TEST CAPABILITY ENHANCEMENTS TO THE NASA LANGLEY 8-FOOT HIGH TEMPERATURE TUNNEL

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ABSTRACT

The NASA Langley 8-Foot High Temperature Tunnel produces true enthalpy environments simulating flight from Mach 4 to Mach 7, primarily for airbreathing propulsion and aerothermal/thermo-structural testing. Flow conditions are achieved through a methane-air heater and nozzles producing aerodynamic Mach numbers of 4, 5 or 7 and have exit diameters of 8 feet or 4.5 feet. The 12-ft long free-jet test section, housed inside a 26-ft vacuum sphere, accommodates large test articles. Recently, the facility underwent significant upgrades to support hydrocarbon fueled scramjet engine testing and to expand flight simulation capability. The upgrades were required to meet engine system development and flight clearance verification requirements originally defined by the joint NASA-Air Force X-43C Hypersonic Flight Demonstrator Project and now the Air Force X-51A Program. Enhancements to the 8-Ft. HTT were made in four areas: 1) hydrocarbon fuel delivery; 2) flight simulation capability; 3) controls and communication; and 4) data acquisition/processing. The upgrades include the addition of systems to supply ethylene and liquid JP-7 to test articles; a Mach 5 nozzle with dynamic pressure simulation capability up to 3200 psf, the addition of a real-time model angle-of-attack system; a new programmable logic controller sub-system to improve process controls and communication with model controls; the addition of MIL-STD-1553B and high speed data acquisition systems and a classified data processing environment. These additions represent a significant increase to the already unique test capability and flexibility of the facility, and complement the existing array of test support hardware such as a model injection system, radiant heaters, six-component force measurement system, and optical flow field visualization hardware. The new systems support complex test programs that require sophisticated test sequences and precise management of process fluids. Furthermore, the new systems, such as the real-time angle of attack system and the new programmable logic controller enhance the test efficiency of the facility. The motivation for the upgrades and the expanded capabilities is described here.

INTRODUCTION

The NASA Langley 8-Foot High Temperature Tunnel (8-Ft. HTT) is a combustion-heated hypersonic blowdown-to-atmosphere wind tunnel that provides flight simulation over a Mach number range from 4 to 7 and an altitude range from 50,000 to 120,000 feet. The facility is used for both air-breathing propulsion testing and aero-thermal/thermo-structural testing. A brief history and general description of the facility is provided in reference 1. The free-jet test section is in a 26-ft diameter vacuum chamber and accommodates large propulsion systems as well as structural and thermal protection system components. The free-jet diameter is either 8-ft or 4.5-ft (depending on the nozzle used) and is 12 feet long from the nozzle exit to the 8-ft diameter diffuser entrance. In addition to its large size, the test section features a model inject / retract mechanism, a radiant heater system to simulate ascent or entry heating profiles, a six-component model force measurement system, optical flow visualization and the capability to deliver multiple pressurized fluids (fuels, coolants, hydraulics) to the model. Stable tunnel flow properties can be provided for 60 seconds, or longer, depending upon the required test condition. The test medium consists of the combustion products of air and methane that are burned in a pressurized combustion chamber to produce a test gas duplicating flight total enthalpy. For air-breathing propulsion tests, a liquid oxygen injection system is utilized for oxygen replenishment. Figures 1 through 4 show photos of propulsion models tested for various hypersonic programs from 1995 through 2006 [2-7].

Figure 1. NASP CDE Model

Figure 2. Hyper-X Engine Model

Figure 3. HyFly DCR Model

Figure 4. X-43C GDE-2 Model

Beginning in 2002, the facility was enhanced to support liquid hydrocarbon fuel-cooled flight-weight scramjet engine testing. A majority of the upgrades were necessary to meet engine system development and flight clearance verification requirements originally defined by the joint NASA-Air Force X-43C Hypersonic Flight Demonstrator Project and later by the Air Force X-51A Program. Enhancements to the 8-Ft. HTT capabilities were made in four areas: 1) fluid systems to deliver hydrocarbon fuel to the test articles; 2) flight simulation capability; 3) facility controls and communication with model systems and 4) data acquisition/processing. Fluid system upgrades include the addition of a gaseous ethylene delivery system and liquid JP-7 storage, delivery, and return systems. Flight simulation upgrades include the installation and calibration of a new Mach 5 nozzle capable of simulating dynamic pressures up to 3200 psf, and a real-time variable model angle of attack system. Facility controls upgrades include a new programmable logic controller (PLC) to improve process control and coordination between facility-controlled and model-controlled events, an interlock system for protecting model hardware, and a Shared Common Random Access Memory Network (SCRAMNet) system for communication between the facility controls and model controls. Additions to data acquisition and processing capabilities include a MIL-STD-1553B capable data acquisition and display system, a 64 channel, 200 kHz high speed data acquisition system and a secure data processing room for customer analysis of classified data.

FACILITY OVERVIEW

A schematic of the 8-Ft. HTT wind tunnel components is shown in Figure 5. Inside the facility combustor, methane and air are burned to create a high temperature flow. For air-breathing propulsion tests, liquid oxygen is added in the combustor such that the combustion products contain twenty-one percent molar oxygen. The combustion products flow through the transpiration-cooled Mach 7 nozzle throat. Water-cooled thermocouple probes upstream of the throat measure and control the combustor stagnation temperature. For Mach 7 testing, the flow is then expanded to the test section through the divergent section of the Mach 7 nozzle. For Mach 4 or Mach 5 testing, the Mach 7 divergent section is replaced with a mixer, followed by a Mach 4 or Mach 5 converging-diverging nozzle, as shown in Figure 6. Unheated air is added in the mixer to achieve the desired lower enthalpy for enthalpy duplication at these Mach numbers. The Mach 4 and Mach 7 nozzles each have an 8-foot diameter exit. There are two Mach 5 nozzles: the original full-scale Mach 5 nozzle with an 8-foot diameter exit, designated as the Mach 5 low dynamic pressure nozzle (M5LoQ), and a new reduced scale Mach 5 nozzle, recently built to deliver higher dynamic pressure, having a 4.5 foot diameter exit (M5HiQ).

Flight simulation capability described here is limited to tests with oxygen replenishment (tests without oxygen replenishment can simulate higher dynamic pressures). Table 1 provides facility conditions corresponding to the maximum dynamic pressure demonstrated thus far for each nozzle. Further increases in dynamic pressure, at the given total temperature, are not possible with the Mach 4, M5LoQ or Mach 7 nozzles. However, dynamic pressure simulation could be increased to an estimated maximum of 3200 psf for the M5HiQ nozzle. For each nozzle, the minimum dynamic pressure the facility can provide is approximately half of the maximum. It is known that water, present as a product of combustion, condenses as the flow expands through the facility nozzle and modifies the thermo- and fluid-dynamic environment of the flow delivered to the test section, relative to gas-phase predictions. Computational fluid dynamic (CFD) modeling of multi-phase flow in both the nozzle and over a representative forebody,[8,9] indicates that forebody compression results in complete re-vaporization of the water and return of the flow properties to very near their gas phase values at the engine entrance plane. Thus, in addition to facility nozzle exit flow surveys, engine entrance plane flow surveys are typically conducted prior to each engine entry. The survey data, in conjunction with CFD analysis, is used to quantify engine inflow and determine the equivalent gas-phase free-stream conditions.

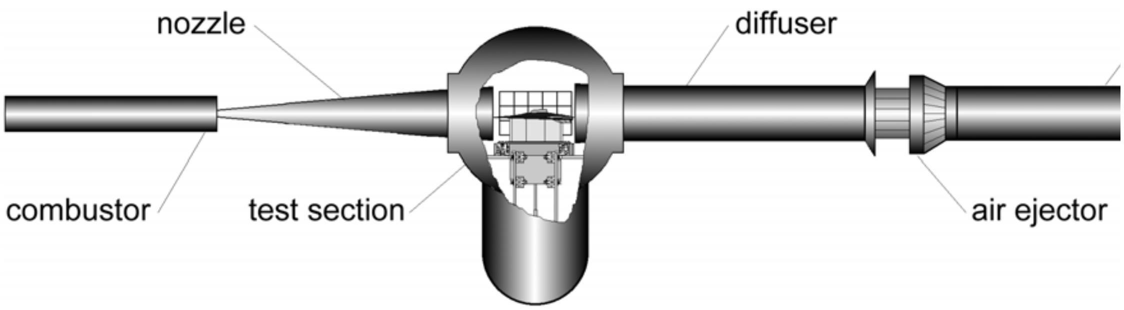


Figure 5. Facility Schematic

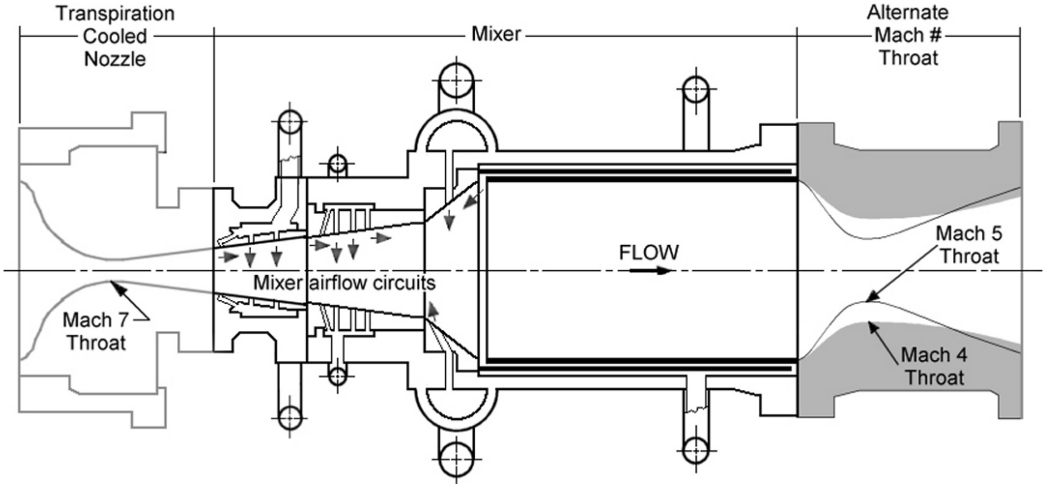


Figure 6. Facility Mixer Configuration (for Mach 4 or 5 Testing)

Table 1. Demonstrated Facility Conditions for Tests with Oxygen Replenishment

Simulated Flight Mach Number[1]	Nozzle Designation, Exit Diameter (ft)	Stagnation Pressure [2] (psia)	Stagnation Temperature [3] (R)	Nozzle Exit Mach Number [4]	Nozzle Exit Dynamic Pressure [4] (psf)	Altitude Simulation [5] (kft)
4	Mach 4, 8 ft	85	1670	4.1	1323	66
5	Mach 5 LoQ, 8 ft	285	2072	4.6	1228	72
5	Mach 5 HiQ, 4.5 ft	549	2145	4.6	2071	62
7	Mach 7, 8 ft	2000	3480	6.3	1273	85

Notes:
1. Corresponding to total enthalpy duplication
2. Measured in the representative plenum region (combustor for Mach 7; mixer for Mach 4 and 5)
3. Measured in nozzle exit flow surveys
4. Calculated using facility nozzle exit flow survey data and assumption that flow is gas phase and in thermal equilibrium
5. Corresponding to static pressures measured in nozzle exit flow survey

Figure 7 shows a schematic of the test section, which consists of a 26-ft. spherical vacuum chamber and a lower 16-ft. cylindrical “pod”. If desired, a model injection system can be used to raise the model from the pod into the test stream during steady state tunnel operation, thus protecting the model from tunnel startup and shutdown loads. Testing of propulsion systems is performed with the propulsion test article attached to a model support system, or pedestal, if desired. The pedestal is mounted on top of the real-time variable Angle of Attack (AoA) system. The AoA system, described in more detail in a later section, is mounted to the Force Measurement System (FMS). After the flow traverses the test section, it is collected in the diffuser and subsonic mixing tube and exhausts to atmosphere. 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 facility can provide several different fuel systems for the test article. Capability exists for gaseous or liquid commodities. Systems are currently configured for gaseous hydrogen, a mixture of gaseous hydrogen and silane, gaseous ethylene and liquid JP-7, but could be used to deliver other gaseous and liquid commodities. Each of these systems provides ambient temperature fuel and has automated control systems to provide pre-programmed fuel and ignition sequences. Gaseous nitrogen purge systems are integrated with each fuel system. An aerial photo, showing the 8-Ft. HTT major fluid support systems is shown in Figure 8. In addition to the facility’s air, methane and LOx supply systems, the location of the new JP-7 and ethylene systems is indicated.

Airbreathing propulsion system research is the most complex type of testing performed in the 8-Ft. HTT, requiring more facility systems than any other type of test. Typically, airbreathing propulsion models have more instrumentation, separate control systems integrated with the facility control systems, moving components actuated by electrical or hydraulic means and cooling systems with multiple circuits. They 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 and therefore require automated interlocks or close visual monitoring during testing. Upgrades to the 8-Ft. HTT to support these complex hypersonic airbreathing propulsion systems are described in the following sections.

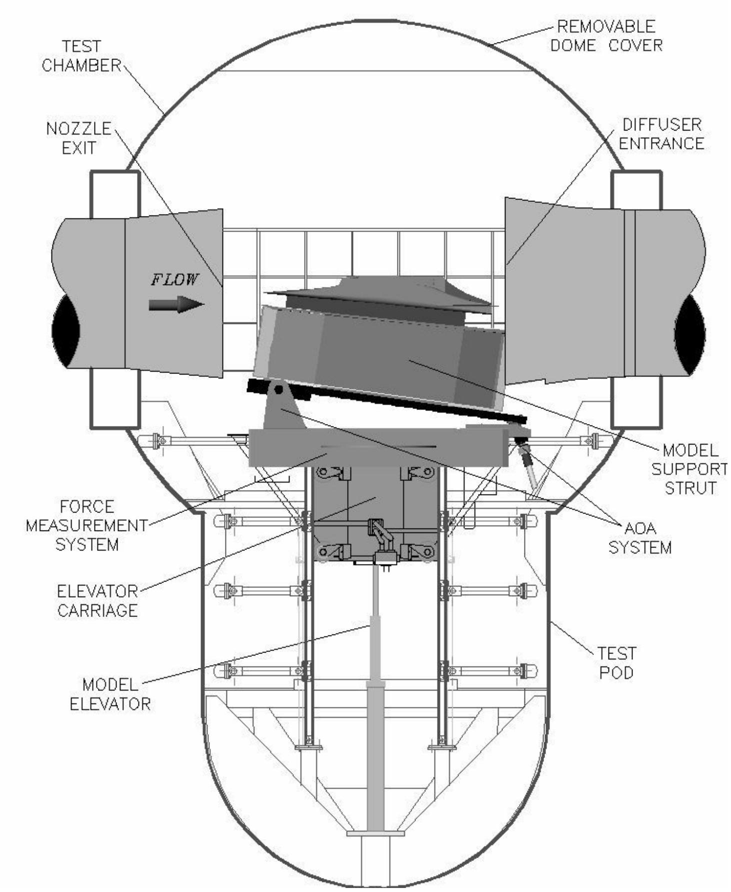


Figure 7. Test Section Schematic

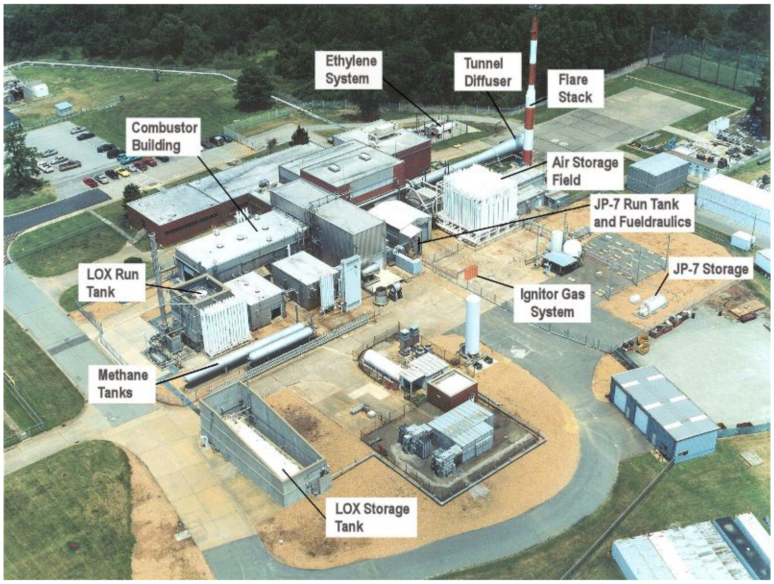


Figure 8. Facility Aerial Photo

FLUID SYSTEM UPGRADES

LIQUID JP-7 SYSTEM

Four distinct JP-7 systems were necessary to support the X-43C/X-51A test requirements: a non-pressurized bulk liquid fuel storage system to provide a large volume of stored fuel, a pressurized system to provide engine coolant/fuel during each run (run tank), a smaller pressurized system to provide power actuation fluid (fuel-draulic) for the fuel distribution valves, and a non-pressurized waste recovery system for non-combusted fuel. The engine fuel and fuel-draulic systems were designed to be completely independent from one another, allowing system checkouts to be less complicated and increasing the robustness of the systems. This design also supported checkouts of engine systems, which allowed the fuel distribution valves to be actuated without requiring engine coolant/fuel to be flowing.

Storage System:

The JP-7 storage system was purchased as commercial off the shelf hardware and installed at the facility in a location that provided the maximum degree of isolation between the storage vessel and potential ignition sources. The new system, shown in Figure 9, provides the capacity to store and condition 6000 gallons of liquid fuel in a stainless steel tank. The system is filled via an offloading pump, which pumps the fuel out of a delivery tanker through a 10 micron filter/separator unit and into the storage tank. The same pump is utilized to periodically re-circulate the stored fuel through the filter/separator and back to the storage tank. The filter separator filters the fuel and removes any moisture that condenses in the tank to keep the fuel uncontaminated. The suction line for the fuel suction pump is a floating system to ensure that uncontaminated fuel is removed from the tank, while a manually operated pump is used to remove water that accumulates (via condensation from the atmospheric vent) at the bottom of the tank. The offloading pump also provides the capability to remove fuel from the tank at a reduced flow rate and pump it from the storage system to the JP-7 run tank and fuel-draulic tank in preparation for each facility run. To minimize particulate contamination of the fuel, the tank and all supply lines are constructed from stainless steel.

Figure 9. JP-7 Storage Tank and Waste Recovery Tank

JP-7 Run and Fuel-draulic Systems:

The JP-7 run fuel system, added to the facility in 2004, consists of a 300-gallon stainless steel holding tank that is filled by pumping fuel from the 6000-gallon storage tank through stainless steel tubing. The run tank is an ASME code stamped vessel rated for service at 3000 psig at ambient temperature. The fuel-draulic supply system consists of three 25-gallon stainless steel tanks manifolded together. Each tank is ASME code stamped for service at 1292 psig at ambient temperature. The run tank and the fuel-draulic tanks are shown in Figure 10. Both tank systems are installed inside a secondary containment pan to contain any fuel spills, as well as a three-sided steel-walled enclosure with a metal roof.

Tank load pressure is provided via gaseous nitrogen applied to the top of each tank through regulators, providing steady delivery pressures up to 2400 psig and 1200 psig for the JP-7 run supply and fuel-draulic systems, respectively. The facility programmable logic controller (PLC) automatically controls the delivery of the JP-7 process fluid to the test article and can provide interlocks on pressure and flow rate as required to protect model systems. In addition, relief valves provide overpressure protection. JP-7 fluid is delivered to the test article through stainless steel tubing to minimize particulate contamination. A 3-micron filter is installed downstream of the fuel-draulic tanks.

Figure 10. JP-7 Run Tank and Fueldraulic Tanks

Waste Recovery System:

To collect waste JP-7 returned from model systems, a 650-gallon waste collection system was installed. The system safely collects and cools heated fuel via a double walled, flexible hose system. Ambient temperature water is fed through the outer jacket of the flex hose at 500 psig and 100 gallons per minute, providing cooling for the hot waste fuel products flowing through the inner flex hose. Results from recent tests indicated that waste fuel was typically cooled to a temperature of 200°F, or below, before exiting the flex hose. The cooled waste fuel is then fed into an all welded stainless steel tube waste fuel line which carries the cooled waste products from the facility to the waste tank. Further precautions are taken by flowing nitrogen through the waste delivery line, to inert the stainless steel waste fuel line and waste fuel tank.

ETHYLENE SYSTEM

An ethylene delivery system was added in 2005. The most cost effective solution entailed modifying the existing ignitor gas (a silane/hydrogen mixture) system to operate with gaseous ethylene, and then to build a new smaller ignitor gas system to maintain this delivery capability. Ethylene is provided to test articles via a tube trailer, shown in Figure 11, at a maximum pressure of 1200 psig. Throttling ethylene from tube trailer pressure to model delivery pressures can result in liquefaction of the ethylene, making flow and pressure control of ethylene problematic. To minimize the potential for liquefaction, a steam-heated water bath was incorporated into the ethylene delivery system upstream of the regulator. Ethylene passes through stainless steel coiled tube heat exchangers, which are immersed in the steam-heated water bath, and exits at a temperature of approximately 160°F before passing through the pressure regulator inlet. During recent testing, ethylene flow remained gaseous at all times and was delivered at near ambient temperature to the test hardware.

Figure 11. Ethylene Delivery System

IGNITOR GAS SYSTEM

The new ignitor gas system consists of 12 K-bottles, each having a volume of approximately 1.5 cubic feet and containing a molar mixture of 20% silane and 80% hydrogen. The bottles are manifolded together in an all-welded construction and are supplied at a maximum pressure of 2400 psi. Ignitor gas flow to the test section is controlled by using a choked orifice in conjunction with a pressure regulator, providing a reliable means of limiting the maximum gas flow based on regulator exit pressure. A relief valve located downstream of the regulator protects the model systems from over-pressure. Facility process (executed via the facility PLC) controls purge the ignitor gas delivery lines with nitrogen prior to priming the system with ignitor gas. Intermediate venting and priming processes ensure that undiluted ignitor gas is delivered to the test article when needed during a test.

FLIGHT SIMULATION AND TEST SECTION UPGRADES

MACH 5 HIGH DYNAMIC PRESSURE NOZZLE

A new Mach 5 nozzle was built to increase the dynamic pressure capability of the facility. The original Mach 5 nozzle, with a 16.9 inch diameter throat, could produce a maximum dynamic pressure of approximately 1200 psf at Mach 5 total enthalpy with the combustor operating at the maximum pressure and temperature. The new nozzle, which has a 9.2-in diameter throat and a 54.4-in diameter exit, can provide dynamic pressures up to 3200 psf at Mach 5 total enthalpy. The smaller nozzle, designated the M5HiQ nozzle, is installed within the existing Mach 5 nozzle structure and is shown in Figures 12 and 13.

The M5HiQ nozzle contour design and mechanical design was performed by NASA Langley [10]. A nozzle throat section and six nozzle expansion segments comprise the 396-in. long nozzle flowpath. The throat section is constructed from 5-in. thick Incoloy 800HT, while all other nozzle segments and support structures are constructed from 304 stainless steel. All components are un-cooled and designed to withstand Mach 5 total enthalpy conditions for 90 seconds. To allow for thermal growth along the nozzle centerline, the nozzle is mounted on linear slide rails. In addition, each segment joint has a 0.050-in. (approx) rearward facing step, so that as the nozzle reaches its design temperature, the steps close down providing a near-smooth nozzle contour. CFD analysis demonstrated that even the full height steps produce negligible reduction in flow uniformity within the nozzle core flow.

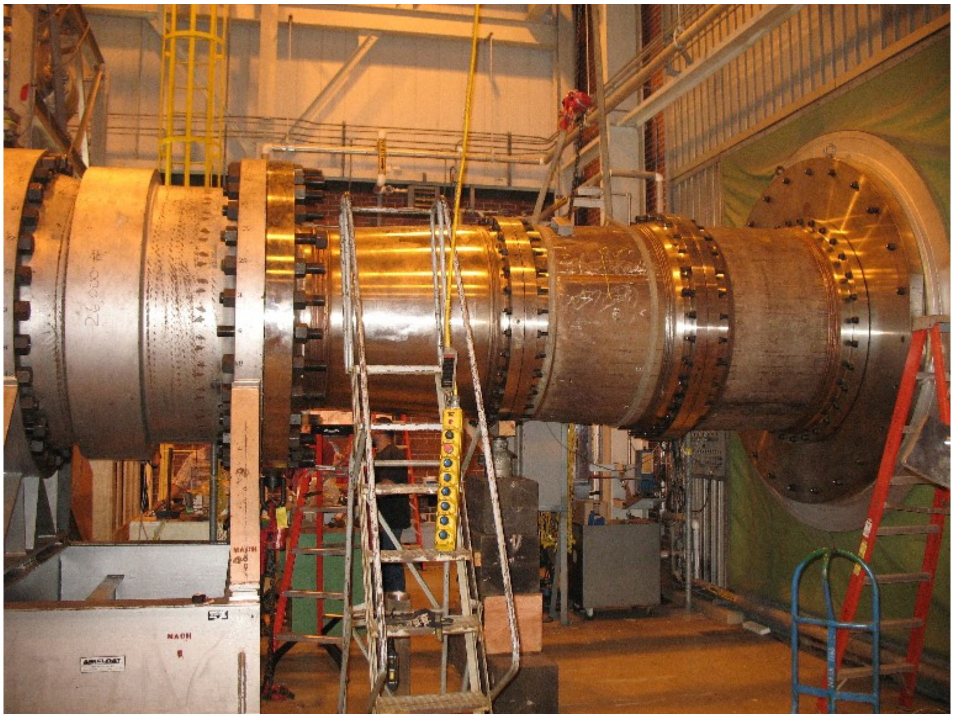


Figure 12. Assembly of M5HiQ Nozzle Extension Pieces

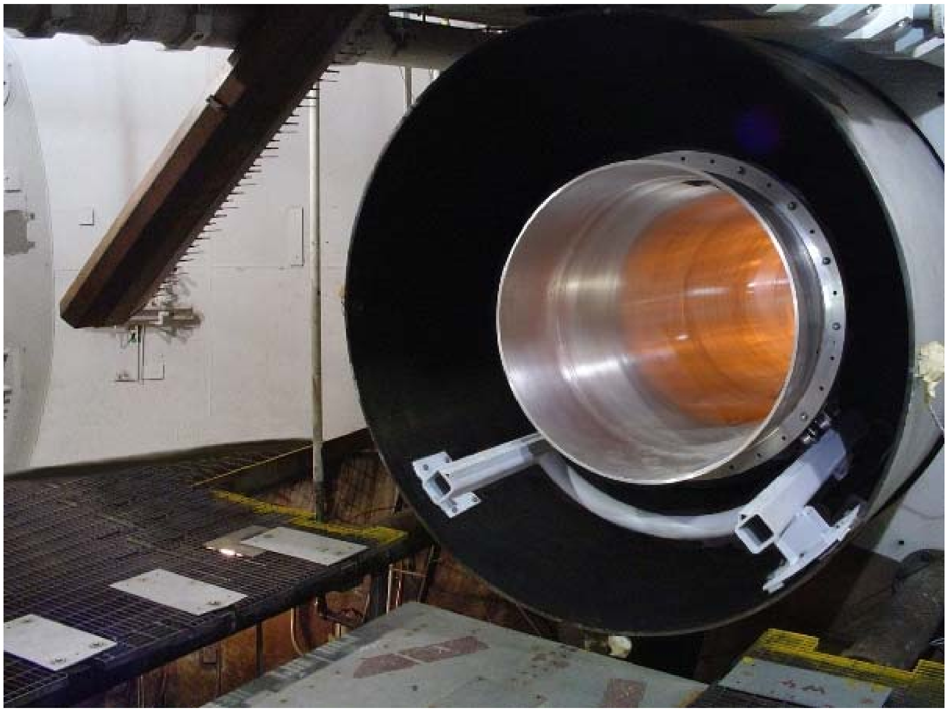
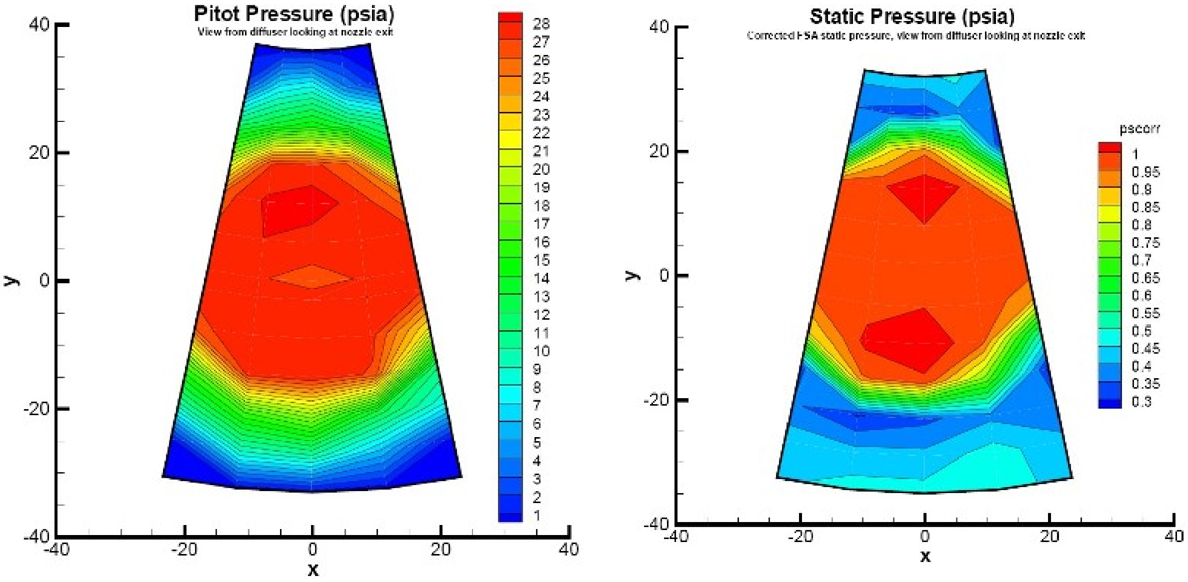


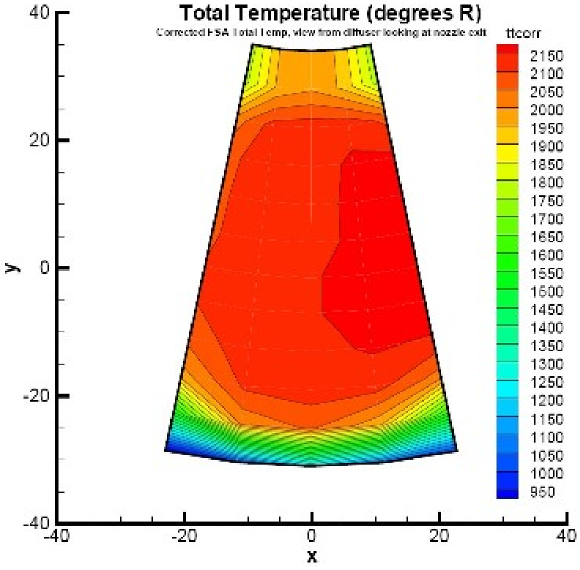
Figure 13. Photo of FSA and M5HiQ Nozzle Exit

The M5HiQ nozzle was calibrated in September of 2006 using the Flow Survey Apparatus (FSA) to survey the nozzle exit flow. The FSA, shown on the left side of Figure 13, is configured with probes measuring static pressure, pitot pressure and stagnation temperature. Rotating about a pivot point above the nozzle, the FSA sweeps across a plane located 28 inches downstream of the nozzle exit plane, dwelling at pre-programmed angles. Results from FSA surveys of the M5HiQ nozzle revealed that the nozzle produces relatively large uniform test cores relative to the nozzle exit diameter. Contour plots generated from these surveys are shown in Figure 14, and demonstrate variations of approximately 1%, 3%, and 4% from averaged values in total temperature, pitot pressure, and static pressure, respectively, within a 20-in. diameter area centered about the nozzle centerline.



(a) Pitot pressure profile

(b) Static pressure profile



(c) Stagnation temperature profile

Figure 14. Contour Plots of Flow Measurements Downstream of the M5HiQ Nozzle Exit Plane

REAL TIME ANGLE OF ATTACK SYSTEM

To improve test efficiency and expand flight simulation capability, a variable model angle of attack (AoA) system was installed in 2003, allowing real-time control of continuous changes in model angle of attack. This new capability was utilized in recent engine tests, allowing multiple angles of attack to be achieved in a single run, which otherwise would have required multiple days. The AoA system also provides expanded flight simulation capability by producing changes in engine mass capture and combustor entrance conditions similar to those experienced in flight (i.e. flight trajectory, maneuvers, dynamics). This type of testing will be useful, for example, to investigate fuel staging or engine operability that might not otherwise be possible with a fixed model angle of attack. Future plans include adding real-time control for enthalpy and pressure variation. Scheduling enthalpy, pressure and AoA variation will significantly advance ground test capability for propulsion system development and verification.

The variable AoA system mounts to the Force Measurement System (FMS), and changes in the model loads are transmitted through the AoA system to the FMS. The AoA system, shown schematically in Figure 15, utilizes two forward trunion mounts to allow the base plate to pivot and an aft mounted hydraulic cylinder to provide base plate inclination. The hydraulic cylinder utilizes the existing model elevator hydraulic system, with a new servo-valve and controller to drive the AoA system to the desired angle(s) during each run. The system is capable of changing the angle of attack at a rate of approximately 1 degree per second over an eight-degree actuation range and has an accuracy of +/- .005 degrees. The system can be programmed to execute an AoA sequence to meet customer requirements.

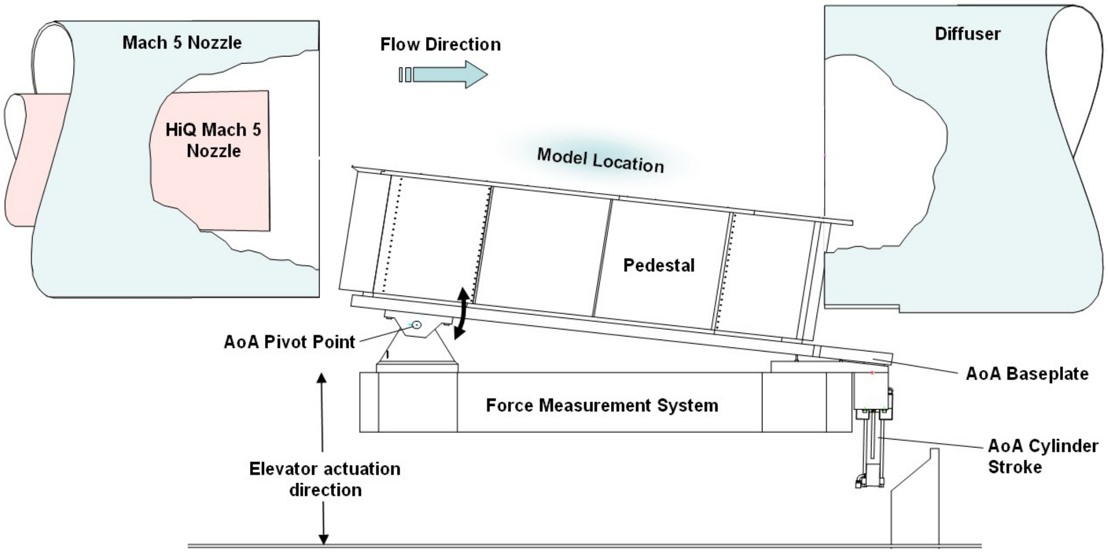


Figure 15. Angle of Attack System

MODEL SUPPORT PEDESTAL

A model support pedestal for housing instrumentation, fluid systems and model control systems was constructed for the X-43C-GDE-2 test and complements the existing suite of pedestals (NASP-CDE pedestal and Hyper-X pedestal) available for customer use. The GDE-2 pedestal, shown in Figure 16, was designed to withstand aerodynamic loads of 49,000lbf axial, (unstart), 1800 lbf normal and 5300 lbf side. It was also designed to withstand thermal loads associated with Mach 7 enthalpy at 1250 psf dynamic pressure for 107 seconds. The pedestal features removable side panels for between-test access, large open areas at the bottom to accommodate power, instrumentation cables and fluid lines. It also features a leading edge rake that contains two total temperature probes and three pitot probes to measure facility nozzle exit flow conditions. The GDE-2 pedestal also accommodates up to five degrees of sideslip (yaw) for models designed with the necessary interface hardware. External dimensions of all three pedestals are approximately 12 feet long, 3 to 4 feet high and 1 to 2 feet wide, with the GDE-2 pedestal containing approximately 100 cubic feet of internal storage volume. The CDE pedestal is comparable in size and the Hyper-X pedestal is slightly smaller.

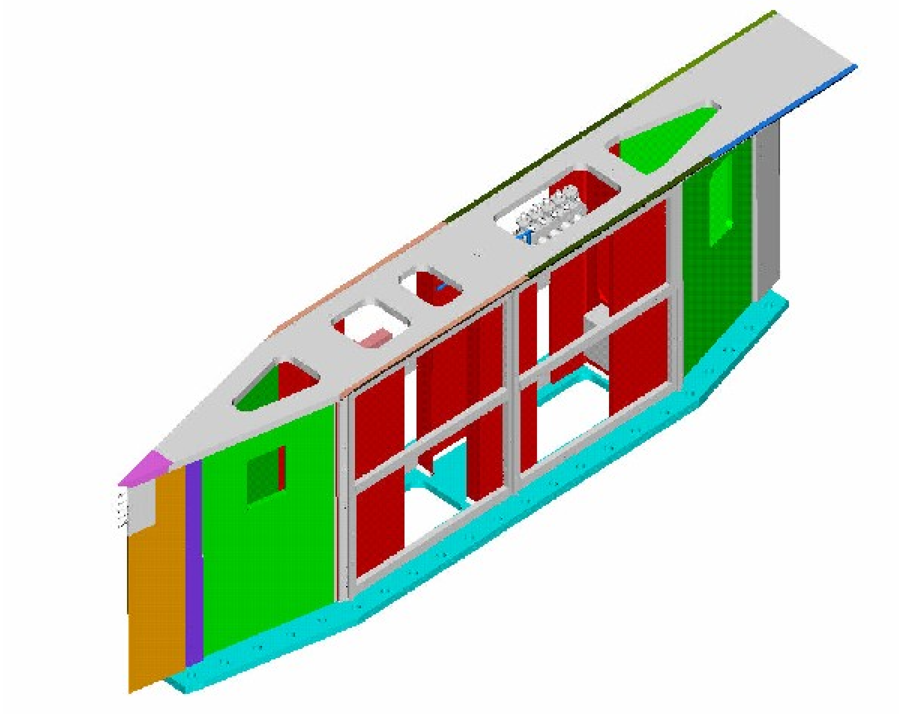


Figure 16. GDE-2 Model Support Pedestal- Side panels removed

CONTROL SYSTEM UPGRADES

INTERLOCK, PLC AND COMMUNICATION UPGRADES

Significant upgrades to the facility were made through the installation of an interlock interface panel, a new programmable logic controller (PLC) sub-system, and Shared Common Random Access Memory Network (SCRAMNet) communication system. The interlock panel is mounted to the model elevator with the test hardware, allowing for close-coupled instrumentation connections for model data channels that are desired to serve as test interlocks. The panel is hard wired to both the facility data system and the facility PLC through programmable signal conditioning modules. The signal conditioning modules allow the instrumentation sensor output to be received and then re-transmitted to the research data system as a higher level signal (i.e., less noise). The modules also have the ability to generate a trigger signal to the facility PLC when sensor inputs exceed a predefined range, allowing for the facility to take a predefined action as a result of the indication. This system provides interlocking capability on these channels while still recording the data from the same channels, allowing the researcher to collect data and simultaneously protect model hardware. The system has the capability for 24 thermocouple, 20 pressure transducer, and 12 flow meter inputs.

The SCRAMNet data link couples a new Allen Bradley PLC system to a customer supplied engine control system. This data link provides a means of communicating key signals between the main facility PLC and the customer's engine control system, allowing proper sequencing of model controlled and facility controlled events. The model control system must contain appropriate hardware and software. In the current installation, signals transmitted between the facility PLC and a remote engine control station via SCRAMNet are written into a MIL-STD-1553B data stream and transmitted to the on-board engine controller. In flight, the 1553B data stream can be utilized to communicate information between the vehicle control system and the engine control system. Thus, the customer's ground test engine control software can be more flight-like, sending and receiving information via 1553B data stream. The SCRAMNet capability allows the facility and model process controls to be integrated and event-driven rather than timer-driven based on pre-test estimated timing, thereby improving test efficiency and reducing risk. Information exchange between the two control systems allows the test to proceed in a controlled manner with appropriate hand-shaking required for the test sequence to advance. Information exchanged between the two systems consists of run progress markers such as Facility Flame On, Model on Centerline, Facility on Point, Facility Normal Stop and others.

The transmission of these markers to the engine control system can be used to initiate model processes such as beginning engine fuel flow, verifying that the engine is ready to be injected into the facility test stream, and beginning the engine ignition process, among others. An example integrated run sequence showing standard facility events and communication between the facility and model controls is shown in Figure 17.

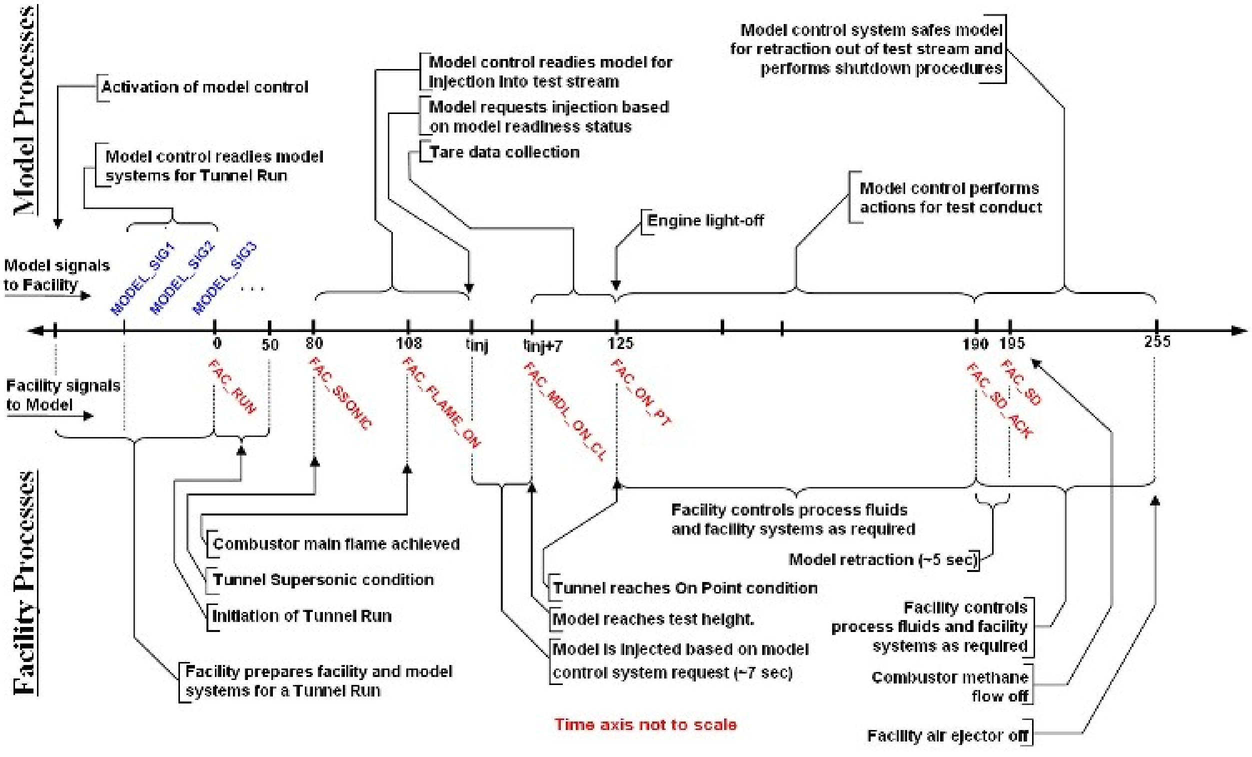


Figure 17. Integrated Facility-Model Run Sequence

DATA ACQUISITION AND PROCESSING UPGRADES

DATA ACQUISITIION OVERVIEW

The data acquisition system (DAS) and processing system at the 8-Ft. HTT consists of the Research Data Acquisition System (RDAS), the Diagnostic Data Acquisition System (DDAS), and the Data Reduction and Processing Software (DRPS). Recent additions include a Dewetron/Precision Filters high frequency DAS and a MIL-STD-1553B capable DAS. The means of collecting and delivering data, interfacing with customer control systems, and overall system architecture is summarized schematically in Figure 18.

The RDAS consists of a NEFF 600 system with NEFF 300 signal conditioners, a Pressure Systems Incorporated (PSI) 8400 Electronically Scanned Pressure (ESP) system, and a NEFF 490 high frequency DAS. RDAS is used to acquire research/model data. 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 Hz. Actual maximum possible 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. 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 up to 1000 ESP channels with a typical acquisition rate of 10 Hz. Actual capture 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 high frequency DAS can accommodate up to 15 channels of high-speed data with input voltage ranges from ±5 millivolts to ±10.24 volts. Each channel card contains a 1 MHz, 12-bit analog-to-digital (A/D) 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. System accuracy is .1% of full scale. The maximum sample rate is 1 million samples per second per channel for 2 seconds. Longer acquisition times can be achieved by using lower sampling rates.

The DDAS, which is used to acquire tunnel operational data, consists of a NEFF 470 system and its associated equipment. The NEFF 470 system can acquire data from up to 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 +/- .05% of full scale and has an aggregate data throughput of 10,000 samples per second. The typical scan rate is 25 Hz. Actual maximum scan rates depend on the number of channels acquired. The NEFF 470 has a fixed filter frequency of 10 Hz per channel.

The NEFF 600, PSI 8400, and NEFF470 systems are interfaced to Personal Computers (PC) running AutoNet data acquisition software. The NEFF 490 system is interfaced to a PC running in-house generated Data Acquisition and Reduction Software (DARS). The NEFF 490 PC downloads data stored in the NEFF 490 internal channel memory after each tunnel run. NEFF 490 data processing and display is performed using DSP Development Corporation's DADiSP software. The AutoNet and DARS software performs device interfacing and calibration, data acquisition, near real-time display, data conversion, and data transfer. Data transportability to third-party data processing programs is available. The RDAS data (with the exception of the NEFF 490 data) and DDAS data are sent to a data processing PC to be reduced and integrated. The data processing PC uses the Data Processing and Reduction Software (DPRS) running under Microsoft Windows XP Professional to perform transducer excitation compensation, ESP reference correction, wind-off correction, data referencing, and specialized data calculations. The DPRS can be configured to produce graphical printouts, Excel spreadsheets, PowerPoint presentations, and ASCII data files according to a predefined setup after each tunnel run. An interactive data processing interface is also available. The NEFF 490 data undergoes no post-processing and is archived separately. Data file transfers and archival is accomplished through CD-R media.

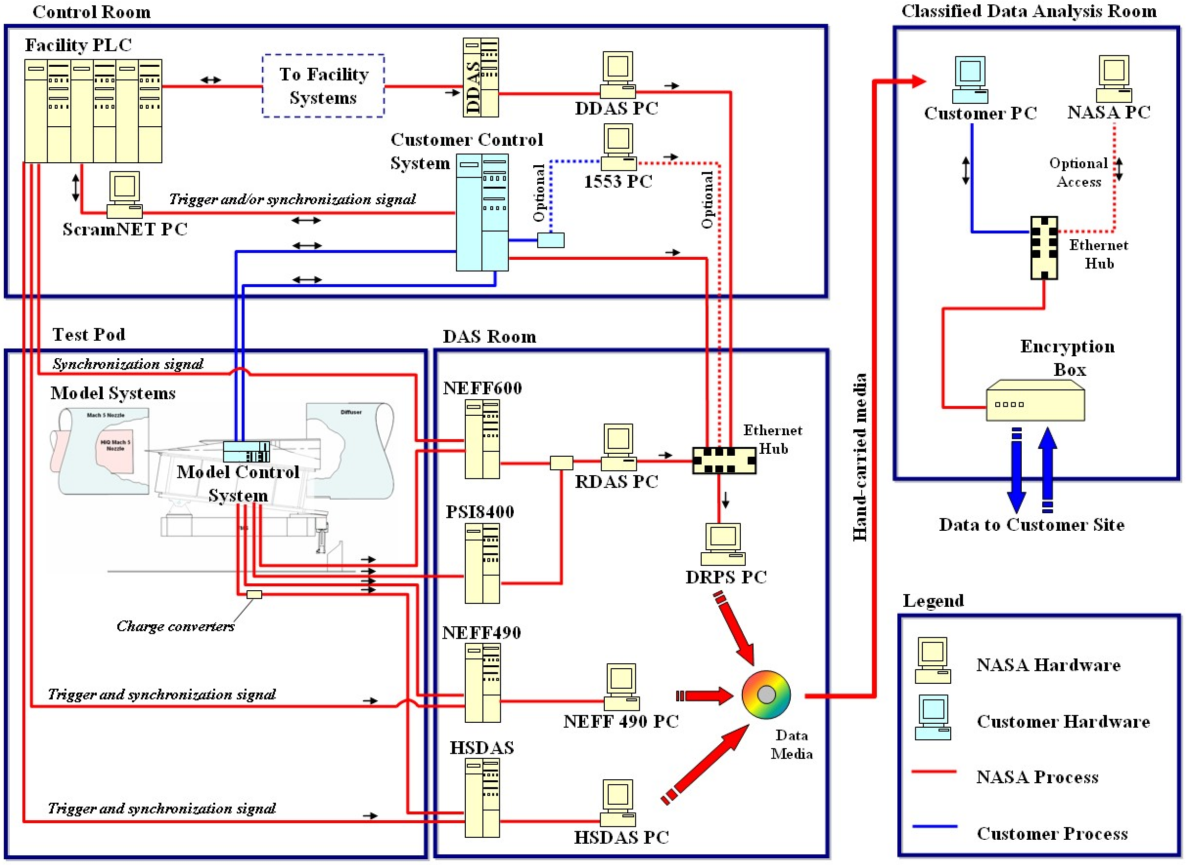


Figure 18. Data Acquisition and Processing Schematic

1553 DATA ACQUISITION

A data acquisition system capable of monitoring and acquiring data from a MIL-STD-1553B data bus has been added. The system consists of a PC with a Data Device Corporation (DDC) data acquisition board along with DDC DataSIMS software. The software provides the interface through which the user defines the proper interpretation of data parameters, including derived parameters, from any active 1553 data stream. In addition, this software provides real-time monitoring and recording of 1553 messages and data, and includes the ability to rapidly configure an optimal graphical presentation of data. The system acts as a bus monitor whose acquisition rate is limited only by the rate of data placed on the bus by the bus controller. This 1553 data acquisition capability was used during recent tests to acquire engine control related data.

HIGH SPEED DATA ACQUISITION

High speed data acquisition capability has been increased through the installation of a Dewetron PCI mainframe with four Dewetron 24-bit A/D cards. Each A/D card consists of sixteen simultaneously sampled channels (total of 64 channels) with a maximum sample rate per channel of 200 kHz. The PCI mainframe is interfaced to a PC running Dewesoft software that performs device interfacing and calibration, data acquisition, near real-time display, data conversion, and data transfer. Data transportability to third-party data processing programs is available. The signal conditioning for this system is accomplished using a Precision Filters, Inc. Precision 28000 system. The Precision 28000 system is a 16-slot chassis capable of conditioning a wide variety of instrumentation using plug-in conditioner cards. These conditioner cards provide excitation, amplification, and filtering for the input devices. A graphical user interface is provided for system configuration and control.

SECURE DATA ANALYSIS ROOM

Customer review of classified information up to the secret level was made possible through the conversion of an existing office at the 8-Ft. HTT into a classified data storage and processing room. The modifications include a cipher lock and spin dial lock on the door, motion detectors and a password activated alarm system. It also includes an encryption box for transferring data off-site (i.e. to the customer's main offices). Customers may bring their own classified PC's for data processing and connecting to the network. The addition of this room provides a convenient means for customers to review classified and sensitive data, without the need to transfer it to off-site customer locations first. Review of test data can take place shortly after the conclusion of each test.

SUMMARY AND CONCLUSIONS

The 8-Ft. HTT is a unique national asset that provides unequaled test capabilities to the hypersonic technologies community. The facility provides a unique national test capability for large-scale component testing at flight enthalpy for hypersonic air-breathing propulsion, structures and materials, and system concept performance validation. The Mach number range provided by the 8-Ft. HTT is critical for understanding transition from ramjet to scramjet operation for many air-breathing engine concepts. To complement and augment this unique asset, significant upgrades were made to the facility over the last five years to support state of the art hypersonic engine testing. The upgrades include hydrocarbon fueling capability, increased dynamic pressure simulation at Mach 5 enthalpy, increased flight simulation capability and test efficiency through a real-time angle of attack system; and state of the art process control equipment and data acquisition systems. The new systems support complex test programs that require a high level of facility-model coordination, strict management of process fluids, and large volumes of high speed data capture. These additions to the facility have not only proven highly beneficial to the test programs that have utilized them, but also represent NASA's continuing efforts to support and foster the development of hypersonic air-breathing propulsion technologies.

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NOMENCLATURE

8-Ft. HTT	NASA Langley 8-Foot High Temperature Tunnel
AoA	Angle of Attack
CDE	Concept Demonstrator Engine
CFD	Computational Fluid Dynamics
DDAS	Diagnostic Data Acquisition System
ESP	Electronically Scanned Pressure
FMS	Force Measurement System
GDE-2	Ground Demonstrator Engine - 2
LOX	liquid oxygen
NASA	National Aeronautics and Space Administration
NASP	National Aero-Space Plane
PLC	Programmable Logic Controller
PSI	Pressure Systems Incorporated
RDAS	Research Data Acquisition System
SCRAMNet	Shared Common RAM Network