New Hypersonic Facility Capability at NASA Lewis Research Center

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NEW HYPERSONIC FACILITY CAPABILITY AT NASA LEWIS RESEARCH CENTER

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Abstract

Four facility activities are underway at NASA Lewis to develop new hypersonic propulsion test capability. Two of these activities consist of upgrades to existing operational facilities. The other two activities will reactivate facilities that have been in a standby condition for over 15 years. This paper discusses these four activities and describes the new test facilities NASA Lewis will have in support of evolving high-speed research programs.

Introduction

As a result of the renewed interest in hypersonic flight motivated primarily by the National Aerospaceplane Program, activity is underway within the government, industry, and the aerospace community to develop expanded hypersonic test capability. These efforts consist of building new facilities as well as reactivating and upgrading existing facilities. Some of the existing facilities have been maintained in various conditions of standby over the past 15 to 20 years and require significant repair, rehabilitation, and/or upgrade in order to bring them back into operational service. At NASA Lewis Research Center, a commitment has been made to develop new hypersonic propulsion system test capabilities. Four separate facility activities are currently underway to provide this capability. Two of the projects involve upgrades of operational facilities. They consist of an expansion of the 1- by 1-ft supersonic wind tunnel to provide Mach 6 aerodynamic test capability and modifications to the Propulsion System Laboratory for Mach 6 direct-connect capability. The third activity is the reactivation of the Hypersonic Tunnel Facility (HTF) at NASA Lewis' Plum Brook Station to restore its originally-designed Mach 5.6 and 7 propulsion test capability. The fourth activity is the planned reconstruction of the 21-in. Hypersonic Wind Tunnel (HWT) which was dismantled and shipped from the Jet Propulsion Laboratory in 1988. Once reconstructed, the 21-in. HWT will provide a Mach 4 to 11 aerodynamic test capability.

This paper will summarize these four activities and describe the new test facilities that NASA Lewis will have in place to support evolving high-speed/hypersonic research programs.

Facility Descriptions

The following sections summarize each of the four activities at NASA Lewis underway to develop new high-speed (hypersonic) facility capability. Four facility activities are underway at NASA Lewis to develop new hypersonic propulsion test capability. Two of these activities consist of upgrades to existing operational facilities. The other two activities will reactivate facilities that have been in a standby condition for over 15 years. This paper discusses these four activities and describes the new test facilities NASA Lewis will have in place to support evolving high-speed research programs.

Facility Descriptions

The following sections summarize each of the four activities at NASA Lewis underway to develop new high-speed (hypersonic) facility capability. Figure 1 illustrates how these activities will augment existing NASA Lewis capability. Before these activities commenced the 10- by 10-ft Supersonic Wind Tunnel (SWT) was the largest, highest speed operational propulsion facility at NASA Lewis. The 10- by 10-ft SWT was capable of a maximum Mach number of 3.5. The 1- by 1-ft SWT had a maximum Mach number limit of 4.0 before its upgrade was initiated. After all of the new activities are completed NASA Lewis will have four facilities capable of Mach 6 and higher through a combination of free-jet, direct-connected, and wind tunnel test capabilities. Brief descriptions of most of the existing facilities shown in Fig. 1 are found in Refs. 1 and 2.

1- by 1-Ft Supersonic Wind Tunnel

The 1- by 1-ft Supersonic Wind Tunnel (1x1 SWT) was constructed in the early 1950's as a continuous-flow, aerodynamic tunnel that utilizes interchangeable two-dimensional nozzle blocks to achieve discrete Mach number settings over a range from 1.3 to 4.0. The facility was used initially for basic inlet research and concept screening. Also, a considerable amount of testing was performed on configurations for subsonic, supersonic, and hypersonic vehicles, and space vehicles, including scaled portions of the Mercury capsules. The facility was removed from service in 1960 and remained inactive for 11 years. It was reactivated and operated in 1972 and 1973, and was retired from service for another 6 years. It was reactivated again in 1980 and has remained operational. The early 1980's concentrated on basic research of boundary layers and shock/boundary layer interactions. Much of this work was oriented toward university graduate studies. In the last several years testing emphasis has changed significantly. The 1x1 SWT has begun to play a key role in various major programs of national interest such as the National Aerospaceplane Program (NASP). It has become one of the most heavily scheduled facilities at NASA Lewis used primarily for subscale inlet and nozzle component testing and also to obtain data for validating newly-developed computational fluid dynamics flow codes. A schematic of the facility is shown in Fig. 2 and a photograph of the test section is shown in Fig. 3. The 1x1 SWT is located within the NASA Lewis Engine Research Building.

Air is supplied to the tunnel from the NASA Lewis central air system at either 40 or 150 psig. Downstream of the diffuser the facility is connected to the central exhaust system which produces a minimum pressure of about 2 psia. Existing nozzle blocks are available to permit operation at Mach numbers of 1.3, 1.6, 2.0, 2.5, 3.0, 3.5, and 4.0. The nozzle blocks are stored on the floor below the facility and are raised into place with a hydraulic lift. Nozzle blocks can be changed and the facility can be operated in approximately 20 min. A range of Reynolds numbers is possible by varying the air supply pressure. The facility has been in continuous operation over the past 15 years. This paper discusses these four activities and describes the new test facilities NASA Lewis will have in place to support evolving high-speed research programs.

Because of the growing interest in high-speed flight an opportunity arose to expand the 1x1 SWT to Mach 6. This was accomplished by adding an electric heater in the air supply line and fabricating new nozzle blocks...
for Mach 5.5 and 6.0. Mach 6 is about the maximum Mach number that can be achieved with a facility of this size that utilizes two-dimensional nozzle blocks. The gap at the throat is very small and higher Mach numbers would not be practical. There is an existing nozzle block for Mach 5.0. However, because the facility originally had no provisions for heating the inlet air, the temperature drop from the expansion to Mach 5 was too large and liquefaction began to occur in the test section. To achieve higher Mach numbers a 650-kW electric heater is being added in the air supply line. This is shown in dashed lines in Fig. 2. The air supply piping has been modified to include the heater so that either heated air enters the upstream surge tank or varying amounts of heated air can be mixed with unheated air upstream of the surge tank to provide a range of temperatures. Temperatures between 560 and 1110 °R will be achievable. This permits an increase in the Reynolds number range at the lower Mach numbers as shown on Fig. 4. Also shown are the Reynolds number limits achievable at the Mach 5.5 and 6.0 conditions. At the higher Mach numbers the maximum unit Reynolds number will be about 10 million per foot. The higher temperature air resulting from the heater addition required a water spray system to be installed in the diffuser section. This system lowers the air temperature to no more than 610 °R before discharging into the central exhaust system. The upgrade modifications are nearing completion and the facility is expected to be at full operational capability by August 1989.

Propulsion Systems Laboratory

The Propulsion Systems Laboratory (PSL) is NASA's only altitude engine test facility. PSL is capable of testing large-scale airbreathing engine systems under simulated altitude, temperature, and pressure conditions. PSL became operational in 1973. A schematic of PSL is shown in Fig. 3. The facility consists of two test chambers, designated PSL-3 and PSL-4. Both chambers are 39 ft in length and 24 ft in diameter. Each test leg consists of an inlet section, test chamber, and exhaust section. The two exhaust sections are joined to a common exhaust plenum chamber, primary cooler, and spray cooler. Both chambers contain thrust beds with a maximum thrust limit of 100,000 lb. Each test leg is connected to the NASA Lewis central exhaust system. The inlet air system provides a range of airflow up to 80 lb/sec over a range of pressure from 1 to 100 psia. Elevated inlet temperature is provided by a vitiation of gaseous-hydrogen-fueled air-heater which allows control of temperature from 560 to 3460 °R. The air heater is a four-burner design with each burner being supplied by a separate, controllable inlet air supply. A gaseous oxygen injection system provides make-up oxygen to compensate for the combustion process. Downstream of the heater a chamber provides settling time and allows mixing of the inlet air. The test article draws air from the settling chamber through a bellmouth duct system. The design envelope for the Mach 6 modification is shown in Fig. 7 superimposed on the original capability. Correct inlet stagnation conditions are provided to the inlet of a test article in direct-connect mode up to Mach 6 within a range of dynamic pressure between 100 and 1000 psf.

A new high-energy propellant transfer and supply system was provided to supply gaseous hydrogen and gaseous oxygen to the inlet air heater and the test article. Gaseous hydrogen and gaseous oxygen are available to the test article at 2.75 and 3.0 lb/sec, respectively, at a pressure of 1000 psig. The allowable run time in the Mach 3 to 6 range is determined by the propellant storage capacity. At maximum design propellant transfer rates, 30 to 60 min of run time are achieved. In addition, kerosene fuels and high pressure methane are available to the test article. Because of the addition of gaseous hydrogen to PSL, a number of safety measures needed to be incorporated. There was particular concern in unburned hydrogen passing into the central exhaust system. Hydrogen detectors and dilution air were added at various places in the test chamber and in the exhaust system. Hydrogen/air torches were also provided in the test cell and exhaust system to flare any unburned hydrogen. Because of hydrogen flame propagation limits, the test article exhaust pressure is maintained at 5 psia and above to assure that the flare torches will consume any unburned hydrogen. Assuming that the test article exit nozzle is choked, this exhaust pressure limitation does not significantly impact the flight simulation since the correct inlet stagnation conditions are set.

By the fall of 1988 the Mach 3 to 6 modifications were completed and checkouts initiated. The checkouts were performed using a hollow pipe (designated the "hot-pipe") which incorporated a calibrated Supersonic Tunnel Association nozzle at the exit. The "hot-pipe" test program demonstrated operational status of all facility modifications and allowed tailoring to provide the desired flow quality at the test article inlet. Thrust and airflow accuracies approached the design goal of 1 percent. Radial and circumferential variations of total temperature and total pressure at the test article inlet also approached the design goal of 1 percent.

HyPERSONIC Tunnel FaciILITY

The Hypersonic Tunnel Facility (HTF) is a Non-viti1ated, blowdown, free-jet facility capable of testing large-scale hypersonic engines and/or components at Mach numbers of 5, 6, and 7. HTF is located at NASA Lewis' Plum Brook Station approximately 50 miles west of Cleveland. The facility is
capable of true, temperature, altitude, and air com-
position simulation. Figure 8 shows an aerial view
and Figure 9 shows a schematic of HTF. The key
reactivation activities have been underway to
address some of the identified long-lead items.

Two key activities of HTF: The first is reactiva-
tion of HTF is a gaseous nitrogen induction storage heater
that is designed to provide maximum heat exit
flow conditions of about 130 lb/sec, 1200 psia, and
5000 °R. Downstream of the heater cold gaseous
oxygen and cold gaseous nitrogen are injected into the
high temperature gaseous stream to provide a sim-
luted air composition and test section. The
stagnation temperature to the nozzle inlet. There
are interchangeable Mach 5, 6, and 7 nozzles, each
having an exit diameter of 42 in. The inviscid
core diameter of the three nozzles is about 2 ft.
The test chamber is 25 ft in diameter and 20 ft
high. The test chamber is evacuated using a
single-stage steam ejector. A diffuser is used to
provide additional pumping capability to achieve a maximum 120 000 ft altitude condition. The test
chamber contains a model injection system and a
thrust mount assembly. The free-jet length of the
test chamber can be adjusted by translating the
diffuser. The maximum length is about 10 ft. Five
gaseous hydrogen roadable tube trailer stations are
available for gaseous hydrogen fuel. The gaseous
induction storage heater is capable of heating
2.5 lb/sec from ambient temperature to 1660 °R for
90 sec. The design operating envelope for HTF is shown in Fig. 10. Altitude is plotted against Mach
core number. Lines of nozzle inlet stagnation tempera-
ture and stagnation pressure are also shown. The
design operating envelope spans from 68 000 to
120 000 ft altitude, 70 to 1200 psia nozzle inlet
stagnation pressure, and 2200 to 4200 °R nozzle
inlet stagnation temperature. The operating enve-
lope is constrained by the limiting factors shown.
Over the range of flow conditions, run times from 42 sec to about 5 min are achievable.

HTF originally became operational in 1971.
From January 1972 to May 1974 the Aerothermody-
namic Integration Model (AIM) version of the Hypersonic
Research Engine (HRE) was installed, checked out,
and tested. Overall, there were 52 tests with an
accumulated total test time of about 112 min.
Approximately 30 min of this time was at Mach 7,
although true temperature simulation of 3700 °R at
Mach 7 was not achieved due to degradation of the
carbon insulating felt in the induction storage
heater. This problem was not resolved at the time
due to priority demands to complete the test pro-
gram. At the completion of the HRE test program
HTF was placed in a standby condition. The key
stimulus for considering reactivation of HTF was the
evolution of the NASP. Due to its being inactive
for almost 13 years, a detailed reactivation study
was conducted in 1986. The thrust of this
study was to determine the cost estimate to reactiv-
ate HTF to its original design operating capabili-
ties. Facility modifications were included in the
cost estimate. Prime interest was placed in ensur-
ing reliable induction storage heater performance.
Two other concerns were recertification of all of the
facility pressure vessels and resolution of a
minor model erosion problem that occurred during
testing of the HRE. Reference 3 describes in more
detail the capabilities and history of HTF and the
results of the reactivation study. In 1987, the
results of the HTF reactivation study were inte-
grated into the NASA Wind Tunnel Revitalization
Program. A FY 1990 Construction of Facilities
(CoF) discrete project will provide $4.1 million
of reactivation funding. Since 1987, low-level

21-in. Hypersonic Wind Tunnel

The 21-in. Hypersonic Wind Tunnel (HWT) is a con-
tinuous-flow, variable-density, aerodynamic tun-
nel that utilizes a two-dimensional flexible nozzle
to provide an infinite choice of test section Mach
numbers from 4 to 11. Figure 11 is a photograph of
the nozzle and test section looking upstream.
Fig-
ure 12 shows a schematic view of the HWT. The
tunnel is closed-loop and contains its own four
stage compressor package. The compressor is capable of heating
maximum 650 psia to the supply section. The supply
air temperature can be varied up to 1810 °R using an
electric heater. The test section Mach number is
established by shimming the nozzle throat to the
required dimension and then adjusting the upper and
lower walls from the throat to the nozzle exit to
provide smooth continuous surfaces. The adjust-
ments are manually performed using hydraulic actua-
tors. This procedure for accurately contouring the
nozzle walls provides high-quality flow to the test
model. The test section is 21 in. wide at the
downstream end and 15 to 28 in. high depending on
the Mach number being set. The test section
length is approximately 6 ft. The test section
sidewalls are removable providing easy access to
the test model. A crescent-type model support sys-
tem provides remote control of the model angle-of-
attack over a 30° range. A diffuser provides
pumping capability to allow simulation of a test
section altitude range from 85 000 to 220 000 ft.
The diffuser throat to the test section Mach number was at Mach 7 for
that time. A tunnel inlet cooler reduces the air temperature to
about 560 °R before the air is routed back to the
compressors.

The 21-in. HWT became operational at the Jet
Propulsion Laboratory (JPL) in 1959. The HWT was
used in support of a variety of Department of
Defense and NASA missile and space vehicle pro-
grams. Basic research programs were conducted to
investigate turbulent boundary layer development
and laminar boundary layer tripping and stability.
The HWT ceased operation in 1975 and was left in a
standby condition. Interest was generated in 1987 in
reactivating the HWT to support the NASP. How-
ever, reactivation of the HWT was not pursued and
consideration was given to moving the HWT to
another NASA center. NASA Lewis aggressively pur-
sued obtaining the HWT for three primary reasons.
First, with NASA Lewis' efforts to expand its aero-
nautics propulsion research program to higher Mach
core numbers the HWT becomes an excellent aerodynamic
test facility to conduct sub-scale model experi-
ments and high-quality validation experiments for
computational fluid dynamics flow code development.
Secondly, the HWT is in good condition and pos-
sesses excellent capabilities - large Mach and
Reynolds number ranges coupled with excellent flow
quality. The operating envelope as shown in Fig. 13. Thirdly, acquisition of the HWT is considered to be timely and cost effective - the replacement cost is projected to be over three times the rehabilitation cost. As a result of its advocacy efforts NASA Lewis was given approval and funding to dismantle and ship the tunnel components. In the last half of 1988 the entire tunnel loop, including drive compressors, was dismantled and shipped. The components presently are being stored at NASA Lewis' Plum Brook Station until funding is approved to reconstruct the tunnel at NASA Lewis. Currently, a FY 91 CoF project is being advocated to provide the funding to reconstruct the HWT. The cost estimate is approximately $11 million. Over the past several months a tunnel site study was conducted and a site selected. Work is currently underway to conduct the detailed engineering studies and designs required to support the CoF project. Based on current schedules, the 21-in. HWT would become operational by mid-1993.

Concluding Remarks

This paper was intended to provide a brief summary of activities underway at NASA Lewis Research Center to develop new high-speed (hypersonic) facility capability to support a variety of evolving research programs. While none of these new facility capabilities may be singularly unique within the industry, they collectively enable NASA Lewis to significantly expand its in-house research activities in the high-speed area and at the same time provide quality test facilities for cooperative programs with industry, academe, and other government agencies.

References

- 21 IN. HYPERSONIC WIND TUNNEL
- HYPERSONIC TUNNEL FACILITY
- PROPULSION SYSTEMS LAB
- 1 FT BY 1 FT SUPersonic WIND TUNNEL
- 10 FT BY 10 FT SUPersonic WIND TUNNEL
- 8 FT BY 6 FT SUPersonic WIND TUNNEL
- 2 FT HIGH SPEED TUNNEL
- ICING RESEARCH TUNNEL
- 9 FT BY 15 FT LOW SPEED WIND TUNNEL

FIGURE 1. - MAJOR PROPULSION TEST FACILITIES AT LEWIS.
FIGURE 3. - 1 FT BY 1 FT SUPERSONIC WIND TUNNEL TEST SECTION.
FIGURE 4. - 1 FT BY 1 FT SUPERSOONIC WIND TUNNEL OPERATING ENVELOPE.
FIGURE 5. - PROPULSION SYSTEMS LABORATORY SCHEMATIC.
FIGURE 6. - PSL-4 DIRECT-CONNECT MODIFICATIONS.

FIGURE 7. - PSL OPERATING ENVELOPES.
FIGURE 8. - HTF AERIAL VIEW.

FIGURE 9. - HTF SCHEMATIC VIEW.
Figure 10. - HTF operating envelope.

Figure 11. - 21 in. hypersonic wind tunnel nozzle and test section.
COMPRESSOR PLANT

FIGURE 12. - 21 IN. HYPERSONIC WIND TUNNEL AIRFLOW SCHEMATIC.
Figure 13. - 21 in. Hypersonic Wind Tunnel Operating Envelope.
Four facility activities are underway at NASA Lewis Research Center to develop new hypersonic propulsion test capability. Two of these efforts consist of upgrades to existing operational facilities. The other two activities will reactivate facilities that have been in a standby condition for over 15 years. This paper discusses these four activities and describes the new test facilities NASA Lewis will have in place to support evolving high-speed research programs.