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Hyper-X Program Status

C. R. McClinton and D. E. Reubush
NASA Langley Research Center, Hampton VA
and
J. Sitz and P. Reukauf
NASA Dryden Flight Research Center, Edwards, CA

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Charles R. McClinton and David E. Reubush
National Aeronautics and Space Administration, Langley Research Center, Hampton, Virginia
Joel Sitz and Paul Reukauf
National Aeronautics and Space Administration, Dryden Flight Research Center, Edwards, California

ABSTRACT

This paper provides an overview of the objectives and status of the Hyper-X program, which is tailored to move hypersonic, airbreathing vehicle technology from the laboratory environment to the flight environment. The first Hyper-X research vehicle (HXRV), designated X-43, is being prepared at the Dryden Flight Research Center for flight at Mach 7. Extensive risk reduction activities for the first flight are completed, and non-recurring design activities for the Mach 10 X-43 (3rd flight) are nearing completion. The Mach 7 flight of the X-43, in the spring of 2001, will be the first flight of an airframe-integrated scramjet-powered vehicle. The Hyper-X program is continuing to plan follow-on activities to focus an orderly continuation of hypersonic technology development through flight research.

ACRONYMS

AETB	Alumina-enhanced thermal barrier tiles
ARRMD	Affordable Rapid Response Missile Demonstrator (DARPA Program)
ASTP	NASA's Advanced Space Transportation Program
CDR	Critical design review
CFD	Computational fluid dynamics
DFRC	NASA Dryden Flight Research Center
DFX	Dual-fuel experimental engine (full-scale, partial-width/length engine)
DOF	Degree-of-Freedom
HSM	HYPULSE scramjet model (full-scale, partial-width/length engine)
8' HTT	LaRC 8' high temperature wind tunnel
HXEM	Hyper-X engine model (full-scale, partial-width/length engine)
HXFE	Hyper-X flight engine (full-scale, dedicated to ground testing)
HXLV	Hyper-X launch vehicle
HXRV	Hyper-X research vehicle (X-43)
HYPULSE	LaRC HYpersonic PULSE Facility
HyTech	USAF Hypersonic Technology
LaRC	NASA Langley Research Center
NASA	National Aeronautics and Space Administration
NASP	National Aero-Space Plane
MSFC	Marshall Space Flight Center
RBCC	Rocket-Based Combined Cycle
TBCC	Turbine-Based Combination Cycle
X-43	Hyper-X research vehicle
X-43B	Hyper-X-related (proposed) follow-on vehicles

INTRODUCTION

NASA initiated the joint LaRC and DFRC Hyper-X Program in 1996 to advance hypersonic airbreathing propulsion and related technologies from the laboratory to the flight environment[1,2]. The program goal is to verify and demonstrate experimental techniques, computational methods and analytical design tools required for the development of hypersonic, hydrogen-fueled, scramjet-powered aircraft. Accomplishing this goal requires flight data from a scramjet-powered vehicle. Because of the highly integrated nature of scramjet-powered vehicles, the complete vehicle must be developed and tested, as propulsion verification cannot be separated from other hypersonic technologies.

This technology is required for any efficient hypersonic cruise vehicle, and has the potential to significantly reduce the cost and increase safety, reliability, and mission flexibility of future single- or two-stage-to-orbit access-to-space systems. In other words, this technology is directly applicable to NASA's need for "revolutionary improvements for safety, cost and aircraft-like operations of the next generation of space vehicles" and the USAF need of "controlling and exploiting the full aerospace continuum."

The X-43 vehicle (figure 1) is small to minimize development cost and the cost of boosting it to the test condition. In addition, to reduce design time and cost, the vehicle configuration was based on an existing Mach 10 cruise, global-reach mission configuration,[3] and the extensive NASP database. Figure 2 depicts key mission events for the X-43 flight. The first view shows the 12-foot long X-43 mounted on the Pegasus-based Hyper-X launch vehicle (HXLV), which is carried to the launch point by the DFRC B-52. The X-43

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will be boosted to approximately 95,000 feet for the two Mach 7 tests and 110,000 feet for the Mach 10 test. The fully autonomous X-43 vehicles will fly preprogrammed 700 to 1000-mile, due-West routes in the Western Test Range off the California coast. Test data, over 500 channels, will be transmitted to aircraft and ground stations. The X-43, the vehicle-to-booster adapter, and the HXLV are in final check-out at DFRC. The first X-43 flight is scheduled for 2001.

The following sections present a brief overview of the program organization and responsibilities; design and risk reduction activities; vehicle development, validation and flight test plans; and other Hyper-X technology. Finally, the connection between the flight tests and technology development for future hypersonic airbreathing engine-powered vehicles is examined.

PROGRAM PARTICIPANTS AND RESPONSIBILITIES

The Hyper-X Program is a joint NASA LaRC-DFRC program, and has featured significant active government participation in development of the X-43 vehicle. NASA LaRC is responsible for hypersonic technology development, including many critical vehicle design and risk reduction activities. NASA DFRC is responsible for vehicle development, including booster integration, system validation and flight testing. The conceptual design for the Hyper-X was completed in May 1995[3] and the preliminary design was completed in October 1996[1,3]. The HXLV contract was awarded to Orbital Sciences Corporation in February 1997 and the HXRV contract to Micro Craft, Inc. (with Boeing, GASL and Accurate Automation Corp. as team members) in March 1997. The Hyper-X Program operates as a closely allied government-industry team. Integrated Product Teams (IPT) for vehicle development and Technology and/or Discipline Teams (T/DT) for technology and flight test activities perform day-to-day program activities. The IPT's are contractor led, with Government participation and the T/DT's are Government led, with contractor participation. In fact, a key management approach was the extent of "positive inclusion" of DFRC participation from program inception. This was in both the IPT's and T/DT's, to assure that the analytical and experimental aspects of the design process completely supported the development of the flight vehicles, flight safety, and mission success requirements. In addition to technology teams and IPT participation, DFRC manages the HXRV and HXLV contracts, to assure that the vehicles will be developed with an emphasis for swift vehicle validation and safe and successful flight tests.

VEHICLE DESIGN AND FLIGHT MISSION RISK REDUCTION

The X-43 was scaled photographically from the Mach 10-cruise global-reach concept[3] Scaling the configuration external lines, with the exception of details such as leading edges, enabled the utilization of existing databases, as well as rapid convergence to a controllable flight research vehicle with low trim-drag penalty. The scramjet flowpath was re-optimized to enhance engine operability and vehicle acceleration. For the single-Mach number scramjet operating condition, the Hyper-X engine geometry is fixed, except for the inlet cowl, which is closed to protect the engine during boost and descent. Although there are differences between the reference (Dual-Fuel, Global-Reach) vehicle and Hyper-X scramjet engine flowpaths, demonstration of the Hyper-X predicted performance validates the design process[4].

Vehicle design and flight test risk reduction required definition of engine flowpath lines; aerodynamic and propulsion database development; vehicle loads definition, structural design and analysis; flight and propulsion control law development; simulation for all phases of flight; and stage separation technology. These technology development tasks are completed for the Mach 7 vehicle (#1), and only small additional efforts are required for the second Mach 7 vehicle.

Aerodynamics

A preliminary aerodynamic database was developed in 1996 from results of quick-look experimental programs. These tests were performed using 8.3% and 3.0% scale models of the X-43 and the HXLV over the Mach number range of 0.6 to 10. The full aerodynamic database includes boost, stage separation, X-43 powered flight (with propulsion data) and unpowered flight back to subsonic speeds. Figure 3 illustrates the range of tests and typical hardware used to develop the Hyper-X aerodynamic database. The final aerodynamic database for the X-43 alone[5] uses results from over 580[8] tests[6] in 10 facilities with 16 models ranging from 3.0% to 21% of full scale (and to 100% when including powered vehicle validation test data from the 8' HTT; see figure 5). In addition, extensive use of CFD[5] was incorporated to account for effects not measured (such as time-accurate stage separation phenomena), or to remove wind tunnel test effects (such as Reynolds number, wall temperature, and effects from sting or blade mounting). CFD was also utilized to account for propulsive effects on the aerodynamic database[7]. These effects were then validated by tests of the full vehicle simulator and engine in the NASA 8-ft HTT[8].

The X-43 aerodynamic database represents the most comprehensive aerodynamic characterization of a hypersonic configuration ever developed. This database shows that the X-43 is statically stable in all three axes at the test conditions, and has adequate control power from the all-moving horizontal tails and the vertical tail/rudder surfaces. As expected, the rudder control decreases and roll-yaw coupling increases at high (10 degrees) angle of attack. Also, the scramjet-powered condition significantly changes the vehicle trim[5].

Quantification of the aerodynamic database uncertainty has been completed[9]. These uncertainties, like the database itself, are the heart of the flight simulations.

Orbital has lead responsibility for launch vehicle aerodynamics. Both Orbital and NASA LaRC performed wind tunnel tests. These tests addressed configuration changes and launch vehicle flight conditions outside of Orbital's existing wind tunnel and flight databases. As with the research vehicle, CFD was extensively utilized to account for flight scaling of the wind tunnel database.

The aerodynamic database required for Mach 7 flight tests is complete. The Mach 10 flight database is nearly complete, and the aerodynamics technology team is awaiting flight data for comparisons with predictions.

Propulsion

Propulsion Team activities included engine flowpath design and validation, flight loads definition and flight propulsion system controls development and validation. "Smart scaling" of the Pratt and Whitney (P&W) designed scramjet flowpath from the Dual-Fuel, Global Reach Vehicle[10] was accomplished by NASA LaRC in 1995 for the X-43 conceptual design. A preliminary assessment of the scaled Mach 7 scramjet flowpath was conducted in 1996 in the Arc Heated Scramjet Test Facility at NASA LaRC, using the Dual-Fuel eXperimental (DFX) engine. Operability and performance were about as expected. Additional design iterations and wind tunnel tests were performed to increase the X-43 acceleration and scramjet engine operation margin. Part of the risk reduction wind tunnel testing for the Mach 7 flight was multiple tests in different facilities (figure 4), to identify anomalies caused by facility contaminants. These tests showed expected performance and operability trends and confirm the excellent performance and operability of the Hyper-X engine at Mach 7.

Validation of the propulsion flowpath structure, performance and control system function was accomplished using the first flight engine and a "vehicle flowpath simulator" in the NASA Langley Research Center 8-foot High Temperature Tunnel (8-ft HTT). This test is illustrated in figure 5. The control system was designed for operation over a range of flight conditions and regulates fuel flow for flight Mach number, altitude and thrust requirements, while monitoring and controlling engine operation to assure fuel ignition and avoid inlet unstart.

This wind tunnel test of an airframe-integrated scramjet powered vehicle configuration chalked-up many "Firsts."

- Full airframe-integrated, scramjet-powered model test in a wind tunnel
- Dual-mode scramjet flight controls for airframe-integrated scramjet-powered vehicle
- Yaw-effects test of a scramjet
- Scramjet test using ablative forebody and nozzle surfaces (joint with DARPA)
- Data to validate conventional scramjet module engine test techniques.

In addition, this test program:

- Verified the powered aerodynamic database developed using aerodynamic models and CFD;
- Quantified the impact of partial-width, full scale testing (DFX and HXEM) on the projected flight performance;
- Validated the scramjet model structure and functionality (54 tests);
- Provided propulsion performance and operability over a large range in dynamic pressure and angle of attack.

Propulsion technology risk reduction issues for the Mach 7 test are complete. The propulsion team is awaiting Mach 7 flight data, and continuing to resolve/understand facility effects. Mach 4-6 tests are continuing to complete the engine characterization down to scramjet take-over (from turbojet system) speeds. Mach 10 performance characterization is continuing.

Vehicle Loads, Structural Analysis and Tests

The major challenges for the Structures Technology Team were definition and development of design loads, dynamic analysis of the mated Hyper-X Launch Vehicle configuration, and thermal-structural design/analysis of the hot structures. Mach 7 vehicle design issues were completed in late 1999. However, a few issues have continued for the Mach 7 vehicle, such as improved resolution of wing spindle bending moments during boost, and more accurate definition of the vehicle vertical center of gravity location, and roll inertia.

Most recent structures team activity has focused on hot structure for the Mach 10-flight vehicle. Thermal-structural analysis and design for the Mach 10 wing, tail, and rudder have now been completed. Leading edges for the vehicle nose will exceed the carbon-carbon (CC) maximum single-use temperature limits. A series of screening tests were performed to identify a replacement for the SiC coated carbon/carbon design used for Mach 7 flights. Six of the thirteen samples tested survived multiple exposure to the Mach 10, 1300 Btu/ft^2-s heat fluxes, and 4 of the samples were recommended for use on the research vehicle.

Flight Control Laws and Mission Simulation

Flight control laws for the research vehicle evolved from preliminary, simple control laws developed at NASA during conceptual design activities. Assessment of these control laws demonstrated that they meet the flight test requirements. Control laws for the Launch Vehicle evolved from the Pegasus Launch system.

Mission simulation was performed with 3-Degree-of-Freedom (DOF) methods early in the program. Final analyses are based on a 6 DOF simulation for launch and X-43 free flight, and 14 DOF simulation for stage separation. Orbital conducted launch simulation, NASA LaRC conducted stage separation simulation, and NASA DFRC conducted X-43 flight simulation. Monte Carlo analyses for each phase of flight have been completed, with input to subsequent flight phases. DFRC has accepted the lead to develop a full mission (drop to splash) simulation with Monte Carlo analyses. This full simulation, with associated Monte Carlo analyses will remove uncertainty generated by manual transmission between the current independent simulations.

Stage Separation

Stage separation remains the single largest challenge to a successful mission. The non-symmetrical, high-dynamic pressure, high-velocity separation event will be another first. An extensive wind tunnel database[11] was generated to cover the potential interactions between the research and launch vehicle as they fly independently, but in close proximity. CFD was utilized[12] to scale test data, aid in resolving sting and blade mounting effects, and estimate the time-accurate effects not modeled in the steady-state wind tunnel tests. Simulation of the stage separation event is performed using a 14 degree-of-freedom (DOF) code: 6-DOF for both the research vehicle and launch vehicle (minus X-43), and 2-DOF for the ejector pistons. Monte Carlo analysis of the stage separation event has been completed utilizing current aerodynamic, structural, flight condition at separation and X-43 vehicle system uncertainties. The analysis incorporates twenty-eight significant independent variables. With these uncertainties, less than 5% of the separation events produced total mission failure.

Hardware performance validation for the stage separation process is completed. This included component-level tests leading up to a full-scale separation test using the first vehicle adapter and second X-43 airframe. This full-scale test included separation sequencing utilizing both HXLV and HXRV "flight type" separation control components, and HXRV position monitoring using a X-43 Flight Management Unit. This test demonstrated good performance of the X-43 FMU when subjected to the stage-separation high-shock dynamic environment. In addition, the test demonstrated the required forces from the ejector-pistons, acceptable X-43 acceleration (less than 10g's), predicted separation velocity; and no adverse yaw or pitching moment initiation.

VEHICLE DEVELOPMENT

The HXLV and HXRV CDR's were held in December 1997 and February 1998, respectively (figure 6).

Hyper-X Launch Vehicle Development

The first HXLV was delivered to DFRC in Dec. 1999 and final validation tests of the booster system were completed in May 2000. The second HXLV is also at DFRC and is undergoing final stand-alone validation testing. Orbital is also responsible for vehicle integration and launch support activities. Mechanical and electrical interface checkouts for the HXLV to B-52 adapter, and HXLV to HXRV adapter (Ballast/Avionics Module) have been performed (figure 7).

X-43 Research Vehicle Development

The first X-43 was delivered to DFRC in Oct. 1999, and stand-alone validation testing is complete. The second X-43 has been completed—including changes required from results of the 1st vehicle validation tests at DFRC. The second vehicle was delivered to DFRC in January 2001. The third vehicle airframe is assembled, and the AETB tile installation is in progress with delivery to MicroCraft's Tullahoma facility in late CY 2000. This vehicle will have engine, wings (horizontal control surfaces), tails, rudders, and C/C leading edges modified to handle thermal loads for the Mach 10 mission. Delivery of this third vehicle is on schedule for mid CY 2001.

VALIDATION TESTS

A large number of preflight tests were conducted at DFRC. These include the following completed tests:

- Structural dynamics, mode interaction, mass properties
- Vehicle management system hardware-in-the-loop and vehicle-in-the-loop
- Radio frequency system
- Fuel system bench tests
- Environmental system
- Installed propellant system leak and functional
- HXRV adapter systems
- HXLV systems
- B-52 systems
- HXLV stack hook release and emergency stack adapter jettison tests.

In addition, the X-43 full-mission simulation, first with inert gases (figure 8) and then with real gases, as well as preliminary integration tests are completed. The HXRV and adapter have been integrated and mission simulation tests completed. This short stack (X-43 and booster adapter) have been integrated with the booster (figure 9). A series of integration tests will be performed on the full stack to assure interface compatibility. A Combined System Test will be performed with all HXRV and HXLV flight systems active to ensure there is no significant electromagnetic interference between systems and to verify the transmission and reception of flight data. Captive Carry Flight tests of the B-52 with the stack attached will be used to exercise the tracking and data reception capabilities of the test range, and provide operational rehearsals. Extension of the validation test schedule, figure 6, is due in part to shifts in NASA risk tolerance following the 1999 Mars Program failures.

X-43 FLIGHT TESTS

The flight test objectives include:

- Acquisition of flight data to document the performance and operability of airframe-integrated hydrogen-fueled, dual-mode scramjet-powered research vehicles at Mach 7 and 10

- Demonstration of controlled powered and unpowered hypersonic aircraft flight.

Specific flight objectives are to safely launch the stack from the B-52, successfully separate the X-43 from the adapter at the appropriate test conditions, and obtain the desired test data in all areas of the flight envelope. Flight research objectives include evaluation of a Flush Air Data System and most importantly, development of flight test techniques applicable to highly integrated, airbreathing engine powered hypersonic vehicles.

Data include 500 instrumentation parameters on the X-43 and 700 parameters on the HXLV. The HXLV instrumentation monitors approximately 400 guidance, navigation, and control parameters and 300 acceleration, discrete, and power system analog sensors, including information on the stage separation sequence. The data will be relayed to the DFRC mission control room and to LaRC for recording and real time display of selected parameters. It will also be recorded at the U.S. Navy Pt. Mugu facility and by two Navy P-3 aircraft. To reduce the risk of data loss, critical scramjet engine data will be rebroadcast at regular intervals following the engine test.

Real time video from the B-52 will monitor the captive carry portion of the flight as well as the initial drop of the stack. The F-18 photo chase will provide video for the initial drop from the B-52, the rocket ignition sequence, and the first portion of the boost trajectory. In addition, two cameras are mounted in the vehicle-to-booster adapter to record the stage separation. A series of rawinsonde balloons, launched at intervals prior to the flight tests, will be used to measure upper atmospheric pressures, temperatures, and winds near the location and altitude of the scramjet test. These data will be used to correct the X-43 performance calculations to standard day conditions and validate the inertial measurement system information. A Mission Data Load will correct for seasonal variations in the atmosphere.

Flight test operations will be conducted in accordance with established DFRC practices. The flight approval process will include Flight Certification, Tech Briefs, a Flight Readiness Review and an authorization to proceed from the Airworthiness and Flight Safety Review Board. A large portion of these reviews is allotted to flight safety. In addition, factors affecting mission success will also be considered.

The first flight is scheduled to occur in mid FY 01 with the following flights scheduled for late CY01 (Mach 7) and Mid CY02 (Mach 10). During each of these flight tests illustrated in figure 10, the B-52 will carry the stack to the launch point where it will be dropped, the rocket motor ignited, and a climbing due west boost trajectory flown to the stage separation point. The HXRV will not be recovered but telemetered test data will be received almost to splash down in the Pacific Ocean.

OTHER HYPER-X TECHNOLOGY

The Hyper-X program technology focus is on four main objectives required for practical hypersonic flight:

- Hyper-X (X-43) vehicle design and flight test risk reduction
- Flight validation of design methods
- Design methods enhancement
- Hyper-X Phase II and beyond.

The first of these was discussed extensively in an earlier section. The other 3 will be briefly discussed in the following sections.

Flight Validation of Design Methods

A primary Hyper-X program goal is flight verification of design methods for scramjet propulsion, hypersonic vehicle aerodynamics and propulsion-airframe integration. This is required to develop confidence in predicted capabilities of future hypersonic vehicle systems. Some issues expected in flight (vis-a-vis wind tunnel) validation include:

- Low free-stream turbulence effects on fuel mixing, shock-induced boundary layer separation, and boundary layer transition
- Full total enthalpy effects on slender-body, hypersonic, wind tunnel-based aerodynamic performance
- Clean-air test gas effects on ignition, flameholding and flame propagation
- Unknowns in propulsion-airframe integration associated with increased DOF in flight.

Method Enhancements

Scramjet engine and scramjet-powered vehicle design requires a matrix of highly integrated design tools encompassing engineering and higher-order CFD-based analysis methods[4], and specialized experimental facilities and measurement systems[14]. Successful development of hypersonic vehicles requires continued refinement of these design tools. Part of the current program focus on parametric engine tests and analysis around the Mach 5, 7 and 10 conditions is to develop these design systems for the X-43 configuration. These design systems will soon be completed and in place to characterize and optimize scramjet engine flowpaths for the Mach 4 to 10 dual-mode scramjet required for future vehicle development. Some typical specific developments include:

- Development of experimental methods for propulsion airframe integrated vehicle testing (8' HTT)
- Upgraded HYPULSE to world's first facility capable of operation as either reflected shock or expansion tunnel
- Validation of scramjet tests methods in pulse tunnels by direct comparison to data from the same flowpath tested in a continuous flow facility
- Validation of engine module testing by comparison to full flowpath test results

- Refinement of SRGULL design code for accurate pitching-moment prediction
- Developed/validated medium fidelity prediction method for yaw effect on scramjet performance.

Hyper-X Phase II and Beyond

This technology area represents the long-term look at future systems, and flight validation of the technology. These long term activities include:

- Alternate engine cycles[15-16]
- Plasma-aero, magneto-hydrodynamics, virtual inlet, and power generation[17]
- System studies to refine existing or identify new concepts and missions for hypersonic airbreathing reusable vehicles[18]
- Hypervelocity scramjet engine technology, Mach 12-20[19]
- Follow-on research vehicle conceptual design and program planning.

The Hyper-X program[20] was originally planned as a two-phase program. Phase I emphasis is on the Mach 5-10, dual-mode scramjet operating speed range. Phase II is not funded, but studies leading to a Phase II program are progressing. The Hyper-X Program, now working closely with the MSFC-led ASTP program, has developed several potential flight program concepts. These programs are built on existing technology, provide a building block approach, advance key hypersonic technologies, which are ready for flight demonstration and provide a capable flight test bed platform. These programs address issues not addressed in the X-43 program, such as:

- Flight weight structures
- Actively cooled engine systems
- Fully-reusable test beds
- Durability testing
- Scramjet operation over a large Mach range, including mode transition
- Scramjet-based combined cycle (RBCC and TBCC)
- Powered vehicle operation over flight envelope
- Hypervelocity (Mach > 10) propulsion
- Powered low-speed and takeoff and landing operation of hypersonic vehicles.

The lowest cost vehicles are illustrated in the lower left portion of figure 11. These include:

- Small scale, expendable, hydrogen-fueled 12' Mach 14 or 15 X-43
- Mach 5 hydrogen-fueled X-43 flight for low-speed operation demonstration
- 50', reusable, piloted Mach 0-0.8 turbojet-powered low speed demonstrator vehicle.

The projected cost for each of these flight vehicle programs is in the $10's M.

Medium cost vehicle programs include air-launched, self-propelled, reusable hypersonic vehicles. These concepts utilize hydrocarbon scramjet technology, developed by the USAF HyTech and DARPA ARRMD programs, to reduce the vehicle size. Also, these programs utilize Hyper-X aerodynamics, flight control laws, and components to reduce development cost. These programs also utilize air launch to reduce the fuel required to get to hypersonic conditions. These programs include:

- 33' long Mach 4 - 7 scramjet demonstrator concept which uses a tail rocket to boost the vehicle to Mach 4
- 33+' long Mach 0.8 - 7 Rocket Based Combined Cycle (RBCC) vehicle which moves the rocket into the scramjet flowpath. (The MSFC Spaceliner program, Boeing and the Integrated System Test of Air breathing Rocket, or ISTAR, RBCC consortium are developing an updated version of this vehicle.)
- 40' Mach 0.8 - 7 version of the same vehicle, with a turbojet low-speed system. This jointly funded (by MSFC and LaRC) vehicle concept is referred to as the "X-43B TBCC."

These hydrocarbon fueled, and air launched vehicles allow Mach 0.8–7 demonstration of hypersonic systems, including mode transition and envelope expansion testing, in a relatively small vehicle. Programs in this class will likely cost $100's M, with increasing cost in the order listed above.

The original Phase II concept (HySID[20]) is a horizontal takeoff and landing, 50+' long turbine based combination engine (TBCC) configuration, which utilizes hydrocarbon fuel to reduce vehicle size. This vehicle can demonstrate the same technology demonstrated in the former group, but adds powered takeoff and landing. The requirement to take off with the higher density hydrocarbon fuel, drives the vehicle modification seen, i.e. the larger wings and canard. The size of this vehicle is also well suited for additional hypersonic experiments, such as those associated with weakly ionized gas phenomena. This vehicle program cost will likely approach $1B, similar to the X-33.

SUMMARY

This paper provided an overview and status of the Hyper-X program. The program is poised to move hypersonic airbreathing technology one step closer to the level required for serious consideration for future systems. The Hyper-X flight test program is making final preparations for the first Mach 7, X-43 flight in spring 2001.

Extensive risk reduction activities for the first flight are complete, and non-recurring design for the Mach 10 vehicle is nearing completion. Pretest predictions and experimental data required for comparison with flight data are in hand, and the technology teams are anxiously awaiting the first flight.

This paper also addressed how the flight test integrates with NASA's technology development effort and future development requirements and plans. Future flight programs are discussed which provide a rational, affordable, building-block approach to maturing hypersonic technology.

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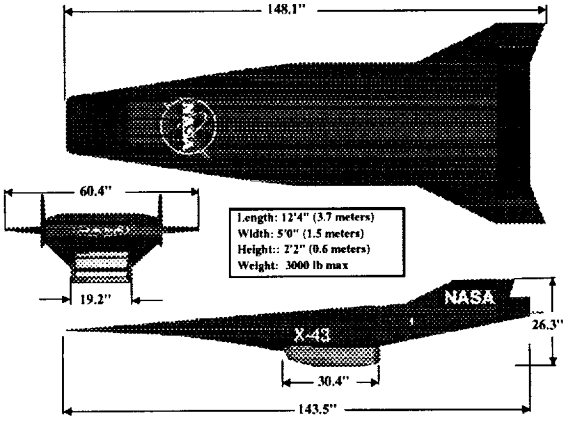


Figure 1. X-43 Vehicle Geometry.

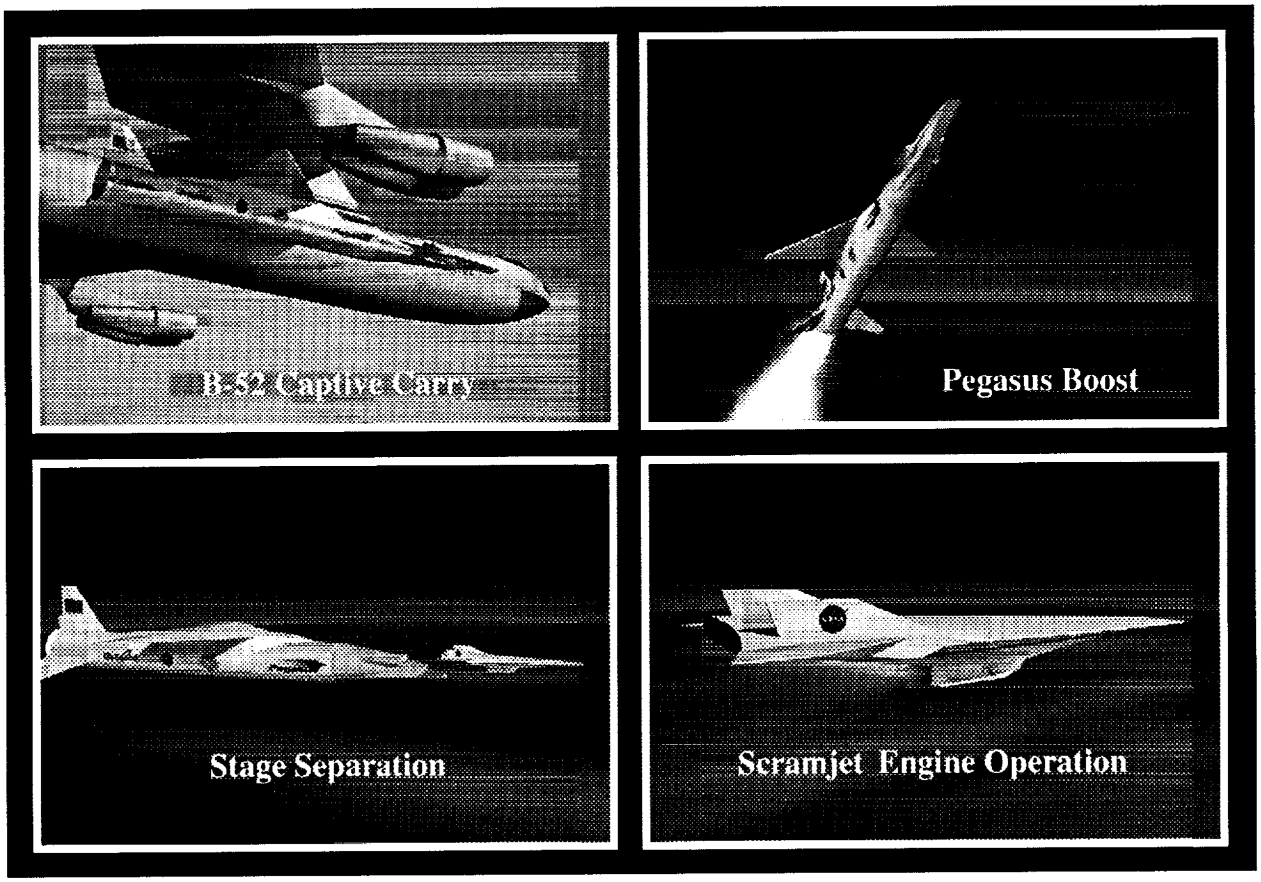


Figure 2. Hyper-X Key Mission Events.

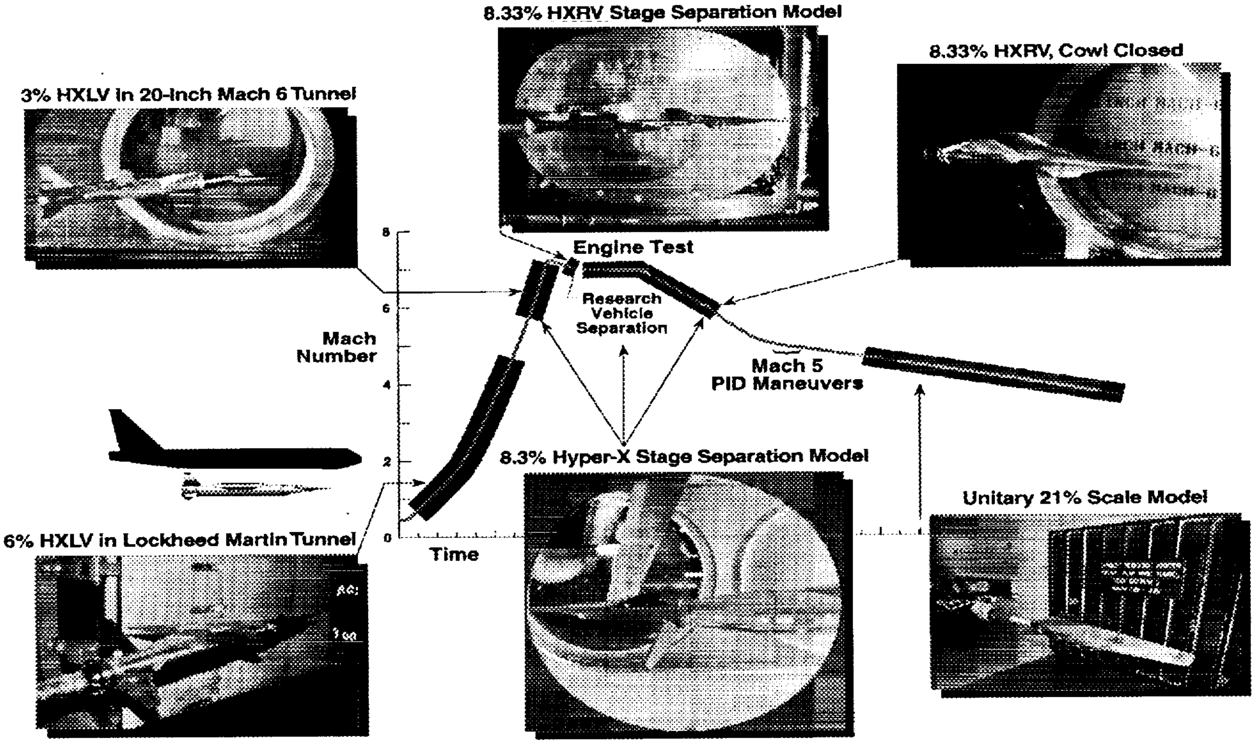


Figure 3. Risk Reduction: Aerodynamic Database.

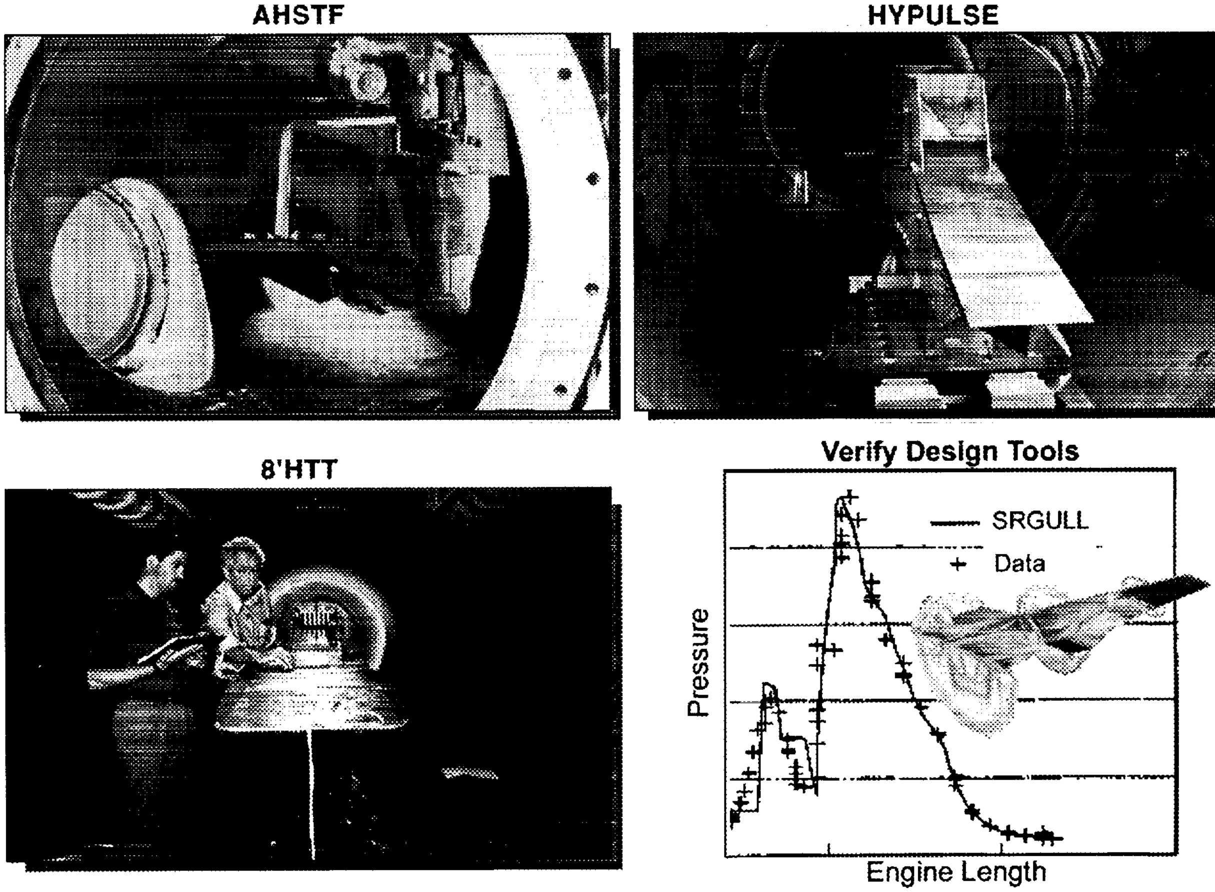


Figure 4. Design/Risk Reduction: Mach 7 Module Testing.

Figure 5. Risk Reduction: Yaw Effects Validation.

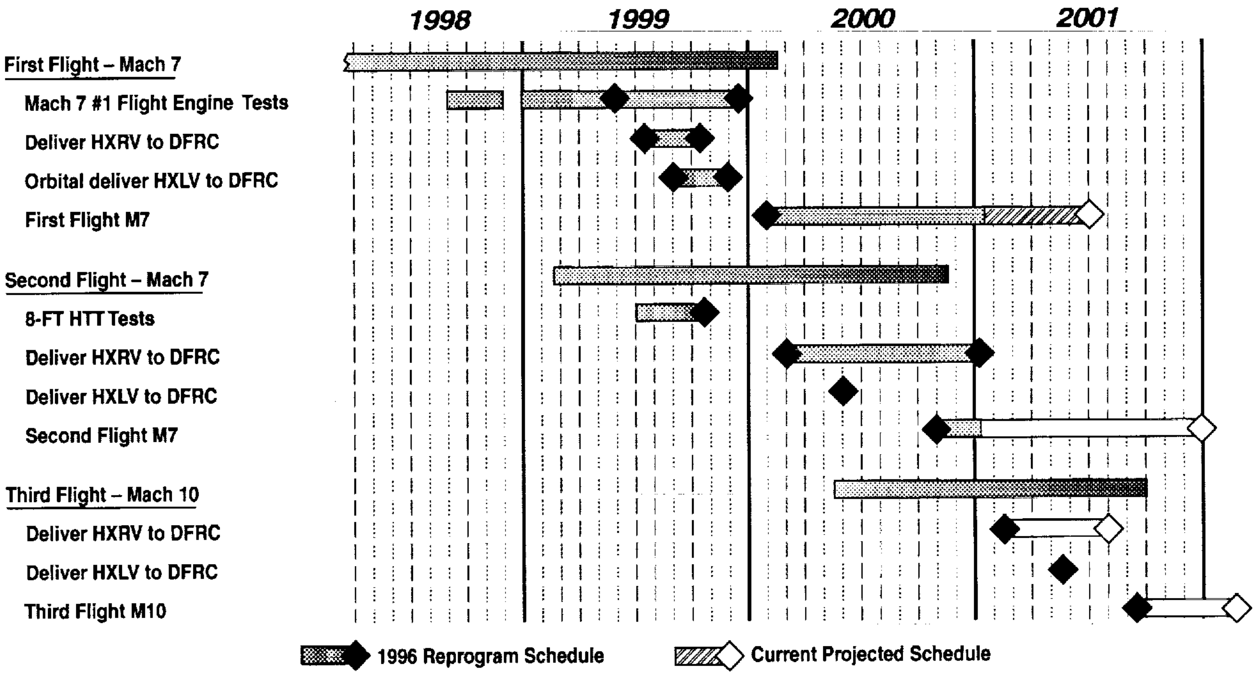
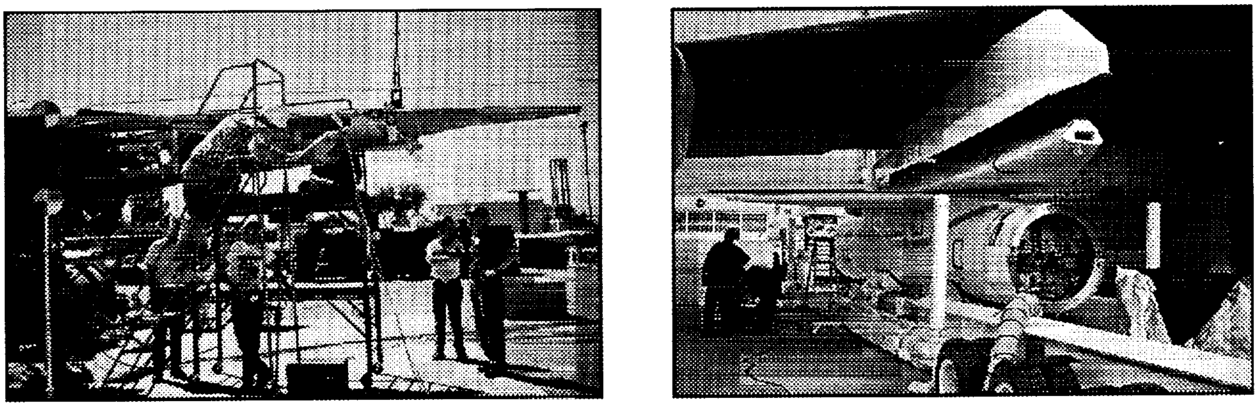
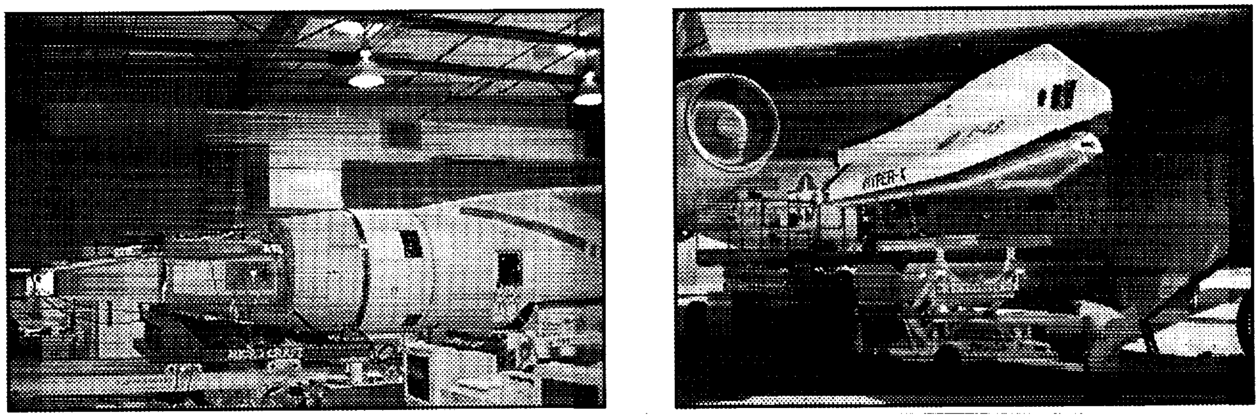


Figure 6. Hyper-X Program Schedule.



X-43-to-Adapter

Booster-to-Pegasus Adapter



Adapter-to-Booster

Wing Pylon to B-52

Figure 7. Integration Activities.

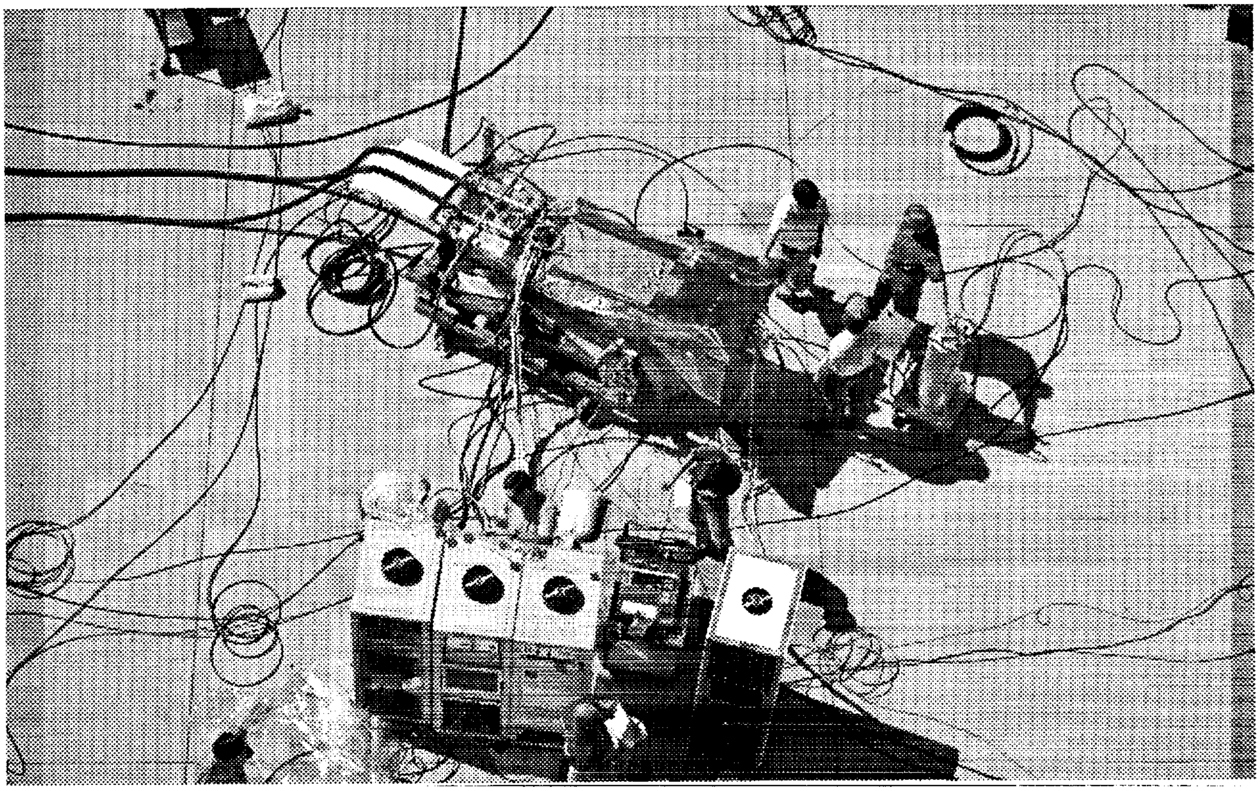


Figure 8. Test Setup—Inert Blowdown/Mission Simulation.

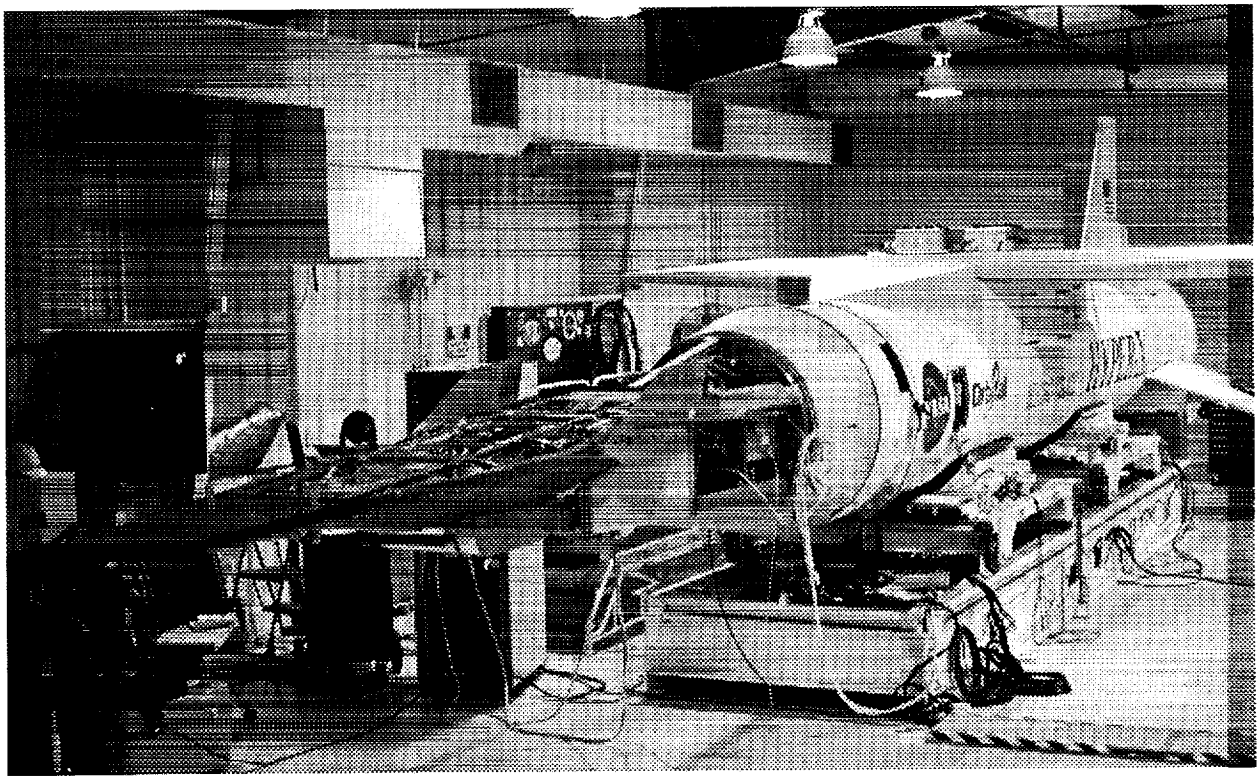


Figure 9. Hyper-X Launch Vehicle Integration.

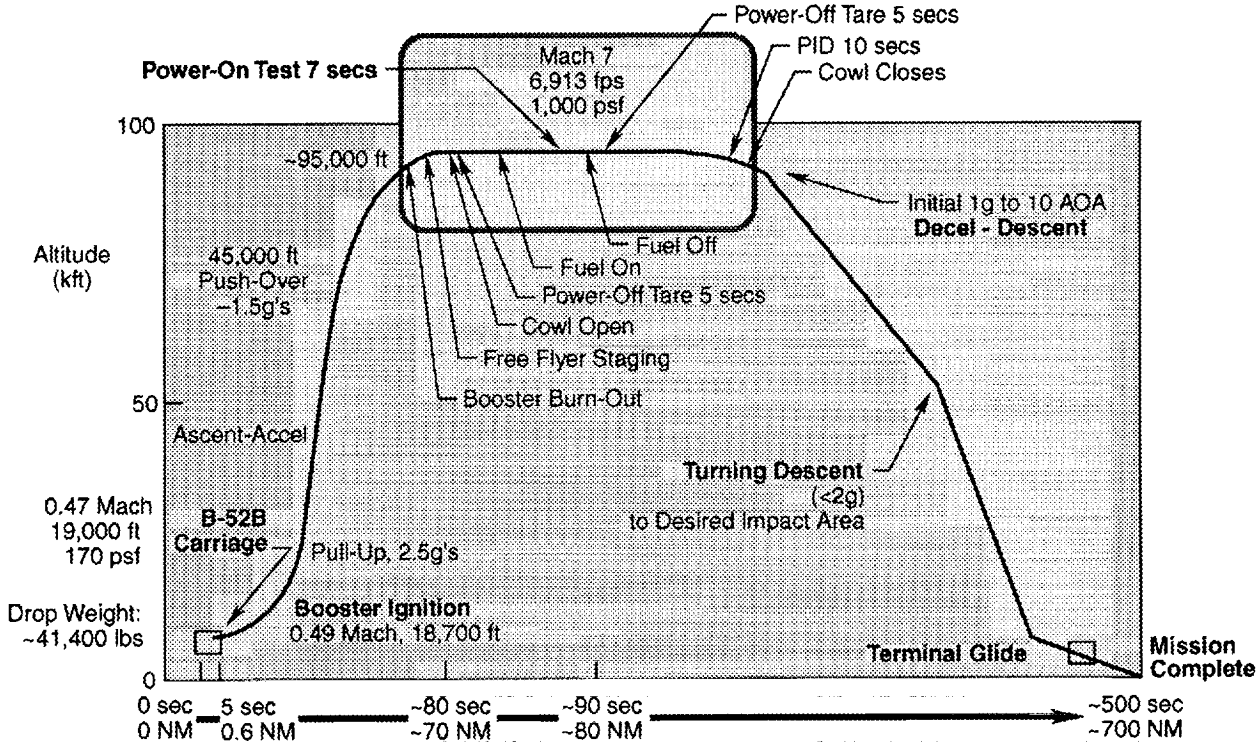


Figure 10. X-43 Mach 7 Flight Trajectory.

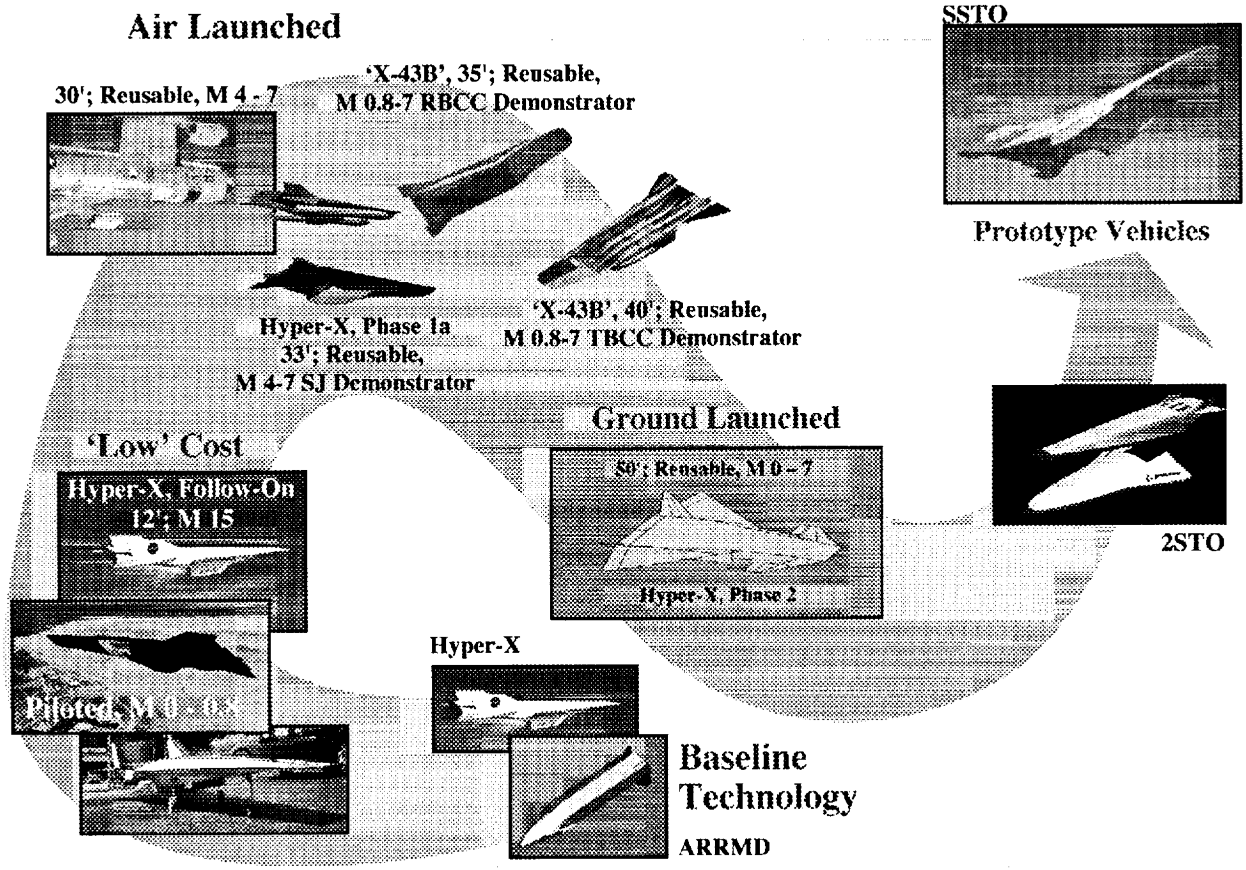


Figure 11. Potential Hypersonic Technology Demonstrators.