AIAA-98-1532

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AIAA 8th International Space Planes and Hypersonic Systems and Technologies Conference

April 27-30, 1998/Norfolk, VA

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Abstract

The Hyper-X Program, NASA's focused hypersonic technology program jointly run by NASA Langley and Dryden, is designed to move hypersonic, air-breathing vehicle technology from the laboratory environment to the flight environment, the last stage preceding prototype development. The Hyper-X research vehicle will provide the first ever opportunity to obtain data on an airframe integrated supersonic combustion ramjet propulsion system in flight, providing the first flight validation of wind tunnel, numerical and analytical methods used for design of these vehicles. A substantial portion of the integrated vehicle/engine flowpath development, engine systems verification and validation and flight test risk reduction efforts are experimentally based, including vehicle aero-propulsive force and moment database generation for flight control law development, and integrated vehicle/engine performance validation. The Mach 7 engine flowpath development tests have been completed, and effort is now shifting to engine controls, systems and performance verification and validation tests, as well as, additional flight test risk reduction tests. The engine wind tunnel tests required for these efforts range from tests of partial width engines in both small and large scramjet test facilities, to tests of the full flight engine on a vehicle simulator and tests of a complete flight vehicle in the Langley 8-Ft. High Temperature Tunnel. These tests will begin in the summer of 1998 and continue through 1999. The first flight test is planned for early 2000.

Nomenclature

AETB – Alumina Enhanced Thermal Barrier
AHSTF – Arc-Heated Scramjet Test Facility
ALFE – Air Launched Flight Experiment
CFD – Computational Fluid Dynamics
CH_4 - Methane
CHSTF – Combustion Heated Scramjet Test Facility
CY – Calendar Year
DAS – Data Acquisition System
DFX- Dual-Fuel Experimental Parametric Engine
DFRC – Dryden Flight Research Center
ESP – Electronically Scanned Pressure
FE – Flight Engine
FFS – Full Flowpath Simulator
FMS –Force Measurement System
GASL – GASL, Inc.
GASL Leg IV – Scramjet Test Facility at GASL, Inc.
H_2 – Molecular Hydrogen
HXEM – Hyper-X Engine Module
HXLV – Hyper-X Launch Vehicle
HXRV – Hyper-X Research Vehicle
HYFLITE – Hypersonic Flight Experiment
HySTP – Hypersonic Systems Technology Program
LaRC – Langley Research Center
LO_2 – Liquid Oxygen
MDA – McDonnell Douglas Aerospace (Now Boeing St. Louis)
MHz – Megahertz
NACA – National Advisory Committee on Aeronautics
NAR – Non-Advocate Review
NASA – National Aeronautics and Space Administration
NASP – National Aero-Space Plane
NM – Nautical Mile
NO – Nitric Oxide
O_2 – Molecular Oxygen
PID – Parameter Identification Maneuver
psf - Pounds force per foot squared
SiH_4 – Silane
TPS – Thermal Protection System
TRL – Technology Readiness Level
WTR – Western Test Range
8-Ft. HTT - 8-Foot High Temperature Tunnel

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Introduction

Program Overview

Airbreathing propulsion offers substantial advantages over rocket propulsion for hypersonic flight, enabling the flight applications illustrated in figure 1. It is an essential ingredient for sustained endoatmospheric hypersonic cruise applications, such as "global reach" vehicles, and can significantly improve the performance of space launch vehicles (ref. 1). Airbreathing supersonic combustion ramjet (scramjet) engines promise to improve mission effectiveness by reducing on-board propellant load in favor of payload and by increasing operational flexibility.

The scramjet engine is the key to airbreathing hypersonic technology. Hypersonic airbreathing propulsion has been studied by NACA/NASA for nearly 60 years (ref. 2). Numerous scramjet tests have been performed in a host of ground facilities (refs. 3 - 7). Significant improvements in design methods, experimental databases, experimental facilities and test techniques, as well as demonstrated engine performance, have been made over the years for both hypersonic airbreathing propulsion and hypersonic aerodynamics. However, many of these tests have limitations, as discussed in reference 8.

NASA, as well as the hypersonic community at large, has long recognized the requirement to fully integrate hypersonic airbreathing propulsion engines with the vehicle airframe (ref. 9). This integration is difficult to demonstrate in ground based, experimental facilities. To mature hypersonic airbreathing propulsion technology for application in the future, NASA has initiated the Hyper-X Program (refs. 8, 10). The goal of the Hyper-X Program is to demonstrate and validate the technology, experimental techniques, and numerical methods and tools for design and performance predictions of hypersonic aircraft with airframe-integrated, hydrogen-fueled, dual-mode scramjet propulsion systems. Accomplishing this goal requires flight demonstration of a hydrogen-fueled scramjet powered hypersonic aircraft.

Previous studies and other work leading up to this program were discussed in ref. 8, and are briefly addressed by figure 2. To meet cost constraints, the flight test portion of the program utilized existing technology, primarily developed in the National Aero-Space Plane (NASP) program, including vehicle design, design tools, databases, flight test approaches and "off-the-shelf" flight test equipment which was identified for the proposed NASP HYFLITE and HySTP flight experiments. Conceptual design for the flight experiment was accomplished in 1995 under a contract to McDonnell Douglas Aerospace (MDA), and preliminary design was accomplished by MDA between Feb. and Oct. 1996. The Hyper-X Program was approved by NASA Headquarters in July 1996, and officially started in Sept. 1996. The flight test approach employs an air-launched boost vehicle to carry the research aircraft to its test point, followed by separation from the booster and free flight of the research vehicle. The current Hyper-X research vehicle (HXRV) and launch vehicle (HXLV) contractor activity commenced in March 1997 and Oct. 1996, respectively. The HXRV, manufactured by a Micro Craft lead contractor team including Boeing North American and GASL, is boosted to the desired test point by the HXLV, which is fabricated and supported by Orbital Sciences Corporation. Additional information about the contractor team and the program organization can be found in reference 8.

Program Objectives

The primary objective of the flight test portion of the Hyper-X Program is to provide data required to advance key hypersonic Technology Readiness Levels (TRL's) from the laboratory level to the flight environment level, a NASA requirement before proceeding with a larger, crewed X-plane or prototype program. In addition, the flight test portion must address and advance many flight test techniques, such as experimental derivation of aerodynamic performance, and develop robust sensors and controls to accurately determine the flight condition and control the vehicle and engine.

The technology portion of the program concentrates on three main objectives:

1) Flight validation of design predictions.
2) Design methods enhancements - i.e., continued development of the advanced tools required to improve scramjet-powered vehicle designs.
3) Risk reduction - i.e., preflight analytical and experimental verification of the predicted aerodynamic, propulsive, structural and integrated vehicle/engine system performance and operability of the HXRV.

These objectives are reached through experimental, analytical and numerical activities applied to the design of the research vehicle and scramjet engine; wind tunnel verification of the vehicle/engine integration, including performance and operability; vehicle aerodynamic and thermal database development; thermal-structural design; boundary-layer transition analysis and control; flight control law development; and flight simulation model development. Much of the current technology effort is expended in objective 3, "risk reduction".

Flight Test Description

The flight test portion of this program consists of three autonomously controlled research flights at speeds up to Mach 10 to demonstrate, validate, and extend scramjet technology. Each of the 12-foot-long, 5-foot-wingspan hypersonic aircraft, illustrated in figure 3, has a single airframe-integrated scramjet. These vehicles will be boosted to flight test conditions using a modified Pegasus™ booster, air launched from the NASA Dryden Flight Research Center (DFRC) B-52 (see figure 4). The desired test condition for the Hyper-X in free flight is a dynamic pressure of 1000 pounds per square foot (psf). The research vehicle will be boosted to approximately 95,000 feet for Mach 7, and 110,000 feet for Mach 10, corresponding to Reynolds numbers of approximately 11 and 8 million, respectively, based on vehicle length.

The nominal flight sequence for the Mach 7 test is illustrated in figure 5. Following drop from the B-52 and boost to the predetermined stage separation point, the HXRV will be ejected from the booster-stack and start the programmed flight test. Once separated from the booster, the HXRV will commence unpowered controlled flight to prepare for the powered test sequence. The powered test sequence, illustrated in figure 5, includes 5 to 10 seconds of hydrogen-fueled scramjet operation. Following the powered engine test and 15 seconds of aerodynamic parameter identification maneuvers (ref. 11 and 12), the cowl door will be closed. The vehicle will then fly a controlled deceleration/descent trajectory. In the process, short-duration programmed test inputs will be superimposed on the control surface motions to aid in the identification of aerodynamic parameters. These fully autonomously controlled vehicles will fly preprogrammed 700 to 1000 nautical-mile due-west routes in the Western Test Range (WTR) off the California coast, telemetering approximately 500 channels of test data.

The airframe design and flight test techniques are expected to be readily adaptable to other advanced-propulsion-technology studies. This flight test of a scramjet-powered vehicle will focus technology on key propulsion-airframe integration issues, provide data to validate hypersonic vehicle design tools, and extend ground based wind tunnel testing methods.

This paper presents an overview of the experimental portion of the Hyper-X Mach 7 engine development and verification program including complete vehicle testing in the Langley 8-Foot High Temperature Tunnel (8-Ft. HTT). An overview of the complete Hyper-X engine and aerodynamic test program is given in reference 13. These wind tunnel tests are an integral part of the overall program and should not be considered as stand-alone activities.

Hyper-X Integrated Vehicle/Engine Design Process

The Hyper-X integrated vehicle/engine design process is illustrated in figure 6. Building on the experience gained during previous hypersonic airbreathing vehicle flight test studies (HYFLITE, HySTP, and ALFE), a flight mission was defined which would satisfy research requirements within program budget and schedule constraints. An integrated vehicle/engine design study was performed to define the initial airframe-integrated engine flowpath. The initial flowpath selection was required to allow design and fabrication of ground test engines and initiation of detailed flowpath analyses such as the powered tip-to-tail CFD solution shown in figure 6. Engine test programs and flowpath analyses were started in the spring of 1996 to verify the engine design, evaluate the engine operating characteristics required to develop autonomous engine controls, and support generation of the propulsion contribution to the aerodynamic database. Although a substantial database existed for this class of engine, the proposed flight test engine required specific tailoring for the small scale to provide the desired thrust to assure vehicle acceleration. These tests and analyses led to the final Mach 7 engine flowpath lines in the spring of 1997. Currently, preparations are being made for integrated engine flowpath and control system verification tests, which will lead to flight. The engine test schedule presented in figure 7 shows the engine verification tests leading up to flight. Also shown are the test programs to develop final engine flowpath lines for the Mach 10 Hyper-X vehicle and a possible future Mach 5 flight.

The Hyper-X Program includes extensive utilization of wind tunnels to support the research vehicle and engine designs. Although conceptual vehicle and engine designs were based on previously demonstrated analytical and numerical design methods, experimental data are a key part of the integrated vehicle/engine design process and provide critical input to the predicted engine flight performance and the vehicle control law development. Successful demonstration of the predicted vehicle performance will be considered as validation of the use of these wind tunnels in the design process. The vehicle aerodynamic wind tunnel test program is described in reference 13, while the following sections will describe the Mach 7 engine wind tunnel test program, which includes propulsion flowpath, integrated aero-propulsion, and engine control verification tests.

Mach 7 Hyper-X Engine Flowpath Development Tests

The engine tests on the initial Hyper-X Mach 7 flowpath were conducted in the NASA Langley Research Center (LaRC) Arc-Heated Scramjet Test Facility (AHSTF). The AHSTF provides high enthalpy test gas, simulating flight conditions at Mach numbers from 4.7 to 8, utilizing an electric arc heater. Arc-heated air (at 3000 Btu/lbm) is mixed with ambient air to provide the desired test gas enthalpy. Power limitations lead to a 500 psf flight dynamic pressure simulation at Mach 7 and about 800 psf at Mach 5. Two facility nozzles, Mach 4.7 and Mach 6.0, each with a nominal 11” square exit are available. Facility test gas contaminants are primarily nitric oxide (NO), at about 0.02 mole fraction for the Mach 7 test conditions. The facility data acquisition system (DAS) includes about 650 channels of data. Typical measurements include surface pressure and temperature, a 6-component force balance, pressure and temperature probe and gas sampling survey capability. The AHSTF is the primary Mach 7 scramjet facility at Langley, and is more fully characterized in reference 3.

The dual-fuel experimental parametric engine, DFX (named for the MDA preliminary design contract), shown in figure 8, was developed in 1996 by modification of NASP engine hardware, to provide a rapid performance/operability evaluation of the Mach 7 Hyper-X initial flowpath design using the LaRC AHSTF. The DFX engine simulates the full scale (height and length) Hyper-X internal engine flowpath, with the correct forebody, cowl and sidewall leading edge radii. The forebody and aftbody have however been truncated, and the engine is partial width (44%), as denoted by the shaded region in figure 9, due to test facility size limitations. The primary function of the DFX is to provide a test article in which flowpath modifications can be evaluated quickly and cost effectively. This function leads to an engine design fabricated primarily from copper, and completely heat sink cooled. This design approach limits the engine to about a 30-second test time at a dynamic pressure of 500 psf, and precludes practical test times at the full flight dynamic pressure of 1000 psf. In addition, an inlet starting concept is employed where the entire cowl rotates about the cowl leading edge, thus reducing internal inlet contraction. While this design approach facilitates flowpath modifications, it does not allow for verification of the Hyper-X design, in which only a forward cowl flap is actuated.

Hyper-X Mach 7 engine performance and operability were verified at a range of Mach number and angle of attack simulations around the nominal, but at reduced dynamic pressure in the DFX tests. These test results verified predicted engine forces and moments as well as inlet and combustor component performances. Operability characteristics including ignition requirements, flameholding limits and combustor-inlet interaction limits were also obtained in these tests. The tests demonstrated excellent engine performance and operability, and provided data for validation of the Hyper-X design methods. The DFX engine was tested over 250 times in a total of 4 different configurations. These tests provided the data required to anchor the final engine flowpath lines and the preliminary Mach 7 propulsion force and moment and operability database required for development of vehicle and engine control laws.

Integrated Engine Flowpath and Control System Verification Tests

Engine flowpath and control system verification tests will be conducted in a number of steps in several facilities, as shown on the engine test schedule in figure 7. This extensive test series isolates the major differences between the preliminary database generated with the partial width, truncated fore/aftbody DFX tests run at reduced dynamic pressure in the AHSTF, and the HXRV flight database. A road map of the Mach 7 flowpath verification test program is presented in figure 10, and the differences between the tests are outlined in Table 1. The main ingredients of this test program are: 1) the NASA Langley 8-Foot High Temperature Tunnel (figure 11), which provides test conditions simulating Mach 7 flight at 1000 psf dynamic pressure, at a scale large enough to accommodate the complete HXRV; 2) the Hyper-X Engine Module (HXEM), which is a replication of the flight engine design at a reduced width for testing in small facilities such as the AHSTF as well as the 8-Ft. HTT; 3) the Hyper-X Full Flowpath Simulator (FFS), which can be configured in several ways, including a complete duplication of the external propulsive flowpath of the HXRV; 4) the Hyper-X flight engine (FE) which is a duplicate Mach 7 flight engine with additional instrumentation. These ingredients allow an integrated test program to isolate the major differences which exist due to test technique and facility limitations, including facility flowfield effects, test gas medium, forebody 3-D and boundary-layer development effects, engine aspect ratio, and dynamic pressure limitations. These effects must be properly accounted for in design and analysis methodologies when using wind tunnel test results as an integral part of flight vehicle/engine design.

8-Ft. HTT

The bulk of the Mach 7 integrated engine flowpath and control system verification tests will be conducted in the NASA LaRC 8-Ft. HTT, which provides a unique capability to test the complete Hyper-X research vehicle and full length engine flowpath at simulated Mach 7 flight conditions. This facility was placed in service in the 1960's to conduct aerothermal loads, aerothermostructures and high-enthalpy aerodynamic research (ref. 14). The high enthalpy test gas is produced by burning methane and air at high pressure, then expanding it through an 8-foot exit-diameter hypersonic nozzle to the 12.5 foot long test cabin. During the late 1980's and early 1990's, the tunnel was modified with an oxygen replenishment system to allow scramjet engine performance testing over a range of flight Mach numbers between 4 and 7, by using three different 8-foot diameter exit hypersonic nozzles, Mach 4, 5 and 7. The primary test gas contaminants are water vapor and carbon dioxide, at about 0.18 and 0.09 mole fraction, respectively, for the Mach 7 test conditions (see ref. 3). A schematic representation of the 8-Ft. HTT configured for airbreathing propulsion tests is shown in figure 11. To facilitate tunnel starting and to protect the test articles from startup and shutdown dynamic loads, they are typically stored beneath the hypersonic test stream and inserted into the stream after steady-state hypersonic flow is established. A hydraulic elevator system inserts the model mounted on a three-component force measurement system (FMS) into the test stream in approximately 1.5 seconds. The data acquisition system can accommodate about 1000 channels of electronically scanned pressures (ESP) and 500 channels of general strain gage measurements. Of these 500 channels, up to 31 high frequency (1 MHz.) measurements are available.

HXEM

The Hyper-X engine module was designed by reducing the width of the flight engine by moving the sidewalls closer together, but maintaining all other design features, and thus overcomes the limitations of the DFX flowpath development engine. The HXEM shares the DFX partial width/truncated length simulation so that it can be tested in the smaller flowpath development facilities. It also incorporates additional parametric capability for Mach 5 and 7 testing, includes the same active cooling as the flight engine to allow testing at full flight dynamic pressure, and includes the articulated, two-position inlet cowl leading edge flap used to close off and start the inlet. Current plans are to test this engine at Mach 7 in the AHSTF, GASL Leg IV (ref. 15), and the 8-Ft. HTT. Tests in the AHSTF provide a direct comparison with DFX results. Tests in GASL Leg IV provide results for full pressure and enthalpy simulation, comparisons of performance for high-to-low pressure tests, and a direct, low-pressure comparison of H_2-Air-O_2 combustion heated facility results with arc-heated facility results. Tests in the 8-Ft. HTT also provide full pressure simulation, as well as a comparison of CH_4-Air-O_2 combustion-heated data for comparison with the Leg IV and AHSTF results. Most significantly, this test provides a benchmark of the 8-Ft. HTT facility effects before testing the Hyper-X flight engine and research vehicle, through the incremental test approach illustrated in figure 10 and discussed previously.

FFS

The Hyper-X Full Flowpath Simulator is a non-flight, partial simulation of the Hyper-X vehicle, designed to be mated with either the Hyper-X research vehicle flight engine or with the partial width HXEM. The lower half of the Hyper-X research vehicle, which provides the external propulsion flowpath, is accurately modeled by the FFS, as illustrated in figure 12. This "boiler-plate" model will also include the correct forebody leading edge radius, flight boundary-layer trips, and the ability to incorporate a forebody surface of either steel, copper, or Alumina Enhanced Thermal Barrier (AETB-12) tile as used in flight. Because of size, this model can only be tested in the 8-Ft. HTT.

The HXEM is shown in three different configurations, with and without the FFS, in figure 13. These different configurations are required to allow the HXEM to be tested in the smaller engine development facilities like the AHSTF and GASL's Leg IV, and the much larger 8-Ft. HTT. For tests in the 8-Ft. HTT, the HXEM will be mounted on two configurations of the FFS, one with full boundary-layer ingestion and the other with part of the boundary-layer diverted as shown in figure 13a and 13b respectively. The boundary-layer diversion feature of the FFS will be used to quantify the effect of the full forebody boundary-layer ingestion vs. the partial boundary-layer ingestion entering the truncated forebody engines. Figure 13c shows the HXEM without the FFS configured like DFX for tests in the AHSTF or other small facilities such as the GASL Leg IV scramjet test facility. In all cases, however, the HXEM (shaded) remains unchanged for clear comparisons.

The HXEM/FFS in the full boundary-layer ingestion configuration is shown mounted in the 8-Ft. HTT in figure 14, and the flight engine/FFS mounted in the 8-Ft. HTT is shown in figure 15. Note that both are mounted on a common support pedestal and force measurement system; however, the FFS is configured differently for the different engines. The HXEM/FFS, shown in detail in figure 16, can be compared to the flight engine/FFS configuration previously discussed in figure 12. Because the HXEM is partial width, the three-dimensional nature of the aftbody flow cannot be duplicated, so the aftbody is simulated with a constant angle nozzle for simplicity. The HXEM is a partial width simulation of the center of the flight engine; so while the first part of the HXRV forebody, including the chines and boundary-layer trips, are duplicated in the HXEM/FFS, the HXEM uses flow fences for approximately half of the forebody length to minimize the three-dimensionality of the flow entering the inlet. The HXEM is mounted on a self contained axial force measurement system within the FFS to obtain a high fidelity measurement of internal flowpath axial force variations with fuel flow level and to allow a more direct force measurement comparison with tests of the HXEM in other facilities.

The HXRV engine control software, which controls the flight-like inlet cowl flap actuator and fuel system, will be used during the HXEM and FE/FFS tests to verify the engine control system. The major components of the engine control system to be verified in these tests are illustrated in figure 17. In flight, the engine control system must open and close the cowl flap to start and end the scramjet test, and must control the flowrates of gaseous hydrogen and engine ignitor gas (a mixture of hydrogen and silane) to the engine. The engine control must provide fuel flow rate control for engine ignition and fuel schedule while compensating for variations in the boost trajectory, so that the fuel flow to the engine will always be within an acceptable range. The engine control will also monitor internal engine flowpath pressures to avoid over fueling the engine, which could cause inlet unstart.

The HXEM tests will provide engine flowpath verification through a comparison of engine databases from different wind tunnels and by providing data on the effects of configurational differences between a partial width truncated flowpath and the full width/length flight engine flowpath. The flight engine/FFS tests will complete the engine flowpath and control systems verification. These tests will demonstrate: 1) inlet starting with the full-length/width vehicle with boundary-layer trips, wall roughness/temperature, and cowl actuation at simulated flight test conditions; 2) fuel control system operation; and 3) engine operation over the fuel sequence without unstarting the inlet. In addition, this test will provide the aerodynamic force and moment incremental data that results from the cowl inlet flap opening and closing and the fuel-on (powered) portion of the flight. The test will not provide overall vehicle force and moment data because the FFS span extends beyond the tunnel core flow, and because of the aerodynamic interference effects associated with the large mounting strut that is required to support the model in the tunnel and house the fuel, purge and instrumentation interfaces. However, because the propulsion flowpath is well within the high quality core flow of the tunnel, the test should provide good quality flowpath force increments. These data will aid in the benchmarking assessments of the computational predictions included in the aero-propulsion database. The preliminary test of the flight engine with a boiler-plate vehicle (FFS) allows rapid closure on the most critical issues without any risk (schedule or hardware) to the first flight.

<u>Wind Tunnel Tests of the Hyper-X Research Vehicle (HXRV)</u>

The Hyper-X Program plans to test the second flight vehicle in the 8-Ft. HTT prior to the flight of the first vehicle for an additional flight readiness demonstration of the integrated engine/vehicle system beyond the verification tests performed with the HXEM, flight engine and FFS. This flight readiness demonstration is composed of three components: 1) verification of the propulsion system; 2) limited structural integrity verification; and 3) verification of selected subsystems in the flight environment. The HXRV mounted in the 8-Ft. HTT is shown in figure 18. The propulsion system verification tests will be the same as those performed earlier with the flight engine/FFS, to check for unexpected effects of any differences between the flight engine/FFS configuration and the actual HXRV. Only limited structural verification will be performed since the test article will not encounter the entire heating history that the research vehicle experiences on the boost/flight trajectory to the test condition. The vehicle's carbon-carbon leading edge; actively-cooled cowl and sidewall leading edges; thermal protection system, coatings and seals; and the engine surfaces will see a portion of the high-enthalpy flow and will be checked for structural integrity following each run and following the entire test series. Subsystem verification includes demonstration that the HXRV subsystems employed in the 8-Ft. HTT tests are working in concert to minimize risk of subsystem interface problems during flight. Additional system validation and verification testing will be performed at DFRC without hydrogen fuel or the harsh hypersonic environment. Currently, subsystems that are planned for the 8-Ft. HTT test include: HXRV flight computer, cowl flap actuation system, water-cooling system, fuel and purge systems, and most vehicle and engine instrumentation.

Additional objectives for testing the HXRV in the 8-Ft. HTT are further characterization of the engine performance and operation at Mach 7 to provide data for ground-to-flight correlation and to develop expanded ground-test capabilities for fully integrated hypersonic vehicles with airbreathing propulsion systems. This test signifies the first time that a full-scale, scramjet-powered flight vehicle will be tested in a wind tunnel prior to flight. The tests provide flight test risk reduction and allow a comparison of wind tunnel test techniques and results with flight results. Flight data will provide validation of scramjet engine test techniques, facilities, and integrated engine/vehicle design methods.

Although it is beyond the scope of this paper, it is important to be mindful of the importance of analysis in the comparison of ground and flight data. Facility contaminants, flow distortion, and turbulence levels make a direct comparison of ground and flight results very difficult and perhaps misleading. The experimental wind tunnel data will be compared with predicted results for the actual wind tunnel conditions. The flight results will then be compared with predicted results for the flight environments, thereby preventing misinterpretation of the test results.

Summary

This paper discussed highlights of NASA's hypersonic technology program, Hyper-X, with a focus on the engine flowpath wind tunnel testing portion of the program. The Hyper-X Program is designed to elevate scramjet powered hypersonic technology readiness levels from the laboratory to the real flight environment, a necessary step before proceeding to prototype or other vehicle development. The wind tunnel part of the program is an integral part of the engine flowpath design, flight test risk reduction, and flight vehicle verification. The flight focus of the program provides a significant challenge to some wind tunnel test methodologies, as no airframe integrated scramjet-powered vehicle has flown. As a direct result, ground-based experimental wind tunnel methods, as well as integrated engine/vehicle design methods, are continuing to be improved to meet program objectives. The flight test will provide critical data required to validate design methods, including analytical, computational and experimental methods. Flight test plans call for the first Hyper-X research vehicle to fly at Mach 7 in early 2000.

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Engine/Facility	Dynamic Pressure (psf)	Test Gas Contaminants	Width	Forebody	Aftbody
DFX/AHSTF	500	NO	Partial	Truncated	Truncated
HXEM/AHSTF	500	NO	Partial	Truncated	Truncated
HXEM/FFS/ 8-Ft. HTT	600/1000	H_20, CO_2	Partial	Truncated (BL Diverted)	Truncated
HXEM/FFS/ 8-Ft. HTT	600/1000	H_20, CO_2	Partial	Full	Truncated
FE/FFS/ 8-Ft. HTT	600/1000	H_20, CO_2	Full	Full	Full
HXEM/GASL Leg IV	500/1000	H_20	Partial	Truncated	Truncated
HXRV/Flight	1000	None	Full	Full	Full

Table 1. Mach 7 Engine Test Matrix

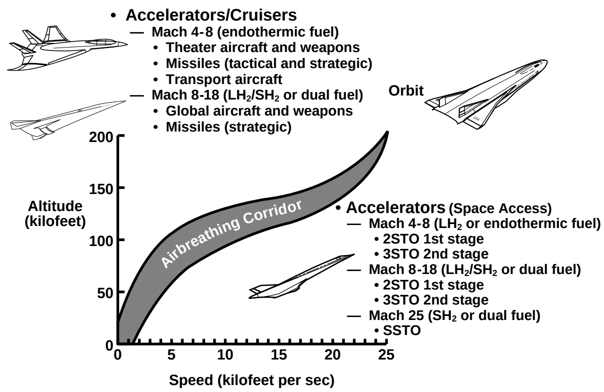

Figure 1. Potential hypersonic airbreathing vehicle applications.

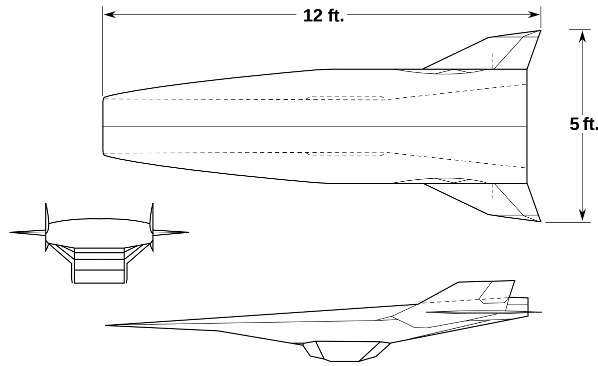

Figure 3. Hyper-X research vehicle configuration.

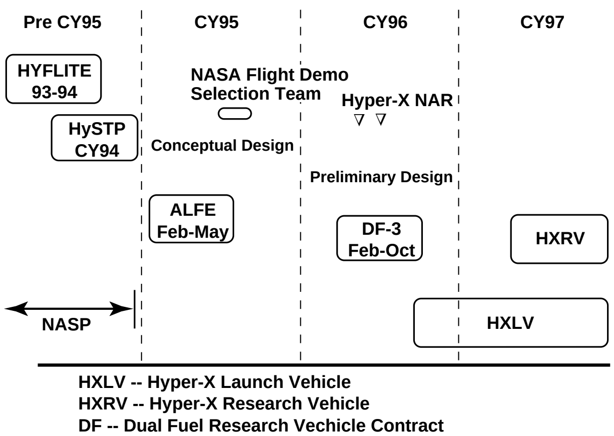

Figure 2. Recent hypersonic flight test design studies.

Figure 4. Illustration of Hyper-X launch vehicle mounted to B-52.

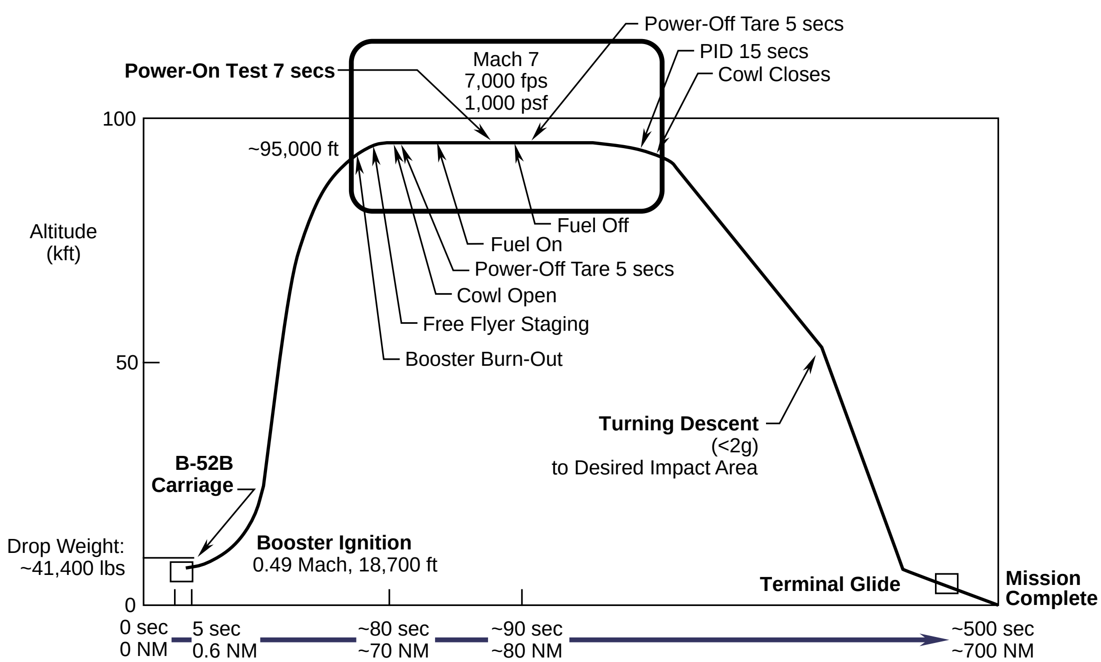

Figure 5. Nominal Hyper-X flight trajectory.

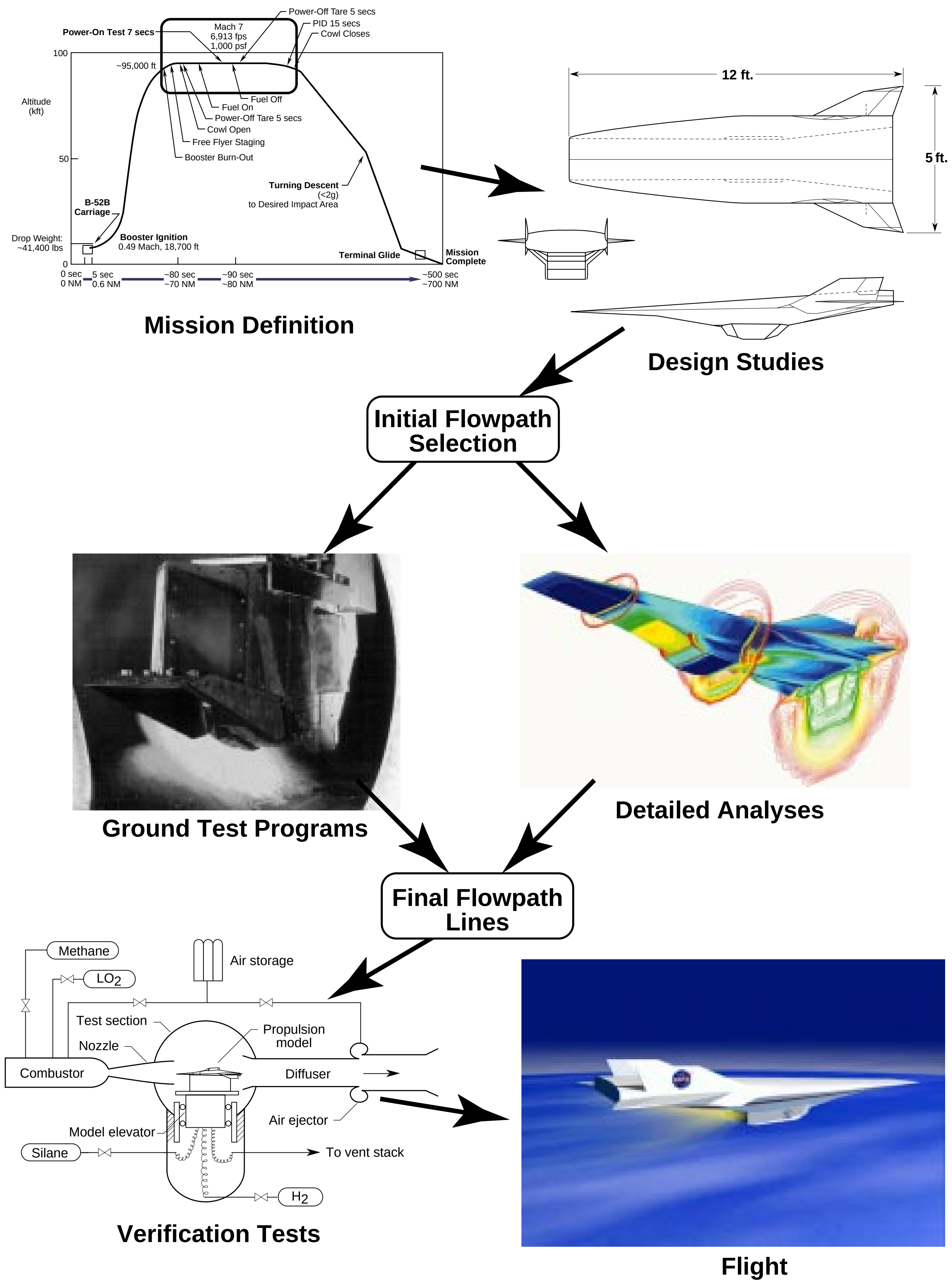

Figure 6. Integrated Hyper-X vehicle/engine development.

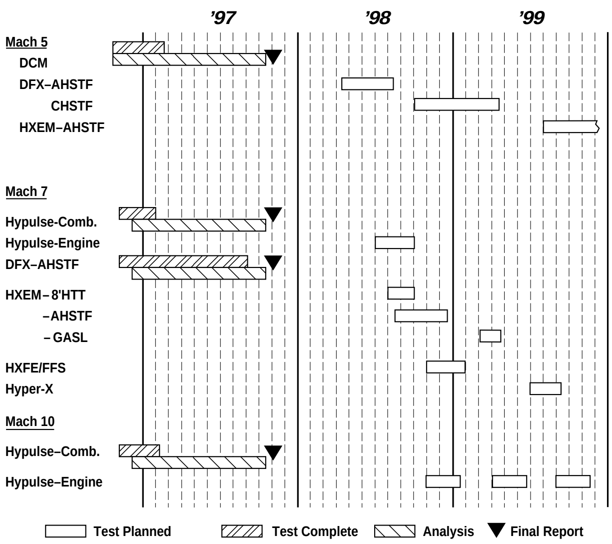

Figure 7. Engine test schedule.

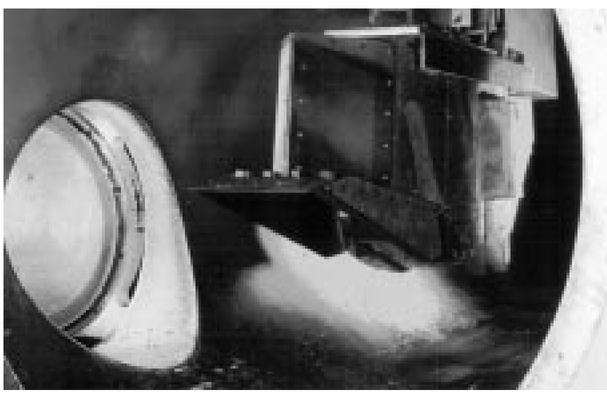

Figure 8. DFX engine test in AHSTF.

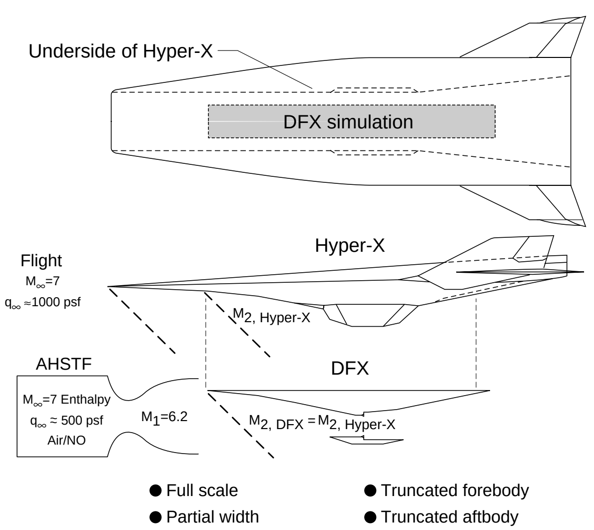

Figure 9. DFX simulation compared to Hyper-X.

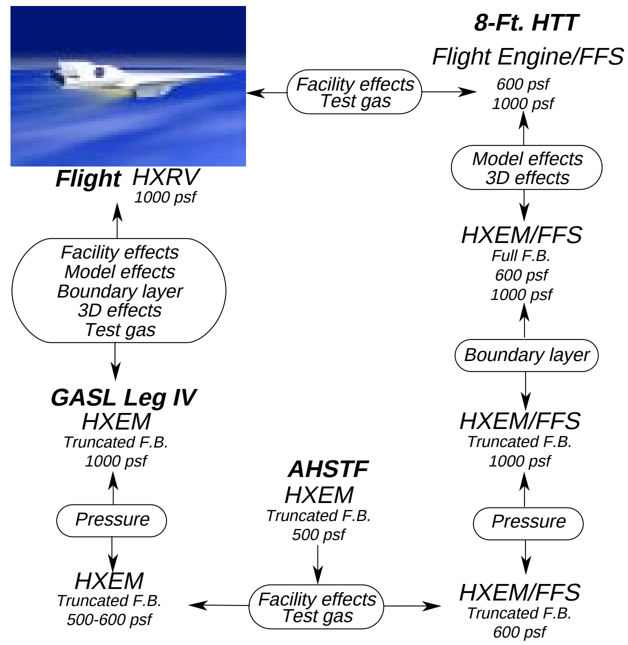

Figure 10. Mach 7 flowpath verification roadmap.

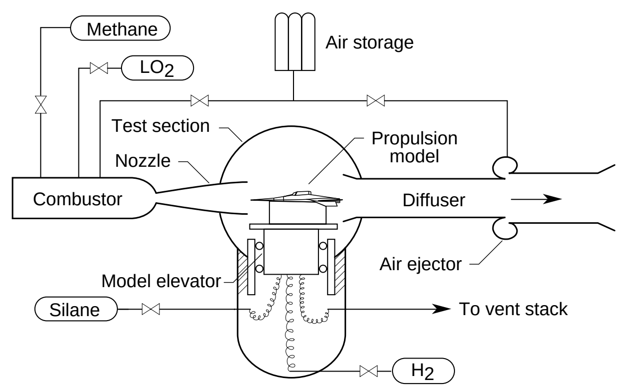

Figure 11. Schematic drawing of the 8-Ft. HTT for airbreathing propulsion testing.

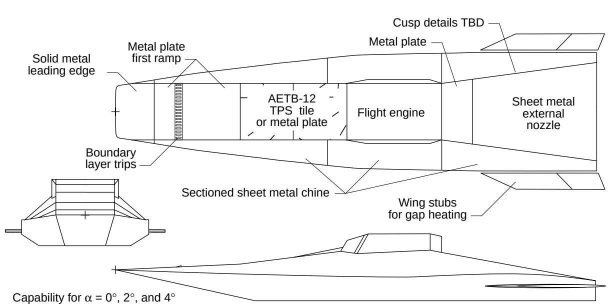

Figure 12. Hyper-X Flight Engine/FFS characteristics.

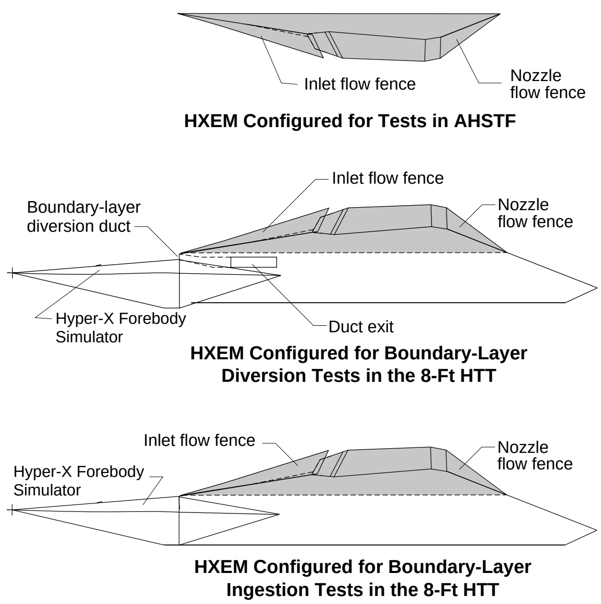

Figure 13. HXEM test configurations.

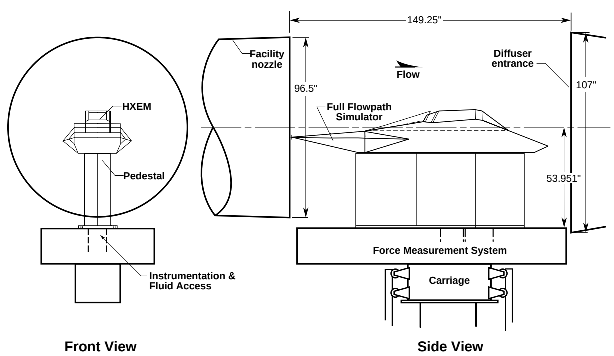

Figure 14. HXEM/FFS installed in the 8-Ft. HTT.

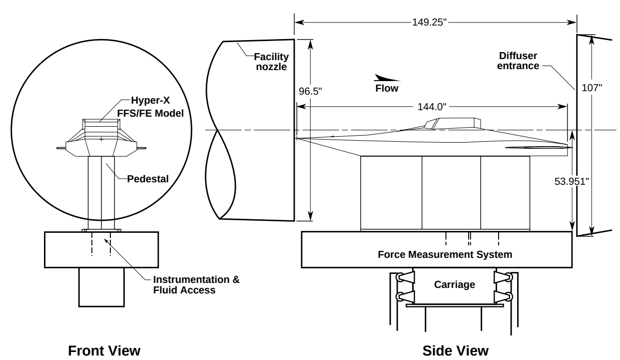

Figure 15. Flight Engine/FFS installed in the 8-Ft. HTT.

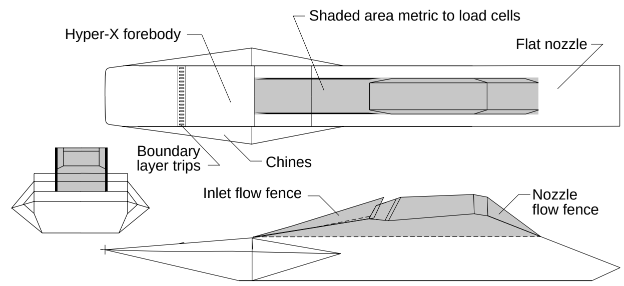

Figure 16. HXEM/FFS features.

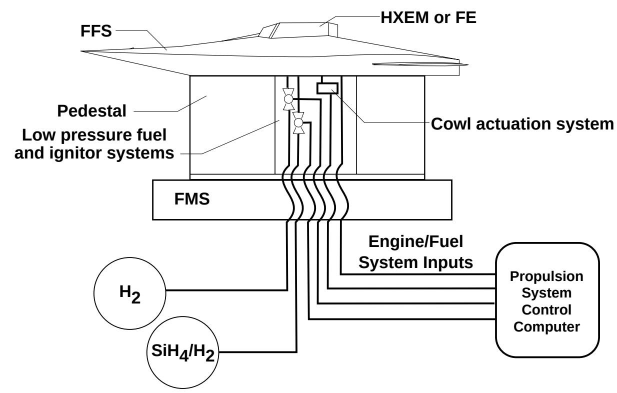

Figure 17. Engine control system features.

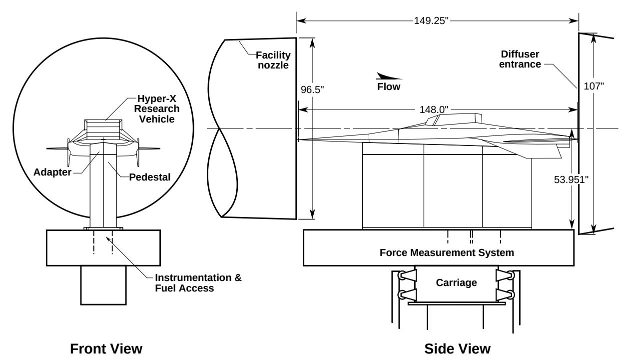

Figure 18. HXRV installed in the 8-Ft. HTT.