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NASA Lewis 9- by 15-Foot Low-Speed Wind Tunnel User Manual

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NASA LEWIS 9- BY 15-FOOT LOW-SPEED WIND TUNNEL USER MANUAL

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1.0 INTRODUCTION

The 9- by 15-ft Low-Speed Wind Tunnel (LSWT), located adjacent to Cleveland Hopkins International Airport at NASA Lewis Research Center in Cleveland, Ohio (fig. 1) is available for use by qualified researchers. This manual describes the facility and details procedures for its use. The Aeropropulsion Facilities and Experiments Division (AFED) manages and operates the facility.

The 9- by 15-ft LSWT is equipped to support low subsonic testing of propulsion system components up to high angle of attack. Recent emphasis has been placed on the testing of components used in vertical and short takeoff and landing (V/STOL) propulsion systems. The tunnel is also used for testing the noise characteristics of propulsion systems and components such as inlets, nozzles, and propellers. Static testing can also be conducted in the 9- by 15-ft LSWT. The tunnel has a Mach number range from 0.05 to 0.20 and the test section is 9 ft high by 15 ft wide by 28.6 ft long. In addition, low speed testing of models from 5 to 23 knots can be accomplished using wing blowers (i.e., fans) located in the Air Dryer building (fig.2).

Inquires concerning the scheduling of tests can be made by contacting the facility manager (appendix A).

2.0 DESCRIPTION 9- BY 15-FT LSWT

2.1 General

The NASA Lewis Research Center 9- by 15-ft LSWT is located in Cleveland, Ohio. Seven major components comprise the NASA Lewis 8- by 6-ft Supersonic Wind Tunnel (SWT) and 9- by 15-ft LSWT facility (fig. 2) complex. The elevation view (fig. 3) shows that the LSWT tunnel consists of entrance flow control, settling, inlet contraction, test, and diffuser and exit sections. At station 0 the tunnel is 35 ft high and 30 ft wide, and at station 236 it is 30 ft by 30 ft (fig. 3).

The flow control section contains two (22 ft high by 12.5 ft wide) sliding flow-control steel doors, which are used to vary the velocity of air in the test section. The cooler is a finned-tube water heat exchanger. The function of the cooler is to control air temperature to the drive compressor (upstream of the 8- by 6-ft leg of the facility (fig. 2)). The drive compressor air temperature is controlled to provide a steady air temperature in the 9- by 15-ft test section for a given test section condition.

In order to improve the test section flow quality, four screens and one honeycomb structure have been installed upstream of the test section. The four screens are 10 by 11½ mesh, and the honeycomb structure consists of 3/8-in. square cells.

The test section dimensions at the inlet (station 27.7 (fig. 3)) are 9 ft by 15 ft. The test-section length is 28.6 ft. A detailed discussion of the test-section slotted walls is covered in section 2.2.

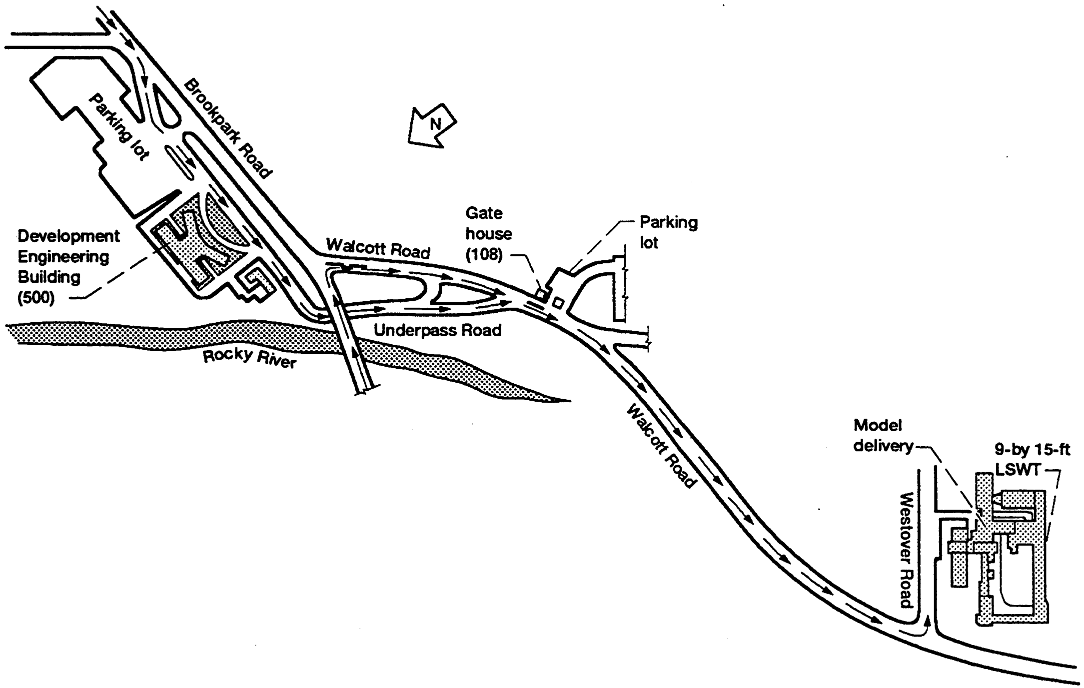


Figure 1.—Directions to 9- by 15-ft Low Speed Wind Tunnel Facility. Note: Underpass Road is the preferred entrance to NASA Lewis from the east but heavy trucks have a height restriction passing beneath Brookpark Road.

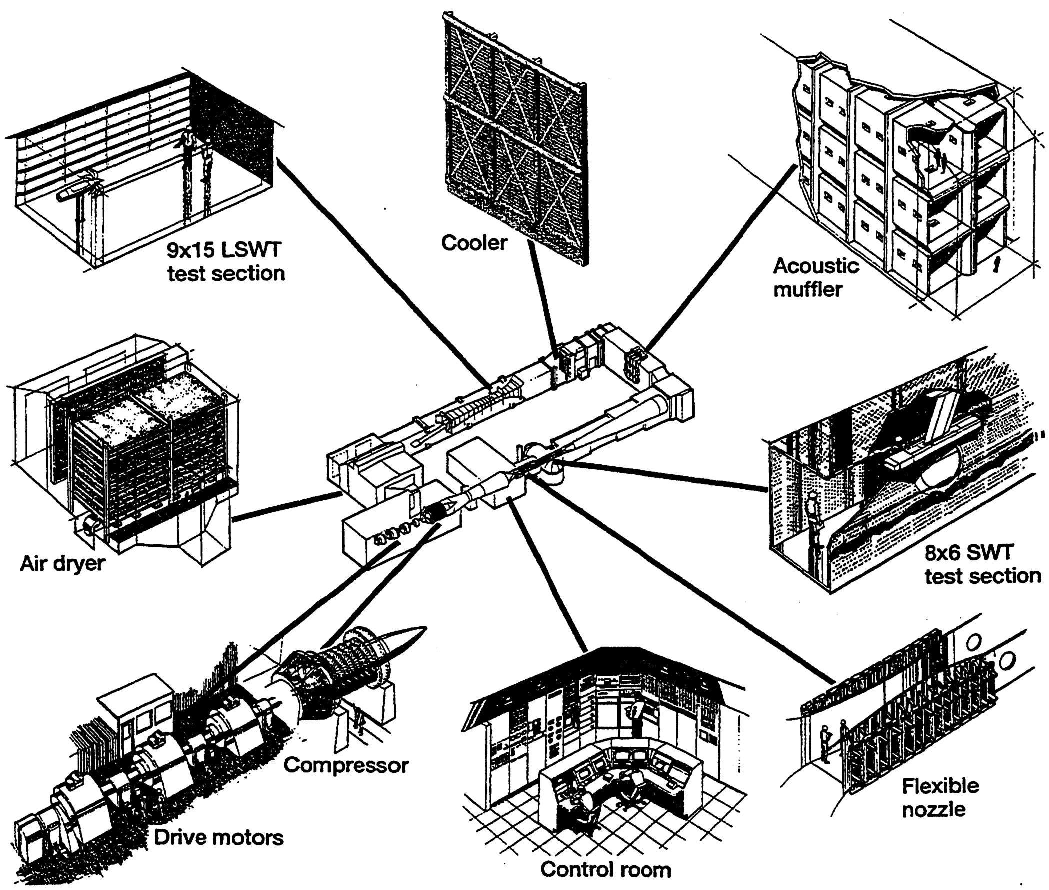


Figure 2.—Facility layout of 8- by 6-ft SWT and 9- by 15-ft LSWT.

The cross-section dimensions at the inlet to the diffuser (station 56.3 (fig. 3)) are 9 ft by 15.25 ft. The dimensions of the diffuser section at the outlet (station 124.3) are 17 ft by 23.25 ft. The length of the diffuser section is 68 ft. The included angle between inlet and outlet sections of the diffuser is 6.73°. A detailed description of the diffuser is presented in appendix C of reference 1.

2.2 Test Section Description

The dimensions at the test section inlet (station 27.7 (fig. 3)) are 9 ft by 15 ft. The cross-section dimensions at the test section exit (station 56.3) are 9 ft by 15.25 ft. The test section length is 28.6 ft long. Each side wall of the test section diverges 0.25° to account for longitudinal boundary layer buildup. The ceiling and the floor of the test section are completely closed. Each side wall has four, 4-in. wide slots that run the entire length of the test section. The walls are slotted to reduce tunnel wall interference effects and promote streamline flow over models during testing. A propeller model installed in the test section of the tunnel is shown in figure 4. The slots in the north wall of the test section are also shown in this figure.

The test section is equipped with removable acoustic panels. These acoustic panels cover the test section ceiling, floor, and walls. The ceiling and wall panels are bolted to the tunnel structure. Behind these panels are boxes that contain Kevlar a fibrous, bulk, sound-absorbing acoustic treatment material. The sides of the boxes that face the test section are open and are covered by a perforated panel. The configuration inside each box consists of two different densities of Kevlar acoustic material, each 6.75 in. thick. The different densities of Kevlar are separated and held in place by a 40-percent open-area, perforated plate which is located at the midpoint of the acoustic box. The Kevlar material closest to the test section has a density of 0.4 lbm/ft^3, and the other Kevlar material has a density of 1.1 lbm/ft^3. Above the test section ceiling and beneath the test section floor are single rows of acoustic boxes that butt up against each other. Behind the slotted test section side walls are two rows of staggered acoustic boxes. The acoustic boxes in the test section extend over a length of 27.5 ft.

A detailed description of experiments conducted to improve the absorptive lining of the 9- by 15-ft test section is presented in reference 2. Recent tunnel tests (spring of 1993) with an improved microphone support have resulted in lower background noise than previously recorded. These data are available from the facility manager and the AFED project engineer. In addition, a calibration of the test section is scheduled for the fall of 1993, and test section acoustic improvement may occur. Contact the facility manager for a report on these results. Typical models that have been tested in the test section are shown in figure 5. The model propeller test plane within the test section is presented in figure 6. Typical test section experiments are described in references 3 to 12. Data from a LSWT test section calibration are presented in reference 13 (published in 1989). The test section velocity can be varied from 43.3 to 148 knots by setting the facility compressor at a rated speed condition and adjusting the flow control doors from fully open to fully closed. When the flow control doors are fully open, the test section velocity can be reduced to 26 knots by reducing the compressor speed to its minimum controlled speed. In addition, four pairs of constant-speed wing blowers, located in the Air Dryer building (fig. 2), can be used for low-speed model testing. The total volumetric flow rate for the four pairs of blowers is 420 000 scfm (i.e., 105 000 scfm per pair of blowers). Because of tunnel losses, the air velocity in the test section varies from 5 to 23 knots, depending on the number of wing blowers used for a given test. Note that velocity conditions, as set by the facility compressor or wing blowers, are for an empty test section. The maximum velocity in the test section will be reduced by the blockage introduced by a particular model. Model blockage effects should be discussed with the AFED project engineer at one of the pretest meetings (see section 7.1).

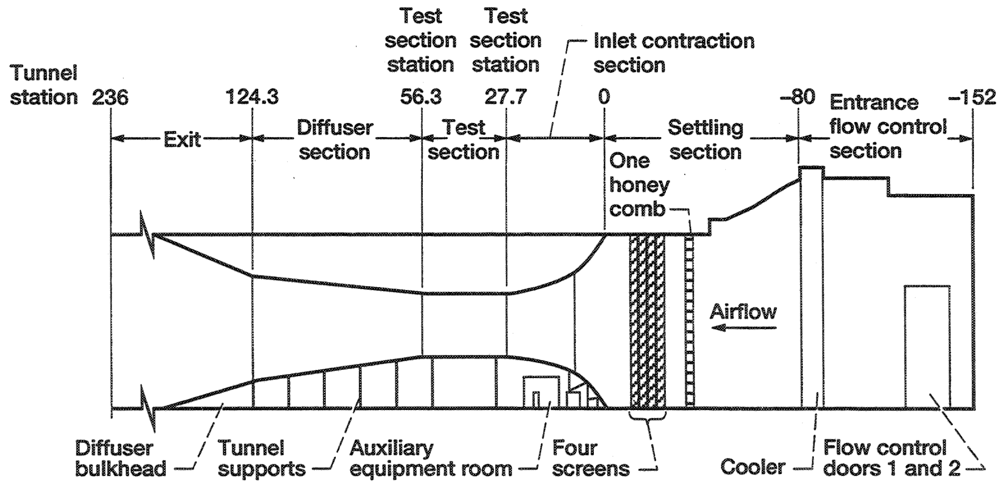


Figure 3.—Elevation view of LSWT facility. (All station numbers are in feet.)

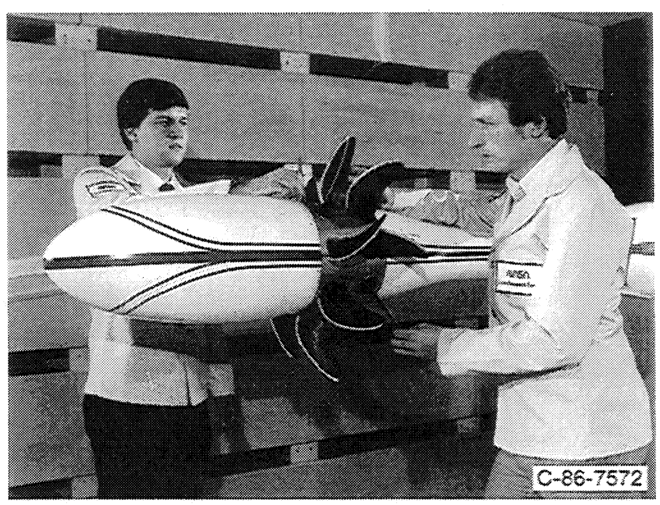
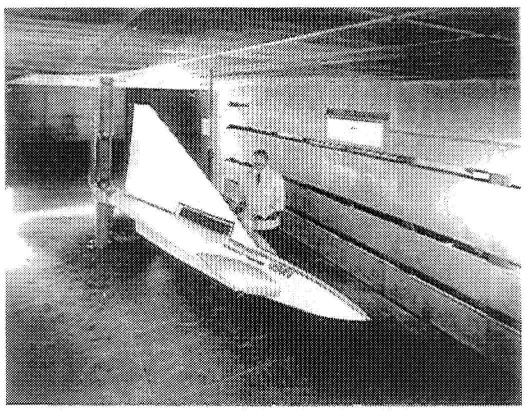
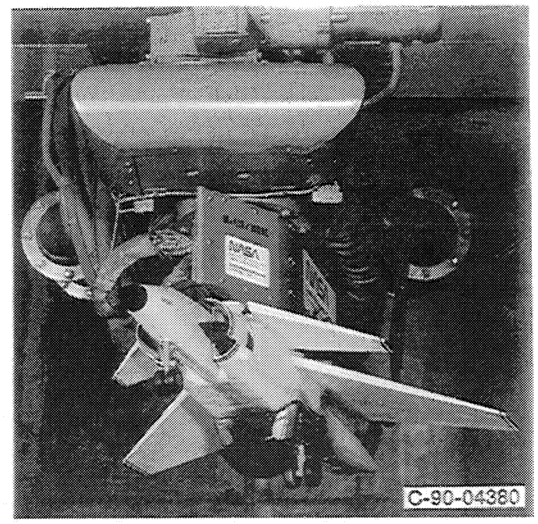


Figure 4.—Propeller experiment in LSWT test section.

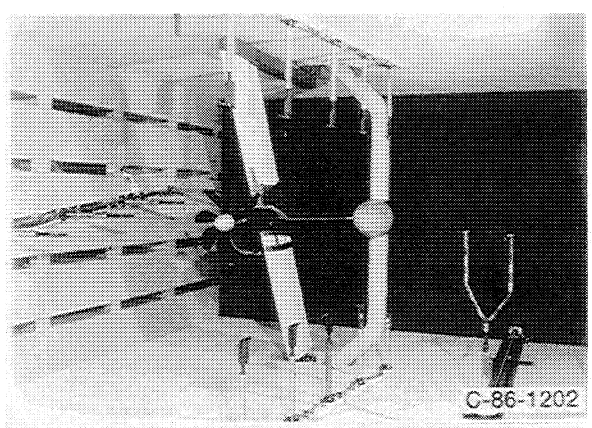


Ejector tests

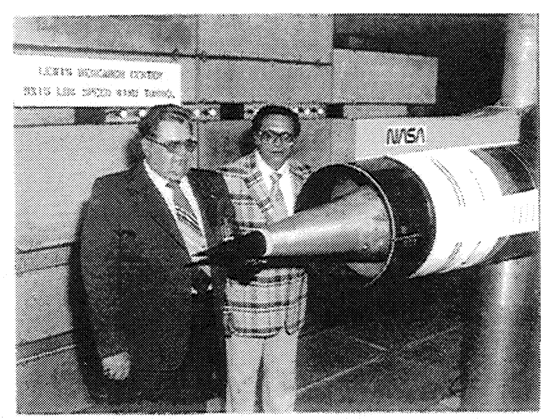


Hot gas ingestion testing

Tilt nacelle inlets



Acoustic testing of propeller rig



Hot gas ingestion testing

Figure 5.—Models installed in LSWT test section.

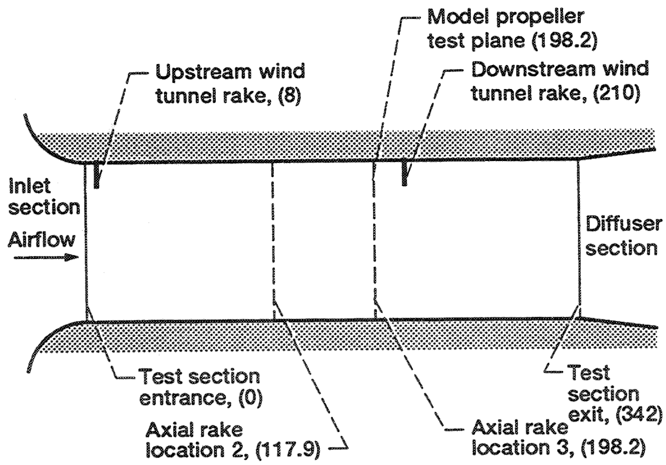


Figure 6.—Axial location of probes on test section ceiling rakes and instrumentation survey rake. (Numbers in parentheses are station locations, in inches.)

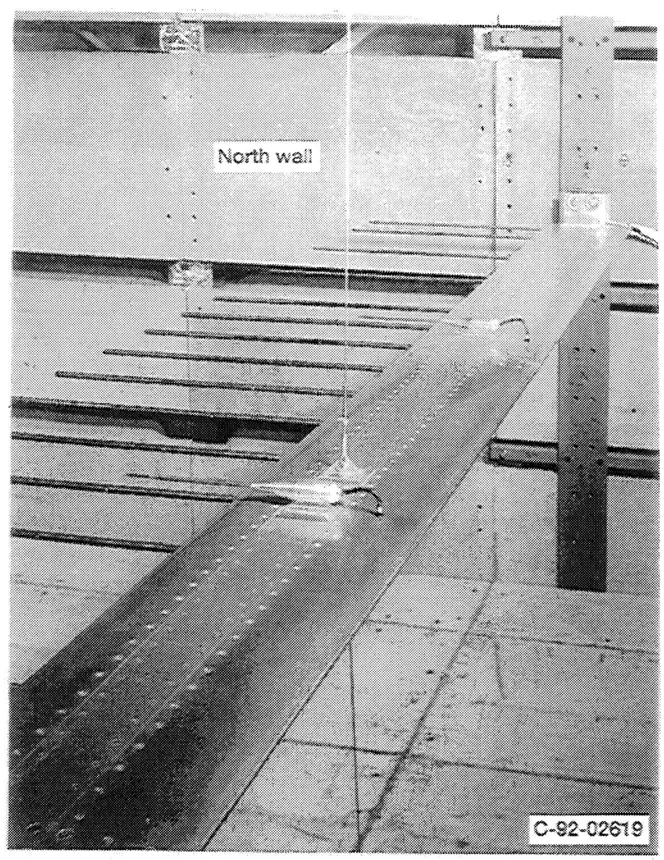


Figure 7.—Flow survey rake.

2.3 Test Section Profiles

Test section total and static pressure data were recorded during a 1992 tunnel test section calibration using the instrumentation rake shown in figure 7. This rake was placed at four test section axial locations. Data from two of these locations (2 and 3, see fig. 6), are presented in this report. Total- and static-pressure data from this rake were normalized to pressure data obtained from a total- and static-pressure ceiling rake which is located at station 210 (figs. 6 and 8). This ceiling rake is offset from the test section longitudinal centerline by 0.09 ft (toward the north wall of the test section (fig. 7)). It should be noted that the data presented in this report were recorded before the installation of the honeycomb and four screens upstream of the test section inlet (fig. 3). A detailed test section calibration is scheduled for the fall of 1993, and an improvement in the test section profiles presented herein may result. Contact the facility manager for a report on the test section calibration.

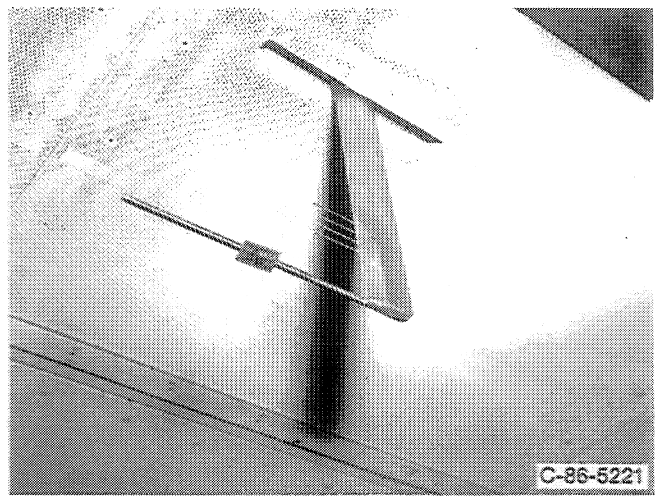
Normalized profiles of total and static pressure are presented in figures 9 and 10. Data are presented at two vertical rake locations (± 3 ft with respect to the test section horizontal centerline). The normalized total pressure profiles show that the pressure data recorded 3.0 ft above and below the tunnel test section horizontal centerline and within ± 5.5 ft of the test section vertical centerline do not vary with an increase in the test section Mach number. The amplitude of total pressure data recorded within 2 ft of the tunnel test section side walls decreases rapidly and is due to boundary-layer effects. Some of the data in the boundary layer is truncated due to the high-resolution ordinate (i.e., reduction in data scatter) selected for the profiles presented in figure 9. It is recommended that model installations be confined to a test-section area that is 11 ft wide by 6 ft high and is centered in the test section.

Normalized static pressure profiles are presented in figure 10. The static pressure profiles are flat across the entire test section for Mach numbers 0.05 and 0.10. There is a small divergence in static pressure profile within 2 ft of the test section side walls for Mach numbers 0.15 and 0.20 (figs. 10(a) and (b)). This divergence is caused by boundary-layer effects at the tunnel test section side walls.

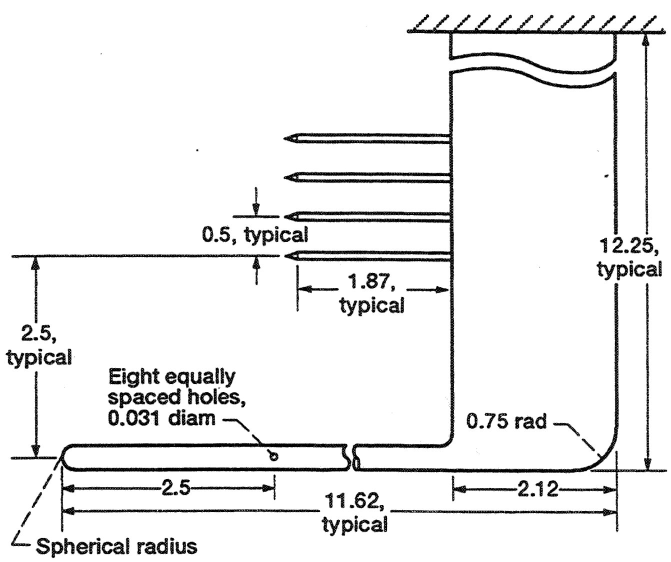
Normalized total and static pressure axial profiles are generated from data recorded at the test section centerline (figs. 11 and 12). Data from two test-section axial rake locations are presented (locations 2 and 3 (fig. 6)) and for four Mach numbers: 0.05, 0.10, 0.15, and 0.20. It is observed that the normalized total pressure axial profiles at the test section center are flat over a length of ± 5.5 ft with respect to the test section vertical centerline (figs. 11(a) to (d)). As the test section Mach number increases, the normalized total pressure profiles decrease in the test section boundary layer (within 2 ft of the test-section side walls). These profile effects are produced by the test-section side-wall boundary layer (figs. 11(b) to (d)).

The normalized static pressure axial profiles are presented in figures 12(a) to (d). At a Mach number of 0.05, the static pressure profile at the test section center is flat across the entire test section (fig. 12(d)). As the test section Mach number increases, the static pressure profile in the boundary layer increases with increasing test section Mach number because of the test-section side-wall boundary layer effects. The least variation in static-pressure axial profiles over a length of ± 5.5 ft with respect to the test section vertical centerline occurs at test section location 2 for a Mach number of 0.05 (fig. 12(d)).

During the 1992 test-section calibration, turbulence intensity levels were measured using hot films. Turbulence intensity for this discussion is defined as the local fluctuating velocity in the x-direction (axial) divided by the free-stream velocity (u_x/U_∞). The data presented in figure 13 show that turbulence intensity levels measured at test section location 3 (station 198.2 (fig.6)) varied from 2.37 percent at 0.10 Mach to 1.77 percent at 0.20 Mach number. These data were also recorded before the installation of the honeycomb and the four screens upstream of the test section (fig. 3). Turbulence measurements will be a



(a) Downstream wind tunnel rake at test section station 210 (near model test plane).



(b) Schematic (dimensions are in inches).

Figure 8.—Test section ceiling rake.

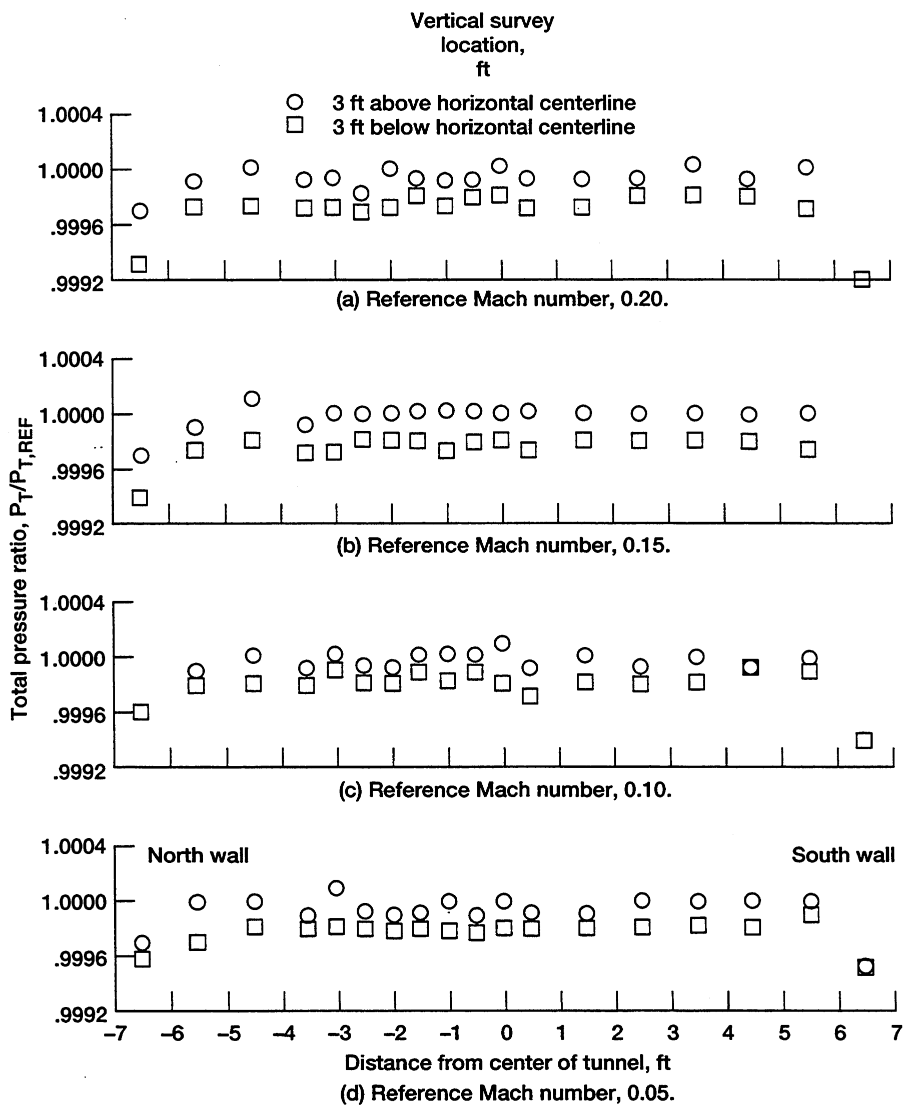


Figure 9.—Total pressure cross-sectional profiles at axial survey location 3 (test section station 198.2).

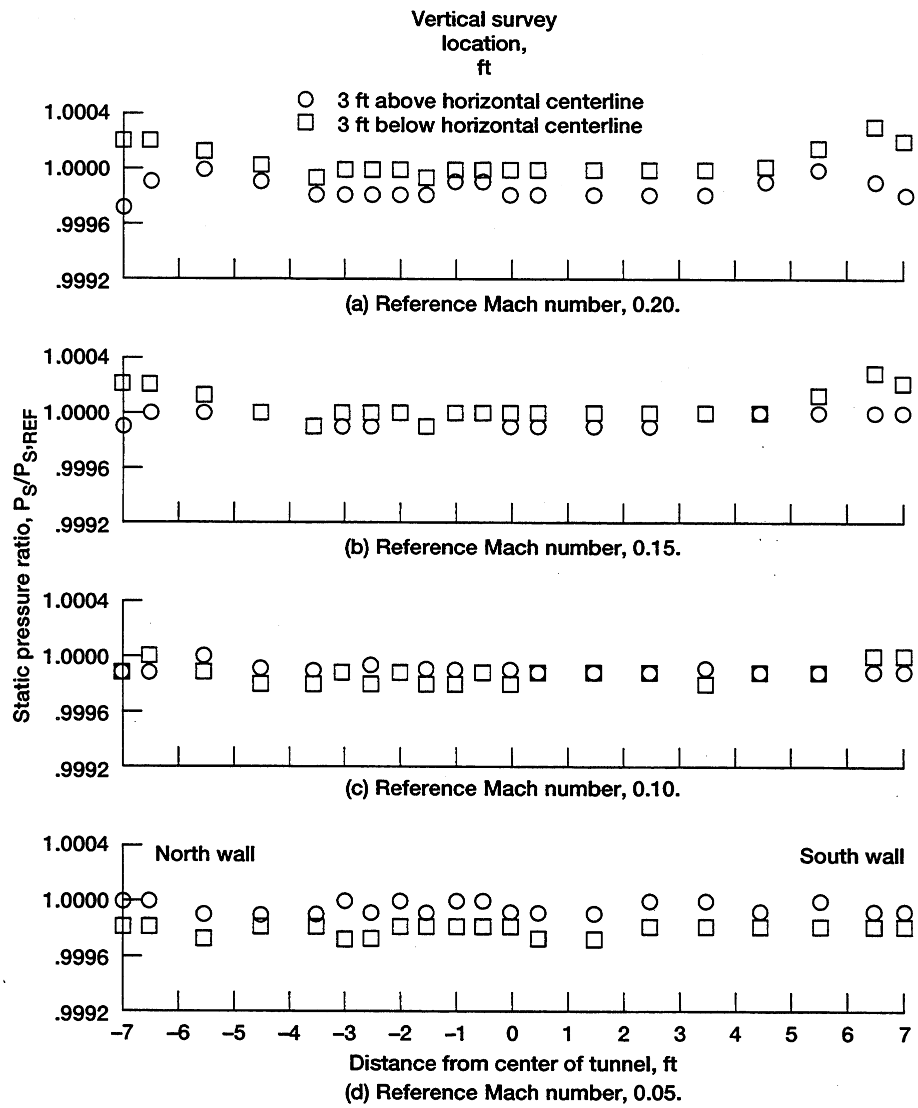
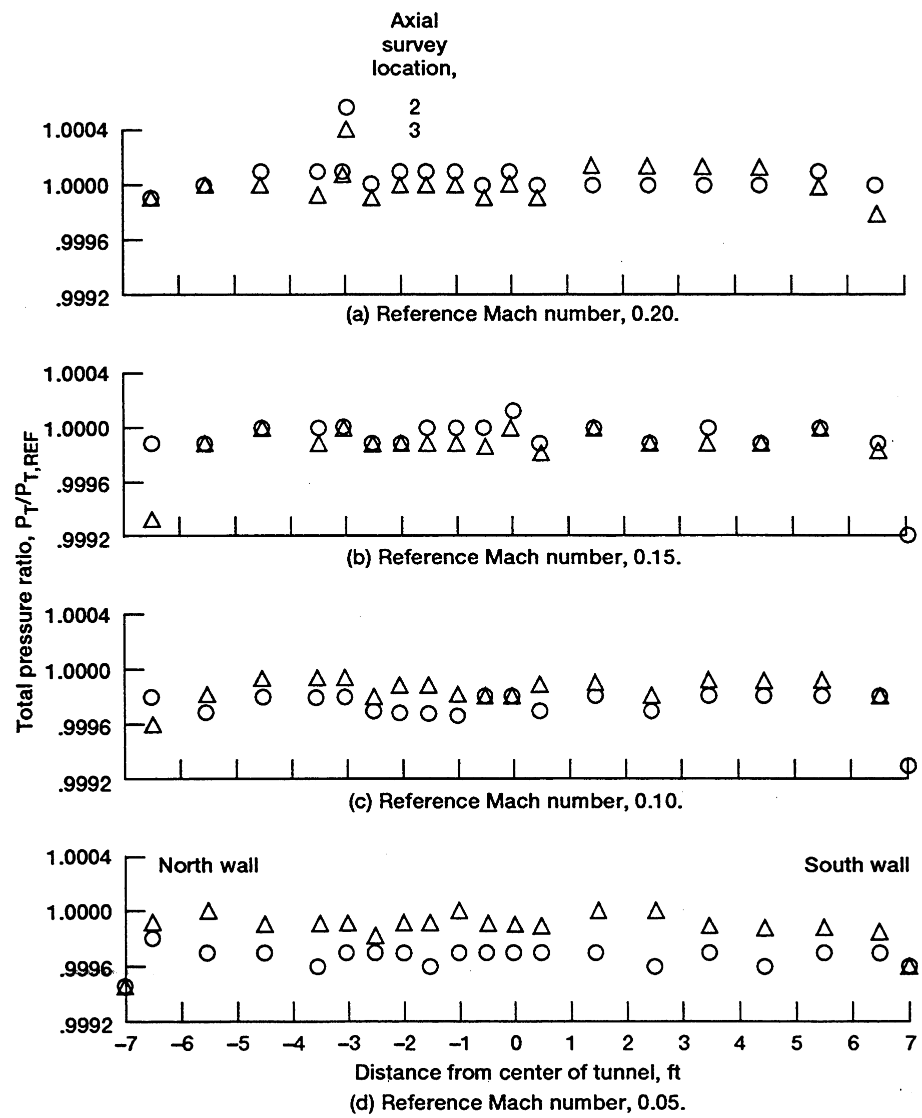


Figure 10.—Static pressure cross-sectional profiles at axial survey location 3 (test section station 198.2).



(d) Reference Mach number, 0.05.

Figure 11.—Total pressure axial profiles at center of tunnel test section.

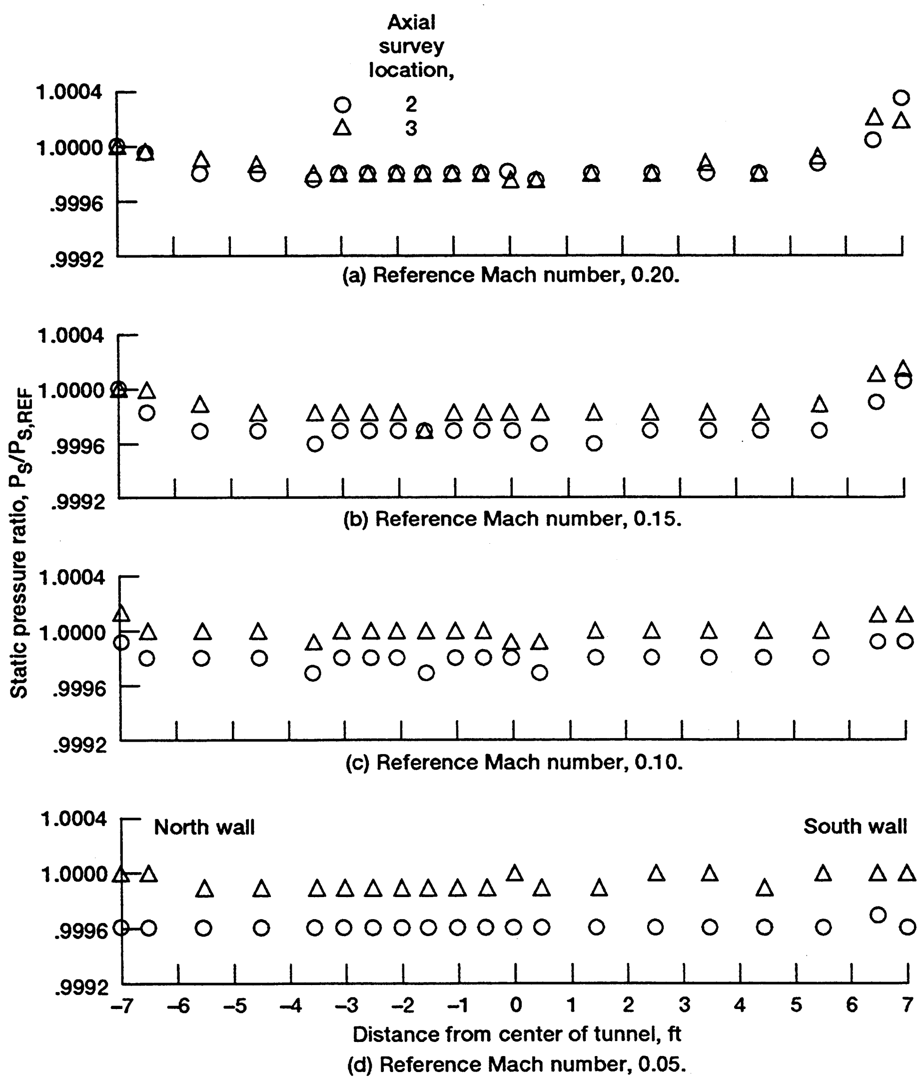


Figure 12.—Static pressure axial profiles at center of tunnel test section.

part of the detailed calibration of the test section in the fall of 1993. A further reduction in turbulence level may result (see facility manager for calibration report).

2.4 Tunnel Components

The major components of the NASA Lewis LSWT, illustrated in figures 2 and 3 (p. 2), are as follows:

Compressor.—Tunnel air is driven by a seven-stage axial-flow compressor, rated at a volumetric flow rate of 56 000 ft^3/sec at a pressure ratio of 1.8. It is driven by three wound-rotor motors having a total power capacity of 87 000 hp.

Acoustic muffler.—The acoustic muffler is housed in the tunnel crossleg upstream of the LSWT test section. The acoustic muffler is used to quiet the discharge air from the compressor.

Flow control doors #1 and #2.—The sliding steel doors are 12.5 ft wide by 22 ft high and are used to vary the velocity in the test section.

Cooler.—The cooler is a finned-tubed water heat exchanger. The cooler is used to control the inlet air temperature to the drive compressor and the result is that the temperature in the test section remains steady at a particular test section condition.

Test section.—The dimensions at the test section inlet are 9 ft by 15 ft. The dimensions at the outlet are 9 by 15.25 ft. The length of the test section is 28.6 ft. See section 2.2 for details on the acoustic boxes.

2.5 Control Room

The control room (fig. 14), used to operate the LSWT and the SWT, is located on the first floor passageway which connects the SWT office building with the facility (fig. 15). The consoles located at the front of the control room are used by the tunnel and model operators. The consoles located in the middle of the control room are reserved for the research engineer (tunnel user) and the AFED project engineer. Each console has the appropriate controls and readouts that the respective operators use. The tunnel is operated from an interactive color graphics, distributive control system referred to as the Westinghouse Distributive Processing Family (WDPF). Controls necessary to set tunnel conditions (e.g., the position of the sliding flow control doors, compressor speed, etc.) 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. A test section model can be remotely viewed through the use of monitors located in the control room.

The control room also contains the NASA Lewis data acquisition system, identified as Escort D Plus, and the electronic scanning pressure system (ESP) available for model instrumentation. The Escort D Plus system is interactive (push button) and can collect, process, display, and record data as accumulated during a test. Refer to sections 5.1 and 5.2 for further details on ESP and Escort D Plus systems.

The control room can be completely secured for classified test programs. Security should be discussed with the 9-by 15-Ft LSWT facility manager and the AFED project engineer during one of the pretest meetings held at NASA Lewis.

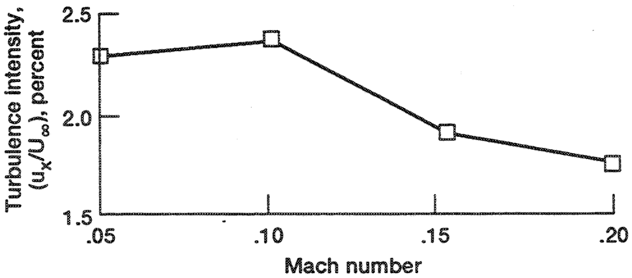


Figure 13.—Turbulence intensity in LSWT test section at axial rake location 3 (see fig. 6).

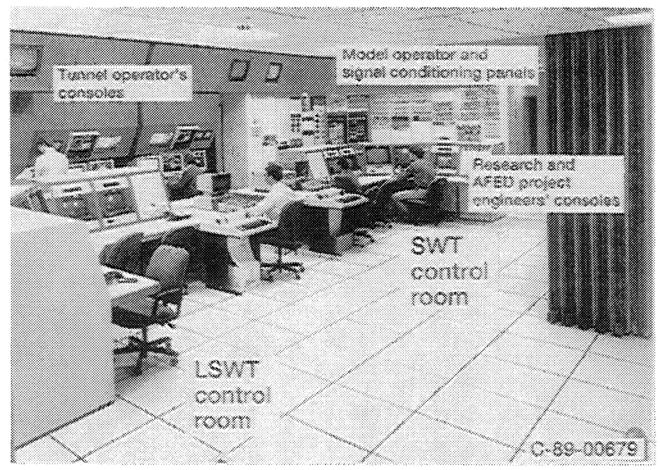


Figure 14.—LSWT and SWT control room.

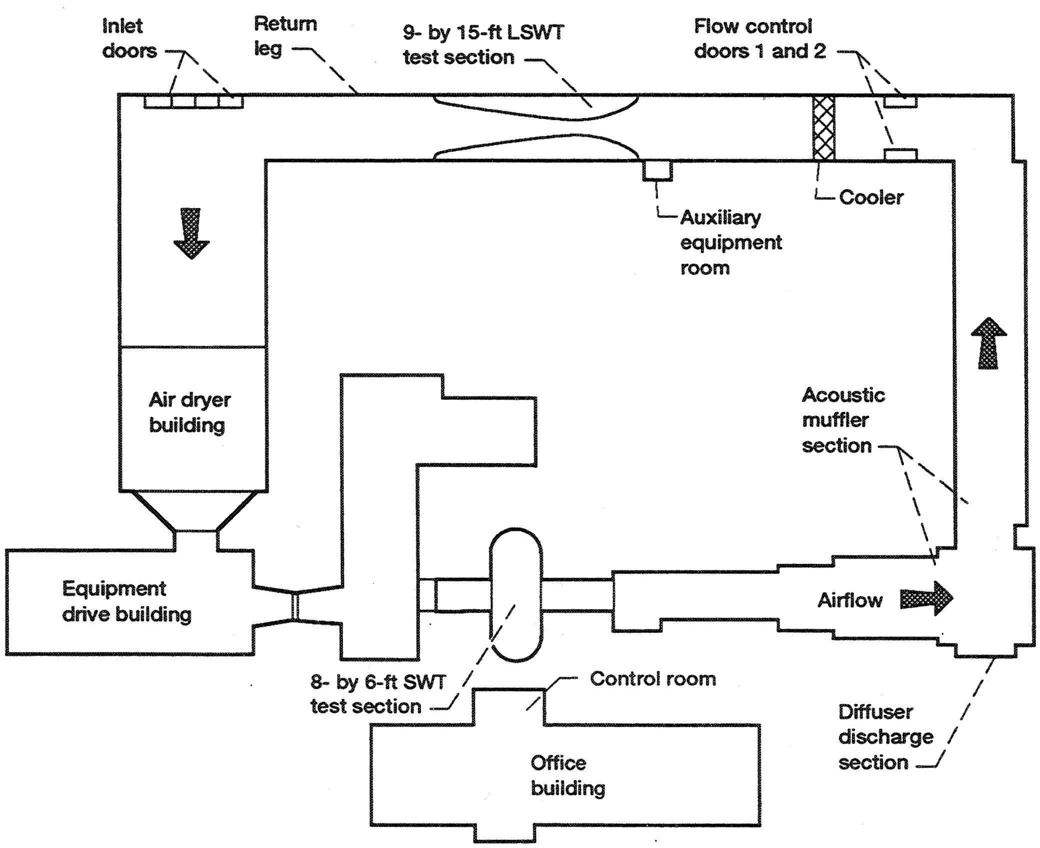


Figure 15.—Plan view of the test section in the return leg of SWT/LSWT facility.

2.6 Auxiliary Equipment Room

The auxiliary equipment room is located one level beneath and north of the test section (fig. 15). This equipment room contains electronic signal conditioning, signal processing and signal amplification equipment that can be used to monitor the model. This equipment can be used during model experiments if the tunnel user, AFED project engineer, and the facility electrical engineer agree that the instrumentation signals sent to the main control room are not sufficient to meet the research needs of the tunnel user.

3.0 GENERAL SUPPORT SYSTEMS

The following table presents pertinent information on facility support systems:

TABLE I.—FACILITY SUPPORT SYSTEMS

System	Weight or volumetric flow rate	Pressure	Volume	Temperature
High pressure air	Variable	14.7 psia to 2600 psig	600 000 ft^3 to 3373 ft^3	-----------
Service air	2.5 lbm/sec	125 psig	-----------------------	-----------
Combustion air	30 lbm/sec	40, 150, or 450 psig	-----------------------	Ambient
Two combustion air heaters	5 lbm/sec	450 psig	-----------------------	1200 °F (max)
Hydraulic	15 gpm	3000 psig (max)	-----------------------	-----------
Nitrogen	2.0 lbm/sec 1.5 lbm/sec	150 psig 1500 psig	----------------------- -----------------------	Ambient Ambient
Gaseous hydrogen	1 lbm/sec	1200 psig	-----------------------	Ambient
Altitude exhaust (a) 24-in. diam. line	24 lbm/sec 30 lbm/sec	[a]13.2 in. Hg abs [a]23.3 in. Hg abs	----------------------- -----------------------	----------- -----------
(b) 12-in. diam. line	6 lbm/sec 10 lbm/sec	[a]13.2 in. Hg abs [a]23.3 in. Hg abs	----------------------- -----------------------	----------- -----------

[a]Other vacuum pressures are available. Consult with the AFED project engineer.

3.1 Air Pressure Systems

3.1.1 High pressure air.—A storage facility with a capacity of 600 000 ft^3 of standard dry air (3373 ft^3 at 2600 psig) is available for use at the 9- by 15-ft LSWT. Two other storage facilities interconnected with it are a 135 000-ft^3 system (759 ft^3 at 2600 psig) located at the 8- by 6-ft SWT (front leg of the facility) and a 216 000 ft^3 (1214 ft^3 at 2600 psig) system located at the 10- by 10-ft SWT. These three facilities together provide 951 000 ft^3 of standard dry air for use at the 9- by 15-ft LSWT. They are charged by a single compressor having a capacity of 1120 ft^3/min of standard air. Total charging time from atmospheric pressure to 2600 psig is approximately 14 hours for the combined systems. The high-pressure air flow from the three storage facilities can be regulated to accommodate model requirements. 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 the capacity of 2.5 lbm/sec continuous service at 125 psig is available.

3.1.3 Combustion air.—A central combustion air system of 40, 150, or 450 psig each at a flow rate of 30 lbm/sec can be delivered to the facility. Three facility heaters are available to heat air. One heater is low temperature (30 lbm/sec at 700 °F) and can be used with the SWT and LSWT facilities. The other two heaters are available for the LSWT only and can be set independently. These heaters are capable of elevating the model air temperature to 1200 °F at a flow rate of 5 lbm/sec.

3.2 Hydraulic System

A hydraulic system is available for actuation or positioning of a model or its components. The system consists of a constant-volume pump delivering 15 gpm at 3000 psig. The model hydraulic pressure is determined by the requirements of each particular model to be tested and is reset prior to each run.

3.3 Nitrogen System

Two nitrogen tanks are located in the courtyard next to the LSWT test section. The nitrogen pressure inside each tank is 2000 psig. The nitrogen from one tank can be delivered to the test section at 1500 psig, and the nitrogen from the other tank can be delivered to the test section at 150 psig. These pressures can be regulated to values that meet the research requirements of the tunnel user. Nitrogen flow rates from the storage tanks to the test section are 2.0 and 1.5 lbm/sec, based on the maximum pressures at the test section (table I, section 3.0). The gaseous nitrogen system is used for pressure control, valve actuation, and purging purposes.

3.4 Gaseous Hydrogen System

A system is available to deliver gaseous hydrogen to a burning model for propulsion testing at a maximum flow rate of 1.0 lbm/sec at 1200 psig and ambient temperature. Up to three gaseous hydrogen trailers, each with a capacity of 70 000 scf (464.6 ft^3 per trailer at 2200 psig), can be simultaneously connected to the system. One flow station controls the flow in the model supply line. The main supply line (1½ in., schedule 80s, stainless-steel pipe) is divided into two model flow measurement supply lines, each having a flow shutoff valve and venturi flowmeter. One or both of the venturies can be resized to measure a wide range of hydrogen flow to the model. Regulators in the main supply line control pressure upstream of the flow control valve.

A gaseous hydrogen detector system is installed throughout the wind tunnel facility to monitor for any gaseous hydrogen accumulations. Thirteen sensors are used and are monitored centrally in the tunnel control room.

The gaseous nitrogen system is used to purge the gaseous hydrogen piping and model supply lines before and after tunnel test runs. A single gaseous nitrogen trailer combined with facility nitrogen, supplies the required nitrogen.

3.5 Infrared System

The infrared system or thermal image management system (TIMS) is composed of a personal computer with keyboard, mouse, system monitor for display of menus, and an input device (either an imager with viewfinder or a VCR with infrared images previously recorded). TIMS is capable of temperature measurement for various analysis menus described below.

The single-point temperature menu permits the operator to measure the temperature of any point on the image. At startup, the crosspoint is at the center of the image. The crosspoint can be moved with a mouse.

The multiple point temperature menu allows the user to select up to 12 crosspoints for temperature measurements on the image. During this menu selection and with emissivity correction enabled, each crosspoint can have its own emissivity value.

The multiple temperature menu selection allows the user to measure the mean, minimum, and maximum temperature within a rectangular area of interest. Just as with multiple crosspoints, there can be up to 12 areas-of-interest defined by the user for one image. When emissivity correction is enabled, each area-of-interest can have a different emissivity value.

The temperature distribution within any selected rectangular area may be displayed with the histogram feature. The size of the area selected is determined by the user. The temperature range is plotted on the rectangular axis, and the relative frequency of occurrence is represented on the vertical axis. The results are normalized to present greater detail.

Additional features of the TIMS include irregular histograms plus isotherm and thermal contours. Infrared system requirements should be specified by the tunnel user during a pretest meeting with the AFED project engineer.

3.6 Laser-Doppler Velocimeter (LDV) System

A laser-Doppler velocimeter (LDV) system is installed adjacent to the LSWT test section. The laser system is a 6-W, argon-ion, four-beam, two-color optics system. The laser system is elevated to the test section level by a structural steel stand mounted to the floor of the facility. The stand is 11.2 ft high, 7 ft wide, and 19 ft long. The function of the stand is to isolate the laser system from tunnel vibration. A portable platform that supports the laser system is placed on top of the stand. The platform is fixed to the stand through the use of four extendable support pads. The portable platform has a power screw and a 3-ft by 5-ft table that supports the laser system. The platform table can be remotely moved 40 in. in the tunnel longitudinal direction, 20 in. in the vertical direction, and 20 in. in the tunnel spanwise direction. Gross position change to the laser system table adjustments are made in the field. In addition, various acoustic boxes can be removed from the north wall of the test section to permit the positioning of a laser system within a rectangular area. The forward location of a standard opening in the test section north wall is 12 ft from the inlet of the test section and 2 ft 3 in. from the test section floor. The opening in the test section north wall is 6 ft long by 4 ft 6 in. high. Numerous laser configurations within this rectangular opening are possible. The tunnel user is required to supply a table to support the laser system within the open area in the test section north wall. This topic should be discussed with the AFED project engineer at one of the pretest meetings.

In figure 16 velocity vectors are measured by determining the fringe-crossing frequency of seed particles embedded in the flow field as they traverse the interference pattern created at the intersection point of two beams of like color.

3.7 Laser Sheet (Flow Visualization) System

The laser sheets used in the facility are produced through use of a 15-W, copper-vapor laser; a 6-W, two 15-W, or one 25-W, argon-ion laser coupled with a fiber-optic system that is used to deliver the laser beam to the test section. An optic head that houses the lenses is coupled to the fiber-optic cable at the test section end. The lenses produce a sheet of light that is approximately 18 in. high and 0.125 in. wide at the centerline of a model. The lenses can be changed to vary these dimensions. The optic package is mounted on a traversing mechanism which allows detail observations over a traverse length of 42 in. The laser operates in the 510.6- and 578.2-nm wavelength. The laser sheets can be setup in different orientations (e.g., parallel to the test sections walls, parallel to the test section ceiling or floor).

The flow field may be viewed through use of an array of video and still cameras. Color video cameras can be mounted at different test section locations in order to get the best views of the flow field and to obtain maximum light levels. This point can be discussed with the AFED project engineer and the facility electrical engineer at one of the pretest meetings. Still photographs can be taken using a combination of remotely controlled 70- and 35-mm cameras. A laser sheet at the centerline of the forward nozzles of the 9.2 percent short takeoff and vertical landing (STOVL) model is presented in figure 17.

3.8 Force Balance System

Provisions can be made to record model force data. All balances and load cells are to be supplied by the tunnel 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.

3.9 Altitude Exhaust System

Altitude exhaust system piping enters the LSWT facility through a 36-in.-diameter steel pipe located above the test section and at a right angle to the test section. A 24-in.-diameter, schedule 40, carbon steel pipe is fitted into the 36-in.-diameter pipe, and is orthogonal to it. The 24-in.-diameter pipe extends above the test section ceiling where it enters a muffler. The piping at the muffler exit is a 16-in.- diameter pipe and it goes through a 90° bend where it enters the test section ceiling. The piping can be modified to fit the exhaust of a given model. In addition, midway along the length of the 24-in.-diameter pipe, an 8-in.-diameter pipe is fitted into it and extends back to a flow control valve. At the exit of this valve is a 12-in.-diameter pipe which extends back to the 36-in.-diameter pipe. The purpose of this 12-in.-diameter line is to fine-tune the altitude exhaust flow; (The smaller diameter pipe contains a smaller diameter flow control valve, and therefore provides better flow control accuracy). A separate 12-in.-diameter, schedule 40, pipe extends above the test section ceiling and is fitted into the 36-in.-diameter line. The 12-in.-diameter line is parallel to the 24-in.-diameter line. This pipe can also be fitted to a model exhaust. Piping modification at the model exhaust can be discussed with the AFED project engineer at one of the pretest meetings. The vacuum and flow rate conditions that can be supplied to either the 12-in.- or 24-in.-diameter piping can be varied over a wide range of conditions. Typical air flow rates and vacuum conditions that can be achieved through each line are listed in table I.

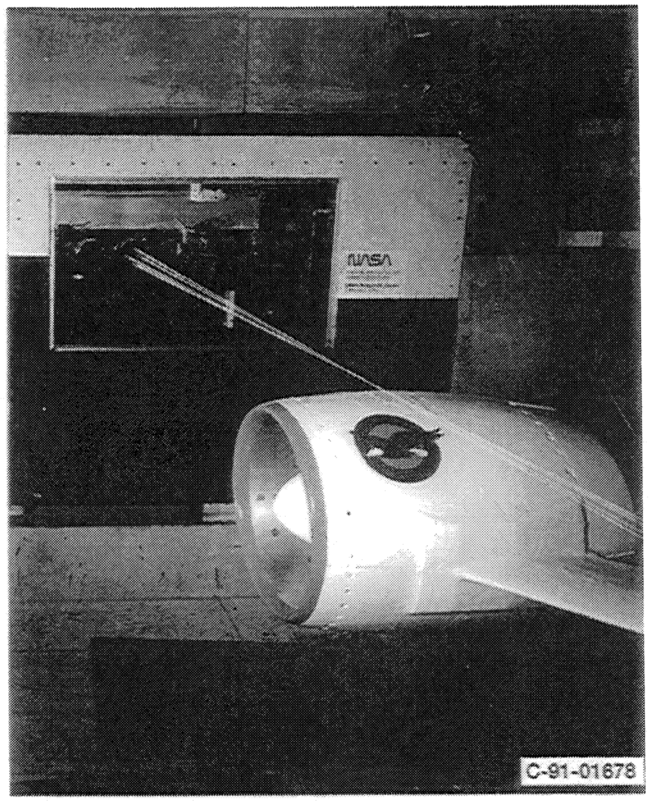


Figure 16.—Laser Doppler velocimeter system used to measure reverse flow velocity from model exhaust.

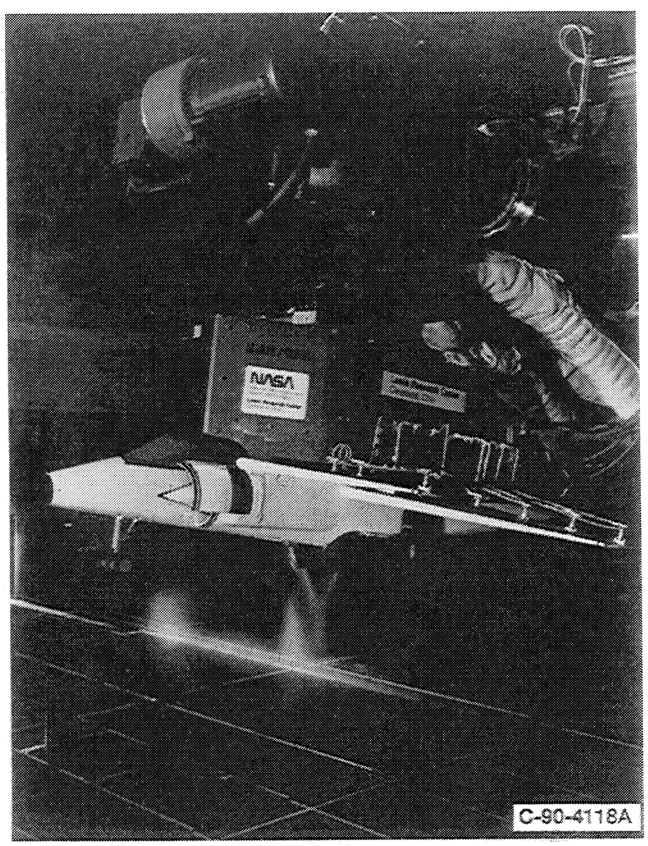


Figure 17.—Spanwise laser sheet at centerline of forward nozzles of 9.2 percent STOVL model.

3.10 Model Support System

3.10.1 Model integrated support system.—The model integrated support system (MISS) provides model yaw, pitch, roll, and vertical height adjustments (fig. 18). The MISS includes high-pressure, hot (1000 °F) air lines and a suction line to provide inlet airflow. A ground plane (an auxiliary piece of equipment—see section 3.10.2) with a sliding trap door opening is also used with this system.

The yaw drive system has a turntable bearing and spur gear that is used to obtain the desired ±180° movement. The turntable spur gear is rotated by a 1/3 hp, single-phase, spark-free ac motor. The motor is equipped with a clutch and brake unit to hold the model position when the drive motor is turned off. The yaw drive system rotation is 0.51°/sec at the model.

The pitch drive system has a turntable bearing and spur gear that is used to obtain the desired ±30° movement. The turntable spur gear is also rotated by a 1/3-hp motor as noted above. The pitch drive system rotation is 0.4°/sec at the model.

The roll drive system has a turntable bearing and spur gear that is used to obtain the desired ±20° movement. The turntable spur gear is also rotated by a 1/3-hp motor as described above. The roll drive system rotation is 0.49°/sec at the model.

Limit switches are used to control directional travel of the yaw, pitch, and roll drive systems. In the event of a limit-switch failure, the yaw, pitch, and roll system gear box housings serve as a mechanical hard stop to eliminate model or facility damage. The gears within the gear housings are designed for gear deformation and lockup before shaft keys will shear to prevent uncontrolled model motion.

The vertical height system is composed of two suction lines, one sliding over the other to obtain the infinitely variable model heights above the test chamber reference plane (i.e., tunnel floor or the ground plane). Wiper seals and O-ring bushings are used to prevent air leaks and rubbing contact of the metal suction lines. Four, 4-in.-diameter stainless-steel case-hardened shafts are used to maintain assembly alignment and absorb system loads. Four, 2.5-in.-double bearings are used to absorb loads from the movable suction lines. Two ballscrew and ballnut combinations provide the finely controlled linear vertical movement. Limit switches are manually positioned to control the vertical displacement. The limit switches are backed up with mechanical stops to prevent damage to the model or facility in the event of overtravel. Power is provided by a 2-hp, variable-speed dc motor coupled to a 30:1 single-worm-gear reduction unit. The motor is equipped with a clutch and brake unit to hold the model position when the drive motor is turned off. The gear reducer drives a dual chain sprocket to move the model at a rate between 0.5 and 14.5 in./min. The motor noted above has both thermal- and current-limiting internal protection. The gear sections are designed for gear deformation and lockup before a shaft key will shear to prevent uncontrolled model motion.

3.10.2 Ground plane.—The ground plane is used during short takeoff and landing (STOL) and STOVL tests in the facility. The width of the ground plane is 176 in. The length of the ground plane can vary from 96 to 336 in. to satisfy the requirements of an experiment. The height of the ground plane above the test section floor can vary from 18 to 61 in. to satisfy the requirements of a model experiment.

When a STOVL model is tested, the ground plane height above the test section floor can be adjusted to meet research requirements. The ground plane configuration used with STOVL models includes a sliding trap door. The trap door opening is 42 in. long and 40.75 in. wide. The position of the trap door within the ground plane area can be changed to suit the objectives of the particular experiment. The trap door system consists of three main components: sliding trap door, ducting, and ejectors. Model nozzle

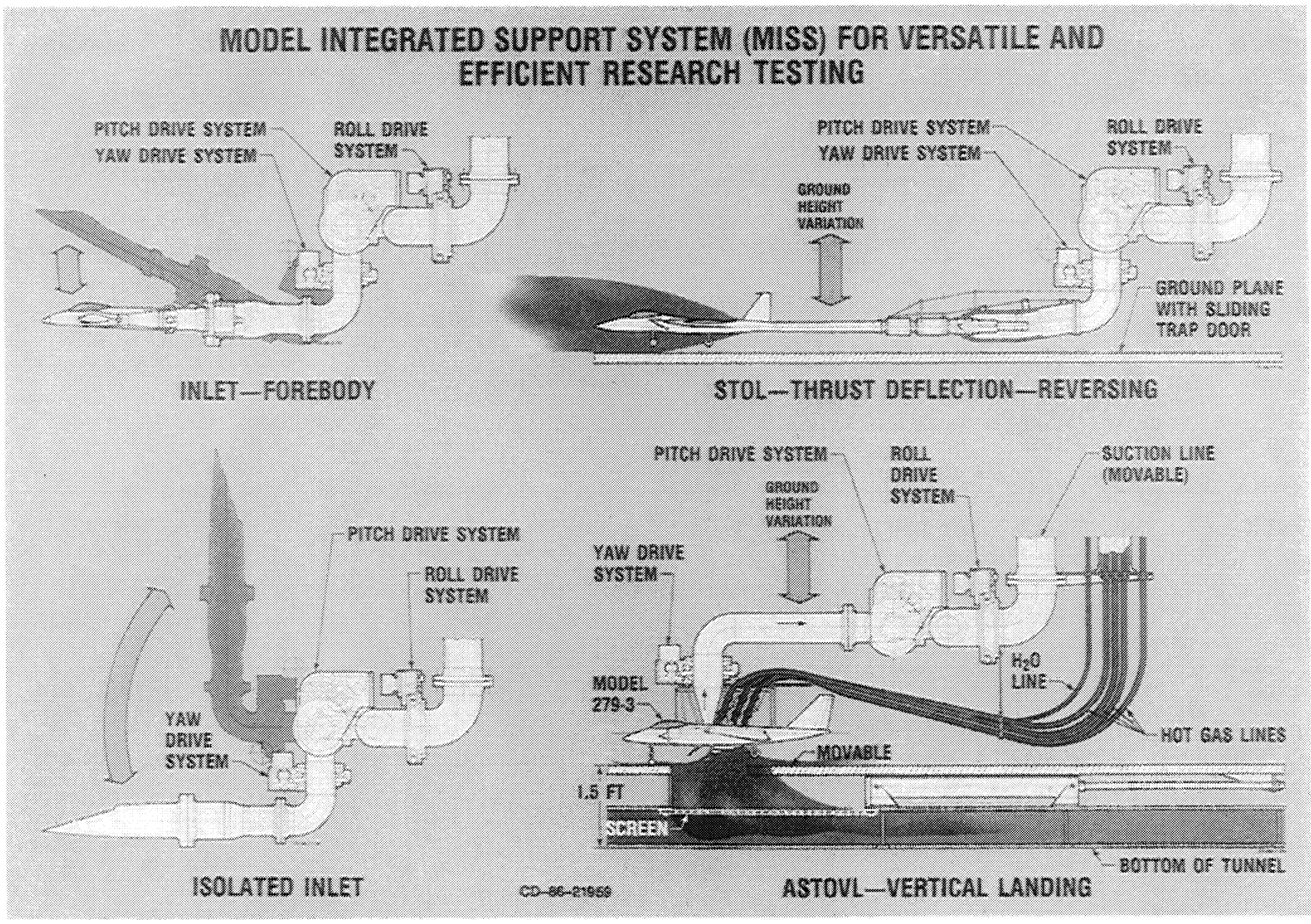


Figure 18.—Schematic of model integrated support system (MISS).

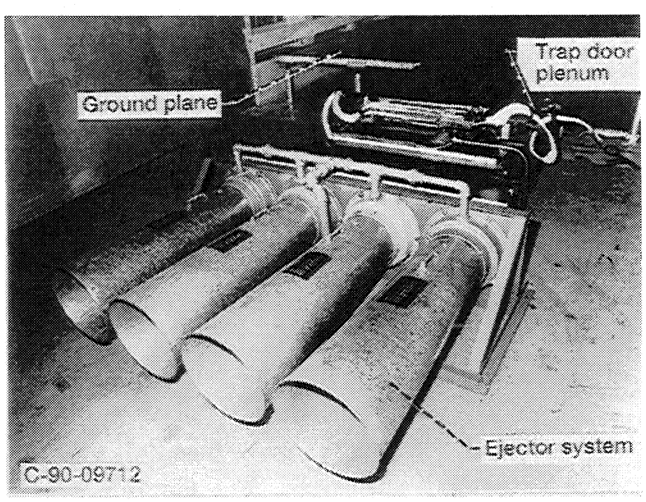


Figure 19.—Aft view of ground plane and ejector system.

flow is sucked through the trap door opening into the duct under the ground plane and is exhausted downstream of the test section by the ejectors (fig. 19). The trap door is open when the STOVL nozzle pressure ratio and temperature is set and is closed after conditions are obtained.

The ground plane centerline can be instrumented with static taps and flush mounted thermocouples (temperature taps) that are isolated from the plate surface in order to measure ground plane air temperature. In addition, double-sided and single-sided instrumentation rakes can be placed at strategic locations on the ground plane. These instrumentation rakes contain total-pressure, total-temperature, and static-pressure measurements. The double-sided rakes are used to measure the free-stream side flow and the flow coming from the nozzle jets (model side). The single-sided rakes measure only the model side of the flow. Additional instrumentation can be added to the trap door in the form of static taps and thermocouples. The ground plane length, width, and height dimensions to satisfy an experiment requirement can be discussed with the AFED project engineer at one of the pretest meetings.

3.10.3 Exhaust support system.—A modified F–15 model is shown in figure 20. The model is supported by twin flow-through stings. These stings are mounted from the NASA Lewis standard suction support system to a core hardware yoke that supports the airframe. The yoke (tunnel user supplied equipment) can move the model to the center of the test section from the tunnel sidewalls. The model has a pitch range up to +30° and a yaw angle ranging from 0° to −30°. The model inlet airflow is supplied by the NASA Lewis altitude exhaust system, and the model nozzle flow is supplied with high-pressure (450 psig), hot (up to 500 °F) air. The nozzle supply system is located on the aft end of the suction-model support system, which is downstream of the model and aft of the test section. Engineering drawings which show the exhaust support system interface that must be accommodated by the tunnel model can be obtained from the AFED project engineer.

3.10.4 Turntable pedestal mount systems.—Two rotating turntables are housed beneath the test section floor (fig. 21). The extent of the turntable rotation is variable and dependent on the positioning of two limit switches that are used with each turntable. The turntables can be rotated at a rate of 1°/sec. The design torque for each turntable is 100 000 in-lbf. A pedestal mount strut is used to mount a counterrotation propeller model (fig. 22) at a negative angle of attack onto the rotating turntable nearest the test section north wall. The turntable center of rotation is 5.2 ft from the aft end of the test section (along the tunnel longitudinal axis) and offset 2.10 ft from the test section centerline towards the test section north wall. The north turntable is used to run high horsepower experiments. It is used to mount single-rotation pedestal mount models, counterrotation pedestal mount models, and pedestal mount propeller and fan models. A three-stage air-turbine using high-pressure air at 450 psig has been used to deliver 1000-shaft hp to drive single-rotation pedestal mount models. A 2000-shaft hp air-turbine using high-pressure air at 450 psig has been used to drive fan models. Both of these air-turbines are available to the tunnel user.

The center of rotation for the test section south wall rotating turntable is 5.2 ft from the aft end of the test section (along the tunnel longitudinal axis) and offset 3.27 ft from the test section centerline towards the test section south wall. The south wall turntable is used for models that require altitude exhaust. A test section floor-to-ceiling mounting support system is used to provide altitude exhaust to a two-dimensional VTOL model (fig. 23). Detailed engineering drawings of the north and south turntables can be obtained from the AFED project engineer.

3.10.5 Inlet pressure bleed air system.—An inlet pressure bleed air system at 125 psig is available for model use at both of the turntables in the LSWT test section. The flow rate for the bleed system is 1.0 lbm/sec. An example of bleed air provided to the inlet of a diffuser model is shown in figure 24. The

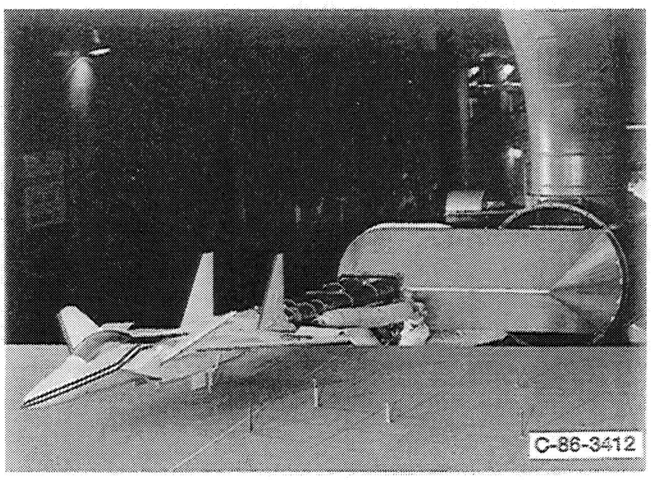
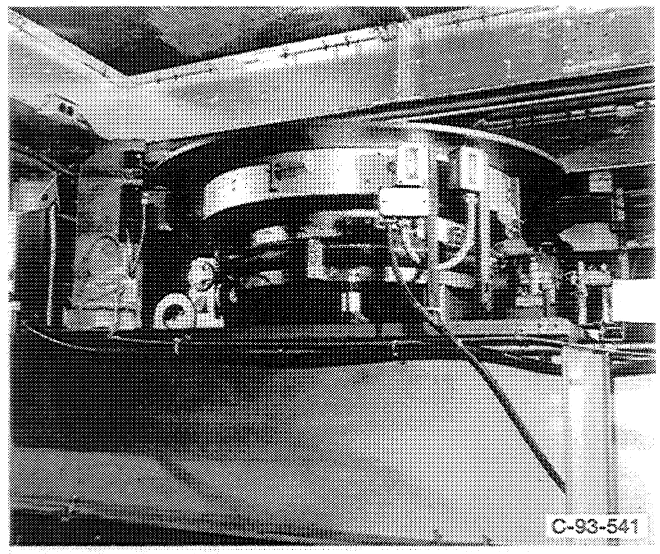
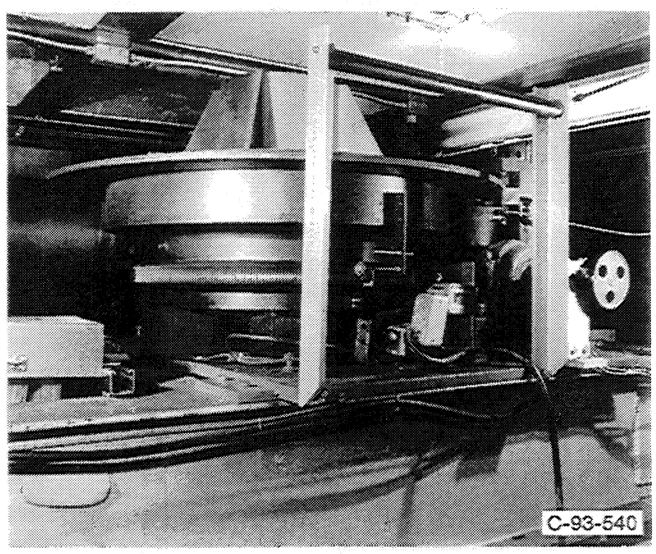


Figure 20.—F-15 STOL maneuvering technology demonstrator model installed on LSWT standard suction support system.



(a) North side turntable.



(b) South side turntable.

Figure 21.—LSWT test section turntables.

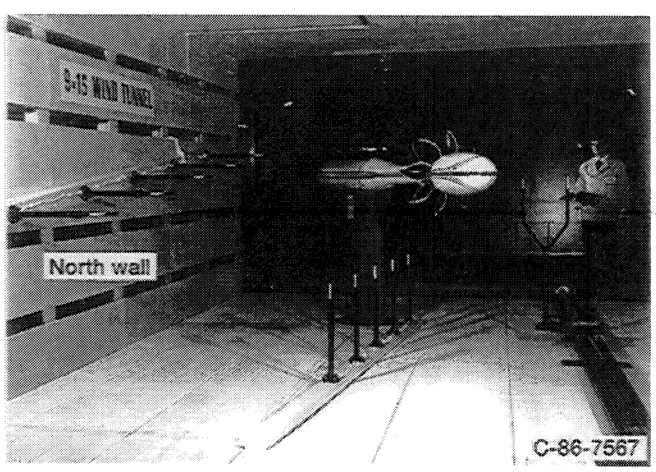


Figure 22.—Counterrotation propeller test rig at negative angle of attack in LSWT test section.

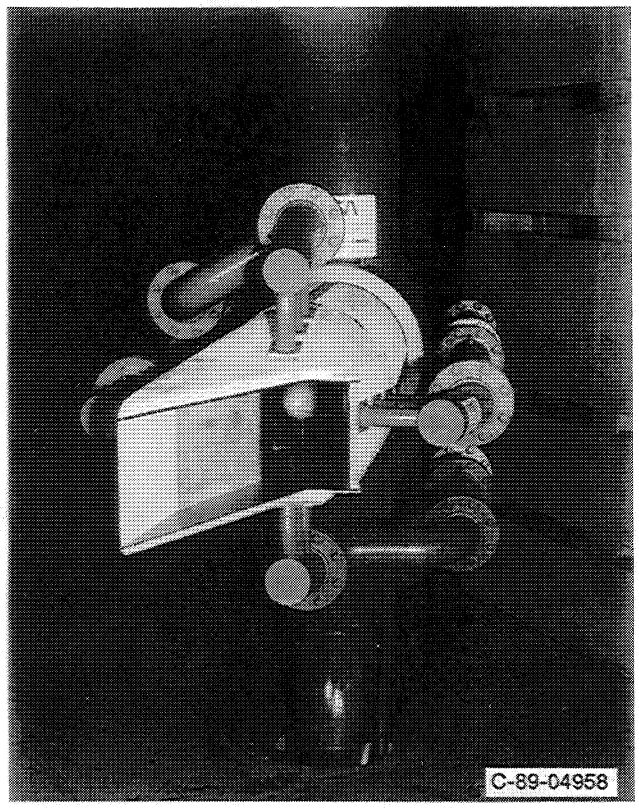


Figure 23.—Short diffuser for two-dimensional VTOL model inlet.

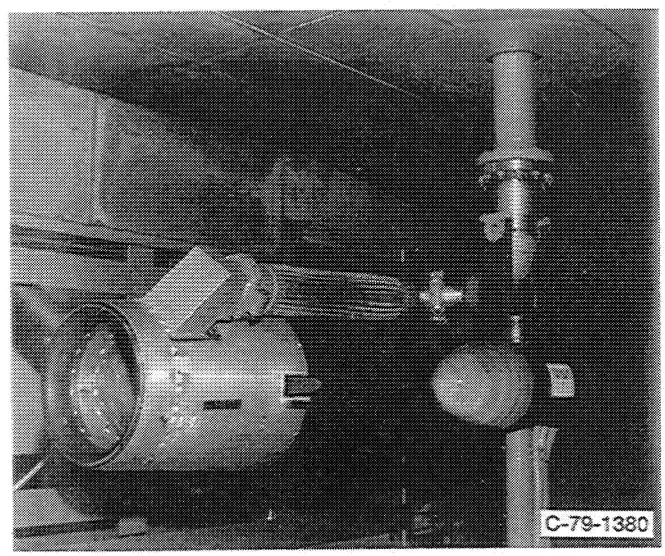


Figure 24.—Inlet bleed flow system installed on inlet of model diffuser.

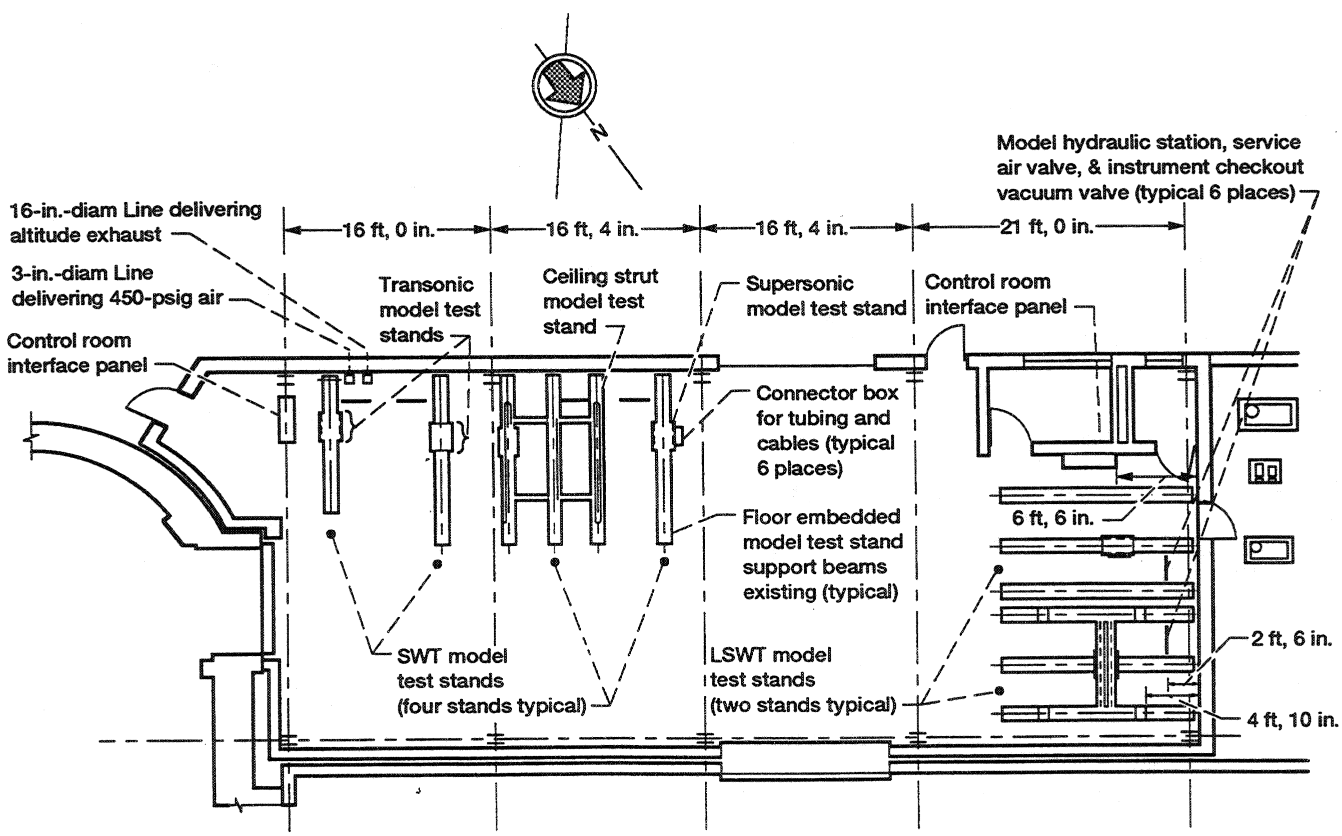


Figure 25.—Model preparation building (floor plan).

test setup was designed to study flow attachment at the inlet lip using a floor-to-ceiling mounting scheme at the north turntable.

3.10.6 Inlet vacuum bleed air system.–An inlet vacuum bleed air system is available for model use at both of the turntables in the LSWT test section. The vacuum bleed system has a flow rate of 1.0 lbm/sec.

3.11 Photographic System

Photographic and television coverage of test section events may be obtained from various locations within the test section. Window assemblies for side wall coverage are not part of the test section. The use of video and still cameras in the test section is permissible. Still photography using 70-mm and 35-mm cameras is discussed in section 3.6.

3.12 Electrical System

At the tunnel test section the following types of electrical power are available:

440 V, 60 cycle, three-phase, ac	120 V, 400 cycle, one-phase, ac
208 V, 60 cycle, three-phase, ac	28 V, dc

3.13 Model Preparation Building

A model preparation building is adjacent to the SWT facility (fig. 25). This model buildup area contains separate bays to allow the buildup of two LSWT and four SWT models concurrently.

Standard services are also available at each model preparation stand. These services include 125-psig service air, a hydraulic system capable of delivering 5 gpm and operating at 2000 psig, a 3-in. line delivering 450-psig air at either ambient temperature or temperatures up to 500 °F, and a 16-in. line capable of delivering altitude exhaust over a wide range of pressures (consult with the AFED project engineer). A vacuum pump station provides vacuum at each model test stand.

The model preparation area dedicated to the LSWT has two stands that can be used to checkout the model integrated support system (MISS) or turntable-supported models. The instrumentation available at these two stands is listed in table II.

TABLE II.—AVAILABLE INSTRUMENTATION CONNECTIONS FOR MISS OR TURNTABLE STANDS

Instrumentation type	Number of connections available
Pressure tubing	512
Accelerometers	10
Low noise cables (heater and motor wire no. 16)	10
Hydraulic lines, 1/2 in.	4
Pressure tubing, 1/4 in.	10
ESP cables	3
Thermocouples CuC	15
Thermocouples CA	48
4-channel shielded, no. 22, AWG cable	38

3.14 Shop Equipment

A bridge crane with a 2-ton capacity is in place above the test section. A 2-ton winch, located in the diffuser ramp, is used to transport models into the test section. The diffuser ramp maximum weight capacity is 5 tons (forklift truck plus model weight). The LSWT facility shop contains numerous machine tools as follows: two 1/2-hp vertical pedestal tool bit grinders, one engine lathe (with 2-in. centers and a 12.5-in. swing), one vertical drill press, two belt sanders, one disk sander, one 3/4-hp horizontal band saw, one 2-hp vertical (variable speed) band saw, one power tube flaring machine, one 1/4-hp, vertical, variable-speed saw, and two standard oxyacetylene and two arc-welding machines.

4.0 INSTRUMENTATION

Model and tunnel instrumentation may include any combination 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 a tunnel 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 supervisory control and data acquisition system with the capability to execute high-speed control algorithms. The WDPF system contains a universal programmable controller which is interfaced to numerous facility subsystems (e.g., compressor drive controls, facility cooler, flow control doors). 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 is primarily monitored by the tunnel operator. Hard copies of the WDPF displays are available to the tunnel user if requested. Most of the facility test section 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 576 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 wire. Leads extending from the model should be long enough to reach the MISS mounting structure, the ground plane, the exhaust mount structure, the pedestal mount structure or any other model support structure. The required length must be determined by the AFED project engineer. Alloy wiring is used from jacks on the upper and lower strut terminal panels to thermocouple-junction reference units. The wire junctions within these reference units are held at room temperature, ± 0.05 °F. Cables are run from the reference units to patchboards in the tunnel control room.

The following table lists the number and the type of thermocouple circuits available at each of the two thermocouple terminal panels. One panel is above and the other panel is below the test section.

Quantity	Wire type (ISA)	
72	Iron/constantan	Type J
432	Chromel/alumel	Type K
24	Copper/constantan	Type T

4.2 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.

5.0 DATA ACQUISITION AND PROCESSING

5.1 Electronically Scanned Pressure (ESP) System

The 9- by 15-ft LSWT electronically scanned pressure (ESP) system provides high accuracy measurement of steady-state model and facility pressures. The system uses plug-in modules, each containing 32 individual transducers that are addressed and scanned at a rate of 10 000 ports/sec. Up to 32 modules with transducer ranges from ± 2.5 to $+500$ psi may be used to provide 992 pressure and 32 reference pressure measurements. Reference and check pressures are obtained from remotely controlled regulators.

An on-line calibration of all transducers is normally performed automatically every 20 minutes 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, are applied in up to three ranges to assure electronic system errors not greater than ± 0.1 percent of full scale.

5.2 Escort D Plus

The NASA Lewis minicomputer-based, Escort D Plus system, which is supported by the NASA Lewis Computer Services Division, is a real-time data acquisition, display, and recording system that can be used for most steady-state tests. Analog data from the experiments are digitized and then acquired by a Microvax 3500 computer located in the LSWT data room (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 processing if desired. Data from sensitive projects are stored on the removable disks of a LSWT facility computer. Batch processing of sensitive data are performed on a facility computer as test runs are completed. In addition, sensitive 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 26. A detailed block diagram of the facility computer is given in figure 27. 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. Module availability can be discussed at one of the pretest meetings.

5.2.1 Real time displays.—A customized Escort D Plus output program displays all data channels and computations selected for a given test program in an alphanumeric format. This output can be displayed on a variety of control-room CRT's. A detailed description of the CRT displays is presented in appendix B. Up to eight alphanumeric color CRT's can be supported on the system and provide a means

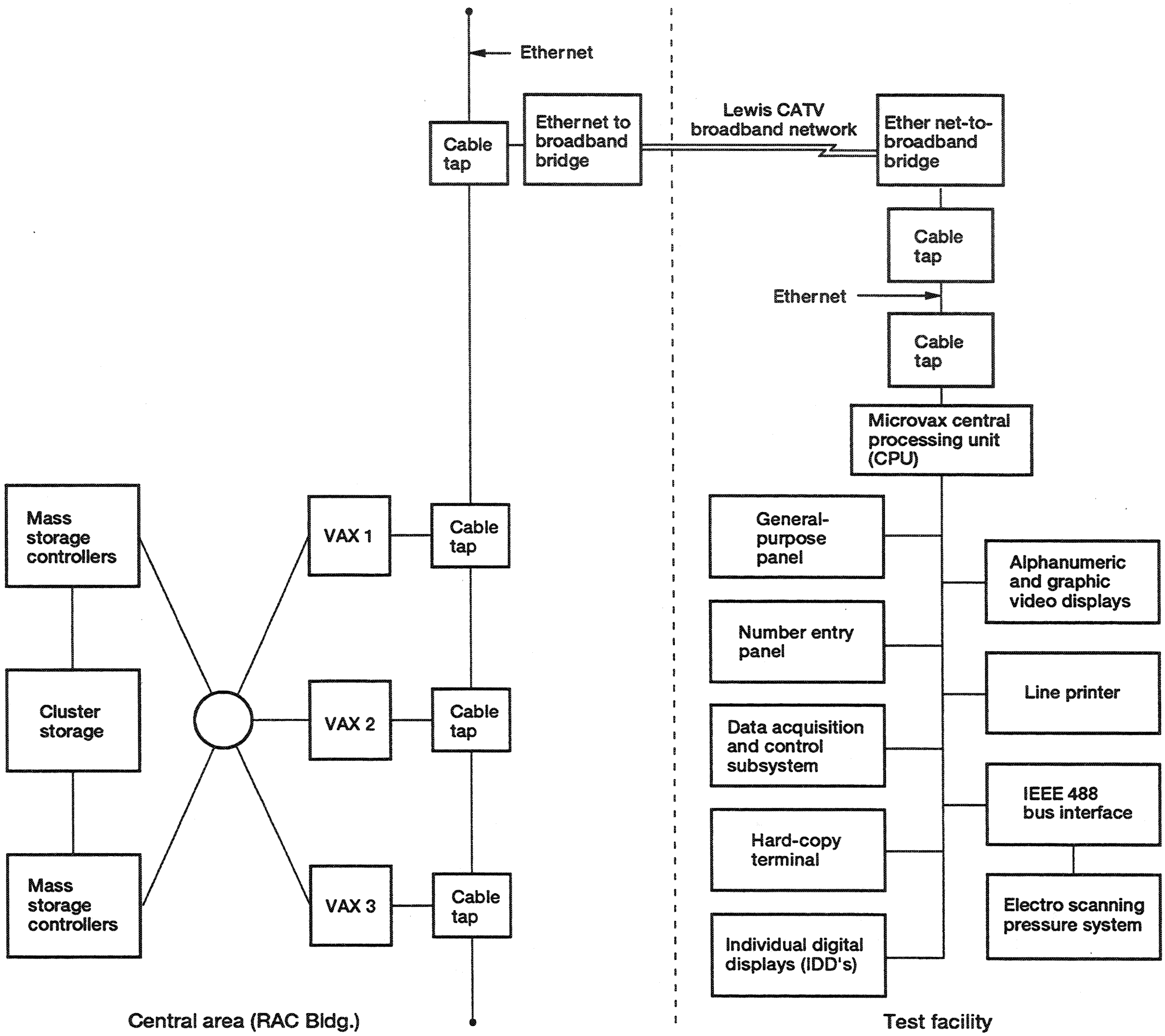


Figure 26. - Overall configuration for ESCORT D Plus system.

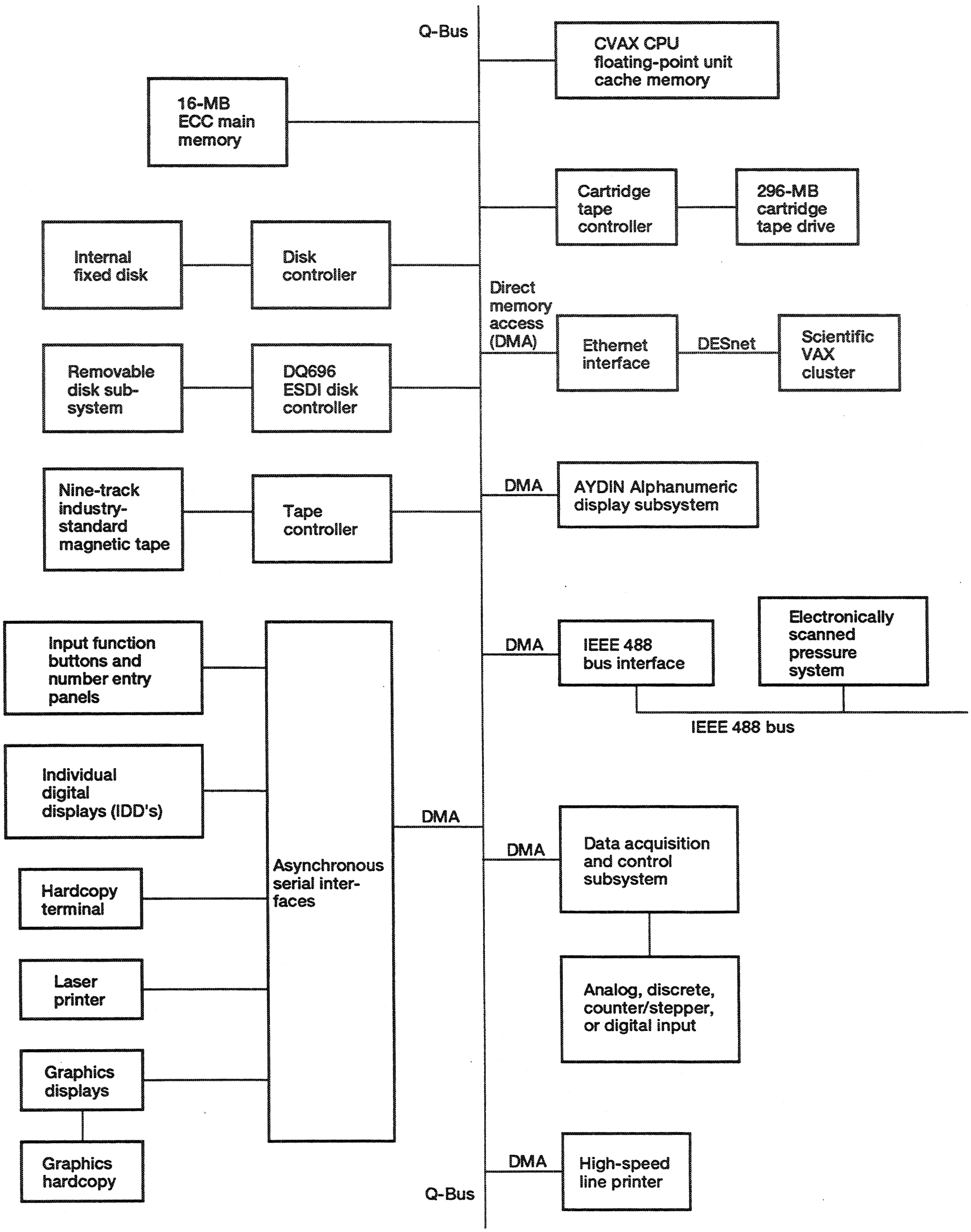


Figure 27.—Facility computer configuration.

of monitoring progress of a test and displaying data sets. Two CRT's are dedicated to the tunnel and model operators. Three CRT's are available to the tunnel users (i.e., research engineers). Each CRT can view any display page at any time. A laser 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 number 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 one 40-alphanumeric character line. 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. In addition the average of N data scans can also be saved as one reading number. Real-time data processing is available when requests include the calculation of ratios or simple engineering parameters. In order to ensure a 1-sec update time, extremely rigorous computing or across-scan computing should be performed off-line by using the NASA Lewis central mainframe computers to obtain the desired output.

If multiple or continuous high-speed scan cycles are needed to define a test condition, a different customized data software module than the one 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 type test or moving probe hardware.

5.3 Dynamic Data Acquisition

5.3.1 Facility tape recorders.—Four tape recorders are available in the control room to record data. Each tape recorder contains 14 channels. Two of the tape recorders are used to record data as per tunnel user specifications, and the other two tape recorders are used to monitor safety requirements of the model (i.e., vibration amplitudes, strain gauge levels, bearing temperatures, etc.). Data recorded on tape can be converted to a digital tape at a later date by using the analog frequency modulated (FM) demultiplexer equipment in the Research Analysis Center (RAC).

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 LSWT using trunk lines that extend from the facility to the RAC building. 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 combine all digital information into a matrix and onto one tape before final processing.

5.3.3 TRADAR-3.—The transient data acquisition and reduction system (TRADAR-3), which is located in the RAC building 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/Masscomp 6700 host computer with data acquisition and front-end signal conditioning hardware (fig. 28). TRADAR-3 can be used in conjunction with the central analog FM multiplex system.

TRADAR-3 receives input from 180 shielded lines that run between the LSWT and the RAC building. Electrical engineers at the LSWT 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 output from the central analog playback equipment (fig. 28). Data recorded by the central analog FM multiplex system, and by the other analog FM or direct instrumentation tape recorders, can be played back and digitized by TRADAR-3. Aggregate digitizing rates 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, 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 auxiliary equipment room (see fig. 15). This system permits the recording of dynamic data on a digital computer during classified or unclassified experiments. The main components of the system are a facility 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. In addition, 28 of the 96 channels can be used to record acoustic data from strategically placed microphones (along the test section floor and side wall; see fig. 5). It is also possible to use 20 of the 28 acoustic channels for FM tape recording. Data recorded during an experiment are stored on disk and can be processed either at the facility or, at a later date, at the RAC building. Sampling rates of 2 MHz/sec (aggregate divisible by the number of channels) will be stored on 1.5 GB of disk storage.

5.4 Model Checkout Cart

The model checkout cart (fig. 29) is a mobile instrumentation, control, and data acquisition system that is used to setup and checkout the model before it is installed in the test section. Its interface to the model is through an interconnect rack (which includes a thermocouple oven), and it has similar panels at the test section. The cart (fig. 29) 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 checkout up to 512 pressures. The Escort D data system has 128 analog input channels to monitor signals during checkout. The cart can be moved next to the LSWT buildup bays in the model preparation building (section 3.13). The AFED project engineer and the facility electrical engineer can discuss the details of cart use with the tunnel user at one of the pretest meetings.

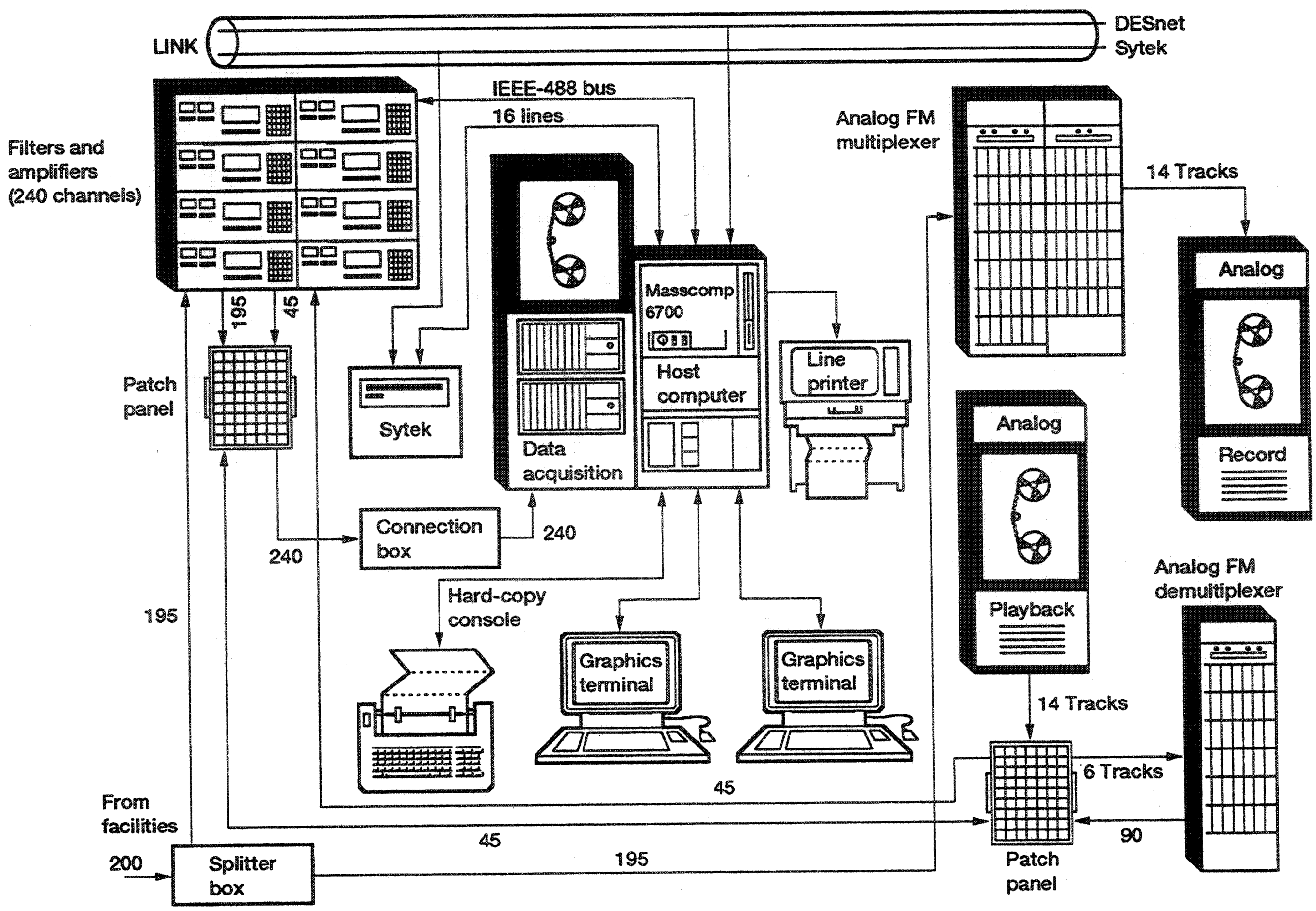


Figure 28.—TRADAR-3 and central analog dynamic data systems.

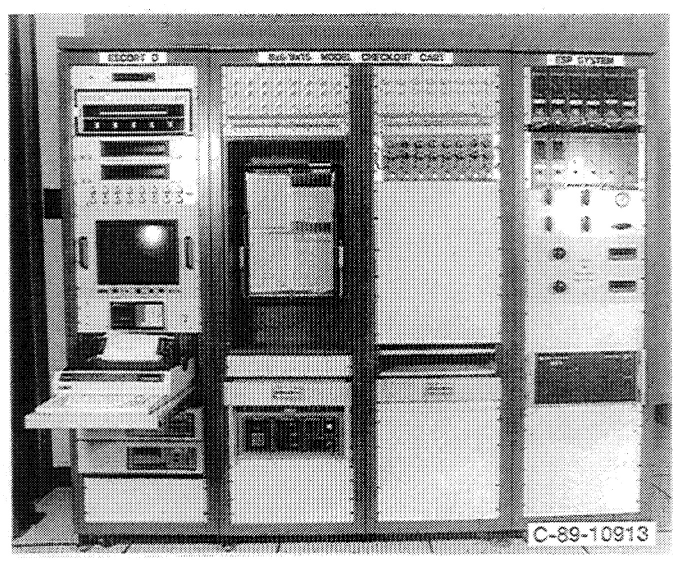


Figure 29.—Model checkout cart.

6.0 PRETEST REQUIREMENTS

The 9- by 15-ft LSWT is scheduled for continual testing throughout the year. It is advisable to contact the facility manager (appendix A) at least 1 year before the desired test time. Early notification will allow the facility manager and the appropriate AFED personnel to review the proposed model design and to insure its compatibility with the tunnel test section. 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 should 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 should prepare a requirements document and make it available to the facility manager and the AFED project engineer at the first pretest meeting at NASA Lewis. The facility manager will inform the tunnel user as to the topics that should be addressed in this document. The procedure to obtain tunnel test time is outlined in appendix C.

6.1 Pretest Agreement

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

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

<u>6.1.2 Instrumentation.</u>—The tunnel user should provide the AFED project engineer with a list of requested instrumentation. Tunnel user instrumentation shall be adapted to the LSWT data system (sections 4.0 and 5.0). If a tunnel-user data system is to be used, that 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 must provide drawings of the model installation in the test section. The AFED project engineer is responsible for providing detailed drawings of the model support systems to assist the tunnel user.

6.1.4 Data requirements.—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 AFED project engineer will contact the appropriate personnel in the RAC and set up any necessary meetings between the tunnel users and RAC engineers to establish ground rules for a computing requirements package writeup. The final 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) Detail 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 model calibration information

(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

All models, instrumentation, and support hardware should be sent to NASA Lewis to the attention of the AFED project engineer (the facility manager will supply the name of this engineer to the tunnel user). All model parts, model internal instrumentation, and tunnel user support hardware should be assembled if possible 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 models before testing will vary according to the complexity of the model installation and the amount of instrumentation to be hooked up to the data-recording system. The tunnel user and the AFED project engineer should agree to an appropriate delivery time.

7.0 RISK 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 procedure for model assembly in the tunnel test section.

7.1 Model Size

The maximum model size (i.e., model plus support structure) that is permissible in the LSWT test section is limited to a frontal blockage between 10 to 12 percent. Any model which presents a greater frontal blockage will prevent the attainment of a test section Mach number of 0.2.

7.2 Model Design Criteria

Tunnel 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 conditions 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 stress shall be taken as one-sixth of the tensile yield stress of the material. Thermal stresses that may occur on the model should be added to the load stresses before determining the factor of safety. The allowable stresses shall be the value at the operating temperature. The material properties that are used in the calculations should be the expected minimum values. The allowable stress in the model columns as well as shroud coverings for the model should not exceed one-third of the Euler critical buckling stress.

Model safety factors discussed above 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 Subsonic 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. In the LSWT when the flow survey rake is positioned at station 198.2 (fig. 6), the largest calculated dynamic pressure is 0.380 psia at 0.2 Mach. Using this value as a criterion, the allowable stress should not exceed one-half of the yield stress. All auxiliary parts of the model exposed to the air stream 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.

As noted previously a full-scale calibration of the test section will occur during the fall of 1993. The maximum dynamic pressure will be computed at various locations in the test section. This information will be noted in a report which discusses the test section calibration (contact the facility manager for the availability of this report).

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, and (5) design factors of safety 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 substitutions of numerical values. 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 structure are to be selected by using the mechanical/electrical properties described in the publications of the following organizations, codes and handbooks:

(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 Electric Code (NEC)

(7) Society of Automotive Engineers (SAE)

(8) National Institute of Standards and Technology (NIST)

(9) Aerospace Structural Metals Handbook—Department of Defense (DOD)

(10) Military Handbook #5—Department of Defense (DOD)

All material properties should be suitably corrected for temperature.

7.2.5 Structural joints.—All counterbores, spotfaces, and countersinks in the model and the 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 will be 4.0 based on yield stress and 5.0 based on the ultimate stress for heat treated hardened bolts. The safety factors are based on bolt cross-sectional area and not the tightened or proof load (i.e., the maximum load that can be applied to a bolt without obtaining a permanent stretch). The cross-sectional area of the bolts is determined by first calculating the model or model support system mating parts flange or joint load (1) at a predetermined hydrostatic, or most severe, test condition and (2) at a room temperature bolting-up condition. The required bolt area is then obtained from the following procedure. First, the allowable stresses are obtained from the bolt material tables at the temperature condition determined from steps 1 or 2 above. It should be noted that the allowable stress selected from the ASME Boiler and Pressure Vessel Code, Section VIII Manuals has the appropriate safety factor figured into the table values. The division of the flange or joint load by the allowable stress defines the total cross sectional area required 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 of a nongasketed flat face joint is addressed in the bolt preload section of reference 14. 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 a small amount, approximately 10 percent (initial joint compressive stress is nearly cancelled by the external tensile stress). The exact amount depends on the relative stiffness between the flange or joint and the bolts and 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). Based on these safety factors, the actual bolt stresses will be equal to one-third to one-fifth of the allowable stresses. Since 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 keys and pins are properly retained.

All welded joints should be designed in accordance with the code of the American Welding Society. All critical joints whose failure could result in the loss of the model or model components or damage to the facility must be x-rayed or inspected by a method which is acceptable to both the tunnel user and the AFED project engineer.

7.2.6 Pressure systems.—Models, 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 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 or fluid 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 LSWT.

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, the format for user supplied electrical schematics, wiring diagrams and connectors at interfaces located at control panels, control boxes, and/or at the model are stated in the test agreement.

7.3 Model Fabrication Requirements

Models should be completely assembled at the manufacture's plant. All model parts are to be inspected to ensure proper fit and certified for the required loads and deflections during testing. The tunnel user can discuss any problems with the certification of model loads and deflections with the AFED project engineer and the facility manager. All remote controlled model functions should be checked out, and position indicators should be calibrated before shipment to NASA Lewis. If it is not possible to assemble the model due to a shipping constraint, the LSWT stands in the model preparation building (section 3.13) can be used for this purpose. After the model is installed in the LSWT test section 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

Detailed instructions are required for the model assembly, installation, and configuration changes in the LSWT test section. These instructions should be submitted to the AFED project engineer at least 8 weeks before the tunnel entry and should include the sequential steps that are to be taken to install the model in the test section. Bolt torquing values to fasten 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 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 LSWT are complex and therefore buildup time in the model preparation building plus the test section installation 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 the 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 user-assigned 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 and are required to check in at the facility shop office. 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 instrumentation rakes and model sharp edges, spikes, tips, etc.

8.1.5 Support during tests.—All requests for manpower assistance, 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 supported at the LSWT on a two-shift operation from Monday through Friday. This test window can be expanded for an ambitious test schedule. Tunnel users should discuss expanding the test time each week with the facility manager if required.

8.2.2 Off-shift coverage.—Access to the 9- by 15-ft LSWT for times other than operating shifts must be coordinated with the facility manager.

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 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 (a material safety data sheet should be provided by the tunnel user)

8.3.2 Test time.—The tunnel test time charged to 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.—Near 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 LSWT at NASA Lewis Research Center depends upon the classification of the test program and the category of the NASA visitor.

During nonclassified test programs the AFED project engineer will notify the NASA Lewis Visitor Control Center at least 3 days before the arrival of a non-NASA visitor who is a U.S. citizen. The information required is the name of the person, the place of employment, and the date and purpose of the visit. A non-U.S. citizen should make arrangements with their embassy in Washington, D.C., prior to their 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 receipt of a visit notification letter from the visitor's company. This letter is to 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 M.S. 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 before 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 9- by 15-ft LSWT. Mail correspondence can be addressed as follows:

NASA Lewis Research Center
Attn: 9- by 15-ft LSWT Facility Manager*
Mail Stop: 6–8
21000 Brookpark Road
Cleveland, Ohio 44135

*The name of the 9- by 15-ft LSWT 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 (organizational code 2810). In the absence of a directory call: (216) 433–4000 (NASA Lewis switchboard operator) and ask the operator to supply the name of the facility manager.

APPENDIX B

REAL-TIME DISPLAY DETAILS

The format for the control room CRT displays 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 normal size characters are used. Rows 1 and 2 are 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 unlabelled block format (a two-dimensional array of 20 rows by 5 columns). These are preprogrammed, off-the-shelf displays.

APPENDIX C

SUMMARY OF PROCEDURE FOR OBTAINING TEST TIME

The following is a summary of the process for obtaining test time:

(1) Tunnel user contacts the 9- by 15-ft LSWT 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 (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 to discuss the test plan, instrumentation, tunnel hardware, and data requirements. Attendees are the requestor and key tunnel user personnel, the facility manager, appropriate AFED branch chiefs, key AFED personnel, and the AFED project engineer.

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13. ABSTRACT (*Maximum 200 words*)

This manual describes the 9- by 15-Foot Low-Speed Wind Tunnel at the Lewis Research Center and provides information for users who wish to conduct experiments in this atmospheric facility. Tunnel variables such as pressures, temperatures, available tests section area, and Mach number ranges (0.05 to 0.20) are discussed. In addition, general support systems such as air systems, hydraulic system, hydrogen system, laser system, flow visualization system, and model support systems are described. Instrumentation and data processing and acquisition systems are also discussed.

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