



# Falcon Hypersonic Technology Vehicle – HTV-2

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## Program Objectives

Develop and test an unmanned, rocket-launched, maneuverable, hypersonic air vehicle that glides through the Earth's atmosphere up to Mach 20 speed.

## Performance Metrics

- High lift-to-drag ratio, advanced carbon-carbon aeroshell.
- High-temperature materials and structures.
- Precision navigation, guidance, and control.
- Proper function of onboard sensors and off-board auxiliary measurements to characterize:
  - Vehicle state.
  - Flight environment.
  - Aerodynamic and aerothermal performance.
  - GNC system performance.

## Military Utility

- Prompt global reach from CONUS.
- Pathfinder for USAF conventional strike missile program.
- Flight #1 completed 22 April 2010:
  - Preliminary review of data indicates the HTV-2 achieved controlled flight within the atmosphere at over Mach 20.
  - Lost vehicle telemetry approximately 9 minutes into the mission.
- Flight #2 planned for 10-17 Aug 2011.
- USAF planning operational demo in 2013.





## HTV-2 flight #1

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### **Inaugural launch of the Minotaur IV booster**

- Demonstration of the ability to fly at extreme angles of attack up to 89 degrees to meet stringent release requirements for the HTV-2.

### **Extensive data captured for critical areas of interest**

- Aerothermal, aerodynamic, thermal protection, navigation, guidance, and control in the hypersonic flight regime.
- Successful demonstration of the first ever use of an autonomous flight termination system.

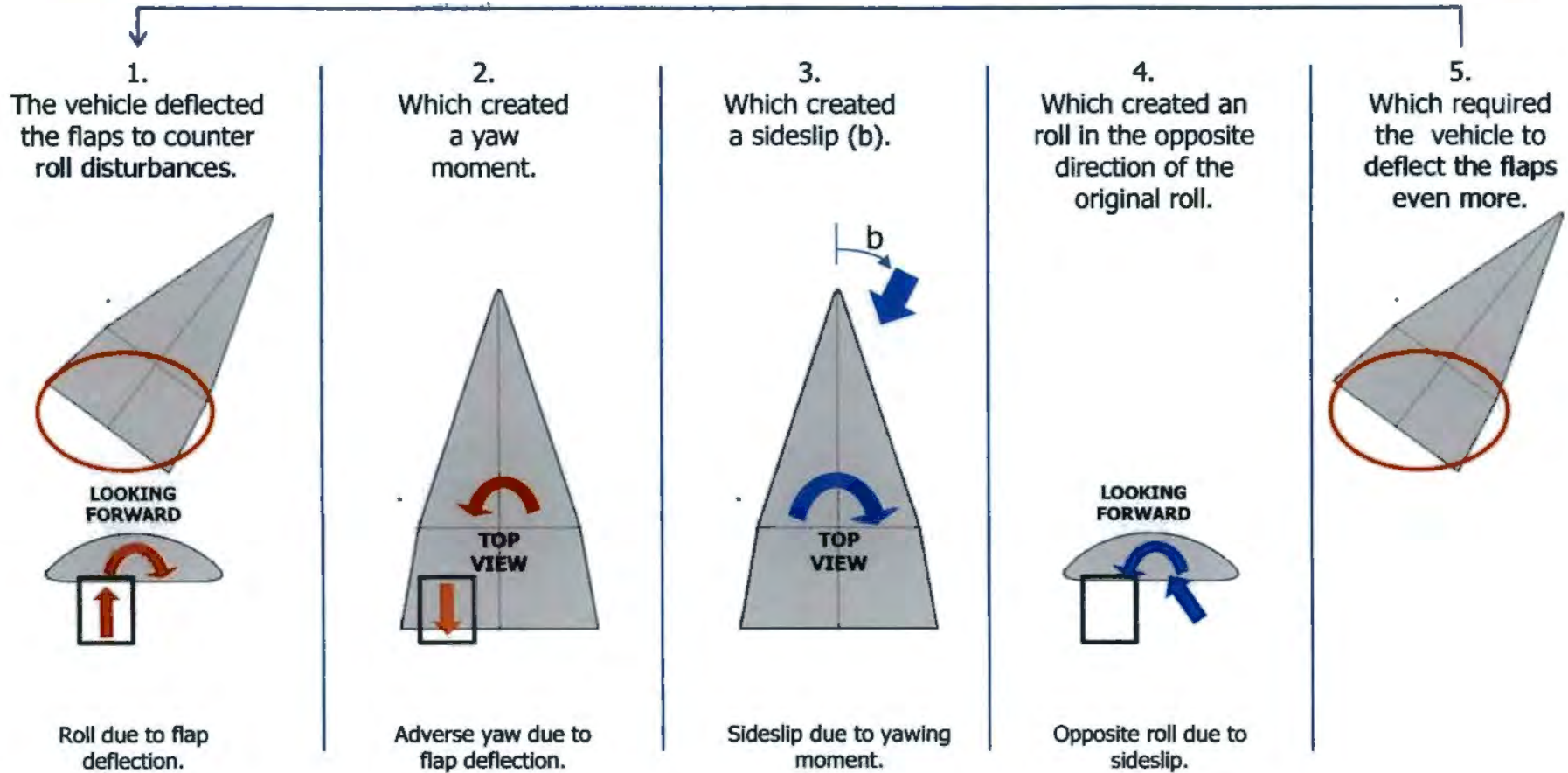
### **Flight dynamic anomalies observed during pull-up phase of flight**

**“Higher than predicted adverse yaw coupled into roll that exceeded the available roll control capability.”**

**(Paulson, 2010, 1)**



# Roll-yaw coupling



**6.) Eventually, the adverse roll moment from the sideslip and disturbances overwhelmed the roll moment available from the differential flap deflections.**





## HTV-2 flight #1 investigation

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### **Independent Engineering Review Board (ERB)**

- ERB chartered to examine data collected during flight #1.
- Extensive six-month review concluded the week of 13 Sep 2010.
- Probable cause and contributing factors to flight anomaly identified.

### **Key findings**

- Flight control authority limitations to operate at the angle of attack the vehicle was programmed to fly for the speed and altitude of the flight.
- Higher-than-predicted yaw, which coupled into roll thus exceeding the available control capability at the time of the anomaly.

### **Remediation plan**

- Adjust the vehicle's center of gravity.
- Decrease the angle of attack.
- Use onboard reaction control to augment vehicle flaps.
- Can be implemented via software, ballast and flight profile changes.



## Summary, conclusions, and the path forward

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### **ERB conclusion**

- Probable cause and contributing factors identified.
- Closure of anomaly investigation phase.
- Recommendation of implementation of remediation actions.
- Effectiveness of remediation strategy to be reviewed at MDR.

**Flight test report to be completed on 15 Jan 2011.**

**Data symposium to be presented at APL on 1-3 Feb 2011.**

### **Remediation actions**

- Engineering fixes (CG, AoA, RCS).
- Scientific fixes (aero model, autopilot, controls).
- Systems engineering and process.

### **No major redesign needed for flight #2**

- High confidence in schedule completion.
- Flight #2 planned for 10-17 Aug 2011.

# TBG and HAWC- RDDS

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## Hypersonic Air-breathing Weapon Concept (HAWC)

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The objective of the Hypersonic Air-breathing Weapon Concept (HAWC) program, an outgrowth of the Integrated Hypersonics program, is to develop and demonstrate technologies that will enable transformational changes in responsive, long range strike against time-critical or heavily defended targets. HAWC will pursue flight demonstration of the critical technologies for an effective and affordable air-launched hypersonic cruise missile. These technologies include advanced air vehicle configurations capable of efficient hypersonic flight, hydrocarbon scramjet-powered propulsion to enable sustained hypersonic cruise, thermal management approaches designed for high-temperature cruise, and affordable system designs and manufacturing approaches. HAWC technologies also extend to reusable hypersonic air platforms for applications such as global presence and space lift. The HAWC program will leverage advances made by the previously funded Falcon, X-51, and HyFly programs. This is a joint program with the Air Force, and HAWC technologies are planned for transition to the Air Force after flight testing is complete.

### *FY 2014 Plans:*

- Conduct hypersonic air-breathing missile objective system trades studies and conceptual design definition.
- Derive hypersonic air-breathing missile demonstration system design from the objective system and begin developing the suite of enabling technologies.
- Begin developing flight testing plans for the hypersonic air-breathing missile demonstrator.
- Initiate risk reduction testing of enabling subsystem technologies for the hypersonic air-breathing missile demonstrator.

### *FY 2015 Plans:*

- Continue risk reduction testing of subsystem technologies for hypersonic air-breathing missile demonstrator.
- Complete preliminary design of hypersonic air-breathing missile flight demonstration system.
- Complete detailed plans for flight testing of the air-breathing missile demonstration system.
- Begin procurement of long lead hardware for hypersonic air-breathing missile flight demonstration vehicle.



## Tactical Boost Glide (TBG)

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The Tactical Boost Glide (TBG) program, an outgrowth of the Integrated Hypersonics program, is a Joint DARPA /Air Force effort that will develop and demonstrate technologies to enable air-launched tactical range hypersonic boost glide systems, including a flight demonstration of a vehicle that is traceable to an operationally relevant weapon that can be launched from current platforms. The program will also consider traceability to, and ideally compatibility, with the Navy Vertical Launch System (VLS). The metrics associated with this objective include total range, time of flight, payload, accuracy, and impact velocity. The program will address the system and technology issues required to enable development of a hypersonic boost glide system considering (1) vehicle concepts possessing the required aerodynamic and aero-thermal performance, controllability and robustness for a wide operational envelope, (2) the system attributes and subsystems required to be both survivable and lethal in relevant operational environments, and (3) approaches to reducing cost and improving affordability for both the demonstration system and future operational systems. TBG capabilities are planned for transition to the Air Force and the Navy.

### *FY 2014 Plans:*

- Complete trade space analysis for tactical range hypersonic boost glide systems.
- Begin development of TBG Concept of Operations (ConOps).
- Begin development of TBG Operational System (OS) conceptual designs and system capabilities.
- Begin development of TBG Demonstration System (DS) conceptual design and system requirements.
- Begin initial technology maturation plans (TMPs).

### *FY 2015 Plans:*

- Complete TBG Operational System conceptual design reviews and system capability documentation.
- Complete TBG Demonstration System conceptual design and systems requirements reviews.
- Complete initial TMPs.
- Select booster and launch platforms.
- Conduct initial test range and range safety coordination.
- Select TBG demonstration test range.
- Complete Phase I aerodynamic and aerothermal concept testing.
- Complete first generation aero databases.
- Develop initial flight test plan.



## NEWS

### Engineering Review Board Concludes Review of HTV-2 Second Test Flight

April 20, 2012

**Aerodynamic design validated and new understanding of thermal material properties gained**

Following an extensive seven-month analysis of data collected from the Aug. 11, 2011, second flight of DARPA's Hypersonic Technology Vehicle (HTV-2), an independent engineering review board (ERB) investigating the cause of a flight anomaly completed its report. The findings of the ERB validated the vehicle's aerodynamic design and uncovered new information regarding the thermal material properties of the vehicle.

"The greatest achievement from Flight Two, which the ERB's findings underscored, was that we successfully incorporated aerodynamic knowledge gained from the first flight into the second flight," said Air Force Maj. Chris Schulz, DARPA program manager, who holds a doctorate in aerospace engineering.

A technology demonstration and data-gathering platform, the HTV-2's second test flight was conducted to validate current models and increase technical understanding of the hypersonic regime. The flight successfully demonstrated stable aerodynamically-controlled flight at speeds up to Mach 20 ([http://www.darpa.mil/external\\_Link.aspx?url=http://www.youtube.com/watch?v=cZuUUyZE0wQ](http://www.darpa.mil/external_Link.aspx?url=http://www.youtube.com/watch?v=cZuUUyZE0wQ)) (twenty times the speed of sound) for nearly three minutes. Approximately nine minutes into the test flight, the vehicle experienced a series of shocks culminating in an anomaly, which prompted the autonomous flight safety system to use the vehicle's aerodynamic systems to make a controlled descent and splashdown into the ocean.

"The initial shockwave disturbances experienced during second flight, from which the vehicle was able to recover and continue controlled flight, exceeded by more than 100 times what the vehicle was designed to withstand," said DARPA Acting Director, Kaigham J. Gabriel. "That's a major validation that we're advancing our understanding of aerodynamic control for hypersonic flight."

The ERB concluded that the "most probable cause of the HTV-2 Flight 2 premature flight termination was unexpected aeroshell degradation, creating multiple upsets of increasing severity that ultimately activated the Flight Safety System."

Based on state-of-the-art models, ground testing of high-temperature materials and understanding of thermal effects in other more well-known flight regimes, a gradual wearing away of the vehicle's skin as it reached stress tolerance limits was expected. However, larger than anticipated portions of the vehicle's skin peeled from the aerostructure. The resulting gaps created strong, impulsive shock waves around the vehicle as it travelled nearly 13,000

miles per hour, causing the vehicle to roll abruptly. Based on knowledge gained from the first flight in 2010 and incorporated into the second flight, the vehicle's aerodynamic stability allowed it to right itself successfully after several shockwave-induced rolls. Eventually, however, the severity of the continued disturbances finally exceeded the vehicle's ability to recover.

According to Schulz, "HTV-2's first flight test corrected our models regarding aerodynamic design within this flight regime. We applied that data in flight test two, which ultimately led to stable aerodynamically controlled flight. Data collected during the second test flight revealed new knowledge about thermal-protective material properties and uncertainties for Mach 20 flight inside the atmosphere, which can now be used to adjust our assumptions based on actual flight data and modify our modeling and simulation to better characterize thermal uncertainties and determine how to assess integrated thermal systems."

Aerodynamic assumptions and extrapolations from known flight regimes proved inadequate when preparing for HTV-2 inaugural flight test. The data from second flight revealed that extrapolating from known flight regimes and relying solely on advanced thermal modeling and ground testing could not successfully predict the harsh realities of Mach 20 atmospheric flight.

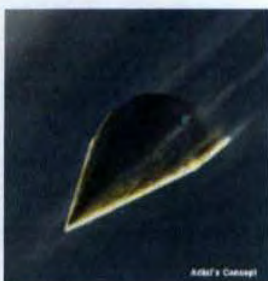
"A group of nationally-recognized experts from government and academia came together to analyze the flight data and conduct extensive additional modeling and ground testing for this review," Schulz said. "The result of these findings is a profound advancement in understanding the areas we need to focus on to advance aerothermal structures for future hypersonic vehicles. Only actual flight data could have revealed this to us."

Moving forward, the HTV-2 program will incorporate new knowledge gained to improve models for characterizing thermal uncertainties and heat-stress allowances for the vehicle's outer shell. The remediation phase will involve further analysis and ground testing using flight data to validate new tools for this flight regime. The ERB findings and remediation phase efforts will inform policy, acquisition and operational decisions for future Conventional Prompt Global Strike initiatives executed by the Office of the Secretary of Defense, Acquisition, Technology & Logistics, Strategic Warfare directorate—the goal of which, ultimately, is to have the capability to reach anywhere in the world in less than one hour.

## Media Queries

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## Images



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## **NEWS**

### **HYPERSONICS—THE NEW STEALTH**

July 06, 2012

#### **DARPA investments in extreme hypersonics continue**

DARPA's research and development in stealth technology during the 1970s and 1980s led to the world's most advanced radar-evading aircraft, providing strategic national security advantage to the United States. Today, that strategic advantage is threatened as other nations' abilities in stealth and counter-stealth improve. Restoring that battle space advantage requires advanced speed, reach and range. Hypersonic technologies have the potential to provide the dominance once afforded by stealth to support a range of varied future national security missions.

Extreme hypersonic flight at Mach 20 (i.e., 20 times the speed of sound)—which would enable DoD to get anywhere in the world in under an hour—is an area of research where significant scientific advancements have eluded researchers for decades. Thanks to programs by DARPA, the Army, and the Air Force in recent years, however, more information has been obtained about this challenging subject.

"DoD's hypersonic technology efforts have made significant advancements in our technical understanding of several critical areas including aerodynamics; aerothermal effects; and guidance, navigation and control," said Acting DARPA Director, Kaigham J. Gabriel. "but additional unknowns exist."

Tackling remaining unknowns for DoD hypersonics efforts is the focus of the new DARPA Integrated Hypersonics (IH) program. "History is rife with examples of different designs for 'flying vehicles' and approaches to the traditional commercial flight we all take for granted today," explained Gabriel. "For an entirely new type of flight—extreme hypersonic—diverse solutions, approaches and perspectives informed by the knowledge gained from DoD's previous efforts are critical to achieving our goals."

To encourage this diversity, DARPA will host a Proposers' Day on August 14, 2012, to detail the technical areas for which proposals are sought through an upcoming competitive broad agency announcement.

"We do not yet have a complete hypersonic system solution," said Gregory Hulcher, director of Strategic Warfare, Office of the Under Secretary of Defense for Acquisition, Technology and Logistics. "Programs like Integrated Hypersonics will leverage previous investments in this field and continue to reduce risk, inform development, and advance capabilities."



The IH program expands hypersonic technology research to include five primary technical areas: thermal protection system and hot structures; aerodynamics; guidance, navigation, and control (GNC); range/instrumentation; and propulsion.

At Mach 20, vehicles flying inside the atmosphere experience intense heat, exceeding 3,500 degrees Fahrenheit, which is hotter than a blast furnace capable of melting steel, as well as extreme pressure on the aeroshell. The thermal protection materials and hot structures technology area aims to advance understanding of high-temperature material characteristics to withstand both high thermal and structural loads. Another goal is to optimize structural designs and manufacturing processes to enable faster production of high-mach aeroshells.

The aerodynamics technology area focuses on future vehicle designs for different missions and addresses the effects of adding vertical and horizontal stabilizers or other control surfaces for enhanced aero-control of the vehicle. Aerodynamics seeks technology solutions to ensure the vehicle effectively manages energy to be able to glide to its destination. Desired technical advances in the GNC technology area include advances in software to enable the vehicle to make real-time, in-flight adjustments to changing parameters, such as high-altitude wind gusts, to stay on an optimal flight trajectory.

The range/instrumentation area seeks advanced technologies to embed data measurement sensors into the structure that can withstand the thermal and structural loads to provide real-time thermal and structural parameters, such as temperature, heat transfer, and how the aeroshell skin recedes due to heat. Embedding instrumentation that can provide real-time air data measurements on the vehicle during flight is also desired. Unlike subsonic aircraft that have external probes measuring air density, temperature and pressure of surrounding air, vehicles traveling Mach 20 can't take external probe measurements. Vehicle concepts that make use of new collection and measurement assets are also being sought.

The propulsion technology area is developing a single, integrated launch vehicle designed to precisely insert a hypersonic glide vehicle into its desired trajectory, rather than adapting a booster designed for space missions. The propulsion area also addresses integrated rocket propulsion technology onboard vehicles to enable a vehicle to give itself an in-flight rocket boost to extend its glide range.

"By broadening the scope of research and engaging a larger community in our efforts, we have the opportunity to usher in a new area of flight more rapidly and, in doing so, develop a new national security capability far beyond previous initiatives," explained Air Force Maj. Christopher Schulz, DARPA program manager, who holds a doctorate in aerospace engineering.

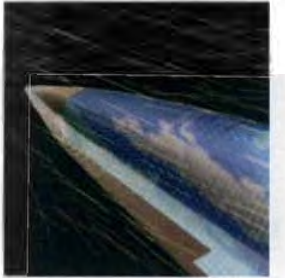
The IH program is designed to address technical challenges and improve understanding of long-range hypersonic flight through an initial full-scale baseline test of an existing hypersonic test vehicle, followed by a series of subscale flight tests, innovative ground-based testing, expanded modeling and simulation, and advanced analytic methods, culminating in a test flight of a full-scale hypersonic X-plane (HX) in 2016. HX is envisioned as a recoverable next-generation configuration augmented with a rocket-based propulsion capability that will enable and reduce risk for highly maneuverable, long-range hypersonic platforms.

More information regarding the August 14 Proposers' Day is available [here](#).

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## Images



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# X-51A Waverider

*Published March 02, 2011*

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## **Mission**

The experimental X-51A Waverider is an unmanned, autonomous supersonic combustion ramjet-powered hypersonic flight test demonstrator for the U.S. Air Force.

## **Features**

The X-51A is designed to be launched from an airborne B-52 Stratofortress bomber. The flight test vehicle stack is approximately 25 feet long and includes a modified solid rocket booster from an Army Tactical Missile, a connecting interstage, and the X-51A cruiser. The nearly wingless cruiser is designed to ride its own shockwave, thus the nickname, Waverider. The distinctive, shark-nosed cruiser has small controllable fins and houses the heart of the system, an SJY61 supersonic combustion ramjet or scramjet engine built by Pratt & Whitney Rocketdyne designed to burn JP-7 jet fuel. Boeing's Phantom Works performed overall air vehicle design, assembly and testing for the X-51's various component systems.

The X-51 was made primarily using standard aerospace materials such as aluminum, steel, inconel, and titanium. Some carbon/carbon composites of the leading edges of fins and cowls are used. For thermal protection, the vehicle utilizes a Boeing designed silica-based thermal protection system as well as Boeing Reusable Insulation tiles, similar to those on board the NASA Space Shuttle Orbiters.

Four X-51As were built for the Air Force. The X-51A program is a technology demonstrator and was not designed to be a prototype for weapon system. It was designed to pave the way to future hypersonic weapons, hypersonic intelligence, surveillance and reconnaissance, and future access to space. Since scramjets are able to burn atmospheric oxygen, they don't need to carry large fuel tanks containing oxidizer like conventional rockets, and are being explored as a way to more efficiently launch payloads into orbit.

In addition to scalable scramjet propulsion, other key technologies that will be demonstrated by the X-51A include thermal protection systems materials, airframe and engine integration, and high-speed stability and control.

## **Background**

The X-51A represents one of the service's most significant reinvestments in hypersonic flight since the rocket-powered X-15 program which flew 50 years earlier.

Air Force officials anticipate the X-51A program will provide a foundation of knowledge required to develop the game changing technologies needed for future access to space and hypersonic weapon applications. For example, hypersonic speeds on the order of flying 600 nautical miles in 10 minutes may provide the ability to accurately engage a long-distance target very rapidly.

The X-51A program is a collaborative effort of the Air Force Research Laboratory and the Defense Advanced Research Projects Agency, with industry partners The Boeing Company and Pratt & Whitney Rocketdyne. Program management is accomplished by the Air Force Research Laboratory Propulsion Directorate at Wright-Patterson Air Force Base, Ohio.

Hypersonic flight, normally defined as beginning at Mach 5, five times the speed of sound, presents unique technical challenges with heat and pressure, which make conventional turbine engines impractical. Program officials said producing thrust with a scramjet has been compared to lighting a match in a hurricane and keeping it burning.

The Air Force currently plans to fly each X-51A on identical flight profiles. Like the X-15, the X-51A is designed to be carried aloft by a B-52 mother ship launched from the Air Force Flight Test Center at Edwards Air Force Base, Calif. It is released at approximately 50,000 feet over the Pacific Ocean Point Mugu Naval Air Warfare Center Sea Range. The solid rocket booster accelerates the X-51A for 30 seconds to approximately Mach 4.5, before being jettisoned. Then the cruiser's scramjet engine, remarkable because it has virtually no moving parts, ignites. The ignition sequence begins burning ethylene, transitioning over approximately 10 seconds to the same JP-7 jet fuel once used by the SR-71 Blackbird.

Powered by its scramjet engine, the X-51A will accelerate to approximately Mach 6 as it climbs to nearly 70,000 feet. Hypersonic combustion generates intense heat so routing of the engine's own JP-7 fuel will serve to both cool the engine and heat the fuel to optimum operating temperature for combustion. The fuel load and flight profile provides for a 240-second engine burn, transmitting vast amounts of telemetry data on its systems to orbiting aircraft and ground stations, before the vehicle exhausts its fuel supply, splashes down into the Pacific and is destroyed, as planned. Flight test vehicles are not recovered.

The X-51A development team elected from the outset not to build recovery systems in the flight test vehicles, in an effort to control costs and focus funding on the vehicle's fuel-cooled scramjet engine. A U.S. Navy P-3 Orion aids in transmitting telemetry data to engineers at both Naval Air Station Point Mugu and Vandenberg AFB, Calif., before it arrives at its final destination, the Ridley Mission Control Center at Edwards AFB.

Conceived in 2004, the X-51A made its first "captive carry" flight Dec. 9, 2009. The flight test verified the B-52's high-altitude performance and handling qualities with the X-51 attached and tested communications and telemetry systems, but the vehicle remained attached to the B-52s wing.

The X-51A made history during its first supersonic combustion ramjet-powered hypersonic flight May 26, 2010, off the southern California Pacific coast. Officials said the flight test vehicle flew as anticipated for nearly 200 seconds, with the scramjet accelerating the vehicle to approximately Mach 5, nearly 3,400 miles per hour. The fuel-cooled scramjet performed as planned transmitting normal telemetry for more than 140 seconds, then observing a decrease in thrust and acceleration for another 30 seconds. An anomaly then resulted in a loss of telemetry, and the test was terminated and vehicle was



destroyed by flight controllers on command.

Despite the anomaly, the May 26 flight is considered the first use of a practical hydrocarbon fueled scramjet in flight. The longest previous hypersonic scramjet flight test performed by a NASA X-43 in 2004 was faster, but lasted only about 12 seconds and used less logistically supportable hydrogen fuel.

Following an extensive analysis of flight data from the X-51A's first hypersonic flight test, slight modifications are planned to strengthen the rear seal area near the engine exhaust nozzles for the three remaining X-51As.

The next two X-51A flights ended prematurely. The second vehicle was boosted by the rocket to just over Mach 5, separated and lit the scramjet on ethylene. When the vehicle attempted to transition to JP7 fuel operation, it experienced an inlet un-start. The hypersonic vehicle attempted to restart and oriented itself to optimize engine start conditions, but was unsuccessful. The vehicle continued in a controlled flight orientation until it flew into the ocean within the test range.

The third X-51A safely separated from the B-52, however after 16 seconds under the rocket booster, a fault was identified with one of the cruiser control fins. Once the X-51 separated from the rocket booster, approximately 15 seconds later, the cruiser was not able to maintain control due to the faulty control fin and was lost.

The final flight of the X-51A occurred May 1, 2013 and was the most successful in terms of meeting all the experiment objectives. The cruiser traveled more than 230 nautical miles in just over six minutes reaching a peak speed of Mach 5.1.

Overall the more than 9 minutes of data collected from the X-51A program was an unprecedented achievement proving the viability of air-breathing, high-speed scramjet propulsion using hydrocarbon fuel.

### **General Characteristics**

**Primary Function:** Hypersonic scramjet-powered flight test demonstrator

**Contractors:** Boeing, Pratt & Whitney Rocketdyne

**Power Plant:** JP-7 fueled/cooled SJY61 supersonic combustion ramjet

**Thrust:** 500 - 1,000 pound class

**Length:** Full stack 25 feet; Cruiser 14 feet; Interstage 5 feet; Solid rocket booster 6 feet

**Weight:** Approx. 4,000 pounds

**Fuel Capacity:** Approx. 270 pounds JP-7

**Speed:** 3,600+ miles per hour (at Mach 6)

**Range:** 400+ nautical miles

**Ceiling:** 70,000 + feet

**Crew:** ground station monitored

**Unit Cost:** Unavailable

**Initial Flight Test:** May 26, 2010

**Inventory:** Four purpose-built for flight test, not designed for recovery (one vehicle expended as of Feb.

1, 2011)



[PHOTO DETAILS](#) / [DOWNLOAD HI-RES](#)

An X-51A WaveRider hypersonic flight test vehicle is uploaded to an Air Force Flight Test Center B-52 for fit testing at Edwards Air Force Base on July 17, 2009. Four scramjet-powered Waveriders were built for the Air Force. The Air Force Research Laboratory, DARPA, Pratt & Whitney Rocketdyne, and Boeing are partners on the X-51A technology demonstrator program. (U.S. Air Force photo/Chad Bellay)



[PHOTO DETAILS](#) / [DOWNLOAD HI-RES](#)

The X-51A Waverider is set to demonstrate hypersonic flight. Powered by a Pratt & Whitney Rocketdyne SJY61 scramjet engine, it is designed to ride on its own shockwave and accelerate to about Mach 6. (U.S. Air Force graphic)



## Air Force Print News Today

Air Force news from around the world

### X-51A Waverider achieves history in final flight

by Daryl Mayer  
88th Air Base Wing Public Affairs

5/3/2013 - WRIGHT-PATTERSON AIR FORCE BASE, Ohio -- The final flight of the X-51A Waverider test program has accomplished a breakthrough in the development of flight reaching Mach 5.1 over the Pacific Ocean on May 1 a little after 10 a.m. Pacific Time.

"It was a full mission success," said Charlie Brink, X-51A program manager for the Air Force Research Laboratory Aerospace Systems Directorate.

The cruiser traveled over 230 nautical miles in just over six minutes over the Point Mugu Naval Air Warfare Center Sea Range. It was the longest of the four X-51A test flights and the longest air-breathing hypersonic flight ever.

"I believe all we have learned from the X-51A Waverider will serve as the bedrock for future hypersonics research and ultimately the practical application of hypersonic flight," Mr. Brink said.

The X-51A took off from the Air Force Test Center at Edwards AFB, Calif., under the wing of a B-52H Stratofortress. It was released at approximately 50,000 feet and accelerated to Mach 4.8 in about 26 seconds powered by a solid rocket booster. After separating from the booster, the cruiser's scramjet engine then lit and accelerated to Mach 5.1 at 60,000 feet.

After exhausting its 240-second fuel supply, the vehicle continued to send back telemetry data until it splashed down into the ocean and was destroyed as designed. All told, 370 seconds of data was collected from the experiment.

"This success is the result of a lot of hard work by an incredible team. The contributions of Boeing, Pratt and Whitney Rocketdyne, the 412th Test Wing at Edwards AFB, NASA Dryden and DARPA were all vital," said Mr. Brink.

This was the last of four test vehicles originally conceived when the \$300 million technology demonstration program began in 2004. The program objective was to prove the viability of air-breathing, high-speed scramjet propulsion.

The X-51A is unique primarily due to its use of a hydrocarbon fuel in its supersonic combustion ramjet, or Scramjet, engine. Other vehicles have achieved hypersonic - generally defined as speeds above Mach 5 - flight with the use of hydrogen fuel. Without any moving parts, hydrocarbon fuel is injected into the scramjet's combustion chamber where it mixes with the air rushing through the chamber and is ignited in a process likened to lighting a match in a hurricane.

The use of logistically supportable hydrocarbon fuel is widely considered vital for the practical application of hypersonic flight.

As a technology demonstration program, there is no immediate successor to the X-51A program. However, the Air Force will continue hypersonic research and the successes of the X-51A will pay dividends to the High Speed Strike Weapon program currently in its early formation phase with AFRL.



The X-51A Waverider prepares to launch its historic fourth and final flight. The cruiser achieved Mach 5.1 traveling 230 nautical miles in just over six minutes, making this test the longest air-breathing hypersonic flight ever. (U.S. Air Force photo/Bobbi Zapka)



## Air Force Print News Today

Air Force news from around the world

### X-51A flight ends prematurely

8/15/2012 - WRIGHT-PATTERSON AFB, Ohio – The X-51A Waverider successfully launched from an Air Force B-52 bomber over Point Mugu Naval Air Warfare Center Sea Range Aug. 14 at approximately 11:36 a.m. PST.

The X-51 safely separated from the B-52 and the rocket booster fired as planned. However after 16 seconds, a fault was identified with one of the cruiser control fins. Once the X-51 separated from the rocket booster, approximately 15 seconds later, the cruiser was not able to maintain control due to the faulty control fin and was lost.

"It is unfortunate that a problem with this subsystem caused a termination before we could light the Scramjet engine," said Charlie Brink, X-51A Program Manager for Air Force Research Laboratory. "All our data showed we had created the right conditions for engine ignition and we were very hopeful to meet our test objectives."

This particular control subsystem had proven reliable in the previous two flights of the X-51A including the historic May 2010 flight when the Waverider flew for more than three minutes at Mach 4.88 under scramjet power - nearly five times the speed of sound.

Program officials will now begin the process of working through a rigorous evaluation to determine the exact cause of all factors at play.

One of the four X-51A vehicles remains. AFRL officials have not decided when or if that vehicle will fly at this time.



The X-51A Waverider is mounted under the wing of a B-52 at Edwards AFB, Calif., in preparation of its Aug. 14, 2012, test flight. On a previous flight, the X-51A flew for more than three minutes at Mach 4.88 under scramjet power. (Courtesy photo)