



In a major collaboration called HIFiRE, the U.S. and Australia will soon undertake a multiyear series of experimental flights to test various facets of scramjet technology. The only exhaust it creates is water vapor—one reason researchers hope this air-breathing technology will find widespread application, in systems ranging from missiles to transatmospheric transport vehicles. Rapid achievement of that goal, however, will depend as much on funding as on science.

In the world of propulsion, from aircraft to missiles to space vehicles, multiple and often conflicting requirements have driven R&D in recent years: In many cases, systems must be not only high speed, reliable, and multiplatform, but also low cost and nonpolluting. One concept frequently cited as offering the best potential combination of these factors is the scramjet, or supersonic combustion ramjet. Scramjet technology was first validated in flight by Australia's University of Queensland (UQ) Centre for Hypersonics during its HyShot program in 2002.

Rather than carrying heavy containers of high-combustion chemicals, a scramjet scoops air into a combustion chamber, where the oxygen combines with hydrogen to produce thrust. The only exhaust produced is water vapor—a major advantage for any widespread application of this technology.

Boeing predicts that such propulsion systems could be on line within the next 10-20 years for hypersonic (Mach 5 or greater) missiles, short- to medium-range aircraft, reusable launch vehicles, and perhaps even the ultrarapid transatmospheric transport of high-value or time-critical payloads, including people. The aerospace giant also sees hypersonics as a possible bridge in the gap between private commercial suborbital flight—such as that being developed by Virgin Galactic—and the ultimate goal of private commercial orbital flight.

A previous Boeing venture into scramjet research, the X-43A Hyper-X vehicle, recorded the fastest speed by an air-breathing vehicle at Mach 9.68 (6,600 mph), in a 2004 flight test.

High hopes for HIFiRE scramjet

100 months Down Under

Now Boeing and the UQ have joined with the Air Force Research Lab (AFRL), NASA, and Australia's Defence Science and Technology Organisation (DSTO) for a six-year, \$54-million program called Hypersonic International Flight Research Experimentation, or HIFiRE. In one of the largest U.S./Australian collaborations of its kind, up to 10 flights testing various aspects of scramjet technology and hypersonic aerodynamics are planned from the 127,000-km² Woomera rocket test range, a South Australian version of America's Cape Canaveral and Edwards AFB, beginning in early 2008.

"HIFiRE is a 100-month project arrangement with Australia, within which are 66 months of technology demonstrations, with the 10 launches between March 2008 and 2011, then 24 months of technical studies and 10 months of technology transition," explains Doug Dolvin, program manager for Applied

Hypersonics Integration and Demonstration at AFRL's Air Vehicle Directorate.

"The first part is all about demonstrations of science and technology; with the additional 34 months, we could move into looking at dependencies between multiple technologies. The current program is 10 separate experiments, very propulsion- and aerodynamic-centric; the follow-on would add better propulsion and aerodynamics, sensors, and the interaction between disciplines."

The right time and place

In many respects, HIFiRE is the result of advances in microcircuitry, recent Australian successes in hypersonic flight, a confluence of military and commercial interest in scramjets, and growing military requirements coming together at the right time in the right place.

"The maturity of the codes predicting hypersonic phenomena is a major enabler to this

HIFiRE is a follow-on to the University of Queensland's HyShot series of sounding rocket flights.

by **J.R. Wilson**
Contributing writer



“It’s in the same area as the F-117—they cost a lot, but can do more in less time with greater survivability.”

- Doug Dolvin, program manager, Applied Hypersonics Integration and Demonstration, AFRL Air Vehicle Directorate

program. Next is an affordable approach using sounding rockets, and the use of miniaturized instrumentation based on solid-state circuitry and LEDs [light-emitting diodes]. Previous hypersonic research vehicles had very little experimental instrumentation,” Dolvin notes. “The first launch vehicle payload is only 14 in. in diameter and has less than a 2-m-long payload, but has 326 instruments on it. That could never have been done before.

“We could have built these vehicles before, but they couldn’t get much data. Now we can collect a lot of good data. We’ve launched hypersonic reentry modules before, but they were huge and splashed into the ocean, so we could not recover them. And we couldn’t telemeter data down; this first flight will telemeter 40 Mbps, which is a lot of data that previous efforts couldn’t get.”

Flight plans

Using Woomera for HIFiRE is critical to Australia’s efforts to increase use of the test range and its international image as a viable launch facility in the Southern Hemisphere. However, it also forces some limitations on programs that require atmospheric testing and downrange recovery. Weather conditions are optimal only twice a year, for about two months each, beginning in March and October. HIFiRE originally was to have made its first launch in the Aus-

tralian spring of this year, but officials say it now has slipped out of that window and into the first 2008 window, next March.

The first flight will use a cone cylinder whose purpose is to look at boundary-layer transition and shock-boundary interaction, while the second flight will focus on propulsion. The third will merge the two.

“The program is very open [to new technology]. Each flight has five months to a year for design, taking into account all the knowledge and technology we have to apply. Each payload is uniquely designed for that test. The booster [sounding rocket] is just what pushes it to speed and altitude; the payload is designed specifically for that flight, and within a year or less of that flight,” says Kevin G. Bowcutt, HIFiRE technical lead and chief hypersonics scientist at Boeing Phantom Works.

“Flight 4 is where we are interested in flying one of our advanced WaveRider concepts. Our collaborative team will look at the objectives and restraints, design the payload, and look at the WaveRider, but it may or may not end up being the vehicle. We’re targeting this fall for those discussions. Flights 8 and 9 currently are defined as powered configurations, putting an engine on the glider. There is almost no way to divide between aerodynamics and propulsion; they are complete, blended functions of the vehicle—aeropropulsion, if you will.”

A waverider is an aerodynamic shape that generates a shock wave attached along its entire leading edge. While the specific design of the HIFiRE payloads will depend on flight experiment objectives agreed to by all collaboration partners, waverider is considered a strong contender because of its aerodynamic efficiency. Differences in requirements between HIFiRE and Boeing’s previous X-51 WaveRider, however, will likely lead to a shape bearing little resemblance to the X-51.

A closer look

Dolvin says HIFiRE will provide new information critical to future scramjet use for space flight, but has no space component itself. It also differs sharply from most aerospace experi-

“We have concepts on the drawing boards for hypersonic missiles, UAVs, and space launch vehicles; we’re certainly not doing this with no hope of future products.”

- Kevin G. Bowcutt, chief scientist of hypersonics and HIFiRE technical lead, Boeing Phantom Works

ments involving flight tests, he adds.

“For example, in both ground and flight experimentation, we’re investing quite heavily in prediction of boundary-layer transition. That would benefit all vehicles with a reentry objective, whether military or civilian—and not just Earth, but any planet with an atmosphere,” he says. “We have three flights just looking at that on one-, two-, and three-dimensional bodies. That greatly affects heating, thermal protection systems, how long they survive, thickness, type of material. Right now predicting that is empirical, and we’re trying to make it a science.

“The HIFiRE program is about simulation—a lot of simulation and ground testing leading up to the flight tests. I have ground tests going on now at three different locations, with more team members working on simulations than on flight vehicles. That’s something that just hasn’t come out strong enough: The flight tests are basically there to validate the science—a means to the end, not the end state. Most flight demos are so expensive they capture all the attention; but that’s not the case here, because we are using cheap platforms, so it is a lot more balanced than most programs.”

Most HIFiRE projects begin with a full set of ground tests and simulations, validate those with the flight test, then conclude with another ground test using the same conditions as the flight, bringing the circle full around. Each will look at—in order of importance—engines, aerodynamics, and a combination of the two. Each also will have primary, secondary, and possibly tertiary experiments incorporated on a noninterference basis. This is so the flight can go ahead when the primary is ready, dropping any secondary or tertiary experiments that are not ready, then reviving them later.

As currently scheduled, the first flight has one primary, three secondary, and one tertiary, says Dolvin. The second flight has one primary and one secondary.

“Each usually has one to four secondary experiments, although no secondaries have been defined beyond Flight 6,” he says. “The plan is, if you are a secondary and don’t make one flight, we’ll try to get you on the next.

“A secondary means it is functioning in the right environment, gathering the right data behind the primary. A tertiary is in the wrong environment to collect data, but evaluating whether it functions at all. For example, we have a plasma probe that won’t be in a plasma environment for the first few flights, but they also need to know something about performance. There aren’t too many examples of tertiary; they tend to cost more than predicted.”



HyCAUSE

Australia added to its status as the world’s leader in hypersonic technology on June 15 with the successful launch of the HyCAUSE Mach 10 scramjet from the Woomera rocket test range in South Australia.

The first successful scramjet flight was conducted at Woomera in 2002 by the University of Queensland Centre for Hypersonics as part of its HyShot program.

The university also was key to the HyCAUSE experiment, along with Australia’s Defence Science and Technology Organisation, the University of New South Wales at the Australian Defence Force Academy (ADFA), and a U.S. consortium led by the Defense Advanced Research Projects Agency. Along with the technology and experience coming out of the university’s lower speed HyShot, the multimillion-dollar HyCAUSE collaboration incorporated sophisticated flowfield and thermal structural simulations by ADFA and advanced scramjet flowpath design and a two-stage booster rocket from the American team.

Mission success involved converting the scramjet flowpath into a working, instrumented, autonomous flight within the extremely hostile environment at Mach 10.

The team will validate their preflight simulations with the actual flight data. By determining the accuracy of their models—and tweaking them as needed—they will be better able to design future hypersonic aircraft.

Division of duties

While data from all flights will be available to all HIFiRE participants, each experiment has its own national and team sponsors. The U.S. is responsible for five and Australia four (the 10th flight has not yet been defined).

“The HyShot group at UQ is exclusively involved in the design, ground testing, analysis, and flight testing of scramjets,” Michael Smart, UQ’s group lead on HyShot, tells *Aerospace America*. “In early 2007, a significant portion of our group moved over to DSTO to conduct scramjet flight testing.

“In essence, the new DSTO group will be

“Hypersonics could be the ‘next great step’ in the transformation of the Air Force into a completely integrated Aerospace Force.”

- USAF Scientific Advisory Board

responsible for the flight testing aspects of scramjet development, whereas the UQ will continue research on the more scientific aspects of scramjet design and also continue to conduct ground testing. Obviously, there is significant interaction between the two groups, and the new arrangement is working out very well.

“DSTO is primarily responsible for all four Australian flights, with the University of Queensland heading a collaboration with Boeing, DSTO, and the Queensland state government to support three of those. We hope to learn some very fundamental information about how scramjets perform in flight, which will then guide our future designs. We would hope that our research will eventually lead to civilian hypersonic flight for both freight and passengers, as well as cheaper access to space.”

Data and methodologies from HIFiRE also will be shared with a DOD-recognized technical coordinating panel comprising Australia, Canada, Great Britain, New Zealand, and the U.S., Dolvin adds.

HIFiRE’s primary focus is fundamental research, with the flight experiments gathering data that might be difficult to acquire from ground and wind tunnel tests, as well as validating previous ground and flight data, Bowcutt explains.

“It is going after fundamental aspects of aerodynamics—boundary-layer transition (laminar to turbulent flow), shock-boundary layer interaction, and aerodynamic heating effects,” he explains. “To some degree, these have been and can be tested on the ground, but there are limitations. Most ground facilities are relatively noisy, which affects boundary-layer transition.

“There also are propulsion aspects, looking at scramjet engines and testing different concepts. Another is advanced flight control, such

as adaptive flight control: How do you fly a hypersonic body with perhaps a less than perfect understanding of the aerodynamics and propulsion, and maintain controlled flight? And, if something goes wrong, how do you adapt? The last [information to be gathered] is in the area of high-temperature materials and thermal protection systems.”

Applications and goals

The Air Force sees missiles as the first likely application of scramjets, taking advantage of the high speed and altitude (60,000 ft and higher) to conduct a more lethal precision strike with a greatly reduced chance of interception.

The advantage would be “getting to the target quicker, and—an even greater desire for the user community—more efficiently, with more range. And there are no movable parts, [they’re] compact, leaving room for fuel,” Dolvin says of hypersonic missiles.

“In the context of force multiplication—the number of assets required to roll back a given set of targets and enable more conventional threats to come in—you would only use this for the first 4 hr of a conflict, not for sustained attack; maybe the first day for bigger payload assets. In a global sense, more reach and penetration with fewer assets is what the whole Air Force is about now. And we will pay more for these, but the force multiplier is key.

“We’re encouraged to pursue ranges in the 600-n.mi. area, and the user probably would like 1,000 n.mi., so getting to the target responsively at long range is the first goal. The second is lethality—speed at a given altitude putting more energy on target. Survivability also is very important, letting you get in there with a weapon that is too fast to be locked or tracked or intercepted. So compared to conventional Tomahawks or Joint Direct Attack Munition, you are reaching deep into space with a weapon that is much more difficult to deny or defeat.”

HIFiRE is only intended to take the concept up to Technical Readiness Level 6 (a system prototype having been demonstrated in a relevant environment), with industry and government then developing it further for actual product applications. Dolvin believes the earliest probable deployment for a tactical cruise missile using scramjets would be around 2018.

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- Sen. Sandy MacDonald,
Australian parliamentary secretary for defense

Boeing generally agrees, but notes the actual speed with which the technology advances is as contingent on funding as it is on science.

“For a missile, we’re probably looking at 5-10 years, 10-20 for aircraft, 15-30 for space launch. And within each of those timelines, there are opportunities for operational systems,” Bowcutt says. “HIFiRE and the other programs will give us validated tools and concepts to move forward on those.”


Economic and defense drivers

The Australians’ military and commercial interests mirror those of the U.S. But their interest in further developing the hypersonics technology in which they have been a global leader is also part of an effort to counter the growing space launch capabilities of their two giant neighbors, China and India. Australia offers some of the top people and facilities in the world and is high on the list of nations with whom AFRL wants to create strategic alliances to pursue new technologies.

“The Australian Defence Force is developing a high-technology, network-enabled force,

and its reliance on space is increasing for intelligence-gathering, communications, and a range of support operations,” says Sen. Sandy MacDonald, Australian parliamentary secretary for defense. “Hypersonics offer low-cost methods of transporting payloads into space using reusable air-breathing propulsion systems.”

According to Boeing, HIFiRE will advance the state-of-the-art of hypersonic flight “by producing fundamental science and engineering data on hypersonic fluid dynamic, propulsion, and aerothermodynamic phenomena and verifying in flight advanced aerodynamic, propulsive, and integrated aeropropulsive concepts. Such advanced concepts might increase the performance of eventual operational hypersonic systems, allowing them to be lighter, travel farther, and/or carry more payload (making them more economical).

“We are risk tolerant,” Dolvin says. “Our mission brief from the chief scientist of the Air Force was to embrace the technological challenges and accept failure as part of the learning process. So if we fail a couple, that’s okay—as long as we learn something in the process.” 



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07-016

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