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ABSTRACT

The NASA Langley 8-Foot High Temperature Tunnel is a combustion-heated hypersonic blowdown-to-atmosphere wind tunnel that provides flight enthalpy simulation for Mach numbers of 4, 5, and 7 through an altitude range from 50,000 to 120,000 feet. The open-jet test section is 8-ft. in diameter and 12-ft. long. The test section will accommodate large air-breathing hypersonic propulsion systems as well as structural and thermal protection system components. Stable wind tunnel test conditions can be provided for 60 seconds. Additional test capabilities are provided by a radiant heater system used to simulate ascent or entry heating profiles. The test medium is the combustion products of air and methane that are burned in a pressurized combustion chamber. Oxygen is added to the test medium for air-breathing propulsion tests so that the test gas contains 21 percent molar oxygen. The facility was modified extensively in the late 1980's to provide airbreathing propulsion testing capability. In this paper, a brief history and general description of the facility are presented along with a discussion of the types of supported testing. Recently completed tests are discussed to explain the capabilities this facility provides and to demonstrate the experience of the staff.

NOMENCLATURE

8-Ft. HTT	NASA Langley 8-Foot High Temperature Tunnel
ESP	electronically scanned pressure
FMS	force measurement system
GH2	gaseous hydrogen
GN2	gaseous nitrogen
HXEM	Hyper-X engine model
HXFE	Hyper-X flight engine
LN2	liquid nitrogen
LOX	liquid oxygen
NASA	National Aeronautics and Space Administration
NASP	National Aero-Space Plane
PLC	progammable logic controller
PSI	Pressure Systems Incorporated
RDAS	research data acquisition system
TCN	transpiration-cooled nozzle
TPS	thermal protection system
TSB	NASA Langley Research Center Thermal Structures Branch

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INTRODUCTION

Construction of the 8-Foot High Temperature Tunnel (8-Ft. HTT) was initiated in March 1959 and completed in early 1964. Facility shakedown and checkout began in June 1964 and the first hot tunnel run was achieved in August 1965. Many tunnel flow surveys and blockage studies were conducted during the first several years of operation. Research tests were conducted for reentry configurations, hypersonic thermal structures, and fundamental hypersonic research benefiting activities such as the Scout program (1966), and the Hypersonic Research Engine Structural Assembly Model[1] (1971). However, full operation of all systems (including model injection system, model pitch system, and model radiant heating) over a wide range of conditions (600-2900 psi at 3000°F) was not demonstrated until November 1973. The facility was originally named the 8-Foot High Temperature Structures Tunnel because it was used to test structures and materials concepts designed to withstand hypersonic aerothermal environments. During the 1970's, the facility supported the Shuttle program (Shuttle Reusable Surface Insulation Tiles[2], Shuttle Infrared Leeside Temperature Sensing) and thermal protection system (TPS) development. Another effort supported by the facility was the X-24C program, a Mach 8 lifting body that would provide a testbed for scramjet engines and TPS materials. The 8-Ft. HTT was used to perform gap heating tests, and other studies, in support of the X-24C program. During the late 1970's and early 1980's the facility became more involved in defense programs such as the Strategic Defense Initiative. The 8-Ft. HTT was used to test radomes, nose cone configurations and materials for reentry vehicles and advanced missile warhead concepts. Throughout its history the 8-Ft. HTT has been used to conduct basic research on TPS materials and seals, gap heating, and shock interaction heating.

In the mid-1980's the National Aero-Space Plane (NASP) Program required the capability to perform large-scale scramjet engine testing. This led to the advocacy of modifications to the 8-Ft. HTT to support airbreathing propulsion system testing[3]. The modifications included a liquid oxygen (LOX) system, gaseous hydrogen system, and alternate Mach number capability. The LOX system was required to replenish oxygen in the test medium consumed by the air-methane combustion process in the facility combustor. The gaseous hydrogen system was needed to provide the test article fuel supply. The alternate Mach number capability was required to provide a wider range of test conditions allowing the evaluation of hypersonic engine performance throughout the engine flowpath transition range from subsonic to supersonic combustion (i.e. ramjet combustion to scramjet). Additional facility modifications were required to improve facility control and safety and led to upgrades to the facility controls, data acquisition system, high pressure air system, gaseous nitrogen purge system, model ignition system, and thrust measurement capability. A NASA Construction of Facilities project was approved to produce these modifications and construction was initiated in 1988. The project was augmented by modifications funded by the NASP program and other research-funded programs. The word "Structures" was dropped from the official facility name around the time this project was approved. Shakedown and checkout of the integrated systems began in 1990 and culminated in the first successful hydrogen-fueled test of the NASP Concept Demonstration Engine in June 1994.

Following the NASP program, testing was initiated in support of the X-33 Program which required unique test capabilities to perform flight qualification of the X-33 TPS. Hardware required to provide this test capability had been removed in the focused effort to provide airbreathing engine test capability for the NASP program. The radiant heating and model pitch systems were re-designed to allow rapid transition between engine performance and TPS performance testing. Testing of the X-33 TPS was performed at the 8-Ft. HTT in 1998 after completing these modifications.

FACILITY DESCRIPTION

Major Facility Components

The 8-Ft. HTT is shown schematically in Figure 1. The major components are described in the following section.

The combustor is the heart of the facility where air and methane (and LOX, if required) are combusted to create the required high pressure, high temperature conditions. The internal combustor components are shown in Figure 2 and a schematic of the combustor is shown in Figure 3. The combustor is a 24.3-ft. long pressure vessel with a working pressure of 6000 psi. The incoming air cools the liners and pressurizes the 36-in. I.D. combustion chamber. Methane is injected into the stream at a station 15-ft. from the nozzle throat. LOX is added to the air stream at a station 18.5-ft. from the nozzle throat. A baffle plate to promote uniform mixing of the air and LOX is located 17-ft. from the throat. A Helmholtz resonator is installed at a location 22.5-ft. from the throat to raise the acoustic resonance frequency and reduce fluctuations of pressure and temperature. Water-cooled thermocouple probes 37.5-in. upstream of the throat measure and control the combustor stagnation temperature.

The combustor flow supplies the convergent-divergent supersonic nozzle. The axisymmetric contoured nozzle was designed using a classical method-of-characteristics technique to provide a Mach 7 flow at the 96-in. diameter nozzle exit. The throat section is cooled by injection of air through the nozzle walls into the boundary layer with a technique known as transpiration cooling. This transpiration-cooled nozzle (TCN) starts at the beginning of the 36-in diameter convergent section (25.9-in. upstream of the throat) and continues to a station 59.0-in. downstream of the 5.620-in. diameter throat as shown in Figure 3. Air is injected normal to the wall through the porous nozzle surface into the boundary layer to keep the surface temperature below allowable values. The TCN was fabricated by Aerojet Incorporated using a platelet manufacturing technique. This nozzle is the largest transpiration-cooled hardware ever fabricated by Aerojet and provides an effective method of eliminating the need for nozzle wall cooling.

Alternate Mach number test capability is provided by utilizing a second settling chamber called a mixer. The mixer, depicted in Figure 4, is installed downstream of the TCN whenever Mach 4 or 5 test conditions are required. The 13.3-ft. long mixer has a rapidly divergent conical inlet section which expands the flow from the combustor to a 48-in. constant diameter section 80-in. long. Ambient temperature, high-pressure air is injected through several ports in the mixer to allow thorough mixing with the combustor flow. A nozzle is installed at the discharge end of the mixer to expand the mixer exit flow to provide the Mach 4 (27.203-in. throat diameter) or Mach 5 (16.302-in. throat diameter) contour. The Mach 4 and Mach 5 nozzle assemblies are two separate nozzles. Each nozzle assembly expands the flow to the same 96-in. nozzle exit diameter. From here, the flow enters the open-jet test section.

The test section is enclosed within a 26-ft. I.D. spherical chamber (see Figure 5). Windows are located on each side of the test section 13.75-ft from the nozzle centerline. The test section has a removable dome cover with a 14.5-ft. diameter opening for easy installation of models and large components. The spherical test section is intersected from the bottom by a vertical 16-ft. I.D. cylinder 17.7-ft. high. This cylindrical portion of the vacuum chamber is called the pod. The pod contains a model elevator system used to inject the model into the test stream once steady-state test conditions have been established. The model injection system allows the test article to be protected from startup and shutdown loads as it is out of the flow stream. Two different model support systems are available. For propulsion test models that weigh up to 40,000 lb. an external force measurement system (FMS) is installed on top of the model elevator and a fixed model support strut is installed between the FMS and the propulsion test article as shown in Figure 5. Figure 6 shows the arc sector pitch strut assembly installed on top of the model elevator provides ±20° angle of attack for testing of sting-mounted models weighing up to 10,000 lb. A radiant heating system is also installed in the test section. This heating system can be used to heat test articles prior to injection into the flow either to minimize model thermal shock or to simulate ascent or entry heating profiles.

After the flow traverses the test section it is collected 12.3-ft. downstream of the nozzle exit in the 103-in. diameter diffuser entrance. The diffuser is equipped with a high-pressure air ejector that is used to lower the test section pressure in order to establish supersonic flow. The diffuser and subsonic mixing tube is 174-ft. long and exhausts to atmosphere. The ejector is an annular nozzle that produces a nominal Mach 4 flow around the periphery of the diffuser tube. The ejector is 57-ft. from the diffuser entrance and operates at flow rates up to 1200 lbm/sec. For Mach 7 operation, the ejector maintains the pressure in the test chamber below 1 psia. The ejector is a key safety element of the facility because it minimizes unstart loads imposed on a test article, pumps unburned fuels out of the test chamber, and pumps air out of the test chamber providing a very effective fire prevention/suppression mechanism.

These components collectively allow the facility to provide the test conditions summarized in Table 1.

Mach Number	4	5	7
Stagnation Pressure (psia)	50 - 310	90 - 530	600 - 3500
Stagnation Temperature (°R)	1640	2350	2500-3650
Dynamic Pressure (psf)	525 -3100	350 - 2000	320 - 1900
Reynolds Number (10^6/ft)	0.9- 5.1	0.4–2.6	0.3 - 3.0
Altitude Simulation (K-ft)	47 - 85	65 - 100	80 - 120
Heating Rate (Btu/ft^2 - sec)	7.0 -17.0	10.5 - 25.3	20 - 48

Table 1. Facility operating conditions

Major Facility Systems

The 8-Ft. HTT support systems are shown in Figure 7. The major systems are described in the following section.

Dry high-pressure ambient temperature air is provided by Langley's centralized air dispatch station. A portion of this centralized air distribution system consists of a 6000 psig 39,000 cu. ft. air storage field that is a shared resource for Langley facilities. This system is connected to additional 6000 psig storage vessels at the 8-Ft. HTT by a 12-inch air supply line. The facility air storage field has a volume of 13,200 cu. ft. and is dedicated solely to the 8-Ft. HTT. The high pressure air is distributed from the 8-Ft. HTT storage field to the air ejector, combustor, TCN, and mixer. The facility can also use both it's dedicated storage field and the 39,000 cu. ft. centralized air storage for lower Mach number runs that consume more air. Each of the facility air systems uses hydraulically actuated valves to modulate the flow. The storage field also provides air to a 125-psig system used for pneumatic controls and to a 80-psig TCN purge air system. The TCN cooling air is filtered by a 3.5-micron filter to prevent clogging at the small TCN flow passages.

A commercial utility pipeline provides the facility with methane at approximately 15 psig. Two five-stage compressors are used to compress the methane for storage in vessels rated for 6000 psig with a combined volume of 2,400 cu. ft. These storage vessels provide the methane to the pilot, boost, and main injector. The main injector shown in Figure 8 is a stabilized lifted-flame design that consists of fourteen concentric tubes each having a circular cross-section and inside diameter ranging from 0.30-in to 0.47-in. Each tube has methane injection ports with diameters ranging from 0.04-in. to 0.06-in. These ports inject the methane in a stream-wise direction into the flow. There are 602 injection ports in the main injector with a total injection area of 1.26-sq. in. Each port is surrounded by a pattern of tabs that attach to the tube upstream of the port to create a vortical flowfield that enhances the stability of the flame. The pilot flame is used to ignite the main injector and consists of a small nozzle with a 2-in. diameter exit. Methane flow through the nozzle entrains air to provide a mixture that is ignited by an electrical-resistance heated wire. The pilot flame is produced at the centerline of the tunnel combustor. The boost fuel supply is provided through a 0.277-in. I.D. tube angled down across the pilot. The pilot flame together with the boost fuel produces a robust torch to establish combustion. This torch ignites the fuel from the main injector. Pilot and boost methane flow is terminated after main flame ignition is verified by combustor thermocouples. An optical flameout detection system is used to monitor the combustion process. Main methane flow is terminated and nitrogen purging is initiated if a flameout is detected.

A 25,200-gallon low-pressure cryogenic tank is used for bulk storage of LOX. Prior to each run, LOX is transferred from the storage tank to an 8,000-gallon high-pressure cryogenic run tank. The run tank is rated for 2400 psig and is typically filled to approximately three-fourths capacity prior to a run. During a tunnel run the LOX run tank is pressurized with gaseous nitrogen from the top to force the LOX into the injection ring in the combustor as shown schematically in Figure 9. The LOX injection ring injects the LOX through 240 ports (0.125-in. diameter) radially outwards and angled at 45° away from the combustor liner so that the incoming combustor air mixes thoroughly with the LOX.

Gaseous nitrogen (GN2) is used extensively at the facility to purge the piping systems of combustible fluids (e.g. methane, hydrogen, LOX, silane) before and after the tunnel run processes are completed. Two low-pressure cryogenic tanks (9,000 gal and 7,000 gal) are used for bulk liquid nitrogen (LN2) storage. The LN2 is compressed and passed through vaporizers to produce high pressure GN2 that is distributed to separate purge gas storage fields for each system.

The gaseous hydrogen (GH2) system is comprised of a manifold connected to 2400 psig compressed gas trailers. There are two hydrogen trailers and two helium trailers connected to this common manifold. The nitrogen trailer is connected to the facility GN2 supply and is used to provide purge capability. The helium is used to perform system leak detection tests prior to hydrogen testing. The manifold delivers the GH2 to the test section for use as a fuel for propulsion test articles. A flare stack is used to burn excess hydrogen during purge and venting operations. The hydrogen area is continually monitored by an ultraviolet detection system that will trigger the fire alarm system if a hydrogen leak develops.

A volumetric mixture of 20 percent gaseous silane and 80 percent hydrogen (which will be hereafter referred to as silane for simplicity) is used as the ignition system for hydrogen-fueled engines. Silane is a pyrophoric gas (ignites spontaneously in air at ambient temperatures). The silane is stored in a single trailer that has all-welded construction except for a single connection point between the trailer and the facility silane delivery system. This connection point is continuously monitored by an ultraviolet detection system that will trigger safety systems, including a water deluge system, if a leak develops. The silane system delivers the silane to the test section for use as an ignitor fuel for propulsion test articles.

The facility utilizes four separate hydraulic systems to activate facility components. Hydraulic system number one has six pumps, twenty-four accumulators, two 250 gpm flow control valves, two hydraulic motors, and a total system volume of approximately 1,200 gallons. This system provides hydraulic fluid to operate the model elevator system, the model pitch system, and the radiant heater positioning system. Hydraulic system number two activates the remaining control valves except for the air ejector valve. The third hydraulic system is dedicated to model specific needs. Hydraulic system number four is dedicated for the operation of the ejector control valve.

Cooling water is provided in several circuits. The combustor thermocouple probes are cooled by a 6000 psig water system pressurized by the high-pressure air system. Two water cooling circuits are utilized for model cooling. One provides 1000 psig water, while the other provides 500 psig water. A 100-psig water circuit provides cooling for facility compressors, radiant heater reflector panels, heat exchangers for hydraulic systems, and compressors. Cooling water at 80-psig is available from the standard utility supply.

Facility process controls are automated through the use of progammable logic controllers (PLC). The PLC's control the sequencing of facility operations and ensure that all events occur in a safe, repeatable manner. Spare PLC input and output capability is available so that instrumentation and control equipment on board the test article can be integrated into the facility operation and interlock strategy. This provides a means of protecting the test article by using it's on board instrumentation to signal the facility elevator system to withdraw the model from the flow stream if acceptable limits are exceeded. Analog controllers are utilized to control the facility combustor stagnation pressure and temperature. With a nominal stagnation pressure setpoint of 2000 psia, the combustor pressure can be controlled to within ±10 psi. The stagnation temperature is controlled to within ±100°R of a nominal 3400°R setpoint. The oxygen concentration in the test stream is fixed at a mole fraction level of 0.21 by controlling the LOX-to-fuel ratio delivered to the combustor and is controlled to within ±0.01. Detailed flow surveys were conducted in the facility for airbreathing propulsion testing in 1996[4].

Data Acquisition Sytem

The 8-Ft. HTT Research Data Acquisition System (RDAS) consists of a NEFF 600 system with its associated equipment, a Pressure Systems Incorporated (PSI) Electronically Scanned Pressure (ESP) system, and a NEFF 490 system. The NEFF 600 system acquires data from 512 analog channels with input voltage ranges from ±5 millivolts to ±10.24 volts. It outputs a 16-bit data word with a system accuracy of ±0.02% of full scale and has an aggregate data throughput of 100,000 samples per second. The typical scan rate is 50 frames per second. Actual maximum scan rates depend on the number of channels required. The NEFF 600 has programmable filter frequencies of 1 Hz, 10 Hz, 100 Hz, and 1000 Hz per channel. Uniform temperature reference devices provide thermocouple routing and compensation. The NEFF 300 signal conditioners provide excitation supply, bridge completion, and resistance calibration for wire strain gage based transducers. These signal conditioners support 256 channels from various locations throughout the facility.

The PSI 8400 system acquires data from 1024 ESP channels. The typical acquisition rate is 10 Hz. Actual frame rates depend on the number of channels required. This system can currently support ESP modules ranging from 1 PSIA to 750 PSIA.

The NEFF 490 system can accommodate up to 31 channels of high-speed data. Each channel card contains a 1 MHz analog-to-digital converter, 2 MWords of RAM, and 4 plug-in low-pass filter modules. Available filter ranges are 1 KHz, 5 KHz, 6 KHz, 10 KHz, 50 KHz, and 200 KHz. The maximum sample rate is 1 million samples per second per channel for 2 seconds. The host personal computer downloads data stored in the NEFF 490 internal channel memory after each tunnel run. Data transportability to third-party data processing programs is available.

The NEFF 600 and PSI 8400 systems interface to a Pentium PC. The RDAS computer runs commercial-off-the-shelf data acquisition and control software. This software performs device interfacing and calibration, data acquisition, near real-time display, data conversion, and data transfer. The NEFF 600 and PSI 8400 engineering unit data are transferred from the RDAS computer to a Digital AlphaServer 2000 for posttest data processing and display. The AlphaServer 2000 runs custom data processing software under the Digital OpenVMS operating system. The ATLAS software performs transducer excitation compensation, ESP reference correction, wind-off corrections, and data referencing, and specialized data calculations. This software produces monochrome or color graphs and tabular listings according to a predefined setup after each tunnel run. An interactive data processing interface is also available. Generic ASCII data files provide transportability to third-party data processing software. Data file transfers and archival is accomplished through TCP/IP (FTP), 8mm tape, and 4mm tape.

All 8-Ft. HTT systems using a microprocessor have been evaluated, tested, and certified for Y2K compatibility of hardware and software. This study primarily involved all of the facility controls, data acquisition/reduction systems, and desktop workstations used by the operations staff.

Both sides of the test section have extensive optical access that can be used for Schlieren or standard video and photography at normal or high-speed rates. Infrared imaging and additional video cameras for observation are available inside the test section.

TEST CAPABILITIES

Structures and Materials

Thermal protection system and aerothermal loads definition testing can be conducted by installing a model into a panel holder supplied by the facility. A sting attaches this panel holder to the curved strut pitch system mounted on top of the model elevator as shown in Figure 10. The test article can be exposed to the desired heating profile with a one-megawatt radiant heater system to simulate complete ascent or entry heating profiles prior to and immediately following insertion into the desired wind tunnel test condition.

The radiant heater and model pitch system controls were upgraded in 1997 prior to testing several TPS configurations in support of the X-33 program.

The panel holder, shown in Figure 11, is approximately 4.6-ft. wide by 9.3-ft. long. The opening for test panel installation is 3.5-ft. wide by 5-ft. long. The remaining panel holder area is covered with ceramic tiles to fill out the surface to a uniform height and to protect the structure from heating. A boundary layer trip mechanism is provided with the panel holder to ensure fully turbulent flow across the test panel. The panel holder also has sidewall fences to better simulate a two-dimensional flowfield. Approximately 10-in. of space is provided below the test article for instrumentation installation. The panel holder angle-of-attack can be changed to vary the heating rate. The curved strut provides a ±20° angle-of-attack range, but the panel holder angle-of-attack must be limited to 0° to −15° to avoid flow blockage problems.

The radiant heater system is constructed of two horizontally moving carriages that inject from both sides of the test section to meet above the test panel when it is retracted below the test stream as shown in Figure 12. Both Figures 12 and 13 are cross-sectional views of the test chamber looking from the nozzle towards the diffuser. Each heater carriage has an array of twelve water-cooled gold-plated lamp reflectors. Each of the twenty-four reflector panels are 12-in. by 10-in. and have sixteen 10-in. long 2000 watt quartz lamps. The lamps are located 12-in. above the panel holder surface. The total area covered by the lamp bank array is 4-ft. wide by 7-ft. long. Power is distributed to the lamps through an 800 amp SCR. The lamps are controlled from thermocouples installed at the test panel surface and can heat the model surface up to about 2000° F and provide a maximum rate of temperature rise of 25° F/sec. The lamp array can be controlled by up to six separate control zones to provide a uniform temperature distribution within ±50° F across the test panel. These zones can be wired in multiple configurations to meet test-specific needs based on model design or customer requirements.

A typical test using these systems would begin with the radiant heater system being controlled to provide the desired surface temperature-time history. Aerodynamic loads are desired at a pre-defined point on the temperature profile. The tunnel is started while the radiant heaters continue to maintain the desired temperature after steady-state test conditions are achieved. The radiant heaters are de-energized and retracted, the panel holder is injected into the test stream, and the model pitch is set to 5° while the elevator is rising to reduce blockage effects as the model is injected through the nozzle boundary layer. The model is positioned to the desired angle-of-attack after it reaches the nozzle centerline as shown in Figure 13. The entire process takes about 10 seconds starting from the time the heaters are de-energized until the model is at the desired test orientation. The model is exposed to the desired test conditions for up to 60 seconds and is retracted prior to tunnel shutdown. The radiant heaters can provide a post-run heating cycle if desired to control the cool down process or to continue the desired heating cycle.

Airbreathing Propulsion

Testing of hypersonic airbreathing propulsion system concepts is performed with the propulsion test article attached to a model support pedestal mounted on top of an external force measurement balance as seen in Figure 5. The force balance is a three-component system with the capability to measure normal force (±20,000 lbf), axial force (±7,400 lbf), and pitching moment (±612,000 in-lb).

The facility can provide two different propellant fuel delivery systems for the test article. A gaseous hydrogen system has been used for three different engine tests. A silane system has also been used as the ignition source for the same engine tests. A liquid hydrocarbon delivery system has been designed and fabricated but has not been tested. Both systems provide ambient temperature fuels and have automated control systems to provide pre-programmed fuel and ignition sequences. Gaseous nitrogen purge systems are integrated with both fuel systems.

Airbreathing propulsion system research is the most complex type of test performed in the 8-Ft. HTT. The test mode involves more facility systems than any other type of test. The models typically have more instrumentation, separate control systems integrated with the facility control systems, moving components actuated by electrical or hydraulic means, cooling systems with many circuits, require purging of fuel lines and internal model cavities, and require instrumentation cooling. Many of these additional requirements are to ensure safe facility operations and model health. Therefore, most of these processes are interlocked or closely monitored which requires extensive, planning, review, and checkout prior to testing.

The facility staff is currently conducting the third test of an airbreathing hydrogen-fueled scramjet engine. The facility performed 41 successful tests of approximately 20-second duration each on the NASP Concept Demonstration Engine from June 1994 to December 1995[5]. Support of the Hyper-X Program began with a partial width engine called the Hyper-X Engine Model (HXEM). The HXEM test ran from February through June 1999[6]. This test included optimization of facility control performance at new test conditions, calibration of the facility freestream characteristics at the desired test conditions (to match flight and a smaller scale facility), thorough calibration of engine inlet flow characteristics, and eleven successful engine performance tests. The third engine test is the Hyper-X Flight Engine (HXFE) which began in August 1999[7]. The HXFE test article consists of a spare flight engine mounted on an airframe that duplicates the geometry and scale of the flight vehicle windward surface. The forebody TPS material, forebody boundary layer transition trip mechanism, low pressure fuel supply (piping, controls, and instrumentation) are also being verified for flight with this test.

System Concept Performance Validation

Other testing has been performed by using sting-mounted test articles. The sting is installed in the curved strut that provides ±20° angle of attack capability. Instrumentation, cooling water, and test-specific gases or fluids can be supplied to meet customer requirements. A recent example of this type of test is an 8.5-ft. long 13-in. diameter missile forebody tested at up to +35° angle-of-attack using an offset sting as shown previously in Figure 6. The missile was tested to ensure adequate cooling was provided to protect the dome that covered it's navigational guidance optics. A gas injection system had been designed to move the shock away from the dome and reduce the heating. The testing of the flight prototype hardware performed at the 8-Ft. HTT was required to develop the algorithm to govern the location and mass flow rates of the gas injection as a function of missile pitch and yaw. This model required high-pressure gaseous argon that was supplied by the facility. The new Mach 5 capability of the facility was used to support this missile test during 1997.

OPERATIONS

NASA Langley Research Center successfully completed the ISO-9001 registration process in August 1999. The 8-Ft. HTT was involved in several activities used to train internal auditors and was also one of the facilities reviewed during the final registration audit. All processes used to manage and operate the 8-Ft. HTT are certified to be compliant with ISO 9001, 1994.

An experienced staff is assigned to the dedicated operation of this unique facility. The staff consists of the following: facility manager, facility safety head, test director, systems engineer, controls engineer, engineering technician supervisor, seven mechanical technicians, three electrical technicians, four consumable operations technicians, two data acquisition specialists, two configuration management specialists, and a computer system administrator. The majority of this group of people has been at this facility through all of the recent upgrades and testing. The facility staff participated extensively in the planning, implementation, and checkout of all the recent modifications so they are extremely adept at troubleshooting and correcting problems. The staff has prepared for and conducted, all of the types of testing the facility supports, and has a detailed working knowledge of the numerous complex systems that make up the 8-Ft. HTT as well as a thorough understanding of the integrated operation of all of these systems.

In addition to the 8-Ft. HTT operations staff, Langley Research Center has two organizations that provide analytical and experimental skills to support research in this facility. These organizations can support testing in the 8-Ft. HTT at varying levels ranging from supporting all phases of a wind tunnel test (e.g. test planning, model design/fabrication, model instrumentation, conducting test, data analysis, disseminating results) to providing experienced engineering consulting advice to assist in these test phases. The Thermal Structures Branch (TSB) has utilized the 8-Ft. HTT test capabilities throughout the facility's history. This organization develops efficient structural concepts for future high-speed aircraft and space transportation systems that exploit the benefits of advanced composite and metallic materials. Most recently, the TSB supported testing of the windward and leeward TPS configurations for the X-33 program. The Hypersonic Airbreathing Propulsion Branch has an experienced staff of researchers who design and test hypersonic airbreathing engines. Personnel from this organization have performed scramjet research in the 8-Ft. HTT and other facilities and are currently conducting research on the Hyper-X Flight Engine/Vehicle Flowpath Simulator in the 8-Ft. HTT.

The 8-Ft. HTT typically operates one shift per day (7:00 am – 3:30 pm) on Monday through Friday. A typical test day begins with the staff performing pre-run preparations. The most complex (and procedurally lengthy) type of setup is for a propulsion test, which will be described here. After pre-run preparations are completed, a test readiness review is held to ensure all systems are ready. When all facility, data acquisition, and model systems are ready, the run is started, ($t = 0$ sec) initiating the tunnel sequence timeline depicted in Figure 14. Between 50 and 100 seconds into the run, the engine pre-run fuel system purge with gaseous nitrogen is complete. At about 55 seconds, air flow is initiated in both the combustor and the TCN. With the combustor pressure at 240 psi, a 1200 psig methane pilot fuel light off is activated. When this is achieved, boost methane is delivered at 2700 psig through the pilot flame. Once a combustor temperature of 750°R is reached, the combustion pressure is ramped up to about 600 psig, at which point the air ejector is started and ramped up to establish a vacuum on the tunnel. The test section pressure drops below 1 psia at about 100 seconds into the run. Then, the main-flame methane burner is lit at about 108 seconds and the pilot and boost fuel sequences are terminated. At 111 seconds, the liquid oxygen injection sequence begins. Combustor pressure and temperature are then automatically controlled to the desired test condition. After steady-state conditions are established, the model is injected and the model control and engine fuel sequences are initiated. After the sequences have been completed, main flame fueling is terminated, ejector pressure is increased, and the engine and tunnel purge sequences begin. After the engine purging is complete, the model is retracted out of the flow to protect it from tunnel shutdown loads, the ejector pressure is decreased and the tunnel nozzle flow unstarts. All systems are then returned to their baseline state.

The facility is secured after the run so the test section can be entered by 11:00 AM. Engineering unit data is ready within 15 minutes after the run. The data is analyzed that afternoon and a list is generated of items that must be repaired prior to making another run. The day after a run is typically used to make the required corrective actions. A data review meeting is scheduled before making another run for the operations staff and research customers to discuss the previous run and grant approval for continuing the test. The cycle can then be started again. A goal of two successful tunnel runs per week is used for planning purposes for propulsion testing. One tunnel run each day is possible if a simpler model is being tested.

PLANNED MODIFICATIONS AND UPGRADES

Seventy five percent of the facility high-pressure air storage was removed from service due to safety concerns in 1998. Only Mach 7 testing can be supported in this configuration. A project has been initiated that will replace the lost air storage capacity and reduce the air system hydraulic resistance. This project is scheduled to be completed by February 2001. Mach 4 and Mach 5 testing will be able to conducted after this project is finished.

Combustor flow uniformity will be improved by installing a newly designed methane injector and ignition system. The methane injector will also be located downstream about 2-ft. from the current location to improve acoustics. The piping upstream of the methane injector will be streamlined to improve the uniformity of the incoming air flow. The goal of these modifications, shown in Figure 15, is to improve test section flow uniformity over a wider range of operating conditions.

Other facility improvements include the addition of a liquid hydrocarbon fuel system and improvements to the flow calibration measurement capability. The hydrocarbon fuel system has been designed and fabricated, but the test that required it has been postponed. This system will be checked out and tested as soon as the opportunity arises. The facility flow calibration capabilities will be upgraded to provide improved positioning accuracy and repeatability and a new gas chromatography-mass spectrometry system is being installed to provide improved test media analysis across the test core. Additionally, the flow survey rake is being modified to increase measurement density to provide more detailed measurements of the test core.

SUMMARY AND CONCLUSIONS

The 8-Ft. HTT is a unique national asset as stated in the 1995 National Facility Study and by the Aeronautics and Astronautics Coordinating Board in 1996. The facility provides the only national test capability for large-scale component testing at flight enthalpy for air-breathing propulsion, structures and materials, and system concept performance validation. The Mach number range (4,5,7) provided by the 8-Ft. HTT is critical for understanding transition from ramjet to scramjet combustion for many air-breathing engine concepts. The capabilities described are all the result of recent efforts and experience. The existing infrastructure and staff have demonstrated the ability of this facility to support hypersonic testing. The facility staff is dedicated to the management and operation of this facility. Other Langley organizations can support tests at levels varying from total support (model conceptual design through final data analysis) to providing an advisory role as experienced consultant. The facility provides unequaled capabilities to the hypersonic community.

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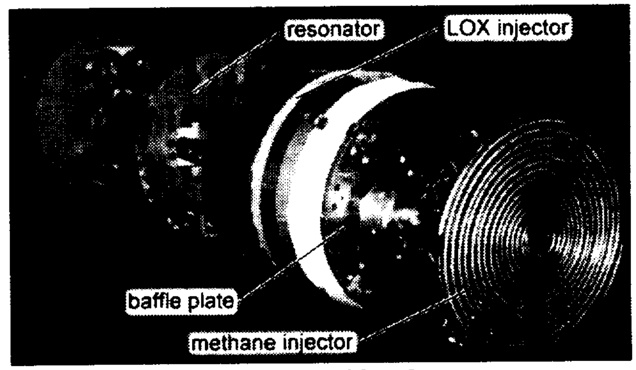

Figure 2. Combustor internal hardware

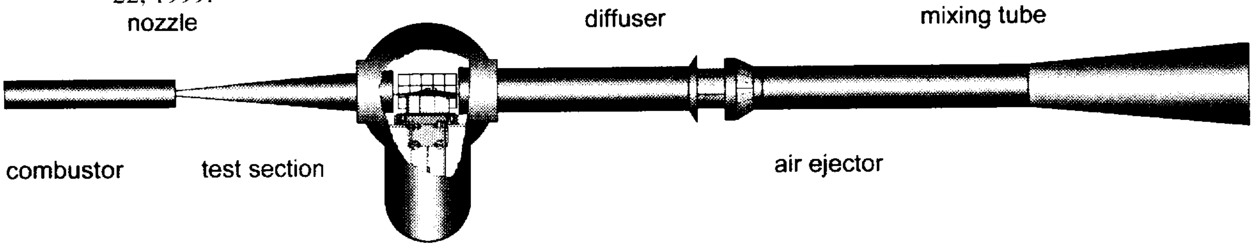

Figure 1. Facility schematic

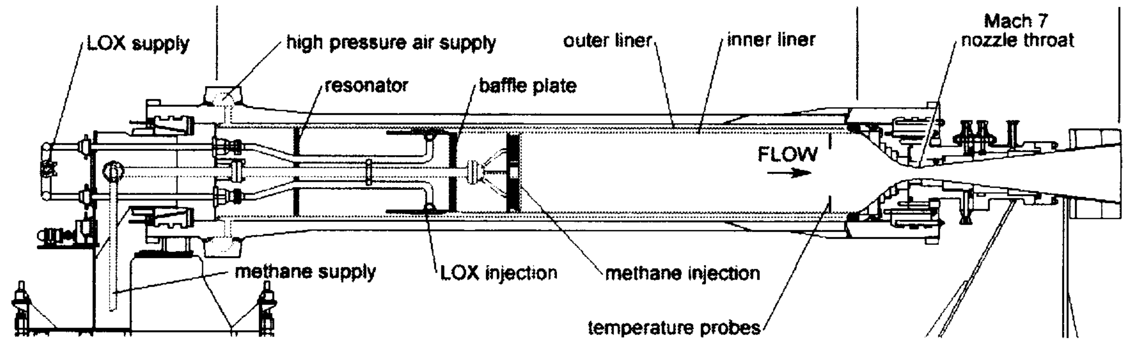

Figure 3. Facility combustor schematic

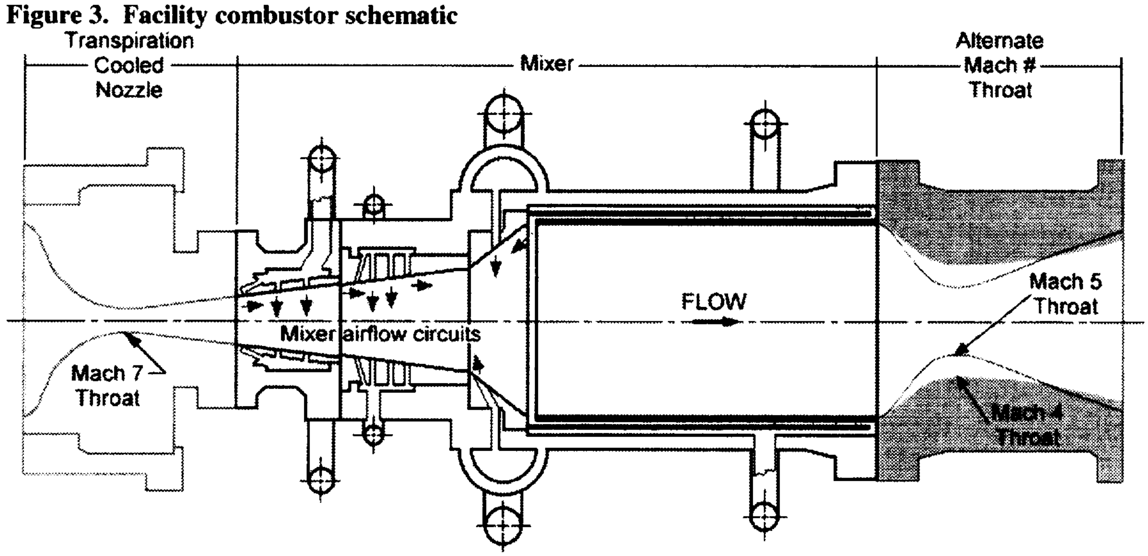

Figure 4. Facility mixer schematic

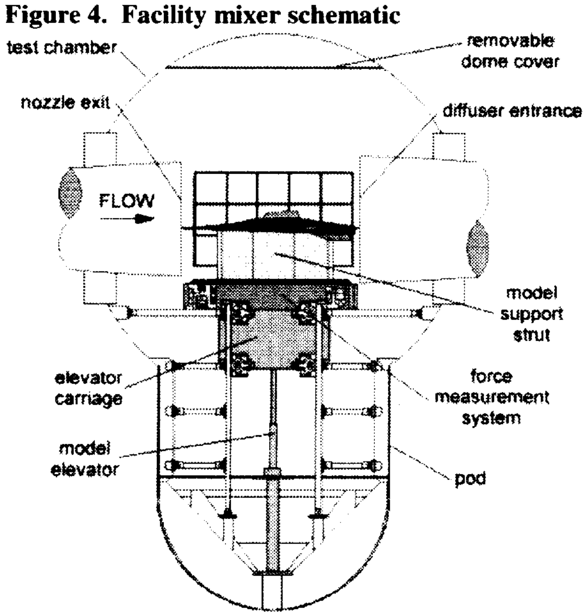

Figure 5. Test section

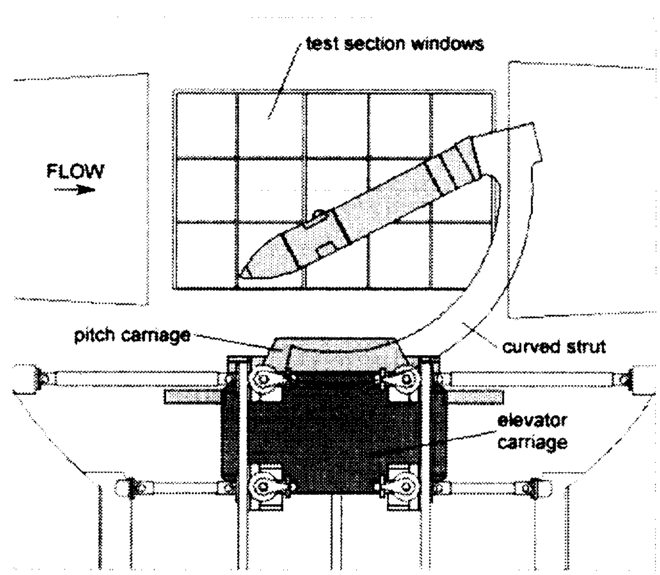

Figure 6. Curved strut model pitch system

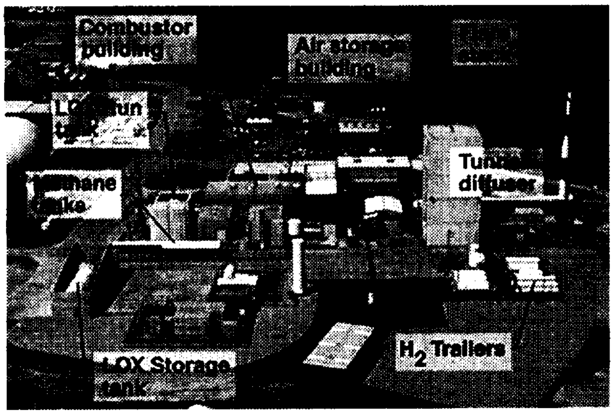

Figure 7. Facility systems

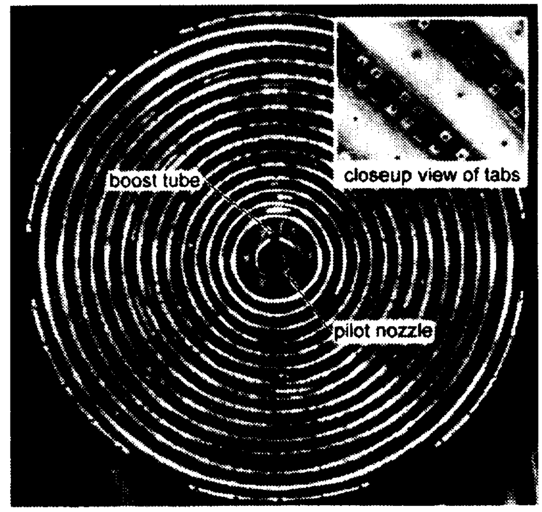

Figure 8. Methane injector

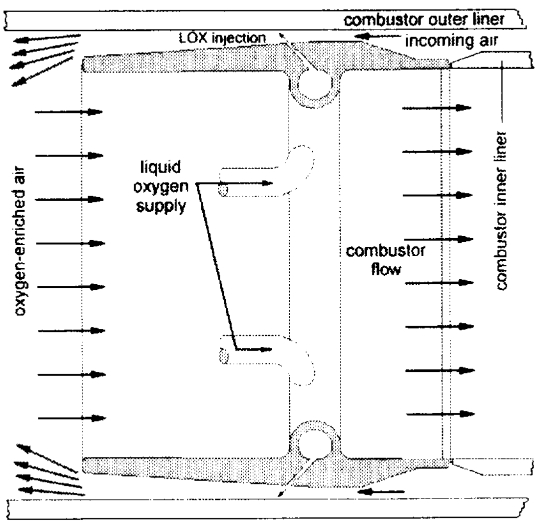

Figure 9. Cross-section view of LOX injector

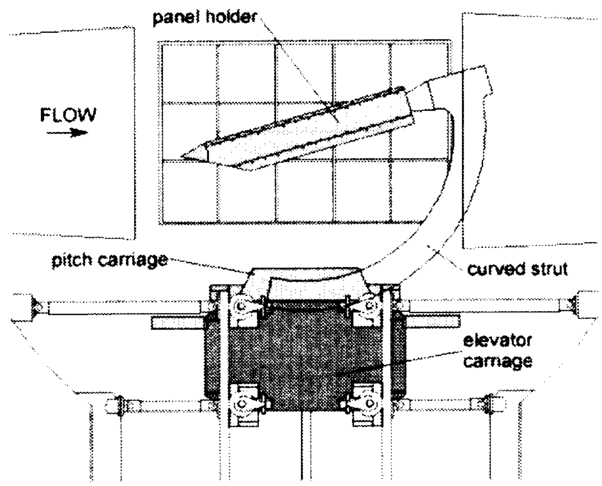

Figure 10. Curved strut with panel holder installed

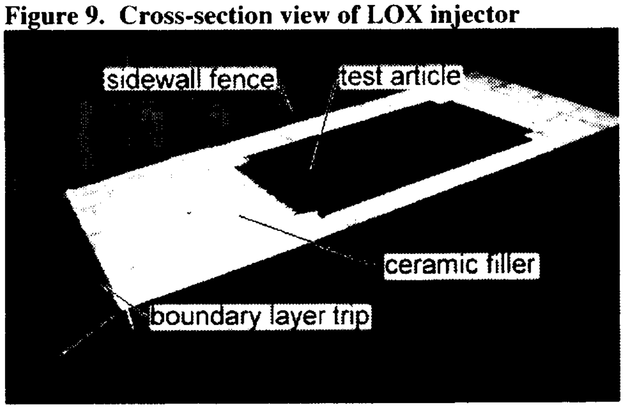

Figure 11. Facility panel holder

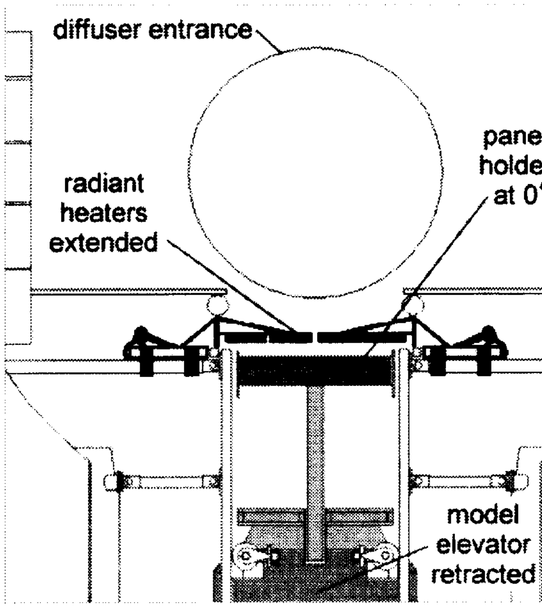

Figure 12. Radiant heaters extended

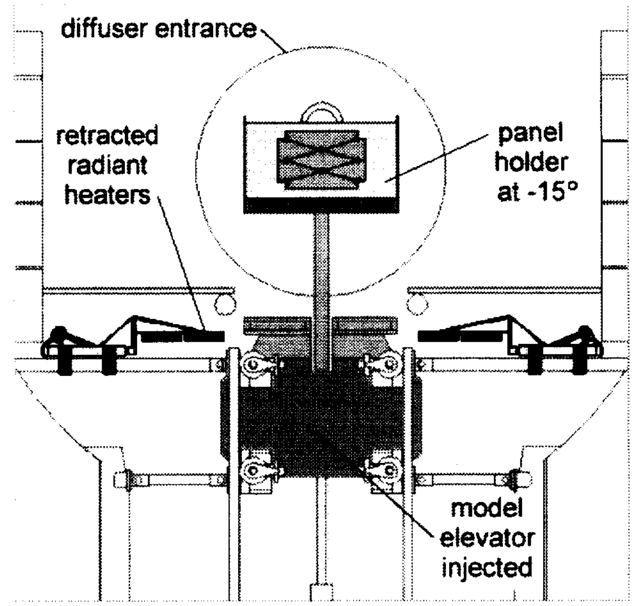

Figure 13. Radiant heaters retracted

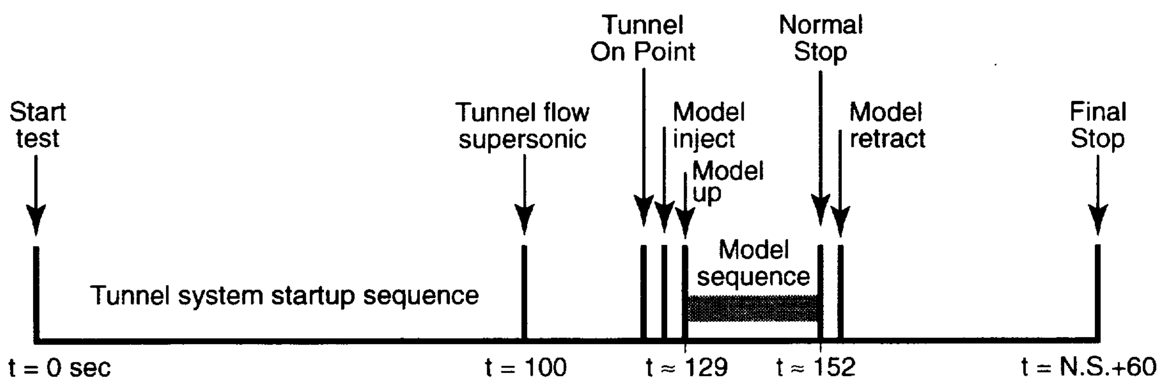

Figure 14. Tunnel run sequence timeline

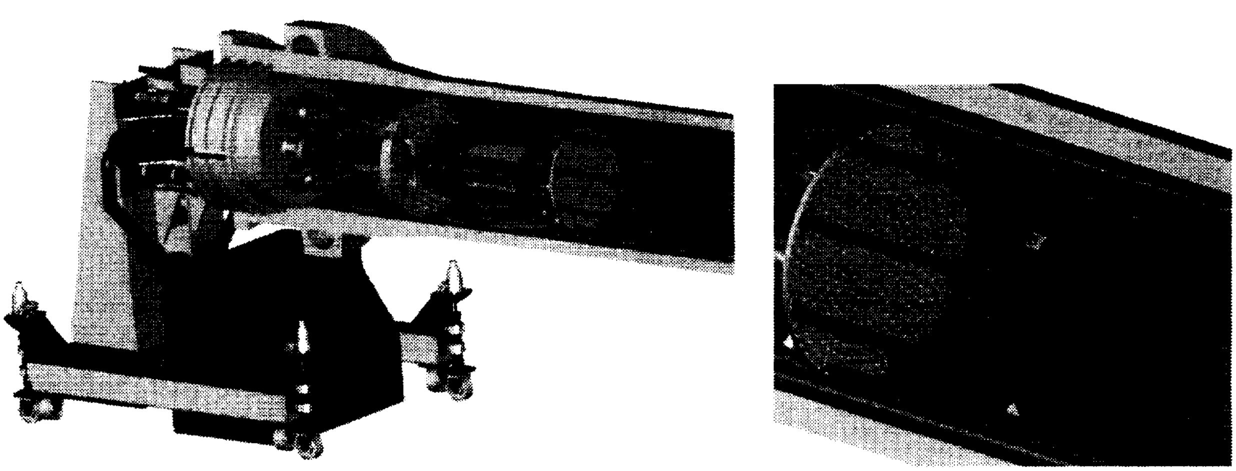
Figure 15. Engineering model for concept of modifications to internal combustor components