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Test Planning Guide

for

NASA Ames Research Center

Arc Jet Complex, Ballistic Range Complex,
and Electric Arc-driven Shock-Tube Facility

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Test Planning Guide for NASA Ames Research Center

Arc Jet Complex and Range Complex

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K	Updated Table 2, including LEAF radiative heating Updated Table 3, correct pin number overlay on DB-25 Figure 2.1, add RSAA to non-NASA customers Figure 4.1.0.1, new aerial photo of the AJ Complex Figure 4.1.0.2, remove 2x9 test bay from N234 schematic Figure 4.1.3.9A, new 6"x6" and 17"x17" radiative heating trend lines Figure 4.1.3.9B, new Gaussian beam peak irradiance vs collimator and power Update 4.2.2 AVGR; 4.2.3 East Facility	Frank Hui FRANK HUI Digitally signed by FRANK HUI Date: 2025.06.30 11:48:15 -07'00'	6/10/2025
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List of Acronyms

ARC	Ames Research Center
AVGR	Ames Vertical Gun Range
AHF	Aerodynamic Heating Facility
AMPS	AHF Model Positioning System
BEAP	Building Emergency Action Plan
CW	Cold wall
DTP	Detailed Test Plan
EAST	Electric Arc-driven Shock-Tube
HVST	High Velocity Shock Tube
HFFF	Hypervelocity Free-Flight Facility
HFFAF	Hypervelocity Free-Flight Aerodynamic Facility
HFFGDF	Hypervelocity Free-Flight Gun Development Facility
IHF	Interaction Heating Facility
LDST	Low Density Shock Tube
LEAF	Laser Enhanced Arc-Jet Facility
LIF	Laser Induced Fluorescence
MOU	Memorandum of Understanding
PI	Principal Investigator
PLC	Programmable Logic Controller
PRM	Photogrammetric Recession Measurement
PTF	Panel Test Facility
RSAA	Reimbursable Space Act Agreement
SCR	Silicon-controlled Rectifier
SDS	Safety Data Sheet
SOP	Standard Operating Procedure
SVS	Steam Vacuum System
TFD	Turbulent Flow Duct
TPS	Thermal Protection System
TRR	Test Readiness Review
TSF	Thermophysics Facilities Branch
TC	Thermocouple
VAC	Volts AC

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1.0 Introduction

The Thermophysics Facilities Branch (TSF) of the Entry Systems and 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 is comprised of 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 is comprised of 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, interfaces, safety constraints, and operational procedures. With this manual, it is intended 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 Agency quality standards.

1.3 Location

The Thermophysics Facilities are located at various locations throughout the Center (see Figure 1.1). 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 N234B houses the boiler for the Steam Vacuum System. The telephone number for N234 facilities is (650) 604-5230; the telephone number for N238 facilities is (650) 604-5974. The Facility Manager for the Arc Jet Complex is Enrique Carballo, (650) 604-0970.

The Ballistic Range Complex currently comprises three facilities. The first of these facilities is the Hypervelocity Free-Flight Facility. It is composed of the Hypervelocity Free-Flight Aerodynamic Facility (HFFAF) and the Hypervelocity Free-Flight Gun Development Facility (HFFGDF). Both of these facilities are located in Building N237. The telephone number is (650) 604-5148.

The second Ballistic 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 104; and target fabrication equipment is in Room 101, Building N205. The telephone number is (650) 604-5526. The Facility Manager for the Range Complex is Charles Cornelison, (650) 604-3443.

Another complex facility is the Electric Arc Shock Tube (EAST) Facility. It is housed in building N229. The High Velocity Shock Tube (HVST) and the Low-Density Shock Tube (LDST) are 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

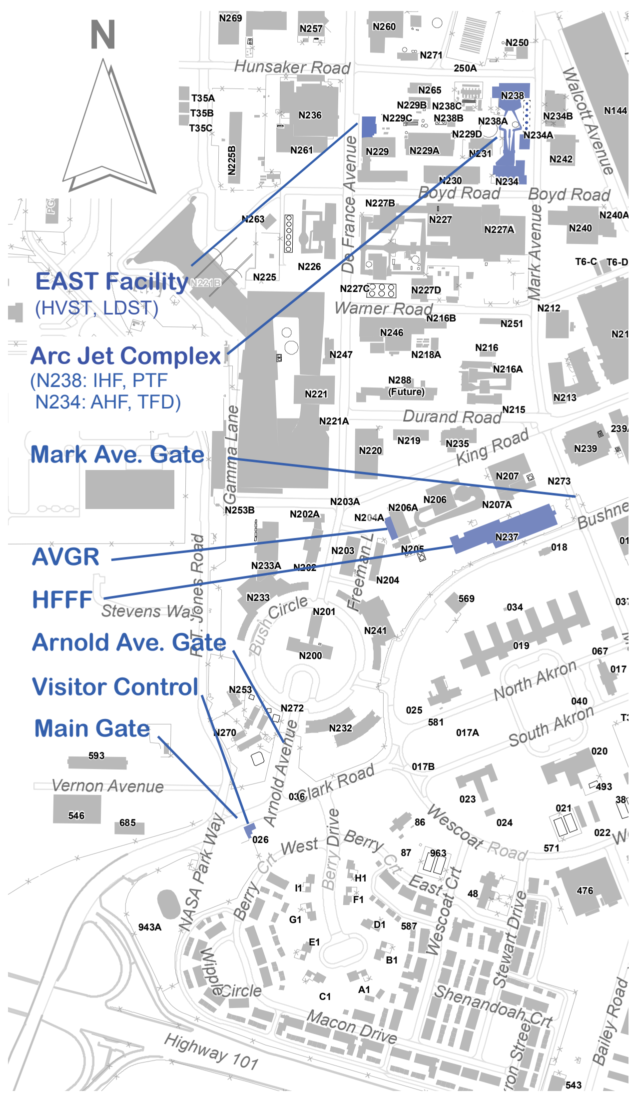


Figure 1.1. Map of Ames Research Center

number is (650) 604-5550. The Facility Manager for the EAST Facility is Ramon Martinez, (650) 604-3485.

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 N234 Room 112
Moffett Field, CA 94035-0001

For tests in the PTF or IHF, the shipping address is
NASA Ames Research Center
Building N238 Room 103
Moffett Field, CA 94035-0001

For tests in the HFFF, the shipping address is
NASA Ames Research Center
Building N237 Room 150
Moffett Field, CA 94035-0001

For tests in the AVGR, the shipping address is
NASA Ames Research Center
Building N204A Room 104
Moffett Field, CA 94035-0001

For tests in the EAST, the shipping address is
NASA Ames Research Center
Building N229 Room 157
Moffett Field, CA 94035-0001

1.3.2 Accommodations

The NASA arc jet complex may accommodate multiple customers at the same time, partnering with other government, industry, DoD, or international organizations. Customers shall be aware of the need for sharing spaces, crew personnel, and daily test times. Daily scheduling priority will be determined by the NASA Facility Manager. Customers shall notify NASA in advance of any special security requirements, model handling and storage, or work spaces, if required. High power laser operations, if ongoing in building N238 only, will periodically interrupt all testing and all work in the high bay area.

1.3.3 Customer-Generated Hazards

Customers shall inform NASA during the planning phases of all hazards introduced by their test articles, hardware, and techniques. Where applicable, Safety Data Sheet (SDS) shall be provided to TSF. Hazards and controls shall be controlled and communicated to all personnel. This may include competing customers who occupy the complex at the same time. NASA shall determine the levels of hazard controls and NASA is responsible to adequately control all hazards, both facility and customer hazards.

1.3.4 NASA Facility Hazards

NASA manages all hazards present during normal operations. NASA will communicate the nominal facility hazards and controls to customers if requested. Normal arc jet operations involves using non-breathable gases inside the basement areas, inside test chambers, and enclosures. Sensors to detect oxygen deficiency are located in the basements of N234 and N238, and ground floor of N234, which alarm inside the building if a hazardous atmosphere is detected. Similar hazardous gases exist in both the Ballistic Range Complex and EAST Facility. In addition, Ballistic Range Complex has and uses explosive and gun powder for its operations.

1.3.5 Work Safety

If requested, NASA may provide limited work areas for a customer. Potential spaces are inside the high bay areas and in the model build-up rooms. Customers shall obtain authorization from NASA before performing any hazardous tasks including, but not limited to: use of shop tools, shop machines and/or welding or brazing operations.

1.3.5.1 ***Personal Protective Equipment (PPE)***

NASA will dispense hearing protection, nitrile gloves, and safety glasses to be used when required. The customer will notify NASA in advanced if additional PPE will be required.

1.3.6 Hazardous Waste

NASA shall manage all hazardous waste according to Santa Clara Code of Ordinances B11- Ch XIII: Hazardous Materials Storage. Customers shall inform NASA during the planning phases of all the potential hazardous wastes they may introduce to Ames. NASA and the customer will agree on how, and who, will regulate the identification, storage, transport, and disposal of all hazardous materials.

1.3.7 Pressurized Systems

Customers shall inform NASA of all pressure systems and equipment that they fabricate and deliver to NASA. Customers will supply all the relevant specifications for this equipment. Customers shall document the static pressure testing of all assemblies before interfacing with NASA facility systems: hydro-static pressure testing is preferred. Customers must justify to NASA prior to performing aerostatic pressure tests. Customers may request NASA to test and install their pressurized equipment (such as water cooled, compressed gas, or hydraulic equipment).

1.3.8 Security

1.3.8.1 Model Security

If requested, NASA will provide storage lockers for securing small portable equipment and test articles; articles up to 20 inches in diameter (or width) and 12 inches in height can be accommodated. Lockers are located in the high bay areas and inside the model build-up rooms.

1.3.8.2 Building Security

All TSF Facilities are locked 24/7. Access is via electronic cards issued to NASA employees or to a customer by special request. Outside of normal duty hours, the buildings are armed with motion sensor alarms that are linked to center-wide dispatch.

1.3.8.3 Data Security and Handling

At the direction of the customer, test materials that are required to have access restricted for regulatory (e.g., ITAR) or proprietary reasons shall be treated as Controlled Unclassified Information (CUI) (CUI now supersedes Sensitive But Unclassified SBU.) CUI information will be controlled in accordance with Executive Order 13556, 32 CFR Part 2002, and NPR 2810.7. If protocols other than NASA's are to be used, detailed information for these procedures must be communicated to NASA before NASA handles any customer CUI materials. If any CUI information is in the test plan, the customer shall provide test planning materials properly formatted according to protocol and, if transmitted electronically, should only be in an encrypted format that is agreed upon with NASA. CUI test data shall only be provided by the cognizant Test Engineer directly to the Principal Investigator or their designee in an encrypted format. Arc Jet Complex personnel receive a background check to qualify them for work in a "Public Trust Position" with sensitive information, receive annual training on how to properly handle CUI material, and are directed to not discuss any information about a CUI test with personnel outside of the immediate test team. Further measures (isolation / segregation of test models and personnel) required to maintain security when testing, particularly when CUI testing is concurrent with other customers in the Arc Jet Complex, shall be negotiated with the Test Engineer and Facility Manager prior to the Test Readiness Review.

1.3.9 Post-Test Model Storage Containers

Customers are requested to provide containers to store and transport their post-test models. In order to best protect the models and minimize risk of damage, it is recommended that the customer suspend the models inside plastic containers to prevent damage during shipping. NASA does not provide test article, pre or post-test, protection outside of in-facility testing storage. Packaging and shipping protection is the responsibility of the customer.

1.3.10 Wireless Internet Access

Non-NASA guests are able to access the ARC wireless network via NASA-Connect after the test engineer or sponsor submits a request on behalf of the guest.

1.3.11 Accuracy of Information

The information in this document is deemed accurate and reliable as of the date of publication. Please bear in mind that these are research facilities and subject to continual improvement and/or upgrades. Information from a cognizant Test Engineer shall supersede information contained herein.

2.0 Administrative Procedures

2.1 Administrative Authority

The Thermophysics Facilities Branch, in the Entry Systems and Technology Division, is responsible for the safe and productive operation of the subject 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 Entry Systems and 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 at the discretion of the Lead Test Engineer, Facility Manager, or their designee as appropriate. The schedules for the facilities of the Arc Jet Complex are maintained by the Facility Manager of the Arc Jet Complex; the schedules for the Ballistic Range Complex are maintained by the Facility Manager or a branch-approved designee; the schedules for the EAST Facility are maintained by the Facility Manager or a branch-approved designee. All these facilities are operated primarily to support government (in particular NASA) aerospace research and developmental testing, as well as US commercial enterprises and academia.

The test initiation and approval process is illustrated in Figure 2.1. For non-NASA customers, a Reimbursable Space Act Agreement (RSAA) is required; it is negotiated between the customer and NASA Ames (with concurrance from NASA HQ). The initial steps in the process consist of informal discussions aimed at determining the feasibility of a concept and, if feasible, which facility is appropriate for the test campaign. 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). The test proposal meeting covers the following topics:

- Define the desired test environment: flow, surface conditions, geometry
- Define the test objectives
- Outline the desired preliminary schedule

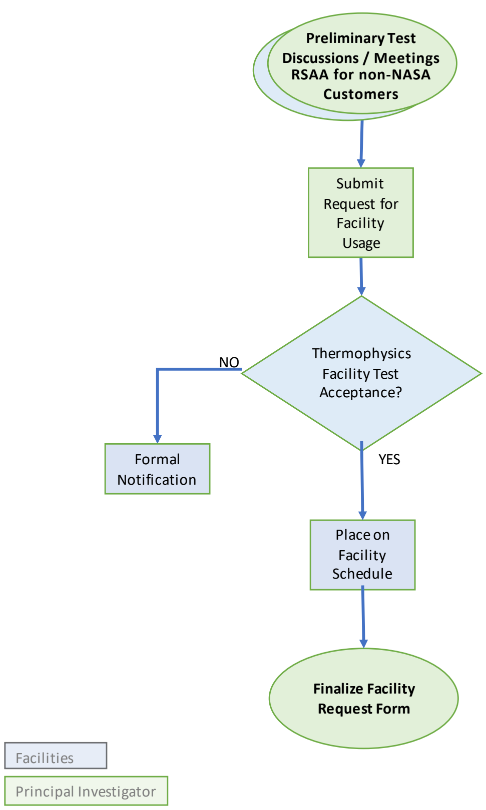


Figure 2.1. Test initiation and approval process

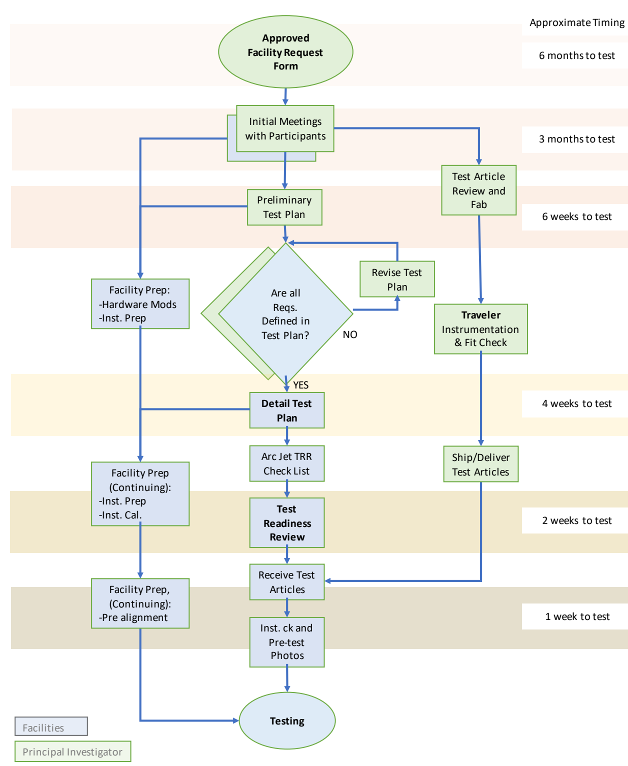


Figure 2.2. Typical test preparation process

- Choose the appropriate facility
- Define classification of security and quality control
- Develop M.O.U. and/or a Detailed Test Plan agreement between requestor and NASA operations management
- Include the new test series in the facility schedule

For more complex tests, more than one meeting might be required to discuss such points as facility suitability and proposed test approach:

- Working meetings for technical details:
  - a.) Facility operational envelope
  - b.) Physical interfaces
  - c.) Instrumentation interfaces
- Preliminary design reviews:
  - a.) Models, adapters, stings
  - b.) Cooling requirements
  - c.) Safety of high pressure, toxicity, etc.
  - d.) Review of all customer drawings and designs
  - e.) All external equipment
- Final design reviews as in above step for preliminary design reviews

The end product of the meeting(s) shall be a completed Request for Facility Use form, as appropriate, 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 Ames Vertical Gun Range

The AVGR is funded primarily through the Planetary Science Enabling Facilities (PSEF) program run by the Planetary Science Division (PSD) at NASA headquarters. Facility access/testing time is secured via selected grant proposals through the Research Opportunities in Space and Earth Sciences (ROSES) program. Typical research falls into one of three PSD disciplines: Solar System Workings, Planetary Protection, and Exobiology. In addition, academic, industry, and other government agencies can acquire occupancy time via Space Act and Interagency Agreements (SAA and IA). All research proposals are initially reviewed by the AVGR PI/Facility Manager and the Science PI to assure they are within the scope of the AVGR's operating capabilities. If the proposal is selected/funded, the researcher/team then works with the AVGR PI/Facility Manager to coordinate the test schedule and develop a test plan. Typical test entries last a week, and upon completion all data is passed along to the researcher/team for subsequent analysis and publication. The AVGR also provides limited, exploratory experiments to test a concept or validate an approach to craft a compelling, future proposal.

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 planning cycle is shown in Figure 2.2 beginning with approval of the test request and following through with the test and the post-test data processing. Not all proposed tests require the full development cycle depicted in Figure 2.2. 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. The test execution process is depicted in Figures 2.2 and 2.3.

For complex tests, 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:

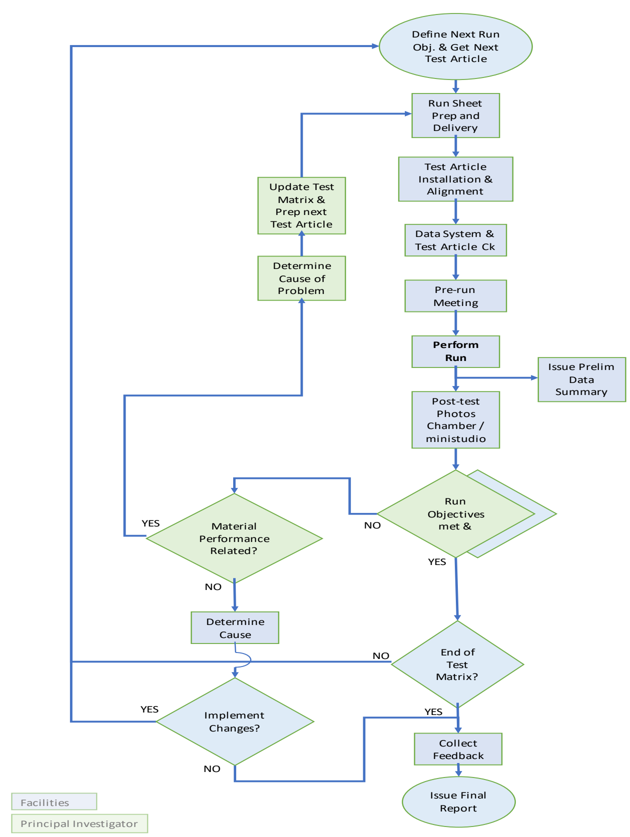


Figure 2.3. Test execution process

- 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 and their required delivery dates relative to the target test date are shown in both Figures 2.2 and 2.4.

The process through which all tests shall proceed, from test approval to post-operation activities is described below.

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, or a Reimbursable Space Act Agreement for non-NASA customers, 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.

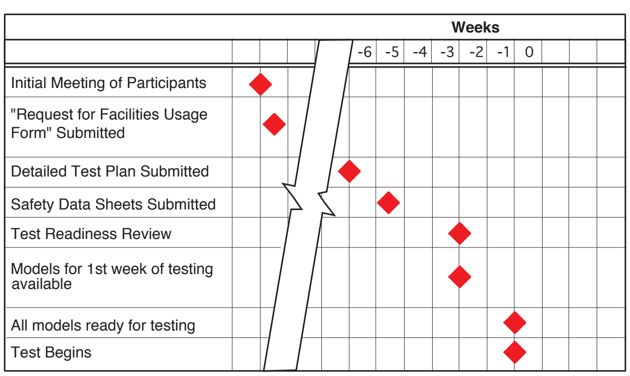


Figure 2.4. Key milestones in the test development process

2.3.1 *Detailed Test Plan*

The Detailed Test Plan (DTP) 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 (PI)/experimenter shall be responsible for preparation of the DTP with the assistance of the Test Engineer or Facility Manager, as appropriate, and both shall sign off the complete plan prior to distribution. If needed, TSF can provide a template (boilerplate) DTP to the PI. A draft DTP shall be provided to the Test Engineer six weeks prior to the start of the test series. The signed DTP shall be delivered to TSF for concurrence by the Test Readiness Review (TRR) meeting, which is nominally at two weeks prior to the start of the test series**.** The signed DTP will be distributed to the Test Readiness Review panel prior to TRR meeting. No systematic effort to prepare for a test will be taken by facility personnel until the Detailed Test Plan is received and approved by NASA.

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

- <u>Overall test objectives</u> and the purpose of the test. State the expected duration of the entry and the facility to be used.
- <u>Approach</u> of the test. State the number of test specimens, describing each type. Describe the proposed run sequence (e.g., calibration runs followed by preliminary screening runs, followed by final evaluation, etc.) and the objective(s) for each run.
- <u>Model description</u>. 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, etc.). Include sketches with dimensions; dimensions must include total model stack-up length. Please note that heavy/oversized models must provide a lifting mechanism, either built-in or detachable handles for example.
- <u>Primary measurements</u>. List the primary measurements to be made, the expected maximum ranges and units, the type of sensor or transducer to be used, whether the sensor will be provided by the customer (in this case, list the power and interface requirements for the sensor) or by the facility. For example:

– Surface temperatures	Thermocouples, Pyrometers, IR camera
– Surface pressures	Capacitance manometers, diaphragm cells
– Heat flux	Water-cooled calorimeter or slug-type (thermal capacitance)
– Duration in the flow	Insertion/retraction schemes
– Model forces	Balance system
– Flow velocity	Two-dimensional laser (Gun Ranges only)
- Time of arrival	Interval timers (Gun Ranges only)

- Primary test parameters (Arc Jets). Nominally, the customer will need to specify the cold-wall heating rate(s) of a particular referenced geometry and its associated pressure. TSF will provide standard calibration probes and plates as required (see Section 4.1.5.1). If the customer wishes to provide its own calibration probe or plate, TSF will work with the customer to make the necessary interfaces and perform the calibration runs as needed. If the customer wants to perform testing with material surface temperature as the primary parameter, then the customer will need to provide a reference material calibration model to the Arc Jets for test temperature calibrations. The customer should understand how this reference material temperature correlates to the actual test material (model) temperature as the potential catalytic effects of the materials can greatly affect the surface temperature of the test material. If the test material's catalytic effects are unknown, TSF may pull in Ames' experts in this area to assist test planning or operations.
- Primary test parameters (LEAF). Radiative heating can be performed with the LEAF lasers only or in combined heating with the IHF Arc Jet. The customer will need to specify the radiative heating in 6-in by 6-in, 17-in by 17-in, or in Gaussian profile in $1/e^2$ cm diameter. LEAF radiative heating is presented in Section 4.1.3.2 under IHF Laser Heating Augmentation.
- 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 inhalation, etc. Include the Safety Data Sheets (SDSs) for all materials used in the test including charred material. For arc jet testing, if high-pressure cooling water or high-pressure gas components are included in a model, indicate all hydrostatic test certifications. If certifications are not available, provide maximum allowable working pressure (MAWP) values so that NASA personnel can perform hydrostatic testing on-site.
- 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 experimenter-supplied equipment is ready to run or properly shut down.
- Video and photo requirements, including infrared video.
- Optical instruments requested, including pyrometer, IR camera, radiometer, spectrometer.
- Alignment template for optical instruments: this might be a full-scale drawing of the test article with “targets” noting where the instruments are to be focused. This full-scale drawing will be placed over the test sample during alignment of the instruments.
- Specialized support external to the Thermophysics Facilities Branch such as PRM (section 4.1.5.6). Please note how this support will be coordinated.
- Emergency procedures with respect to model handling for all anticipated emergencies, including shutdown for fire, earthquake, and loss of building power.
- Model operating envelope and constraints, including adjustment for any model effects and effects of testing to failure 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. Please detail both physical security (i.e., personnel, model handling) and data security (i.e., encryption, means of transfer).
- 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 plane), if necessary.
- Removal of models and post-test handling procedures. Customers are required to bring the containers necessary to transport their post-test models and materials.
- Data recording forms, if necessary.
- Test engineer's (and research engineer's) forms or log sheet, if necessary.
- Packaging and shipping instructions
- Test discrepancy report and protocol for handling, logging, and closing out test discrepancies and test change requests, if necessary.

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 facility of the Thermophysics Facilities Branch shall have a Facility/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. The TRR shall take place at least two weeks before testing begins, as illustrated in Figure 2.4's milestones. A Test Readiness Review is concerned with facility readiness and safety during the conduct of a specific test program. It is intended to bring together all of 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, constructed and tested, 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 fixtures not previously reviewed will require an independent review. A test shall be approved for facility occupancy only after the TRR has been completed and a TRR checklist, 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. Changes to the test sequence are excluded from this requirement.

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 scope or 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 and EAST Facility). As appropriate, the Centerwide Nonconformance Report/Deviation Waiver process shall be used.

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 improve the customer's experience in the future. The scope is to discuss test-related highlights, problems, lessons-learned, and recommendations. All test discrepancies, process change recommendations, and suggestions will be discussed. 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.

3.0 Duties and Responsibilities

The Branch Chief of the 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 Agency 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.

The responsibility of facility operation, safety, maintenance, and raw data acquisition shall be that of the personnel of the Thermophysics Facilities Branch.

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.

In the Ballistic Range Complex and the EAST Facility, the Facility Manager is also responsible for the integrity of the launch package, the gun powder charge, and pump tube pressure.

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 (please see Figure 3.1). 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.

Following the completion of the test, the Test Engineer will prepare a post test data package for delivery to the Principal Investigator. The post test data package will contain final reduced test data, photographs, and video documentation.

The Group Leader of the Test Engineering Group maintains the schedules for the facilities of the Arc Jet Complex and interfaces with the Principal Investigators during the test planning phase of a test program.

3.3 Facility Operator

The Facility Operator is responsible for safely 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 facility 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 and safe for occupancy.

3.4 Instrumentation Technician (Arc Jet Complex)

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

3.5 Data System Technician (Arc Jet Complex)

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.

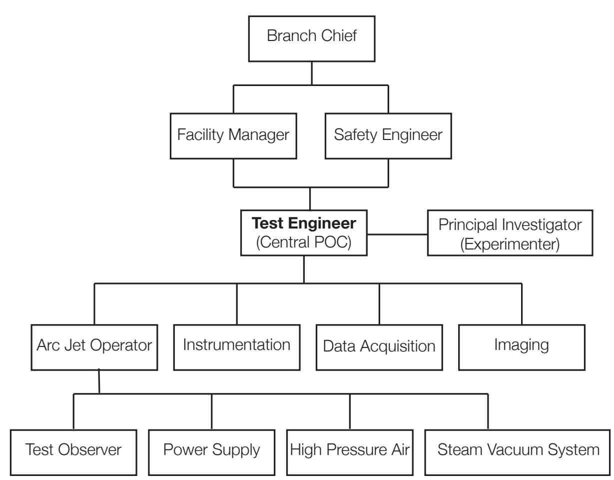


Figure 3.1. Lines of communication during test occupancy.
N.B. The Test Engineer is the central point of contact

3.6 Measurements Engineer (Arc Jet Complex)

The Measurements Engineer is responsible for Engineering oversight of the Instrumentation and Data Acquisition Systems. He/She is responsible for verifying that changes to the Arc Jet Data System configuration are done correctly. His/her duties also include modification of the Arc Jet Data System to integrate new instrumentation or calculations.

3.7 Principal Investigator/Experimenter

Users (also referred to as Principal Investigators or Experimenters) of these facilities are expected to provide a detailed test plan, all hardware, support equipment, and test personnel specific to a given test.

Users are responsible for identifying the hazards associated with all the hardware and materials they bring to Ames, communicating these to NASA and mitigating all of the hazards through engineering design and/or by administrative procedures.

Data reduction/analysis regarding model/test article performance shall be the sole responsibility of the Principal Investigator.

In the Arc Jet Complex, the Principal Investigator interfaces with the test engineer regarding any aspect of his/her test.

For the Range Complex, specifications for the test gases shall be provided by the PI. Assistance may be given by the facility Branch personnel in obtaining test gases other than air.

3.8 Optical Engineer (Arc Jet Complex and EAST)

The optical engineer is responsible for maintaining the optical components of the system in working order, under calibration, and in alignment. The individual also performs in-house calibrations for optical transmission losses on the pyrometer and IR cameras and generates correction coefficients for data reduction. The optical engineer reports to the Test Engineer (Arc Jets) or facility manager (EAST) and interfaces with the PI to the extent necessary for the PI to determine how optical issues impact the technical quality of the data. The optical engineer is a part-time position and may perform other duties in the facility.

3.9 Instrumentation Engineer (EAST)

The instrumentation engineer is responsible for overseeing operation of all instrumentation on the shock tube other than optics. This includes pressure sensors, data acquisition system, control system, and other electrical subsystems. The instrumentation engineer reports to the facility manager and interfaces with the PI as needed for assessing quality of data and its interpretation.

3.10 Data Analyst (EAST)

The data analyst performs post-processing on collected data and synthesizes collected data into a useful format for the PI. This includes analysis of shock velocity, applying calibration factors to spectroscopic data, and producing automation routines. The analyst reports to the PI.

3.11 Foreign National Visitors

A foreign national is any person who is a citizen of another country and who has not been granted status in the United States (U.S.) as a lawful permanent resident. Foreign nationals must undergo specific processes for identity vetting and granting of access to the facilities of the Arc Jet Complex and will require an escort during their visit at NASA. Please allow 4-6 weeks for approval of foreign national visitors.

Escorts are responsible for ensuring that the foreign national visitors adhere to the requirements of their visit. From the moment that the foreign national visitor arrives at the Center until leaving the Center, the foreign national is monitored by the escort. The escort works closely with the host and other program and project personnel to ensure that all requirements of the visit are met.

3.12 Data Transmittal

The Thermophysics Facilities Branch will produce the standard electronic files containing test data as soon as a test is complete. The user is responsible for any subsequent data analysis. Investigators requiring immediate analysis of their test data are urged to provide their own data analysis equipment. Wireless network access is available (e.g. for internet access or e-mail access) in the test facilities. If wireless access is required, the PI should request it in his/her test plan. The cognizant test engineer will coordinate wireless network access.

Immediate transfer of preliminary electronic test data to the investigator, if required, will be done via single-write CDs, encrypted email, a secure data server provided by the PI, or NASA approved and shared cloud storage.

3.13 Costs to Customers

Users are assessed costs based on their occupancy days in the facility. 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.

An Occupancy Day is a shift-day during which necessary operations are conducted to execute the Test Plan on schedule. Such days include setup, calibration, test operations, and quality assurance activities, as well as unusual, application-specific maintenance. Not every day billed as an Occupancy Day is a day of testing.

3.14 Levels of Support Provided

NASA personnel provide the following normal levels of test support: consulting during test development, installation of models into the test facility, connecting instrumentation into the data acquisition system, and reduction of raw data.

Data reduction/analysis relating to facility operation parameters shall be the responsibility of the operating personnel. These data include items such as pressure, temperature, etc. in the test chambers, and, for the Range Complex, projectile velocity, size, and weight, as appropriate.

4.0 Facility Description

4.1 Arc Jet Complex

The Ames Research Center 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 also 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. 4.1.0.1) at ARC has three active test bays located in two separate laboratory buildings. Figure 4.1.0.2 shows a schematic representation of the location of these test bays. 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, data acquisition systems, and other auxiliary systems. The magnitude and capacity of these support systems are 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.

Figure 4.1.0.1. NASA Ames Research Center Arc Jet Complex

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 multi-dimensional nozzles, offer wide versatility for testing both large, flat-surface test objects (Fig. 4.1.0.3) and stagnation-flow models that are fully immersed in a supersonic test stream (Fig. 4.1.0.4).

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 supersonic nozzle, producing the simulated atmospheric-entry heating environment. The design of the cylindrical confining

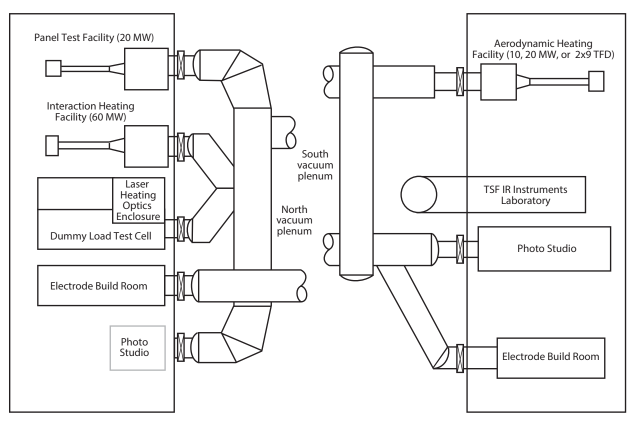


Figure 4.1.0.2. Test bays of the Arc Jet Complex at Ames Research Center

Figure 4.1.0.3. 24×24 in (61×61 cm) panel being tested in the arc jet complex

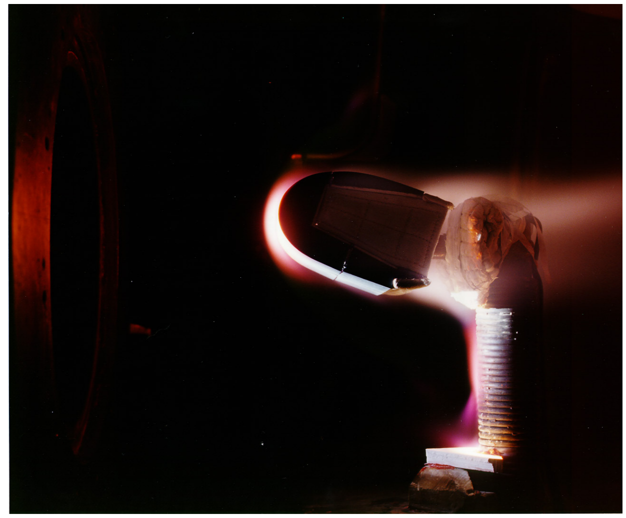


Figure 4.1.0.4. Leading-edge model being tested in the arc jet complex

device must simultaneously satisfy 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 (8,300 °C). 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 of these requirements. Development of increasingly higher power arc heaters has been conducted at ARC over more than 50 years.

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, it is 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 12,000 Btu/lb_m [28 MJ/kg])	Low (to 4,000 Btu/lb_m [9 MJ/kg])
Pressure	Low (to 10 atm [1 MPa])	High (to 16.7 atm [1.7 MPa])
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. 4.1.1.1.) The downstream electrode is electrically grounded by physical contact with the vacuum system piping.

Operation– During operation, the test gas (air, N_2, or Ar) 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

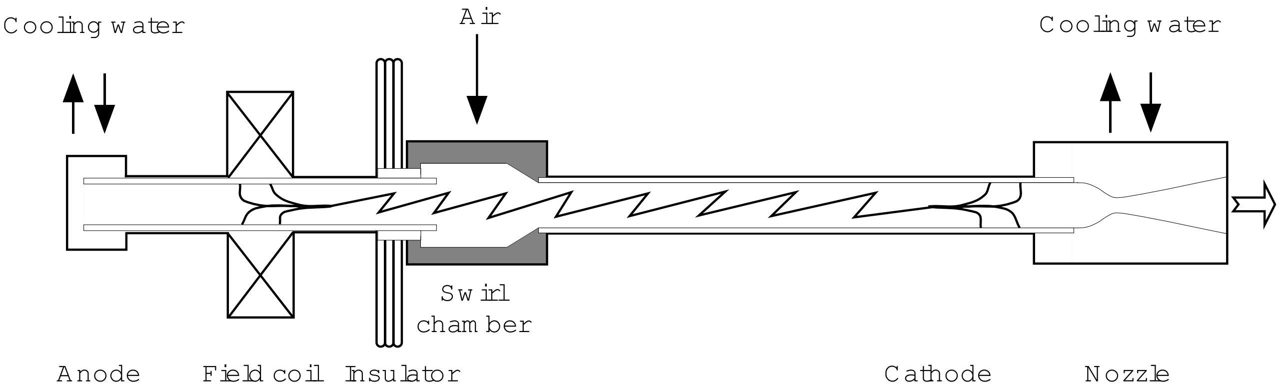


Figure 4.1.1.1. Schematic drawing of the Huels arc heaters used at ARC

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:

- 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 (up to 16.7 atm [1.7 MPa] at ARC), but it produces plasmas at relatively low enthalpies (1,500 to 4,000 Btu/lb_m [3.5 to 9.3 MJ/kg]) 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 4.1.1.1. This arc heater has been used with a variety of nozzles in different test bays and is available in a 20 MW unit. It is available with various downstream electrode lengths, allowing the operator to select a tube length that will best match the expected "natural" arc length. The 100 MW Huels arc heater at Ames has been mothballed.

4.1.1.2 Segmented Arc Heaters

Hardware– The segmented arc heaters are relatively complex units with many components and critical assembly alignments. (See figs. 4.1.1.2 and 4.1.1.3.) 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 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 20 to 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 20 MW and 60 MW segmented heaters (Fig. 4.1.1.2) consist of multiple-ring electrodes contained in assemblies called electrode packages. Each electrode package consists of individual electrode, spacing, and transition rings. Electrodes are wear items that require replacement at regular intervals. 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

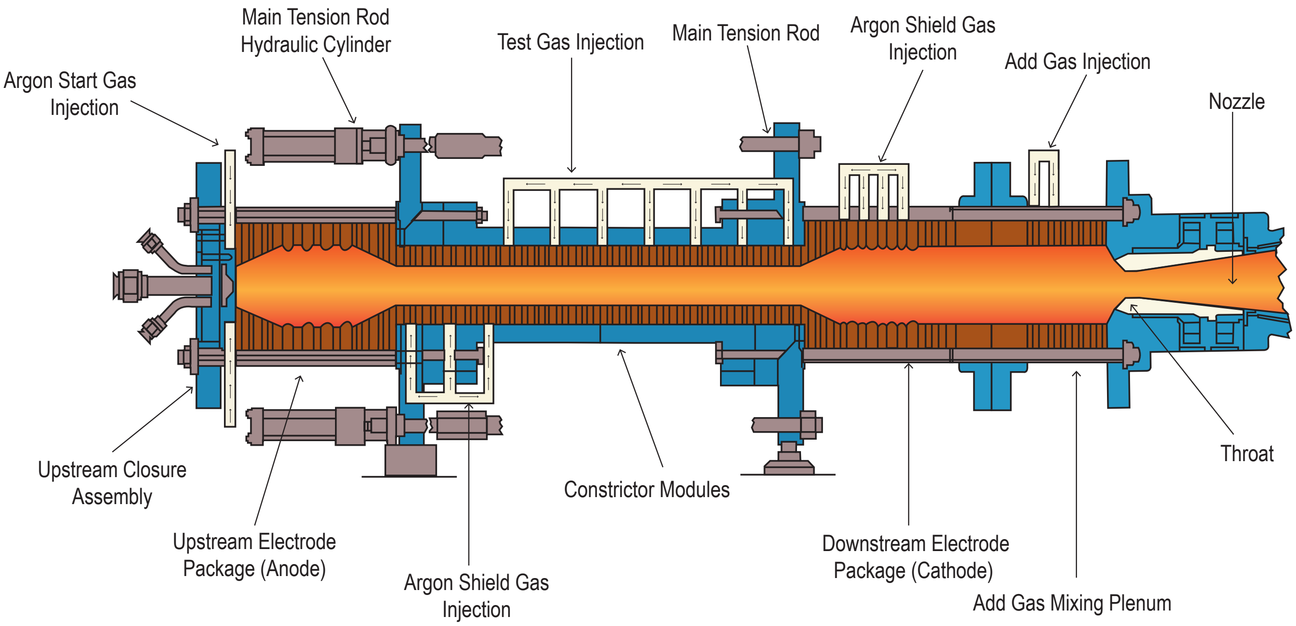


Figure 4.1.1.2. Schematic drawing of the 20 MW and 60 MW segmented arc heaters used at ARC.
N.B. Add gas mixing plenum is: not available for PTF; configurable for AHF; standard for IHF

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.

The anode of the 10 MW segmented arc heater (Fig. 4.1.1.3), located at the downstream end, consists of a copper sleeve surrounded by a water jacket. The cathode, located at the upstream closure, is made of a tungsten alloy, mounted into a water-cooled holder.

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.

20 MW and 60 MW 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.

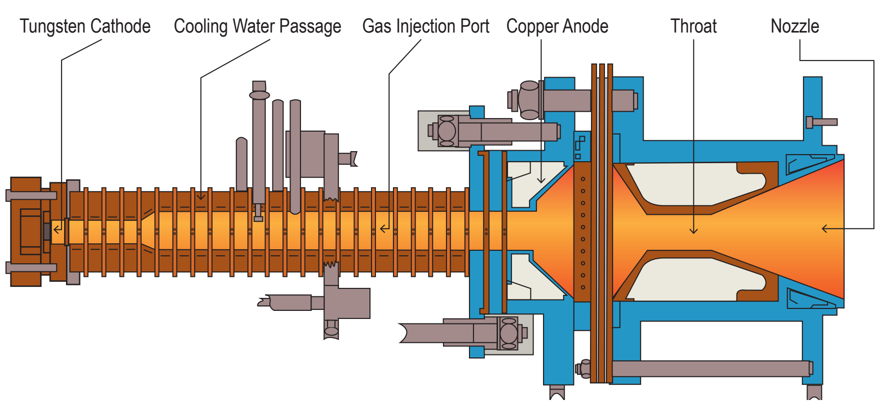


Figure 4.1.1.3. Schematic drawing of the 10 MW dual-bore arc heater

10 MW Operation— The test gas can be either pure nitrogen, or nitrogen and oxygen (nitrogen and carbon dioxide operation is currently under development) (no argon gas is used during testing). Gases are injected at specific locations and are mixed inside the arc column. The upstream cathode must be protected by non-oxidizing nitrogen gas.

The segmented arc heater provides a wider range of enthalpy levels and a more stable and repeatable test condition than does the Huels arc heater. The segmented arc heater can produce relatively high enthalpy levels (2,000 to 12,000 Btu/lb_m [5 to 28 MJ/kg] in air) at relatively low pressures (1 to 10 atm [0.1 to 1 MPa]). It can also be operated at high pressures (above 100 atm [10 MPa]), 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 of the segmented arc heaters at ARC operate at relatively low pressures, less than ten atmospheres.

The basic geometry of the segmented arc heater as operated at ARC is shown in Figures 4.1.1.2 and 4.1.1.3. This type of arc heater is coupled to a variety of nozzles (of both semielliptical and circular cross section) in different test bays; it is available in three sizes: a 6 cm (2.4 in) and 8 cm (3 in) bore constrictor tube, and the 10 MW arc heater with dual-bores of 3.8 cm (1.5 in) and 6 cm (2.4 in) inside diameters. The 20 MW and 60 MW arc heaters use the same electrode package components and are assembled with either four or eight electrode rings in the package.

A past configuration of the 6 cm (2.4 in) bore segmented arc heater, now mothballed, has operated at power levels up to 80 MW using hydrogen/helium mixtures as the test gas.

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 three- or two-dimensional 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, 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. 4.1.2.1). A flat-panel test article is mounted flush to the bottom flat surface of the nozzle in a semiopen jet at the nozzle exit. The model surface may be inclined to adjust the surface heating rate.

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. Variations in streamwise heating and pressure distribution increase at higher inclination angles and higher arc current levels.

The 20 MW PTF has two semielliptical nozzles available:

- a nozzle of 17 in (43 cm) exit width to provide aerodynamic heating onto a 14 × 14 in (36 × 36 cm) flat panel; and
- a nozzle of 6.7 in (17 cm) exit width to provide

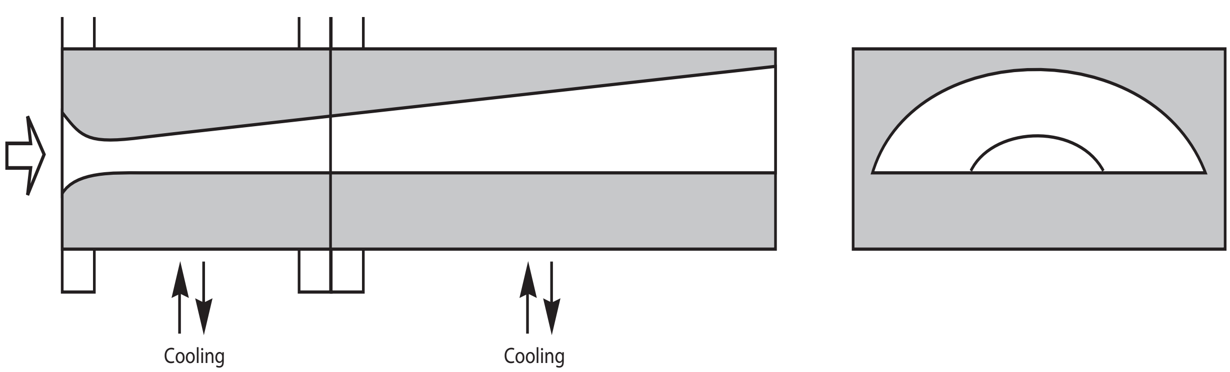


Figure 4.1.2.1. Schematic drawing of the semielliptical nozzles at ARC

aerodynamic heating onto a 4 × 4 in (10 × 10 cm) flat panel.

The 60 MW IHF also has two semielliptical nozzles available.

- a nozzle of 32 in (81 cm) exit width to provide aerodynamic heating onto a 24 × 24 in (61 × 61 cm) flat panel; and
- a nozzle of 22 in (56 cm) exit width to provide aerodynamic heating onto an 18 × 18 in (46 × 46 cm) flat panel.

The larger of the semielliptical nozzles for both PTF and IHF operate at an approximate Mach number of 4.4-5.5 and are fitted with an uncooled, high-temperature plate over the final 20 percent of the length of the flat portion of the nozzle (upstream of the test panel). 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 an atmospheric entry 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.

The smaller (truncated) semielliptical nozzles produce flows at approximately Mach 2.2-3.6. Compared with their companion larger semielliptical nozzles, they can simulate higher heating rate, higher pressure, and higher shear. Installing the truncated PTF nozzle requires adding the extended test chamber onto the PTF. All of the Ames semielliptical nozzles allow the test panel to be inclined at positive and negative angle of attack with respect to the flow stream.

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 three conical nozzle systems:

- 20 MW Aerodynamic Heating Facility
  - Throat diameters of 1.0, 1.5, and 2.0 in (2.5, 3.8, and 5.1 cm)
  - Exit diameters of 7, 12, 18, 24, 30, and 36 in (18, 30, 46, 61, 76, 91 cm)
- 60 MW Interaction Heating Facility
  - Throat diameter: 2.375 in (6.033 cm)
  - Exit diameters of 3, 6, 9, 13, 21, and 30 in (15, 23, 33, 53, 76 cm)
- 10 MW Aerodynamic Heating Facility
  - Throat diameter: 2.25 in (5.72 cm)

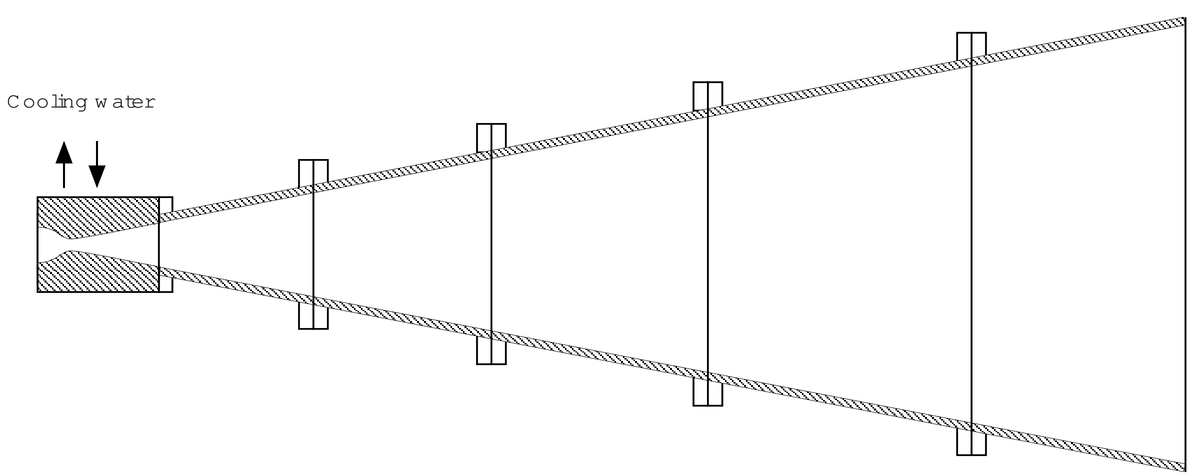


Figure 4.1.2.2. Schematic drawing of a conical nozzle family

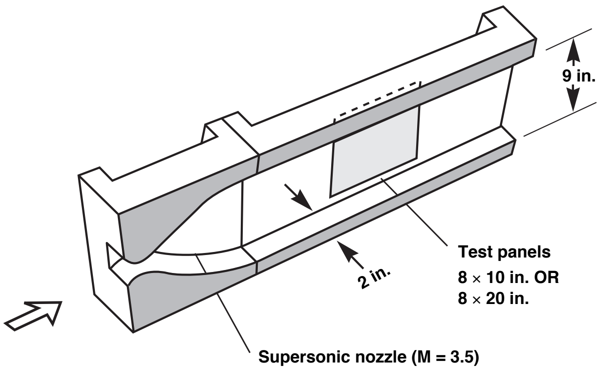


Figure 4.1.2.3. Schematic representation of the TFD nozzle and test section

– Exit diameters of 5, 7.5, 10, 15, 20, 25, 30, 35 and 40 in (13, 19, 25, 38, 51, 63, 76, 89, 102 cm)

In each facility, the location of the nozzle exit plane usually 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 4.1.2.2 shows a schematic drawing of a typical conical nozzle family.

4.1.2.3 Multi Dimensional Nozzle

A special-purpose nozzle is available for use with the TFD; it is described below

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 × 1.600 in (2.865 × 4.064 cm). One wall expands to the 9 in (20 cm) 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 3¹⁄₁₆ in (7.50 cm) from the minimum section extending to the nozzle exit. Figure 4.1.2.3 shows a sectional view of the 2" × 9" 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.

4.1.3.1 Aerodynamic Heating Facility (AHF)

The AHF (Figure 4.1.3.1) is a highly flexible arc jet facility that operates with either of two 20 MW arc heaters and a family of conical nozzles or a 10 MW arc heater which has its own family of conical nozzles. The two segmented arc heaters operate at reservoir pressures from 1 to 10 atm (0.1 to 1 MPa) and enthalpy levels, in air, from 2,000 to 12,000 Btu/lb$_m$ (5 to 28 MJ/kg). The Huels arc heater operates at pressures from 1 to 16.7 atm (0.1 to 1.7 MPa) and enthalpy levels, in air, from 1,500 to 4,000 Btu/lb$_m$ (3.5 to 9.3 MJ/kg). Most of the testing in the AHF is done using the segmented arc heaters because of their high enthalpy performance, low stream contamination, and long history of repeatable operation.

20 MW Arc Heaters—Available test gases for both of the 20 MW arc heaters are air, nitrogen, and argon. They can be coupled with a family of 8°-half-angle conical nozzles of exit diameters of 7, 12, 18, 24, 30, or 36 in (18, 30, 46, 61, 76, 91 cm) (Figure 4.1.2.2). Each nozzle has an interchangeable throat of diameters of 1.0 or 1.5 in (2.5 or 3.8 cm). The Huels heater has an additional throat of 2 in diameter (5.1 cm).

10 MW Arc Heater—The 10 MW arc heater runs with mixtures of nitrogen and oxygen (capability to run with a mixture of nitrogen and carbon dioxide is in development); it does not use argon gas except to initiate the arc discharge. The 10 MW arc heater is coupled with its own family of conical nozzles having 15 degrees-half angle expansions and exit diameters of 5, 7.5, 10, 15, 20,

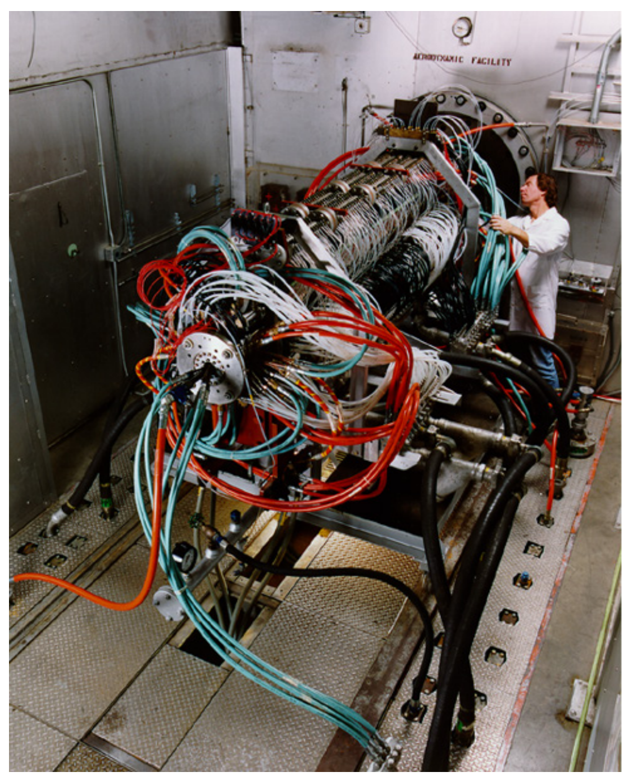


Figure 4.1.3.1. The 20 MW segmented arc heater in the AHF

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

	Aerodynamic Heating Facility		2×9 Turbulent Flow Duct[Ψ]	Panel Test Facility		Interaction Heating Facility			
Nozzle Configuration	Conical		Multi-Dimensional	Semielliptic		Semielliptic		Conical	
Test Gas	Air + Argon, Nitrogen + Argon, Argon	$N_2 + O_2$ (CO_2 in development)	Air, Nitrogen, Argon	Air + Argon	Air + Argon	Air + Argon	Air + Argon	Air + Argon	
Input Power, MW	20	10	12	20	20	60	60	60	
Type of test Article	Stagnation, Wedge	Stagnation, Wedge	Flat Plate	Flat Plate	Flat Plate	Flat Plate	Flat Plate	Stagnation, Wedge	
Nozzle Exit Dimension, in	7, 12, 18, 24, 30, 36 (diameter)	5, 7.5, 10, 15, 20, 25, 30, 35, 40 (diameter)	2 × 9	17 × 4.25 (2a × b)	6.7 × 1.68 (2a × b)	32 × 8 (2a × b)	22 × 5.5 (2a × b)	3, 6, 9, 13, 21, 30 (diameter)	
cm	18, 30, 46, 61, 76, 91 (diameter)	13, 19, 25, 38, 51, 63, 76, 89, 102 (diameter)	5 × 23	43 × 10.8 (2a × b)	17 × 4.3 (2a × b)	81 × 20 (2a × b)	56 × 14 (2a × b)	8, 15, 23, 33, 53, 76 (diameter)	
Throat Dimension, in	1.0, 1.5, and 2.0 (diameter)	2.25 (diameter)	1.128 × 1.6	1.141 × 0.707	1.414 × 0.707	4.75 × 1.1875	4.75 × 1.1875	2.375 (diameter)	
cm	2.5, 3.8, and 5.1 (diameter)	5.72 (diameter)	2.865 × 4.064	0.56 × 0.28 (2a × b)	0.56 × 0.28 (2a × b)	12.07 × 3.02 (2a × b)	12.07 × 3.02 (2a × b)	6.033 (diameter)	
Mach Number	4 – 9	4 – 12	3.5	4.4	2.2	5.5	3.6	4 – 9	
Sample Size, in	Area blockage ratio < 0.3	Area blockage ratio < 0.3	8 × 10 8 × 20	14 × 14	4 × 4	24 × 24	18 × 18	Area blockage ratio < 0.3	
cm	Area blockage ratio < 0.3	Area blockage ratio < 0.3	20 × 25 20 × 51	35 × 35	10 × 10	61 ×61	46 × 46	Area blockage ratio < 0.3	
Bulk Enthalpy, Btu/lb$_m$	2,000 – 12,000	2,000 – 12,000	1,500 – 4,000	3,500 – 9,000	3,500 – 9,000	2,000 – 12,000	2,000 – 12,000	2,000 – 12,000	
MJ/kg	5 – 28	5 – 28	3.5 – 9.3	8 – 21	8 – 21	5 – 28	5 – 28	5 – 28	
Surface Pressure, kPa	0.5 – 50	0.5 – 75	2 – 15	0.05 – 5	2 – 25	0.01 – 2	0.1 – 5.5	1 – 600	
Convective Heating Rate[*], Btu/ft^{2}sec	8 – 750	8 – 750	2 - 60	0.5 – 40	22 – 200	0.5 – 45	0.88 – 81	50 – 6600	
W/cm^2	9 – 850	9 – 850	2 – 70	0.6 – 45	25 – 230	0.6 – 51	1.0 – 92	56 – 7500	
Radiative Heating Rate, Btu/ft^{2}sec	0	0	0	0	0	0	9-80[††]	16-352[†]	0.8-35k[#]
W/cm^2	0	0	0	0	0	0	10-90[††]	18-400[†]	1-40k[#]

[*] Convective heating rate for conical nozzles measured on 4-in (10 cm) dia. sphere; for flat plate panels, convective heating rate measured on centerline near the leading edge.
[#] Gaussian beam (with 1/e^2 of 1 cm) on flat sample mounted on a wedge.
[†] 6"×6" flat-top beam on sample mounted on a wedge.
[††] 17"×17" flat-top beam on sample mounted vertically on an actuating model box.
[Ψ] 2X9 TFD is to be integrated into the AHF test bay in the near future.

25, 30, 35 and 40 in (13, 19, 25, 38, 51, 63, 76, 89, 102 cm). The throat diameter is 2.25 inches (5.715 cm).

The nozzles discharge into a 8 × 8 × 10 ft (2 × 2 × 3 m) walk-in test chamber. Flow in the cabin is collected by the 60 in (150 cm)-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 (10 to 1000 Pa), depending on mass flow and pumping rates. Test 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 a three swing-arm model support mechanism (new AHF Model Positioning System, AMPS). This electric system can insert models to either a fixed position (such as the center of the flow) or sweep across the flow for flowfield characterization. Either stagnation flow (see Fig. 4.1.0.4) or wedge-shaped models can be inserted into the test stream. Water manifolds are available to cool the 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.

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 4.1.3.2 shows the range of conditions attainable on a 4 in (10 cm) diameter sphere/cylinder stagnation test article using the 20 MW segmented arc heater. Figure 4.1.3.3 shows the operating envelope using the Huels arc heater. Figure 4.1.3.4 shows the operating envelope for a 4 in (10 cm) iso-q-shaped body using the 10 MW segmented arc heater. Run durations as long as 30 minutes are possible, with a 45-minute cool down period between runs.

20 MW AHF Mixing-Air Plenum— The capability for mixing in room-temperature test gas into the arc jet stream immediately upstream of the nozzle throat is an option for the 20 MW segmented arc heater. This modification greatly increases the simulation capability into a range of higher stagnation pressure and lower stream enthalpy (below 1000 Btu/lb_m [2 MJ/kg]).

10 MW Add-Gas Plenum— A plenum to inject room-temperature test gas exists with the following options: Nitrogen can be mixed into a plasma of nitrogen or into a mixture of nitrogen and oxygen; the capability to inject carbon dioxide into the plasma is in development. The mass flow rate of injected gas is controlled independently of the flow of gases into the arc column.

4.1.3.2 Interaction Heating Facility

The 60 MW IHF (Fig. 4.1.3.5) 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 (0.1 to 1 MPa) and enthalpy levels, in air, from 2,000 to 12,000 Btu/lb_m (5 to 28 MJ/kg). Cold air can be added in the downstream plenum to obtain centerline enthalpies below 1,000 Btu/lb_m (2 MJ/kg). Two nozzle geometries are used in the IHF: conical axisymmetric (Figure 4.1.2.2) and semielliptical (Figure 4.1.2.1). The nozzles direct the flow into a walk-in, 8×8×10 ft (2×2×3 m) test chamber. Flow in the cabin is collected by the 54 in (130 cm)-diameter diffuser before being pumped into the steam-ejector vacuum system. Static pressure in the test chamber ranges from 0.1 to 10 torr (10 to 1,000 Pa), depending on mass flow and pumping rates. Test samples are exposed to the plasma in an open jet formed between the nozzle exit and the entrance to the diffuser.

Two nozzle types are available for the IHF:

- Conical nozzles (10° half angle)
  - Exit diameters of 3, 6, 9, 13, 21, and 30 in (8, 15, 23, 33, 53, and 76 cm).
  - Throat diameter of 2.375 in (6.033 cm).
  - Used for simulation of atmospheric entry over 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 nozzles

  Two nozzle configurations are available:
  - Truncated nozzle
    - Exit width of 22 in (56 cm)
    - Panel dimensions approx. 18×18 in (46×46 cm)

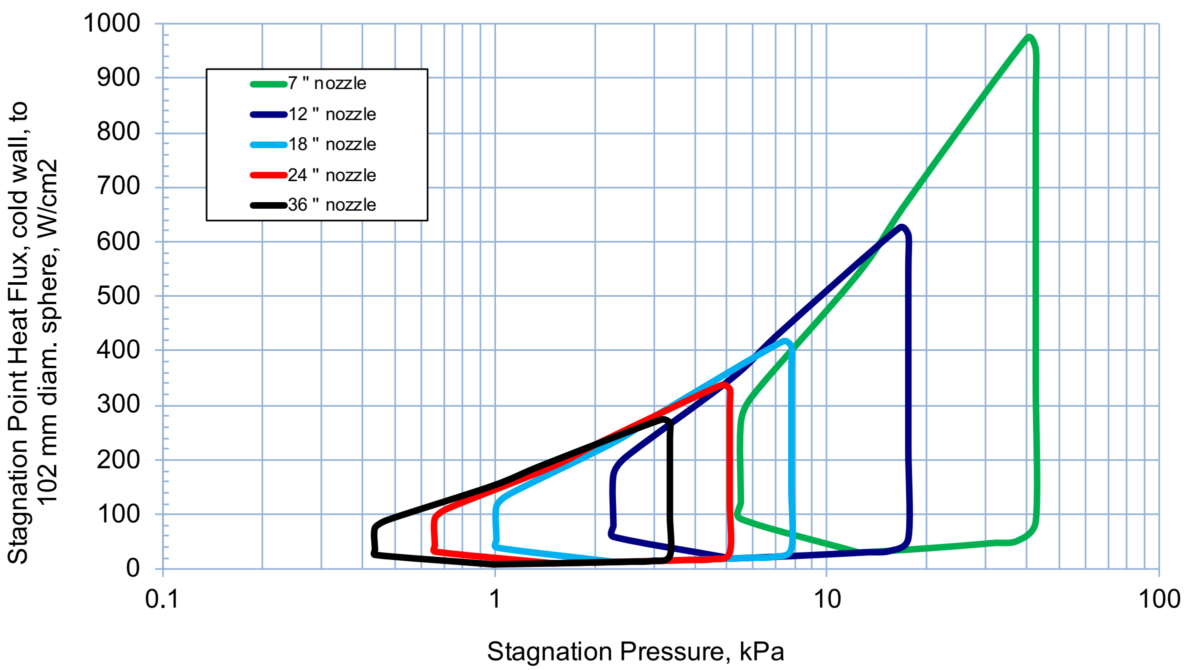


Figure 4.1.3.2. Operating envelope of the AHF with 20-MW segmented arc heater

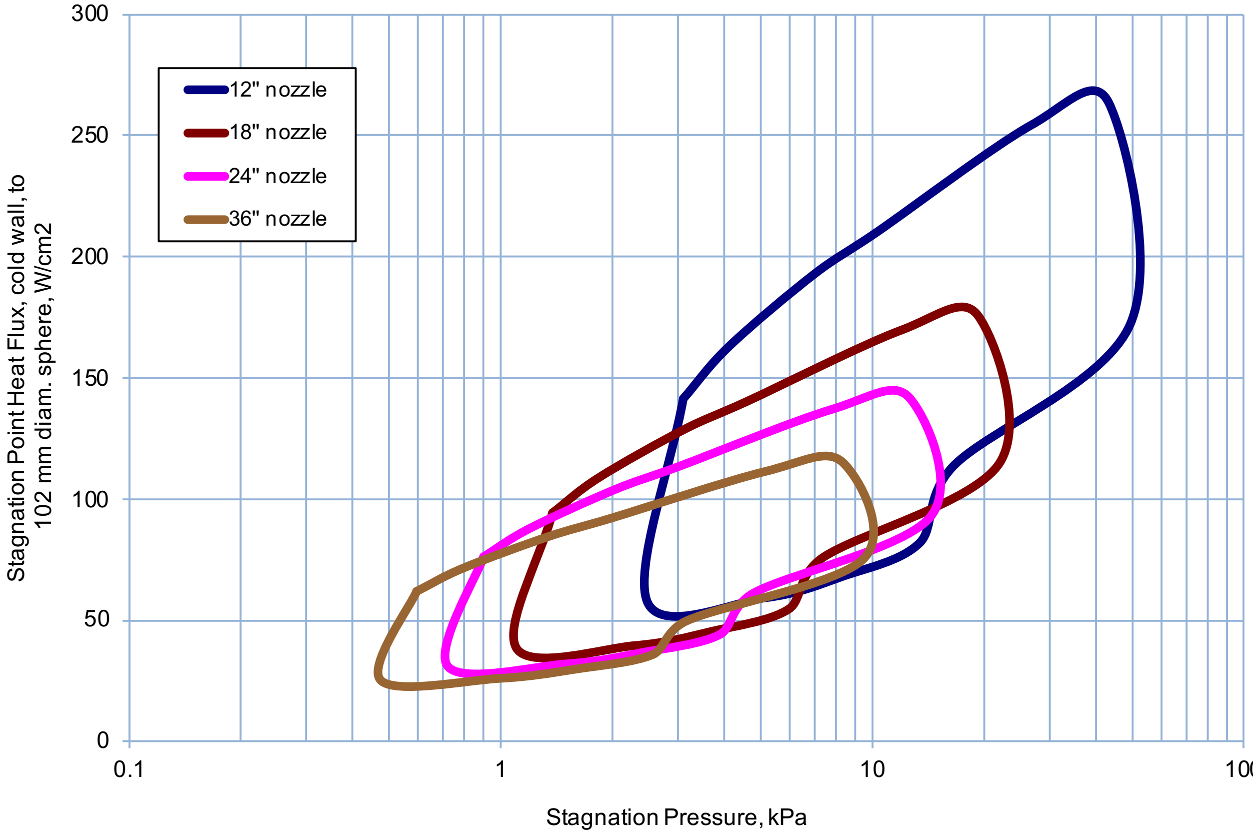


Figure 4.1.3.3. Operating envelope of the AHF with 20 MW Huels arc heater

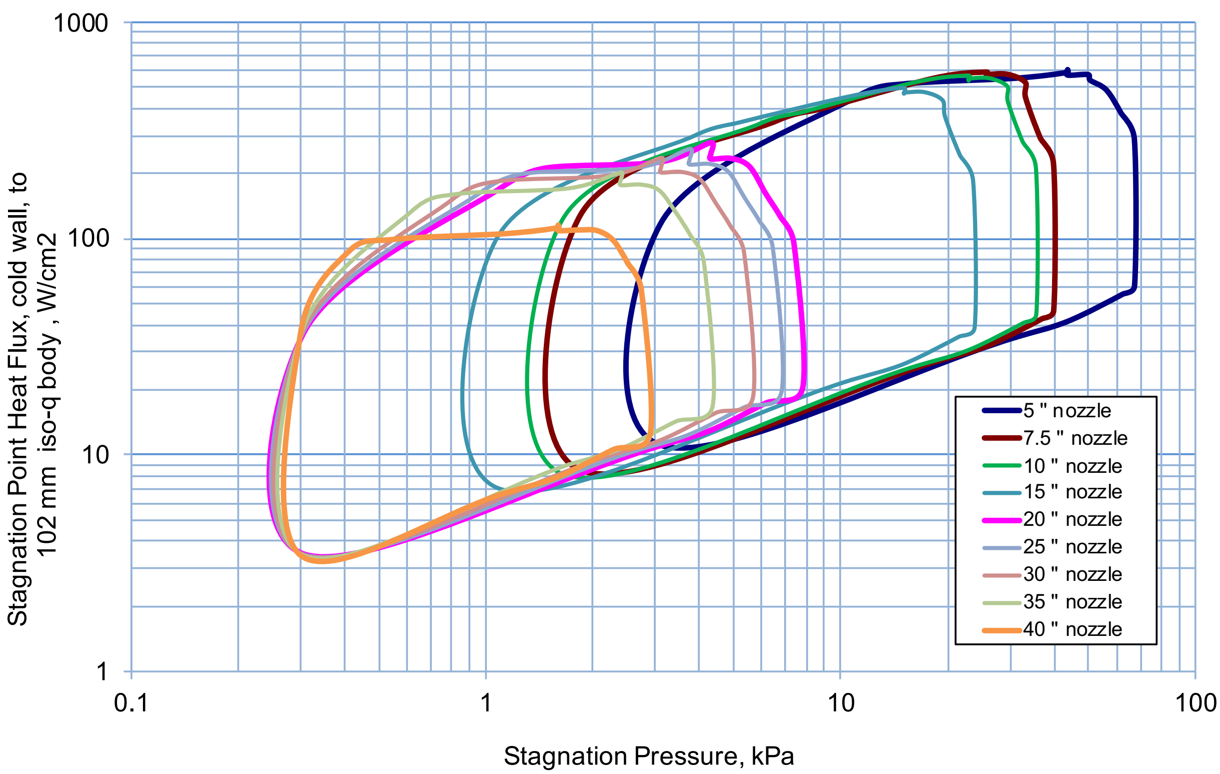


Figure 4.1.3.4. Operating envelope of the AHF with 10-MW dual-bore segmented arc heater

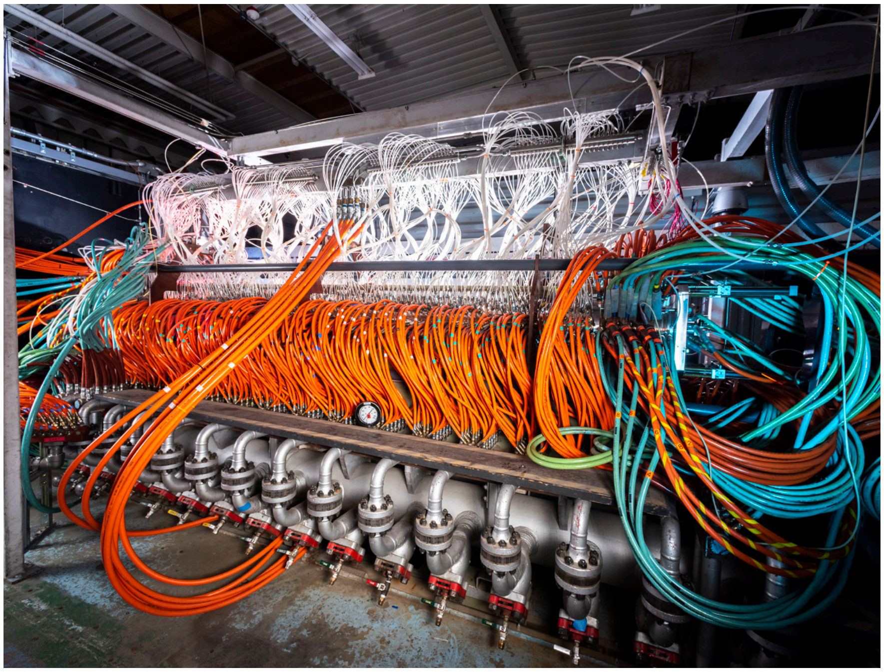


Figure 4.1.3.5. 60 MW segmented arc heater in the IHF

– The panels can be inclined at angles of -4° to 6°

- Standard nozzle
  - Exit width of 32 in (81 cm)
  - Panel dimensions approx. 24×24 in (61×61 cm)
  - The panels can be inclined at angles of -4° to 6°

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).

The test chamber houses three hydraulically-actuated model insertion mechanisms mounted on the ceiling of the test chamber. 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 semi-open 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 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.

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 4.1.3.6. The envelope of surface conditions attainable on a 20° wedge (cf. Fig. 4.1.5.3) is shown in Figure 4.1.3.7. The operating envelope for the semielliptical nozzles is given in Figure 4.1.3.8. Run durations as long as 60 minutes are possible, with a 30-minute cool down between runs.

IHF Mixing Plenum — Similarly to the AHF, the IHF also incorporates the capability for mixing in room-temperature air into the arc jet test stream just ahead of the nozzle throat. The optional mixing-air plenum (known as the add-air plenum) may be installed as an assembly, separate from the electrode package. The primary benefit of the new plenum is that the uniformity of the gas flow before the expansion process is greatly improved, resulting in more uniform conditions (enthalpy, pressure, and heat flux) in the supersonic free-jet to which the test samples are exposed.

IHF Laser Heating Augmentation—An optional infrared laser heating system is available for use in the IHF test chamber. The laser system operates independently of the arc heater and can thus be used to provide purely radiative heating or radiative heating augmentation to the nominal convective flow of the IHF. Radiative heating augmentation is available with the 9-inch or larger conical and truncated semielliptical nozzles.

The laser system, Laser Enhanced Arc-Jet Facility (LEAF), is a fiber-based system and operates at nominal wavelength of 1.07 µm. It consists of four individual lasers that are housed in environmentally-controlled enclosures outside of the Arc Jet building. The individual lasers are routed to the Optics Enclosure, which is next

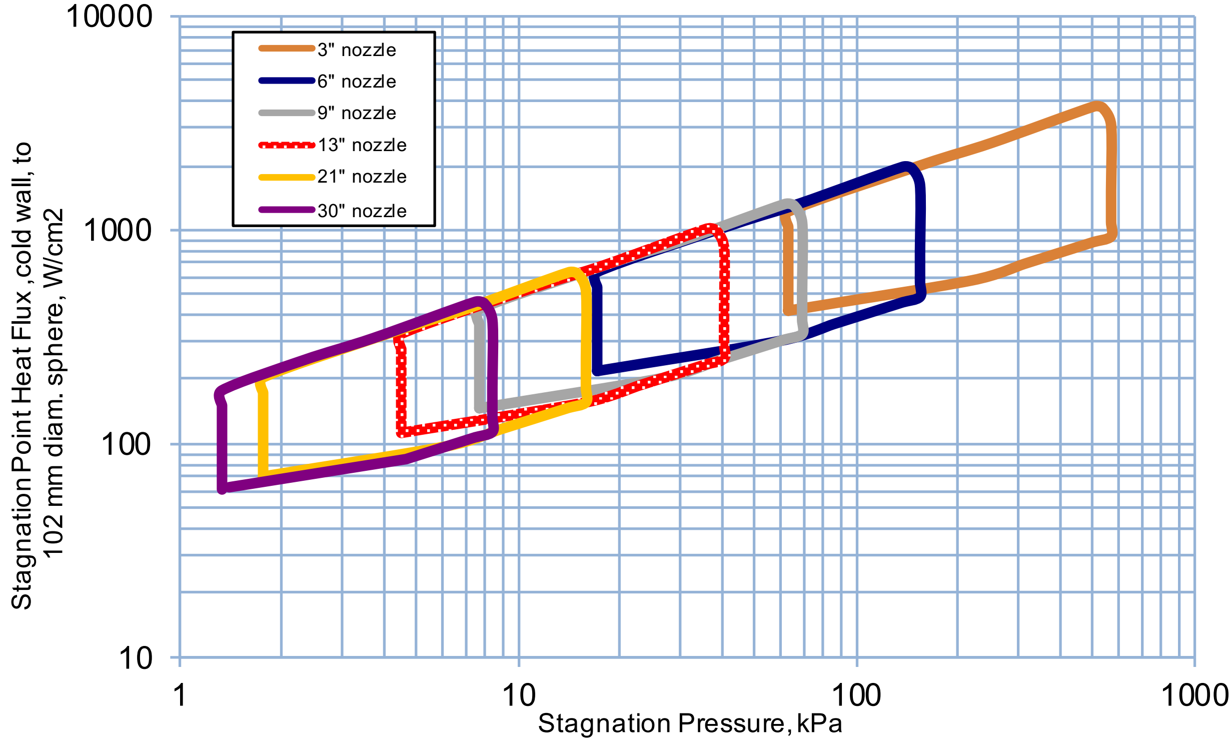


Figure 4.1.3.6. Operating envelope of the IHF with conical nozzles, stagnation point

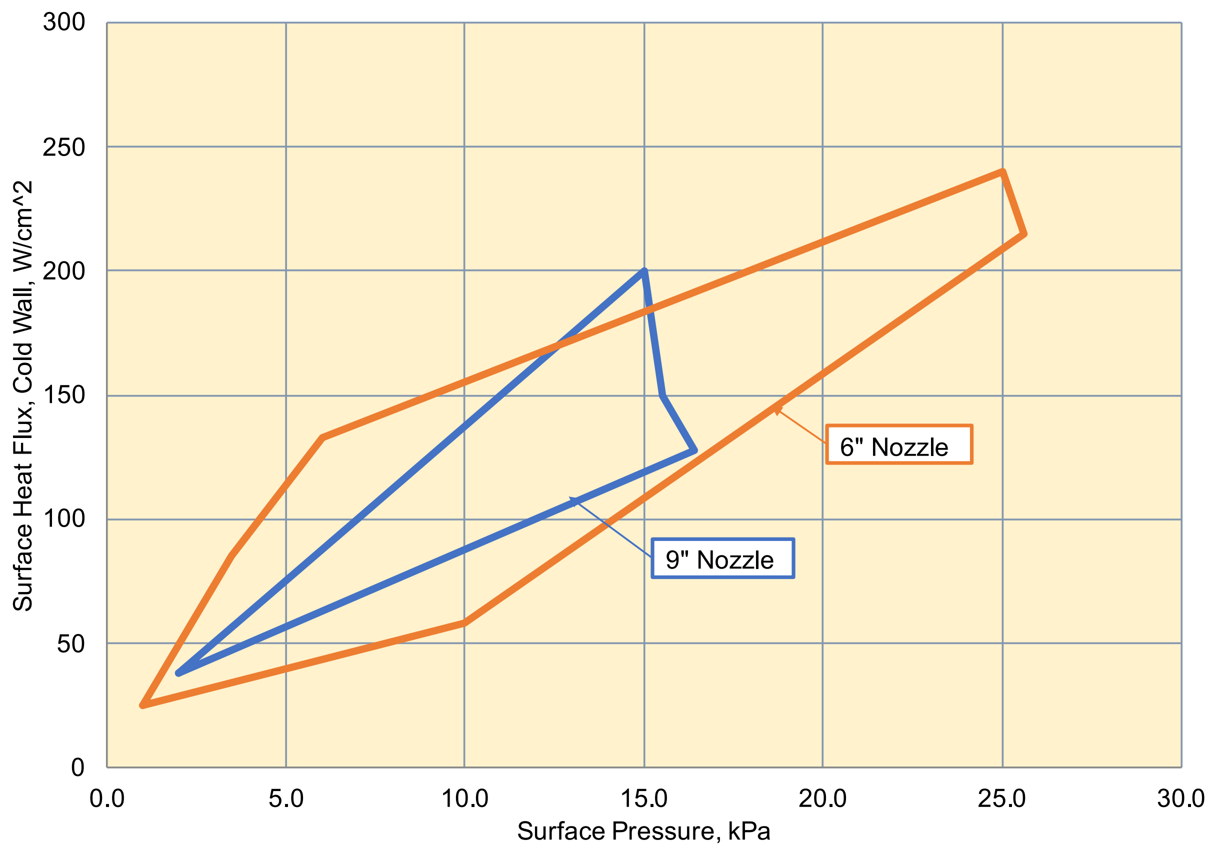


Figure 4.1.3.7. Operating envelope of the IHF with conical nozzles, flat plate on 20° wedge

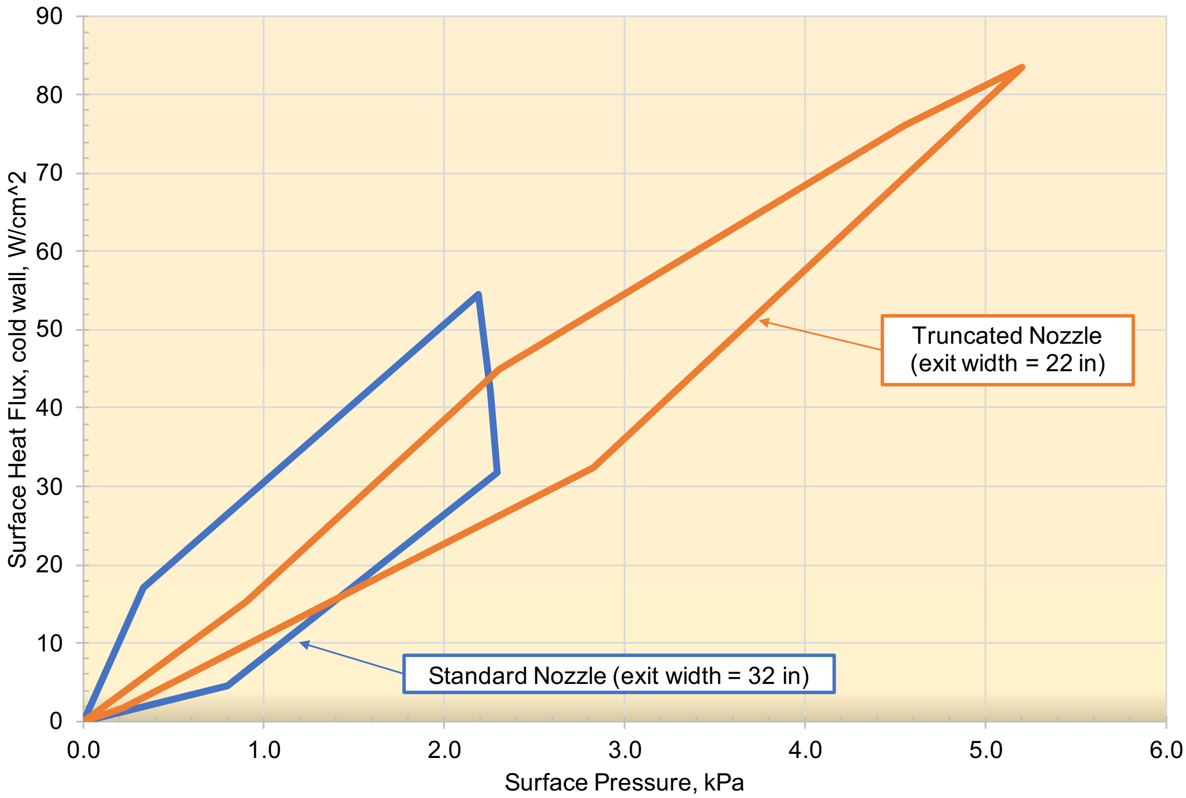


Figure 4.1.3.8. Operating envelope of the IHF with semielliptical nozzles

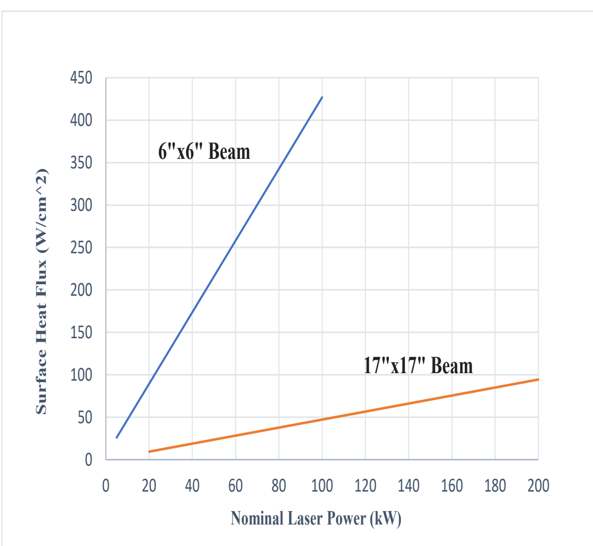


Figure 4.1.3.9.a Laser Power vs. Radiant Calorimeter Readings on 6"×6" and 17"x17" Targets

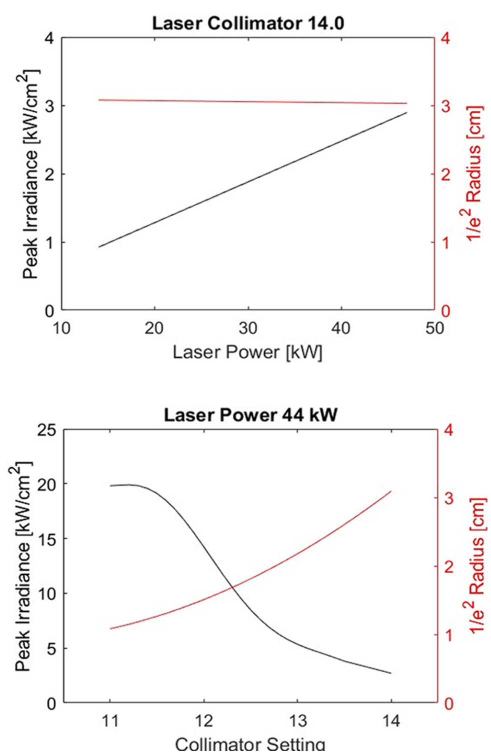


Figure 4.1.3.9.b Laser Power vs. Gaussian Peak Irradiance on radius of 1/e^2 intensity

to the IHF, via fiber optics cables. After the laser beams are conditioned, aligned, and steered, the individual beams are directed into the IHF test chamber, where the combined beams are targeted at the test article. The laser beams are nearly perpendicular to the Arc Jet flow axis in the test chamber; as such, it is not possible to target the laser beams at stagnation articles.

Each of the four lasers can provide up to 50 kW of continuous wave infrared radiative heating. With total laser power of 200 kW, the system allows testing in two configurations: 6 in by 6 in flat-top beam -- test article mounted in 20° 8.7 in wedge can be tested to 400 W/cm^2 with two of the 50 kW lasers (this may be combined with up to 160 W/cm^2 of convective heating from the arc heater in the 9-inch nozzle); and 17 in by 17 in flat-top beam -- test articles mounted in the truncated semielliptical nozzle can be tested to 90 W/cm^2 radiative heating using all four of the 50 kW lasers (this may be combined with up to 80 W/cm^2 convective heating from the arc heater in the truncated semielliptical nozzle). Figure 4.1.3.9a shows the nominal laser power vs calorimeter readings on the radiant calibration plate for the 6 in by 6 in and 17 in by 17 in target. The flat-top beam will have about ±15% uniformity; however, for the 17 in by 17 in flat-top beam, the vertical centerline variation could be as low as -25% versus center of the beam.

Smaller circular beam with a super-Gaussian intensity profile is also possible; peak irradiance of over 10 kW/cm^2 per beam can be achieved. Currently, up to two 50 kW lasers can be configured for Gaussian beam operations. Radiative heating for Gaussian beam operations is shown in Figure 4.1.3.9b. The LEAF can also be configured to operate with one laser in 6 in by 6 in beam and with another laser in Gaussian beam simultaneously.

Gaussian beam or 6 in by 6 in flat-top beam operations (in the Ames supplied 8.7 in wedge) may be combined with convective heating operations in the 9 in or larger conical nozzles.

Due to the nature of solid state lasers, minimum radiative heating is restricted by lasering threshold at 10% of rated power. In the 6 in by 6 in flat-top beam, that minimum radiative heating is about 18 W/cm^2.

4.1.3.3 Panel Test Facility

The 20 MW Panel Test Facility (Fig. 4.1.3.10) consists of a 20 MW segmented arc heater coupled to a semielliptical nozzle. The test stream is suitable for the simulation of boundary layer heating environments on flat-panel samples. The panel test fixture attaches at the nozzle exit and sits flush with the flat portion of the nozzle (Fig. 4.1.3.11). Two nozzle configurations are available:

- Truncated nozzle (T-PTF)
  - Exit width of 6.7 in (17 cm)
  - Panel dimensions approx. 4×4 in (10×10 cm)
  - The panels can be inclined at angles of -4° to 4°
  - Discharges in a semifree jet into a 30×30×30 in (76×76×76 cm) vacuum chamber
- Standard nozzle (PTF)
  - Exit width of 17 in (43 cm)
  - Panel dimensions approx. 14×14 in (36×36 cm)
  - The panels can be inclined at angles of -5° to 8°
  - Discharges in a semifree jet into a 4×4×4 ft (1×1×1 m) vacuum chamber

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 chamber allow imaging of the

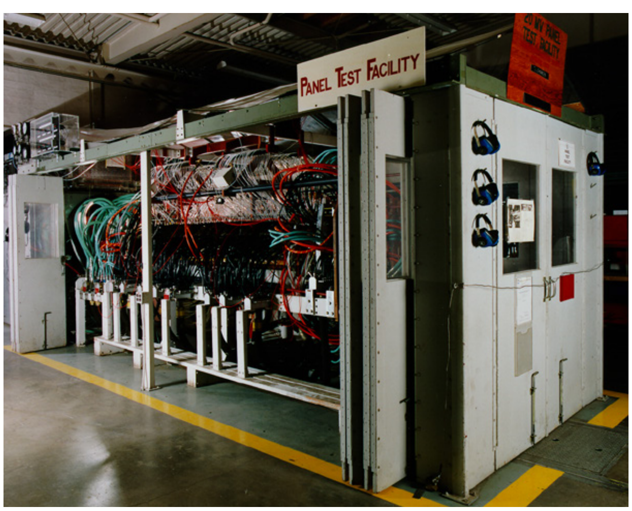


Figure 4.1.3.10. 20 MW PTF

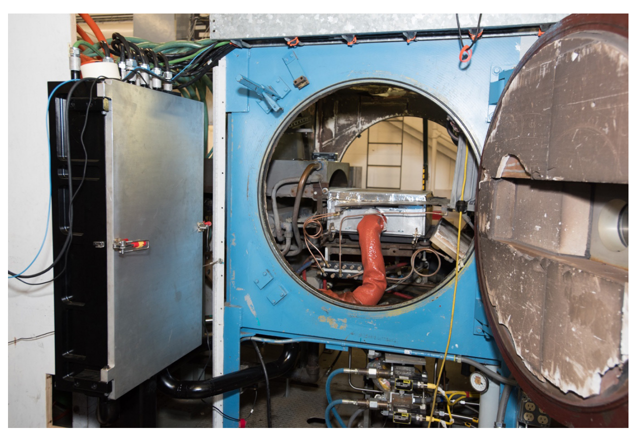


Figure 4.1.3.11. PTF test chamber and patch panel

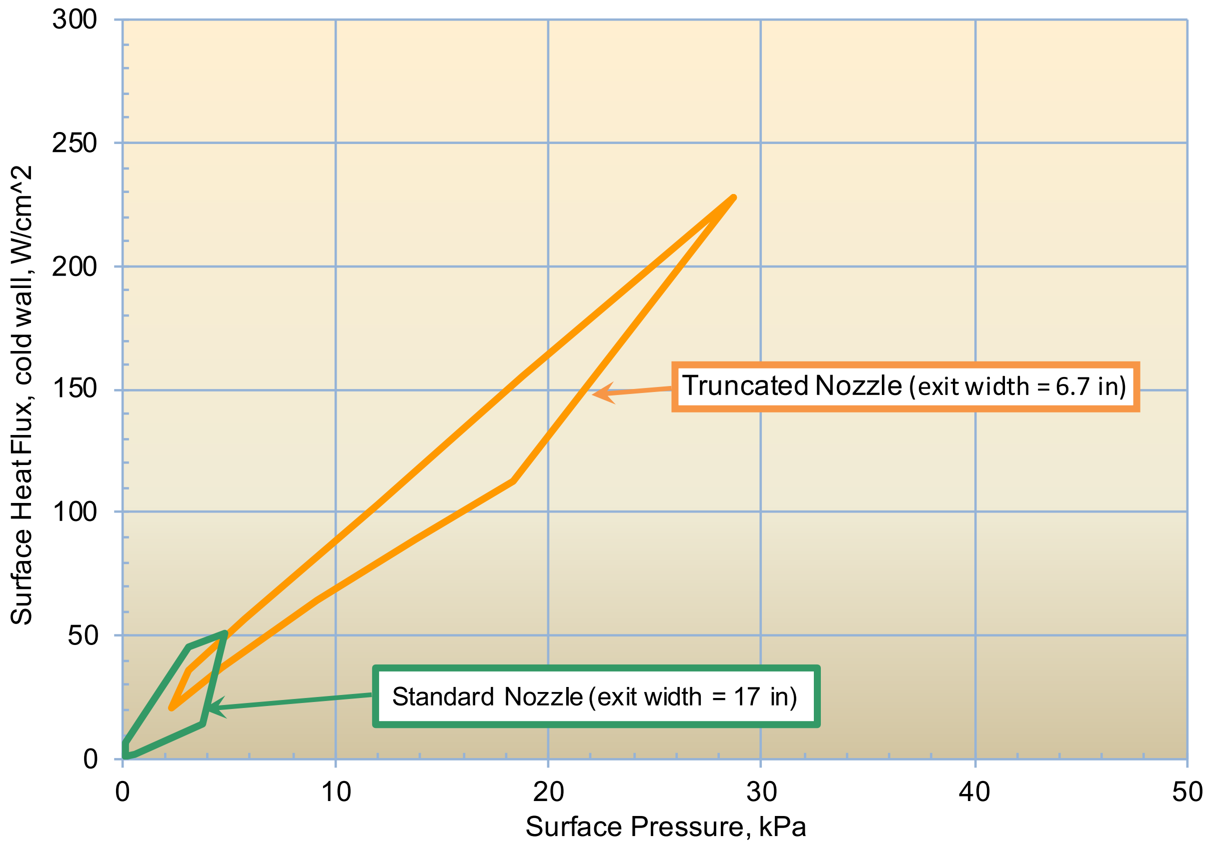


Figure 4.1.3.12. Operating envelope of the PTF

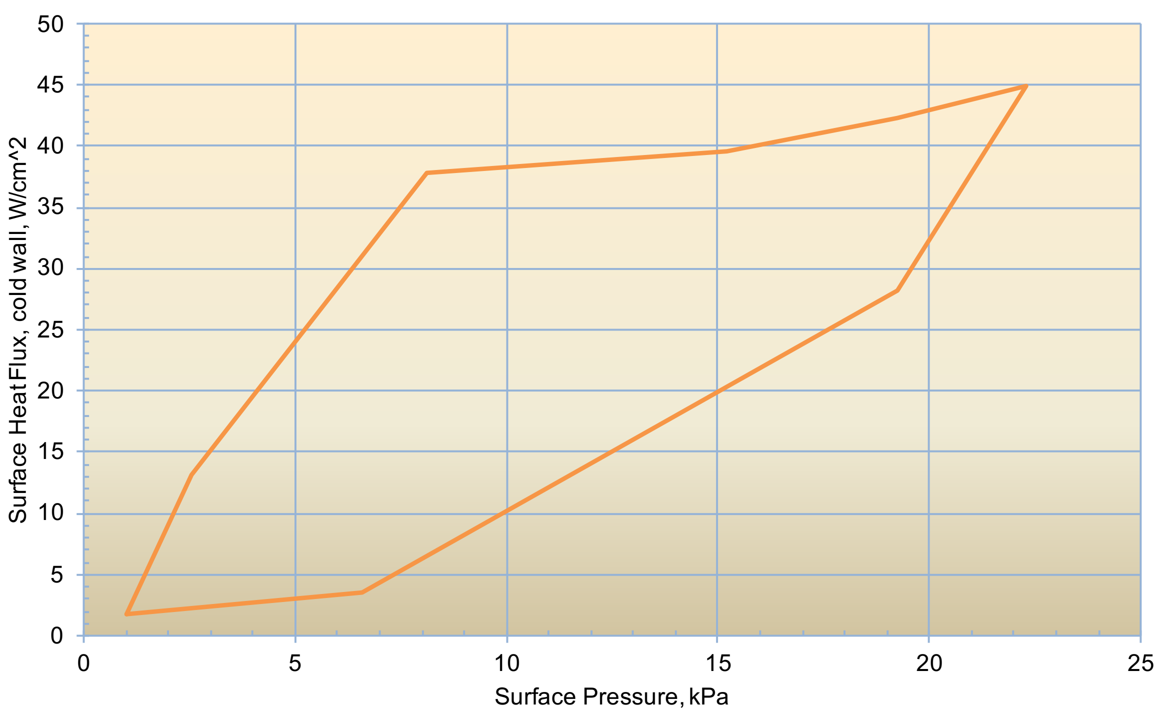


Figure 4.1.3.13. Operating envelope of the TFD

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 (10 to 1,000 Pa). 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 (0.1 to 1 MPa) and enthalpy levels in air from 3,500 to 9,000 Btu/lb_m (8 to 21 MJ/kg). The PTF has simulated some of the conditions experienced by the Space Shuttle heat shield tiles, such as heat flux, surface pressure, and gap flow, and was 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 and backshell environments for Orion and Mars missions. The envelope of surface conditions on the test article for the PTF is shown in Figure 4.1.3.12 and the physical parameters are listed in Table 2. Run durations as long as 30 minutes are possible, with a 45-minute cool down between runs.

PTF Add-Air Option— Three special disks may be inserted into the downstream electrode package to allow the injection of room-temperature air into the plasma stream to reduce the temperature of the plasma test gas. This option is rarely used.

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 in (5 × 23 cm), hence its name. The test article, of dimensions 8 × 10 in (20 × 25 cm) or 8 × 20 in (20 × 50 cm), is mounted flush to the 9 in (23 cm) side of the test section, see Fig. 4.1.2.3. The opposite wall of the test section is instrumented with pressure ports and flush-mounted calorimeters (heat-flux gages). The nozzle is also instrumented with pressure and heat-flux ports at various locations.

Features of the TFD include:

- 20 MW Huels arc heater provides flow enthalpy in the range 1,500 to 4,000 Btu/lb_m (3.5 to 9.3 MJ/kg) (air)
- Maximum arc heater power input is 12 MW because of cooling limitations of the nozzle throat
- The reservoir pressure ranges from 1 to 16.7 atm (0.1 to 1.7 MPa)
- Heat fluxes up to 60 Btu/sec·ft^2 (70 W/cm^2) (cold wall, air) can be applied to flush, wall-mounted test articles; higher heat fluxes are applied to inclined wedges
- Surface temperatures of 3,000°F (1,650°C) have been routinely produced on TPS tile samples
- Simulation conditions on the test article are controlled by varying the arc current and gas mass flow rate through the arc heater
- Test gas can be air, nitrogen, or argon

The physical and performance parameters of the TFD are listed in Table 2. Figure 4.1.3.13 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.

(2x9 TFD is being relocated to the AHF test bay. Please contact us on its status and availability.)

4.1.4 Facility Interfaces

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

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 4.1.6.8. 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 if they are identified during the test planning process. The facility can provide a number of pressure transducers, albeit a limited number. Any request for ARC to provide transducers must be negotiated during the test planning phase. 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

Table 3. Minimum lead-length requirements and number of channels supported (continued on next page)

<table>
<tr><th colspan="5">DAS TEST BOX ANALOG SIGNAL CHANNELS WITH VOLTAGE ISOLATORS</th></tr>
<tr><th></th><th>IHF</th><th>PTF</th><th>AHF</th><th>TFD (2×9)</th></tr>
<tr><td></td><td>East & Overhead Sting Arm:
24 Analog Data Channels

West Sting Arm:
24 Analog Data Channels</td><td>48 Analog Data Channels</td><td>48 Analog Data Channels

Each Sting Arm:
10 TSP* Pin Type U Connectors Pressure Transducers and T_{REF} located in Sting Tray</td><td>20 Analog Data Channels</td></tr>
<tr><th colspan="5">MODEL INSTRUMENTATION LEAD WIRE MINIMUM LENGTHS (Without Wiring Extensions)</th></tr>
<tr><th>MODEL TYPE</th><th colspan="2">IHF (2" Sting ID)</th><th colspan="2">AHF (2" Sting ID)</th></tr>
<tr><td>Stagnation</td><td colspan="2">≤ 6 TC: 12" length of Model Sensor wire from the end of the model holder. Stagger @ 2 TC every 2 inches
----
> 6 TC: By special arrangement. Consult with Test Engineer

Model Pressure tubing (0.06" OD x 6"L SS - may be cut to length)</td><td colspan="2">≤ 6 TC: Model Sensor wire length shall be 6" min from the back of the model. Stagger @ 2 TC every 2 inches
----
> 6 TC: By special arrangement. Consult with test engineer (D25 Configuration)
or
>6 Model Sensor wiring: 60" for each model sensor. If extension wiring is used, the initial connector wire length shall not be less than 8". Connectors shall not be allowed beyond the "radius" of the Sting Arm.

Model Pressure tubing (0.125" OD x 6"L SS - may be cut to length) terminated to the transducer(s) located in the Instrumentation Tray with 48" to 60" of 0.125" OD Teflon pressure tubing.</td></tr>
<tr><td>Wedge</td><td colspan="2">Without Plug & Play Adapter
< 6 each Sensors with Mini Connectors: 10"
≥ 6 each Sensors with D25 Connectors: 10"

Plug and Play Adapter Without Pressure Transducers:
≤ 6 each Sensor wires with Mini Connectors in Plug & Play Sensor Wire Length: 4"
> 6 each Sensor wires on D25 Connector in Plug & Play Wire Length: 4"

Plug and Play Adapter with Pressure Transducers
MAX: 3 each pressure transdducers located in Plug & Play; connectors located in Sting Arm
< 6 each Sensor wires with Mini Connectors in Sting Arm
Min Wire Lengths: 12" and staggered in pairs of 2" apart
≥ 6 each Sensor wires with D25 Connector in Sting Arm
Min Wire Length: 12"</td><td colspan="2">With Plug and Play Adapter:
4 each TC Mini-Connector (Max) with 4" sensor wires beyond model adapter attachment point
-- or --
1 each D25 Connector
(12 Differential Measurements) with 4" length model wiring.

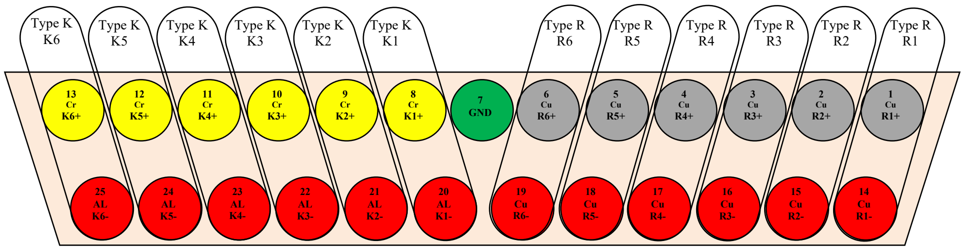
Model Pressure tubing is 10" long, 0.06" OD, SS or Cu. Pressure transducer will be located int the Instrumentation Tray adding 48" to 60" Teflon tubing from the model.</td></tr>
<tr><th>MODEL TYPE</th><th colspan="2">IHF (2" Sting ID)</th><th>PTF</th><th>TFD (2×9)</th></tr>
<tr><td>Panel
or
Flat Plate</td><td colspan="2">SENSOR WIRE LENGTHS
(Rear of the Model to Connector): 18"
CONNECTOR: Type U Pins

Model Pressure Tubing:
Tubing: SS 0.06" OD tubing, extends 6" beyond the back of the Model.</td><td>18" sensor wire length from back of the model to connector
----
Model Pressure tubing is 0.06"OD x 8"L, SS or Cu</td><td>18" sensor wire length from model to connector
----
Model Pressure tubing is 0.06"OD x 8"L, SS or Cu</td></tr>
<tr><td colspan="5">Note: SS Pressure Tubing Measurements: For all models exceeding 2 seconds exposure time shall require pressure tubing length be long enough prevent heated gas from damaging the transducer</td></tr>
<tr><th colspan="5">INSTRUMENTATION CONNECTORS</th></tr>
<tr><td colspan="5">TSF institutional harnesses are terminated with female thermocouple mini connectors. The customer must provide male connectors which meet the specifications of the Omega SMPW mini size flat 2 pin thermocouple connectors: https://www.omega.com/pptst/SMPW_SMP_HMP_HMPW.html
For D25 connectors, the customer must provide the female connector:
https://www.omega.com/en-us/sensors-and-sensing-equipment/temperature/thermocouple-and-rtd-connectors/p/SM-SUB-D-CONN
Please note that the configuration for D25 connectors is very specific and is detailed on the next page. In particular, please note that there is minimal clearance around the connectors once they are mated and installed inside the stings.
N.B. The inclusion of the links noted above is for reference only; it is not intended to constitute or imply the endorsement, recommendation, or favoring of NASA</td></tr>
<tr><td colspan="5">THESE VALUES ARE FOR REFERENCE ONLY AND ASSUME TYPICAL CABLING AND CONNECTORS.
PLEASE CONSULT WITH TEST ENGINEER FOR FINAL CONFIGURATIONS.</td></tr>
</table>

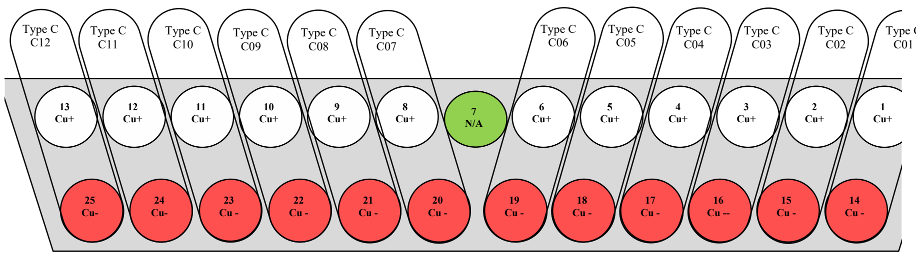
* TSP = twisted shielded pair
TC = thermocouple

Table 3 (continued)

Required customer configuration for D25 connectors.
Alternate configurations may be available by special request.



D25S Front View (6 each Type R; 6 each Type K)
With Thermocouple insulation color code



D25S Front View (12 each Type C)
With Thermocouple insulation color code

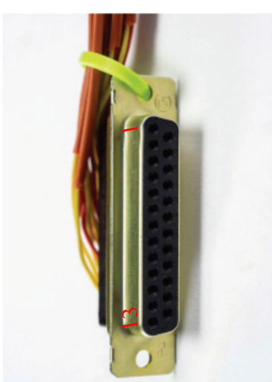
Cable No	ID	Wire Type	Positive (Insul Color)	Socket Material*	Socket #	Negative (Insul Color)	Socket Material*	Socket #
1	R1	Type R	R1+ : Black	Copper	**#1**	R1- : Red	Copper	**#14**
2	R2	Type R	R2+ : Black	Copper	**#2**	R 2- : Red	Copper	**#15**
3	R3	Type R	R3+ : Black	Copper	**#3**	R 3- : Red	Copper	**#16**
4	R4	Type R	R4+ : Black	Copper	**#4**	R 4- : Red	Copper	**#17**
5	R5	Type R	R5+ : Black	Copper	**#5**	R 5- : Red	Copper	**#18**
6	R6	Type R	R6+ : Black	Copper	**#6**	R 6- : Red	Copper	**#19**
	GND	Ground	22 AWG Grn		**#7**			
7	K1	Type K	K1+ : Yellow	Chromega	**#8**	K1- : Red	Alomega	**#20**
8	K2	Type K	K2+ : Yellow	Chromega	**#9**	K2- : Red	Alomega	**#21**
9	K3	Type K	K3+ : Yellow	Chromega	**#10**	K3- : Red	Alomega	**#22**
10	K4	Type K	K4+ : Yellow	Chromega	**#11**	K4- : Red	Alomega	**#23**
11	K5	Type K	K5+ : Yellow	Chromega	**#12**	K5- : Red	Alomega	**#24**
12	K6	Type K	K6+ : Yellow	Chromega	**#13**	K6- : Red	Alomega	**#25**

D25S Connector Wire List (6 each Type R; 6 each Type K)
***Pin Material: Omega Engineering**

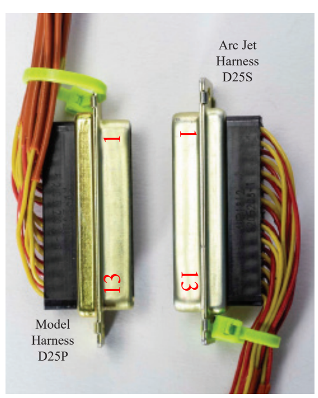
TC No	Wire ID	Wire Type	Positive TC Insulation Color: White	Socket Material*	Socket #	Negative TC Insulation Color: Red	Socket Material*	Socket #
1	C01	Type C	C01+: White	Copper	**#1**	C01- : Red	Copper	**#14**
2	C02	Type C	C02+: White	Copper	**#2**	C02- : Red	Copper	**#15**
3	C03	Type C	C03+ : White	Copper	**#3**	C03- : Red	Copper	**#16**
4	C04	Type C	C04+ : White	Copper	**#4**	C04- : Red	Copper	**#17**
5	C05	Type C	C05+ : White	Copper	**#5**	C05- : Red	Copper	**#18**
6	C06	Type C	C06+ : White	Copper	**#6**	C06- : Red	Copper	**#19**
	N/A	N/A	Not Used		**#7**			
7	C07	Type C	C07+ : White	Copper	**#8**	C07- : Red	Copper	**#20**
8	C08	Type C	C08+ : White	Copper	**#9**	C08- : Red	Copper	**#21**
9	C09	Type C	C09+ : White	Copper	**#10**	C09- : Red	Copper	**#22**
10	C10	Type C	C10+ : White	Copper	**#11**	C10- : Red	Copper	**#23**
11	C11	Type C	C11+ : White	Copper	**#12**	C11- : Red	Copper	**#24**
12	C12	Type C	C12+ : White	Copper	**#13**	C12- : Red	Copper	**#25**

D25S Connector Wire List (12 each Type C)
***Pin Material: Omega Engineering**

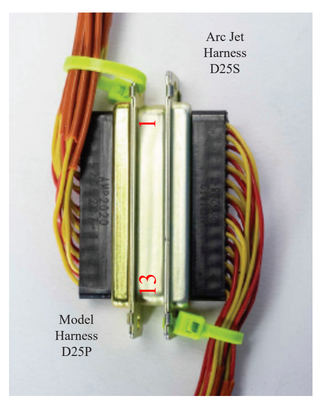
Required wire bend configuration for D25 connectors
for sting-mounted models



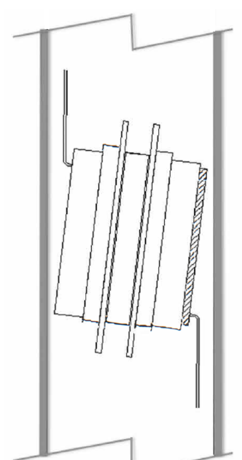
Model D25S Harness Layout with 12 each Type K Thermocouple Wires



Pre-Mated Connectors



Model and Arc Jet Connectors, Mated



Mated Connectors Inside the Sting (Please note minimal clearance) each facility. For investigators who require lead lengths different from those in Table 3, it is recommended that they fabricate a properly-labeled extension bundle 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.

Installation of instrumentation into the test articles shall follow industry standards. If the standards are not followed, ARC cannot guarantee the integrity of the resultant data.

In order to verify that data from Gardon-type calorimeters are valid, these sensors must be manufactured with a thermocouple near the sensing surface.

During installation into the facility, instrumentation shall be labeled sequentially and by type (e.g., Type K thermocouples: TC K1 through TC K24; Type R thermocouples: TC R1 through TC R5; 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 responsibility to keep track of the correspondence between the sequential and nonsequential naming.

4.1.4.2 Mechanical Interfaces

Mechanical interfaces shall be made prior to the user's arrival, as last-minute changes can cause significant delays. The following standard interfaces are described for each facility. It is required that test models be fabricated to fit within the following specifications.
It is required 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. ARC reserves the right to re-test any pressurized component.

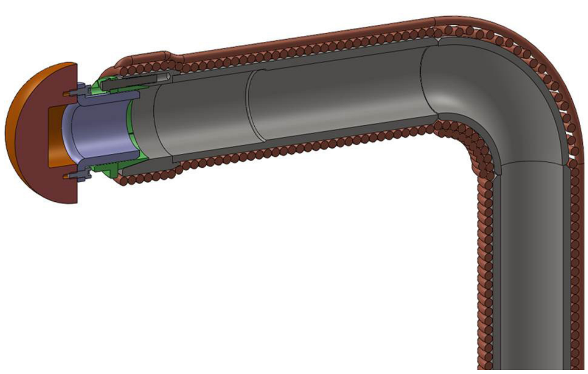


Figure 4.1.4.1. Cut-away view of AHF sting with model


Figure 4.1.4.2. Typical test setup in the AHF, view from East

AHF Mechanical Interfaces– The Aerodynamic Heating Facility is equipped with a five-arm carriage. Each sting arm is a hollow steel pipe (Figure 4.1.4.1) wrapped with copper cooling coils. Instrument wires are pulled through the inside of the sting. The minimum centerline-to-centerline distance between two stings is 11 in (28 cm); however the model support system can also be operated with only the first and fifth stings in use: in this case the centerline-to-centerline distance between two stings is 44 in (112 cm). The maximum distance from the nozzle exit plane to the test article face is approximately 12 in (30 cm). Transverse motion is controlled by the facility operator during testing via a computer-controlled interface. The locations of the carriage and lifting stings are recorded by the data acquisition system. A view of the inside of the AHF test box, showing the five-arm carriage is shown in Figure 4.1.4.2.

The carriage is normally operated in one of three modes:

- Traverse mode: inserts one of two models horizontally with the outermost stings (1 and 5) locked on vertical centerline;
- Pop-up mode: traverses up to five models while stowed below the flow stream, then lifts them up (one at a time) onto nozzle centerline.
- Hybrid mode: a combination of Pop-up and Traverse mode that allows for partially stowing the sting arms and/or lifting the sting arms when they are not on centerline and traversing across the flow.

The weight limit of sample/holders on the sting arms is dependent on the required acceleration and speed of

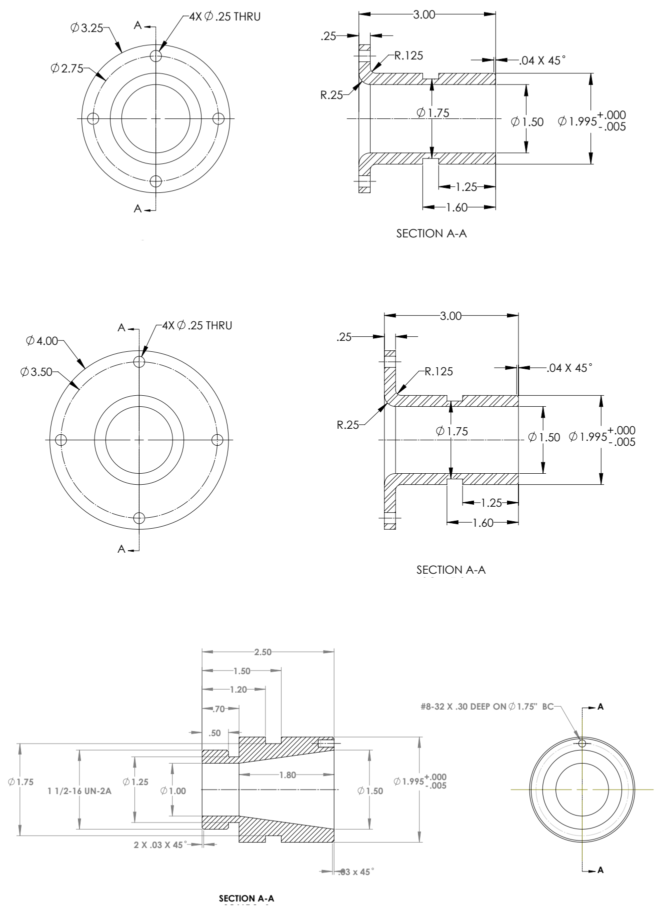


Figure 4.1.4.3. Available sting adapters

insertion. The maximum weight under nominal operations is 45 pounds (20 kg); heavier test articles may require nonstandard sting attachment methods or special handling equipment.

Depending on their size and on the diameter of the nozzle exit, all models can usually be mounted to the stings in such a way that none are subsequently exposed to the flow either during power ramp-up to the desired test condition (duration of approximately one to two minutes) or when an adjacent model is inserted into the plasma stream. These “usual” configurations may be altered to meet individual test requirements. A major consideration in the configuration of the model support system is test throughput and insertion time:

- Traverse mode
  - requires approximately four seconds to move from the edge of the flow to the centerline
  - accommodates two models only
  - can accommodate larger models,
  - allows positioning of models closer to the nozzle exit plane
- Pop-up mode
  - a sting arm can be inserted in less than one second
  - accommodates up to five models
  - limitations based on model geometry
    - 6-in dia. models may be mounted no closer than 12 in from the nozzle exit plane
    - larger models may have to be slightly further away

Figure 4.1.4.3 shows available sting adapters supplied by ARC. Test articles shall be fabricated to mate with these adapters. Alternately, the investigator may supply their own adapters that meet the sting interface requirements of Figure 4.1.4.3.

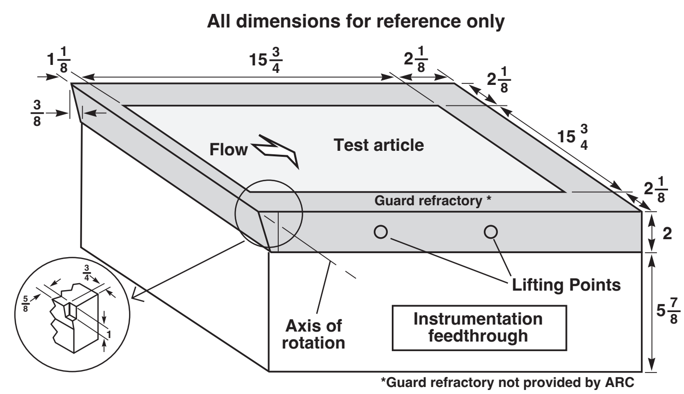


Figure 4.1.4.4. Test fixture assembly for PTF
N.B. Notches not required if the width of the leading edge brick is less than 20 inches

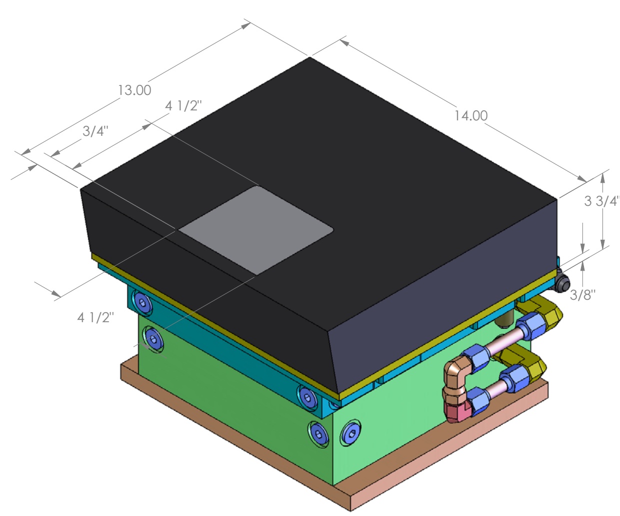


Figure 4.1.4.5. Typical model assembly for TPTF

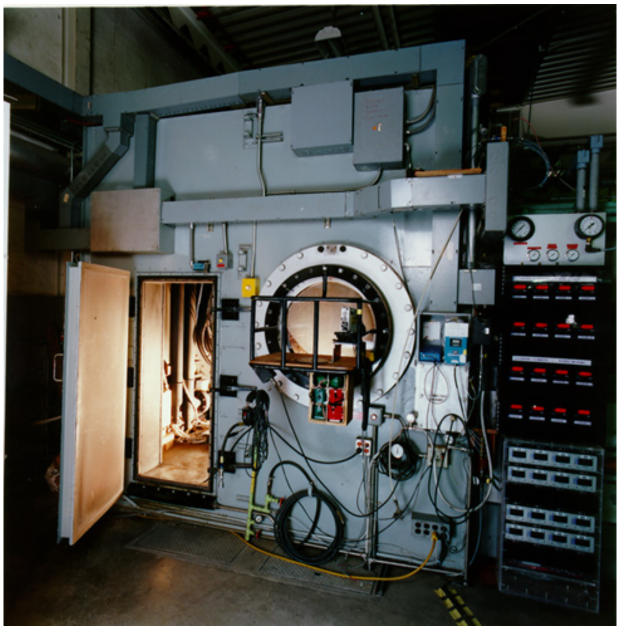


Figure 4.1.4.6. Main access door and viewing window for the IHF, view from East

The AHF is equipped with a flexible system of water cooling for test articles. Typical cooling water pressure is 500 psig (4,000 kPa) at flow rates of approximately 150 gpm (9.5 L/s).

** *<u>AHF model support system is being replaced with a new 3-swing arm system as described in Section 4.1.3.1</u>***

PTF Mechanical Interfaces— The PTF is always configured with a semielliptical nozzle and the model support system is standardized. All test articles shall fit within and be secured to the test fixture provided by ARC, or one fabricated with equivalent dimensions. A schematic drawing of the test fixture is shown in Figure 4.1.4.4; Figure 4.1.4.5 shows the test fixture for the truncated PTF nozzle (TPTF). The maximum model/holder weight under nominal operations for PTF is 200 pounds (91 kg) and for TPTF is 100 pounds (45 kg); heavier test articles may require special handling equipment.

The test assembly is installed by passing it through a round hatch on either side wall of the 32 in (81 cm) test chamber (Fig. 4.1.3.11). The hatches are of 28 in (71 cm) 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. Please note that it may be necessary to make a cut-out on the leading edge piece of refractory brick to account for the pivoting hardware, as indicated in the balloon in Figure 4.1.4.4.

A hydraulically-actuated piston located underneath the test chamber provides calibrated tilt-table inclination angles. The inclination angle is manually controlled by the operator, and the angle is recorded by the data acquisition system.

All instrumentation wires from the model feed through a flexible conduit attached to one side of the test fixture. It is imperative that the instrumentation leads extend at least 18-inches outside of the test fixture, even when extensions will be used. (See Figs. 4.1.4.4, 4.1.4.5, and Table 3).

Water cooling manifolds are available in the PTF test chamber at a supply pressure of approximately 500 psig (4,000 kPa) and flow rates of approximately 100 gpm (6 L/s).

IHF Semielliptical Nozzle Mechanical Interfaces— For the IHF with a 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. The test fixture is similar to the one shown in Figure 4.1.4.4; detailed drawings and dimensions are available upon request. The maximum weight under nominal operations is 200 pounds (91 kg); heavier test articles may require special handling equipment.

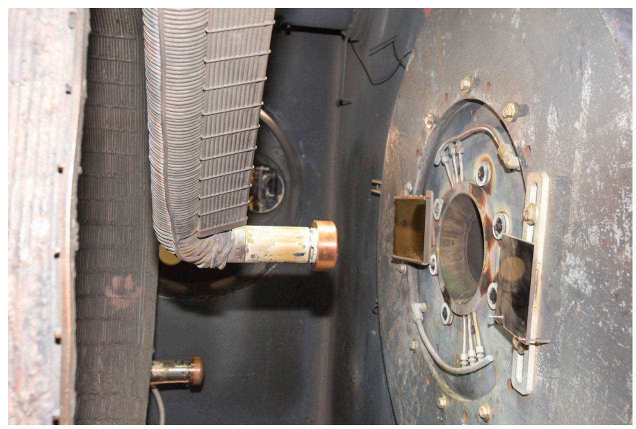


Figure 4.1.4.7. Typical test setup in the IHF, view from East

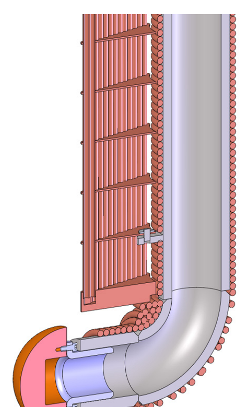


Figure 4.1.4.8. IHF sting

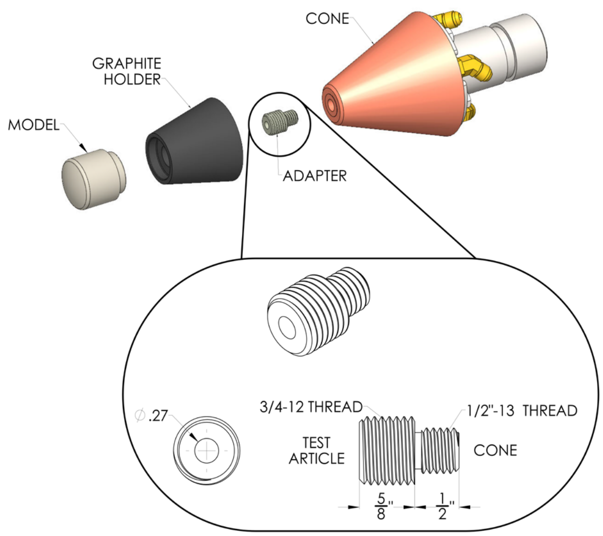


Figure 4.1.4.9. Typical test set up for models with small diameter and thread details for typical mating connector

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 5×2 ft (150×61 cm) main access door (Fig. 4.1.4.6). The hatches are of 35 in (89 cm) diameter.

A remotely-actuated piston provides calibrated tilt-table inclination angles. The table angle (angle of attack) is manually controlled by the operator from the control room and recorded by the data acquisition system.

All instrumentation wires from the model feed through on one side of the test fixture. It is imperative that the instrumentation leads shall extend at least 12 inches outside of the test fixture, even when extensions will be used. (See Fig. 4.1.4.4, and Table 3).

Water cooling manifolds are available in the IHF test chamber at a supply pressure of approximately 500 psig (4,000 kPa) and flow rates of approximately 250 gpm (16 L/s).

IHF Conical Nozzle Mechanical Interfaces— When a conical nozzle is installed in the IHF, the IHF is equipped with three swing-arm model supports mounted on the ceiling of the test chamber (see Figure 4.1.4.7). Figure 4.1.4.8 shows a typical IHF sting. Each sting arm is a hollow pipe. Instrument wires are pulled through the inside of the sting. The inside-diameter bore of the model stings is normally 2.0" -.000/+.002 (51 mm -0.00/+0.05). ARC-supplied sting adapters are shown in Figure 4.1.4.3. Test articles shall be fabricated to interface with the sting adapters or directly to the stings. NB: models with small base diameters (less than 3") may need to be mounted on cones, Figure 4.1.4.9. The customer shall evaluate potential effects resulting from this geometry (ie, in some instances, a gradual transition from the test article to the cone might be desirable.)

Table 4. Available viewports and IR-quality windows

	AHF		PTF		IHF		TFD	
	No. of ports	Diam. (in)	No. of ports	Diam. (in)	No. of ports	Diam. (in)	No. of ports	Diam. (in)
Side-view	2	11	0	-	3	10	1	0.866
	2	6			2	6		
	or				2	5		
	2	4			2	4		
Top-view	0	–	5	6*	6	6	0	–

* These ports can be adapted to 4" windows

	Window Diam. (in)	Window Material	Transmission Wavelength (µm)	Transmissivity (percentage)
Window size availability and technical specs.	11	Fused Silica, Quartz (SiO_2)	0.25 to 2.5	>90%
	10	Fused Silica, Quartz (SiO_2)	0.25 to 2.5	>90%
	6	Fused Silica, Quartz (SiO_2)	0.25 to 2.5	>90%
	6	Sapphire (Al_2O_3)	0.30 to 5.0	80 to 85%
	5	Fused Silica, Quartz (SiO_2)	0.25 to 2.5	>90%
	4	Fused Silica, Quartz (SiO_2)	0.25 to 2.5	>90%
	4	Zinc Selenide (ZnSe)	1.0 to 14	70%
	4	Barium Fluoride (BaF_2)	0.2 to 9.0	>90%

The weight limit of sample/holders on the sting arms is dependent on the required acceleration and speed of insertion. The maximum weight under nominal operations is 45 pounds (20 kg); heavier test articles may require nonstandard sting attachment methods or special handling equipment.

TFD Mechanical Interfaces– A schematic representation of the mounting of the test article for the TFD is shown in Figure 4.1.2.3. In this facility, the test articles are flush-mounted on the wall of the test section. Test panels measuring 8×10 in (20×25 cm) or 8×20 in (20×50 cm) 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. The model must make a pneumatic vacuum seal. 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.

4.1.4.3 Optical Access

All of the arc jet facilities (except TFD) have optical access to the test articles when they are inserted into the flow stream. The flow stream and test article(s) in the AHF, PTF, and IHF are viewed through large windows in the test chambers. The windows provide instrumentation and line-of-sight observations. Table 4 lists the available windows per facility. The TFD has limited access for optical instrumentation through existing heat-flux sensor ports in the wall facing the test article (with a port diameter of 5/8 inch).

In addition to the standard facility monitoring instrumentation, ARC will provide optical pyrometers, thermal IR imagers, and photographic and video coverage of the tests, as required by the investigator. (A list of the optical pyrometers available at ARC is given in Table 5; Table 6 lists the available IR cameras.)

4.1.4.4 Personnel Access Outside the Test Chamber

Access to the area immediately outside the test chamber during a run is allowed on a limited basis 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.

4.1.4.5 Model Sizing/Configuration Guidelines

The size limit of sample/holder assemblies is dependent on multiple factors, including nozzle diameter, diffuser diameter, spacing between nozzle and diffuser, and location of the test sample. A general rule of thumb that may be used in determining the maximum dimensions of proposed test articles is that the area 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 relative to the geometry of the nozzle and the diffuser; thus this rule of thumb is offered only as a general guideline. For test articles that do not conform to this rule of thumb, consideration should be given to running blockage tests prior to running the test articles. Blockage tests will be charged at the usual occupancy rate.

For test articles that weigh greater than 25 pounds, it is recommended that the investigator provide either a lifting mechanism or detachable handles .

In order to expedite installation of test articles into the test facilities, it is recommended that the test articles have clear vertical and horizontal markings, with particular attention to a "top" indicator. It is also useful to mark the model ID on the side of the model that faces a camera for ease in identification when reviewing video footage.

It has been a general practice at Ames to produce blunt body stagnation test articles for arc jet tests with radius of curvature on the front forward facing surface. This is especially important for small bodies where the velocity gradient in the stagnation region is greater than it is for larger ones. Unavoidably, there are slight misalignments of the test bodies relative to the flow vector when inserted

Figure 4.1.5.1. Examples of typical slug-calorimeter probes

Figure 4.1.5.2. Examples of null-point/coaxial TC calorimeter probes

Figure 4.1.5.3. Example of wedge calorimeter probe

into the flow stream, and these unwanted variations in angle of attack will occur between test runs. For a test article with radiused front surface, the flow field over the front surface will be less sensitive to change under conditions of unanticipated angle of attack. Given an unwanted yaw, the stagnation point will "move" away from the desired location at the center of the blunt cylinder, causing non-uniform velocity gradients and heat flux to the test article. This effect accounts for some of the scatter in calibration data from run to run at the same facility operating conditions and is one of the reasons why hemispheres are preferred as the standard shape for calorimeters.

4.1.4.6 Guidelines for Testing in Wedge Configuration

Testing in wedge configuration presents some unique challenges and can be very destructive to the test facilities. In order to minimize risk of damage to the AHF, wedges should not be tested in nozzles smaller than 12 inches. In IHF, a wedge should not be mounted on the West sting arm if it is to dwell in the flow for longer than 30 seconds. Down time to repair facility damage caused by an unfavorable wedge configuration will be billed as an occupancy day.

Table 5. Optical pyrometers provided by ARC

Manufacturer	Model	Type	Temperature Range (°C)	Spectral Response (μm)	Field of View Ratio	Quantity
Mikron	M90V	Infrared	800-3000	0.65	300:1	1
	M190V	Infrared	800-3000	0.65	300:1	3
	M190H	Infrared	600-3000	0.78-1.06	180:1	4
	M190HX	Infrared	1200-3500	0.78-1.06	180:1	1
	M90R2	Infrared	900-3000	2-color *	180:1	1
	M190R2	Infrared	900-3000	2-color *	180:1	3
	M680	Infrared/ fiber optic	900-3600	0.63-0.70	300:1	1 w/ 4 channels
Lumasense / Mikron	PhotriX	Infrared/ fiber optic	650-5000	0.90	177:1	2**
	PhotriX	Infrared/ fiber optic	500-3000	0.88	220:1	2
	PhotriX	Infrared/ fiber optic	200-3000	0.7-1.65	220:1	2
Impac	IN 5/5	Infrared	400-2500	5-14	50:1	1
	IN 5/9	Infrared	0-1500	8-9.7	62:1	1
Dias	PyroSpot DSR 10NV	Infrared	900-3000	0.7 - 1.1	300:1	1
	PyroSpot DY 10LV	Infrared	0-1000	8 - 14	100:1	2
	PyroSpot DSR 56NV	Infrared	900-3000	0.7 - 1.1	300:1	1

*2-color response bands are 0.78–1.06 μm and 0.9–1.06 μm

**Fixed focal distance for 3” nozzle use

4.1.5 Instrumentation Options

4.1.5.1 Calorimeters

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

For many years, the primary sensors for characterizing centerline stream conditions has been the slug-type calorimeter probe. These probes are available in: 2.4, 3.0, and 4 in (6.1, 7.6, and 10 cm) -diameter hemispherical probes; 4.0, 5.0, 6.0, and 8.0 in (10, 13, 15, and 20 cm) -diameter flat-faced cylinders with a 0.375 in (0.953 cm) corner radius; and 3.0 and 4.0 in (7.6 and 10 cm) -dia. iso-q (base diameter = nose radius) geometry. Most of these probes are also equipped with a pitot pressure port. Other configurations are available by special request. Figure 4.1.5.1 shows some representative slug calorimeters: 3 in hemisphere, 4 in iso-q, and 6 in flat face.

Several null point calorimeters and coaxial thermocouple gages are also available to map the distribution of stagnation point heat flux across the test stream. These are available in various geometries, including 15°-taper cones with a 0.18 in (4.6 mm) and 0.25 in (6.4 mm) nose radius and a family of hemispherical, iso-q-shaped and flat-faced bodies of 1 in (25 mm), 2 in (50 mm), and 4 in (100 mm) nose radii. Figure 4.1.5.2 shows some representative null point calorimeters: 4 in iso-q , 4 in hemisphere, and a small-diameter sphere/cone.

Water-cooled calibration plates that mount onto wedge-type holders in the location of the test article (see Figure 4.1.5.3) are available for both AHF and IHF when using conical nozzles, and also in the flat-plate sample holders used in PTF and IHF when using the semielliptical nozzles (see Figures 4.1.4.4 and 4.1.4.5). The plates are equipped with Gardon-type calorimeters and static pressure taps distributed throughout the surface of the plate in order to obtain heat flux and pressure distributions along the test surface.

Table 6. Infrared Cameras provided by ARC

Manufacturer	Model	Max. Capture Rate (FPS)	Temperature Range (°C)	Spectral Response (μm)	Accuracy %	Quantity
Lumasense / Mikron	M9200	60	800-3000	0.78-1.08	± 0.5	1
	MCS640	60	800-3000	0.78-1.08	± 0.5	4***
	MCL640HT	50	200-1600	8-14	±2	1

Lens options for both models are: 8mm, 12mm, 25mm, 50mm, and 75mm
***Two of the MCS640 have a 1.07μm fixed filter on a 75mm lens
FPS = frames per second

Table 7a. N234 (AHF) HD Video Cameras provided by ARC

Manufacturer	Model	Maximum Resolution	Maximum FPS	Quantity
RED Digital Cinema	Komodo	6K	120	4

Fame Rate	Resolution		Display Format	Recording
30 fps	2K	2048 x 1080	17:9	**Standard Recording**
40 fps	6K	6144 x 3240	17:9	*Available*
60 fps	4K	4096 x 2160	17:9	*Available*
120 fps	2K	2048 x 1080	17:9	*Available*

Table 7b. N238 (IHF, PTF) HD Video Cameras provided by ARC

Manufacturer	Model	Maximum Resolution	Maximum FPS	Quantity
RED Digital Cinema	Komodo	6K	120	3
RED Digital Cinema	DSMC2 Weapon	6K	240	2

Camera	Fame Rate	Resolution		Display Format	Recording
Komodo	30 fps @	2K	2048 x 1080	17:9	**Standard Recording**
Komodo	40 fps @	6K	6144 x 3240	17:9	*Available*
Komodo	60 fps @	4K	4096 x 2160	17:9	*Available*
Komodo	120 fps @	2K	2048 x 1080	17:9	*Available*
DSMC2 Weapon	30 fps @	2K	2048 x 1080	17:9	**Standard Recording**
DSMC2 Weapon	75 fps @	6K	6144 x 3240	17:9	*Available*
DSMC2 Weapon	120 fps @	4K	4096 x 2160	17:9	*Available*
DSMC2 Weapon	240 fps @	2K	2048 x 1080	17:9	*Available*

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

4.1.5.2 Pyrometers

The Thermophysics Facilities Branch will provide optical pyrometers to support measurements of surface temperature. Several models are available and are listed in Table 5. Transmission corrections are generated by ARC to correct for window and/or mirrors losses. These corrections are typically applied via software and are specific to the test set up.

4.1.5.3 IR cameras

The Thermophysics Facilities Branch offers capabilities in infrared thermal imaging as an additional source of data for high temperature applications. The Thermal Imagers available at ARC are listed in Table 6. There are two temperature ranges of IR cameras. The standard ones detect temperatures between 800 °C and 3000 °C with various standard lenses (8, 12, 25, 50, 75 mm) while the low temperature one senses temperatures between -40 °C and 500 °C. Typical thermal data are presented in the form of line profiles, time temperature reports, and videos. Line profiles provide temperature data along a line in the image. The time temperature reports allow a region of interest to be examined as a function of time and temperature. The videos provide a sequence of qualitative images. All thermal imagers are calibrated by the manufacturer with NIST Certifications. Additional transmission corrections are generated by ARC and are applied to the imagers before testing to correct for window and/or mirrors losses. These corrections are specific to the test set up.

4.1.5.4 Video and Photographic Documentation

Video and photographic recordings of the tests are always provided. The standard arc jet photographs typically comprise three views of the test samples: front, side, and oblique. These are taken both pre- and post-test. Additional views will be taken as required to document any abnormalities that may have occurred during testing, or any features of particular interest.

Video views depend upon the facility in use. Three views are standard in IHF: front-view, typically recorded off of a mirror, side view, and top view. In AHF, typically a front view (also off of a mirror) and a side view are provided. In PTF, a top view and side view are standard. For TFD, video recording is a challenge and, currently, a standard view has not been established. Available video cameras are listed in Table 7.

Additional views and photographs can also be accommodated. These must be requested in the test plan.

4.1.5.5 Spectrometer Measurements

This service is provided by the Thermophysics Facilities Branch's optical diagnostic team and can be arranged as part of the testing services in the Arc Jets.

Spectrometer measurements are similar to pyrometer measurements, but they operate over a much wider spectrum. In addition to surface temperature measurement, surface emissivity values can be determined. Currently two OceanInsight spectrometers are employed for combined measurement; one operates from Ultraviolet to near Infrared while another operates from near Infrared to mid Infrared. Their combined effective operating wavelength is 500 to 2500 nm.

Spectrometer measurements can be made in AHF, IHF, and PTF.

4.1.5.6 Photogrammetric Recession Measurement

This service is not provided by the Thermophysics Facilities Branch and must be arranged separately with the responsible branch.

Photogrammetric Recession Measurement (PRM) is an optical technique for measuring the recession time histories of an arbitrary number of points distributed over the face of a TPS test article during testing. It is non-intrusive, requires no external light source (in particular, no lasers), and requires no modifications to the test article. The principal requirements of PRM are: (1) that the face of the model exhibit some texture as it ablates; and (2) that the ablating surface can be imaged from at least two directions.

A typical PRM system consists of two high-resolution (2K × 2K pixels) video cameras; neutral density filters to attenuate the light that reaches the cameras; a PC computer with camera interface cards and software for acquiring images; one mirror for each camera mounted to the bulkhead of the test chamber to reflect light from the test article to the camera; and an external signal generator to provide a pulse train that synchronizes the cameras. Also required is a calibration object that can be installed at the position of the test article before or after a test. This may be a flat plate with a rectangular array of targets mounted on a micrometer-driven translation stage. Finally, custom software is used for calibrating the cameras and extracting recession data from the camera images.

PRM has been applied in many tests in the Interaction Heating Facility. Measurements have been made on flat-faced and iso-q stagnation models and on wedge-mounted panel models. For stagnation models, the diameter of the arc jet nozzle and the distance of the model from the nozzle exit plane are the test-geometry variables that most affect the viewing angles of the face of the test articles and thus the feasibility of making PRM measurements. With the 13 in nozzle, the model should not be less than 10 in from the nozzle. For tests in the 13 in nozzle, one camera was mounted on top of the test chamber and pointed at a mirror mounted to the upstream bulkhead at about 1:00 o'clock relative to the nozzle. The second camera was mounted on the west side of the test chamber and was pointed at a mirror at about 8:00 o'clock. Measurements have been made on wedge-mounted panel models in the 6 in and 9 in nozzles. For these tests, the west camera viewed the face of the model directly, and the mirror for the top camera was at about 10:00 o'clock.

It can take up to several hours to install and calibrate a PRM system. The most time-consuming part is aligning

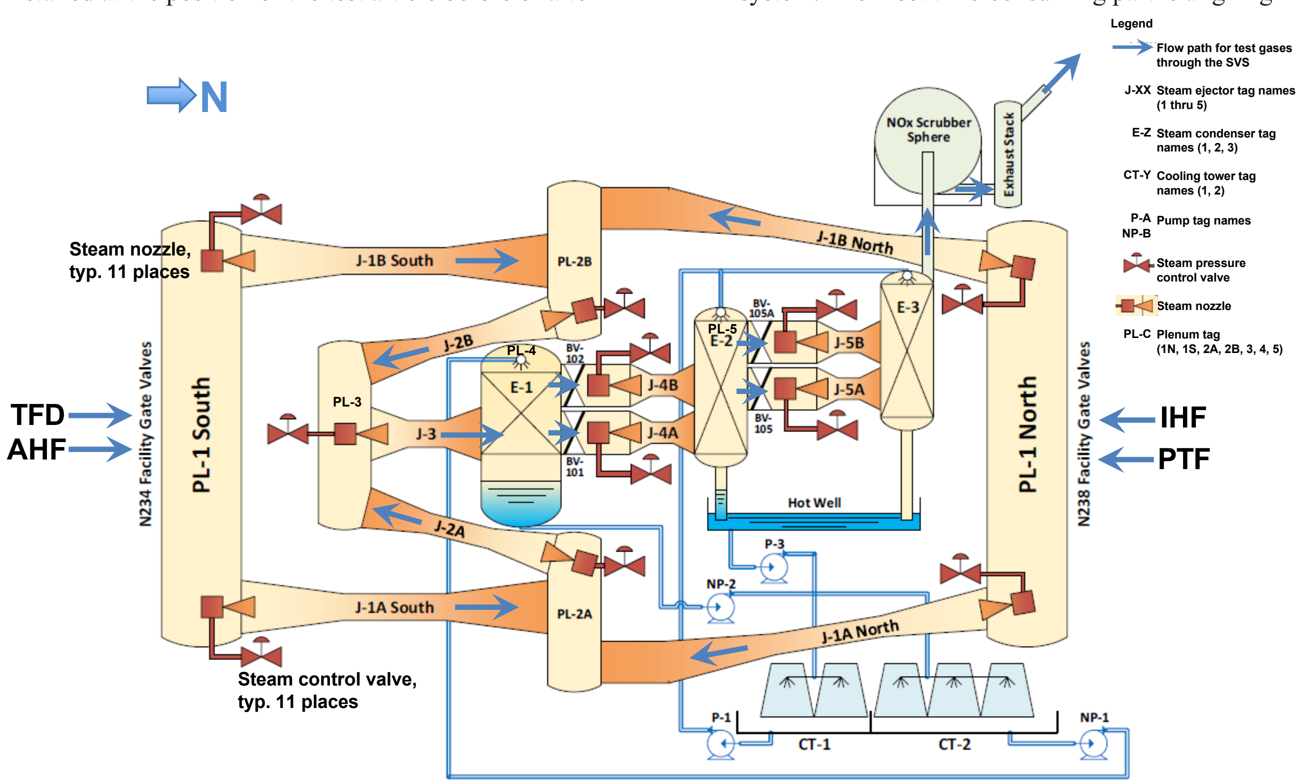


Figure 4.1.6.1. Schematic diagram of the five-stage SVS

the mirrors and cameras. Calibration involves installing the calibration object and imaging it in several positions. This can take about 30 min. Run data acquisition simply involves recording images from the cameras and adjusting the camera exposures by adjusting the duty cycle of the signal from the signal generator. Images are typically recorded at 16 Hz for runs of 1 min or less; lower rates are recommended for longer runs. The imaging rate corresponds to the frequency of the synchronizing pulse train and thus is controlled at the pulse generator. Data reduction is a computationally intensive process that can take one to several hours, depending on the number of measurement points. The product of PRM measurements is the recession time history at each measurement point.

4.1.6 Facility Support Equipment

The arc jet complex is serviced by common facility support equipment that is shared among all of 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.

4.1.6.1 Steam-Ejector Vacuum System

The Steam Vacuum System (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 4.1.6.1 shows a schematic diagram of the SVS; the SVS is visible in Figure 4.1.0.1. The steam is provided by a set of three natural-gas fired boilers with a generating capacity of 360,000 lb/hr (40.9 kg/s) at a pressure of 275 psi (1.9 MPa); however, only two boilers are required to generate the necessary steam of 200,000 lb/hr for Arc Jet operations (5-stages of vacuum). 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 (0.2 kg/sec) of air while maintaining a plenum pressure of about 1.0 torr (absolute). Using three stages, the capacity is about 3 lb_m/sec (1.4 kg/sec) at 10 torr (1.3 kPa). A standby operating mode is used to save energy between tests when two stages are operated, producing about 15 torr (2 kPa) with no gas flow.

4.1.6.2 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 modules, which can be configured into any compatible series/parallel combination. Each module is rated at 5500 volts open circuit, 4,350 volts into a load, and 2,700 amperes (A) continuous, 6,000 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 windings that receive primary power from the distribution grid at 115 kV 60 Hz. Secondary transformers step down the voltage to 4,070 VAC feeding into the rectifier modules. Rectification is accomplished using three parallel strings of 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-pulse 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 in (8 cm), water-cooled, copper piping. 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.

4.1.6.3 20 MW DC Power Supply

The 20 MW power supply provides DC power to arc heaters in buildings N234 and N238. It comprises five identical modules. Each of the 5 modules consists of 2 rectifier banks (or half modules). Each half module is nominally rated for 1,600 amps at 1,250 V; open circuit voltage is 2,500 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 15 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 key interlocks.

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.

4.1.6.4 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 ft (12 m) 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 5 pumps circulate cooling water at approximately 8,000 gpm (500 L/s) at a pressure of 500 psig (5,000 kPa) 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.

So-called "gravity" cooling water is also available directly from the 168,000 gallon tank at about 15 psig (100 kPa) 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 (350 kPa), if necessary.

4.1.6.5 Arc Jet Air System (AJAS)

The arc heaters at ARC usually operate with air as the main test gas. Dry air with dew point lower than -40 °F (-40 °C) is supplied by a 3,000 psi (20 MPa) distribution system located at ARC. The primary storage facility used by the Arc Jet Complex has a storage capacity of 5.9 million standard cubic feet (167,255 cubic meters) and fed by a 5000 hp reciprocating compressor producing 8,346 standard cubic feet per minute. Air flows into air control panels located in the basement below each arc jet facility. From there the bench board controls are used to command a PLC to regulate the flow rate of air to the specific facility via manual or automated controls actuated by the facility operator. Instrument air or shop air can also be used for auxiliary purposes such as moving or cooling portions of test articles.

4.1.6.6 High Pressure Gases—Nonair

Some of 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 2400 psig (16.5 MPa) pressurized nitrogen gas storage trailer located near the 60 MW power supply. Piping distributes the nitrogen to facilities in Buildings N234 and N238. The nitrogen can be used as a main test gas (AHF and TFD) or as an auxiliary gas for purging, cooling, or other purposes.
- Argon— Argon gas is used by the 20 MW and 60 MW constricted arc heaters in small amounts at all times. A small flow of argon is used to aid in starting the arc discharge at the beginning of each run. A small amount of argon is also injected between constrictor disks and electrode rings to reduce the occurrence of arcing between adjacent components of the arc heater. The AHF and TFD can be operated with argon as a main gas. Argon is supplied to the Arc Jets from 2400 psig rated trailers next to N234 and N238 buildings.
- Oxygen— The 10 MW arc heater in AHF uses a mixture of pure oxygen mixed with pure nitrogen to form synthetic air test gas. A flow of nitrogen must always accompany oxygen to protect the tungsten cathode. Oxyen is supplied to the Arc Jet from a 2400 psig rated trailers next to N234 buildings.
- Carbon Dioxide– The capability to operate the 10 MW heater in AHF with a mixture of N_2 and CO_2 as the test gas is under development.

4.1.6.7 Air Pollution Control System

Nitrogen Oxides (NO_x) in the exhaust streams produced by the arc heaters must be reduced from the high concentrations generated in the arc heater to meet the requirements specified in the permit from the Bay Area Air Quality Management District before exhausting into the atmosphere. Removal is accomplished by a combination containment and scrubbing system, which neutralizes the nitric acid that results from NO_x reacting to water spray deluge with a caustic Sodium Hydroxide solution. Air discharge quality is monitored continuously for compliance with local ordinances.

4.1.6.8 Data Acquisition System

The current arc jet data acquisition system consists of Windows PC-based work stations. Test data storage is accomplished by a host workstation for each of the arc jet facilities. Data reduction is accomplished on either the facility host or a central data storage workstation for post-run analysis. Any fourteen channels may be displayed and changed at any time during the test without loss of data. Seven of these can be plotted on a chart showing % Full Scale vs. Time; the other seven are only displayed numerically. Sampling rates may be changed during a run via operator input to the data system controller interface. Output is available in the form of electronic files of the tabular data as a function of time or graphical plots of multiple data channels. The system network is isolated from the Internet for reasons of security and data integrity. Each facility has a standard set of facility data that is always acquired, but may not appear on reduced test data reports. With some variation, the data reported include: arc voltage, arc current, power supply bus voltage, air and argon mass flows, arc heater pressure, and test chamber vacuum level. In some cases, other data are reported as facility data, including individual electrode current levels.

Each facility has dedicated front-end equipment designed to condition the sensor signals, digitize them, and pass them to the facility host computer. For safety, the host computer is connected via fiber-optic ethernet link to an operator console and display that controls the host during the run. The fiber-optic link isolates the operator console from high-voltage potentials that could be induced on instruments connected to test articles and the arc heater itself. In addition, all channels from the test articles must be ungrounded, or electrically floating and, if subject to charging by the arc jet flow, may first pass through a galvanic isolator. Exceptions are made for Huels arc heaters whose downstream electrodes are electrically grounded.

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

- Windows PC-based workstations
    - Facility host systems run the Multifunction Arc Jet Instrumentation and Computation (MAJIC) custom data system software for data acquisition and reduction
    - Control room remote systems control the hosts virtually over a fiber optic network link
    - Data system server provides online storage of archival data and other network server functions
- VXI-based data system front end
    - Chassis controller: National Instruments VXI-MXI-2
        - Provides interface between VXI bus system and host computer.
    - KineticSystems Corp. V207 analog-to-digital converter
        - Capable of 500,000 samples per second, aggregate
        - 16-bit resolution (one part in 65,536)
    - KineticSystems Corp. V243 96 or 48-channel, Low-level Signal Conditioner and Multiplexor
        - Programmable gain from 1 to 2000 with the first stage gain (1, 10, 1000) set for each bank of 8 channels, and individual 2nd stage gain (1, 2, 5, 10, 20)
        - Selectable low-pass filters: 10, 50, 500 Hz (5 kHz unfiltered bandwidth) set for each bank of 8 channels, or left unfiltered
    - KineticSystems Corp. V246 8-channel Bridge Signal Conditioner
        - Programmable gain from 1 to 1000 with first stage gain (1, 10, 100) and 2nd stage gain (1, 2, 5, 10) set independently for each channel
        - Selectable low-pass filters: 20, 200, 1000, 2000 Hz (20 KHz unfiltered bandwidth) se individually for each channel, but if any channels are filtered, all must be
        - Used in the Interaction Heating Facility for test chamber channels
- Support System Programmable Logic Controllers (PLCs)
    - Analog data from the Gas Flow control systems and the LEAF radiant heating system is acquired independently at up to the PLC update rate
    - PLC data is merged with the VXI data when the report is generated
- Acquisition Parameters:
    - Data Rate
        - Sample rates range between 10 seconds/ sample to 5000 samples/second/channel

          Note: Actual maximum data rate = 500 kS/s

/ [Total number of recorded test and facility channels], rounded to the next lower interval of 1, 2, or 5. Recorded data rates can be any whole number division of the maximum rate. Example: With 128 channels, the maximum data rate is 2 kS/s, and available rates are 2 K, 1 K, 66.6 K... 0.1 S/s.

Lower data rates are achieved by run-time oversampling (record the average of N samples acquired at the maximum rate) or decimation (record every Nth sample of the maximum rate).

    - Capable of selecting any available sample rate at any time during the test
  - Real-time display
    - Real-time computations for display of any 14 channels
    - Capable of selecting any 14 channels at any time during the test
    - Preset configurations of displayed channels can be saved prior to testing for quick changes during the test.
- Data reduction processing is completed within minutes after each run, depending on the data file size.
  - Post-test oversample averaging is also available if different levels of filtering and report size are desired.
- Test article sensors:
  - Thermocouples: Type B, C, D, E, G, J, K, N, R, S, and T conversions available
  - Pressure transducers
  - Calorimeters: slug (Cu, Pt, Au, Ag, W), null-point/coaxial thermocouple (Cu only), and Gardon
  - Radiometers
  - Pyrometers
  - RTDs: Callendar–Van Dusen and Kaye conversions available
  - Venturi flow meters
  - Miscellaneous analog sensors with voltage output up to ±10 volts or current loop output in any milliamp range, with either linear or cubic calibration fits
- Special equations, lookup tales, and other virtual (software-based) channels can be programmed upon request (with sufficient lead time)
- Output types:
  - ASCII, time-stamped, tab-delimited file
  - Available on CD-R, DVD
  - Electronic file transfer to remote sites
- Output hardcopy data types:
  - Channel to channel or time history plot containing up to 10 channels per plot

*<u>A new DAS for the complex is in the works. The first portion of this system will be implemented in AHF and is expected to be operational by the fourth quarter of 2025.</u>

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4.2 Ballistic Range Complex

The Ballistic Range Complex comprises the Hypervelocity Free-Flight Facilities , the Ames Vertical Gun Range; and the Electric Arc Shock Tunnel.

4.2.1 Hypervelocity Free-Flight Facilities

The Hypervelocity Free-Flight Facilities at Ames Research Center currently include two facilities: the HFF Aerodynamic Facility (HFFAF) and the HFF Gun Development Facility (HFFGDF). Both facilities became operational in 1964 and are located in Building N-237. These are NASA's only aeroballistic facilities and two of only small handful remaining in North America. What makes the HFFAF truly unique is its ability to test at sub-atmospheric pressures and in test gases other than air.

4.2.1.1 Hypervelocity Free-Flight Aerodynamic Facility

The Hypervelocity Free-Flight Aerodynamic Facility is a combined Ballistic Range and Shock-Tube. 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 4.2.1.1). The primary purpose of the facility is to examine the aerodynamic and aero-thermodynamic characteristics and flow-field structural details of free-flying aeroballistic models.

For 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, including CD, CL, Cma, Cmq + Cma. For aerothermodynamic testing, a suite of visible ICCD and Infra-red, thermal imaging cameras can be installed at various stations to record surface temperature profiles of a model at various points during its flight. Such imagery can be used to infer such quantities of interests as heat transfer rates, and transition to turbulence locations. The facility can also be configured for hypervelocity impact testing. In this mode, a light gas gun is typically used to launch impact particles (such as metallic spheres) at target materials mounted in either the impact/test chamber or test section.

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 quite costly. Moreover, flow field chemistry uncertainty/ contamination can make data interpretation challenging. Consequently, this mode of testing was discontinued in 1974. From 1988 to 1995, however, the HFFAF was operated as a standalone, shock tunnel. For this type of operation, 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 then used to generate a short-duration reservoir of high-temperature, high-pressure test

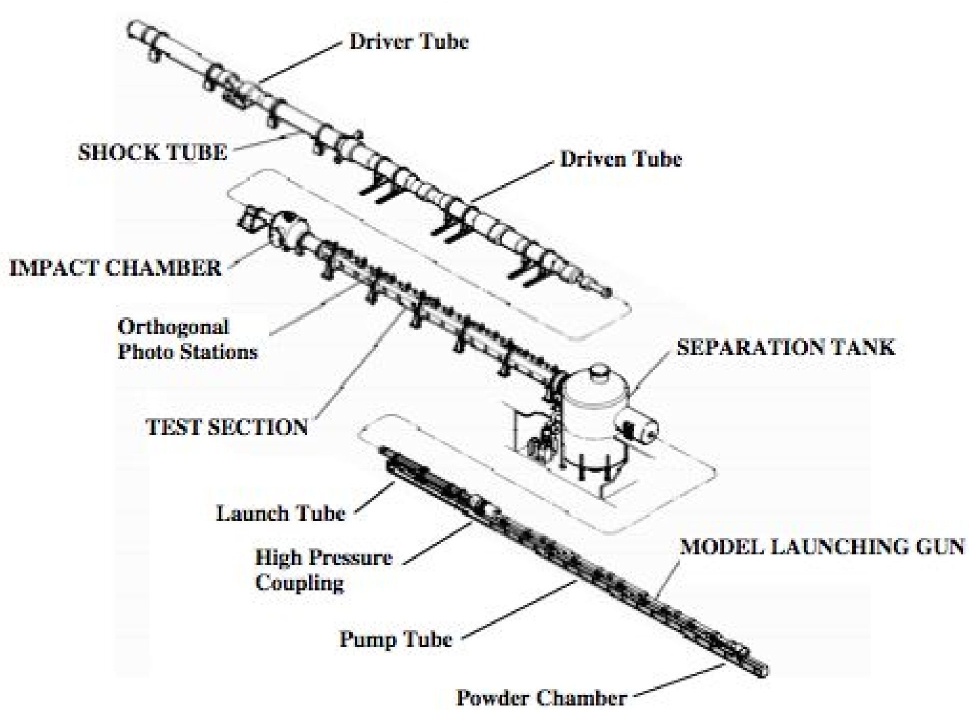

Figure 4.2.1.1. The Hypervelocity Free-Flight Aerodynamic Facility

gas for expansion through the nozzle and over the test article.

Most of the HFFAF aerodynamic research effort to date has centered on Earth atmosphere entry configurations (Apollo, Shuttle, and Orion), planetary entry designs (Viking, Pioneer Venus, Galileo, and MSR), and aerobraking (AFE) configurations (AFE – Aeroassist Flight Experiment, SIAD – Supersonic Inflatable Aerodynamic Decelerator, HIAD – Hypersonic Inflatable Aerodynamic Decelerator, and ADEPT – Adaptable Deployable Entry Placement Technology). The HFFAF has also provided testing for private industry customers such as SpaceX (Dragon) and Blue Origin (New Shepard). Aerothermodynamic testing has focused primarily on roughness augmented heat transfer and turbulent transition studies (for both NASA and the NSWC – Naval Surface Weapons Center). Hypervelocity impact testing was the mode of choice to simulate micro-meteoroid/orbital debris impacts on the International Space Station (ISS) and Reuseable Launch Vehicle (RLV/X-33). Lastly, shock tunnel testing was used to conduct scramjet propulsion studies in support of the NASP (National AeroSpace Plane) program. Figure 4.2.1.2 shows a variety of aeroballistic models that have been tested over the years.

4.2.1.1.1 Model Launching Guns

An extensive suite of model launching guns is available for use in this facility. Included in this arsenal are four light-gas guns: 0.28 cal. (7.1 mm), 0.50 cal. (12.7 mm), 1.00 cal. (25.4 mm), and 1.50 cal. (38.1 mm). 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 4.2.1.1). A deformable plastic piston is inserted into the upstream end of the pump tube. The launch package (model and sabot – a segmented plastic cylinder which supports and aligns the model during launch), 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 hydrogen gas in the pump tube or first stage of the gun. At a predetermined pressure, the burst disk ruptures and the compressed hydrogen gas pushes 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: 0.79 cal (20 mm), 1.74 cal (44 mm), and 2.40 cal (61 mm). A powder gun is a simpler design

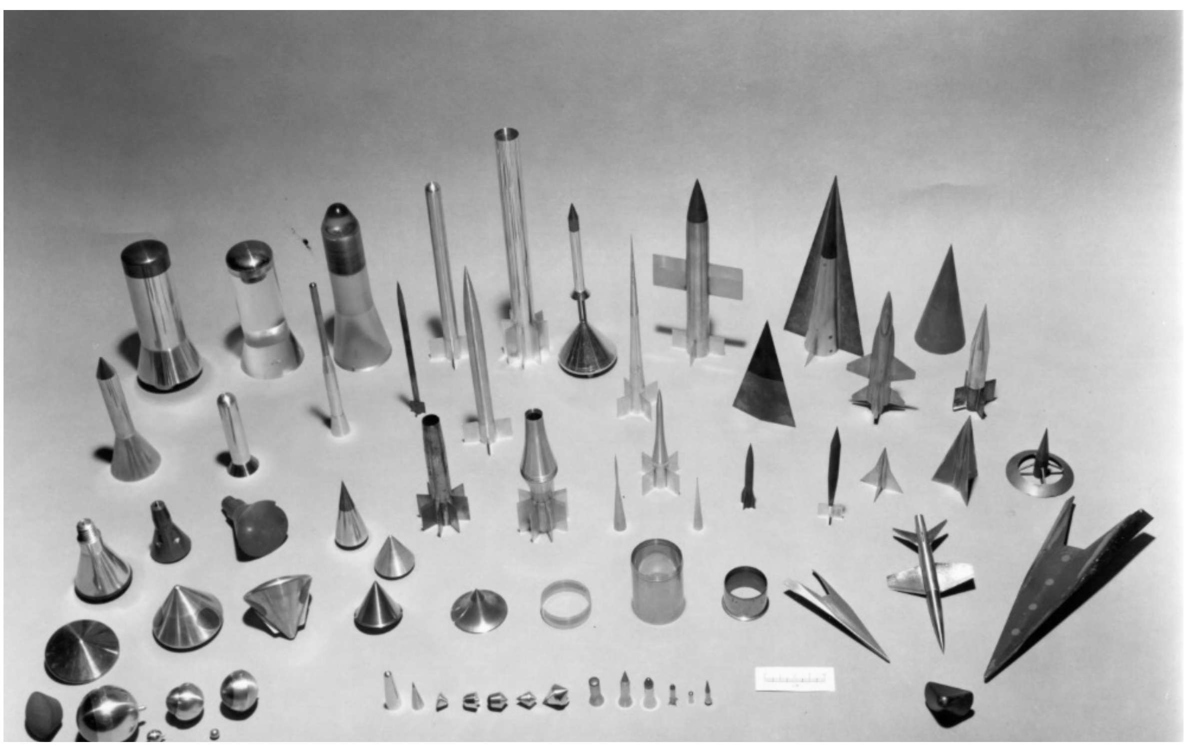

Figure 4.2.1.2. Examples of Aeroballistic Models

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 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). The lower limit velocity for each of the light-gas guns is approximately 6,500 ft/s (2 km/s). The ARC powder guns typically operate over a range of 1,000 to 7,000 ft/s (0.3 to 2.1 km/s). Model diameters typically vary between 15 to 75% of the gun barrel diameter, and model masses typically vary from 0.01 to 100 grams.

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 ft^3 [140 m^3]) 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 7 in [1.3 to 17.8 cm] diameter) which allows model passage, while the conical structure deflects and ultimately stops the sabot pieces. A thin (typically ½ mil), 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 ft (10 m) and the volume (including the transition extensions) 5,100 ft^3 (140 m^3).

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 cfm [140 L/s]), and a Roots-type booster pump (4,950 cfm [2,340 L/s] at 100 microns Hg [13 Pa] inlet pressure) which are attached to the test section transition extension. In addition to this, another pair of 300 cfm (140 L/s) rotary pumps are attached directly to the dump tank. Pressures of 50 microns Hg (7 Pa) are attainable in the test section, with leak rates of less than 10 microns Hg (1 Pa) per minute, despite the large numbers of windows and connections. Vacuum system 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 80 ft (24 m) long, with sixteen orthogonal shadowgraph stations spaced five feet apart. The octagonal cross-section is approximately 40 in (1 m) 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 in (30 cm) nominal for stations 1 through 9, and 15 in (38 cm) for stations 10 through 16. Window thicknesses are 1 in (2.5 cm) and 1.25 in (3.2 cm) or 1.5 in (3.8 cm), 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 ft [2 m]), mounted on the facility walls; A 40 ns Kerr Cell shutter at the focal point of the second mirror; and imaging optics and a digital camera (Nikon D3200, 23.2 × 15.4 mm DX format CMOS sensor, 6,016 × 4,000 pixels). 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 in (6.4 cm) thick steel back stop plus a 24 in (61 cm) 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 (38 cm) 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 [5.8 m] long with an exit diameter of 39 in [99 cm]). 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 in (160 cm) 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 [20 m] long, 17 in [43 cm] inside diameter), and a driven tube (86 ft [26 m] long, 12 in [30 cm] inside diameter), (See Figure 4.2.1.1.) 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 attains a chosen critical pressure, 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 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 ms, as the flow passes through the nozzle and over the test object (mounted in the test chamber). 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 number. For example, the slow-burn mode can produce a 4,400 ft/s (1,300 m/s) flow at a static temperature of about 150° R (83 K), while fast-burn can yield flow velocities up to 12,000 ft/s (3,700 m/s) at temperatures approaching 694 K (1,250° R).

This capability was last utilized in 1994.

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; an atmospheric test chamber; and a model catcher. This facility can be used to conduct gun performance enhancement studies wherein 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 can also be configured to perform aerodynamic testing at atmospheric pressure. For this type of testing, an atmospheric test chamber that is 6.5'h × 6.5'w × 16'l (2m × 2m × 4.9m) and is equipped with multiple ICCD cameras (orthogonally oriented) along its length to provide a nearly unobstructed view of the entire model flight path is utilized. In 2004, this set up was used to launch simulated pieces of foam debris and record their trajectory. The high-fidelity-imagery records served as data needed to validate predictive codes as part of the Shuttle Return to Flight effort.

The facility operates in a manner similar to the HFFAF. The sabot and projectile exit the launch tube of the gun and enter a separation tank wherein the sabot is stripped away from the projectile either aerodynamically or using gun gases. The projectile passes through a small aperture, enters the atmospheric test chamber, and ultimately impacts a model catcher/target. As the model passes through the test chamber, pairs of orthogonally positioned ICCD cameras are used to capture multiple exposure images, which together provide a high-resolution record of the entire flight trajectory. The total flight path (from launch tube exit to impact) for this facility is 28 ft (8.5 m) as compared to 114 ft (34.7 m) for the HFFAF. The facility utilizes the same arsenal of light-gas guns and powder guns as the HFFAF (see section 4.2.1.1.1), plus a 1.0-cal (25.4 mm) air gun. With this arsenal of guns, models ranging in size from 1/16 in (1.6 mm) diameter to 2 in (50.8 mm) base diameter can be accelerated to velocities ranging from sub-sonic to hypersonic. Multiple, ballistic light screens are located within the test chamber and are used to detect model passage, trigger cameras and determine model velocity.

This capability was last utilized in 2007 and is currently in “standby” mode of operation.

4.2.1.3 Bibliography

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4.2.2 Ames Vertical Gun Range (AVGR)

The AVGR, Figures 4.2.2.1 and 4.2.2.2, is NASA's premier hypervelocity impact testing facility for conducting planetary science research in the arenas of Solar System Workings, Planetary Protection, and Exobiology, plus developing new planetary missions. The AVGR has been a workhorse for the Planetary Science community for nearly six decades. The facility became operational in 1966 to replicate (on a small scale) geomorphological features on the moon to assess the nature of the lunar surface to aid with landing site selection and the Lunar Excursion Module (LEM) design for the Apollo program. Shortly thereafter, it was realized the AVGR had the potential to do much more than replicate morphological features and soon its capabilities were being used to study fundamental aspects of planetary impact processes, crater-scaling relations, impact products, threats from impact-generated tsunamis, and the evolution of the lunar surface (crater degradation, survival/degradation of solid bodies, etc…).

In 1980, the AVGR was designated as a national facility and began hosting investigators funded through competitive proposals. Studies expanded further to include: impacts into a broader range of target materials; the effects of atmospheric environments; hypervelocity momentum transfer; asteroid disruption; magnetic field generation; impactor survival; the role of impact-generated shear; seismic efficiency; ejecta-velocity evolution; evolution of oblique impacts; the nature of impacting bodies on the Moon and Mars; plus many other topics. Such experiments have contributed to a better understanding of impacts on small bodies (e.g., Vesta, 9P Tempel 1, Bennu, Ryugu, and Dimorphos) and are laying the foundation for the future encounter with 16 Psyche. Likewise, AVGR experiments have provided important insights into the formation of craters on larger bodies (e.g., Mercury, Venus, and Mars), as well as the delivery and capture of water on the Moon. In addition, the AVGR has been used to simulate micro-meteoroid impact events on solar system traversing spacecraft, performance testing of micro-meteoroid detection systems, and understanding impacts and airbursts on the Earth (including extinction events such as the Chicxulub impact).

AVGR research has contributed to the development of proposals for new lunar and planetary science missions including SCIM, Aladdin, Stardust, Deep Impact, and LCROSS. For instance, the AVGR developed a micro-particle launching system and use of aerogel as a capture medium, critical for enabling the Stardust mission. This micro-particle launching technique has since been used to simulate ice particle collection environments for potential missions to Enceladus and similar icy moons. Moreover, continued studies of capture media resulted in the next generation of aerogels. Lastly, the AVGR has robust history of studies of hypervelocity momentum transfer response relative to kinetic-impact asteroid deflection.

Experiments conducted in the AVGR provide support to multiple disciplines that are core to NASA's Planetary Science Division (PSD) as currently defined (circa 2025), including Solar System Workings, Planetary Protection Research, and Exobiology. In addition, testing in the AVGR has also benefitted (both directly and via information published by PSD sponsored research) many NASA missions including Apollo, Viking, Cassini, Stardust, Magellan, Deep Impact, Stardust-NExT, LCROSS (Lunar Crater Observation Sensing Satellite), Mars Odyssey, MER (Mars Exploration Rovers), DART (Double Asteroid Redirection Test), OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, and Security – Regolith Explorer), and Psyche.

A key feature that makes the AVGR truly unique is the ability to vary gun orientation from horizontal to vertical. Built in part from a repurposed Nike missile launching

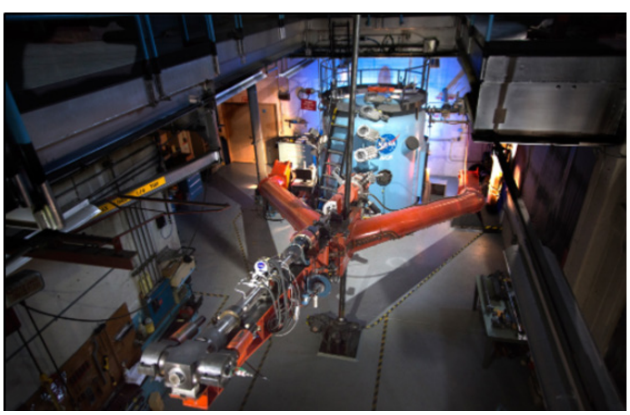

Figure 4.2.2.1. Photograph of the Ames Vertical Gun Range Facility

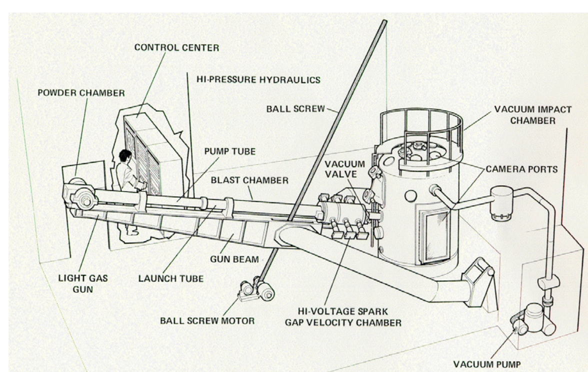

Figure 4.2.2.2. Sketch of the Ames Vertical Gun Range Facility

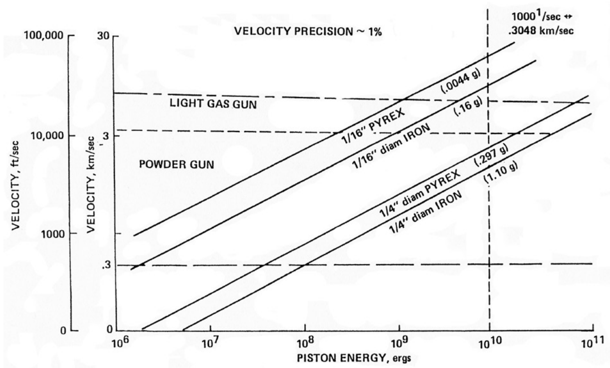

Figure 4.2.2.3. Typical gun performance

platform, the gun support structure can be used to adjust the gun orientation in 15° increments from 0° to 90°, thus permitting oblique angles of impact with respect to the gravitational vector (see Figure 4.2.2.2). This is particularly important when studying crater morphology and ejecta evolution (timing, speed, angle) as a function of obliquity and is essential when impacting loosely bound or fluid target materials such as soil, sand, regolith analogs, gravel, snow, water, etc. No other facility in North America has this capability.

4.2.2.1 Model-Launching Guns

4.2.2.1.1 Light Gas Guns

Since its inception, the AVGR has utilized a .30 cal. (7.5mm) light-gas gun to launch projectiles to velocities ranging from 2.5 to nearly 7 km/sec (8,200 to 23,000 ft/s). More recently (circa 2008) a .22 cal. (5.6mm) and a .62 cal. (15.7mm) gun were brought on-line to improve performance (consistency and accuracy) for certain particle sizes, and to enable launching larger particles. All three guns use conventional smokeless powder to drive a plastic piston into a long tube (pump tube) filled with hydrogen. This provides as a long-stroke, single compression of the hydrogen gas, which is squeezed into a heavy-wall section called the "high pressure coupling.". Here the gas reaches 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) drives the projectile down the launch tube (gun barrel). Typical launch capabilities are shown in Figures 4.2.2.3 and 4.2.2.4.

4.2.2.1.2 Powder Gun

A .30 cal. (7.5mm) powder gun is available that can propel models to velocities ranging from 0.5 to 2.5 km/s (1,600 to 8,200 ft/s). Figure 4.2.2.3 gives the performance envelope for this gun. It is worth noting that the powder gun is easier to use, less expensive to operate, and can produce more test rounds per day than the light-gas gun

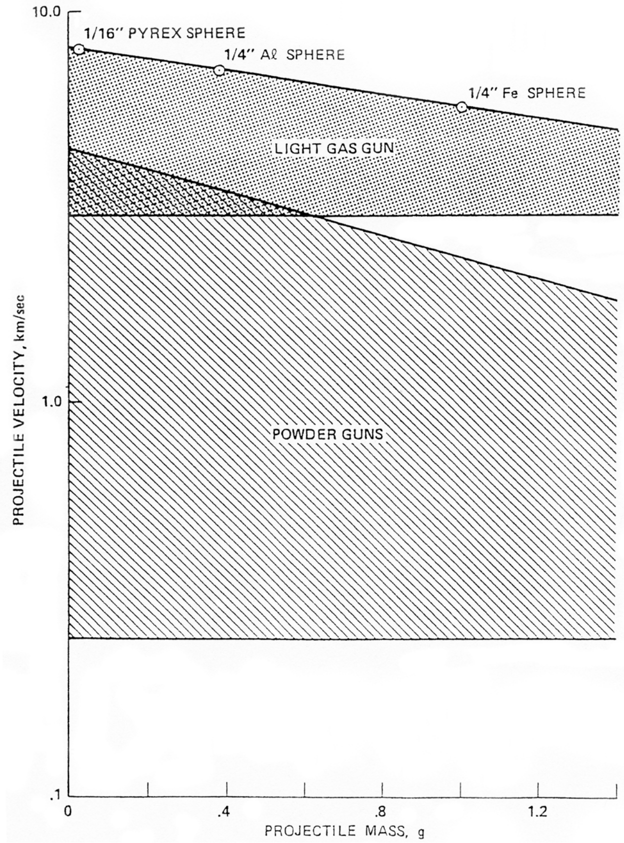

Figure 4.2.2.4. Light gas and powder gun performance

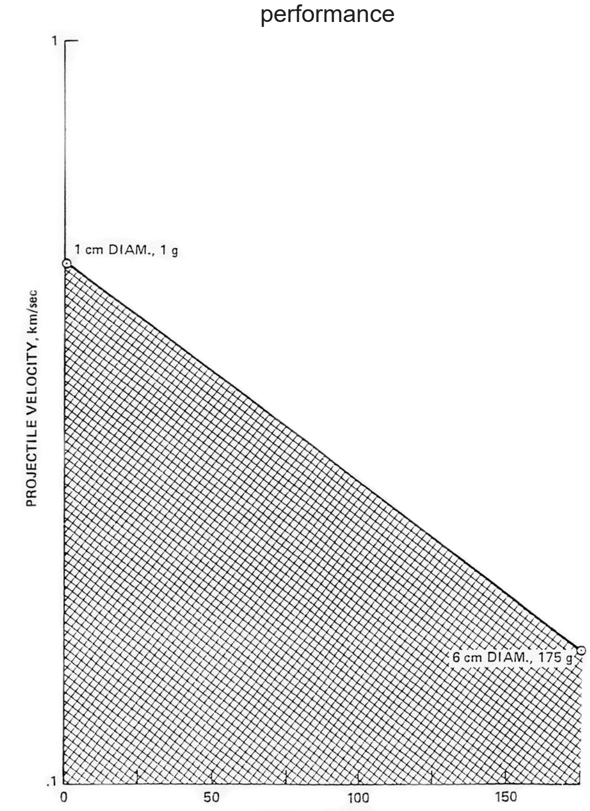

Figure 4.2.2.5. Air gun performance

(e.g., 10 vs. 4). Therefore, it is to the experimenter's benefit to use this gun unless restricted by velocity considerations.

4.2.2.1.3 Pressurized Air Gun

For low-speed testing (below 1 km/s [3,300 ft/s] for model sizes up to 2.54 cm [1 in] diameter), a model-launching gun is available that uses compressed air in a small volume reservoir for the propelling gas. This gun provides a very economical means of launching models, if low-speed impacts are desired. Performance capabilities for the air gun are indicated in Figure 4.2.2.5

4.2.2.2 Projectiles and Sabots

The types of projectiles that can be launched include spheres, cylinders, irregular shapes, and clusters of many small particles. Projectiles can be metallic (e.g., aluminum, copper, brass, steel), mineral (e.g., quartz, basalt), or glass (e.g., borosilicate-Pyrex soda-lime). For example, aluminum spheres can be launched individually for sizes ranging from 1.5 to 12.7mm (1/16 to 1/2 inch) in diameter; in groups of three for sizes ranging from 0.2 to 1.2mm; or as a cluster of many particles for sizes ranging from 2 to 200-µm. In all of the guns, the projectiles are typically saboted (encased in a segmented, cylindrical, plastic carrier) to support and align them during their passage through the launch tube. This sabot is "stripped" away (via centrifugal force for all but the air gun) after exiting the launch tube, leaving the projectile(s) in free flight to the target. The types of projectiles that are most commonly used are spheres, and many standard size (spherical particle) sabots are in kept stock at the AVGR. Non-standard sizes and shapes can be accommodated. However, the experimenter must communicate his/her desired particle size and geometry, to the AVGR operational staff, well in advance of the test date to provide enough time for design and fabrication.

4.2.2.3 Sabot Separation and Velocity Chamber

Immediately downstream of the gun apparatus are the sabot separation and velocity chambers. Sabot segments or "fingers" are separated from the projectile by way of spin induced centrifugal force. The projectile then passes through a small, conical aperture (sabot stripper) before entering the velocity chamber. The velocity chamber contains three, laser-line intervalometers (see Figure 4.2.2.6). As the projectile passes through each laser sheet, a signal is sent to an interval timer to record time of passage. Knowing the elapsed time and precise distance between the detectors, the projectile velocity can then be calculated. A digital, shadowgraph camera is employed at one of the stations to capture an image of the projectile in flight and verify its integrity. In addition, proportional

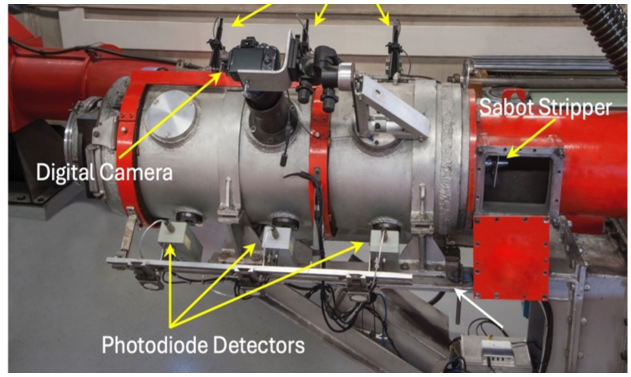

Figure 4.2.2.6. Projectile integrity and velocity measurement stations

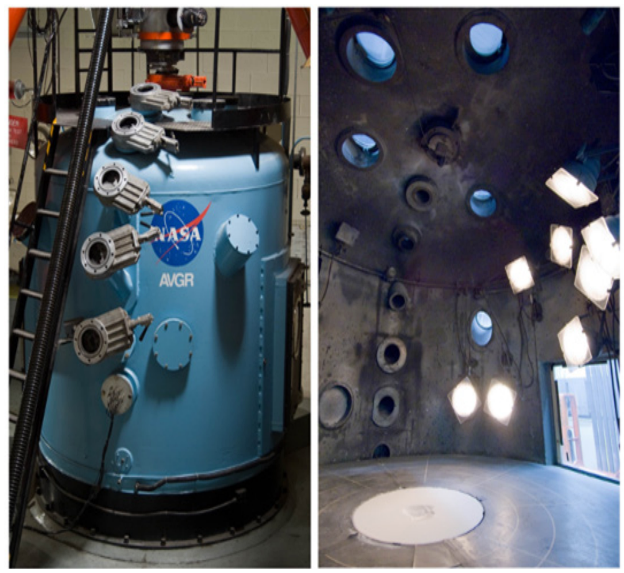

Figure 4.2.2.7. AVGR impact vacuum tank

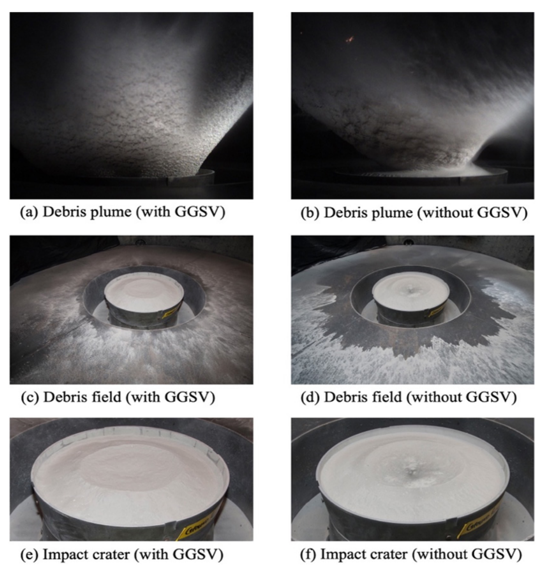

Figure 4.2.2.8. AVGR impact test photos

time delay generators can be configured to use the intervalometer timing pulses to calculate the expected time of impact and deliver precise trigger pulses to cameras and other instrumentation at desired times during the impact event.

4.2.2.4 Impact Chamber

A large (14.7 m3) target impact chamber (approximately 2.5 meters in diameter and 3 meters in height) can accommodate sizable targets of varying composition (solid, liquid, aggregate, etc.), as well as support/mounting fixtures. It can be evacuated to vacuum levels as low as 0.5 mbar, and it can also be back filled with various, non-reactive gases to simulate atmospheric effects on entry processes and crater formation. Numerous window ports and lighting configurations allow recording (via a suite of high-speed, digital imaging cameras) the impact events from various perspectives (see Figure 4.2.2.7). One large side window allows for multiple imaging systems (with different framing rates plus stereo imaging), laser sheets (3D PIV), shadowgraphs, and detectors (e.g., high-speed spectrometers). Instrumentation plates with assorted, feed-through, connector arrays can be installed to provide isolated instrumentation leads which can be connected to devices within the chamber (e.g., target sensors and capture devices). Similarly, a liquid nitrogen, feed-through plate can be installed to enable active cooling of chilled targets and instrumentation.

One of the challenges that is common to both light-gas gun and powder gun testing is minimizing the amount of target contamination and perturbations to both the target and ejecta due to the impingement of trailing gun gases. In the AVGR, this problem is partially mitigated by its uniquely large impact chamber volume. Targets are positioned nearly 6 m away from the gun muzzle, and the gun gases expand into the impact chamber with

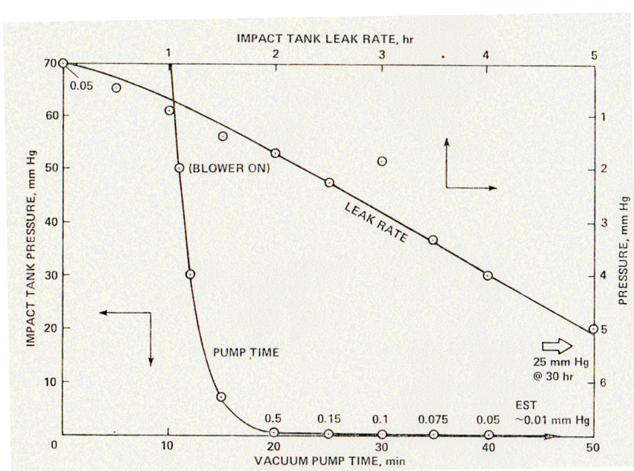

Figure 4.2.2.9. AVGR vacuum system performance

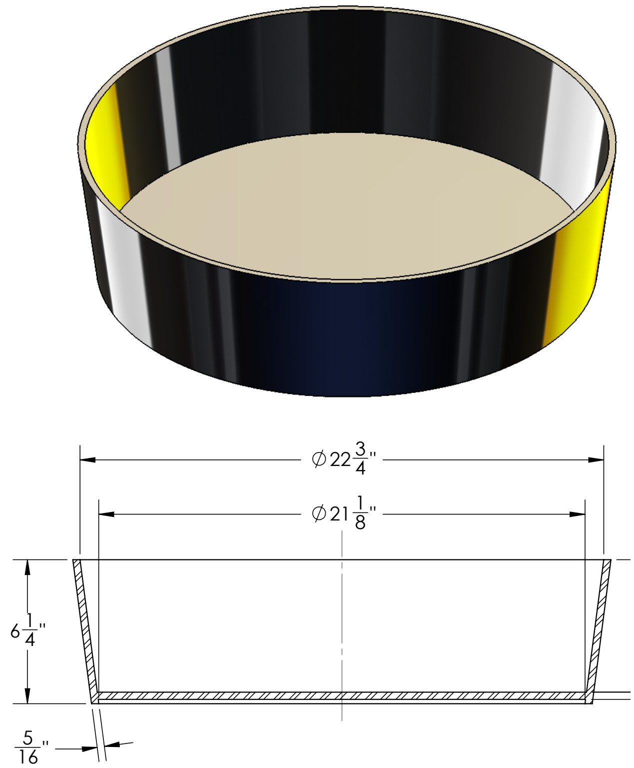

Figure 4.2.2.10. Ames standard bucket dimensions

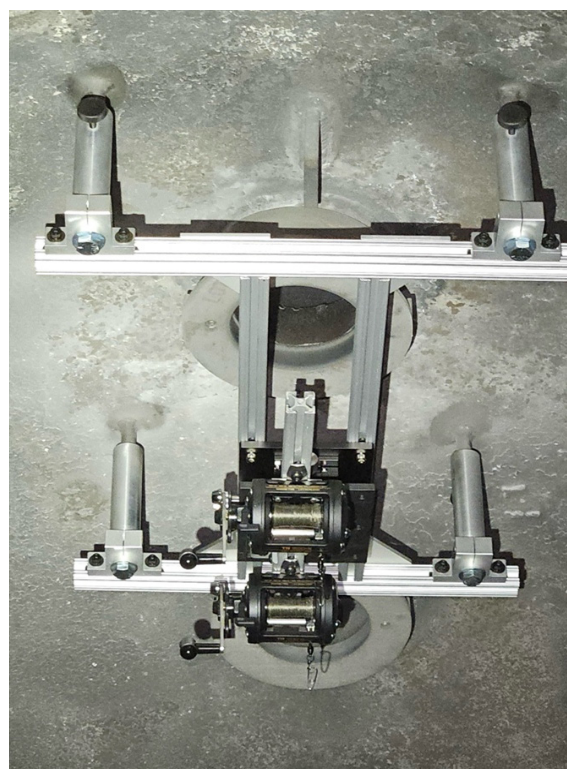

Figure 4.2.2.11. AVGR suspened target positioning fixture

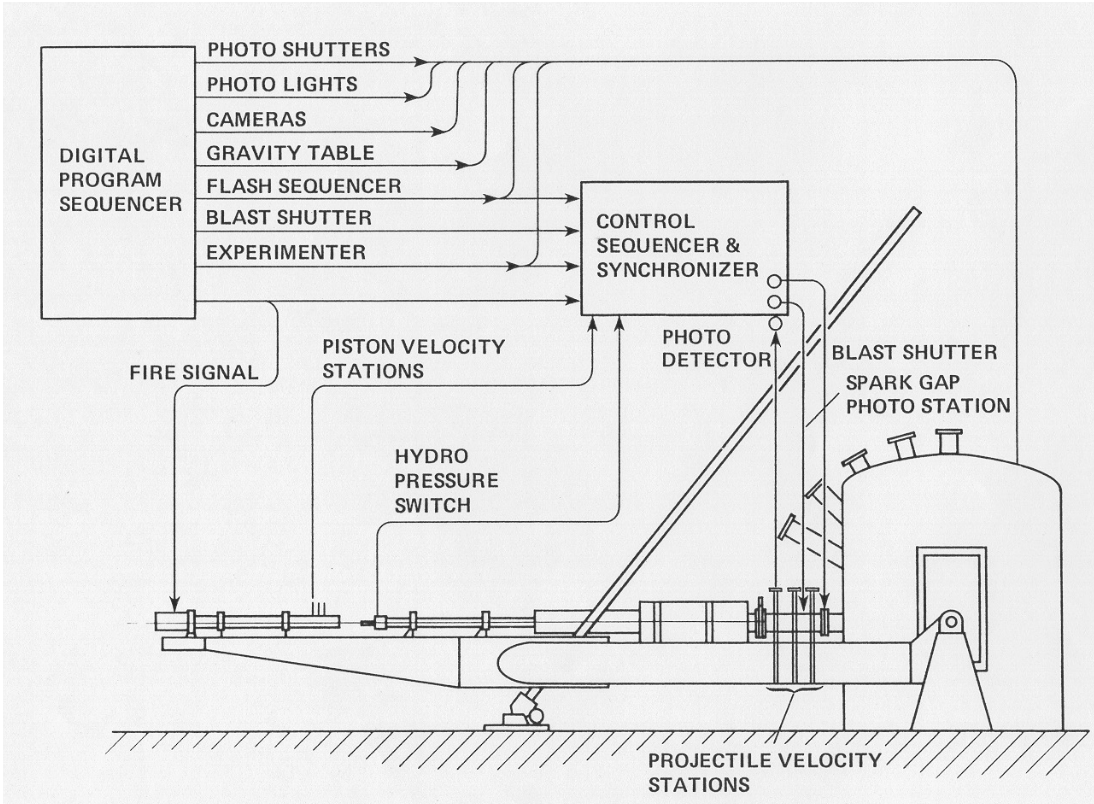

Figure 4.2.2.12. AVGR simplified block diagram

only a slight pressure increase which, in turn, greatly dissipates any resultant pressure pulses imparted to the target. However, for low density target materials (e.g., fine-grained sand, microspheres, pumice, perlite) and for certain hypervelocity momentum transfer experiments, this is insufficient. Without any mitigation, gun gases trailing the projectile can affect the resulting crater shape, ejecta dispersion patterns, and momentum measurements. The AVGR uses three different strategies to minimize these effects. The first method involves spaced mylar sheets with holes that are just large enough to allow the projectile to pass through. This strategy delays the arrival of any gun gases, as demonstrated in numerous imaging and measurement results of impacts into sensitive targets (e.g., fine pumice, perlite, microspheres). The second method introduces a small amount of gas (1 mb helium, nitrogen, or air), in addition to the series of baffles. This further delays the arrival of any gun gas. However, for certain experiments, a more robust system is required. For this, a fast-acting, gun-gases suppression valve (GGSV) has been devised and implemented. The GGSV is a portable device that can be mounted at any of the impact chamber ports (see Figure 4.2.2.7, interior view). Each port is equipped with a vent flange that is configured in such a manner so that when the valve closes, just after the impactor/projectile passes, the trailing gun gases are vented out along the chamber walls, away from the target (see Figure 4.2.2.8). The valve can be triggered from various timing events that occur during the shot sequence so that valve closure occurs less than 10 milliseconds after the impactor passes, well before the gun gases arrive for most test conditions.

The impact chamber evacuation or pump down rate can be varied depending upon the nature of the target material being tested. Low density materials such a free-fall pumice or powdered dolomite require a very slow pump down to avoid target disturbances. Conversely, solid materials (e.g., rock, metal, ice, etc.) can be pumped down rapidly. Figure 4.2.2.9 shows the maximum pump down and leak rates for the impact chamber vacuum system.

Aggregate target materials (e.g., sand, gravel, regolith simulant, snow, etc.) are typically placed in a standard target bucket (see Figure 4.2.2.10). The resulting target assembly is then positioned in the chamber such that the target surface is at the same elevation as the chamber floor structure. Since the floor is aligned with the gun hinge axis, positioning the gun at any of the chamber ports (15º to 90º) will provide an impact location at the same point on the target surface. For other target

V10 Resolution		
H	V	Max FPS
2400	1800	480
1600	1200	1016
1920	1080	978
1440	1440	943
1280	720	1992
1152	1152	1419
960	720	2619
960	480	3902
768	768	2919
576	576	4756
576	288	9280
480	480	6420
192	192	24242
96	96	51282
96	8	153846

V12 Resolution		
H	V	Max FPS
1280	800	6242
1280	720	6933
1024	768	7921
1024	512	11854
800	600	11364
720	576	13485
640	480	18769
512	512	20978
512	384	27865
320	240	64516
256	256	66997
256	128	128998
128	64	330469
128	32	560224
128	16	852514

V2512 Resolution		
H	V	Max FPS
1280	800	25600
1280	720	28500
1024	800	30500
1024	512	47300
896	800	33600
768	768	39100
640	480	69900
512	512	75400
512	384	99500
384	256	170600
256	256	205000
256	128	375700
128	64	764700
128	32	1000000
128	16	1000000

Figure 4.2.2.13. AVGR camera resolution and frame rate selection

types/materials, experiment-specific fixturing can be assembled/created to position the targets as required. For example, when conducting hypervelocity momentum transfer experiments, meteoric target materials are often suspended in a pendulum fashion using the fixture shown in Figure 4.2.2.11. Note, the reels can be positioned in tandem to accommodate long targets with multiple attachment points, or side-by-side to minimize out of plane motion.

4.2.2.5 Data Instrumentation

A programmable digital sequencer, located in the control room (101), is typically used to activate the AVGR and various instrumentation systems (see Figure 4.2.2.12). This preset controller synchronizes the gun "fire" pulse, with the activation of various cameras, light sources, and trigger pulses for other instrumentation and devices during a test. A variety of high-speed digital imaging equipment can be used to accurately record the time history, and morphological evolutionary details, of impact and crater formation processes. This equipment includes: pairs of Vision Research, Phantom V10, V12, and V2512 cameras; and a pair of Shimadzu HPV-1 cameras. All of the Phantom camera types are color, can be operated over a wide range of framing rates, exposure times, resolution levels, variable aspect ratios (image sizes), and extensive record lengths. For instance, the V10 units are 14-bit devices and are particularly well suited for, yet not limited to, framing rates up to 10,000 fps. Likewise, the V12 and V2512 units are 12-bit devices and are well suited for framing rates up to 30,000 and 100,000 fps respectively, yet they can go as high as 1,000,000 fps. Figure 4.2.2.13 show how resolution varies with frame rate for each of the Phantom cameras.

The Shimadzu cameras are 10-bit devices, monochromatic, and maintain an image size of 312 x 260 pixels and a record length of 102 frames for all framing rates (up to 1,000,000 fps). Since there are pairs of each camera type, they can be configured and synchronized to capture stereoscopic video sequences. Note: data files from all of the camera systems are delivered to the Principal Investigator (researcher) in either .avi or stacked .tiff format.

In addition, a suite of interval timers that are accurate to within 10 nanoseconds are used to record projectile time of arrival information (generated by the velocity chamber projectile detection equipment). A proportional time delay generator, which can use the time of arrival signals to calculate and deliver trigger pulses that coincide with the expected impact timing, is also available. Instrumented targets can be readily accommodated using standard vacuum feed-thru plates. Lastly, oscilloscopes and spectrographic equipment can be accommodated through special arrangement with the Science Coordinator and Facility Manager.

4.2.2.6 Office Space

Building N-204A houses the AVGR and the offices of the operational crew (i.e. site leader, technicians and imaging technologist). 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 gun elevation system is used to raise the gun and align it with the various impact chamber ports. The elevation system includes: the gun mounting beam and hinge assembly; the elevation ball-screw; the ball-screw drive-motor; and the associated control pendant. A photograph of this system is shown in Figure 4.2.2.14.

4.2.2.7.2 High Pressure Hydraulics Systems

The high-pressure hydraulic system is used to pressurize the clamping mechanism within the high-pressure coupling. This mechanism is used to maintain a leak tight seal between the coupling and the launch tube. The system consists of a hydraulic pump and hose plus a pneumatic supply and actuator.

4.2.2.7.3 Light-Gas Gun Loading System

The LGG gas loading system is used to pressurize the pump tube. The system consists of a control panel and it's assortment of valves and gauges, hydrogen and helium cylinders (located in a protected enclosure outside N204A), and the associated high-pressure tubing, hoses etc. Helium is used to purge and leak check the pump tube prior to filling with hydrogen.

4.2.2.7.4 Impact Chamber Gas Loading System

The impact chamber gas loading system is used to fill the impact chamber with gases other than air. This capability is most often utilized to simulate non-earth atmospheric environments. The system consists of: a small control panel (located near the impact chamber) and it's various valves; gas cylinders such as nitrogen, helium, argon and carbon dioxide (located outside N204A); and the associated high-pressure tubing system.

4.2.2.7.5 Vacuum System

There are two vacuum systems that support the operation of the AVGR, one for the gun itself and one for the impact chamber. For the gun, a small (Welch) mechanical (rotary) pump and its associated valves, fittings and lines is used to evacuate the pump tube to 1 torr or less. For the impact chamber two larger capacity, rotary pumps plus a "roots" type blower are used to achieve vacuum levels of 0.03 torr or less. A large, 26 × 40 in (66 × 100 cm) glass viewing window is located on one side of the chamber, plus several smaller ports at various locations, to provide numerous viewing angles.

4.2.2.7.6 Gunpowder Storage and Charge Preparation Area

The gunpowder storage and charge preparation area is cipher lock secured and located within the AVGR control room (101). It is used to store limited amounts (up to

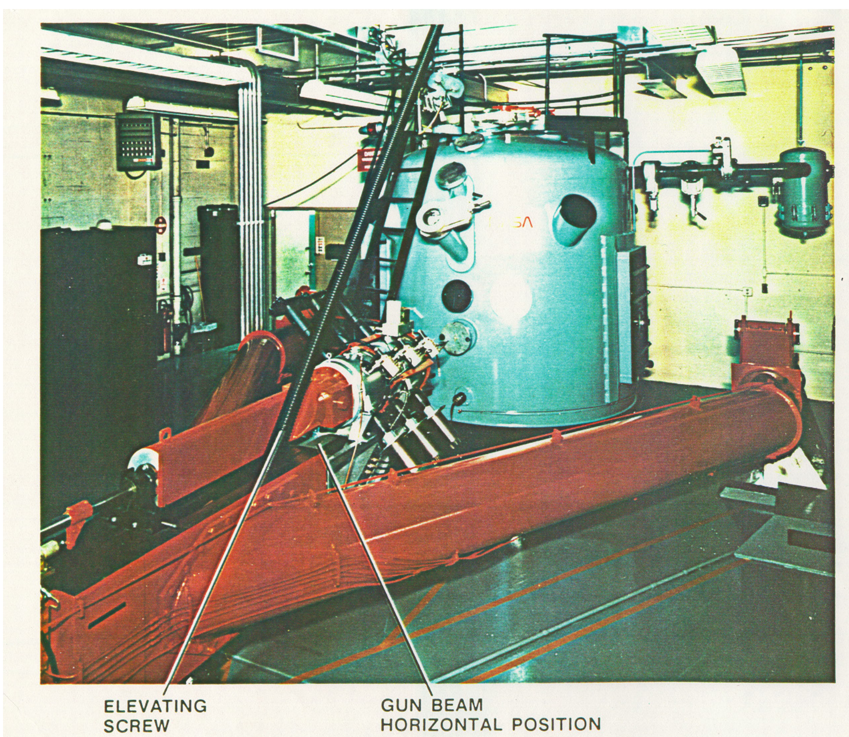

Figure 4.2.2.14. Photograph of gun elevation system, beam in horizontal position

50-lbs. net explosive weight) of smokeless powder, rounds, primers, and electro-explosive devices (EED's). It also serves as a powder weighing and charge preparation workshop in accordance with NASA Explosives Safety Regulations. The floor is covered with conductive plastic sheeting and all bench tops and cabinets are electrically bonded and grounded. Access to this room is controlled by the Ballistic Range Facility Staff, and occupancy is restricted to a maximum of one person at any time. Eye protection (either safety glasses or face shield) is required when preparing explosive devices within this room. In addition, to prevent static charge buildup and possible spark discharge during the assembly of devices containing explosives, all personnel are required to wear grounding wrist straps and cotton clothing while performing these activities. The integrity of the wrist strap must be verified with the testing device prior to any charge preparation activities. All personnel who handle and/or transport explosives are trained in accordance with NASA and Ames requirements.

4.2.2.7.7 Control Room

The AVGR control room is located in room 101 in Building N204A. Firing of the gun and activation of the instrumentation is controlled from this location. The control system equipment is mounted in three equipment racks. The center rack contains the digital sequencer, igniter tester, various indicator displays, and the firing control panel. The left rack contains the interval timers, the start pulse generator, a digital oscilloscope, and can accommodate various test specific devices. The right rack contains the power supplies, amplifiers and displays for the projectile detection and imaging equipment. It should be noted that no personnel are allowed in the gun room (102) or test area (201) during firing operations. Also, only AVGR staff members are allowed in the control room during this time, unless special arrangements are made with the Facility Manager.

4.2.2.8 Bibliography

The following papers illustrate some of the research performed in the AVGR. This list is by no means exhaustive, nor does it include numerous abstracts or PhD theses.

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4.2.3 *EAST Facility*

The Electric Arc-driven Shock-Tube Facility at NASA Ames Research Center consists of two high enthalpy shock tubes, shown schematically in Figure 4.2.3.1. The electric arc creates high-velocity, short duration shock waves of speeds up to Mach 50. Shock waves are produced in the 4" diameter High Velocity Shock Tube (LDST). Freestream densities of 1E-5 kg/m3 to 1.0 kg/m3 in any test gas composition (incl. Air, CO2/N2, H2/He, N2/CH4 etc) may be employed.

4.2.3.1 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 6,126 μF (1,530 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.

4.2.3.2 Collector Assembly and Discharge Chamber

The current collector and arc chamber are shown schematically in Figure 4.2.3.2. 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 coiled 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 initiate the arc discharge.

The arc chamber is designed for a pressure of 1000 atm (100 MPa) 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.

4.2.3.3 Driver Tube

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

The driver configuration is a 17.7-cm conical drive configuration with a 10.16 cm (4 in) exit (driver volume = 632 cm3 [39 in3]).

4.2.3.3.1 Primary Diaphragm

The diaphragm is made of mylar 0.35 to 0.50 mm (0.013 to 0.019 in) or aluminum foil (0.012 to 0.35 in) in thickness. It is ruptured due to the rise in pressure within the driver during the arc discharge. There is a time lag of 20 to 40 μs between the instant that the breaking pressure is reached (approximately 11.5 atm [1.2 MPa] for a 0.35 mm [0.013 in] diaphragm) and the diaphragm is fully open.

4.2.3.4 Shock Tube

The design of the shock-tube portion of the facility, as with 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 (4 in) ID tube 12 m (40 ft) in length made of aluminum known as HVST; the other is a 54.3 cm (21.37 in) ID tube 17.6 m (57.9 ft) in length

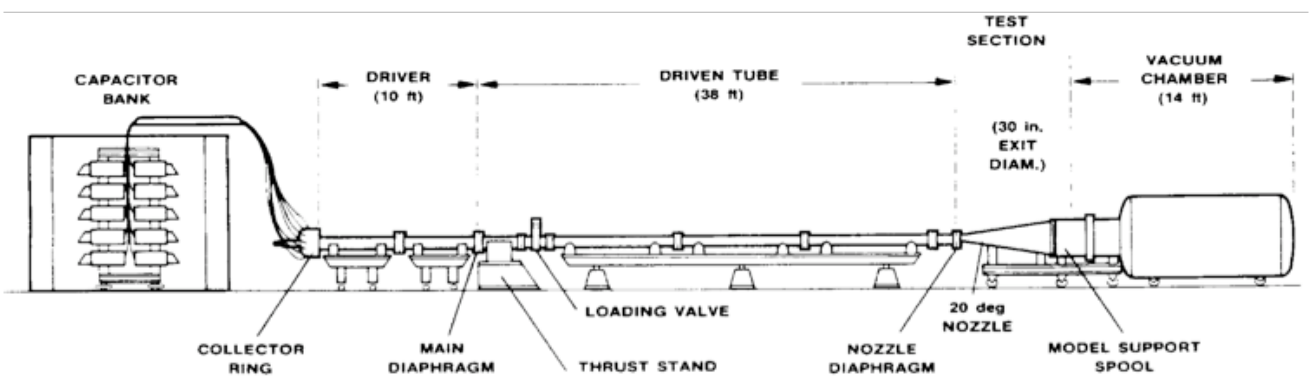

Figure 4.2.3.1. Schematic diagram of the EAST Facility

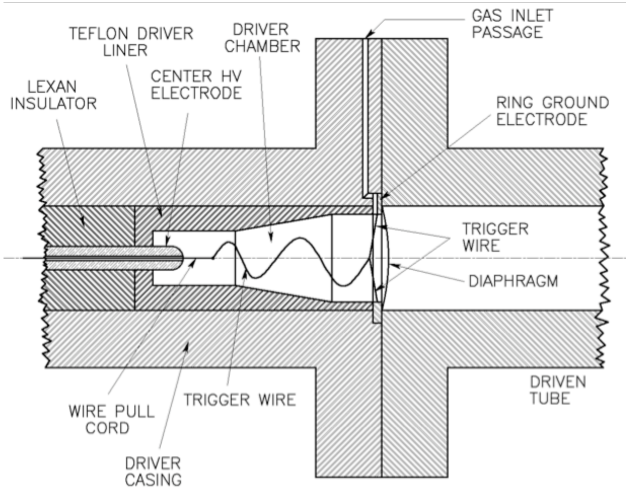

Figure 4.2.3.2. EAST Facility current collector and arc chamber

made of aluminum known as LDST. LDST also has a transition section from the driver to an expansion cone that is 10 cm (4in) ID tube 4.5 m (14.6 ft) in length made of stainless steel.

The driven tube is shown in Figure 4.2.3.3 along with other components of the facility. Marked on the image are the location of the various diagnostic ports. The inset depicts the test section. On either side of the test section are the upstream and downstream portions of the driven tube. Several ports on the upstream section are used for monitoring the shot, while the downstream portion is mostly unused. Available round ports are labeled by letters in alphabetical order starting from the port closest to the driver section. The labels each represent one axial location along the length of the tube. In most cases, there are two ports on opposite sides of the tube at each location. Exceptions are ports F, G, H, I, K, M, O, Q which have four locations, 90 degrees apart and ports L and P which have only one location. Port A is occupied on the west side by the gas loading valve and port D is occupied on the east side with the pressure port.

4.2.3.4.1 Upstream

The upstream section has 6 port locations available, two of which are occupied by the gas loading valve and facility pressure gauges. The remaining ports may accommodate pressure sensors or observation windows. Different holders exist for the pressure sensors and observation windows and the design of these holders differ from the holders used in the test section.

4.2.3.4.2 Test Section

The test section has 30 round diagnostic ports and 2 rectangular slot (long) window ports. The ports consist of primary and secondary inserts, between which is mounted either a window or pressure sensor holder. Some ports, being unused at present, have a single blank in place of the primary/secondary arrangement. The primary inserts are installed within the tube with intention of seldom being removed.

4.2.3.4.3 Vacuum System

There are two primary pumping stations, denoted 1 & 2. At each station a facility (poppet) valve isolates

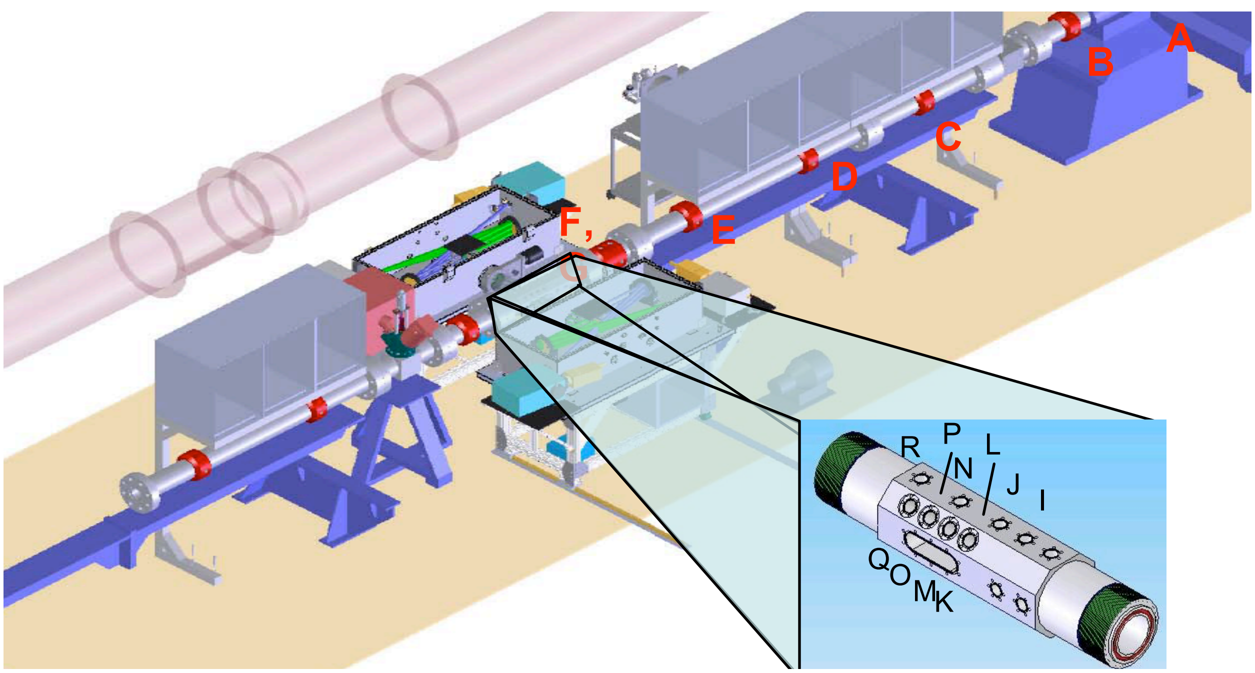

Figure 4.2.3.3. EAST Facilty Driven Tube and components

the tube from the pumping station and a gate valve isolates the high vacuum turbo pumps from the facility manifold. Gate Valve 2 is a three position valve, with the intermediate position being used to throttle gas flow and maintain the tube in intermediate pressure range (0.1-1.0 torr). The tube pressure is measured through a port C, through a valve whose state is pneumatically tied to facility valve 2. Port C has a gauge manifold with both a high vacuum ion gauge and high accuracy capacitance manometer. All the valves on the system are controlled by the gas loading system.

The vacuum system instrumentation is comprised of various pressure gauges, gauge controllers, cabling and a LabView based Data Acquisition System for recording vacuum pumping performance. The system also has a Residual Gas Analyzer (RGA) installed on the down stream pump valve. The RGA is used to determine the vacuum quality, indentify vacuum leaks and gas contaminates and verify proper test gas mixtures.

4.2.3.4.4 Heater

The heater, designed by TGM, consists of a series of silicone blankets wrapped around different portions of the tube and covered with foam insulation. The blankets all have embedded thermocouple measurements which feed back to the heater control system. The heater control system uses PID control on 8-zones to adjust power delivered to maintain the temperature set point. The temperature set point is entered manually on the front panel. The heater may be turned on/off manually, or is cycled by the PLC as part of the automated pump down procedure.

4.2.3.5 Dump Tank

The dump tank is maintained at low vacuum and is isolated from the rest of the shock tube by a diaphragm. The dump tank has its own pumping and valving system which are operated independently from the driven tube vacuum system. During facility pump down, a pressure differential of several torr in either direction across the diaphragm may cause unintentional rupture of the diaphragm. To alleviate this, a bypass line was recently installed which connects the dump tube directly to the driven tube. This bypass line is intended to be open only during initial pump down of the dump tube and driven tube. This line should be closed when moving from rough to high vacuum and is operated manually.

4.2.3.6 Nozzles

Two conical nozzles exist for the 10 cm (4 in) tube of the facility: one is 1.8 m (6 ft) in length with an area ratio of 1000; the other has an area ratio of 10.

The EAST Facility layout is shown in Figure 4.2.3.4.

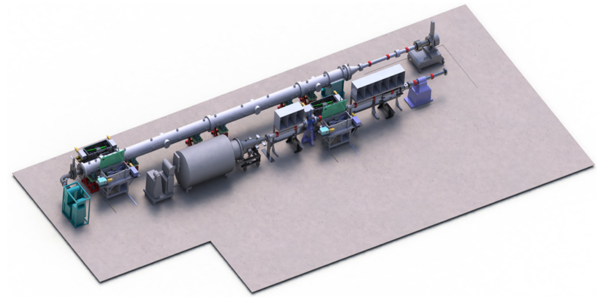

Figure 4.2.3.4. EAST Facility Layout

4.2.3.7 Facility Performance

Using the different driven tubes and nozzles and 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 (10,000 to 164,000 ft/s) have been obtained. The following is a list of the ranges of operating conditions:

- Driver charge pressure: 1.0 to 27.2 atm (100 to 2,800 kPa)
- Driven tube initial pressure: 0.01 to 10 torr (1 to 1,300 Pa) for the 60 cm (24 in) tube; 0.1 to 760 torr (13 to 100,000 Pa) for the 10 cm (4 in) 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 6,126 μF

4.2.3.8 Shock Tube 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 photomultiplier tubes and high frequency pressure transducers.

4.2.3.8.1 Photomultiplier Tube Time of Arrival Sensors

The photomultiplier tube time of arrival sensors consist of several different components, including the PMT Slit Assembly, Fiber Optic Adapter and PMT Panel.

4.2.3.8.1.1 PMT Slit Assembly

The PMT Slit Assembly consists of two 50 μm wide slits aligned perpendicular to the shock tube with a separation of 4.2”. Two variations of this assembly exist for mounting on the test section and upstream sections of the shock tube.

The test section mounts sit in a collar adapter that bolts directly on to the secondary round ports. On the upstream section, it is not possible to clock the slit assembly to the window port and therefore it must be oriented manually.

A set-screw on the window port is used to secure the slit holder in position.

4.2.3.8.1.2 Fiber Optic Adapter

The fiber optic adapter assembly consists of three parts. The cage rod assembly from Thorlabs inserts into the PMT Slit Assembly collar on one side, and the fiber optic mount on the other side. The fiber optic mount consists of an SMA fiber optic adapter, a collimating lens, and a mount body with 6 degree of freedom adjustment. This assembly is installed directly onto the PMT slit assembly. Prior to mounting on the PMT slit assembly, the fiber optic adapter must be aligned by attaching a fiber optic illuminator and adjusting the mount settings so that the image produced is properly aligned to the mount. The mount can then be placed on the PMT slit assembly and then alignment checked by illuminating via fiber optic through the slit and examining the image of the slit produced. This fiber optic adapter is then installed into the observation port and attached to the PMT panel via multimode fiber optic cable.

4.2.3.8.1.3 PMT Panel

The PMT panel is designed to interface an optical signal coupled from the shock tube via fiber optic and convert it to an electric signal to be collected by the data acquisition system. The PMT panel is a custom 3U 19” rack mounted panel, each with 7 SMA style fiber optic adapters for input. Each SMA adapter has a corresponding BNC connector for output signal. The SMA fiber optic adapters bolt to the front of the panel and directly couple light to the Hamamatsu H6780-20 PMTs bolted on the back of the panel.

Three panels are available for a total of 21 channels.

4.2.3.8.2 Pressure Sensors

The pressure sensors are piezoelectric sensors designed for detection of high pressure shocks. Two types of pressure sensors are employed in the EAST facility, both manufactured by PCB electronics. Previously the PCB 113A21 style pressure sensor was used and is currently being phased out however, may still be used in the upstream ports on the shock tube and are fully compatible with the existing control units for the PCBs.

The newer style sensor is the PCB 132A35. These sensors were selected for their smaller sensor cross-section which was expected to allow for more accurate detection of shock arrival. The quoted response time of these sensors is 1 µs, though experimental observation shows that the accuracy of detecting shock arrival is much higher than this.

4.2.3.8.3 Spectroscopy

4.2.3.8.3.1 Vacuum Box

The rectangular aluminum vacuum box (Figure 4.2.3.5) contains all the imaging optics for the EAST spectroscopy implementation. The vacuum box (V-box) couples to the spectrometers through window ports for visible and IR spectrometers and through a sealed port for VUV spectrometers. This port design is such that either a window mounting plate or a vacuum monochromator may be installed on it. High vacuum levels such as 1.0E-07 can be achieved in the V-box without bake-out.

The pumping system on the vacuum box uses a 300 l/s turbo pump mounted directly underneath the box with gate valve isolation. An oil-free mechanical pump backs this turbo pump. A second gate valve is used on the side of the vacuum box facing toward the test section. There are also several ports on the opposite side of the box which are used as feedthroughs for optical mount motor controllers and pressure gauges. The second gate valve on the tube side accesses the v-box coupling vestibule described below. While this box may in principle be used to evacuate the vacuum monochromator, this would entail pulling a rough vacuum through a narrow optical slit which may be damaged by the flow and would be inefficient. Therefore, the vacuum monochromator is evacuated with its own small 70 l/s turbo pump, which is backed by the V-box mechanical pump. The V-box is intended to remain under vacuum at all times during facility operation and surrounding appendages are designed to interface with it in a manner that does not require disruption of vacuum.

The V-box coupling vestibule couples the vacuum box to the shock tube. It consists of a bellows adaptor which bolts directly on to the rectangular secondary port. For operational purposes, it was decided that the secondary would remain bolted to the bellows adaptor at all times.

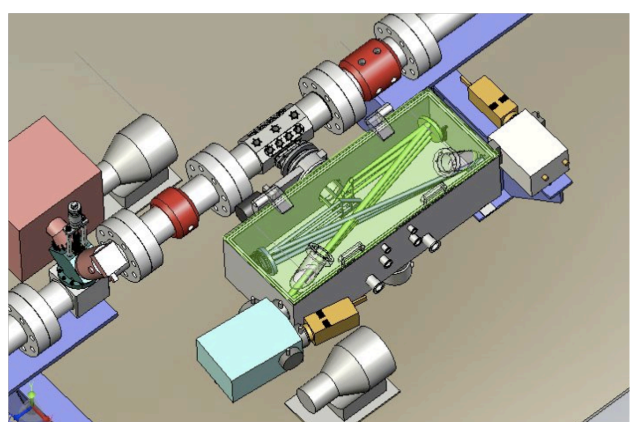

Figure 4.2.3.5. Vacuum Box

This allows for the window to remain installed in its operational position during both calibration and shot data collection. While not installed in the test section or a calibration mount, the window is held on by its keeper and the force of vacuum in the vestibule. The vestibule is evacuated through a roughing port on the gate valve that is oriented toward the vestibule. Once at rough vacuum, the gate valve may be opened to pump the vestibule to high vacuum.

At present, vacuum operation is manual. The gate valves and angle valves are pneumatically controlled and can be opened or closed using a manual switch box

The V-box frame is installed on a linear glide system that allows the entire assembly to easily be coupled to and removed from the shock tube.

Two vacuum boxes are mounted on the test section, though only one box is currently operated under vacuum. The other box may be retrofitted for vacuum operation as required.

4.2.3.8.3.2 Optics

The optics design (Figure 4.2.3.6) is mounted on a breadboard in each vacuum box. Each vacuum box contains two optical paths, which are each created by a series of six mirrors. The two optical paths enter the test section through the slot windows at slightly different angles, and pass through a focal point at the center axis of the tube. The first two mirrors rotate the image of the slot to a vertical orientation. The remaining mirrors direct the image and focus it onto the spectrometer slits. Each set of mirrors is chosen to optimize particular wavelength ranges depending on the spectrometer with which they are associated; thus, spectrometers may not be placed at any of the four locations arbitrarily. The mirror set associated with one camera may use an independent magnification factor.

All mirrors are mounted on high-stability optical mounts. The intent being to avoid regular adjustment of optical mounts to compensate for thermal (or other) drifts. As the v-box system requires some effort to open and adjust, frequent realignment may create significant delays in facility turnaround time. Mount stability is paramount and therefore the system must remain under vacuum at all times. The final mirror in the optical path is mounted on a motorized mount (Newport). Motor control cables are fed through vacuum sealed 15-pin feedthroughs so the mirror position may be adjusted while the system is under vacuum. The motor control switchbox (for knob selection) and joystick for position adjustment are mounted on the breadboard directly outside the vacuum box.

4.2.3.8.3.3 Spectrometers

The four spectrometers employed are from PI-Acton and include three 0.3 m spectrometers (2 x 2300i, 1 x SP300i) and one 0.4 m vacuum spectrometer (VM504). The spectrometers are equipped with three gratings each as summarized in the Table 7.

Spectrometers are wavelength calibrated in WinSpec using the Spectrometer->Calibrate function. More information on the process may be found in PI-Acton application notes. This calibration needs to be performed whenever the camera is adjusted relative to the spectrometer. If the camera remains stably positioned, this calibration should be used for testing, but may be checked by taking a calibration spectrum at a stable position with a pen lamp.

Operation of the spectrometers is to be performed using VBScript macros executable in WinSpec. These macros automatically configure the cameras to desired settings and solicit user input for settings that might change under different run conditions. These macros also automate the calibration process and apply calibration factors against the data so that data is obtained in absolute radiance units.

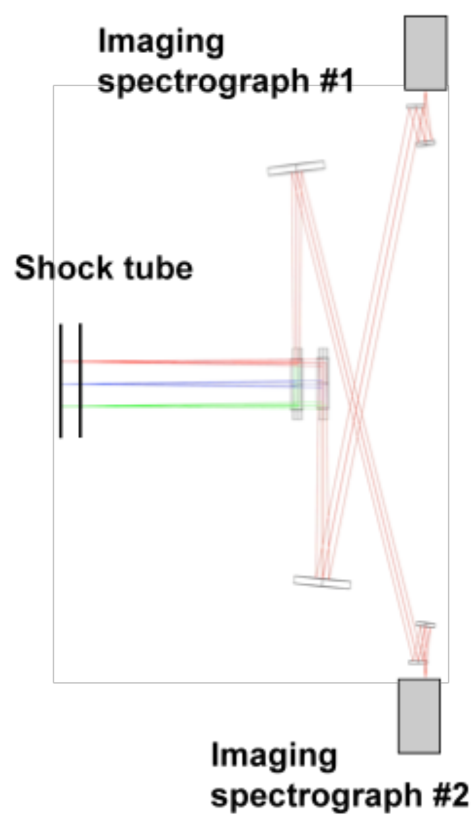

Figure 4.2.3.6. Optical paths in Vacuum Box

Table 8. Spectrometers in use at EAST Facility

Spectrometer	Position	Camera	Lo-Res Grating		Lo/Md Res Grating		Hi-Res Grating	
			Blaze/ Range	Ruling (g/mm)	Blaze/ Range	Ruling (g/mm)	Blaze/ Range	Ruling (g/mm)
VUV (VM504)	SE	1024x1024 ICCD	300 nm 200-450	150	150 nm 120-300	600	150 nm 120-300	2400
UV/VIS (SP2300i)	NE	512x1024 ICCD	300 nm 200-450	150	HVIS 200-450	1200	HUV 185-375	3600
VIS/NIR (SP300i)	NW	512x512 ICCD	500 nm 335-750	150	750 nm 500-900	1200	HVIS 300-800	2400
IR (SP2300i)	SW	256x312 InGaAs	800 nm 535-1200	150	1250 nm 830-1900	150	1250 nm 830-1900	600

4.2.3.8.3.4 Cameras

Four CCD cameras are employed, one per spectrometer as detailed above. The cameras are all from PI-Acton and compatible with WinSpec software. In addition, an IR camera from FLIR (Phoenix) is available for usage if needed. The InGaAs camera does not cover wavelengths below 900 nm as the FLIR camera does. This range is covered by the PI-MAX ICCD camera. Three of the four cameras are intensified CCD arrays which are capable of making high intensity measurements at short sub-microsecond (μs) exposure times. These arrays are optimized for different ranges of the spectrum and are associated with the spectrometers corresponding to these ranges.

The InGaAs camera uses liquid nitrogen cooling to reduce dark noise, which may completely overwhelm the signal in the IR region, where thermal excitation of electrons at room temperature is comparable to or larger than the photo-excited electrons being measured. This requires the camera dewar to be filled with liquid nitrogen approximately 30 min. in advance of usage to allow temperature, and thus dark noise, stabilization. The InGaAs camera is not intensified and has a minimum exposure time of 1 μs. At present, it is not known whether the sensitivity of the InGaAs camera is linearly proportional to exposure time; the FLIR camera was not. This means that absolute radiance calibration may require additional correction if the exposure time must be adjusted.

4.2.3.8.5 Calibration Sources

Two calibration sources are employed: an integrating sphere for wavelengths > 300 nm and a Deuterium lamp for wavelengths < 300 nm. Both calibration sources have a coupling piece designed to allow attachment to the vacuum box through the secondary slot window holder.

4.2.3.8.5.1 Integrating Sphere

The integrating sphere (Figure 4.2.3.7) is a 12” diameter sphere with 4” exit port providing a calibrated absolute radiance output. The integrating sphere uses 5 individual lamp sources, including 4 Quartz-Tungsten Halogen (QTH) lamps and a Xenon arc lamp. The xenon arc lamp is UV filtered to prevent excess energy deposition into the integrating sphere. As the lamps provide approximately 1.2 kW of power, the integrating sphere becomes very hot and requires external cooling by way of an N2 purge line with a flow interlock which protects the highest power QTH lamp. Other lamps may be used without the N2 flow on, but if the flow deviates from its set point, the high power lamp will be locked out.

Calibration data for the integrating sphere is provided by the manufacturer at various settings. The integrating sphere is also equipped with a fiber-optic coupled spectrometer with sensitivity from 300-900 nm and a germanium photodiode with sensitivity in the IR. These detector sources are deemed to be more reliable radiance standards than the manufacturer provided radiance curves due to possible drifts in the lamps. Nevertheless, the QTH lamps should be operated using current (not

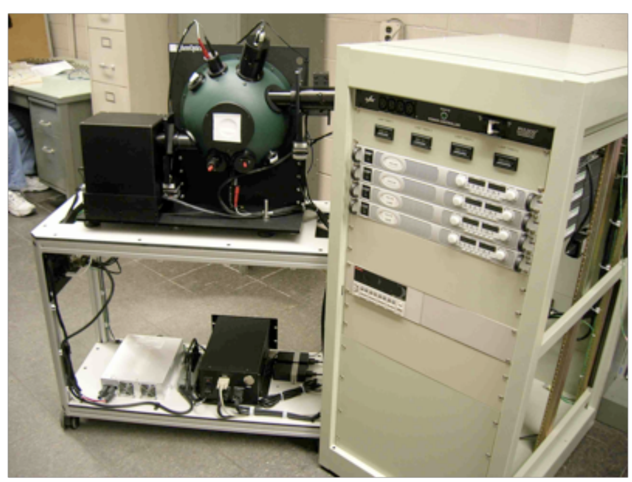

Figure 4.2.3.7. Integrating Sphere

voltage) settings that match the manufacturer's calibration conditions (4.490 A on ITHS-600 and 6.250 A on the other three lamp power supplies).

The spectrometer, from Ocean Optics, uses SMS software to monitor the integrating sphere absolute radiance. This data may be saved in the form of a .scn file which is used as the calibration standard by the Matlab CCDResponse function. If the range of interest is outside of that detected by the spectrometer, the photodiode current, displayed on the Keithley picoammeter should be recorded and used to normalize the calibration data against the reference data. This function is performed entirely within the software.

4.2.3.8.5.2 Deuterium (D2) Lamp

The D2 lamp is an arc source with absolute radiance calibration standard and vacuum spectrometer mounting configuration. In order to obtain the D2 lamp spectrum over the spatial dimension of the imaging spectrometer, a translating stage was constructed for the D2 lamp. The D2 lamp is mounted directly onto the translating stage, which in turn couples to the V-box. The region between the translation stage and window is equipped with a purge port to remove oxygen from the calibration path. A flow of argon or nitrogen is controlled from the rotameter panel. Approximately 15 min. of purging should be performed to remove the oxygen and effectiveness of the purge may be verified by collecting spectra in the VUV and identifying the elimination of absorbance at 140 nm.

The translation stage is attached to EZII motorized linear stage from Oriental Motors. The motor settings may be programmed via EZED2 software. Once programmed, the settings are stored within the motor and it may be operated without computer interface.

4.2.3.9 Support Systems

4.2.3.9.1 Control Systems

The EAST has multiple control systems that operate both current and legacy equipment. The legacy equipment, including the West (60cm) tube and cold driver systems, are largely disconnected though parts of these control systems are still in place and in some cases include interlocks to equipment that is still used. Complete demolition of these systems may be attempted sometime in the future. The control systems that are presently in use are the firing control system and the new gas loading system.

4.2.3.9.1.1 Fire Control

The firing control system dates back to the initial construction of the facility and controls the capacitor bank charge and discharge with multiple safety interlocks. Complete understanding of this system would require reference back to older historical documents and wiring diagrams. This document details only some of the relevant changes made in 2007-2008.

When the fire sequence is initiated, the capacitor bank charges up at a rate of 500 V/sec. The digital gauge operates as a simple on/off controller that ends the charging process once the programmed set point is obtained. This allows the set point to be set deterministically with accuracy on the order of 10 V.

The fire control system is interlocked to prevent access to the shock tube during charging and firing. The fire control system has also been integrated with the gas loading system, described below. When firing sequence is engaged the gas loading sequence is initiated. If the gas loading sequence does not conclude after 1 minute, the fire sequence is halted by tripping the 86 breaker. The firing sequence includes multiple time delay relays which must be set to make the fire sequence longer than the time programmed into the gas loading sequence.

4.2.3.9.1.2 Gas Loading Control

The gas loading control system involves several components, many of which are depicted in the P&ID above. Gas flow is controlled by MKS mass flow controllers (MFCs). The MFCs are in turn controlled via the MKS 250E pressure control system. The MKS 250E adjusts the flow rate on the MFCs in order to maintain a pressure set point within the shock tube. The MKS 250E may be operated manually by front panel control or automatically by a programmable logic controller (PLC). The set points on the individual MFC channels determine what the maximum flow rate can be during the gas fill process. Succesful operation of the 250E also requires the gas loading valve to be open and the shock tube gate valve 2 set to intermediate position.

The PLC controls all aspects of the gas loading system as well as the facility vacuum system. Interface to the PLC is possible via Proficy software to diagnose errors or edit the PLC program, though routine operation of the PLC is performed via the gas loading panel installed on the racks above the shock tube. The gas loading panel may be switched between manual and automatic mode. In manual mode, the gas loading panel allows for manual operation of 5 pneumatic valves – two facility valves, two gate valves and the gas loading valve. In automatic mode, these valves are controlled according to preset sequences, along with the tube heater and gas loading system.

The pre-programmed sequences of the Gas Loading system are meant to perform two primary functions: overnight shock tube evacuation and purging and test gas gas loading. The evacuation function cycles through 5 stages, denoted as: Evacuate/Heat, Heat/Purge, Evacuate/Heat, Heat/Purge, Evacuate, each of which last approximately two hours. Purge processes use the gas loading function, maintaining the pressure set point on the MKS250E, while the heat processes maintain the heater at the set points on the heater controller. If an error occurs during this process, the system fault light is illuminated and the system is placed in 'Evacuate' mode (i.e. pumping valves open). If the fault is related to an inability to maintain vacuum in the system, all valves will be closed and the system will be left in 'Quiescent' mode. If an operator is present during the pumpdown sequence, the stages may be cycled through using the Next Stage/Previous stage buttons. A 5-second delay occurs before actuating valves so the operator may skip over stages without actually entering them.

4.2.3.9.2 High Voltage System Measurements

The high voltage (HV) system includes the capacitor bank, HV Transformer, HV switches, cabling and associated measurement systems. The high voltage system is controlled by the firing control system. Measurement of voltage on the capacitor bank is obtained by connection to a resistive voltage divider. The signal on the voltage divider reads 114 mV per kV on the capacitor bank. Measurement of current is performed by use of a voltage divider on the ground line between the capacitor bank and arc driver. Both the Voltage and Current signals are run to the data acquisition system.

4.2.3.9.3 Instrument Rack

A series of new instrument rack was installed in the EAST facility directly over the shock tube. These racks were installed on a cantilevered structure so as not to restrict access on the east side of the tube. Minimal interference is introduced on the west side by these structures. Three structures with three 19" racks each were installed, two over the upstream section and one over the downstream section. All electronics, controls and computers for operation of the facility are installed in these racks, excepting the firing control in the control room and controls for the V-boxes and spectroscopy equipment which are mounted under the V-box support tables.

There is 80U of space available for additional instrumentation outside of the permanently installed facility related systems.

4.2.3.9.4 Gas Delivery

4.2.3.9.4.1 Gas Rack

The Gas Rack was installed adjacent to the driver and allows permanent placement of the test gas next to the loading valve. The gas rack is designed to accommodate three full sized cylinders and two half-sized cylinders. The panel above the gas rack contains regulators for the gases, the mass flow controllers and a manifold for mixing prior to introduction into the test section. The regulators are mounted on the panel with pigtail connections to the cylinders for ease of change out. The test gas regulator has a three way valve which allow the test gas to be changed between two cylinders (presently Air and Mars gas mixture) without disconnecting any systems. Upstream of each regulator is installed a 0.013" diameter orifice as part of a M-M NPT connector. Downstream of each regulator are pressure relief valves with adjustable discharge pressure from 50-150 psi. In the event of a regulator failure, these valves will discharge the gas and prevent damage to the MFCs from overpressure. The upstream orifice limits the maximum flow rate through the regulator so that the pressure relief valves may discharge gas without additional pressure buildup beyond their cracking limit.

4.2.3.9.4.2 Compressed Air

The compressed air system is used to control all pneumatic valves on the shock tube and vacuum boxes. Tubing connected to the compressed air source is blue in color. At present the compressed air source comes from another building and we have no control over its availability. In the future a dedicated air compressor will be installed for the facility.

4.2.3.9.4.3 Purge Gas System

The purge gases refer to gases plumbed to three rotameters near the downstream end of the test section. These gases are used to convectively cool the integrating sphere, purge the VUV camera of moisture and oxygen and to purge the deuterium lamp calibration mount. The first two sources are connected to a nitrogen source via green tubing while the final one may be connected to either nitrogen or argon. Due to the potential large quantities of nitrogen used for purging, the nitrogen is connected to the gas boil off outlet of a liquid nitrogen dewar at the west wall of the facility. This provides a longer lasting source of pure N2 gas than a gas cylinder can. This dewar is also used to provide liquid nitrogen for cooling the InGaAs detector.

Two of the rotameters have laser based flow sensor interlocks. The laser sensor on the right side of each rotameter detects the presence of the rotameter flow ball and enables the interlock when the ball intersects the laser. In other words, the interlock is on when the flow rate matches the position of this sensor. The left sensor is not used. Deviation from this set point on either the high or low side will trip the interlock. The interlock corresponding to the integrating sphere is set near 40 sccm and controls the 600W QTH lamp. The interlock for the VUV camera is set at 5 sccm and is connected to a time delay relay which requires the purge to run for 30 min. before power is provided to the camera. The rotameter for the D2 lamp purge is not interlocked.

4.2.3.9.5 *Data Acquisition System*

The data acquisition system is housed within a VXI crate from Spectral Dynamics. Within the crate are several card slots. Presently the first 5 slots are occupied by ZT412 high speed oscilloscopes from ZTEC instruments and the next 3 slots are occupied VX2805 Data Acquisition Modules by Spectral Dynamics. The ZT412s operate 4 channels each at up to 400 MS/s. The VX2805 have 8 channels each at 5MS/s. Both cards use 16-bit digitization and are controlled by IMPAX software from Spectral Dynamics. Channels on the ZT412 are directly connected via coaxial connectors. The VX2805s use two 9-pin connectors for data acquisition. The cables for these are connected directly to coaxial patch panels directly beneath the VXI crate. The BNC inputs on each patch panel are labeled 1-8 corresponding to the 8 channels on each card. The panels from top to bottom correspond to cards from left to right within the crate.

In the IMPAX-SD software, channels are numbered sequentially from 1-36, with no obvious distinction between the cards responsible for each channel. Channel numbers therefore are read on the cards from left to right, so that channels 1-4 originate from the first ZT412 card, 5-8 from the second, and so on. The first VX2805 card therefore operates channels 21-28. The first ZT412 card serves as a master to the remaining ZT412 cards, while the first VX2805 card is the master to the second VX2805. The system trigger is configured via the first ZT412 Trig In input. The ZT412 in turn sends trigger signals via ECL0 and TTL1 on the backplane, which are used to trigger the slaved ZT412s and the VX2805, respectively. A slight mismatch on the order of 10 ns is observable between the slaved ZT412s and is attributed to trigger signal propagation time. The ZT412 trigger in may be set as an edge or level signal at any value between -1 to 1 V. The current input, which is logged on the low speed cards, is also wired to the trigger input. Because of the low range of voltages allowed on Trig In, a 10x coax attenuator is installed on this coaxial line, and the card is set to trigger when this signal reaches 0.13 V. This trigger level is chosen for similarity to the old master signal source signal, which was based on a voltage level of 13V in the absence of attenuator or additional voltage dividers. The trigger signal does require a low-pass filter to remove high frequency noise originating from the closure of relays in cap bank control circuit. A coaxial line filter with 1 MHz cutoff is employed for this purpose. The arc current is observed to have a ringing on the order of 100 kHz so is not affected by this filter.

The voltage signal from the cap bank is also recorded on the data acquisition system. Contrary to the other signals, the voltage signal is a slowly varying signal, accumulating over the course of several seconds prior to the shot. This requires a time base that is vastly difference from that of the digitizers and would not be possible to record with use of a special feature in IMPAX-SD known as “Real Time Monitor”. The Real Time Monitor collects and averages data from the VX2805 channels on a continuous basis and exports it to a log file. This function may run continuously until the cards are triggered. Therefore, to record the voltage profile along with other data, the Real Time Monitor must be started first, being set to record only the voltage signal and no others. The entire system is then armed while real time monitor is running via the Run->Manual command prior to the shot. At completion of the shot, individual channel data is stored in files of the format 0nn0nn.001, where nn is the channel number, while the real time monitor data is stored in a .log file specified by the operator. These files may then be loaded into Matlab and processed automatically using the ProcessDAS routine to produce a single file of compiled data.

Operation of the IMPAX-SD software is non-intuitive and settings should be made by individuals well trained in the operation of the program. A usage manual prepared in-house is available which is more useful for learning its operation than the IMPAX manual. In general, it is recommended to load the existing experiment as a template for new runs rather than attempting to configure all settings from scratch. Within a single test series, shot data should be collected using a single configuration file rather than creating new configuration files for each shot.

4.2.3.9.6 *Laboratory Network*

The EAST facility uses 8 computers in its operation. This includes 4 spectrometer computers (one per spectrometer/camera), an integrating sphere control computer, data acquisition system control computer, vacuum data acquisition system (VDAS) computer and a license/software server. The VDAS computer also controls the residual gas analyzer and interfaces with the PLC. These computers are all connected on a single private laboratory network which does not interface to any other internal or external network. The computers are connected by a single router. Also interfaced on the router are the PLC and two COM over IP units that interface the SRS controllers, RGA and weather station. All computers have a network-shared Z: drive which enables file interchange over the network. Furthermore, a RAID array backup system on the network automatically pulls and archives files from the computers nightly.

Six of these computers, including server, integrating sphere and spectrometer computers, are connected to a two-user KVM switch. The KVM switch feeds mouse, keyboard and monitor connectivity to these computers to one of two mobile terminal carts on opposite sides of the tube. Any one of these computers may be accessed from the cart by pressing PrntScrn. In addition, the four spectrometer computers each have a ‘local’ KVM connection over Cat5 cable that allows the spectrometers to be controlled from dedicated stations in the control room. The two data acquisition computers share a single KVM switch with terminals located both in the control room and on a stationary table in the facility. These terminals use the same KVM switch so that they simultaneously access the same computer.

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 which cover the operation of the Facility and note safety procedures and regulations. Copies of these manuals are kept in the offices of the respective Facility Manager. Every building at ARC also has a Building Emergency Action Plan (BEAP) that identifies hazards and evaculation procedures. 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 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.

To request emergency services, as for fire or ambulance, call the Ames emergency number—911 from a Center phone, or (650) 604-5555 from a cell phone.

6.0 Primary Hazards and Safety Features

Primary 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.

The facilities are located adjacent to active machine shop areas. As such, it is not allowed for personnel (including investigators) working in the facility buildings to wear open-toed shoes nor short pants. It is strongly recommended that these personnel wear steel-toe safety shoes; hearing and eye protection are required during facility operations.

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 regions of the arc heater or the test chamber. After personnel are evacuated from within the arc heater barrier enclosure and the test section, a key interlock system ensures that the barriers are in place and the test section is closed before the power supply can be energized. The hazard of arc-over from the high-voltage components 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 (7,000 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 TSF branch management during the test readiness review process.

The HFFAF test section contains 72 glass windows ranging in size from 12 to 15 in (30 to 38 cm) in diameter. These windows are inspected frequently to prevent implosive fracture. Located on top of the sabot separation tank is a 48 in (120 cm) 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 (13.8 MPa) 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 no one remains in the facility.

6.7 High Noise (Arc Jet Complex)

Inside the Arc Jet buildings and around the Arc Jet Complex are considered high noise areas. During normal operation hours, boilers, steam ejectors, cooling towers, and water pumps generate noises that may be subject to OSHA threshold. Warning signs about hazardous noise levels are posted inside the building and around the complex. When visiting NASA Ames Arc Jets, please be cognizant of all warning signs and take precautionary measures to avoid prolonged exposure to hazardous noise. Hearing protection is located at the entrance of all exterior doors, it should be utilized during testing, and or when outside of the test facility.

7.0 Emergency Procedures

Emegency procedures to be followed in the case of a facility failure are outlined in the respective facility and building 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. if the scene is safe and you are not in danger;
2. provide assistance to injured persons;
3. take action to limit or prevent further injuries or damage;
4. 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;
5. notify the Facility Manager and the Branch Chief;
6. secure the identity of witnesses; and
7. 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, as described in the BEAP.