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Glenn Research Center Propulsion Systems Laboratory Customer Guide

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Contents

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Summary

This guide describes the Propulsion Systems Laboratory (PSL) at the NASA Glenn Research Center. It was written to help customers understand the various components involved in conducting a program within the PSL. The PSL complex supports two large-engine test cells that simulate altitude flight conditions for a wide range of research and experimental tests. These test cells operate at altitudes up to 90,000 ft and speeds from subsonic to above supersonic. Test points such as pressure, temperature, and Mach number can be set at the engine or test article inlet based on customer requirements. The facility's support systems include the heated and cooled combustion air systems; altitude exhaust system; hydraulic system; nitrogen, oxygen, and hydrogen systems; thrust measurement system, which includes the facility's single- and multiple-axis thrust stands; inlet system; and electrical systems. In addition to providing a detailed description of PSL systems and capabilities, this guide discusses the facility's history and past tests and addresses facility safety procedures, pretest requirements, and test operation standards.

1.0 Introduction

This report describes the NASA Propulsion Systems Laboratory (PSL) and provides information for customers who wish to conduct propulsion testing or other forms of research in this world-class facility. The PSL is located at the NASA Glenn Research Center in Cleveland, Ohio, adjacent to Cleveland Hopkins International Airport. It is operated by the Facility Testing Division (Code FT).

The PSL provides experiment and test evaluation capability in support of NASA's research and technology development in a number of areas, including air-breathing propulsion altitude performance, engine component evaluation, and engine icing at altitude. The PSL also supports the Department of Defense, other Government entities, and private industry with engine and component evaluation and verification testing.

The PSL contains two large-engine test cells capable of simulating flight at altitudes up to 90,000 ft and maximum forward airspeeds of Mach 3 (in PSL–3) and Mach 4 (in PSL–4). Limited Mach 6 is achievable in PSL–4 with major facility subsystem reactivation. The nonvitiated combustion air supplied to the engine for testing is conditioned with the capability to control pressure, temperature, and humidity.

Tests may be scheduled by contacting the PSL facility manager, whose contact information appears in Section 12.0.

An overview of the PSL is provided in Section 2.0. Section 3.0 describes the various general support systems, and Section 4.0 describes the facility control systems. The inclement weather/icing system is addressed in Section 5.0. Section 6.0 describes facility operation, including standard operating procedure, emergency response, and facility protection. Section 7.0 discusses data acquisition and processing. A history of the PSL is provided in Section 8.0. Section 9.0 covers pretest requirements, and Section 10.0 discusses risk assessment. General information on support, operations, planning and debriefing, and security is provided in Section 11.0, and Section 12.0 gives contact and shipping information. Acronyms are defined in Appendix A.

2.0 Propulsion Systems Laboratory Overview

This section describes the PSL complex, test chambers PSL–3 and PSL–4, the control room, and the data room.

2.1 General Description

The PSL is part of the NASA Glenn Research Center, which supports a wide variety of test cells advancing aviation and space research. The PSL's two large test chambers, PSL–3 and PSL–4, are NASA's only full-scale propulsion altitude test cells.

The test cells achieve simulated aircraft flight by mounting the test article in a fixed position and flowing air through a facility plenum to the engine inlet at the stagnation pressure and temperature that matches the altitude and Mach number of flight conditions or other specified test conditions. The test cell in which the test article or engine is mounted is set to a static pressure based on the atmospheric conditions of the flight altitude. Flight conditions that can be simulated range from altitudes of approximately 5,000 to 90,000 ft, with simulated flight speeds of up to Mach 3 in both test cells and a possible maximum of Mach 4 (or limited Mach 6 with major subsystem reactivation) in PSL–4. The two test cells normally operate as direct-connect engine test cells and are coupled to the Center's central air supply system. Atmospheric air can also be supplied to the engine inlet of the specified test cell to perform short, low-power engine checks at sea level without the ability to condition temperature. PSL–4 can operate in a free-jet configuration up to

Mach 3.5. PSL–3 was upgraded in 2012 with an inclement weather/icing capability that can simulate engine icing conditions at altitude at flight speeds of up to Mach 0.8.

The Central Air Equipment Building (CAEB) supplies both inlet and exhaust services to the facility via large centrifugal compressors and exhausters. The machines are driven by electric motors and can, combined, produce over 200,000 hp. Descriptions of the many types of research conducted in the PSL over the past 30 years can be found in later sections of this paper and in References 1 to 30; highlights are presented in Section 8.2.

2.2 Test Cells

The two test chambers designated as PSL–3 and PSL–4 have been in operation since 1973. Each test chamber is 24 ft in diameter and 39 ft in length 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 (Figure 1). With this configuration, only one cell can be operated at a time while the nonoperating cell is isolated from the exhaust by a movable 17-ft-diameter davit valve. The inlet air for the test cell not in use is also isolated.

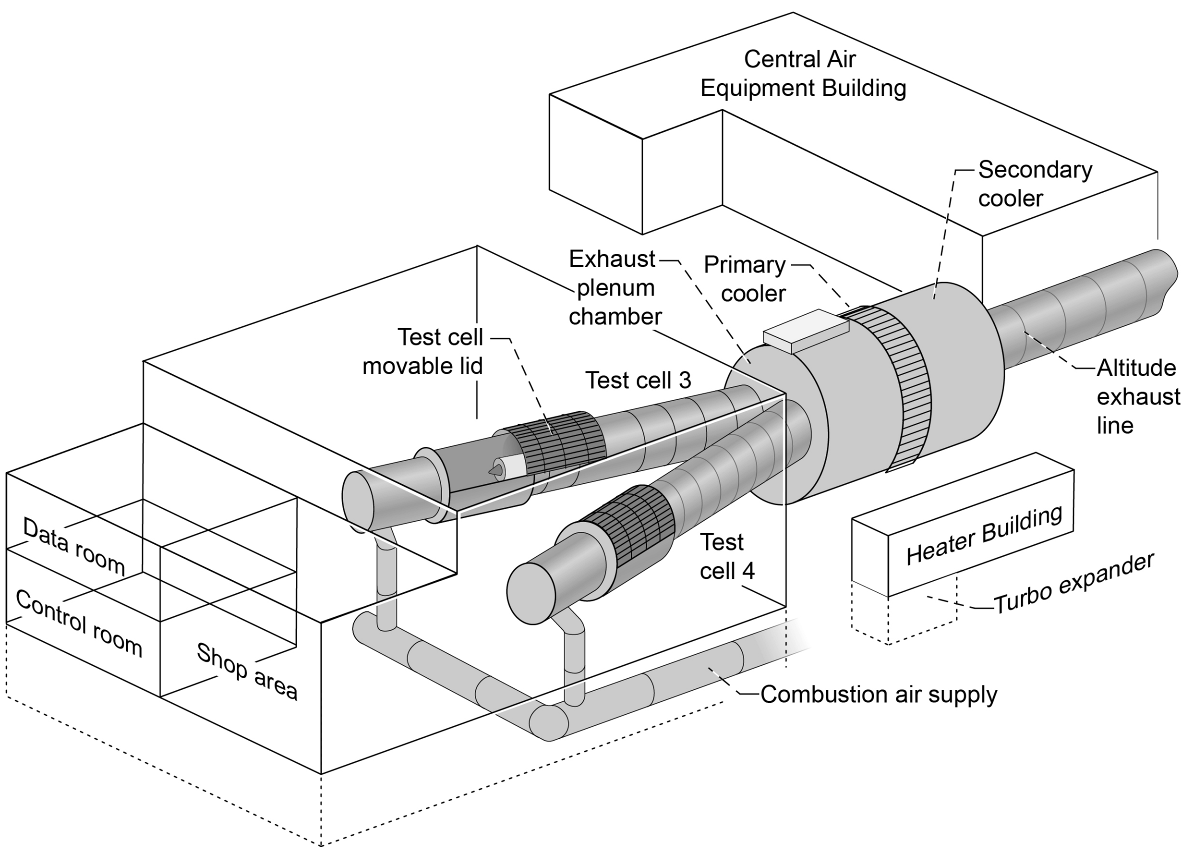

Figure 1.—General layout of the PSL facility showing PSL–3 and PSL–4 altitude tanks, control room, and data rooms.

Each test chamber can be configured with a multiple-axis thrust stand with a capacity of up to 50,000 lbf axial thrust, with a centerline that is 72 in. from the test chamber floor. The test cell legs receive combustion air directly from the compressors in the CAEB and expel all exhaust air directly to the CAEB; these systems are discussed in Sections 3.1 and 3.3, respectively. The test cells are normally direct-connect altitude simulation facilities. A general operating envelope for a turbofan engine tested in PSL–3 and PSL–4 is presented in Figure 2, and basic characteristics of PSL–3 and PSL–4 are presented in Table I.

A map of the altitude capability as a function of exhaust flow rate with and without water sprays is presented in Figure 3. Additional information concerning the development of this map can be obtained from the PSL facility engineer. The specific requirements of the facility test customer, as well as combustion air and exhaust capabilities, are discussed with the facility manager and the PSL engineering team at one of several test-planning meetings held both virtually and at NASA Glenn. These meetings can be conducted in a secure environment as needed.

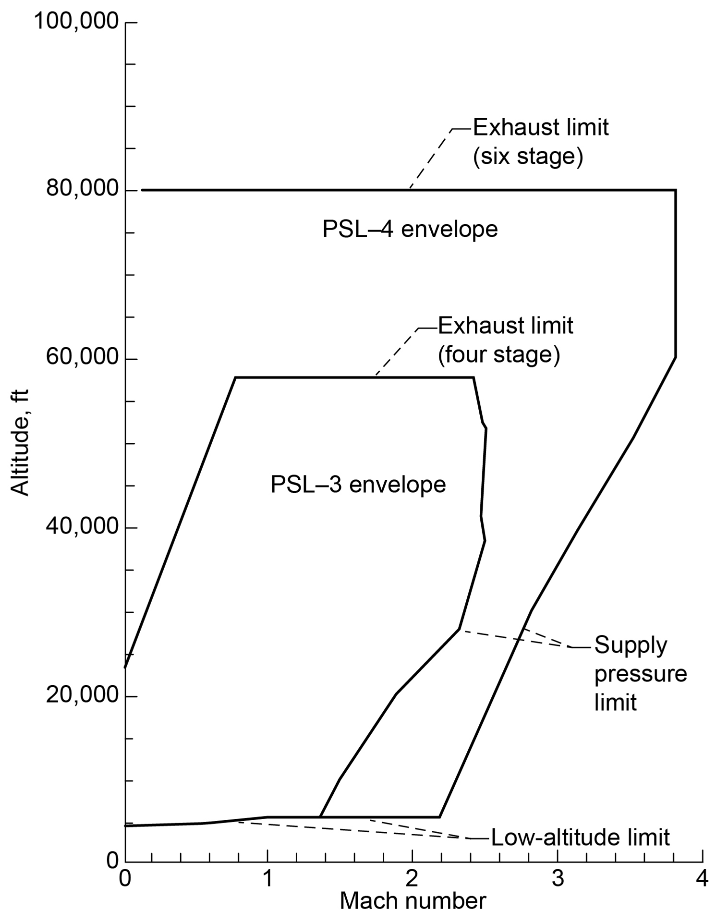

Figure 2.—Typical operational envelopes for PSL–3 and PSL–4.

TABLE I.—PSL CHARACTERISTICS

Parameter	PSL–3	PSL–4
Diameter, ft	24	
Length, ft	39	
Engine centerline above thrust bed, ft	6	
Altitude range, ft	0 to 90,000	
Mach number range	0 to 3.0	0 to 5.0
Inlet air supply		
Pressure range, psia	0 to 55	
Temperature range, °F	–50 to 800	0 to 165
Mass flow range, lbm/s[a]	0 to 480	–90 to 1,200 (1,800 planned)
Exhaust capability		
Pressure range, psia	Atmosphere to 0.4	
Mass flow range at sea level, lbm/s[b]	750	
Test cell cooling air		
Pressure range, psia[c]	55 to 165	
Mass flow range, lbm/s	0 to 100	
Model cooling air		
Pressure range, psia	0 to 465	
Mass flow range, lbm/s	0 to 100	
Fuel supply		
Flow rate, gal/min	0 to 200	
Pressure range, psia	0 to 65	
Thrust measurement capability		
Multiple axis, lbm		
Horizontal	40,000/50,000	
Vertical and lateral	15,000	
Single axis, lbm	5,000/10,000/40,000/50,000	

[a]Limited to central air services system 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.

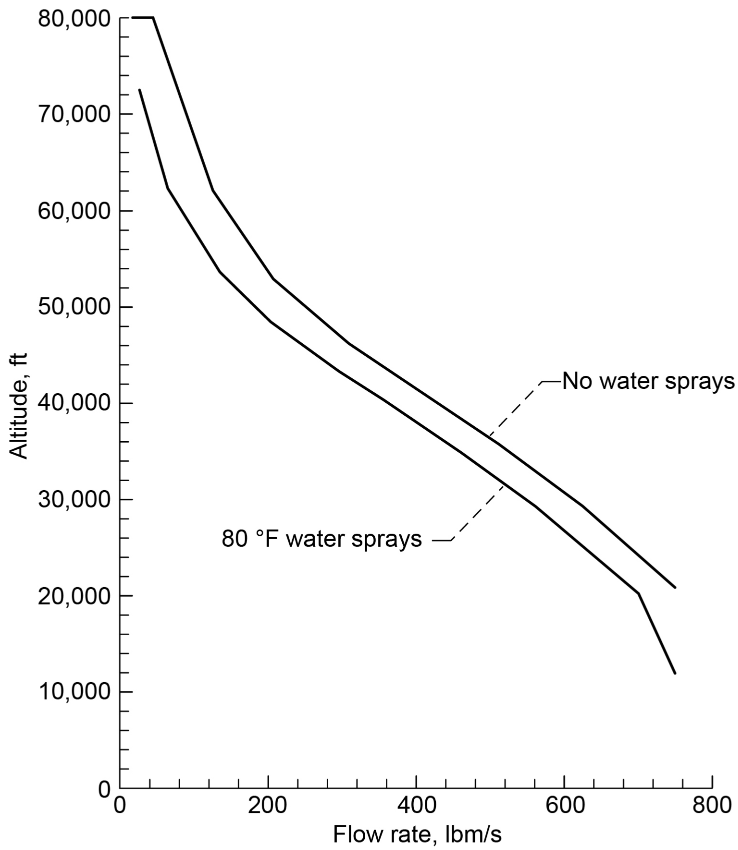

Figure 3.—Altitude as a function of exhaust flow rate.

In 1990, a pressure vessel was installed inside the PSL–4 test facility inlet plenum, depicted in Figure 4, to increase pressure and temperature capabilities of the system. With the addition of the pressure vessel insert, PSL–4 test capabilities increased to 280 lbm/s at 165 psia and 800 °F, or 380 lbm/s at 165 psia and 450 °F. The pressure vessel is 30 ft 4 in. long and has an inlet diameter of 75 in. and an outlet diameter of 108 in. A 24-in.-diameter bypass line 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 quality of the air through the pressure vessel insert can be improved by passing air through two perforated plates and a honeycomb structure. The insert facilitates testing of free jets, core engines, turbine engines, high-Mach-number engines, and hypersonic rigs. Figure 5 shows the PSL–4 plenum configuration for free-jet tests. A maximum condition of the plenum insert is 165 psia, 280 lbm/s at 1,050 °F (1,150 °F with topping heater). Figure 6 shows the PSL–4 plenum configuration for engine core tests. A maximum condition of the plenum insert is 165 psia, 380 lbm/s at 800 °F. Figure 7 shows the PSL–4 plenum configuration for turbine engine tests. A maximum condition of the plenum insert is 60 psia, 480 lbm/s at 600 °F. Figure 8 shows the PSL–4 plenum configuration for high-Mach-number engine tests. A maximum condition of the plenum insert is 165 psia, 380 lbm/s at 800 °F. Figure 9 shows the PSL–4 plenum configuration for hypersonic direct-connect tests. A maximum condition of the plenum insert is 165 psia, 100 lbm/s at 600 °F.

In 2012, PSL–3 was upgraded with an inclement weather capability to simulate engine operation in icing clouds at altitude. Ten spray bars are installed in the PSL–3 inlet plenum consisting of 222 individually selectable spray nozzles. The nozzle designs are based on those used in Glenn's Icing Research Tunnel (IRT) and use internally mixed city or deionized water and service air to set a wide variety of cloud conditions. Both conventional icing and ice crystal clouds can be produced. Further information is provided in Section 5.0.

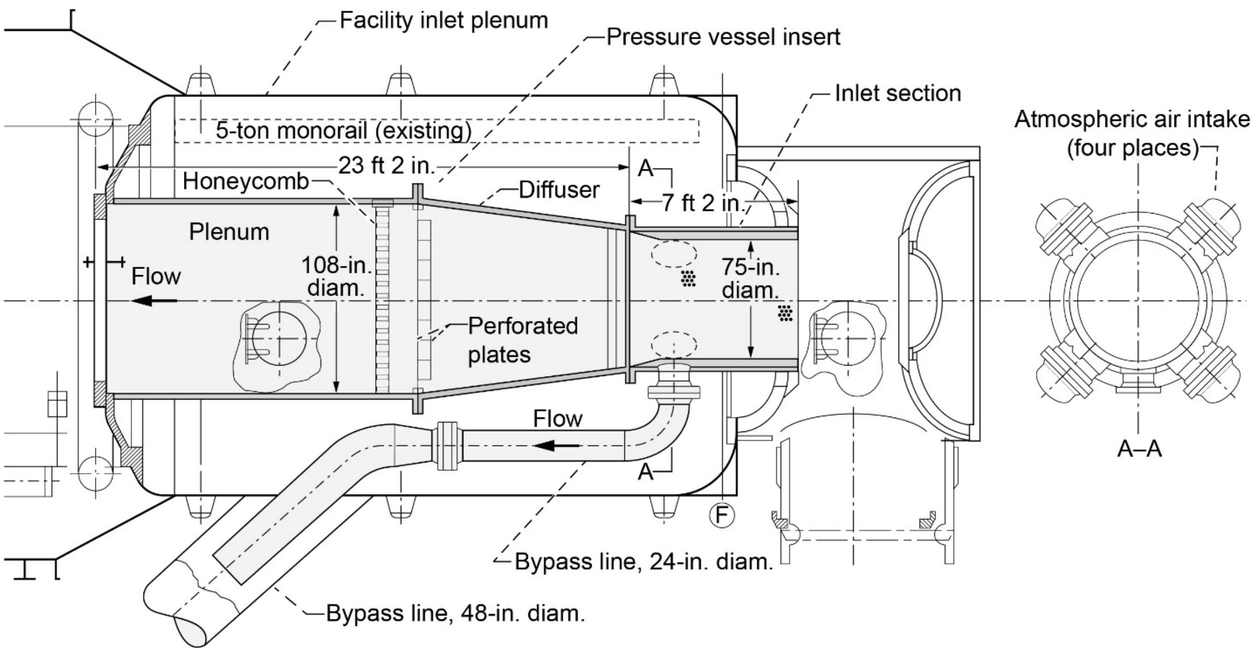

Figure 4.—PSL–4 pressure vessel insert in facility inlet plenum.

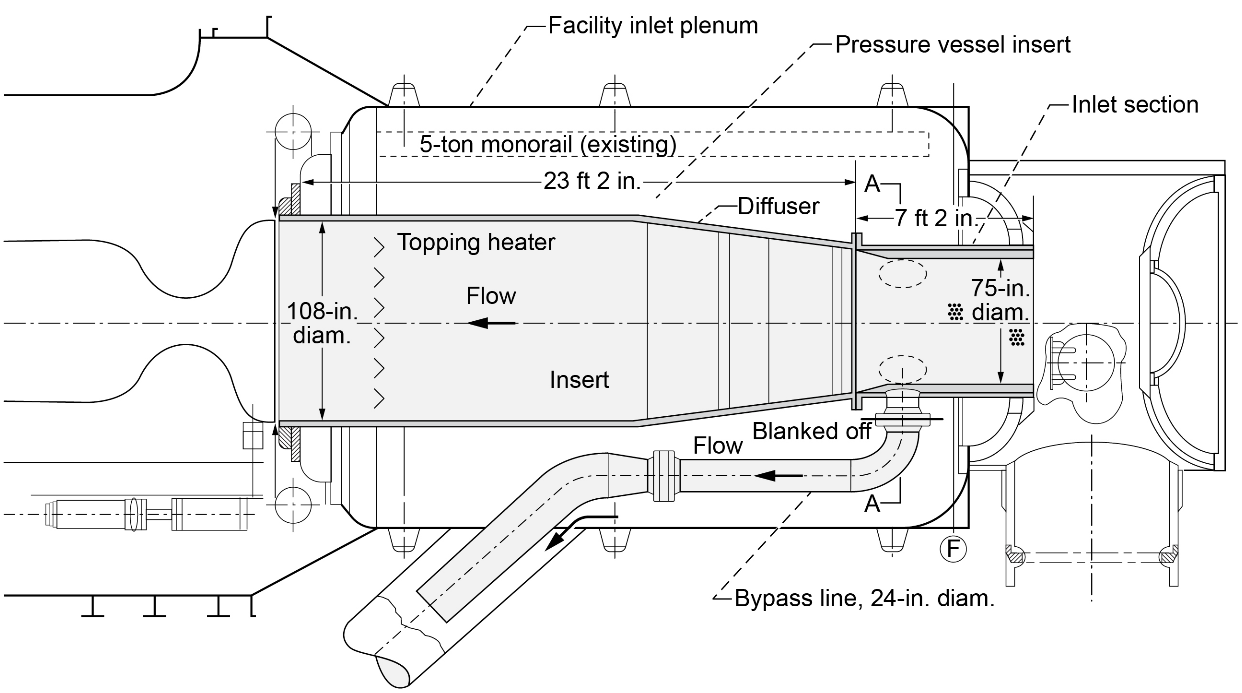

Figure 5.—PSL–4 plenum vessel insert configuration for free-jet tests.

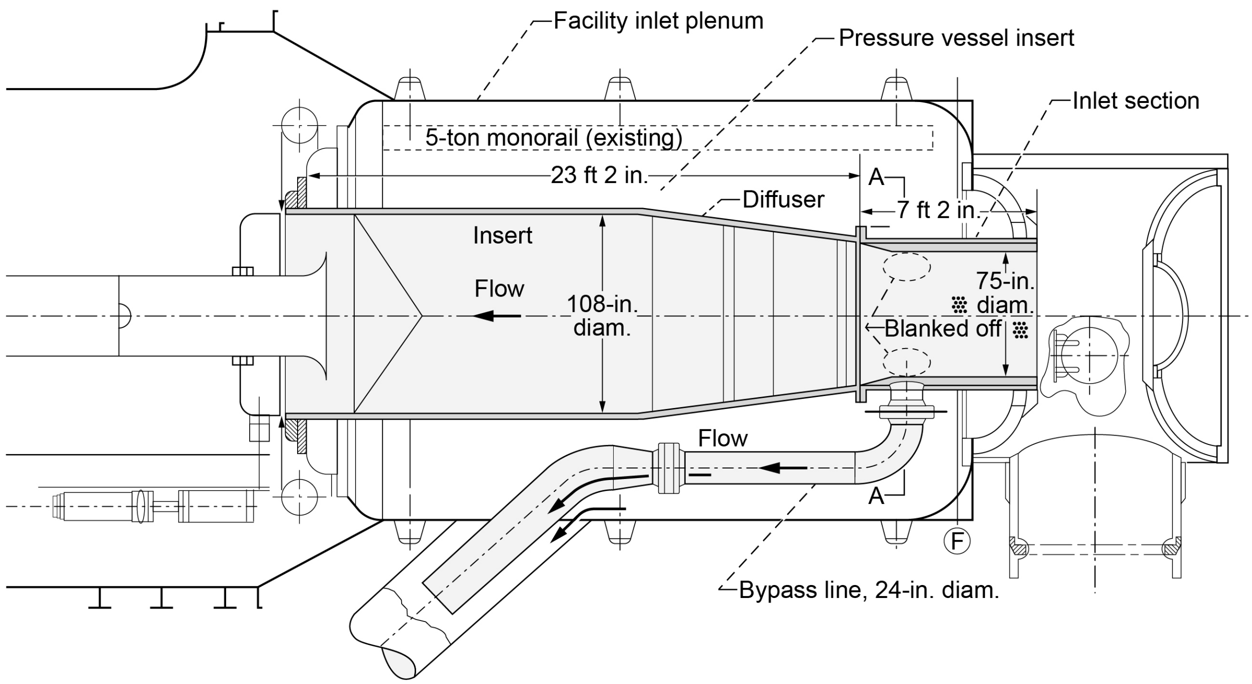

Figure 6.—PSL–4 plenum vessel insert configuration for engine core tests.

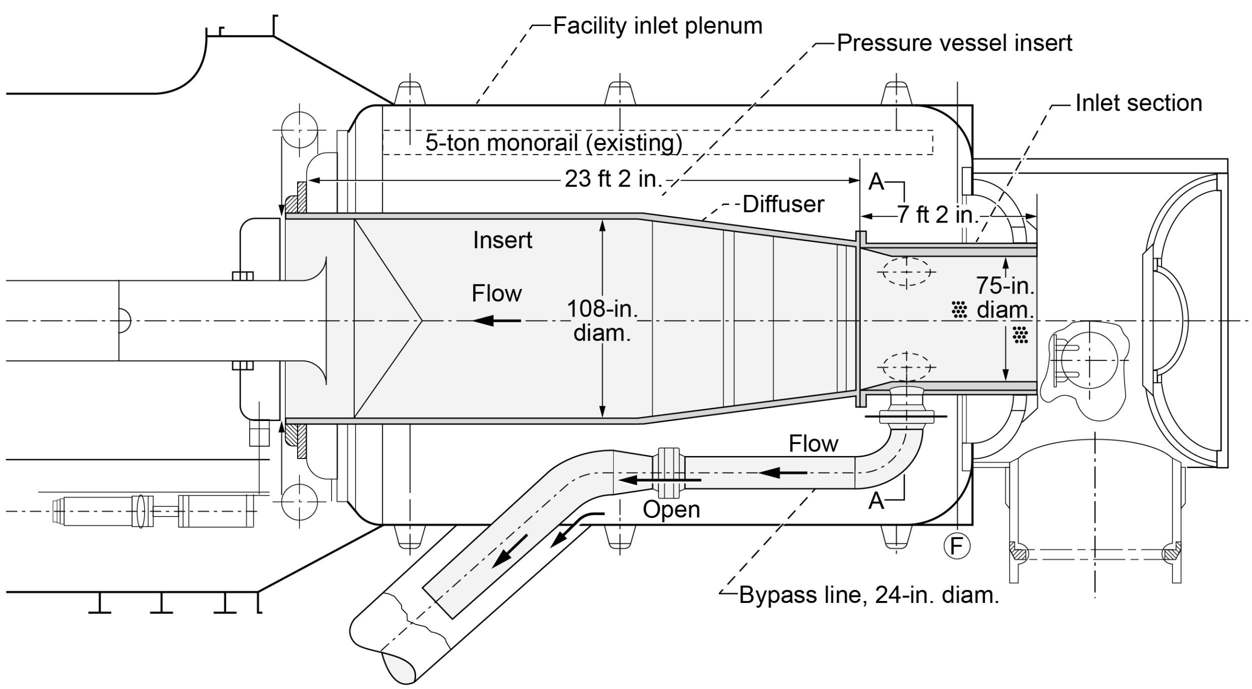

Figure 7.—PSL–4 plenum vessel insert configuration for turbine engine tests.

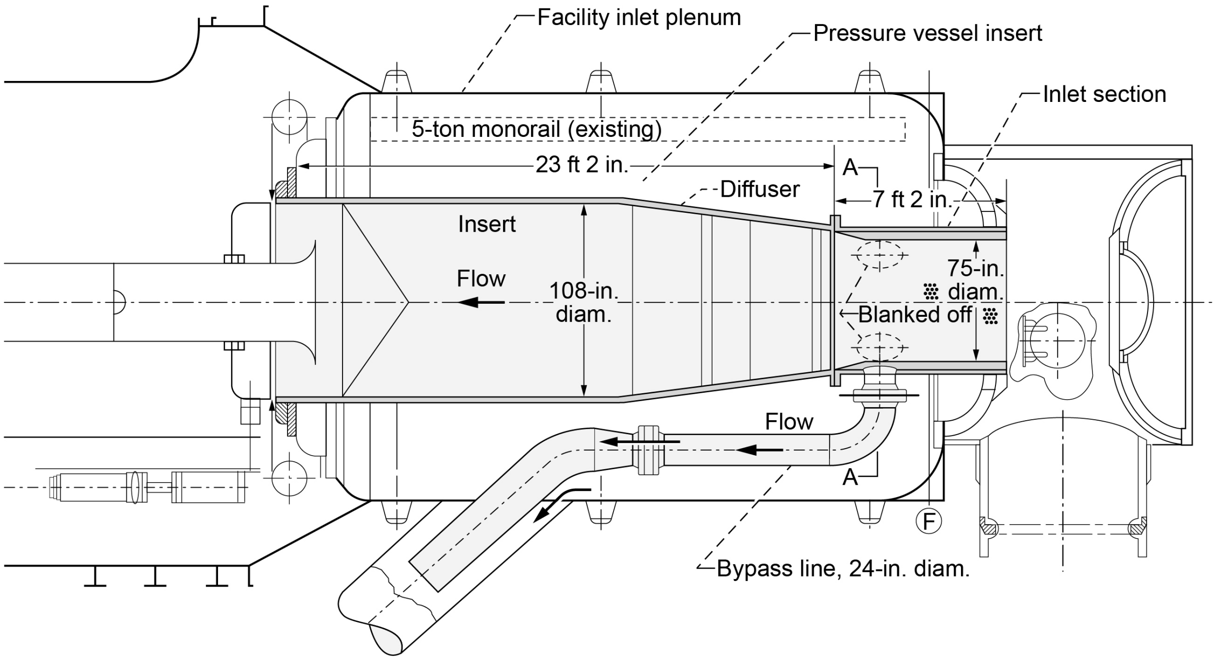

Figure 8.—PSL–4 plenum vessel insert configuration for high-Mach-number engine tests.

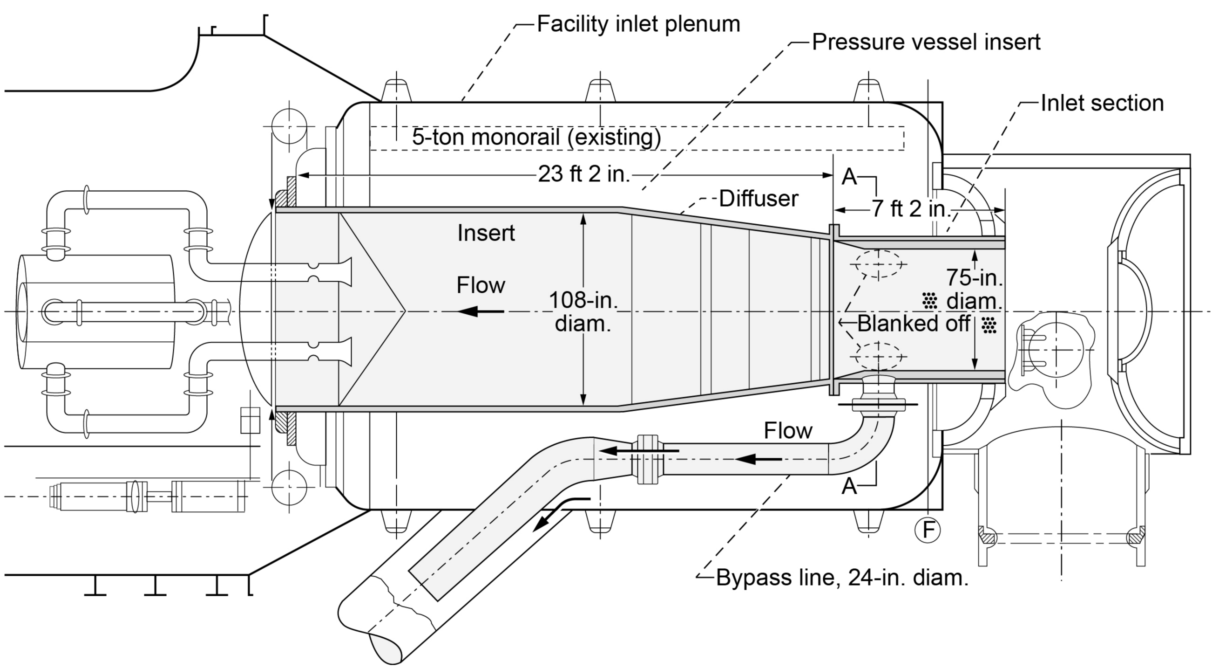

Figure 9.—PSL–4 plenum vessel insert configuration for hypersonic direct-connect tests.

2.3 Control Room

The facility is operated from the control room, located on the first floor of the PSL building. Figure 10 shows a staffed control room configured for engine icing testing, and Figure 11 shows a typical control room layout schematic. In Figure 11, the bottom of the figure represents the front center of the control room. Here, the facility distributed control system (DCS) stations are staffed by facility operators who are responsible for setting test conditions, including combustion air pressure, temperature, humidity and mass flow, exhaust pressure, and cell cooling air, as well as operating all auxiliary systems.

Figure 10.—PSL control room during engine icing operations. (C-2017-07278)

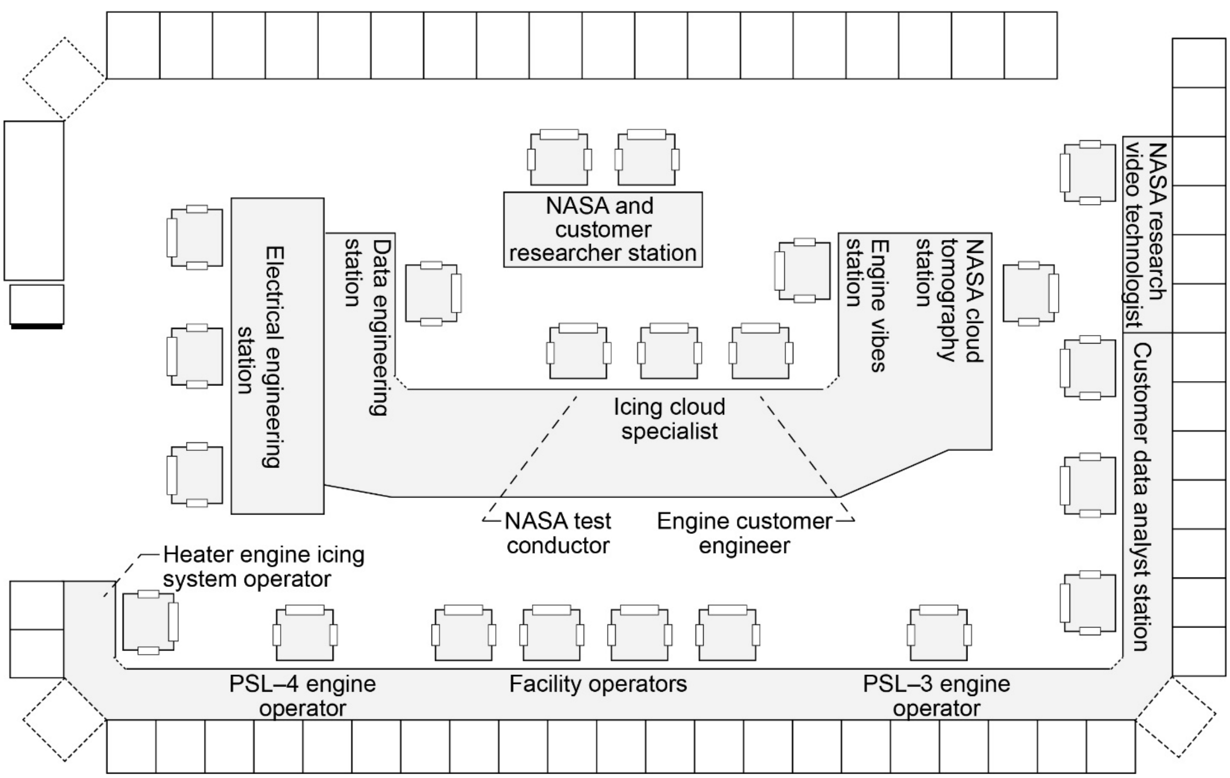

Figure 11.—PSL control room layout schematic showing typical personnel station locations. (Bottom of figure represents front center of control room.)

The PSL–3 engine operator station is to the right of the facility operators in Figure 11, with the PSL–4 engine operator station at front left. Farther left is the heater engine and icing operation station. The customer-provided auxiliary system stations are located in available space at the far-right side of the control room.

The central console in the control room is reserved for time-critical decision staffing. The test conductor, as the focal point of the command structure for any test, occupies the central location. The data engineering station is to the left of the test conductor in Figure 11.

In a conventional engine test, the customer engine principal engineer sits directly beside the test conductor. In the case of an engine icing test, the NASA icing cloud specialist sits between the test conductor and the customer principal engineer.

Engine vibrations are typically monitored at stations located to the right of the customer principal engineer. Placed directly behind the test conductor is the NASA and customer researcher station, giving the researchers direct access to the test conductor.

The facility electrical engineering station is on the left periphery of the central console, permitting easy access to the facility operators up front.

The right center console periphery and right side of the control room is typically utilized by the customer engineers analyzing real-time and near-real-time telemetry. In the case of an icing test, a NASA cloud tomography station will be located in this area. The right-side rear position is reserved for a NASA research video image technologist.

Each console has controls and readouts appropriate to the specific tasks of the operators and engineers who operate and monitor the facility and the test article. The facility is operated with an Emerson Ovation™ (Emerson Electric Co.) DCS; see Section 5.0 for details of this system. The engine conditions are set and monitored with the controls and instrumentation located at the engine operator's station. Similarly, the test cell inlet conditions are set with controls located at the combustion air operator's station. The combustion air operator also sets the cooling airflow rate through the test cell cooling torus to maintain test cell temperature within instrumentation limits (typically 70 to 150 °F). Test chamber pressure altitude is set by the exhaust operator. The operators are in communication with the equivalent operators in the CAEB who are operating the compressors and exhausters supplying air/exhaust flow rates to the PSL. The propulsion or experimental test article is viewed remotely on video monitors in the control room from cameras mounted inside the test cell.

2.4 Data Room

A data room is located on the second floor, above the control room. Each test cell has a dedicated low-speed data acquisition system (COBRA, for Collect, Observe, Broadcast, Record, and Analyze) located in the data room along with a standalone computer that controls the NetScanner™ (Measurement Specialties, Inc.) steady-state pneumatic pressure measurement system. Signal processing equipment and shared dynamic data acquisition equipment is also located in the data room. The low-speed and dynamic data acquisition systems are interactive systems that can collect, process, and display computed test results in real time. Section 7.0 provides details on both of these systems.

The entire PSL facility, including the test cell, control room, and data room, can be completely secured for Controlled Unclassified Information (CUI) or higher security-level test programs. The need for security is determined by the PSL facility manager and the PSL engineering team during test-planning meetings.

3.0 General Support Systems

This section describes the numerous systems that support the PSL with combustion air, exhaust, heating and cooling, research hydraulics, liquid fuel, gases, and other testing needs.

3.1 Combustion Air System

3.1.1 Main Supply Systems

Equipment in the CAEB, adjacent to the PSL, provides compressed air to the two PSL test cells. Only one test cell can operate at a time because the cells share a common air supply, exhaust supply, and exhaust-gas-cooling system. The schematic in Figure 12 shows how the combustion air system is tied into PSL–3 and PSL–4. Combustion air is delivered to PSL–3 and PSL–4 by four sets of 40-psig centrifugal compressors. The airflow rates can be varied from approximately 10 to 480 lbm/s at 60 °F. Two sets of boost compressors can be used to raise the air pressure to a maximum of 150 psig at a temperature of 100 °F, with a reduction of flow capacity to 380 lbm/s. For non-icing tests, a portion of the combustion air is bypassed from the inlet plenum to the exhaust line to maintain a constant airflow and inlet pressure demanded by the propulsion system being tested. These test-cell bypasses enable tighter control of inlet Mach number as engine mass flow changes due to changes in engine power demand. To avoid ice accretion and buildup within the bypass duct, the bypass inlet is blocked off during engine icing tests in PSL–3.

3.1.2 Cooling Air Systems

Compressor equipment in the CAEB supplies cooling air to the PSL to keep the test cells and the surrounding support equipment and instrumentation from overheating during engine operation. Cooling air can also be used to support subsystems that need pressurized air. The test conductor determines the configuration of the cooling air based on test requirements. The cooling air is injected into the test cell from a cooling air torus with multidirectional nozzles at the forward section of the test cell.

The CAEB compressor equipment delivers cooling air to the test cells through a 20-in.-diameter line that is part of the PSL facility. This cooling air is available as compressed air at the following conditions:

1. 40 psig at an ambient inlet temperature and a flow rate of 100 lbm/s
2. 150 psig at an ambient inlet temperature and a flow rate of 100 lbm/s

High-pressure compressor equipment in the CAEB can also supply cooling air to the test chambers at 450 psig through a 10-in.-diameter line. The maximum capacity of cooling air available is 450 psig compressed air at an ambient inlet temperature and a flow rate of 75 lbm/s.

3.2 Heater Engine Building

Combustion air for PSL–3 and PSL–4 is heated and cooled in the PSL's Heater Engine Building (also called the Heater/Refrigeration Building). This building also houses a specialized PSL–4 low flow, cold air supply line that can supply combustion air at temperatures as low as –90 °F.

3.2.1 Combustion Air Heater System

The Heater Engine Building was designed and built to provide high-temperature combustion air to PSL–3 and PSL–4. As illustrated in Figure 13, combustion air from the CAEB flows through two heat exchangers in the Heater Engine Building, where it is heated to a target temperature (100 to 700 °F). 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.

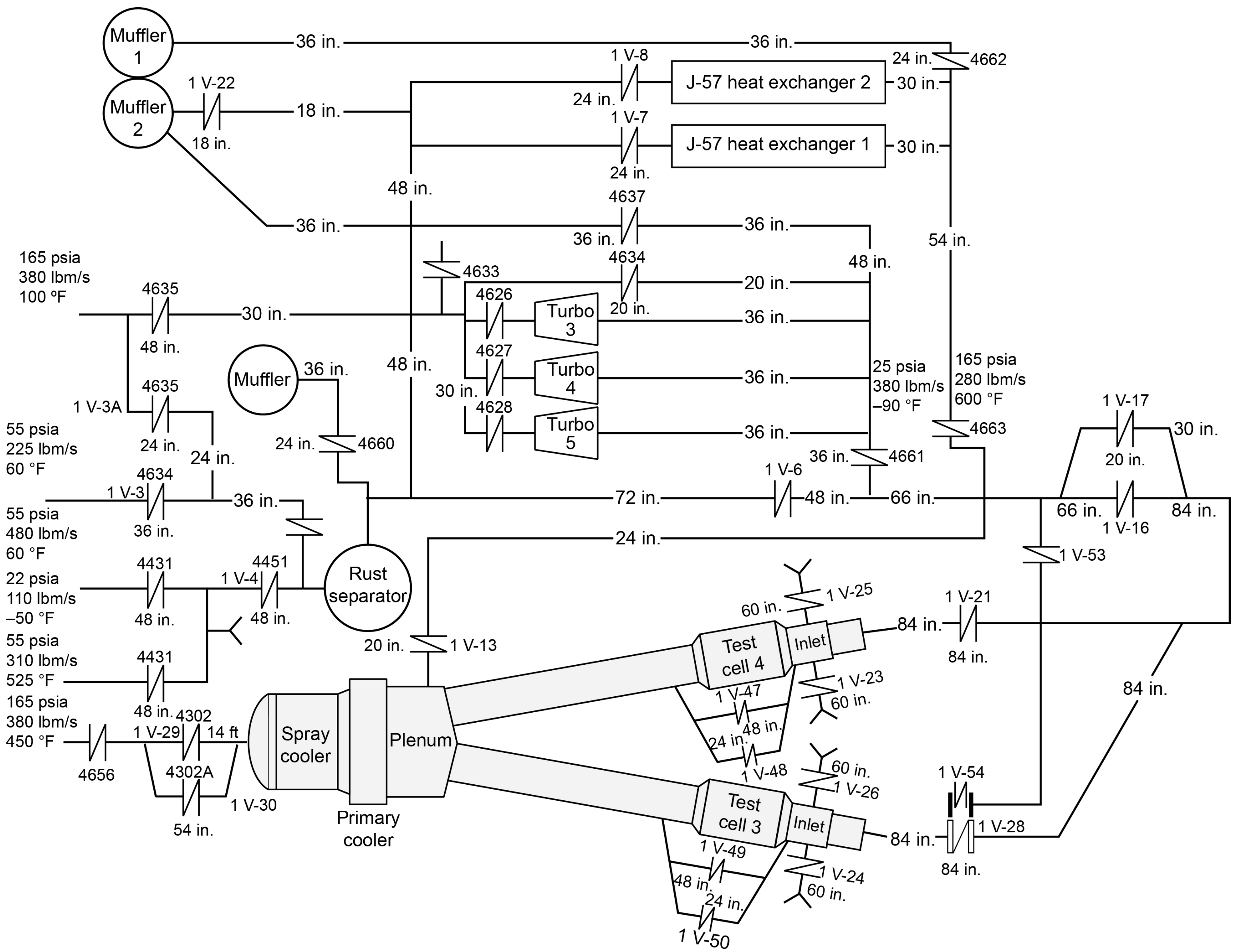

Figure 12.—Combustion air system piping tied into PSL–3 and PSL–4 facility.

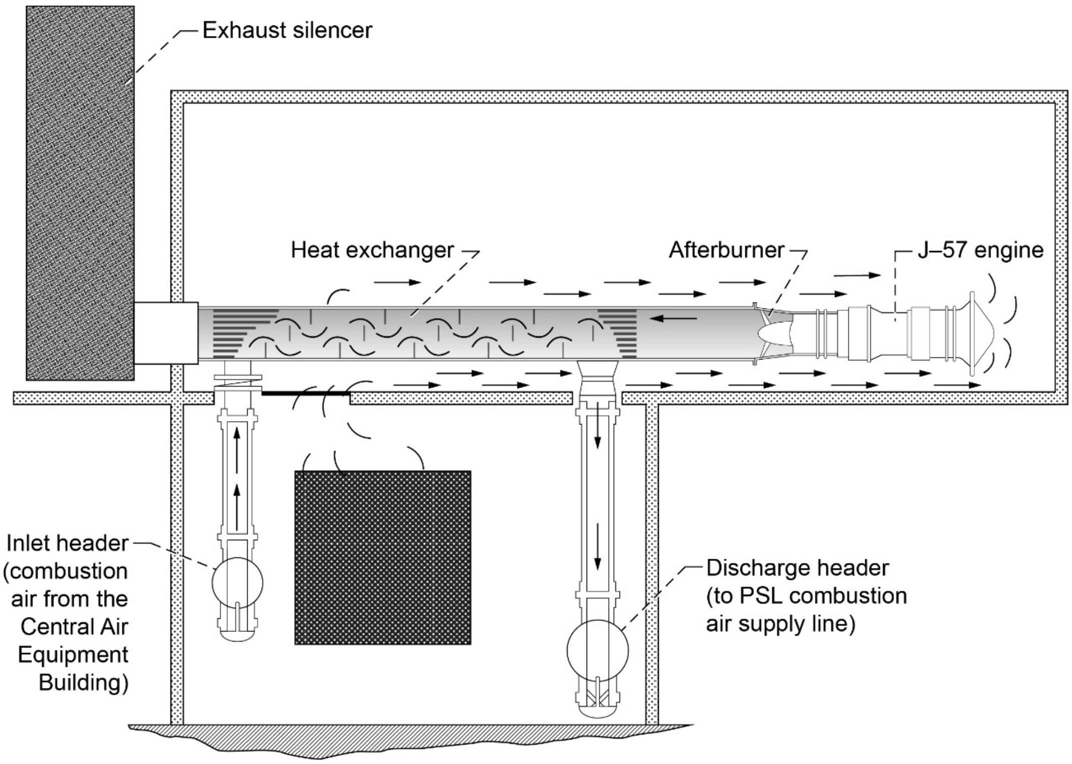

Figure 13.—Combustion air heater system.

Each of the two nonvitiated heat exchangers in the Heater Engine Building is designed to heat the 150-psig air (max. flow rate 140 lbm/s) via exhaust gas from two augmented Pratt & 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 to heat the exhaust to a higher temperature to achieve approximately 700 °F air at the engine face. The resulting temperature of the combustion gas is limited by the material used to design the two counterflow heat exchangers.

Inlet air for the J–57 engines comes into the Heater Engine Building through a large door in the basement of the building. It then flows up through the heater room floor, circulating through the Heater Engine 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 hot exhaust gas enters the far-right end of the horizontal heat exchanger and flows through a group of parallel tubes. The J–57 hot exhaust gas exits the heat exchanger at the far-eft end via a vertical exhaust silencer to atmosphere. The CAEB-supplied combustion air comes into the Heater Engine Building via an inlet header in the basement and enters at the far-left end of the horizontal heat exchanger. The heated CAEB supplied combustion air exits the heat exchanger at the far-right end via the discharge header to the PSL. The two gases do not mix inside the heat exchanger in order to provide nonvitiated heated combustion air to the PSL (Figure 13).

3.2.2 Cooled Combustion Air System

The cooling equipment in the Heater Engine Building consists of three turbo-expanders that can be configured in parallel to lower the inlet air conditions at the PSL test cells up to the following:

1. Temperature, –90 °F
2. Pressure, 10 psia
3. Flow rate, 110 lbm/s each

The total airflow can be increased to 380 lbm/s with additional ambient bypass air, but this will increase combustion air temperature. The test cell plenum inlet pressure can also be increased from turbo maximum output of 10 psia by blending with higher pressure ambient-temperature combustion air. This will slightly increase combustion air temperature as well.

3.2.3 PSL–4 –90 °F Combustion Air Line

A custom-installed 14-in.-diameter insulated supply line can deliver up to 30 lbm/s of –90 °F combustion air from the turbo-expander discharge header to the inner plenum in PSL–4. This air can be blended with the chilled air coming from the main combustion air line for better temperature control, or the test article can use this air exclusively to reach temperatures as low as –90 °F.

3.3 Altitude Exhaust System

Four sets of exhausters matched to the flow capability of the test cell produce altitude exhaust in the facility exhaust plenum. This altitude exhaust is utilized to simultaneously evacuate the test article's exhaust gases and test cell cooling air and set the flight pressure altitude in the test cell external to the test article. Butterfly valves positioned upstream and downstream of the exhausters are controlled to propel the exiting test cell/combustion air. The maximum flow capacity of the exhaust system is 750 lbm/s at 5,000 ft.

3.4 Cooling Tower Water and Spray Systems

The cooling tower water and spray systems cool water for the facility, the special research needs, the Heater Engine 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 facility components that are subjected to high-temperature gases. These components are the exhaust duct and plenum chamber, the davit valve, the combustion air lines, and the inlet section of PSL test chambers.

Additional facility cooling functions are provided by the primary and secondary coolers, depicted in Figure 1. The primary cooler is a water-cooled heat exchanger array consisting of 3,000 tubes arranged in 20 rows, or banks. It cools the hot exhaust gases from the test article to 600 °F before the gases enter the secondary, or spray, coolers. The spray cooler system consists of two spray pumps, each operating at a flow rate of 2,000 gal/min and a pressure of 350 psig, and three banks of spray nozzles. There are 172 individual spray nozzles. This system further cools the exhaust gases from the test article to 150 °F or less before they enter the temperature-limited CAEB altitude exhaust line. The spray coolers also scrub unburned hydrocarbons from the engine exhaust. The secondary spray water is separated from the cooling tower water system by collection in a spray receiver tank.

3.5 Research Hydraulic System

The two hydraulic pumps can pump hydraulic oil (military specification MIL–H–83282) with a flashpoint of 400 °F to PSL–3 and PSL–4 test chambers at a rate of 50 gal/min and a pressure of 3,000 psig. The hydraulic system can also actuate valves associated with the test article and the test hardware systems. Customers may discuss additional applications for this system with the PSL test team at a test-planning meeting.

3.6 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 where it is preheated up to 300 °F prior to entering PSL–3 or PSL–4. One of the storage tanks is reserved for Jet A fuel. The other normally contains Jet A fuel, but it can use alternate fuels requested by the customer, provided the facility manager approves.

There is also a special fuel system that consists of a 500-gal steel aboveground tank and 2-in.-diameter supply and return lines rated at 2,000 psig. This system can be configured to meet customer requirements if an alternative fuel is needed for the research test article.

3.7 Gas Supply Systems

The PSL has gas supply systems for natural gas and gaseous nitrogen, hydrogen, and oxygen. Figure 14 shows the propellent supply locations for the PSL.

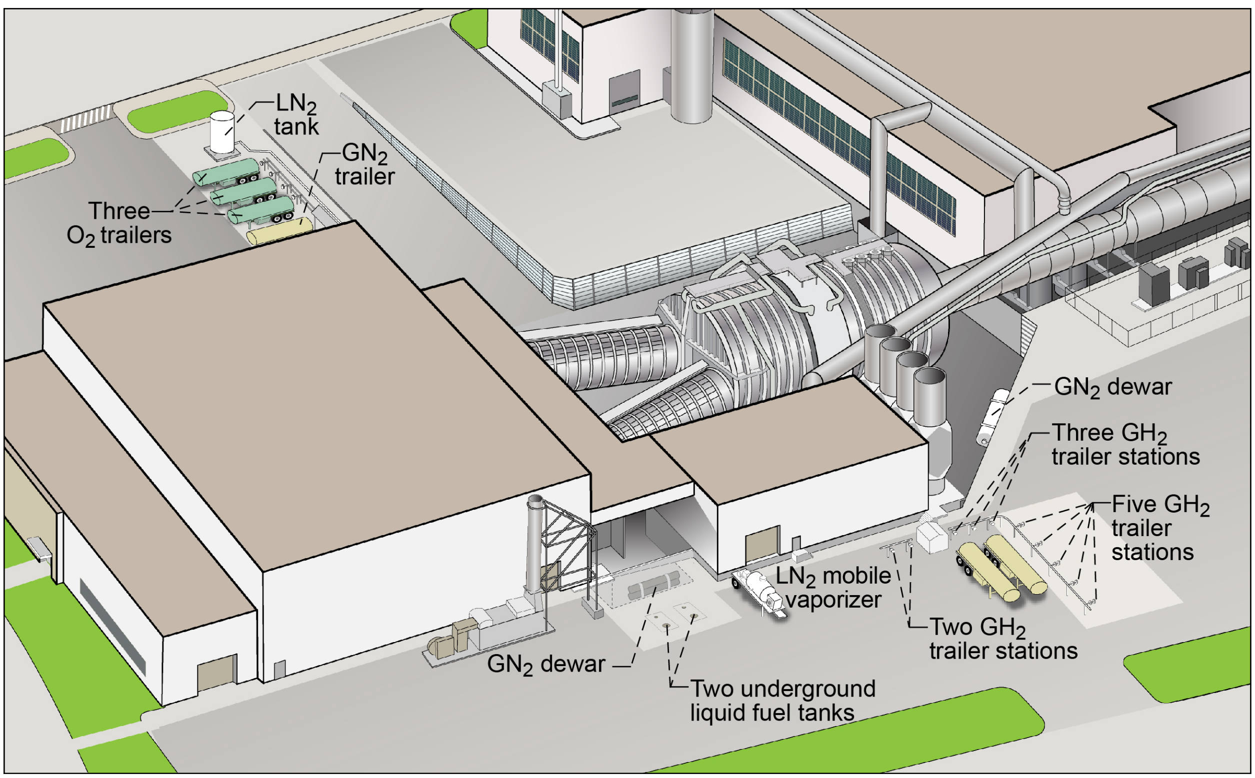

Figure 14.—Locations of PSL propellant supply.

3.7.1 Natural Gas System

Natural gas enters the Heater Engine Building at a pressure of 45 psig and then diverges, flowing into two lines that feed the afterburners 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 throttle valve is 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-operated and remotely operated valves for isolating the igniter system supply, and a third remotely operated valve for this purpose is located outside the Heater Engine Building. If the entire Heater Engine Building needs to be isolated from the natural gas supply, two valves for this purpose—one hand operated, one remotely operated—are located with the fuel system controls between the PSL building and the Heater Engine Building.

3.7.2 Gaseous Nitrogen System

The PSL gaseous nitrogen system consists of three pressure vessels connected to the facility distributions system. With individual capacities of 53.3, 52.8, and 307 ft^3, the three vessels have a combined capacity of 413.1 ft^3 at a pressure of 1,987 psig. Pressure is typically regulated to 1,500 psig and lower. These vessels are pumped up via mobile vaporizers. In addition, there is a trailer station located in the north parking lot at the rear of the Heater Engine Building where two 70,000-$stdft^3$ tubers can be connected to the nitrogen vessels to provide additional flow capacity. The nitrogen system is used for general building use and for supplying any required nitrogen to test articles installed in PSL–3 or PSL–4. Examples of general facility use include purging the natural gas system and the facility hydrogen system (discussed in Section 3.7.3). It should be noted that the facility's oxygen system is purged with nitrogen from a separate 70,000-$stdft^3$ nitrogen trailer located in the south parking lot of the PSL facility.

3.7.3 Gaseous Hydrogen Systems

The PSL has a five-trailer hydrogen system and a three-trailer hydrogen system. The five-trailer system underwent a total overhaul in 2020 and is fully functional. The system can see pressures up to 2,400 psia and can select between several flow rates from 0.8 to 5.8 pps. The flow rates are selected by opening a combination of three parallel valves, each with its own flow venturi. The system is designed to allow for venting and nitrogen purging of individual zones.

The three-trailer hydrogen system may be used as a stand-alone system or in conjunction with the five-trailer system. More information is available upon request.

3.7.4 Gaseous Oxygen System

The PSL has a gaseous oxygen system available in working pressures of 400 to 2,400 psi. More information is available upon request.

3.7.5 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 2,400 psig. The facility's 1-in.-diameter pipeline can deliver high-pressure air to PSL–4 at 1,200 psig (other pressures are available) and a flow rate of 1 lbm/s.

3.7.6 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, on rare occasions, to start the engines that are being tested. A 3-in. supply line extends to each cell, providing air to the engine-start motor. Service air is also used for the icing system spray nozzles' atomizing air and cooling air.

3.7.7 High-Pressure Steam System

A high-pressure steam system is available in PSL–3 and PSL–4 for research activities. The facility piping can deliver 100-psig steam at 300 °F and a flow rate of 5 lbm/s. This high-pressure steam system has previously been used in gas-sampling studies.

Steam is also injected into the combustion air supply during inclement weather tests to produce the required humidity ratio of the combustion air at the spray bars within the PSL–3 plenum. This is required because all combustion air is typically passed through desiccant drying beds that lower the dew point to –80 °F prior to entering the PSL facility. Typical test runs will experience an uncommanded increase in dew point as the desiccant beds lose capacity to dry combustion air throughout the test run. This creates an unstable humidity ratio and an unfavorable cloud particle evaporation rate, which makes it difficult to produce calibrated inclement-weather test conditions. To combat this effect, humidity ratio is measured directly in the inlet plenum and the facility combustion air supply line inlet. Additionally, the required amount of steam is added at the combustion air supply line inlet to produce the required humidity ratio at the spray bars in the PSL–3 plenum. This allows for the precise control and calibration of various cloud test conditions for inclement-weather-related test points.

3.7.8 Chilled Air System

PSL–4 is equipped with a chilled air capability for use in research testing. The PSL–3 icing system supplies the air at a temperature of –40 °F at 125 psig with a flow rate of 4 pps. The supply enters the test cell under the subfloor on the aisle side.

3.8 Thrust Measurement System

3.8.1 Test-Specific Thrust Measurement Preparation

It is important that the customer specify during the initial planning stages of the test program which one of the following two thrust measurement techniques will be required:

1. Absolute thrust—thrust generated by the test article
2. Delta thrust—the difference or trend in thrust between two different test points

Absolute thrust is the accurate measurement of test-article-generated thrust and requires the development of complex governing equations accounting for all forces acting on the live testbed and possible design and fabrication of test-enabling hardware (which could necessitate long lead times). Delta thrust is the simple tracking of either the trend of measured thrust or the difference in thrust measured between two different test points. Absolute thrust requires two additional tests not required by delta thrust:

1. Area delta-pressure test
2. Cooling-air tare test

The thrust stand is a precision measurement device with a fixed base mounted to the test cell floor and a live bed connected to the fixed bed via precision load cells. The engine mounting frame and all other test hardware attached to it are mounted to the live bed of the thrust stand and separated from direct-connect combustion air supply hardware via a metric break. The metric break is typically a labyrinth seal (airgap) upstream of the PSL Station 1 measurement plane (combustion air supply mass airflow measurement plane). (An image reference for the labyrinth seal can be seen in Figure 18.) The thrust stand has two types of load cells for each axis measured: calibration load cells and measurement load cells. The calibration load cells are removed and sent for National Institute of Standards and Technology (NIST) traceable calibration preceding and following every test program. These calibration load cells are used for in situ characterization of the measurement load cells, which are not removed. This so-called in situ characterization process allows the thrust stand to be characterized before, during, and after the test program. It allows for the identification and correction of impacts to thrust measurement by unforeseen or unknown occurrences during test buildup and test operations.

3.8.2 Ormond Multi-Axis Thrust Stand

Multi-axis thrust is measured by using one of the two six-component precision thrust measuring systems manufactured by Ormond, Inc. (Figure 15). The differences in the two systems are the thrust measurement capacity (either 40,000 or 50,000 lbf) and the arrangement of the axial calibration load cells. The PSL research test engineer can discuss the differences in the two systems with the customer at a test-planning meeting.

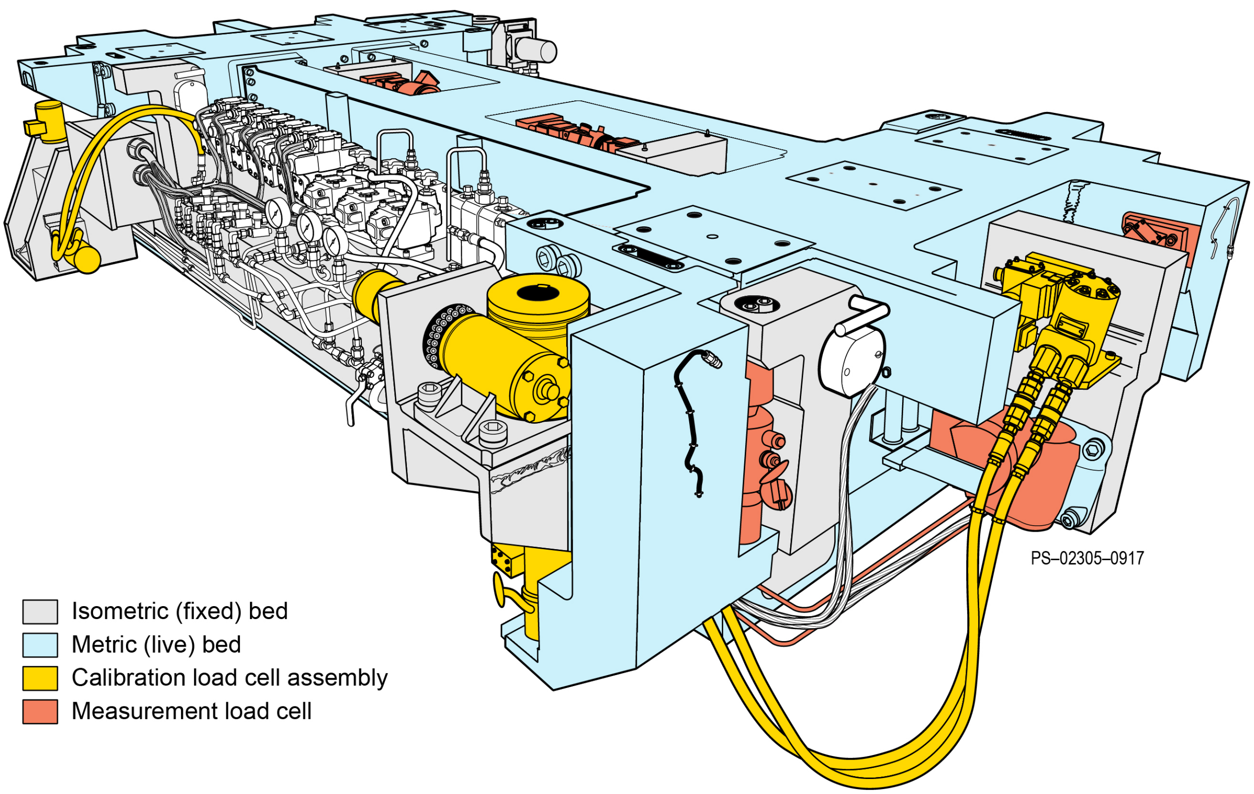

Figure 15.—Isometric view of PSL Ormond three-dimensional thrust measurement system (TMS).

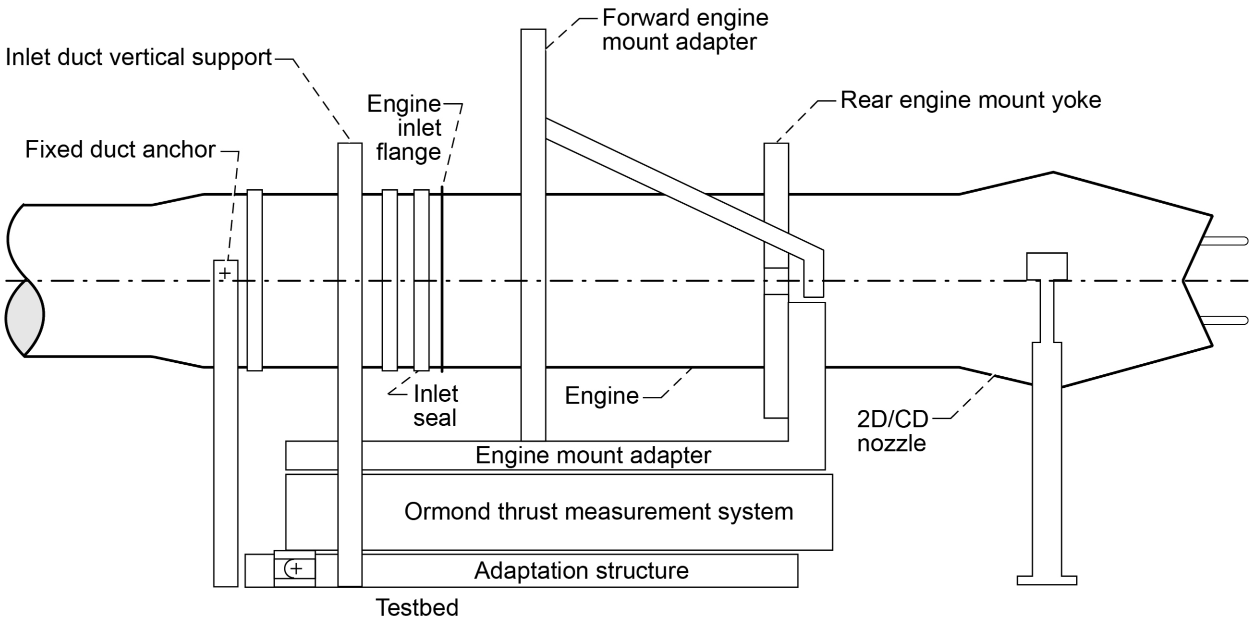

Figure 16.—Position of engine equipped with two-dimensional converging/diverging (2D/CD) nozzle in relation to Ormond multi-axis thrust stand.

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 testbed bending, torsional stresses, or deflections. The test article is held atop the thrust bed by an engine mount adapter, which cradles the engine, nozzle, or afterburner while transferring the forces to the Ormond system (Figure 16).

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 these load cells 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 testbed corner. The placement of the load cells is specific and serves to eliminate mounting interactions. Figure 17 shows the location of the thrust and calibration load cells in a typical Ormond stand. T_1 through T_{14} are measurement load cells; P_1 through P_8 are calibration load cells. All load elements are compression positive. Forces and moments indicated are positive.

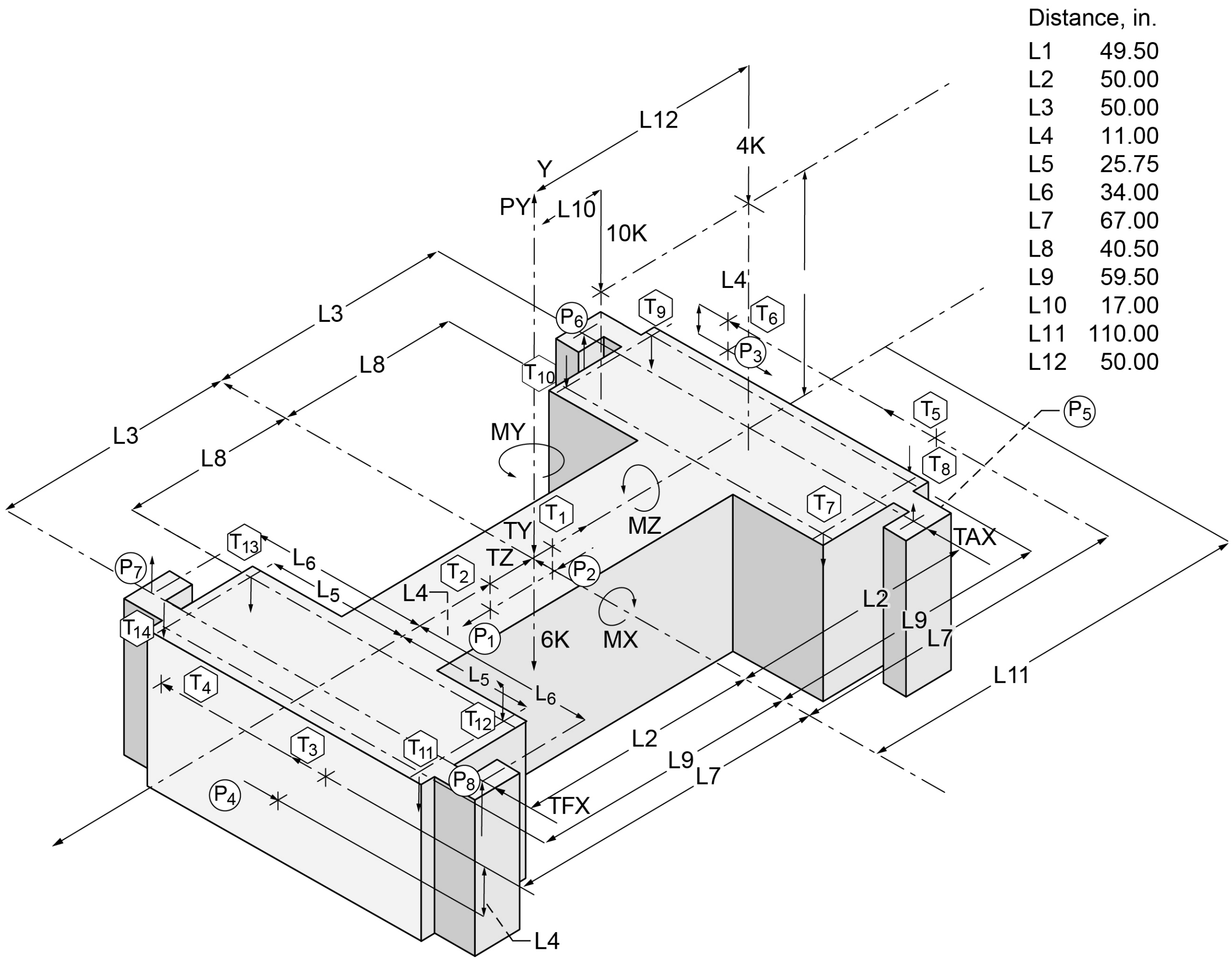

Figure 17.—Schematic of a typical Ormond three-dimensional thrust stand used in PSL.

3.8.3 Single-Axis Thrust Stand

The PSL also has available a single-axis axial thrust stand from Force Measurement Systems. It can be used in either test cell. This thrust stand also has a metric (live) bed and an isometric (fixed) bed and is mounted to the PSL test cell floor at various locations specific to the test requirements. It has an in-frame calibration system. The load cells are placed so that compression and tension hysteresis is minimized. It has a 5,000 or 10,000 lbf capacity depending on customer requirements.

3.9 Inlet System

3.9.1 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 18. Various bellmouths are available to accommodate the inlet diameters of propulsion test articles. Special configurations have been used to accommodate turboshaft engines. Presently, the inlet bellmouths available at the PSL facility have exit diameters of up to 30 in. With sufficient lead time and funding, a new bellmouth can be fabricated to suit customer requirements. The inlet bellmouth is unavailable for use during icing testing in PSL–3. Carbon fiber transition inserts are used instead to help deliver a uniform icing cloud to the test article.

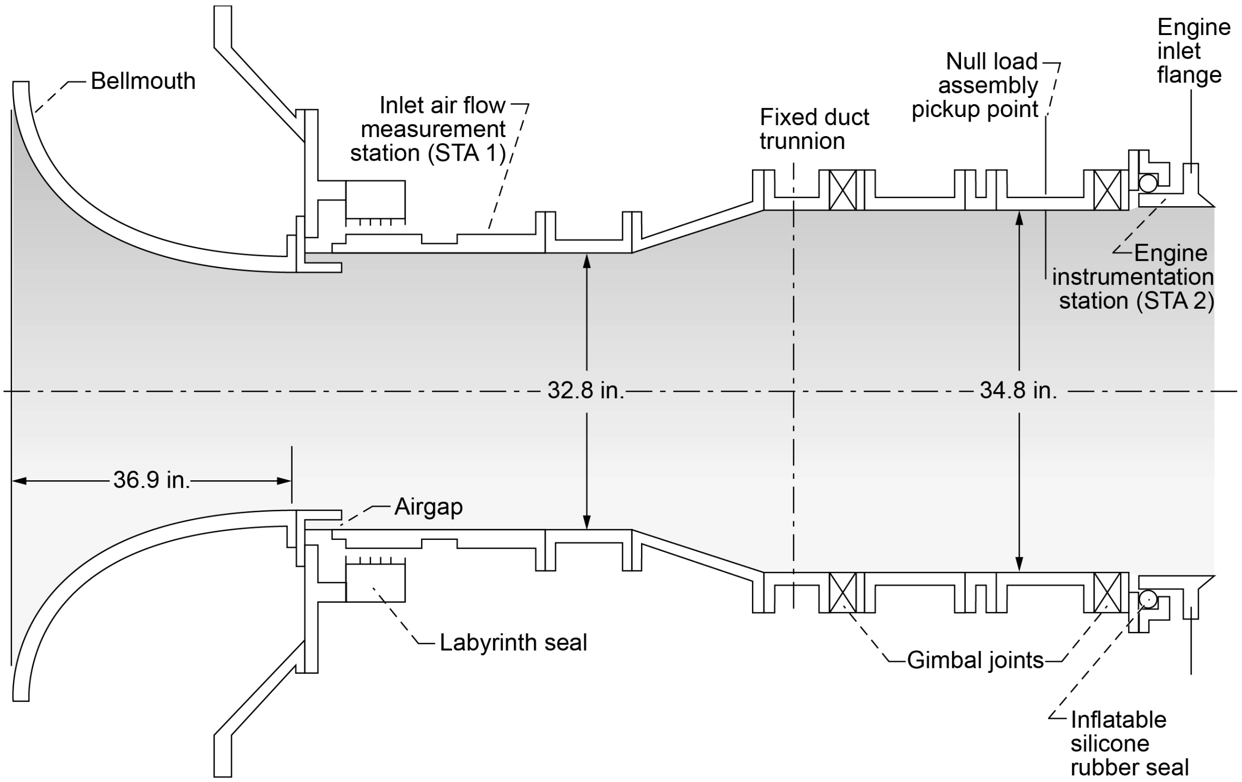

Figure 18.—Typical inlet ducting arrangement.

3.9.2 Inlet Flow Measurement

The inlet flow measurement station, designated as Station 1 or STA 1, contains thermocouples for measuring steady-state duct metal temperatures, steady-state total pressures, and static wall pressures (Figure 18). The total airflow is determined by implementing boundary layer rakes that measure the total pressure at various annular area regions across the cross section of Station 1. The rakes are designed to strategically measure total pressures both within and outside of the boundary layer while minimizing the effects of blockage and flow disruption. Static pressure is measured by several static pressure taps equally spaced circumferentially at the Station 1 total-pressure measurement plane. Static pressure is considered constant at Station 1. Mass flow is calculated for each annular area and the summation of these mass flows results in the total mass flow accounting for viscous effects in the boundary layer. If the boundary layer is neglected, the measured mass flow based only on the freestream total pressure will be too high. A typical circumferential layout for such instrumentation at Station 1 is presented in Figure 19.

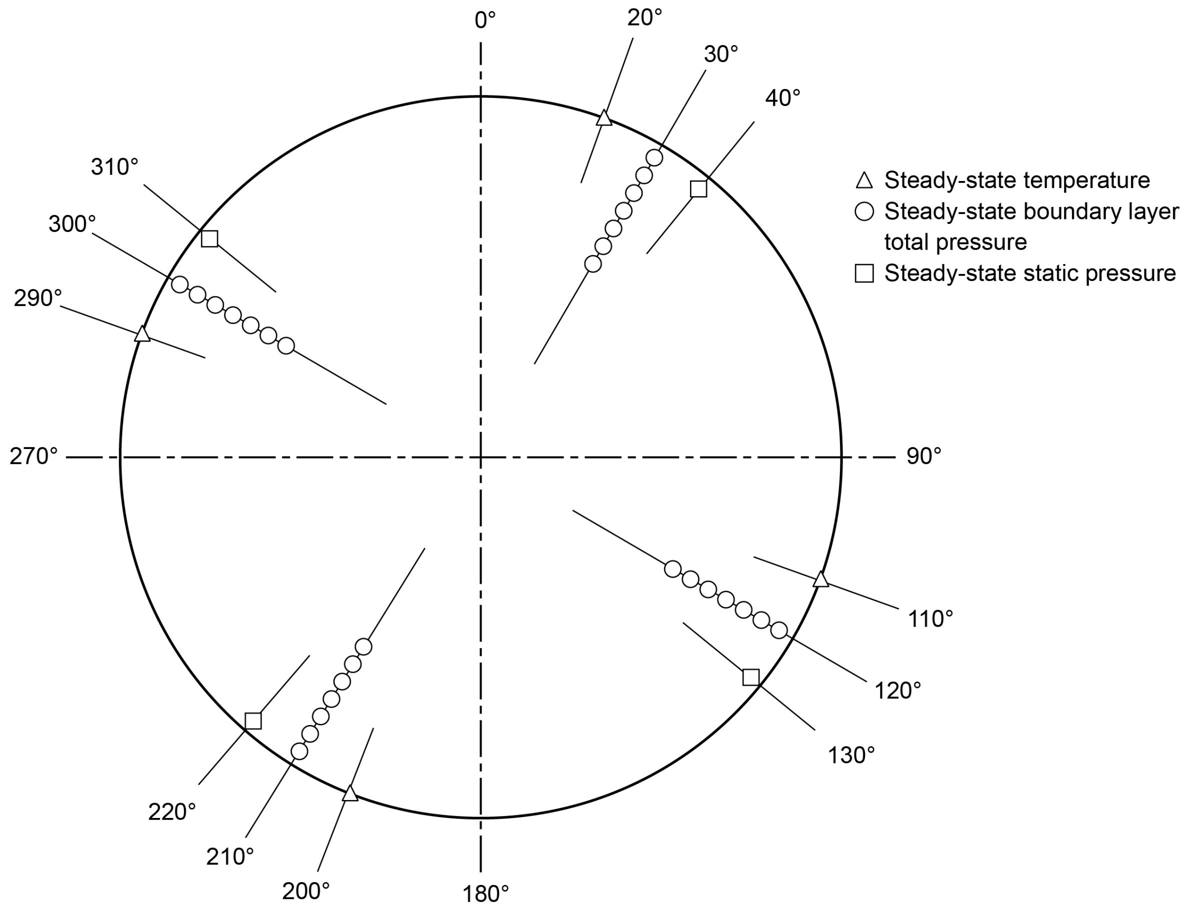

Figure 19.—Typical steady-state airflow measurement instrumentation at Station 1 .

3.10 Electrical Systems

The facility's main 2,400-Vac, 3-phase power is fed via multiple feeds from the Center. This medium-voltage power is distributed via switchgear (Figure 20) to transformers to provide 480-Vac electrical power to multiple motor control centers as well as 120/208-Vac power to numerous load centers throughout the facility. In addition, the facility has an online Eaton Powerware uninterruptible power supply (UPS) system used to provide power to critical systems, including the facility control and data systems.

The following types of electrical power are available for customer systems in the PSL facility:

- 480-Vac, 3-phase, 60-Hz
- 120/208-Vac, 3-phase, 60-Hz
- 120-Vac, 60-Hz, UPS-protected
- 28-Vdc control voltage
- 28-Vdc engine-starter power; 2,400 A maximum/600 A continuous (Figure 21)
- 115/200-Vrms, 3-phase, 400-Hz, U.S. Military Standard (MIL–STD) 704-compliant, 15-kVA (Figure 22)

In the event that test electrical power needs exceed what the facility can provide, it is typical to rent generators to provide the additional power.

Figure 20.—PSL main 2,400-Vac switchgear. (C-2014-08192)

Figure 21.—PSL 28-Vdc engine-starter power. (C-2014-08197)

Figure 22.—PSL 400-Hz power supply.

4.0 Facility Control Systems

The PSL operates using multiple control systems. The major test facility subsystems—including combustion air, altitude exhaust, fuel systems, cooling tower water system, hydraulic systems, steam systems, nonvitiated combustion air heaters, and inclement weather systems—are operated via the facility DCS. The DCS is used to achieve test-point conditions while testing. The DCS has the ability for one-direction communication to the facility steady-state data system during open testing. The DCS also provides a historian function.

Each test cell has a dedicated programmable logic controller (PLC) control system used to control research engines and customer-specific support equipment as well as test-cell-specific subsystems, which vary with each test campaign. A separate dedicated PLC control system is used to gather large quantities of health monitoring information from the two facility J–57 heater engine augmenters. A fourth PLC control system has been developed to mimic the actions of the facility DCS for operator training.

4.1 Facility Ovation Distributed Control System

The facility DCS is an Emerson Ovation™ system (Emerson Electric Co.) (Figure 23). The system includes seven redundant model 5X00241G02 digital central processing units (CPUs), seven four-screen operator stations, a historian server, domain controller, and engineering station, all connected via a fully redundant copper Ethernet network. Each of the CPU pairs include a local node of eight branches each, with up to eight input/output (I/O) electronics and personality module pairs (Figure 24). The system also includes a remote node of eight remote branches to operate the two facility heater engines, and two remote nodes of eight remote branches each to operate the PSL–3 inclement weather systems.

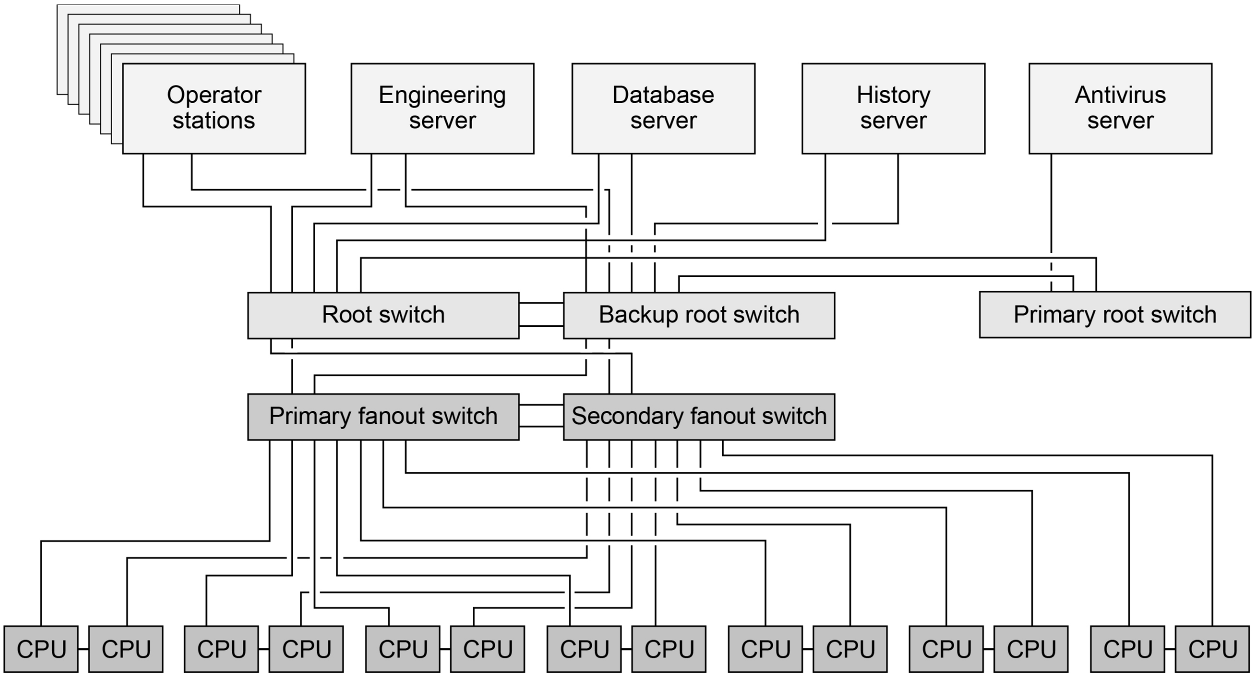

Figure 23.—Facility Ovation™ (Emerson Electric Co.) distributed control system network.

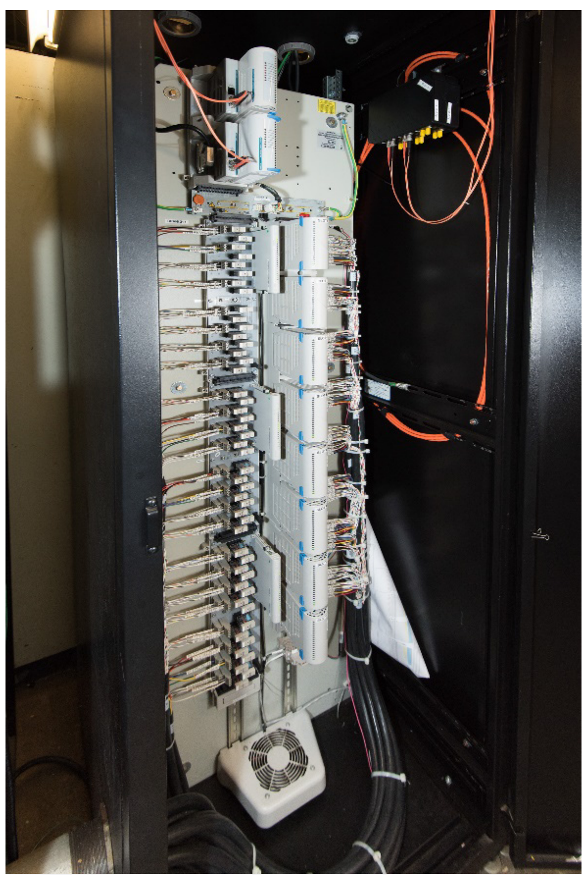
Figure 24.—Facility Ovation™ (Emerson Electric Co.) distributed control system typical input/output modules.

The Emerson Ovation™ system is covered by a SureService™ contract for technical support. The system is regularly updated through Emerson Evergreen upgrades and has been since its initial installation as a Westinghouse Distributed Process Facility control system in the 1990s. Each Evergreen upgrade is immediately followed by a comprehensive facility DCS revalidation encompassing all subsystems over several weeks prior to any test campaign.

4.2 Facility Historian

The Emerson Ovation™ facility DCS includes a process historian that provides mass storage and retrieval of process data and operator actions. The historian has redundant scanners that collect all I/O parameters as well as selected calculated or derived parameters. This historical data is stored short-term on redundant scanners. Redundancy in the system precludes loss of short-term data collection. Recently collected data is transferred to primary storage in a dedicated historian server. In the event of communication loss with the server, the scanners store their acquired data for up to 24 h. Primary storage maintains a history of data for multiple years on an internal RAID 5 (Redundant Array of Independent Disks, Level 5) disk array.

Historical review is a valuable tool for ad hoc evaluation of Ovation™ historical data as needed. Data available for review include point value and point status as well as alarm messages and operator events. This examination is utilized for incident investigation only, and these data are not available for customer use.

4.3 Test Cell Programmable Logic Controller (PLC) Control Systems

Systems within the test cell, as well as systems installed to support a specific test, are controlled by the individual test cell PLC control system for the specific test cell (Figure 25). The twin PLC systems, one for each test chamber, are controlled via Schneider Electric Modicon M580 series processors. The processors are each connected to 13 drops of Modicon Quantum 140 series I/O via Ethernet I/O via a combination of copper and fiber (Figure 26).

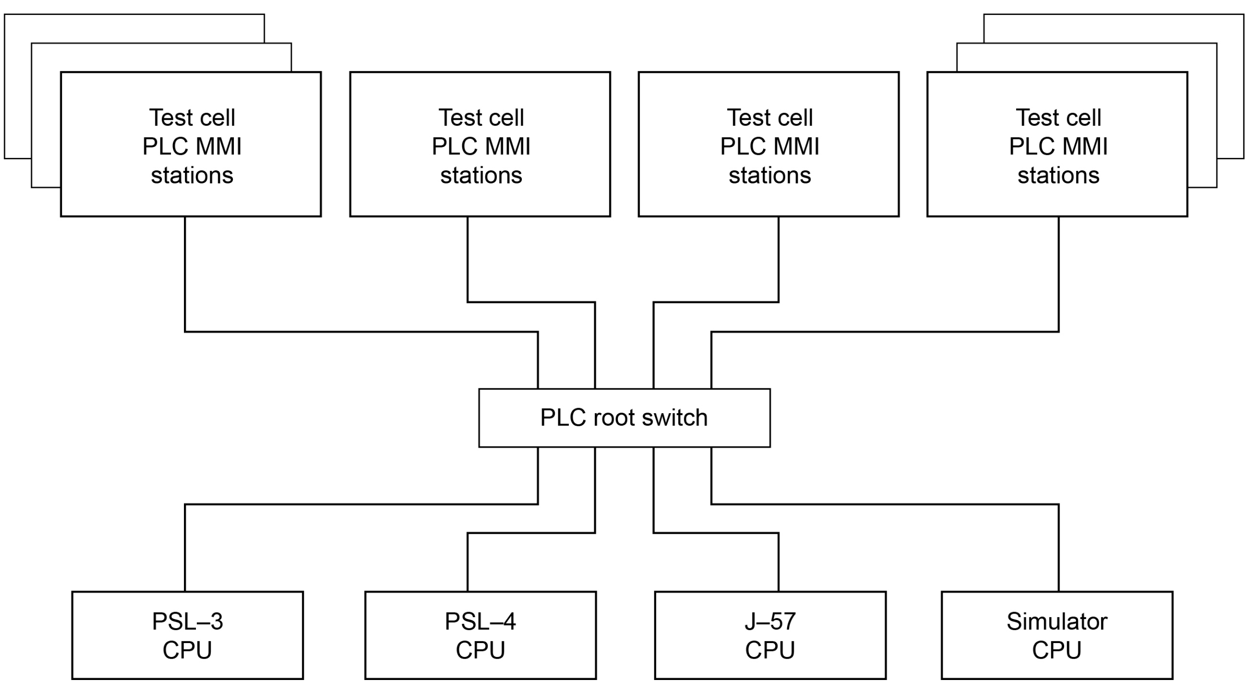

Figure 25.—Test cell programmable logic controller (PLC) network. Man–machine interface, MMI.

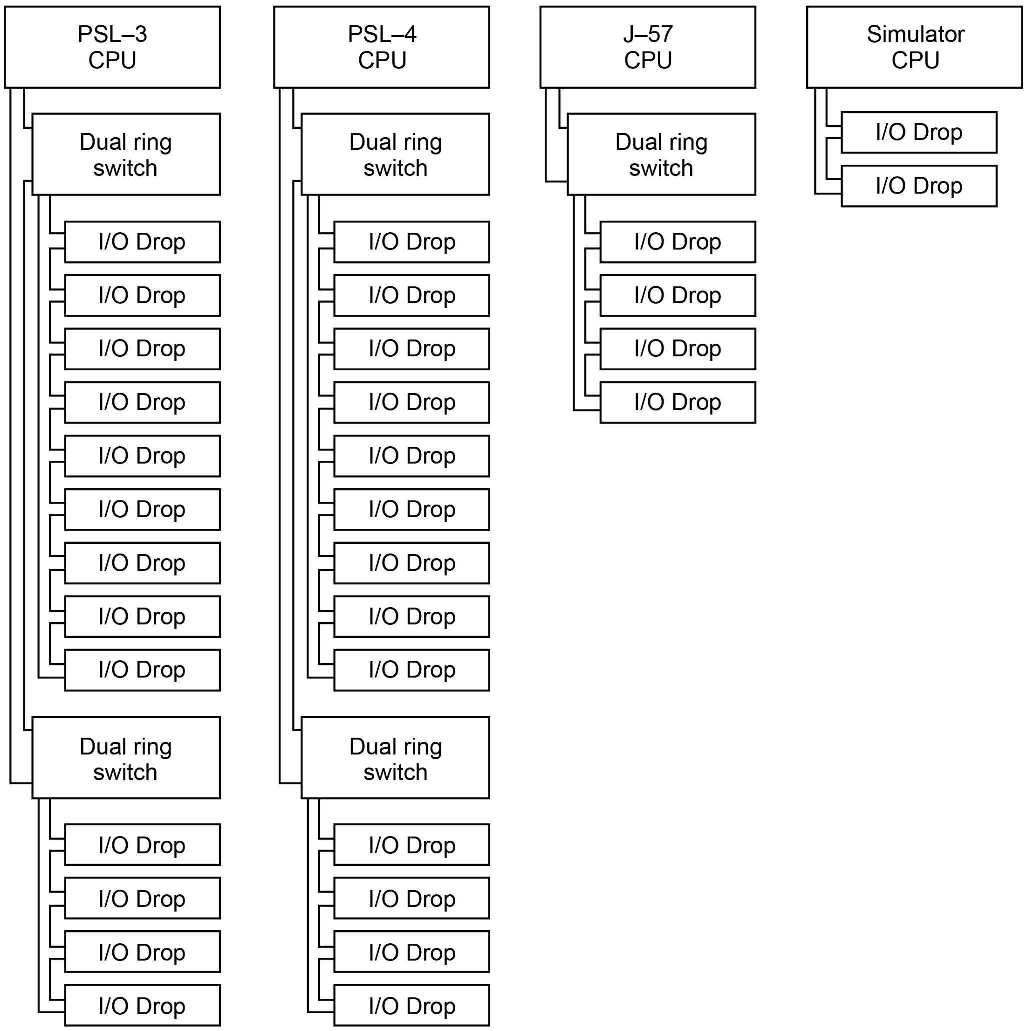

Figure 26.—Test cell PLC control system input/output (I/O).

I/O control power for the two test cell PLC systems are separately made safe via key switches with a single shared key that enables control power only to the active test chamber. Schneider Electric Unity programming software is used to configure and program each PLC system.

The facility utilizes multiple AVEVA™ Wonderware (AVEVA Group) human–machine interface stations, each with a single 4K display screen for control and operation of the test cell PLC control system. Additional stations can be added as required.

4.4 Annunciation

The facility has numerous audible annunciation systems, each with a unique indication. These systems are an integral part of the facility DCS or test-cell PLC control systems. Each annunciator is displayed on dedicated monitors and provides individual windows for out-of-limit indication as well as first-out detect with silent return.

The various annunciators are shown as grayed out for normal operation. The four increasing levels of annunciator alarm severity are indicated by their respective color, in increasing order from low to high severity:

1. White—purely informational (no action required)
2. Amber—immediate action required

3. Blue—the respective control system will take an autonomous non-shutdown action in response (e.g., automatically chopping a research engine to idle)
4. Red—associated system has been shut down or aborted

4.4.1 Facility Annunciators

The facility DCS operates the main facility annunciator. The facility annunciator (Figure 27) fills four separate large monitors prominently displayed in the control room and including over 150 active windows. All facility annunciators are revalidated on a biennial basis. Annunciation windows are grouped by facility systems, including exhaust, combustion air, shop air, gaseous nitrogen, cooling tower water, jet fuel, hydrogen system, oxygen system, facility hydraulic systems, electrical power, protective services, and climate control.

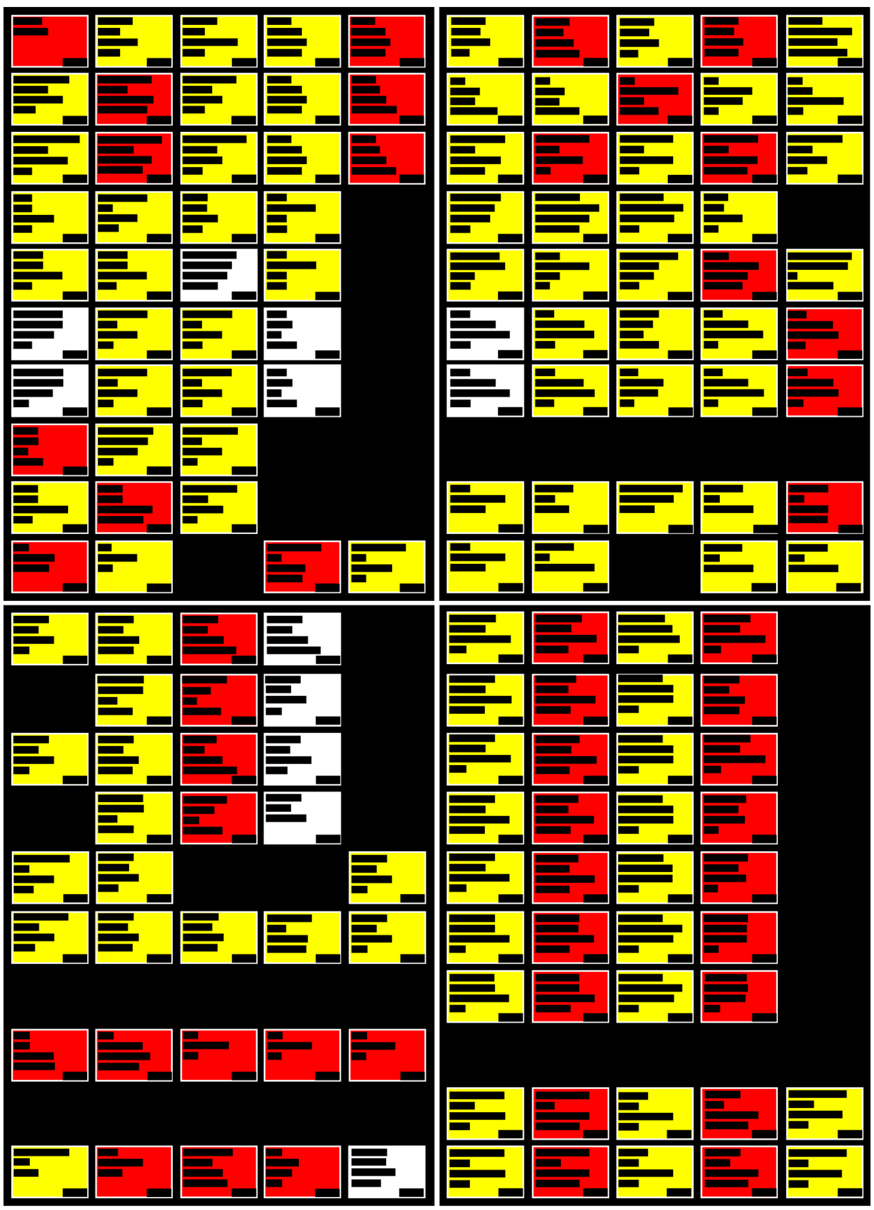

Figure 27.—Facility annunciator, four-monitor display.

The facility DCS also provides three additional separate annunciator functions: one for the PSL–3 facility icing systems and two additional annunciators for the two facility heater engines.

4.4.2 Research Annunciator

The test cell PLC system in each cell provides audible annunciation for test-specific systems. The research annunciator is displayed on two adjacent monitors above the engine operator.

The left monitor (Figure 28) is baselined to include PLC system alarms as well as common test cell and engine alarms. To facilitate ease of research engine operation by facility personnel, the common engine alarms are located in static locations regardless of test. These common engine alarms include overspeed, over temperature, fuel pressure, oil temperature and pressure, engine vibes, and loss of power lever angle (PLA) control. The safety permitting process requires all research engine tests to include facility-controlled overspeed and over-temperature shutdown.

The right monitor is completely reconfigured for each test campaign. It is facility practice for all blue and red alarms to have a lower-level amber alarm. The research annunciator has a unique audible indication. The research annunciator is completely validated prior to the start of each test campaign, and all engine shutdowns are also validated on a daily basis.

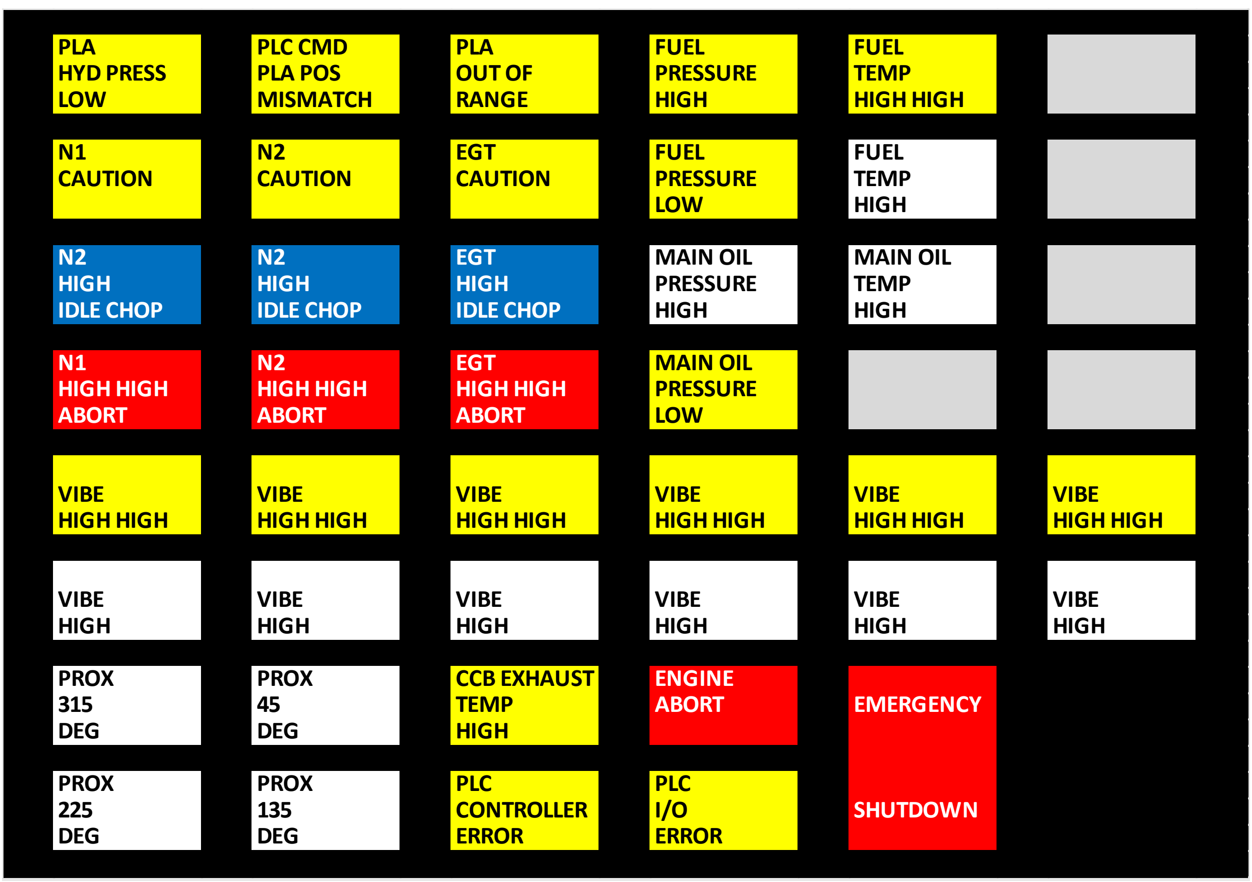

Figure 28.—Research engine annunciator. (Power level angle, PLA; hydraulic, HYD; programmable logic controller, PLC; command, CMD; positive, POS; exhaust gas temperature, EGT; proximity probe, PROX; central compressor building, CCB; input/output, I/O.)

4.5 Emergency Stop

The facility maintains a hard-wired Emergency Stop (E-Stop) circuit with multiple actuation buttons located in the front of the control room. The E-Stop circuit is used to safe the jet fuel system by disabling the jet fuel pumps and closing the test cell fire valves that prevent the delivery of fuel into the test cells. The circuit is used to close the customer engine fuel fire valve located immediately prior to the fuel connection to the research engine. During an E-Stop condition, research engines with hydromechanical control will have their PLA command setpoint chopped to zero. Research engines with some form of electronic fuel control will be provided with a contact closure to react to a facility E-Stop. If the test article requires the facility to perform an E-Stop, the customer control system should likewise provide a contact closure for facility use.

4.6 Key Switch Interlocks

The facility includes a number of key switches for control and lockout of systems. Systems controlled by key switch include combustion air valve control, secondary cooling air valve control, exhaust system valve control, jet fuel system, natural gas system, hydrogen system, oxygen system, facility heater engines, facility Stahl nonvitiated 450-psi combustion air heater, facility icing system, laser permission system, and test cell PLC control system.

In addition, there are controlled key switches that override interlocks for combustion airline inspection and laser permission system override.

4.7 Crash System

Critical parameters are continuously recorded on the facility 32-channel DEWE–43 (DEWESOFT d.o.o.) crash data system. The input channels to this system must be analog voltage and have selectable ranges of ±10 V, ±1 V, ±100 mV, and ±10 mV. The sampling rate ranges from 1 to 100 kHz (effective bandwidths of 420 Hz to 32 kHz). The facility reserves a number of channels for critical parameters. Critical parameters include test point conditions set by the facility and critical engine health, including temperatures, engine speeds, and critical vibrations.

All parameters are sent to the crash system as electronic signals, which are buffered through isolation amplifiers to preclude interaction with other data systems. Thermocouple signals are converted to high-level analog voltage signals through the facility test cell PLC system for recording in the crash system. The crash system is active during the entire test period and data is commonly overwritten during the subsequent test period.

4.8 Facility Safety Video System

The facility has numerous facility safety and security cameras to monitor the test chamber and key subsystems throughout the complex. For safety, each test cell has four cameras, one in each corner of the chamber. It is facility practice to install a temporary camera to monitor the research engine’s oil sight glass. Subsystems routinely monitored include the facility fuel farm, icing water system, cooling tower water pit, primary cooler, facility Stahl nonvitiated 450-psi combustion air heater, and rented electrical power generators. In addition, it is facility practice to install safety cameras to monitor customer support equipment such as lube carts, load banks, and other equipment as requested or otherwise deemed necessary.

Facility safety video is distributed through a Chameleon video router, which can display any image on any facility video monitor. It is common practice to multiplex four images on a single large monitor. The facility safety video is stored on a 16-channel digital video recorder (DVR) unit that is active during the entire test period, and video is commonly overwritten during the subsequent test period. This video is utilized for incident investigation only and is not commonly available for customer use. Separate research video capabilities are discussed in Section 7.5.2.

4.9 Separation of Data and Control Systems

It is the policy and practice of the test facility to maintain a separation of data and control systems. In some cases, it is permissible for a single piece of instrumentation to be shared between the test cell PLC system and the various data systems; however, it is not permissible for the facility DCS to share a single piece of instrumentation with any data system.

The facility DCS and the test cell PLC systems are not classifiable. During higher-than-CUI tests, these systems are not permitted to communicate with the facility steady-state data system, dynamic data system, or customer-provided data system. Interaction between these systems can only occur utilizing analog signals such as 4 to 20 mA or via contact closures.

It is not permissible for any facility or customer control system to perform closed-loop control utilizing analog outputs from a facility data system.

5.0 Inclement Weather System (Icing System)

PSL–3 was retrofitted with an inclement-weather engine test capability in 2012 (Ref. 31). PSL gained the ability to produce and introduce ice crystal and supercooled liquid water droplet clouds into the combustion air supply for test articles to simulate an array of inclement-weather engine operations throughout the operating envelope of a test article. Drawing upon the expertise and experience of airframe icing cloud generation in the IRT, a modified IRT spray bar system was installed in the PSL–3 inlet plenum. This system provides the capability to produce a variety of inclement weather conditions in a controlled research environment, allowing for parametric studies of inclement-weather engine operations. The system utilizes advanced instrumentation for cloud characterization and calibration. Table II lists the system capabilities. Calibrations are typically required for each inclement-weather test entry due to the wide parameter space of conditions available for testing. Testing can include full-scale engines or core-flow-path driven rigs if the total mass flow rate of a full-scale high-bypass engine exceeds the PSL maximum mass flow capability.

5.1 Spray Bars

Ten spray bars are mounted on struts in the PSL–3 inlet plenum just downstream of the inlet screens and flow straighteners (Figure 29). This retrofit of the PSL–3 plenum involved extensive modifications to install several systems: the spray bars in the inlet plenum, support pumps and accumulators in the basement, and controls adjacent to the test cell.

The spray bars contain and utilize two types of flow nozzles, Standard and Mod1. Both are internally mixed nozzles that use water (municipal or deionized) and atomizing air pressure differential to set droplet size. The nozzles are similar in design to those used in the IRT but have different discharge-tube diameters. The Standard nozzle has a larger discharge diameter and is typically used for medium- and high-flow conditions. The Mod1 nozzles have a smaller discharge diameter and are typically used for low-flow conditions. Each nozzle undergoes a flow check procedure to generate a flow coefficient prior to install and use. Nozzle flow coefficients within ±2 percent of the average are used in the spray bars to provide a uniform water flow rate.

The nozzles are mounted 6 in. apart on the spray bars and alternate between Mod1 and Standard, so that each type of nozzle is repeated every 12 in. There are 110 Standard and 112 Mod1 nozzles installed in the spray bar system for a total of 222 nozzles installed at any given time. Figure 30 shows a closeup view of a typical spray nozzle. Each spray condition utilizes only one type of nozzle, but each nozzle can be individually selected "on" or "off" so the spray pattern and cloud intensity can be varied. The spray zones are divided into three tiers so pressure regulators can accurately set supply pressure and account for changes in pressure due to height. The cloud exits the plenum through a carbon fiber transition duct (Figure 31), which increases the velocity of the air, resulting in a decrease of static pressure and temperature.

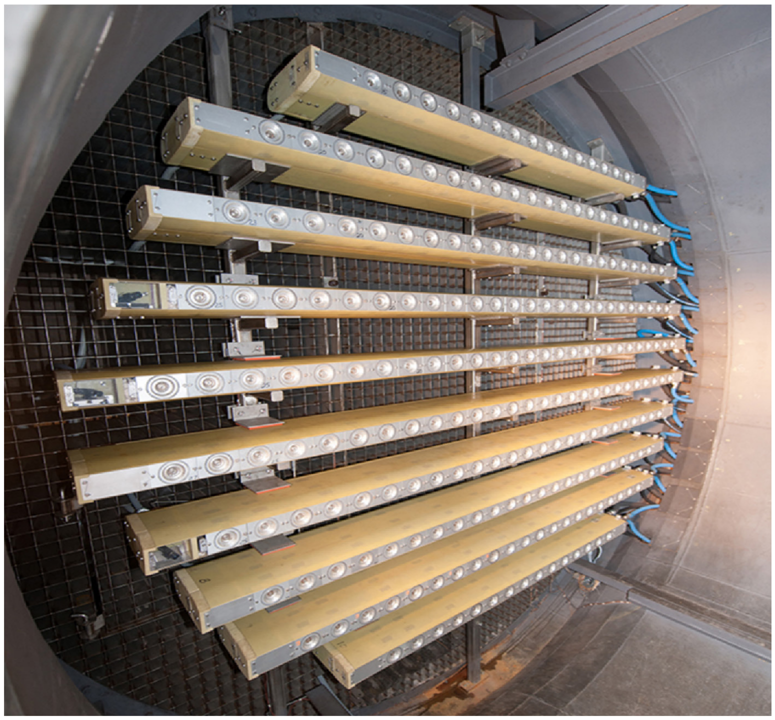

Figure 29.—Spray bars mounted in PSL–3 inlet plenum.

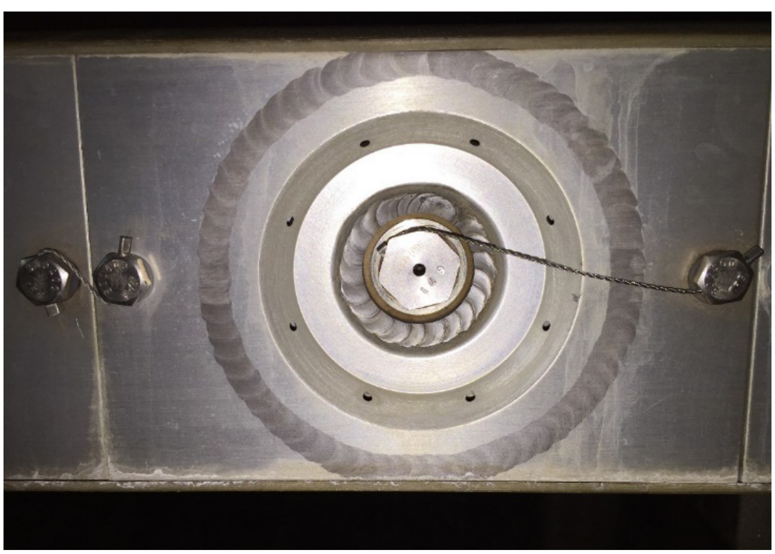

Figure 30.—Typical nozzle on spray bar.

Figure 31.—Carbon fiber transition duct mounted in PSL–3 inlet plenum.

5.1.1 Water Supply

Water is supplied to the spray bars from either city water or a deionized water system. City water can be used for ice crystal research as it gives the droplet a nucleation site for ice crystal formation. Deionized water with seeding can also be used to create ice crystal clouds, but city water is typical. Deionized water is used for conventional supercooled liquid water icing clouds. Deionized water resistivity is monitored in real time. Both city water and deionized water can be sprayed continuously. The temperature of the water is adjusted between 40 and 150 °F through the use of a chiller or heater in accordance with test conditions.

5.1.2 Atomizing Air

The spray bars utilize internally mixed nozzles to produce the droplets of the icing cloud. The relationship between water supply and atomizing air determines the droplet size range. Atomizing air is supplied by the Center's service air system. The air is filtered, dried, and chilled once it enters PSL and is then supplied to the spray bars.

5.1.3 Nozzle Cooling Air

A series of holes around each nozzle can utilize air at –40 °F to assist with freezing the droplets, if necessary (Figure 30). This cooling air is also supplied by the Center's service air system and is further filtered, dried, and chilled through a liquid nitrogen heat exchanger. Testing has shown that this system is not typically needed to achieve ice crystals. This system can also be supplied to PSL–4 as a chilled air source in the test cell.

5.1.4 Cloud Calibration

The icing system is calibrated for each icing entry to determine the system settings necessary to produce the clouds required for the scope of the test program. The calibration is developed in consultation with the PSL project engineers, ice cloud specialist, and research test engineer. A wide parameter of spray settings must be determined through cloud measurements before the actual research icing test. The facility has a variety of instrumentation for determining cloud uniformity, cloud median volumetric diameter (MVD), cloud total water content (TWC), and phase. Laser tomography is utilized for measurement of cloud uniformity. This tomography system is also available in situ during the engine or rig test within the inlet ducting. Table II shows the range of capabilities of the PSL–3 icing system.

5.2 Cold Soak System

The cold soak system (Figure 32) was designed for an auxiliary power unit test that was being installed in PSL–4. This system uses the liquid nitrogen heat exchanger from the icing system currently installed in the basement of PSL–3. Facility shop air (125 psig) was run through the heat exchanger and the flow rate achieved was approximately 6 pps. This cold air was then routed through newly installed 4-in.-diameter stainless steel piping over to PSL–4 where the cold soak testing took place.

TABLE II.—PSL ICING CAPABILITIES

Specification	Minimum	Maximum
Engine/rig diameter, in.	24	72
Airflow rate, lb_m/s	10	330
Altitude, ft	5,000	50,000
Total temperature, °F	–60	50
Mach number	0.15	0.80
TWC, g/m^3	0.5	[a]8.0
MVD, µm	15	[b]>100

[a]Evidence suggests probe undermeasured higher TWC conditions.

[b]Particles larger than ~60 µm are likely not fully glaciated.

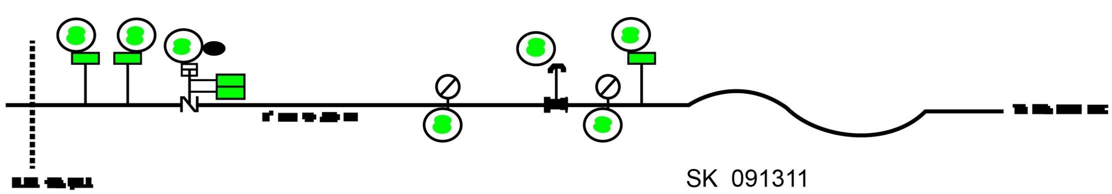

Figure 32.—Cold soak system.

6.0 Facility Operation

This section describes the PSL's standard operating procedure, response to an emergency condition, and facility protection procedures.

6.1 Standard Operating Procedure

6.1.1 Check Sheets

PSL–3 and PSL–4 utilize detailed check sheets to ensure proper setup and shutdown of the facility, engine, and/or test article. The PSL also follows set procedures for proper operation of the engine or test article and responses to an emergency condition.

Check sheet content will be determined prior to the start of a test by the PSL test conductor, PSL facility engineer, PSL electrical engineer, PSL lead technician, and the customer. If modifications are required, they must be approved by these personnel and can only be modified upon confirmation that the change poses no impact to safety.

6.1.2 Test Plan and Test Operations

Prior to each test, the PSL test conductor and the customer will meet to discuss the plan for the test. This plan will consist of facility startup; engine or test article startup; test points to be gathered; emergency procedures described in Section 6.2; and facility, engine, and test article shutdown. This plan will be utilized by the PSL test conductor and facility operators while conducting the test. During a test run, commands to change condition of the facility or test article may only be given by the PSL test conductor. If the customer desires a change to the test plan or test article, the request must be made to the test conductor, who will then direct the change with safety of personnel and facility as a priority.

The main facility air supply and exhaust systems are controlled by three operators who have been qualified to run the facility. These operators control temperature as well as inlet and exhaust air supplies, setting and maintaining total pressure, total temperature, and humidity for the inlet air supply. (For icing tests, an additional qualified operator is required and is assigned exclusively to the humidity controls.) Another operator controls exhaust systems, setting and maintaining test cell static pressure for the exhaust air. The third operator controls the heater engines used to condition inlet air to an elevated temperature or the inclement weather (icing spray bar) system, if applicable. The engine or test article may be operated by a qualified operator who is supplied by either NASA or the customer.

Typical engine testing operations will begin after buildup is complete and control and instrumentation checkouts are concluded. It has been said that engines run on dark air, and the PSL continues this tradition. PSL testing typically occurs on either second shift (1600 to 2400, 4 p.m. to 12 a.m.) or third (2400 to 0800, 12 a.m. to 8 a.m.) to accommodate the power load and air supply loads available at the Center. After a review to ensure the test cell is secure and all systems are ready for testing, the test cell will be set to a slightly lower than ambient pressure to check the pressure instrumentation and set a low altitude. An inlet air pressure is then set and slowly increased to obtain enough airflow through the engine to begin rotation to an acceptable start level and activate ignition via a windmill start. Compressed air starters and electric starters can also be supported if the engine or testing requires such a start.

6.2 Response to an Emergency Condition

If an emergency arises, the PSL test conductor shall be the individual charged with directing all personnel, both NASA and non-NASA, in proper emergency procedures. The PSL test conductor is responsible for the safe shutdown of the facility and the test article. These procedures will be determined in advance of testing by the customer and approved by the PSL test conductor. They are to cover a wide range of potential situations that may arise, such as overspeed or stall of the compressor, high vibrations in the turbine or compressor sections, and so forth. The order of importance (highest to lowest) for these established emergency responses will be to protect personnel, the facility, and the test article. These procedures will be documented in the project safety manual and set for review by the Area Safety Committee.

6.3 Facility Protection Procedures

The PSL has many safeguards in place to prevent facility-specific hazards. These 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 (see Figure 1). The four pressure relief caps in each movable test cell lid open when the pressure differential across the test chamber lid is 0.16 psi above atmospheric pressure. The eight relief hatches in the primary cooler open when the pressure differential across the test chamber lid is 0.43 psi above atmospheric pressure. This pressure relief system vents the test chamber and exhaust duct as well as the exhaust plenum areas. If these measures fail to restore atmospheric pressure to the cell and the pressure differential exceeds 4.00 psi, the locking latches are designed to fail to return the cell to atmospheric pressure.

In the event of high hydrogen gas detector readings, alarms, or loss of line pressure, the test conductor will determine if the lines in the test cell need to be vented.

To prevent penetration of the test cell by failed engine parts, a containment shield is placed over the high-energy turbine region of all engines tested in PSL. In the event of a failure, this shield is designed to absorb all the kinetic energy produced and keep it contained in the test cell. As an added precaution, during a test, no personnel are permitted to be in the vicinity of either of the test chambers while the engine is operating above idle rotational speeds.

7.0 Data Acquisition and Processing

This section describes the PSL’s steady-state data acquisition and dynamic data systems as well as system inputs, signal conditioning, specialized research systems, and calibrations.

7.1 COBRA Steady-State Data Acquisition System

COBRA (Collect, Observe, Broadcast, Record, and Analyze) is the next-generation steady-state data acquisition system for all Aeronautics Test Program facilities at Glenn. COBRA represents a multigenerational leap forward for steady-state data acquisition at the Center. It is a full system replacement for the Escort systems used in Center test facilities since the 1970s. Table III offers a quick guide to COBRA specifications.

7.1.1 Architecture

COBRA is a distributed, network-based, low-speed data system. The architecture of COBRA implements a component-based solution for low-speed data acquisition. This allows COBRA to be scalable to fit different facility needs and requirements. Figure 33 shows the components of a COBRA data system.

TABLE III.—COBRA SPECIFICATIONS

Architecture	Distributed/Network
Input channels capacity	Over 5,000
Calculations capacity	Over 20,000
Sampling rate	12.5 (default), 25, 50, 100, 200, 400, 800 samples per second Note: Higher samples can be taken, but all channels will be upsampled to match the new rate.
Display windows/views	21 stations with multiple pages/monitors per station
Display update	12.5 updates per second but can be filtered to update at different rates
Display type	Alphanumeric and graphics on same page
Storage	Terabytes (scalable to petabytes)
Signal conditioning support	Precision Filters, Inc.; Endevco (PCB Piezotronics); Pacific Instruments, Inc.; etc.
Time stamping	[b]IRIG–B, Global Positioning System
System configuration/setup	Graphical
User interfaces	Graphical
Available analog channels	64 signal-conditioned, ~480 regular
Available NetScanner™ channels	~450
Available thermocouple (Scanivalve [a]DTS) type K	~480
Available thermocouple (Scanivalve DTS) type E	~60
Available frequency channels	~10
Other input capabilities	Modbus, [c]MIL–STD–1553, [d]ARINC–429

[a]Digital Thermocouple Scanner.

[b]Inter-Range Instrumentation Group timecode B.

[c]Military Standard.

[d]Aeronautical Radio, Incorporated.

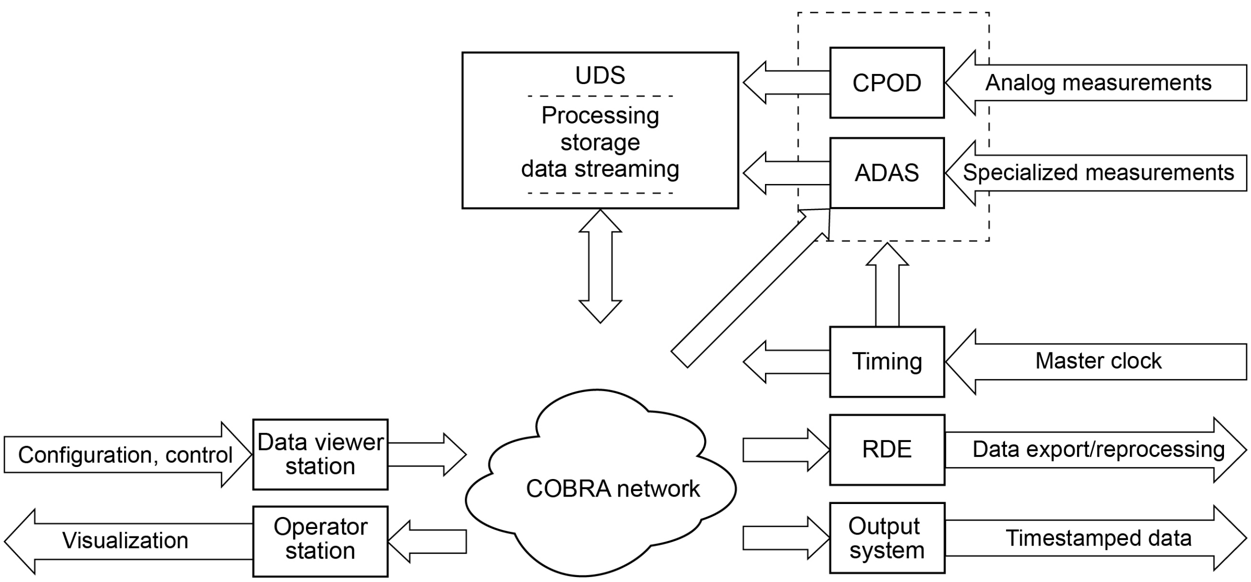

Figure 33.—Collect, Observe, Broadcast, Record, and Analyze (COBRA) data system. Universal data server, UDS; control pod (CPOD)/analog-to-digital conversion box; auxiliary data acquisition system, ADAS; reprocessing data export, RDE.

7.1.1.1 COBRA Configuration Tool

The COBRA Configuration Tool (CCT) is the interface for defining the hardware configuration of a COBRA system. This is the interface that organizes and maintains all instrumentation raw inputs. The CCT informs the calculator within the universal data server (UDS) to execute necessary calculations and maintains coefficients and data system limits. These limits are set up and are used as alerts of over-limit and under-limit conditions. (This feature is used for visual alert only and cannot take any actions.) The CCT is organized as inline channels, where one line represents a specific channel or calculation result. When channels need to be coded out, removed, added, or edited during a test, this is done in the CCT. It is the main tool the data engineers use to maintain the steady-state data acquired during testing.

The CCT cannot be edited during a recording or when it is in “monitor system” state, so any edits must be done between data points. A full pausing of the steady-state system may be required for certain edits to be made, such as adding a new channel. This has no physical effect on the test, which can still be operating at a steady state in the background, but it does mean that data from COBRA will not update until the changes are made, and the system is put back into monitor state. This does not stop the test in progress, nor does it affect visual data from facility control systems—only that of the data system.

7.1.1.2 Auxiliary Data Acquisition System Architecture

The auxiliary data acquisition system (ADAS) provides an interface to several independent measurement systems for COBRA. ADAS devices are configured by the CCT. When connected to the COBRA system, a device’s state can be changed using the Device Control software application.

7.1.1.3 COBRA Calculator Processor

The COBRA Calculation Processor (CCP) is the COBRA subsystem responsible for performing runtime calculations. It receives sampled channels as inputs from the acquisition devices and outputs calculated results into designed channels. The calculated channels are recorded and stored as part of the legal data of record along with the sampled channels and other metadata.

The CCP is designed to run at the same rate as the COBRA system and performs calculations once per cycle. The system is designed so that multiple CCP nodes can be incorporated, each running at different rates. The current system consists of one CCP node operating at 12.5 Hz.

7.1.1.4 COBRA Operator Development Interface

The COBRA Operator Development Interface (CODI) manages custom facility-specific and program-specific calculations and functions. The custom functions or subroutines can be used to code more complex calculations, such as loops, array mathematics, complex logical statements, and iterative algorithms. These functions or subroutines can be programmed in C or C++.

7.1.1.5 Reprocessing Data Export Tool

The reprocessing data export (RDE) tool exports collected data for postprocessing. The exported data is output as a comma-separated value (CSV) file and can be viewed after each recording is completed. These outputs can be edited to include every channel from the test or specific channels of interest. The RDE tool generates an output file containing all of the data at 12.5 Hz (cyclic). It can also average the data over the course of the recording and give a single average value. Default output files for distribution contain both cyclic and averaged files of the entire data. Unique output files can be requested from the data engineer before testing begins. The files can include units and tags from channels as requested.

7.1.1.6 Data Viewer

The data viewer is the main interface for viewing recorded or live data from the COBRA system. The data viewer is organized so users can create custom pages that can be edited to showcase whatever data they wish to see, such as numeric listings of channels and calculation or different kinds of plots and charts. These pages can then be saved in groups called albums so that when the user opens an album, all associated pages are opened.

7.1.2 Processing

Data processing is managed through the RDE. Data files, recorded readings of one or more data points, are available to be processed immediately following the closing of the record. Typically, data is immediately processed following each recording, but data can be held and processed in a batch. Offsite data transfer is available. The default output file type is .csv. Customer-specified output file types can be accommodated.

7.1.3 Display

The data viewer provides a way to display deterministic data so that researchers, engineers, test operators, and customers can monitor live data during testing. Capabilities:

- Allows the user to create, modify, and save displays without the help of a programmer. Customers can create and edit local displays to suit their interests. The data engineer will assist with local display development if necessary.
- Allows display pages created or edited in one data viewer to be available to another data viewer. Displays developed for test operations will be globally available. These displays will be read-only to prevent inadvertent changes.
- Allows data to be filtered so that data being acquired at a high rate can be displayed without aliasing.
- Ensures data integrity (does not lose data, or reports it if it does).
- Runs independently of the COBRA data acquisition system.

In playback mode, viewers can also view saved history and simulated data. Capabilities:

- Allows the user to load saved files.
- Allows the user to step, play, and loop through the data.
- Allows the user to jump to specific locations in the dataset.
- Displays event information.

7.1.4 Customer Interface Development

Data viewer pages and albums are stored in two different locations, both of which can be accessed and viewed by any data viewer station. The data engineers will create and maintain a core set of display pages and albums, which are stored in the first location. These can only be edited by the data engineers, and all other data viewer stations will have read-only access to them. All of the data viewer stations have both read and write privileges to the second location. This is where the customer or anyone else can save, view, and store custom or edited pages. Customers can inform the facility data engineers which instrumentation, calculations, and/or other system information they wish to see on their personal data viewing stations. Customers have the option of having custom pages created for them, and they can also edit existing pages or create their own pages.

7.2 DEWETRON Dynamic Data Acquisition System

The facility uses a DEWETRON (DEWETRON GmbH) dynamic data system. The DEWETRON hardware consists of an isolated low-voltage input signal conditioning module (model DAQP–V) per channel and an Orion–1624 Sigma Delta analog-to-digital converter (ADC) card. A typical system contains 64 DAQP–V modules and 4 Orion–1624 ADC cards (16 channels each, dedicated ADC/channel). The PSL uses two of these 64-channel systems. The first channel on each system is allotted for a remote trigger to record data, leaving 63 channels per system for a total of 126 dynamic data channels. Math channels can also be created within the software in addition to these 126 channels. Each system that is used is synchronized with the same timecode as other data systems: Inter-Range Instrumentation Group timecode B (IRIG–B). The inputs for DEWETRON must be analog voltage and have selectable ranges of ±50 V, ±10 V, ±5 V, ±1 V, ±100 mV, and ±10 mV. The sampling rate ranges from 1 to 100 kHz (effective bandwidths of 420 Hz to 32 kHz).

The customer can view the live data via DEWETRON View Client computers. For each 64-channel system, there can be two View Clients that display live data from that particular 64-channel system. The software is DEWESoft® 7.1 (DEWESoft d.o.o.) and is free to download from the internet. The interface is user friendly (drag and drop) and configurable by the customer. Help in navigating the software is also available online. Display options include digital meters, bar graphs, recorders (time history), scopes, and fast Fourier transform (FFT). Data files are in a DEWETRON native .d7d format that is only viewable in DEWESoft® software. A MATLAB® (The MathWorks, Inc.) format (.mat) can also be provided if requested.

7.3 System Inputs

7.3.1 Analog Signal Routing

Analog signal interconnects for all common signal types are present throughout the facility. Signals destined for one of the data systems are routed through the facility electronic patchboard system. Each test cell has a primary three-patchboard system.

The signal input patchboard collects high-level analog signals from strain gage signal conditioners, charge amplifiers, frequency-to-voltage converters, and 4- to 20-mA voltage converters as well as raw analog signals from the test cell, shop area, and control room.

The signals are sorted as they transition to the middle data system patchboard to establish the scan pattern for the COBRA data system. Signals can be optionally patched to the third outputs patchboard. This patchboard permits the signals to be sent to one of several secondary systems:

1. High-speed transient data system
2. Facility crash system
3. Facility PLC system
4. Control room panel meters
5. Customer-provided data or control system

Isolation amplifiers are used to isolate signals as required.

7.3.2 Digital Thermocouple Scanners

Each of the test cells has a temperature measurement system utilizing Scanivalve Corporation's digital thermocouple scanners (DTSs). Each of the individual DTS units has a total of 64 channels, which is a combination of four separate 16-channel analog-to-digital (A/D) converters in a single chassis. Each of these 16-channel A/D converter blocks has two resistive temperature devices (RTDs), one on each side, that act as the uniform temperature reference (UTR). These UTRs have an accuracy of ±0.1 °C. To avoid temperature gradients and to achieve temperature stabilization, all DTS units are mounted inside insulated equipment racks (Figure 34 and Figure 35).

The facility is an altitude test cell with numerous electrical devices operating during testing. It is therefore recommended that all customer research thermocouples be ungrounded.

Of the 64 channels, 59 are utilized for facility or customer temperature measurements. The remaining channels consist of one temperature inside of the insulated equipment rack monitoring air temperature next to the DTS unit, and four temperature references that are connected to an ice point reference. These four references read a constant 32 °F and are connected to the first channel on each of the 16-channel A/D converter sections to monitor health of the DTS unit. The DTS units are calibrated before each program, and an internal A/D calibration is performed each day before testing to eliminate any drift in the A/D hardware.

PSL–3's temperature measurement system utilizes 12 individual 64-channel DTS units, all of which are terminated as Type K thermocouples, with accuracies of ±0.5 °C. This gives a total of 708 thermocouple channels for use by both the facility and customer. PSL–4's temperature measurement system utilizes 13 individual 64-channel DTS units with accuracies of ±0.5 °C; 12 are terminated as Type K, and 1 is terminated as Type E. This gives a total of 708 Type K and 59 Type E thermocouples for use by both the facility and customer. Both PSL–3 and PSL–4 have all channels terminated into interconnects in the test cells. The DTS units communicate with the data system via 100 base-T Ethernet connections using Transmission Control Protocol/Internet Protocol (TCP/IP) or User Datagram Protocol (UDP).

Figure 34.—Typical digital thermocouple scanner (DTS) equipment rack. (C-2014-08134)

Figure 35.—Digital thermocouple scanner (DTS) support rack. (C-2014-08133)

7.3.3 NetScanner™ Pressure Scanning System

Each test cell has a dedicated NetScanner™ System with a Rackmount Intelligent Pressure Scanner that provides ±0.05 percent measurement accuracy of steady-state test article and facility pneumatic pressures. This system is shown in Figure 36.

Each NetScanner™ System has four 8-module racks (512 channels) and one 4-module rack (64 channels) for a total input capacity of 576 channels per system. Each module contains 16 individual transducers that are addressed and transmit their signal information via 10/100/1G Base-T Ethernet.

The four 8-module racks accommodate module ranges of ±15, ±45, or ±100 psid. The one 4-module rack is configured for ±750-psid modules.

The rack-mount equipment is in a climate-controlled room on a mezzanine level next to the test cell. The climate-controlled environment keeps the equipment stabilized and maintains system accuracy. A high-accuracy Heise® (Ashcroft, Inc.) pressure transducer, located in the mezzanine room, provides atmospheric reference pressure for each module in the system.

All transducers are evaluated for accuracy before and after each test run via a validation system located in the mezzanine room. A list of out-of-tolerance channels is automatically generated and kept on file. All out-of-tolerance channels are examined and corrected, if necessary.

7.3.4 Serial Inputs

The COBRA system can accept a variety of serial inputs from customer hardware. Currently, the system has provisions to communicate via MIL–STD–1553, Aeronautical Radio, Incorporated (ARINC) 429, and Modbus® (Schneider Electric USA, Inc.) protocols. The system can be configured to monitor and accept signals over these methods or, in the case of Modbus®, act as a transmitting device to customer machines. Critically, however, if COBRA is acting as a transmitter to a customer system, the data being streamed must not be used for model control and/or safety.

Figure 36.—NetScanner™ pressure scanning system.

7.3.4.1 ARINC 429 Interface

The COBRA system ADAS ARINC 429 interface utilizes a Peripheral Component Interconnect Express (PCIe) card from Astronics Advanced Electronic Systems (AES) that provides up to 32 ARINC 429 Receiver channels. Glenn's Data and Systems Branch (DSB), Code FTK, has developed a custom, rack-mountable hardware interface to break out the two onboard low-force helix (LFH–60) connectors to a bare wire interface. Troubleshooting of the system is accomplished with Ballard CoPilot® (Astronics AES) software running on a standalone laptop and connected to the ADAS through a universal serial bus (USB) multiprotocol breakout cable. This setup allows the PSL to test the continuity of the ARINC 429 input and ensure that the system is working correctly.

7.3.4.2 MIL–STD–1553

Through the ADAS 1553 interface, COBRA can act as a bus monitor that is capable of recording 1553 messages. It takes advantage of the same Astronics AES PCIe cards as the ARINC 429 interface. Currently, the system can only support the following message structures:

- Remote terminal to bus controller
- Bus controller to remote terminal

The ADAS interface has no direct control over the devices connected to the 1553 bus infrastructure; it is simply monitoring for specific messages that are specified in the CCT. This system can also utilize the Ballard CoPilot® software to check continuity and troubleshoot the 1553 connection. System input capacity can be tailored to the customer's hardware.

7.3.4.3 Modbus® Protocol

Most customers utilize Modbus® protocol to pass values, both raw engineering units and calculated values, between the COBRA system and their own system(s). There is nothing in the Modbus® protocol that specifies how many channels (registers) are written to the register array. It is up to the operator of the external Modbus® device to know how many registers to read, where to begin reading from, and in what endian format (endianness) to read the data. The same goes when configuring the COBRA Modbus® server to read from the external Modbus® device.

7.4 Signal Conditioning

7.4.1 Bridge Completion

Each test cell has 128 channels of wideband transducer signal conditioning, with planned expansion capability for up to 192 channels. The present standard utilizes Precision 21844 (Precision Filters, Inc.) quad-channel bridge/dynamic strain conditioning cards. The unit can provide up to 20 Vdc excitation voltage or 20 mA constant current, alternating current/direct current (AC/DC) coupling, variable gain up to 8,192 maximum, and electable 4-pole low-pass filtering with cutoffs from 1 Hz up to 204.6 kHz with flat mode similar to a Butterworth filter or pulse mode similar to a Bessel filter.

7.4.2 Charge Amplifiers

Each test cell has 24 channels of Trig-Tek™ (Astronics Test Systems, Inc.) 203PC–2 charge amplifiers. The charge amplifier signals are connected to the test cell via coax and are typically extended using microdot cabling. The charge amplifiers can accept 0.100 to 199.9 pC/g, mV/g, or mV/ips with selectable gain of ×0.1, ×1.0 and ×10.0. Input frequency can be up to 40 kHz, and 48 dB/decade filtering is available. Low-pass filtering cutoffs are selectable from 100 Hz to 20 kHz in 100-Hz steps, and high-pass filtering is settable from 5 to 999 Hz in 1-Hz steps.

Four output types are available: acceleration, velocity, displacement, and DC.

7.4.3 Frequency-to-Voltage Conversion

The facility has 12 Anadex model PI–608 frequency-to-voltage converters per test cell. These are commonly used to condition rotation speeds as well as flow meters as needed. PI–608 converters operate over a range from near DC to 51.2 kHz with salient features including 0.025-percent terminal linearity, high transient response rate, low output ripple, and transformer-coupled input. Multiple outputs are provided, including DC level and pulse, the latter of which is both squared and clipped to a maximum of 10 Vpp for the protection of the data system.

7.5 Specialized Research Systems

This section describes the specialized research systems available for use in the PSL during testing.

7.5.1 Tomography

Designed by an internal optics researcher, the PSL tomography system uses a nonintrusive technique to measure particle uniformity in an airflow. A set of lasers and receivers is fired across the airflow in a set manner, and the level of light extinction measured by the receivers is then calculated to determine uniformity and relative density of particles in the flow. The system has been used fore of engine to measure cloud uniformity of both liquid water and ice crystal particles ingested by the engine; aft of engine, it has been used to measure uniformity of engine exhaust particles.

7.5.2 Research Video Systems

The PSL has developed a research video station to support recording research videos specific to the test program. Testing supported by this station includes (1) ice cloud monitoring, (2) external and internal ice accretion on test articles, (3) engine exhaust, and (4) afterburner and subsystem monitoring. An intake and monitoring station in the control room with recording capabilities is connected to the PSL file server for customer access to the video data during testing.

7.5.3 Particle Characterization

The PSL–3 icing cloud simulation system must be calibrated for the desired window of interest in each customer test program. This is accomplished by a customer-funded calibration test program performed prior to and in conjunction with the customer’s test program. The particles of this cloud are characterized using two main metrics, TWC and MVD. The instruments used to take these measurements are discussed in the following subsections.

7.5.3.1 Multiprobe Traversing System

The multiprobe traversing system was designed to calibrate the icing cloud through a 36-in. duct. This traversing system can insert four probes anywhere in the upper half of the flow path. This system can support two hot-wire probes and two temperature measurement probes. The probe measurement functions and the target locations are set in the control room.

7.5.3.2 High-Speed Imaging Probe

The High-Speed Imager (HSI) probe is a nonintrusive laser system developed by Artium Technologies, Inc., to measure MVD and particle size. This probe uses a laser system and high-speed camera to capture the particles as they enter an area of interest within the cloud to get a measurement of the total particles of a certain size. The HSI probe focuses on nonspherical particles and article number density.

7.5.3.3 Phase Doppler Interferometer Probe

The Phase Doppler Interferometer (PDI) probe is a nonintrusive laser system developed by Artium Technologies, Inc., to measure MVD and particle size. The PDI probe uses two lasers to set a sample volume that is then monitored for the scatter of the light after a particle passes through. Particle velocity can also be measured by this probe.

7.5.3.4 Multiwire Probe

The PSL utilizes a hot wire probe referred to as the “multiwire probe” to measure TWC, ice water content (IWC), and liquid water content (LWC). This multiwire measures the TWC and sees freezeout. The probe was designed and supported by Science Engineering Associates, Inc. (SEA). The measurement from the probe is read into the M300 data system (further described in Section 7.5.3.6). This data can be transferred to the COBRA steady-state data system for continuity, monitoring, and preservation.

7.5.3.5 Isokinetic Probe

The isokinetic probe (IKP) is a flight probe utilized in the PSL to measure TWC in the simulated cloud. The probe uses a stream tube to collect a portion of the cloud and evaporates the cloud to measure relative humidity. The measurement is then compared with the outside relative humidity to get an accurate TWC measurement. This probe can be mounted on the centerline or traversed at the exit plane of the duct using a support system to move the probe to any location in the 36-in. duct plane.

7.5.3.6 M300 Inclement Weather Probe Data Acquisition System

The M300 data system is a data acquisition system developed by SEA. It is used for multiple icing-specific instrumentation, including the multiwire probe and the IKP. This system has limited capability for data synthesis and can connect to the steady-state data system, COBRA, and transfer information to that system as well as receive information from the system about current facility conditions.

7.6 Calibrations

The Metrology Services Calibration Laboratory at Glenn maintains specific standards highlighted in GLPR 8730.6, GRC Control of Measuring and Test Equipment, to ensure the quality of calibrated equipment. This standard focuses on measurement uncertainty analysis, false accept risk analysis, documented calibration procedures, certification procedures, and traceability.

The Calibration Laboratory is able to calibrate a large range of equipment, including signal conditioners, data acquisition instrumentation, dimensional measurement instrumentation, mass measurement instrumentation, flow devices, pressure instrumentation, electrical test and measurement instrumentation, radiofrequency and microwave test and measurement instrumentation, temperature and humidity instrumentation, vibration and acceleration instrumentation, load cells, and acoustic devices.

The Calibration Laboratory completes most of the needed instrumentation calibrations. If the laboratory is unable to meet specific needs, the piece of instrumentation will be sent to an offsite test facility or the part manufacturer for calibration. Any outside calibrations must still conform to the same standards used at NASA (see above for specific standards). On average, it takes about 30 days for a piece of instrumentation to be calibrated by the Calibration Lab. That average increases to between 30 and 60 days if the instrumentation needs to be sent to an offsite calibration facility. The amount of time between calibrations is based upon manufacturer specifications and varies from 6 months to a year.

To ensure quality data, all test-specific instrumentation is calibrated before and after a test, and a detailed record of all relevant information (asset number, channel identification, calibration dates, etc.) is kept. All calibration sheets for a specific test are labeled accordingly and kept for records. If a piece of instrumentation is out of tolerance at the time of calibration, an impact analysis form is sent to the PSL team to notify them. The PSL team looks at the data and the impacted channels and informs the customer of any possible impact.

7.6.1 Pressure Transducers

Pressure transducers come in a variety of types. Most of the PSL's transducers are one of the following types:

- Druck series PMP 3000 (Baker Hughes, a General Electric Company) and Unik 5000 transducers (General Electric Company). The PSL has hundreds of these two models, both of which are voltage output devices. The PMP 3000 has a 7/16 UNJF pressure fitting. The Unik 5000 has a 7/16-20 UNF 37° flare tip pressure fitting.
- NASA U91 specification devices, manufactured by Bell & Howell, MB Electronics, Gilmore, Data Sensors, and others. All of these are voltage output devices.
- Setra models 204 and C204 (Setra Systems). These models are more commonly used for facility instrumentation. The output is either 5 Vdc or 4 to 20 mA.

In addition to these, a range of dynamic strain gauge pressure transducers can be supported, including the Kulite XTL–375 series (Kulite Semiconductor Products, Inc.).

All pressure sensors are calibrated at unique pressure points from 0 to full scale in both ascending and descending order. The units are typically calibrated at ambient temperature (around 73 °F), but if specific temperature data is needed, a special calibration can be requested from the Calibration Laboratory. Calibration data is used by the data engineers to generate conversion coefficients for the COBRA data system or the PFI signal conditioners.

The Pressure Calibration Laboratory can calibrate a variety of absolute, differential, and gauge pressure transducers, including strain gauge, piezoresistive, solid state, thin film, current output, amplified and nonamplified voltage output, and current-to-pressure (I/P) transducers. They can also calibrate high-accuracy pressure standards, mechanical pressure gauges up to 10,000 psi, electropneumatic (E/P) converters, and NetScanner™ pressure calibration units.

The Pressure Calibration Laboratory's full capabilities are as follows:

- Two fully automated systems that use DH Instruments (DHI) calibrators able to calibrate up to 10 devices at pressures from 1 to 3,000 psi
- Two semiautomated systems able to calibrate up to 10 devices at pressures from 1 in. of water to 1,500 psi
- Two Ruska (Fluke Corporation) deadweight systems able to calibrate at pressures up to 1,000 psi
- One DHI deadweight system able to calibrate at pressures up to 10,000 psi
- Two environmental chambers able to provide temperature testing from –73 to 200 °C (–99.4 to 392 °F)

7.6.2 Flow Meters

The most common flow meter used in the PSL is a Flow Technology, Inc. (FTI) turbine meter with attached Linear Link linearizer. Unless otherwise requested, the Flow Laboratory will calibrate with water at ambient temperature (approx. 73 °F). Upon request, the Flow Laboratory can calibrate a variety of viscosities and temperatures using the NIST software package REFPROP 9 (Reference Fluid Thermodynamic and Transport Properties Database).

The Flow Laboratory's full capabilities are as follows:

- Air stand able to calibrate devices at flows up to 4 pps at pressures up to 240 psi using air
- MesaLabs, Inc., system able to calibrate devices at flows up to 50 SLPM at pressures up to 100 psi using inert gases, air, oxygen, flammable (methane, propane, butane, ethane, and ethylene) gases, carbon monoxide, and hydrogen
- Cox® (Badger Meter, Inc.) test stand used to calibrate devices at flows up to 285 gal/min at pressures up to 50 psi using water
- Molbox (Fluke Calibration) test stand used to calibrate devices at flows up to 60 SLPM at pressure up to 100 psi using nitrogen. Can also perform tests using heated nitrogen (150 °C/302 °F)
- Nitrogen test stand used to calibrate devices at flows up to 2 pps at 2,400 psi using nitrogen
- Shop air test stand used to calibrate devices at flow rates up to 2 pps at 125 psi using shop air
- FTI MT–50 system used to calibrate a piston through a pipe at flow rates up to 50 gal/min using a calibrating fluid, the most common of which is a 4 percent propylene glycol/water mix, but others can be used upon special request
- Spray nozzle stand used to characterize spray nozzles and similar injectors at pressures up to 500 psi using water
- Thunder Scientific® (Thunder Scientific Corporation) dew point system used to calibrate dew point sensors using 300 psi nitrogen

8.0 Facility History

PSL–3 and PSL–4 were first opened in 1973. The two altitude test chambers inside the PSL were among the largest in the world at the commencement of operation. Each test chamber is 39 ft in length and 24 ft in diameter. Altitudes ranging from near sea level up to 90,000 ft can be simulated inside of each chamber, and conditioned combustion air can also be provided, at temperatures ranging from –90 to 1,100 °F.

8.1 Facility Upgrades

Over the years, both PSL–3 and PSL–4 have undergone facility upgrades that have provided each of them with unique capabilities (Ref. 32). While their outward appearance has not changed, significant improvements have been made within the confines of each of these test chambers.

In PSL–3, the exhaust collector was modified to accept geometries other than round nozzle configurations and thrust vectoring. PSL–3 also underwent a major upgrade with the installation of the icing system, which consists of 10 spray bars containing a total of 222 spray nozzles inside the inlet plenum, and a carbon fiber insert to prevent ice buildup and shedding upstream of the engine inlet. This icing system is removable to allow the cell to be configured for engine performance testing once again.

PSL–4 has undergone numerous upgrades, beginning with the installation of a smaller diameter settling chamber (inserted and constructed) inside of the full-sized inlet plenum, which is water jacketed. This settling chamber was installed as a part of a facility upgrade to support hypersonic testing by being able to achieve pressures of 150 psig and high temperatures up to 1,200 °F. A –90 °F line was installed to allow for temperatures of –90 °F to be achieved at the inlet face of the test article at a flow rate of 10 pps at 40 psig.

8.2 Representative Tests

The PSL has tested engines ranging in size from the small ducted fan engines used in remotely controlled aircraft to F100/F110 thrust class engines. The PSL has also tested a driven rig that used a 5,000-hp motor encapsulated in an environmental enclosure installed inside the test cell to drive it. While a complete list of engine rigs tested in the PSL over the years could be provided, that list would be quite extensive. Instead, this section describes a range of PSL engine tests to highlight the versatility and ability of the facility to test a significant majority of engines in service today.

8.2.1 General Aviation/Business Jet Inclement Weather Testing

The first full-scale engine test in PSL–3 after it had been modified to perform engine ice crystal icing testing was the Honeywell ALF502–R5 engine (serial number LF01) (Figure 37). The engine had previously experienced an ice crystal icing event during flight tests designed to measure engine and weather conditions while seeking to duplicate such an event. This unique engine was then used as a test article in a test campaign designed to duplicate the environment and engine response and thereby demonstrate the PSL’s ice crystal capabilities. The test was a resounding success; the event was duplicated during the first attempt.

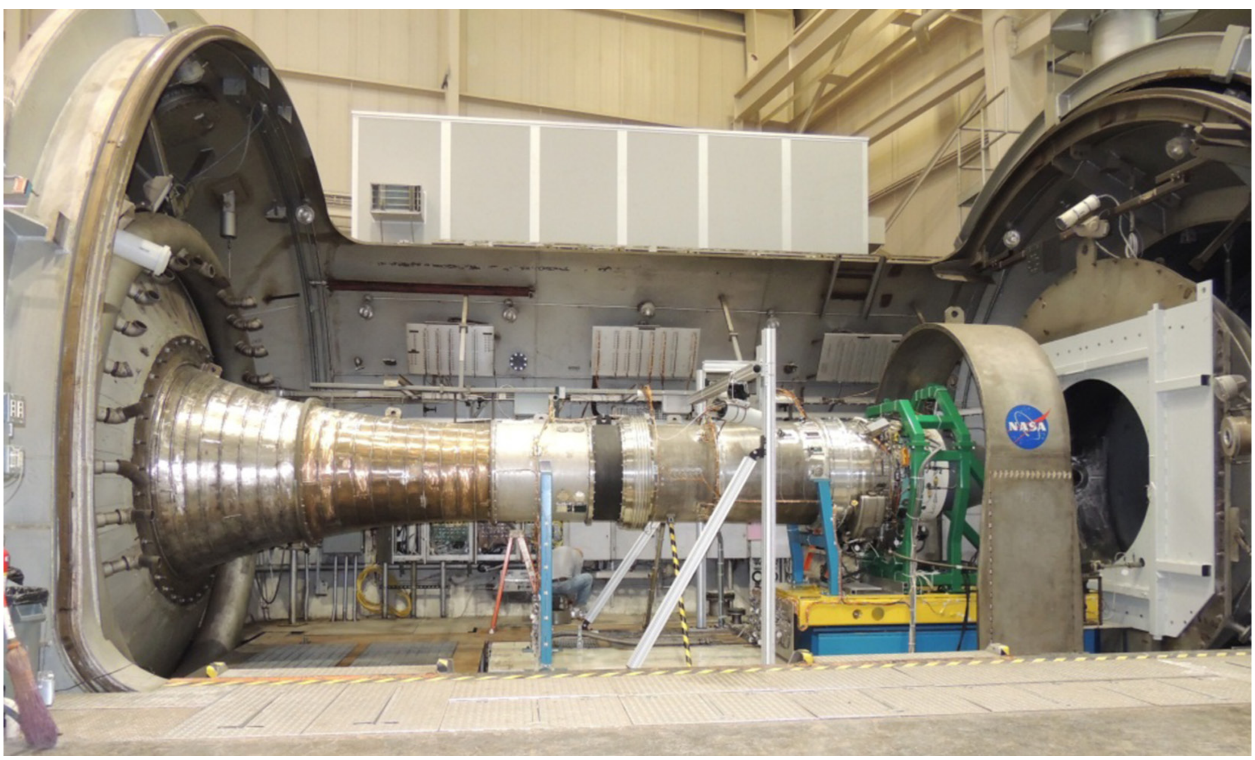

Figure 37.—Honeywell ALF502–R5 (serial number LF01) engine test.

8.2.2 High-Altitude/High-Speed Performance

The modification to the PSL–4 inlet plenum has allowed for elevated inlet temperatures and pressures to simulate high-speed flight. Previous testing in the PSL that has utilized this capability includes research into high-Mach turbine development and other means of high-speed air-breathing propulsion. This research is typically done at high-altitude conditions, above 50,000 ft, where the flight application is most likely to occur. Figure 38 depicts a high-altitude/high-speed engine test performed in 1998 for a General Electric J85 engine.

8.2.3 Military Fighter Engine Development

Engine development testing has been performed on various engines used by the military, ranging from those used in unmanned aerial vehicles (UAVs) to full afterburning engines used in today's fighter jets. Some examples of this type of testing include determining the engine's baseline performance, stall line mapping, and component improvement testing. Figure 39 depicts the setup for a military fighter engine test.

8.2.4 Engine Operability and Stall Resistance

The PSL performed compressor stall mapping and engine operability testing at various altitudes using a Rolls Royce F405 engine. The U.S. Navy had been experiencing issues with compressor stalls on the T–45 Goshawk after the inlet had been redesigned. A representative operability and stall resistance test is shown in Figure 40.

Figure 38.—High-altitude/high-speed engine test of General Electric J85 engine, 1998. (C-98-730)

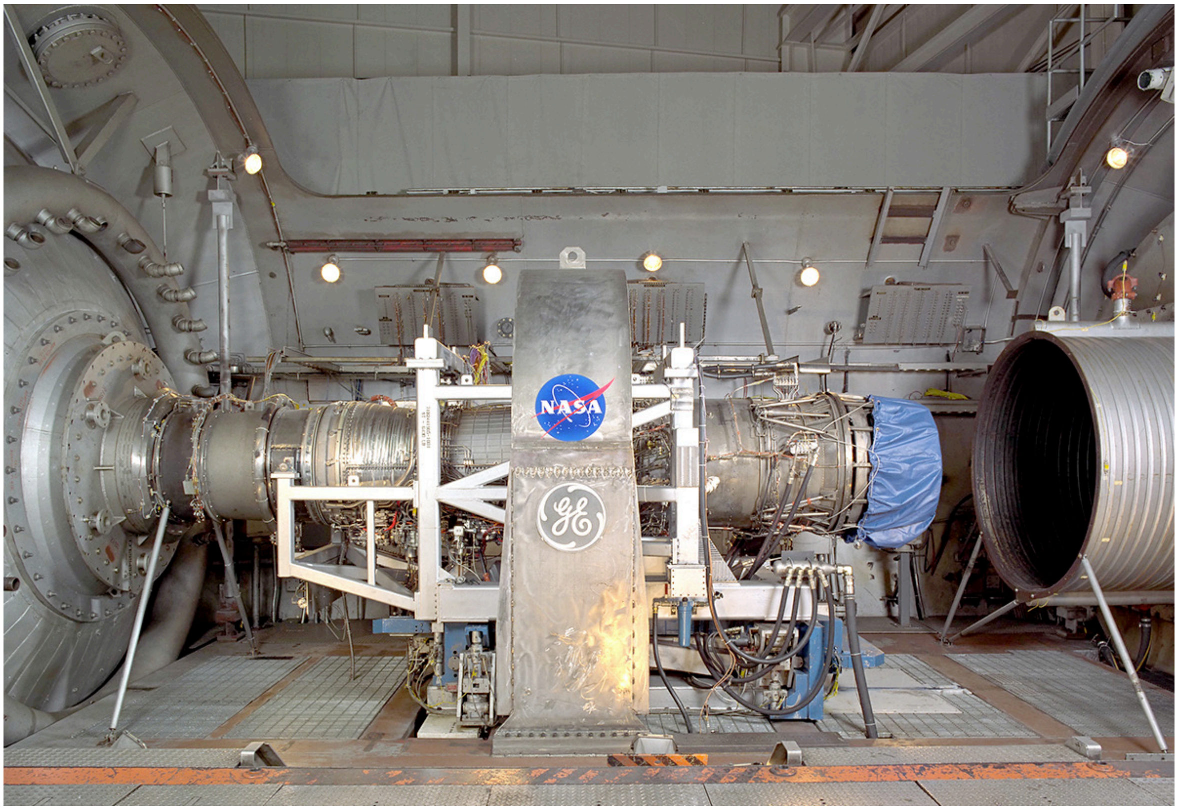

Figure 39.—Military fighter engine test.

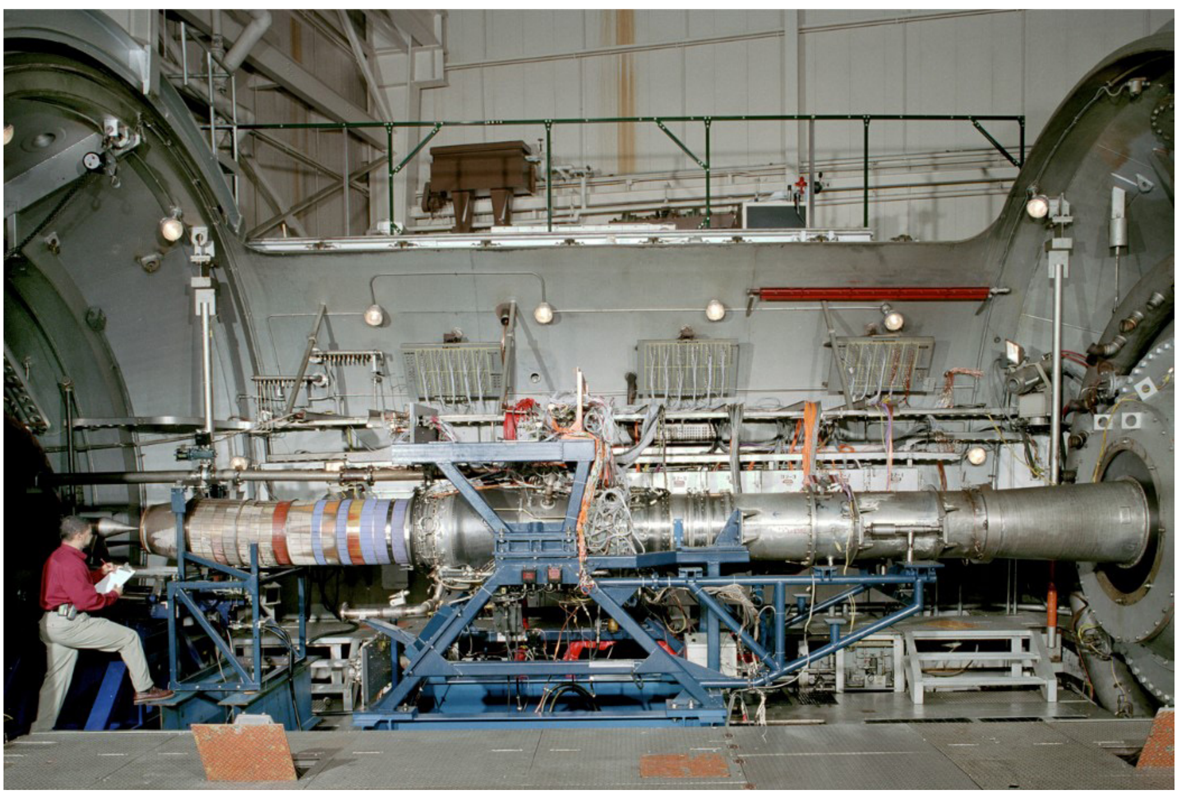

Figure 40.—Engine operability and stall resistance test.

8.2.5 Helicopter Turboshaft Engine Testing

The PSL ran its first engine designed solely for use in a helicopter when it tested the T800 engine (Figure 41). The engine at that time was developed by the Light Helicopter Turbine Engine Company (LHTEC), a collaboration between the Allison Gas Turbine Division of General Motors Corporation and the Garrett Engine Division of Allied-Signal Aerospace, Inc. The engine used an air box, inlet particle separator, water brake, torque meter, and dynamometer. The entire setup was mounted on a skid that was bolted into place in the test cell. Testing included doing performance, operability, and pressure and temperature distortion using a 6-zone hydrogen burner.

8.2.6 Unmanned Aerial Vehicle/Missile Engine Testing

The PSL has tested a JetCat engine (CAT, Markus Zipperer GmbH) designed for use in remotely controlled aircraft or small UAVs in the 50-lbf-thrust range. The PSL also tested some existing high-bypass turbofans for use in UAVs, as they offer great fuel efficiency. A representative test setup is shown in Figure 42.

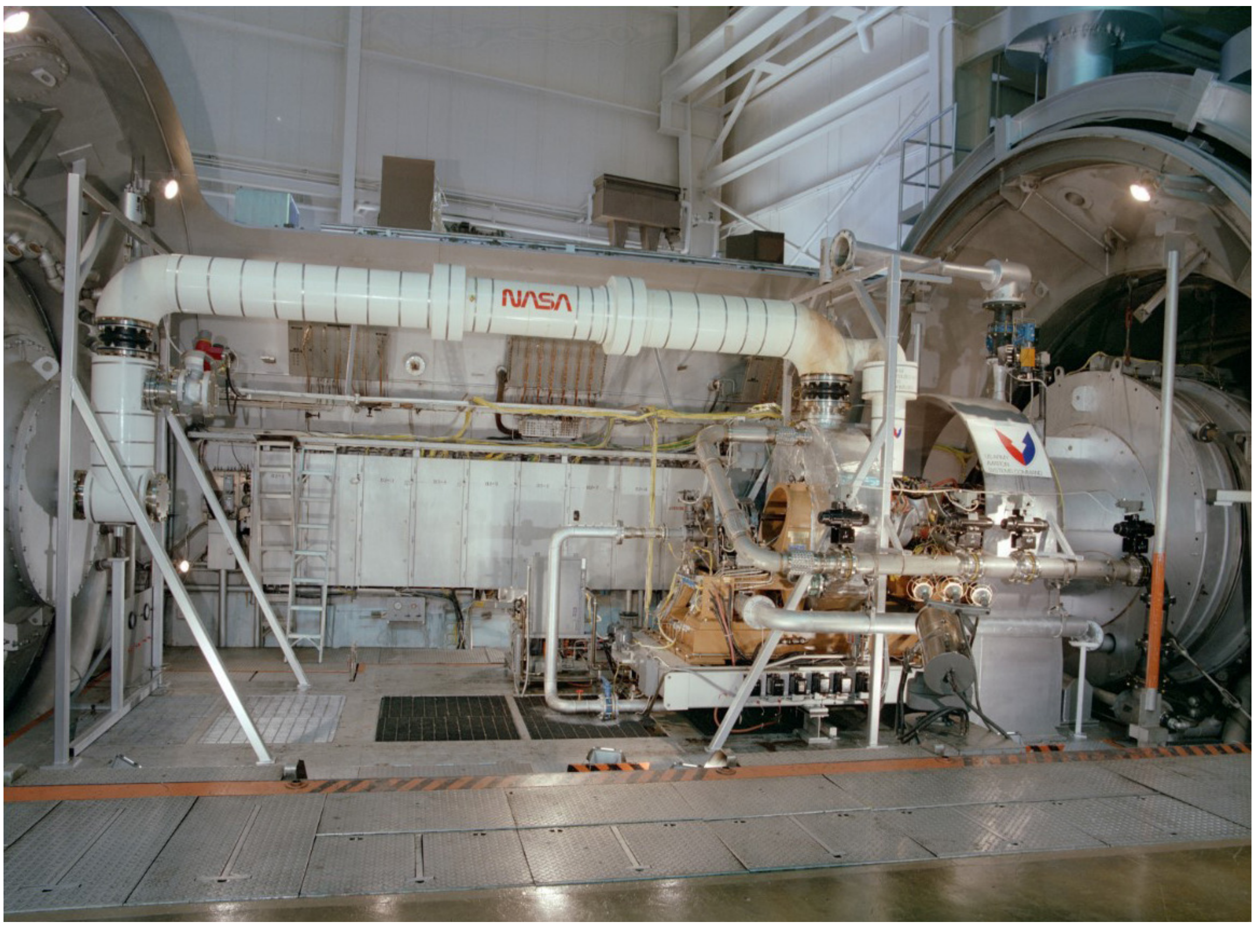

Figure 41.—Helicopter turboshaft engine test.

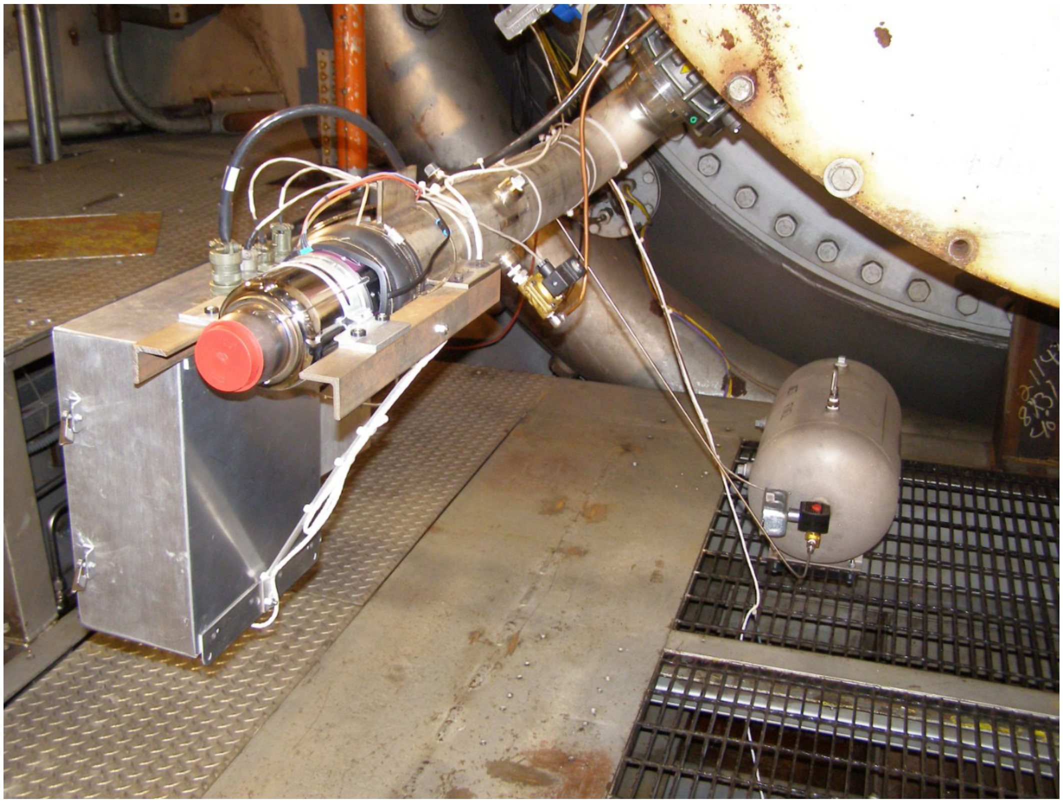

Figure 42.—Unmanned aerial vehicle/missile engine test.

8.2.7 Hypersonics

The PSL can be configured to perform hypersonic vehicle engine testing. Customers may request details by contacting the facility manager and technical lead team.

9.0 Pretest Requirements

The PSL facility is a high-demand facility due to its various capabilities and ability to integrate unique programs. It is advisable to contact the facility manager at least 1 year in advance of the desired test time. Early notification will allow the facility manager and appropriate PSL personnel to review the proposed engine or test article installation and ensure compatibility between the engine or test article and the PSL test chamber. A customer may submit a test request to the facility manager or Test Facility Management Office via email or the Facility Request Form located on Glenn's Facilities website (https://www1.grc.nasa.gov/facilities/testing/). Further contact information is provided in Section 12.0.

After contact, the facility manager or designated point of contact will provide the customer with applicable facility information and inform the customer of the documentation required for a preliminary assessment of the test cost, schedule, and risk. The test scope, requirements, and cost and schedule estimates are typically iterated and refined until a test agreement is signed. Before a test program is integrated and tested in the PSL, a series of test-planning meetings are held 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 these meetings are the customer, their stakeholders, and the key personnel listed in Section 12.2.

9.1 Pretest Agreement

After a customer submits a test request and the test requirements have been iterated to a sufficient level of detail, the facility manager works with the test team (the test project team lead and engineering technical leads) to provide cost and schedule estimates. For non-NASA customers, a Space Act Agreement is developed based on the scope, cost, and schedule estimates.

9.1.1 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.

9.1.2 Engine or Test Article and Associated Hardware

At the direction of the PSL facility engineer, Glenn personnel will prepare an installation drawing of the engine or test article and its supporting hardware installed in the PSL test chamber.

9.1.3 Instrumentation

The PSL customer should provide the PSL project engineer with a list of instrumentation that must be adapted to the PSL data system. 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.

9.1.4 Data Requirements

PSL customers requesting data reduction services must provide data inputs, data outputs, and calculations to the PSL project engineer a minimum of 6 months before the start of testing in the facility. The PSL project engineer will contact the appropriate personnel in the Data and Systems Branch (DSB) and set up any necessary meetings between the PSL customers and the DSB application programmers to establish the ground rules for a computing requirements package writeup. Final computing instructions are due from non-NASA PSL customers to DSB 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.

9.2 Deliverables

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

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
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 a bill of material
5. Initial computing instructions for the project engineer and the data engineers, if applicable

Where data obtained from an experiment are agreed to be mutually beneficial, the customer may be asked to supply selected engine or test article drawings and photographs for reproduction in NASA technical papers.

9.3 Engine or Test Article and Equipment

The engine or test article, along with instrumentation and support hardware, should be sent to the attention of the PSL project engineer at the PSL (Bldg. 125) at NASA Glenn. To reduce installation time and troubleshooting delays in the PSL test cell, the engine or test article and PSL customer-support hardware should be test fitted when possible before shipment to the PSL. 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 varies according to the complexity of the engine or test article installation and the amount of instrumentation that is to be connected to the data recording system. The customer and the PSL test conductor should agree to delivery times as part of the contract. The typical installation period is approximately 8 weeks from when the customer hardware arrives.

All test article and support equipment coming to PSL will go through the south overhead door. The door's opening is 13 ft 9 in. wide by 16 ft high. The preferred method of delivery is to have the hardware arrive on an open-sided lowboy trailer. The truck will back the trailer into the building, where the equipment can be offloaded with the building's 25-ton crane. All small equipment will be unloaded in the PSL south parking lot with the building's 8,000-lb capacity forklift. All auxiliary pumps, lube carts, and other items that contain oil or hazardous fluids shall be drained of fluid and capped at the customer site before shipment. The units will be refilled once they are installed into the location required for testing.

10.0 Risk Assessment to Facility, Engine, Test Article, and Test Hardware

This section describes the PSL's safety systems, engine history and inspection requirements, engine support hardware, and other considerations for assessment of risks associated with testing in the PSL.

10.1 Facility Safety System

10.1.1 Fire Suppression System

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. System specifics can be discussed with the PSL test conductor at one of the test-planning meetings.

10.1.2 Evacuation Alarms

Evacuation alarms are placed at each exit of the PSL and heater buildings. When the fire suppression system begins to discharge, the evacuation alarms are initiated and Glenn first responders are alerted.

10.1.3 Fire Detection

Smoke detectors in the 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 facility control room annunciator panel and Glenn first responders are contacted. If a computer mainframe overheats in the second-floor data room, alarms go off at the facility control room annunciator panel and Glenn first responders are contacted.

10.1.4 Gaseous Hydrogen Detection System

Gaseous hydrogen detection units are located 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 Glenn first responders are contacted. In addition, the test article and the facility will proceed through an orderly shutdown.

10.1.5 Fuel Detection System

Fuel detection units are located inside both PSL test cells. If fuel is detected in either test cell, alarms are set off at the facility control room annunciator panel and Glenn first responders are contacted.

10.1.6 Facility Ventilation System

There are six ventilation fans on the facility roof. Each fan has 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.

10.2 Engine History and Inspection Requirements

The facility's engineers may request that the PSL customer provide documented engine history, maintenance, and inspection records to protect PSL personnel and the facility from any undue risk.

10.3 Engine Support Hardware

10.3.1 Support Structures

All engine and test article support structures shall be designed so that the allowable stress for maximum loading is the smaller of one-fifth of the minimum ultimate stress or one-third of the minimum yield stress of the material. This corresponds to a safety factor of 5 on ultimate stress and a safety factor of 3 on yield stress. If a structural code analysis using finite element analysis is employed, then a safety factor of 1.5 on yield and 3.0 on ultimate stress can be used.

10.3.2 Structural Joints

The minimum safety factor for bolted joints that clamp an engine, test article, or auxiliary structure shall be 3.0 based on yield stress, and 5.0 based on ultimate stress, for heat-treated hardened bolts.

Shear loads should be transmitted using 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 damage to the facility or loss of an engine, test article, or engine or test article component) must be x rayed or dye-penetrant inspected.

10.3.3 Pressure Systems

Engine or test-article support and test equipment that uses hydraulic, pneumatic, or other systems with operating pressures above 15 psig shall be designed, fabricated, inspected, tested, and installed in accordance with the American Society of Mechanical Engineers (ASME) Process Piping Code B31.3 or ASME Boiler and Pressure Vessel Code, as applicable.

10.3.3.1 Pressure Vessels

Pressure vessels are defined as all vessels (e.g., 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 (Section IX for welding qualifications and Section 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.

10.3.3.2 Pressure Piping

All piping shall be designed, fabricated, inspected, tested, and installed in compliance with the latest edition of the American National Standards Institute (ANSI)/ASME Standard Piping Code B31.3. 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 support systems, labels must be affixed that properly identify the working pressures, the flow direction, and the fluid or gas being carried.

10.3.4 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.

An additional concern is the operation of electrical and electronic components at altitude. Electrical systems must be close-coupled within 50 ft of the test article and must be able to withstand the environmental conditions within the test cell or must be enclosed in a pressure vessel.

10.4 Nondestructive Testing of Instrumentation Rakes

If instrumentation rakes are to be placed upstream of or inside a test article, 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. Glenn requires that one prototype rake 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 (<1,000 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 vibrations and shock tests is defined in References 33 and 34. The scope of testing for the instrumentation rakes should be agreed upon by the research engineer, the facility test project engineer, and the rake test engineer from the Materials and Structures Division (Structural Systems Dynamics Branch). The other rakes that are used with the full-scale engine or test article experiments are to be subjected to low-level vibration tests.

10.5 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.

10.6 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 sketches.

11.0 General Information

The following information is provided to familiarize the PSL customer with the services available, the operating schedule, planning meetings, and security considerations.

11.1 Support

11.1.1 Engine or Test Article Buildup

The buildup for a test begins when the previous test has completely vacated the facility. Most tests in the PSL are complex, and buildup times vary from test to test. 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.

11.1.2 User Responsibility

Depending on the complexity of installation of the engine or test article, it is advantageous to have the customer supply knowledgeable personnel 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.

11.1.3 Operation of Government Equipment

The customer's research personnel should not operate Government-furnished equipment or make connections to this equipment without the approval of Glenn personnel.

11.1.4 PSL Test Chamber Safety

All personnel entering the test chamber for an extended period to examine the engine or test article or any auxiliary equipment should be accompanied by Glenn 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. Trip hazards and penetrations in the test cell should be clearly marked.

11.1.5 Facility Support During Tests

The customer shall direct all requests for manpower, shop and facility services, or COBRA programming services to the PSL lead project engineer, who will then coordinate the request with the appropriate member of the PSL staff.

11.2 Operations

11.2.1 Normal Operating Days and Shifts

PSL tests are typically run from 1600 to 2400 (4 p.m. to 12 a.m.), Monday through Friday. In the event of schedule conflicts with other major Glenn facilities, testing can be scheduled 2300 to 0700 (11 p.m. to 7 a.m.) Monday night through Saturday morning. The daily test window can be extended past 8 hours a day on a case-by-case basis.

Each week during testing, the PSL customer and the PSL facility manager should discuss whether extended daily test windows are required. On the Wednesday prior to the week of testing, services must be scheduled by the PSL project engineer with the CAEB. The schedule request will be reviewed, and the official schedule will be posted on Thursday for all of the Center test facilities. After services are scheduled, if a change in air services from CAEB is necessary, it must be coordinated through the PSL project engineer, who will determine with the CAEB if the change can be accommodated. Testing is scheduled for 5 days a week. However, when planning a test window, customers should use three runs a week as an average to account for any unpredictable issues that arise during the various test runs.

11.2.2 Off-Shift Coverage

Due to the nature of test programs in general, the PSL is not a fully open facility. Access to the PSL, particularly outside of normal first shift hours (0600 to 1430, 6 a.m. to 2:30 p.m.), must be coordinated with the PSL facility manager and/or an appointed facility representative.

11.3 Planning and Debriefing

11.3.1 Pre-Run Safety Meeting

The PSL project engineer shall prepare and submit a Safety Permit Request via Glenn's Safety Permit website. The safety permit addresses test programs as they relate to the Glenn Safety Committee to ensure the successful, safe completion of test programs in the PSL. Items covered in the safety permit include test objectives; run schedule; and instrumentation, subsystems, and hardware utilized. The safety permit process culminates in a review with the Facility Safety Committee to secure their approval. The safety permit must be approved before testing can begin at the PSL. All safety-related information from the customer will be provided to the PSL project engineer no later than 6 weeks prior to the start of testing. This deadline will allow the PSL project engineer to meet the requirement that 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:

- Use of radioactive materials or gases
- Use of high-speed rotating engine or test article parts without suitable shrouds
- Ejection of explosive gases into the PSL circuit

- Use of toxic materials (Safety Data Sheets are required)

If the test program plans to utilize resources that require special action on the part of the Glenn Area Safety Committee, information will need to be submitted to the PSL project engineer a minimum of 8 weeks before test start.

The PSL will conduct an internal safety meeting with personnel to ensure that the facility understands what hazards exist and how to mitigate these hazards. This will be conducted prior to the start of testing. Additionally, if hazards change during testing or new hazards arise, the PSL project engineer will brief affected personnel prior to the hazards becoming relevant. Daily safety briefings can be instituted upon customer request.

11.3.2 Program Test Window

The time charged to a PSL test window for non-NASA customers typically encompasses the total time that the facility is available to the customer. The test window typically starts with the arrival of test-associated hardware and includes the time required for installation, testing, and removal of the test article. Additionally, it includes shipping the test article back to the customer and returning the PSL facility to its pretest condition. Extensions to a test window may be negotiated by the customer's lead engineer and the PSL facility manager. PSL personnel familiar with a specific test program can assist the customer and PSL facility manager in making a rough order of magnitude estimate of the time required to complete the test program. NASA customers should contact the PSL facility manager for specific information about their test window.

11.3.3 Post-Run Planning Meeting

After the end of each test period, the PSL project engineer holds a post-run planning meeting to review that night's run. This meeting also covers any action items that need resolution before the next run as well as the run plan for the next test period.

11.3.4 NASA Debriefing

When the test program is nearing completion, the PSL facility manager provides the customer's lead engineer with a survey evaluating the effectiveness of PSL support during the test program. The PSL customer may request a meeting with the facility manager to discuss facility performance if the survey is deemed insufficient.

11.4 Security

The advance notice required to obtain access to the PSL depends on the classification of the test program and the category of the non-NASA visitor.

11.4.1 Controlled Unclassified Information Test by U.S. Citizen or Legal Permanent Resident

During Controlled Unclassified Information (CUI) test programs, the PSL project engineer will notify the Glenn visitor control office at least 3 days prior to the arrival of a non-NASA visitor who is a U.S. citizen. The information required includes the name of the visitor, the place of employment, whether the visitor is a U.S. citizen or U.S. permanent resident, and the date(s) and purpose of the visit.

11.4.2 Controlled Unclassified Information Test by Non-U.S. Citizen

All non-U.S. citizens, as well as U.S. citizens employed by foreign-owned companies, must be sponsored and may require a background investigation. The lead PSL project engineer of the test is responsible for obtaining all necessary approvals for these individuals. This information must be submitted to the PSL project engineer at least 8 weeks prior to the visit. Computer system security plans should be coordinated with the Glenn information technology (IT) security manager. This contact can be found through the PSL project engineer. All computer system requirements should be validated with the Glenn IT security manager. The Internal Visitor Coordinator can provide the name of this manager to the research engineer.

11.4.3 Sensitive Test by U.S. Citizen

Arrangements for programs requiring greater-than-CUI security requirements can be accommodated. This requirement should be communicated to the PSL facility manager when the program request is submitted.

11.4.4 PSL Physical Access Controls

The PSL facility is secured with an enterprise physical access control system. Access of personnel to protected areas off the main lobby, including test cells, control room, data room, and facility subsystems, will be strictly controlled by the PSL security representative. Only personnel with approved access and validated need to know will be provided necessary credentials for accessing the facility.

11.4.5 Isolated Networks

PSL can accommodate the integration of customer data acquisition and control systems into its secured state regardless of the sensitivity of the data. PSL facility control systems are fully separated from customer data generated for all test programs, regardless of the sensitivity of the data.

12.0 Contact and Shipping Information

Contact information was current at the time of publication but is subject to change. Visit the PSL website at https://www1.grc.nasa.gov/facilities/psl-3/#contact for current contact information.

12.1 Facility Manager

The facility manager is the key contact person at the PSL. The facility manager may be contacted in any of the following ways:

- Email: Richard.F.Bozak@nasa.gov
- PSL website: https://www1.grc.nasa.gov/facilities/psl-3/#contact
- Phone (Facility Management and Planning Office): 216–433–5160
- Mailing address:

NASA Glenn Research Center at Lewis Field
Attn: Richard Bozak
Mail Stop 6–8
21000 Brookpark Road
Cleveland, Ohio 44135

12.2 Key Personnel

At the time of this document's publication, key personnel were as follows:

PSL Facility Manager:	Rick Bozak	216–433–5160	Richard.F.Bozak@nasa.gov
PSL Operations Technical Lead:	Kyle Zimmerle	216–433–5391	Kyle.D.Zimmerle@nasa.gov
PSL Electrical Technical Lead:	Paul Lizanich	216–433–5724	Paul.J.Lizanich@nasa.gov
PSL Research Technical Lead:	Dr. Michael J. Oliver	216–433–6361	Michael.J.Oliver@nasa.gov
Wind Tunnels Branch Chief:	G. Scott Williamson	216–433–5717	Gary.S.Williamson@nasa.gov
Data Systems Branch Chief:	Debashis Sadhukhan	216–433–6567	debashis.sadhukhan-1@nasa.gov

12.3 Shipping Information

Customer test articles may be shipped to the following address:

NASA Glenn Research Center at Lewis Field
Attn: Kyle Zimmerle
Mail Stop 125–1
21000 Brookpark Road
Cleveland, Ohio 44135

13.0 Conclusion

The NASA Glenn Research Center's Propulsion Systems Laboratory (PSL) is located in Cleveland, Ohio. The PSL is a full-scale, ground-based, air-breathing propulsion test facility with altitude and inclement weather simulation capabilities, providing customers the ability to perform air-breathing propulsion testing throughout the entire operating envelope of their respective test articles. The PSL staff created this customer guide to provide common technical information and details typically exchanged with PSL customers for a test program. The structure of this customer guide is developed to provide a high-level, general introduction for potential test customers. Upon request to the PSL Facility Manager, customers are provided a more detailed description of the test facility and its capabilities to address specific test program requirements. The PSL staff intends for this document to facilitate customer understanding of the PSL's capabilities and the process of conducting a test in this world-class test facility.

Appendix A.—Acronyms

2D/CD	two-dimensional converging/diverging
AC	alternating current
A/D	analog to digital
ADAS	auxiliary data acquisition system
ADC	analog to digital converter
AES	Advanced Electronic Systems
ANSI	American National Standards Institute
ARINC	Aeronautical Radio, Incorporated
ASME	American Society of Mechanical Engineers
CAEB	Central Air Equipment Building
CCP	COBRA Calculation Processor
CCT	COBRA Configuration Tool
COBRA	Collect, Observe, Broadcast, Record, and Analyze
CODI	COBRA Operator Development Interface
CPOD	control pod
CPU	central processing unit
CSV	comma-separated value
CUI	Controlled Unclassified Information
DC	direct current
DCS	distributed control system
DHI	DH Instruments
DSB	Data and Systems Branch
DTS	digital thermocouple scanner
DVR	digital video recorder
EGT	exhaust gas temperature
E/P	electropneumatic
FFT	fast Fourier transform
FT	Facility Testing Division
FTI	Flow Technology, Inc.
FTK	Data and Systems Branch
HSI	High-Speed Imager
IKP	isokinetic probe
I/O	input/output
I/P	current to pressure
IRIG–B	Inter-Range Instrumentation Group timecode B
IRT	Icing Research Tunnel
IT	information technology
IWC	ice water content
LFH	low-force helix
LHTEC	Light Helicopter Turbine Engine Company
LWC	liquid water content
MIL–STD	Military Standard
MMI	man–machine interface
MVD	median volumetric diameter

NIST	National Institute of Standards and Technology
PCIe	Peripheral Component Interconnect Express
PDI	phase Doppler interferometer
PLA	power lever angle
PLC	programmable logic controller
PSL	Propulsion Systems Laboratory
RAID	redundant array of independent disks
RDE	reprocessing data export
REFPROP	Reference Fluid Thermodynamic and Transport Properties Database
RTD	resistive temperature device
SAE	SAE International (formerly Society of Automotive Engineers)
SEA	Science Engineering Associates, Inc.
STD	standard
TCP/IP	Transmission Control Protocol/Internet Protocol
TWC	total water content
UAV	unmanned aerial vehicle
UDP	User Datagram Protocol
UDS	universal data server
UNF	Unified National Fine thread series
UNJF	Unified National Fine thread series type J
UPS	uninterruptible power supply
USB	universal serial bus
UTR	uniform temperature reference

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