NASA Technical Memorandum 106569

IN-09
19875
51P

# NASA Lewis Propulsion Systems Laboratory Customer Guide Manual

Ronald H. Soeder
*Lewis Research Center*
*Cleveland, Ohio*



August 1994

National Aeronautics and
Space Administration

TABLE OF CONTENTS

NASA LEWIS PROPULSION SYSTEMS LABORATORY CUSTOMER GUIDE MANUAL

Ronald H. Soeder
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

## 1.0 SUMMARY

This manual describes the Propulsion Systems Laboratory (PSL) at NASA Lewis Research Center. The PSL complex supports two large engine test cells (PSL-3 and PSL-4) that are capable of providing flight simulation to altitudes of 70 000 ft. Facility variables at the engine or test-article inlet, such as pressure, temperature, and Mach number (up to 3.0 for PSL-3 and up to 6.0 planned for PSL-4), are discussed. Support systems such as the heated and cooled combustion air system, the altitude exhaust system, the hydraulic system, the nitrogen, oxygen, and hydrogen systems, hydrogen burners, rotating screen assemblies, the engine exhaust gas-sampling system, the infrared imaging system, and single- and multiple-axis thrust stands are addressed. Facility safety procedures are also stated.

## 2.0 INTRODUCTION

This report describes the NASA Lewis Research Center Propulsion Systems Laboratory (PSL) and provides information for customers who wish to conduct experiments in it. The facility is located at the NASA Lewis Research Center (see fig. 1) in Cleveland, Ohio, adjacent to Cleveland Hopkins Airport. It is managed and operated by the Aeropropulsion Facilities and Experiments Division (AFED).

PSL provides experiment and evaluation capability in support of NASA's research and technology studies of turbine engine altitude performance and engine component evaluation. PSL also supports the Department of Defense and private industry with engine and component evaluation and verification tests.

The PSL Engine Test Building contains two large engine test cells capable of simulating flight at up to 70 000 ft. Maximum forward air speed is Mach 3.0, with a planned capability of Mach 6.0 (PSL-4 only). Each test cell is 24 ft in diameter and 38 ft in length. The air supplied to the engine for testing is pressure-, temperature-, and humidity-conditioned.

Tests may be scheduled, or more information obtained, by contacting the facility manager (see appendix A).

## 3.0 PSL DESCRIPTION

### 3.1 General Description

The PSL is part of the NASA Lewis Research Center in Cleveland, Ohio. Figure 2 shows the front entrance to the building on Durand Road and the side entrance on Westover Road. This building contains two large test chambers (designated PSL-3 and PSL-4) that are NASA's only active full-scale turbine-engine altitude test cells.

The test cells can simulate aircraft flight. This is achieved by mounting the engines in a fixed position and flowing air through the engine inlet at the stagnation pressure and temperature that matches the altitude and Mach number of flight conditions. In these test cells, flight conditions that can be simulated range from near sea level to 70 000 feet, with forward speeds of up to Mach 3.0 in PSL-3 and a planned capability to Mach 6.0 in PSL-4. The two test cells normally operate as direct-connect engine test cells that are coupled to the NASA Lewis Central Air Supply System. Atmospheric air can also be supplied to the engine inlets. PSL-4 has operated with freejets up to Mach 3.5. The altitude is simulated by evacuating the air of each test cell to produce the proper static pressure level. Large centrifugal compressors and exhausters, driven by electric motors that can produce over 200 000 hp, supply both inlet and exhaust services to the facility. Descriptions of the many types of research conducted in the PSL over the past 20 years can be found in references 1 through 21; highlights are portrayed in figure 3.

### 3.2 Test Cells

The two test chambers designated as PSL-3 and PSL-4 have been in operation since 1973. Each test chamber is 38 ft in length and 24 ft in diameter and has a test cell leg consisting of an inlet section, a test chamber section, and an exhaust section. The two exhaust sections both connect to a common exhaust plenum chamber, primary cooler, and secondary spray cooler (fig. 4). With this configuration, only one cell can be operated at a time; the non-operating cell is isolated from the exhaust by a moveable 17-ft-diameter davit valve.

Each test chamber has a main thrust bed with a maximum thrust limit of 100 000 $lb_f$, and each has a centerline that is 6 ft from the test chamber floor. Their test cell legs receive air directly from the NASA Lewis Central Compressed Air System and exhaust it to the Central Exhaust System. These systems are discussed in sections 4.1 and 4.3. The test cells are normally direct-connect altitude simulation facilities. A general operating envelope for a turbofan engine tested in PSL-3 is presented in figure 5. The basic characteristics of the PSL are presented in Table I.

The PSL facility customer can discuss the PSL combustion air and exhaust capabilities with the test conductor at a test-planning meeting held at NASA Lewis (several planning meetings are held).

In 1990 the PSL-4 test facility was modified to increase the pressure and temperature capabilities of the inlet plenum. This modification was accomplished by installing a pressure vessel inside the facility inlet plenum (fig. 6). This new pressure vessel is 30 ft 4 in. long, has an inlet diameter of 75 in., and has an outlet diameter of 108 in. A 24-in.-diameter bypass line (fig.6) draws air through the pressure vessel insert to establish test conditions. The discharge from the 24-in.-diameter bypass line is directed into a 48-in.-diameter bypass line. It is also possible to pull atmospheric air into the pressure vessel through four 30-in.-diameter ports located circumferentially around the insert near the bypass line inlet. The flow of the air through the pressure vessel insert can be improved by passing air through two perforated plates and a honeycomb structure (fig. 6). The insert also allows testing of freejets, core engines, turbine engines, high-Mach-number engines, and hypersonic rigs. Figures 7 to 11 show the various plenum vessel insert configurations, along with other hardware that can be installed, to conduct these five tests. The maximum conditions inside the plenum insert are listed on the figures. As a result of the pressure vessel insert, test conditions achievable in the PSL have increased to a massflow of 380 $lb_m$/sec at 165 psia and 1200 °F. The specific requirements of the facility customer can be discussed with the facility manager and the PSL project engineer at one of the test-planning meetings held at NASA Lewis.

### 3.3 Control Room

A control room (fig. 12) is located on the first floor of the PSL building. Engineers and technicians are positioned in the room as shown in figure 13. The consoles in the front of the control room are used by those who operate the controls, the engine or test article, the combustion air, and the exhaust. The consoles in the

TABLE I.—PSL CHARACTERISTICS

| | |
|---|---|
| Test cell | |
| Diameter, ft | 24 |
| Length, ft | 38 |
| Engine centerline height above thrust bed, ft | 6 |
| Mach number range | |
| Cell 3 | 0 to 3.0 |
| Cell 4 | |
| Current | 0 to 4.0 |
| Planned | 0 to 6.0 |
| Altitude range, ft | 0 to 70 000 |
| Inlet air supply | |
| Pressure range, psia | |
| Cell 3 | 0.5 to 55 |
| Cell 4 | 0.5 to 165 |
| Temperature range, °F | |
| Current | −60 to +800 |
| Planned for Cell 4 | 1100 |
| Massflow[a] range, $lb_m$/sec | 0 to 480 |
| Exhaust capability | |
| Pressure range, psia | atm to 0.2 |
| Massflow,[a,b] $lb_m$/sec at sea level | 750 |
| Test cell cooling air[c] | |
| Pressure range, psia | 40 to 150 |
| Massflow range, $lb_m$/sec | 0 to 100 |
| Fuel supply | |
| Flow rate, gal/min | 0 to 200 |
| Pressure range, psia | 0 to 65 |
| Thrust measurement capability, $lb_f$ | |
| Horizontal axis | 50 000 |
| Vertical axis | 15 000 |
| Lateral axis | 15 000 |

[a]Limited to Central Air Services capability.
[b]Varies with altitude.
[c]Sum total of inlet air supply and test cell cooling air cannot exceed capability of Central Air Services System.

middle of the control room are reserved for the PSL project engineer, the PSL operations engineer (test conductor), and the research engineer. If any other AFED engineers are necessary to support the test run, they will also be stationed in the middle of the room.

Each console has controls and readouts appropriate to the specific tasks of the operators and engineers who operate and monitor the facility and the engine or test article. For example, the facility is operated from an interactive, color graphic distributed-control system, known as the Westinghouse Distributed Processing Family (WDPF); see section 6.0 for details of this system. The engine conditions are set and monitored from the controls and instrumentation located at the engine operator's station. Similarly, the test-cell airflow rate is set from controls located at the combustion air operator's station. The test article itself (e.g., turbojet, turbofan, or turboshaft engine, high-Mach-number turbine engine, supersonic freejet, etc.) can be remotely viewed from monitors in the control room.

A data room is located on the second floor, above the control room (fig. 4). It contains a NASA Lewis data acquisition system (Escort D Plus) and a personal computer that controls the electronically scanned pressure system (ESP), from which most of the engine or test-article and test-cell pressures are obtained. Escort D Plus is an interactive system that can collect, process, and display computed test results in real time. Refer to sections 7.1 and 7.2 for more details on these systems.

The entire PSL facility, including the test cell, control room, data room, and flutter instrumentation room (located in the basement of the PSL building), can be completely secured for sensitive test programs. The need for security should be discussed with the PSL facility manager and the PSL project engineer during one of the test-planning meetings.

## 4.0 GENERAL SUPPORT SYSTEMS

### 4.1 Combustion Air System

4.1.1 Main supply systems.—Equipment in the Lewis Research Center Combustion Air Equipment Building (CAEB), adjacent to PSL, provides compressed air to the two PSL test cells. However, only one test cell can operate at a time since the cells share a common air supply, exhaust supply, and exhaust gas cooling system. Combustion air is delivered to PSL-3 and PSL-4 (fig. 14) by four sets of 55-psia centrifugal compressors. The air flow rates can be varied from 225 $lb_m$/sec to 480 $lb_m$/sec at 60 °F by adjusting the exit guide vanes of the centrifugal machines. Two sets of boost compressors may be used to raise the air pressure to a maximum of 165 psia at a temperature of 100 °F, with a reduction in flow capacity to 380 $lb_m$/sec.

4.1.2 Twenty-inch line with 40- or 150-psig system.—The PSL test cells receive cooling air at 40 or 150 psig from compressor equipment in the CAEB. The cooling air flows through a 20-in.-diameter line that is part of the PSL facility; it is processed by a turboexpander and is available as compressed air at the following conditions: (1) at 55 psia at an inlet temperature of 100 °F and a flow rate of 100 $lb_m$/sec; (2) at 165 psia at an inlet temperature of 100 °F and a flow rate of 76 $lb_m$/sec; and (3) at 20 psia at -20 °F and a flow rate of 30 $lb_m$/sec.

4.1.3 Ten-inch line with 450-psig system.—High pressure compressor equipment in the CAEB sends cooling air at 450 psig to the PSL test chambers through a 10-in.-diameter line that is part of the PSL facility. The maximum capacity of cooling air available is 465-psia compressed air at an inlet temperature of 100 °F and a flow rate of 38 $lb_m$/sec.

### 4.2 Heater/Refrigeration Building

4.2.1 Heated-combustion-air system.—The PSL Heater Building (also called the Heater/Refrigeration Building) was designed and built to provide high temperature combustion air to PSL-3 and PSL-4. Combustion air from the CAEB flows through two heat exchangers in the Heater Building (fig. 15), where it is heated to some predetermined temperature. The heated combustion air then returns to the main combustion air line where it blends with lower temperature air. The resultant combustion-air temperature is regulated by a butterfly valve that controls the flow rate through and around the heat exchangers.

Each of the two nonvitiated heat exchangers in the Heater Building is designed to heat the 150-psig air to a temperature of 1200 °F, with a maximum flow rate of 140 $lb_m$/sec. The air is heated by exhaust gas from two Pratt and Whitney J-57 engines that burn Jet A fuel. The J-57 engines are controlled and operated from the PSL main control room. Each J-57 engine is coupled to a natural-gas-fueled afterburner that was designed and built by NASA. The resultant temperature of the combustion gas is limited by the material used to design the two counterflow heat exchangers. The PSL project engineer can discuss this point with the PSL customer.

Inlet air for the J-57 engines comes into the Heater Building through a large door in the basement of the building; it then flows up through the heater room floor, circulating through the Heater Building and into the J-57 bellmouths. When the two J-57 engines are running, the air in the building is continuously being passed over the engines to cool them. The J-57 combustion gas flows through a group of parallel tubes and exhausts to the atmosphere via a vertical silencer stack. The combustion air comes into the heat exchangers, which are horizontal, at the hot gas outlet end (fig. 15) and flows counter to the heating fluid.

4.2.2 Cooled-combustion-air system.—The refrigeration equipment in the Heater/Refrigeration Building adjacent to the PSL consists of three turboexpanders that can be configured in parallel to lower the inlet air conditions at the PSL test cells to the following: temperature, -50 °F; pressure, 25 psia; and flow rate, 110 $lb_m$/sec.

## 4.3 Altitude Exhaust System

Four sets of exhausters matched to the flow capability of the test cell produce altitude exhaust in the facility exhaust plenum. Butterfly valves positioned both upstream and downstream of the exhausters are adjusted to propel the exiting combustion air. Maximum flow capacity of the exhaust system is 750 $lb_m$/sec.

## 4.4 Cooling-Tower Water and Spray Systems

Cooling towers and spray coolers cool the water for the facility, the special research needs, the Heater/Refrigeration Building equipment, the combustion air system, and the altitude exhaust system.

Two cooling towers equipped with seven pumps can provide 100 000 gal/min of cooling water to the PSL complex. The main function of this water is to cool those facility components that are subjected to high temperature gases. These components are the exhaust duct and plenum chamber (fig. 4), the davit valve (a valve in the exhaust plenum chamber used to block off the PSL test chamber path that is not being used), the combustion-air lines, and the inlet section to the PSL-4 test chamber.

Other important facility cooling functions are provided by the primary and secondary coolers (fig. 4). The primary cooler is a water-cooled heat exchanger array consisting of 3000 tubes arranged in 20 rows (banks). It cools the hot exhaust gases from the test article to 600 °F before the gases enter the spray coolers. The spray cooler system is the secondary cooler. It consists of 2 spray pumps, each operating at a flow rate of 2000 gal/min and at a pressure level of 350 psig, and 3 banks of spray nozzles (i.e., 172 individual nozzles). This system further cools the exhaust gases from the test article—to 150 °F or less—before these gases enter the CAEB altitude exhaust line. The spray coolers also scrub unburned hydrocarbons from the engine exhaust.

## 4.5 Research Hydraulic System

Two hydraulic pumps can pump hydraulic oil (Mil-H-83282) with a flash point of 400 °F to the PSL-3 and PSL-4 test chambers at a rate of 50 gal/min and a pressure of 3000 psig. The hydraulic system can also actuate valves associated with the engine or test article and the test hardware systems. Additional applications for this system can be discussed with the PSL project engineer at one of the test-planning meetings.

## 4.6 Liquid Fuel System

Liquid fuel for engine testing is stored underground in two 25 000-gal fiberglass tanks at the facility site. Each tank is connected to a 200-gal/min centrifugal pump that transfers the fuel from the tanks to the PSL test chambers at 50 psig. The piping and the components of the system are constructed of stainless steel. The fuel is sent through a water separator and, if required, through a steam heat exchanger (to be preheated to 300 °F) prior to entering PSL-3 or PSL-4. One of the fuel storage tanks is reserved for Jet A/JP-5 fuel. The other is reserved for special fuels requested by the customer, providing the facility manager approves.

## 4.7 Gas Supply Systems

4.7.1 Natural gas system.—Natural gas enters the Heater/Refrigeration Building at a pressure of 45 psig. In the building it diverges, flowing into two lines that feed the afterburners which are coupled to the two J-57 engines. On each of these feeder lines is a hand valve, a remotely operated valve, and a throttle valve, the latter operated by the facility computer or the engine operator. A natural gas igniter supply line also feeds into each afterburner. These lines each have hand and remotely operated valves for isolating the igniter system supply. There is also a remotely operated valve outside the Heater Building for this purpose. If the entire Heater Building needs to be isolated from the natural gas supply, there are two valves that serve this purpose, a remotely operated valve and a hand valve. These valves are located in a pit between the PSL Building and the Heater/Refrigeration Building.

4.7.2 Gaseous nitrogen system.—There are two gaseous nitrogen bottles located in a pit between the PSL facility and the Heater/Refrigeration Building. These bottles contain 18 300 standard $ft^3$ (SCF) of nitrogen at a pressure of 2400 psig. These nitrogen bottles are for general facility use. In addition, there are two 70 000-SCF nitrogen trailers at a pressure of 2400 psig located in the north parking lot at the rear of the Heater Building (fig. 16). They can be tied into the nitrogen bottles for added capacity. The nitrogen gas is used to purge the natural gas lines that feed the NASA afterburners which are coupled to the two J-57 engines; however, the pressure of the gaseous nitrogen must be reduced to 75 psig before it can be used to purge the natural gas lines in the Heater/Refrigeration Building. The gaseous nitrogen is also used to purge the facility's gaseous hydrogen system (sec. 4.7.3) and to supply nitrogen to test articles installed in PSL-3 or PSL-4. The facility's oxygen system is purged with nitrogen from a 70 000-SCF nitrogen trailer located in the south parking lot of the PSL facility (fig. 16).

4.7.3 Gaseous hydrogen systems.—There are two separate gaseous hydrogen systems at the PSL complex. The first system consists of three 70 000-SCF trailers (fig. 16) that provide gaseous hydrogen fuel to either PSL-3 or PSL-4, thereby giving each cell the capability of producing turbojet or turbofan engine inlet distortion and high temperature turbine exhaust gas simulation. The trailers are connected to one manifold located in the north parking lot at the rear of the Heater Building. Separate supply lines deliver the gaseous hydrogen to the inlet plenums and cell areas of PSL-3 and PSL-4. Each line has its own remotely operated isolation valve. The three-trailer system was designed to supply up to 1 $lb_m$/sec at 350 psig. The maximum supply pressure is 2400 psig and the minimum, 700 psig. The trailer pressure can be reduced via two pressure regulators in series. Typically, the gaseous hydrogen provided to either cell has been in the 100- to 200-psig range. The flow to each cell can be measured at a high-flow or low-flow measurement station, which consists of a venturi and a remotely operated selector valve. Each cell can be isolated from the system by a remotely operated valve located outside the PSL building.

The second hydrogen system serving the PSL provides hydrogen fuel to test articles in PSL-4 at up to 2.75 $lb_m$/sec at 1000 psig. This system (fig. 16) can accommodate up to five 70 000-SCF hydrogen tube trailers at pressures up to 2400 psig. All five trailers are connected to a common manifold. When the pressure of the hydrogen supply in the manifold decreases to approximately 250 psig above the required test-article supply pressure (which happens as the hydrogen is used), testing is halted.

As the gaseous hydrogen is used by a test article, there is a possibility that the unburned hydrogen could accumulate in the PSL exhaust system; if it is not disposed of properly, an explosion could result and cause injury to personnel or damage to the facility or exhaust equipment. To prevent or detect such accumulations of flammable mixtures (ref. 22), dilution air, hydrogen-sensitive detectors, and hydrogen-air torches are used.

4.7.4 Gaseous oxygen system.—The PSL oxygen system consists of three 70 000-SCF oxygen tube trailers located in the PSL south parking lot (fig. 16). Piping is already in place from the trailers to PSL-4 to accommodate research activities. The gaseous oxygen flows at 11.5 $lb_m$/sec and 2400 psig to PSL-4 through a 4-in.-diameter line. Valves in the piping system split the main supply line into two lines for delivering gaseous oxygen to the facility; flow rates of 10 $lb_m$/sec at 300 psig or 3 $lb_m$/sec at 1000 psig can be selected to accommodate a test-article's requirements. The supply pressure of the gaseous oxygen can be kept below 2400 psig to accommodate research requirements.

4.7.5 High pressure air system.—An auxiliary high pressure air system is in place at PSL-4 to accommodate research activities. A trailer stand adjacent to the PSL can accommodate one trailer carrying high pressure air at 2400 psig. The facility's pipeline (1-in.-diam.) can deliver high pressure air to PSL-4 at 1200 psig (other pressures are available) and a flow rate of 1 $lb_m$/sec.

4.7.6 Service air and instrument air system.—Service air or instrument air, which is supplied at 125 psig, is sometimes used to cool both facility and engine instrumentation. In addition, service air is used to actuate pneumatic valves and, at rare times, to start the engines that are being tested. A 3-in. supply line extends to each cell, providing air to the engine-starting motor.

4.7.7 High pressure steam system.—There is a high pressure steam system for research activities in PSL-3 and PSL-4. The facility piping can deliver 100-psig steam at 300 °F and a flow rate of 5 $lb_m$/sec. This high pressure steam system has previously been used in gas-sampling studies.

## 4.8 Specialized Research Systems

4.8.1 Rotating screen assemblies.—Two rotating screen assemblies are used to produce pressure distortion at the inlet to a turbine engine. They can accommodate a 34.8- or 44-in. inlet to a turbofan engine. Figure 17 shows the 34.8-in. rotating screen assembly. From the facility control room, it can be rotated with an electric motor to within ±1° of a given circumferential location. A screen mesh of the desired extent and blockage can be wired to the face of the screen assembly to produce the specified inlet distortion effects. Figure 18 shows a rotating screen assembly installed in the inlet ducting upstream of a high-bypass-ratio turbofan engine. A detailed description of the effects of steady-state pressure distortion at the inlet of low- and high-bypass-ratio turbofan engines is given in references 23 and 24.

4.8.2 Hydrogen burner.—A gaseous-hydrogen-fueled burner that is used to produce steady-state or time-dependent temperature disturbances at the inlet of a turbine engine is presented in figure 19. The burner is installed in the facility plenum upstream of the inlet duct bellmouth. Two burner assemblies are available to accommodate engines with inlets that vary from 34.8 to 44 in. The burner, which is divided into four individually controlled quadrants, can be rotated ±30° from the center position. Air passing through the burner can be heated in selected quadrants. References 25 to 29 describe the distortion to both low- and high-bypass-ratio turbofan engines caused by inlet steady-state temperature and combined steady-state pressure and temperature.

During time-dependent experiments, a high response valve on each burner quadrant ensures a uniform flow of hydrogen gas from each quadrant of the hydrogen burner to the engine inlet. This valve goes from fully closed to fully open in 3 msec. Time-dependent temperature distortion at the inlet to a low-bypass-ratio turbofan engine is discussed in references 30 and 31.

4.8.3 Exhaust gas sampling.—The apparatus used to measure pressure and temperature data of the engine exhaust at the nozzle is shown in figure 20. The rake is mounted vertically on a motor-driven actuation system that provides for both lateral and vertical movement. During engine operation, the pressure and temperature probes are located 1 in. downstream of the exit plane of the engine exhaust nozzle.

The configuration of the probes on the instrumentation rake is shown in figure 21. The water-cooled instrumentation rake body contains three total-pressure sensors and two unshielded wedge-type thermocouples. The total-pressure tubes are made of a platinum–13-percent-rhodium alloy, and the thermocouple wires are made of an iridium-iridium–40-percent-rhodium alloy. A detailed description of a survey test of the turbofan engine exhaust is presented in reference 32.

4.8.4 Infrared imaging system.—There are three complete infrared imaging systems available in PSL to meet research needs. Each system consists of an imager with an internal detector that collects infrared energy and an electronics processor unit that converts the detector output to a temperature-related gray scale and then creates a color output display. The infrared imager (camera and internal infrared detector) can be mounted outside or inside the test chamber, depending on the specific research requirements, and the entire system can be operated remotely from the facility control room. A schematic of a infrared system that is typical of those used in PSL is presented in figure 22. The specifics of these systems can be discussed with the PSL electrical engineer at one of the test-planning meetings. A detailed discussion of data recorded by an infrared imaging system is presented in reference 33.

4.8.5 Marquardt heater system.—The Marquardt heater system consists of four hydrogen-fueled, air-cooled sudden expansion (SUE) burners that are arranged in parallel and are used to raise the temperature of the air needed for high-Mach-number research applications. This heater was designed to operate with inlet air at temperatures up to 600 °F, and at pressures, temperatures, and total air flow rates ranging from 2 to 65 psia, 59 to 2700 °F, and 3 to 70 $lb_m$/sec, respectively. The combustion process produces vitiated air; thus there may be a need for makeup oxygen. In PSL-4 the three-trailer gaseous hydrogen system fuels the Marquardt heater. The pressure vessel insert used in the facility inlet plenum is shown in figure 6, and the piping from the inlet plenum to the Marquardt heater in the test chamber is presented in figure 11.

### 4.9 Exhaust System Periscopes

Both PSL-3 and PSL-4 are equipped with an exhaust system periscope. These instruments are positioned, respectively, on the centerline of the test chamber and in the exhaust collector. Their function is to view the exhaust plume of a turbojet or turbofan engine. The periscope instrument, which has a viewing port made of quartz, is coupled to a video camera. This camera, in turn, is connected to a control room monitor that allows remote qualitative inspection of the engine exhaust plume. A tape of the monitor display can be made with a video cassette recorder.

### 4.10 Thrust Measurement System

4.10.1 Facility single-axis stand.—Single-axis thrust is measured with a single-axis thrust bed (ref. 34). In each chamber the bed is suspended by four multiflexured vertical rods that are attached at their upper ends to the chamber walls. The bed's alignment with the airflow direction is maintained by two multiflexured horizontal rods located at the front and rear of the thrust bed. The thrust bed is restrained from free movement by a dual-load-cell system that allows the bed to be loaded before thrust is measured. This dual-load-cell system can also be used to determine the metric system spring and drag forces during prerun thrust calibrations. The maximum strain gauge capacity of load cells used to measure the thrust of an afterburner-equipped engine is 50 000 $lb_f$. An engine program, however, may dictate the use of smaller capacity load cells to match smaller engine thrust capability. The load cells are independently calibrated and mounted beneath the thrust bed. The configuration for single-axis thrust measurement of an afterburner-equipped turbojet engine is presented in figure 23.

4.10.2 Ormond multiaxis stand.—Multiaxis thrust is measured by using one of the two six-component precision thrust measuring systems, manufactured by Ormond, Inc. The differences in the two systems are (1) the thrust measurement capacity (40 000 $lb_f$ for the PSL-3 stand and 50 000 $lb_f$ for the PSL-4 stand) and (2) the arrangement of the axial calibration load cells. The PSL test conductor can discuss the differences in the two systems with the customer at one of the test-planning meetings.

An isometric drawing of the Ormond thrust stand used in the PSL is presented in figure 24. The Ormond system is mounted to the test cell with a three-point suspension adapter located beneath the floor. The adapter isolates the test article from any facility test-bed bending, torsional stresses, or deflections. The test article is held atop the thrust bed by an engine mount adapter (fig. 25), which cradles the engine, nozzle, or afterburner while transferring the forces to the Ormond system. The Ormond system is composed of a metric (live) bed, an isometric (fixed) bed, and an in-frame calibration system. Measurements can be made in the axial, horizontal, and vertical directions as well as in the pitch, yaw, and roll moment planes. Twenty-two load cells are used for calibration and measurement. Eight of them are for in-frame calibration—two in the axial direction, two in the horizontal direction (one each in the thrust-bed forward plane and aft plane), and four in the vertical direction (one at each corner of the thrust bed). The remaining 14 load cells are measurement cells distributed as follows: two in the axial direction, two in the forward horizontal direction, two in the aft horizontal direction, and two in the vertical direction at each test-bed corner. The placement of the load cells is specific and serves to eliminate interactions. Figure 26 shows the location of the thrust and calibration load cells in the Ormond stand.

## 4.11 Inlet Systems

4.11.1 Bellmouths.—Conditioned air is directed from the facility inlet plenum chamber through an uncalibrated bellmouth. A typical bellmouth inlet ducting arrangement is presented in figure 27. Various bellmouths are available to accommodate the inlet diameters of both turbojet and turbofan engines. Special configurations have been used to accommodate turboshaft engines. The inlet bellmouths available at the PSL facility have exit diameters of 21, 27, 32.4, and 44 in.

4.11.2 Inlet flow measurement.—The total engine airflow is determined with boundary layer rakes and area integration. The inlet flow measurement station, designated as station 1 (fig. 27), contains thermocouples for measuring steady-state duct metal temperatures and steady-state total pressures and static wall pressures. The steady-state total pressures are composed of boundary-layer and free-stream pressure measurements. These steady-state measurements are fed into a computer code that computes the flow rate of inlet air to the engine face. A typical circumferential layout for such instrumentation at station 1 is presented in figure 28.

## 4.12 Electrical Systems

At the PSL test chamber the following types of 60-cycle, alternating current, electrical power are available:

| Type | Voltage |
|---|---|
| Three phase | 440 |
| Three phase | 208 |
| One phase | 120 |

# 5.0 FACILITY OPERATION

## 5.1 Standard Operating Procedure

In both PSL test cells, detailed check sheets are used, which include facility setup procedures, engine or test-article operational procedures, engine or test-article and facility shutdown procedures, and PSL personnel response procedures to an emergency condition (sec. 5.2). The PSL test conductor and the PSL electrical engineer will meet with the customer (i.e., research engineer) to discuss the content of the mechanical and electronic check sheets at one of the test-planning meetings. The check sheets can be modified or tailored to meet the requirements of each research program as long as safety is not jeopardized.

## 5.2 Response to an Emergency Condition

When an emergency arises, the PSL test conductor shall be the individual charged with directing all PSL personnel, AFED personnel, research engineers, and non-NASA individuals in the PSL control room during the engine test. The PSL test conductor is responsible for the safe shutdown of the facility and the test article. Responses to facility and test-article anomalies or to emergency shutdowns (such as overspeed or stall of the compressor, high vibrations in the turbine or the compressor, etc.) should be discussed with the PSL customer and approved by the test conductor. Such responses shall be documented in the project safety manual, and reviewed and approved by the Area Safety Committee.

## 5.3 Facility Protection Procedures

Some potential facility hazards include overpressurization of the test chamber or exhaust duct, breaks in the hydrogen line, and penetration of the test chamber by failed engine parts. The facility has been designed to prevent overpressurization through the placement of relief caps in the test cell movable lid, and relief hatches in the primary cooler region of the facility (fig. 4).

The four pressure-relief caps in each test cell movable lid open when the pressure differential across the test chamber lid is 0.16 psi above atmospheric pressure. When the pressure differential across the test chamber lid becomes 0.75 psi above atmospheric pressure, the total vent flow rate is 150 $lb_m$/sec at 250 °F.

Eight relief hatches in the primary cooler open up when the pressure differential across the test chamber lid is 0.43 psi above atmospheric pressure. This pressure-relief system vents the test chamber, exhaust duct, and the exhaust plenum areas. The total flow rate of the relief hatches is 560 $lb_m$/sec at 600 °F.

There is one more facility pressure-relief feature: the locking latches on the test cell lids fail if the test cell internal pressure exceeds 4 psi above atmospheric pressure.

High hydrogen-gas-detector readings or alarms and loss of line pressures require that valves be closed automatically and that the test conductor decide whether to vent hydrogen lines in the test cell. The proper action must be taken to prevent a hydrogen explosion.

The current facility operating procedure minimizes the hazard associated with penetration of the test chamber hatch. A containment shield is placed over the turbine region of all engines tested in PSL-3 and PSL-4. In addition, during a test in the facility, PSL personnel are not permitted to be in the vicinity of the test chambers (specifically in the plane of rotation of the test engine).

## 6.0 INSTRUMENTATION

Test-article and test-chamber instrumentation may include any combination of electronically scanned pressure modules, individual pressure transducers, thermocouples, strain gauges, accelerometers, potentiometers, and such. Measurements taken by these instruments can be monitored and recorded by the facility data acquisition system (Escort D Plus, see sec. 7.2) or a PSL customer-supplied data acquisition system.

The output of facility instrumentation used to operate PSL-3 and PSL-4 is normally displayed on the Westinghouse Distributed Processing Family (WDPF) system. The WDPF system is a supervisory control and data acquisition system that can execute high-speed control algorithms. It contains a universal programmable controller that interfaces with numerous facility subsystems (e.g., primary cooler, secondary cooler, altitude exhaust line, etc.). In addition the WDPF system can also perform such data acquisition functions as data scanning and processing; alarm monitoring and reporting; data collection, storage, and retrieval; and numerical calculations. Although the WDPF system is primarily monitored by the PSL test conductor, hard copies of its displays may be requested by the research engineer. Most of the PSL test chamber instrumentation output is also duplicated on the Escort D Plus data acquisition system (each test cell has its own dedicated system). If required, hard copies of these displays can be obtained by the research engineer in the control room. On each of the two Escort D Plus systems, 256 analog channels are reserved for PSL customer-defined model instrumentation. Other data recording devices can be used to supplement the Escort D Plus system (see secs. 7.3 and 7.4). Requirements for data acquisition, processing, and recording should be covered in early test-planning meetings.

At each test cell there are 300 thermocouples available for use by the PSL customer (research engineer). (All thermocouples used in engines or test articles must be made of high-temperature wire.) These thermocouples are connected to leads that run from the engine or test article to facility terminal panels. At the terminal panels, alloy wiring extends from jacks thereon to thermocouple junction reference units (the temperature of the wire junctions within these reference units is held at 150 °F ±0.05 °F). Cables run from the reference units to patchboards that are housed in the second floor data room of the facility.

The type and number of thermocouple circuits available at the PSL-3 and PSL-4 thermocouple terminal panels are given in table II.

Table II.—THERMOCOUPLE CIRCUITS

| Quantity | Wire (ISA) | Type |
|---|---|---|
| 480 | Chromel/alumel | K |
| 24 | Platinum/rhodium | B |

The Escort D Plus system can accommodate a total of 480 thermocouple measurements to satisfy both facility and research requirements (this includes both Type K and Type B thermocouples). Details such as these can be discussed with the PSL test conductor at one of the test-planning meetings.

## 7.0 DATA ACQUISITION AND PROCESSING

### 7.1 Electronically Scanned Pressure System

Each of the test cells has an electronically scanned pressure (ESP) system that provides highly accurate measurement of steady-state test-article and facility pressures. Each system uses 32 plug-in modules, each of which contains 16 individual transducers that are addressed and scanned at the rate of 10 000 ports/sec. The module transducers cover a range from ±15 psid to +500 psia and can provide a total of 480 test pressure measurements plus 32 reference pressure measurements. Reference and check pressures are obtained from remotely controlled regulators.

All transducers are normally calibrated automatically online every 20 min, when a pneumatic valve in each module switches the system into a "Calibrate" mode. Three calibration pressures, which are measured with precision digital quartz transducers, are applied in up to three ranges to ensure that electronic system errors are not greater than ±0.1 percent of full scale.

### 7.2 Escort D Plus

The NASA Lewis Escort D Plus system is a minicomputer-based, real-time data-acquisition display and recording system that is generally applicable to steady-state tests. Analog data from measurement transducers are digitized and then acquired by a MicroVAX 4000-300 computer (for PSL-3) or a MicroVAX 3800 computer (for PSL-4). Recorded data for unclassified projects are transmitted through a network link to a mainframe computer in the Research Analysis Center (RAC) for later processing if desired. Appropriate provisions exist for handling sensitive data. Real-time processing tasks typically include acquiring data, converting raw counts to engineering units, performing online calculations, updating facility display devices (both alphanumeric and graphical), and transmitting data for archival recording on a data collector. Figure 29 shows the flow of information between the facility computer and the RAC computers. A detailed block diagram of the facility computer is given in figure 30. Update time for a standard program is 1 sec. Data can be acquired and processed by using standard data software or software specifically designed and programmed for a particular test. Processing requirements can be discussed at one of the test-planning meetings.

7.2.1 Real-time displays.—A customized Escort D Plus output program displays all data channels and computations for a given test program in an alphanumeric format. This output can be displayed on a variety of control room and data room CRT's. A detailed description of the CRT displays is presented in appendix B. In the control and data rooms, PSL has 12 alphanumeric color CRT's and 2 graphics CRT's, which provide a means of monitoring the progress of a test and displaying the data sets. These 14 CRT's can be switched to either the PSL-3 or PSL-4 Escort D Plus data acquisition system, depending on which test cell is in use. Two of the CRT's are dedicated to the test-article operator and the facility operator. Three others are reserved for use by the PSL test conductor, the PSL project engineer, and the PSL customer (research engineer). The remaining nine CRT's are for the AFED support engineers and other research engineers. Each CRT can view any display at any time. There are also two laser printers for printing hard copies of the data being displayed on the CRT.

Online plots can be defined through a graphics specification language. The initial graphics specification is done by the Escort programmer, but changes can be made at the facility through an interactive editor. Plots and alphanumeric information displayed on the CRT's can be changed at any time.

With individual data displays (IDD's), specific test parameters defined by the test conductor and the customer can be highlighted during a run. Each IDD is individually addressable and accommodates two lines, each with twenty 0.375-in.-high alphanumeric characters. Cursor addressing allows data labels to be fixed and the data to be updated every second.

Each CRT has special function buttons that allow the PSL customer to control display functions, such as subsets of test parameters and data in different units (i.e., engineering units, millivolts, or counts), and to print the data being displayed on the CRT.

7.2.2 Data collection.—When a customized data software module is installed on the Escort D Plus system and the data "Record" button is activated, all data channels are scanned once, saved on the data collector, and assigned a unique reading number. In addition, a selected number of data scans can be averaged and saved as one reading number. Real-time data processing is available for those whose requests include the calculation of ratios or engineering parameters. Extremely rigorous computing or across-scan computing should be performed offline by using the Center's central mainframe computers to obtain the desired output; this ensures an update time of 1 sec.

If multiple or continuous high-speed scan cycles are needed to define a test condition, a customized data software module other than that previously noted must be created and used on the Escort D Plus system. Activating the data "Record" button would then result in automatic multicyclic scanning per reading, as defined in the customized module. Multicyclic data are usually applicable to slow transient tests or moving probe hardware.

## 7.3 Control Room Plotting Equipment

The PSL control room is equipped with two Masscomp 5550 digital computers that can monitor 32 channels of data. The computer can scan at a rate of 50 samples/sec/channel, and it can monitor these channels over the course of a test evening and store the results in a circular buffer which holds in excess of 100 million samples. Furthermore, the computer can operate on the data channels monitored and develop parameters such as pressure ratio and corrected weight flow. These parameters can be plotted in an x-y relationship (i.e., one as a function of the other).

## 7.4 Dynamic Data Acquisition

7.4.1 Facility tape recorders.—There are four tape recorders available in the PSL control room to record data. Each test chamber is assigned 2 of these 14-track tape recorders. One of them monitors safety requirements of the engine or test article (i.e., engine vibrations, turbine temperature limits, bearing temperature limits, strain gauge levels, etc.). The other one can be used by the research engineer as required to monitor data.

7.4.2 Electrostatic recorders.—There are two Gould Electronics electrostatic ES 2000 recorders in the PSL control room. These recorders consist of (1) a data acquisition and control unit, (2) an electrostatic paper writer, (3) a display screen, and (4) a keyboard. Each recorder can utilize digital or analog input/output modules to acquire data from various sources (signal conditioners, sensors, computers, etc.). The data can then be displayed on the electrostatic writer (visicorder) or on the display screen. The control unit, which can be programmed from the keyboard or from an outside computer, has easy access to a 3.5-in. disk drive for making backup diskettes of the programming adjustments, settings, and texts prepared for a recording configuration. Each recorder can accommodate up to 20 different signals. If 20 or fewer signals are monitored, then the frequency response on the display screen is easy to inspect visually. The facility electrical engineers are available to discuss the detailed functions of these recorders at the test-planning meetings.

7.4.3 Transient data acquisition system.—The transient data acquisition and reduction system is located in the facility data room. The main components of the system are a facility host computer with data acquisition and the front-end signal conditioning hardware. This system can receive inputs from 256 shielded analog lines that run from the engine, test article, or various points in the facility to the transient data acquisition system. The outputs of such measuring devices as high-response pressure transducers, high-response thermocouples, strain gauges, accelerometers, and vibration and speed pickups can be sent along these shielded analog lines to the data acquisition system. Data recorded during an experiment are stored on disk and can be processed either at the PSL facility or at a later date at the RAC building. Sampling rates of 660 kHz/sec (aggregate divisible by the number of channels) will be stored on 1.5 GB of disk storage.

## 8.0 PRETEST REQUIREMENTS

The PSL facility is scheduled for continuous testing throughout the year, so it is advisible to contact the facility manager (see appendix A) at least 1 year in advance of the desired test time. Early notification will allow the facility manager and the appropriate PSL personnel to review the proposed engine or test-article installation and to ensure compatibility between the engine or test article and the PSL test chamber. A formal request to use the PSL test chamber should be sent (by non-NASA requestors only) to the Director of Aeronautics at NASA Lewis. Pertinent information regarding the formal letter of request can be obtained from the facility manager.

On receipt of a formal request for PSL test time, the Director of Aeronautics will review the project with the facility manager. If the project is accepted, a test agreement will be prepared and sent to the requestor (non-NASA requestors only) to be signed and returned. The test agreement outlines the legal responsibilities of NASA Lewis and the PSL customers during the time the project is at the Center (from engine or test-article arrival, through test time and engine or test-article return).

There are four types of test agreements, depending on the participants. They are categorized as follows:

(1) NASA test program
(2) NASA/industry cooperative program (nonreimbursable Space Act agreement)
(3) Other U.S. Government agency program (reimbursable or nonreimbursable interagency agreement)
(4) Industry proprietary or noncooperative program (reimbursable Space Act agreement)

The PSL customer should prepare a requirements document and make it available to the facility manager and the PSL test conductor at the first test-planning meeting. The facility manager will tell the PSL customer what topics should be addressed in this document. The procedure for obtaining PSL test time is outlined in appendix C.

### 8.1 Pretest Agreement

Before a test is run in PSL, a series of test-planning meetings are held at NASA Lewis to discuss the test plan, the engine or test-article instrumentation, the hardware that is to be installed in the test chamber, and the data requirements. The number of test-planning meetings held will usually be a function of the complexity of the test. Those who should attend this meeting are the requestors (e.g., the research engineers), the PSL manager, the PSL Branch Chief and Deputy Branch Chief, key PSL personnel, AFED engineers, and application programmers from the RAC, if required.

8.1.1 Test objectives.—The PSL customer should submit a statement indicating the test objectives and thoroughly explaining any special test procedures. The customer's lead engineer should provide a prioritized run schedule that is compatible with the available test window.

8.1.2 Engine or test article and associated hardware.—At the direction of the PSL project engineer, the Engineering Directorate at NASA Lewis will prepare the drawings of the engine or test article and its supporting hardware installed in the PSL test chamber. The customer will pay for the preparation of the drawings.

8.1.3 Instrumentation.—The PSL customer should provide the PSL project engineer with a list of instrumentation that must be adapted to the PSL data system (secs. 6.0 and 7.0). If the customer's data system is to be used, this point should be discussed with the PSL project engineer and the PSL facility electrical engineers at one of the test-planning meetings.

8.1.4 Data requirements.—Data reduction information consisting of data inputs, data outputs, and calculations must be provided for cases in which NASA Lewis reduces the data for the customer. The customer (non-NASA requestors only) shall forward this information to the PSL project engineer 6 months before the start of testing in the facility. The PSL project engineer will contact the appropriate personnel in the RAC and set up any necessary meetings between the PSL customers and the RAC application programmers to establish the groundrules for a computing requirements package writeup. The final computing instructions are due from non-NASA PSL customers to the RAC application programmers 2 months before the start of testing.

The customer may choose to bring a self-contained computer system for data processing. This should be discussed with the PSL project engineer and the PSL facility electrical engineers at one of the test-planning meetings. The PSL electrical engineers will integrate the customer's self-contained computer system if feasible.

## 8.2 Deliverables

The PSL customer should provide the following information to the PSL project engineer at least 6 months before the scheduled test:

(1) The test envelope for the engine or test article
(2) Engineering drawings that show the engine or test article and the support systems installed in the facility test chamber (see sec. 8.1.2)
(3) A list of all customer-supplied equipment, plus block diagrams and wiring schematics
(4) A stress analysis based on the maximum load anticipated for a piece of equipment to be used inside the test chamber, if it is not considered to be "Bill of Material" (see sec. 9.3)
(5) The initial computing instructions for the project engineer and the RAC application programmers, if required (see sec. 8.1.4))

When the PSL customer and NASA Lewis agree that the data obtained from an experiment are mutually beneficial, the customer may be asked to supply selected engine or test-article drawings and/or photographs for reproduction in NASA technical papers.

## 8.3 Engine or Test Article and Equipment

All engine or test-article instrumentation and support hardware should be sent to the attention of the PSL test conductor (the name of this engineer will be supplied by the PSL facility manager) at PSL (Bldg. 125) at NASA Lewis. To reduce installation delays, all engine or test-article parts or internal instrumentation, and PSL customer-support hardware, should be assembled, if possible, before shipment to NASA Lewis. Large shipping crates must have skids so that they can be handled by forklift trucks. The due date for delivery of equipment, engines, and test articles (before the test) varies according to the complexity of the engine or test-article installation and the amount of instrumentation that is to be hooked up to the data recording system. The customer and the PSL test conductor should agree to delivery times.

# 9.0 RISK ASSESSMENT TO FACILITY, ENGINE OR TEST ARTICLE, AND TEST HARDWARE

## 9.1 Facility Safety System

9.1.1 Cardox.—A carbon dioxide discharge system to counteract a fire is available in each PSL test chamber and can be actuated from the PSL control room. The particulars of the system can be discussed with the PSL test conductor at one of the test-planning meetings.

9.1.2 Evacuation alarms.—Evacuation alarms are placed at each exit of the PSL and Heater Buildings. When the Cardox system begins to discharge, the evacuation alarms are initiated and the NASA Lewis Fire Station is alerted.

9.1.3 Fire detection.—Smoke detectors in PSL are located in the first floor control room, the second floor data room, and the second floor electronics room. If smoke is detected, alarms are set off at the NASA Lewis Fire Station and at the facility control room annunciator panel. If a computer mainframe overheats in the second floor data room, alarms go off at the facility control room annunciator panel and at the NASA Lewis Fire Station.

9.1.4 Gaseous hydrogen detection system.—Gaseous hydrogen detection units have been placed inside both the PSL-3 and PSL-4 test cells. If gaseous hydrogen is detected, alarms are set off at the facility control room annunciator panel and at the NASA Lewis Fire Station. In addition, the test article and the facility will proceed through an orderly shutdown.

9.1.5 Fuel detection system.—Fuel detection units are located inside both of the PSL test cells. If fuel is detected in either test cell, alarms are set off at the facility control room annunciator panel and at the NASA Lewis Fire Station.

9.1.6 Facility ventilation system.—On the facility roof are six ventilation fans, each having a capacity of 10 000 $ft^3$/min. These fans disperse any noxious fumes that may occur inside either PSL test cell or in the building.

## 9.2 Engine History and Inspection Requirements

The facility manager might request that the PSL customer provide documented engine history, maintenance, and inspection records. Since most of the programs that are run in the facility are naturally high risk, it is prudent to obtain such documentation for the engines and test articles that use the facility, thereby protecting PSL personnel and the facility from any undue risk.

## 9.3 Engine Support Hardware

9.3.1 Structural joints.—The minimum safety factor for bolted joints that clamp an engine, test article, or engine or test-article auxiliary structure shall be 4.0 based on yield stress, and 5.0 based on ultimate stress, for heat-treated hardened bolts.

Shear loads should be transmitted through the use of keys and pins. Provision must be made to properly retain these pins and keys.

Welded joints should be designed in accordance with the American Welding Society Code. All critical joints (those whose failure would result in the loss of an engine, test article, or engine or test-article component or in damage to the facility) must be x-rayed.

9.3.2 Pressure systems.—Engine or test-article support and test equipment that use hydraulic, pneumatic, or other systems with operating pressures above 15 psig shall be designed, fabricated, inspected, tested, and installed in accordance with the ASME Boiler and Pressure Vessel Code (Sec. VIII) or the American Standards Association (ASA) codes of the ASME.

Pressure vessels are defined as all vessels (such as shells, chambers, tanks, or components) that are used in the transmission of a gas or a fluid and in which pressures exceed 15 psig. The welding of pressure vessels shall be in accordance with the ASME Boiler and Pressure Vessel Code (Sec. IX for welding qualifications and Sec. V for nondestructive inspection).

Pressure-relief devices may be required in a hydraulic or pneumatic system. These devices should be capable of relieving the overpressure under the conditions causing the malfunction. The facility manager and the PSL project engineer shall be given the following information on all components of a pressure system: volume capacity, temperature range, working pressure, and proof-test pressure. After proof-testing and before delivery to the PSL facility, all components of a pressure system should be stored in a clean, dry, and sealed condition.

9.3.3 Pressure piping.—All piping shall be designed, fabricated, inspected, tested, and installed in compliance with the latest edition of the ANSI/ASME Standard Piping Code. Engine or test-article support systems may contain pressure vessels that are constructed from standard pipe fittings and standard flanges, if the pressure vessels are considered to be pressure piping and use the ANSI/ASME Standard Piping Code.

On all service lines into and out of engines, test articles, or engine or test-article support systems, labels must be affixed that properly identify the working pressures, the flow direction, and the fluid or gas being carried.

9.3.4 Electrical equipment components.—Only qualified hardware, equipment, and materials (i.e., those conforming to the National Electrical Code) are permitted to be used in the PSL facility. All pressure transducers, strain gauges, vibration pickups, and other low-voltage devices should use shielded cable. The test agreement shall specify details regarding customer-supplied control panels and the associated wiring to the facility control room. It should also specify the format for customer-supplied electrical schematics, wiring diagrams, and connectors at interfaces located at control panels, control boxes, and/or the engine or test article.

## 9.4 Nondestructive Testing of Instrumentation Rakes

If instrumentation rakes are to be placed upstream of or inside of full-scale turbojet or turbofan engines or a test article, then it is necessary to verify the instrumentation rake design. To avoid severe damage to the engine or test article, as well as damage to the facility, instrumentation rake failure must be prevented. A procedure in use at NASA Lewis Research Center calls for one prototype rake to be manufactured for each different rake design that is to be used in a full-scale engine or test-article experiment in PSL-3 or PSL-4. The prototype rake should be subjected to shock and vibration tests such as (1) sinusoidal sweep vibrations, (2) dwells at low frequencies (< 1000 Hz), (3) random vibrations over three axes, and (4) shock tests on all three axes. The test rake should be subjected to sinusoidal sweep vibrations in the circumferential direction only. The scope of these vibration and shock tests is defined in reference 35. The scope of testing for the instrumentation rakes should be agreed upon by the research engineer, the AFED project engineer, and the rake test engineer from the Structural Systems Division. The other rakes that are used with the full-scale engine or test-article experiments are to be subjected to low-level vibration tests.

### 9.5 Engine or Test-Article Checkout

After an engine or test article is installed in PSL-3 or PSL-4, there is a final end-to-end check of all instrumentation and a final calibration of all remotely controlled engine or test-article functions.

All electrical leads and pneumatic lines from the engine or test article should be clearly identified. In addition, the pneumatic lines should be cleaned (free of oil and debris) and leak-checked at operating pressures. End-to-end checks are required for the electrical, pneumatic, and instrumentation systems of the engine or test article.

### 9.6 Quality Assurance Requirements

Detailed instructions are required for installation of the engine or test article in the PSL test chambers and for any configuration changes during a given test program. These instructions should be submitted to the PSL test conductor at least 8 weeks before the engine or test article is scheduled for entry into one of the test chambers. These instructions should include the sequence of steps for installing the engine or test article in the test chamber; bolt-torquing values for fastening the engine or test article to the facility support structures; and directions for assembling, installing, and checking out customer-supplied hardware. The installation instructions should be supplemented with the necessary drawings and/or sketches.

## 10.0 GENERAL INFORMATION

The following information is provided to familiarize the PSL customer with the services available and the standard operating procedures.

### 10.1 Support

<u>10.1.1 Engine or test-article buildup.</u>—Most engines or test articles tested in PSL-3 or PSL-4 are complex, and therefore, their buildup times in the PSL test chambers vary greatly. The PSL customer should discuss with the PSL facility manager and the test conductor the appropriate arrival time for the engine or test article and any other customer-supplied auxiliary equipment.

<u>10.1.2 User responsibility.</u>—If the engine or test-article installation is complex, it is advantageous to have the PSL customer supply a knowledgeable person or persons to assist with the installation. All special tools, spare parts, special equipment, and supplies necessary to perform work on the engine or test article are to be supplied by the customer. At least one customer-assigned test engineer who is familiar with the engine or test article and the test objectives should be onsite during the test program.

<u>10.1.3 Operation of Government equipment.</u>—The customer's research personnel should not operate Government-furnished equipment or make connections to this equipment without the approval of NASA Lewis personnel.

10.1.4 PSL test chamber safety.—All personnel entering the test chamber for an extended period of time to examine the engine or test article or any auxiliary equipment should be accompanied by NASA Lewis personnel. Care should always be exercised to avoid injury from the sharp edges on the engine or test article or from instrumentation probes or rakes that may protrude from the engine or test article.

10.1.5 Support during tests.—The PSL customer shall direct all requests for manpower, shop and/or facility services, or Escort programming services to the PSL project engineer.

## 10.2 Operations

10.2.1 Normal operating days and shifts.—Tests are usually run at the PSL from 4:00 to 11:00 p.m., Monday through Friday. This test window can be expanded for an ambitious test schedule. Each week the PSL customer and the facility manager should discuss whether an expanded test time is required.

10.2.2 Off-shift coverage.—Access to the PSL facility for times other than operating shifts must be coordinated with the PSL facility manager and the PSL project engineer.

## 10.3 Planning

10.3.1 Prerun safety meeting.—The PSL project engineer and/or the test conductor shall prepare a Safety Permit Request that describes the test. This document addresses the safety aspects of the test as well as test objectives, run schedule, instrumentation, hardware, and such; it is sent to the Center's Environmental Compliance Office and the Area Safety Committee for their review and approval. The Safety Permit Request shall be written and available at least 4 weeks before the start of testing.

The following conditions require that the facility's Area Safety Committee take special action:

(1) Use of radioactive materials or gases
(2) Use of high-speed rotating engine or test-article parts without suitable shrouds
(3) Ejection of explosive gases into the PSL circuit
(4) Use of toxic materials (in which case a Material Safety Data Sheet should be provided by the PSL customer)

10.3.2 Test time.—The PSL test time charged to an experiment (non-NASA customers) includes the total time that the facility is available to the customer. This time includes the time required for installing the engine or test article and instrumentation, testing the engine or test article, removing the engine or test article and instrumentation, returning the PSL facility and associated areas to their pretest conditions, and crating the customer's engine or test article and equipment for shipment. Extensions to a test window may be negotiated by the PSL customer's lead engineer and the PSL facility manager. AFED personnel who have experience with the facility can assist the PSL customer in making a fairly accurate estimate of the time required to complete the test program.

10.3.3 NASA debriefing.—When the test program is nearly completed, the PSL customer's lead engineer shall meet with the PSL facility manager to evaluate the test support received by the PSL customer. The facility manager shall make the arrangements for the meeting.

## 10.4 Security

The amount of advance notice required to obtain access to the PSL facility at NASA Lewis Research Center depends upon the classification of the test program and the security category of the non-NASA customer.

During nonclassified test programs, the PSL project engineer notifies the NASA Visitor Control Center at least 3 days prior to the arrival of a non-NASA visitor who is a U.S. citizen. Visitor Control requires the name and the place of employment of the visitor and the date and purpose of the visit. Non-U.S. citizens should make arrangements with their individual embassies in Washington, D.C., prior to their intended visit to NASA Lewis. The appropriate embassies should work with NASA Headquarters in Washington D.C., to establish the necessary clearances.

For a test program classified as "sensitive," non-NASA visitors must send a visit notification letter to the NASA Lewis Security Office. The PSL facility manager will tell the non-NASA visitor what information is to be included in the letter. Visit notification letters are to be sent to the following address:

NASA Lewis Research Center
Attn: Security Office, M.S. 21-5
21000 Brookpark Road
Cleveland, Ohio 44135
Phone: (216) 433-3062
Fax: (216) 433-6664

## 11.0 APPENDIX A

## CONTACT PERSON

The facility manager is the key contact person at the PSL. Mail correspondence should be addressed as follows:

NASA Lewis Research Center
Attn: PSL Facility Manager, M.S. 6-8
21000 Brookpark Road
Cleveland, Ohio 44135

The name of the PSL facility manager can be obtained from a NASA switchboard operator; call (216) 433-4000 and ask the operator to supply the name of the facility manager.

# 12.0 APPENDIX B

## REAL-TIME DISPLAY DETAILS

The control room CRT displays are formatted so that page one is the page directory and the other output pages (designed by the PSL customer) show test plan objectives. A display can contain 2 sizes of characters: a matrix of 24 rows of normal size characters by 80 columns, or a matrix of 48 rows of reduced size characters by 80 columns. When normal size characters are used, row 1 is reserved, and when reduced size characters are used, rows 1 and 2 are reserved. These rows always contain standard identification information (i.e., facility name, program number, last reading taken, current time, barometer and electronically scanned pressure calibration countdown time). Data channels may also be displayed in an unlabeled block format (a two-dimensional array of 20 rows by 5 columns). These are preprogrammed, off-the-shelf displays.

## 13.0 APPENDIX C

## PROCESS FOR SCHEDULING TESTING TIME

Arrangements to use the PSL test facilities are made as follows:

(1) At least 1 year before the test, the PSL customer contacts the PSL facility manager and submits the overall test requirements.

(2) The facility manager and appropriate Aeropropulsion Facilities and Experiments Division (AFED) personnel review the request.

(3) The PSL customer (non-NASA requestors only) submits a formal letter of request to the Director of Aeronautics at NASA Lewis.

(4) If the project is accepted, a test agreement is prepared and signed (for non-NASA requestors only).

(5) A series of test-planning meetings are held to discuss the test plan, instrumentation, hardware, and data requirements. The attendees are the PSL customers (i.e., the research engineers), the facility manager, the PSL Branch Chief and Deputy Branch Chief, key PSL personnel, AFED engineers, and RAC application programmers, if required.

## 14.0 REFERENCES


1. Kurkov, A.P.; Soeder, R.H.; and Moss J.E.: Investigation of the Stall-Induced Shock Wave (Hammershock) at the Inlet to the Engine. NASA TMX-71594, 1974.

2. Wenzel, L.M.; Moss, J.E.,Jr.; and Mehalic, C.M.: Effect of Casing Treatment on Performance of a Multistage Compressor. NASA TMX-3175, 1975.

3. Biesiadny, T.J.; and Grey, R.E.: Altitude Performance of a Low-Noise-Technology Fan In a Turbofan Engine With and Without a Sound Suppressing Nacelle. NASA TMX-3385, 1976.

4. Johnsen, R.L.; and Cullom, R.R.: Altitude Test of Several Afterburner Configurations on a Turbofan Engine With a Hydrogen Heater To Simulate an Elevated Turbine Discharge Temperature. NASA TP–1068, 1977.

5. Mehalic, C.M.; Dicus, J.H.: and Kurkov, A.P.: Effect of Pressure and Temperature on the Subsonic Stall Flutter Region of a YF100 Engine. NASA TMS-73785, 1977.

6. Cullom, R.R.; and Johnsen, R.L: Operating Condition and Geometry Effects on Low-Frequency Afterburner Combustion Instability in a Turbofan at Altitude. NASA TP–1475, 1979.

7. Bobula, G.A.; Soeder, R.H.; and Burkardt, L.A.: Effect of a Part-Span Variable Inlet Guide Vane on the Performance of a High-Bypass Turbofan Engine. AIAA Paper 81-1362, July 1981.

8. Lee, D.: High-Response Measurements of a Turbofan Engine During Nonrecoverable Stall. NASA TM–81759, 1981.

9. Straight, D.M.; and Cullom, R.R.: Performance of a 2D-CD Nonaxisymmetric Exhaust Nozzle on a Turbojet Engine at Altitude. NASA TM–82881, 1982.

10. Wooten, W.H.; et al.: Altitude Testing of a Flight Weight, Self-Cooled, 2D Thrust Vectoring Exhaust Nozzle. SAE Paper 841557, Oct., 1984.

11. Biesiadny, T.J.; et al.: Uniform Engine Testing Program Phase VII: NASA Lewis Research Center Second Entry. NASA TM–877272, 1986.

12. Abdelwahab, M.; Biesiadny, T.J.; and Silver, D.: Measurement Uncertainity for the Uniform Engine Testing Program Conducted at NASA Lewis Research Center. NASA TM–88943, 1987.

13. Mehalic, C.M.; and Lottig, R.A.: Full-Scale Thrust Reverse Testing in an Altitude Facility. AIAA Paper 87-1788, June, 1987.

14. Lorenzo, C.F.; Chiaramonte, F.P.; and Mehalic, C.M.: Determination of Compressor In-Stall Characteristics from Engine Surge Transients. J. Prop. and Power, vol. 4, no. 2, Mar.-Apr., 1988, pp. 133–143.

15. Block, H. B.; et.al.: Techniques Utilized in the Simulated Altitude Testing of a 2D-CD Vectoring and Reversing Nozzle. NASA TM–100872, 1988.

16. Mehalic, C.M.: Effect of Spatial Inlet Temperature and Pressure Distortion on Turbofan Engine Stability. AIAA Paper 88–3016, July 1988.

17. Werner, R.A.; and Abdelwahab, M.: Fan Stall Stability of an Advanced Turbofan Engine With Off-Schedule Guide Vanes and Nonuniform Inlet Flow. NASA TP–2819, 1988.

18. Jones, R.R. III; and Abdelwahab, M.,: An Analysis of the Aerodynamic Performance of the Reverse Thrust Exhaust Gas Management System for the S/MTD Engine In Altitude Test Cell PSL-3. NASA CR–187107, 1991.

19. Duncan, B.; and Thomas, S.: Computational Analysis of Ramjet Engine Inlet Interaction. AIAA Paper 92–3102, July, 1992.

20. Trefny, C.J.: Experiments and Analysis Concerning the Use of External Burning to Reduce Aerospace Vehicle Transonic Drag. NASA TM–105397, 1992.

21. Merrill, W.C.; et al.: Advanced Detection, Isolation and Accommodation of Sensor Failures. NASA TP–2836, 1988.

22. Lottig, R.A.; and Huber, G.T.: Development and Use of Hydrogen-Air Torches in an Altitude Facility. NASA TM–106047, 1993.

23. Soeder, R.H.; and Bobula, G.A.: Effect of Steady-State Pressure Distortion on Flow Characteristics Entering a Turbofan Engine. NASA TM–79134, 1979.

24. Soeder, R.H.; and Bobula, G.A.: Effect of Steady-State Pressure Distortion on Inlet Flow to a High-Bypass-Ratio Turbofan Engine. NASA TM–82964, 1982.

25. Braithwaite, W.M.; and Soeder, R.H.: Combined Pressure and Temperature Distortion Effects on Internal Flow of a Turbofan Engine. AIAA Paper 79–1309, 1979.

26. Soeder, R.H.; and Bobula, G.A.: Effect of Steady-State Temperature Distortion and Combined Distortion on Inlet Flow to a Turbofan Engine. NASA TM–79237, 1979.

27. Soeder, R.H. and Mehalic, C.M.: Effect of Combined Pressure and Temperature Distortion Orientation on High-Bypass-Ratio Turbofan Engine Stability. NASA TM–83771, 1984.

28. Soeder, R.H.; Mehalic, C.M.; and Stancik, K.: Effect of Steady-State Temperature Distortion on Inlet Flow to a High-Bypass-Ratio Turbofan Engine. NASA TM–86896, 1985.

29. Biesiadny, T.J.; et al.: Summary of Investigations of Engine Response to Distorted Inlet Conditions. NASA TM–87317, 1986.

30. Abdelwahab, M.: Effects of Temperature Transient at Fan Inlet of a Turbofan Engine. NASA TP–1031, 1977.

31. Abdelwahab, M.: Effects of Fan Inlet Temperature Disturbances on the Stability of a Turbofan Engine. NASA TM–82699, 1981.

32. Burns, M.E.; and Kirchgessner, T.A.: Airflow Calibration and Exhaust Pressure Temperature Survey of an F-404, S/N 215-209, Turbofan Engine. NASA TM–100159, 1987.

33. Burns, M.E.: Temperature Measurement Using Infrared Imaging Systems During Turbine Engine Altitude Testing. NASA TM–105871, 1993.

34. Straight, D.M.; and Cullom, R.R.: Thrust Performance of a Variable-Geometry Nonaxisymmetric, Two-Dimensional, Convergent-Divergent Exhaust Nozzle on a Turbojet Engine at Altitude. NASA TP–2171, 1983.

35. Armentrout, E.C. and Kicks, J.C.: Pressure Instrumentation for Gas Turbine Engines—A Review of Measurement Technology. NASA TM–73864, 1978.

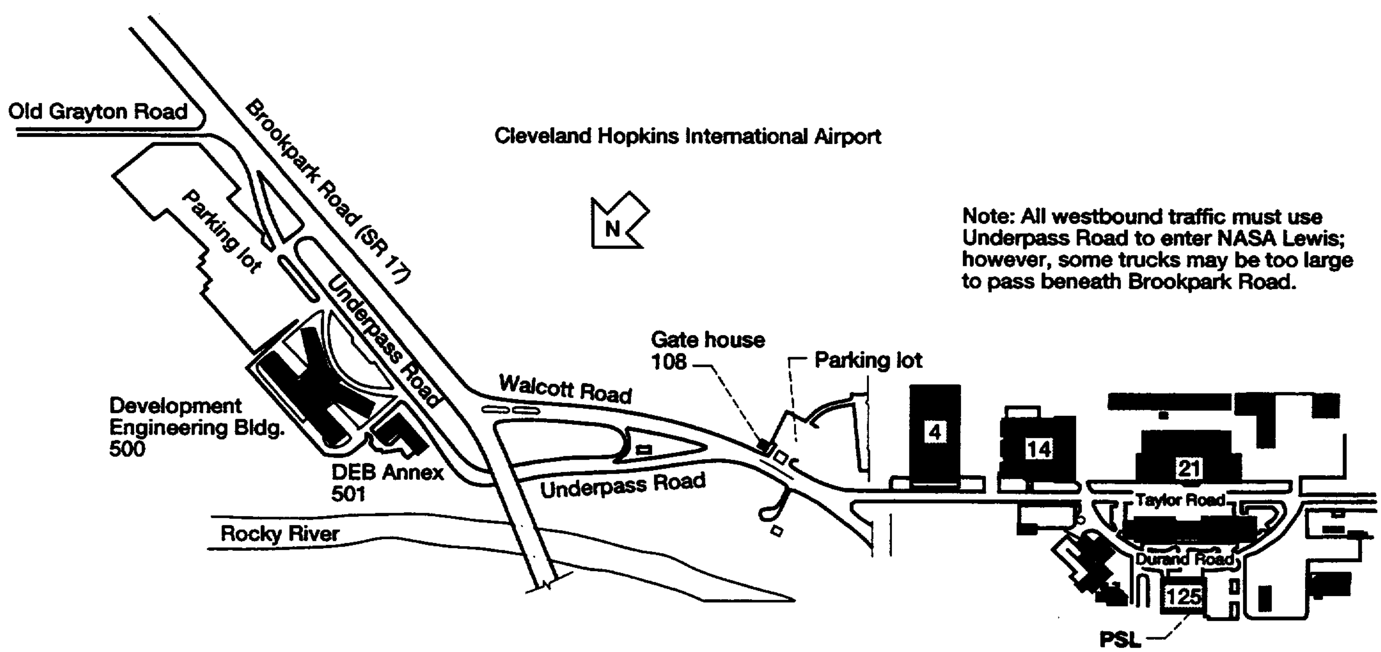



Figure 1.—Directions to Propulsion Systems Laboratory.

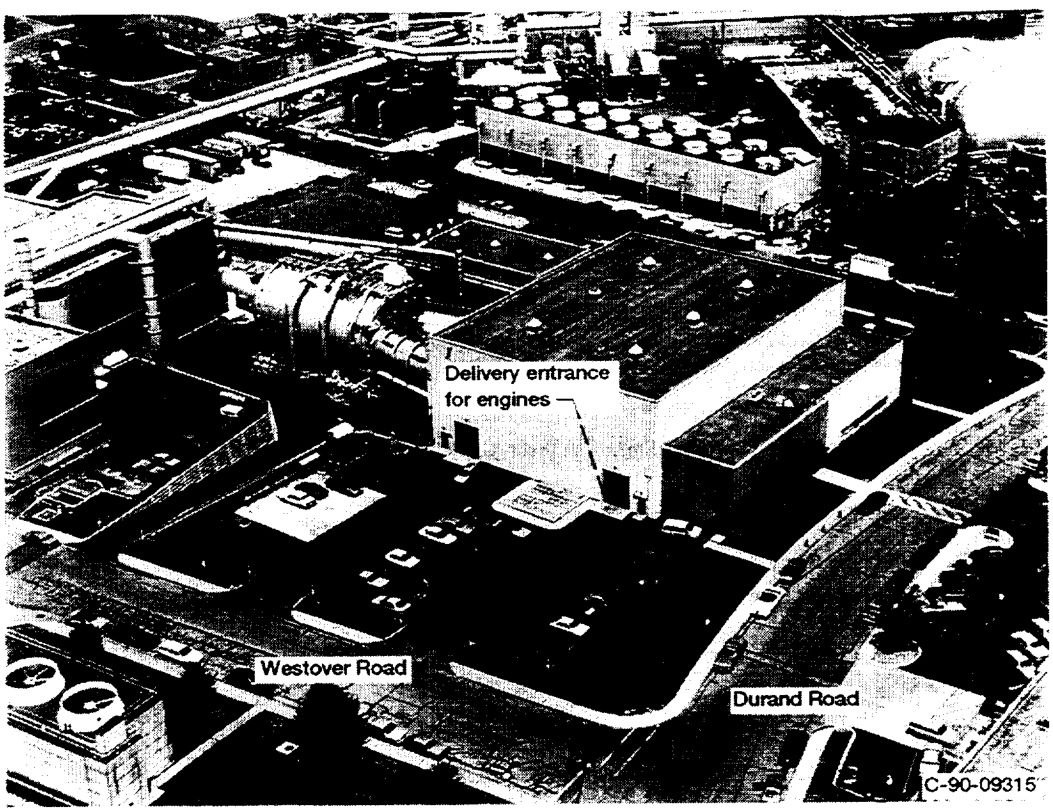



Figure 2.—Propulsion Systems Laboratory engine-test building.

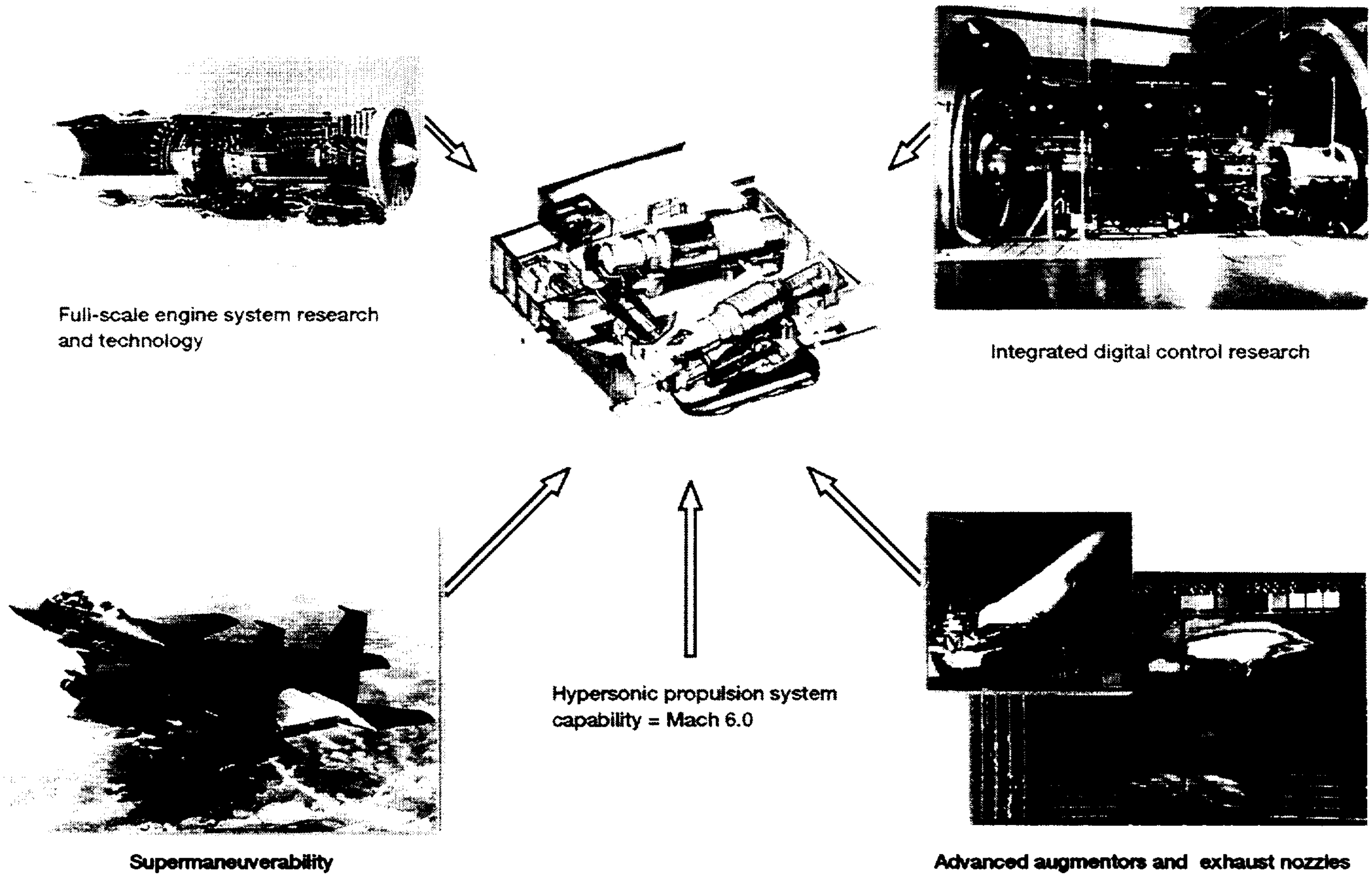



Figure 3.—Typical research testing activities that occur in PSL facility.

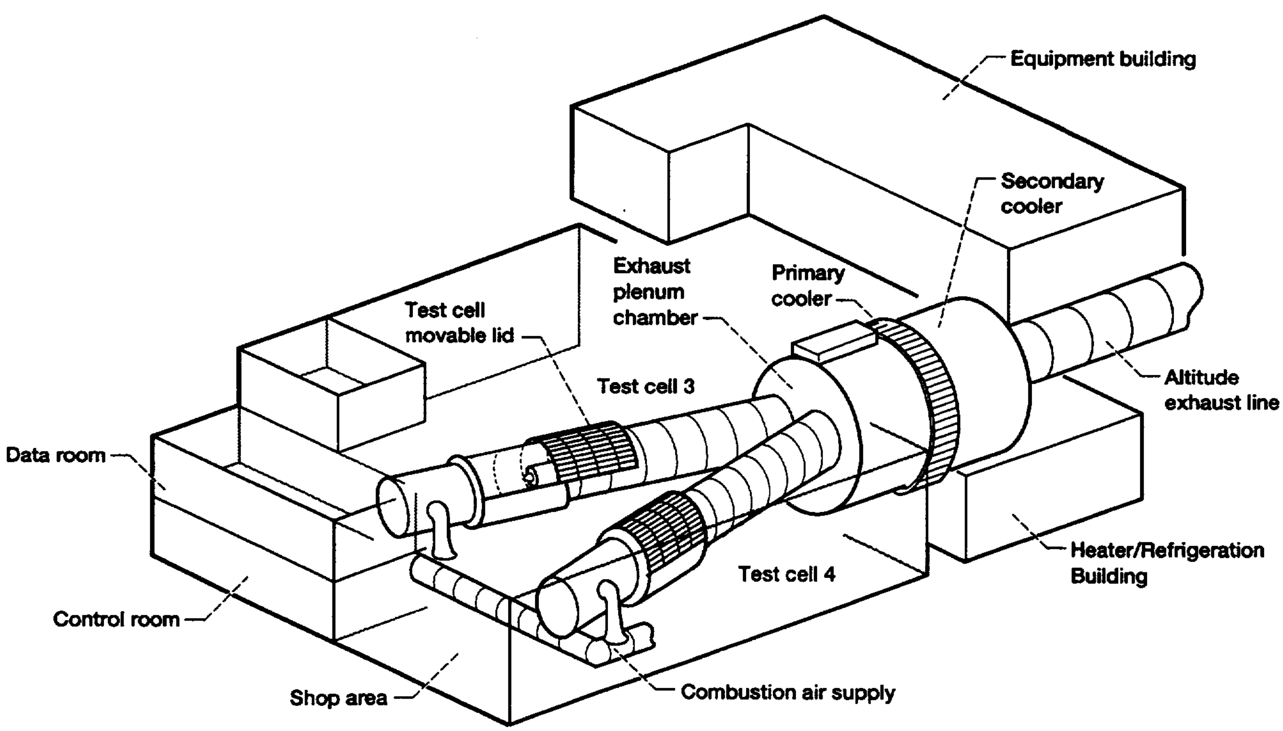



Figure 4.—Location of PSL-3 and PSL-4 altitude tanks in the Propulsion Systems Laboratory building.

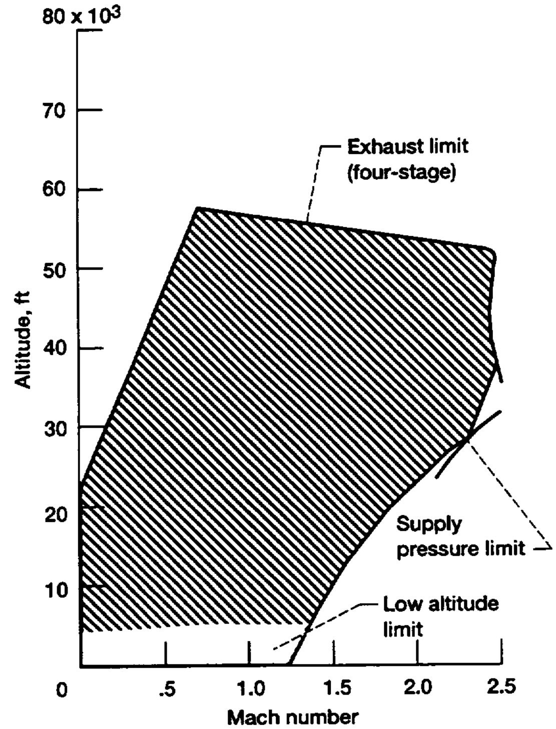



Figure 5.—Turbofan engine operating envelope in PSL-3.

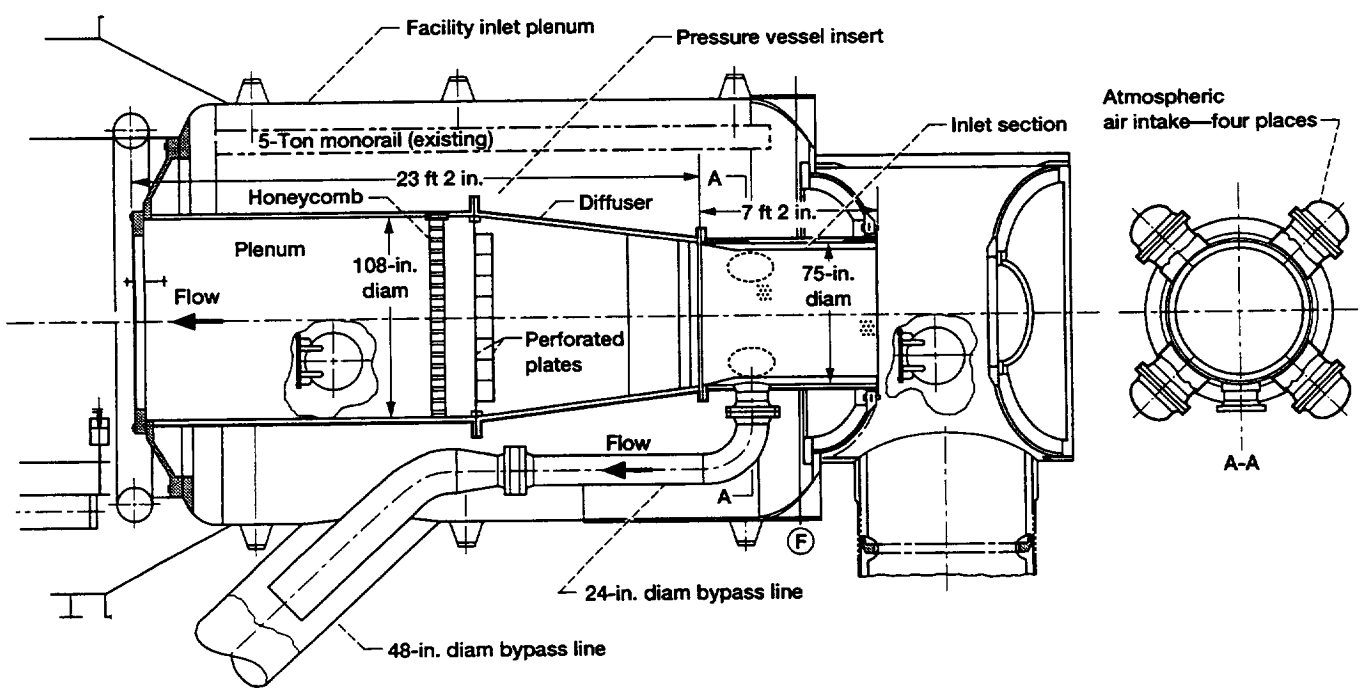



Figure 6.—PSL-4 pressure vessel insert in facility inlet plenum.

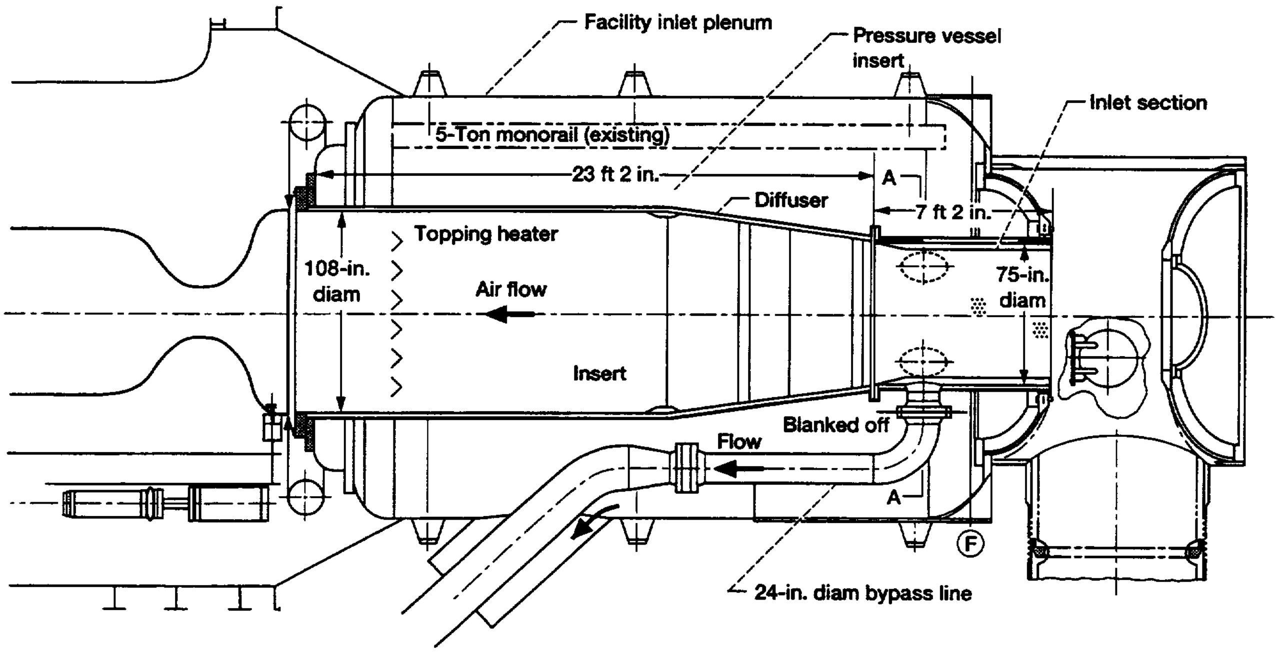



Figure 7.—PSL-4 plenum vessel insert configuration for freejet tests (maximum conditions inside plenum insert: pressure, 150 psig (165 psia); temperature, 1050 °F (1150 °F with topping heater); flow rate, 280 $lb_m$/sec).

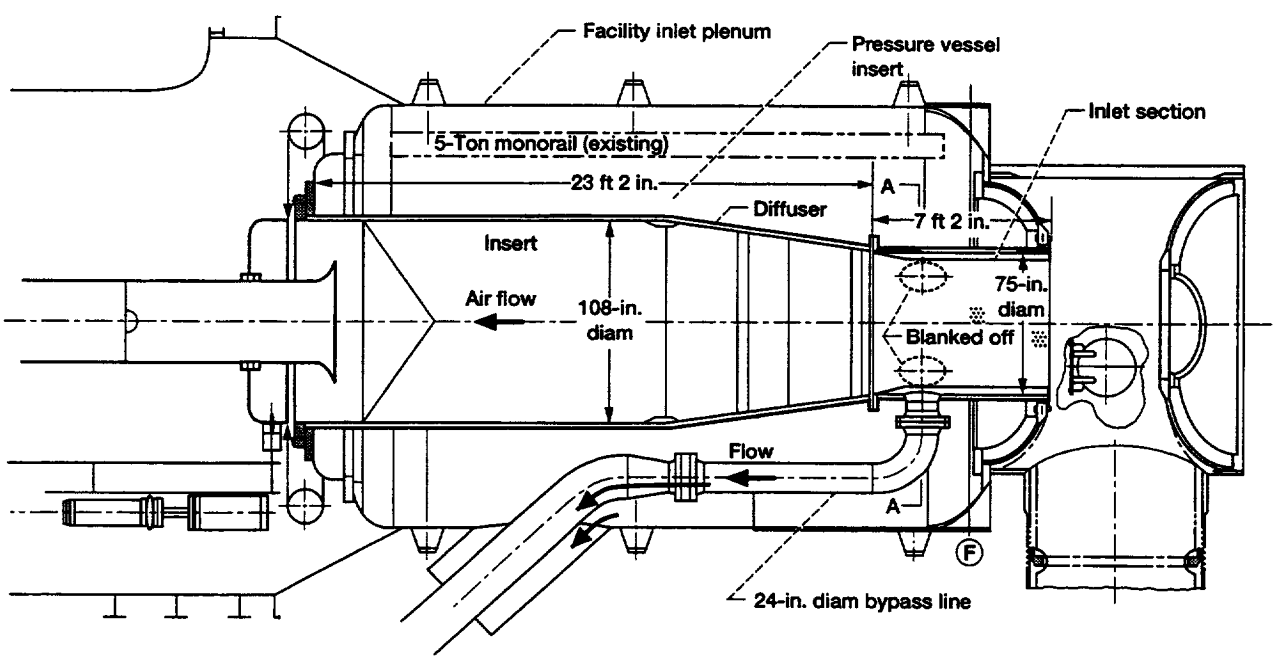



Figure 8.—Plenum vessel insert configuration for testing core engines (maximum conditions inside plenum insert: pressure, 150 psig (165 psia); temperature, 800 °F; flow rate, 380 $lb_m$/sec).

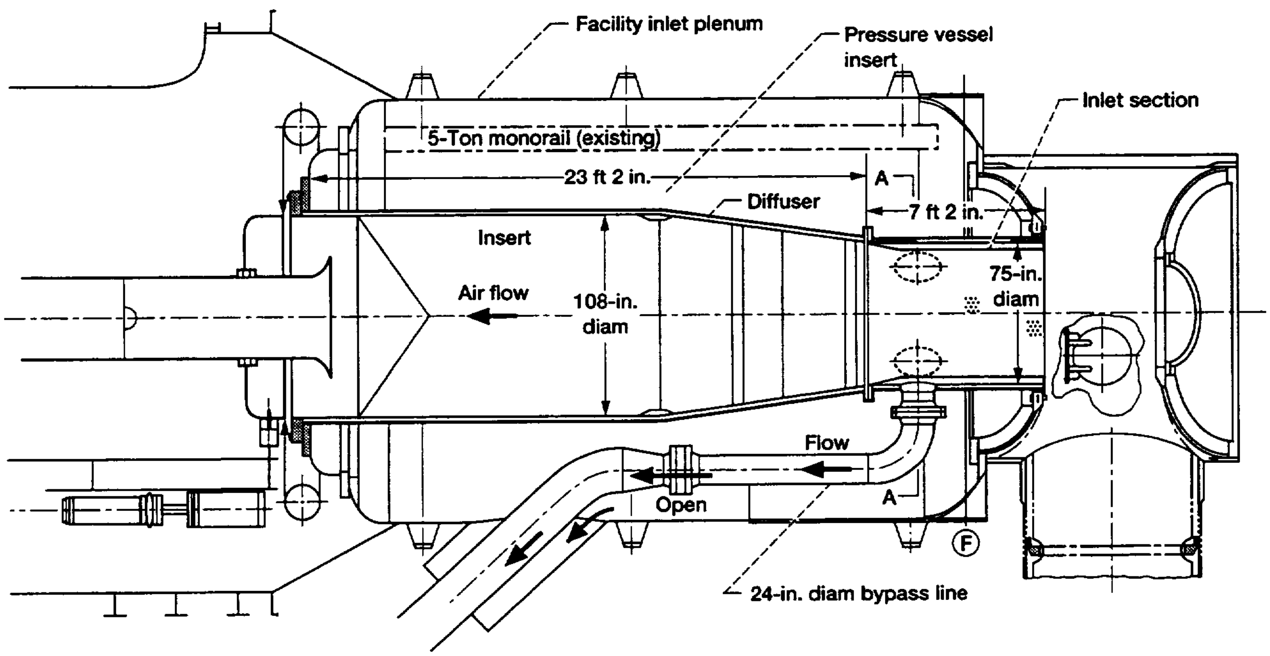



Figure 9.—PSL-4 plenum vessel insert configuration for turbine engine tests (maximum conditions inside plenum insert: pressure, 60 psia; temperature, 600 °F; flow rate, 480 $lb_m$/sec).

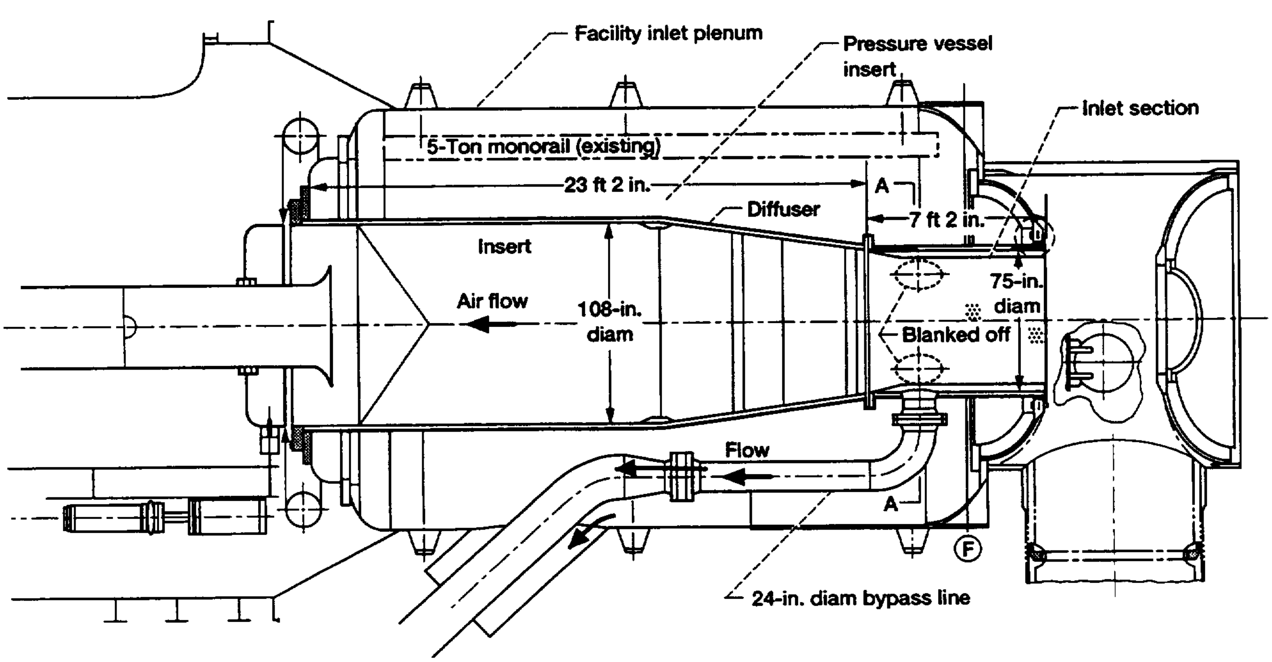



Figure 10.—PSL-4 plenum insert configuration for testing high Mach number engines (maximum conditions inside plenum insert: pressure, 150 psig (165 psia); temperature, 800 °F; flow rate, 380 $lb_m$/sec).

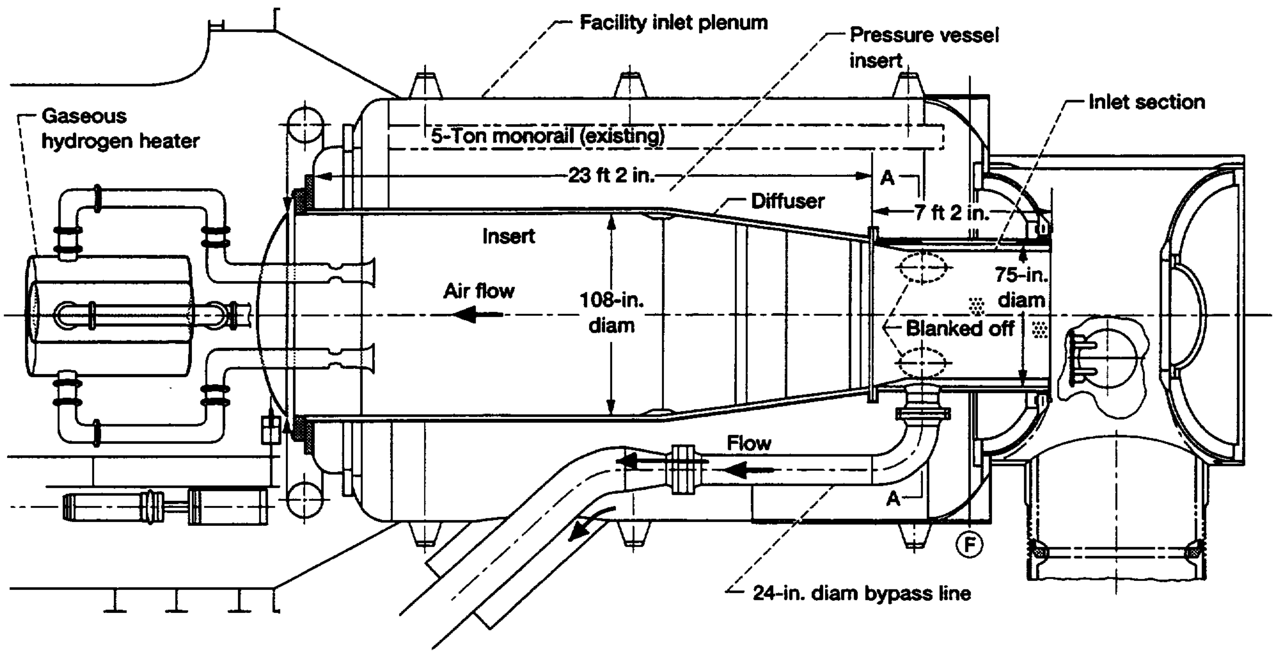



Figure 11.—PSL-4 plenum insert configuration for testing hypersonic direct-connect rigs (maximum conditions inside plenum insert: pressure, 150 psig (165 psia); temperature, 600 °F; flow rate, 100 $lb_m$/sec).

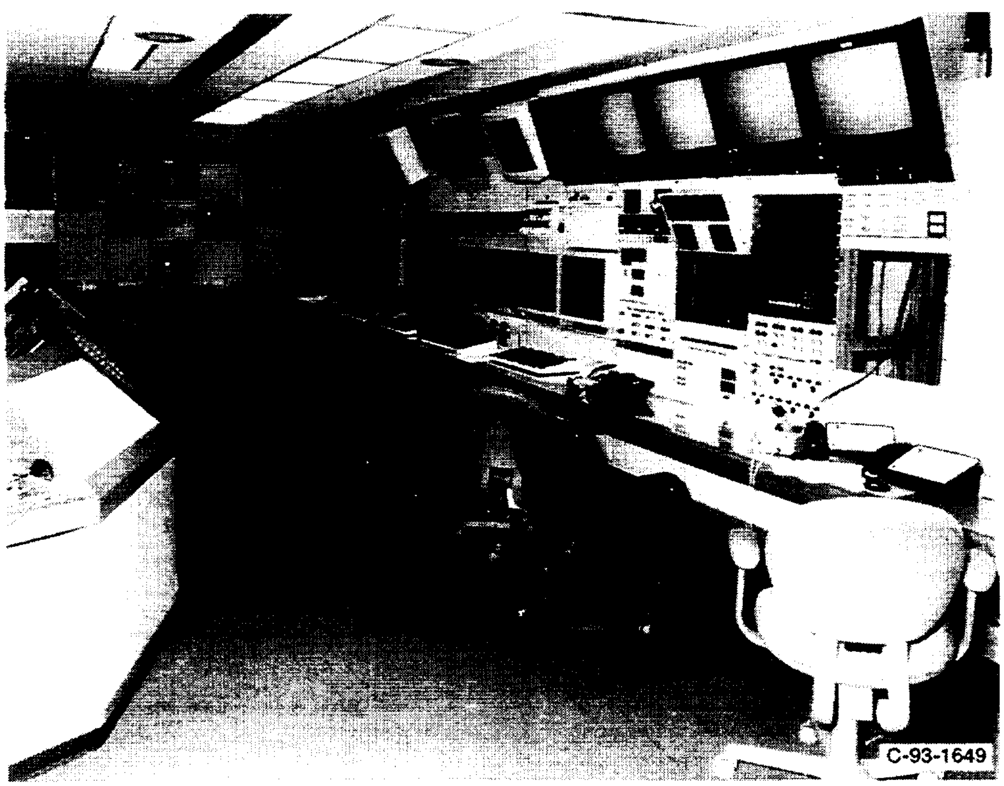



Figure 12.—Propulsion Systems Laboratory control room.

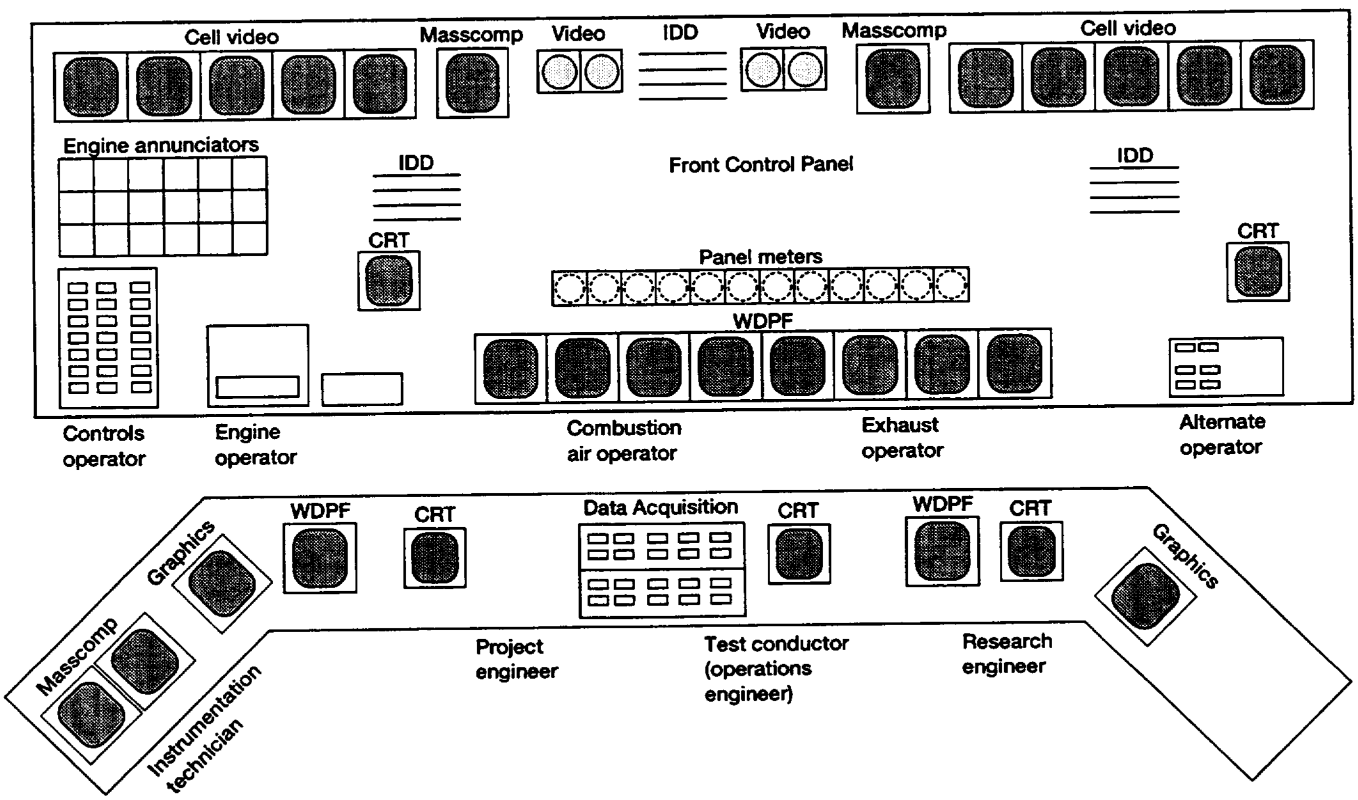



Figure 13.—Propulsion Systems Laboratory control room showing placement of personnel.

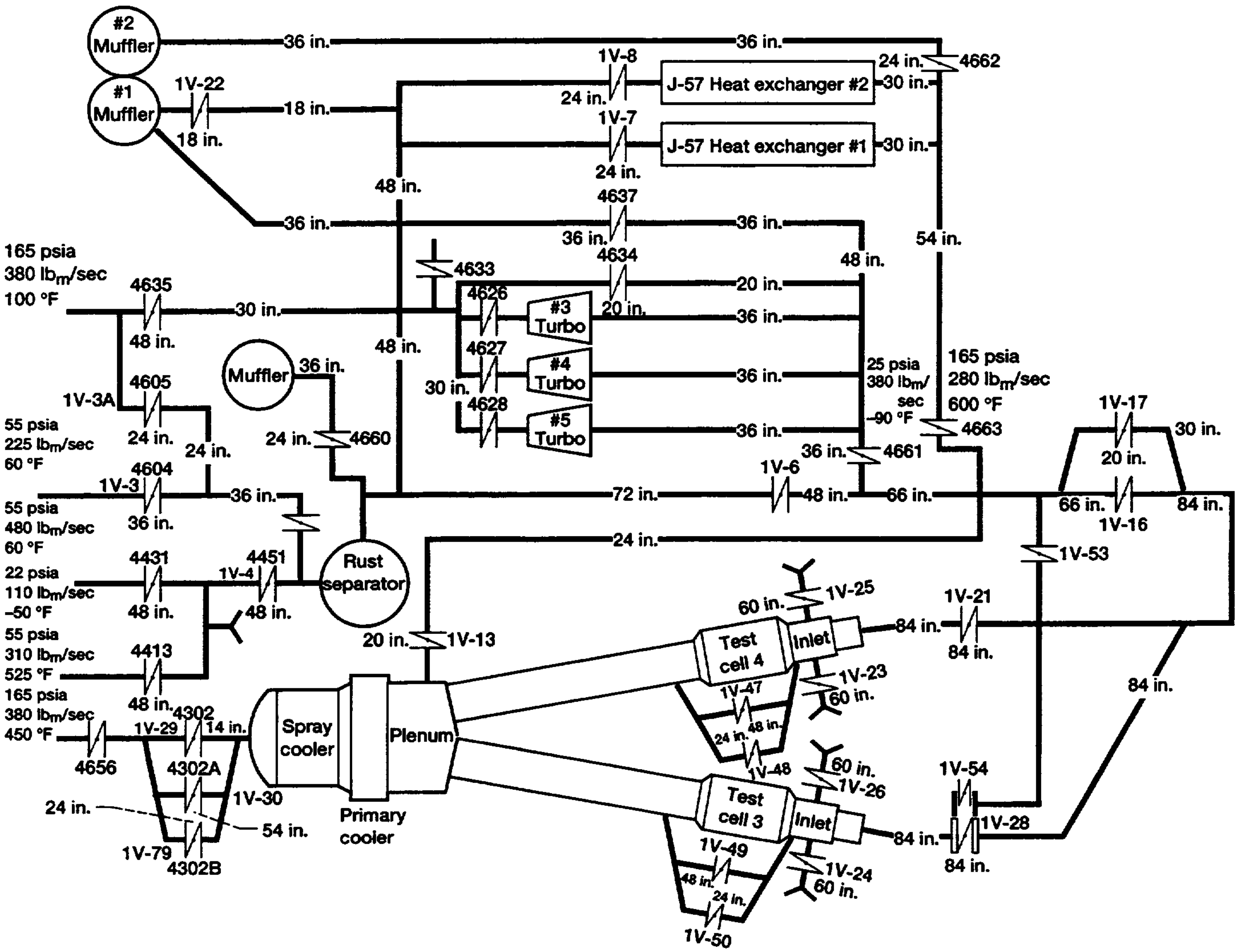



Figure 14.—Combustion Air System piping tied into PSL-3 and PSL-4 facility.

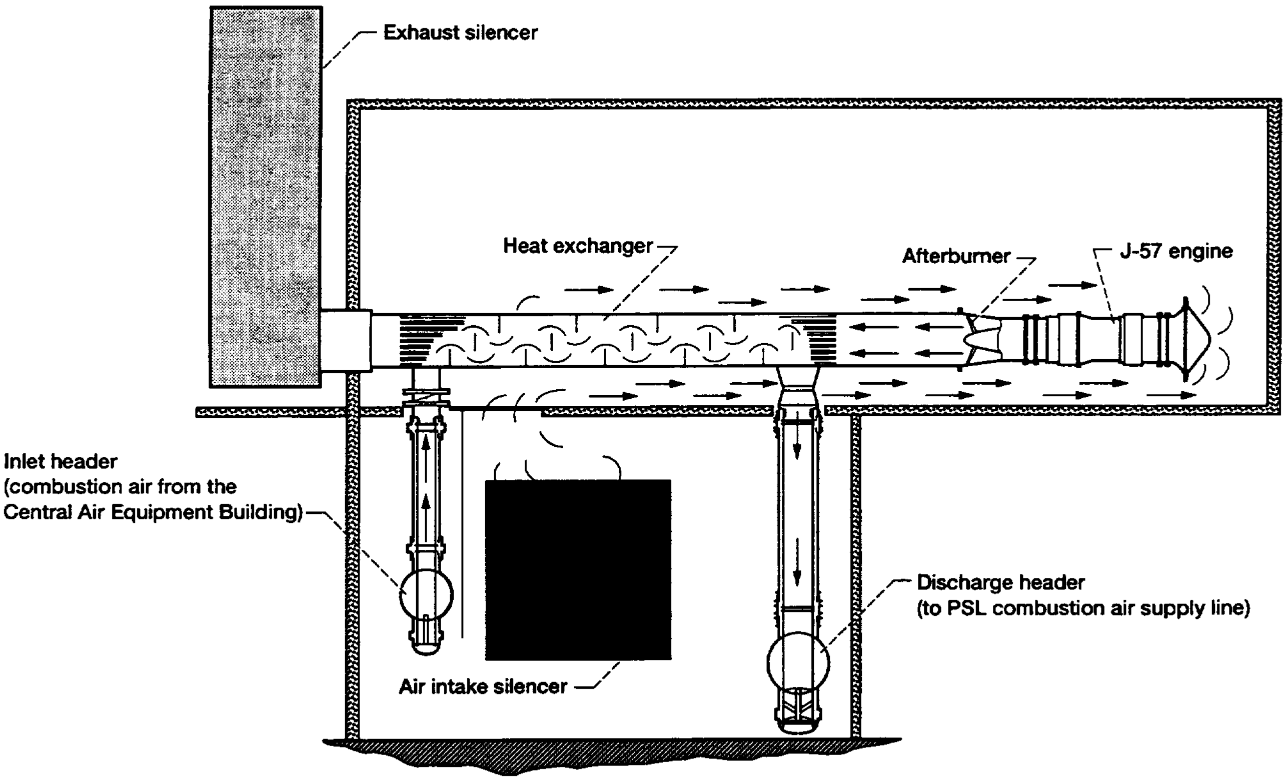



Figure 15.—Combustion air heater.

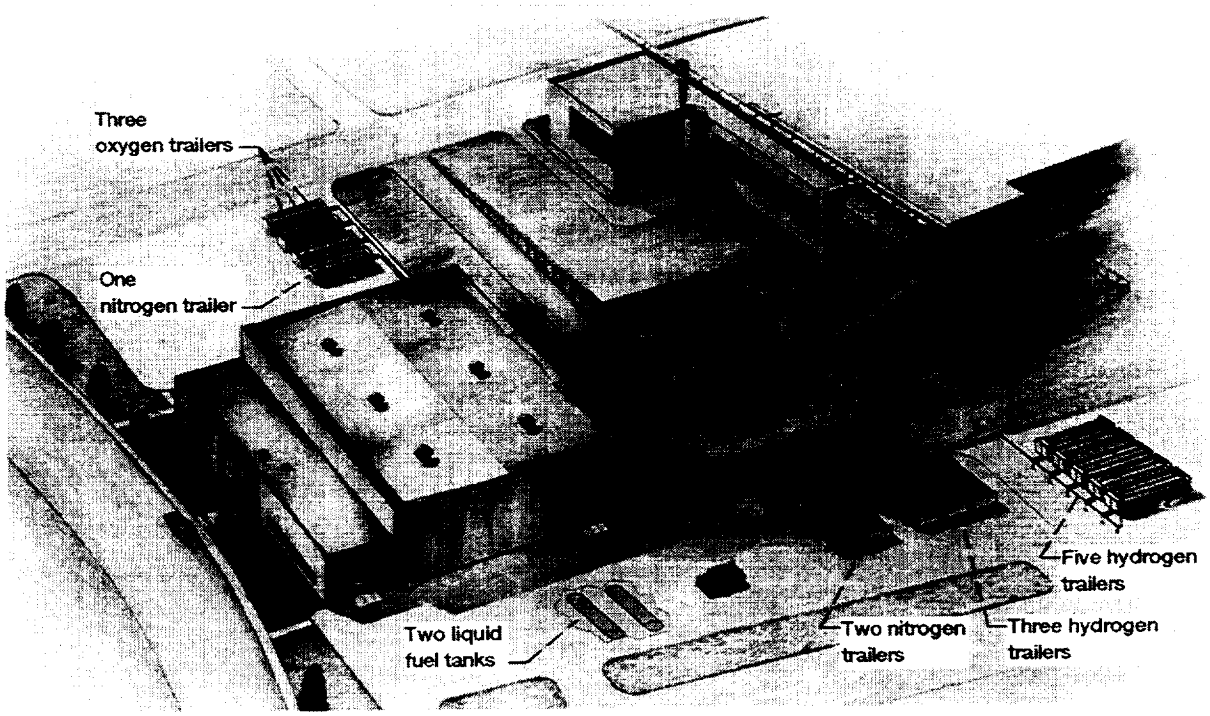



Figure 16.—Locations of PSL propellant supply.

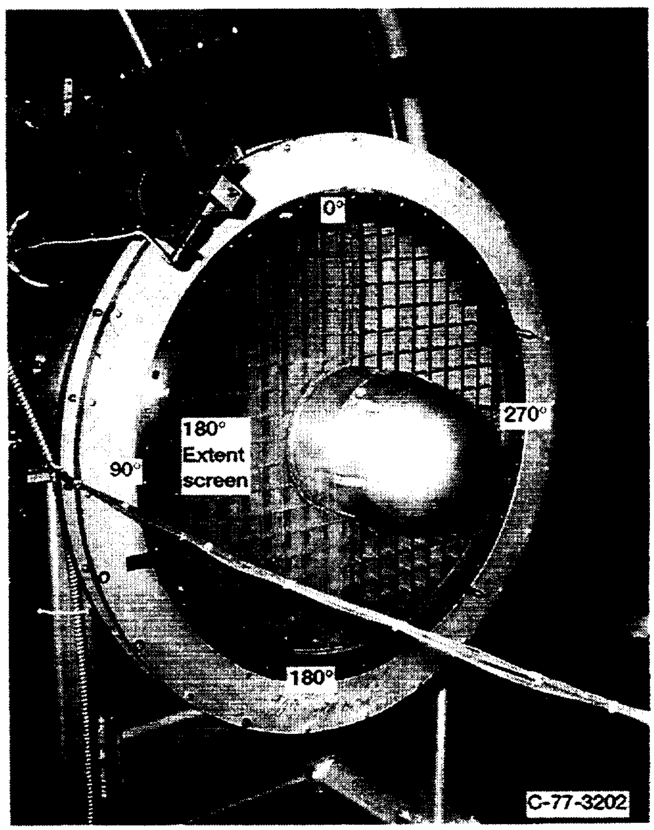



Figure 17.—Rotating screen assembly viewed in the direction of engine inlet.

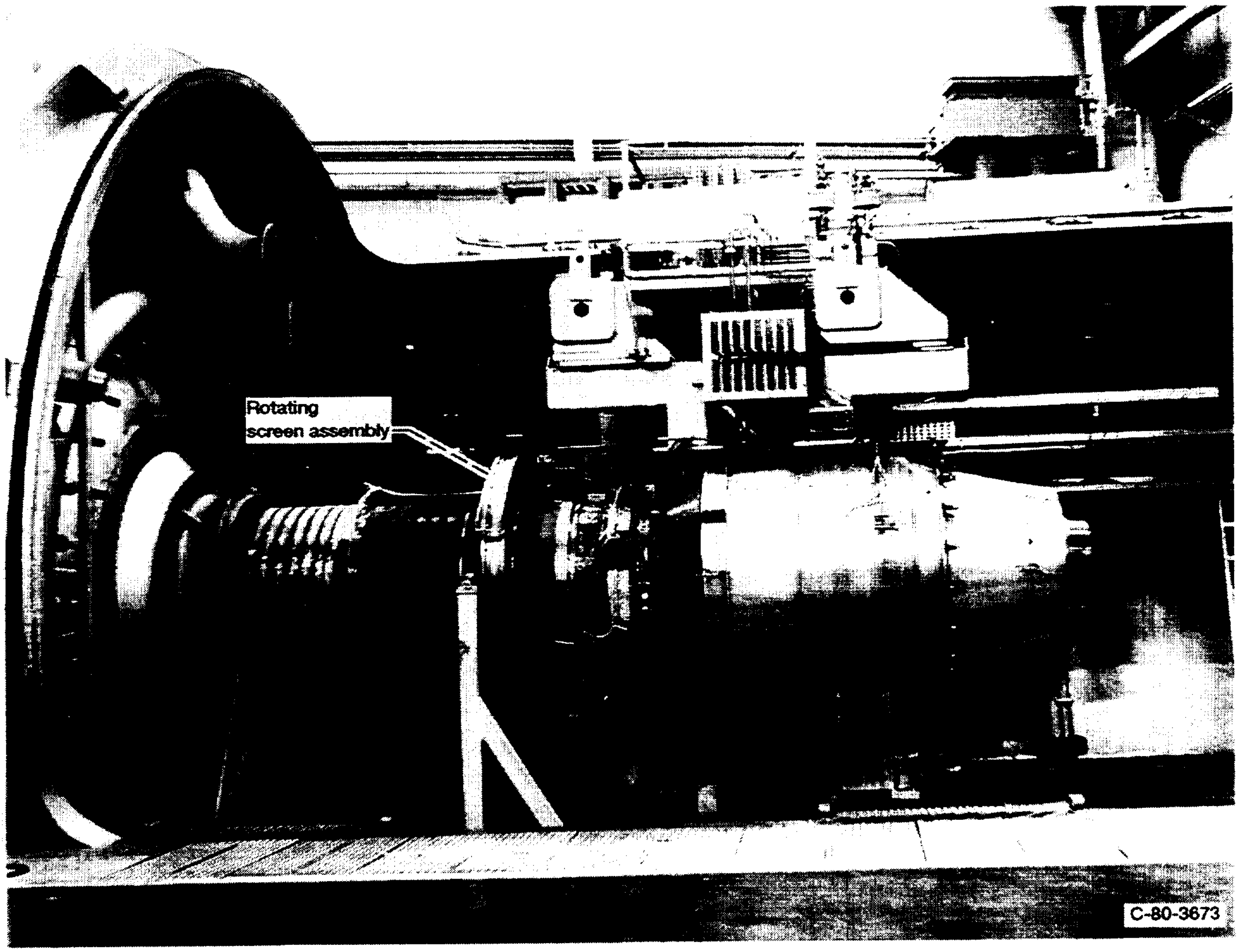



Figure 18.—Rotating screen assembly installed upstream of a high-bypass-ratio turbofan engine.

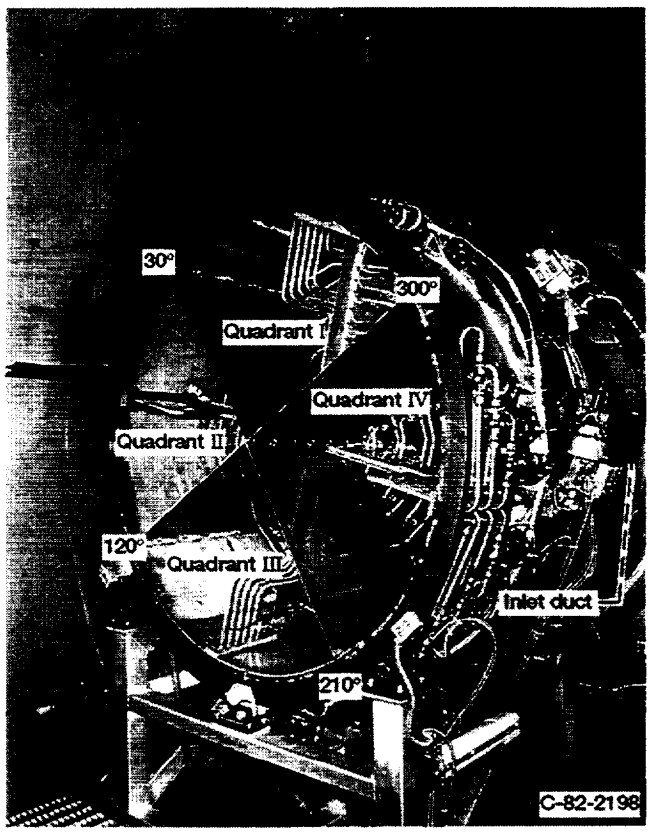



Figure 19.—Gaseous-hydrogen-fueled burner viewed in the direction of the engine inlet.

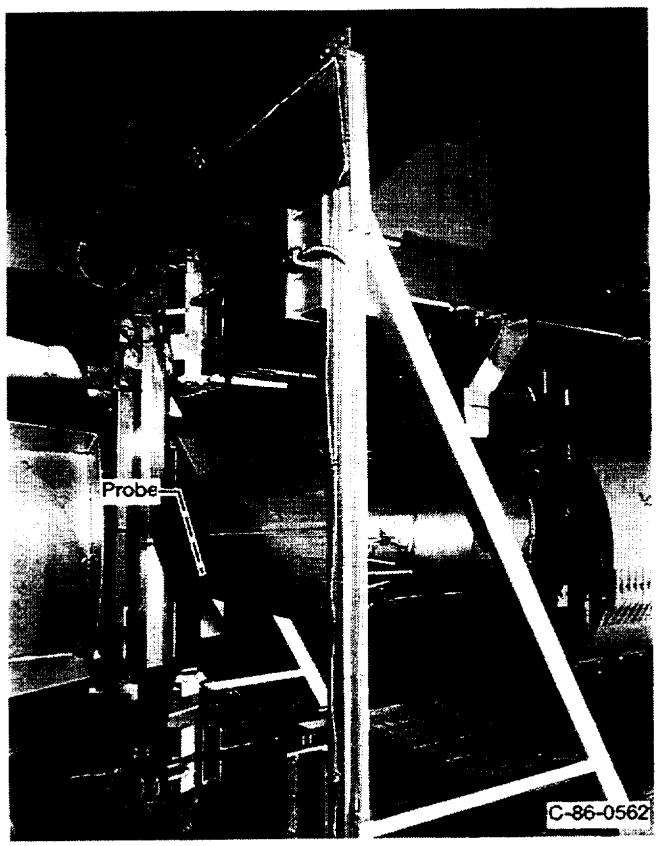



Figure 20.—Traversing probe installed on exhaust nozzle.

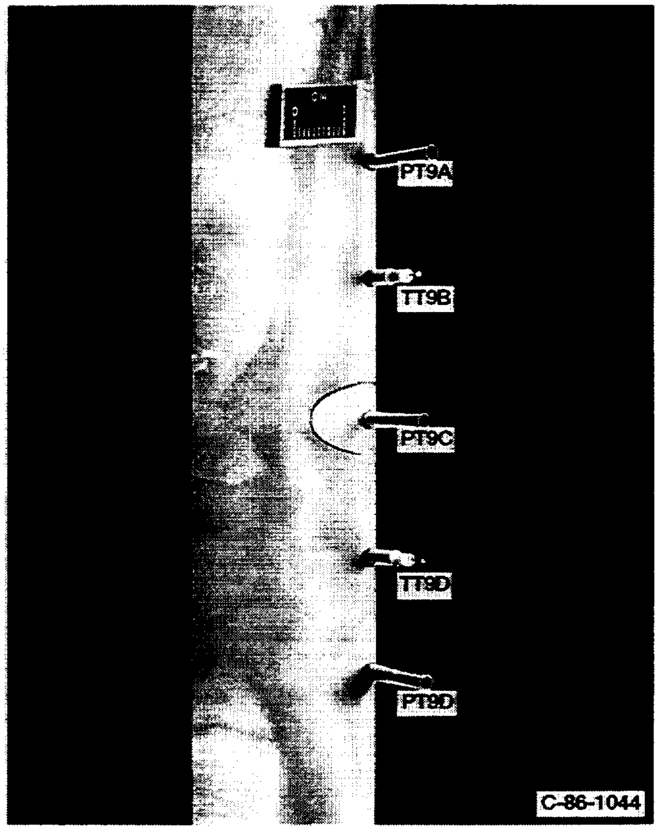



Figure 21.—Configuration of traversing probes on instrumentation rake.

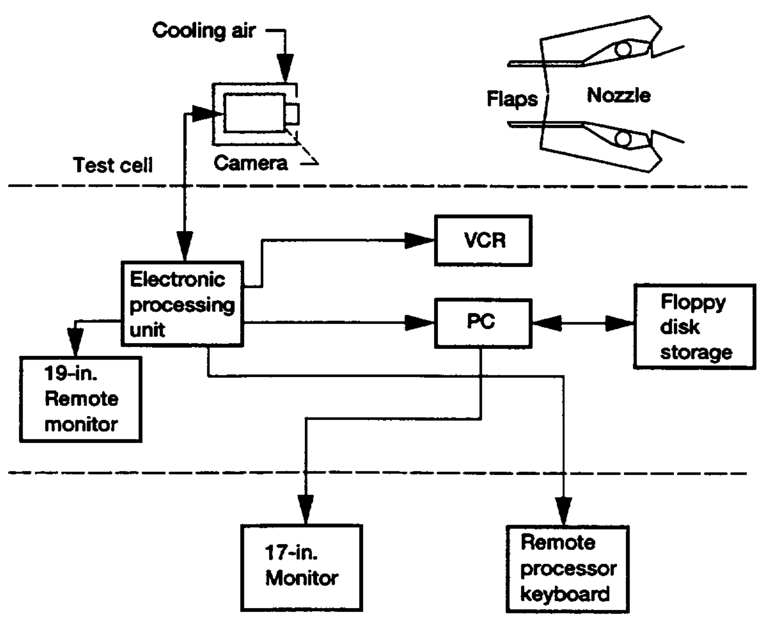



Figure 22.—Typical infrared system used in PSL.

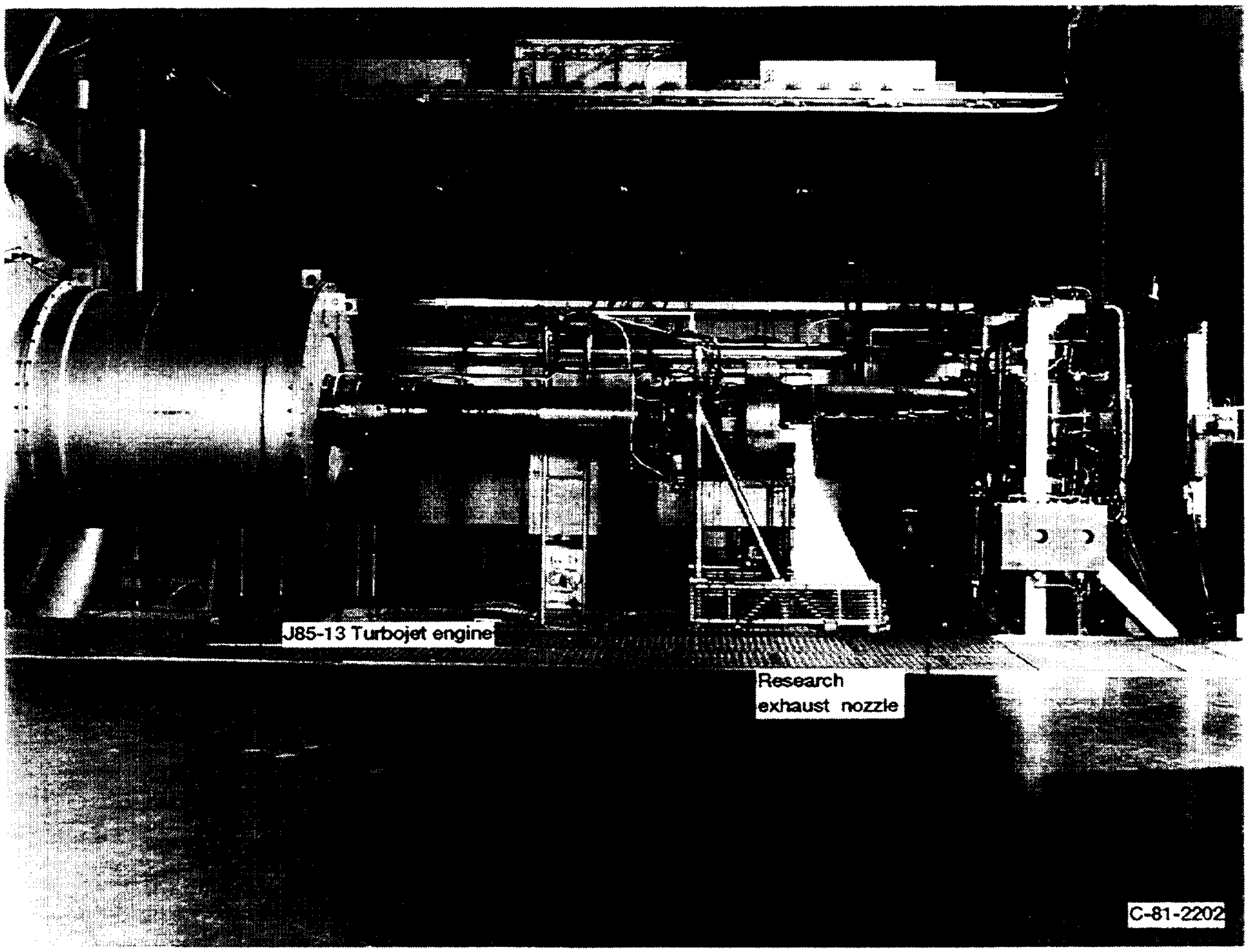



Figure 23.—Single-axis thrust measurement configuration of afterburner-equipped turbojet in PSL-3.

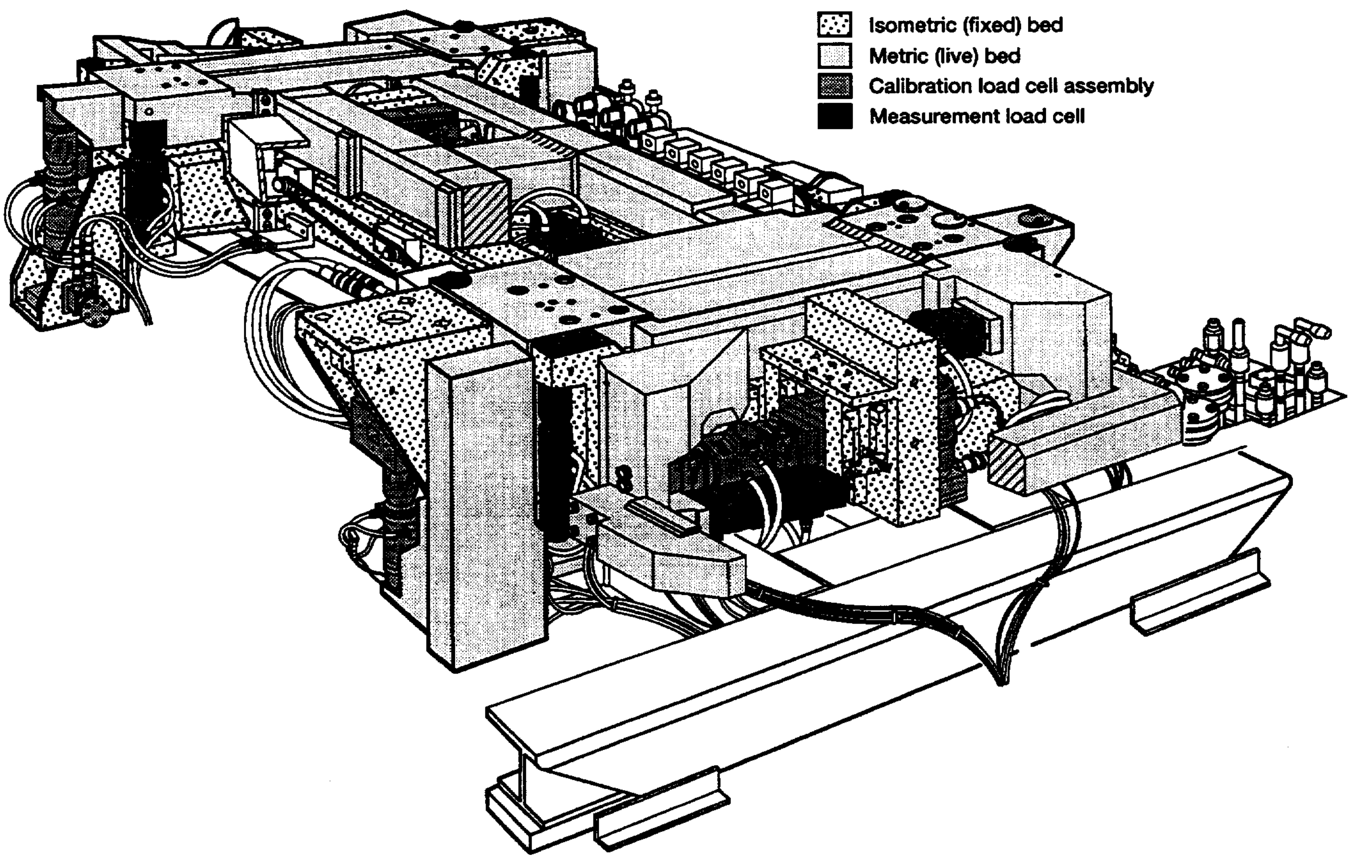



Figure 24.—Isometric view of Ormond three-dimensional thrust stand used in PSL.

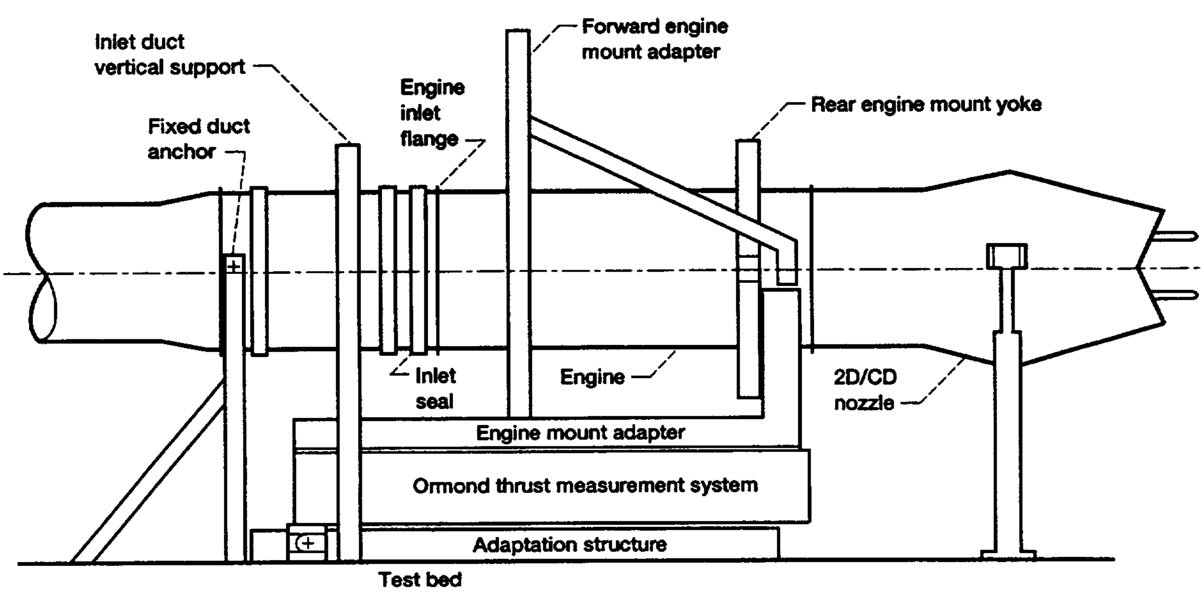
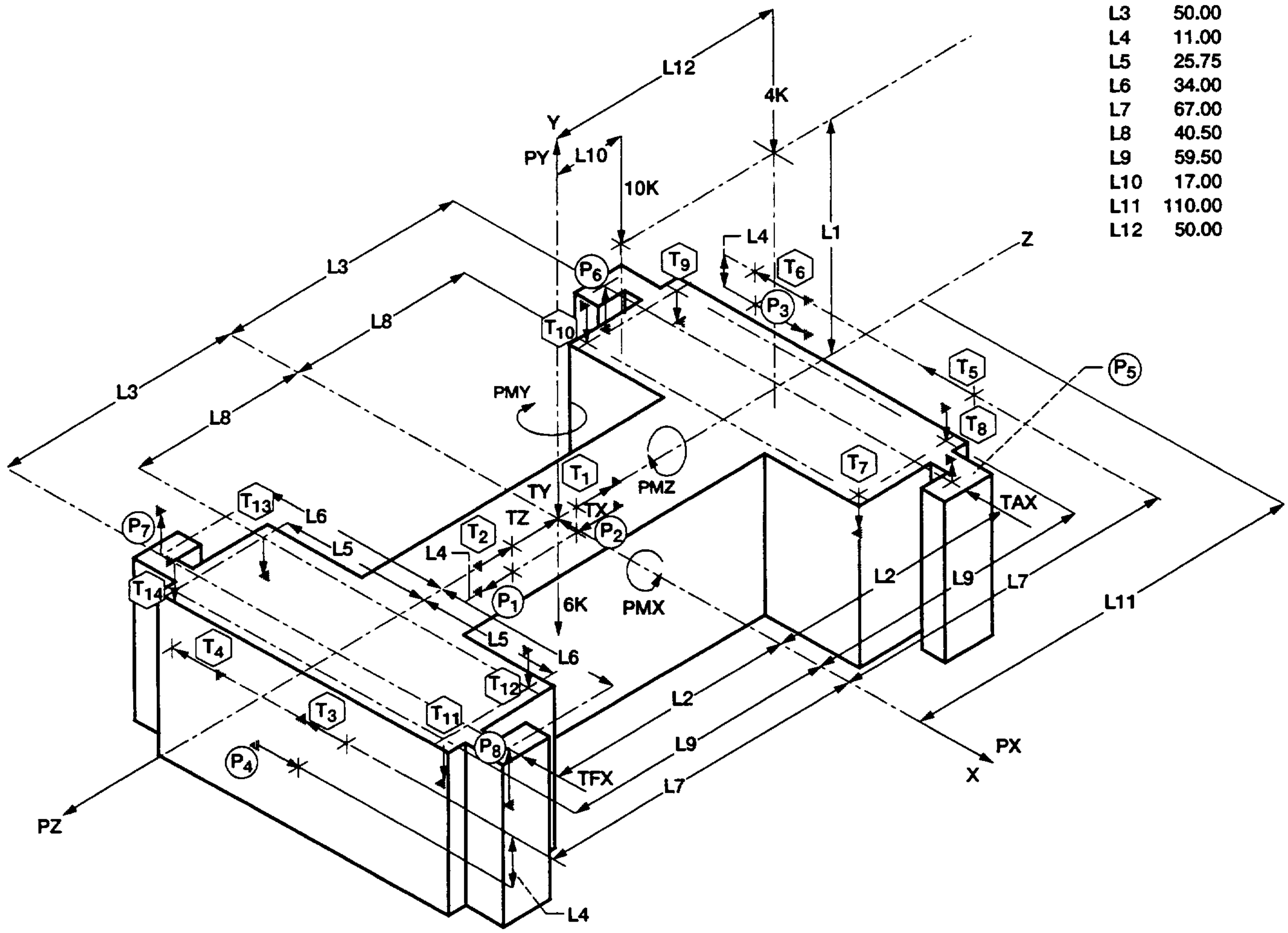



Figure 25.—Position of engine equipped with a two-dimensional converging/diverging (2D/CD) nozzle in relation to Ormond multiaxis thrust stand.




| | Distance, in. |
|---|---|
| L1 | 49.50 |
| L2 | 50.00 |
| L3 | 50.00 |
| L4 | 11.00 |
| L5 | 25.75 |
| L6 | 34.00 |
| L7 | 67.00 |
| L8 | 40.50 |
| L9 | 59.50 |
| L10 | 17.00 |
| L11 | 110.00 |
| L12 | 50.00 |

Figure 26.—Schematic of a typical Ormond three-dimensional thrust stand used in PSL; $T_1$ to $T_{14}$ are thrust load cells; $P_1$ to $P_8$ are calibration load cells (all load elements are compression positive; forces and moments indicated are positive).

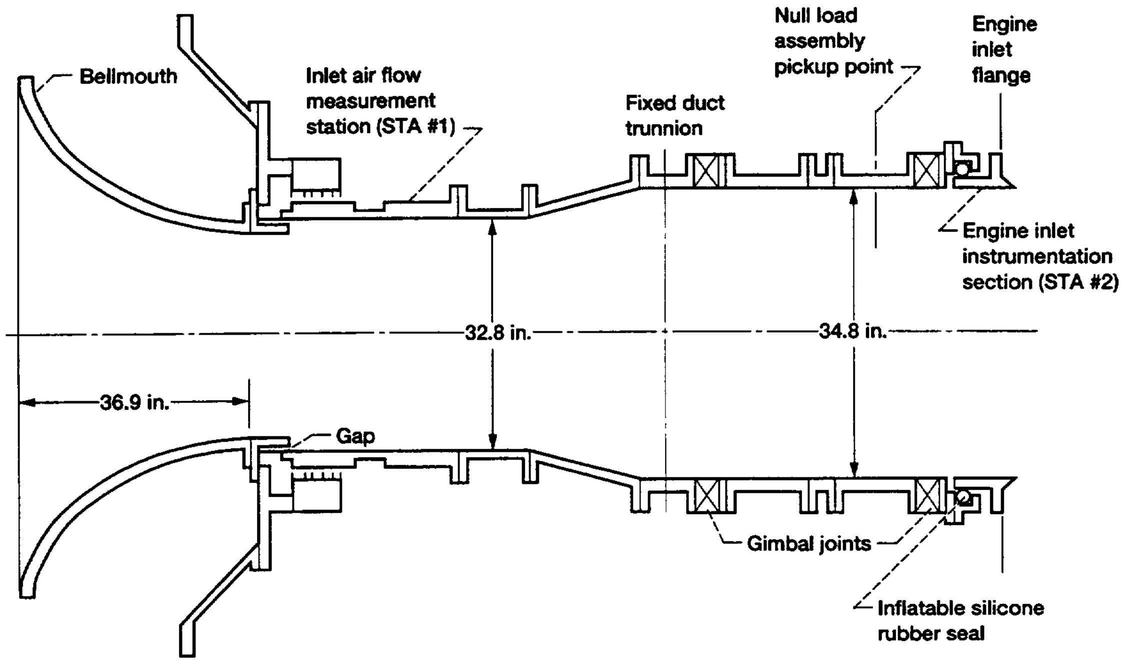



Figure 27.—Typical inlet ducting arrangement.

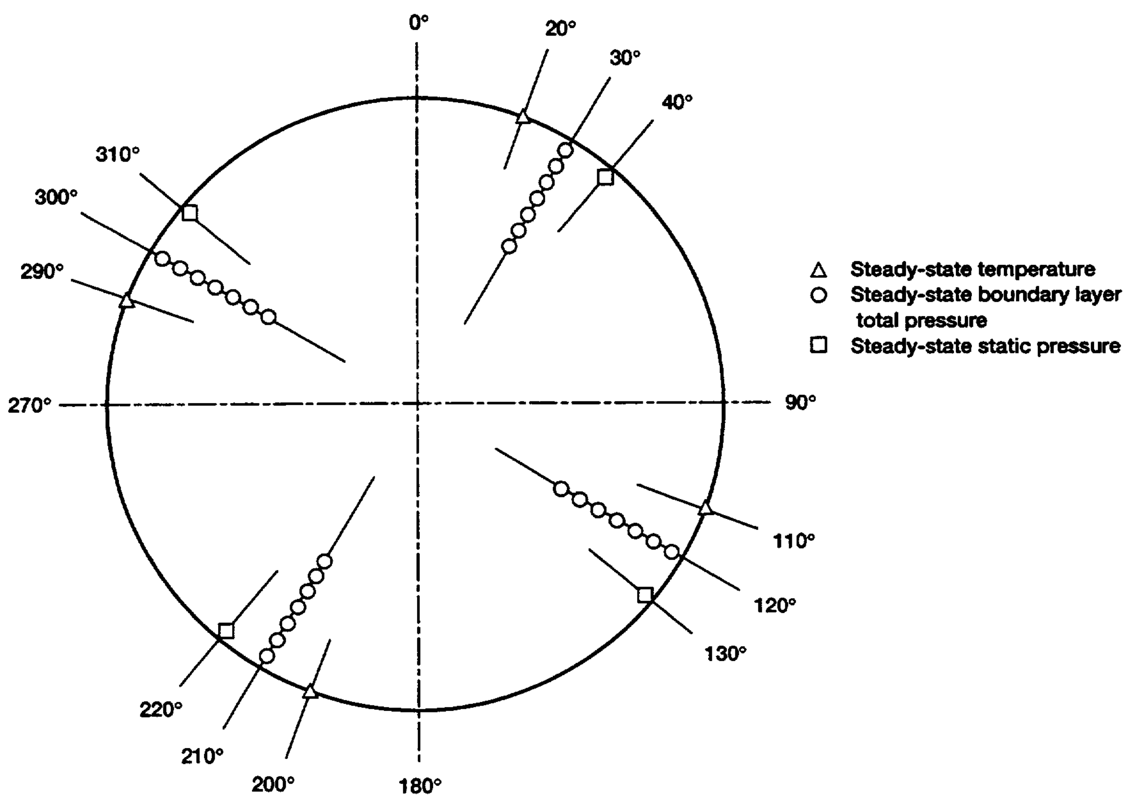



Figure 28.—Typical steady-state measurement instruments at station 1 (airflow metering station).

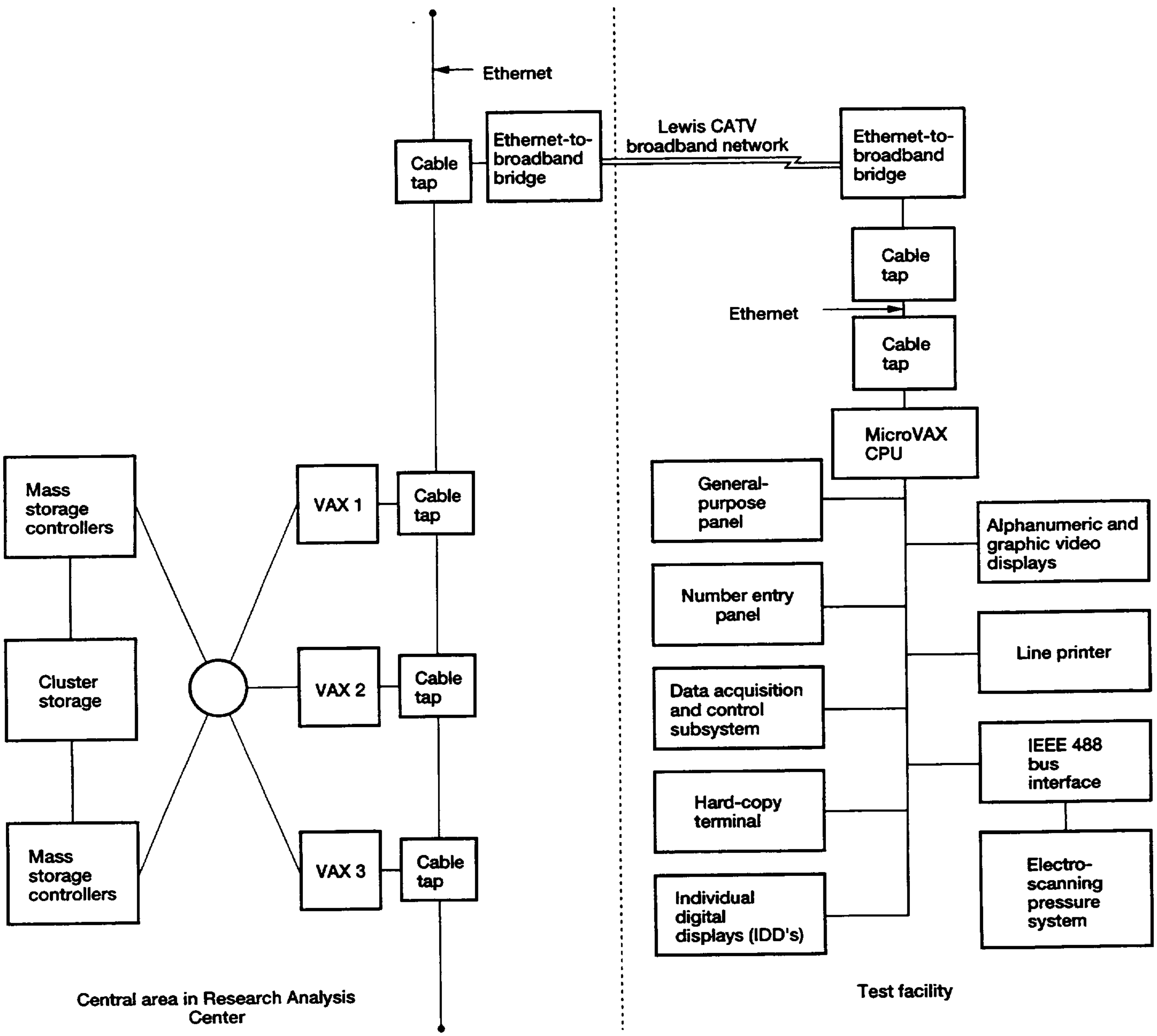



Figure 29.—Overall configuration for Escort D Plus system.

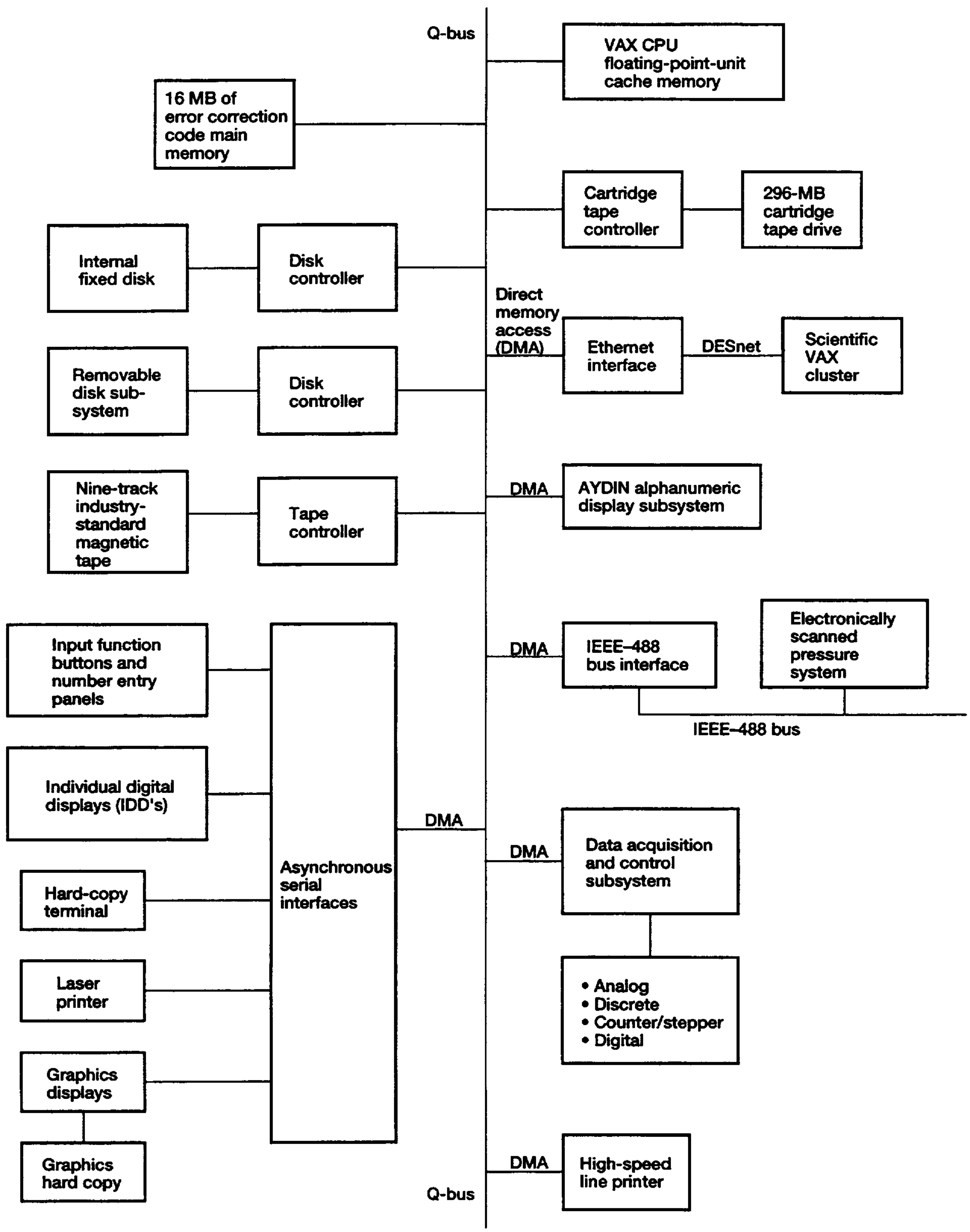



Figure 30.—Facility computer configuration.

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



| 1. AGENCY USE ONLY (*Leave blank*) | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | August 1994 | Technical Memorandum |

**4. TITLE AND SUBTITLE**

NASA Lewis Propulsion Systems Laboratory Customer Guide Manual

**5. FUNDING NUMBERS**

WU–505–62–84

**6. AUTHOR(S)**

Ronald H. Soeder

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135–3191

**8. PERFORMING ORGANIZATION REPORT NUMBER**

E–8769

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

National Aeronautics and Space Administration
Washington, D.C. 20546–0001

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

NASA TM–106569

**11. SUPPLEMENTARY NOTES**

Responsible person, Ronald H. Soeder, organization code 2830, (216) 433–5713.

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**

Unclassified - Unlimited
Subject Categories 09 and 07

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** ***(Maximum 200 words)***

This manual describes the Propulsion Systems Laboratory (PSL) at NASA Lewis Research Center. The PSL complex supports two large engine test cells (PSL-3 and PSL-4) that are capable of providing flight simulation to altitudes of 70 000 ft. Facility variables at the engine or test-article inlet, such as pressure, temperature, and Mach number (up to 3.0 for PSL-3 and up to 6.0 planned for PSL-4), are discussed. Support systems such as the heated and cooled combustion air systems, the altitude exhaust system, the hydraulic system, the nitrogen, oxygen, and hydrogen systems, hydrogen burners, rotating screen assemblies, the engine exhaust gas-sampling system, the infrared imaging system, and single- and multiple-axis thrust stands are addressed. Facility safety procedures are also stated.

**14. SUBJECT TERMS**

Full scale turbine engine altitude facility; Subsonic and supersonic turbine engine testing

**15. NUMBER OF PAGES** 51

**16. PRICE CODE** A04

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | |