill. No mention has been made of Dewar's help to Hill and Capt Flack in connection with problems of flying at high altitude because they were given to understand that this should be regarded as confidential at present. Asks if he might call to see Dewar to discuss questions relating to this, including commercial supply of oxygen for medical purposes.

Royal Aeronautical Society

The *Royal Aeronautical Society* (RAeS) in London (UK) has a great number of old aviation magazines and original photographs. Some original material is stored in their special collections, including an archive of the aeroplane manufacturer *Bristol* (henceforth referred to as the *Bristol-Collection*, BC), who was behind the British height record flights of the 1930s. Hence, some interesting reports and correspondence could be found.

- "Report on a high altitude flight made on the 23rd Sep 1937, Flight Lt. M.M. Adam, to: Officer Commanding, Experimental Flying Section, R.A.E. Date: 30th Sep 1937". Report discussing flight tests, notes on the pressure suit included.

- Letter from A. P. Puitt (RAE South Farnborough), dated September 10, 1936 to Mr. C.W. Tinson, B.A. Co. Discusses issues on press releases, no material is cleared until the record flight is achieved.

- Minutes of a meeting at Bristol, dated November 13, 1935. R. Davis and J. Gunn from Siebe & Gorman are present to discuss the placing of the oxygen pressure gauge on the cockpit dashboard.

- Minutes of a meeting in Filton, dated June 14, 1935. R. Davis of Siebe & Gorman is present, but does not participate much. Discussions are on technical issues of the plane, including the machine gun that might be attached if needed.

- "Air Ministry, Directorate of Scientific Research; Ref No. 329959/34; Spec No 2/34: Aircraft for operation at high altitudes; Approved by D.R. Frye for Directorate of Scientific Research; Date: 28/04/1934". Specifies the features the plane should have: generally one seated, but should be easily expandable to two seats; installation of either a) machine gun (.303 Vickers), b) electrically-operated camera, type F.24, or c) an R/T set, type T.R.X.9.

Oxford Physiological Laboratory

The *Sherrington Library* (SL) is the library of the *Physiological Laboratory* of the *University of Oxford* (UK). This was the laboratory where J.S. Haldane, J.G. Priestly, J. L. Smith, M. P. Fitzgerald, C. G. Douglas and others all worked (on the campus where the lab is, there is a small dead end street named after J.S. Haldane). The library holds a collection of C.G. Douglas's archival material, mostly correspondence and manuscripts, much of it relating to Haldane, and shows Douglas' devotion to him.

Folder B.22 & B.23

Manuscripts by Douglas, those of interest were:

- Manuscripts for the "Conference on the physiology and pathology of gas poisoning", Nov 17–19, 1917, in Paris.

- Manuscripts for the "International conference on gas warfare", March 1–5, 1918, in Paris.

Folder B.32

- Letter to JS Haldane, dated September 15, 1916. Discussing gas poisoning.

Folder B.33

- Various letters to and from Yandell Henderson to Douglas, discussing gas poisoning. Henderson was member of the US committee on gas warfare.

Folder C.11

- Letter from Henderson to Douglas, dated August 27, 1935. Henderson asks Douglas whether he could propose Haldane as *Professor Emeritus*. Much praise for Haldane.

- Letter from Henderson to Douglas, dated March 28, 1936. Expresses grief over Haldane's death.

- Letter from Henderson to Douglas, dated April 7, 1936. Tells Douglas that he was asked to write an obituary for the *Journal of Industrial Hygiene*, also congratulates Douglas on the obituary he wrote that appeared in the *Times*.

Folder C.12

- Letter from Naomi Mitchison dated June 10, 1936. Gives Douglas the address of her aunt so Douglas can retrieve some more information for his obituary on Haldane for the *Royal Society*.

- Letter from Cyril Harcombs (Ministry of Transport) dated June 29, 1936. Explains Haldane's efforts on counseling in the Dartford-Purfleet-Tunnel planning and expresses his delight at how convenient the cooperation was with Haldane.

Folder C.13

- Letter from JBS Haldane to Douglas March 22, 1936. Discusses the distribution of JS Haldane's manuscripts and apparatuses among Douglas, Priestly and Graham.

- Handwritten manuscript of a speech, which appears to be in the handwriting of Douglas. Many corrections and strikeouts. Not dated, seems to be the eulogy for Haldane's burial.

Folder C.14

- Letter from S.L. Cummins to Douglas, dated March 16, 1936. Wishes to attend Haldane's burial, asks for the date.

Folder A.20

- Letter from Yandell Henderson to Douglas, dated November 30, 1938. Discusses Henderson's new book "Adventures in Respiration" and his scientific claims therein. Some words on the Pike's Peak expedition.

Bundesarchiv/Militärarchiv

The German *Bundesarchiv* (Federal Archive) with its *Militärarchiv* (Military Section, BA-MA) in Freiburg im Breisgau holds most of the official records from military divisions and institutions of German history. Much material was destroyed in World War II during allied bomb raids on Berlin, where the archival items were stored before 1945. Allied Forces also took much material back to their respective home countries. While most of these records have been returned, it remains unclear if all of the records were given back.

For the investigations for this publication the records from the Technical Division of the *Reichsluftfahrtministerium* (RLM, German Air Ministry) concerning the pressure suit development were most interesting. The material available on this topic was scarce though. Additionally, minutes of meetings in the RLM, Technical Director Milch, were consulted to see how high-altitude flying was discussed during the war.

RL 3: Files of the "Generalluftzeugmeister"

Folder 24: Minutes of the meeting

This folder contains various minutes of the meeting in the office of Milch, with *Luftwaffe* officials and aircraft industry engineers and administrators taking part.

- F214–318: Meeting on August 17, 1943, RLM Berlin. Discussing and comparing the various models of high-altitude fighters from Messerschmitt and Focke-Wulf regarding performance. General Galland was displeased with the lack of working pressure-cabins. Milch, Galland, Messerschmitt, Tank and others present.

Folder 37: Minutes of the meeting

This folder contains various minutes of the meeting in the office of Milch, with *Luftwaffe* officials and aircraft industry engineers and administrators taking part.

- F311–421: Meeting on May 28, 1943. Discussion over performance specification in respect to high-altitude fighters between Milch, Galland and others.

- F3–145: Meeting on June 15, 1943. Discussing various issues including high-altitude flight.

Folder 60: Minutes of the meeting

Various minutes of the meeting from sessions at Milch's office or Göring's private residence Carinhall in late 1942 and early 1943. Among other things issues in high-altitude flying are discussed. Göring is quite irated over the slow progress being made in this field – as in aircraft production and innovation in general.

Folders 156, 248, 262, 269, 418: Documents related to the Dräger's high-altitude breather

Various documents related to Dräger's high-altitude breather and its use by the Luftwaffe.

- 156: Guidelines for using the high-altitude breather. July 2, 1934.
- 248: Letters from Dräger to RLM with suggested prices for the breather, and instructional boards. January & March 1936.
- 262: Report from Hirschlauer to the senate of the RLM, December 1934. Among other things suggests the purchase of new high-altitude breathers from Dräger. The ones used so far were usable up to 7000m height, the newer ones supposedly higher.
- 269: Documents dealing with high-altitude breathers from Dräger and Auer, late 1936. Test reports, etc.
- 418: "Werkbericht" (Company report) on the Drägerwerke, Lübeck. 7 pages with address, commercial register entry, sales volume (1934/35), CEO, leading personnel, departments, types and number of engines and transport vehicles.

Folder 491

Various reports with tables and photos on the possibility of using the Junkers Ju35 as a bomber, from 1928. Installation of bay doors, brackets for 50kg and 300kg bombs and Goerz targeting devices are discussed. Photos of the Ju35 with mock-ups of bombs (made of wood) are included.

Folder 2516

This folder contains the "Vorläufige Vorschrift für Wartung der Höhenflugzeuge" (Engl: Preliminary Instruction to Maintain High-Altitude Airplanes), by the *General der Truppentechnik*, Dept. G/ IIC of the German Air Ministry from August 23, 1944. It details the instructions for the maintainance of high-altitude airplanes, like maintaining the pressure cabin or the oxygen apparatus.

Folder 1898

This folder contains a translation into German of a Soviet book on stratospheric flying. No author or date is given, the only indication of its Soviet origin is that the original figures were cut and pasted into the typewritten translation. The captions of these figures are all in Kyrillic letters.

Remarks on Pezzi's height record from 1938 are made, but no war activities are mentioned. It may thus be concluded that the book is from 1938/39. Also, in the appendix, Marshall Kliment Voroshilov (1881–1969) is addressed as the "People's Commissar for Defence". Voroshilov attained that post in 1934, and it was taken away from him in the winter war of 1939/40 due to his "incompetence". This reference to Voroshilov and his post as "People's Commissar" serves as another indication of the year 1938/39 as the creation date for the book.

The book as such deals with aviation medicine, discussing physiological limits and counter-measures like pressure suits etc. It refers to seminal works in the field like Paul Bert, Paul Garsaux, Jacob Jongbloed, and a number of Soviet aviation physiologists. It also displays pictures of Pezzi's and Herrera's suits and mentions the British height records with the Haldane-Davis suit and the Italian ones by Pezzi.

It gives a detailed account of the physiological and engineering aspects of pressure suits and cabins, citing numerous international publications in aviation medicine and general physiology. From the amount of pages dedicated to this topic it must be concluded that this compilation of material and its discussion makes it the most complete contemporary reference in pressure suit and cabin design. It looks as though the book, of which no original title is given, never made it into the international scientific community.

Folder 70: Pressure Suits

In this folder all the official German activities (i.e. those mandated by the Air Ministry) in pressure suit research are located. Since these weren't too volominous, neither is the folder. Besides the very interesting photographs, the folder actually consists of not much more than Tietze's report he prepared for the CIOS team and some original test reports from the war that were appended to Tietze post-war report. His report, plus the appendices and the photos give an accurate account of the suits designed on behalf of the Air Ministry, but not the discussion and testing phase. It is, however, the best and nearly only source of information on German pressure suit design, in regard to the official Dräger-Air Ministry cooperation. The folder consists of:

- Report "Prepared for the CIOS investigating team commander Vorwald. Bericht über Druckanzug-Entwicklung.", by Tietze, Drägerwerk Lübeck, May 18, 1945.
- Prüfbefund "Dehnungs- u. Zerreissprüfung an einem Seidenband, Protokoll Nr. 1386", by Tietze, Drägerwerk, Feb 25, 1936.
- Prüfbefund "Zerreiß- u. Dehnungsprüfung einer Seidenkordel, Protokoll Nr. 1258", by Tietze, Drägerwerk, Oct 11, 1935.
- Appendix to report prepared for the CIOS team: "Verzeichnis der von der Kommission ausgesuchten Bilder" (Directory of photographs selected by the committee)
- Chart "Höhengewinn durch Druckanzüge" (Altitudes attainable by pressure suits), by Tietze, Drägerwerk, 1943.
- Drawing "Arten der Druckanzüge" (Types of pressure suits), by Tietze, Drägerwerk, 1943.
- Technical drawing "Druckfestes Walzengelenk" (Pressure resistant pivot joint), by Tietze, Drägerwerk, 1943.
- Technical drawing "Gasdichtes Kugellager" (Gas-tight ball joint), by Tietze, Drägerwerk, 1943.
- Technical drawing "Gasdichter Schnellanschluß für Helm" (Gas-tight quick connector for helmet), by Tietze, Drägerwerk, 1943.
- Report "Versuchsbericht Nr. 0435: Laderanzapfung für Druckanzüge", by H. Ide, Schäffer & Budenberg GmbH, Magdeburg, Sept 24, 1943.
- Various photographs of the pressure suits designed by Drägerwerke, from 1936 and 1940–1945. All together there are 33 photographs of 12 different suits and 2 breathing masks.

RL 36: Reichswetterdienst

The *Reichswetterdienst* (RWD, National Weather Service) used to be a department of the German Ministry of Transportation, until it was transferred to be a department to the Air Ministry in 1935. Since Klanke was an employee of the RWD (as a "weather pilot") at the *Wetterflugstelle Köln* (Weather pilot's office, Cologne) at the time he constructed his pressure suit, I deemed it interesting to see whether there are any documents related to him or his department. According to the finding aids, however, most material on the RWD was destroyed in the war. So, actually there was only one relevant document:

- F186: "Personalstand 1935 RWD", a record of the personnel employed by the RWD from 1935. Upon the transfer to the Air Ministry, a list of employees and their data was made by all offices of the RWD, including the one in Cologne where Klanke was situated. The data included date of birth, date of employment, affiliation with the Nazi Party, degree, salary group, occupation. Klanke entered the RWD on April 27, 1931, after he finished his PhD (with an "A") the same year. He was not a party member and was employed as pilot.

RL 39: Forschungsinstitute der Luftwaffe

Folder 630

DVL-Bericht Vf 25/3 "Prüfung runder Fensterscheiben für das Höhenflugzeug Junkers J 49", 10.06.1932

Folder 644

DVL-Bericht Vf 15/9 "Bericht über die dritte Hochfahrt des Höhenballons 'Bartsch von Sigsfeld' am 11. Juli 1928" 10.08.1928, E. Thomas

Times Digital Archive

The archives of *The Times* (London) are accessible through the Internet (via `http://infotrac.galegroup.com/menu`) for subscribing organizations and individuals. The complete newspaper from 1785–1985 is full-text searchable, thus broad researches on persons etc. are possible. All quotations from and references to *Times* articles in this thesis were retrieved from the *Times Digital Archive*.

British Library, Newspaper Section

The *Newspaper Section* of the *British Library* (BL) in London (UK) was consulted to find contemporary newspaper articles on the British height records, especially on the Haldane-Ridge link. All citations and quotes of articles from the *Daily Mail*, *Flight*, *Aeroplane* etc. were retrieved from the BL.

Library of Congress, Microfilm Section & Newspaper Section

A short visit to the *Library of Congress* (LOC) in Washington DC was done to find contemporary articles from the *Boston Globe* and *Everyday Science and Mechanics*. The quotes and references from and to articles of said magazines were taken from copies of the respective magazines in the LOC.

Science Museum

In the 1960s, after Davis' death in 1960, Siebe & Gorman (SG) was sold and dissolved. The contents of the company's museum were finally handed over to the *Royal Navy Submarine Museum* in Gosport (UK), chiefly diving helmets and other equipment and manuals were handed over to the museum's library. Some remnants of SG materials were also handed over to the Science Museum in London (UK):

1. Ref. Nr. E2001.128.93, Siebe & Gorman Accounts book 1888–1897. Book lists account tasks done by SG, mainly repair jobs. Chief among these were fixings of refrigeration (the company's original orientation when Augustus Siebe obtained licenses for refrigeration machines in 1850) and diving equipment. The repair of diving equipment, especially the list of customers, shows the wide-spread use of SG equipment, having various engineering and salvaging companies in their ranks, besides the Royal Navy (UK), the Royal Navy of Spain and general "Government repair".

Science Museum Library

The *Special Collection* of the *Science Museum Library*, London (UK) contains – among other things – material on S. Pearson & Son Ltd, which was involved in the diving research by Haldane et al. in 1906 – 1908.

Box PEA Cowd 3

- 3/1: Report on the New York Improvement and Tunnel Extension, booklet, 34p. August 1910.

Box PEA 8

- Various memorandums and correspondence between S. Pearson & Son Ltd. concerning cost calculations for the East River Tunnel excavations.

Box PEA 46

- Among other items, documents on the Mersey Vehicular Tunnel project, incl. hearings before the parliamentary commission, incl. one from June 1925 in which J.S. Haldane is giving his opinion and expertise regarding expected carbon monoxide levels in the tunnel.

TIME online

The web-site of the *TIME Magazine* (`http://www.time.com`) offers an article archive from which individual items can be purchased. The archived articles are full-text searchable, allowing broad researches. All TIME-articles quoted and referenced in this thesis were taken from the online archive. Unfortunately the archive does not store the page numbers of the original publications.

Oral History

Interview partners from the eras my thesis is focused on are naturally hard to find anymore. *Oral History* as a method for my thesis was not really in my line anyway. Thus, I have restricted myself to one short telephone interview with Gerhard Klanke's son, Manfred Klanke (b. 1939), on August 14, 2006. The interview lasted 45 min. and did not reveal much on Klanke's design of the pressure suit, since his son wasn't even born at the time of its creation. Manfred Klanke didn't see his father much during the war, and – as was common among the war generation – after the war he didn't dare to ask his father about his activities before and during the war. Most information was thus concerned with post-war activities, besides some minor information about Gerhard Klanke's career in the 1930s. Manfred Klanke also still has his father's pilot logbook in his possession, though it did not reveal much. Since the information was comparably distant from my research field, I did not make a full transcript of the interview, but rather took only a few notes.

CEGES/SOMA

The Belgian CEGES/SOMA institute is a documentation center of the Second World War. Their archive can be searched on `http://www.cegesoma.be/Database/Catalogue_CEGES_SOMA/webOpacE.htm`. Through it I found the images of the Garsaux-Rosenstiel-Suit. The text for the pictures says that the original photo of image no. 42198 were taken by the *New York Times*, whereas no. 42321 was originally from *Service général de la presse*. There are also images of the crashed Renard R-35 available (image nos. 38569, 38571, 38573, 40111 and 40113), and a photo of pilot van Damme prior to the flight (image no. 40087). Furthermore, 17 pictures of Farman's high-altitude airplanes can be found.

Patents

I cite and quote a number of patents in this thesis, including drawings taken from these. All of the patents were searched on and retrieved from the online databases of the respective country's patent office:

USA: All US patents were retrieved from the *United States Patent and Trademark Office* (USPTO) homepage: `http://www.uspto.gov/patft/index.html`. Patents prior to 1976 are only searchable by number, date or classification. However, since newer patents have to list up earlier patents they refer to, a "snowball" search yielded good results.

UK: All UK based patents were retrieved from *European Patent Office* (EPO) espacenet database, British section: `http://gb.espacenet.com/`. The British Patent Office no longer maintains its own database, but has fully switched over to the EPO system.

All others: All other patents, i.e. from Germany and France, were retrieved from the *Deutsches Patent- und Markenamt* (DPMA, German Patent and Trademark Office) DEPATISnet database: `http://depatisnet.dpma.de/`. It includes patents from other European countries as well, searches by name and title are usually only possible from the 20^{th} century on, before that only by patent number.

Bibliography

Abramov, I.; A.I. Skoog; I.P. Abramov; and I. Skoog (2003): *Russian Spacesuits*. Springer, London.

Adorno, Theodor W. and Max Horkheimer (1997): *Dialectic of Enlightenment*. Verso, London & New York. Reprint of the 1944 original.

Akerman, John D. (1938): Letter to the Editor. *Journal of the Aeronautical Sciences*, 5(8):320.

Akerman, John D. (1943): *Pressure-Applying Aviator's Suit with Helmet.* Patent Specification 2404020, USA. Date of Application: March 10, 1943. Accepted: July 16, 1946.

Alford, B. R. (1998): Historical ties between otolaryngology – head and neck surgery and aviation and space medicine. *Otolaryngology – Head and Neck Surgery*, 118(3):2–4.

Allen, Garland E. (1967): J.S. Haldane: The Development of the Idea of Control Mechanisms in Respiration. *Journal of the History of Medicine*, 22(4):392–412.

Andrews, A.H. (1945): *The Aviation Medicine Organization of the Luftwaffe.* CIOS Target Number 24/36, Washington DC.

Anonymous, ed. (1903): *Protokoll über die vom 20. bis 25. Mai 1902 zu Berlin abgehaltene dritte Versammlung der Internationalen Kommission für wissenschaftliche Luftschiffahrt*, Strassburg. DuMont-Schauberg.

Anonymous (1936a): 49,967 Feet. New World Height Record established by the 'Bristol' 138a Monoplane and Pegasus Engine. *The 'Bristol' Review*, pp. 9–11.

Anonymous (1936b): Flugkapitän Neuenhofen und Ing. Kreft†. *Luftwelt*, 3(2):75.

Anonymous (1936c): Neue Höhenflug-Weltbestleistung. *Luftwissen*, 3(9):260.

Anonymous (1936d): Stand der Rekorde. *Luftwissen*, 3(5):133–135.

Anonymous (1937a): Height Record Home Again. *Flight*, 36:a–b.

Anonymous (1937b): Neuer Höhenweltrekord. *Luftwissen*, 4(5):158.

Anonymous (1937c): Stand der Rekorde. *Luftwissen*, 4(6):191–193.

Anonymous (1938): Supercharging for Passengers. *The Aeroplane*, 57:511–513. Report on Younger's presentation to the Royal Aeronautical Society, cf. Younger (1938b).

Anonymous (1939): Stand der Rekorde. *Luftwissen*, 6(6):210–212.

Anonymous, ed. (1941a): *Bericht über die Sitzung 'Höhenkabinen für Kampfflugzeuge' am 16. bis 18. Januar 1941 in Dessau*, Berlin. Lilienthal-Gesellschaft für Luftfahrtforschung. ZWB-Report LG 129.

Anonymous (1941b): Der heutige Stand des Höhenflugzeuges. *Technische Blätter, Wochenschrift der Deutschen Bergwerks-Zeitung*, (7):97–99.

Anonymous (1955): Deutsche Höhenflugzeuge. *Flugwelt*, (3):133–136.

Argelander, Hermann (1972): *Der Flieger. Eine charakteranalytische Fallstudie*. Suhrkamp, Frankfurt/M.

Armstrong, Harry George (1939): *Principles and Practice of Aviation Medicine*. Williams, Baltimore.

Armstrong, H.G. (1936a): Medical aspects of National Geographic Society - U.S. Army air corps stratosphere expedition of Nov. 11, 1935. *Journal of Aviation Medicine*, 7:55–62.

Armstrong, H.G. (1936b): Medical problems of sealed high-altitude aircraft compartments. *Journal of Aviation Medicine*, 7:2–8.

Armstrong, H.G. (1936c): Physiological requirements of high altitude aircraft compartments. *Aero Digest*, 29:25–28.

Armstrong, H.G. (1938): The Influence of Aviation Medicine on Aircraft Design and Operation. *Journal of Aeronautical Sciences*, 5(5):193–198.

Baldick, Chris (2004): *The Concise Oxford Dictionary of Literary Terms*. Oxford University Press, Oxford.

Balint, Michael (1959): *Thrills and Regression*. The Hogarth Press, London.

Barcroft, J.; C. G. Douglas; L. P. Kendall; and R. Margaria (1931): Muscular exercise at low barometric pressure. *Archivio di Scienze Biologiche*, 16(6):609–615.

Barcroft, Joseph (1925): *The Respiratory Function of the Blood*, vol. 1: Lessons from High Altitudes. Cambridge University Press, Cambridge.

Bauer, Louis Hopewell (1926): *Aviation Medicine.* Williams & Williams, Baltimore.

Beall, H. W. (1940): *Pressure Producing Apparatus.* Patent Specification 2335474, USA. Date of Application: Sept. 18, 1940. Accepted: Nov. 30, 1943.

Beers, Mark H.; Robert S. Porter; Thomas V. Jones; Justin L. Kaplan; and Michael Berkwits, eds. (2006): *The Merck Manual.* Merck Research Laboratories, Whitehouse Station (NJ), 18th edn.

Behringer, Wolfgang and Constanze Ott-Koptschaijski (1991): *Der Traum vom Fliegen. Zwischen Mythos und Technik.* S.Fischer, Frankfurt/M.

Benford, Robert J. (1979): *The Heritage of Aviation Medicine. An Annotated Directory of Early Artifacts.* Aerospace Medical Association, Washington D.C.

Bennet, Peter and David Elliot, eds. (1993): *The Physiology and Medicine of Diving.* W.B. Saunders, London, 4th edn.

Benzinger, Th. (1939): *Atemgeräte oder Druckkammer für Langstreckenflüge in 6-8000 m Höhe?* ZWB-Report Rech 194, Erprobungsstelle der Luftwaffe, Rechlin.

Benzinger, Th. (1942): Tätigkeitsbericht der medizinischen Abteilung der Erprobungsstelle Rechlin. In: *Jahrbuch der deutschen Luftfahrtforschung*, Oldenbourg, Berlin & München, p. 62.

Benzinger, Th. and W. Hornberger (1941): *Die Druckfallkrankheit der Höhenflieger.* ZWB-Report DAL 34-31, Deutsche Akademie der Luftfahrtforschung, Berlin.

Bernhardt, Karl-Heinz (2000): Zur Erforschung der Atmosphäre mit dem Freiballon – die Berliner wissenschaftlichen Luftfahrten (1888–1899). *Dahlemer Archivgespräche*, 6:52–82.

Bernhardt, Karl-Heinz (2004): Die Berliner wissenschaftlichen Luftfahrten und der Beginn der internationalen Zusammenarbeit zur Erforschung der freien Atmosphäre. *Dahlemer Archivgespräche*, 10:105–123.

Bert, Paul (1878): *La pression barométrique, recherches de physiologie expérimentale.* Masson, Paris.

Bert, Paul (1943): *Barometric pressure: researches in experimental physiology.* College Book Company, Columbus. English translation of Bert (1878), translated by Mary Alice Hitchcock.

Beuvaix, Heinrich; Karl Kössler; Max Mayer; and Christoph Regel, eds. (1998): *Flugerprobungsstellen bis 1945.* Die deutsche Luftfahrt, Bd. 27. Bernhard & Graefe, Bonn.

BG (1937): *Grundsätze für die Zulassung von Tauchern, Signal- u. Pumpenvormännern sowie ihr Verhalten im Betrieb.* See-Berufsgenossenschaft, Hamburg.

BG (1948): *Taucherlehrbuch.* Verband der gewerblichen Berufsgenossenschaften, Lübeck.

Böhme, Gernot and Hartmut Böhme (1996): *Feuer, Wasser, Erde, Luft. Eine Kulturgeschichte der Elemente.* Beck, München.

Bilderdijk, Willem (1813): *Kort verhaal van eene aanmerkelijke luchtreis en nieuwe planeetontdekking.*

Blakeney, T.S. (1970): A.S. Hinks and the First Everest Expediton 1921. *The Geographical Journal*, 136(3):333–343.

Bley, Wulf (1941): Wider englische Propagandalügen und Propagandatricks. *Gasschutz und Luftschutz*, 11(12):232–236.

Bohrmann, Hans and Claudia Bartels, eds. (1999): *NS-Presseanweisungen der Vorkriegszeit : Edition und Dokumentation*, vol. 6: 1938, Teil 4: Register. Saur, München.

Boyle, Robert (1966): *The Works*, vol. II. Georg Olms, Hildesheim.

Bremen, L. v. (1873): Taucher-Apparate, System Rouquayrol-Denayrouze in Paris. *Dinglers Polytechnisches Journal*, 208(4):241–262.

Brick, Martyn, ed. (2002): *Collins/Robert French-English English-French Dictionary. Unabridged.* Harper Collins/Dictionaires Le Robert, Glasgow & Paris.

Briggs, Lyman J., ed. (1936): *The National Geographic Society – U.S. Army Air Corps Stratosphere Flight of 1935 in the Balloon 'Explorer II'.* National Geographic Society, Washington DC.

Bry, Hans Dietrich von (1722): *Sonderbahre und bißher verborgen-gewesene Geheime Künste.* Bry, Frankfurt & Leipzig.

Cailletet, L. (1903): Sur l'emploi de l'oxygène dans les ascensions à grandes hauteurs. In: Anonymous (1903), pp. 98–102.

Campbell, Joseph (1973): *The Hero with a Thousand Faces.* Princeton University Press, Princeton, 2nd edn.

Cardarelli, François (2003): *Encyclopedia of scientific units, weights and measures: their SI equivalences and origins.* Springer, Berlin, rev. and exp. edn.

Carr, E.H. (1990): *What is History?* Penguin, London, reprint of the 2nd edn. First published in 1961, 2nd edn from 1987.

Cassirer, Ernst (1946): *Language and Myth.* Dover, New York. Translated by Susanne K. Langer.

Chadarevian, Soraya de (1993): Graphical Method and Discipline: Self-Recording Instruments in Nineteenth-Century Physiology. *Studies in History and Philosophy of Science*, 24(2):267–291.

Chapelle, Jean-Baptiste de la (1775): *Traité de la construction théoretique et pratique du scaphandre, ou du bateau de l'homme : approuvé par l'Académie Royale des Sciences.* Debure, Paris.

Chapin, Seymour L. (1991): An Active Interface Between Medical Science and Aeronautical Technology: The Physiological Investigations for the XC-35. *History and Philosophy of the Life Sciences*, 13:235–248.

Chazeaux, Olivier de (1999): *Marysze Hilsz. La femme qui aimait tant le ciel.* JC Lattès, Paris.

Clark, David M. (1989a): The development of the Partial Pressure Suit and something of its value (as remembered by myself, Dave Clark): Part I. *Aviation, Space, and Environmental Medicine*, 60(6):624,626.

Clark, David M. (1989b): The development of the Partial Pressure Suit and something of its value (as remembered by myself, Dave Clark): Part II. *Aviation, Space, and Environmental Medicine*, 60(7):727,729.

Clark, J.M. (1993): Oxygen Toxicity. In: Bennet and Elliot (1993), pp. 121–169.

Clynes, Manfred E. and Nathan Kline (1995): Cyborgs and Space. In: *The Cyborg Handbook*, ed. Chris H. Gray, Routledge, London, pp. 29–33. Reprinted from 'Astronautics', September 1960.

Cohan, Phil (1986): Heavenly Hoax. *Air & Space*, 1(2):87–95.

Colin, Jean (1992): Geschichte der Luftfahrtmedizin. In: *Illustrierte Geschichte der Medizin*, ed. Richard Toellner, Müller, Erlangen, vol. 6, pp. 2947–2973.

Colley, R.S. (1942): *Partitioned Inflatable Suit.* Patent Specification 2404567, USA. Date of Application: Aug. 20, 1942. Accepted: July 23, 1946.

Cooper, James B. (1941): Höhenanpassung von Flugzeugkabinen. *Beilage zu Technische Berichte*, 8(2):1–8.

Cortada, James W., ed. (1982): *Historical Dictionary of the Spanish Civil War, 1936–1939.* Greenwood Press, Westport & London.

Cüppers, Stefan (1994): *Die geschichtliche Entwicklung der Höhenphysiologie und ihre Bedeutung für die Luftfahrtmedizin bis 1961.* Shaker, Aachen.

Cross, C. A. (1950): Lunar Spacesuit. *Journal of the British Interplanetary Society*, 9(5):258–259.

Cross, C. A. (1951): Lunar Spacesuit. *Journal of the British Interplanetary Society*, 10(2):94–95.

Crouch, Tom D. (1983): *The eagle aloft: Two centuries of the balloon in America.* Smithsonian Institution Press, Washington DC.

Crouch, Tom D. (2003): *Wings. A History of Aviation from Kites to the Space Age.* W. W. Norton & Co., New York & London.

Csendes, Peter, ed. (1999): *Österreichisches Biographisches Lexikon 1815–1950*, vol. 11. Verlag der Österreichischen Akademie der Wissenschaften, Wien.

Cunningham, Andrew, ed. (1992): *The Laboratory Revolution in Medicine.* Cambridge University Press, Cambridge.

Cunningham, D.J.C. and B.B. Lloyd, eds. (1963): *The Regulation of Human Respiration. The proceedings of the J. S. Haldane Centenary Symposium held in the University Laboratory of Physiology, Oxford.* Blackwell, Oxford.

Damant, G.C.C. (1925): Notes on the 'Laurentic' Salvage Operations and the Prevention of Compressed Air Illness. *Journal of Hygiene*, 25(1):26–49.

Dasch, Julius, ed. (2005): *The Oxford Dictionary of Space Exploration.* Oxford University Press, Oxford.

Davis, Robert H. (1907): *Improvements in Diving Dresses.* Patent Specification 25821, Great Britain. Date of Application: 21st Nov., 1907. Accepted: 19th Mar., 1908.

Davis, Robert H. (1917): *Improvements in Air Supply and Respiratory Apparatus in Diving and like Apparatus.* Patent Specification 112788, Great Britain. Application Date: Aug. 18, 1917. Complete accepted: Jan. 31, 1918.

Davis, Robert H. (1934): Deep Diving And Under-Water Rescue, Part III. *Journal of the Royal Society of Arts*, 82:1069–1080. Thomas Gray Lectures, delivered February 12th, 1934.

Davis, Robert H. (1935): *Deep Diving and Submarine Operations: A Manual for Deep Sea Divers and Compressed Air Workers*. Saint Catherine Press, London.

Davis, Robert H. (1947): *Breathing in Irrespirable Atmospheres*. Saint Catherine Press, London.

Davis, Robert Henry and Leonard Erskine Hill (1906): *Improvements in Breathing Apparatus for use by Workers in Irrespirable Gases and Under Water*. (Provisional) Patent Specification 28586, Great Britain. Date of Application: 14th Dec., 1906. Complete Specification Left: 14th June, 1907. Accepted: 14th Dec., 1907.

Dejours, Pierre and Sally Dejours (1992): The Effects of Barometric Pressure According to Paul Bert: The Question Today. *International Journal of Sports Medicine*, 13(Suppl. 1):S1–S5.

Demetriades, S.T. (1954): On the Decompression of a Punctured Pressurized Cabin in Vacuum Flight. *Jet Propulsion*, 24(1):35–36.

Denayrouze, Auguste (1866): *Note sur l'appareil plongeur Rouquayrol: a air comprimé et son emploi dans la marine*. Bertrand, Paris.

Dessau (1943): *Beschlagsverhinderung an Höhenkammer-Sichtscheiben*. Konstruktionsrichtlinien Nr. 5, Entwicklungs-Untergruppe "Konstruktive Gestaltung von Höhenkammern", Junkers-Flugzeugwerke, Dessau. ZWB-Report Nr. 13927.

DeVorkin, David H. (1989): *Race to the Stratosphere. Manned Scientific Ballooning in America*. Springer, New York.

Dille, J. Robert (1990): Aviation Medicine Heritage. *Aviation, Space, and Environmental Medicine*, 61(2):192.

Diringshofen, H. v. (1935a): *Luftfahrtmedizinische Stellungnahme zum Unfall des Höhenballons 'Bartsch von Sigsfeld' am 13.5.1934*. ZWB-Report FB 202, Berlin.

Diringshofen, Heinz v. (1935b): Luftfahrtmedizinische Fragen und Aufgaben unter besonderer Berücksichtigung der Beschleunigungswirkungen. In: Géronne (1935), pp. 27–39.

Donald, K.W. (1963): J.S. Haldane's Contributions to Applied Physiology in the Armed Forces, with Special Reference to Diving. In: Cunningham and Lloyd (1963), pp. 83–91.

Douglas, C. G. (1944): Obituary: Prof. Yandell Henderson. *Nature*, 153(3880):308–309.

Douglas, C.G.; Y. Henderson; J.S. Haldane; and E.C. Schneider (1913): Physiological Observations Made on Pike's Peak, Colorado, with Special Reference to Adaptation to Low Barometric Pressures. *Philosophical Transactions of the Royal Society, Series B*, 203:185–381.

Douglas, Claude Gordon (1911): A method for determining the total respiratory exchange in man. *Journal of Physiology*, 39:vii–viii.

Douglas, Claude Gordon (1936): John Scott Haldane 1860–1936. *Obituary Notices of the Fellows of the Royal Society*, 2:115–139.

Douglas, Claude Gordon (1953): Sir Leonard Erskine Hill. *Obituary Notices of the Fellows of the Royal Society*, 8(22):431–443.

Dräger, B. (1904): Über Sauerstoffinhalation bei Hochfahrten. *Illustrierte Aeronautische Mittheilungen*, 8:249–252.

Ellis, Max (1923): Respiratory volume of men during short exposures to constant low oxygen tensions attained by rebreathing. *Air Service Information Circular*, 5(403):45–50.

Encyclopedia Britannica (2004): Encyclopedia Britannica Deluxe Edition 2004 CD-ROM.

Faure, Georges le and Henri de Graffigny (1889a): *Aventures extraordinaires d'un savant russe. 1-re partie: La Lune.* Edinger, Paris.

Faure, Georges le and Henri de Graffigny (1889b): *Aventures extraordinaires d'un savant russe. 2e partie: Le Soleil et les petites planètes.* Edinger, Paris.

Fellowes, P. M.; L.V. Stewart Blacker; John Buchan; and Robert M. McBride (1934): *First over Everest. The Houston-Mount Everest Expedition 1933.* Pilgrims Publ., London.

FIAT (1945): *Report Index on German Aeronautical Research Documents.* Report No. 948, FIAT.

Finnegan, Diarmid A. (2005): Natural history societies in late Victorian Scotland and the pursuit of local civic science. *British Journal for the History of Science*, 38(1):53–72.

Fischer, Albert (2003): *Luftverkehr zwischen Markt und Macht (1919–1937). Lufthansa, Verkehrsflug und der Kampf ums Monopol.* Franz Steiner Verlag, Wiesbaden.

Flack, Martin (1920): The Human Machine in Relation to Flying. *The Aeronautical Journal*, 24(120):650–663.

Foregger, Richard (1974): Development of Mine Rescue and Underwater Breathing Apparatus: Appliances of Henry Fleuss. *Journal of the History of Medicine*, 29(3):317–330.

Foucault, Michel (1972): *The Archaeology of Knowledge*. Tavistock, London.

Frank, Zephyr and Aldo Musacchio (2002): The International Natural Rubber Market, 1870-1930. EH.Net Encyclopedia, http://eh.net/encyclopedia/article/frank.international.rubber.market. Last access: February 10, 2007.

Fritzsche, Peter (2007): 'Airmindedness' – der Luftfahrtkult der Deutschen zwischen der Weimarer Republik und dem Dritten Reich. In: Trischler and Schrogl (2007), pp. 86–101.

Förster, Stig, ed. (2002): *An der Schwelle zum Totalen Krieg. Die militärische Debatte über den Krieg der Zukunft 1919–1939*. Schöningh, Paderborn.

Fulton, J.F. and E.C. Hoff (1942): A Five-Foot Shelf on Aviation Medicine. *Bulletin of the Medical Library Association*, 30(4):368–371.

Gamillscheg, Ernst (1928): *Etymologisches Wörterbuch der französischen Sprache*. Carl Winter's Universitätsbuchhandlung, Heidelberg.

Garsaux, Paul (1919a): Essais de résistance à la dépression atmosphérique à l'aide d'un mélange réspiratoire oxygène et acide carbonique. *Comptes Rendus des Sèances de la Sociéte de Biologie*, 82:646.

Garsaux, Paul (1919b): Présentation de l'appareil réspiratoire automatique en service dans l'aviation francaise. *Comptes Rendus des Sèances de la Sociéte de Biologie*, 82:647.

Garsaux, Paul (1963): *Histoire anecdotique de la médecine de l'air*. Scorpion, Paris.

Gauer, O. and S. Ruff (1939): Die Erträglichkeitsgrenzen für Fliehkräfte in Richtung Rücken-Brust. In: Reichluftfahrtministerium (1939), pp. 147–150.

Gerresheim, Helmut (2001): *Boeing. Die Modell- und Typengeschichte. Alle Flugzeuge seit 1916*. Motorbuch Verlag, Stuttgart.

Gibbs-Smith, Charles H. (2003): *Aviation. An historical survey from its origins to the end of the Second World War*. Science Museum, London.

Gibson, T.M. and M.H. Harrison (1984): *Into thin air. A History of Aviation Medicine in the RAF.* Robert Hale, London.

Gibson, William C. (1962): Medical Pioneers in Aviation. *Journal of the History of Medicine*, 17(1):83–93.

Gilchrist, Paul (2006): The politics of totemic sporting heroes and the conquest of Everest. *Anthropological Notebooks*, 12(2):35–52.

Ginzburg, Carlo (1999): *History, Rhetoric, and Proof.* University Press of New England, Hanover.

Ginzburg, Carlo (2002): *Spurensicherung. Die Wissenschaft auf der Suche nach sich selbst.* Wagenbach, Berlin.

Gippenreiter, Eugene and John B. West (1996): High Altitude Medicine and Physiology in the Former Soviet Union. *Aviation, Space, and Environmental Medicine*, 67(6):576–584.

Glaisher, J.; C. Flammarion; W. de Fonvielle; and G. Tissandier (1870): *Voyages Aériennes.* Libraire de L. Hachette & Cie., Paris.

Goldbeck, Gustav (1960): Zur Entwicklungsgeschichte des Freikolben-Gaserzeugers. *MTZ*, 21(11):481–483.

Goodrich, H.B. (1955): E.C. Schneider, Pioneer in Aviation Medicine. *Science*, 121(3143):412–413.

Gori, Gigliola (2000): *Physical Education and Sporting Activity for Women during the Fascist Era.* Ph.D. thesis, Fachbereich Sozialwissenschaften der Georg-August-Universität, Göttingen.

Greene, Raymond (1931): Oxygen and Everest. *Nature*, 128(3239):893–894.

Greene, Raymond (1932): Oxygen and Everest (Letter to the Editor). *Nature*, 129(3246):94.

Géronne, A., ed. (1935): *Verhandlungen der Deutschen Gesellschaft für Innere Medizin. 47. Kongreß gehalten zu Wiesbaden vom 25.–28. März 1935*, München. Bergmann.

Gross, H. and H.W. Romberg (1943): *Untersuchungen am Menschen über den gleichzeitigen Einfluß von Kälte und Sauerstoffmangel.* Forschungsbericht FB 1851, Reichsluftfahrtministerium, Berlin.

Grossmann, John (1989): The Blue Collar Spacesuit. *Air & Space*, 4(4):58–67.

Gunga, Hanns-Christian (1989): *Leben und Werk des Berliner Physiologen Nathan Zuntz (1847–1920), unter besonderer Berücksichtigung seiner Bedeutung für die Frühgeschichte der Höhenphysiologie und Luftfahrtmedizin.* Abhandlungen zur Geschichte der Medizin und der Naturwissenschaften, Bd. 58. Matthiesen, Husum.

Gunga, Hanns-Christian and Karl August Kirsch (1995a): Nathan Zuntz (1847–1920) — A German Pioneer In High Altitude Physiology And Aviation Medicine, Part I: Biography. *Aviation, Space, and Environmental Medicine*, 66(2):168–171.

Gunga, Hanns-Christian and Karl August Kirsch (1995b): Nathan Zuntz (1847–1920) — A German Pioneer In High Altitude Physiology And Aviation Medicine, Part II: Scientific Work. *Aviation, Space, and Environmental Medicine*, 66(2):172–176.

Gunn, Simon (2000): *The Public Culture of the Victorian Middle Class. Ritual and Authority and the English Industrial City 1840–1914.* Manchester University Press, Manchester & New York.

Günther, Hanns (1928): *Die Eroberung der Tiefe.* Franckh, Stuttgart.

Habermas, Jürgen (1976): *Legitimation Crisis.* Heinemann, London.

Haldane, J. S. and J. G. Priestly (1905): The regulation of the lung-ventilation. *Journal of Physiology*, 32:225–266.

Haldane, J.B.S. (1960): The scientific work of J.S. Haldane (1860–1936). *Nature*, 187:102–105.

Haldane, John (1895): The Relation of the Action of Carbonic Oxide to Oxygen Tension. *Journal of Physiology*, 18:201–217.

Haldane, John and Richard Haldane (1883): The relation of philosophy to science. In: *Essays in Philosophical Criticism*, eds. Andrew Seth and Richard Burdon Haldane, Longmans & Green, London, pp. 41–66.

Haldane, John Scott (1892): A New Form of Apparatus for Measuring the Respiratory Exchange of Animals. *Journal of Physiology*, 13:419–430.

Haldane, John Scott (1912): *Methods of Air Analysis.* Griffin, London.

Haldane, John Scott (1917): *Organism and Environment as Illustrated by the Physiology of Breathing.* Yale University Press, New Haven.

Haldane, John Scott (1922): *Respiration.* Yale University Press, New Haven.

Haldane, John Scott (1928): *The sciences and philosophy.* Hodder & Stoughton, London.

Haldane, John Scott and John Gillies Priestly (1935): *Respiration.* Yale University Press, New Haven, 2nd edn.

Haldane, J.S. (1931): *The Philosophical Basis of Biology.* Hodder and Stoughton, London. Donnellan Lectures, University of Dublin, 1930.

Haldane, J.S.; A.E. Boycott; and G.C.C. Damant (1908): The Prevention of Compressed Air Illness. *Journal of Hygiene*, 8:342–443.

Haldane, J.S.; F.T. Hamilton; H.S. Bacon; and E. Lees (1907): *Report of a Committee appointed by the Lords Commisioners of the Admiralty to Consider and Report upon the Conditions of Deep-Water Diving.* Parliamentary Paper C.N. 1549/1907, H.M. Stationary Office, London.

Haldane, J.S. and J.L. Smith (1893): The Physiological Effects of Air Vitiated by Respiration. *Journal of Pathologic Bacteriology*, I:168–186.

Haldane, Louisa Kathleen (1961): *Friends and Kindred. Memoirs of Louisa Kathleen Haldane.* Faber and Faber, London.

Haldane, Mary Elizabeth (1925): *A Record of a Hundred Years (1825–1925).* Hodder & Stoughton, London.

Haldane, Richard Burdon (1929): *An Autobiography.* Hodder & Stoughton, London.

Hall, Stuart (2001): Foucault: Power, Knowledge and Discourse. In: *Discourse Theory and Practice: A Reader*, eds. Margaret Wetherell; Stephanie Taylor; and Simeon J. Yates, Sage, London.

Hampe, P.; J. Wenzel; L. Vogt; and E.W. Müller (1993): Die Dekompression ist ein gemeinsames Problem der Luftfahrt, Raumfahrt, Caissonarbeit und des Tauchens. In: *Tauchmedizin - Fortschritte in der Tauch- und Überdruckmedizin: 5. Jahrestagung der GTÜM e.V.*, ed. O.F. Ehm. ecomed, Landsberg, pp. 11–19.

Hansen, Asmus (1927): *Allseitig geschlossene gasdichte Kabine.* Patent Specification 488395, Germany. Patent granted July 22, 1927.

Hård, Mikael and Andrew Jamison, eds. (1998): *The Intellectual Appropriation of Technology. Discourses on Modernity 1900-1939.* The MIT Press, Cambridge (Mass.).

Hård, Mikael and Andrew Jamison (2005): *Hubris and Hybrids. A Cultural History of Technology and Science.* Routledge, New York.

Hart, Philip S. (2001): *Up in the air : the story of Bessie Coleman.* Carolrhoda, Minneapolis, 3rd edn.

Hawkins, Michael F. (1995): Some Problems of High Altitude in the 1930's: A World Record Attempt. *Aviation, Space, and Environmental Medicine*, 66(12):1212–1214.

Heim, J.W. (1938): Physiologic Considerations Governing High Altitude Flight. *Journal of the Aeronautical Sciences*, 5(5):189–192.

Heller, Richard; Wilhelm Mager; and Hermann von Schrötter (1900): *Luftdruckerkrankungen. Mit besonderer Berücksichtigung der sogenannten Caissonkrankheit.* Hölder, Wien.

Henderson, Yandell (1919): The Physiology of the Aviator. *Science*, 49(1271):431–441.

Henderson, Yandell (1932): Oxygen and Everest (Letter to the Editor). *Nature*, 129(3261):649–650.

Henderson, Yandell (1938): *Adventures in Respiration.* Yale University Press, New Haven.

Henderson, Yandell and E.G. Seibert (1989): Organization and Objects of the Medical Research Board, Air Service, U.S. Army. *Aviation, Space, and Environmental Medicine*, 60(5):467–469. Originally appeared in: Journal of the American Medical Association, 1918; 71: 1382–1385.

Hermann, Dietmar (2004): Messerschmidt Me209 gegen Focke-Wulf Ta153. *Jet & Prop*, (5):22–26.

Herrera, Emilio (1965): Il y a 30 ans ... Le scaphandre de l'espace. *Ingénieurs et Techniciens*, (189):44–46.

Herrera Linares, Emilio (1935a): La ascensión estratosférica del globo Explorer II. *Madrid Científico*, 42:374–375.

Herrera Linares, Emilio (1935b): La prensa soviética y mi proyectada ascensión estratosférica. *Madrid Científico*, 42:309–311.

Höhler, Sabine (2001): *Luftfahrtforschung und Luftfahrtmythos. Wissenschaftliche Ballonfahrt in Deutschland 1880–1910.* Campus, Frankfurt/M.

Höhler, Sabine (2007): Ballonfahrer und Meteorologen: Die Frühgeschichte der Luftfahrtforschung. In: Trischler and Schrogl (2007), pp. 28–49.

Hill, Leonard (1932a): Altitudes to be Reached by Air Pilots by Breathing Oxygen. *Nature*, 130(3280):397.

Hill, Leonard (1932b): Oxygen and Everest (Letter to the Editor). *Nature*, 129(3246):93–94.

Hill, Leonard (1934): Limit of high flying when breathing oxygen. *Proceedings of the Royal Society B*, 115:298–306.

Hill, Leonard and John Argyll Campbell (1933a): Studies in the saturation of the tissues with gaseous nitrogen. I. Rate of saturation of goat's bone marrow in vivo with nitrogen during exposure to increased atmospheric pressure. *Quarterly Journal of Experimental Physiology*, 23:197–210.

Hill, Leonard and John Argyll Campbell (1933b): Studies in the saturation of the tissues with gaseous nitrogen. II. The gaseous nitrogen content of certain fats, fatty acids, etc., saturated with air, as estimated by a new apparatus. *Quarterly Journal of Experimental Physiology*, 23:197–210.

Hill, Leonard and John Argyll Campbell (1933c): Studies in the saturation of the tissues with gaseous nitrogen. III. Rate of saturation of goat's brain, liver and bone marrow in vivio with excess nitrogen during exposure to +3, +4 and +5 atmospheric pressure. *Quarterly Journal of Experimental Physiology*, 23:197–210.

Hill, Leonard and Martin Flack (1919): *A text book of physiology*. Arnold, London.

Hill, Leonard and M. Greenwood (1906): The Influence of Increased Barometric Pressure on Man – No. I. *Proceedings of the Royal Society B*, 77:442ff.

Hill, Leonard and M. Greenwood (1907a): The Influence of Increased Barometric Pressure on Man – No. II. *Proceedings of the Royal Society B*, 79:21–27.

Hill, Leonard and M. Greenwood (1907b): The Influence of Increased Barometric Pressure on Man – No. III. The Possibility of Oxygen Bubbles Being Set Free in the Body. *Proceedings of the Royal Society B*, 79:284–287.

Hill, Leonard and J.J.R. Macleod (1903a): Caisson Illness and Diver's Palsy. An Experimental Study. *Journal of Hygiene*, 3(4):401–445.

Hill, Leonard and J.J.R. Macleod (1903b): The Influence of Compressed Air and Oxygen on the Gases of the Blood. *Journal of Physiology*, 29(4/5):382–387.

Hill, Leonard and J.J.R. Macleod (1903c): The Influence of Compressed Air on the Respiratory Exchange. *Journal of Physiology*, 29(6):492–510.

Hill, Leonard Erskine (1912): *Caisson Sickness and the Physiology of Work in Compressed Air*. Arnold, London.

Himanen, Pekka (2001): *The Hacker Ethic and the Spirit of the Information Age*. Secker & Warburg, London.

Hoff, Ebbe Curtis and John Farquhar Fulton (1942): *A Bibliography of Aviation Medicine.* Charles C Thomas, Springfield & Baltimore.

Hornberger, W. (1942): *Höhen-Rettungssturz.* ZWB-Report Rech 268, Erprobungsstelle der Luftwaffe, Rechlin.

Hornberger, W. and Th. Benzinger (1942): Druckfallkrankheit. *Luftfahrtmedizin*, 7(1):9–34.

Hornberger, W. and D. König (1942): *Über die Möglichkeit, bei Rettungsdruckanzügen für Stratosphärenflug einzelne Gliedmassen ausserhalb zu belassen.* ZWB-Report Rech 271, Erprobungsstelle der Luftwaffe, Rechlin.

Howard, Harvey J. (1923): A New Apparatus for Testing Accommodation. *Air Service Information Circular*, 5(403):71–74.

Hughes, Thomas P. (1989): *American Genesis : A Century of Invention and Technological Enthusiasm, 1870–1970.* University of Chicago Press, Chicago.

Ide, Hans and Siegfried Grünert (1939): *Regler zur Druckerhaltung in Höhenkammern.* Patent Specification 735803, Deutsche Versuchsanstalt für Luftfahrt, Germany. Patent accepted: Jan 14, 1939. Published: April 22, 1943.

Iggers, Georg G. (1997): *Historiography in the Twentieth Century: From Scientific Objectivity to the Postmodern Challenge.* Wesleyan University Press, Middletown.

Jacoby, Sally and Elinor Ochs (1995): Co-Construction: an Introduction. *Research on Language and Social Interaction*, 28(3):171–184.

Jane's Publishing Company, ed. (1995): *Jane's Fighting Aircraft of WWII.* Studio Editions, London, reprint from 1946/7. edn.

Jardine, Nicholas (1992): The Laboratory Revolution in Medicine as Rhetorical and Aesthetic Accomplishment. In: Cunningham (1992), pp. 304–323.

Jenkins, Keith (2007): *Re-thinking History.* Routledge, London & New York, reprint edn.

Jünger, Ernst, ed. (1928): *Luftfahrt ist not!* Deutscher Luftfahrtverband e.V., Berlin.

Johnson, Harry M. and F.C. Paschal (1921): Psychological effects of deprivation of oxygen, detereoration of performance as indicated by new substitution test. *Air Service Information Circular*, 3(237):38–72.

Jones, Edwin R. and Richard L. Childers (1993): *Contemporary College Physics*. Addison-Wesley, Reading, Mass., 2nd edn.

Jongbloed, Jacob (1929): *Bijdrage tot de physiologie der vliegers op grote hoogten*. Bruna, Utrecht.

Jung, Michael (1999): *Das Handbuch Zur Tauchgeschichte*. Verlag Stephanie Nagelschmidt, Stuttgart.

Junkers, Hugo (1930a): *Propellergetriebenes Luftfahrtzeug für Flüge in großer Höhe*. Patent specification 578933, Germany. Patent granted July 03, 1930. Published June 01, 1933.

Junkers, Hugo (1930b): *Sicherungsvorrichtung für Luftfahrzeuge, die für Flüge in großen Höhen bestimmt sind*. Patent Specification 553458, Germany. Accepted: Oct. 29, 1930. Published: June 9, 1932.

Junkers, Hugo (1931a): *Einrichtung zum Abschluß von Öffnungen in den Wänden von Höhenflugzeugkammern*. Patent specification 564033, Germany. Patent granted Oct 25, 1931. Published Oct 27, 1932.

Junkers, Hugo (1931b): *Unter innerem Überdruck stehende doppelwandige Kammer für Höhenflugzeuge*. Patent Specification 595504, Germany. Accepted: Nov. 1, 1931. Published: March 29, 1934.

Kaufmann, R. (1941): *Richtlinien für Bau und Erprobung von Überdruckkammern für Höhenflugzeuge*. ZWB-Report Rech 236, Erprobungsstelle der Luftwaffe, Rechlin.

Kehrt, Christian (2005): "Schneid, Takt und gute Nerven". Der Habitus deutscher Militärpiloten und Beobachter im Kontext technisch strukturierter Handlungszusammenhänge, 1914-1918. *Technikgeschichte*, 72(3):177–201.

King, Paul B. and Thomas Carroll (1924): *High Altitude Flying*. NACA Technical Notes No. 193, Langley Memorial Aeronautical Laboratory, Washington DC.

Klanke, Gerhard (1925): *Geschwindigkeitsmesser*. Patent Specification 438397, Germany.

Klanke, Gerhard (1931): *Zur Meßtechnik aerologischer Flüge*. Ph.D. thesis, University of Hamburg.

Klanke, Gerhard (1933): *Antriebsvorrichtung für Hilfsgeräte in Luftfahrzeugen*. Patent Specification 712305, Germany.

Klanke, Gerhard (1938): Erfahrungen über die gesundheitlichen Beanspruchungen bei regelmäßigen Wetterhöhenflügen (5000m) und ihre Herabsetzung durch einen Flieger-Überdruckanzug. *Luftfahrtmedizinische Abhandlungen*, II(3/4):182–189.

Klemperer, W.B. (1938): The Trend Toward Higher Altitudes in Commercial Air Transport. *Journal of the Aeronautical Sciences*, 5(5):186–188.

Klose, Carl (1926): *Druckluftkabine für Höhenflugzeuge.* Patent Specification 476537, Germany. Accepted: Nov. 16, 1926. Published: May 2, 1929.

Koppes, Clayton R. and Gregory D. Black (1987): *Hollywood goes to War: How Politics, Profits and Propaganda shaped World War II Movies.* University of California Press, Berkeley & Los Angeles.

Kosin, Rüdiger (1990): *Die Entwicklung der deutschen Jagdflugzeuge.* Die deutsche Luftfahrt. Bernhard & Graefe, Koblenz, 2nd edn.

Kozloski, Lillian D. (1994): *U.S. Space Gear: Outfitting the Astronaut.* Smithsonian Institution Press, Washington DC.

Kragh, Helge (1991): *An Introduction to the Historiography of Science.* Cambridge University Press, Cambridge.

Kranzhoff, Jörg Armin (2001): *Arado-Flugzeuge: Vom Doppeldecker zum Strahlflugzeug.* Die deutsche Luftfahrt, Bd. 31. Bernhard & Graefe, München.

Kronecker, Hugo (1881): Apparate für Physiologie. In: *Bericht über Die Wissenschaftlichen Apparate Auf der Londoner Internationalen Ausstellung im Jahre 1876*, ed. A.W. Hofmann, Vieweg & Sohn, Braunschweig, pp. 583–638.

Kylstra, J.A.; C.V. Paganelli; and E.H. Lanphier (1966): Pulmonary gas exchange in dogs ventilated with hyperbarically oxygenated liquid. *Journal of Applied Physiology*, 21:177–184.

LaFolette, Hugh and Niall Shanks (1994): Animal experimentation: the legacy of Claude Bernard. *International Studies in the Philosophy of Science*, 8(3):195–210.

Lanham, Richard A. (1991): *A Handlist of Rhetorical Terms.* University of California Press, Berkeley, 2nd edn.

Larsen, Carl N. (1923): A new type of rebreather and other respiratory apparatus. *Air Service Information Circular*, 5(403):8–15.

Latour, Bruno (2005): *Reassembling the Social: An Introduction to Actor-Network-Theory.* Oxford University Press, Oxford.

Liddel, Henry George; Robert Scott; and Henry Stuart Jones, eds. (1958): *A Greek-English Lexicon.* At The Clarendon Press, Oxford.

Lünen, Alexander von (2006a): Goats and Gases: 'The Prevention of Compressed Air Illness' by Haldane et al – A Commentary. *Wilderness & Environmental Medicine*, 17(3):195–196.

Lünen, Alexander von (2006b): Who needs scientific instruments? Philosophers! Physiology and Philosophy in the fin de siècle. In: *Who needs Scientific Instruments. Conference on scientific instruments and their users. 20–22 October, 2005*, eds. Bart Grob and Hans Hooijmaijers. Museum Boerhaave, Leiden, pp. 29–36.

Lünen, Alexander von (2008): Die Deutsche Forschungsanstalt für Segelflug. In: *Ein Jahrhundert Luftfahrtgeschichte zwischen Tradition, Forschung und Landschaftspflege. Der August-Euler-Flugplatz in Darmstadt/Griesheim*, eds. Andres Göller and Annegret Holtmann-Mares, Wissenschaftliche Buchgesellschaft, Darmstadt, pp. 209–239.

Lünen, Alexander von (2009): 'Splendid Isolation'? Aviation Medicine in World War II. In: *Scientific Research in World War II*, eds. Ad Maas and Hans Hooijmaiers, Routledge, London, pp. 96–108.

Loewy, A. (1928): Hermann von Schrötter†. *Deutsche Medizinische Wochenschrift*, 54:365.

Lofficier, Jean-Marc and Randy Lofficier (2000): *French Science Fiction, Fantasy, Horror & Pulp Fiction: A Guide to Cinema, Television, Radio, Animation, Comic Books and Literature from the Middle Ages to the Present.* MacFarland, Jefferson & London.

Lommel, Horst (2000): *Geheimprojekte der DFS. Vom Höhenaufklärer bis zum Raumgleiter 1935–1945.* Motorbuch Verlag, Stuttgart.

Lomonaco, T. (1970): Necrologio: Paul Garsaux. *Minerva Medica (Torino)*, 61(74):3971.

Lomonaco, Tomaso (1967): In Memoria del Generale Mario Pezzi. *Rivista Medicale Aeronautica e Spatiale*, 30:415–424.

Lovelace, W.R.; A.J. Vorwald; C.L. Pratt; G.T.B. Boissard; and V.J. Wulff (1945): *Draegerwerk Luebeck, Germany: Ventilation, air purification and other apparatus used in aircraft, submarines, tanks and air-raid shelters. Chemical warfare and medical apparatus.* File No. XXVII-61, Item No. 8, 24 and 27, CIOS.

Lutz, W. (1941): *Technische Vorschläge zur Vermeidung von Höhenkrankheit nach Verletzung von Gleichdruck-Kabinen.* ZWB-Report FB 1/41, Berlin.

Lutz, W. (1942): Die Überlebenszeit nach Drucksturz in größten Höhen. *Luftfahrtmedizin*, 7(1):84–97.

Maase, Kaspar (2001): *Grenzenloses Vergnügen. Der Aufstieg der Massenkultur 1850–1970.* Fischer, Frankfurt/M., 3rd edn.

Mackowski, Maura Phillips (2002): *Human factors: aerospace medicine and the origins of manned space flight in the United States.* Ph.D. thesis, Arizona State University.

Mackowski, Maura Phillips (2006): *Testing the Limits. Aviation Medicine and the Origins of Manned Space Flight.* Centennial of Flight Series. Texas A&M University Press, College Station.

Mallan, Lloyd (1971): *Suiting Up for Space. The Evolution of the Space Suit.* The John Day Company, New York.

Margaria, Rodolfo (1932): Oxygen and Everest (Letter to the Editor). *Nature*, 129(3254):397–398.

Marshall, G.S. (1933): The Physiological Limitations of Flying. *Journal of the Royal Aeronautical Society*, 37:389–410.

Marshall, G.S. (1936): Respiration in High Flying. *Proceedings of the Royal Society of Medicine*, 30:995–1006.

Mayer, Edgar (2001): *Glanzlichter der frühen Luftfahrt in Köln. 75 Jahre Butzweiler Hof.* Schardt Verlag, Oldenburg.

McCallum, R.I., ed. (1967): *Decompression of compressed air workers in civil engineering. Proceedings of an international working party held at the Ciba Foundation, London, 1965*, Newcastle-upon-Tyne. Oriel Press.

McDougall, Walter A. (1985): *...the Heavens and the Earth. A Political History of the Space Age.* Basic Books, New York.

McGinn, Robert E. (1991): *Science, Technology, and Society.* Prentice Hall, Englewood Cliffs.

McIvor, Arthur and Ronald Johnston (2007): *Miners' Lung: A History of Dust Disease in British Coal Mining.* Ashgate, Aldershot.

Mierau, Peter (2006): *Nationalsozialistische Expeditionspolitik. Deutsche Asienexpeditionen 1933–1945.* Utz, München.

Millar, John (1937): The Economics of High-flying. *The Aeroplane*, 56:403–405.

Minkowski, Helmut (1935): Die fliegerische Ausbildung der englischen Studenten. *Luftwelt*, 2(1):11, 13.

Mitchell, Ronald K. and Bradley R. Agle (1997): Toward a theory of stakeholder identification and salience: Defining the principle of Who and What really counts. *Academy of Management Review*, 22(4):853–886.

Mitchison, Naomi (1974): The Haldanes: Personal Notes and Historical Lessons. *Proceedings of the Royal Institution of Great Britain*, 47:1–21.

Mitscherlich, Alexander and Fred Mielke, eds. (1978): *Medizin Ohne Menschlichkeit. Dokumente des Nürnberger Ärzteprozesses.* Fischer Taschenbuch Verlag, Frankfurt/M.

Müller, Reinhard (2006): *Junkers Flugtriebwerke. Benzinmotoren, Flugdiesel, Strahlturbinen.* Aviatic Verlag, Oberhaching.

Mohler, S.R. and B.H. Johnson (1971): *Wiley Post, His Winnie Mae, and the World's First Pressure Suit.* Smithsonian Institution, Washington DC.

Mohler, Stanley R. (1998): The World's First Practical Flight Pressure Suit. *Aviation, Space, and Environmental Medicine*, 69(8):802–805.

Mohler, Stanley R. (1999a): Opening the Envelope: The Continuing Legacy of Maj. Gen. Harry G. Armstrong, USAF, MC (Ret.). *Aviation, Space, and Environmental Medicine*, 70(9):942–948.

Mohler, Stanley R. (1999b): Opening the Envelope: The Continuing Legacy of Maj. Gen. Harry G. Armstrong, USAF, MC (Ret.). *Aviation, Space, and Environmental Medicine*, 70(8):819–825.

Morella, John; Edward Z. Epstein; and John Griggs, eds. (1973): *The Films of World War II.* Citadel, Secaucus.

Morgan, Eric and Edward Shacklady (2000): *Spitfire. The History.* Key Books, Stamford.

Morrow, John H. Jr. (2006): Downfall of the Regia aeronautica, 1933-1943. In: *Why air forces fail: the anatomy of defeat*, eds. Robin Higham and Stephen J. Harris, University Press of Kentucky, Lexington.

Munslow, Alan (1997): *Deconstructing History.* Routledge, London.

Muttray, J. (1939): Die Luftdrucküberkammer und die Sauerstoffkammer für Höhenflüge. Lilienthal-Gesellschaft, Zentrale für Wissenschaftliches Berichtswesen (ZWB), Göttingen, no. 26–34.

Muttray, J. (1944): *Die erforderliche Dichtheit von Höhenkammern.* ZWB-Report Konstruktion 2, Junkers, Dessau. Issued Oct 18, 1944.

Needham, Joseph (1932): Berkleian Biology. *Nature*, 129(3258):524–525. Review of Haldane (1931).

Nelson, Clark W. (1999): Lovelace, William Randolph, II. In: *American National Biography*, eds. John A. Garraty and Mark C. Carnes, Oxford University Press, New York & Oxford, vol. 14, pp. 10–11. Published under the auspices of the American Council Of Learned Societies.

Nes, Wilhelm von; Franz Meyer; and Hans Lucht (1939): *Regulierventil für Druckluftkammern von Luftfahrzeugen.* Patent Specification 742555, Arado Flugzeugwerke GmbH, Germany. Patent accepted: Dec 21, 1939. Published: Oct 21, 1943.

Neuber, Hans (1940): *Druckkabine für Höhenflugzeuge.* Patent Specification 715460, Henschel Flugzeugwerke, Germany. Accepted: July 6, 1940. Published: Nov 27, 1941.

Neufeldt, Michael J. (1990): Weimar Culture and Futuristic Technology: The Rocketry and Spaceflight Fad in Germany, 1923–1933. *Technology & Culture*, 31(4):725–752.

Neumann, Alexander (2007): Die Luftfahrtmedizin von der Weimarer Republik bis zur frühen Bundesrepublik. In: Trischler and Schrogl (2007), pp. 135–152.

Nicolau, Stéphane and Élizabeth Mismes-Thomas (2004): *Aviatrices. Un siècle d'aviation féminine francaise.* Éditions Altipresse, Levallois-Perret.

Nicolaus, Friedrich (1939): *Druckkabine für Höhenflugzeuge.* Patent Specification 707313, Henschel Flugzeugwerke, Germany. Accepted: April 9, 1939. Published: May 15, 1941.

Nicolson, Malcolm (1993): Medicine. In: *Scotland: A Concise Cultural History*, Mainstream Publ., Edinburgh, pp. 327–342.

Noë, Adrianne (1989): *Medical principle and aeronautical practice: American aviation medicine to World War II.* Ph.D. thesis, University of Delaware.

Noordung, Hermann (1929): *Das Problem der Befahrung des Weltraums.* R.C. Schmidt, Berlin.

Norris, Vincent P. (1999): Post, Wiley. In: *American National Biography*, eds. John A. Garraty and Mark C. Carnes, Oxford University Press, New York & Oxford, vol. 17, pp. 734–735. Published under the auspices of the American Council Of Learned Societies.

Nye, Piers C. and John T. Reeves (2001): A High Point in Human Breathing: John Scott Haldane of Oxford on Pike's Peak. In: *Attitudes on Altitude. Pioneers of Medical Research in Colorado's High Mountains*, eds. John T. Reeves and Robert F. Grover, University Press of Colorado, Boulder, pp. 25–58.

O'Bear, G.B. (1920): A note on the low-pressure chambers installed in the Medical Research Laboratory of the Air Service. *Air Service Information Circular*, 1(99):100–108.

O'Bear, G.B. (1923): A note on the low-pressure chamber installed in the school of aviation medicine (Revised). *Air Service Information Circular*, 5(403):75–80. Revised version of O'Bear (1920), revised by L.H. Bauer.

Oberth, Hermann (1923): *Die Rakete zu den Planetenräumen*. Oldenbourg, München.

Odell, N. E. (1931): Oxygen and Everest (Letter to the Editor). *Nature*, 128(3242):1037–1038.

Odell, N. E. (1932): Oxygen and Everest (Letter to the Editor). *Nature*, 129(3250):244–245.

O'Hara, J.A. (1945): *Report on the DFS Ainring*. Report No. XXXII-66, CIOS.

Oudshorn, Nelly and Trevor Pinch, eds. (2003): *How Users Matter. The Co-Construction of Users and Technologies*. The MIT Press, London.

Parkinson, Bob, ed. (2008): *Interplanetary: A History of the British Interplanetary Society*. British Interplanetary Society, London.

Partin, Clyde (2001): Sir Leonard Erskine Hill. *Clinical Cardiology*, 24:169–171.

Pateras-Pescara, Raoul (1923): *Scaphandre aérien*. Patent Specification No. 564676, France. Date of Application: Apr 4, 1923. Accepted: Oct 27, 1923. Published: Jan 8, 1924.

Pauly, Philip J. (1999): Henderson, Yandell. In: *American National Biography*, eds. John A. Garraty and Mark C. Carnes, Oxford University Press, New York & Oxford, vol. 10, pp. 579–580. Published under the auspices of the American Council Of Learned Societies.

Pawlas, Karl R. (1975): Berlin B9 Versuchsflugzeug. *Luftfahrt International*, (12):1823–1834.

Pettenkofer, Max von (1873): *Was man gegen die Cholera thun kann*. Oldenbourg, München.

Pezzi, M. (1937): Il Volo in Alta Quota / Der Höhenflug. In: *Gesammelte Vorträge der Hauptversammlung der Lilienthal-Gesellschaft für Luftfahrtforschung*, ed. Anonymous. Lilienthal-Gesellschaft für Luftfahrtforschung, Mittler, Berlin, pp. 52–83.

Pfau, Hans (1939): *Einrichtung zur Regelung von Druck und Temperatur in Höhenkabinen, insbesondere für Flugzeuge.* Patent Specification 731963, Deutsche Versuchsanstalt für Luftfahrt, Germany. Patent accepted: May 26, 1939. Published: Jan 21, 1943.

Phillips, John L. (1998): *The Bends – Compressed Air in the History of Science, Diving and Engineering.* Yale University Press, New Haven.

Piccard, Auguste (1950): *Between Earth And Sky.* The Falcon Press, London.

Piccard, Auguste (1954): *Über den Wolken – unter den Wellen.* Brockhaus, Wiesbaden.

Piccard, Jean and Jeanette Piccard (1935): Some problems connected with stratosphere ascensions. *Industrial and Engineering Chemistry*, 27(2):121–127.

Poe, Edgar Allan (1966): *Complete Tales and Poems.* Mladinska Knjiga, Ljubljana.

Pol, B. and P. J. J. Watelle (1854): Méthode sur les Effets de la Compression de l'Air, etc. *Annales d'Hygiène Publique et de Médicine Legale (Industrielle et Sociale), Série Deux*, 1:241–279.

Poppen, J.R. (1941): Recent Trends in Aviation Medicine. *Journal of Aviation Medicine*, 12:53–71.

Post, Wiley (1934): Wiley Post seeks new record. *Popular Mechanics*, 62:492–495.

Prevost, M. and Roman d'Amat, eds. (1954): *Dictionaire de Biographie Française*, vol. 6: Bergeron – Bournon. Libraire Letouzeyet Ané, Paris.

Proctor, Donald F., ed. (1995): *A History of Breathing Physiology.* Lung Biology in Health and Disease, vol. 83. Marcel Dekker Inc., New York.

Radkau, Joachim (1999): *Technik in Deutschland.* Suhrkamp, Frankfurt/M.

Raitt, David; Jean-Claude Dunyach; Billy Boy; Patrick Gyger; and Arthur Woods (2003): *Innovative Technologies from Science Fiction for Space Applications.* Report, European Space Agency (ESA). Available from `http://www.itsf.org`.

Rauschenbach, Boris (1995): *Hermann Oberth 1894–1989. Über die Erde hinaus, eine Biographie.* Dr. Böttiger Verlags-GmbH, Wiesbaden.

Raymond, Eric (2001): *The cathedral and the bazaar: musings on Linux and open source by an accidental revolutionary.* O'Reilly, Cambdrige, Mass.

Raymond, Eric S. (1991): *The New Hacker's Dictionary.* MIT Press, Cambridge (Mass.).

Reichluftfahrtministerium (1939): *Jahrbuch der deutschen Luftfahrtforschung.* Oldenbourg, Berlin & München.

Reynolds, Barbara, ed. (1975): *The Concise Cambridge Italian Dictionary.* Cambridge University Press, Cambridge.

Richards, Stewart (1986): Drawing the Life-Blood of Physiology: Vivisection and the Physiologists' Dilemma, 1870–1900. *Annals of Science*, 43:27–56.

Richardson, B.W. (1879): Some observations on Fleuss' new process of diving and remaining underwater. *Nature*, 21:62–64.

Rieger, Bernhard (2005): *Technology and Modernity in Britain and Germany 1890–1945*, Cambridge University Press, Cambridge, chap. Pilots as popular heroes: risk, gender, and the aeroplane, pp. 116–157.

Riha, Frank (1992): *Kritik, Satire, Parodie: gesammelte Aufsätze zu den Dunkelmännerbriefen, zu Lesage, Lichtenberg, Klassiker-Parodie, Daumier, Herwegh, Kürnberger, Holz, Kraus, Heinrich Mann, Tucholsky, Hausmann, Brecht, Valentin, Schwitters, Hitler-Parodie und Henscheid.* Westdeutscher Verlag, Opladen.

Römer, Botho von (1929): Der Kampf um Geschwindigkeit und Höhe. *ADAC-Motorwelt*, 26(37):9–11.

Römer, Hans von and Botho von Römer (1930): *Wunder der Technik in Gegenwart und Zukunft.* Aviatik Zigarettenfabrik, Breslau.

Römer, Hans von and Botho von Römer (1935): *Technische Wunder von heute und morgen.* Köhler, Minden.

Römer, Hans von and Botho von Römer (1936): Ein deutscher 'Taucher-Anzug' für Flieger. *Luftwelt*, 3(3):100.

Römer, Hans von and Botho von Römer (1937): Höhenflüge mit neuartigen Stratosphären-Anzügen. *Deutsche Technik*, 5(10):491–493.

Robinson, Douglas H. (1973): *The Dangerous Sky. A history of aviation medicine.* University of Washington Press, Seattle.

Robinson, Victor (1943): Aviation Medicine in the A.E.F. In: *Aviation Medicine*, ed. George Rosen. Ciba Symposia, Ciba Pharmaceutical Products, Summit (N.J.), vol. 5, pp. 1639–1646.

Rosenberg, Nathan (1974): Science, Invention, and Economic Growth. *The Economic Journal*, 84:90–108.

Rosenberg, Nathan (1985): *Inside the black box. Technology and Economics.* Cambridge University Press, Cambridge.

Rosenstiel, M. (1933a): La physiologie et le vol dans la stratosphère. *La Presse Médicale*, 41(46):941–942.

Rosenstiel, M. (1933b): Les problèmes de physiologie soulevés par les essais de sauvetage à bord des sous-marins. *La Présse Medicale*, 41(13):261.

Rosenstiel, M. (1935): Le Scaphandre Aérien. Une solution au problème physiologique des hautes altitudes. *La Presse Médicale*, 43(76):1476–1477.

Ross, H. E. (1949): Breathing in Irrespirable Atmospheres (Review). *Journal of the British Interplanetary Society*, 8(1):40–41.

Ross, H. E. (1950a): Lunar Spacesuit. *Journal of the British Interplanetary Society*, 9(1):23–37.

Ross, H. E. (1950b): Lunar Spacesuit. *Journal of the British Interplanetary Society*, 9(6):300–302.

Rouqayrol, Benoist [sic!] (1866): *Improvement in Regulating the Flow of Gases in Apparatus for Diving.* Patent Specification 59529, USA. Patented Nov. 6, 1866.

Ruff, Siegfried (1939): Biologische Probleme des Hochgeschwindigkeitsfluges. In: *Schriften der Deutschen Akademie der Luftfahrtforschung, Heft 13.* Oldenbourg, München & Berlin.

Ruff, Siegfried (1942): *Über Rettungsmöglichkeiten beim Flug in großen Höhen.* Schriften der Deutschen Akademie der Luftfahrtforschung 1057/42g, Berlin.

Ruff, Siegfried (1989): Höhenflug. In: Ruff et al. (1989), pp. 11–50.

Ruff, Siegfried; Martin Ruck; and Gerhard Sellmayr, eds. (1989): *Sicherheit und Rettung in der Luftfahrt.* Die deutsche Luftfahrt, Bd. 13. Bernard & Graefe, Koblenz.

Ruff, Siegfried and Hubertus Strughold (1939): *Grundriß der Luftfahrtmedizin.* Barth, Leipzig.

Ruff, Siegfried and Hubertus Strughold (1942): *Atlas der Luftfahrtmedizin.* Barth, Leipzig.

Ryan, W.F. and Peter Norman, eds. (1995): *The Penguin Russian Dictionary.* Viking, Harmondsworth.

Saint-Exupéry, Antoine de (1939): *Terre des Hommes.* Gallimard, Paris.

Saint-Exupéry, Antoine de (1942): *Airman's Odyssey.* Reynal & Hitchcock, New York. Second Printing.

Saint-Exupéry, Antoine de (1948): *Wind, Sand und Sterne.* rororo, Hamburg.

Saint-Exupéry, Antoine de (2002): *Wind, Sand, and Stars.* Harvest Books, New York.

Süßbrich, D. (1938): Der Höhenflug. *Luftwehr*, 5(7):274–276.

Schabel, Ralf (1994): *Die Illusion der Wunderwaffen. Die Rolle der Düsenflugzeuge und Flugabwehrraketen in der Rüstungspolitik des Dritten Reiches.* Oldenbourg, München.

Schaffer, Simon (1999): Enlightened Automata. In: *The Sciences in Enlightened Europe*, eds. William Clark; Jan Golinski; and Simon Schaffer, University of Chicago Press, Chicago, pp. 126–165.

Schilling, C. (1981): *A History of the Development of Decompression Tables.* Undersea Medical Society, Bethesda.

Schimank, Uwe (2002): Organisationen: Akteurkonstellationen – korporative Akteure – Sozialsysteme. In: *Soziologie der Organisation*, eds. Jutta Allmendinger and Thomas Hinz, Westdeutscher Verlag, Wiesbaden, pp. 29–54. Sonderheft 42/2002 der Kölner Zeitschrift für Soziologie and Sozialpsychologie.

Schimank, Uwe (2005): *Die Entscheidungsgesellschaft. Komplexität und Rationalität der Moderne.* Verlag für Sozialwissenschaften, Wiesbaden.

Schmidt, Ingeborg (1938): *Bibliographie der Luftfahrtmedizin. Eine Zusammenstellung von Arbeiten über Luftfahrtmedizin und Grenzgebiete bis Ende 1936.* Springer, Berlin.

Schmidt, Ingeborg (1943): Bibliographie der Luftfahrtmedizin. Zweite Folge. Eine Zusammenstellung von Arbeiten über Luftfahrtmedizin und Grenzgebiete 1937 bis Ende 1940. *Luftfahrtmedizin*, 8(1):1–128.

Schmookler, Jacob (1966): *Invention and Economic Growth.* Harvard University Press, Cambridge, Ma.

Schneider, Edward C. (1923): A Cardio-Vascular Rating as a Measure of Physical Fatigue and Efficiency. *Air Service Information Circular*, 5(403):9–13.

Schneider, Edward C. (1989): Medical Studies in Aviation: II. Physiologic Observations and Methods. *Aviation, Space, and Environmental Medicine*, 60(6):609–615. Originally appeared in: Journal of the American Medical Association, 1918; 71: 1382–1400.

Schneider, Edward C. (1990): A Cardiovascular Rating as a Measure of Physical Fatigue and Efficiency. *Aviation, Space, and Environmental Medicine*, 61(3):277–281. Originally appeared in: 'Journal of the American Medical Association', 1920, 74: 1507–1510. Also: Schneider (1923).

Schneider, Edward Christian and B.R. Lutz (1923): Aveolar air and respiratory volume at low oxygen tension. *Air Service Information Circular*, 5(403):38–48.

Schnell, Walter (1935): *Luftfahrtmedizin. Einführung in die Biologie und Hygiene des Flugwesens.* Volkmann, Berlin.

Schrötter, Hermann von (1899): *Zur Kenntnis der Bergkrankheit.* Braumüller, Wien/Leipzig.

Schrötter, Hermann von (1902): Über Höhenkrankheit mit besonderer Berücksichtigung der Verhältnisse im Luftballon. *Wiener Medizinische Wochenschrift*, pp. 1294, 1351–1354, 1417–1420.

Schrötter, Hermann von (1903): Über Höhenkrankheit mit besonderer Berücksichtigung der Verhältnisse im Luftballon. In: Anonymous (1903), pp. 102–129.

Schrötter, Hermann von (1904): *Der Sauerstoff in der Prophylaxe und Therapie.* Hölder, Wien.

Schrötter, Hermann von (1907a): *Die Hygiene der Aëronautik.* Sportverlag Grethlein & Co., Leipzig, Berlin, München & Paris.

Schrötter, Hermann von (1907b): *Vorrichtung zur Vermeidung der Gefahr der raschen Dekompression von den bei Tiefseetauchungen herrschenden hohen Drücken.* Patent Specification 212770, Germany. Accepted: Nov. 17, 1907. Published: Aug. 11, 1909.

Schrötter, Hermann von (1912): *Hygiene der Aeronautik und Aviatik.* Wilhelm Brauer K.U.K. Hof- und Universitätsbuchhändler, Wien.

Schrötter, Hermann von (1919): Bemerkungen zur praktischen Physiologie des Fliegers. *Wiener Klinische Wochenschrift*, 32(28):731–736.

Schubert, Gustav (1935): Die Belastung des menschlichen Körpers beim Hochleistungsflug unter besonderer Berücksichtigung des Höhenfluges. In: Géronne (1935), pp. 14–27.

Schurmeier, Harry L. (1989): Observations on the Physical Effects of Flying. *Aviation, Space, and Environmental Medicine*, 60(2):180–182. Reprinted from Journal of the American Medical Association, 1917; 69: 584–586.

Schuster, P. (1924): Die Eroberung der Luft. In: *Taten der Technik. Ein Buch unserer Zeit*, ed. Hanns Günther, Rascher, Zürich, vol. 2, pp. 16–114.

Schwerdtfeger, W. and U. Luft (1944): *Die ärztliche Betreuung der englischen und amerikanischen Flieger*. ZWB-Report FB 26/44, Berlin.

Sci.Amer. (1861): India-Rubber Manufacturers for Army and Navy Purposes. *Scientific American*, 4(25):388–389.

Scott, V.T. (1920): Why an aviator is examined by the rebreathing method and how often the examination should be made. *Military Surgeon*, 40:407–409.

Seeler, Henry (1950a): German Altitude Oxygen Equipment (Ground Service And Aircraft Equipment) From 1934 To 1945. In: The Surgeon General, US Air Force (1950).

Seeler, Henry (1950b): Pressure Suits and Pressure Cabins in German Aviation. In: The Surgeon General, US Air Force (1950).

Seemann, K. (1967): Decompression tables in civil engineering in Germany. In: McCallum (1967), pp. 56–64.

Segrè, Claudio G. (1987): *Italo Balbo: A Fascist Life*. University of California Press, Berkeley.

Serviss, Garrett P. (2005): *Edison's Conquest of Mars*. Apogee, Ontario.

Shayler, David J. (1990): Origins of Soviet Space Pressure Suits, 1930–1963. *Journal of the British Interplanetary Society*, 43:417–423.

Shelton, Jack B. Jr. (1999): Altitude sickness and the Oxygen Mask. *Journal of the American Aviation Historical Society*, 44(4):282–287.

Shindler, Colin (1979): *Hollywood goes to War: Films and American Society 1939–1952*. Routledge, London.

Simpson, J.A. and E.S.C. Weiner, eds. (1989): *The Oxford English Dictionary*, vol. VII. Clarendon Press, Oxford, 2nd edn.

Smith, Colin, ed. (1996): *Collins Spanish-English English-Spanish Dictionary. Unabridged*. Harper Collins, Glasgow, 4th edn.

Smith, George (1949): *Dictionary of National Biography, 2nd Supplm. 1931–1940*. Oxford University Press, Oxford.

Smith, Henry Ladd (1991): *Airways. The History of Commercial Aviation in the United States.* Smithsonian Institution Press, Washington D.C. Reprint. Original from 1942.

Smith, R. A. (1948): The Man Carrying Rocket. *Journal of the British Interplanetary Society*, 7(3):100–111.

Smolczyk, Eduard (1938): Höhenatmung. *Die Gasmaske*, 10(1):1–6.

Sobolew, Dimitri Alexejewitsch (2000): *Deutsche Spuren in der sowjetischen Luftfahrtgeschichte. Die Teilnahme deutscher Firmen und Fachleute an der Luftfahrtentwicklung in der UdSSR.* Mittler, Hamburg/Berlin/Bonn.

Sponsel, Heinz (1955): *Piccard.* Theodor Oppermann Verlag, Hannover.

Süring, R. (1909): Wissenschaftliche Ballonhochfahrten. In: *Wir Luftschiffer. Die Entwicklung der modernen Luftschifftechnik in Einzeldarstellung*, ed. Dr. Bröckelmann, Ullstein, Berlin & Wien, pp. 48–65.

Steadman, S.J.; H.L. Green; J.M. Wright; and O.R. Hertel (1945): *Drägerwerk Factories at Lübeck, Hamburg and Uetersen.* Report 110, BIOS, London.

Stelzner, Hermann (1913): Dräger-Tauchretter für Wasserflugzeuge. *Dräger-Hefte*, (11):81–83.

Stelzner, Hermann (1915): Dräger-Flugzeug-Tauchretter für Luftfahrt-Betriebe. *Dräger-Hefte*, (33/34):259–260.

Stelzner, Hermann (1926): Sauerstoffbedarf und Arbeitsleistung. *Dräger-Hefte*, (113):1222–1223.

Stelzner, Hermann (1931): *Tauchertechnik.* Coleman, Lübeck.

Stelzner, Hermann (1943): *Tauchertechnik.* Coleman, Lübeck, 2nd edn.

Sturdy, Steven (1987): *A Co-ordinated Whole: The Life and Work of John Scott Haldane.* Ph.D. thesis, University of Edinburgh, Edinburgh (UK).

Sturdy, Steven (1988): Biology as Social Theory: John Scott Haldane and Physiological Regulation. *British Journal of the History of Science*, 21:315–340.

Sundstroem, Edward Sigfried (1919): *Studies on adaption of man to high altitudes.* University of California Press, Berkeley.

Sundstroem, E.S. and W.R. Bloor (1920): The Physiological Effects of Short Exposures to Low Pressures. *Journal of Biological Chemistry*, 45:153–170.

Swan, A. (1937): Problems of the Altitude Record Flight. *Shell Aviation News*, (10):14–19.

Symington, Neville (1993): *Narcissism: a new theory*. Karnac, London, 2nd edn.

Taylor, Blaine (1996): *Fascist Eagle: Italy's Air Marshall Italo Balbo*. Pictorial Histories Publishing Company, Montana.

The Surgeon General, US Air Force (1950): *German Aviation Medicine: World War II*, vol. 1. US Government Printing Office, Washington DC.

Thomas, E. (1928): *Bericht über die dritte Hochfahrt des Höhenballons 'Bartsch von Sigsfeld' am 11. Juli 1928*. DVL-Bericht Vf 15/9, Deutsche Versuchsanstalt für Luftfahrt, Berlin.

Tilgenkamp, Erich (1959): *August Piccard – Reisen in ungewöhnliche Räume*. Welsermühl, Wels.

Toggenburg, Paul (1935): Ein Mädchen im Dom. *Luftwelt*, 2(1):12–13.

Tomlin, Russel S.; Linda Forrest; Ming Ming Pu; and Myung Hee Kim (1997): Discourse Semantics. In: *Discourse as Structure and Process*, ed. Teun A. van Dijk, Sage, London, pp. 63–111.

Tomlinson, D.W. (1938a): *High Altitude Flying Observations and Economic Calculations*. Tagungsband Hauptversammlung 1938, Lilienthal-Gesellschaft für Luftfahrtforschung, Berlin.

Tomlinson, D.W. (1938b): Nearing the Stratosphere. *Journal of the Aeronautical Sciences*, 5(4):125–131.

Tresch, John (2002): Extra! Extra! Poe invents science fiction! In: *The Cambridge Guide to Edgar Allan Poe*, ed. Kevin J. Hayes, Cambridge University Press, Cambridge.

Trischler, Helmuth (1992): *Dokumente zur Geschichte der Luft- und Raumfahrtforschung in Deutschland 1900–1970*. DLR-Mitteilung 92-08, Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR).

Trischler, Helmuth (1998): Im Spannungsfeld Von Individuum und Gesellschaft. Aufgaben, Themenfelder und Probleme Technikbiographischer Forschung. In: *Biographie und Technikgeschichte*, eds. Wilhelm Füßl and Stefan Ittner, Leske & Budrich, pp. 42–58.

Trischler, Helmuth and Kai-Uwe Schrogl, eds. (2007): *Ein Jahrhundert im Flug. Luft- und Raumfahrtforschung in Deutschland 1907–2007*. Campus, Frankfurt.

Tsiolkovsky, Konstantin (1960): *The Call of the Cosmos*, Foreign Languages Publishing House, Moscow, chap. Ouside the Earth, pp. 161–332. Translated by V. Talmy.

Tucholsky, Kurt (1928): Meine Flieger – deine Flieger. *Weltbühne*, 24(18):686. Published under pseudonym "Theobald Tiger".

Tucker, Jennifer (1996): Voyages of Discovery on Oceans of Air: Scientific Observation and the Image of Science in an Age of 'Balloonacy'. *Osiris*, 11:144–176.

Turnhill, Reginald and Arthur Reed (1980): *Farnborough. The Story of the RAE.* Robert Hale Ltd., London.

Umschau (1918): Verhütung von Taucherkrankheiten. *Die Umschau*, 21:692–694.

USN (1916): *Diving Manual.* Navy Department, Washington D.C.

Valier, Max (1924): *Der Vorstoss in den Weltenraum. Eine Technische Möglichkeit.* Oldenbourg, München & Berlin, 4th edn.

Valier, Max (1928): *Raketenfahrt.* Oldenbourg, München & Berlin. 5. Auflage von "Vorstoss in den Weltenraum. Eine technische Möglichkeit".

Vernaleken, Christoph and Martin Handig (2003): *Junkers Ju388. Entwicklung, Erprobung und Fertigung des letzten Junkers-Höhenflugzeuges.* Aviatic Verlag, Oberhaching.

Verne, Jules (2005): *From The Earth To The Moon.* Barnes & Noble, New York.

Vitz, Paul C. (1988): *Sigmund Freud's Christian Unconscious.* Guilford Press, New York.

Vocke, Ernst (2002): *Die Wetterflieger. Von Temp zu Temp. Die Geschichte des Wetterfluges.* VDM, Zweibrücken.

Voigt, E. (1940): *Technische Richtlinien für Höhenkabinen (Überdruckkammern).* ZWB-Report Rech 154, Erprobungstelle der Luftwaffe, Rechlin.

Wagner, Wolfgang (1991): *Kurt Tank – Konstrukteur und Testpilot bei Focke-Wulf.* Die deutsche Luftfahrt. Bernhard & Graefe, Bonn, 2nd edn.

Walder, D. N. (1967): The effectiveness of the British decompression table. In: McCallum (1967), pp. 65–70.

Ward, R.O. (1908): Alveolar Air on Monte Rosa. *Journal of Physiology*, 37:378–389.

Weitekamp, Margaret A. (2004): *Right Stuff, Wrong Sex: America's First Women in Space Program.* Gender Relations and the American Experience Series. John Hopkins University Press, Baltimore.

West, John B. (1998a): *High Life: A History of High-Altitude Physiology and Medicine.* Oxford University Press, New York & Oxford.

West, John B. (1998b): Yandell Henderson, April 23, 1873 – February 18, 1944. *Biographical Memoirs of the National Academy of Sciences*, 74:145–158.

West, John B. (2003): George I. Finch and his pioneering use of oxygen for climbing at extreme altitudes. *Journal of Applied Physiology*, 94:1702–1713.

West, John B. (2006): Meeting Report. Challenging the Altitudes: One-Day Conference on the History of Altitude Medicine, December 5, 2005, Manchester, UK. *High Altitude Medicine and Biology*, 7(1):90–91.

Whitney, James L. (1989): Medical Studies in Aviation III: Cardiovascular Observations. *Aviation, Space, and Environmental Medicine*, 60(7):711–714. Originally appeared in: Journal of the American Medical Association, 1918; 71:1382–1400.

Wiesehöfer, Hans (1939): Über Flugversuche zur Frage der Erträglichkeit hoher Beschleunigung bei liegender Unterbringung der Flugzeuginsassen. In: Reichluftfahrtministerium (1939), pp. 134–139.

Wilmer, W.H. (1935): The Early Development of Aviation Medicine in the United States. *Military Surgeon*, 77(3):115–135.

Wilson, K. T. (1985): Spacesuit Development: The American Experience. *Journal of the British Interplanetary Society*, 38:51–60.

Windschuttle, Keith (1997): *The Killing of History: How Literary Critics and Social Theorists are Murdering our Past.* The Free Press, New York.

Winston, A.W. (1936): The Design and Construction of the Gondola for 'Explorer II'. In: Briggs (1936), pp. 248–249.

Winter, Frank (1992): Planning for Spaceflight: 1880s to 1930s. In: *Blueprint for Space: Science Fiction to Science Fact*, eds. Frederick I. Ordway and Randy Liebermann, Smithsonian Institution Press, Washington and London, pp. 104–112.

Wolfe, Tom (1979): *The Right Stuff.* Farrar, Straus, Giroux, New York.

Yolton, John; Pat Rogers; Roy Porter; and Barbara Stafford., eds. (1991): *The Blackwell Companion to the Enlightenment.* Blackwell, Oxford.

Young, Desmond (1963): *The Man in the Helmet*. Cassel, London.

Young, Desmond (1966): *Member for Mexico: A Biography of Weetman Pearson, First Viscount of Cowdray*. Cassell, London.

Younger, J.E. (1938a): Structural and Mechanical Problems Involved in Pressure (Supercharged) Cabin Design. *Journal of the Aeronautical Sciences*, 5(5):181–185.

Younger, John E. (1938b): Engineering Aspects of Commercial High Altitude Flying. *Journal of the Royal Aeronautical Society*, 42:1055–1083.

Zegenhagen, Evelyn (2007): *Schneidige deutsche Mädel: Fliegerinnen zwischen 1918 und 1945*. Wallstein, Göttingen.

Zeidler, Manfred (1994): *Reichswehr und Rote Armee 1920–1933. Wege und Stationen einer ungewöhnlichen Zusammenarbeit*. Oldenbourg, München, 2nd edn.

Zschokke, Conradin (1896): *Druckluft-Gründungen*. Verlag von Wilhelm Engelmann, Leipzig.

Zuntz, Nathan (1882): *Physiologie der Blutgase und des respiratorischen Gaswechsels*. F.C.W. Vogel, Leipzig.

Zuntz, Nathan (1912): *Zur Physiologie und Hygiene der Luftfahrt*. Springer, Berlin.

Zuntz, Nathan and Hermann von Schrötter (1902): Ergebnisse zweier Ballonfahrten zu physiologischen Zwecken. *Pflügers Archiv*, 92:479–520.

Zuntz, Nathan and Leo Zuntz (1897): *Über die Wirkungen des Hochgebirges auf den menschlichen Organismus*. Paetel, Berlin.

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