

Breathing new hope into hypersonics



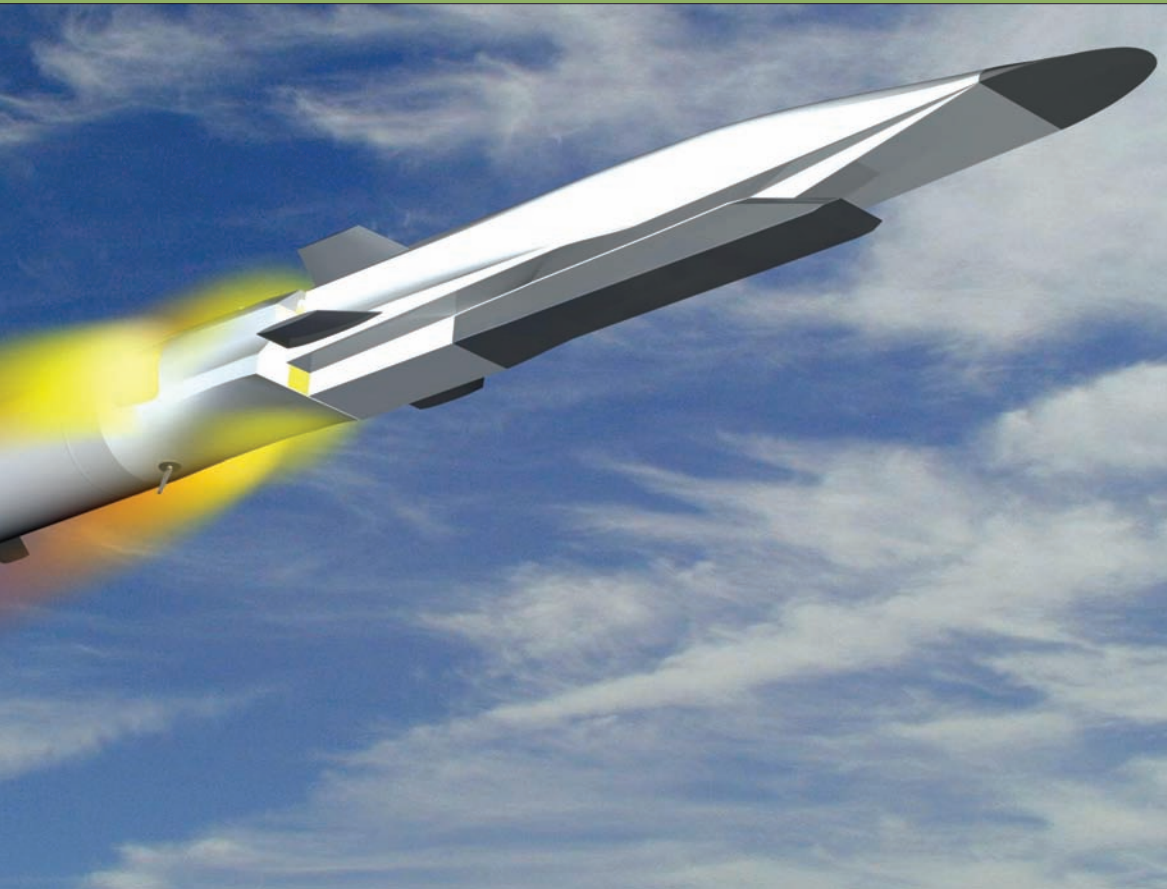
Hypersonics technology development has faced many obstacles, not all of them technical. But interest in the field has increased following successful ground tests of the new NASA/DARPA/Air Force X-51A engine. Officials say the program's short-term purpose is only to prove the practicality of hypersonic scramjet propulsion. But they also note that this is an essential first step toward development of a high-speed, long-range missile and, ultimately, of an operationally responsive hypersonic space launch vehicle.

Hypersonic flying machines powered by air-breathing scramjet engines are finally coming into focus as the quick-response space launchers and superswift, far-ranging missiles of the future. Development of supersonic combustion propulsion for hypersonic vehicles is showing the positive results and solid promise that have proved elusive in the past, officials claim.

A key activity in the widening realm of hypersonics research is the X-51A program, in which the Air Force, NASA, and DARPA are developing a scramjet engine that burns hydrocarbon fuel to propel a 14-ft airframe that looks like a missile. Participants sound upbeat about the program and optimistic that it will succeed.

By all accounts, the ground tests of the Pratt & Whitney Rocketdyne (PWR) X1 scramjet engine at NASA Langley have been rigorous and highly successful. Flight tests of the engine

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in the Boeing-built X-51 airframe are scheduled to begin in 2009.

A first step

Program officials emphasize that they are developing the X-51A primarily to demonstrate the practicality of hypersonic scramjet propulsion, not to create a prototype of an operational hypersonic missile. They also point out that the X-51A program is an essential first step toward the ultimate development of such missiles, and of hypersonic space launch vehicles as well.

Many in the aerospace community view scramjet thrust as the bright hope of the future for U.S. space activities. Aficionados believe it will be the principal propellant of two-stage-to-orbit vehicles and of single-stage-to-orbit spacecraft yet to come.

"The short-term goal of scramjet technology is its application to a high-speed, long-

range, operationally responsive strike weapon," explains Charles Brink, X-51A program manager at the Air Force Research Laboratory at Wright Patterson AFB, Ohio. "But the ultimate goal...is its application to operationally responsive space assets. So the primary purpose of our research is to see if we can generate enough air-breathing thrust to gain access to space."

Mark Lewis, chief scientist of the Air Force, shares this view. An avowed hypersonics enthusiast, Lewis describes the X-51A as "our dream program, a tremendously exciting effort." He calls it "the key to developing hypersonic missile technology" and views its success thus far as evidence that such technology is now "readily at hand."

"The technology that we develop for a hypersonic weapon applies directly to things that we can then apply in space," Lewis declares. "Developing the engine that powers a hyper-



NASA's B-52B launch aircraft carried an X-43A hypersonic research aircraft attached to a Pegasus rocket to launch altitude. About an hour later the Pegasus booster was released from the B-52 to accelerate the X-43A to its intended speed of Mach 10. (Photo by Carla Thomas.)

sonic missile gives us most of what we need to know for the first stage of a reusable two-stage-to-orbit system that might fly us into space using an air-breathing cycle."

Striking potential

Hypersonic flight begins at or about Mach 5, or five times the speed of sound in air. For some time, the Air Force has set its sights on the hypersonic, sky-splitting, intercontinental-range missiles that the X-51A may well presage. The service has no immediate operational requirement for such a weapon, but is closely monitoring the X-51A program with this requirement in mind for the future, officials say.

Lewis notes that a hypersonic precision-strike weapon—"something that flies at Mach 7"—would give the Air Force "phenomenal capability" to hit global targets in a matter of minutes. At the same time, he says, "we don't have a mission for a hypersonic airplane that flies in the atmosphere....A Mach 10 airplane would not be able to fly far enough to do much good before it has to come back."

Brink stresses that in the X-51A program, "our goal is to demonstrate the technology, not to build a weapon." He also notes, however, that "we are in discussion with [USAF's] Air Combat Command about what steps we need to take in pursuit of weapons technology."

Building on a legacy

The X-51A is considered the logical extension of NASA's X-43A, an experimental air-breathing hypersonic vehicle that was successfully but very briefly flight tested in 2004. Officials note that the X-43 program was poised for bigger things ahead but fell victim to NASA's shift of

emphasis and funding from aeronautical research to programs in keeping with the Bush administration's manned space initiatives: future exploratory flights to the Moon and Mars.

"The X-43 was a big step forward," asserts Kenneth Rock, director of NASA Langley's Air Breathing Propulsion Branch. "It demonstrated that a scramjet engine could produce enough thrust to accelerate the vehicle."

The X-43A was fueled by liquid hydrogen. In contrast, the X-51A runs on hydrocarbon fuel—the same JP7 aviation fuel that fed the J58 turbojet engine of the SR-71 Blackbird spy plane. Unlike liquid hydrogen, JP7 hydrocarbon fuel is in ready supply, is slow to ignite, is not volatile, and can easily be stored. It also is conducive to "active cooling" of the scramjet engine, which utilizes its fuel to self-cool certain hot parts of the engine while in flight. The X-43A scramjet engine could hardly cool itself at all with liquid hydrogen.

Curtis W. Berger, PWR's X-51A program manager, explains that the "hydrocarbon fuel absorbs a significant amount of heat from the [engine] structure. So we run the fuel through a heat exchanger in the engine to cool the structure and also to fuel the combustor.

"We're excited about our scramjet demonstrator engines," Berger declares. "We expect this program to succeed. Our confidence is very high. I couldn't be more emphatic about that."

The X-1 engine of the X-51A is made of inconel, a nickel-based alloy, and weighs less than 150 lb. It is much lighter and yet more durable than the 1,000-2,000-lb copper scramjet engines of the past. PWR is well along in constructing its second inconel engine, the X-2, for the X-51A test program.

The relatively light X-51A airframe is made of aluminum and titanium, with a tungsten nose, and is coated with a heat-resistant ablative material to withstand the metal-melting temperatures that hypersonic flight induces on airframes. The underbelly of the X-51A, which heats up the most in flight, is covered by the same tiles that cover the space shuttle. This is an example of how X-51A technology "will be directly applicable to reentry from space," Brink explains.

Both the X-43A and the X-51A programs grew out of the National Aerospace Plane (NASP) program that began in 1986. The goal of that program was to develop and demonstrate a scramjet-powered experimental test vehicle—the X-30—as the forerunner of an operational aerospace plane. As envisioned, that operational plane would be capable of taking off from a conventional runway, reaching a

space-access velocity of at least Mach 25, or roughly 19,000 mph, vaulting into LEO as a one-stage vehicle, flying in space, reentering the atmosphere, and making a runway landing.

The NASP program was alluring but, as it turned out, overly ambitious, and was canceled in 1992. It was predicated on three main sets of technologies: propulsion, advanced materials, and computation, including computers and software. While the computational technology proved adequate, the propulsion and materials technologies of the time failed to meet the daunting requirements of an air-breathing hypersonic aerospace plane.

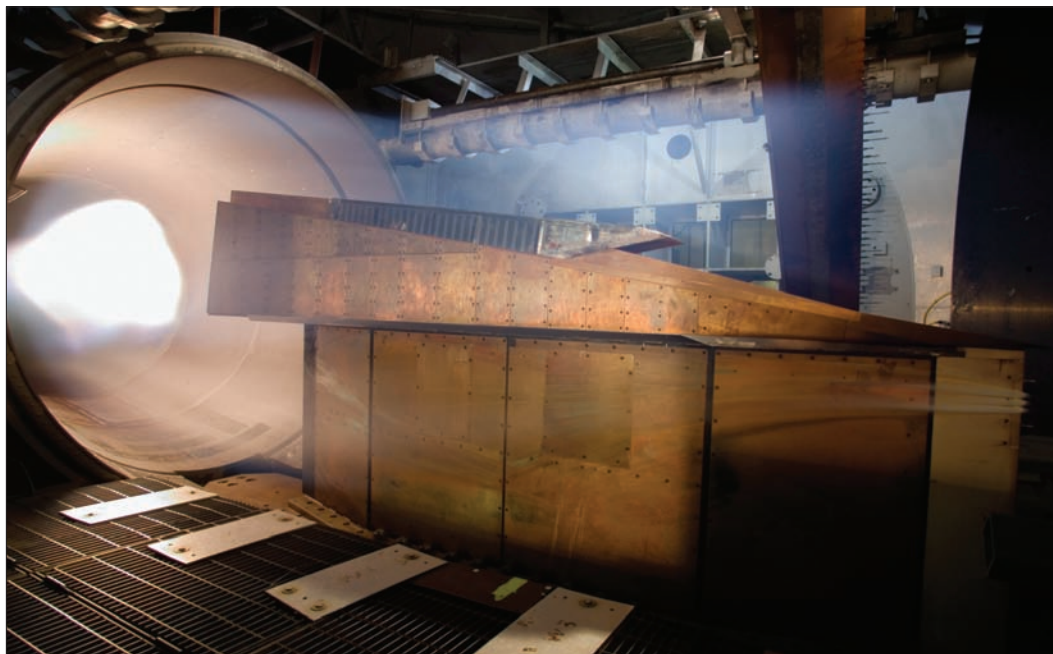
Advantages and drawbacks

Scramjet-powered air-breathing vehicles are more efficient than rockets and have greater range. They also can carry heavier payloads because they extract oxygen from the air to sus-

5 under rocket power. Regulating the supersonic airflow, both to prevent shock waves from overwhelming the engine and to keep the engine-ignition process stable and efficient, will be a major challenge, say researchers.

Ignition of a scramjet engine in flight can be tricky. On the X-51A, for example, the JP7 fuel will not ignite on its own when introduced into the combustion chamber at Mach 4 and above. This is why ethylene liquid must be added to the mix. The sequence begins with ignition of a small amount of readily combustible ethylene from an on-board bottle. The ethylene is fed into the combustor along with the JP7, and combines with it to induce combustion of the fuel, Brink explains.

The scramjet ignition sequence is well understood, but some of the basic physics of shock wave interaction with hypersonic flow is not. Learning about this interaction and how to



The X-1 scramjet undergoes its first simulated flight.

tain propulsion and thus need not carry oxygen on board. Rockets must carry oxidizers along with fuel, accounting for much of their launch weight. Moreover, researchers note, scramjets can be at least as reliable and durable as turbine engines, even while operating in a much harsher environment, because they have few moving parts and none of the rotating machinery characteristic of conventional engines.

But scramjet engines can be uniquely problematic. They require a supersonic flow of compressed air through their combustors. This cannot happen, and a scramjet cannot kick in, until the vehicle first accelerates to Mach 4.5 or Mach

manage it is the goal of the HIFiRE program, which involves the Air Force in partnership with Australian hypersonics research agencies. In it, researchers will examine the effects of airflow over the surfaces of small-scale hypersonics rockets launched from the Woomera Test Facility. They will study, for example, what happens when shock waves induced by hypersonic flight collide with each other, and try to understand the physics involved. (See "High hopes for HIFiRE scramjet," page 32.)

"We need to understand that fundamental physics if we're going to build something like the X-51 vehicle," Lewis declares.

The X-51A program grew out of the NASP program that began in 1986.



Shock waves are a prime consideration in hypersonics research. The X-51A was originally called the WaveRider because it generates and appears to be riding atop shock waves that compress the ambient air and direct it into the rectangular engine inlet, Brink explains.

Joseph T. Vogel, Boeing's X-51A program manager, observes that the vehicle is designed to "capture the wave and use it for the [air] compression." He calls the X-51A "an airframe built around an engine."

"This is a really cool program," Vogel asserts. "We will fly this vehicle, and it will fly well. Right now, we do not think there is any challenge that we cannot overcome."

A brief history of hypersonics



Hypersonic flight began nearly 60 years ago under rocket power. The first flight at more than five times the speed of sound was made in 1949 by a WAC Corporal rocket launched at White Sands Missile Range, N.M., as the upper stage atop a German-made V-2 rocket. At 100 mi. altitude, the WAC Corporal ignited, separated from the V-2, and

accelerated to 5,150 mph. It climbed to 244 mi. altitude and came back down at more than 5,000 mph.

According to Steven J. Walker, DARPA's deputy director of tactical technology, the first human to experience hypersonic flight was Yuri Gagarin, who reentered the atmosphere at more than Mach 25 aboard the Soviet Vostok I spacecraft in 1961. Later that year, Alan Shepard became the first American to fly hypersonically when he reentered the atmosphere in his Gemini capsule at more than Mach 5 after a suborbital transatlantic flight.

Finally, notes Walker, in 1961, Air Force Maj. Robert White became the first human to fly hypersonically in a winged aircraft, reaching Mach 5.3 in his rocket-propelled X-15.

But not until more than 40 years later would an air-breathing flying machine—NASA's X-43A—attain hypersonic speeds up to Mach 9.6, or nearly 10 times the speed of sound. In the interim, space capsules, space shuttles, and intercontinental ballistic missiles all flew at hypersonic speeds, but all were rocket powered.

The X-43A was initially propelled by a winged Pegasus booster rocket, and then by its scramjet engine. Its flight under scramjet thrust lasted only 11 seconds, but long enough to make a telling point.

NASP's payoff

The NASP program gave the aerospace research community a better appreciation and understanding of the technological challenges in the air-breathing hypersonics regime, researchers agree. Some of NASP's derivative technologies are paying off handsomely today.

NASA's Rock is among many who give the NASP program its due. "NASP was a good investment," he declares, noting that "tremendous technology came out of that program." NASP paved the way for today's scramjet demonstrator engine and also bequeathed "this great facility"—the 8-ft High-Temperature Tunnel (8-ft HTT) at Langley—for ground-testing scramjets, he observes. Exhaustive testing in that tunnel—putting the X1 engine through roughly 40 cycles and ramping up the Mach numbers from 4.6 to 5.0 and finally to 6.5—have convinced Rock that "we are on the brink of success" with the X-51A.

This is also the view of Steve Harvin, manager of the 8-ft HTT. He asserts that the flight-weight X1 engine being tested in that tunnel "has already demonstrated its durability" there.

The NASP program was managed in its initial stage by DARPA. Steven M. Walker, deputy director of DARPA's tactical technology office, is also among those who acknowledge NASP's constructive legacy. From that program, he remarked in a recent speech, "we have learned that the ultimate goal of a single-stage-to-orbit air-breathing access-to-space vehicle needs to be achieved with a series of 'stepping stone' flight demonstration vehicles over time, beginning with expendable vehicles, leading to reusable cruise vehicles, and finally ending with reusable, accelerator-access-to-space vehicles."

Other hypersonics efforts

DARPA has a hand in the X-51A program as well, and is teamed with the Air Force and Lockheed Martin in a farther term hypersonics research program called FALCON (Force Application and Launch from the Continental United States). The program initially aimed to develop and build two scramjet-powered transatmospheric hypersonic technology vehicles and begin testing the first of them this year. Technical difficulties interrupted and delayed the program. FALCON's ultimate goal is to attain, by 2025, a reusable hypersonic cruise vehicle capable of carrying about 12,000 lb of payload over a 9,000-mi. nautical range in less than 2 hr.

Hypersonics programs abound. At the behest of Congress, DOD established the Joint Technology Office on Hypersonics last May under the director of defense research and engi-

neering to coordinate and devise a road map for all current and future DOD RDT&E (research, development, test, and evaluation) and systems demonstration programs in hypersonics. The new office will review each program annually to judge its conformity with the road map.

DARPA and the Office of Naval Research are partners in the Hypersonic Flight Demonstration (HyFly) effort to develop a hydrocarbon-fueled scramjet engine for an aircraft-launched hypersonic missile. The program will also develop lightweight, heat-resistant materials for airframes and engines. Boeing is the HyFly airframe builder.

DOD and Australian agencies are partners in other hypersonics projects as well. DARPA is teamed with Australia's Defence Science and Technology Organization and the Australian Hypersonics Initiative in HyCAUSE (Hypersonic Collaborative Australian/U.S. Experiment), a program to develop and test technologies for improving scramjet performance. The program looks promising. Last June, the international hypersonics team successfully tested an experimental scramjet engine in a vehicle that reached Mach 10 in a flight from Woomera. The vehicle was boosted into flight and up to scramjet speeds by a TALOS rocket.

After that test, DARPA's Walker was quoted as saying the agency had "obtained the first-ever flight data on the inward-turning scramjet" and that "DARPA will compare this flight data to ground test data measured on the same engine configuration in the U.S."

An inward-turning scramjet has a circular air inlet that feeds air into a funnel-shaped combustion chamber. By contrast, the air inlets on the X-43A and X-51A are rectangular, and feed air into combustors of rectangular design.

ATK, formerly Alliant Techsystems, built the hydrogen-fueled X-43A scramjet engine. Now the company has come up with a hydrocarbon-fueled scramjet engine with a circular combustor and a circular inlet that could be chosen to propel a future X-51 variant, possibly to be called the X-51B, some observers believe. They emphasize, though, that the Air Force has no immediate plans and no ready money for an X-51B program.

ATK designed its latest scramjet engine for the Freeflight Atmospheric Scramjet Test Technique (FASTT) program cosponsored by DARPA and the Office of Naval Research. Launched nearly two years ago at the Wallops Flight Facility in Virginia, the FASTT hypersonic vehicle made the first-ever flight of a scramjet using conventional, liquid-hydrocarbon jet fuel. The vehicle, approximately 9 ft long and 1 ft in di-



The air inlets on the X-43A—as well as the X-51A—feed air into rectangular combustors.

ameter, separated from its booster rocket at 60,000 ft and flew up to Mach 5.5 under scramjet thrust for about 15 sec.

Center stage

At present, the X-51A occupies center stage in the hypersonics arena as the Air Force's most notable scramjet engine demonstrator program. It is expected to fly farther and longer—and more purposefully—than any other scramjet-powered hypersonic vehicle tested thus far, officials note.

Ground testing of the second PWR flight-weight scramjet engine is scheduled to begin next January at NASA Langley and run for about four months. Flight tests of the X-51A integrated vehicle and scramjet engine are slated to begin in the summer of 2009 and end in the spring of 2010. Four test flights are planned.

The flight tests will take place over the Navy's test range at Point Mugu, Calif. The X-51A will be ferried aloft on the wing station of a B-52 bomber out of Edwards AFB, Calif., released at about 50,000 ft, and boosted by an Army ATACMS (advanced tactical missile system) rocket to Mach 4.5, fast enough for the scramjet engine to start up and begin providing thrust. The X-51A will fly under scramjet power hundreds of miles over the Pacific Ocean at altitudes of 62,000-100,000 ft, and will be tested through a range of Mach numbers up to Mach 6.5.

Participants in the X-51 program express confidence that it will continue to meet its technical and testing challenges and pass muster when all is said and done. But they acknowledge that the biggest challenge of all in this arena is the one that lies ahead—making hypersonics operational in air and space. ▲