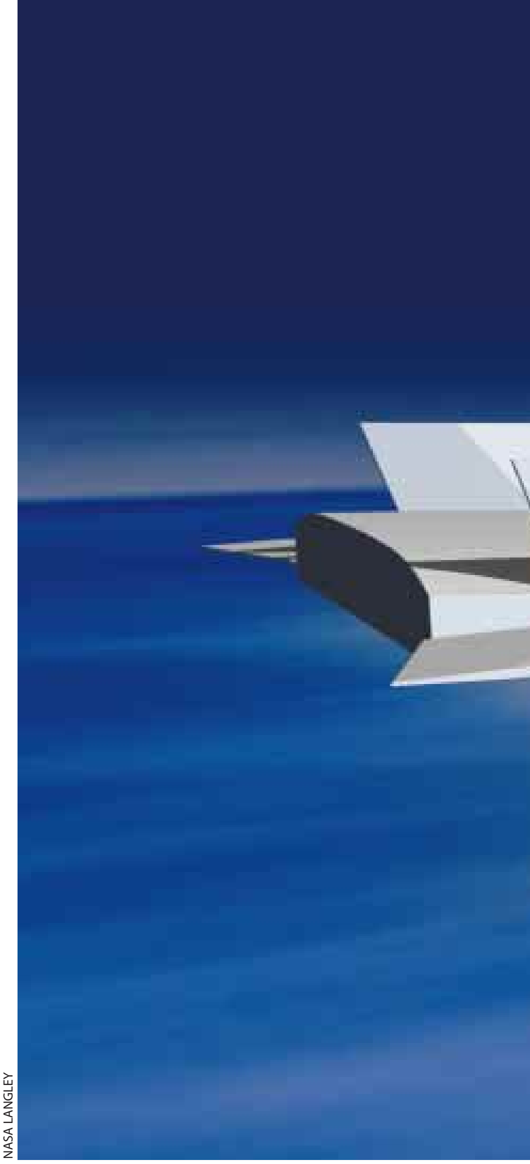
Harder Than Rocket Science

If launching a rocket to the moon sounds tough, try flying an aircraft into space at speeds topping Mach 20

by Ken Howard



NASA LANGLEY

As a project manager with the National Aeronautics and Space Administration, Charles McClinton likes to pilot his own single-engine Cessna to business meetings. He also flies on vacations with his wife, who is writing a book about their flight experiences, entitling one chapter "Terror in the Cockpit." But McClinton, an engineer by training, has a cautious approach to flying. "Close calls?" he asks. "Not really, but I've had plenty of adventure ... expanding the envelope to learn the limits ... without exceeding them."

That may be true for McClinton the pilot (his wife's protests aside), but for the past 30 years McClinton the NASA engineer has been trying to break through one limit, working to build a jet aircraft capable of hypersonic speeds so far reached only by rockets. Early next year NASA's Hyper-X program, on which McClinton serves as technology manager, will test the world's first air-breathing—that is, nonrocket—engine to be propelled by its own power to Mach 7, or seven times the speed of sound.

If this new type of jet engine succeeds, the implications could be huge. "The paradigm shift could be as significant as the shift from propellers to jets," asserts Hyper-X program manager Vincent Rausch. "It brings new potentials to access space and get from one place to another faster."

Air-breathing engines are what conventional military and passenger aircraft use for propulsion: air is sucked into an engine to be mixed with burning fuel, creating thrust, which propels the aircraft forward. Most of these engines are turbojets, which have a maximum performance of between Mach 3 and 4. The fastest aircraft propelled by an air-breathing engine, the SR-71 Blackbird, reached speeds of just over Mach 3. The Concorde can fly at Mach 2 and an F-15 fighter at Mach 2.5, whereas a 747 limps along at a

relatively sedate Mach 0.8, or about 550 miles per hour (880 kilometers per hour).

But to break free of Earth's atmosphere and enter space, a vehicle must reach the range of Mach 20 to 25. For satellite launches and the space shuttle, giant rockets provide this thrust. But rockets are heavy and nonreusable, and they have relatively low maneuverability and require vertical takeoffs. Safety is another issue. "There is a great advantage in getting away from solid rockets, where you're basically lighting a Roman candle and letting it burn," notes Laurence R. Young, Apollo Professor of Astronautics at the Massachusetts Institute of Technology.

Well aware of the disadvantages of rockets, scientists at NASA, the U.S. Air Force and many foreign laboratories have been trying to develop an alternative. Their efforts have yielded significant advances in engine design over the past 40 years. In conventional turbojets, turbines compress the incoming air, putting it under great pressure as it is fed to burning fuel. The combustion products then expand back to atmospheric pressure as they exit the engine, thus creating thrust. But turbines are inherently limited in how fast they can power a plane. As the blades spin faster, they bring in more air and create greater thrust. With the increase in plane speed, however, the air hitting the turbines dissipates more heat. The danger with supersonic flight is that the engine could literally melt away. According to McClinton, even state-of-the-art turbine materials can handle speeds only up to about Mach 3.5.

MUCH FASTER THAN A SPEEDING BULLET: A vehicle powered with a scramjet, a new type of jet engine currently under development at NASA and elsewhere, could theoretically fly faster than Mach 20, or 20 times the speed of sound.

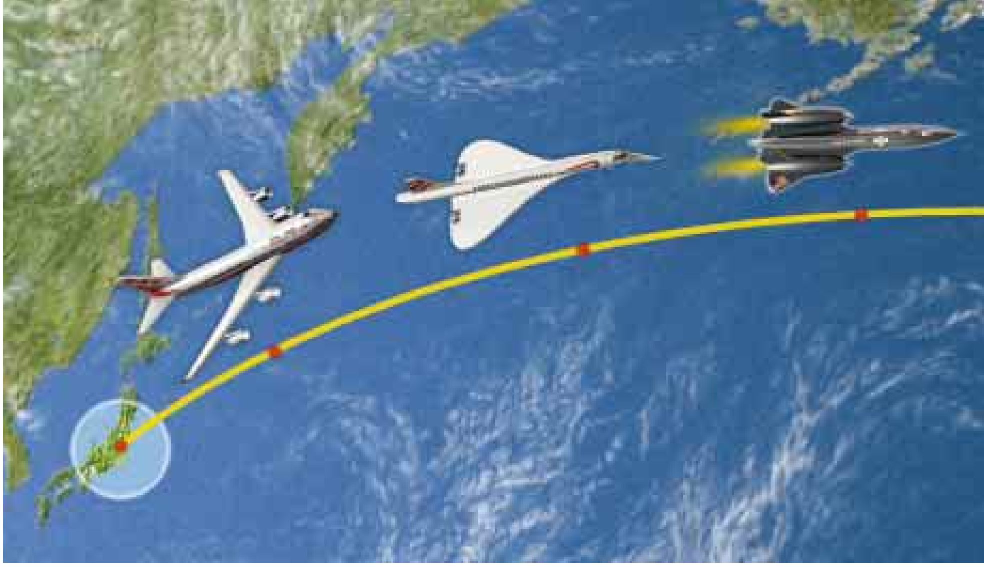
For faster vehicles, engineers have taken advantage of the supersonic airflow into the engine by designing the system to act as its own compressor. Turbines and a mechanical compressor are replaced by an inlet valve that funnels the air, ramming it into a space so quickly that it compresses itself. These engines, called ramjets, have enabled a leap in speed up to about Mach 6. They have been used with missiles in which propulsion is switched to ramjets once the rockets have achieved supersonic velocities.

Under such conditions, however, the air is moving so fast that when it hits the combustion chamber to mix with fuel, the resulting drop in airflow speed generates tremendous heat. At Mach 6, the temperature reaches 6,000 degrees Fahrenheit (3,300 degrees Celsius), leading to chemical dissociation. Combustion begins, but instead of water forming—which would be accompanied by a tremendous rise in pressure and enormous thrust—the reaction produces free radicals at much lower pressure and thrust. In other words, the aircraft slows.

To prevent that, engineers again redesigned the engine, changing the inlet valve so that the decrease in airflow speed is less severe. As a result, the temperature does not surge to the point at which the combustion process breaks down. Because this new design relies on the supersonic combustion of the rammed airflow, the engine was dubbed a scramjet.

But solving one problem—high temperatures—led to another. Now the challenge was to get the supersonically moving air to mix uniformly with the fuel and combust within milliseconds. The perfection of this technology, details of which are currently classified, finally allowed for the construction of a functional scramjet, McClinton says. According to him, the theoretical maximum speed has been upped again, this time to at least the Mach 20 to 25 needed to reach orbit and perhaps higher, as an upper limit has yet to be determined.

One drawback with scramjets (as well as with ramjets) is that they cannot operate at low speeds. "A scramjet doesn't do any good on the runway; it needs compressed air going into it," explains Joel Sitz, NASA project manager for X-43 flight research. One solution being investigated is multimode operation, with an aircraft being propelled first by an advanced turbine engine (for speeds up to about Mach 2 or 3), then a ramjet (to roughly Mach 6) and next a scramjet. "You then reach a point in the atmosphere where you run out of oxygen and a rocket would take over," Sitz says.


DAVID FIERSTEIN

Such plans aside, the actual operation of a scramjet remains theoretical. Although researchers have performed flight tests, most recently by Russia in conjunction with NASA in 1998, those experiments never used a vehicle flown under scramjet power. The engines, which were mounted on rockets, did provide thrust, so their aerodynamics, combustion and propulsion could be studied, but they never flew at hypersonic speeds (above Mach 5) under their own power.

In addition to rocket-assisted tests, vehicles and engines have been evaluated with models, both in wind tunnels and in computer simulations. But such investigations are restricted to about Mach 7, says Jack L. Kerrebrock, professor of aeronautics and astronautics at M.I.T. "As you go up in the Mach numbers," he explains, "the stagnation temperature, where the airflow is stopped at the nose of the vehicle, has to be simulated, and it gets to be very high. For Mach 10, it would be more than 4,000 kelvins. We don't know how to heat air to that temperature in a stationary facility sufficient for wind-tunnel tests."

Modern understanding of fluid dynamics is likewise limited, because above Mach 7 the physical phenomena, including the airflow through the engine, become too complex to model, even on powerful computers. "It's a very difficult flow to calculate accurately," Kerrebrock says, "and we don't have experimental data to validate the calculations, which is what the Hyper-X program will provide."


ANN STATES SABA

TO THE TEST: Charles McClinton, a NASA engineer, will soon learn whether scramjets can indeed fly. An unmanned prototype (a full-scale replica is shown here, upside down) is scheduled for a flight test at Mach 7 in spring 2000.

Indeed, scientists are eagerly awaiting the results from the NASA program's upcoming flight test, scheduled for spring 2000, of an unmanned scramjet at Mach 7. "People have been working on scramjets for 40 years, and this is the first time we have an integrated vehicle that we're confident about," Sitz says. "There are two main challenges for this test: getting it to move and not melt in the process."

The vehicle, called the X-43, is air-

FASTEN YOUR SEATBELTS: A scramjet traveling at Mach 7 (about 4,600 miles per hour) could fly from Tokyo to Washington, D.C., in 1 1/2 hours. In that time, an SR-71 Blackbird, the fastest military jet, would not have traveled half the distance; the Concorde would have flown less than a third, and a 747 would still have more than 10 hours to go. A disadvantage of hypersonic travel, though, is the considerable sonic boom that such flights would generate.

craft and engine as a single unit. Because of the extreme hypersonic stresses and the need to decrease them by fine-tuning the aerodynamics, there is no functional difference between aircraft and engine, McClinton says. The 12-foot-long (3.5-meter-long) vehicle, weighing 3,000 pounds (1,400 kilograms), was designed to minimize weight while providing maximum thermal protection. Specifically, the X-43 must withstand intense heat generated from combustion and the resulting shock waves caused by the aircraft's hypersonic movement through the atmosphere.

The five-foot wingspan is constructed from a high-temperature alloy, and the structural components and outer surface are a combination of titanium, steel and aluminum lined with the same thermal-protection tiles used on the space shuttle. The wing, tail and vehicle nose are reinforced with carbon-fiber composite material, which actually strengthens as the temperature rises. Gaseous hydrogen will serve as the fuel, with silane, a chemical that ignites on contact with air, acting as the spark plug. The test data will come principally from more than 500 gauges on the vehicle, which measure pressure, temperature and strain.

NASA will mount the X-43 onto a modified Pegasus rocket, dubbed the Hyper-X launch vehicle (HXLV). The X-43 and the HXLV will be attached to a B-52, which will travel at Mach 0.5 at an altitude of approximately 20,000 feet off the coast of California near Los Angeles. From there the Pegasus will be launched, and the rocket will boost the X-43 to Mach 7 into the stratosphere at about 100,000 feet, after which the X-43's engine will fire. The rocket and X-43 will then separate, leaving the aircraft to fly on its own. This particular maneuver at hypersonic speeds is the high-risk part of the experiment. "[The] aerodynamics haven't been tested anywhere," Sitz says. "We have it modeled, but you're never sure until you fly something."

On separation, the X-43 has approximately seven seconds of fuel, during which researchers hope the vehicle will accelerate. Once its engine shuts down, the X-43 will follow a preprogrammed course of maneuvers so that scientists can assess its stability control, lift and drag as it decelerates and loses altitude. The total journey will be about 700 nautical miles and last for approximately 12 minutes, culminating in a splashdown at up to 300 miles per hour. Even at that speed, the vehicle should survive the water impact. "This thing is built like a brick," McClinton says.

And like a brick, it will sink to an unrecoverable 16,000 feet. The performance data, though, will have already been collected. During the flight, a U.S. Navy P-3 aircraft will record and transmit the X-43 measurements to the ground while another P-3 and an F-18 will videotape the flight. Additionally, a weather balloon will record atmospheric temperature and pressure in the area.

This experiment is the first in a series of three, with a second flight at Mach 7 scheduled for fall 2000 and another at Mach 10 a year later. The goals are to prove that a scramjet-powered vehicle can indeed fly and then to use the data acquired to validate and recalibrate the design methods, including the wind-tunnel experiments and computer simulations.

Beyond the initial tests, the possibilities are intriguing, including President Ronald Reagan's dream of passenger service from Washington, D.C., to Tokyo in two hours. But Rausch, the Hyper-X program director, cautions that even the most likely first application—lighter military missiles that can then be fired from more remote (and safer) locations while still reaching a target quickly—is probably eight to 20 years in the future. Scramjet flight into space, then, might be decades away.

Even McClinton, in the dual roles of cautious pilot and intrepid engineer, is quick to acknowledge that the X-43 is just one step along the way to an operational system. Still, after first becoming captivated by hypersonic air-breathing propulsion in the 1960s, McClinton can hardly be blamed for his mounting excitement. "Taking something to flight is a researcher's dream," he declares. "It gets us fired up." SA

About the Author

KEN HOWARD is a freelance writer based in New York City. He would like to be a passenger on the inaugural hypersonic flight from Tokyo to Washington, D.C., but only if he has sufficient legroom.