Development of Unmanned Robotic Vehicles based on the Three-Wing Planform Technology

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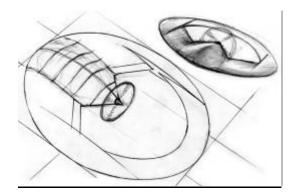
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Abstract: We present a new category of unmanned robotic vehicles (URV) based on Three-Wing Planform technology. Due to its low-aspect circular all wing shape, this URV manifests unique flying characteristics which e.g. allow it to fly at extremely low speeds, perform complex maneuvers, take off and land on very short runways (VSTOL), or carry loads higher than most other airplanes or helicopters of similar size. The low-aspect ratio of our URV furthermore gives it an extremely low radar signature. Equipped with various sensors, and/or cameras, this URV can be employed in search and rescue operations or catastrophe missions such as earthquakes, flooding or forest fires and seaport security for ships. These URVs are designated to operate autonomously or by remote control by one or several user(s) employing virtual reality (VR) or augmented reality (AR) technology.

Key Words: Unmanned robotic vehicle (URV), airplane, remote controlled (R\C), virtual reality (VR), augmented reality (AR), search and rescue, catastrophe missions, Unmanned Autonomous Vehicle (UAV), 3-wing planform technology, Very Short Take-off and Landing (VSTOL), Skyblade

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Introduction

The Three-wing planform aircraft is a new approach to the design and building of aircraft based upon the concepts of a circular/lenticular/low aspect planform. In the past, circular planform designs (figure 1) and in [Appendix A]



Figure 1

have been unstable (figure 2) even with computer control systems, resulting in many failures. Three-wing planform technology circumvents these problems, providing a stable aircraft, which has maneuvering capabilities similar to high performance aircraft.



Figure 2

Over the past ten years prototypes (figure 3) of the three-wing planform have been constructed of balsa wood using standard hobby construction techniques and have flown very successfully as R/C models by many people all around the world. The NAIST/TAO Skyblade Project* is the first serious attempt to construct large-scale three-wing planform.



Figure 3

Recent interests in UAV technology for search and rescue, surveillance, and other uses that require a high stability – high performance (between the very slow to subsonic) vehicle that is not easily detectable by radar and other means of detection have motivated designers to look for other exotic concepts of aircraft designs. Three-wing planform is one of the few known technologies available that has the ability to meet or exceed these challenges, depending upon mission requirements.

The benefit of a planform that has 360degree field of view for imaging, sensors and communications while maintaining stability at altitude for long periods of time, and having good maneuverability has been widely known for some time. This technology is brings fresh ideas into the AUV community.

This paper presents current progress in the development of the Skyblade Project unmanned demonstrator version on the three-wing planform technology concept.

The Skyblade three-wing planform smallscale demonstrator was built to:

1. Study handling qualities of three-wing planform technology aircraft

- 2. Investigate R/C and computer control algorithms for robotic control
- Act as a flying test bed for 360-degree vision system technology developed at NAIST
- 4. Demonstrate the feasibility of three-wing technology aircraft for search and rescue operations in Japan.
- Promote technology development and basic research at NAIST and TAO from 2003 ~ 2008 and apply the development to a search and rescue system in Japan.

The demonstration vehicle's configuration also matches the design currently in development for both manned and unmanned operations, which uses either a pusher propeller or a jet engine design depending upon the intended mission. The full size 15-meter diameter (turboprop version) aircraft can be exchangeable for either 6 passengers or carrying a large payload.

There are two demonstrator vehicles under construction. One using traditional Radio Control (R/C) technology and the other using an autonomous computer control system, all other characteristics are basically the same. The Skyblade demonstrators are 2 meters in diameter and are expected to weigh approximately 20 pounds fully loaded. A Zenoah 80cc engine, providing thrust, with a pusher propeller configuration powers both. At this weight and engine size there is a good match between the dynamic scaling of the demonstrator and the full-size design. Aerodynamic controls consist of ailerons, two inside (split type) and two outside, and an elevator that runs across the backside that is also split.

The R/C version uses standard off the shelf radio and servo control. The autonomous version however, carries an onboard computer with both up-link and downlink capability, with separate bands for video and real-time telemetry transmission for Virtual Reality (VR) control. The telemetry bands transmit and receive; however many of the sensors are one-way, so the up-link data stream flows are kept to a minimum.

The primary airframe structure of the Skyblade demonstrator is composed of a Carbon / Kevlar / GRAPHLITE * / Divinycell sandwich core, with some Fiberglass for reinforcement.

Demonstrator Design

Skyblade Design

The Skyblade demonstrators are based upon patented Three-wing planform technology under license from C60World Corporation. The design was chosen by the author to fulfill some primary requirements for a search and rescue system, also under development by the author.

The requirements are as follows:

- The means of lofting 360-degree vision technology augmented by a Hyperspectral imaging and a telecommunications system to a high place and maintain stable control for as long periods of time.
- In Japan, where space is premium, the requirement of a vehicle, with a minimum footprint, which could be stored upon rooftops (figure 4) in special enclosures (patent pending) for long durations that could be activated immediately and reliably.
- 3. A vehicle, which upon activation would airborne within minutes.
- The ability of a vehicle to maneuver safely and reliably within a major metropolitan city under a crises situation in which stress and panic levels have become endemic.
- 5. A vehicle that in the event of a crash will cause minimum damage to the environment or people involved.
- 6. The vehicle must be stable and easily flown by personnel with minimum training.

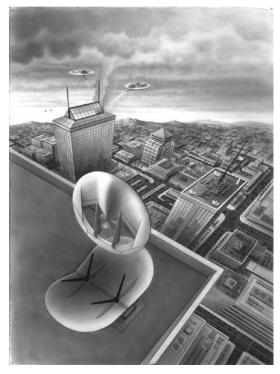


Figure 4

So, what is a Three-Wing circular planform vehicle? It is an airplane consisting of three different wings (a forward-swept front wing, a backward-swept rear wing, and left/right wingtips), which are combined to form a circular shaped body, with a large opening in the center. The central opening is determined by the inside edges of the three wings, as shown in (Figure 6). The center of gravity (CG) of the aircraft lies near the trailing edge of the front wing (along the center line of the airplane), thus the lifting forces are distributed rather uniformly about the CG, while still being forward-biased.

Skyblade Construction

Airframe

The primary structure consists of a multilayer sandwich that consists of layers of carbon fabric bonded by using a vacuum bagging technique on a layer of Divinycell/GRAPHLITE superstructure (figure 5), which is to be formed in a female mold that was produced from a plug.



Figure 5

The result is a vehicle that can carry high aerodynamic loads. Internally we use a wing-box design, which supports the landing gear, engine mounts, and payload. The wing-box consists of an S-glass/Divinycell composite with aircraft aluminum brackets bonded on to support the attachments.

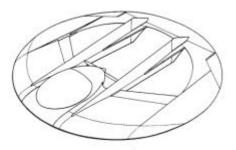


Figure 6

There are nine control surfaces, visible in the artists' sketch (figure 6), of the current Skyblade design. It is controlled by servos that have been modified for maximum torque load. They consist of four ailerons, four rudders (optional [1]) and one elevator. These surfaces have been produced out of Styrofoam using the Rutan composite construction method [2].

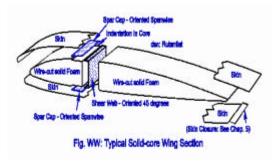


Figure 7

Propulsion

The aircraft is powered by a Zenoah 80cc engine, which has 8HP to produce a consistent thrust to weight ratio to simulate the 15-meter aircraft.

The engine feeds from a minimum of twogallon fuel tank located in the wingtips, the same as the full size aircraft. The wingtip location was chosen for to isolate the fuel from the engines to maximize safety concerns of fire and fuel leakage. In the event of an accidental crash [3], the aircraft should not explode or cause a major fire as in current aircraft designs; where the fueltank structure supports the engine(s) and landing gear, thus making Skyblade type aircraft safe for use in urban environments.

Landing Gear

The aircraft uses; three off-the-shelf traditional retractable type landing gear in a tripod style configuration. The aircraft will take off and land with a 45-degree sweep and/or VSTOL, which is the same as the fullscale version. A servo is linked mechanically to one of the landing gears to produce the required results in steering.

Electronic Hardware

The hardware is still in the experimental stage as we are building the autonomous control system from the ground up. We are considering two main types of hardware systems but will discuss only one of them in this paper. The current configuration (figure 8) of the aircraft electronics is straightforward. The project uses off-the-shelf hardware component technology as much as possible. Software, on the other hand is composed of a mixture of commercial libraries and inhouse codes that have been optimized for maximum performance and the special requirements related to experimental systems and sensor fusion.

Wheel Steering Servo Zencah Engine	Radio Rx 10 Channel PCM	360-degree Vision System
Servo Front Allerons Servo		3-axis gyro Sensor
Rear Allerons Servo	Flight Computer	Airspeed Indicator Sensor
Elevator Servo		
Vertical Rudders (Left) Servo		Ultrasound Sensor
Vertical Rudders (Right) Servo		Green Laser Senso
Top 360-degree Camera Servo Bottom 360-degree Camera Servo	Data Storage	Real-time imaging collision detection system

Figure 8

Flight Computer

The on-board flight computer is a commercially available unit, which consists of 32 inputs and outputs. All flight information is stored on battery protected flight RAM memory that can be transferred after each flight for data comparison and verification.

The unit is enclosed in a crash protected casing in the event of a mishap. The system has a high level of real-time control cycle for the high data rates required for simultaneous video and telemetry transmission and reception. Redundant telemetry and a single redundant backup camera (not shown in figure 8) are also on board.

Sensors

Aircraft sensors include:

- 1. 360-degree vision (figure 9) system coupled with a separate upward and downward viewing system.
- 2. A commercially available 3-axis rate gyro.
- 3. Airspeed indicator to measure aircraft speed.
- 4. Ultrasound sensor and an experimental green laser for take-off and landing.
- 5. Experimental onboard video cameras using a real-time vision-based object collision detection system from the NAIST robotics group.



Figure 9

The uniqueness of the Skyblade project is in the sensor equipment that has been put into place to be utilized by the Skyblade aircraft. The aircraft 360-degree vision system (figure 10) can be used to



Figure 10

create panoramic (figure 11), partial panoramic, perspective vision, or a combination of the above in real-time. This type of system with a low-aspect stealth vehicle makes the perfect spy in the sky.

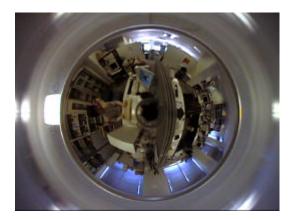


Figure 11

Actuators

There are nine control surfaces in the current Skyblade design. These surfaces are controlled by servos that have been modified for maximum torque load. They consist of four ailerons, four rudders (optional [6]) and one elevator. High-torque high-speed servos are required control the surfaces, especially in aerobatic fly conditions.

There are two 360-degree vision systems as well as three top and three bottom fish-eyed camera clusters and engine starter that required additional servos.

Electrical Power

The aircraft has two power systems, one based upon nickel-cadmium and another based upon lithium. Both supply power for their associated systems via voltage regulators. Both have onboard umbilical attachments for tether type recharging.

Portable Radio Up-Link

A commercially available radio control transmitter that has been modified into an Augmented Virtual Reality system to up-link the pilot commands into the aircraft.



Figure 12

The prototype unit (figure 12) is made up of a video antenna receiver, light-weight arm mount which employs the radio control technology and various feedback sensors (not shown – patents pending), 6-axis floating joy stick – modified with a gyroscope (not shown) and integrated into a portable computer system with a Linux OS that is coupled by a GPS unit (not shown) which communicates to the portable computer by bluetooth technology.



Figure 13

Bluetooth technology was chosen because of limitations in ports for other GPS systems. Also, since the user doesn't move so quickly, the GPS system's accuracy is good enough. The lighting conditions in the field environment are very severe. We are also experimenting with head mounted displays (figure 13) of various types and designs to study the human effectiveness of such devices.

The development of this device is in the experimental stage and is not an operational device at this time. Initial tests however are showing promise.

CAVE Ground Station

As stated earlier in this paper, the motivation to develop on a planform of this type was to enhance our capabilities for search and rescue technology. Our search and rescue system (figure 14) is composed of several key components:

- 1. Pilot CAVE
- 2. Command & Control CAVE "CYLINDRA"
- 3. Laser link
- 4. Skyblade aircraft
- 5. Mobile Augmented Virtual Reality devices
- 6. Software and database integration system

The "pilot" CAVE, which is located at the TAO research facility about 500 meters from NAIST, allows a pilot to operate the aircraft on a motion bed platform, (which could, in theory be located anywhere), that is coupled to the motion of the aircraft. This motion bed is surrounded by three screens behind which, are backside projectors, which project the incoming data and information on the screens in, 3-Dimensions, thus surrounding the pilot with real-time information and data to act on.

The pilot CAVE has a direct link to the aircraft's video and telemetry and communicates with the aircrafts onboard computer. It can also be used to edit flight schedule code, download and upload data and analyze data in real-time.

Upon receiving this data, the data is then retransmitted via a Laser Link and ATM Link to the Command and Control CAVE called "CYLINDRA" – name is taken from its shape.

In the Command & Control CAVE, officials, police, fire chiefs, and others may gather to monitor and influence the situation at the disaster site. These officials also have a separate communications link to the pilot via the Command & Control CAVE operations chief who doubles as a kind of co-pilot.

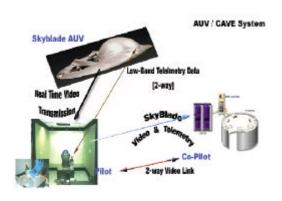


Figure 14

Conclusions and Future work

This project, which started in April 2002 and will conclude this phase on March 30, 2003, has accomplished several milestones:

- 1. Establishment of a composite research facility
- 2. Construction of four Skyblade aircraft of two types and two sizes
- Implementation of a portable Augmented Virtual Reality type of device prototype that may decrease the learning curve in flying remote aircraft and increase the ease of use and operation of aircraft or other AUV type technologies.
- 4. We expect to have a functional prototype search & rescue system operational by March 30, 2003
- 5. Two of the authors are working to establish an UVS Association which is to be composed of Universities in Japan that will work with the US and EUC UVS community

The project is still in development phase and is expected to go into operational phase by the beginning of 2003. At this time we plan to generate more data on design, flight, Electromagnetic signatures, wind tunnel tests and more.

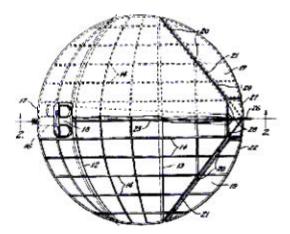
In the next phase of the project, beginning on April 2003 the project is expected to be part of a national project and to take part in other basic research programs. Nagoya University is expected to assist the project by sharing multi-vehicle control system technology.

Additional information can be found at the official NAIST website at the following URL:

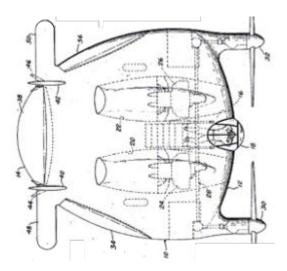
http://www.aist-nara.ac.jp/~rieken

APPENDIX A

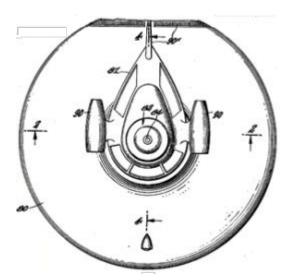
In the years since the invention of the patent system there have been so many, hundreds of, lenticular, bowl, cone, flat, long shape type of aircraft. While many seem to frown on this, it is in reality a testament to humankind's inventiveness and will to develop, invent and create. I have placed but a few samples below that are directly related to this paper and the Three-Wing planform concept.



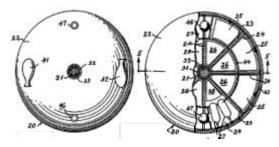
(11-8-32) ~ Aircraft Construction



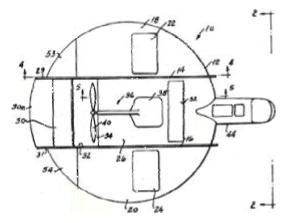
(11-18-47) ~ Airplane - Low Aspect Ratio



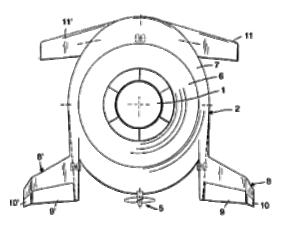
(7-30-57) ~ Saucer-Shaped Aircraft



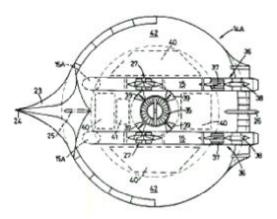
(8-10-65) ~ Circular Wing Flying Craft



(3-18-75) ~ Circular Wing Aircraft



(4-19-94) ~ Ducted Fan in Circular Wing



(11-17-98) ~ Flying Craft & Circular Wing

References

- Lambie, J., "Composite Construction for the Home Built – 2nd Edition", Aviation Publishers Book, 2000.
- Bingelis, T., "The Sportplane Builder Aircraft Construction Methods", EAA, 2001.
- Bingelis, T., "Sportplane Construction Techniques – A Builders Handbook", EAA, 1998.
- Schwartz, H., "Composite Materials Handbook – 2nd Edition", McGraw-Hill, 1992.
- OHTA, Y., Tamura H., "Mixed Reality Merging Real and Virtual Worlds", Ohnsha Ltd., Springer-Verlag, 1999.
- 6) Barfield, W., Caudell T., "Fundementals of Wearable Computers and Augmented Reality", Lawrence Erlbaum Associates, Publishers, 2001.
- Rutan, B., "Moldless Composite Homebuilt Sandwitch Aircraft Construction – 3rd Edition", Rutan Aircraft Factory, September 1993.
- Sherry, FILM "Burnelli A Name From The Past, Planes For The Future", Sherry Productions – Vero Beach, Florida, Date Unknown.
- 9) Sierra Flight Systems Inc., EFIS-2000 telemetry information and data, http://www.sierraflightsystems.com,.
- 10) Meacham, B., "An Inexpensive Homebrew Inertial Guidance System"
- Verhage, L.P., "Asimov II Getting a Near-Space Project Off the Ground", Circuit Cellar, Issue 113, December 1999.
- 12) Bachiochi, J., "Part 1: All We Have Left is Velocity", Circuit Cellar, Issue 112, November 1999.
- 13) Bachiochi, J., "Part 2: All We Have Left is Velocity", Circuit Cellar, Issue 113, December 1999.
- 14) Mathian, M., Korolkewicz, E., Gale, P., Lim, E. G., "Design Of A Circularly Polarized 2x2 Patch Array Operating In The 2.45 GHz ISM Band", Microwave Journal, May 2002.
- 15) Kraus Telemetry, "MT32 Mini Telemetry System up to 32 channels, direct sensor connection", data and information

http://www.kraustelemetry.com.

16) Hennessey, C., "FireMite Thesis Report – Autonomous Control of a Scale Airplane", Simon Fraser University, April 14, 2000.

17) Hennessey, C., "FireMite Website", <u>http://www.craighennessey.com/firemite.</u> <u>htm</u>.

References Notes

[1] It has been considered that the rudder sleeves may be optional on Three-Wing planform designs and can be used as fuel or payload pods or taken off to lower the signature of the aircraft.

[2] Methods developed and pioneered by Burt Rutan for composite foam construction, which essentially takes a part that is preformed out of foam and wraps the part with a fiber, usually fiberglass, and then soaks the fiber in an epoxy. Upon drying, the resultant object is harder and stiffer than most metals.

[3] Film - Bernoulli Story, Flight safety and explicitly showing the dangers in current aircraft designs as flying bombs.

* GRAPHLITE® is a lightweight carbon composite prepeg that has optimized fiber alignment in one direction. Thus providing a material in high-tension that is the strongest and lightest (on a strength-to-weight ratio) carbon prepeg currently available on the market. C60World Corporation is the exclusive distributor of GRAPHLITE in Asia, Oceania, Russia, Middle East and Africa.

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