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User Manual for NASA Lewis 10- by 10-Foot Supersonic Wind Tunnel

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Ronald H. Soeder
Lewis Research Center
Cleveland, Ohio

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

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1.0 INTRODUCTION

This report describes the NASA Lewis Research Center's 10- by 10-Foot Supersonic Wind Tunnel (SWT) and provides information for users who wish to conduct experiments in this facility. The facility is located at the NASA Lewis Research Center in Cleveland, Ohio, adjacent to Cleveland Hopkins Airport. The 10- by 10-Foot SWT is managed and operated by the Aeropropulsion Facilities and Experiments Division (AFED). The location of the 10- by 10-Foot SWT within NASA Lewis is shown in figure 1.

The 10- by 10-Foot SWT is NASA's only high-speed (Mach >2.0) propulsion wind tunnel. It is capable of attaining test section flow in the Mach number range 2.0 to 3.5. It can be run in either an aerodynamic cycle (closed loop) or a propulsion cycle (open loop). The full Mach number range can be achieved in either cycle. The cross section at the test section entrance is 10 ft high by 10 ft wide. The test section is 40 ft long.

Inquiries concerning the scheduling of tests and the operation of the 10- by 10-Foot SWT can be made by contacting the facility manager (see appendix A).

2.0 DESCRIPTION OF 10- BY 10-FOOT SWT

2.1 General

The NASA Lewis Research Center's 10- by 10-Foot SWT is always operated on the aerodynamic cycle (closed loop) unless contaminants, such as the products of combustion, or potentially dangerous gases are introduced during testing. When the tunnel is operated on the aerodynamic cycle, valve 6908 (a 24-ft valve) is placed in the closed or A position as shown in figure 2.

On the propulsion cycle the tunnel is operated as an open system with air continuously drawn through the air dryer and exhausted into the atmosphere. Valve 6908 (a 24-ft valve) is placed in the open (or B) position as presented in figure 2. This cycle is used for models that introduce contaminants into the airstream (e.g., engine or model exhaust) and/or when the tunnel air heater is utilized (see ref. 1).

2.2 Tunnel Operating Envelope

Operating envelopes of the tunnel for the aerodynamic and propulsion cycles are presented in figures 3 and 4, respectively. These figures show test section altitude, dynamic pressure, Reynolds number, total pressure, and total temperature as a function of Mach number over the tunnel operating range. Two curves are presented for total temperature envelope in figure 4: flight total temperature variation in the tropopause and tunnel minimum temperature variation (heat of compression input). The increase in tunnel minimum temperature at Mach 2.5 is the result of adding compressor 2. Compressor 1 is in operation at all speeds. If Mach numbers greater than 2.5 are desired, compressor 2 is started at Mach 2.5 and utilized for all higher speeds. The difference between the flight curve and the tunnel minimum temperature curve is the temperature rise required of the air heater in order to simulate flight. The air heater was designed to equal or exceed this required temperature rise up to a maximum of 1140 °R. This maximum temperature is limited by the thermal expansion rate of the tunnel structure. At the maximum temperature the hot run time is about 5 min before the heater must be shut down to allow the tunnel walls to cool. See reference 1 for details of how the vitiated air heater affects the test section flow field.

Recent test section calibration experiments conducted in the tunnel from September to October 1991 suggest that research tests should be conducted when the dewpoint temperature is −15 to −20 °F. Although this dewpoint range is considerably above the static temperature that exists in the tunnel during supersonic operation (the test section Mach number range is 2.0 to 3.5), the amount of water in the air does not result in a test section fog condition. The calibration results indicated that, when the dewpoint temperature increased, the Mach number in general decreased continuously and that at a dewpoint of 10 °F the test section Mach number had decreased 0.05 Mach from the calibrated value.

2.3 Test Section Description

The test section plan view, cross section, and elevation views are shown in figures 5, 6, and 7, respectively. The upstream cross section at the end of the flexible-wall nozzle is 10 ft wide by 10 ft high. The test section side walls are 1 3/8-in.-thick, type-410 stainless steel and diverge 0° 22′ each to a width of 10.51 ft at the downstream end. This divergence compensates for boundary layer growth. The top and bottom plates are parallel to each other. The location of the test rhombus (region ideally free of the incident and reflected shock waves) is shown in figure 5.

The test section floor can be lowered to the first level by means of screwjacks attached at its corners (see fig. 6) to facilitate model installation. The resulting opening measures 33 ft, 4 1/8 in. long by 10 ft wide. A model dolly is used to move the model onto the floor plate. A 25-ton traveling overhead crane, which is capable of running the length of the building that houses the test section, is available for model installation. The crane has a 5-ton auxiliary.

The test section has removable top and bottom plates (see fig. 5). Plate removal can result in a ceiling and/or floor opening that can vary up to 20 ft long by 3.5 ft wide depending on the selection of insert plates. This opening can be used for installing model supports and auxiliary apparatus. The tunnel insert plates cannot be altered; therefore new inserts are required if it is necessary to attach research apparatus to these plates. Model mountings described in section 3.5 (Model Supports) are installed through these openings.

Personnel access doors (3 ft by 7 ft see fig. 7(a)) are located opposite each other at the downstream end of the test section. The test section can be secured during classified test programs. Arrangements can be made through the 10- by 10-Foot SWT facility manager.

2.4 Tunnel Components

The major components of the NASA Lewis 10- by 10-Foot SWT are illustrated in figure 2.

<u>2.4.1 Test section</u>.—The test section elevation view is presented in figure 7. The test section is constructed of type-410 stainless steel plates that are 1 3/8 in. thick. The test section is 10 ft wide by 10 ft high at the inlet and 10.51 ft wide by 10 ft high at the exit. The test section is 40 ft long. Typical

models and a Mach 5 inlet installation are presented in figures 8 and 9. Previous research projects are described in references 2 to 8.

2.4.2 Second throat.—The two side walls are movable; each side consists of two hinged plates actuated by electrically driven screwjacks. The top and bottom plates are fixed. The second throat is used to conserve power, primarily at high Mach numbers, by reducing the Mach number of the air aft of the test section before the tunnel normal or terminal shock wave.

2.4.3 Cooler 1.—Cooler 1, a finned-tube, water coil type of heat exchanger, is used to cool the air entering compressor 1. It is designed to cool 1880 lbm/sec of air from 650 °F down to 120 °F with a pressure drop of 3 in. of water.

2.4.4 Compressor 1.—Compressor 1 is an eight-stage, axial-flow compressor that is rated at a volumetric airflow rate of 78 000 ft^3/sec at a pressure ratio of 2.8. It is driven by four wound-rotor induction motors having a total power capacity of 150 000 hp. Compressor 1 with the case open is shown in figure 10.

2.4.5 Valves 6906 and 6907.—Valves 6906 and 6907 are 8-ft- and 4-ft-diameter butterfly valves. Valve 6906 is used as a bleed valve for compressor 1 to match compressor flow to tunnel airflow requirements. Valve 6907 is used only for compressor surge protection. (Refer to fig. 2 for all valve locations.)

2.4.6 Valve 6908.—Valve 6908 is a 24-ft-diameter valve that is used to change the tunnel cycle from the aerodynamic cycle (valve in the A position in fig. 2) to the propulsion cycle (valve in the B position in fig. 2).

2.4.7 Exhaust muffler.—The exhaust muffler is used to quiet the discharge of air from the tunnel when it is operated on the propulsion cycle.

2.4.8 Air dryer.—The air dryer removes moisture from atmospheric air prior to its introduction into the tunnel. It contains 1900 tons of type I, grade D, activated alumina in six beds each 3 ft thick. The dryer is designed to pass 1838 lbm/sec of air entering at 85 °F with a dewpoint of 73 °F and leaving with a dewpoint of −40 °F for a 2-hr period. Reactivation of the activated alumina beds requires 4 hr of heating and 4 hr of cooling.

2.4.9 Valve 6900.—Valve 6900 is a 15-ft-diameter butterfly valve that is used to control the airflow from the air dryer building when the tunnel is operated on the propulsion cycle. This valve is closed during the aerodynamic cycle.

2.4.10 Valve 6901.—Valve 6901 is a 4-ft-diameter electric butterfly valve that is open at all times during tunnel operation. This valve is also used as a safety valve in case valve 6909 fails because of hydraulic problems. Valve 6901 is then closed in order to permit pumpdown and tunnel shutdown.

2.4.11 Valve 6909.—Valve 6909 a 4-ft-diameter butterfly valve that is used to control the makeup airflow from the air dryer building when the tunnel is operated in the aerodynamic cycle.

2.4.12 Cooler 2.—Cooler 2, a finned-tube, water coil type of heat exchanger, is used to cool the air entering compressor 2. It is designed to cool 2670 lbm/sec of air from 350 °F down to 120 °F with a pressure drop of 10 in. of water.

2.4.13 Compressor 2.—Compressor 2 is a 10-stage, axial-flow compressor that is rated at a volumetric airflow rate of 22 000 ft^3/sec at a pressure ratio of 2.4. It is driven by three wound-rotor induction motors having a total power capacity of 100 000 hp. Compressor 2 with the case open is shown in figure 11.

2.4.14 Valves 6903 and 6904.—Valves 6903 and 6904 are 6-ft- and 2 1/2-ft-diameter butterfly valves. Valve 6903 is used as a bleed valve for compressor 2 to match the compressor airflow to the tunnel airflow requirements. Valve 6904 is used only for compressor surge protection.

2.4.15 Valve 6905.—Valve 6905 is a 15-ft-diameter butterfly valve that is used to bypass air around compressor 2 for tunnel operation in the Mach 2.0 to 2.5 range when compressor 2 is not required.

2.4.16 Exhauster building.—The exhauster building houses two Cooper-Bessemer piston type of exhausters, giving a total exhauster capacity of 100 000 ft^3/min. The exhausters reduce the air density in the tunnel when it is operated on the aerodynamic cycle.

2.4.17 Valves 6400 and 6401.—Valves 6400 and 6401 are 4-ft- and 20-in.-diameter butterfly valves. These valves (in conjunction with valve 6909) are used to set tunnel altitude by controlling the amount of air that is bled from the tunnel.

2.4.18 Valve 6402.—Valve 6402 is a 20-in.-diameter butterfly valve. This valve is used to route airflow from the tunnel when the exhausters are shut off and the pressure in the upstream bellmouth is greater than 2700 lbf/ft^2 abs.

2.4.19 Air heater.—The air heater system utilizes the combustion of natural gas in the tunnel airstream to raise the air temperature to 1140 °R. Use of this heater is limited to the propulsion cycle and to a time increment of 5 to 10 min at maximum temperature (longer at lower temperature) because of tunnel wall thermal expansion.

2.4.20 Flexible-wall nozzle.—The flexible-wall nozzle produces supersonic flow in the test section (i.e., Mach number varies from 2.0 to 3.5). The nozzle consists of two flexible, type-322 stainless steel side walls 10 ft high, 76 ft long, and 1 3/8 in. thick. The side walls are actuated by hydraulically operated screwjacks. The side walls can be positioned in increments to produce variations of 0.1 Mach in the test section. The top and bottom plates are fixed.

2.5 Control Room

The control room is located on the first floor passageway that connects the 10- by 10-Foot SWT office building with the tunnel shop (see fig. 2). The control room is shown in figure 12. A test section model can be remotely viewed through the use of monitors located in the control room. Each console has the appropriate controls and readouts for the respective operator's use. The tunnel is operated from an interactive color graphics, distributed control system known as the Westinghouse Distributed Processing Family (WDPF); see section 4.0 for details of this system. Controls necessary to set tunnel conditions (e.g., valves, flexible-wall nozzle, and second throat positions) are located on the tunnel operator's console. Model or test article controls used to set model conditions are located on the model operator's console. Drive motors, air dryer, and exhausters are controlled from other buildings.

The control room also contains the NASA Lewis data acquisition system, which is identified as Escort D Plus, and the electronically scanned pressure system (ESP), which is available for model instrumentation. The Escort D Plus system is interactive and can collect, process, and display computed results in real time during a test. Refer to sections 5.1 and 5.2 for more details on these systems.

The control room can be completely secured for classified test programs. The need for security should be discussed with the 10- by 10-Foot SWT facility manager and the AFED project engineer during one of the pretest meetings held at NASA Lewis.

3.0 GENERAL SUPPORT SYSTEMS

Table I presents pertinent information on facility support systems. Sections 3.1 to 3.4 describe these support systems in greater detail.

3.1 Air Systems

3.1.1 High-pressure air.—A storage facility is available with a capacity of 216 000 ft^3 of standard dry air (i.e., 1215 ft^3 at 2600 psig) for use at the tunnel. Two other storage facilities are interconnected with it. These are a system of 135 000 ft^3 of standard dry air (i.e., 766.6 ft^3 at 2600 psig) and a system of 600 000 ft^3 of standard dry air (i.e., 3400 ft^3 at 2600 psig), which are located at the 8- by 6-Foot Supersonic Wind Tunnel and the 9- by 15-Foot Low-Speed Wind Tunnel. These three facilities together provide a total capacity of 951 000 ft^3 of standard dry air for use at the 10- by 10-Foot SWT. They are charged by a compressor having a capacity of 1120 ft^3/min of standard air. Total charging time from atmospheric pressure to 2600 psig is approximately 14 hr for the combined systems. The high-pressure airflow from the three storage facilities can be regulated (i.e., variable run time) for model use. This point can be discussed with the AFED project engineer at one of the pretest meetings.

3.1.2 Service air.—A service air system with a capacity of 2-lbm/sec continuous service at 125 psig is available.

3.1.3 Combustion air.—A heated combustion air system with a capacity of 12 lbm/sec at 450 psig is available. Air temperatures can be varied up to 300 °F.

3.2 Hydraulic System

A hydraulic system is available for actuation or positioning of a model and/or its components. This system consists of three axial-piston, constant-volume pumps, each rated at 25 hp and delivering 27.1 gal/min at 1200 rpm. The hydraulic pressure is determined by the requirements of each particular model to be tested. The maximum pressure that can be obtained by the system is 3000 psig.

3.3 Gaseous Hydrogen System

A system is available to deliver gaseous hydrogen to a burning model at a maximum flow rate of 0.66 lbm/sec, a pressure up to 1200 psig, and ambient temperature. Up to three trailers, each with a capacity of 70 000 standard cubic feet (i.e., 464.6 ft^3 per trailer at 2200 psig), can be simultaneously connected to the system. Dual-flow measuring stations using venturi flowmeters are provided. One station measures the total gaseous hydrogen flow from the trailers. The second station measures the flow in the individual model supply lines. The main supply line (1 1/2 in., schedule-80 stainless steel pipe) is divided into two model supply lines (1 in. and 1/2 in. stainless steel tubing), each having a flow control valve. A regulator in the main supply line controls pressure upstream of the flow control valves. Use of the gaseous hydrogen system is permitted only during tunnel propulsion cycle operation.

A gaseous hydrogen detector system installed throughout the wind tunnel facility consists of eight sensors that are used to check for leaks. These sensors are monitored centrally in the tunnel control room.

A gaseous nitrogen system is used for fuel control, valve actuation, and purging purposes. The gaseous hydrogen piping and model supply lines are purged before and after tunnel test runs. A single gaseous nitrogen trailer supplies the required nitrogen.

3.4 Liquid Fuel System

The liquid fuel system is made of stainless steel and has a total flow capacity of 70 gal/min at 40 psia. The maximum pressure available is 950 psia at a flow of 30 gal/min. Fuel is filtered to 10-μm particle size before delivery to the test section. The liquid fuels that can be used in burning models are: JP (aviation) blends.

3.5 Model Supports

3.5.1 Sting strut and adapters.—The strut for sting-mounted models presented in figure 13(a) is extended through the test section floor when in use. The strut centerline can be located between 13 ft, 11 in. and 23 ft, 5 in. from the floor joint datum line (see fig. 5) in 6-in. increments. The strut has a chord length of 4 ft and a thickness of 8 in.

The strut can be remotely rotated about a pin in the vertical plane located 9.5 in. below the test section floor. The angle of attack can be varied from -5° to 20°. The strut height is also remotely variable to keep the model in the schlieren window for testing at angle of attack. The maximum radius of rotation is 6 ft, 10 in., and the minimum radius is determined by interference of the strut socket with the tunnel floor. The strut angle and height are displayed on the operator's console in the control room.

Electrical cables available at the lower strut interface plate are discussed in section 3.8.1. Pressure tubing is used to connect model pressure leads to the ESP modules located beneath the test section.

Allowable sting-strut loads are indicated in figure 13(a). Details of the sting end that mates with the strut are shown in figure 13(b). The sting end must be made in strict accordance with the dimensions shown.

An adapter, presented in figure 14, is available to permit the use of stings designed for the NASA Lewis 8- by 6-Foot Supersonic Wind Tunnel. In addition NASA Langley stings can be retrofitted to NASA Lewis struts by using the special adapter presented in figure 15.

3.5.2 Ceiling strut assembly.—A ceiling strut assembly with a typical model installed is presented in figure 16. The strut details will vary with each model, but the operating mechanism will be the same and will be furnished by NASA Lewis. All struts must be designed to fit this operating mechanism. Any details not included will be furnished by the AFED project engineer.

Strut thickness, which can vary from 3 to 10 in., is limited by the travel of the bearing pads that support the strut in its housing. The maximum chord length of the strut is 7 ft. However, in special cases longer chord struts may be used, but these require special insert plates at one or both ends of the strut housing.

The angle of attack of the model is controlled by a screwjack mechanism that rotates the strut around a 3-in.-diameter pin located 7 in. above the inside surface of the tunnel top plate. The screwjack can be mounted on either end of the strut housing, depending on clearances to the tunnel structure. The angle of attack (pitch plane) can be adjusted through a total range of 20° (i.e., if the screwjack mechanism is arranged to give a maximum negative angle of attack of −5°, the maximum positive angle of attack will be 15°). Other combinations of positive and negative angles of attack that total 20° are available. It must be possible to adjust the model to 0° angle of attack in order to minimize starting loads.

Electrical wiring from the strut is connected to terminal panels on top of the test section (see section 3.8.2). Pressure tubing is used to connect model pressure leads to the ESP modules located on top of the section.

<u>3.5.3 Rotating sting adapter</u>.—The rotating sting adapter assembly is attached to the fixed rear sting adapter (see fig. 17). The front adapter sleeve assembly can be manually rotated 90° with respect to the fixed rear sting adapter to provide yaw plane test capability. If any additional model rotations are needed, the requirements should be discussed with the AFED project engineer, since tunnel-user-supplied equipment may be needed.

The front end of the rotating sting adapter that mates with the tunnel user's equipment is available in four different diameters (3.38, 4.51, 5.63, and 8.01 in.). The AFED project engineer can provide detailed drawings of the rotating sting adapter to the tunnel user.

3.6 Schlieren System

The tunnel is equipped with two identical schlieren systems that can be used independently or simultaneously. These systems are located at the upstream and intermediate sets of test section windows and are capable of showing flow patterns in the test section. The plan and elevation views of the schlieren system are shown in figures 18 and 19. The test section windows are mounted eccentrically in 5-ft-diameter disks. These disks can be rotated to position the windows on a 10.5-in. radius (see fig. 7(a)). A third pair of windows located downstream of the intermediate windows are used as model observation ports. When the air heater is used to elevate test section temperature (maximum of 1140 °R), a pair of 18-in.-diameter fused silica windows are used in one of the two schlieren systems.

A shuttle model as viewed through a 10- by 10-Foot SWT test section schlieren window is shown in figure 20. A shuttle model tail section that was photographed using the schlieren system shows visible Mach cones in figure 21.

Schlieren images are viewed on facility monitors. Video cassette recorders are used to record these images on tape to permit analysis at a later date. Photographs of the schlieren images are taken by a 35-mm camera. In addition a Fastex 16-mm, high-speed motion picture camera capable of taking 100 to 4000 frames per second is available for photographing the schlieren images. Color schlieren images (a light beam is focused on a color slide) are standard; however, black-and-white schlieren images using conventional knife edges can be produced. If necessary, this topic can be discussed at one of the pretest meetings.

3.7 Electrical Power

At the shop model stands or at the tunnel test section, the following types of electrical power are available:

(1) 440 V, 60 Hz, three phase, a.c.
(2) 208 V, 60 Hz, three phase, a.c.
(3) 120 V, 60 Hz, one phase, a.c.
(4) 28 V, d.c.

3.8 Electrical Cabling

3.8.1 Lower strut interface plate.—The lower strut contains an interface plate that is located at an elevation just below the sting level. This plate contains high-density bulkhead connectors with the following cables attached:

Control	8 six-conductor #16 American Wire Gauge (AWG)
Transducers	30 eight-conductor, shielded #24 AWG
Miscellaneous signal	36 four-conductor, shielded #24 AWG
Coaxial	14 RG 174/U
Thermocouples:	
Chromel/Alumel, type K	24 alloy pairs, shielded
Iron/constantan, type J	12 alloy pairs, shielded
Copper/constantan, type T	12 alloy pairs, shielded

The other ends of the cables can be terminated on the lower strut terminal panels in the tunnel basement. These terminal panels and associated cabling provide the interfacing between testing area and control room. Additional cabling bypassing the interface plate can be used, if needed.

Total numbers of cables available on the lower strut terminal panels are

Power	3 six-conductor #10 AWG
Control	20 six-conductor #14 AWG
Transducers	100 eight-conductor, shielded #22 AWG
Miscellaneous signal	48 four-conductor, shielded #22 AWG
Coaxial	24 RG 58C/U
Thermocouples:	
Chromel/Alumel, type K	48 alloy pairs, shielded
Iron/constantan, type J	24 alloy pairs, shielded
Copper/constantan, type T	24 alloy pairs, shielded

3.8.2 Upper strut terminal panel.—There is no internal interface plate in the upper strut. The following cables are available at the upper strut terminal panels above the test section:

Power	3 six-conductor #10 AWG
Control	20 six-conductor #14 AWG
Transducers	100 eight-conductor, shielded #22 AWG
Miscellaneous signal	96 four-conductor, shielded #22 AWG
Coaxial	24 RG 58C/U

Thermocouples:

Chromel/Alumel, type K	48 alloy pairs, shielded
Iron/constantan, type J	24 alloy pairs, shielded
Copper/constantan, type T	24 alloy pairs, shielded
Platinum/rhodium, type R	24 alloy pairs, shielded

Information on connector types, pin assignments, and other details can be obtained from the AFED project engineer and the facility electrical engineer at one of the pretest meetings.

3.9 10- by 10-Foot SWT Shop

3.9.1 Model stands.—Six model stands are located in the shop area, four are used for sting-mounted models and two are used for strut-mounted models. Sketches of the two types of stands are shown in figures 22 and 23. The models are installed in their respective shop stands exactly as they will be installed in the tunnel. In order to minimize tunnel occupancy time, these stands are used to check out all model instrumentation and controls prior to tunnel installation.

The model is mounted exactly as it will be in the tunnel, using the same sting, in the sting-mounted model stand. The sting is fastened at the rear of the stand and the model overhangs the front of the stand. The model centerline is located 48 or 60 in. above the stand bedplate depending on whether a spacer is used. A model checkout cart (discussed in section 5.4) is provided to allow a complete operational checkout and calibration of all model instrumentation and controls prior to tunnel entry.

In the suspended-strut model stand the model is suspended exactly as it will be in the tunnel on the same strut. All lines to and from the model (e.g., instrumentation, electrical, and hydraulic) are routed exactly as they will be in the tunnel. The models can be suspended at a convenient working height. A model checkout cart is also used to check out and calibrate all instrumentation on suspended strut models.

Air, vacuum, hydraulic, and electrical services are available to two sting-mounted and two suspended-strut model stands. The AFED project engineer will inform the tunnel user which stands have these capabilities. Service air at 125 psig and process vacuum are available at these four stands. A 3000-psig hydraulic system and a 2200-psig nitrogen system that are used for hydraulic accumulators are also available. Electrical services provided at the shop stands are noted in section 3.7.

3.9.2 Shop equipment.—The wind tunnel shop contains an overhead 20-ton crane and numerous machine tools including two engine lathes (one 14-in. model and one 12-in. model), six drill presses, and one 2-hp vertical milling machine. Metal cutting machines include one 36-in. bandsaw, one 4-ft electric sheet-metal shear, two cutoff saws, and one turret punch. Also available are one 5-ft and one 2-ft metal brake, several hydraulic arbor presses, numerous pedestal grinders, and one 2-in.-diameter-tube bender.

Standard gas, electric, and tungsten inert gas welding equipment and a welding booth are available. Several towmotors and pallet carts may also be used. All other tools and equipment that may be required and have not been discussed should be supplied by the user.

3.9.3 Shop enclosures.—Two secured enclosures for classified model buildup are provided in the shop area. One enclosure is 20 ft, 5 in. wide by 28 ft, 5 in. long by 10 ft high and is used to work on classified sting-mounted models. The second enclosure is 19 ft, 8 in. wide by 34 ft, 4 in. long by 14 ft, 6 in. high. This enclosure is used to work on classified ceiling-suspended models. The electrical services that are available at these shop stand enclosures are noted in section 3.7. The shop air available at both enclosues is 125 psig. A data reduction analysis building also exists. The enclosure is 12 ft, 6 in. wide by 16 ft long by 8 ft high. This building is equipped with tables, chairs, desks, and telephones and is used by contractor personnel to review tunnel test data and communicate with their respective companies.

4.0 INSTRUMENTATION

Model and tunnel instrumentation may consist of pressure modules, individual pressure transducers, thermocouples, attitude indicators, strain gauges, and potentiometers. Measurements by this instrumentation can be monitored and recorded by the facility data acquisition system (Escort D Plus, see section 5.2) or by a user-supplied data acquisition system.

The output of facility instrumentation used to operate the tunnel is normally displayed on the Westinghouse Distributed Processing Family (WDPF) system graphics. The WDPF system is a distributed control and data acquisition system with the capability to execute high-speed control algorithms. The WDPF control system is interfaced to numerous facility subsystems (e.g., main and secondary drive controls, air dryer, flexible wall, second throat, tunnel heater, high-pressure air system, and 450-psig air system). In addition the WDPF system can also perform data acquisition functions, such as data scanning and processing, alarm monitoring and reporting, data collection, data storage, data retrieval, and numerical calculations. The facility data are primarily monitored by the tunnel operator. Hard copies of the WDPF displays are available to the tunnel user if requested. Most of the facility instrumentation output is duplicated on the Escort D Plus data acquisition system. Hard copies of the Escort D Plus cathode ray tube (CRT) displays can be obtained in the control room. An additional 200 analog channels are reserved on the Escort D Plus system for tunnel-user-defined model instrumentation.

4.1 Thermocouples

All model thermocouples should be made of high-temperature, heavy-gauge thermocouple wire. Leads extending from the model should be long enough to reach the appropriate sting strut or ceiling strut terminal panel. Detailed information on the length of the thermocouple leads will be supplied to the user by the AFED project engineer and the facility electrical engineer at one of the pretest meetings. Alloy wiring is used from connectors on the lower strut interface plate and the upper strut terminal panels to thermocouple junction reference units. The temperature of the wire junctions within these reference units is held to 150 °F $\pm$ 0.25 °F. Cables are run from the reference units to a patchboard in the data room near the tunnel control room.

The type and number of thermocouple circuits available at the lower strut interface plate is presented in section 3.8.1, and the type of thermocouple circuits available at the upper strut terminal panel is presented in section 3.8.2.

4.2 Angle-of-Attack Indicator

A model angle-of-attack indicator system is available to determine true model attitude. This makes it possible to correct for sting and balance system deflections. The system consists of an angle-of-attack transducer (see fig. 24) installed in the model and a signal conditioner in the control room. The angle-of-attack range is $-15°$ to $15°$ with an overall system accuracy of $\pm 0.1°$. The wiring provided in the model for the transducer should be four-conductor, shielded, high-temperature #22 or #24 AWG wire. This indicator will be installed and calibrated at NASA Lewis. A mockup unit is available for fit checks and shop assembly of the model.

4.3 Actuators and Position Indicators

Screwjacks and hydraulic cylinders are commonly used to remotely position wind tunnel model components. Electrically driven screwjacks should be provided by the tunnel user with limit switches to protect the model and the mechanism from damage due to overtravel. Hydraulic cylinders should be sized so that their travel cannot exceed safe limits, and they should be cushioned if they are to move rapidly. The hydraulic system capacity is noted in section 3.2. Remote position indication is often provided by a linear or rotary potentiometer. All actuators and position transducers must be capable of withstanding tunnel test section operating conditions.

4.4 Force Balances

Provisions can be made to record model force data. All balances and/or load cells must be supplied by the user. The data can be recorded on either a user-supplied data system or the facility data system. This point can be discussed with the AFED project engineer at one of the pretest meetings.

5.0 DATA ACQUISITION AND PROCESSING

5.1 Electronically Scanned Pressure System

The 10- by 10-Foot SWT electronically scanned pressure (ESP) system provides high-accuracy measurement of steady-state model and facility pressures at a high acquisition rate. The system utilizes plug-in modules, each containing 32 individual transducers that are addressed and scanned at a rate of 10 000 ports per second. Up to 32 modules with transducer ranges from ± 2.5 psi to 500 psi may be used to provide a total of 1024 pressure channels. Reference and check pressures are obtained from remotely controlled regulators.

An on-line calibration of all transducers is normally performed automatically every 20 min by the operation of a pneumatic valve in each module that switches the system into a calibrate mode. Three calibration pressures, which are measured with precision digital quartz transducers, may be applied in up to six ranges to ensure overall system errors not greater than ± 0.1 percent of full scale.

5.2 Escort D Plus System

The NASA Lewis Escort D Plus system (described in ref. 9), which is supported by the NASA Lewis Computer Services Division, is a minicomputer-based, real-time, data acquisition, display, and recording system that is generally applicable to steady-state tests. Analog data from the experiments are digitized and then acquired by a MICROVAX 3800 computer located in the 10- by 10-Foot SWT data room, which is next to the control room. Recorded data are transmitted through a network link (for unclassified projects) to a mainframe computer in the Research Analysis Center (RAC) for later batch processing if desired. Data from classified projects are stored on removable disks associated with the MICROVAX 3800. Batch processing of classified data is performed on the MICROVAX 3800 as test runs are completed. In addition, classified data may be transferred to tape for later processing on other secured computer systems. Real-time processing tasks include acquiring data, converting raw counts to engineering units, performing on-line calculations, updating facility display devices (both alphanumeric and graphical), and transmitting data for archival recording on a data collector. A schematic that shows the flow of information between the facility computer and the RAC computers is presented in figure 25 (see ref. 9 for additional information). A detailed block diagram of the facility computer is given in figure 26 (see ref. 9). Update time for a standard program is 1 sec. Data can be acquired and processed by using standard data software modules along with software specifically designed and programmed for a particular test.

5.2.1 Real-time displays.—A customized Escort D Plus output program displays in alphanumeric format all data channels and computations that are selected for a given test program. This output can be displayed on a variety of control-room CRT's. CRT displays are described in detail in appendix B. Six control room alphanumeric color CRT's are supported on the system (the system can support eight CRT's) and provide a means of monitoring test progress and displaying data sets. Two CRT's are dedicated to the tunnel and model operators. Three CRT's are available to the research engineer and/or tunnel users. Two high-resolution graphics terminals are also available. Each CRT can view any display page at any time. A 160-character-per-second line printer is provided to produce a hard copy of the data being displayed on the CRT.

On-line plots can be defined through a graphics specification language. The initial graphics specification is done by the Escort programmer, but changes can be made at the facility through an interactive editor. Plot pages and alphanumeric pages displayed on the CRT's are changed by entering their page numbers on a number entry panel.

Individual data displays (IDD's) are provided to highlight specific test parameters that are defined by the user during a run. Each IDD is individually addressable and has two 20-alphanumeric-character lines. The characters are 0.375 in. high. Cursor addressing allows data labels to be fixed and the data to be updated every second.

Special function buttons are provided with each CRT to allow the user to control display functions, such as subsets of test parameters, data in different units (i.e., engineering units, millivolts, or counts), and printing of the data being displayed on the CRT.

The tunnel user should have any request for customized output program displays available for review at least 8 weeks before the start of the program.

5.2.2 Data collection.—When a customized data software module is installed on the Escort D Plus system and the data record button is activated, all data channels are scanned once, saved on the data collector, and assigned a unique reading number. Real-time data processing is available when requests include the calculation of ratios or simple engineering parameters. Extremely rigorous computing or across-scan computing should be performed off-line by using the Center's central mainframe computers to obtain the desired output; this is to ensure a 1-sec update rate. The user can press the data record button as often as required to collect a new data sample.

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

5.3 Dynamic Data Acquisition

5.3.1 Facility tape recorders.—Dynamic data can be recorded at the facility on two 14-track instrumentation tape recorders that are available in the control room. Data recorded on tape can be converted to digital tape at a later date by using the analog frequency-modulated (FM) demultiplexer equipment in the Research Analysis Center (RAC). This procedure can be discussed with the AFED project engineer at one of the pretest meetings.

5.3.2 Central analog system.—The NASA Lewis central analog FM multiplex system can record up to 180 channels of dynamic data from the 10- by 10-Foot SWT by using trunk lines that extend from the facility to the RAC. Each data channel has an 8-kHz analog bandwidth. The central analog FM multiplex system can simultaneously record and play back 45 channels of analog data. Because only 45 channels of data can be digitized at any one time, the usual procedure when using all 180 channels requires multiple passes of the analog tape through the analog FM demultiplexer equipment to convert the data from analog to digital signals. A digital merge program is used to merge all digital information into a matrix and onto one tape before final processing occurs.

5.3.3 TRADAR–3.—The Transient Data Acquisition and Reduction System (TRADAR–3), which is located in the RAC, permits the recording of dynamic data during unclassified experiments and the postprocessing of these data at a later date by using various digital signal processing and data analysis software. The main component of the system is a Concurrent Computer Corp./Masscomp 6700 host computer with data acquisition and front-end signal conditioning hardware (see fig. 27). TRADAR–3 can also be used in conjunction with the central analog FM multiplex system.

TRADAR–3 receives input from 180 shielded analog lines that run between the 10- by 10-Foot SWT and the RAC. Electrical engineers at the facility can connect outputs from accelerometers, pressure transducers, etc., to these lines and send the signals to TRADAR–3. In addition to the 180 analog lines that are fed into TRADAR–3, it also receives 45 lines of input from the central analog playback equipment (see fig. 27). Data recorded by the central analog FM multiplex system and by other analog FM or direct instrumentation tape recorders can be played back and digitized by TRADAR–3. Aggregate digitizing rates of over 600 000 samples per second are attainable with this system. Tunnel users can discuss the utility of the system with the AFED project engineer, the facility electrical engineer, and the RAC engineers at one of the pretest meetings.

5.3.4 Transient data acquisition system.—A transient data acquisition and reduction system is located in the facility control room. This system permits the recording of dynamic data on a digital computer during classified or unclassified experiments. The main component of the system is a Concurrent Computer Corp. 7500 host computer with data acquisition and front-end signal conditioning hardware. This system can receive inputs from 96 shielded analog lines that run from the model or various points in the facility to the transient data acquisition system. The outputs of measuring devices, such as high-response pressure transducers, high-response thermocouples, strain gauges, accelerometers, and vibration and speed pickups, can be sent through these shielded analog lines to the data acquisition system. Data recorded during an experiment are stored on disk and can be either processed at the facility or postprocessed at the RAC at a later date. Sampling rates of 2 MHz/sec (aggregate divisible by the number of channels) will be stored on 1.5 gigabytes of disk storage.

5.4 Model Checkout Cart

The cart is a mobile instrumentation, control, and data system that is used to set up and check out the model before it is installed in the test section. It interfaces to the model through an interconnect rack (which also includes a thermocouple oven) and is similar to the panels at the test section. The cart (fig. 28) comprises four distinct parts: instrumentation signal conditioning, model controls, an ESP pressure measurement system, and an Escort D data system. These systems are tied into a patchboard for configuration purposes. The signal conditioning and model controls can be configured for the specific model requirements. The ESP system has 256 channels and incorporates pneumatic quick-disconnects to check out up to 1024 pressures. The Escort D data system has 128 analog input channels to monitor signals during checkout. The cart is moved adjacent to the sting-mounted or strut-mounted model stand located in the 10- by 10-Foot SWT shop. The AFED project engineer and the facility electrical engineer can discuss the details of cart use with the tunnel user.

6.0 PRETEST REQUIREMENTS

The 10- by 10-Foot SWT is scheduled for continuous testing throughout the year. It is advisable to contact the facility manager (see appendix A) and submit the overall test requirements at least 1 year in advance of the desired tunnel test time. Early notification will allow the facility manager and the appropriate AFED personnel to review the proposed test requirements and to evaluate the feasibility of conducting the test during the desired tunnel test time. A formal request for tunnel use should be sent to the director of aeronautics at NASA Lewis (for non-NASA requestors only). Pertinent information regarding the formal letter of request can be obtained from the facility manager.

Upon receipt of a formal request for tunnel test time, the director of aeronautics will review the project with the facility manager. If the project is accepted, a test agreement will be prepared and sent to the requestor for signature (for non-NASA requestors only). The test agreement outlines the legal responsibilities of NASA Lewis and the tunnel users during the time the project is at the Center (model arrival, test time, model return, etc.). The tunnel user is requested to sign the test agreement and return it to NASA Lewis.

The four types of test agreements are as follows:

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

The tunnel user is also requested to prepare a requirements document and make it available to the facility manager and the AFED project engineer at the first pretest meeting held at NASA Lewis. The facility manager will inform the tunnel user as to the topics that should be addressed in this document. The procedure for obtaining tunnel test time is outlined in appendix C.

6.1 Pretest Meetings

A series of pretest meetings will be held at NASA Lewis to discuss the test plan, the instrumentation, the tunnel hardware, and the data requirements. The number of pretest meetings held at Lewis will usually be a function of test complexity. The attendees will be the requestor (e.g., the lead engineer plus key tunnel user personnel), the facility manager, appropriate AFED branch chiefs, key AFED personnel, and the AFED project engineer.

6.1.1 Test objectives.—The tunnel user should provide a statement indicating the test objectives and goals and thoroughly explaining any special test procedures. The tunnel user's lead engineer should also provide a prioritized run schedule that is compatible with the available test window.

6.1.2 Instrumentation.—The tunnel user should provide a list of requested instrumentation to the AFED project engineer. Tunnel user instrumentation shall be adapted to the 10- by 10-Foot SWT data system (see sections 4.0 and 5.0). Use of a tunnel user's data system should be discussed with the AFED project engineer and the facility electrical engineer at one of the pretest meetings.

6.1.3 Hardware.—The tunnel user is required to provide drawings of the model installation in the test section. The AFED project engineer will provide detailed drawings of ceiling-mounted struts or floor-mounted sting-strut assemblies to assist the tunnel user.

6.1.4 Data acquisition and reduction.—Data reduction information consisting of data inputs, data outputs, and equations in engineering language must be provided for cases where NASA Lewis performs data reduction activities for the tunnel user. The user should provide this information to the AFED project engineer 16 weeks before the start of testing. The AFED project engineer will contact the appropriate personnel in the RAC and set up any necessary meetings between tunnel users and RAC engineers to establish ground rules for a computing requirements package writeup. The computing instructions writeup from the tunnel user to the RAC engineers is due 8 weeks before the start of testing.

The tunnel user may choose to bring a self-contained computer system for data processing. This point can be discussed with the AFED project engineer and the facility electrical engineer at one of the pretest meetings.

6.2 Deliverables

The tunnel user should provide the following information to the AFED project engineer 8 weeks before the scheduled test:

(1) Test envelope for the model
(2) Loading on the model as related to Mach number, dynamic pressure, and model attitude
(3) Stress analysis based on maximum loads that are anticipated on all sections of the model, per criteria in section 7.2.4
(4) Detailed drawings of the cross-sectional area distribution of the model to allow blockage and airload calculations
(5) Drawings that show model installation and model support systems
(6) All calibration information that is to be supplied by the tunnel user
(7) A list of all tunnel-user-supplied equipment plus block diagrams and wiring schematics

When the tunnel user and NASA Lewis agree that the data are mutually beneficial, the tunnel user may be asked to supply selected model drawings and/or photographs for reproduction in NASA technical papers.

6.3 Model and Equipment Delivery

All models, instrumentation, and support hardware should be sent to NASA Lewis and to the attention of the AFED project engineer (the facility manager will supply the name and address of this engineer to the tunnel user). All model parts, model internal instrumentation, and tunnel user support hardware should be assembled before shipment to NASA Lewis in order to reduce installation delays. Large shipping crates must have skids so that they can be handled by forklift trucks. The delivery date of equipment and/or models before testing will vary according to the model's complexity. The tunnel user and the AFED project engineer should agree on an appropriate delivery time.

7.0 TEST ASSESSMENT OF WIND TUNNEL MODEL AND TEST HARDWARE

The following sections discuss permissible model blockage in the tunnel test section, model design criteria pertaining to loads and allowable stresses, and model fabrication and quality assurance requirements.

7.1 Model Size

The maximum projected frontal area (model plus support strut) for tunnel starting is presented in figure 29. Because the limiting model size is influenced by such factors as model shape and location in the test section, each model proposal must be evaluated independently.

7.2 Model Design Criteria

Tunnel test models should be designed for the following applicable load and stress conditions.

7.2.1 Steady-state loads and allowable stresses.—The model design steady-state loads and stresses must be established and submitted to the AFED project engineer 8 weeks before the scheduled test.

Allowable stresses for the maximum loading condition are limited to the smaller of one-fifth of the ultimate stress or one-third of the yield stress of the material at test conditions. The maximum shear theory of failure (i.e., elastic failure is defined to occur when the maximum shear stress equals one-half of the yield stress or elastic limit) will be used when allowable levels for combined stresses are calculated. In cases where the shear stress of the material is not known, the maximum allowable shear stresses shall be taken as one-sixth of the tensile yield stress of the material. Thermal stresses that may occur on the model should be subtracted from the ultimate stress and the tensile yield stress before factors for allowable stresses are applied. The material properties that are used in the calculations should be the expected minimum values. The allowable stress in the model support columns as well as in the shroud coverings for the model should not exceed one-third of the Euler critical buckling stress.

These model safety factors can be reduced provided that model calculations and material allowable stresses are based on the rules stated in the latest edition of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 and/or Division 2 Manuals.

7.2.2 Supersonic starting loads.—The following conditions should be included when establishing the loading that the model must withstand. An additional 10° flow angle should be added to the desired model angle of attack when establishing the model design loads. The dynamic pressure used should be the maximum tunnel dynamic pressure as given in figure 3 or figure 4. When using this criterion the allowable stresses should not exceed one-half of the yield stress. All auxiliary parts of the model exposed to the airstream and nominally at a 0° angle of attack should be evaluated at 10° angle of attack for steady-state and starting loads. This technique for considering starting loads is given as a general guide. Therefore models unusual in size, shape, or operation require special analysis.

7.2.3 Model stress analysis.—The tunnel user must submit a stress analysis to the AFED project engineer 8 weeks before the start of testing. The stress analysis should include

(1) Dynamic factors that may result from flow separation
(2) Thermal stresses on the model
(3) Stress concentration factors
(4) Wind tunnel steady-state and starting loads
(5) Design factors for both types of loading

The previous calculations should show that allowable stresses are not exceeded for the worst load case.

The tunnel user should prepare a sketch for each section of the model that is analyzed showing the forces and moments acting on that section. The analysis of each section should list approximations, assumptions, model section properties, and the heat-treatment condition of the material. All general equations should be listed before numerical values are substituted. Shear and moment diagrams should be given for a worst-case distribution. A sufficient number of model sections should be analyzed to determine allowable shear, axial load, bending, and torsion in order to facilitate a check on the location of the critical model section.

The stress analysis report should show that the model, the mounting points, and the restraints are statically and dynamically stable within the model test envelope. The effects of Reynolds number, Mach number, surface conditions, etc., in the development of the equations noted in the analysis should be discussed. The range of mass and inertia parameters plus stiffness coefficients used in the analysis should be noted.

7.2.4 Material selection.—Materials for the model and the support structures are to be selected by using the mechanical or electrical properties described in one of the following standards:

(1) American Society for Testing Materials (ASTM)
(2) American National Standards Institute (ANSI)
(3) American Institute for Steel Construction (AISC)
(4) American Welding Society (AWS)
(5) American Society of Mechanical Engineers (ASME)
(6) National Electrical Code (NEC)
(7) Society of Automotive Engineers (SAE)
(8) National Bureau of Standards (NBS)
(9) Aerospace Structural Metals Handbook
(10) Military Handbook #5

All material properties should be suitably corrected for temperature.

7.2.5 Structural joints.—All counterbores, spotfaces, and countersinks in the model and other support structures must be properly aligned so that no bending is applied to the fasteners by torquing.

The minimum safety factor for bolted joints that clamp a model, sting, model auxiliary structure, or model equipment shall be 4.0 (based on yield stress) and 5.0 (based on ultimate stress) for heat-treated hardened bolts. The safety factors are based on bolt cross-sectional area and not on the tightened or proof load (i.e., the maximum load that can be applied to a bolt without obtaining a permanent set or permanent stretch).

The cross-sectional area of the bolts is determined by first calculating the flange or joint load for the model or the model support system mating parts (1) for a predetermined hydrostatic, or most severe, test condition and (2) at a room-temperature bolting-up condition. The flange or joint load is then divided by the allowable stress (obtained from bolt strength-of-material tables) at the temperature condition determined from step 1 or 2. The term "allowable stress" is defined as the smaller value of either the yield stress or the ultimate stress divided by the appropriate safety factor. If the allowable stress is used from tables such as those found in the Pressure Vessel Code, the appropriate safety factor is being used in the calculations and further safety factors do not need to be added. Before the yield or ultimate stress values are used, they must be divided by the appropriate safety factor to obtain the allowable stress value. The division of the flange or joint load by the allowable stress defines the total cross-sectional area for the bolts. This calculation does not define the tightness or tension required on the bolts.

Current engineering practice requires tightening bolts from 75 to 90 percent of proof load. The individual bolts will have a safety factor of 1.25 to 1.50 (based on ultimate stress divided by the proof stress of the material), but the flange or joint will have a much higher safety factor based on the required area. Then the bolt load will only increase an incremental amount with a large external load when the bolt is properly pretensioned. An example for a nongasketed flat-face joint is, if the bolts have a high preload of 90 percent of proof load and then an external load of up to 100 percent of the preload is applied to the bolts, the bolt tension will only increase by a small amount, approximately 10 percent. (The initial joint compressive stress is nearly canceled by external tensile stress; see ref. 10.) The exact amount depends on the relative stiffness between the flange or joint and the bolts and on the compression area.

The bolt flange or joint is designed for a safety factor of 3.0 to 5.0 (based on the yield or ultimate stress as the controlling factor). On the basis of these safety factors the actual bolt stresses will be 1/3 to 1/5 of the allowable stresses. Because bolt stresses and loads are proportional, the bolt loads will vary from 33 to 20 percent of the allowable loads while the bolt preload is 90 percent of the proof load. Therefore, if the bolt does not fail during tightening, it will not likely fail under static loading conditions; the cyclic, tensile, and thermal loads would still have to be considered.

Shear loads should be transmitted through the use of keys and pins. Provision should be made that the pins and keys are properly retained.

Welded joints should be designed in accordance with the code of the American Welding Society. All critical joints whose failure would result in the loss of the model or model components or in damage to the facility must be x rayed.

7.2.6 Pressure systems.—Models and support and test equipment that use hydraulic, pneumatic, or other systems with operating pressures above 15 psig shall be designed, fabricated, inspected, tested, and installed in accordance with the ASME Boiler Pressure Vessel Code (section VIII), the ASA codes of the ASME, and/or Department of Transportation (DOT) regulations. Pressure vessels are defined as all shells, chambers, tanks, or components that are used in the transmission of a gas where 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 but not necessarily in the model. These devices should be capable of relieving the overpressure by discharging sufficient flow from the pressure source under the conditions causing the malfunctions.

The following information on all components of a pressure system should be available to the facility manager and the AFED project engineer: volume capacity, temperature range, working pressure, and proof test pressure. It is suggested that all components of a pressure system be stored in a clean, dry, and sealed condition after proof testing and before delivery to the 10- by 10-Foot SWT.

7.2.7 Pressure piping.—All piping shall be designed, fabricated, inspected, tested, and installed in compliance with the latest edition of the ANSI/ASME Standard Piping Code. Powered models have internal piping that falls under this code. Pressure vessels that are constructed from standard pipe fittings and standard flanges are also considered pressure piping and use the ANSI/ASME Standard Piping Code.

The welding of pressure piping shall follow the procedure outlined in section IX of the ASME Boiler and Pressure Vessel Code plus the ANSI Standard Piping Code.

All service lines into and out of the model should be properly identified as to the working pressures, the flow direction, and the fluid or gas being carried.

7.2.8 Electrical equipment components.—In the facility test section only qualified hardware, equipment, and material conforming to the National Electrical Code should be used. All pressure transducers, strain gauges, vibration pickups, and other low-voltage devices should use shielded cable. Details regarding user-supplied control panels plus the associated wiring to the facility control room and electrical wiring diagrams and connectors at interfaces located at control boxes and/or at the model should be discussed with the AFED project engineer and the facility electrical engineer at one of the pretest meetings.

7.3 Model Fabrication Requirements

Models should be completely assembled at the manufacturer's plant. All model parts are to be inspected to ensure proper fit and certified for the required loads and deflections during testing. All remotely controlled model functions should be checked out, and position indicators should be calibrated before the model is shipped to NASA Lewis. If it is not possible to assemble the model at the user's facility owing to a shipping constraint, the sting-mounted or ceiling-mounted buildup stands (see section 3.9.1) can be used for model assembly. After the model is installed in the tunnel test section at NASA Lewis, a final end-to-end check of all instrumentation and a final calibration of all remotely controlled model functions will be made.

All electrical leads and pneumatic lines from the model should be clearly identified. In addition the pneumatic lines should be cleaned and free of oil and debris and leak checked at operating pressures. End-to-end checks are required for both the model electrical and pneumatic systems.

7.4 Quality Assurance Requirements

Procedures are required for model assembly, installation, and configuration changes in the 10- by 10-Foot SWT test section. These procedures should be submitted to the AFED project engineer at least 8 weeks before tunnel entry. These procedures should include the sequential steps that are to be taken to install the model in the tunnel test section. Bolt torquing values for fastening the model to the sting and other support structures should be given. The assembly, installation, and checkout of user-supplied hardware should also be addressed. The model installation procedures should be supplemented with the necessary drawings and/or sketches.

8.0 GENERAL INFORMATION

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

8.1 Support

8.1.1 Model buildup.—Most models tested in the 10- by 10-Foot SWT are complex, and therefore model buildup time in the shop plus tunnel test section installation time varies greatly. It is suggested that the tunnel user discuss with the facility manager the appropriate arrival time for the model and any other user-supplied auxiliary equipment.

8.1.2 User responsibility.—If the model installation is complex, it is advantageous to have the tunnel user supply mechanics to assist with that installation. All tools, spare parts, special equipment, and supplies necessary to perform work on the model are to be supplied by the tunnel users. A test engineer familiar with the model and the test objectives should be available on site during the test.

8.1.3 Operation of Government equipment.—Tunnel user personnel should not operate Government-furnished equipment or make connections to this equipment without the approval of NASA Lewis personnel.

8.1.4 Tunnel safety.—All personnel entering the tunnel for an extended period of time to examine the model or the auxiliary equipment in the tunnel test section should be accompanied by NASA Lewis personnel. Care should be exercised to avert injury from sharp edges on the model or from instrumentation probes or rakes that may be positioned in the tunnel test section. The tunnel user should provide guards and/or shields for all exposed rakes and model sharp edges, spikes, tips, etc.

8.1.5 Support during tests.—All requests for manpower assistance and shop or facility services should be made by the tunnel user to the AFED project engineer.

8.2 Operations

8.2.1 Normal operating days and shift hours.—Tests are usually run from 4:30 p.m. to 11:00 p.m. Monday through Friday. This window can be expanded if the schedule warrants it. Tunnel users should discuss expanding the test time each week with the AFED project engineer if required.

8.2.2 Off-shift coverage.—Access to 10- by 10-Foot SWT for other than operating shifts must be coordinated with the AFED project engineer.

8.3 Planning

8.3.1 Prerun safety meeting.—The AFED project engineer will prepare a safety permit request that describes the test. This document will discuss the safety aspects of the tests as well as test objectives, run schedule, instrumentation, hardware, etc., and is sent through the facility manager to the Center's Environmental Compliance Office and the Facility Safety Committee for their review and approval. The safety permit request should be written and available for review at least 4 weeks before the start of testing.

The following conditions would require special action to be taken by the Facility Safety Committee:

(1) Experiments using radioactive materials or gases
(2) High-speed rotating model parts without suitable shrouds
(3) Ejection of material or gases into the tunnel circuit that may cause an explosion
(4) Use of toxic materials (The tunnel user should supply a material safety data sheet.)

8.3.2 Test time.—The tunnel test time charged an experiment (non-NASA users) includes the total time that the facility is available to the user. This time includes model and instrumentation installation, model removal, experiment time, and return of the tunnel and associated areas to their pretest conditions. The time required to crate the user's model and equipment for shipment must also be included. Extensions to a test window may be granted. This point is negotiable between the tunnel user's lead engineer and the facility manager. Discussions with NASA personnel who have experience with the facility should assist the tunnel user to make a fairly accurate estimate of the time required to complete the test program.

8.3.3 NASA debriefing.—At the completion of the test program the tunnel user's lead engineer will meet with the facility manager. The purpose of the meeting is to evaluate the test support received by the tunnel user during the test program. The facility manager will make the arrangements for the meeting.

8.4 Security

The advance notice required to obtain access to the 10- by 10-Foot SWT at the NASA Lewis Research Center depends on the classification of the test program and the category of the non-NASA visitor.

During nonclassified test programs the AFED project engineer will notify the NASA Lewis Visitor Control Center at least 3 days prior to the arrival of a non-NASA visitor who is a U.S. citizen. The information required is the name of the visitor, the place of employment, and the date and purpose of the visit. A non-U.S. citizen should make arrangements with his or her embassy in Washington, D.C., prior to the intended visit to NASA Lewis. The appropriate embassy should work with NASA Headquarters in Washington, D.C., to establish the necessary clearances.

A classified test program at NASA Lewis requires that the proper security clearance be in place prior to the arrival at Lewis of a non-NASA visitor who is a U.S. citizen. The NASA Lewis Security Office requires the reception of a visit notification letter from the visitor's company. This letter must include the following information for each visitor:

(1) Social Security number
(2) Full name
(3) Date and place of birth
(4) Security clearance level
(5) Date clearance was granted
(6) Who granted the clearance
(7) Date and duration of visit
(8) NASA contact

Visit notification letters are to be sent to the following address:

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

The AFED project engineer will notify the NASA Lewis Security Office and the Visitor Control Center 3 days prior to the arrival of non-NASA visitors who wish to participate in a classified test program at the Center.

APPENDIX A

CONTACT PERSON

The facility manager is the key contact person at the 10- by 10-Foot SWT. Mail correspondence can be addressed as follows:

NASA Lewis Research Center
Attn: 10- by 10-Foot SWT Facility Manager, MS 6–8
21000 Brookpark Road
Cleveland, Ohio 44135

The name of the 10- by 10-Foot SWT facility manager can be obtained from a NASA Lewis telephone directory. This information is presented in the organizational listing under Aeropropulsion Facilities and Experiments Division, Facilities Management Branch (organization code 2810). In the absence of a directory, call (216) 433–4000 (NASA Lewis switchboard operator) and ask the operator for the name of the 10- by 10-Foot SWT facility manager.

APPENDIX B

REAL-TIME DISPLAY DETAILS

The format for the control room CRT display is as follows: Page one of the CRT display is the page directory. The other output pages are designed by the tunnel user to meet test plan objectives. A display can contain two sizes of characters: a matrix of 24 (normal-size characters) or a matrix of 48 (reduced-size characters) by 80 columns wide. Row 1 is reserved when reduced-size characters are used. These rows always contain standard identification information (i.e., facility name, program number, last reading taken, current time, barometer, and ESP calibration countdown time). Data channels may also be displayed in an unlabeled block format (a two-dimensional array of X rows by Y columns). These are preprogrammed, off-the-shelf displays.

APPENDIX C

SUMMARY OF PROCEDURE FOR OBTAINING TEST TIME

1. Tunnel user contacts the 10- by 10-Foot SWT facility manager and submits the overall test requirements at least 1 year before the test.

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

3. Tunnel user submits formal letter of request to director of aeronautics at NASA Lewis (for non-NASA requestors only).

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

5. A series of pretest meetings are held at NASA Lewis to discuss the test plan, the instrumentation, the tunnel hardware, and the data requirements. Attendees are the requestor and his or her key personnel, the facility manager, appropriate AFED branch chiefs, key AFED personnel, and the AFED project engineer.

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6. Mitchell, G.A.; and Cubbison, R.W.: An Experimental Investigation of the Restart Area Ratio of a Mach 3.0 Axisymmetric Mixed Compression Inlet. NASA TM X–1547, 1968.

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9. Blaha, R.J.: Escort D Plus Users Manual. NASA Lewis Research Center, Cleveland, OH, May 1991. (Available from Aeropropulsion Facilities and Experiments Division project engineer.)

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TABLE I.—FACILITY SUPPORT SYSTEMS

System	Weight or volumetric flow rate	Pressure	Volume, ft^3 (std.)	Temperature
High-pressure air	Variable	2600 psig (max.)	216 000	----------------
Service air	2 lbm/sec	125 psig	---------	----------------
Combustion air	12 lbm/sec	450 psig	---------	300 °F (max.)
Hydraulic	27.1 gal/min	3000 psig (max.)	---------	----------------
Gaseous hydrogen	0.66 lbm/sec	1200 psig (max.)	---------	Ambient
Liquid fuel	70 or 30 gal/min	40 or 950 psia (max.)	---------	----------------

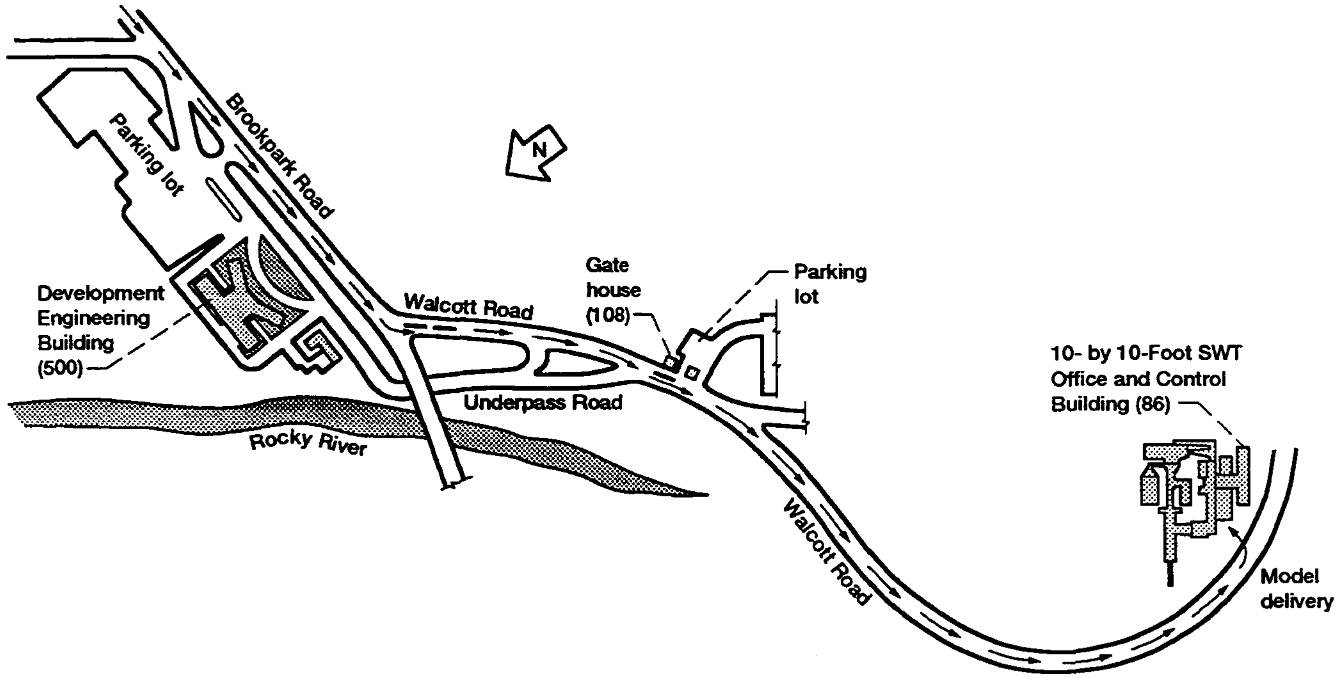


Figure 1.—Directions to 10- by 10-Foot Supersonic Wind Tunnel Facility. Note: Underpass road is an alternative entrance to NASA Lewis, but large trucks have a height restriction passing beneath Brookpark Road.

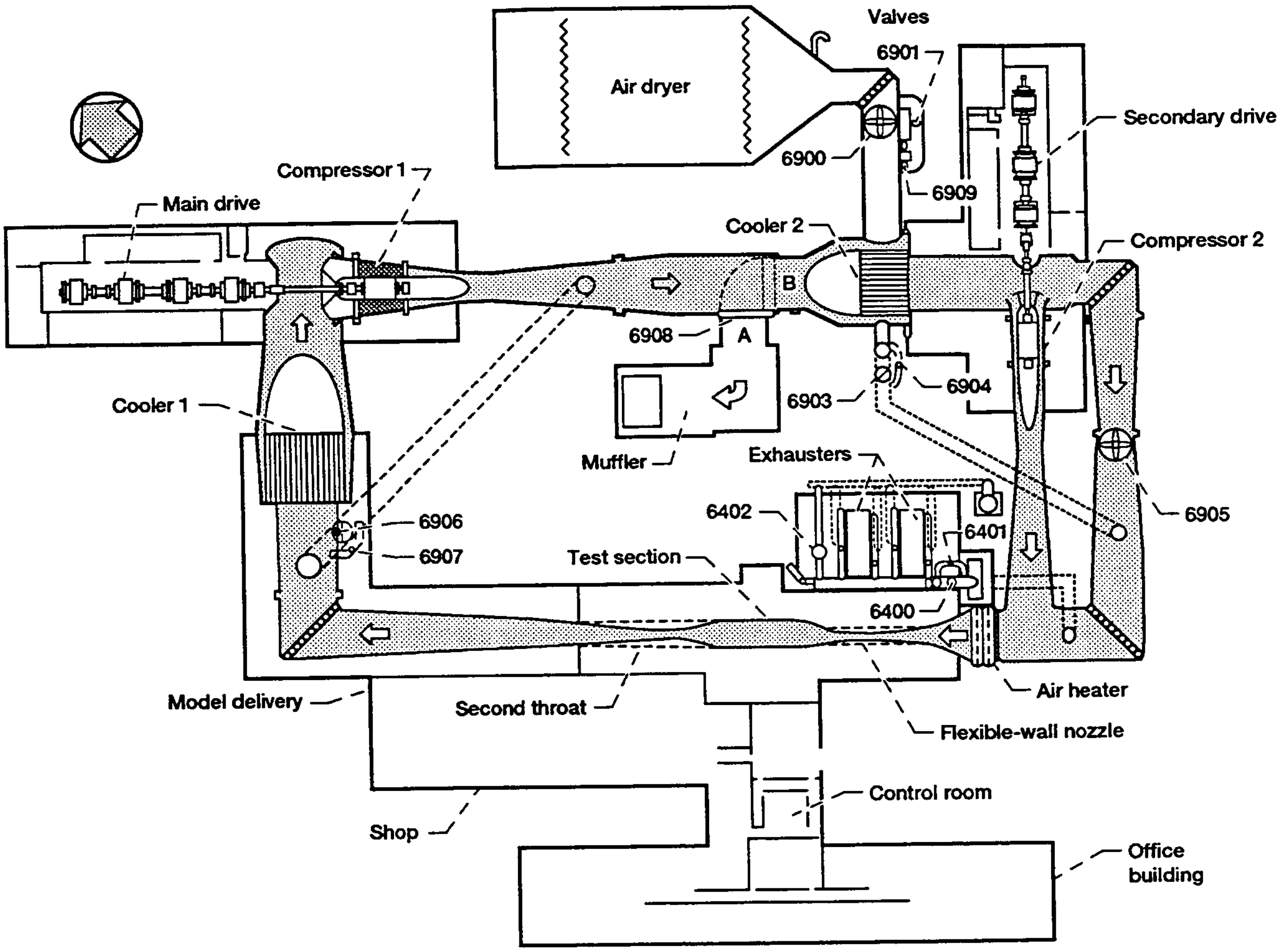


Figure 2.—Schematic of 10- by 10-Foot Supersonic Wind Tunnel Facility.

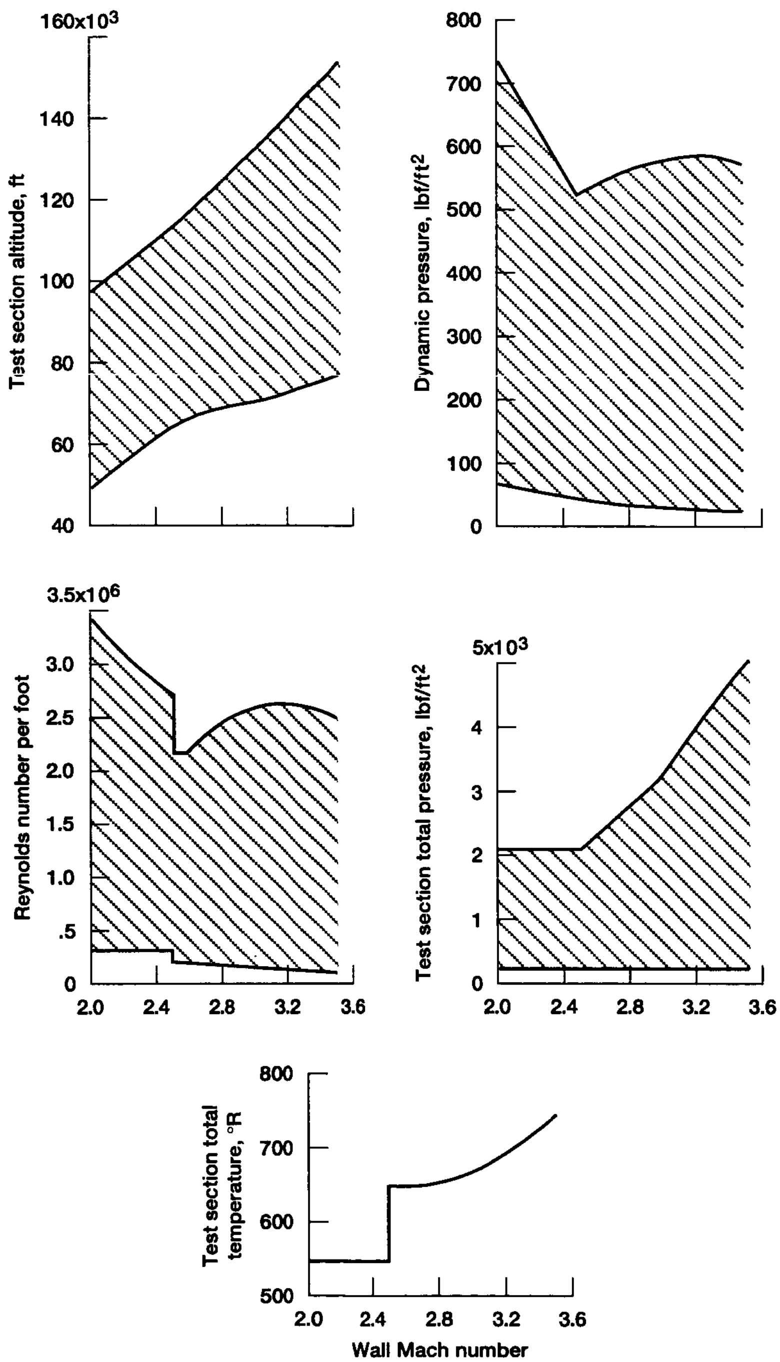


Figure 3.—Operating envelopes for aerodynamic cycle of 10- by 10-Foot Supersonic Wind Tunnel.

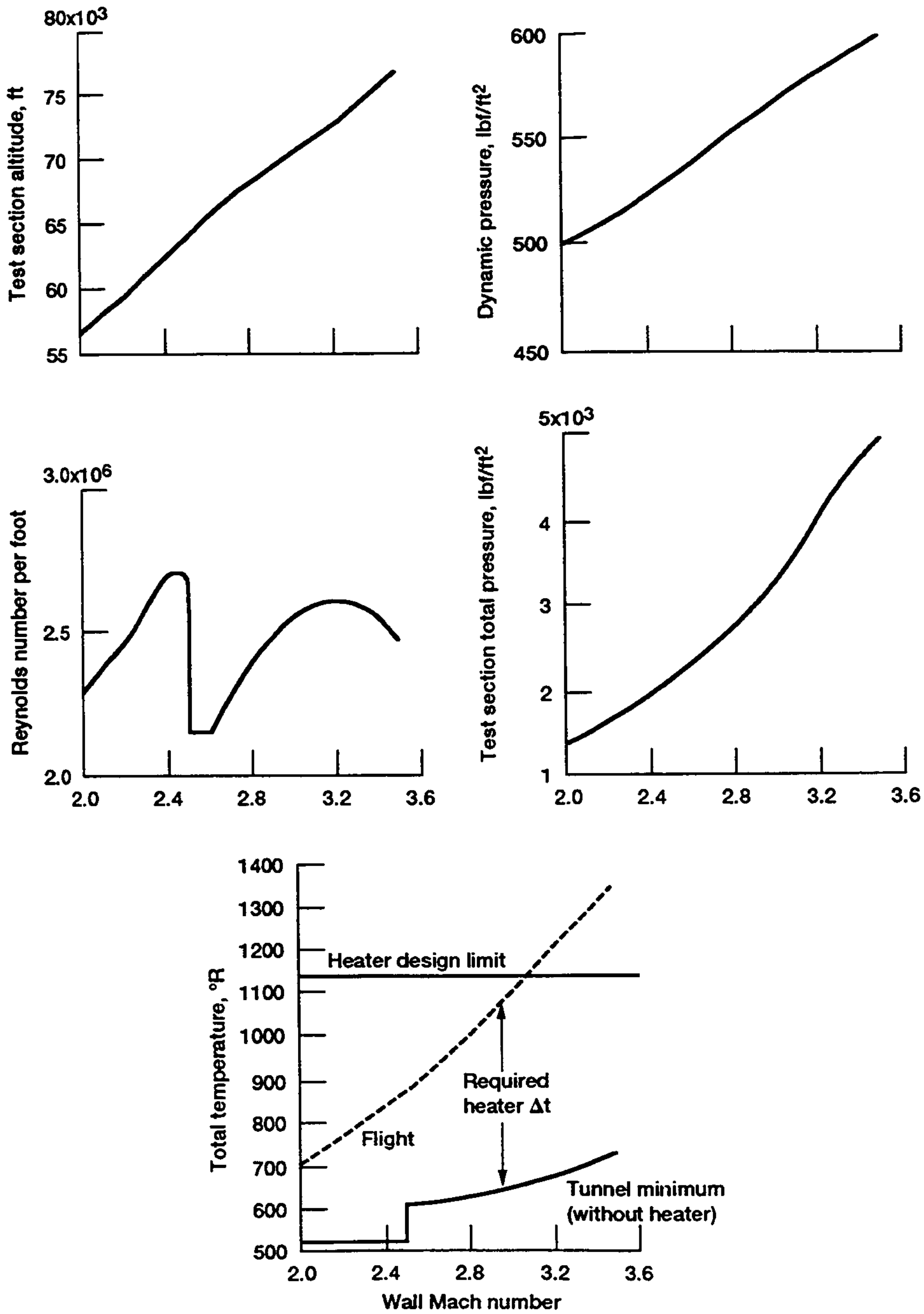


Figure 4.—Operating envelopes for propulsion cycle of 10- by 10-Foot Supersonic Wind Tunnel.

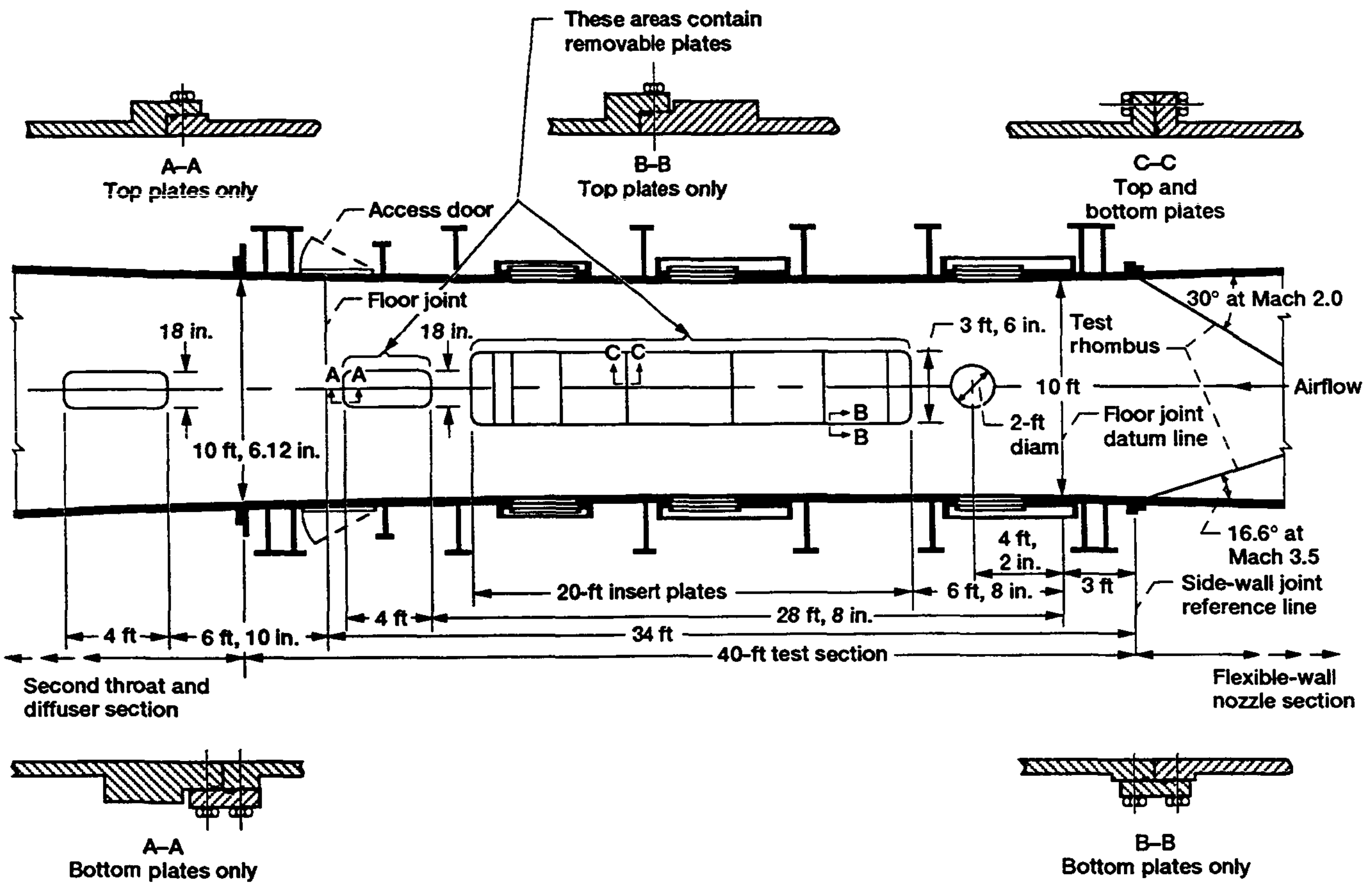


Figure 5.—Test section plan view. (Various-size insert plates are available for the top and bottom of the test section. For complete details of plate openings the AFED project engineer can obtain NASA drawings CE–107998 and CE–107999.)

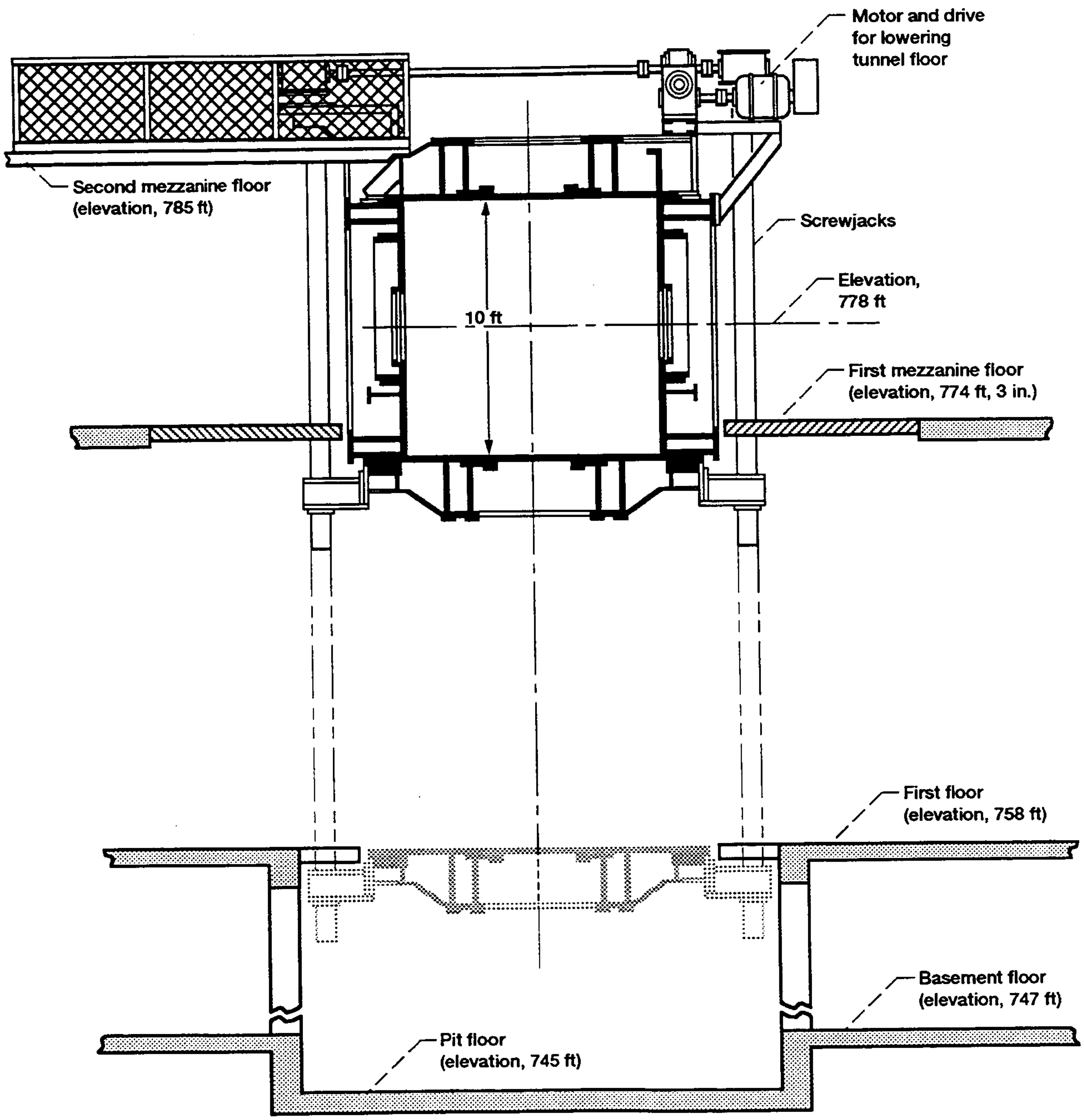
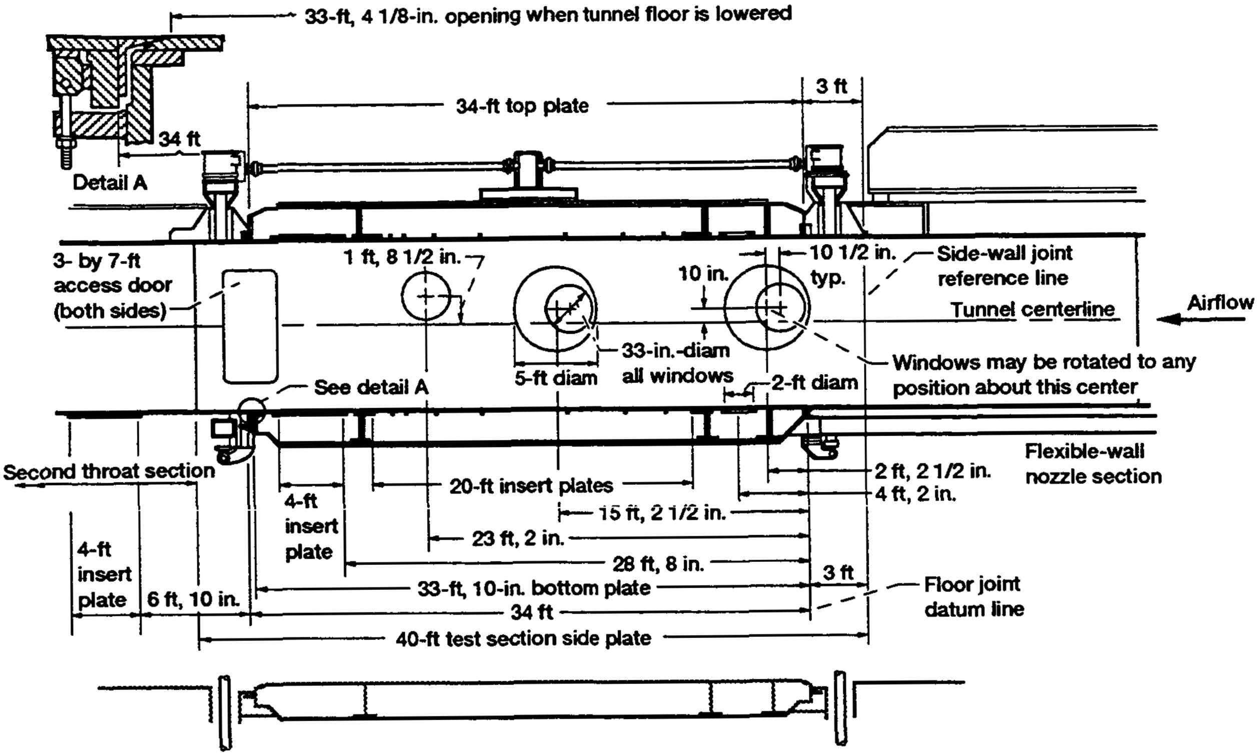
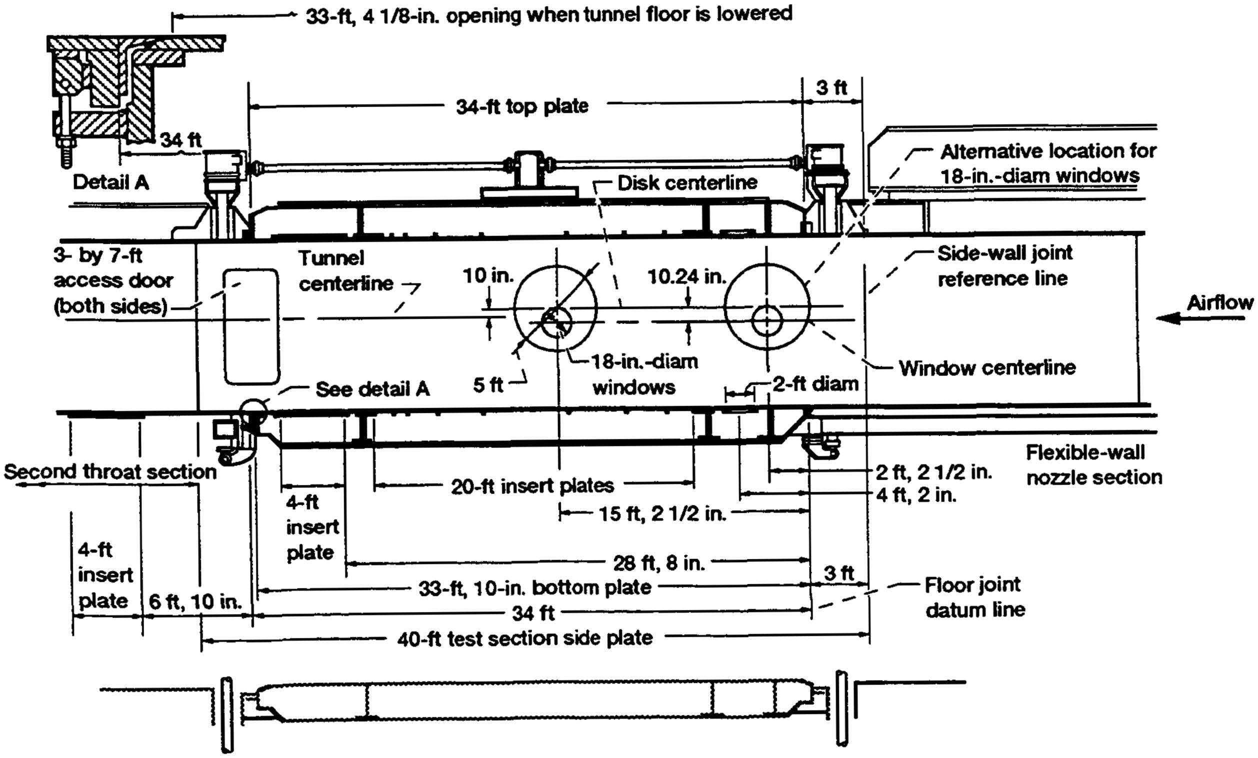


Figure 6.—Test section cross section.



(a) 33-in.-diameter schlieren windows.



(b) 18-in.-diameter schlieren windows.

Figure 7.—Test section elevation view.

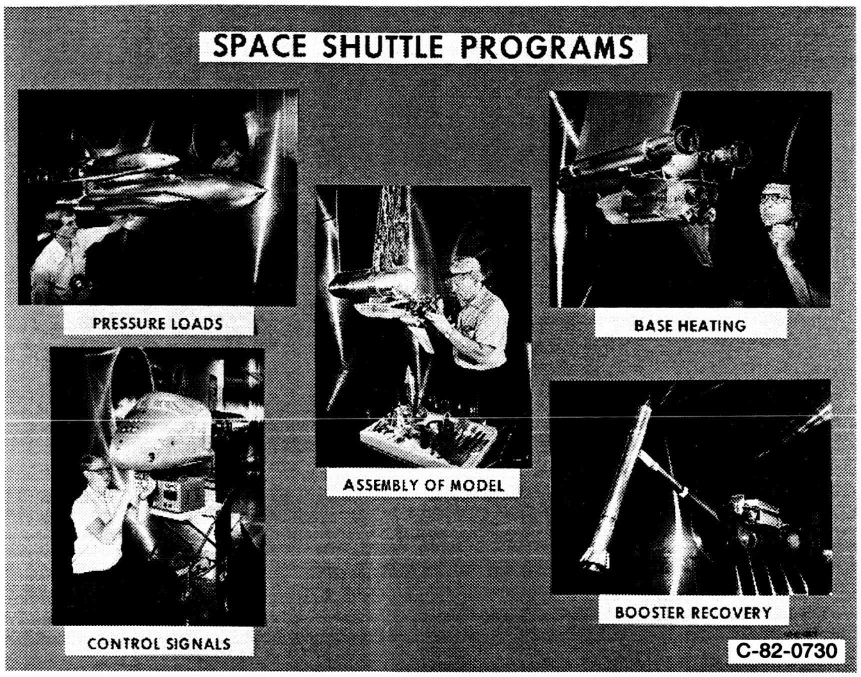


Figure 8.—Typical models and experiments installed in test section.

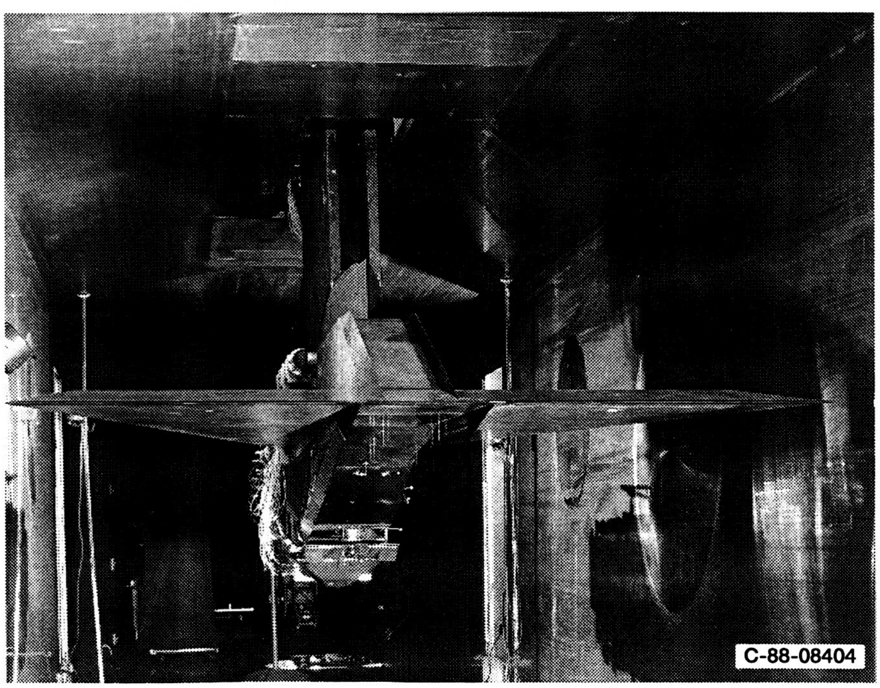


Figure 9.—Mach 5 inlet installed in test section.

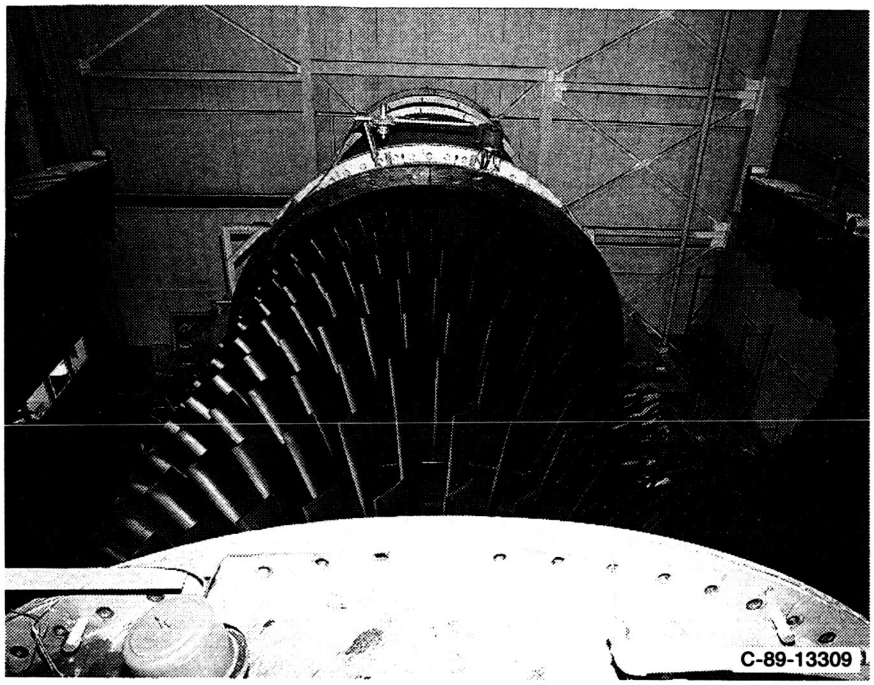


Figure 10.—Compressor 1 with case open.

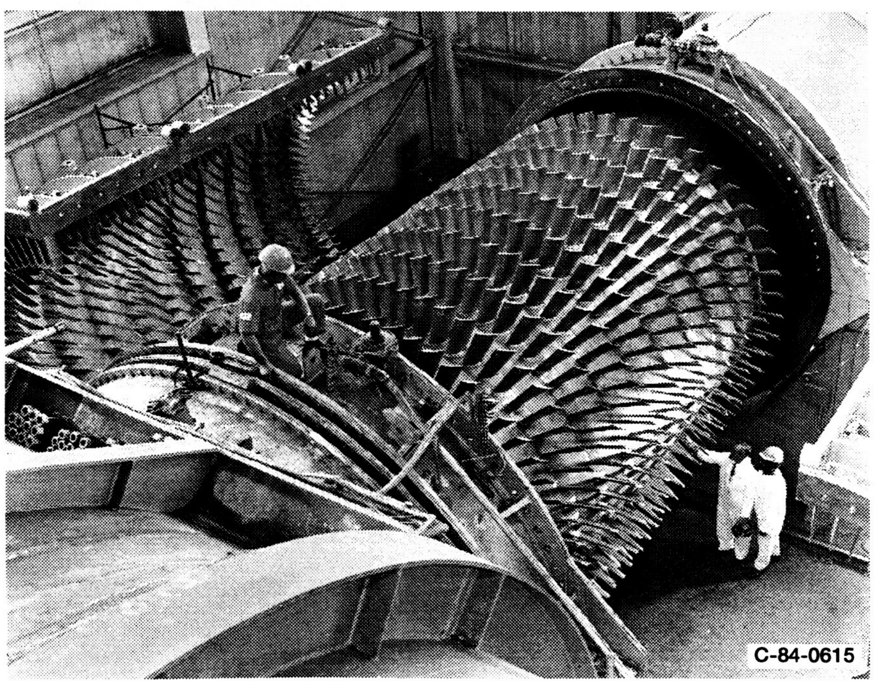
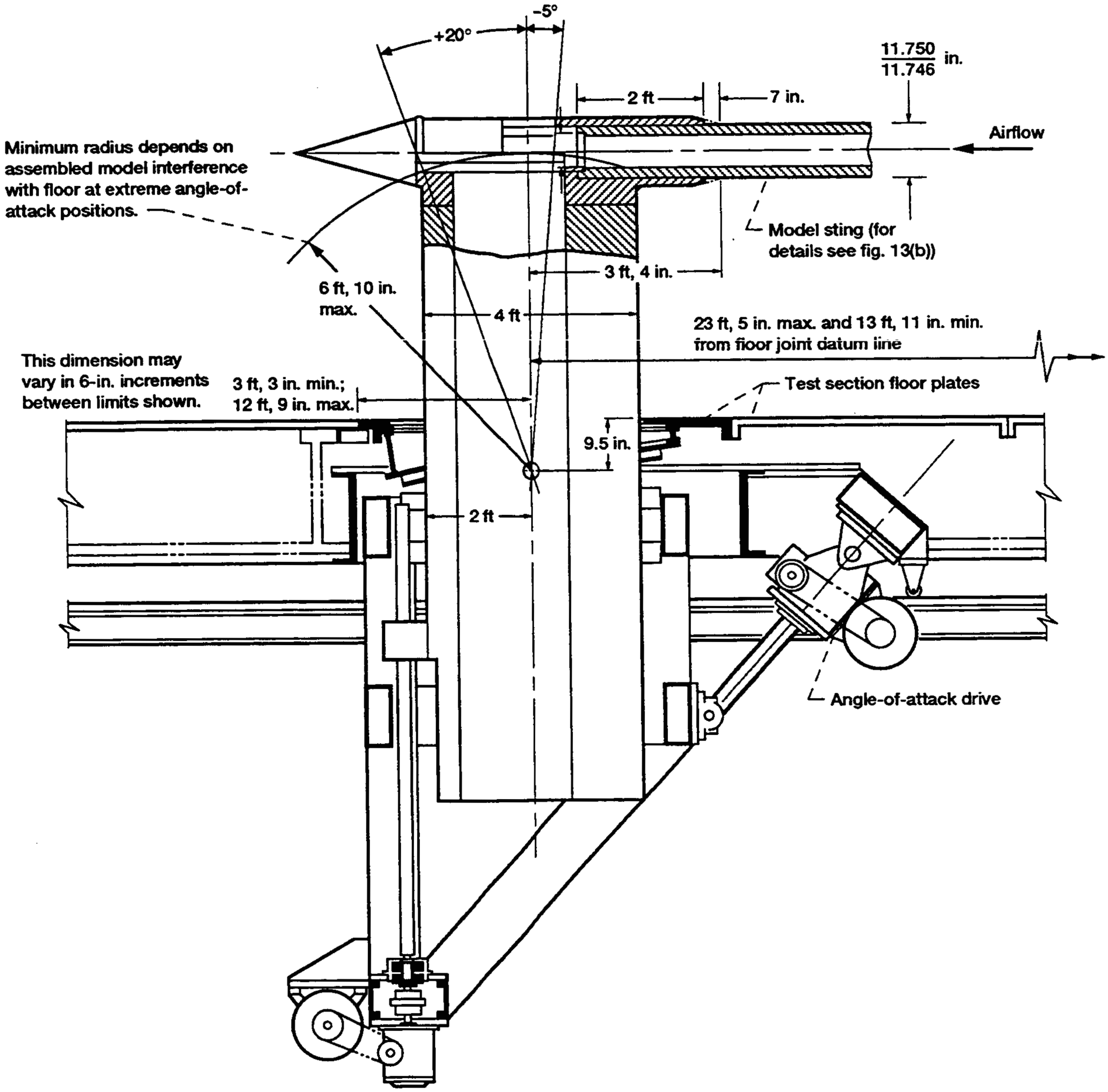


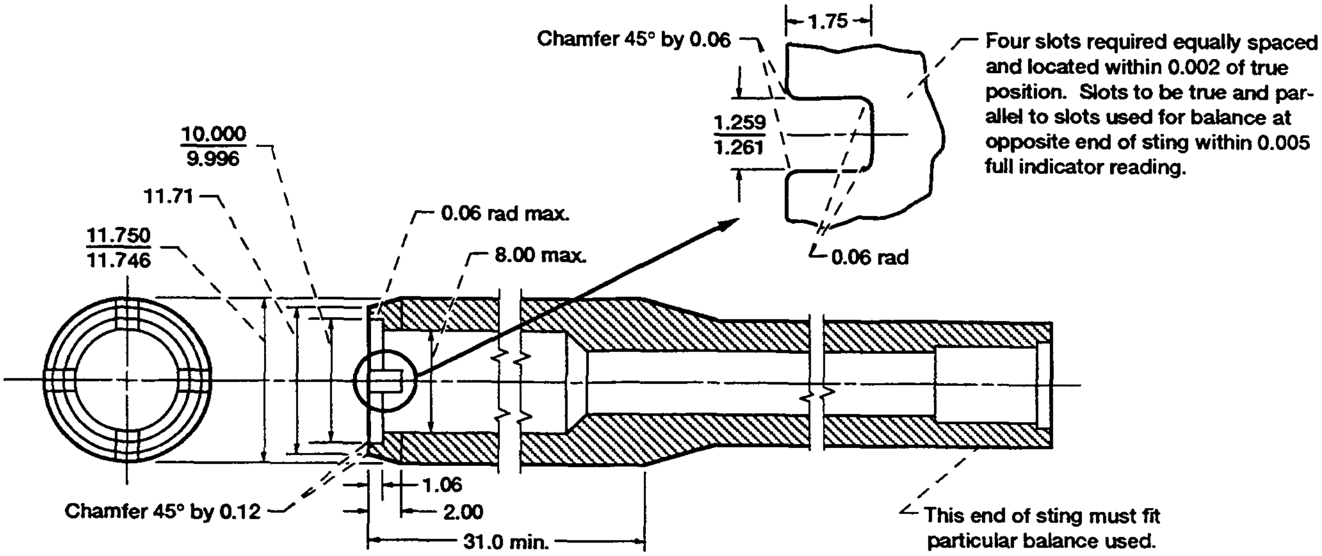
Figure 11.—Inspection of compressor 2 blades.

Figure 12.—Control room.



(a) Sting strut. Design loads 3 ft ahead of vertical centerline; normal force, +9000 lbf, –7000 lbf; axial force, 3500 lbf; maximum moment, +125 000 ft-lbf, –115 000 ft-lbf.

Figure 13.—Sting strut and adapters. (The AFED project engineer can provide reference assembly drawing CE–72053.)



(b) Sting end details. (Dimensions are in inches unless otherwise noted.)

Figure 13.—Concluded.

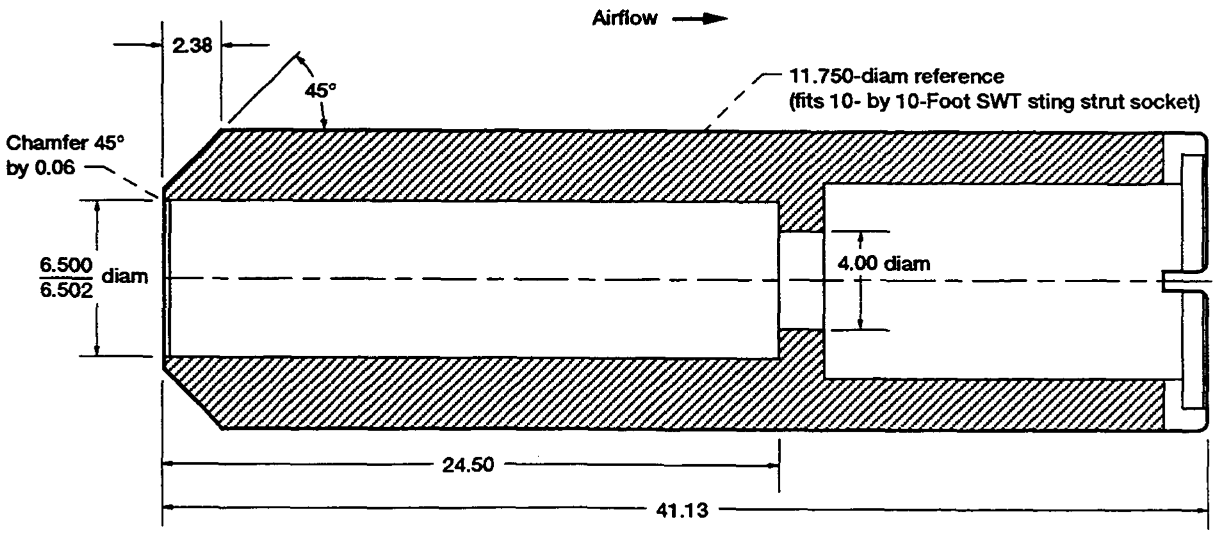


Figure 14.—Sting adapter for use with 8- by 6-Foot Supersonic Wind Tunnel stings. (Dimensions are in inches unless otherwise noted.)

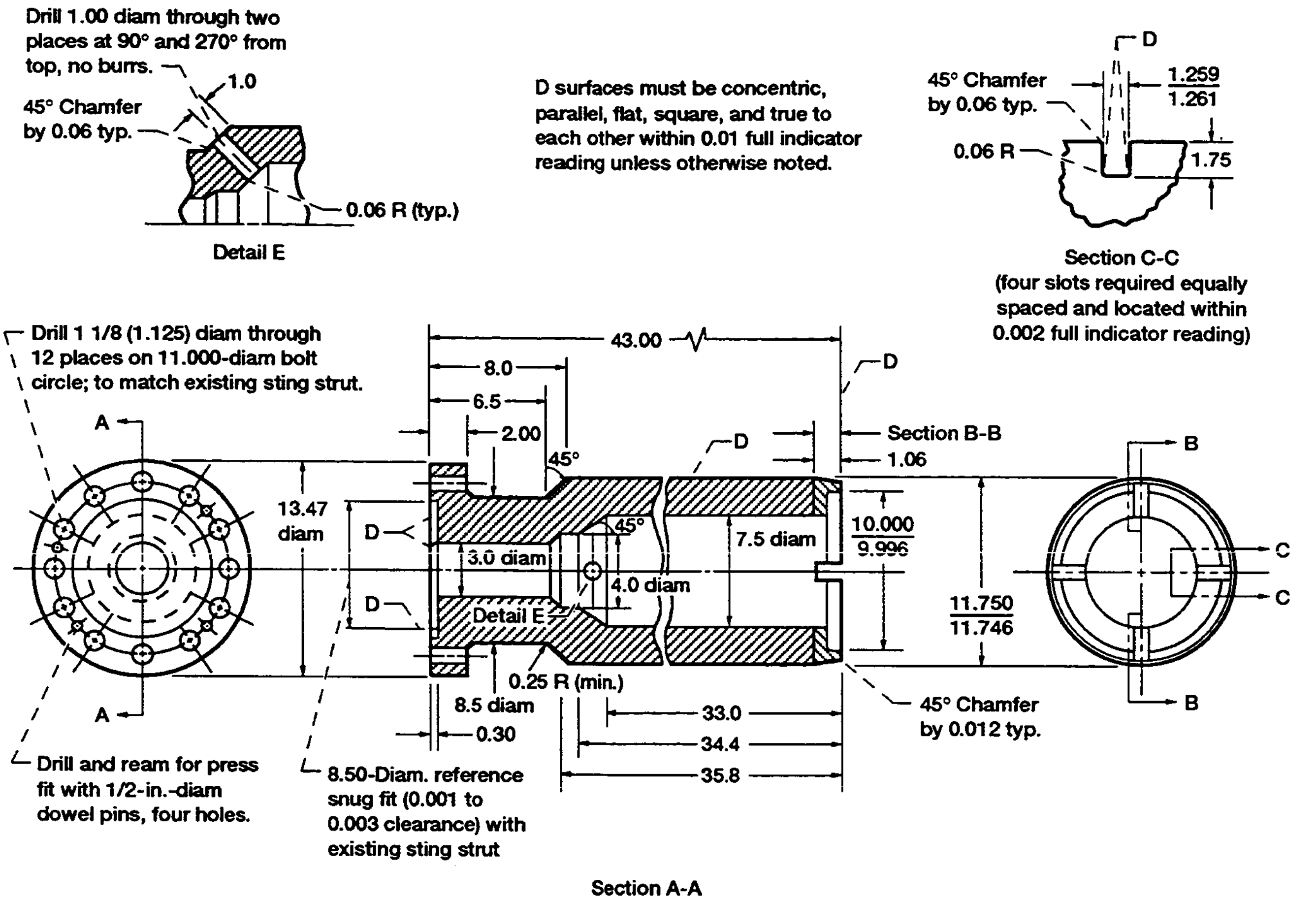


Figure 15.—Adapter used to mate NASA Langley stings to NASA Lewis strut. (Dimensions are in inches.)

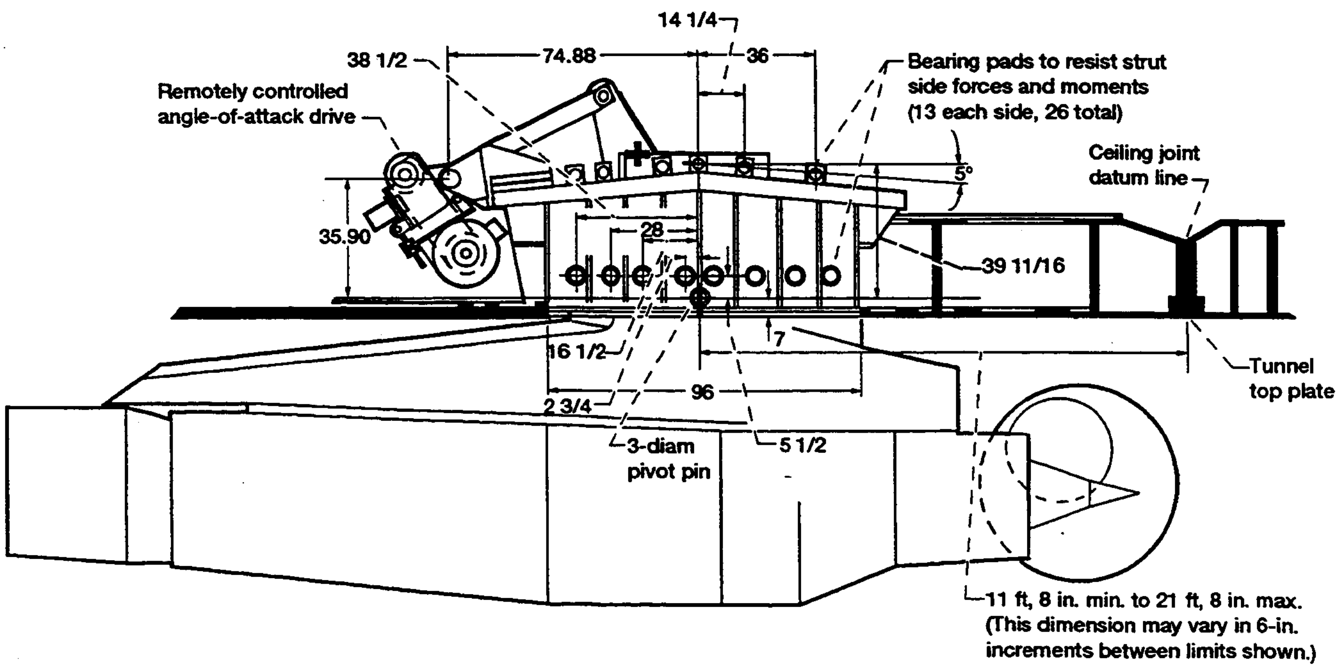


Figure 16. —Ceiling strut assembly. Normal force, ± 50 000 lbf; axial force, ± 50 000 lbf; pitching moment, ± 175 000 ft-lbf. (Dimensions are in inches unless otherwise specified. The AFED project engineer can provide reference drawings for assembly of strut support (CR-72200) and installation of model (CF-74320) if requested.)

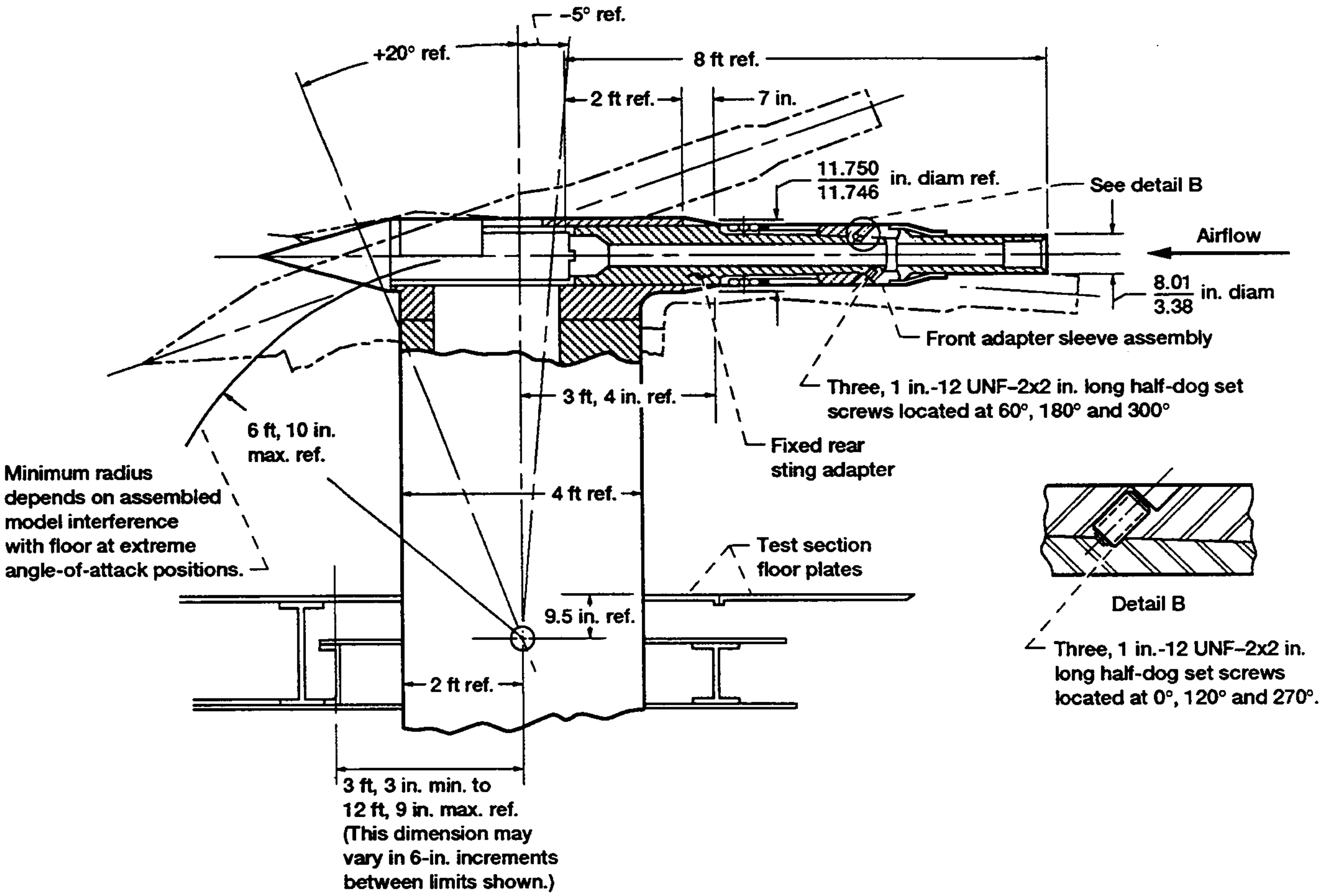


Figure 17.—Rotating sting adapter. (The AFED project engineer can supply reference drawings 28013M40A100 through 28013M40A108 if requested.)

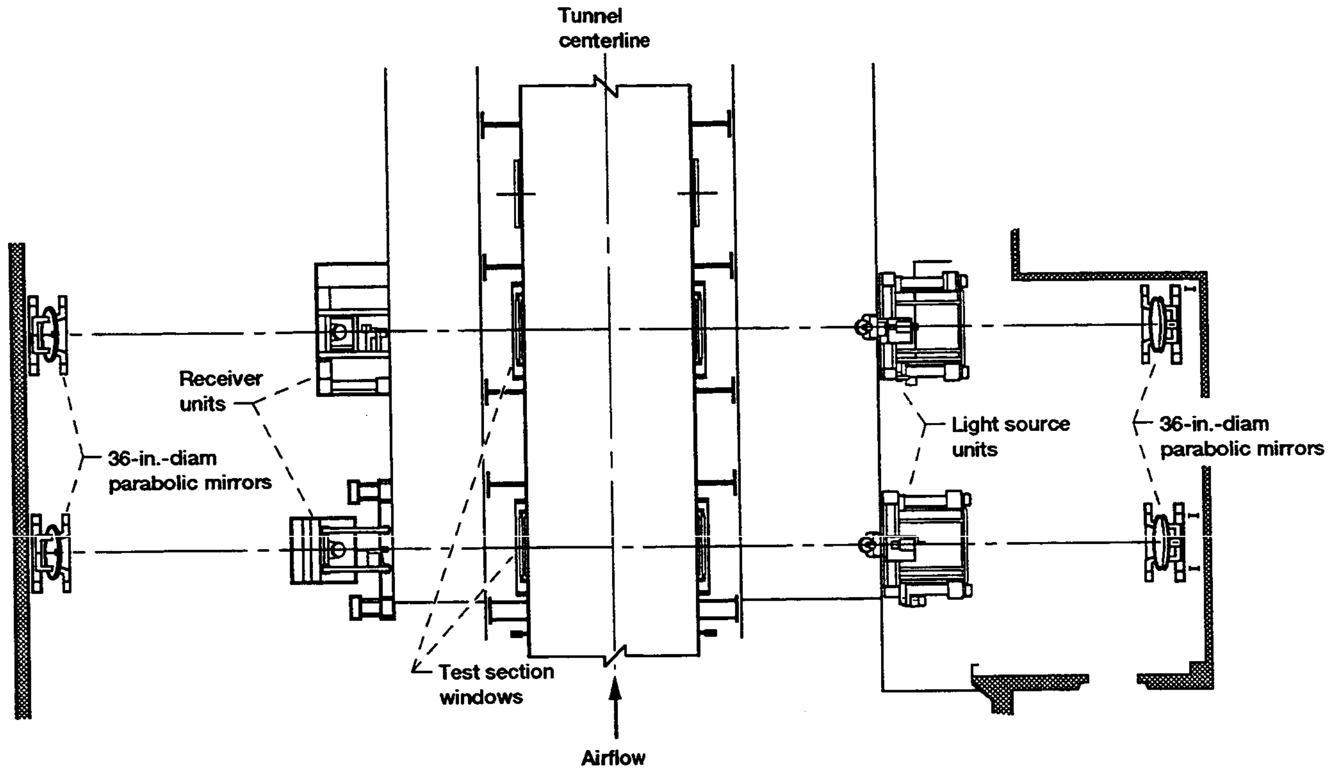


Figure 18.—Schlieren system plan view.

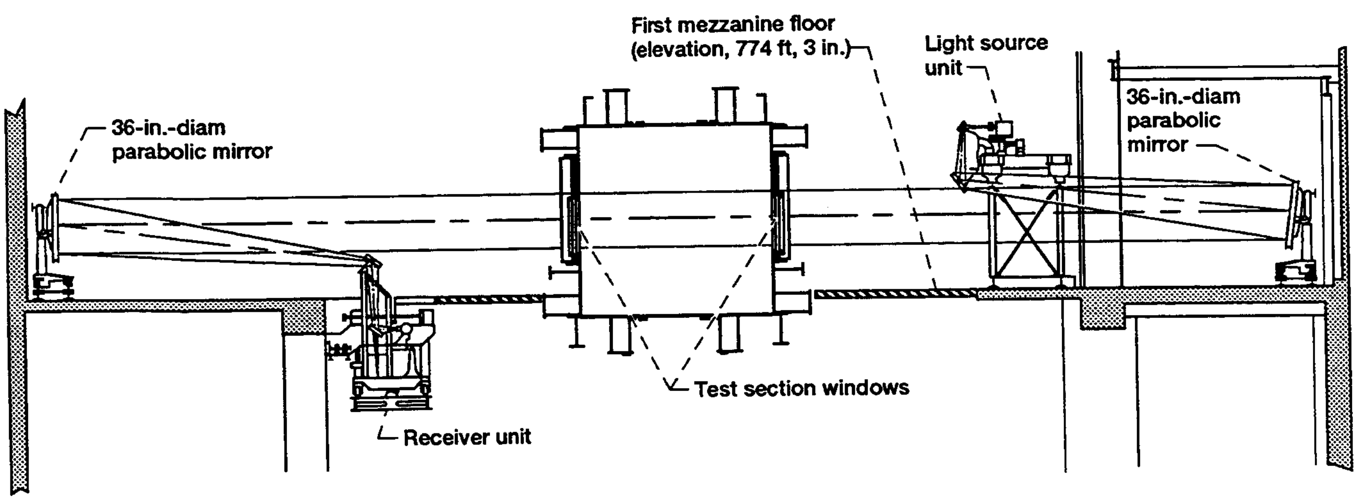


Figure 19.—Schlieren system elevation view (looking downstream).

Figure 20.—Shuttle model viewed through test section schlieren window.

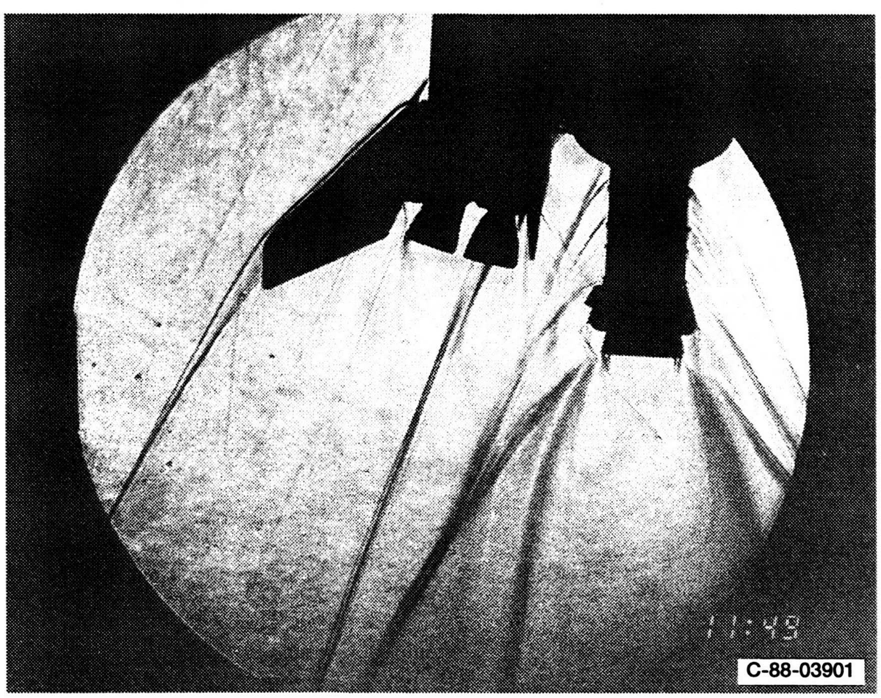


Figure 21.—Model photo using schlieren system.

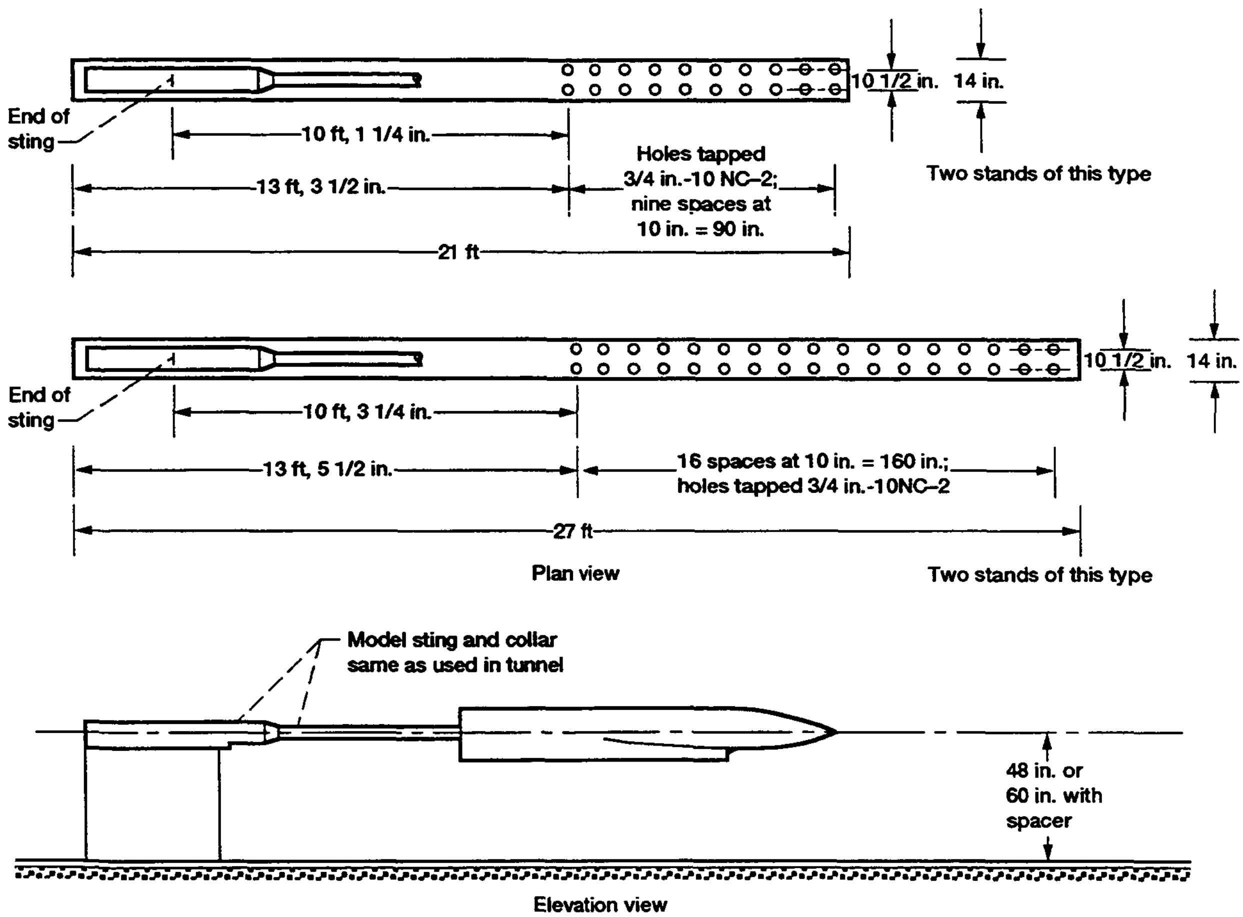


Figure 22.—Shop stands for sting-mounted models.

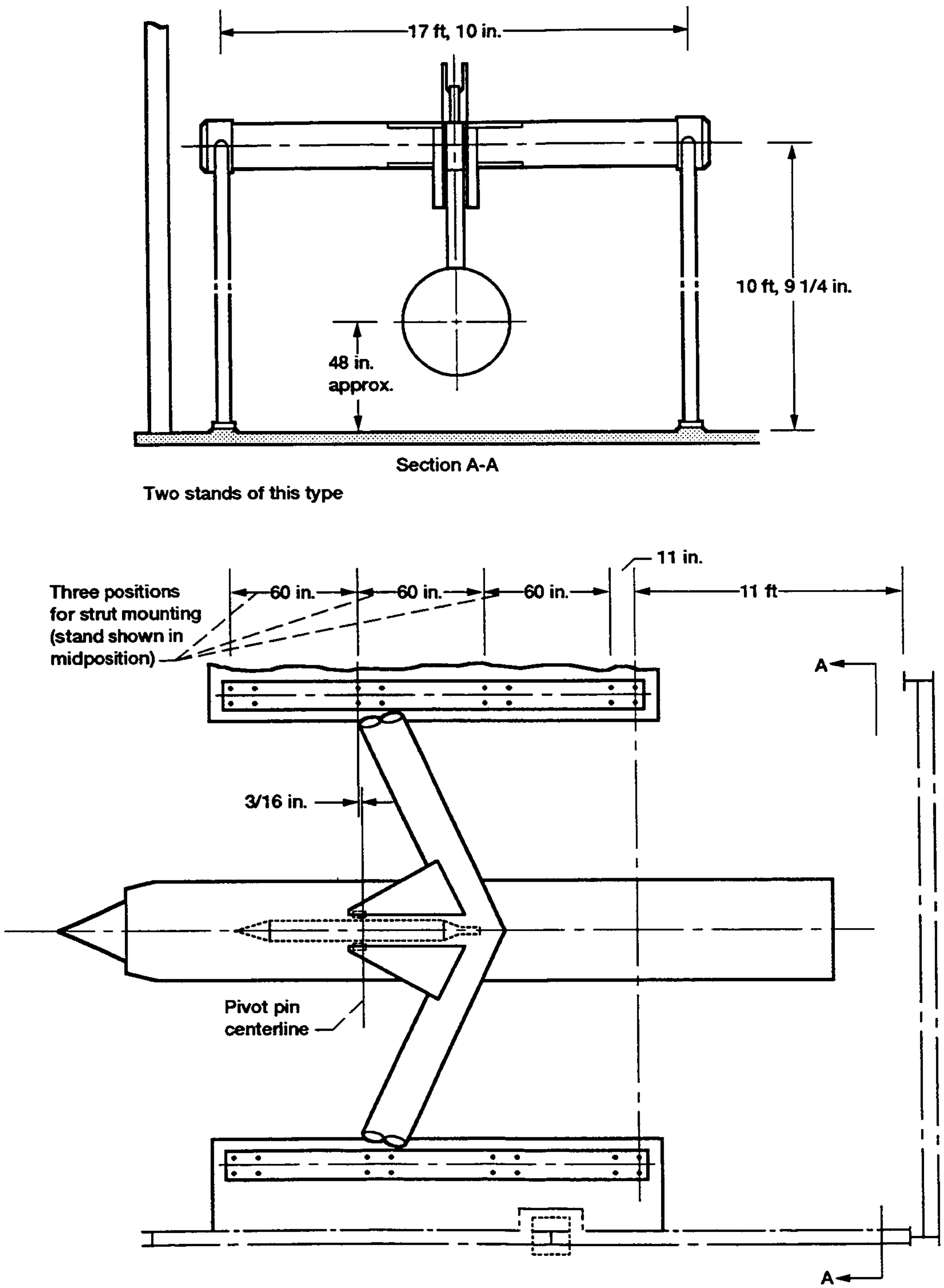


Figure 23.—Shop stands for ceiling-suspended models.

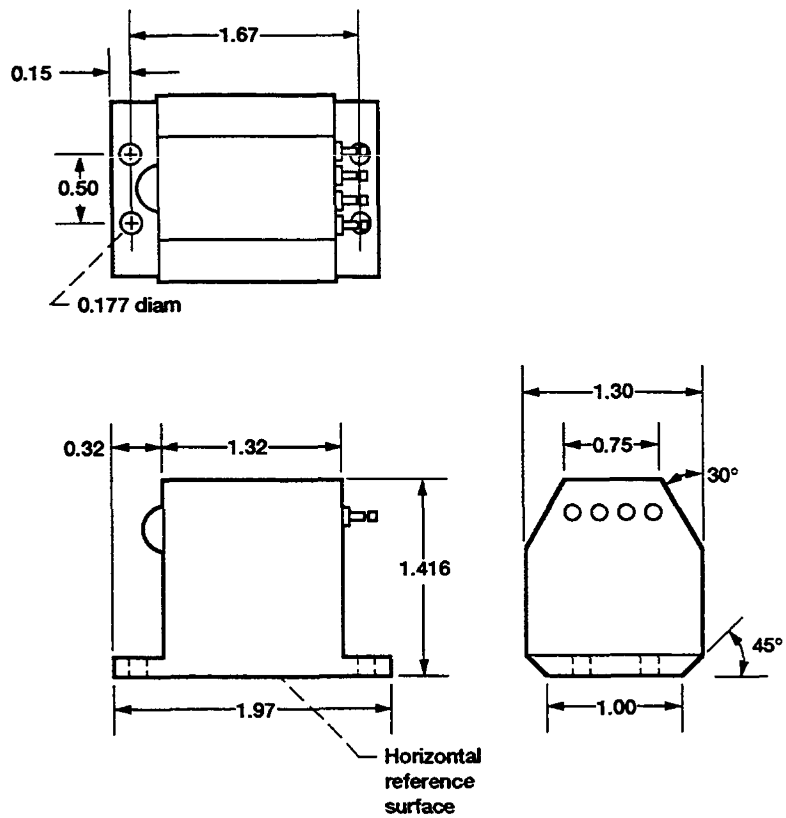


Figure 24.—Angle-of-attack transducer. (Linear dimensions are in inches. Reference drawings are available from the AFED project engineer, transmitter details in CF 89287 and electrical installation in MDS 900.)

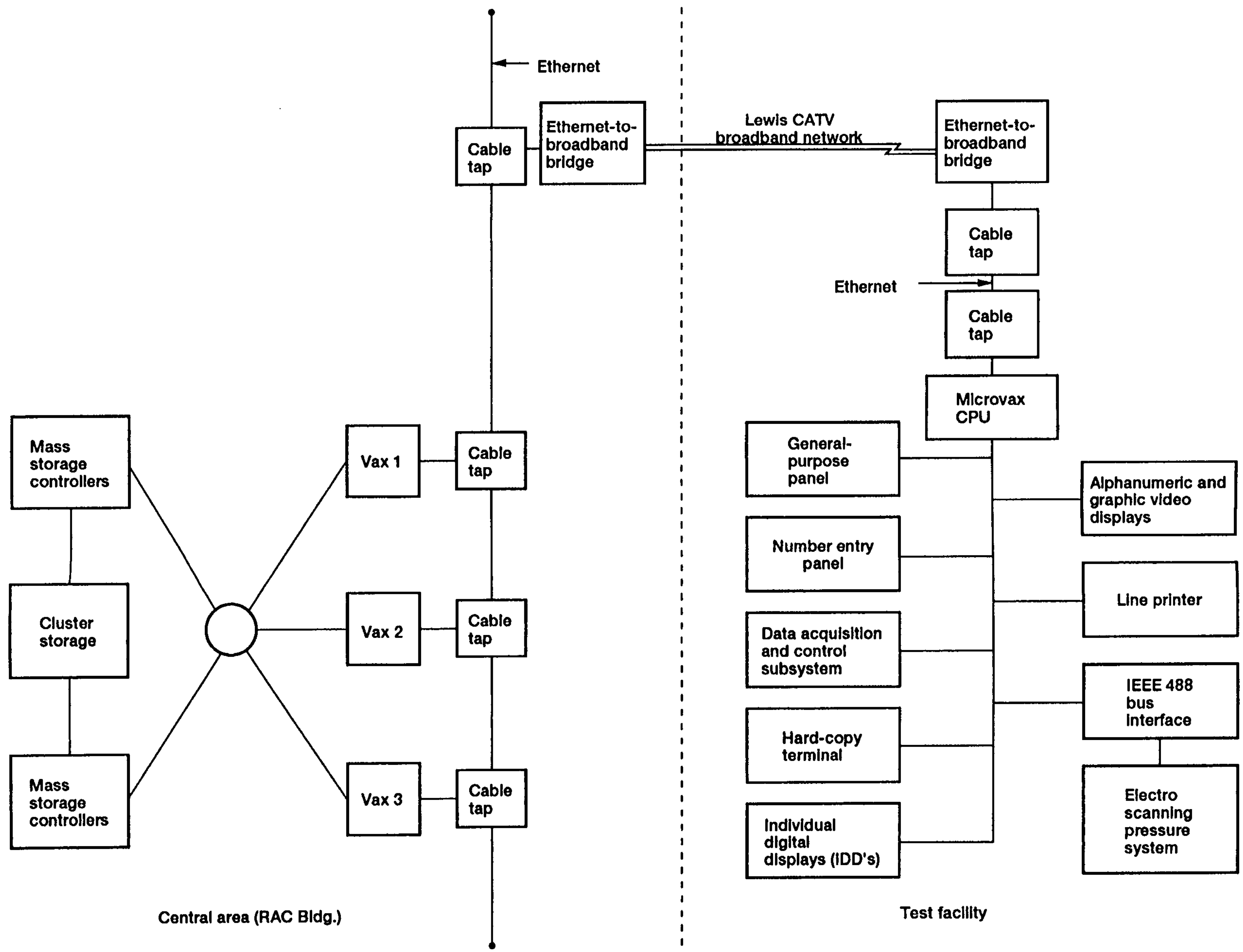


Figure 25.—Overall configuration for escort D plus system.

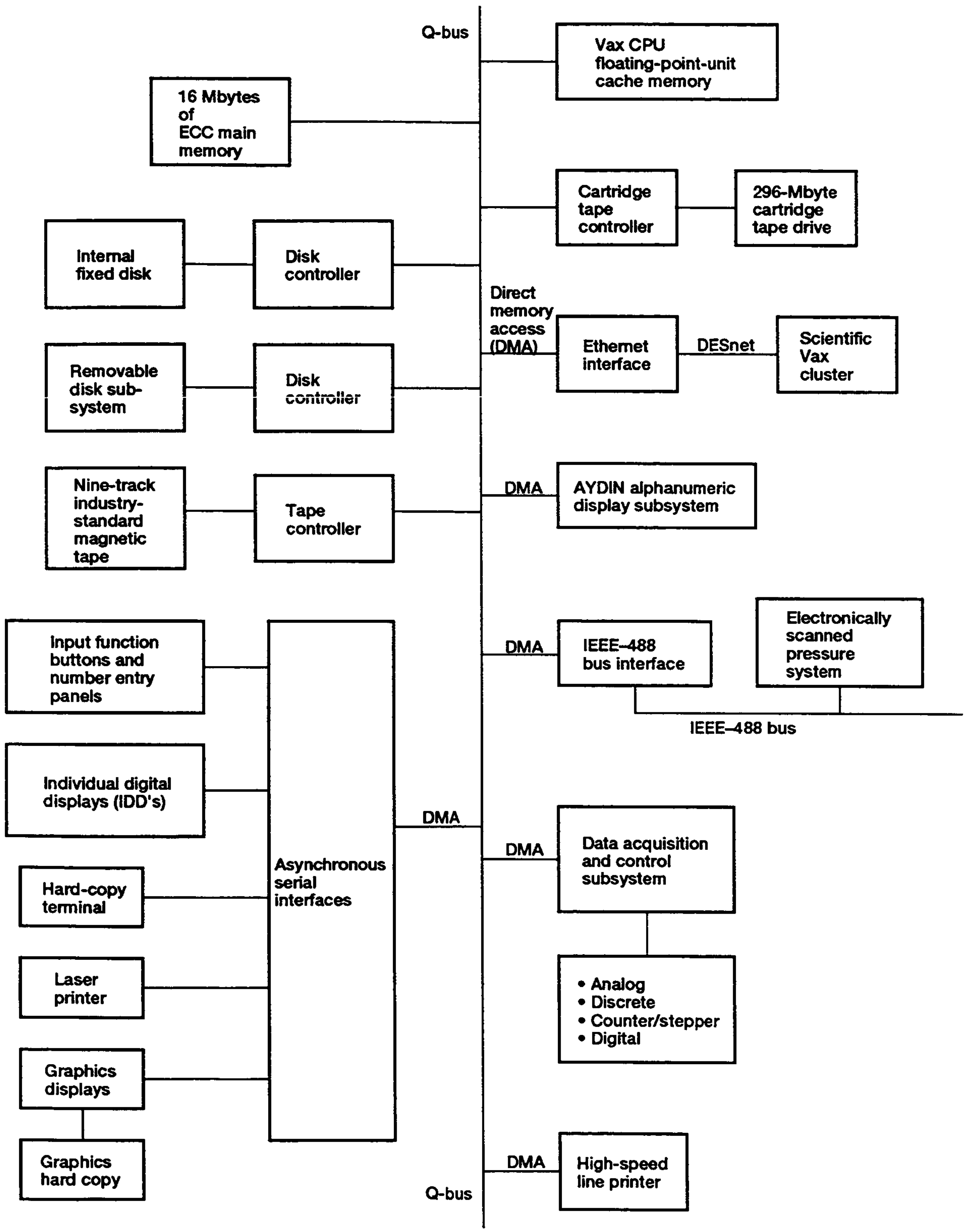


Figure 26.—Facility computer configuration.

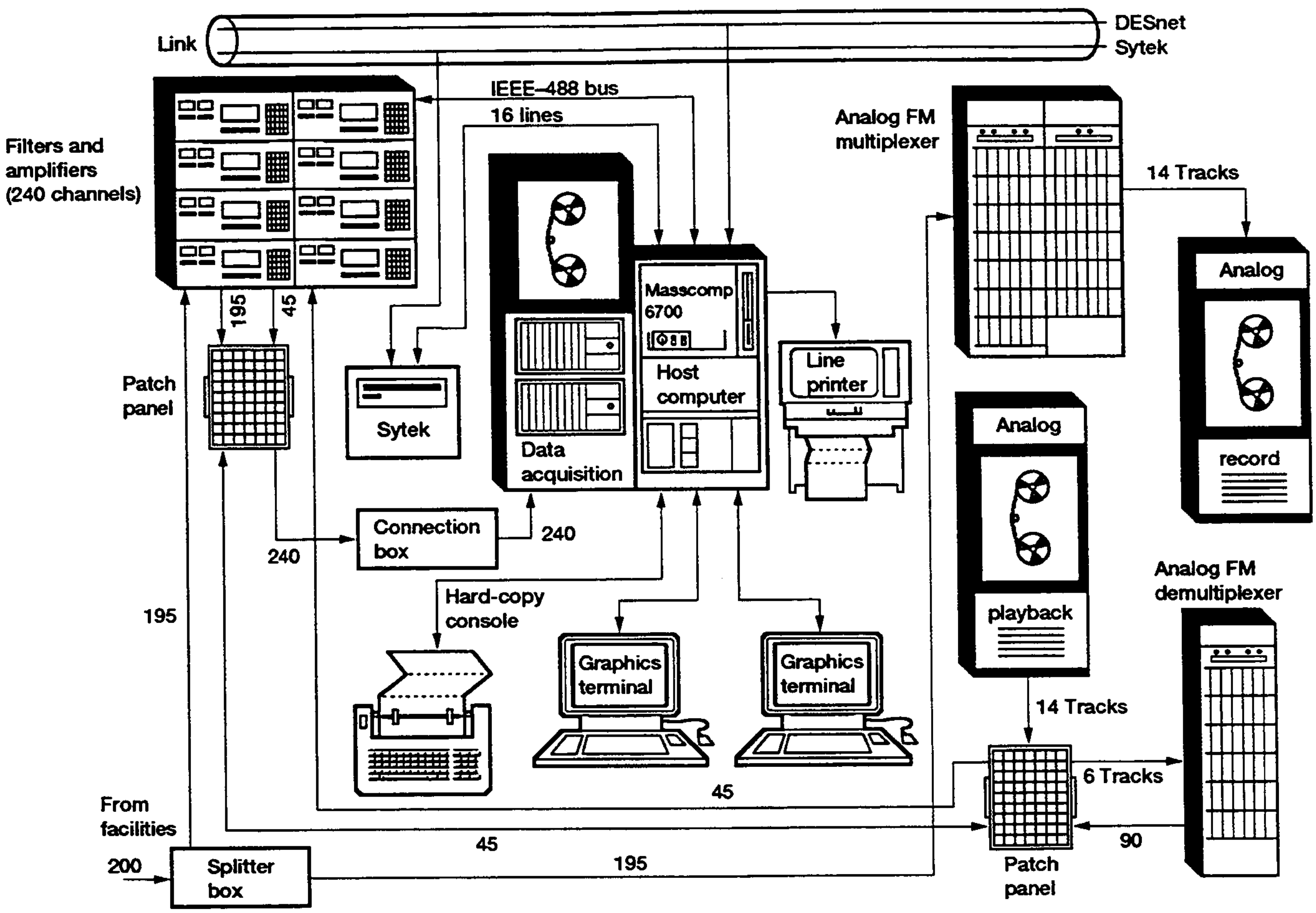


Figure 27.—TRADAR-3 and central analog dynamic data systems.

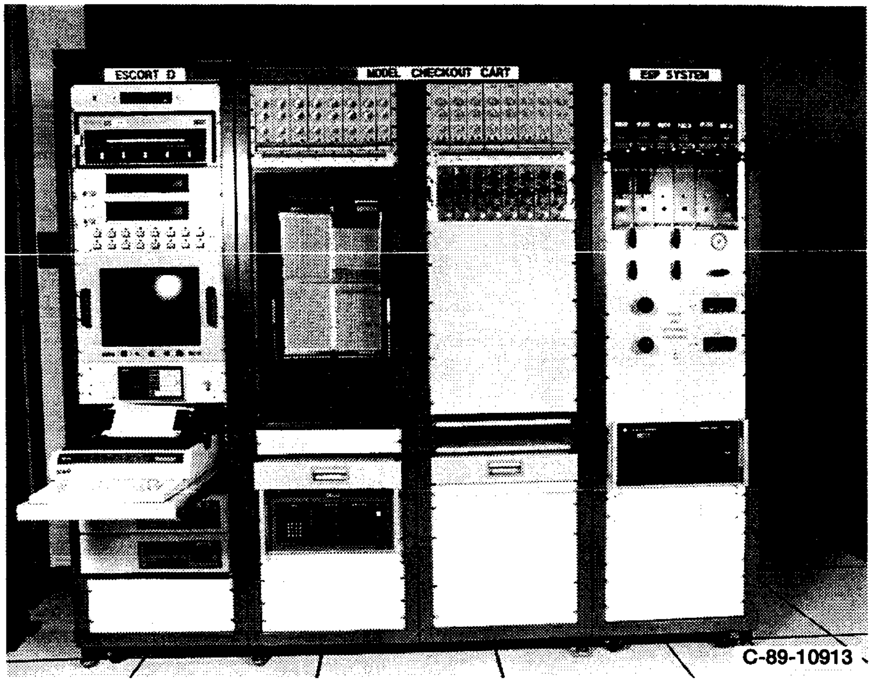


Figure 28.—Model checkout cart.

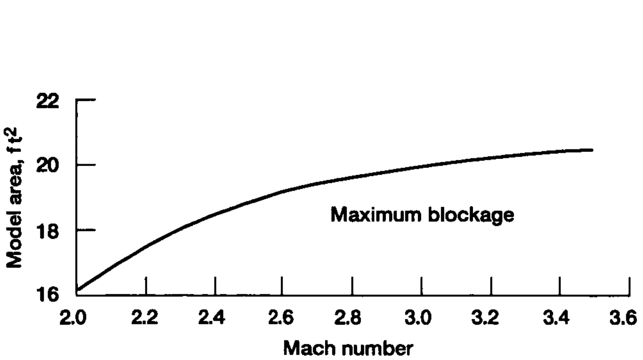


Figure 29.—Starting limitations.

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

This manual describes the 10- by 10-Foot Supersonic Wind Tunnel at the NASA Lewis Research Center and provides information for users who wish to conduct experiments in this facility. Tunnel performance operating envelopes of altitude, dynamic pressure, Reynolds number, total pressure, and total temperature as a function of test section Mach number are presented. Operating envelopes are shown for both the aerodynamic (closed) cycle and the propulsion (open) cycle. The tunnel test section Mach number range is 2.0 to 3.5. General support systems, such as air systems, hydraulic system, hydrogen system, fuel system, and schlieren system, are described. Instrumentation and data processing and acquisition systems are also described. Pretest meeting formats and schedules are outlined. Tunnel user responsibility and personnel safety are also discussed.

14. SUBJECT TERMS

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