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Test Planning Guide

for

ASF Facilities

Prepared by
Imelda Terrazas-Salinas
and
Charles Cornelison
Thermophysics Facilities Branch
Space Technology Division

NASA Ames Research Center
Moffett Field, CA 94035

Test Planning Guide

for

ASF Facilities

APPROVAL SIGNATURES		Date
Author:		
I. Terrazas-Salinas	*Signature on File*	*3/24/99*
Review and Approval Team as follows:		
G. Joseph Hartman	*Signature on File*	*3/24/99*
Scott G. Eddlemon	*Signature on File*	*3/24/99*

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B	Added section 1.3.1 Expanded section 3.2 Revised figures 2 and 3 Revised sections 1, 2, 3, and 4.1.4 to conform to standard ARC ISO use of "shall" and to reflect the revisions to figures 2 and 3 Revised section 4.1.4.2 and deleted table 6 Removed figure 28; renumbered figure 29 as 28; added new figure 29 Expanded section 4.1.4.5 to include slug calorimeters Removed appendices C and D Rearranged headers and footers	I. Terrazas-Salinas	3/24/99

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1.0 Introduction

The Thermophysics Facilities Branch of the Space Technology Division at NASA Ames Research Center, Moffett Field, CA, 94035 operates the Arc Jet Complex and the Range Complex for the investigation of atmospheric entry/high-velocity phenomena. The Ames Arc Jet Complex comprises four active arc jet facilities: the Aerodynamic Heating Facility (AHF), the Interaction Heating Facility (IHF), the Panel Test Facility (PTF), and the 2×9 Turbulent Flow Duct Facility (TFD). The Range Complex comprises the Hypervelocity Free-Flight Facility (HFFF), the Ames Vertical Gun Range (AVGR); and the Electric Arc Shock Tunnel (EAST).

1.1 Purpose

This Testing Guide shall serve as an Experimenter's Handbook for all experimenters proposing active investigations using the facilities of the Thermophysics Facilities Branch. Listed are the capabilities of the facilities, safety restraints, and operational procedures. With this manual, it is hoped that the prospective experimenter can design his/her tests to fit the capabilities of the respective facilities.

1.2 Scope

This document has been prepared to inform all personnel proposing experiments in the Thermophysics Facilities of the details regarding Facility capabilities and operational procedures. It is designed to be used in conjunction with the current safety and operational manuals of the respective facilities. Additional procedures are in place to ensure that data/product quality conforms to the ISO 9000 quality standards.

1.3 Location

The Thermophysics Facilities are located at various locations throughout the Center (see figure 1). The facilities of the Arc Jet Complex are located in Buildings N234 and N238. The Aerodynamic Heating Facility and the Turbulent Flow Duct Facility are located in Building N234; the Panel Test Facility and the Interaction Heating Facility are located in Building N238; Building N234A houses the boiler for the Steam Vacuum System. The telephone number for N234 facilities is (650) 604-5230; that for N238 facilities is (650) 604-5974. The Facility Manager for the Arc Jet Complex is Jerry Mitvalsky, (650) 604-6166.

The Range Complex currently comprises three facilities. The first of these facilities is the Hypervelocity Free-Flight Facility (HFFF). It is composed of the Hypervelocity Free-Flight (HFF) Aerodynamic Facility and the HFF Gun Development Facility. Both of these facilities are located in Building N-237. The telephone number is (650) 604-3443.

The second Range Complex facility is the Ames Vertical Gun Range. It is housed in Building N204A. The gun and test chamber are located in Room 102; the control console in Room 101; support machinery is in Room 201; and target fabrication equipment is in Room 101, Building N205. The telephone number is (650) 604-5526.

The third Range Complex Facility is the Electric Arc Shock Tunnel (EAST) Facility. It is housed in building N229. The shock tube is located in Room 157; the capacitor bank/power supply in Room 156; the control console in room 158A; and the laser lab in Room 160. The telephone number is (650) 604-5550.

The Facility Manager for the Range Complex is Charles Cornelison, (650) 604-3443.

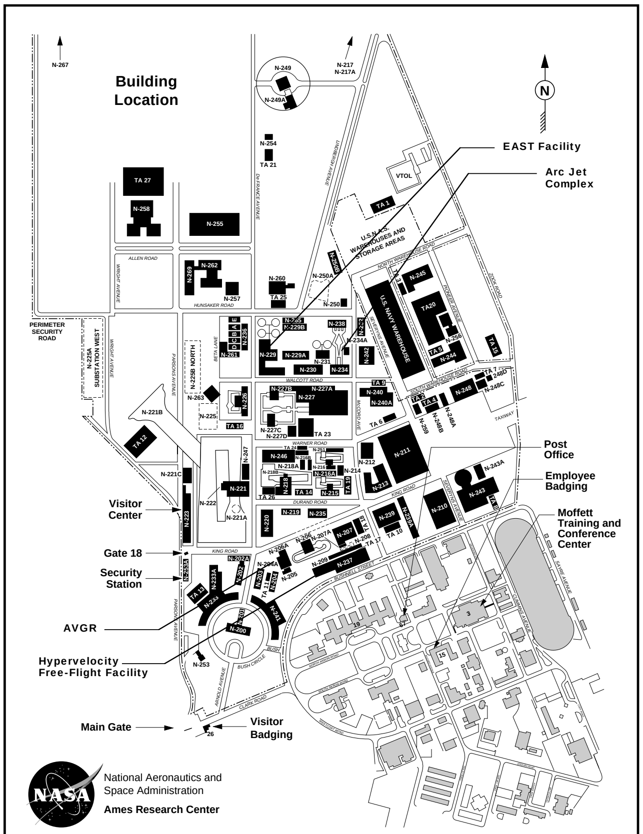

Figure 1. Ames Research Center.

1.3.1 Shipping Addresses

Test-related hardware shall be shipped to the attention of the test engineer or the facility manager at the respective test facility, as follows.

For tests in the AHF or TFD, the shipping address is
NASA Ames Research Center
Building 234 Room 112
Moffett Field, CA 94035-1000

For tests in the PTF or IHF, the shipping address is
NASA Ames Research Center
Building 238 Room 103
Moffett Field, CA 94035-1000

For tests in the HFFF, the shipping address is
NASA Ames Research Center
Building 237 Room 150
Moffett Field, CA 94035-1000

For tests in the AVGR, the shipping address is
NASA Ames Research Center
Building 204A Room 104
Moffett Field, CA 94035-1000

For tests in the EAST, the shipping address is
NASA Ames Research Center
Building 229 Room 157
Moffett Field, CA 94035-1000

2.0 Administrative Procedures

2.1 Administrative Authority

The Thermophysics Facilities Branch (Code ASF), in the Space Technology Division, is responsible for the safe and productive operation of these facilities. The Facility Manager enforces the established operating limits of the respective facility and has the authority to judge the acceptance of proposed test programs.

2.2 Test Approval and Scheduling Procedure

It is the policy of the Space Technology Division at NASA Ames Research Center to encourage the maximum utilization of the ARC Thermophysics Facilities within the limits imposed by safety, schedule, funding, and personnel availability.

The Thermophysics Facilities are managed by the Chief of the Thermophysics Facilities Branch. For all of these facilities, with the exception of the AVGR, all tests shall be requested to, and approved by the branch chief. Tests are placed on the facility schedules after receipt of an approved Request for Facility Usage Form. The schedules for the facilities of the Arc Jet Complex are maintained by the Group Leader of the Test Engineering Group; the schedules for the Range Complex are maintained by the facility manager or a branch-approved designee. The facilities are operated primarily to support government (in particular NASA) aerospace research and developmental testing.

The test initiation and approval process is illustrated in figure 2. The initial steps in the process are informal discussions aimed at determining the feasibility of a concept and, if feasible, which facility is appropriate. These technical discussions occur between ARC engineers and the proposing organization. The process includes examining the test objectives and evaluating the feasibility of accomplishing the objectives. The process continues with a determination of the appropriate facility to carry out the objectives. These activities are accomplished by means of discussions with the test requester, or as appropriate, through a (series of) Test Proposal Meeting(s), as illustrated in figure 2.

For more complex tests, more than one meeting might be required to discuss such points as facility suitability and proposed test approach. The end product of the meeting(s) shall be a completed Request for Facility Usage form, which summarizes the overall test concept, the objectives, and the proposed approach. This form is then submitted for Branch/Division approval as required.

The process then advances to the Test Development stage, described in Section 2.3.

2.2.1 AVGR

The AVGR is operated as a National Scientific Test Facility. As a national facility, policy guidance is formu-

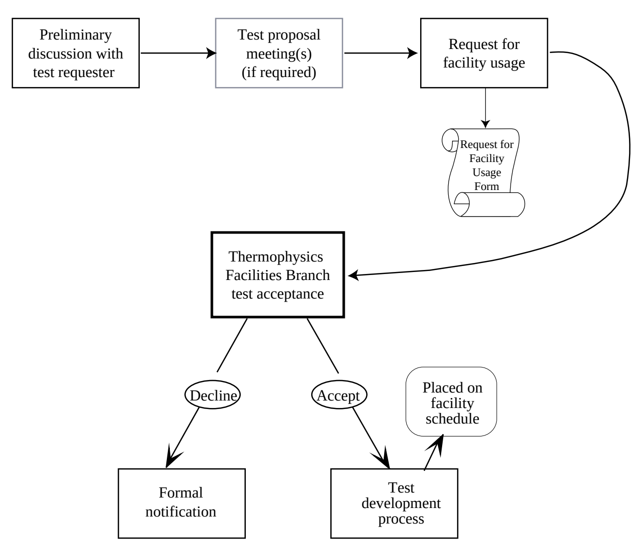

Figure 2. ARC thermophysics facilities test initiation and approval process.

lated by a Steering Committee, Ames Research Center, Science Coordinator, and NASA Headquarters. Scientific proposals of potential investigators are reviewed through the appropriate Program (Planetary Geology and Geophysics, Exobiology, and Origins Programs) regarding scientific worth. Successful investigators funded by NASA Headquarters are directed to the AVGR Science Coordinator, who provides further practical advice on: preparing for an experimental series; avoiding unnecessary redundancy; and scheduling issues. The AVGR also supports limited exploratory experiments to test a concept or validate an approach for future proposal submissions. The AVGR Science Coordinator is Dr. Peter Schultz. Dr. Schultz can be reached at (401) 863-2417.

2.3 Test Development and Preparation

After a test proposal has been accepted, the test development process begins. This process may take weeks or months, depending on the complexity of the test and the amount of fabrication or facility modification required. A typical test development cycle is shown in figure 3, beginning with approval of the test request and following through with the test and the post-test data analysis. Not all proposed tests require the full development cycle depicted in figure 3. For example, use of existing models and test fixtures would eliminate the model design and fabrication element. On the other hand, complex model development and fabrication may require a rather lengthy review and approval element. Most test programs fall between these two extremes.

A major step in the Test Development sequence is to have a meeting with all research and operations personnel involved in the test. The objectives of this meeting are:

- to begin an interactive exchange between the principal groups;
- to communicate the requirements given in the Request for Facility Usage form;
- to assign tasks to the various groups involved; and
- to explore alternatives where possible.

This meeting provides an opportunity for the technicians in the operations group to talk to the engineers about the test, its objectives, its problems, and its priority. It also allows all personnel to meet each other and to gain an understanding of each other's roles in developing and conducting the test. The meeting is intended to foster a free flow of information, generally through discussions interspersed with questions and answers. The result of this meeting shall be the formation of the Detailed Test Plan. The moderator for the meeting is the cognizant Thermophysics Facility Manager or his/her designee.

Although the Test Development process details may vary from test to test, the general milestones are essentially the same for all tests. These milestones are shown in figure 4.

2.3.1 Detailed Test Plan

The Detailed Test Plan is a key document that guides all anticipated activity in the test. The plan shall be a complete, stand-alone document that addresses all aspects of the proposed test. The Principal Investigator/experimenter shall be responsible for preparation of the Detailed Test Plan with the assistance of the Test Engineer or Facility Manager, as appropriate, and both shall sign off the complete plan prior to distribution. The signed Detailed Test Plan will be distributed to the Test Readiness Review panel prior to the Test Readiness Review (TRR) meeting. It is preferred that the plan be distributed at least two weeks before the TRR meeting to allow the panel ample time to read the plan. This scenario means that the Detailed Test Plan should be completed at least four weeks (six weeks is preferred) before the expected

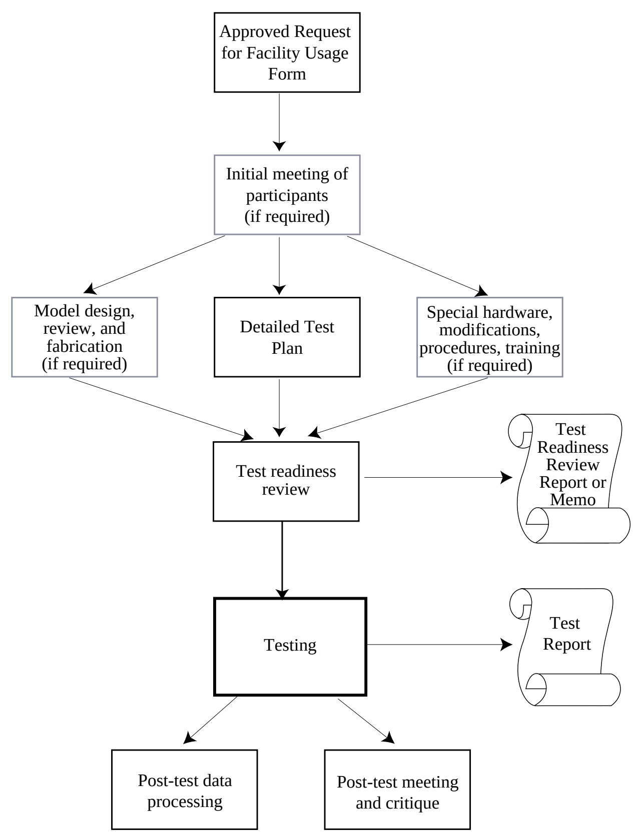

Figure 3. Typical test development process.

start of the test. No systematic effort to prepare for a test will be taken by facility personnel until the Detailed Test Plan is received.

The Detailed Test Plan addresses **ALL** aspects of the test, and includes most or all of the following:

- Overall test objectives and the purpose of the test. State the expected duration of the entry and the facility to be used.
- Approach of the test. State the number of test specimens, describing each type. Describe the porposed run sequence (e.g., calibration runs followed
  by preliminary screening runs, followed by final evaluation, etc.) and the objective(s) for each run.
- Model description. Describe the test article(s), including the overall size(s), weight(s), physical requirements (e.g., cooling water flow, shrouds, special handling, and storage procedures). Include sketches with dimensions.
- Primary measurements. List the primary measure-ments to be made and the type of sensor or trans-ducer to be used. For example:

– Surface temperatures	Thermocouples
– Surface pressures	Scanivalves, diaphragm cells
– Heat flux	Water-cooled calorimeter
– Duration in the flow	Insertion/retraction schemes
– Model forces	Balance system
– Flow velocity	Two-dimensional laser
- Time of arrival	Interval timers

- Software requirements. Specify the type of data reduction required. Include the desired type of data output (e.g., type and number of graphs, tabular hard copy printouts, electronic data files, etc.).
- Special requirements or hazards. Describe any special or unusual model or facility needs. Describe any hazards associated with handling or testing the model, such as high pressure, toxicity, dust inhala-tion, etc. Include the material safety data sheets (MSDS's) for all materials deemed hazardous. For arc jet testing, if high-pressure cooling water or high-pressure gas components are included in a model, indicate all hydrostatic test certifications.
- Auxiliary data system/instrumentation. Describe any user-supplied instrumentation and data recording system(s) to be used (not a part of the facility data acquisition system) and their required interfaces.
- List of required personnel and their duties (e.g., facility operator, data technician, photographer, critical systems monitor, etc.).
- Special Standard Operating Procedures (SOPs) that integrate the operation of both the facility and the model, including pre-run and post-run checklists to ensure that equipment is ready to run or properly shut down.
- Emergency procedures for all anticipated emergen-cies, including shutdown for fire, earthquake, and loss of building power.

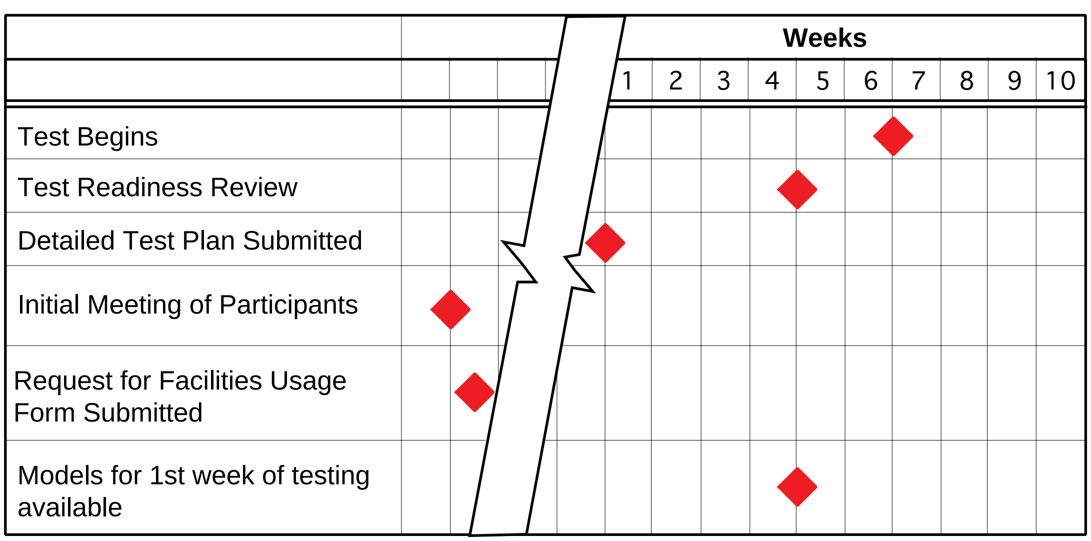

Figure 4. Key milestones in the test development process.

- Model operating envelope and constraints, including adjustment for any model effects on established facility limits.
- Communications procedures and protocol, if necessary.
- Pre-run and post-run meeting checklist, if necessary.
- Training plans for the crew to promote test safety and team cohesion, if necessary.
- Security plan, if necessary.
- Inspection plan for post-run (or pre-run) inspection of critical items, if necessary.
- Installation plan for model installation, including rigging and handling as necessary and desired stream coordinates of the model during testing (relative distances from the nozzle exit), if necessary.
- Data recording forms, if necessary.
- Test engineer's forms (and research engineer's) for log sheet, if necessary.
- Test discrepancy report and protocol for handling, logging, and closing out test discrepancies and test change requests.

The Detailed Test Plan shall be thoroughly reviewed at the Test Readiness Review and will become a central part of the Test Readiness Report/Memo. Facility schedules shall be updated as required.

2.4 Test Readiness Review

In order to ensure that all test programs and models are reviewed, critiqued, and approved before the start of testing, there is a standing Branch policy that **ALL** test programs conducted in any ASF Branch Facility shall have a Test Readiness Review (TRR). The TRR shall be scheduled and conducted by the Facility Manager, or approved designee (for tests in the Arc Jet Complex, the TRR shall be scheduled by the test engineer), unless there are unusual hazards or excessive risks involved which require a higher level review (see Chapter 5 of the Ames Safety Manual). A Test Readiness Review is concerned with safety during the conduct of a specific test program. It is intended to bring together all the personnel directly involved in the test to ascertain that problem areas have been resolved, that all procedures are clear and complete, that all hardware is properly designed, and that the operating crews are trained and know what to expect from the test. The review also assures that the instrumentation technicians are aware of their role and that proper instrumentation is available, all operating procedures are within the facility's normal operating envelope, emergency procedures are adequate, all possible hazards are discussed and evaluated, the test plan is reasonable and complete and will accomplish the test objectives. Above all, the review shall ensure that adequate safety measures have been taken to assure the safety of the personnel, facility, and test hardware.

An approved TRR only applies to the test plan, models, and hardware discussed. Any change in model configuration, hardware, or test plan, that in the opinion of the Facility Manager significantly alters the basis for the original approval will require a new review. Any models, targets, or support fixture not previously reviewed will require an independent review. A test shall be approved for facility operation only after the TRR has been completed and a summary memo or report has been signed by the Branch Chief and/or Facility Manager.

2.5 Test Change Control

It is the policy of the Branch that all test and model activity shall be conducted with Test Change Control as an integral part of the activity. Test-related changes will be the responsibility of the Test Engineer and/or the Principal Investigator. At a minimum, these changes shall be documented in the Test Engineer's Log Book, and/or indicated as "red-line" changes to the test plan. The red-line changes shall be initialled by the Test Engineer and/or the Principal Investigator. The Facility Manager, or his/her designee, shall review and approve all Test Change Requests unless there are unusual hazards or excessive risks involved which require a higher level review. Depending on the nature of the requested change, testing may be halted until the change is approved.

2.6 Handling of Test Discrepancies During Experiment Occupancy

Discrepancies that arise during the course of a test program shall be handled at the discretion of the Facility Manager or his/her designee. He/She shall evaluate the impact of the discrepancy as it relates to the objectives of the test program and to possible safety-related risks. Discrepancies and their resolution shall be logged in a Test Discrepancy Log (Arc Jet Complex) or on the test data sheet (Ballistic Range Complex).

2.7 Post-Test Review

It is Branch policy to conduct post-test review meetings with customers of the Thermophysics Facilities Branch. The purpose of this meeting is to discuss test-related highlights, problems, lessons-learned, and recommendations. All test discrepancies, process change recommendations, and suggestions will be discussed. Notes from this meeting will be noted in the Test Engineer's Log Book or by the Principal Investigator. At the discretion of the test engineer/Principal Investigator, issues which warrant management involvement shall be brought to the attention of the Branch Management.

Each customer shall be asked to provide a Post Test User Review Report/memo. This report/memo will provide a written critique to the Branch in order that the Branch may improve its processes.

2.8 Testing Responsibility

The responsibility of facility operation, safety, maintenance, and raw data acquisition shall be that of the personnel of the Thermophysics Facilities Branch. The Facility Manager shall be responsible for all aspects of the facility operation, including, for the Range Complex, the integrity of the launch package, the gun powder charge, and pump tube pressure. He/She shall be responsible for assuring that all operating parameters selected for a particular test are within the safe operating limits of the equipment. Assistance may be given by the facility Branch personnel in obtaining test gases other than air, however, the specifications shall be provided by the experimenter/PI. Data reduction relating to facility operation parameters shall be the responsibility of the operating personnel. These data concern items such as projectile velocity, size, weight, as appropriate, and other standard data such as pressure, temperature, etc. in the test chambers. Data reduction regarding model/test article performance shall be the sole responsibility of the Principal Investigator.

The process through which all tests shall proceed, from test approval to post-operation activities, has been outlined in Section 2.3. The Thermophysics Facilities Branch shall be responsible for managing this process and for safely conducting the tests. Emphasis shall be placed on those steps that ensure that all safety requirements are met. Not all test preparations are the same because of differences in facilities and in test requirements. However, all tests shall be subjected to similar milestones and undergo the standard review and approval process before testing begins. These steps generally include: (1) initiation of the Request for Facility Usage form and its acceptance by the Thermophysics Facilities Branch; (2) development of test model hardware, test conditions, interfaces, procedures, and the Detailed Test Plan; (3) fulfilling the requirements of the Test Readiness Review; and, (4) the test operations and data distribution.

3.0 Duties and Responsibilities

The Branch Chief, Thermophysics Facilities Branch, is responsible for all aspects of the operation, safety procedures, and maintenance of the facilities. He/she delegates some of the operational responsibility and operational duties as detailed below. The day-to-day operation of the Facilities is under the technical guidance of the respective Facility Manager. All branch personnel follow ISO 9000 quality policies and procedures as set forth by Center, Directorate, Division, and Branch Management in order to ensure that the data/product delivered by the Branch meets or exceeds the customer's requirements.

3.1 Facility Manager

The Facility Manager is responsible for the technical, efficient, and safe utilization of the facilities within the Thermophysics Facilities Branch. He/she enforces the established operating limits of his/her respective facilities and has the authority to judge the acceptance of all proposed tests. He/she conducts a Test Readiness Review with the Principal Investigator/experimenter and the operating personnel for ALL proposed tests. He/she maintains certification for all operating personnel and schedules retraining when required.

3.2 Test Engineer (Arc Jet Complex)

The Test engineer is responsible for the conduct of the test program and coordinates all aspects of the tests once testing has begun. He/She is responsible for maintaining the Test Discrepancy Log and for working post-test with the customer to resolve any discrepancies that arise during the test occupancy in the facilities.

The Group Leader of the Test Engineering Group maintains the schedules for the facilities of the Arc Jet Complex.

3.3 Facility Operator

The Facility Operator is responsible for operating the facility according to the test program. He/she has been certified to operate the facility by the Facility Manager. His/her duties include operation using documented procedures and checklists, and making entries in the facility operation log book. He/she is responsible for ensuring that the facility is operational.

3.4 Instrumentation Technician

The Instrumentation Technician is responsible for ensuring proper functioning of the instrumentation required for the tests and for connecting these to the data acquisition system, as appropriate.

3.5 Data System Technician

The Data System Technician has the primary duty to support data acquisition activities and to reduce the recorded data as required by the test program. Additionally, he/she is responsible for archiving the data and performing periodic backups of the data acquisition system.

3.6 Principal Investigator/Experimenter

NASA personnel provide normal levels of test support, including test development, model preparation and installation, instrumentation checkout, and data reduction. Users (also referred to as Principal Investigators or Experimenters) of these facilities are expected to provide all hardware, support equipment, and test personnel specific to a given test. Users are responsible for funding any facility modification costs and for any nonstandard operational costs that are required to properly meet the objectives of the requested test program. In certain instances the user may be required to fund all operational costs associated with a test. Specific details on the policies for funding test costs are addressed by Branch and Division Management.

4.0 Facility Description

4.1 Arc Jet Complex

The Ames Research Center (ARC) currently operates a variety of arc-heated facilities within the Arc Jet Complex. These facilities are used to generate flow environments that simulate the aerothermal environment that an object experiences when traversing the atmosphere of a planet. They are used primarily to test heat shield materials and thermal protection system (TPS) components for planetary entry vehicles, planetary probes, and hypersonic flight vehicles, although other investigative studies are performed in some of these facilities. In the arc jet facilities, TPS components are exposed to the aerothermodynamic heating conditions that they will encounter during high-speed flight.

The Arc Jet Complex (fig. 5) at ARC has nine available test bays located in two separate laboratory buildings. Figure 6 shows a schematic representation of the location of these test bays. Presently, four bays contain operational arc jet units of differing configurations. The arc jet facilities are serviced by common facility support equipment, including two dc power supplies, a steam-ejector vacuum system, a de-ionized water cooling system, high-pressure gas systems, a data acquisition system, and other auxiliary systems. The magnitude and capacity of these support systems is what primarily distinguishes the ARC Arc Jet Complex as unique in the aerospace testing world. In particular, the large dc power supply can deliver 75 MW for 30 minutes. High-power capability, in combination with the high-volume steam-ejector vacuum system, yields a unique suite of facilities that simulate high-altitude atmospheric flight on relatively large test objects.

The arc heater units were designed at NASA Ames and are of both the segmented design and the Huels-type design. These arc heaters, combined with a variety of conical, semielliptical, and two-dimensional nozzles, offer wide versatility for testing both large, flat-surface test objects (fig. 7) and stagnation-flow models that are fully immersed in the test stream (fig. 8).

4.1.1 Arc Heaters

The arc heaters are key features of the arc jet complex; they contain three fundamental elements: a cylindrical volume for containment of the arc discharge (or arc), a pair of electrodes (anode and cathode), and a nozzle. The desired test gas is injected into the cylindrical section and an arc discharge passes between the electrodes, heating the gas to a high temperature. The plasma then flows through a converging/diverging nozzle, producing the simulated atmospheric-entry heating environment.

The design of the cylindrical confining device must be such that it simultaneously satisfies numerous difficult requirements. The confining device must incrementally withstand the voltage potential between the electrodes, which can total more than 20,000 volts (V). It must be highly water cooled in order to contain the plasma, which can reach temperatures in excess of 15,000 °F. It must serve as a pressure-containment vessel; as such, all seals and joints must be adequate to prevent leakage at conditions ranging from vacuum up to pressure levels of several hundred pounds per square inch (psi). It must have adequate mechanical strength for the loads involved. Finally, the materials used must have the proper electrical, thermal, mechanical, and chemical properties to meet all these requirements. Development of increasingly higher-power arc heaters has been conducted at ARC over more than 30 years.

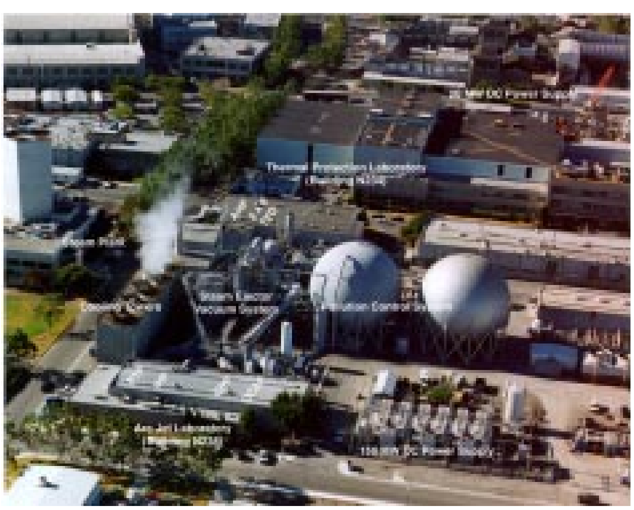

Figure 5. NASA Ames Research Center Arc Jet Complex.

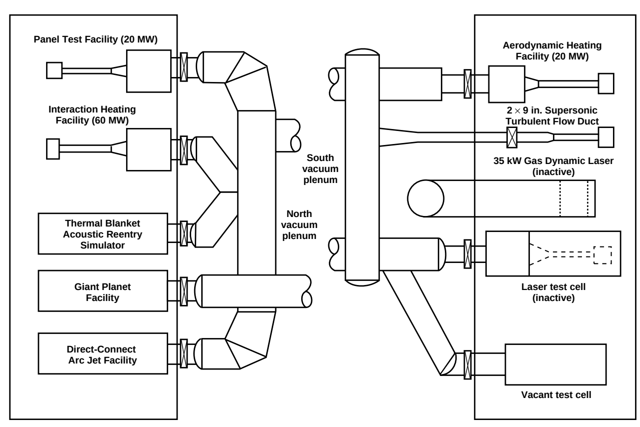

Figure 6. Test bays of the arc jet complex at Ames Research Center.

Figure 7. 24- × 24-inch panel being tested in the arc jet complex.

Figure 8. Leading-edge model being tested in the arc jet complex.

Two basic types of arc heaters are used at ARC. The arc jet facilities are driven by either a segmented (also called “constricted”) arc heater or by a Huels-type (also called “Linde-type” and “vortex-stabilized”) arc heater. These two basic arc heater types, which have quite different operating characteristics, have proved themselves over the years and are used extensively for a wide variety of testing. Segmented arc heaters produce lower contamination levels in the flow stream compared to Huels-type arc heaters. The stream contamination produced from the electrode material in a segmented arc heater is less than 10 parts per million (ppm) of the mass flow; in a Huels type, an order of magnitude higher. The salient features of these two types of arc heaters and the major differences between the two designs are described in the next section. Table 1 compares the features of the two arc heater types.

Table 1. Comparison of the features of the arc heaters at ARC

Feature	Segmented arc heater	Huels arc heater
Enthalpy	High (to 20,000 Btu/lb_m)	Low (to 4000 Btu/lb_m)
Pressure	Low [to 10 atmospheres (atm)]	High (to 100 atm)
Flow contamination	Low (< 10 ppm)	High (>10 ppm)
Arc column	Fixed length	Natural (variable) length
Repeatability	Repeatable performance	Inconsistent performance
Hardware	Complex	Simple
Maintenance	Difficult	Relatively easy

4.1.1.1 Huels Arc Heater

Hardware– The Huels arc heater is a relatively simple unit containing few components. The arc heater comprises two water-cooled cylindrical electrodes, separated by an enlarged cylindrical swirl chamber and a single large insulator, which withstands the entire voltage potential between electrodes. (See fig. 9.) The downstream electrode is electrically grounded by physical contact with the vacuum system piping.

Operation– During operation, dry air is introduced tangentially into the swirl chamber; the strong vortex thus formed is largely responsible for stabilizing the arc discharge. A magnetic field coil surrounding the upstream electrode rotates the arc attachment point. This rotation reduces electrode erosion and fixes the axial attachment location of the arc. The arc is driven into the upstream electrode by the vortex and is restrained from attaching to the closed end of the electrode by the magnetic field of the coil. In some cases a similar field coil is used on the downstream electrode to prevent the arc from blowing through the nozzle.

The operating characteristics of a Huels arc heater are somewhat variable. The arc discharges in a somewhat erratic mode, and does not necessarily locate on the anode and cathode in a repeatable fashion from one run to another. The discharge voltage is a function of the length of the arc, which is governed by two competing factors:

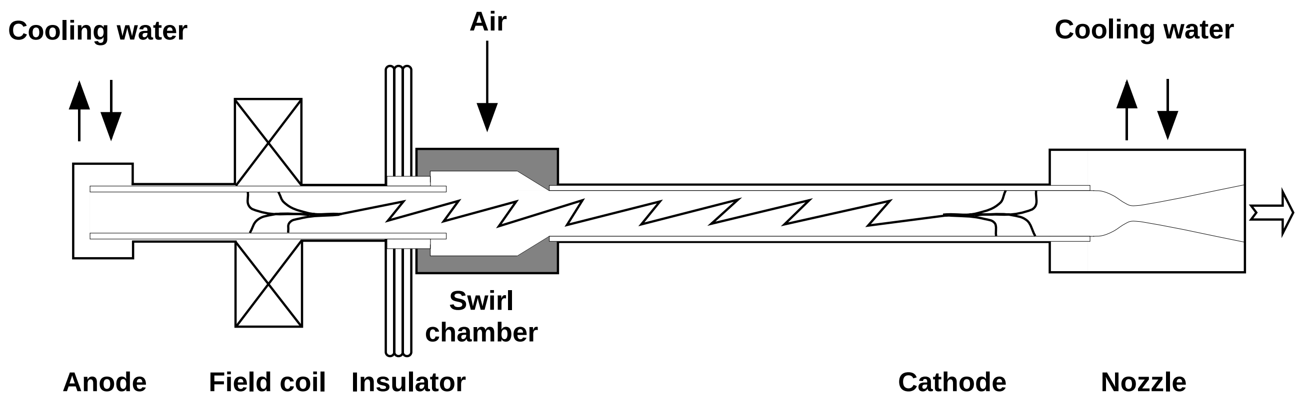

Figure 9. Schematic drawing of the Huels arc heaters used at ARC.

- The arc discharge seeking a free path of least resistance, and
- The cold gas near the walls from the vortex flow preventing conduction to the walls.

Because the arc seeks an equilibrium between these two competing parameters, it is said to seek its "natural" operating length, in contrast with the fixed-arc-length characteristic of the constricted arc heater.

The Huels arc heater can be operated at high pressures (over 100 atm), but it produces plasmas at relatively low enthalpies (1500 to 4000 Btu/lb_m) because of the inherently low current density of the vortex-stabilized arc. The simplicity of the unit, however, allows for relatively easy maintenance and short turnaround times during testing.

The basic Huels arc heater geometry as operated by ARC is shown in figure 9. This arc heater has been used with a variety of nozzles in different test bays and is available in three sizes: 5-, 20- , and 100-MW units. Each of the units is available with various downstream electrode lengths, allowing the operator to select a tube length that will best match the expected "natural" arc length. Current designs are for a Huels arc heater operating at a power level of 100 MW with pressure capabilities to 100 atm, which requires gas flow rates of 15 lb_m/sec or more. Power levels as high as 55 MW have been demonstrated in a Huels arc heater at ARC.

4.1.1.2 Segmented Arc Heaters

Hardware– The segmented arc heaters are relatively complex units with many components and critical assembly alignments. (See fig. 10.) Therefore, the segmented arc heater requires more frequent inspection and maintenance than the Huels-type arc heater. The primary components of the segmented arc heater are the electrodes (anode and cathode) and the constrictor tube. The entire arc heater, including both electrodes, is electrically isolated from the ground.

The constrictor tube, or column, consists of a few hundred individually water-cooled copper disks, or segments, clamped together to form a cylinder. Electrically isolated from the others, each disk is supplied with water cooling. (The incremental voltage potential between adjacent disks in the constricted arc heater is relatively low, usually less than 50 volts, in contrast to the Huels-type arc heater in which a single insulator stands between anode and cathode potentials of up to 33 kV.) The disk segments and the associated insulators and seals are packaged into modules of 30 disks for ease of assembly and testing.

The length of the constrictor tube is tailored to the desired arc heater performance, with proper consideration for the mass flow, voltage, and arc current. The arc length is fixed by the length of the constrictor tube, in contrast to the "natural" arc length of the Huels arc heater. As a result, the segmented arc heater operates in a relatively stable fashion, with excellent repeatability.

The anode and cathode of the segmented heaters consist of multiple-ring electrodes contained in assemblies called electrode packages. Each electrode package consists of individual electrode, spacing, and transition rings. Each electrode ring is electrically isolated from the others and is individually ballasted. The diameter of the copper electrode rings is larger than that of the disks in the constrictor column, thus forming a plenum. Each electrode ring contains an internal magnetic spin coil in series with the arc current. The coil produces a magnetic field that acts to rotate the arc attachment point around the inside of the electrode ring, thus reducing erosion from the highly concentrated arc foot.

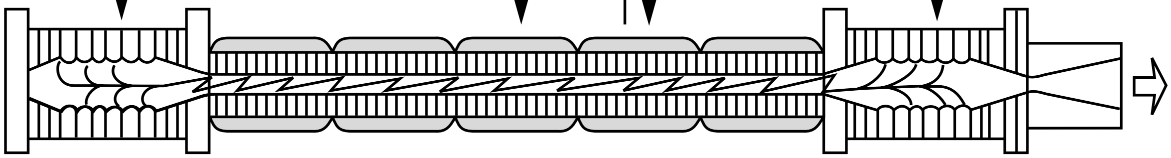

Figure 10. Schematic drawing of the segmented arc heaters used at ARC.

Both of the power supplies that service the Arc Jet Complex are current-controlled; thus the total arc current is specified at all times. An electrode package is assembled with a sufficient number of electrode rings to handle the anticipated operating current. By adjusting the variable ballast resistors, the parallel electrode rings within a package can be forced to share current approximately equally. A small amount of argon gas is injected between each electrode ring to ensure that sufficient ionization is maintained near the surface of the electrodes. Because the total arc current is divided between multiple electrodes, each of the multiple arc attachment points produces a lower thermal load to the electrode wall compared to the single attachment point in a Huels arc heater. The total amount of argon in the test stream is controlled by operator inputs.

Operation– During operation, the gas (usually air) is introduced between adjacent disks along the entire length of the constrictor tube. The mass flow distribution of test gas along the constrictor tube and the type of gas can be changed to tailor the performance of the arc heater. For instance, a small flow of argon is bled in between disks near the anode, or upstream electrode, to prevent intersegment arcing.

The segmented arc heater provides a wider range of enthalpy levels and a more stable and repeatable test condition than the Huels arc heater. The segmented arc heater can produce relatively high enthalpy levels (5000 to 20,000 Btu/lb_m in air) at relatively low pressures (1 to 10 atm). It can also be operated at high pressures (above 100 atm), but the design problems associated with high-pressure operation are considerable because of the complexity of the segmented construction. ARC has elected to restrict operations to the lower pressure range; thus all the segmented arc heaters at ARC operate at relatively low pressures.

The basic geometry of the segmented arc heater as operated at ARC is shown in figure 10. This type of arc heater is coupled to a variety of nozzles (of both semi-elliptical and circular cross section) in different test bays; it is available in two sizes: a 6-cm-bore and an 8-cm-bore constrictor tube. The arc heaters of both sizes use the same electrode package components and are assembled with four to eight electrode rings in the package. The number of electrode rings in the package is determined by the level of arc current that is required.

Another configuration of the 6-cm-bore segmented arc heater has operated at power levels up to 80 MW using hydrogen/helium mixtures as the test gas. This arc heater utilizes carbon-rod cathode electrodes located downstream of the nozzle exit so that the arc discharge passes through the nozzle. This configuration was selected to ensure the maximum possible energy transfer to the gas, thereby attaining the extremely high enthalpy levels for simulation of entry into the atmosphere of the giant planets. A small-exit-diameter nozzle was used for testing samples in an open jet at extremely high heating rates.

4.1.2 Nozzles

A supersonic nozzle is coupled to the downstream end of the arc heater to produce the desired flow environment. The ARC arc jet facilities customarily use nozzles of two cross-sectional geometries: asymmetric semielliptical and axisymmetric conical nozzles. The nozzles are fully water cooled to allow for continuous operation. With the exception of the 2×9 Supersonic Turbulent Flow Duct (TFD), the nozzles operate with an open jet test section.

4.1.2.1 Semielliptical Nozzles

The semielliptical nozzles have an asymmetric cross section that is one-half of an ellipse. The flat, bottom portion of the nozzle forms the major axis of the elliptical section (fig. 11). A flat-panel test article is mounted flush to the bottom, flat surface of the nozzle in a semiopen jet at the nozzle exit.

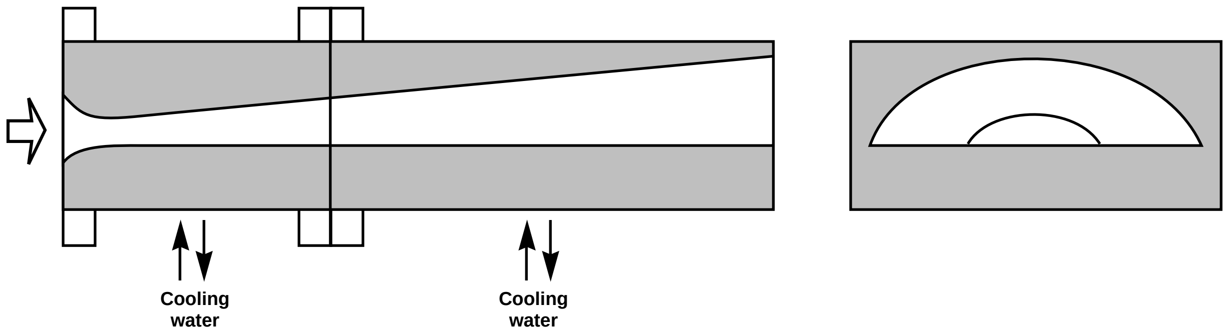

Figure 11. Schematic drawing of the semielliptical nozzles at ARC.

The semielliptical nozzles were developed at ARC to test large, flat surfaces in high-temperature boundary layer flows (e.g., development of the Space Shuttle heat shield tiles). All nozzles have a circular subsonic inlet transitioning to a semielliptical throat, which expands conically to the test section. The semielliptical cross section produces a relatively uniform heat flux and surface pressure distribution over a large, flat test article. Choice of this configuration was based on the results of a nozzle development program in a pilot facility that showed that rectangular, two-dimensional nozzles with high aspect ratio produce unacceptable nonuniformity at the test section. About 75 percent of the nozzle exit width is usable in a semielliptical nozzle. At the nozzle exit, the transverse variation in heat transfer rate and surface pressure is less than 15 percent. The magnitude of the transverse and streamwise variation is shown in Appendices A and B. Variations in streamwise heating and pressure distribution are greater at higher inclination angles and higher arc current levels.

Two semielliptical nozzles are available:

- a 17-inch nozzle matched to a 20-MW segmented arc heater, used in the Panel Test Facility (PTF); and
- a 32-inch nozzle matched to a 60-MW segmented arc heater.

Both nozzles operate at an approximate Mach number of 4.5 and are fitted with an uncooled, high-temperature plate over the final 20 percent of the length of the flat portion of the nozzle. This boundary layer conditioner plate, of length greater than 10 times the thermal boundary layer thickness, tailors the boundary layer of the flow before it reaches the test article so that it better simulates the boundary layer flow experienced on the windward side of a reentry vehicle. The simulated length Reynolds number is approximately 1×10^6, based on boundary layer growth beginning at the throat and continuing to the nozzle exit.

4.1.2.2 Axisymmetric Nozzles

The arc jet complex uses a variety of axisymmetric conical nozzles; most are not contoured. This conical design was chosen because

- design and fabrication are relatively simple;
- mating sections of conical nozzles offers great flexibility in varying the area ratio;
- the conical nozzles are not restricted to a fixed Mach number, as are contoured nozzles; and
- ARC has had vast experience in developing heat shield materials using conical nozzles in the presence of high-enthalpy reacting flows.

Nozzle throat sections are fabricated using water-cooled copper. Expander sections are either aluminum with deep-drilled water cooling passages or water-jacketed steel.

The arc jet complex has two conical nozzle systems:

- 20-MW Aerodynamic Heating Facility (AHF)
  - Throat diameters of 1.0, 1.5, and 2.0 inches
  - Exit diameters of 12, 18, 24, 30, and 36 inches
- 60-MW Interaction Heating Facility (IHF)
  - Throat diameter, 2 3/8 inches
  - Exit diameters of 6, 13, 21, 30, and 41 inches.

In each facility, the location of the nozzle exit plane remains fixed when the number of frustum sections in the nozzle is changed. The arc heater assemblies are mounted on wheeled carriages to make up the difference in axial location for various nozzle configurations. Figure 12 shows a schematic drawing of a typical conical nozzle family.

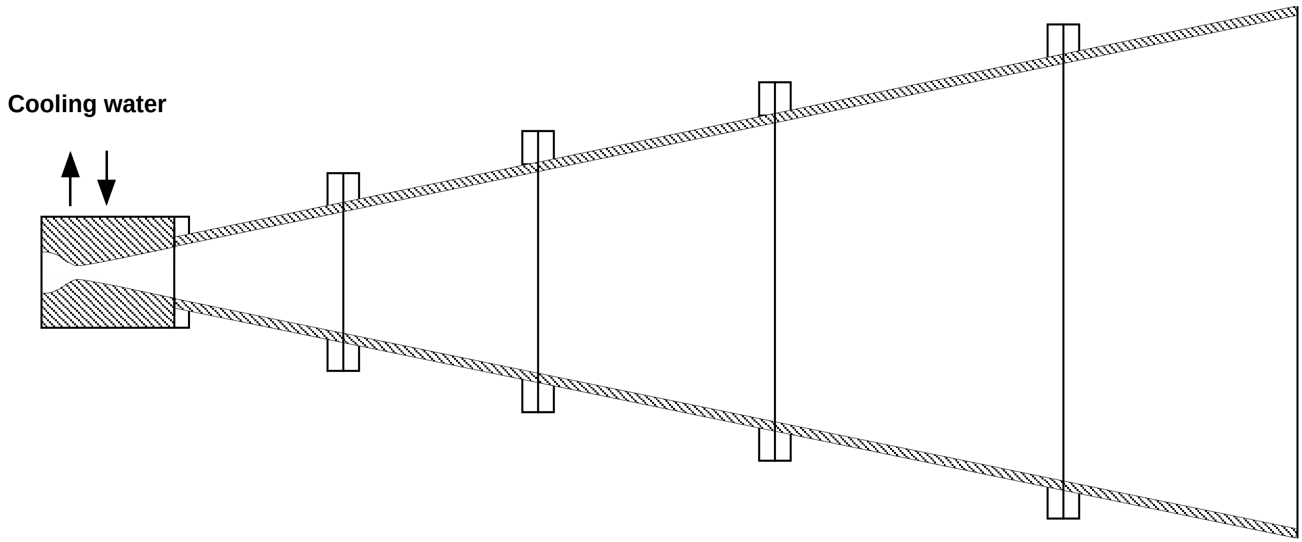

Figure 12. Schematic drawing of a conical nozzle family.

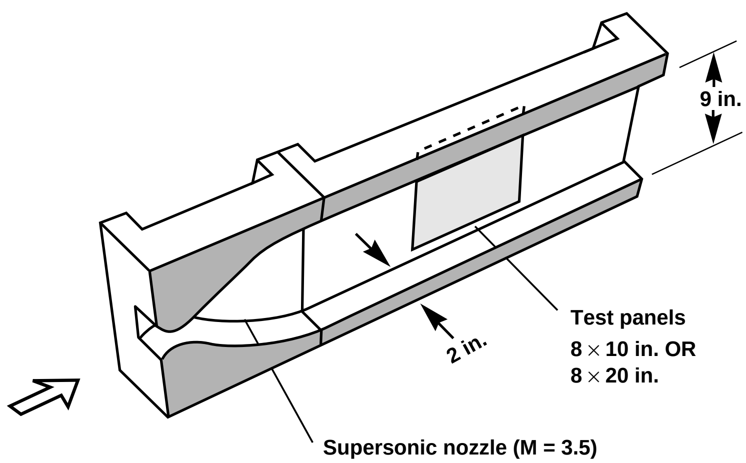

Figure 13. Schematic representation of the TFD.

4.1.2.3 Other Nozzles

Other special-purpose nozzles are available for use with specific arc heaters. They are described in the following paragraphs.

2 × 9 TFD Nozzle– The TFD is driven by a 20-MW Huels arc heater to produce turbulent flow over the surface of a wall-mounted panel in the constant-area section of a duct. The subsonic section of the nozzle is circular, transitioning to a rectangular throat section of dimensions 1.128 by 1.600 inches. One wall expands to the 9-inch dimension with a slight boundary layer correction divergence (less than 0.5°). The other wall is contoured to complete the expansion. The TFD nozzle is made of copper, with internal passages for water cooling. Static pressure ports and heat-flux sensor ports are spaced along the centerline from a point 3 1/16 inches from the minimum section extending to the nozzle exit. Figure 13 shows a sectional view of the 2- by 9-inch duct nozzle and test section.

4.1.3 Description of the Arc Jet Test Facilities

There are currently four active facilities in the ARC Arc Jet Complex. The features of these facilities are described in this section and summarized in table 2.

Table 2. Operating characteristics of the arc jet facilities at ARC

	Aerodynamic Heating Facility		2 × 9 Supersonic Turbulent Flow Duct	Panel Test Facility	Interaction Heating Facility	
Nozzle configuration	Conical		2-dimensional	Semielliptical	Semielliptical	Conical
Gas	Air, nitrogen		Air, nitrogen	Air	Air	Air
Input power, MW	20		12	20	75	75
Nozzle exit dimension, in.	12, 18, 24, 30, 36 (diameter)		2 × 9	4 × 17	8 × 32	6, 13, 21, 30, 41 (diameter)
Mach number	4–12		3.5	5.5	5.5	<7.5
Bulk enthalpy, Btu/lbm	5000 to 14,000		1500 to 4000	2000 to 14,000	3000 to 20,000	3000 to 20,000
Type of test article	Stagnation point	Wedge	Flat plate	Wedge	Wedge	Wedge stagnation point
Sample size, in.	8 (diameter)	26 × 26	8 × 10 8 × 20	14 × 14	24 × 24	18 (diameter)
Surface pressure, atm	0.005 to 0.125	0.001	0.02 to 0.15	0.0005 to 0.05	0.0001 to 0.02	0.010 to 1.2
Convective heating rate, Btu/ft²sec	20 to 225	0.05 to 22	2 to 60	0.5 to 75	0.5 to 45	50 to 660
Radiative heating rate, Btu/ft²sec	0		0	0	0 to 5	0 to 20

4.1.3.1 Aerodynamic Heating Facility

The AHF is a highly flexible arc jet facility that operates with either of two 20-MW arc heaters and a family of conical nozzles. The segmented arc heater, shown in figure 14, operates at pressures from 1 to 10 atm (reservoir pressure) and enthalpy levels from 5000 to 14,000 Btu/lb_m (air). The Huels arc heater operates at pressures from 1 to 40 atm and enthalpy levels from 1500 to 4000 Btu/lb_m (air). Most of the testing in the AHF is done using the segmented arc heater because of its high enthalpy performance, low stream contamination, and long history of repeatable operation. Alternate test gases are nitrogen and argon. Either arc heater can be coupled with a family of 8°-half-angle conical nozzles of exit diameters of 12, 18, 24, 30, or 36 inches (figure 12). Each nozzle has an interchangeable throat of diameters of 1.0, 1.5, or 2.0 inches. The nozzle discharges into an 8- × 8- × 8-foot walk-in test cabin. Flow in the cabin is collected by the 60-inch-diameter diffuser before being pumped through a heat exchanger into the steam-ejector vacuum system. Static pressure in the cabin ranges from 0.1 to 10 torr, depending on mass flow and pumping rates. Samples are exposed to the plasma in an open jet formed between the nozzle exit and the entrance to the diffuser. The chamber houses two model support mechanisms: one double-support carriage and a swing-arm sting. Either stagnation-flow (see fig. 8) or wedge-shaped models can be inserted into the test stream. Water manifolds are available to cool test articles. Instrumentation connections are made to a data recorder via patch panels inside the chamber. Optical access through ports on both sides and in the ceiling of the test chamber allow imaging of the test article and plasma stream.

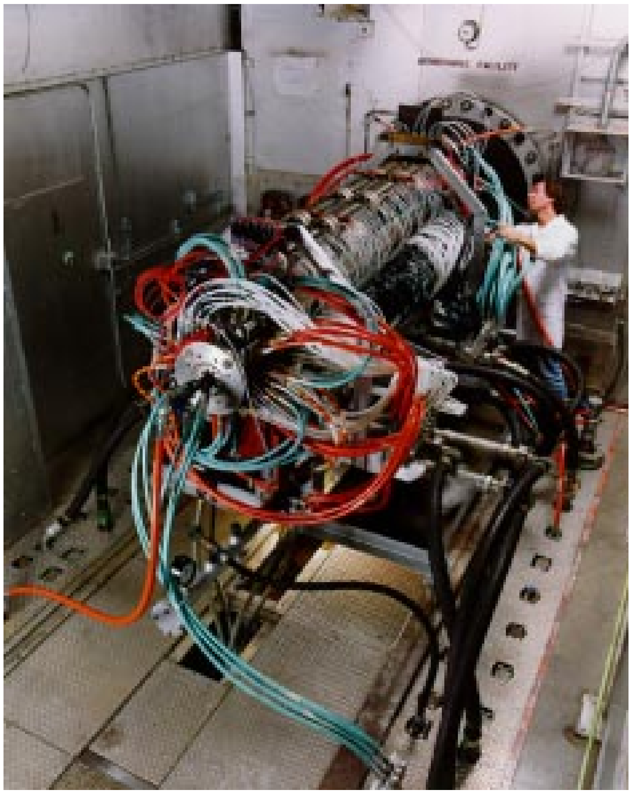

Figure 14. The segmented arc heater in the AHF.

Surface conditions on the model can be varied in two ways: nozzle area ratio and arc operating parameters (arc current and mass flow). Table 2 summarizes the physical characteristics and performance of the AHF. Figure 15 shows the range of conditions attainable on a 4-inch-diameter sphere/cylinder stagnation test article using the segmented arc heater. Figure 16 shows the operating envelope using the Huels arc heater. Run durations as long as 30 minutes are possible, with a 45-minute cool down between runs.

AHF Mixing-Air Plenum- The capability for mixing cold gas into the arc jet stream just ahead of the nozzle throat has been added to the Aerodynamic Heating Facility. This modification greatly increases the simulation capability of the AHF particularly into a range of higher stagnation pressure and lower stream enthalpy (below1000 Btu/lb_m), see figure 15.

4.1.3.2 Interaction Heating Facility

The 60-MW IHF (fig. 17) was designed to study aerodynamic heating in the thermal environment arising from the interaction of an energetic flow field with an irregular surface. It was specifically sized for testing of large-scale models at conditions simulating the peak heating of Shuttle entry.

The IHF is equipped with a 60-MW segmented arc heater that operates with air at pressures from 1 to 10 atm and enthalpy levels from 3000 to 20,000 Btu/lb_m (air). Cold air can be added in the downstream plenum to obtain centerline enthalpies below 1000 Btu/lb_m. Two nozzle geometries are used in the IHF: conical axisymmetric (figure 12) and semielliptical (figure 11). The nozzles direct the flow into a walk-in, 8- × 8- × 8-foot test chamber. Flow in the cabin is collected by the 54-inch-diameter diffuser before being pumped into the steam-ejector vacuum system. Static pressure ranges from 0.1 to 10 torr in the cabin, depending on mass flow and pumping rates. Samples are exposed to the plasma in an open jet formed between
the nozzle exit and the entrance to the diffuser.

The test chamber houses two hydraulically-actuated model insertion mechanisms mounted on the floor of the test cabin. Tests are conducted using conical nozzles with either stagnation-flow or wedge-shaped test bodies inserted into the free-jet stream. Panels mounted at the exit of the semielliptical nozzle are exposed to a semiopen test stream. Water manifolds are available for cooling the test articles. Instrumentation connections are made to a data recorder via patch panels within the test cabin. Optical access through ports on both sides and in the ceiling of the test chamber allow imaging of the test article and plasma stream.

Two nozzle types are available for the IHF:

- Conical nozzles (10° half angle)
  - Exit diameters of 6, 13, 21, 30, and 41 inches.
  - Throat diameter of 2.375 inches.
  - Used for simulation of atmospheric entry over large stagnation flow models or wedge-shaped models immersed in the test stream.
  - Variations of surface conditions are accomplished by changing:
    - nozzle area ratio, and
    - arc current and mass flow.
- Semielliptical nozzle
  - Provides a test stream suitable for flat panels up to 24 × 24 inches in boundary layer heating environments.
  - Test article pivoting at the lip of the nozzle exit can be remotely inclined at angles from –8° to 8°.
  - Variations of surface conditions are accomplished by changing:
    - inclination angle of the tilt-table, and

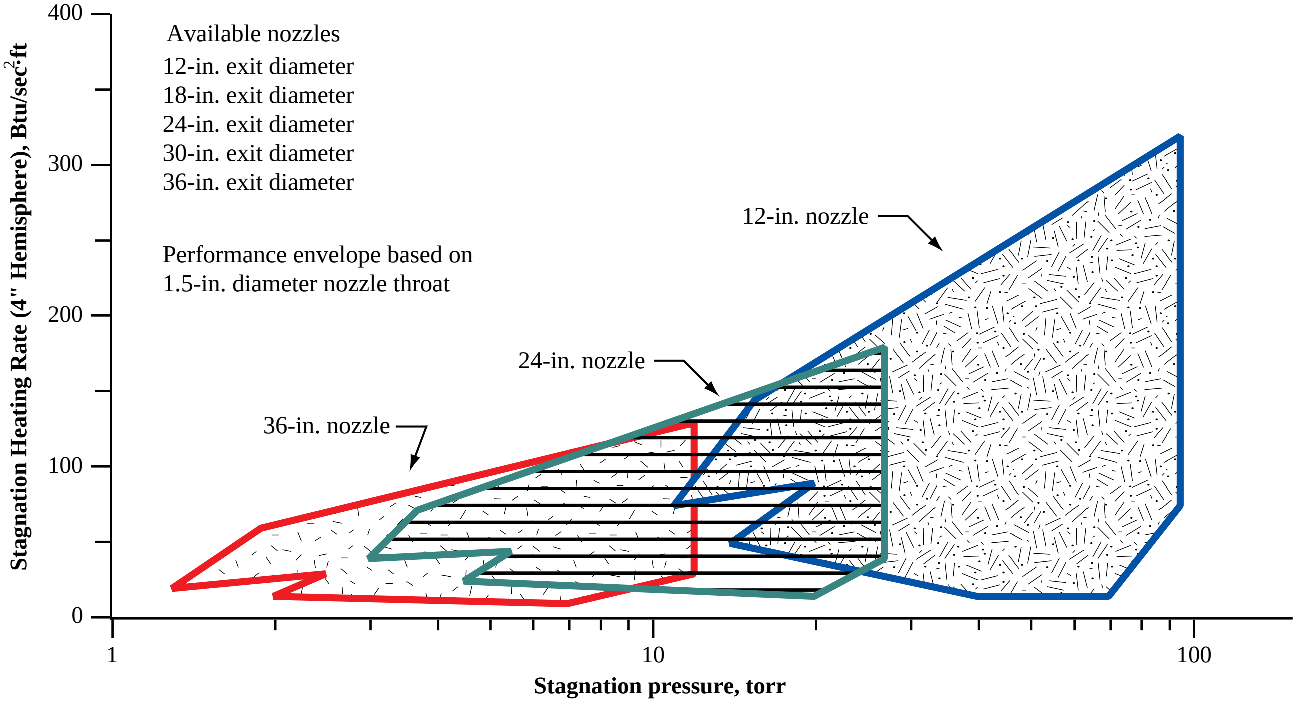

Figure 15. Operating envelope of the ARC AHF with 20-MW segmented arc heater.

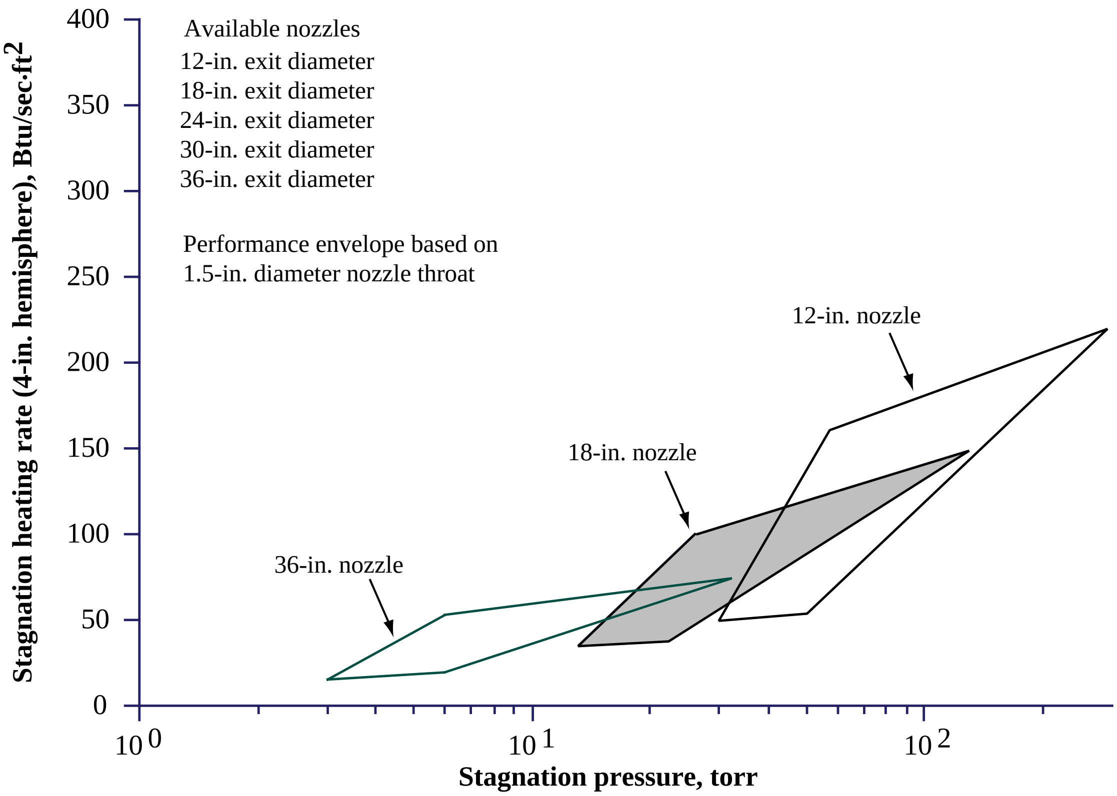

Figure 16. Operating envelope of the ARC AHF with 20-MW Huels arc heater.

Figure 17. 60-MW IHF.

- arc current and mass flow.

Physical and performance figures for the IHF are given in table 2. The envelope of stagnation-point conditions attainable on a 4-inch-diameter sphere/cylinder in the IHF is shown in figure 18. The operating envelope for the semielliptical nozzle is given in figure 19. Run durations as long as 30 minutes are possible, with a 30-minute cool down between runs.

4.1.3.3 Panel Test Facility

The 20-MW Panel Test Facility (PTF, fig. 20) consists of a 20-MW segmented arc heater coupled to a semielliptical nozzle. The nozzle discharges in a semifree jet within a 4- × 4- × 4-foot test cabin where the panel test fixture attaches at the nozzle exit (fig. 21). The test stream is suitable for the simulation of boundary layer heating environments on flat-panel samples of approximately 14 by 14 inches. The panels can be inclined an angles of –4° up to 15°, although 6° is the practical maximum. Surface conditions on flat-plate test articles can be varied in two ways: inclination angle of the tilt table and selection of the arc operating parameters (current and mass flow rate). Optical access through both doors and the roof of the test cabin allow imaging of the flow and the test article. Flow is evacuated from the test chamber by the steam-ejector vacuum system, providing static pressures in the range of 0.1 to 10 torr. Water cooling manifolds are available inside the test chamber for cooling of test article components.

The heater operates at pressures from 1 to 10 atm and enthalpy levels from 1000 to 14,000 Btu/lb_m (air). The lower enthalpy range is achieved by mixing cold air with the test stream in the plenum, or downstream electrode package. The PTF simulates some of the conditions experienced by the Space Shuttle heat shield tiles, such as heat flux, surface pressure, and gap flow, and has been used extensively in Space Shuttle heat shield development and certification. Other test programs in the PTF have focused on testing flexible thermal protection blankets for next-generation reusable launch vehicles. The envelope of surface conditions on the test article for the PTF is shown in figure 22 and the physical parameters are listed in table 2. (See Appendix A.) Run durations as long as 30 minutes are possible, with a 45-minute cool down between runs.

4.1.3.4 2 × 9 Supersonic Turbulent Flow Duct

The 2 × 9 Supersonic TFD is unique because panels of TPS materials can be exposed to turbulent boundary layer flow at a relatively high enthalpy. The test section has a rectangular cross section measuring 2 × 9 inches (hence its name). The test article, of dimensions 8 × 10 or 8 × 20 inches, is mounted flush to the 9-inch side of the test section. The opposite wall of the test section is instrumented with pressure ports and flush-mounted calorime-

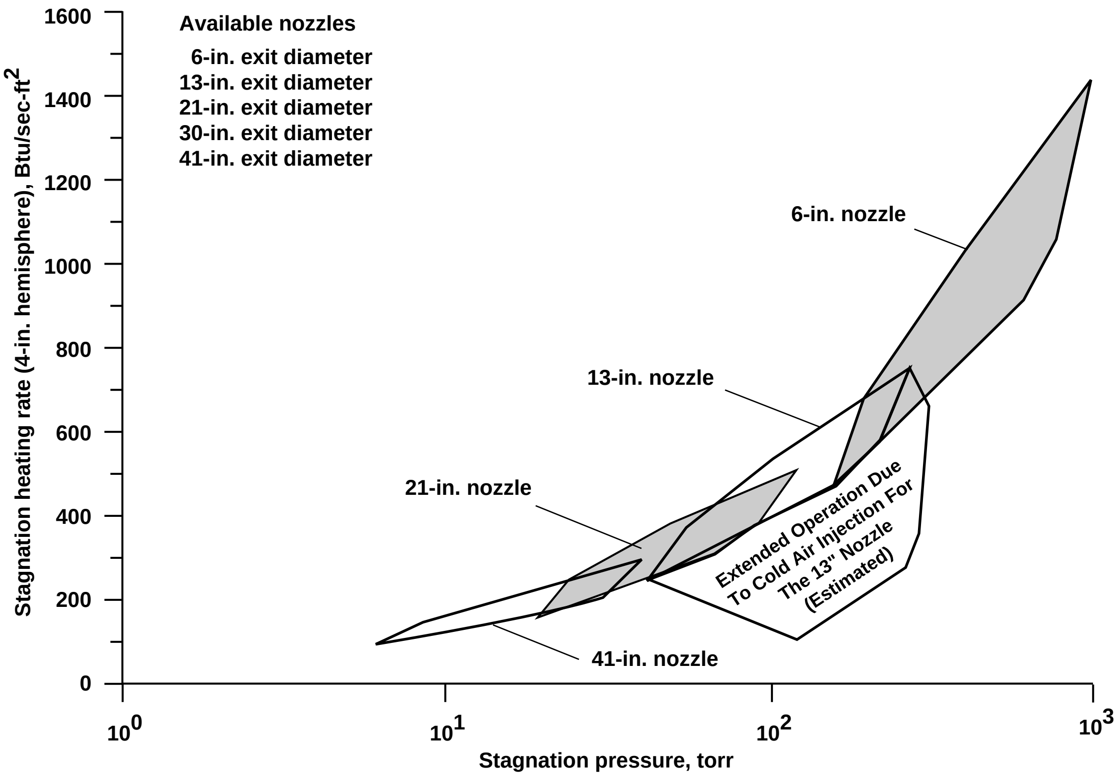

Figure 18. Operating envelope of the ARC IHF with conical nozzles.

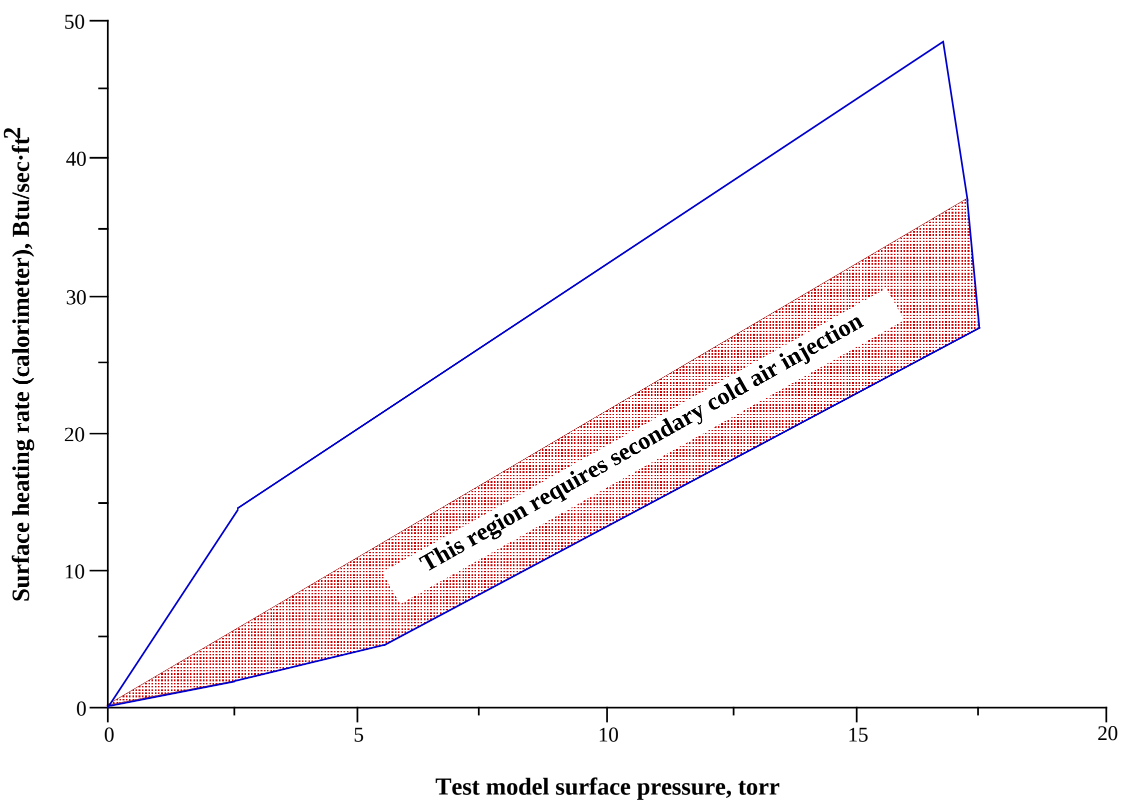

Figure 19. Operating envelope of the ARC IHF with semielliptical nozzle.

Figure 20. 20-MW PTF.

Figure 21. Test panel installed in the PTF test cabin.

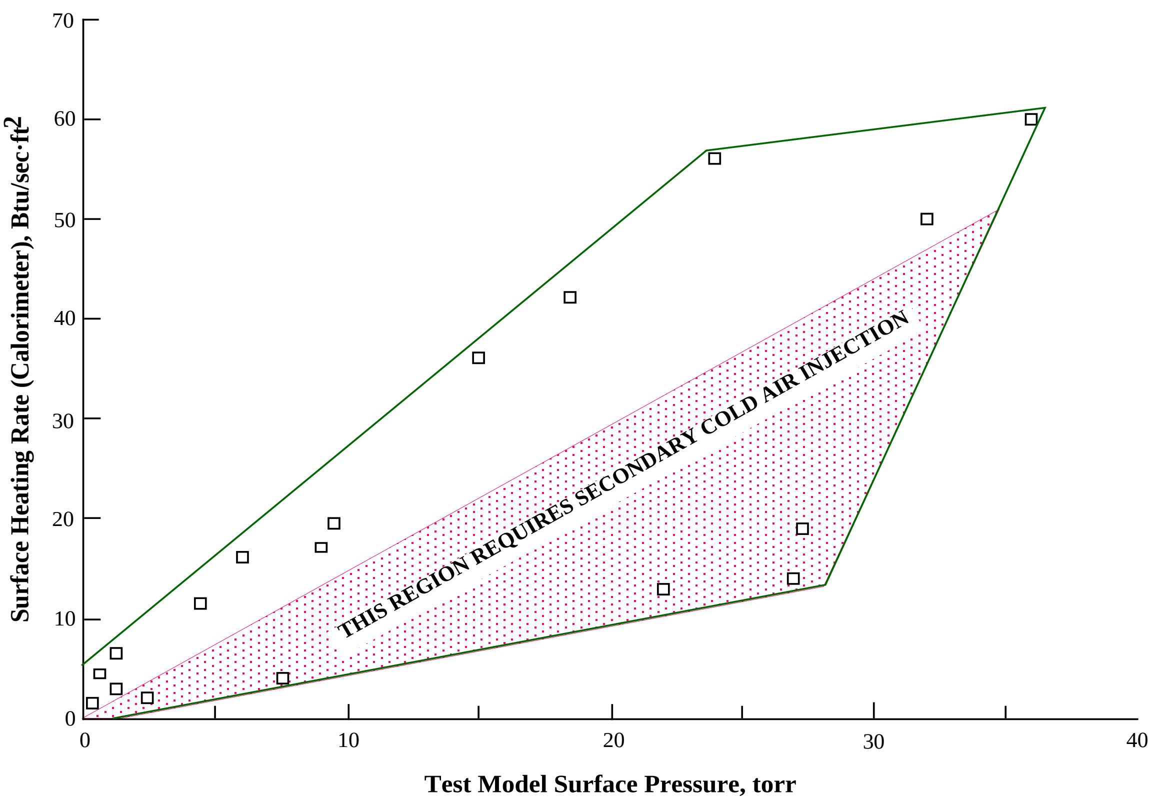

Figure 22. Operating envelope of the ARC PTF.

ters (heat-flux gages). The nozzle is also instrumented with pressure and heat-flux ports at various locations.

Features of the TFD include:

- A 20-MW Huels arc heater provides flow enthalpy in the range 1500 to 4000 Btu/lb_m (air).
- Maximum arc heater power input is about 12 MW because of cooling limitations of the nozzle throat.
- The reservoir pressure ranges from 1 to 20 atm.
- Heat fluxes up to 60 Btu/sec·ft^2 (cold wall, air) can be applied to flush, wall-mounted test articles; higher heat fluxes are applied to inclined wedges.
- Surface temperatures of 3000°F have been routinely produced on TPS tile samples.
- Simulation conditions on the test article are controlled by varying the arc current and air mass flow rate through the arc heater.

The physical and performance parameters of the TFD are listed in table 2. Figure 23 shows the operating envelope based on surface temperature and pressure of the test article for this facility. Other test gases available are nitrogen and argon. Run durations as long as 30 minutes are possible, with a 45-minute cool down between runs. The TFD has performed thousands of tests since its construction in 1970 and has the capability for quick turnaround and high production rates. An extensive series of development and certification tests were performed in this facility during the Space Shuttle thermal protection development process.

4.1.4 Facility Interfaces

The interfaces between investigator-supplied test equipment and the arc jet facilities are described briefly in this section. Although attempts have been made to standardize these interfaces as much as possible, some flexibility is required. Thus it is recommended that investigators coordinate these interfaces closely with the test engineers to ensure that nonstandard interfaces can be accommodated. Adhering to the interfaces listed herein will ensure the smoothest installation of test models and minimum delay to the test schedule.

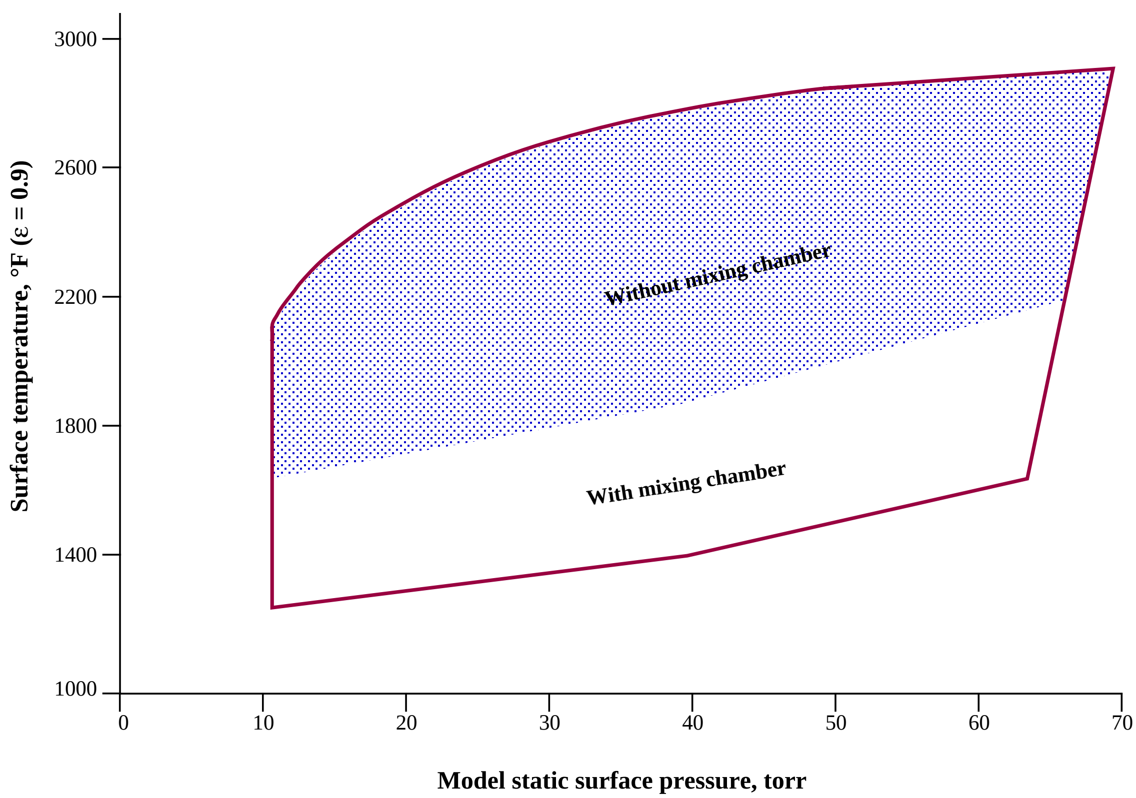

Figure 23. Operating envelope of the ARC TFD.

Table 3. Minimum lead-length requirements and number of channels supported

	AHF	PTF	IHF	
Minimum lead[‡] length, ft	12	8	15[*]	10[§]
No. of channels available for customer use	72	72	96	

[*] With conical nozzles installed
[§] With semielliptical nozzle installed
[‡] Insulation on instrument leads shall be glass-type or Kapton

4.1.4.1 Test Article Instrumentation

Instrumentation signal outputs are acquired and recorded by a common system of hardware and software in the ARC Arc Jet Complex. This system is described in section 4.1.5.8. Typically, customers supply test articles with the following types of sensors installed in them for recording by the arc jet data acquisition system: thermocouples, pressure ports, and heat-flux gages (Gardon type). Other types of sensors can also be accommodated. Because the arc jet facilities differ physically from each other, each facility has its own unique hookup configuration for instrumentation. Table 3 defines the minimum requirements for the length of instrumentation leads and the maximum number of channels supported at each facility. For investigators who require lead lengths different from those in table 3, it is recommended that they fabricate an extension bundle, properly labeled, in order to minimize delays. Instrument leads and/or extensions shall have glass-type or Kapton insulation. For tests using the semielliptical nozzles, all instrumentation shall be electrically isolated from the test fixture (figure 26).

Installation of instrumentation into the test articles shall follow the appropriate industry standards. If the appropriate standards are not followed, the Branch can not vouch for the integrity of the resultant data. In order to certify that data from Gardon-type calorimeters is valid, these sensors must be manufactured with a thermocouple near the sensing surface: this is required for sensors being used in the IHF; and recommended for those to be used in the other arc jet facilities.

During installation into the facility, instrumentation shall be labeled sequentially (e.g., thermocouple (TC) 1 through TC 24, calorimeter 1 through calorimeter 6, etc.). In order to avoid confusion, it is recommended that the investigator label his/her instrumentation likewise. If a nonsequential naming convention must be used, the investigator should provide dual labels: The nonsequential labels and a corresponding label that fits within the facility-specified names. It is the investigator's

Figure 24. Typical test setup in the AHF.

responsibility to keep track of the correspondence between the sequential and nonsequential naming.

4.1.4.2 Mechanical Interfaces

Mechanical interfaces can be adapted onsite, but last-minute changes can cause significant delays. The following standard interfaces are described for each facility. It is recommended that test models be fabricated to fit within

Table 4. Sting options in the AHF

Sting type	Bend radius of sting arm, inches	Sting inside diameter (ID), inches $^{+0.002}_{-0.000}$ [a]	Number available
Standard (carriage)	2.5	1.250	2
Standard (overhead)	–	0.750	1
Highly water cooled	6	1.500	1
Highly water cooled	5	2.000	1
Extra strength	*b*	*b*	1

[a] Test body male sting adapters shall be at least 1 1/2 diameters long.
[b] This sting has a mitered 90° bend and a short-coupled 4- × 6-inch bolt flange with an approximate ID of 3 inches.

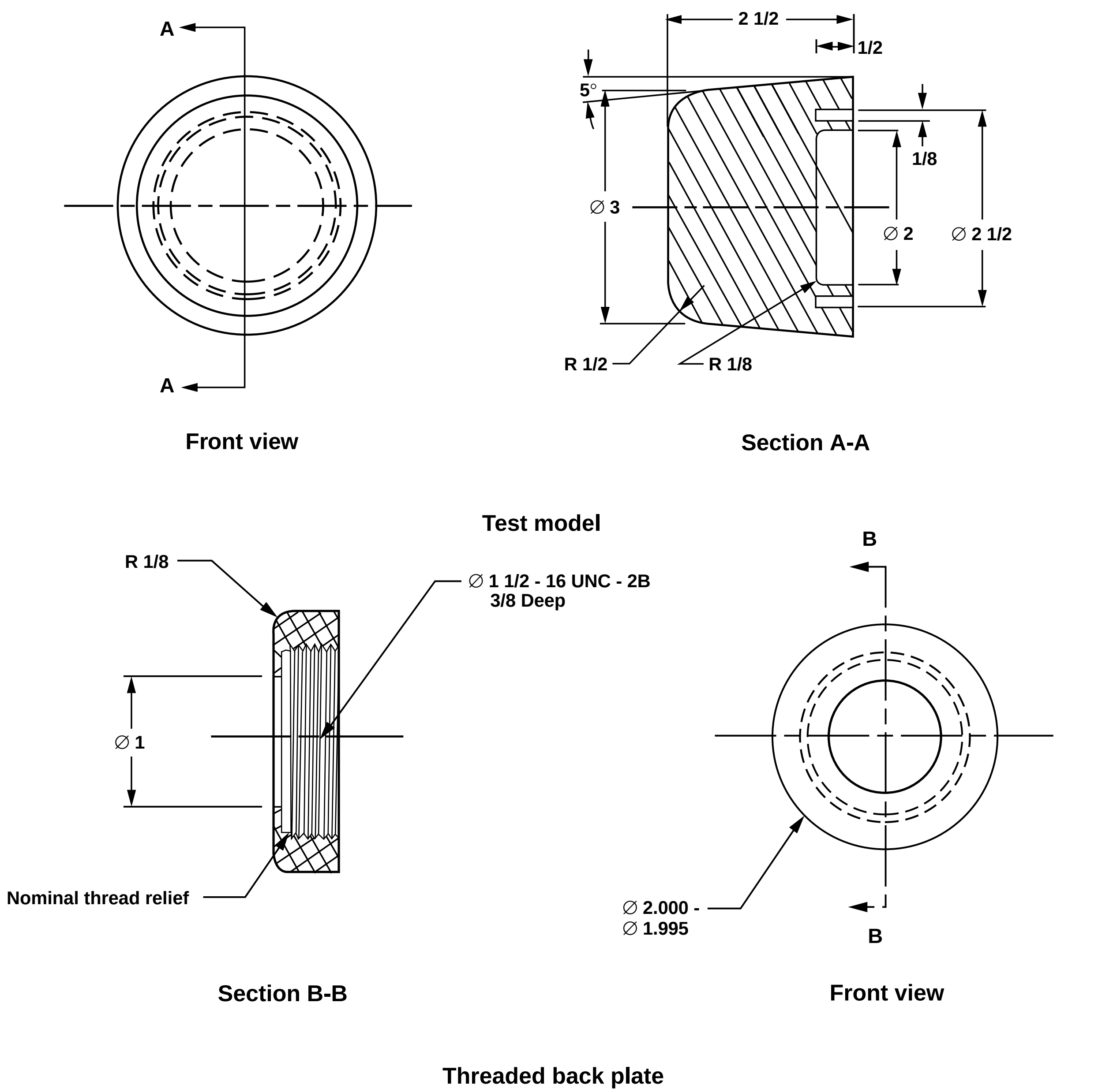

Figure 25. Typical AHF test article configuration (all dimensions in inches).

the following specifications. It is requested that all test articles using high-pressure components, whether for water cooling, hydraulics, or gas systems, be hydrostatically pressure tested at the vendor's site before they are shipped to Ames. If this is not possible, prior arrangements must be made to have Branch personnel perform these checks.

AHF Mechanical Interfaces– The Aerodynamic Heating Facility is equipped with a dual-strut traversing sting carriage and an overhead swing arm. The centerline-to-centerline distance between the two traversing stings is 34.5 inches. The maximum distance from the nozzle exit plane to the test article face is approximately 16 inches. Transverse motion is controlled manually by the facility operator. The location of the carriage is recorded by the data acquisition system.

The usual configuration in this facility has a 4-inch hemispherical probe mounted on the overhead swing arm (containing a heat-flux gauge and a pressure tap at the stagnation point), and up to two test articles, one on each of the two floor-mounted traverse stings (fig. 24). Depending on their size and on the diameter of the nozzle exit, two items can usually be mounted to the traversing sting in such a way that neither is subsequently exposed to the flow during arc heater startup and power ramp-up to the desired test condition (duration of approximately one to two minutes). This "usual" configuration may be altered to meet individual test requirements. A major consideration in the configuration of test articles is the model insertion time: the traversing sting requires approximately seven to ten seconds to move from the edge of the flow to the centerline, whereas the swing arm can be inserted in approximately one to two seconds.

Several sting combinations are possible in the AHF; they are summarized in table 4. A pair of water-cooled junctions that act as model adapter extensions for instrumentation connections is available. (They are visible in fig. 24.) They provide a place for thermocouple junctions to be made close to the test article. These TC junction adapters locate the test body about 3 inches closer to the nozzle exit plane; thus the maximum distance from the nozzle exit to the face of a 2.5-inch-thick test article (fig. 25) is approximately 13 inches (fig. 24).

Test articles should be fabricated with an adapter that will mate with the ID specifications listed in table 4 in order to minimize test delays. A typical test body is depicted in figure 25.

The AHF is equipped with a flexible system of water cooling for test articles. Typical cooling water pressure is 600 psig at flow rates of approximately 150 gpm. All high-pressure components supplied by customers must be hydrostatically pressure tested and certified before installation in the arc jet facility.

PTF Mechanical Interfaces– For the PTF, which is always configured with a semielliptical nozzle, the model support system is standardized. All test articles shall fit within the test fixture provided by ARC, or one fabricated with equivalent dimensions. A schematic drawing of the test fixture is shown in figure 26, and the dimensions are shown in table 5. The test assembly is installed by passing it through a round hatch in either side wall of the 4-foot test chamber (fig. 21). The hatches are of 36-inch diameter. The test fixture attaches to two pivot points, one on each side of the nozzle, such that the axis of rotation is at the lip of the nozzle. A hydraulically-actuated piston located underneath the test chamber provides calibrated tilt-table inclination angles, which are controlled manually from the control room and recorded by the data acquisition system. All instrumentation wires feed through a flexible, water-cooled conduit attached to one

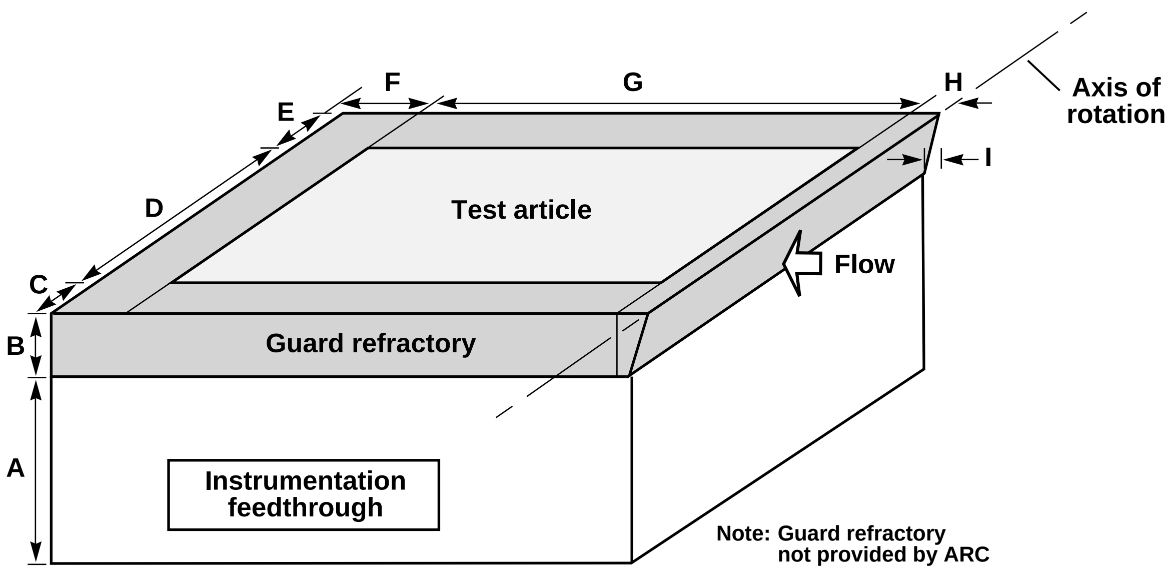

Figure 26. Test fixture assembly for PTF and IHF (semielliptical nozzle) (dimensions are in table 5).

Table 5. Dimensions for IHF and PTF panel test fixtures (drawing shown in fig. 26)

Callout, fig. 24	A*	B*	C*	D*	E*	F*	G*	H*	I*
PTF	5 7/8	2	2 1/8	15 3/4	2 1/8	2 1/8	15 3/4	1 1/8	3/8
IHF	5 7/8	2	3	30	3	4	30	2	3/8

*All dimensions are in inches.

side of the test fixture. It is imperative that the instrumentation leads shall extend at least one foot outside the test fixture, even when extensions will be used. (See fig. 26.) Water cooling manifolds are available in the PTF test chamber at a supply pressure of approximately 600 psig and flow rates of approximately 100 gpm. All high-pressure components supplied by customers shall be hydrostatically pressure tested and certified before installation in the arc jet facility.

IHF Semielliptical Nozzle Mechanical Interfaces– For the IHF with the semielliptical nozzle, the model support system is standardized. All test articles must fit within the test article fixture provided by ARC, or one fabricated with equivalent dimensions. A schematic drawing of the test fixture is shown in figure 26, and dimensions are shown in table 5. The test fixture attaches to two pivot points, one on each side of the nozzle, such that the axis of rotation is at the lip of the nozzle. The test assembly is installed by passing it through round hatches in the west wall and the ceiling of the walk-in test chamber, or through the 5-ft × 2-ft main access door (fig. 27). The hatches are of 35-inch diameter. A hydraulically-actuated piston located underneath the test chamber provides calibrated tilt-table inclination angles, which are controlled manually from the control room and recorded by the data acquisition system. All instrumentation wires feed through on one side of the test fixture. It is imperative that the instrumentation leads shall extend at least one foot outside the test fixture, even when extensions will be used. (See fig. 26.) Water cooling manifolds are available in the IHF test chamber at a supply pressure of approximately 600 psig and flow rates of approximately 250 gpm. All high-pressure components supplied by customers shall be hydrostatically pressure tested before installation in the arc jet facility.

IHF Conical Nozzle Mechanical Interfaces– When a conical nozzle is installed in the IHF, the IHF is equipped with two swing-arm model supports: one each on the west and east side, mounted on the floor of the test chamber (see figure 28). The inside-diameter bore of the model adapters is normally 1.987 in. Test articles shall be fabricated with a shaft/adapter to interface with these bores; the shaft/adapter shall be at least 1 1/2 diameters in length. No standard adapters exist for use in the IHF.

TFD Mechanical Interfaces– A schematic representation of the mounting of the test article for the TFD is shown in figure 13. In this facility, the test articles are flush mounted on the wall of the test section. Test panels measuring 8 × 20 or 8 ×10 inches can be mounted in the TFD. The test panels are secured in place by bolts around the perimeter of the backing flange of the test article. Instrumentation feedthrough connectors supplied by ARC are used to patch sensor data out of the back of the test-article flange and into the data recording system. Water cooling manifolds are available.

Figure 27. Main access door for the IHF.

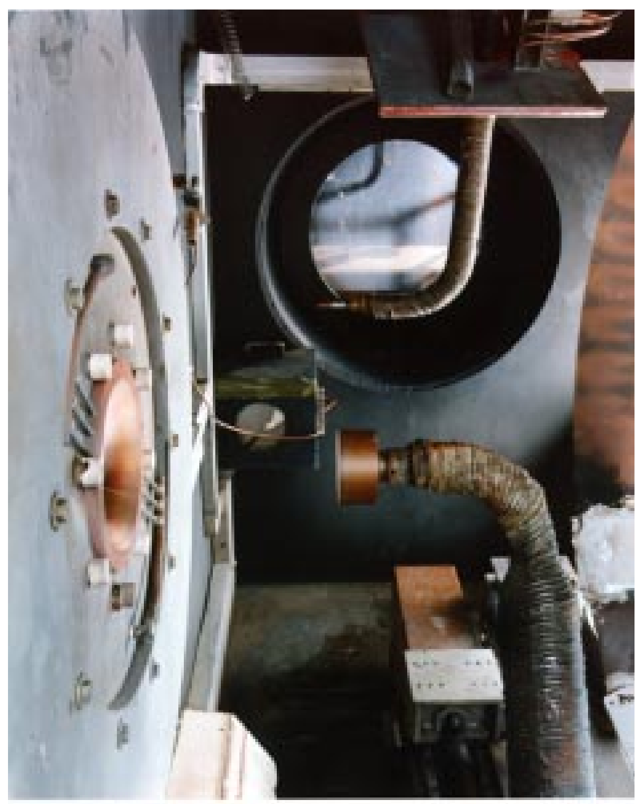

Figure 28. Typical test setup in the IHF.

Table 6. Sting options in the IHF—deleted

Table 6 has been deleted
Other stings are available
by special request

4.1.4.3 Optical Access

All the arc jet facilities have optical access to the test articles. The flow stream and test article(s) in the AHF, PTF, and IHF are accessed through large windows in the test chambers for instrumentation and line-of-sight observations. (See table 7.) The TFD has limited access for optical instrumentation through existing heat-flux sensor ports in the wall facing the test article.

Table 7. Number of viewports available

	AHF	PTF	IHF
Side viewing	7	4	5
Top viewing	3	4	6

In addition to the standard facility monitoring instrumentation, ARC will provide optical pyrometers and will coordinate photographic and video coverage of the tests, as required by the investigator. (A list of the optical pyrometers supplied by ARC is given in table 8.)

4.1.4.4 Personnel Access Outside the Test Chamber

Access to the area immediately outside the test chamber during a run is limited because of the safety aspects of high-voltage and high-pressure systems. If needed, such access must be coordinated with the test personnel during the planning phase of the test program.

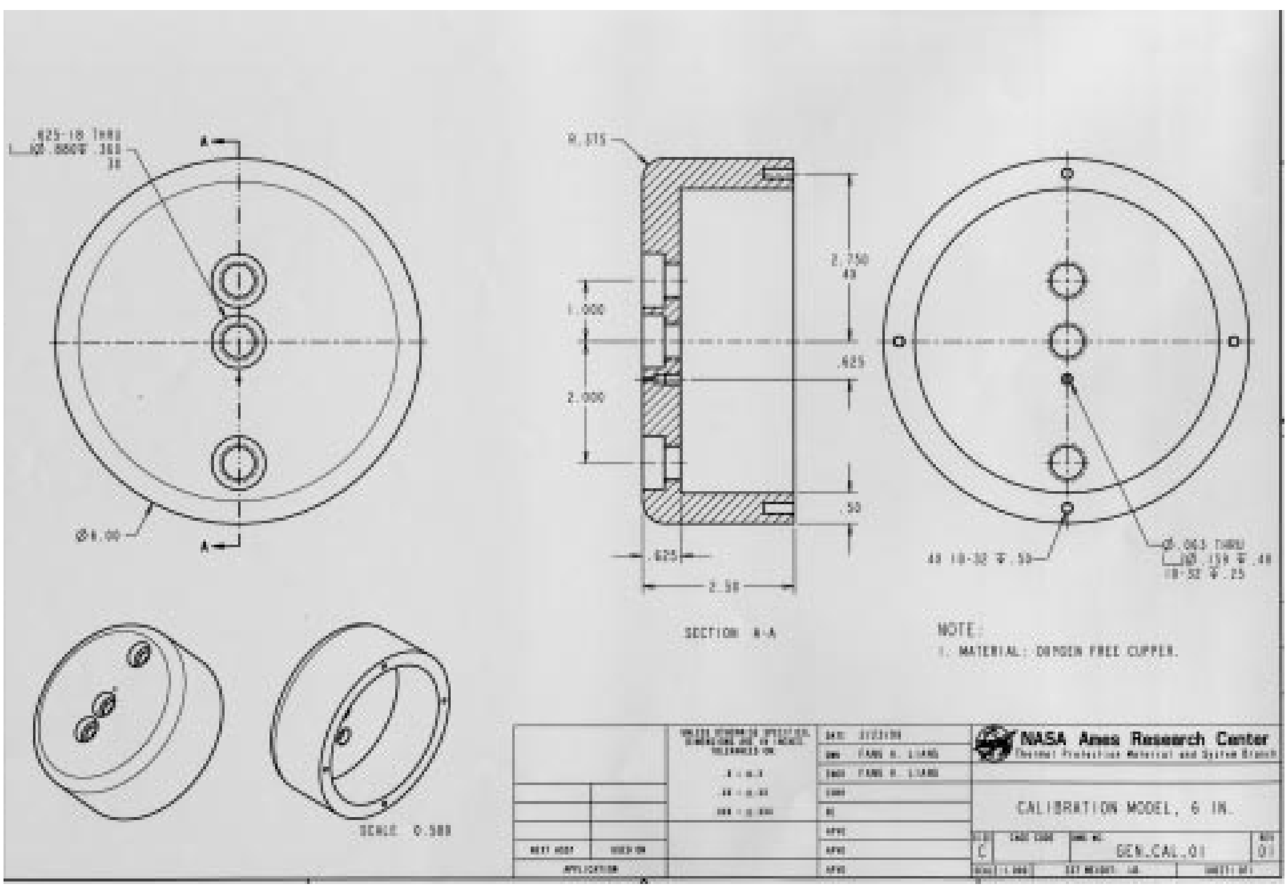

Figure 29. Typical slug-calorimeter-probe configuration.

Table 8. Optical pyrometers provided by ARC

Brand name	Type	Temperature range	Field-of-view (FOV) ratio	Spectral response	Model	Serial number
Mikron	Infrared	900–3000°C	300:1	0.65 µm	M90V	44384
Mikron	Infrared	600–3000°C	180:1	0.78–1.06 µm	M90H	44388-1
Mikron	Infrared	600–3000°C	180:1	0.78–1.06 µm	M90H	44388-2
Mikron	Infrared	600–3000°C	180:1	0.78–1.06 µm	M190H	50195
Mikron	Infrared	600–3000°C	180:1	0.78–1.06 µm	M190H	000866-1
Mikron	Infrared	600–3000°C	180:1	0.78–1.06 µm	M190H	000866-2
Mikron	Infrared	900–3000°C	180:1	2-color	M90R2	50194
Mikron	Infrared	900–3000°C	180:1	2-color	M190R2	
Mikron	Infrared/ fiber optic	700–2600°C	180:1	0.78–1.06 µm	M668L	50482
Mikron	Infrared/ fiber optic	900–2500°C	60:1	0.65 µm	M668L	50550
Raytek	Infrared		150:1		250SC	A2454
Raytek	Infrared		150:1		300SC	A2304
Raytek	Infrared		150:1		300SC	A2447
Raytek	Infrared		150:1		300SC	A2448
Raytek	Infrared		150:1		300SC	A2445
Raytek	Infrared	1300–5000 K			300SK	A3367
Raytek	Infrared	400–3000°C			RAYSHHTCF3 RAYT4BAHT	15020A 15020L
Pyro Instruments	Optical/ visible	700–3200°C			M5402	
Pyro Instruments	Optical/ visible	900–3500 K			M5816	

4.1.4.5 Calorimeters (Provided by ARC)

ARC can also provide a selection of heat-flux (and/or pressure) sensing devices for calibrating the flow environment for both stagnation and flat-plate tests. Some of these instruments are water cooled for continuous operation.

A family of hemisphere/cylinder probes designed for the AHF are available, ranging in diameter from 2.5 to 4 inches. Each contains a removable Gardon-type heat-flux sensor at the stagnation point, and a pitot pressure port located just off the stagnation point. Blunted-cylinder probes of the same design are also available. Additionally, a set of water-cooled 5/8-inch-diameter hemisphere/cylinder probes are available for both the AHF and the IHF (for use with the large nozzles). Each probe contains one of either a heat-flux sensor or a pitot pressure port, located at the stagnation point.

Slug-type calorimeter probes are also available. These are recommended for the high-heat flux environment of the IHF 13- and 6-inch conical nozzles. These probes are available in 2.4- and 3.0-inch-diameter hemispherical probes and 4.0- and 6.0-inch-diameter flat-faced cylinders with a 0.375-inch corner radius. Most of these probes are also equipped with a pitot pressure port. For other flat-faced configurations, the investigator may fabricate his/her own calorimeter probe to accept the standard slug calorimeter insert. Figure 29 shows the 6-inch-diameter probe as a reference for investigators who will fabricate their own probe(s).

Water-cooled calibration plates that mount in the location of the test article are available for both the PTF and the IHF with the semielliptical nozzle. (See fig. 26.) The plates are equipped with Gardon-type calorimeters and static pressure taps distributed throughout the surface of the plate in order to obtain distributions along the test surface. Data from the flat panel calibration plates are plotted in Appendices A (PTF) and B (IHF).

The wall opposite the test panel in the TFD is instrumented with heat-flux sensors and static pressure ports.

4.1.4.6 Model Sizing Guidelines

A general rule of thumb that may be used in determining the maximum dimensions of porposed test articles is that the areal blockage ratio should not exceed 0.25 to 0.30. The size of test articles that can be successfully tested in the facilities depends on the geometry of the test articles; thus this rule of thumb is offered only as a general guideline.

4.1.5 Facility Support Equipment

The arc jet complex is serviced by common facility support equipment that is shared among all the arc jet facilities described in this section. In many cases, the frequency of facility operations is determined by the availability of these support systems. Only one arc jet facility may be operated at any time because of safety considerations as well as the need to share common support equipment. Several facilities share the same power supply, so an adequate cool-down period between runs is necessary. Some common data system components are shared between the various arc jet facilities.

4.1.5.1 Steam-Ejector Vacuum System

The SVS servicing the arc jet complex is one of the largest steam-ejector vacuum systems of its type. The SVS provides the high-mass-flow vacuum conditions required for arc jet facility operations. Each of the arc jets is plumbed into the SVS via large-diameter piping and isolation gate valves. The SVS consists of five stages of steam ejectors that are operated in series. Figure 30 shows a schematic diagram of the SVS; the SVS is visible in figure 5. The steam is provided by a natural-gas-fired boiler with a generating capacity of 200,000 pounds of steam per hour. Using all five stages, the system pumps to a blankoff (no flow) pressure of 80 microns of mercury. Five-stage operation can pump 0.5 lb_m/sec of air while maintaining a plenum pressure of about 0.1 torr (100 microns). Using three stages, the capacity is about 3 lb_m/sec at 3 torr. A standby operating mode is used to save energy between tests when two stages are operated, producing about 15 torr with no gas flow. The pumping characteristics of the SVS are shown in figure 31.

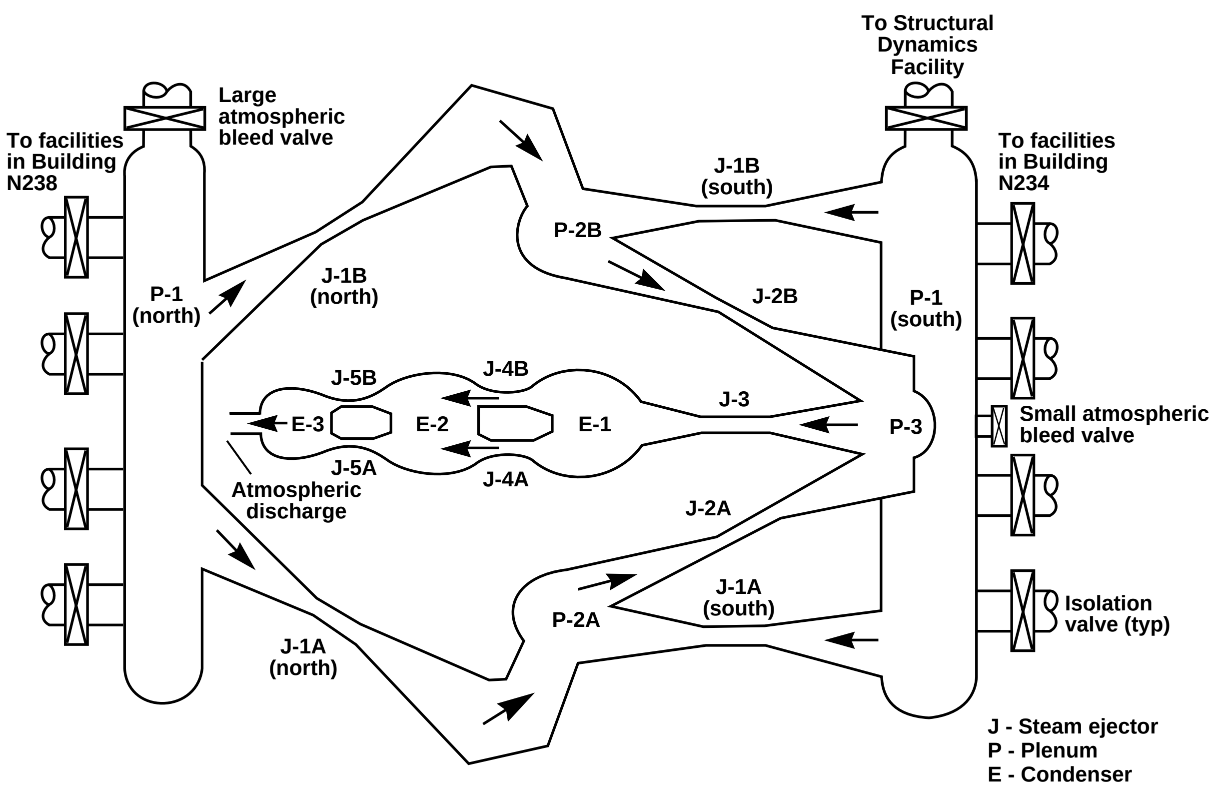

Figure 30. Schematic diagram of the five-stage SVS.

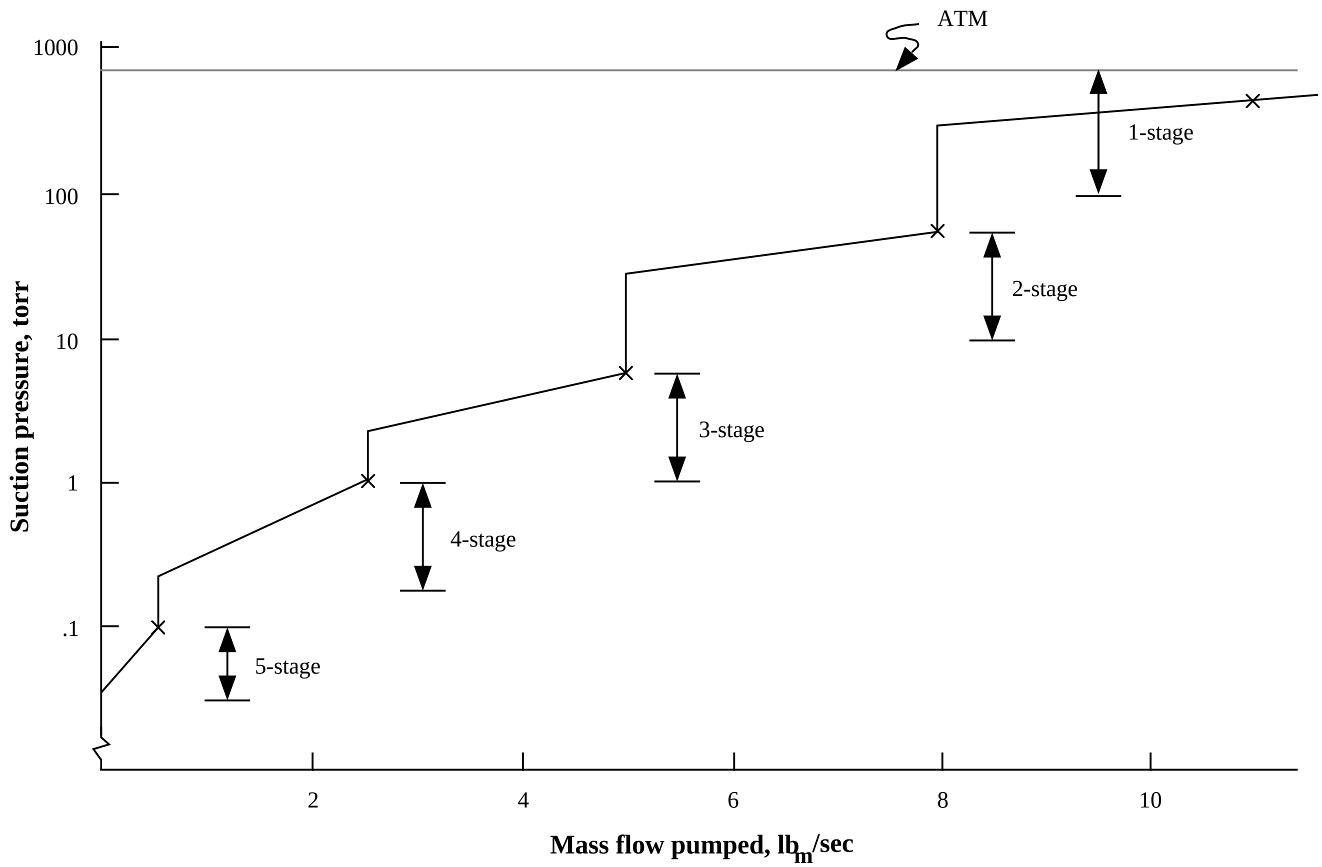

Figure 31. Pumping characteristics of the SVS.

4.1.5.2 60-/150-MW DC Power Supply

Originally constructed in 1975 at 60-MW maximum power, this power supply was modified a few years later to upgrade its power capacity. This power supply is a current-controlled, three-phase, full-bridge, phase-controlled silicon controlled rectifier (SCR) type that provides the dc power source for the arc jet facilities in Building N238. It consists of six SCR module pairs, which can be configured into any compatible series/parallel combination. Each module is rated at 5500 volts open circuit, 4350 volts into a load, and 2700 amperes (A) continuous, 6000 A short term. The entire power supply has a power rating of 75 MW for a 30-minute-on, 30-minute-off duty cycle, and up to 150 MW for 15 seconds. The operator selects a module configuration to provide open circuit voltage that slightly exceeds the expected arc voltage. Current is controlled via a set point manually input at the control board by the facility operator. Current and voltage are recorded on the data acquisition system. The entire power supply is isolated from ground to 33 kV.

The rectifier modules are fed from three double, secondary transformers that receive primary power from the distribution grid at 115 kV, 60 Hz. Secondary transformers step down the voltage to 4170 VAC feeding into the rectifier modules. Rectification is accomplished using three parallel strings of 14 SCRs, one leg for each phase. The output from each module is shunted with a double string of four free-wheeling diodes and is connected in series with a 4-millihenry inductor. The transformer secondaries are shifted 30° with respect to each other; therefore, adjacent modules connected to the output bus produce an effective 12-phase rectifier with a corresponding reduction in dc ripple.

The output from the power supply is transmitted to each of the four facility load switches in the basement of Building N238 through 3-inch, water-cooled, copper piping. The power supply and its components are insulated for 33-kV dc power. The power supply is cooled by an independent, deionized, cooling water system consisting of a storage tank, a cooling tower, deionizers, a circulating pump, and associated hoses and pipes. The system uses deionized, chemically treated, low-conductivity water to cool the SCRs, free-wheeling diodes, output inductors, and the dc power bus.

4.1.5.3 20-MW DC Power Supply

The 20-MW power supply comprises five identical modules that can be connected to provide 20 MW of dc power. Each of the 5 modules consists of 2 rectifier banks (or half modules). Each half module is nominally rated for 1600 amps at 1250 V; open circuit voltage is 2500 V. The 10 half modules may be connected in various combinations by using setup switches to provide a desired open circuit voltage, or desired current level, depending on the anticipated arc jet load requirement. Current is controlled manually from the bench board by means of a bias control setting, which adjusts current output via saturable reactors. There is no direct voltage control. The operating current and voltage are recorded for reference. The entire power supply is isolated from ground to 30 kV.

The power output is brought into Buildings N234 and N238 by a set of high-voltage power cables, and then is distributed to the facilities through a main load switch and individual facility disconnect switches. These switches are interlocked to prevent unwanted energizing by means of limit switches and a key interlock system.

With appropriate connections between the rectifier banks, the power supply can deliver approximately 19 MW for 5 minutes and 12 to 14 MW for up to 30 minutes.

4.1.5.4 Deionized Water Cooling System

The arc jet facilities use a common, closed-loop, deionized water cooling system, which provides the majority of the heat rejection needs. Deionized cooling water is stored in a 168,000-gallon storage tank located near the steam vacuum system. The water from this tank has been demineralized and deionized to reduce the resistivity and oxidation. The tank provides about a 40-foot static pressure head when full.

The water system is used as primary cooling for the arc heaters, test article supports, nozzles, and other facility hardware. A set of 10 pumps circulate cooling water at approximately 8000 gpm at a pressure of 700 psig to the selected facility and then back to the tank. A heat exchanger in a secondary circuit permits cooling of the stored water, but at a low rate.

A separate water cooling system in Building N234 (400 psig discharge) cools the plenum heat exchanger, valve shield, etc. So-called “gravity” cooling water is also available directly from the 168,000-gallon tank at about 15-psig pressure. This water is used to cool the diffuser pipes of the AHF and TFD. It is collected in a sump and then recirculated back to the main tank. City water is available at about 50 psig, if necessary.

4.1.5.5 High-Pressure Air System

The arc heaters at ARC usually operate with air as the main test gas. Air is supplied by a 3000-psi distribution system located at ARC; the storage facility has a total storage capacity in excess of 7 million standard cubic feet. This distribution system is common to all the wind tunnel facilities at ARC. Large reciprocating compressors pressurize the storage and distribution network. Air flows into air control panels located in the basement below each arc jet facility. From there the bench board controls are used to regulate the flow rate of air to a facility via manual or automated controls actuated by the facility operator. Air can also be used for auxiliary purposes such as actuating or cooling portions of test articles.

4.1.5.6 High Pressure Gases—Nonair

The arc heaters at ARC can operate with gases other than air as the main test gas.

- **Nitrogen–** A liquid nitrogen storage tank feeds a 4000-psig pressurized nitrogen gas storage tank yard located near the steam-ejector vacuum system. Piping distributes the nitrogen to facilities in Buildings N234 and N238. The nitrogen can be used as a main test gas or as an auxiliary gas for purging, cooling, or other purposes.
- **Argon–** Argon gas is used by the constricted arc heaters in small amounts at all times. A small bleed of argon is used to aid in starting the arc discharge at the beginning of each run. A small amount of argon is injected between constrictor disks and electrode rings to reduce the occurrence of arcing between adjacent components of the arc heater. In addition, the AHF can be operated with argon as a main gas.
- **Other gases–** Other gases can be used as needed.

4.1.5.7 Air Pollution Control System

Nitrogen oxides in the exhaust streams produced by the arc heaters must be removed before exhausting into the atmosphere. Removal is accomplished by a combination containment and scrubbing system, which neutralizes the resultant nitric acid with a caustic solution. Air discharge quality is monitored often for compliance with local ordinances.

4.1.5.8 Data Acquisition System

The current arc jet data acquisition system consists of a DEC Alpha or Pentium-based workstations. Data reduction is accomplished by a workstation in each of the arc jet buildings. Eight channels of data are displayed in a real-time display in the control room and in the test observation area. Any eight channels may be displayed and changed at any time during the test without loss of data. Two modes of acquisition are possible: static and dynamic (specification list follows). Toggling between modes, or between sampling rates in the static mode, is accomplished by software inputs during a run. Output is available in the form of: printed columnar data as a function of time; electronic files of the tabular data as a function of time; or graphical plots of multiple data channels. Under proper security protocols, data can be transmitted via the Internet to remote sites.

Each facility has a standard set of tunnel data that is always acquired. With some variation, the required data include: arc voltage, arc current, power supply output voltage and current, arc pressure (reservoir pressure), air supply pressure, and test chamber vacuum level. In some cases other data are recorded as tunnel data, including individual electrode current levels and the mass flow rates of the test gases.

Each facility has dedicated front-end equipment designed to condition the sensor signals, digitize them, and then transmit over fiber-optic links to the acquisition computer. The fiber-optic link provides an important isolation from high-voltage potentials induced on test articles and the arc heater itself—all data channels from the arc heater and test article must be isolated by this system. In addition, all channels from the test articles must be ungrounded, or electrically floating. Exceptions are made for Huels arc heaters whose downstream electrodes are electrically at zero potential, or grounded.

Specifications of the ARC arc jet data acquisition system are as follows:

- Pentium II workstation or DEC Alpha workstation for data acquisition and data reduction
- GPIB crate controller CAMAC KineticSystems' 3988
    - Provides interface between a GPIB system and a CAMAC crate
    - Supports data transfer rates up to 600 kilobytes per second with the actual rate limited only by the controller and/or host computer. All command and data information are passed between the host computer and the 3988 in binary form, not ASCII characters. Read and Write data can be transferred in 8, 16, or 24 bit form.
    - Meets all IEEE488 requirements
    - Power requirements
        - +6 volts/-3.7A
- CAMAC KineticSystems' 3516/3518 - 32 channel, scanning A/D converter
    - 32-channel capability
    - 16-bit resolution (one part in 65,536)
    - Programmable gain from 1 to 1024
    - Self-scanning, differential inputs, high-frequency noise filtering on inputs
    - Temperature and pressure measurement
    - The 3516/3518 is precalibrated for ±10 volts inputs.

  The Model 3516/3518 is a single-width CAMAC module which converts 32 analog voltages into their equivalent digital values. Once channel scanning is initiated, each channel's input is selected, the preloaded gain factor is applied to it, the amplified signal is converted, and the resultant binary information is storred in the on-board memory. Conversions take place at the rate of one every 250 microseconds (all 32 channels in eight milliseconds).
- Acquisition Parameters:
    - Data Rate
        - Sample rates range between 10 seconds/sample to 100 samples/second per channel
        - Capable of selecting any sample rate at any time during the test
    - Real-time display
        - Real-time computations for display of any 8 channels
        - Capable of selecting any 8 channels at any time during the test
        - Real-time display remains active at all sample rates
- Data reduction processing is complete within 3 minutes after each run.
- Test article sensors:
  – Thermocouple types: K, S, R, J, T, G, and E
  – Pressures: Barocel, Statham, ESP
  – Calorimeters: slug and gardon
  – Radiometer

  - Pyrometer
  - Miscellaneous analog sensors with voltage output up to ±10 volts or current loop output in any milliamp range
- Special equations and soft channels can be programmed upon request
- Output types:
  - ASCII, comma-delimited file on a 3.5-inch floppy disk
  - Electronic file transfer to remote sites
- Output hardcopy data types:
  - Tabular printout (time history)
  - Channel to channel or time history plot containing up to 10 channels per plot

4.1.6 Bibliography

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4.2 Range Complex

The Range Complex comprises the Hypervelocity Free-Flight Facility (HFFF), the Ames Vertical Gun Range (AVGR); and the Electric Arc Shock Tunnel (EAST).

4.2.1 Hypervelocity Free-Flight Facility

The Hypervelocity Free-Flight Facility (HFF) at Ames Research Center (ARC) currently comprises two active facilities: the HFF Aerodynamic Facility and the HFF Gun Development Facility. Both facilities were constructed in 1964 and are located in Building N-237.

4.2.1.1 Hypervelocity Free-Flight Aerodynamic Facility

The Hypervelocity Free-Flight Aerodynamic Facility is a combined Ballistic Range and Shock-tube Driven Wind Tunnel. The HFFAF consists of: a model launching gun (light-gas or powder); a sabot separation tank; a test section (with 16 orthogonal shadowgraph imaging stations); an impact/test chamber; a nozzle; and a combustion-driven shock tube (see figure 32). The primary purpose of the facility is to examine the aerodynamic characteristics and flow-field structural details of free-flying aeroballistic models. For this mode of traditional aeroballistic testing, each of the shadowgraph stations can be used to capture an orthogonal pair of images of a hypervelocity model in flight along with its associated flow-field. These images combined with the recorded flight time history can be used to obtain various aerodynamic coefficients CD, CLa, Cma, Cmq + Cma. For very high Mach number (i.e. M> 25) simulation, models can be launched into a counter flowing gas stream generated by the shock tube. This “counterflow” mode of testing tends to be both technically demanding and expensive. The facility can also be configured for hypervelocity impact testing. In this mode, a light gas gun is used to launch impact particles (typically spheres) at target materials mounted in the impact chamber. A fourth mode of operation is shock tunnel testing. For this type of testing a fixed, instrumented model is mounted in either the impact/test chamber or at one of the shadowgraph stations in the test section. The combustion driven shock tube is used to generate a short duration reservoir of high-temperature, high-pressure test gas for expansion through the nozzle and over the test article. Most of the research effort to date has centered on Earth atmosphere entry configurations (Mercury, Gemini, Apollo, and Shuttle), planetary entry designs (Viking, Pioneer Venus, and Galileo), and aerobraking (AFE) configurations (see figure 33). The facility has also been used for scramjet propulsion studies (NASP) and meteoroid/orbital debris studies (Space Station, and RLV).

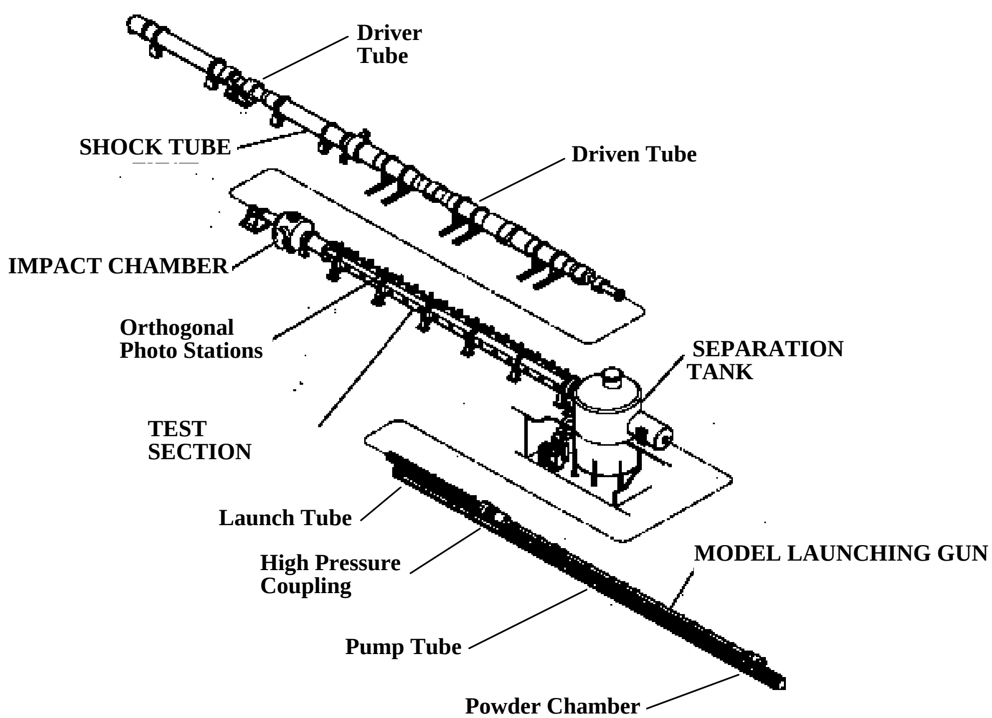

Figure 32. The Hypervelocity Free-Flight Aerodynamic Facility

4.2.1.1.1 Model Launching Guns

There is an arsenal of model launching guns that are available for use in this facility. Included in this arsenal are four light-gas guns: a 0.28cal (7.1mm); a 0.50cal (12.7mm); a 1.00cal (25.4mm); and a 1.50cal (38.1mm) gun. The size is designated by launch tube (barrel) diameter. A two-stage light-gas gun typically consists of a powder chamber, pump tube, high pressure coupling, and launch tube (see figure 32). A deformable plastic piston is inserted into the upstream end of the pump tube. The sabot (which holds the model) is inserted into the launch tube breech, and a burst disk (diaphragm) is placed between the high pressure coupling and launch tube. The pump tube is evacuated and filled with a predetermined amount of hydrogen, and a gun powder charge is placed in the powder chamber. To launch the model, the gun powder charge is ignited. The resultant release of chemical energy accelerates the piston, compressing the H_2 gas in the pump tube or first stage of the gun. At a predetermined pressure, the burst disk ruptures and the compressed H_2 gas acts upon the base of the sabot, accelerating it down the launch tube or second stage of the gun. When the sabot and model exit the launch tube, they enter the separation tank, wherein the sabot is stripped away from the model aerodynamically. The model passes through a small aperture, enters the test section, and ultimately impacts a wall of polyethylene in the impact chamber.

In addition to light-gas guns, the facility arsenal contains three powder guns: a 0.79cal (20mm); 1.74cal (44mm); and a 2.40cal (61mm) gun. A powder gun is a simpler design and consists of a powder chamber and a launch tube. The launch package (sabot and model) is loaded into the launch tube breech, and a gun powder charge is placed in the powder chamber. To launch the model, the gun powder charge is ignited. The resultant release of chemical energy accelerates the launch package (sabot and model) down the launch tube and into the separation tank. The path from this point on is the same as for a light-gas gun.

The performance of the light-gas guns depends upon many, and sometimes conflicting, variables such as pump tube pressure, piston weight, gunpowder charge, burst disk (diaphragm) pressure rating and launch package weight. Theoretically, the maximum attainable velocity for each of the ARC guns is approximately 35,000 ft/s (10.7 km/s). However, a more realistic upper value is

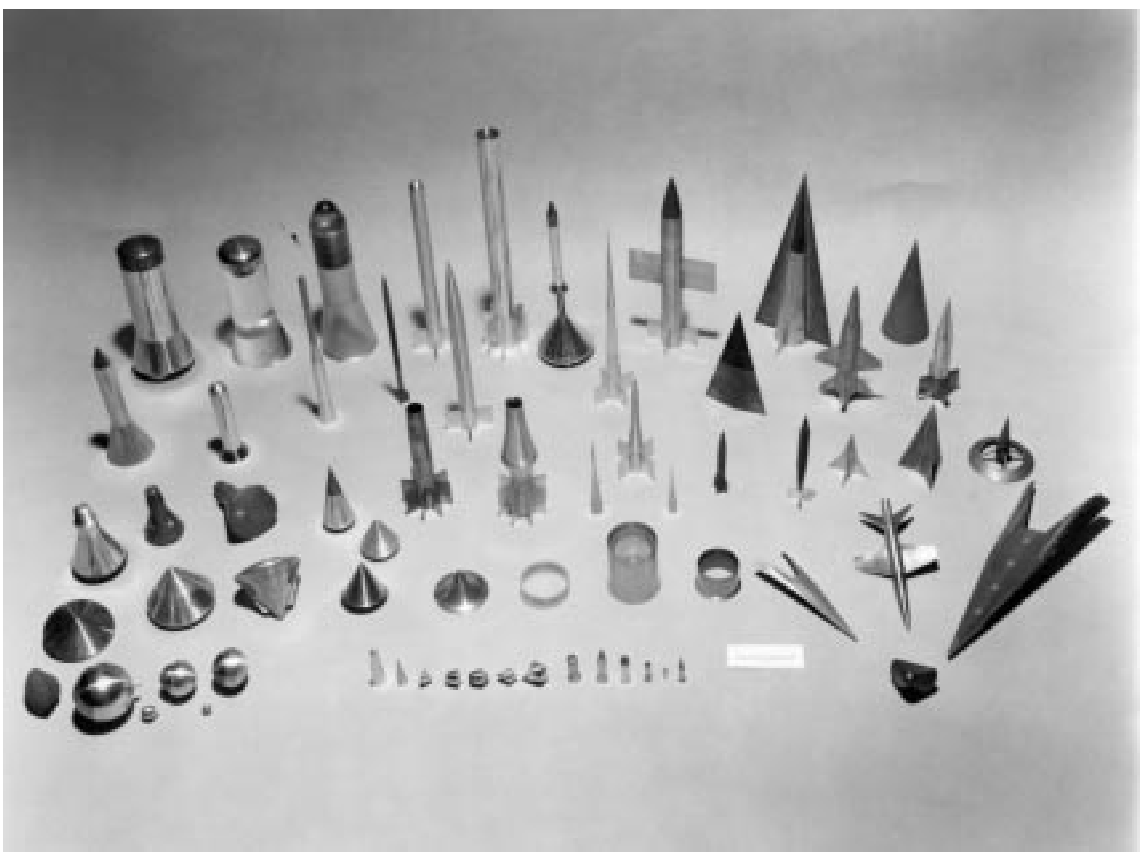

Figure 33. Examples of Aeroballistic Models

28,000 ft/s (8.5 km/s) for robust models such as spheres and cylinders. For delicate aeroballistic models, maximum velocities are typically limited to 15,000 to 21,000 ft/s (4.5 to 6.5 km/s). Model diameters typically vary between 15 to 75% of the gun barrel diameter. Similarly, model masses typically vary from 0.01 to 100 grams. The lower limit velocity for each of the light-gas guns is approximately 6500 ft/s (2 km/s). The ARC powder guns typically operate over a range of 2000 to 8000 ft/s (0.6 to 2.4 km/s).

4.2.1.1.2 Sabot Separation Tank

The sabot separation tank (also referred to as the dump tank) consists of a vertical cylindrical tank (approximately 4800 cubic feet) with transition extensions on either side that are in line with the test section and the light-gas gun. Inside the dump tank and attached to the entrance of the test section extension is a large conical sabot stripper. This device has an adjustable aperture (0.5 to 2.5 inch diameter) which allows model passage, while the conical structure deflects and ultimately stops the sabot pieces. A thin mylar diaphragm can be placed inside the stripper device to isolate the test section from the dump tank. The gun extension includes an entry hatch. At the top of the dump tank, extending above the building roof, is a diaphragm port to limit internal pressures to approximately atmospheric. Overall length of the assembly is approximately 32 feet and the volume (including the transition extensions) 5100 cubic feet.

The associated vacuum pumping system is located below ground level adjoining the dump tank. The system consists of a pair of Stokes rotary pumps (300 cubic feet per minute), and a Roots-type booster pump (4,950 cubic feet per minute at 100 microns inlet pressure) which are attached to the test section transition extension. In addition to this, another pair of 300 cfm rotary pumps are attached directly to the dump tank. Pressures of 50 microns of mercury are attainable in the test section, with leak rates of less than 10 microns per minute, despite the large numbers of windows and connections. Valves are pneumatically operated and electrically controlled from the control room under the west end of the test section.

4.2.1.1.3 Test Section

The test section is 75 feet long, with sixteen orthogonal shadowgraph stations spaced five feet apart. The octagonal cross-section is approximately 40 inches across the flats (at station 16) and is tapered (increasing as one moves towards station 1). The reason for this taper is to compensate for boundary-layer growth that occurs during shock tunnel flow conditions. Each shadowgraph station includes four windows (top, bottom and both sides). The window diameters are 12 inches nominal for stations 1 through 9, and 15 inches for stations 10 through 16. Window thicknesses are 1 inch and 1.25 inches respectively. At each station a shadowgraph can be taken in both the horizontal and vertical planes. Each view utilizes the following: A microsecond-duration spark light source mounted on the test section wall; A pair of spherical mirrors, with diameter to match the station window (the focal length is roughly 6 feet), mounted on the facility walls; A 40 ns Kerr Cell shutter at the focal point of the second mirror; and a light-excluding box for mounting an 8×10 inch sheet film holder. Other instrumentation on the test section includes the spatial reference system, halogen lamp w/photomultiplier tube model detectors, and ports on the upper diagonal surface of the test section wall at each station. These ports are used for vibration-isolated static pressure cell mountings, or as possible feed-through points for cables, gas supplies, thermocouples etc.

4.2.1.1.4 Impact/Test Chamber

The impact/test chamber is located between the test section and shock tube nozzle and has two primary roles. When the facility is operated as a ballistic range, a 2.5 inch thick steel back stop plus a 24 inch thick wall of polyethylene are installed at the nozzle exit to stop the aeroballistic models at the end of their flight. Similarly, hypervelocity impact targets can be mounted in the chamber for this mode of operation. When the facility is operated as a shock tunnel, the chamber can be used as a free-jet test cabin for mounting large, highly instrumented models. For this mode of operation, the steel and polyethylene wall is removed and diffuser panels are installed to smoothly redirect the shock tube flow into the test section. The impact/test chamber has numerous instrumentation feed-through ports, and four large access hatches (top, bottom, and both sides). Each hatch has two 15-in. diameter windows to provide optical access if desired.

4.2.1.1.5 Nozzle

Attached to the shock tube side of the impact/test chamber is the Mach number 7 contoured nozzle (approximately 19-ft long with an exit diameter of 39-in.). The nozzle consists of five major components: a throat insert assembly which slides into the driven tube end-wall, and is connected to the nozzle trunnion by means of a Marmon clamp; the trunnion section which is mounted to a heavy foundation block (this fixes the longitudinal location of the entire test section); and three nozzle expansion sections, each of which are 62 inches long. The nozzle insert assembly contains a thin mylar diaphragm which separates the initial driven tube and test section pressures. A variety of throats can be used to vary the area ratio between 80 and 300.

4.2.1.1.6 Shock Tube

A combustion driven shock tube is used to generate a reservoir of high-pressure, high-temperature test gas for expansion through the nozzle and test section. It consists of a driver or combustion tube (70-ft long, 17-in. inside diameter), and a driven tube (86-ft long, l2-in. inside diameter), see figure 32. The driver and driven tubes are initially separated by a flat, stainless-steel diaphragm with a thickness and score depth selected to provide self-break at a desired pressure. In a similar fashion, the driven tube and nozzle are separated by a thin Mylar diaphragm. The driver tube is filled with a combustible mixture (typically H_2 and O_2 along with He as a diluent); the driven tube is filled with the desired test gas (usually air); and the impact/test chamber (plus test section and dump tank) is evacuated to a low enough pressure to ensure proper flow establishment. To initiate the test flow, the combustible mixture is ignited by use of a hot-wire ignition system. When combustion nears completion, and the driver-tube pressure attains a certain critical value, the primary (stainless steel) diaphragm ruptures. As the heated, high-pressure driver gas (typically He and combustion products) begins to expand into the driven tube, the resulting induced pressure waves coalesce into a shock wave. The shock wave traverses the length of the driven tube, heating and pressurizing the test gas as it propagates. When the shock reaches the end of the driven tube, it reflects off the end-wall and breaks the Mylar diaphragm, thus establishing a relatively stable, high-temperature, high-pressure test gas reservoir. This reservoir, with enthalpy as high as 5,200 Btu/lbm (12,200 J/gm), typically persists for roughly 20 msec, as the flow passes through the nozzle and over the test object (mounted in the test cabin). During this time various pressure, heat-transfer, and optical-diagnostic measurements can be recorded by the facility’s data acquisition system (DAS).

The shock tube has been operated primarily in two combustion modes, heated-air (“slow-burn”) or pseudo-stoichiometric (“fast-burn”). For the slow burn mode, the driver tube is filled with a mixture of 8 percent hydrogen and the remainder air. The mixture can be thermally stirred by passing a heating current through the ignition wire(s) prior to actually igniting the mixture. For the fast-burn mode, a nearly stoichiometric mixture of hydrogen and oxygen along with a sizable amount of diluent (usually helium and/or nitrogen) is used. The pressure in the driver tube rises by a factor of about 4 for slow burn and 8 for fast-burn.

The so-called “tailored operation” of the shock tubes is often used to produce essentially constant reservoir conditions for upwards of 20 milliseconds. The flow is typically near Mach 7 (based on area ratio), but temperature and flow velocity may be varied jointly or discretely by changing nozzle throat size, and simultaneously adjusting the driver gas composition and driven tube fill pressure. This provides a great amount of flexibility in adjusting the total enthalpy, and effective Mach no. For example, the slow burn mode can produce a 4,400 feet/second flow at a static temperature of about 150 °R, while fast burn can yield flow velocities up to 12,000 feet/second at temperatures to 1250 °R.

4.2.1.2 Hypervelocity Free-Flight Gun Development Facility

The HFF Gun Development Facility consists of: a light-gas gun; a sabot separation tank; a flight tube; and an impact chamber. This facility is used primarily for gun performance enhancement studies. In particular, operational parameters and hardware configurations are adjusted/modified in an effort to increase maximum velocity (and/or launch mass capabilities), while maintaining acceptable levels of gun barrel erosion. The facility operates in a manner similar to the HFFAF. The sabot and projectile exit the launch tube of the gun and enter the separation tank, wherein the sabot is stripped away from the projectile aerodynamically. The projectile passes through a small aperture, enters the flight tube, and ultimately impacts a target/catcher in the impact chamber. The total flight path (from launch tube exit to impact) for this facility is 38ft (11.6m) as compared to 114ft (34.7m) for the HFFAF. The facility utilizes the same arsenal of light-gas guns as the HFFAF (see section 4.2.1.1.1) except for the 1.50cal (38.1mm) gun. This is because the considerably smaller separation tank has a suboptimal gun-blast receiver volume for the 1.50cal gun. With the arsenal of guns, spherical aluminum particles ranging in size from 1/16 inch (1.6mm) diameter to 3/4 inch (19mm) diameter can be accelerated to hypervelocity speeds. There are five photomultiplier tube based time of arrival stations, whose outputs are recorded by digital scopes. During the projectile’s flight (from launch tube exit to impact) the shock layer radiation is sensed by each of the photomultiplier tubes as the projectile passes by the time of arrival stations. These times are used to calculate projectile velocity. Several of the outputs can be used to trigger flash x-ray channels.

4.2.1.3 Bibliography

The following papers describe the ballistic range facilities, their history, and some recent research programs performed in them at Ames Research Center. The list is not exhaustive.

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4.2.2 AVGR

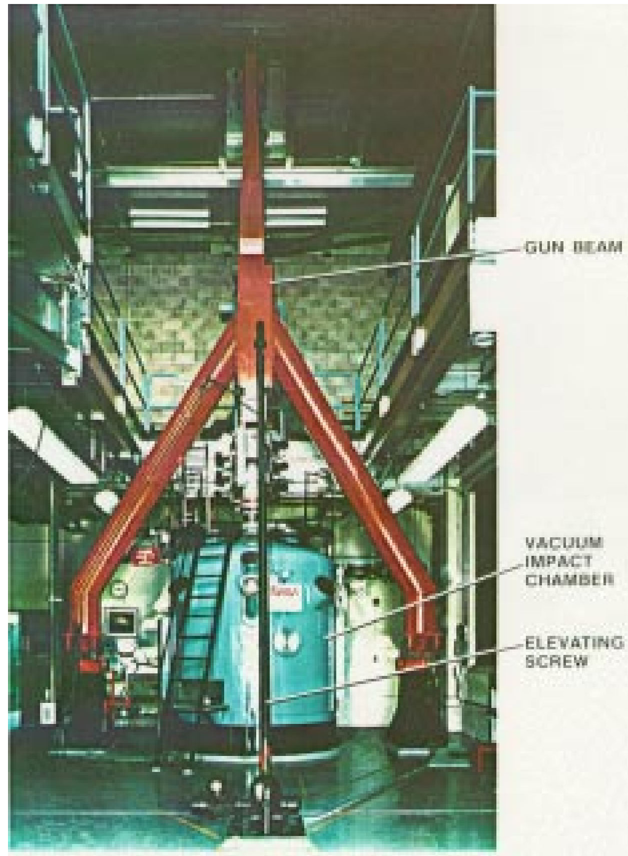

Figure 34. Photograph of the Ames Vertical Gun Range Facility.

The Ames Research Center Vertical Gun Range (AVGR) was designed to support scientific studies of impact processes during the Apollo missions. In 1979, it was established as a National Facility, funded through the Planetary Geology and Geophysics Program. In 1995, increased science needs across various discipline boundaries resulted in joint core funding by three different science programs at NASA Headquarters (Planetary Geology and Geophysics, Exobiology, and Origins Programs). In addition, the AVGR provides programmatic support for various proposed and ongoing planetary missions through special arrangements with the Facility Manager and Science Coordinator.

Ballistic technologies, utilizing a light-gas gun, powder guns, and various pressurized air guns, enable acceleration of projectiles up to 8 km/sec. By varying the gun's angle of elevation with respect to the target vacuum tank, impact angles from 0° to 90° with respect to the gravitational vector are possible. Figure 34 shows a photograph and figure 35 shows a sketch of the Ames Vertical Gun Range Facility.

4.2.2.1 Model-Launching Guns

4.2.2.1.1 Light Gas Gun

The light-gas gun available for use in this facility has the capability of launching projectiles up to 7.5-mm diameter

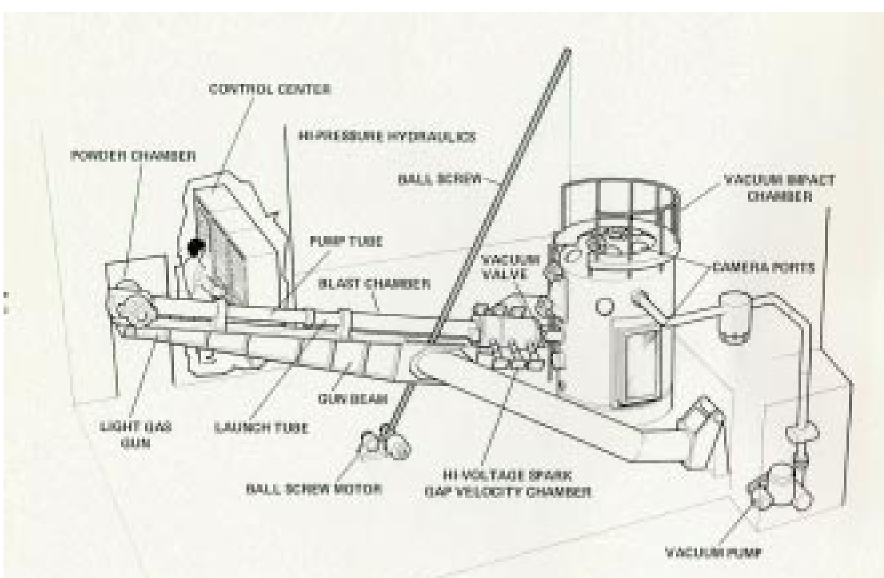

Figure 35. Sketch of the Ames Vertical Gun Range Facility.

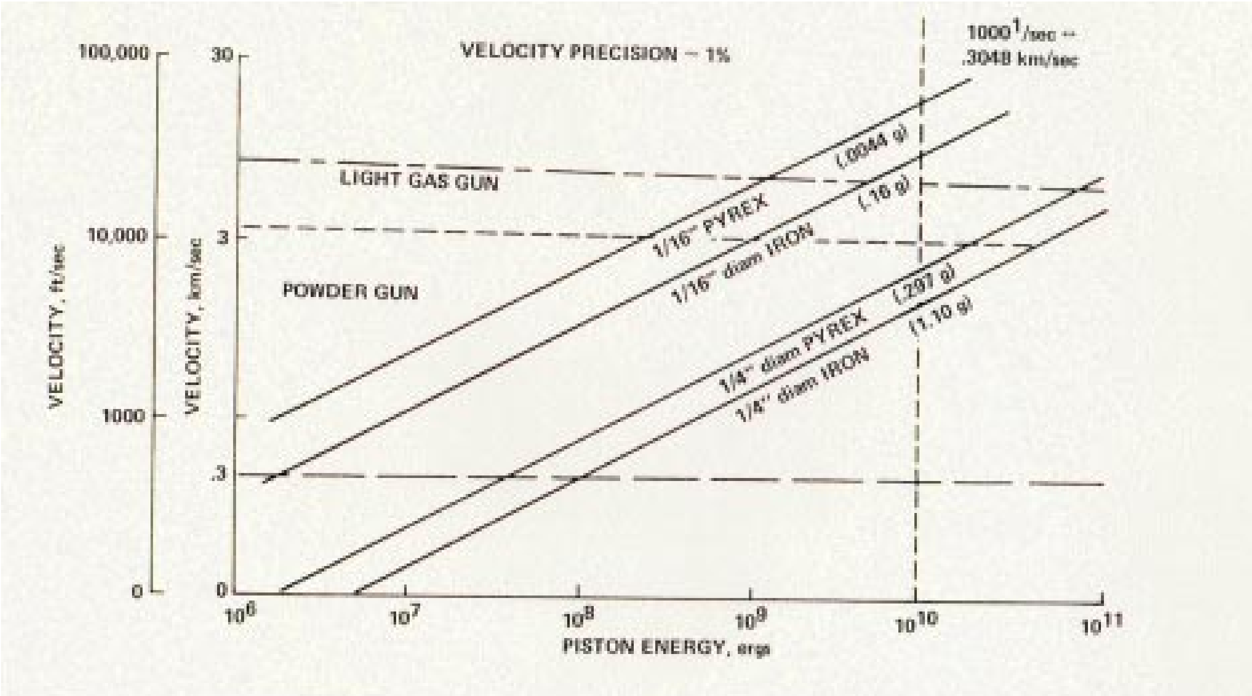

Figure 36. Typical gun performance.

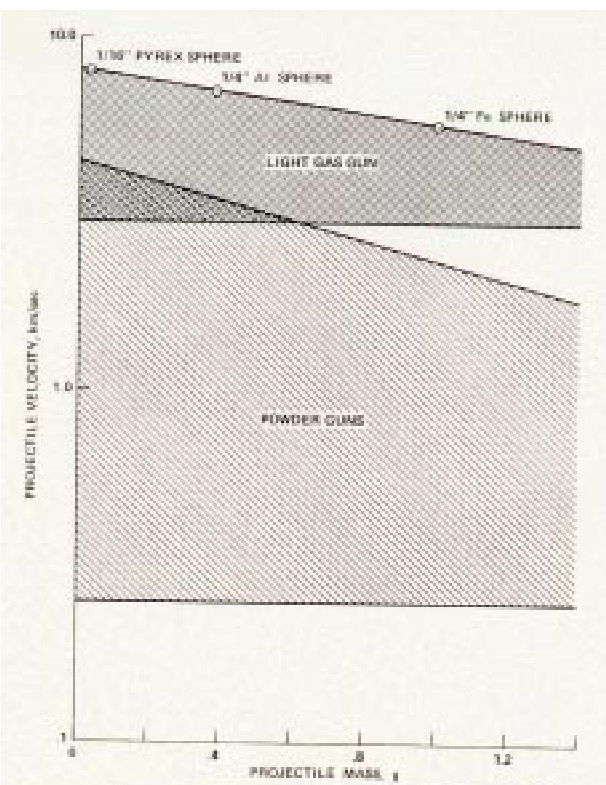

Figure 37. Light gas and powder gas gun performance.

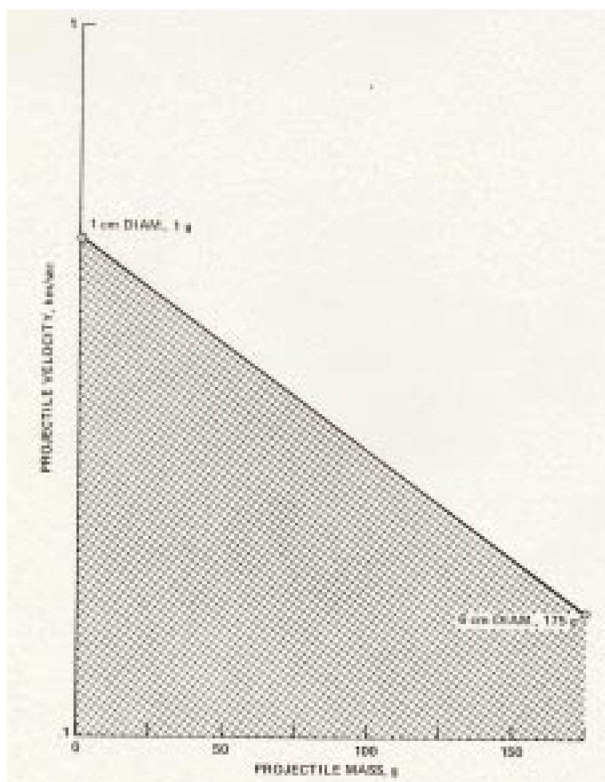

Figure 38. Air gun performance.

at velocities approaching 8 km/sec. The gun uses conventional smokeless powder to drive a plastic piston (pump piston) down the pump tube. This serves as a long-stroke, single compression of the hydrogen gas into a heavy-wall section called “high pressure coupling”. Here the gas is raised to extreme pressure and temperature. A break valve in the high-pressure coupling, which initially seals the launch tube from the pump tube, then ruptures, and the propellant gas (hydrogen) drive the projectile down the launch tube. Launch capabilities for this gun are shown in figures 36 and 37.

4.2.2.1.2 Powder Gas Gun

A 7.5-mm powder gas gun is available that will propel models to approximately 3 km/sec. Figure 36 gives the performance envelope for this gun. It should be noted here that the powder gas gun is easier to use, cheaper to operate, and can produce more test rounds per day than the light-gas gun. Therefore, it is to the experimenter’s benefit to use this gun unless restricted by velocity considerations.

4.2.2.1.3 Pressurized Air Guns

For low speed (below 1 km/sec for model sizes up to 6-cm diameter), there are available various model-launching guns using compressed air in a small volume reservoir for the propelling gas. These guns represent an extremely inexpensive means of launching models, if low-speed impacts are desired. Performance capabilities for the air guns are indicated in figure 38.

4.2.2.2 Models and Sabots

In all the various guns, the projectiles are usually saboted (encased in a plastic carrier) to protect them during their passage through the launch tube. This sabot falls away after exiting the launch tube, leaving the projectile in free flight to the target. Projectiles used in this facility consist primarily of spheres made of pyrex, steel, plastic, or aluminum. Various diameter spheres of may different materials are available and provided to the experimenter. Sabots are also available in stock for some of the spheres. The experimenter is responsible for determining

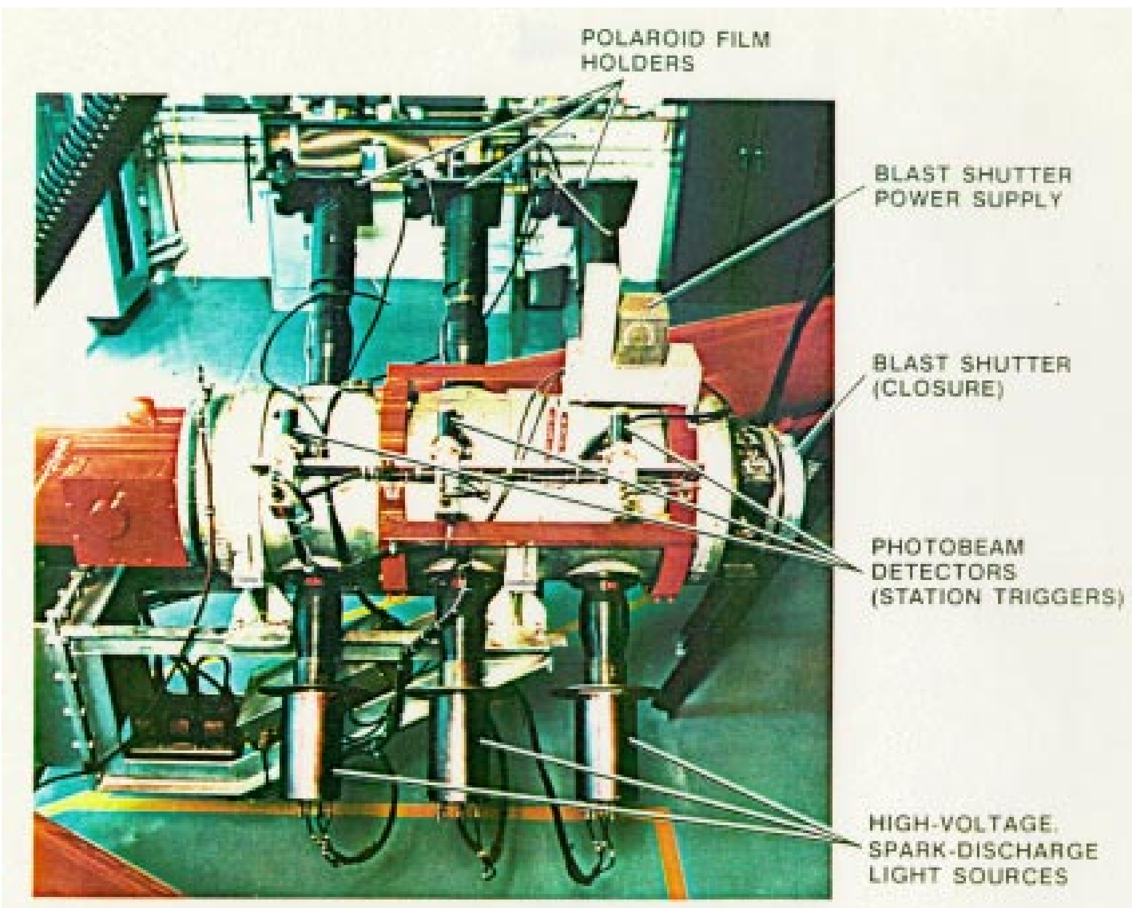

Figure 39. Photograph of the velocity measuring chamber.

availability of models and sabots well in advance of his/her test dates.

4.2.2.3 Velocity Chamber

The velocity chamber, as the name implies, contains instrumentation to measure projectile velocity. This is done by three spark gap stations which consist of a photocell light beam that sets off a high-voltage spark when interrupted. This spark provides illumination for a shadowgraph picture of the projectile in flight. The spark also actuates an electronic counter which measures the time interval between spark stations, and hence allows the projectile velocity to be determined. A photograph of the velocity chamber is shown in figure 39. The shadowgraphs are taken on 4” × 5” “Polaroid” film so that model integrity and position can be determined immediately after the run is made.

4.2.2.4 Vacuum Impact Chamber

The impact chamber is shown in figures 40 and 41. Experimental targets are contained within this 2.5-meter diameter vacuum chamber which is capable of maintaining a reduced pressure of approximately 10^{-2} torr. Pump down rates and leak rates for this vacuum system are

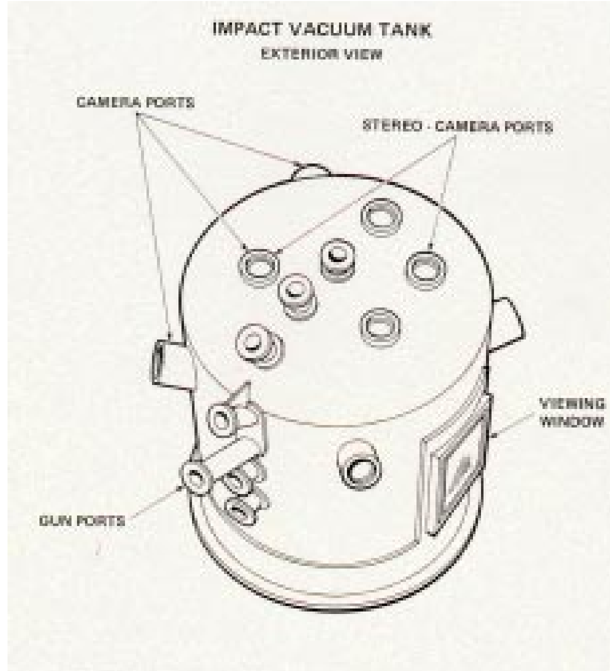

Figure 41. Impact vacuum tank.

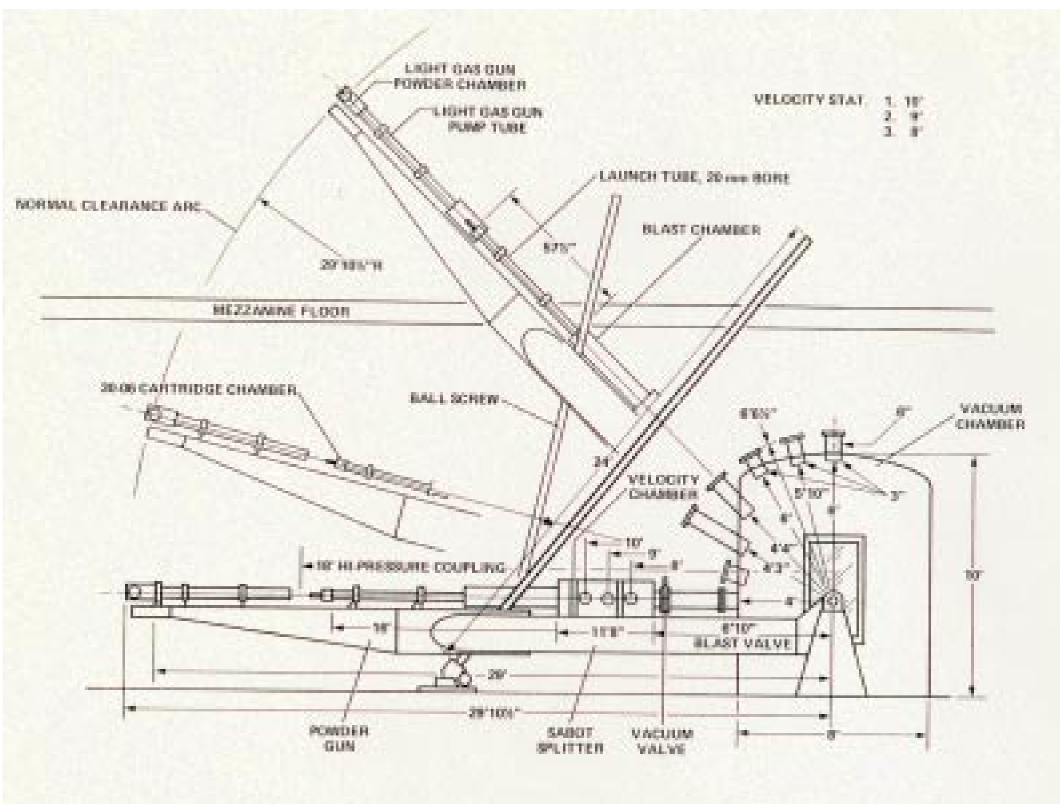

Figure 40. AVGR dimensions.

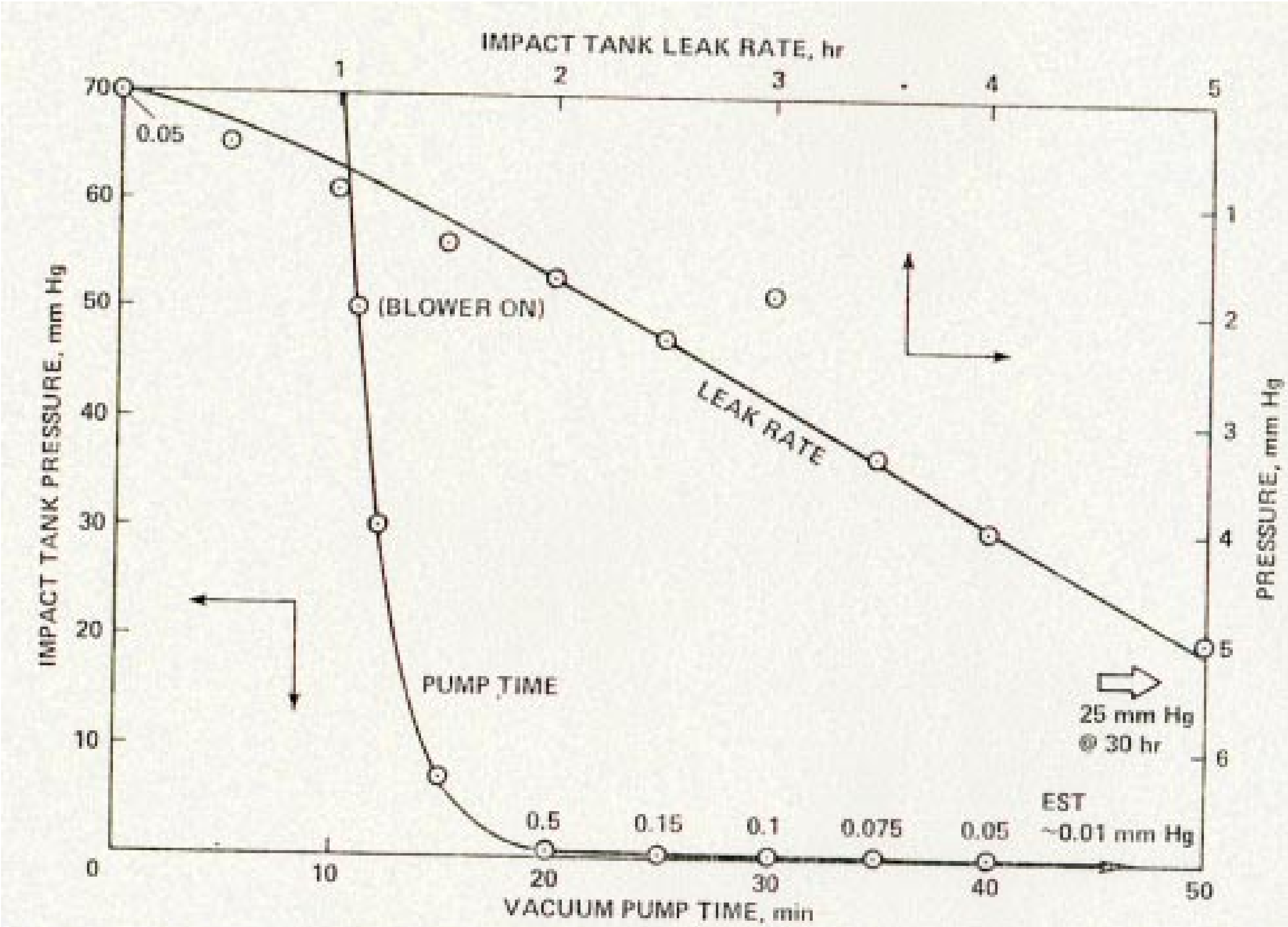

Figure 42. AVGR vacuum system performance.

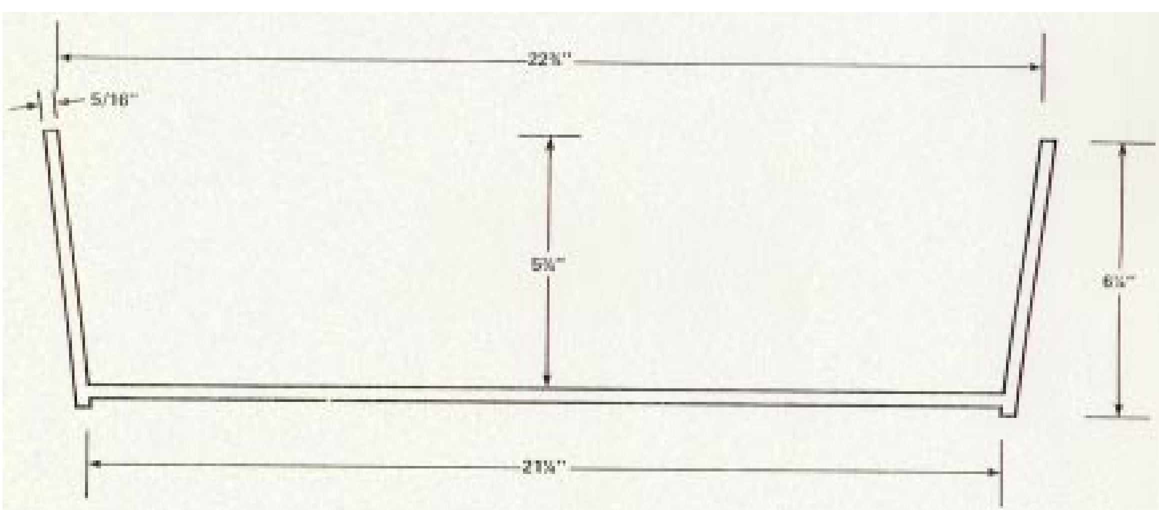

Figure 43. Ames standard bucket dimensions.

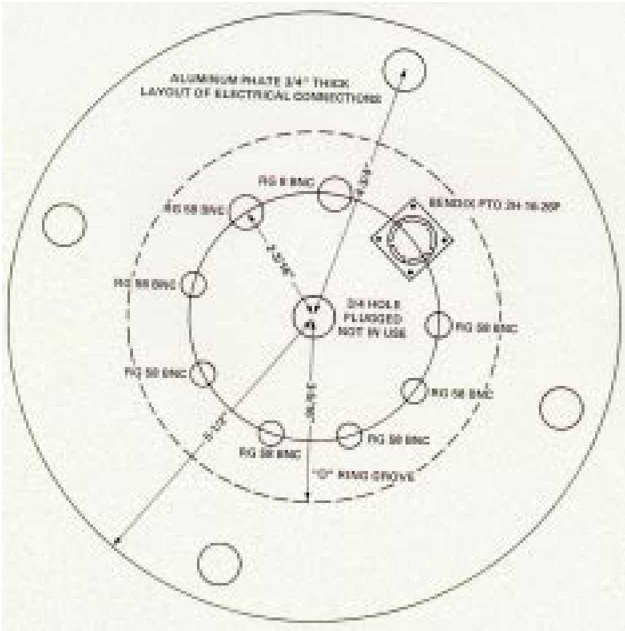

Figure 44. AVGR standard vacuum feed-through plate.

shown in figure 42. Targets are to be constructed in the standard target bucket, figure 43. Various target construction capabilities allow the placement of colored substrate to be used as markers to show crater formation. Targets can be either fixed within the chamber or they can be accelerated vertically to change the net gravitational effect during impact and crater formation. As is noted in the sketch of the vacuum impact chamber (figure 41) the model launching gun can be positioned at various angles: seven positions at 15° intervals from 0° to 90°. This allows impacts at angles with respect to the gravitational vector. Instrumentation leads into the vacuum impact chamber are fed through the instrumentation plate provided. Figure 44 shows the connectors that are available.

4.2.2.5 Data Instrumentation

A digital program sequencer is used to activate the AVGR instrumentation system -- see figure 45. This preset controller synchronizes the cameras and light sources in the Facility. Specialized photographic equipment is employed to document the experiments. A 16-mm movie camera, capable of 10^4 frames per second constitutes the major means of recording the impact process. Additional capabilities include framing cameras capable of recording movies in stereo at a mechanically synchronized rate of 60 frames per second. These recordings provide a highly accurate analytical growth history of the impact and crater phenomena. In addition, the target can be sliced and photographed after the test to study subsurface flow details. Targets constructed with colored substrates as layered markers emphasize subsurface disturbances. Instrumentation is constantly being changed: it is to the experimenter's benefit to check before his/her test as to the availability of equipment. Requests for specialized data recording instrumentation should be received by the AVGR Coordinator at least one month before scheduled start of a test.

4.2.2.6 Office Space

Building N-204A houses the AVGR and the offices of the Range Supervisor and operating technicians. Additional office space within this building is available for both the current and future Principal Investigators. There is in addition, a complete machine shop with welding facilities and a target preparation room.

4.2.2.7 Subsystems

The Ames Vertical Gun Range consists of the following systems.

4.2.2.7.1 Gun Elevation System

The elevation system includes the gun mounting beam, elevation ball screw, ball screw drive motor, and associated control panel. A photograph of this system is shown in figure 46.

4.2.2.7.2 High Pressure Hydraulics Systems

The high pressure hydraulics system consists of the high-pressure pumps, lines, and associated actuators utilized in maintaining the high-pressure seals at the coupling-launch tube joint.

4.2.2.7.3 Pressurized Gas System

The pressurized gas system consists of helium and hydrogen tanks, meters, and controls. The helium is utilized to purge the pump tube prior to filling with hydrogen. Gas bottles are located outside the building.

4.2.2.7.4 Synchronization and Control System

The synchronization and control system consists of the spark gap velocity chamber, counters, timers, high-voltage supplies, camera controls, and firing circuits.

4.2.2.7.5 Data Acquisition System

The data acquisition system consists primarily of cameras, subsystems, and velocity counters. The cameras normally used are (a) a Cordin and Imacon for super-high frame rates; (b) and an NAC for the lower frame rates.

4.2.2.7.6 Vacuum System

The vacuum systems consist of two pumps, filters, lines, and impact tank. A small vacuum pump is used to

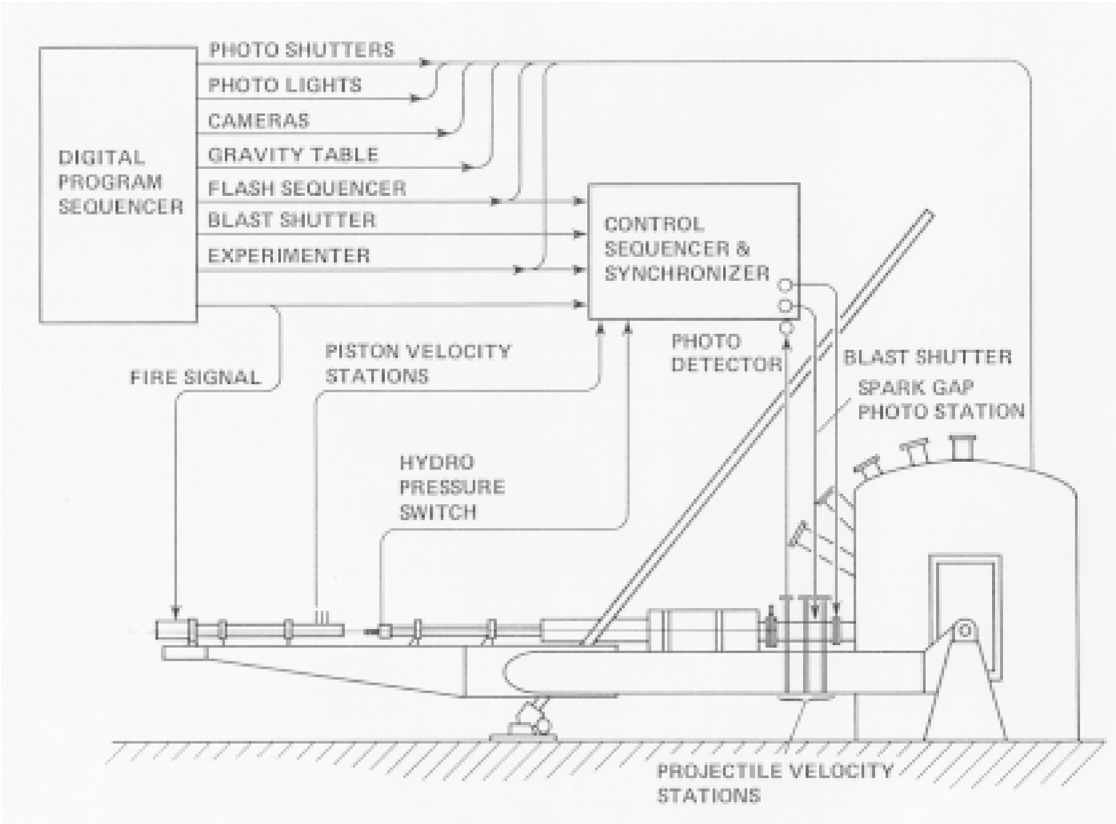

Figure 45. AVGR simplified block diagram.

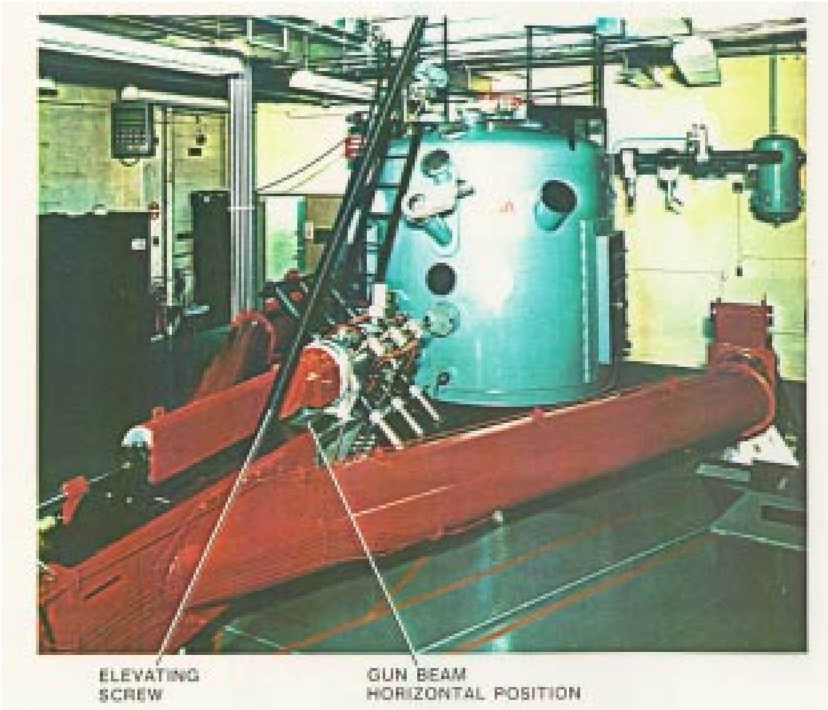

Figure 46. Photograph of gun elevation system, beam in horizontal position.

evacuate the light-gas gun, launch tube, and blast chamber. A large capacity 5 HP (Kinney) vacuum pump is utilized to evacuate the vacuum impact chamber. Pumpdown pressure of about 0.01 mm Hg can be reached. There is a 26” × 40” glass viewing window on the left side of the chamber. Because of potential explosion hazard, personnel access to the window region is restricted by a safety gate.

4.2.2.7.7 Gun Powder Charge Preparation Room

The powder storage and preparation room is key-secured and located in Room 101A. This room is used to store limited amounts of smokeless powder, primers, and electrically actuated squibbs. It also serves a powder weighing and preparation workshop. The floor is covered with conductive plastic sheeting and all bench tops and cabinets are electrically grounded. Access to this room is controlled by the Range Supervisor and occupancy is restricted to a maximum of two persons at any time. Safety glasses are required for all personnel while in this room and full face shields are mandatory when preparing explosive charges. To prevent static charge buildup and possible spark discharge, all persons engaged in assembly of devices containing explosives shall wear grounding wrist straps.

Large amounts of explosive items, supplies in excess of that required for one week’s testing, shall be stored in bunkers controlled by the Air National Guard (at Moffett Federal Air Field). Distribution is controlled by ARC personnel certified to transport explosive material. Certified personnel are:

Jean Brian, Code ASF, extension 45230
Frank Custer, Code ASF, extension 45230

4.2.2.7.8 Control Room

Actuation of the AVGR is controlled from the Control Room (Room 101) in Building N-204A. The instruments for the fire control sequencer are located in the left cabinet while the velocity counters and relays are in the two center cabinets of the console. The spark gap power supplies and trigger delays are located in the right cabinet. No personnel, other than the gun crew, are permitted in the Control Room during firing.

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4.2.3 EAST Facility

The Electric Arc-driven Shock-Tube Facility at NASA Ames Research Center is a high enthalpy shock tunnel. In it, a high-velocity stream of test gas is created that is large enough for detailed model studies, but of short duration. The design reservoir enthalpy is 29000 J/g (equivalent stream velocity of 7.6 km/sec). A reflected shock reservoir with a tailored-interface restriction allows for a range of reservoir enthalpies.

4.2.3.1 Energy Storage and Delivery Systems

4.2.3.1.1 Capacitor Bank

Energy to the driver is supplied by a 1.24-MJ, 40-kV capacitor energy-storage system. The six-tier capacitor bank has 220 capacitors. By using different combinations of series-parallel connections, the capacitance of the bank can be varied from 149 μF to its maximum value of 6126 μF (1530 μF for 40-kV operation). Nominal total system inductance exclusive of the load (arc) is 0.26 μH, and the resistance is 1.6 mΩ.

4.2.3.1.2 Collector Assembly and Discharge Chamber

The current collector and arc chamber are shown schematically in figure 47. The collector ring consists of two coaxial copper cylinders. The outer cylinder is flanged to the driver tube and is electrically grounded; the inner cylinder is connected by a copper spring contact plate to the main electrode. The high-voltage electrode has a hollow core through which a rod extends back to the piston of a pneumatic solenoid (air cylinder). The solenoid actuates the trigger. Several different materials have been used for the trigger wire, but most of the tests have been made with tungsten wire. The trigger wire is extended along the length of the arc chamber to the ground plate. When the slack wire is drawn to the high-voltage electrode, the current flow is initiated. The thermionic emission from the trigger wire helps ignite the discharge.

The arc chamber is designed for a pressure of 1000 atm and fabricated of a nonmagnetic stainless steel in two sections. An insulating liner of filament-wound fiberglass with a bonded inner layer of silicone rubber forms the inner wall of the chamber. This liner is surprisingly durable and can be reused many times; techniques have been developed to replace the rubber inner layer as often as required.

4.2.3.1.3 Instrumentation

Voltage and current waveforms are recorded during each discharge. The shock velocity is computed by recording the time of shock arrival at various locations along the length of the tube, using conductivity probes and digital counters.

4.2.3.2 Driver Tube

The arc-heated driver tube can be viewed as an energy convertor, changing electrical energy into pressure and temperature energy, which serves as the connecting link between the energy source and the test-gas generator.

The driver can be operated in two configurations: a 17.7-cm conical drive configuration with a 10.16-cm exit (driver volume = 632 cm^3); and a variable length (34 - 137 cm) 10-cm i.d. cylindrical configuration (driver volume =

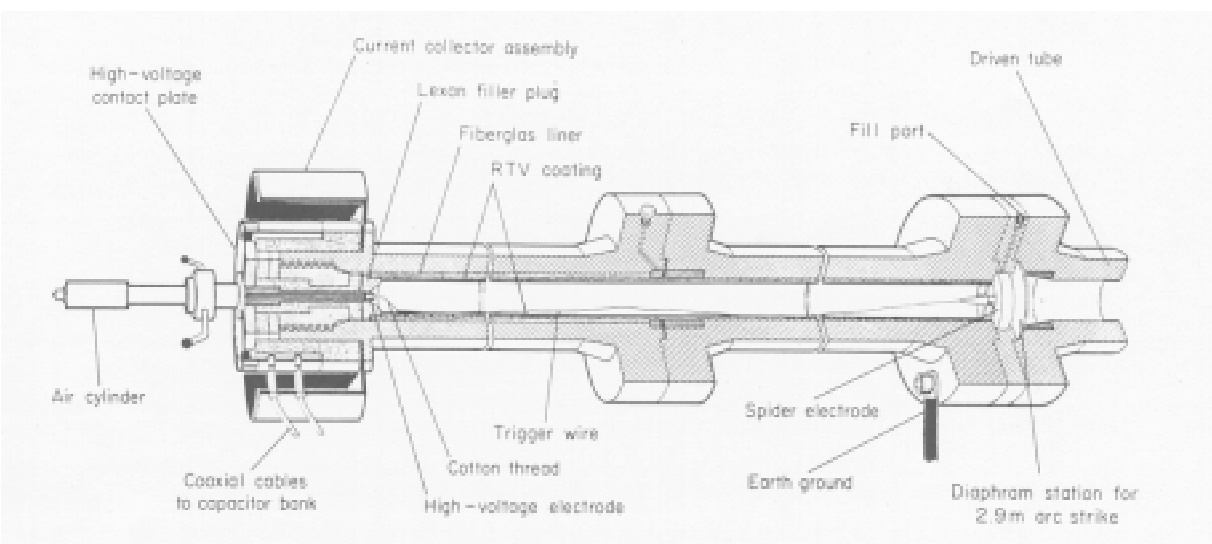

Figure 47. EAST Facility driver assembly.

2669 to 10752 cm^3). The length of the cylindrical drivers can be varied by using a Lexan filler plug.

4.2.3.2.1 Primary Diaphragm

The diaphragm is made of mylar 0.35 to 0.50 mm in thickness. It is ruptured due to the rise in pressure within the driver during the capacitor discharge. There is a time lag of 20 to 40 µs between the instant the breaking pressure is reached (approximately 11.5 atm for a 0.35 mm diaphragm), and the instant the diaphragm is fully open.

4.2.3.3 Shock Tube

The design of the shock-tube portion of the facility, as for the driver chamber, is predicated upon its use to develop a reflected-shock reservoir of test gas of sufficient quantity and duration to supply a large supersonic nozzle.

The facility consists of one driver system and two parallel driven tubes: one is a 10-cm i.d. tube 12 meters in length; the other is a 60-cm i.d. tube 21 meters in length; both are made of stainless steel.

4.2.3.4 Nozzles

Two conical nozzles exist for the 10-cm tube of the facility: one is 1.8 m in length with an area ratio of 1000; the other has an area ratio of 10.

4.2.3.5 Facility Performance

Using the two different driven tubes, by varying the driver/driven gas combination, driver charge pressure, and preset capacitor bank voltages, shock velocities in the range of 3.0 to 50.0 km/s have been obtained. The following is a list of the ranges of operating conditions:

Driver charge pressure: 1.0 to 27.2 atm
Driven tube initial pressure: 0.01 to 10 torr for the 60-cm tube; 0.1 to 760 torr for the 10-cm tube
Driver gas: H_2, He, N_2, H_2/Ne
Driven gas: Air, H_2, O_2, Ne, Kr
Capacitor bank: 16.0 to 38.0 kV voltage; 149 to 6126 µF

4.2.3.6 Bibliography

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5.0 Operating and Safety Procedures

5.1 Use of the Operating and Safety Manual

There are manuals for each of the facilities covering the operation of the Facility and noting safety procedures and regulations. Copies of these manuals are kept in the offices of the respective Facility Manager. Experimenters and temporary personnel working on or utilizing the Facilities should become familiar with safety rules and emergency procedures noted within these manuals. A summary of this information is given in Section 7.0 Emergency Procedures.

5.2 Emergency Aid and Information

Resident personnel working alone after normal business hours must notify the Ames Duty Office at extension 4-5416. Additionally, personnel must advise the Duty Office when departing for the night. Should an emergency arise in the Facility, response teams will be aware of your presence. Also, for safety and security reasons, keep exterior building doors secured after entering or exiting the building.

Any requests for emergency services, as for fire or ambulance, call the Ames emergency number -- 911.

6.0 Primary Hazards and Safety Features

Hazards which exist in the Thermophysics Facilities are high voltages, high-pressure gases and water, vacuum chambers, explosives, flammable gases, non-breathable gases, and personnel entrapment. These hazards are examined in the following paragraphs.

6.1 High Voltage

6.1.1 Arc Jet Complex

The high voltage on the arc heater is rendered safe by placing the unit behind a barrier which removes the possibility of contact with personnel. Continual vigilance is required to ensure that no electrical conductor be allowed to violate the barrier either in the region of the arc heater itself or in the regions of the test chamber. After personnel are evacuated from within the arc heater barrier enclosure and the test section, a key interlock system insures that the barriers be in place and the test section be closed before the power supply can be energized. The hazard of arc-over from the high-voltage is minimized by the heater design, which utilizes only non-conducting materials in the vicinity of the arc heater, and by maintenance of insulation integrity between heater components. Only qualified personnel are allowed to contact the arc heaters and all supporting power distribution equipment.

6.1.2 Range Complex

In the Range complex, high voltage devices which can be potentially hazardous include capacitor banks (40 kV), spark gaps (7000 volts), kerr-cells (24,000 volts) and their respective power supplies. All of the high voltage components (i.e. capacitors) are well-sealed and contained within grounded enclosures. Similarly all of the cables and connectors are grounded and insulated. Under routine operating conditions, these devices are only energized just prior to a test when no personnel are present. Thus the most likely hazard to arise with any of these items is when they are being serviced. Only electricians and experienced facility staff members, using appropriate electrical test equipment, are allowed to service these devices.

6.2 High-Pressure Gases and Water

High-pressure gases in standard steel bottles are used in all of the Thermophysics Facilities. These bottles are restrained to prevent falling in the event of seismic activity. Furthermore, these bottles are always used with regulated output. All storage and delivery systems are subject to standard guidelines for high pressure component design and maintenance as outlined in the Ames Health and Safety Manual.

High-pressure gases and water in the arc heaters are rendered safe by placing the units behind the arc heater barrier. The high-pressure-gas systems are provided with relief valves and rupture disks.

6.3 Vacuum Chambers/Non-breathable Gases

6.3.1 Arc Jet Complex

The vacuum enclosures in the Arc Jet Complex include the test sections and diffusers during facility operation. These elements are designed to contain the pressure difference of one atmosphere, however, since the test stream is very energetic, constant vigilence must be maintained to avoid overheating of these elements which could reduce their material strength. Plexiglass covers are maintained in place over the large side windows to provide shielding in the event of window breakage. Entry into the test chambers by persons other than Branch personnel is restricted except under close supervision. Entry into the SVS is only via strict procedures for confined space entry outlined in the Ames Health and Safety Manual.

Test chambers and enclosures are plumbed to non-breathable gas storage cylinders (e.g. argon and nitrogen). Entry is restricted to Branch operations personnel except under close supervision. Because hazards due to asphyxiation and toxicity can exist inside closed spaces, adequate ventilation must be established prior to entry. Leakage of non-breathable gases into basements, enclosures, or trenches could cause asphyxiation. Therefore, oxygen deficiency detectors are mounted in various locations in N234 and N238 which will alarm before these dangerous conditions can build up. The exception is the walk-in test chambers where such oxygen sensors can not function after exposure to vacuum. Careful entry practices must be observed.

6.3.2 Range Complex

Each facility in the HFFF has a vacumm chamber which consists of a sabot seperation tank, test section, and impact chamber. Each of the vacuum chambers is considered to be a “confined space” because of egress restrictions. For routine operating conditions none of the chambers requires an entry permit. However, for specialized experiments that use test section environments other than air, it may be necessary to develop special entry procedures. These procedures might include such things as extended purging periods and/or use of oxygen deficiency meters. Special entry procedures must be approved by both the Center’s safety office and ASF branch management during the test readiness review process.

The HFFAF test section contains 72 glass windows ranging in size from 12-inch diameter to 15-inch diameter. These windows are inspected frequently to prevent implosive fracture. Located on top of the sabot separation tank is a 48-inch diameter blow-off diaphragm to prevent over-pressurization of this segment of the facility. Prior to evacuating the test section and dump tank, the entire facility (gun, test section, and shock tube rooms) is secured, doors locked, and “Testing in Progress” signs posted. All personnel that are not directly involved with the test must either remain in the control room, or leave the facility entirely. Furthermore, personnel who must enter the test section room, while this portion of the facility is evacuated, are instructed to remain behind the film boxes. This is to minimize possible injury should a window fail.

6.4 Explosives (Range Complex)

Smokeless powder and electrically activated detonators are used for routine testing in both the Ballistic Range Complex and the AVGR facility. Powder charges are assembled within a specially equipped “powder preparation rooms.” The floors of these rooms are covered with conductive sheeting. This combined with the complete grounding of all benches and cabinets effectively prevents the buildup of static electricity. Personnel use wrist grounding straps whenever they perform tasks within the room. Wrist strap integrity (conductivity) is checked prior to entering the powder preparation room. Furthermore, full face safety shields are utilized whenever handling explosive charges and all electrically actuated devices are shorted and grounded until their actual installation. As a general rule, only those supplies (powder and detonators) required for one week of testing are stored in the powder preparation rooms, all remaining supplies are retained in the Air National Guard explosives bunker.

6.5 Flammable Gases

Hydrogen in standard 2000 psi steel bottles, is routinely used as the propellant gas in light-gas guns. The hazards associated with having this flammable gas within the Ballistic Range Complex and the AVGR facilities are minimized by only hooking up one hydrogen cylinder per gas loading cart, and by having high-flow supply and exhaust fans operating whenever a supply valve is opened. In addition, no personnel are present (in the gun room) when the guns are actually loaded.

6.6 Personnel Entrapment

6.6.1 Arc Jet Complex

Personnel entrapment in the test section and subsequent evacuation of the test section is a potentially lethal hazard. This is prevented by thorough inspection by the facility operator required in the operating procedure, and the interlock system. If both of these should fail, an emergency push-button is available to anyone inside of the test section which will sound an alarm, give indication on the annunciator, close the vacuum isolation valve, and prevent the electrical power from being applied. Entry into the SVS for maintenance is strictly controlled via confined space entry procedures outlined in the Ames Health and Safety Manual.

6.6.2 Range Complex

In the Range Complex, the Firing Officer assigned to each test, is personally responsible for inspecting the interior of the test section and sabot separation tank prior to locking the access doors. All facility personnel are instructed to lock the door in the open position and flip down the “Man in tank” sign upon entering the dump tank and test section. This sign alerts the firing officer that someone is within the vacuum chamber, and prevents the access door from shutting and sealing completely. Furthermore, the operating procedures requires several facility checks, to make certain that all personell are accounted for and that nobody remains in the facility.

7.0 Emergency Procedures

Emegency procedures to be followed in the case of a facility failure have been outlined in the respective facility safety manual. The facility operators are trained to deal appropriately with these emergencies; in the case of any accident causing injury or property damage, the following procedures will be followed.

7.1 Direct Response Action

Immediately following an accident, any qualified person on the scene will take the following actions until relieved by competent authority:

1) provide assistance to injured persons;

2) take action to limit or prevent further injuries or damage;

3) call the Emergency Control Center, 911, giving necessary information on the nature of the accident, the type of assistance needed, and the location of the accident;

4) notify the Facility Manager and the Branch Chief;

5) secure the identity of witnesses

6) secure the area to prevent actions that could hamper or prevent investigation of the accident

7.2 Fire Alarm

The operation of this alarm is initiated by smoke and heat sensors located in the building and is a signal to evacuate the building and stand by outside to direct emergency personnel to the source of the trouble. In all cases of fire, even when it is controlled by facility personnel with fire extinguishers, the fire department shall be called. One person shall be directed to stand outside the building to direct emergency personnel to the source of the trouble. This is important because of the possible danger of a secondary flareup of the fire. The Principal Investigator and/or his/her staff may be called upon for this duty.

In order to function quickly in the case of an emergency, the Principal Investigator and his/her staff should learn the location of fire extinguishers and of all exits from the building.

Appendix A

Distribution of Normalized Heating Rate and Surface Pressure across the Test Surface in the PTF

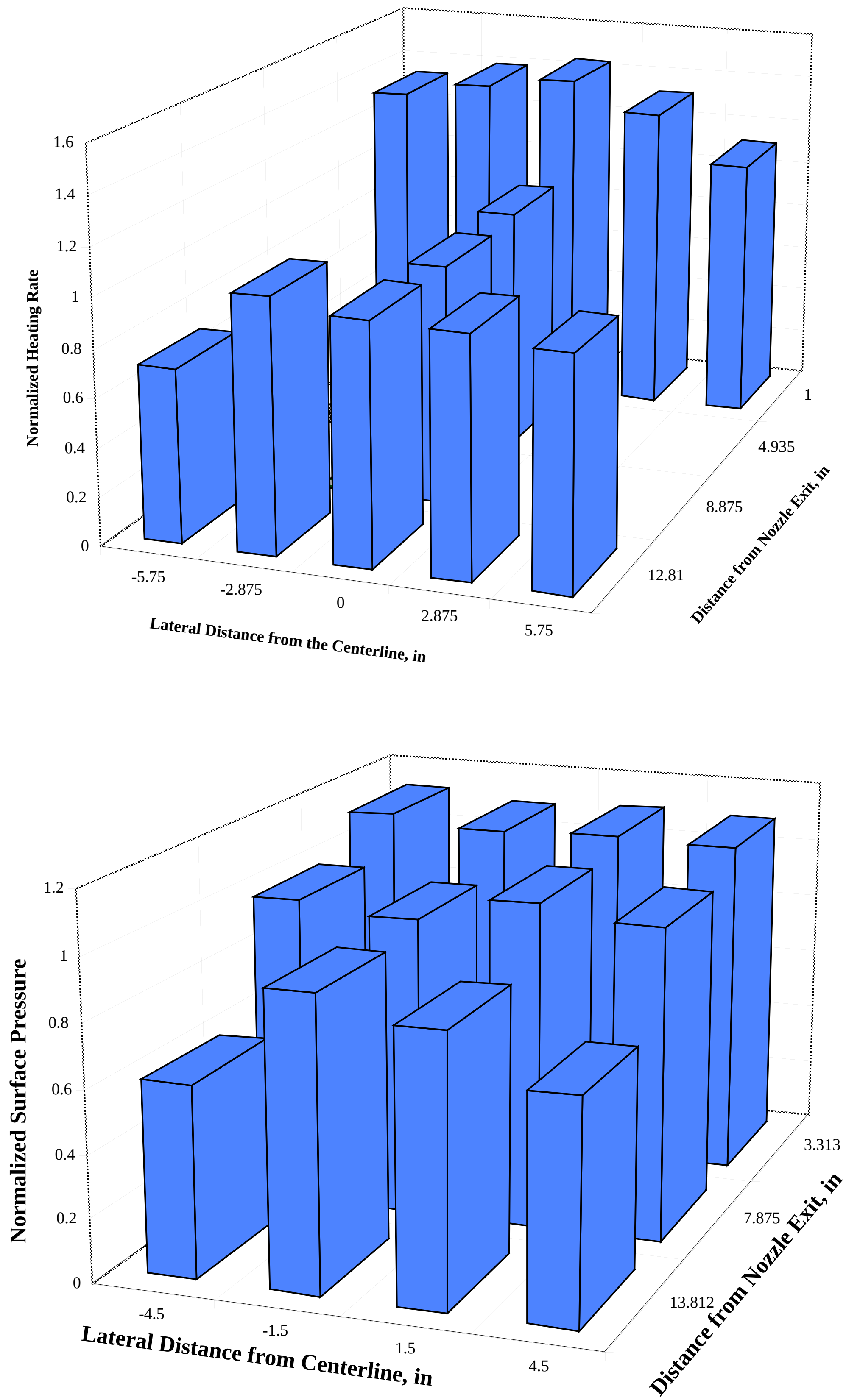


Figure A1. PTF calibration plate; inclination angle of 2°.

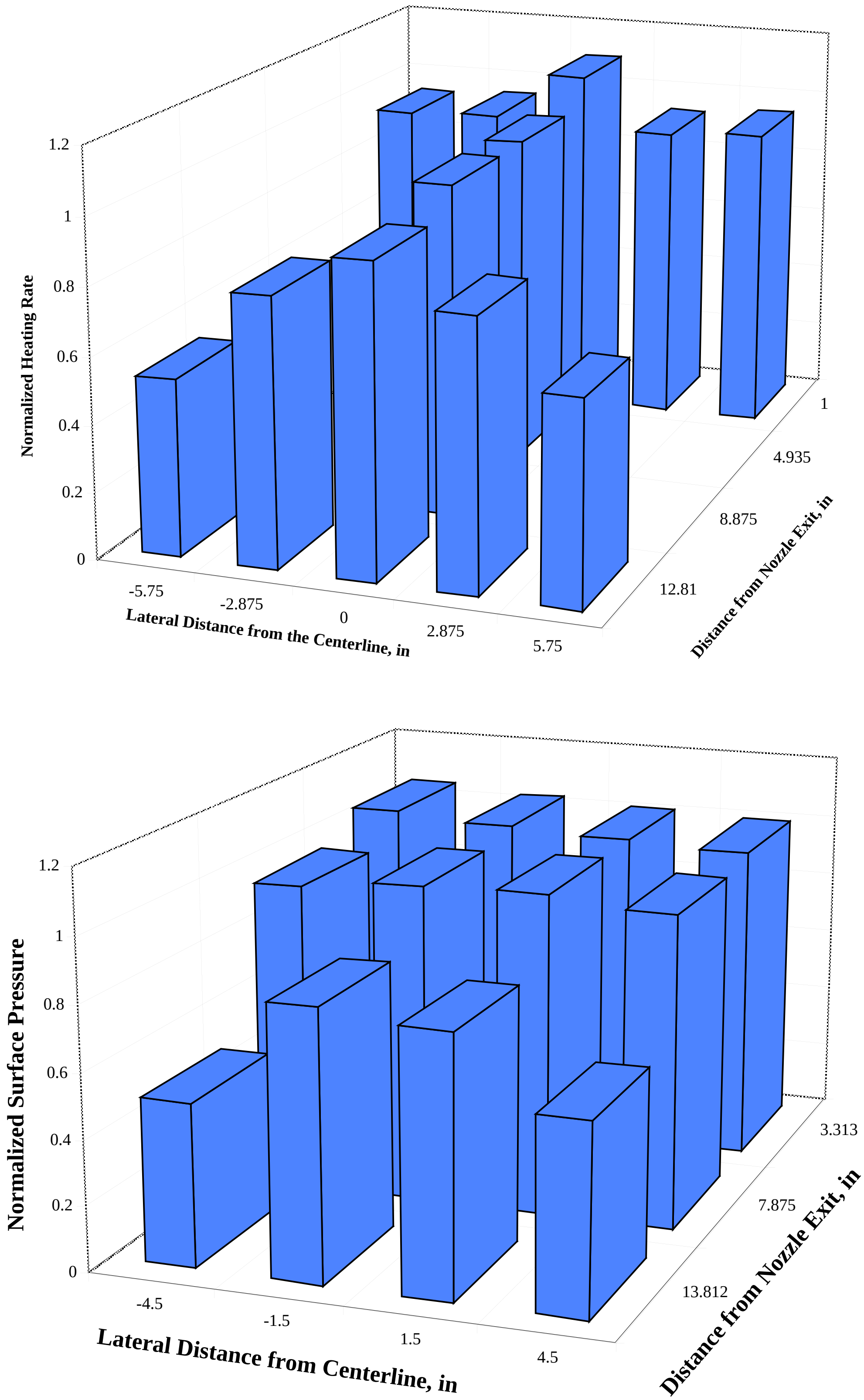
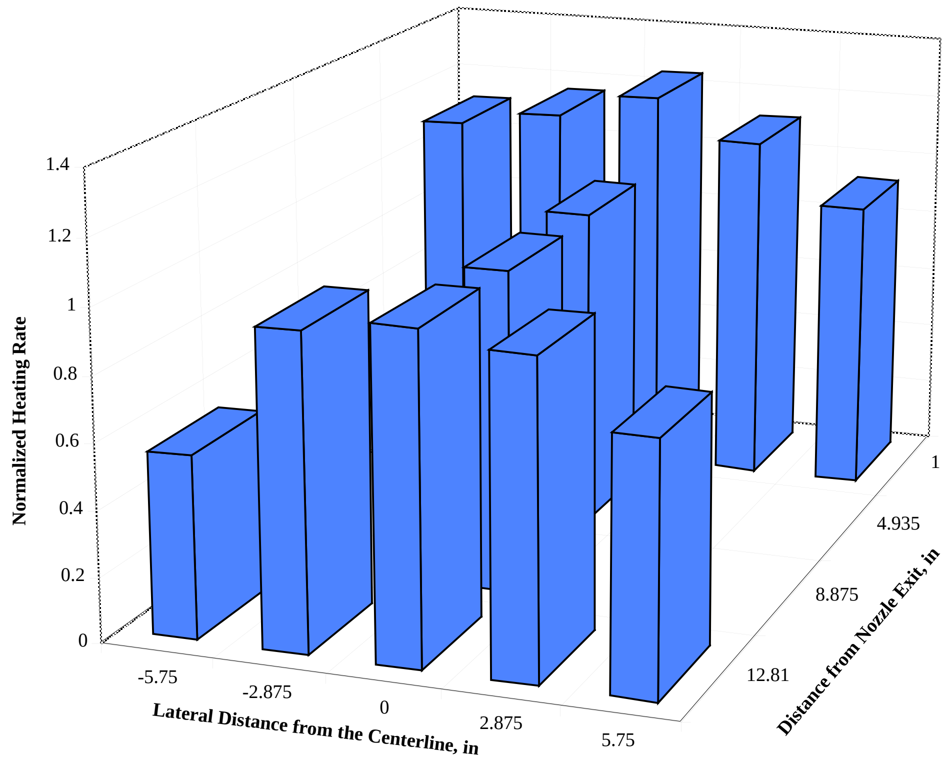


Figure A2. PTF calibration plate; inclination angle of 4°.



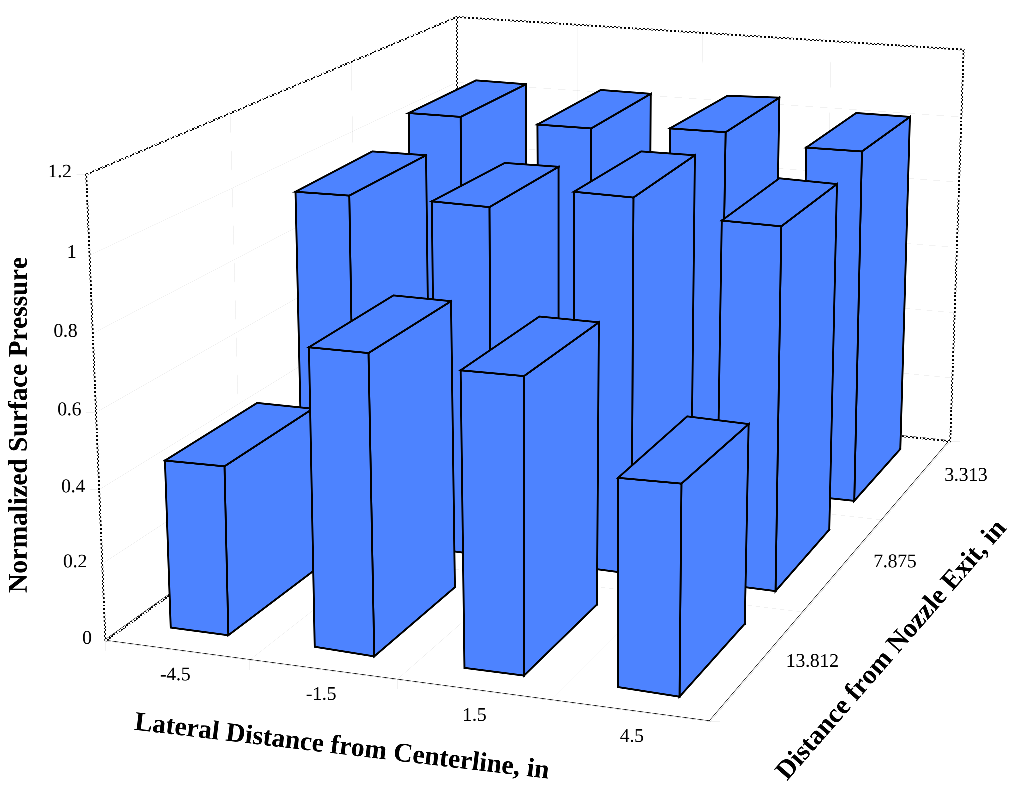


Figure A3. PTF calibration plate; inclination angle of 6°.

Appendix B

Distribution of Normalized Heating Rate and Surface Pressure across the Test Surface in the IHF

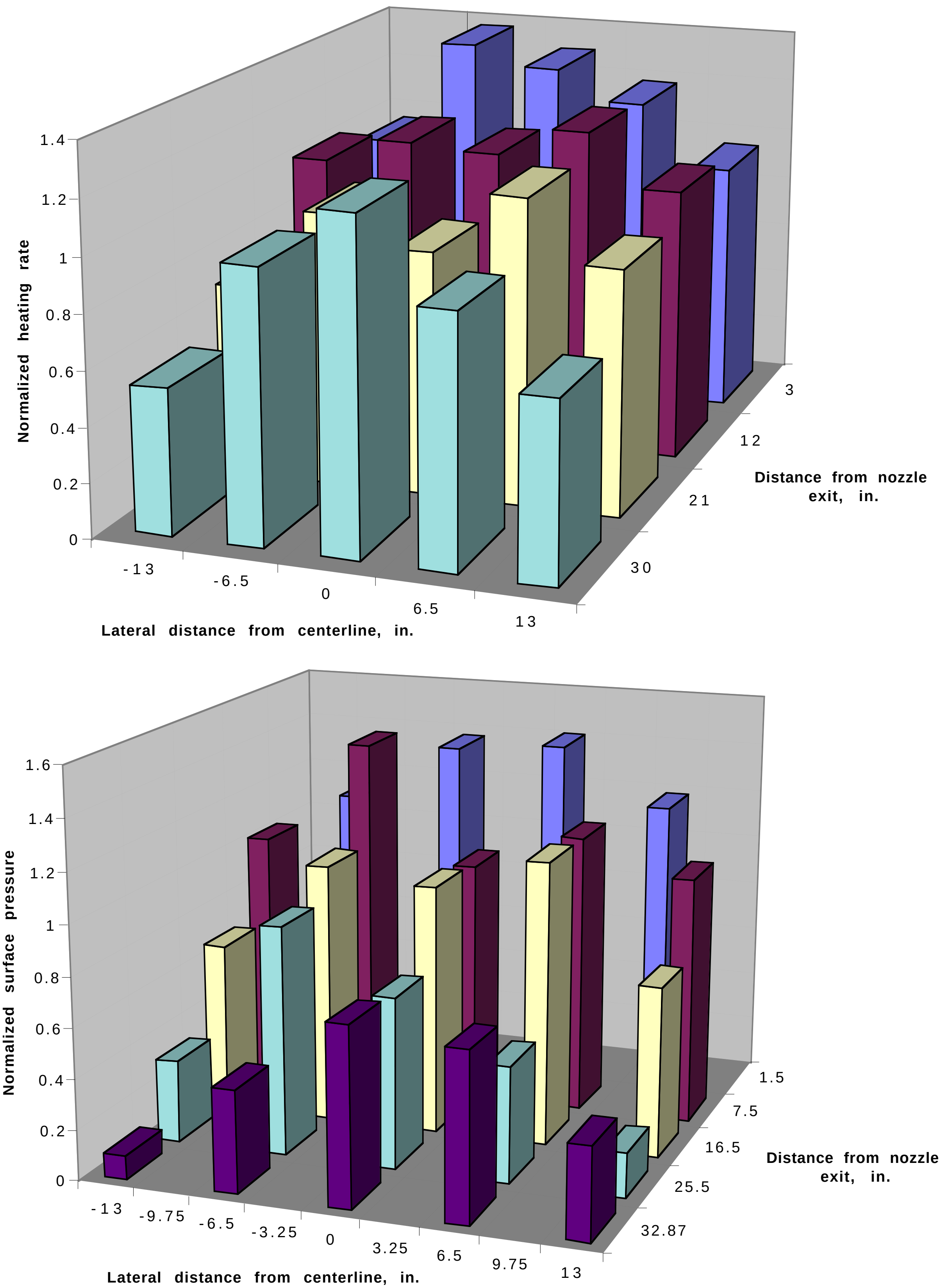
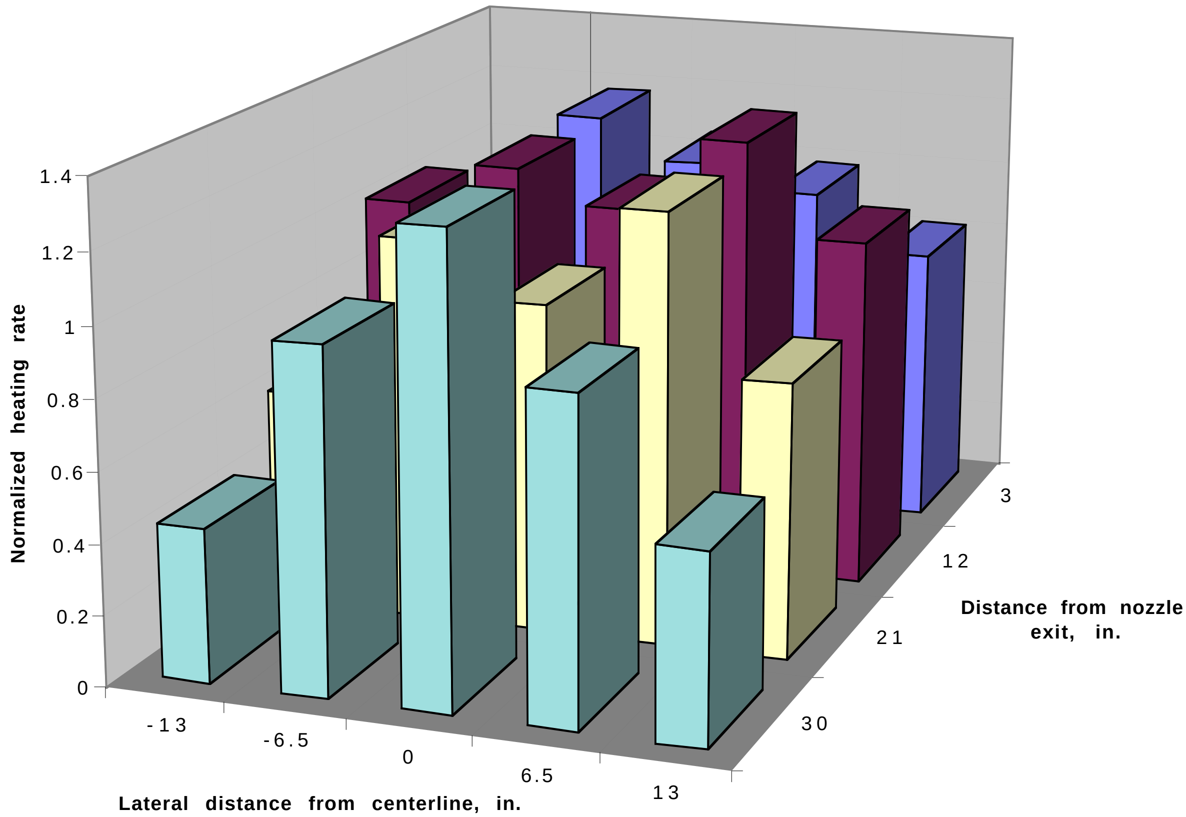


Figure B1. IHF calibration plate; inclination angle of 0°.



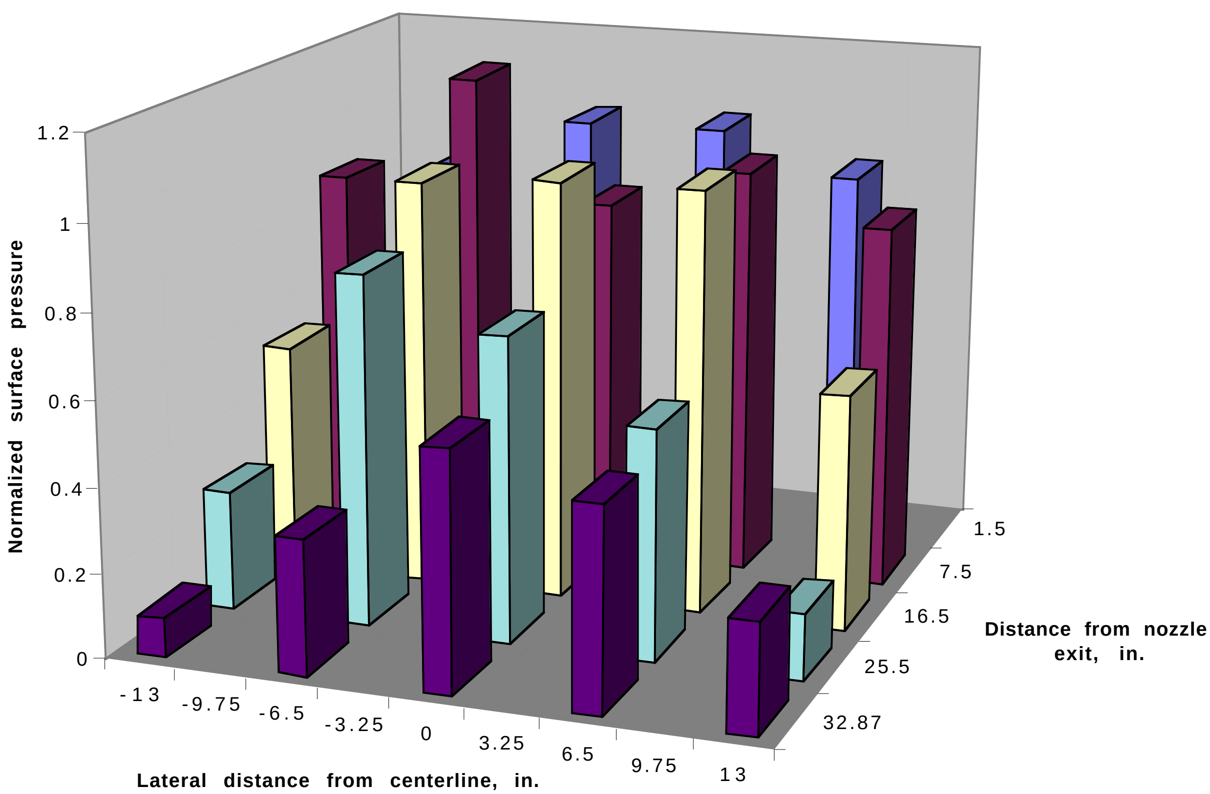
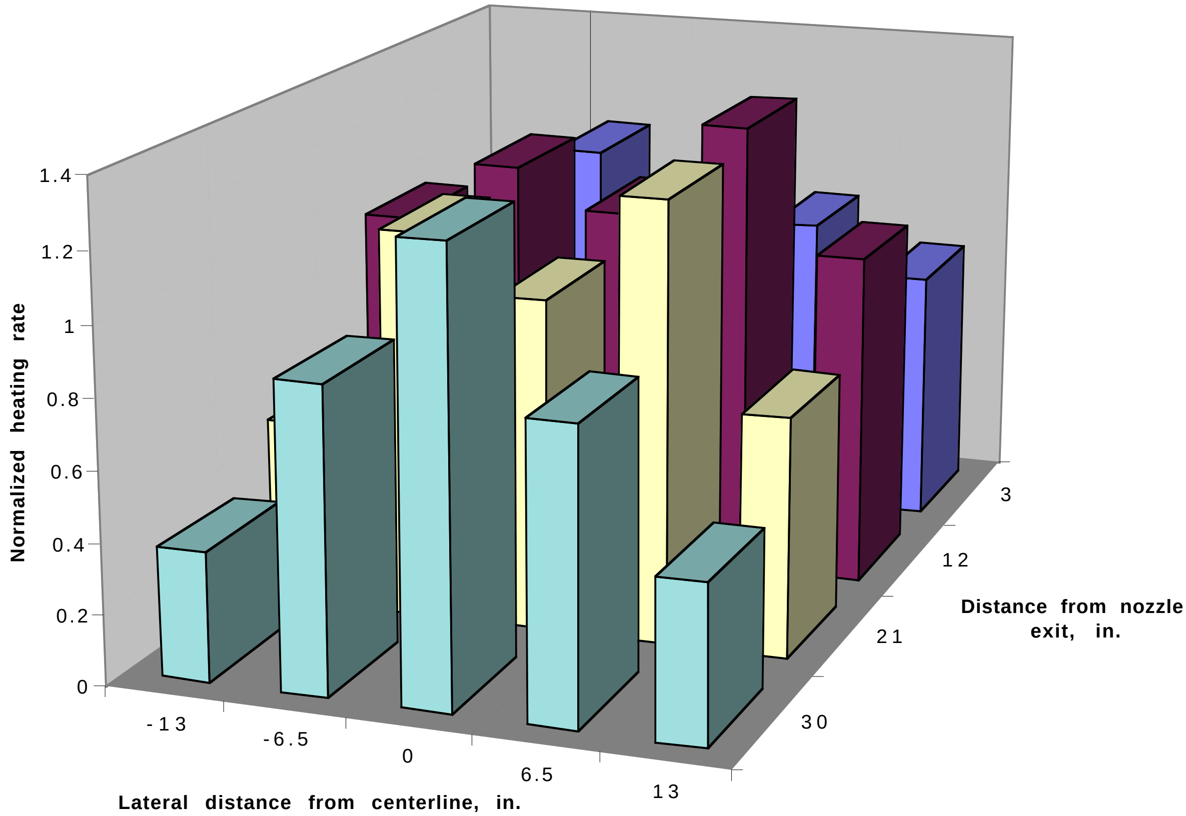


Figure B2. IHF calibration plate; inclination angle of 4°.



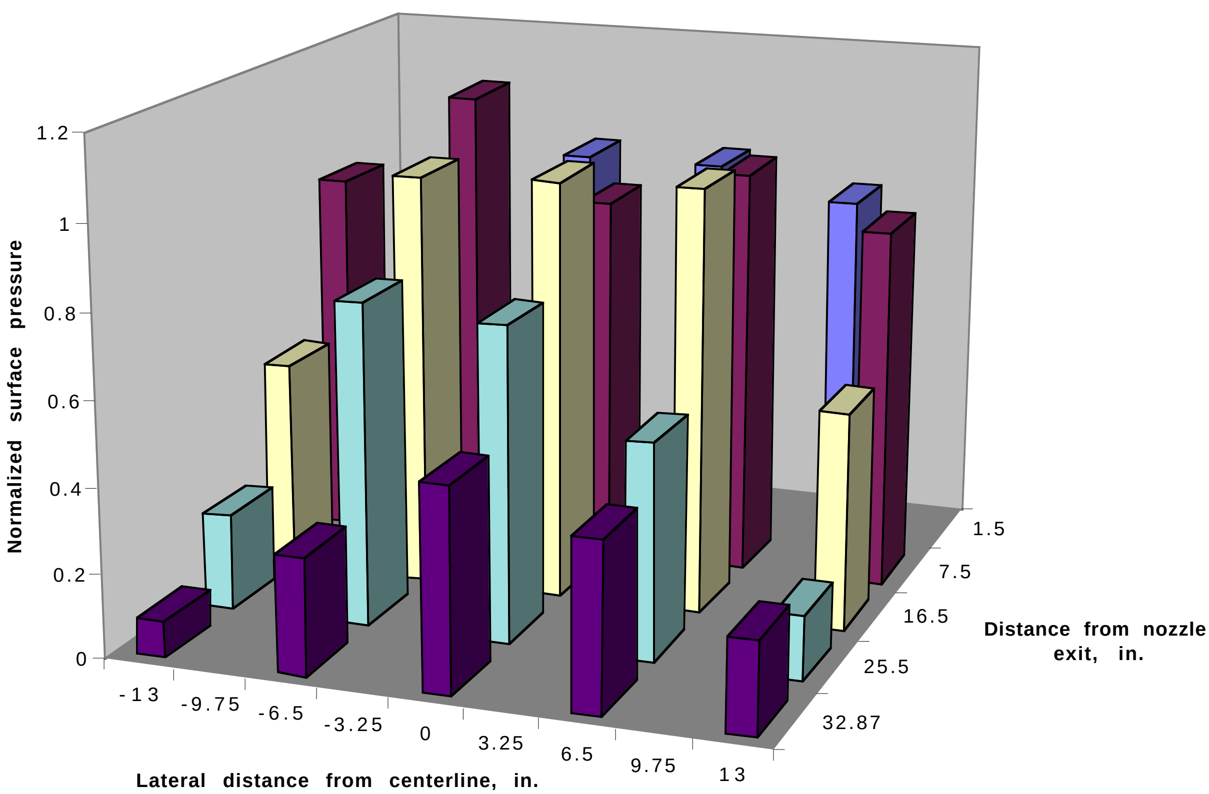
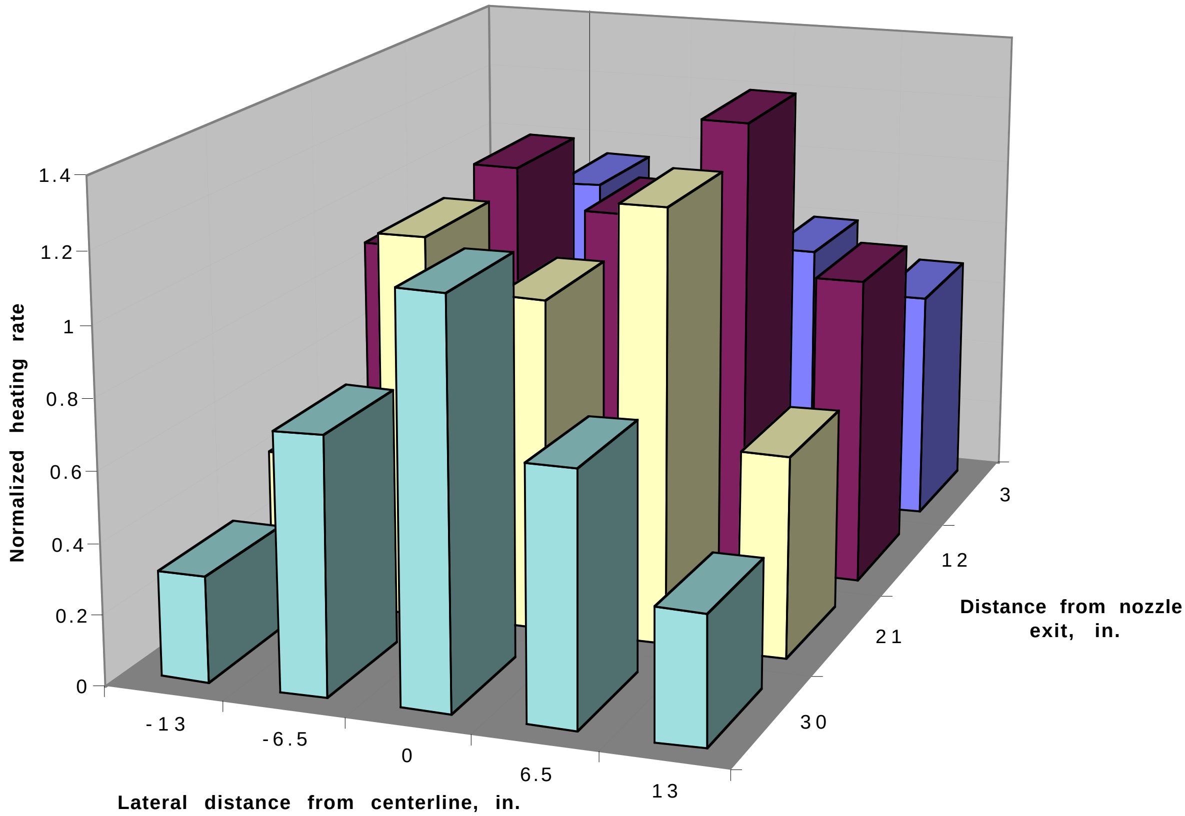


Figure B3. IHF calibration plate; inclination angle of 6°.



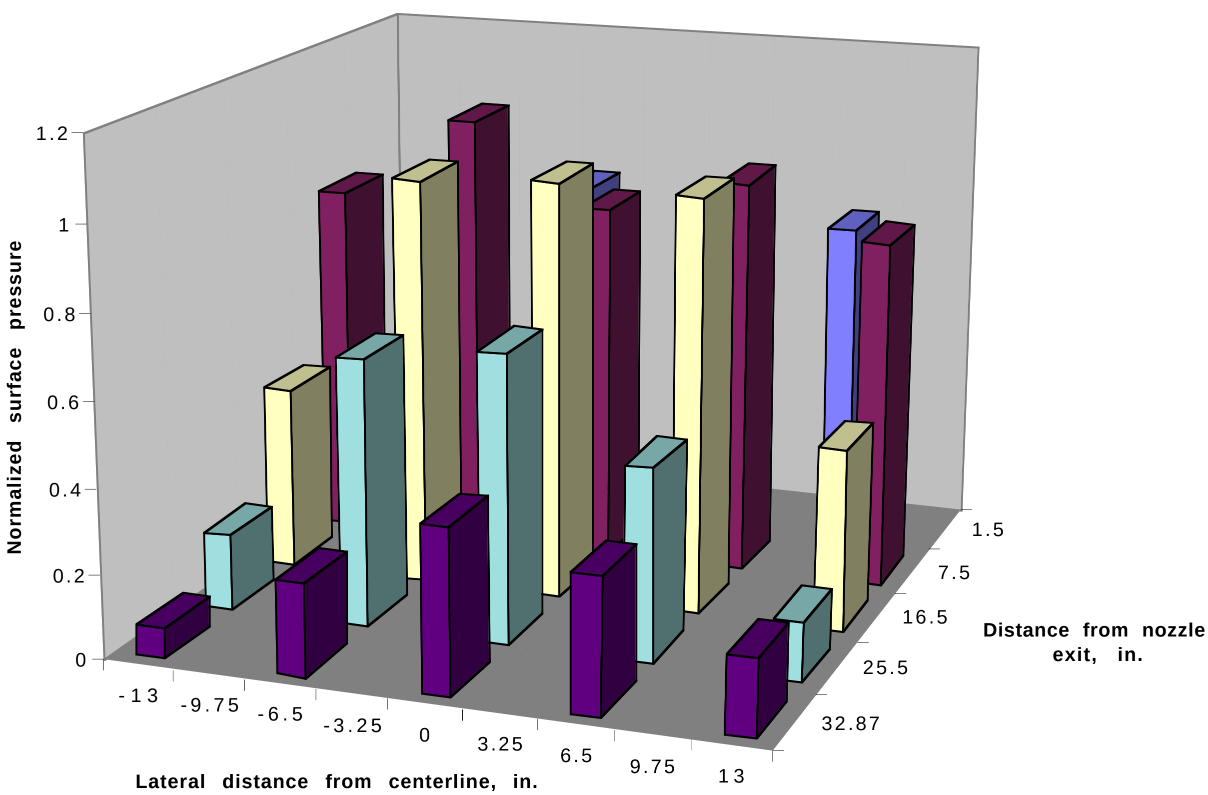


Figure B4. IHF calibration plate; inclination angle of 8°.