NASA Technical Memorandum 89918
AIAA-87-1886

Reactivation Study for NASA Lewis Research Center's Hypersonic Tunnel Facility

Jeffrey E. Haas
Lewis Research Center
Cleveland, Ohio

(NASA-TM-89918) REACTIVATION STUDY FOR NASA LEWIS RESEARCH CENTER'S HYPERSONIC TUNNEL FACILITY (NASA) 14 p Avail: NTIS HC A02/MF A01 CSCL 14B

N87-23664
Unclas
H1/09 0079704

Prepared for the
23rd Joint Propulsion Conference
cosponsored by the AIAA, SAE, ASME, and ASEE
San Diego, California, June 29—July 2, 1987

NASA

E-3614

REACTIVATION STUDY FOR NASA LEWIS RESEARCH CENTER'S HYPERSONIC TUNNEL FACILITY

Jeffrey E. Haas
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

SUMMARY

The Hypersonic Tunnel Facility (HTF) at NASA Lewis Research Center's Plum Brook Station is a blowdown, free-jet, nonvitiated propulsion facility capable of Mach 5, 6, and 7 with true temperature, altitude, and air composition simulation. The facility has been in a deactivated status for 13 years. This paper discusses the capabilities of HTF and summarizes the results of a reactivation study that was recently conducted to determine the cost, schedule, and technical effort required to restore HTF to its original design operating capabilities.

INTRODUCTION

Over the past several years renewed interest has been generated in hypersonic flight. This interest has been stimulated primarily by the evolvement of the National Aerospaceplane Program (NASP). To support NASP a broader experimental data base is required in a variety of areas, including propulsion, structures, aerodynamics, aerothermal management, and propulsion integration. However, in the propulsion area, there are few facilities currently available in which to test full or large-scale hypersonic propulsion systems and the components of these systems. Many of the facilities that exist are old and have been in a standby mode for a number of years. Upgrading of these facilities is required. One facility that has been deactivated for almost 13 years and is available for hypersonic propulsion testing is the Hypersonic Tunnel Facility (HTF) at NASA Lewis Research Center's Plum Brook Station. This facility is unique in that it is the largest nonvitiated hypersonic propulsion facility with demonstrated capability. The facility is capable of Mach 5, 6, and 7 with true temperature, altitude, and air composition simulation.

Because of the need for hypersonic propulsion facilities for NASP and the belief that HTF could play a key role in that program, a detailed study was conducted from March to June 1986 to determine the cost, time, and technical effort required to reactivate HTF. This paper will discuss the capabilities of HTF, review the history of the facility, and summarize the results of the reactivation study and the current facility status.

FACILITY DESCRIPTION

General Description

The Hypersonic Tunnel Facility (HTF) at Lewis Research Center's Plum Brook Station is a nonvitiated, blowdown, free-jet facility capable of testing large-scale hypersonic engines and models at Mach numbers of 5, 6, and 7. The facility is capable of true temperature, altitude, and air composition simulation. Figure 1 shows an aerial view and figure 2 shows a schematic view of the facility. The heart of the facility is a gaseous nitrogen (GN_2) induction storage heater that is designed to provide maximum heater exit flow conditions of about 130 lb/sec, 1200 psia, and 4500 °R. Downstream of the heater cold gaseous oxygen and cold gaseous nitrogen are injected into the high temperature gaseous stream to provide a simulated air composition and the correct inlet 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. The ejector evacuates the test chamber to a 1.3 psia pressure level. A diffuser is used to provide additional pumping capability to reach 0.07 psia (120 000 ft altitude). The test chamber contains a model injection system and a thrust mount assembly. The model injection system is designed to handle research packages weighing up to 16 000 lb. The system pivots on bearings mounted at the top of the test chamber. The vertical centerline swings 22.5° off-center, moving the model centerline 4 ft. The thrust table is designed to handle an 8500 lb thrust load and can be pitched from the aft to achieve an angle of attack to 5°. The table can be translated axially about 2.5 ft to allow insertion of a model into the rhombus area of the nozzle. The free-jet length of the test chamber can be adjusted by translating the diffuser. The maximum length is about 10 ft.

Referring to figure 1, the steam supply system for the ejector originates approximately 3000 ft away from HTF. The boiler house equipment consists of four operational boilers each capable of supplying 25 000 lb/hr of saturated steam at 500 psig to five accumulators. The accumulators each supply 28 900 lb of steam when discharging from 500 psig saturated steam to 200 psig saturated steam. The steam consumption for the HTF ejector is 500 lb/sec at 130 psig. The control room for HTF is about 1500 ft off to the left of figure 1. Also shown in figure 1 is some of the gas and cryogenic storage. A fixed oxygen gas storage of 500 000 standard ft^3 at 2400 psig is available for mixing with high temperature nitrogen to provide simulated air. Five gaseous hydrogen tuber stations are available for engine fuel with a total capacity of 350 000 standard ft^3 at 2400 psig. A gaseous hydrogen pebble bed resistance heater is capable of heating 2.5 lb/sec from ambient temperature to 1660 °R for 90 sec. For engines using liquid hydrogen as a fuel a 6000 gal super insulated, vacuum jacketed high pressure storage dewar is available. A key part of the facility that is not shown in figure 1 is a portable gaseous nitrogen railcar having a capacity of 726 000 standard ft^3 at 5000 psig. This railcar is the gaseous nitrogen supply for the induction storage heater. The railcar was removed from the site about 1980 and is presently being used at the NASA National Space Technology Laboratory (NSTL) in Bay St. Louis, MS. Additional facility description is contained in reference 1.

Graphite Induction Heater

A schematic of the graphite induction storage heater is shown in figure 3. The heater consists of a stacked array of 15 drilled graphite cylinders, each 6 ft in diameter and 2 ft high. The blocks are aligned with hexagonal key blocks. A typical graphite section and key block are shown in figure 4. There are approximately 1100 drilled holes in each block. The graphite core assembly is thermally insulated with an approximate 7-in.-thick layer of carbon felt and a 2-in.-thick silicon carbide tile wall. Water-cooled copper induction coils are located around the tile wall. A steel pressure vessel contains the entire heater assembly. Power to the coils is a maximum 3 MW. Downstream of the heater in the horizontal hot train piping (fig. 2) a shutter valve isolates the heater from atmospheric oxygen during periods of heating the graphite core. In operation, the graphite blocks are heated very slowly (~30 °R/hr above 2500 °R) to avoid thermal-induced cracking. During the heating cycle, a 5 psig nitrogen purge is maintained in the heater. When the blocks are at the prescribed temperature the upstream shutter valve and the valve between the heater and portable railcar are opened. The ambient gaseous nitrogen enters the bottom of the heater (fig. 3) and pressurizes the space between the tile wall and external shell. The nitrogen is routed back to the bottom of the heater where it flows through the holes in the blocks and is heated. The flow exits the heater and makes a right-hand turn (fig. 2). The piping between the heater exit and shutter valve is carbon-lined and water cooled. Diluent oxygen and nitrogen are added at the diluent injection flange to create synthetic air and to control the inlet stagnation temperature to the nozzle.

Operating Envelope

The design operating envelope for HTF is shown in figure 5. Altitude is plotted against Mach number. Lines of nozzle inlet stagnation temperature 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 envelope is constrained by the limiting factors shown. The stagnation pressure limit of 1200 psia is based on the maximum allowable GN_2 induction heater operating pressure. The mixture temperature limit is based on the maximum allowable GN_2 heater exit temperature. The mass flow limit is based on the maximum allowable GN_2 heater flow rate. The altitude limit is established by the minimum pressure attainable with the steam ejector system. A summary of the flow conditions at the three Mach numbers is shown in table I. At each Mach number the minimum and maximum design flow conditions are tabulated for the nozzle and the test section. The nozzle flow rate includes the combined hot nitrogen flow and the diluent flow. Over the range of flow conditions run times from 42 sec to about 5 min are achievable.

HTF HISTORY

The history of HTF spans approximately 5 years. In 1966 the facility was initially constructed as a hydrogen heat transfer facility. From June 1969 to June 1971 modifications were made to convert the facility to a hypersonic tunnel. The major modifications were the addition of the horizontal hot train piping and nozzles, the test chamber, the steam ejector, and the conversion of the induction storage heater from a pebble-bed design to the drilled graphite core design. From June 1971 to December 1971 the facility was calibrated. The facility nozzles were calibrated over a range of stagnation pressure and temperature from 200 to 1000 psia and 1980 to 3150 °R. Vertical and horizontal surveys of Mach number were made for each nozzle and a gas sample to determine the test gas composition was obtained at Mach 6. The results from these calibration tests are discussed in reference 1. From January 1972 to October 1973 the Hypersonic Research Engine (HRE) was installed and checkout runs were made.

The HRE Project was initiated for the purpose of advancing the technology of airbreathing propulsion for hypersonic flight. The internal aerodynamic performance tests were conducted in HTF on a full-scale, water-cooled, gaseous hydrogen fueled version of the HRE called the Aerothermodynamic Integration Model (AIM). The purpose of the tests in HTF was to integrate the aerothermodynamic components (inlet, combustor, and nozzle) and to assess the engine performance at Mach numbers of 5, 6, and 7. For these tests the gaseous hydrogen was heated to 1500 °R prior to injection to simulate a regeneratively cooled system. A photograph of the HRE installed in HTF without the external shrouding is shown in figure 6. The engine was an axisymmetric model with a translating spike. The engine was 18 in. in diameter at the cowl and 87 in. long. During the tests the engine was nearly completely enshrouded, except for an 11-in. gap between the facility nozzle exit and the front of the shroud. The combined model and strut blockage was about 50 percent.

The HRE test program was conducted from October 1973 to May 1974. A summary of the test conditions is shown in table II. Overall, there were 52 tests over a span of about 112 min. Approximately 30 min of this time was at Mach 7. It should be noted that true temperature simulation of 3700 °R at Mach 7 was not achieved. At the completion of the Mach 7 testing a maximum temperature of only about 3000 °R could be obtained. This decreased temperature was attributed to GN_2 induction heater deterioration and a lack of time to implement necessary repairs. This heater deterioration problem will be discussed later. In spite of this heater problem, as well as minor foreign object damage caused by eroded carbon duct liners, the HRE test program was considered successful. Besides obtaining a large data base which helped to advance the state-of-the-art in hypersonic propulsion, valuable experience was acquired in free-jet testing in a ground test facility with large model blockage and combustion. References 2 to 5 present a detailed summary of the HRE AIM test results. At the completion of the HRE test program, HTF was placed in a standby condition. As will be discussed in the next section, the facility remained in a standby mode until a reactivation study was initiated in March 1986.

REACTIVATION STUDY

From the early 1970's until 1985 there was little interest in hypersonic propulsion or hypersonic flight. As a result, a number of hypersonic propulsion facilities were placed in standby condition. The key stimulus for the revival in hypersonic flight was the evolvement of the National Aerospaceplane Program (NASP). Along with this revival is the need to reactivate existing hypersonic facilities, as well as to construct new facilities. Because HTF has remained the largest nonvitiated hypersonic propulsion facility with demonstrated capability in spite of being inactive for about 13 years, interest was generated to consider reactivation of HTF. It was evident that after the years of inactivity, a detailed study was required to determine the cost, schedule, and technical effort required to reactivate HTF. In March 1986 a $120 000 4-month reactivation study was initiated by the Aeropropulsion Facilities and Experiments Division of NASA Lewis' Aeronautics Directorate. Two key assumptions were made at the outset of the study. First, only facility related costs were to be included. No model related costs were considered. Secondly, the study was to determine the minimum cost necessary to reactivate HTF. Wherever possible, rehabilitation or repair of facility systems hardware was to be considered rather than replacement. The major inspection items during the course of the study were the GN_2 induction storage heater, the hot train components, the steam system, the instrumentation, control and data systems, the process and electrical systems, and the facility structure. In addition, four other concerns needed to be addressed. First, because of the previously stated problem with the GN_2 induction heater, the need to assess the reasons for the heater deterioration was considered critical. In order to return HTF to its original design operating capabilities, reliable heater operation is deemed essential. Secondly, the cause for the previous HRE model erosion problem needed to be resolved. Good flow quality is necessary for propulsion testing. Thirdly, because of the large number of 15 to 20 year old pressure vessels in use at HTF, recertification of these vessels needed to be included. Finally, environmental concerns needed to be addressed. The steam accumulators and about half of the steam line are asbestos insulated. Over the years this insulation has deteriorated and needs to be replaced. In addition, a number of polychlorinated biphenyl (PCB) transformers and capacitors need to be cleaned or replaced.

REACTIVATION STUDY FINDINGS AND CONCLUSIONS

The reactivation study was completed in June 1986. All of the facility systems were found to be in good condition. No "show stoppers" were uncovered. The study concluded that the HTF systems components can be repaired or replaced to bring the facility back to its original design capabilities. In addition, the previous GN_2 induction heater integrity and model erosion problems were studied and solutions proposed. The overall cost to reactivate HTF was estimated to be about $4.6 million. The minimum reactivation time would be 16 months. This includes 12 months to rehabilitate the facility systems, two months to conduct an integrity systems checkout, and two months to conduct about four hot blowdowns with calibration rakes installed to reestablish the baseline flow quality.

The annual operating costs once HTF is fully reactivated were also estimated during the study. Two separate estimates were made, one based on 25 runs per year and the other based on 100 runs per year. For the 25 runs per year case, the estimated cost per run would be $77,000. This includes the cost of the consummables (oxygen, nitrogen, fuel oil), electrical power to run the induction heater, and the manpower support to operate the facility. For the 100 runs per year case, the cost per run would be reduced to $31 000. The difference between the two cases is due to the fact that when the facility is operated on a more frequent basis, the steam accumulators and the induction heater are maintained in a standby status. This significantly reduces the cost of the fuel oil to heat the steam boilers and the electrical power for the induction heater.

Significant time was devoted to the two previous facility problems. During the study the top eight graphite blocks in the heater were removed. These eight blocks are at the hottest temperature during operation. Inspection of the heater after disassembly showed that the heater problem was due to a serious deterioration of the carbon insulating felt (fig. 3) that existed down to the eighth block level. The deterioration was attributed to two sources. First, leaks existed in the water-cooled induction heating coils. When the heater was at elevated temperatures a serious chemical attack of the water on the carbon felt resulted. Felt integrity is critical to maintaining heater integrity. The hot insulating felt was particularly vulnerable because of its large surface to volume ratio. A second problem source was oxygen contamination in the gaseous nitrogen from the railcar. A review of facility logbooks from the HRE test program showed that only random samplings for oxygen contamination were made and one or two of these samplings indicated higher than desired contamination levels. However, the water leaks and oxygen contamination did not appear to have a deleterious effect on the 15 graphite blocks. Nevertheless, one of the blocks was cracked and needs to be replaced. A three-part solution to the heater problem was proposed. Graphite felt should be used as an insulator rather than carbon felt. When the graphite felt is manufactured it goes through additional heat treatment and is more impervious to any water or oxygen attack. In addition, an alternate cooling media for the induction heater coils should be considered. A Freon-based system could be used instead of a water system. In the event of a leak the Freon would be inert and not attack the felt. Thirdly, constant oxygen monitoring in the heater and in the gaseous nitrogen supply line to the heater is required. Oxygen contamination no greater than 10 parts per million can be tolerated.

The model erosion problem was also studied in detail. The source of the problem was major erosion of the carbon liner in the piping upstream of the shutter valve (fig. 2). During disassembly of the hot train piping about a 1-ft length of this liner was missing and another 1-ft length significantly eroded. The liner erosion was attributed to water flashback during facility shutdown after a test run. The shutter valve is slow-closing (about 30 sec to close) and was designed to accept no differential pressure. As a result, as the ejector was being shutdown and the pressure began rising in the test chamber, backflow would occur. Steam from the ejector, as well as water from the spray-ring in the diffuser and from leaks in the water-cooled engine would flow back up the hot train piping. Since the shutter valve was slow closing, the water would go past the valve and impinge on the hot carbon liner. The liner seriously eroded and during subsequent runs the carbon particles would be blown back down the tunnel and impinge on the model. This water flashback was also considered a possible additional cause for the heater carbon felt deterioration problem. The solution to this erosion problem is to add a valve in the hot train piping immediately downstream of the existing shutter valve. This second valve would be designed to accept a higher differential pressure (about 150 psia) and would be fast-closing. A rescheduling of the operational facility shutdown procedures could also be done. With the addition of this backup valve water flashback would not be allowed to impinge on the carbon liners.

CURRENT FACILITY STATUS

At present, a minimum reactivation effort is underway. Several of the cricital-path activities are being addressed. The induction heater is being completely disassembled. The graphite blocks will be rehabilitated and replacement graphite felt purchased. The previous heater problem is being restudied to ensure that the proper solutions are selected. The large gaseous nitrogen railcar is being returned from NSTL, repaired and recertified. The hot train components are being rehabilitated. Final designs are underway for the additional hot train valve and the new cooling system for the induction heater coils. No commitments exist for the balance of the required reactivation funding. However, it is hoped that funding will be made available to allow resumption of operation in HTF in the 1989 or 1990 timeframe.

CONCLUDING REMARKS

The Hypersonic Tunnel Facility is an unique facility whose capabilities are suitable for a variety of hypersonics programs in the areas of propulsion, structures, aerodynamics, aerothermal management, and propulsion integration. To date, there is no heater system being proposed that provides higher temperature simulated air conditions than HTF was designed to provide. HTF would not only be suitable to support NASP, but also could support a supersonic cruise propulsion program. Even though the facility is not yet reactivated, plans are being developed to expand the operational envelope. Costs are being determined to purchase a Mach 4 free-jet nozzle and also to modify the facility to provide a Mach 10 direct-connect capability. For this Mach 10 capability, a vitiated heater would be installed downstream of the induction heater to provide Mach 10 enthalpies. New two-dimensional nozzles would also be installed in the Mach 3 to 3.5 range. This expanded capability would provide the ability to study the effects of vitiation on supersonic combustion.

REFERENCES

1. Cullom, R.R. and Lezberg, E.A., Calibration of Lewis Hypersonic Tunnel Facility at Mach 5, 6 and 7," NASA TN D-7100, 1972.

2. Andrews, E.H. Jr. and Mackley, E.A., "Hypersonic Research Engine/Aerothermodynamic Integration Model - Experimental Results. Vol. I - Mach 6 Component Integration," NASA TM X-72821, 1976.

3. Andrews, E.H. Jr. and Mackley, E.A., "Hypersonic Research Engine/Aerothermodynamic Integration Model - Experimental Results. Vol. II - Mach 6 Performance," NASA TM X-72822, 1976.

4. Andrews, E.H. Jr. and Mackley, E.A., "Hypersonic Research Engine/Aerothermodynamic Integration Model - Experimental Results. Vol. III - Mach 7 Component Integration and Performance," NASA TM X-72823, 1976.

5. Andrews, E.H. Jr. and Mackley, E.A., "Hypersonic Research Engine/Aerothermodynamic Integration Model - Experimental Results. Vol. IV - Mach 5 Component Integration and Performance," NASA TM X-72824, 1976.

TABLE I. - HTF FLOW SUMMARY

Mach number	Nozzle					Test section			
	Pressure, psia	Temperature, °R	Flow, lb/sec	Throat diameter, in.	Exit diameter, in.	Static pressure psia	Static temperature, °R	Altitude, 1000 ft	Run time
5	410 70.5	2200 2420	189 30.9	7.2 7.2	42	0.74 .118	384 428	68 108	103 sec 4.9 min
6	1200 144	2965 3310	222 25.4	4.9 4.9	42	.61 .071	390 451	72 120	42 sec 4.9 min
7	1200 430	3830 4190	104 36.19	3.5 3.5	42	.33 .071	412 451	93 120	90 sec 3 min

TABLE II. - HRE TEST SUMMARY

Mach number	Number of tests	Time at test condition, min	Stagnation pressure, psia	Stagnation temperature, °R
5	5	19.5	210/415	2210/3000
6	36	63.3	470/750/930	1500/3000
7	11	29.0	1000	3000/3500
Total	52	111.8		

- Test period
  - Mach 6 10/73 to 12/73
  - Mach 7 01/74 to 03/74
  - Mach 5 03/74 to 04/74

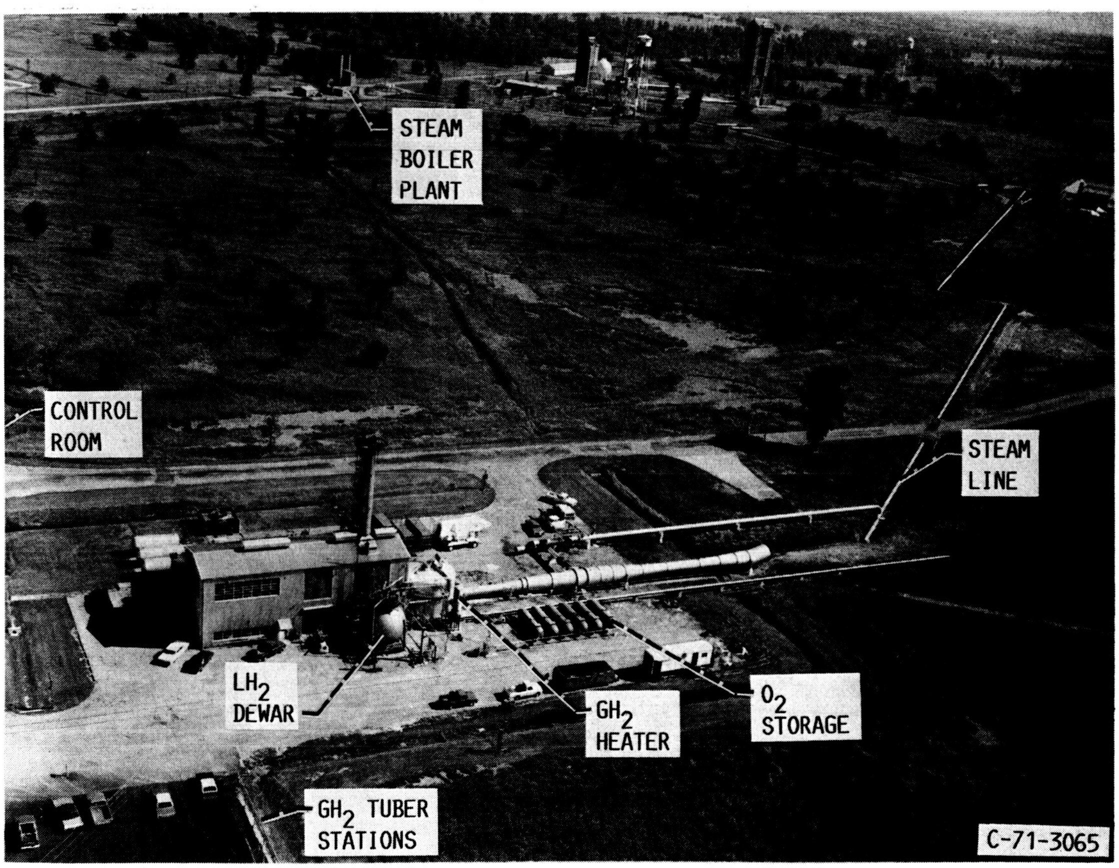
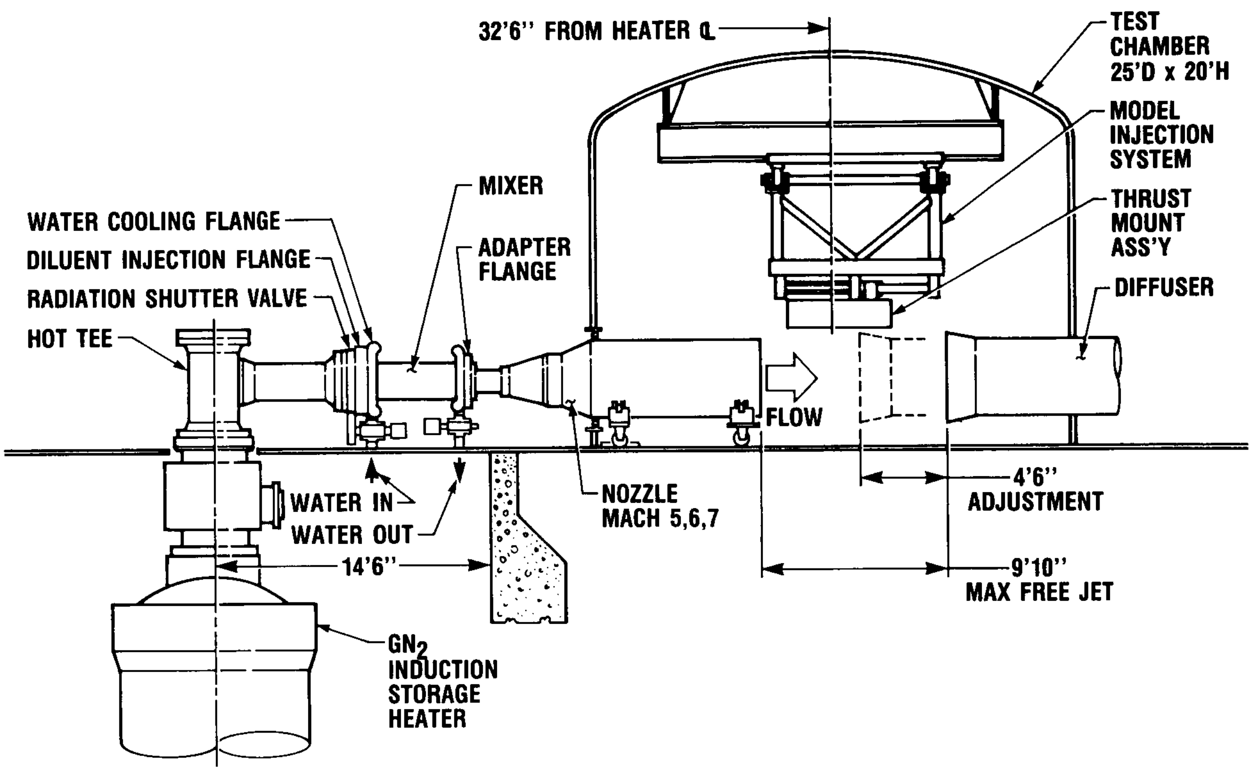
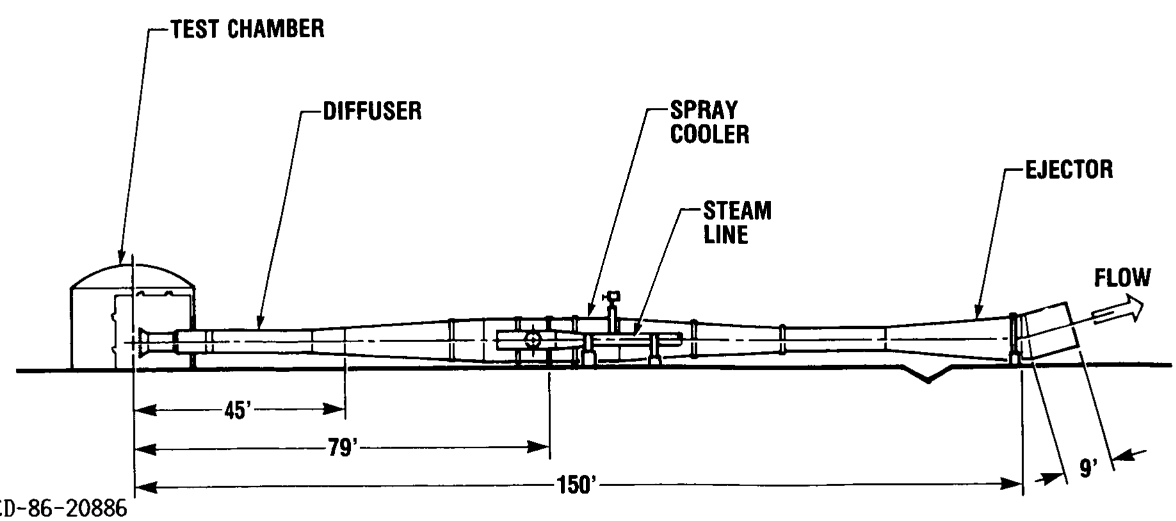


FIGURE 1. - HTF AERIAL VIEW.



(A) HOT TRAIN AND TEST CHAMBER.



CD-86-20886

(B) DIFFUSER AND EJECTOR.

FIGURE 2. - HTF SCHEMATIC VIEW.

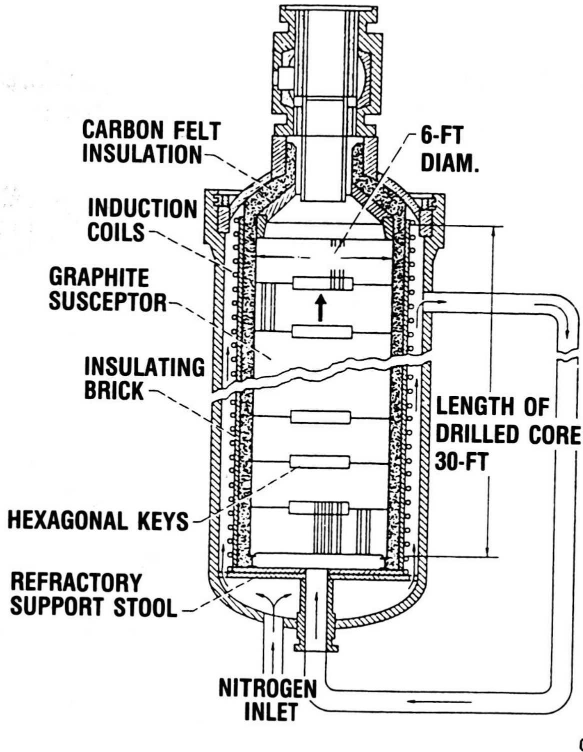


FIGURE 3. - NITROGEN INDUCTION STORAGE HEATER.

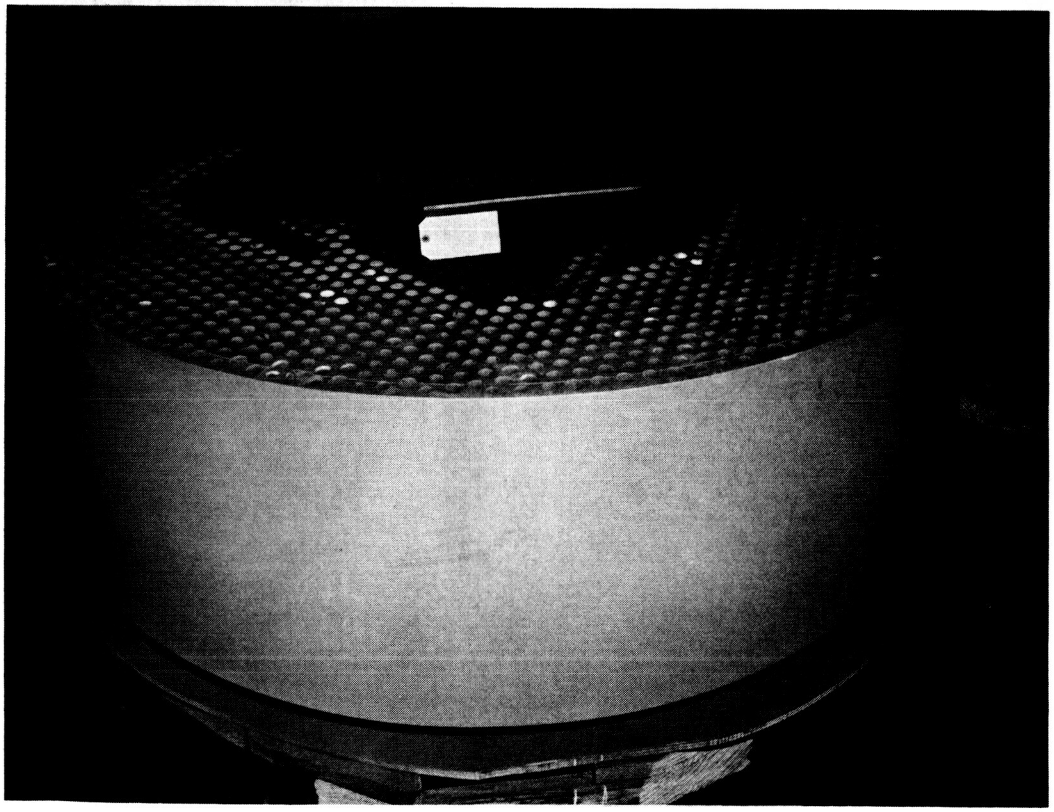


FIGURE 4. - GRAPHITE BLOCK FROM INDUCTION STORAGE HEATER.

ORIGINAL PAGE IS
OF POOR QUALITY

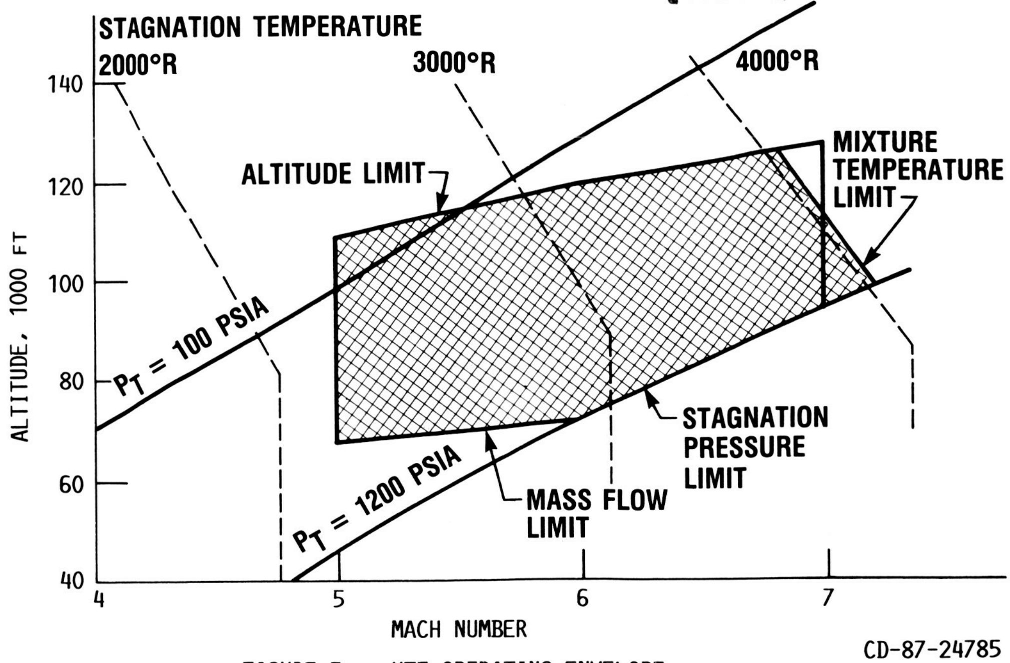


FIGURE 5. - HTF OPERATING ENVELOPE.

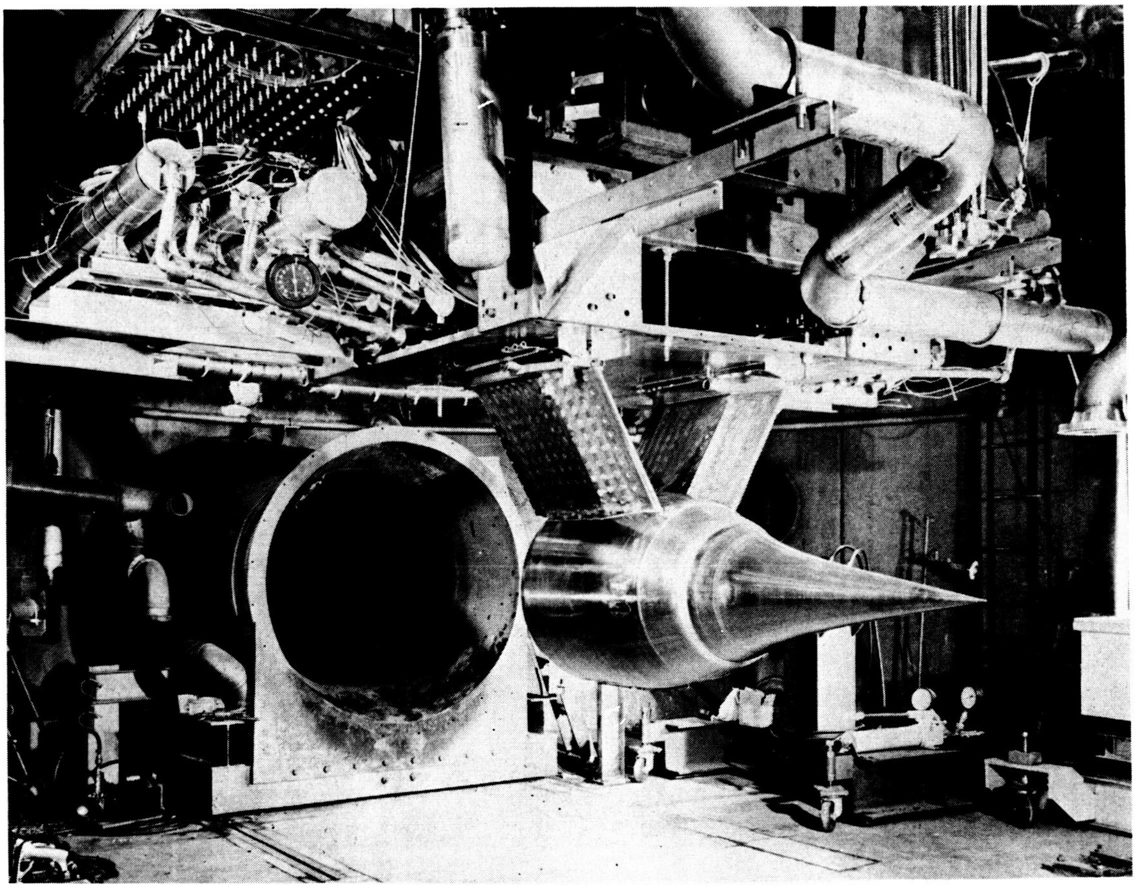


FIGURE 6. - HRE MODEL INSTALLATION.

1. Report No. NASA TM-89918 AIAA-87-1886	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Reactivation Study for NASA Lewis Research Center's Hypersonic Tunnel Facility		5. Report Date
		6. Performing Organization Code 505-62-3B
7. Author(s) Jeffrey E. Haas		8. Performing Organization Report No. E-3614
		10. Work Unit No.
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Prepared for the 23rd Joint Propulsion Conference cosponsored by the AIAA, SAE, ASME, and ASEE, San Diego, California, June 29 - July 2, 1987.

16. Abstract

The Hypersonic Tunnel Facility (HTF) at NASA Lewis Research Center's Plum Brook Station is a blowdown, free-jet, nonvitiated propulsion facility capable of Mach 5, 6, and 7 with true temperature, altitude, and air composition simulation. The facility has been in a deactivated status for 13 years. This paper discusses the capabilities of HTF and summarizes the results of a reactivation study that was recently conducted to determine the cost, schedule, and technical effort required to restore HTF to its original design operating capabilities.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Hypersonic test facilities Vitiation Induction storage heater	Unclassified - unlimited STAR Category 09

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
Unclassified	Unclassified	13	A02

*For sale by the National Technical Information Service, Springfield, Virginia 22161