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

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1.0 INTRODUCTION

This report describes the NASA Glenn 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 Glenn Research Center in Cleveland, Ohio, adjacent to Cleveland Hopkins Airport. The 10-by 10-Foot SWT is managed and operated by the Research Testing Division (RTD).

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.

In order to meet the demand for subsonic testing at NASA Glenn, a program was initiated in 1996 to investigate the use of the 10-by 10-Foot Supersonic Wind Tunnel for subsonic testing. These tests showed that the facility could be safely and accurately operated in the Mach range from 0 to 0.36 (see ref. 1).

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 Glenn Research Center's 10-by 10-Foot SWT is 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 fig.1.

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 and valve 6900 is opened. 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. 2).

2.2 Tunnel Operating Envelope

Operating envelopes of tunnel supersonic operation for aerodynamic and propulsion cycles are presented in figures 2 and 3, respectively. These figures show test section altitude, dynamic pressure, Reynolds number/foot, total pressure, and total temperature as a function of Mach number over the tunnel operating range. Two curves are presented in figure 3 for the total temperature envelope for the propulsion cycle: flight total temperature variation in the stratosphere (56,820 to 76,820 ft, see altitude versus wall Mach number variation in figure 3) and tunnel minimum temperature variation (heat of compression input from compressors #1 and #2). The increase in tunnel minimum temperature at Mach 2.5 is the result of adding the heat of compression from 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 1140ºR. 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 to 10 min. before the heater must be shut down to allow the tunnel walls to cool. See ref.2 for details of how the vitiated air heater affects the test section flow field.

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 -15º to -20ºF (or lower). 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 10ºF the test section Mach number had decreased 0.05 Mach from the calibrated value.

Subsonic tunnel operation is accomplished by running the main drive system at lower operating speeds. This was accomplished by running the drive system on one, two, three or all four of the electric drive motors used to power the main compressor. Also, very low test section airspeed conditions (below Mach 0.1) were set using the air blowers in the facility air dryer building. Tests conducted in April, 1996, proved that the facility could be safely and accurately operated over the subsonic Mach number range of 0 to 0.36 by using either the facility blowers or the main drive compressor (see ref. 1). Maps of tunnel altitude and Reynolds number per foot both as a function of test section velocity for subsonic operation of the tunnel are presented in figs. 4 and 5.

2.3 Test Section Description

The test section plan view, cross section, and elevation views are presented in figures 6, 7, and 8, respectively. The test section 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 6.

The test section floor can be lowered to the first level by means of screwjacks attached at its corners (see fig. 7) 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. 6). 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 3.6 (Model Supports) are installed through these openings.

Personnel access doors (3 ft by 7 ft, see fig. 8(a)) are located opposite each other at the downstream end of the test section. The test section can be secured during sensitive 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 Glenn 10-by 10-Foot SWT are illustrated in figure 1.

2.4.1 Test section. - The test section elevation view is presented in figure 8. 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 the Mach 5 inlet model installation are presented in figures 9 and 10. Previous research projects are described in refs. 2 to 8.

2.4.2 Second throat. - The two side walls downstream of the test section 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 which decreases the pressure loss across 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 lb_m/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 166 000 hp. Compressor 1 with the case open is shown in figure 11.

2.4.5 Valves 6906 and 6907. - Valves 6906 and 6907 are 8-ft- and 4-ft-diameter hydraulic 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. 1 for all valve locations.)

2.4.6 Valve 6908. - Valve 6908 is a 24-ft-diameter hydraulic valve that is used to change the tunnel cycle from the aerodynamic cycle (valve in the A position in fig. 1) to the propulsion cycle (valve in the B position in fig. 1).

2.4.7 Exhaust muffler. - The exhaust muffler is used to quiet the discharge of air from the tunnel when it is operated in 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 lb_m/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 electric 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 is a 4-ft-diameter hydraulic 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 lb_m/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 124 500 hp. Compressor 2 with the case open is shown in figure 12.

2.4.14 Valves 6903 and 6904. - Valves 6903 and 6904 are 6-ft- and 2 1/2-ft-diameter hydraulic 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 electric butterfly valve that is used to bypass air around compressor 2 when additional compression is not required for tunnel operation in the Mach 2.0 to 2.5 range.

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

2.4.17 Valves 6400 and 6401. - Valves 6400 and 6401 are 4-ft- and 20-in.-diameter hydraulic 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 through the exhausters.

2.4.18 Valve 6402. - Valve 6402 is a 20-in.-diameter electric 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 lb_f/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 minutes at maximum temperature (longer at lower temperature) because of tunnel reduced 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. 1). The control room is shown in figure 13. 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 2.6 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 Glenn 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 sensitive test programs. The need for security should be discussed with the 10- by 10-Foot SWT facility manager and the RTD project engineer during one of the pretest meetings held at NASA Glenn.

When tunnel customers are on-site during a test program, provision can be made to permit e-mail communication between on-site customers and their home office. It is suggested that the customers bring a laptop computer with them to Glenn. The specifics of this arrangement can be addressed with the tunnel electrical engineer at one of the pretest meetings.

2.6 Facility Controls

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 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 alarm monitoring and reporting, data collection, historical data storage and retrieval, and numerical calculations. The facility is primarily monitored by the tunnel operator. Hard copies of the WDPF displays are available to the customer if requested.

3.0 GENERAL SUPPORT SYSTEMS

Table I presents pertinent information on facility support systems. Sections 3.1 to 3.5 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., 759 ft^3 at 2600 psig) and a system of 600 000 ft^3 of standard dry air (i.e., 3373 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 RTD project engineer at one of the pretest meetings.

3.1.2 Altitude exhaust.- Altitude exhaust can be provided to simulate an engine for inlet testing. Flowrates up to 20 lb_m/sec can be provided through a 16 inch header. Currently two 12-inch lines can provide independent and measured flows up to 10 lb_m/sec using ASME orifice plates and hydraulic flow control valves.

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

3.1.4 Combustion air. - A heated combustion air system with a capacity of 12 lb_m/sec at 450 psig is available. Air temperatures can be varied up to 300°F. Venturis, flowmeters, and hydraulic valves are used to measure and control flow.

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 upgrade is presently underway to deliver gaseous hydrogen to a burning model at a maximum flow rate of 2 lb_m/sec, at 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 Gaseous Oxygen System

A system is in progress to deliver gaseous oxygen to a burning model at a maximum flow rate of 23 lb_m/sec. at 1500 psig, and at ambient temperature. Up to two trailers, each with a capacity of 70 000 standard cubic feet (i.e., 426.1 ft^3 per trailer at 2400 psig), can be simultaneously connected to the system. The main supply line is 4-in. schedule-80 stainless steel pipe). A regulator in the main supply line controls the pressure upstream of the main flow control valve. Use of the gaseous oxygen system is permitted only during tunnel propulsion cycle operation.

3.5 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: kerosene base blends.

3.6 Model Supports

3.6.1 Sting strut and adapters. - The strut for sting-mounted models presented in figure 14(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 figs. 6 or 8 for this location) 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 -6° to +19°. 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 (see fig. 14(a) for the max. and min. dimension from the sting centerline to the test section floor at zero angle-of-attack). The strut angle and height are displayed on the operator's console in the control room. The design loads for this strut are defined 3 feet ahead of the vertical centerline of the strut. These loads are a normal force of +9000 lb_f/-7000 lb_f; an axial force of 3500 lb_f; and a maximum moment of +125,000 ft-lb_f/ -115,000 ft-lb_f. Details of the sting end that mates with the strut are presented in figure 14(b). The sting end must be made in strict accordance with the dimensions shown.

An adapter, presented in figure 15, is available to permit the use of stings designed for the NASA Glenn 8-by 6-Foot Supersonic Wind Tunnel. In addition NASA Langley stings can be retrofitted to NASA Glenn struts by using the special adapter presented in figure 16.

Yaw and pitch angles of attack can be accommodated through the use of a hydraulically controlled sting. Figure 17 shows the range of the right and left yaw angle and the positive and negative pitch angle range. This hydraulically operated pitch-yaw sting is used with the 8X6 SWT adapter and a sting holder that has a 6.50-in. outside diameter and a 4 ¾ in. inside diameter. The sting holder is inserted into the 8X6 SWT adapter. The design loads for the hydraulically controlled sting are a maximum pitch moment of 3200 ft-lb_f and a maximum yaw moment of 1250 ft-lb_f.

A sting knuckle model support is also available for customer use. This piece of hardware is presented in figure 18. If the cylinder arm is extended, the angle of attack is +5º, if the cylinder arm is retracted the angle of attack is -60º. This model support can be rotated 90º in order to provide yaw capability. The load rating on this hardware is as follows: normal force of +3200/-4600 lb_f, an axial force of 3500 lb_f and a pitching moment of +16800/-24150 ft-lb_f. The 10X10 SWT project engineer is available to discuss the features of the hydraulically controlled sting and the sting knuckle model support with the customer.

A rotating sting adapter assembly (see fig. 19) can be used to manually rotate and set a model at various roll angles over a 360º range. The front end of the rotating sting adapter that mates with the customer's equipment is available in four different diameters (3.38, 4.51, 5.63, and 8.01 in.). The RTD project engineer can provide detailed drawings of the rotating sting adapter to the customer.

Electrical cables available at the lower strut interface plate are discussed in section 3.9.1. Pressure tubing is available in the strut to connect model pressures to the rack-mount ESP modules located beneath the test section.

3.6.2 Ceiling strut assembly. - A ceiling strut assembly with a typical model installed is presented in figure 20. The strut interface details will vary with each model, but the operating mechanism will be the same and will be furnished by NASA Glenn. All struts used are designed to fit this operating mechanism. Details on available upper struts can be provided. Any details not included will be furnished by the RTD project engineer.

The tunnel upper strut box can accommodate a strut thickness, from 3 to 10 inches. The strut thickness is limited by the travel of the bearing pads that support the strut in its housing. The usual strut thickness is 5 or 8 inches. 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 screw-jack 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 20º (i.e., if the screwjack mechanism is arranged to give a maximum negative angle of attack of -5º, the maximum positive angle of attack will be 15º). Other combinations of positive and negative angles of attack that total 20º are possible. It is required to adjust the model to 0º angle of attack in order to minimize starting loads. There is no vertical travel to bring the model back to the tunnel centerline, so model length may limit the attainable angle of attack. The loads for this strut assembly are a normal force of ±50,000 lb_f; an axial force of ±50,000 lb_f; and a pitching moment of ±175,000 ft-lb_f.

Electrical wiring from the strut is connected to terminal panels on top of the test section (see section 3.9.2). Pressure tubing is used to connect model pressure leads to the ESP modules located on top of the section.

3.7 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 21 and 22. 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. 8(a)). When the air heater is used to elevate test section temperature (maximum of 1140ºR), 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 23. A shuttle model tail section that was photographed using the schlieren system shows visible Mach cones in figure 24.

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 high-speed video system with the capability of up to 1000 frames per second is available. If necessary, this topic can be discussed at one of the pretest meetings.

3.8 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.

3.9 Electrical Cabling

3.9.1 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 .... 54 eight-conductor, shielded #24 AWG
Miscellaneous signal .... 48 four-conductor, shielded #24 AWG
Coaxial .... 24 RG 174/U
Thermocouples:
  Chromel/Alumel, type K .... 36 alloy pairs, shielded
  Iron/constantan, type J .... 18 alloy pairs, shielded
  Copper/constantan, type T .... 18 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

3.9.2 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

Additional cabling can be provided to satisfy customer requests. Information on connector types, pin assignments, and other details can be obtained from the RTD project engineer and the facility electrical engineer at one of the pretest meetings.

3.10 10- by 10-Foot SWT Shop

3.10.1 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 25 and 26. 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. 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 is used for hydraulic accumulators are also available. Electrical services provided at the shop stands are noted in section 3.8.

3.10.2 Shop equipment. - The wind tunnel shop contains an overhead 10-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 two 2-ft metal brakes, two hydraulic arbor presses (one hydraulic and one manual), 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.

3.10.3 Shop enclosures. – Two of the model stands described in section 3.10.1 are enclosed secured buildings within the shop for sensitive model buildup. One enclosure is 20 ft, 5 in. wide by 28 ft, 5 in. long by 10 ft high and is used to work on sensitive 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 sensitive ceiling-suspended models. The services that are described in section 3.10.1 are available at these shop stand enclosures.

A data reduction analysis building also exists in the shop. 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 customer personnel to review tunnel test data and communicate with their respective companies.

4.0 INSTRUMENTATION

Model and tunnel instrumentation may consist of Electronically Scanned Pressure (ESP) modules, individual pressure transducers, thermocouples, attitude indicators, strain gauges, and potentiometers to name a few. 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.

Most of the facility instrumentation is collected by the Escort D Plus data acquisition system. Color and black and white hard copies of the data acquisition system 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 RTD 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 ± 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 3.9.1, and the type of thermocouple circuits available at the upper strut terminal panel is presented in section 3.9.2.

4.2 Angle-of-Attack Indicator

A model angle-of-attack (AOA) 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. 27) installed in the model and a signal conditioner in the control room. The angle-of-attack range is -15° to +15° with an overall minimum system accuracy of

±0.05°. This indicator will be installed and calibrated at NASA Glenn.

The seismic element of the AOA Sensor is very accurate but extremely delicate. Any shock to the unit must be avoided. It should be installed on a model only after all hammering on any part of the model or sting is complete; otherwise irreparable damage to the AOA indicator in terms of its bias, stability and sensitivity to vibration will occur. If any hammering on the model or sting is required after the unit is installed, it should first be removed. It is therefore necessary to mount the unit in an accessible area of the model for ease of removal. For pre-run verification, a reference surface must be built-in to the model. The unit must be cooled for temperatures above 160°F. Specific information with regards to AOA indicator mounting, cabling temperature/accuracy specifications and the reference surface can be obtained from the RTD project engineer.

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 customer 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 RTD 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 rack-mount or miniature Digitally Temperature Compensated (DTC) scanners, each containing 32 individual transducers that are addressed and scanned at a rate of 50 000 ports per second. Up to 32 modules with transducer ranges from ±2.5 to 500 psi may be used to provide a total of 1024 pressure channels. A standard “check” pressure is applied to the first port of every scanner and measured by a stand-alone pressure gage to verify the proper operation of the system. On-line calibration of all transducers is normally performed automatically every 1 to 2 hours to ensure overall system errors not greater than ±0.05 percent of full scale.

5.2 Escort D Plus System

The NASA Glenn Escort D Plus system which is supported by the NASA Glenn Information Services Division, is a microcomputer-based, real-time, data acquisition, display, and recording system for steady-state tests. Data acquired by the Escort system includes analog measurements of temperatures, pressures, and other voltage inputs; discrete I/O for significant events; and data from modular instrument systems (such as ESP). Raw data can be converted to engineering units using complex calculations and displayed in real time. Up to 192 analog channels (full-scale ranges of ±5 mV to ±10.24 V) are available with accuracies of ±0.02% FS + 2μV. An additional 64 channels may be requested with accuracies of ±0.05% FS. This data is digitized and then acquired by a Compaq AlphaServer ES40 computer located in the 10-by 10-Foot SWT data room, which is next to the control room. For non-sensitive projects, the system is networked to a central UNIX server in the Research Analysis Center (RAC) for software development, data recording and post-run data processing. Data from sensitive projects is stored on removable disks interfaced to the Compaq AlphaServer ES40. Batch processing of sensitive data is performed in the facility 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, limit checking, updating facility display devices (both alphanumeric and graphical), and transmitting data for archival recording on a data collector. A detailed block diagram of the facility computer is given in figure 28. Data can be acquired at once to twice per second 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 program displays selected data channels and computations in alphanumeric and graphical format. This output is displayed at a rate of once to twice per second on the control-room CRT's. Eight control room alphanumeric color CRT's are supported on the system and provide a means of monitoring test progress and displaying data. Three CRT's are dedicated to the tunnel and model operators. Four CRT's are available to the research engineer and/or customers. One CRT is used to monitor facility parameters. Each CRT can display data in calculated engineering units, millivolts or raw counts. Limits may be applied to any channel. The data for these "limit checked" channels will display in inverse video when limits are exceeded. In addition, output relays can be energized, data recorded or history files frozen upon limit violations. Color and monochrome laser printers are available for hard copy of CRT data.

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 Digital 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 data scan.

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 customer should have any request for customized output program displays available for review at least 6 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. (Averaged data may also be specified). Real-time data processing is available when requests include the calculation of ratios or engineering parameters. Extremely rigorous computing or across-scan computing should be performed off-line to ensure the system 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 customized data software module

(Superplex Data Acquisition) must be created and used on the Escort D Plus system. Superplex Data Acquisition is a method of sampling a subset of the data channels at a rate of ten times per second. The subset of channels is sampled repeatedly at specified time intervals all within one scan of data. This repeated scan (the subset) is referred to as the fast scan. Activating the data record button would then result in automatic Superplex scanning per reading as defined in the customized module.

5.3 Dynamic Data Acquisition

5.3.1 Transient data acquisition system. - A transient data acquisition and reduction system is located in the facility control room. The main component of the system is a Concurrent Computer Corporation host computer with data acquisition and front-end signal conditioning hardware. This system has the capability of recording up to 160 channels. The system uses 16 bit A/D converters with a sampling rate of 2.5 MHz per channel with a sustained throughput of greater than 40 megasamples per second. This system can receive inputs from 160 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.

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. 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 up to 192 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 RTD project engineer and the facility electrical engineer can discuss the details of cart use with the customer.

5.5 Test Matrix Sequencer

The Test Matrix Sequencer (TMS) is a system that automates repetitive tasks by integrating the collection of data and the sequencing of a model or parts of a model, through a series of movements (e.g., alterations in pitch and/or yaw angle, control surfaces, etc.) during the test run. When the test plan calls for numerous model adjustments, the use of the TMS can significantly reduce customer costs by increasing the speed with which data is recorded.

The TMS is programmed via a simple spreadsheet interface prior to the start of the test run. Upon initiation, the TMS commands the model to the first set of positions, waits a pre-determined time for the data to settle and then sends a signal to the Escort D system to record data. The Escort D system then sends the TMS a signal that confirms the recording of the data point and allows the TMS to continue to the next set of conditions in the test matrix. This sequence is repeated until the test matrix is complete. The TMS can be enhanced even further by allowing the data system to automatically determine the data settling time. The facility electronic engineer is available to discuss the capability of the TMS with the customer at one of the pretest meetings.

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 RTD 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 Engineering and Technical Services at NASA Glenn (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 Engineering and Technical Services 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 Glenn and the customers during the time the project is at the Center (model arrival, test time, model return, etc.). The customer is requested to sign the test agreement and return it to NASA Glenn.

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

6.1 Pretest Meetings

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

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

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

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

6.1.4 Data acquisition an reduction. - Data reduction information consisting of data inputs, data outputs, and equations in engineering language must be provided for cases where NASA Glenn performs data reduction activities for the customer. The user should provide this information to the RTD project engineer 6 weeks before the start of testing. The RTD project engineer will contact the appropriate personnel in the RAC and set up any necessary meetings between customers and RAC engineers to establish ground rules for a computing requirements package writeup. The computing instructions writeup from the customer to the RAC engineers is due 6 weeks before the start of testing.

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

6.2 Pretest Documentation

The customer should provide the following information to the RTD project engineer 8 weeks before the scheduled test:

(1) Test envelope for the model (e.g., Mach number range, Reynolds number range, pitch and yaw angle-of-attack, etc.)

(2) Loading on the model as related to maximum dynamic pressure

(3) Stress analysis based on maximum loads that are anticipated on all sections of the model, per criteria in section 7.2.3

(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 customer

(7) A list of all tunnel-user-supplied equipment plus block diagrams and wiring schematics

When the customer and NASA Glenn agree that the data are mutually beneficial, the customer 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 Glenn and to the attention of the RTD project engineer (the facility manager will supply the name and address of this engineer to the customer). All model parts, model internal instrumentation, and customer support hardware should be assembled before shipment to NASA Glenn 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 customer and the RTD 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 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

All tunnel test articles 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 RTD project engineer 8 weeks before the scheduled test.

Allowable stresses for 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. Shear stress calculations and the relationship between yield strength and ultimate tensile strength are presented in ref 9. 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.

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 (pitch and yaw directions) 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 figures 2 or 3. 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 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 (see Table II in ref. 10).

7.2.3 Model stress analysis. - The customer must submit a stress analysis to the RTD project engineer 8 weeks before the start of testing. The stress analysis should include:

(1) Wind tunnel startup loads and their effects on the model
(2) Wind tunnel steady-state loads on the model
(3) Thermal stresses on the model
(4) Stress concentration factors
(5) Design safety factors for startup and steady-state model loading

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

The customer 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.

In the case of dynamic testing or subsonic shedding frequencies the stress analysis report should show that the model, the mounting points, and the restraints are statically and dynamically stable (i.e., that model test matrix data points do not coincide with model resonant frequency points within the 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 used in the analysis should be noted.

Slender body stings must be checked for divergence. The divergence criteria that is to be used should be discussed between the customer and the RTD project engineer.

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)Aerospace Structural Metals Handbook
(9)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 at any model stress condition for the fasteners that clamp the model, sting, model auxiliary structure or model equipment is 3.0 on the basis of yield strength and 5.0 on the basis of ultimate strength for heat-treated hardened bolts. The safety factors are based on bolt cross-sectional area, not on the proof load (lb_f) or proof strength (psi). The proof strength is roughly equivalent to the yield strength applied to a bolt without obtaining a permanent set. The proof load and proof strength concept is discussed in ref. 11.

The total cross-sectional area of the bolts, based on the required safety factor, is determined by first calculating the load on the joint for the most severe test condition. The joint load is then divided by the allowable stress obtained from the bolt material tables at the condition determined above. Note that the allowable stress sometimes has a safety factor figured into its table value (this depends on the reference used). This calculation does not assist in the definition of the preload required on the bolts. The safety factors noted in this section do not include a bolt preload or prestress condition. Bolt preload and prestress condition is defined in ref. 9. In addition references that describe target preloads as a percentage of bolt yield strength, and a nut factor or torque coefficient are discussed in the mechanical connections section in ref.10.

Current engineering practice requires tightening bolts to 75 percent of the proof strength. The individual bolts will have a safety factor based on ultimate strength divided by the stress produced by the preload 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-faced joint is, if the bolts have a preload of 70 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 increase by approximately 30 percent. (The initial joint compressive stress is nearly canceled by external tensile stress; see ref. 11). 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).

Shear loads should be transmitted through the use of keys, pins and shoulders; the keys and pins should be prevented from any movement. A joint system where shear loads are minimal in relation to the axial loads are addressed in ref. 9.

All structural non-pressure vessel weld joints should be designed in accordance with the American Welding Society (AWS) structural codes. All critical joints whose failure could damage the facility, the model or model components must be either radiographed to the requirements of the applicable AWS code or an alternative nondestructive evaluation (NDE) method may be used, but it must meet the AWS codes. The RTD project engineer may enlist the assistance of the Quality Management Office (8200) to evaluate model welds.

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 RTD 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 the above 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.

7.2.8 Electrical equipment components. – All hardware, equipment, and material that is used in the facility test section must conform to the National Electrical Code. 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 RTD project engineer and the facility electrical engineer at one of the pretest meetings.

7.3 Model Fabrication Requirements

All model parts are to be customer inspected to ensure proper fit and models should be completely assembled at the manufacturer's plant. All remotely controlled model functions should be checked out, and position indicators should be calibrated before the model is shipped to NASA Glenn. 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 3.10.1) can be used for model assembly. After the model is installed in the tunnel test section at NASA Glenn, 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 any pneumatic and hydraulic lines inside of the model should be tagged. 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 model electrical, pneumatic and hydraulic systems.

7.4 Model Installation Procedures

Written procedures for model assembly, installation, and configuration changes in the 10-by 10-Foot SWT are required. They should be submitted to the RTD project engineer at least eight weeks before tunnel entry. These procedures should list sequentially the steps that are to be taken to install the model in the tunnel test section. They should also indicate the model's alignment in the test section and the bolt torque 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 customer 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 customer discuss with the RTD project engineer 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 customer supply mechanics to assist with the installation. Special tools and equipment, spare parts, and supplies necessary to perform work on the model are to be supplied by the customers.

8.1.3 Operation of Government equipment. - Customer personnel should not operate Government-furnished equipment or make connections to this equipment without the approval of NASA Glenn 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 follow NASA Glenn guidelines. 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 customer 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 customer to the RTD project engineer.

8.2 Operations

8.2.1 Normal operating days and shift hours. - Tests are usually run from 11:00 p.m. to 7:00 a.m. Monday night through Saturday morning (5 runs per week). This window can be expanded if the schedule warrants it. Customers should discuss expanding the test time each week with the RTD 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 RTD project engineer.

8.3 Planning

8.3.1 Prerun safety meeting. - The RTD 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 by the RTD project engineer to the Glenn Safety Office and then to the Environmental Management Office (if applicable) 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 customer 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 customer's lead engineer and the facility manager. Discussions with NASA personnel who have experience with the facility should assist the customer 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 customer's lead engineer will meet with the facility manager. The purpose of the meeting is to evaluate the test support received by the customer during the test program. The facility manager will make the arrangements for the meeting.

8.4 Security Requirements

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

8.4.1 Nonclassified test by U.S. citizen.- During nonclassified test programs the RTD project engineer will notify the NASA Glenn 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.

8.4.2 Nonclassified test by non-U.S. citizen. – All non-U.S. citizens, as well as U.S. citizens employed by foreign-owned companies, must be sponsored and may require a National Agency Check. The sponsor (the Glenn research engineer) of the test is responsible to obtain all necessary approvals for these individuals. The approval process is initiated with the completion of NASA form C-216 (Non-U.S. Citizen Access Request), which is found on the NASA Glenn research Center's internal Web site at http://forms.grc.nasa.gov/forms/PublicUser/Index.cfm. Upon completion of this form, it is submitted to the International Visitor Coordinator (IVC) of the Security Management and Safeguards Office (SMSO) at Glenn at least 8 weeks prior to the visit. The name of the IVC can be found by going to the SMSO home page http://smo.grc.nasa.gov. Selecting the Foreign Visitor Access Procedures link opens the International Visitors Program home page, and the name of the IVC is listed on the bottom of the first page. Specific security plans for the facility, technology control plans, and computer system security plans should be submitted as soon as possible to the SMSO after submission of the C-216 form. An outline of the Security and Export Control Plan (incorporating plans for facility security and technology control) may be obtained from the IVC or by selecting the IVC Security Plan link on the IVP home page. Computer system security plans should be coordinated with the Glenn Information Technology (IT) Security Manager, who resides in the Computer Services Division. All (computer) system requirements should be validated with the Glenn IT Security Manager. The IVC can provide the name of this manager to the research engineer.

8.4.3 Sensitive test by U.S.citizen. -A classified test program at NASA Glenn requires that the proper security clearance be in place prior to the arrival at Glenn of a non-NASA visitor who is a U.S. citizen. The NASA Glenn Security Management and Safeguards 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 sent to the following address:

NASA Glenn Research Center at Lewis Field
Attn:Security Management and Safeguards Office
Mail Stop 105-2
21000 Brookpark Road
Cleveland, Ohio 44135
Phone:(216) 433-8976
Fax: (216) 433-8000

The RTD project engineer will notify the NASA Glenn Security Management and Safeguards 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.

8.4.4 Hirsch access controls.– The 10X10 SWT facility is secured with a Hirsch keypad access system. Access of personnel to the protected areas of the shop, the control room and the facility will be strictly controlled by the 10X10 SWT security representative. Each person cleared to enter the restricted areas will be issued a Hirsch personnel identification number (PIN).

8.4.5 Isolated networks. – A portion of the computer network architecture that resides within the 10X10 SWT office building and instrumentation and controllers that are located inside of the tunnel facility building are part of a protected zone that is separated from the rest of a general network by an encryptor. This encryptor makes information exchange between protected machines and unprotected machines unintelligible. This effectively isolates protected machines from the rest of the network. A machine connected to the network with a matching encryptor, however, will be able to communicate with the protected machines. An example of this is the performance of software maintenance of the 10X10 SWT Escort system from the NASA Glenn Research Analysis Center. Similarly, a matching encryptor at a remote customer site can be used to deliver data to the customer. The details of such an arrangement can be discussed at one of the pretest meetings at NASA Glenn with the customer, the 10X10 SWT project engineer, the 10X10

SWT electronic engineer and one of the NASA Glenn computer representatives.

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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 Glenn Research Center at Lewis Field
ATT.: (Name of 10-by 10-Foot SWT facility manager)
Mail Stop 6-8
21000 Brookpark Road
Cleveland, Ohio 44135

The name of the appropriate facility manager can be obtained from a facility portal uniform resource locater (URL) which is as follows: http://facilities.grc.nasa.gov/. On this home page under Test Information in the left hand column, click on the Contact Information link. The names and the phone numbers of the facility managers are listed on this page. The above noted URL is valid for customers that are either off-site or on-site. In the absence of a computer, call the administrative assistant at (216) 433-5731 and ask for the name of the current facility manager.

Customer models and equipment can be shipped to the following address:

NASA Glenn Research Center
ATT.: (Name of the 10X10 SWT facility manager
or the RTD project engineer *)
Building 113 Shop Area
21000 Brookpark Road
Cleveland, OH 44135

* The name of this person can be supplied to the customer by the 10X10 SWT facility manager

APPENDIX B

SUMMARY OF PROCEDURE FOR OBTAINING TEST TIME

1. Customer contacts the 10-by 10-Foot SWT facility manager and submits the overall test requirements at least 1 year before the test.
2. The tunnel facility manager and appropriate Research Testing Division personnel review the request.
3. Customer submits formal letter of request to Director of Engineering and Technical Services at NASA Glenn (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 Glenn 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, RTD project engineer, RTD electrical engineer and key RTD personnel.

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1. Arrington, E. Allen, Gonsalez, Jose C.,and Curry, Monroe R.: Subsonic Calibration of the NASA Glenn Research Center 10-by 10-Foot Supersonic Wind Tunnel (1998 Tests). AIAA-2000-2448, June, 2000.

2. Cubbison, R.W.; and Meleason, E.T.: Water Condensation Effects of Heated Vitiated Air on Flow in a Large Supersonic Wind Tunnel. NASA TM X-1636, 1968.

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7. Weir, L.J.; Reddy, D.R.; and Rupp, G.D.: Mach 5 Inlet CFD and Experimental Results. AIAA Paper 89-2355, 1989.

8. Reddy, D.R.; Benson, T.J.; and Weir, L.J.: Comparison of 3D Viscous Flow Computations of Mach 5 Inlet With Experimental Data. NASA TM-102518, 1990.

9. Chambers, Jeffrey A.: Preloaded Joint Analysis Methodology for Space Flight Systems. NASA TM-106943, 1995.

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11. Shigley, J.E.: Mechanical Engineering Design. Mc Graw-Hill, Inc., New York, 1977.

TABLE I. FACILITY SUPPORT SYSTEMS

System	Weight Volumetric Flow Rate	Pressure	Volume ft^3 (std)	Temperature
High-pressure air	Variable	2600 psig (max.)	216 000	Ambient
Service air	2 lb_m/sec	125 psig	------------	Ambient
Combustion air	12 lb_m/sec	450 psig	------------	300 ºF (max.)
Hydraulic	27.1 gal/min	3000 psig (max.)	------------	110°F
Gaseous hydrogen	0.66 lb_m/sec	1200 psig (max.)	------------	Ambient
Gaseous oxygen	23 lb_m/sec	1500 psig (max.)	-------------	Ambient
Model altitude exhaust	20 lb_m/sec (max.)	28 in. Hg vacuum	------------	-----------
Liquid fuel	70 or 30 gal/min.	40 or 950 psia (max.)	------------	Ambient

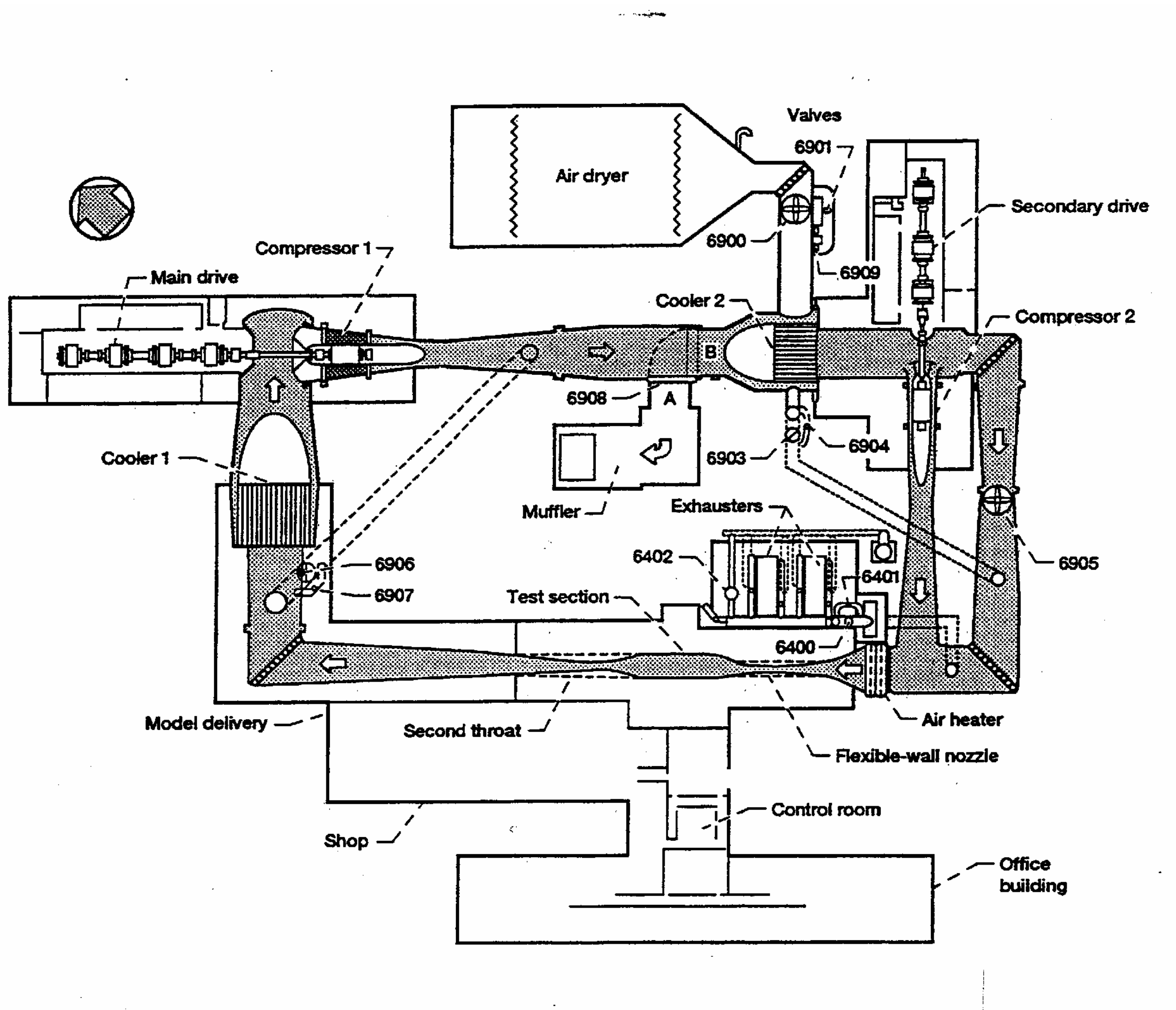

Figure 1. – Schematic of 10-by 10-Foot Supersonic Wind Tunnel

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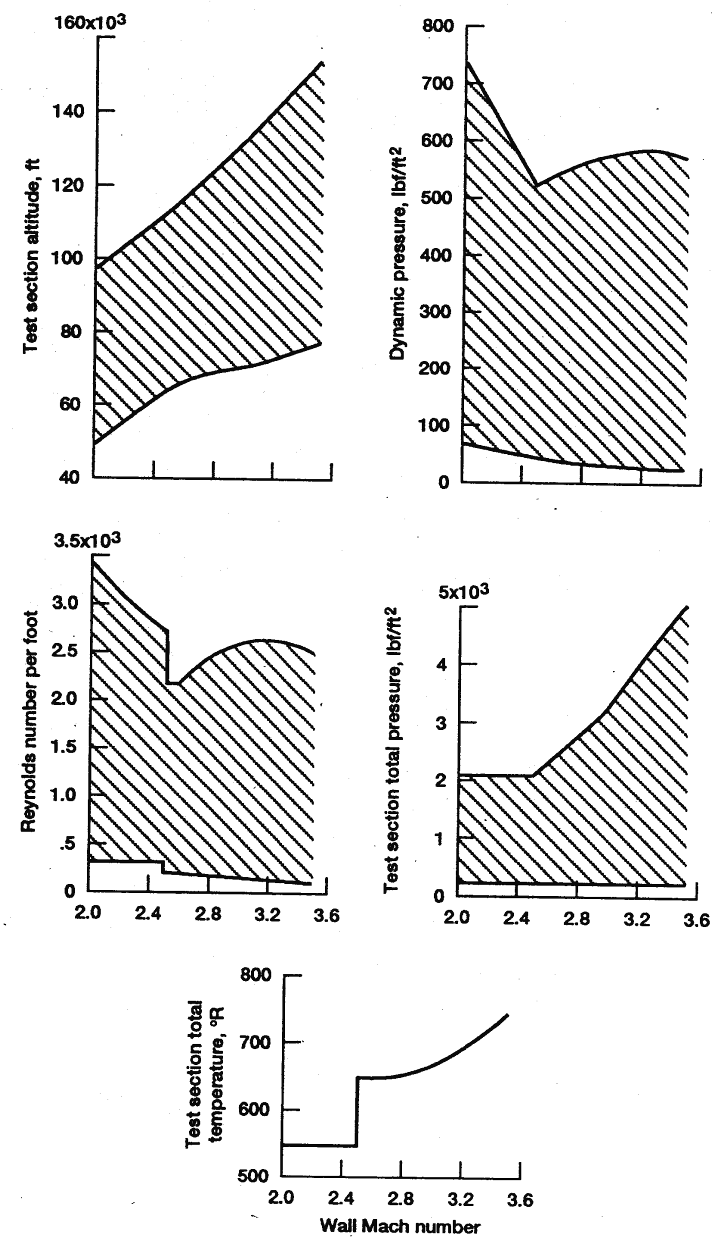

Figure 2. – Operating envelopes for aerodynamic cycle (supersonic) of 10-by 10-Foot Supersonic Wind Tunnel.

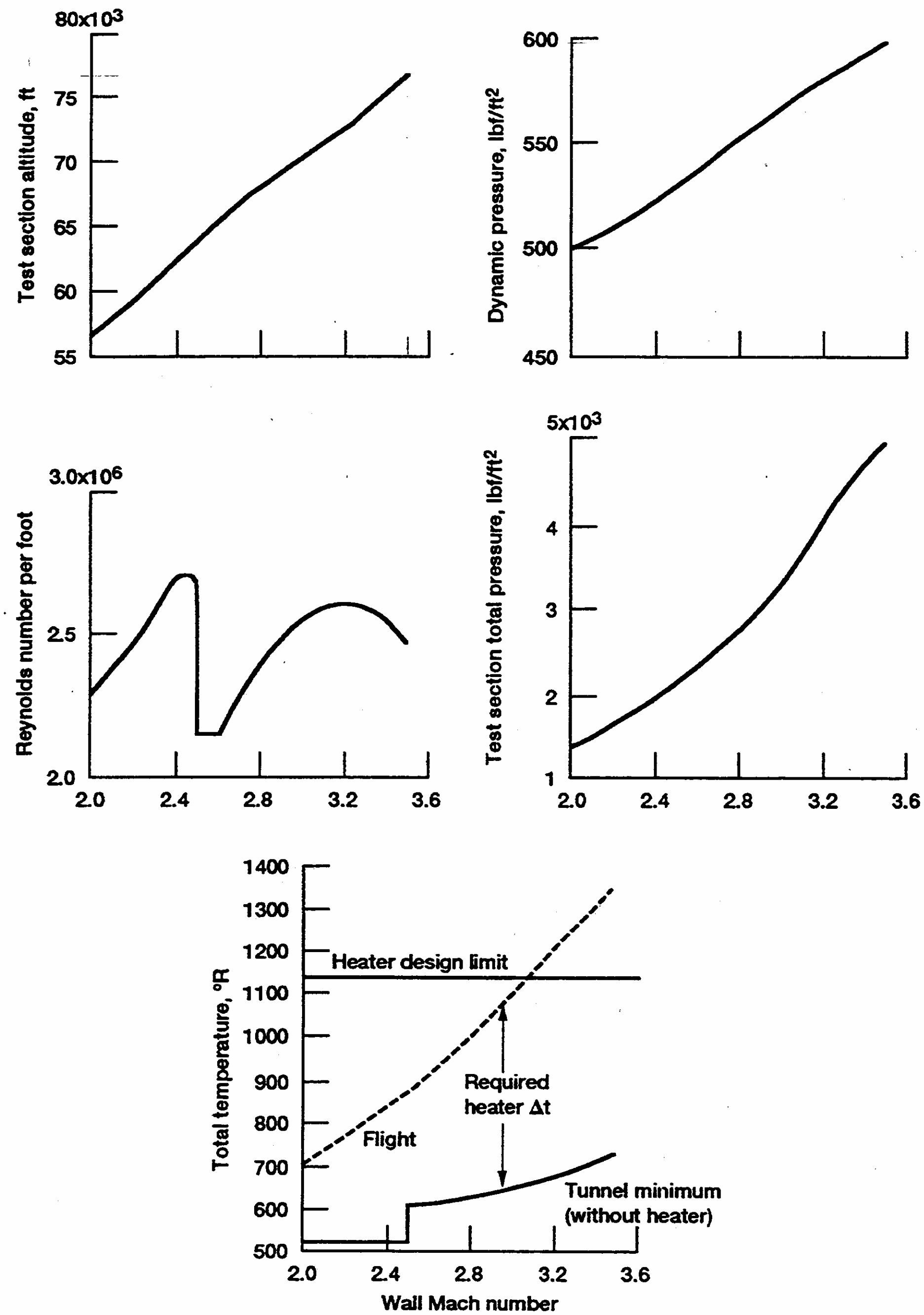

Figure 3. – Operating envelopes for the propulsion cycle

(supersonic) of the 10-by 10-Foot Supersonic Wind Tunnel.

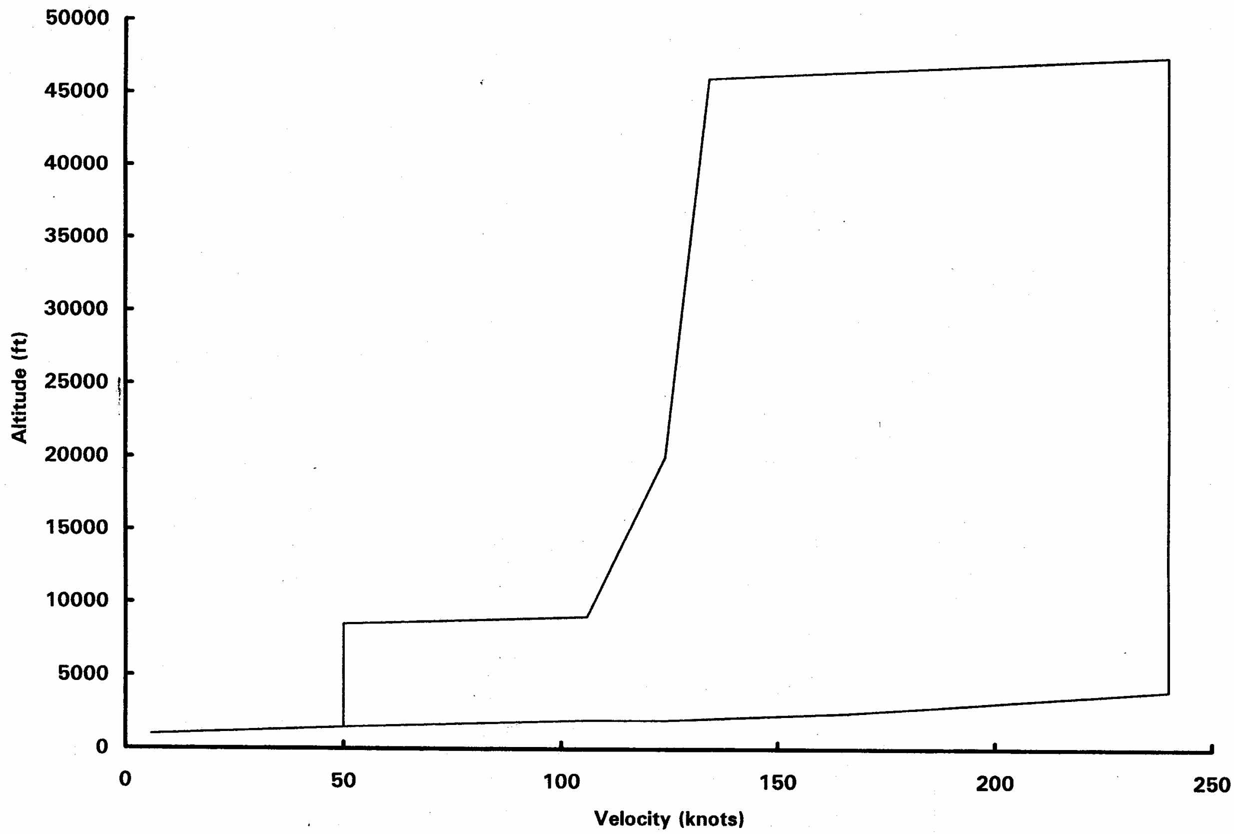

Figure 4. – Subsonic altitude capability for the 10-by 10-Foot Supersonic Wind Tunnel.

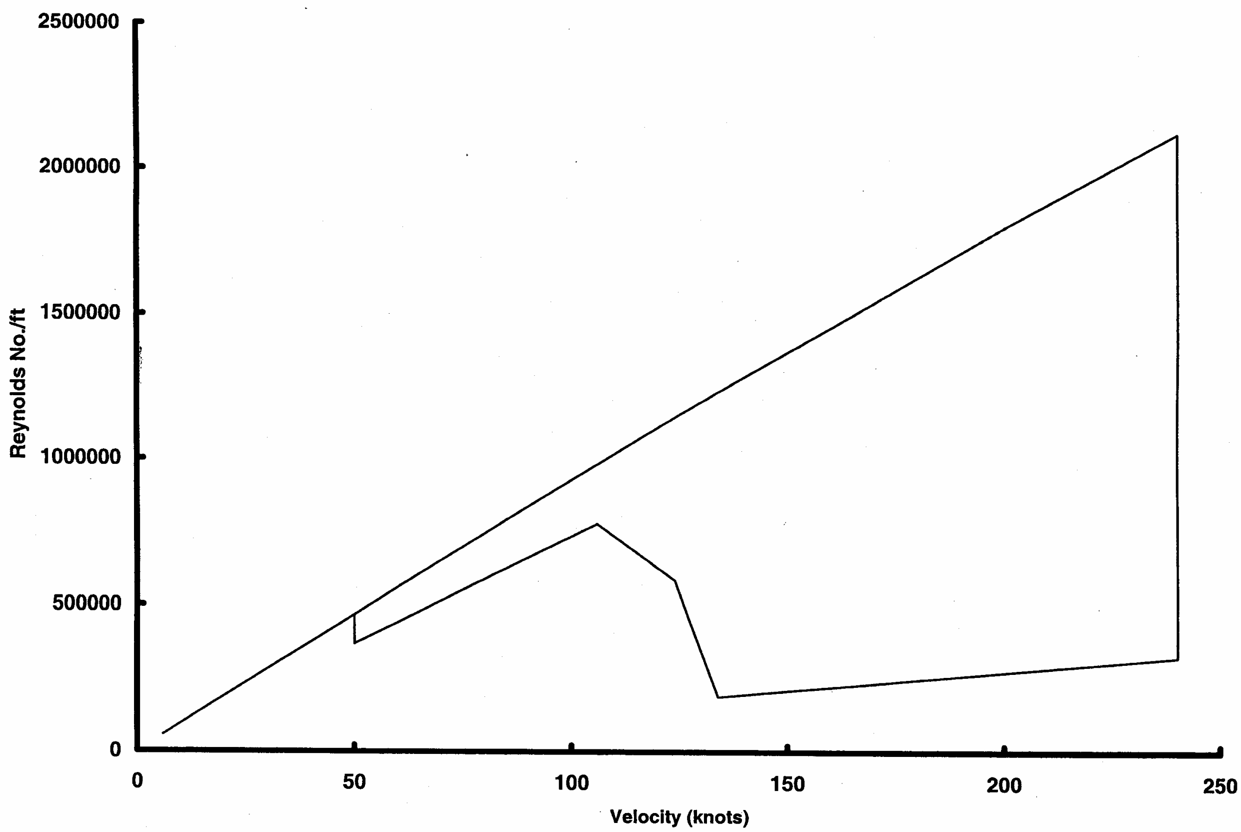

Figure 5. – Reynolds No./ft range for subsonic operation of the 10-by 10-Foot Supersonic Wind Tunnel

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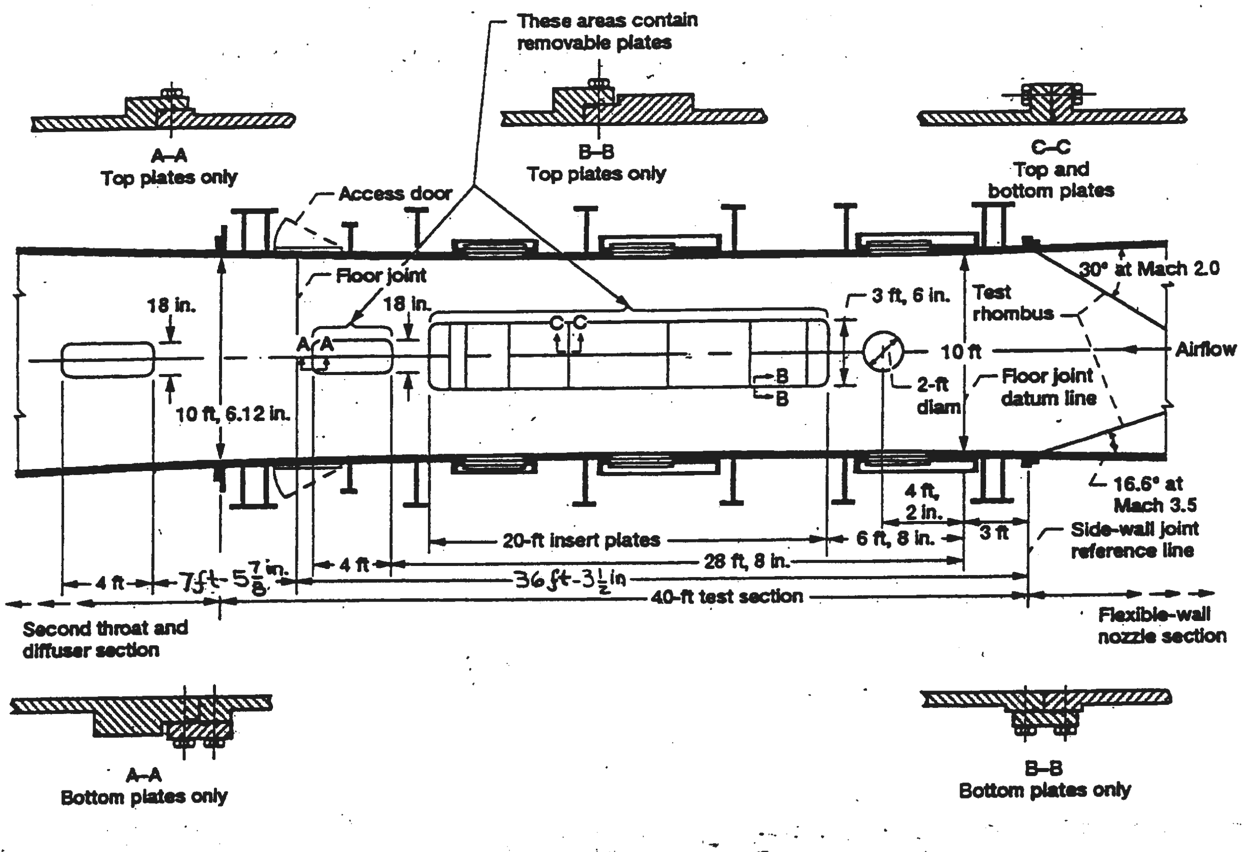

Figure 6. – Test section plan view. (Various-size insert plates are available for the top and bottom of the test section. For complete details of plate openings the RTD project engineer can obtain NASA drawings CE-107998 and CE-107999).

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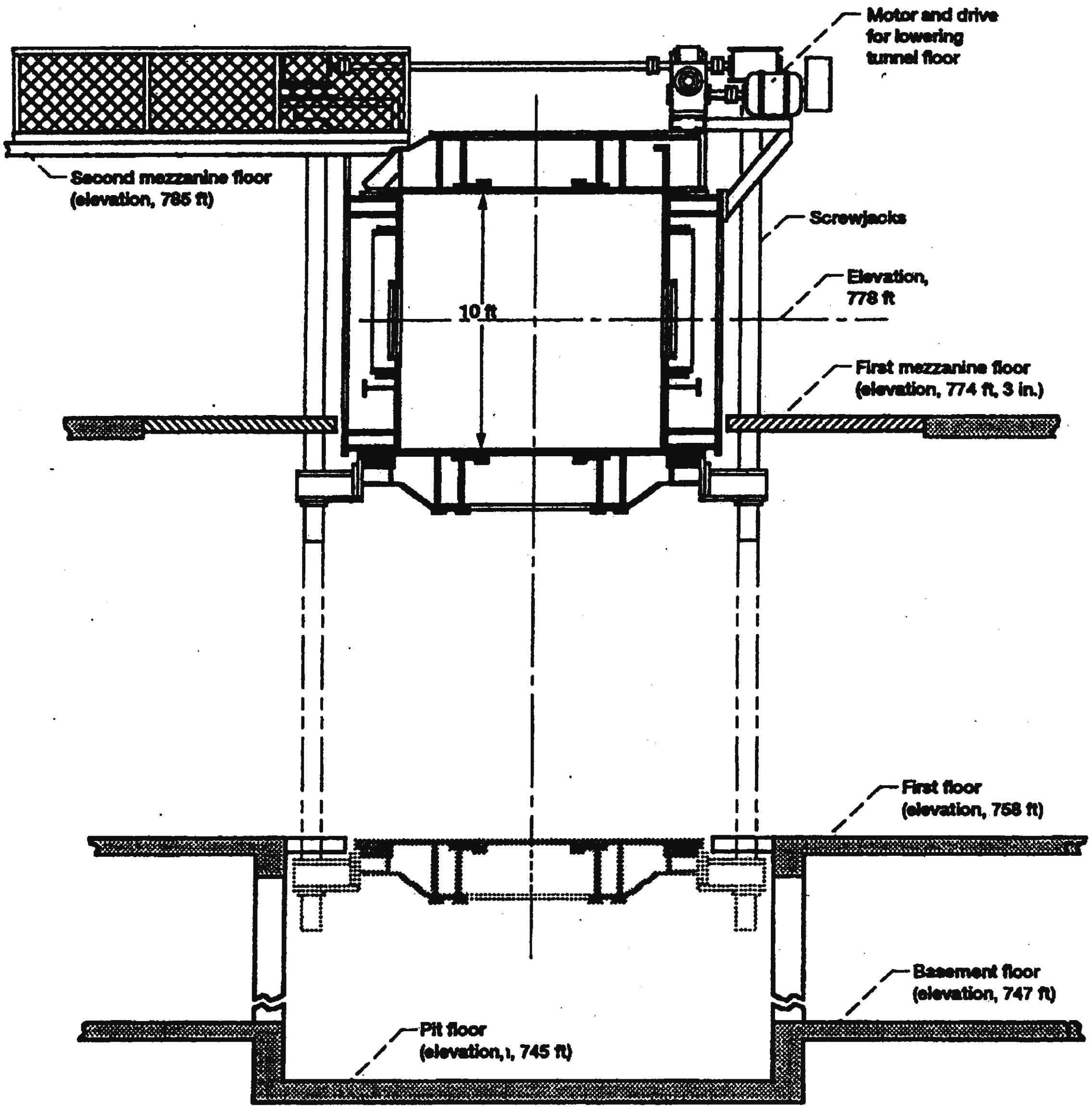
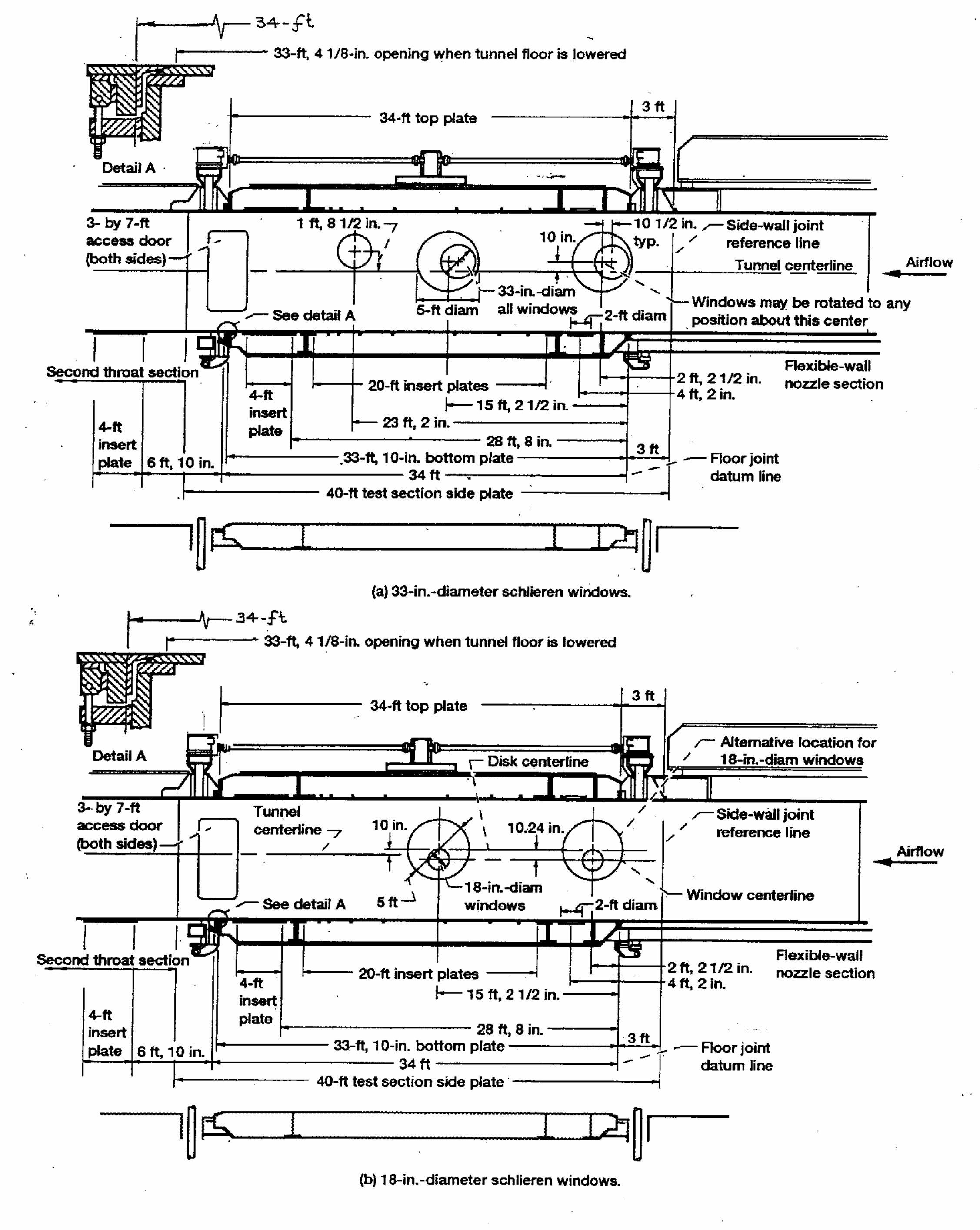


Figure 7. – Test section cross section.



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

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

Figure 8. – Test section elevation view.

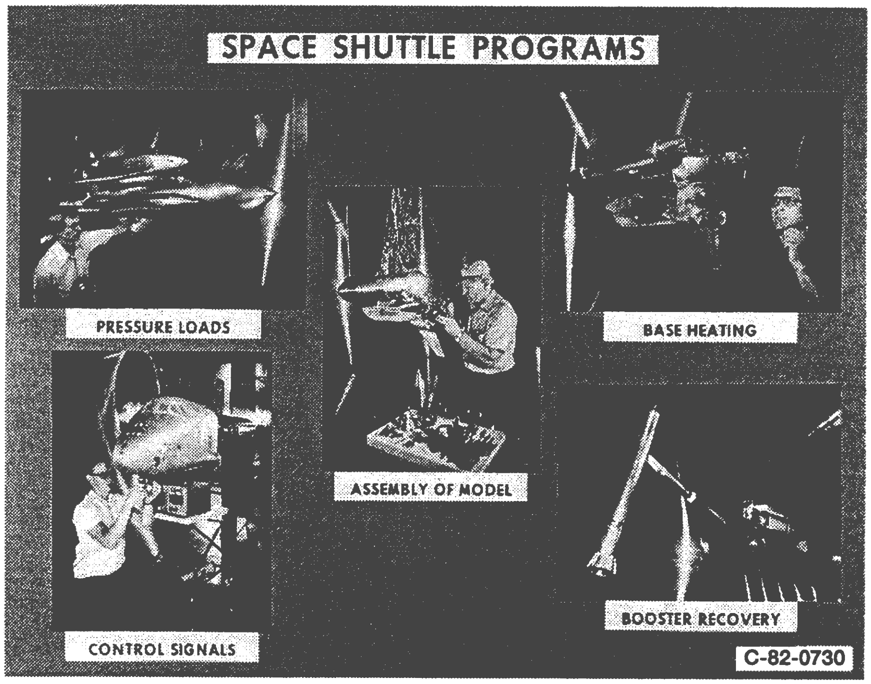


Figure 9. – Typical models and experiments installed in the test section.

Figure 10. – Mach 5 inlet installed in test section.

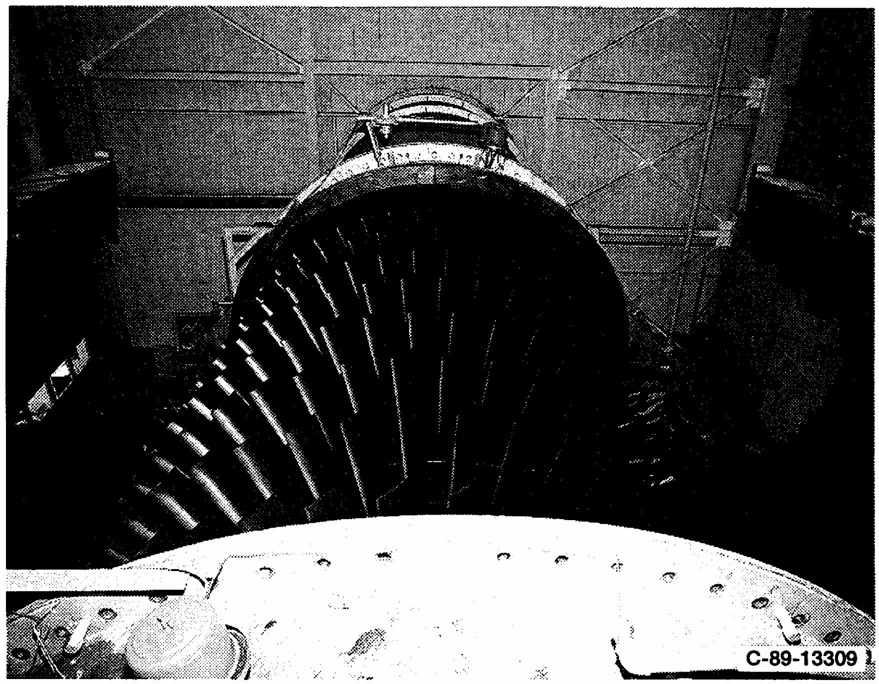


Figure 11. – Compressor 1 with case open.

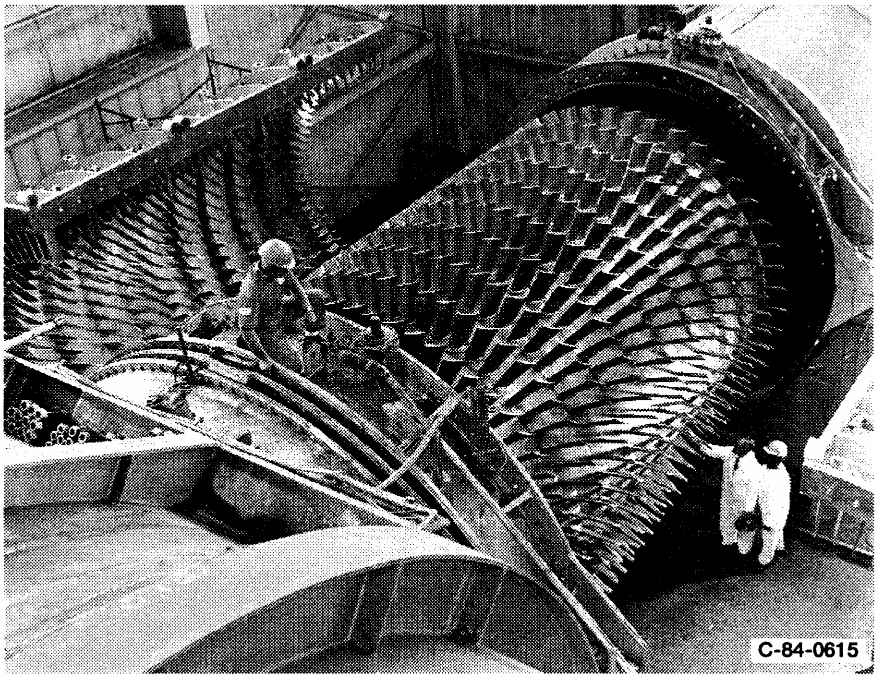


Figure 12. – Inspection of compressor 2 with case open.

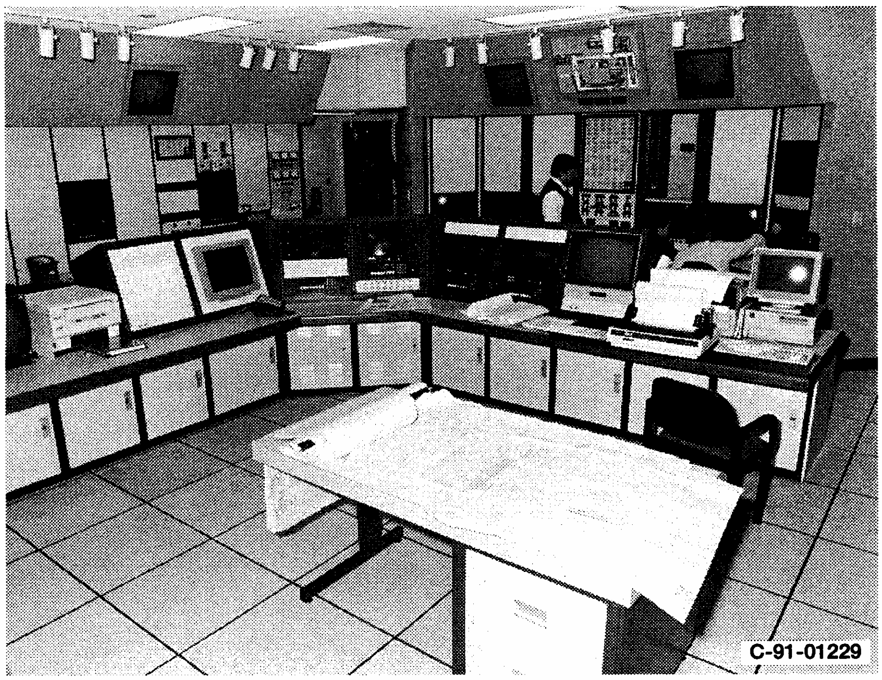


Figure 13. – Control room

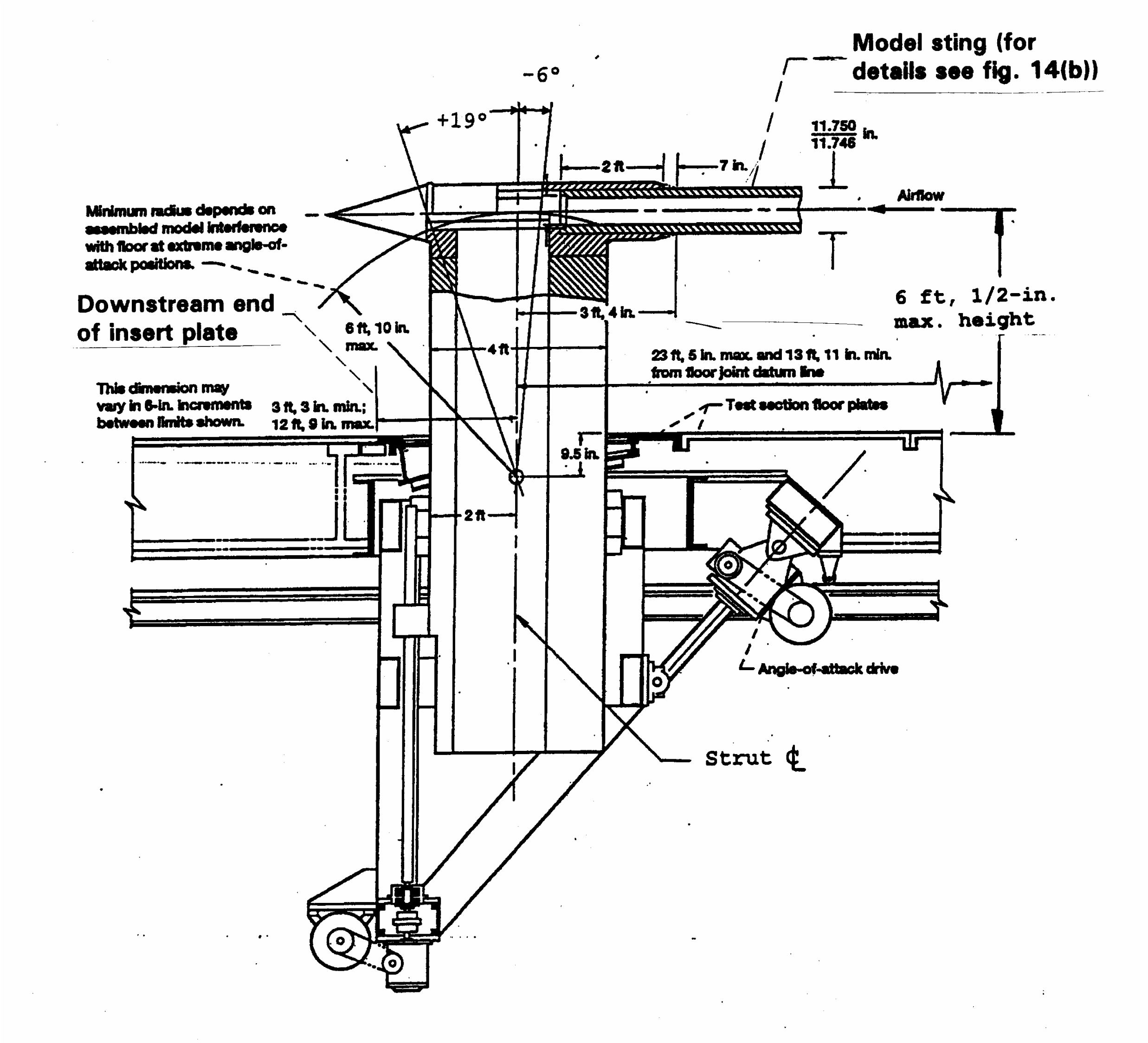


Figure 14(a). - Sting strut and adapters. (The RTD project engineer can provide reference assembly drawing CE-72053).

Design loads for strut (3 ft ahead of vertical centerline of strut): normal force is +9000 lb_f/-7000 lb_f; axial force is 3500 lb_f; and max. moment is +125,000 ft-lb_f/-115,000 ft-lb_f.
***Note: At zero degrees angle-of-attack, the minimum centerline height above floor is approximately 8 ¼ inches. However, this,**

minimum height may increase depending on model installation.

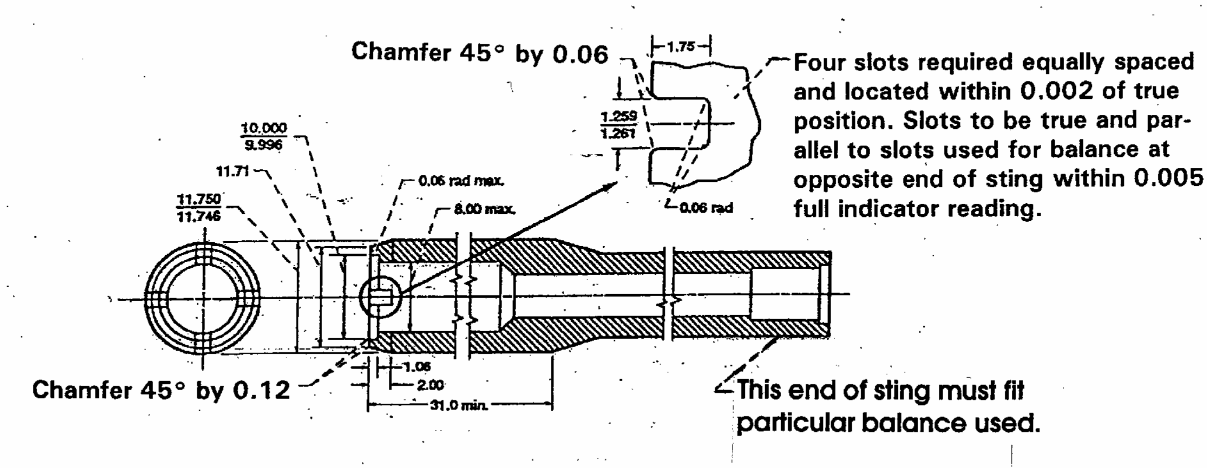


Figure 14(b) Sting end details. Dimensions are in inches unless otherwise noted.

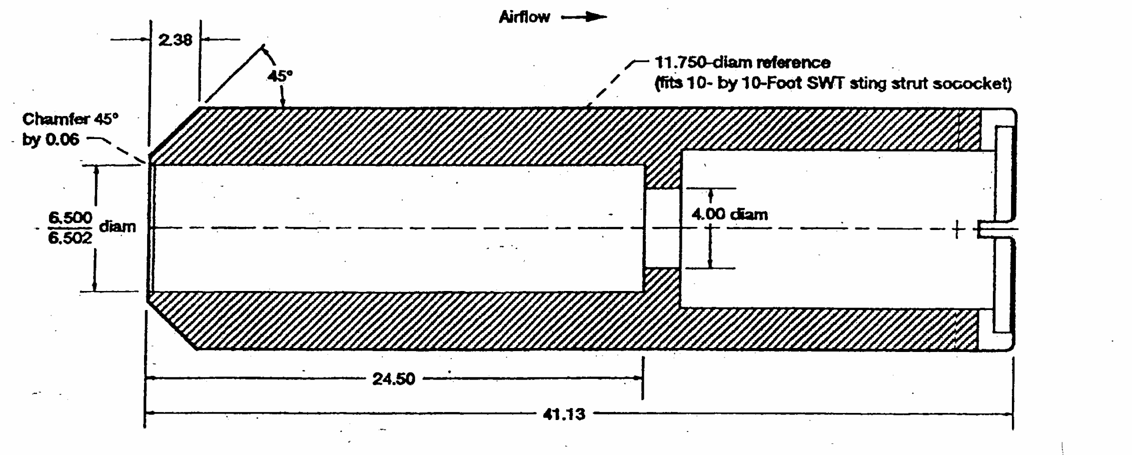


Figure 15.- Sting adapter for use with 8-by 6-Foot Supersonic Wind Tunnel stings. (Dimensions are in inches unless otherwise noted).

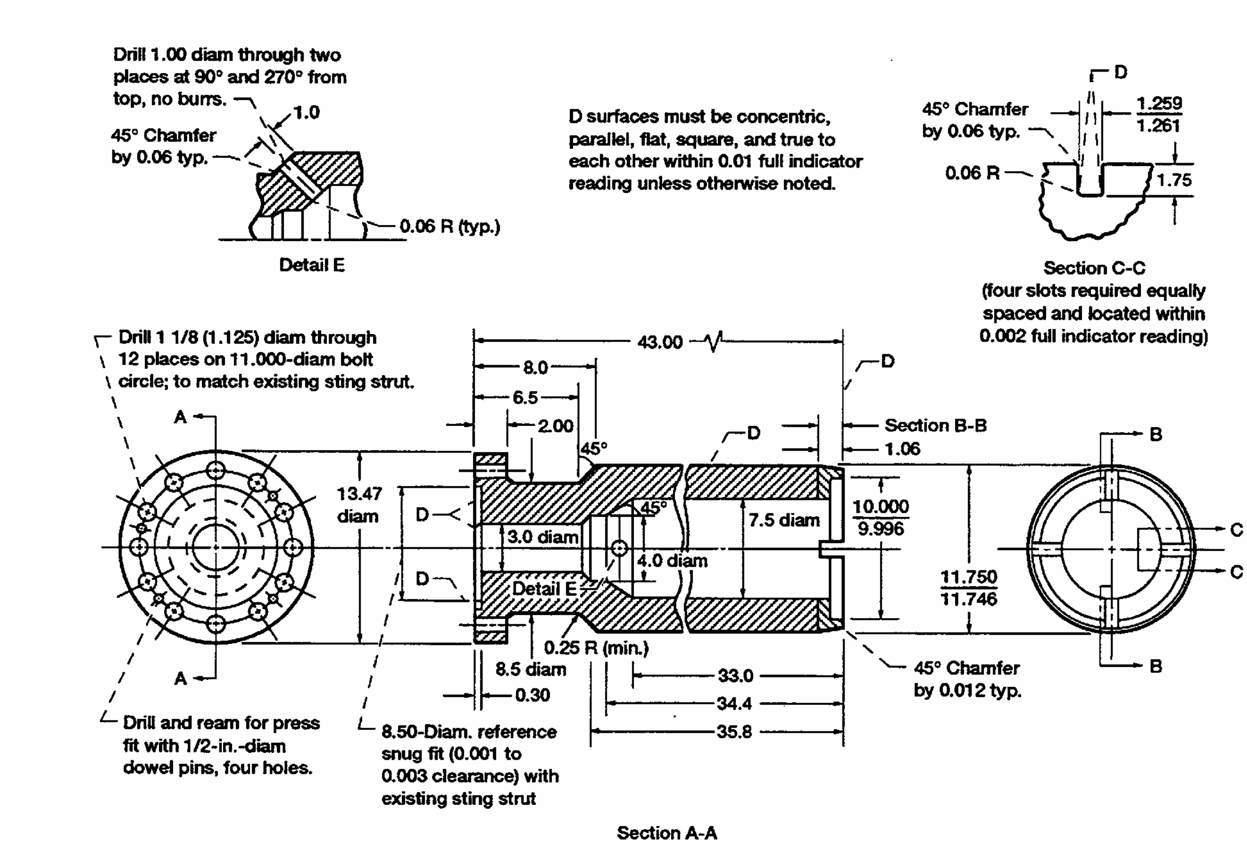


Figure 16. – Adapter used to mate NASA Langley stings to NASA Glenn strut. (Dimensions are in inches).

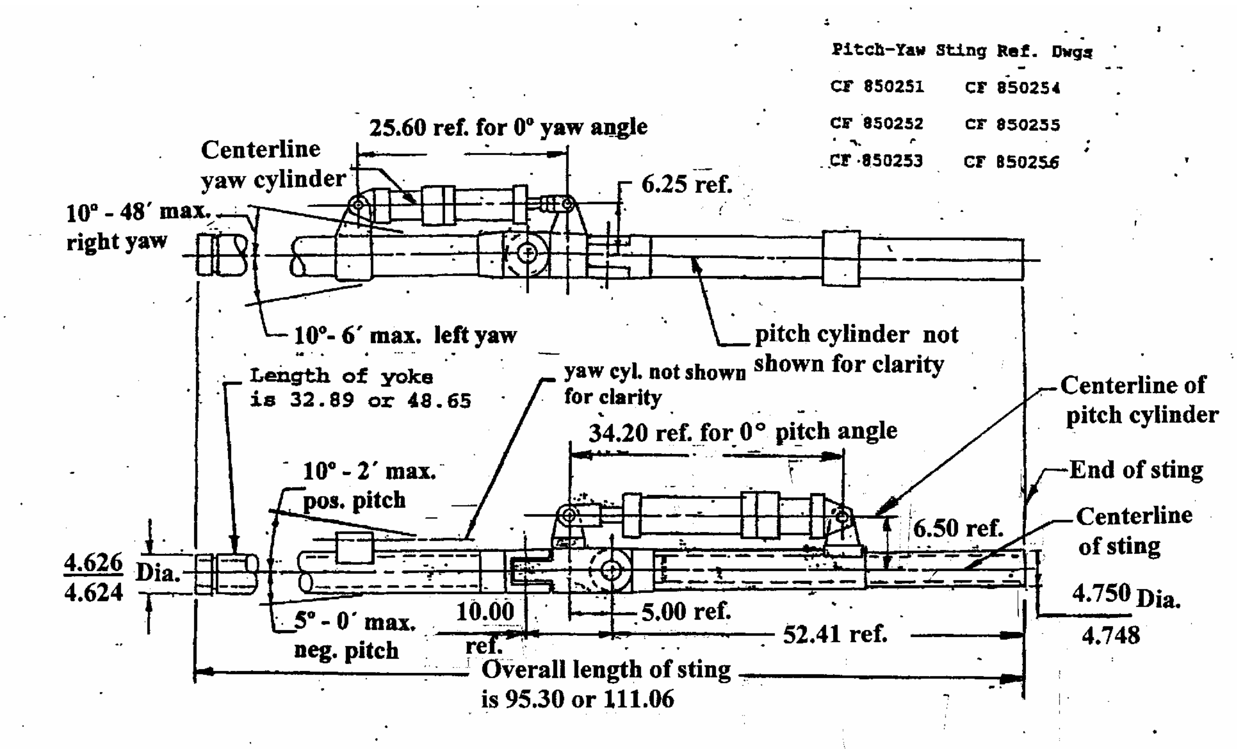


Figure 17. – Hydraulically operated pitch-yaw sting (for use at the 10X10 SWT and the 8X6 SWT). See ref. drawings noted above. All dimensions are in inches.

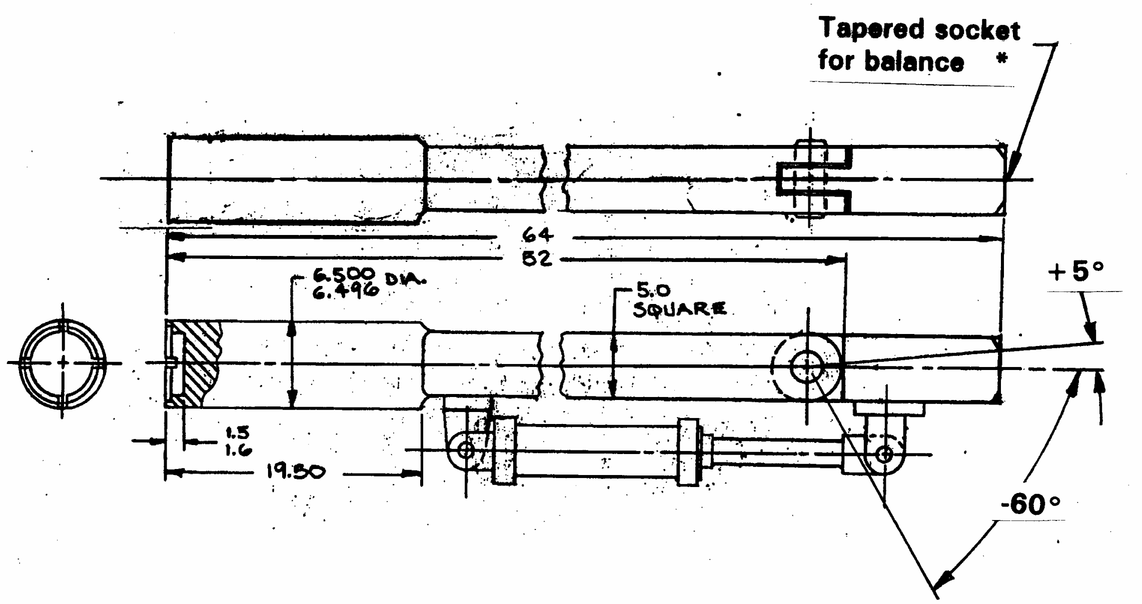


Figure 18. – Sting knuckle
(see drawing #CR643361 for more details).
All dimensions are in inches

Load Rating:
Normal Force: +3200/-4600 lb_f

Axial Force: 3500 lb_f

Pitching Moment: +16,800/-24,150 ft-lb_f

* Socket details can be provided.

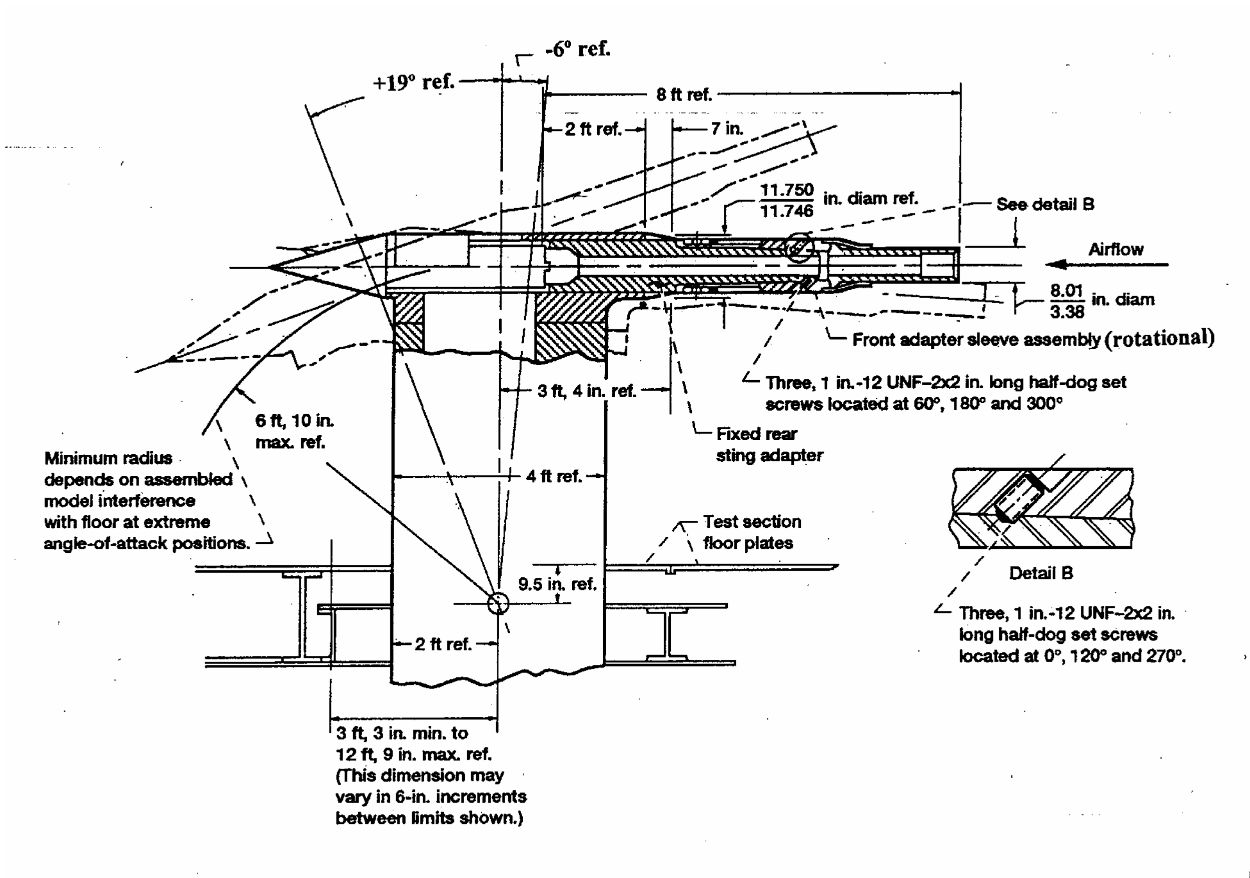


Figure 19. – Rotating sting adapter. (The RTD project engineer can supply reference drawings 28013M40A100 through 28013M40A108 if requested). All dimensions are in inches.

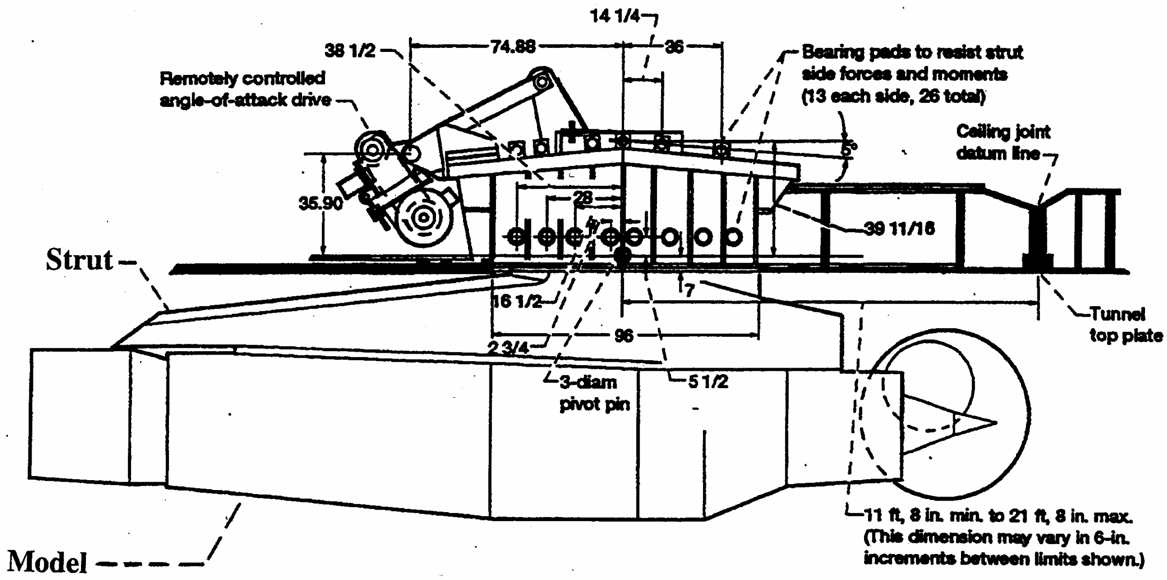


Figure 20. – Ceiling Strut assembly. Normal force, ±50 000 lb_f; axial force, ±50 000 lb_f; pitching moment, ±175 000 ft-lb_f. (Dimensions are in inches unless otherwise specified. The RTD project engineer can provide reference drawings for assembly of strut support (CR-72200) and installation of model (CF-74320) if requested). All dimensions are in inches.

* Details of available ceiling struts can be provided.

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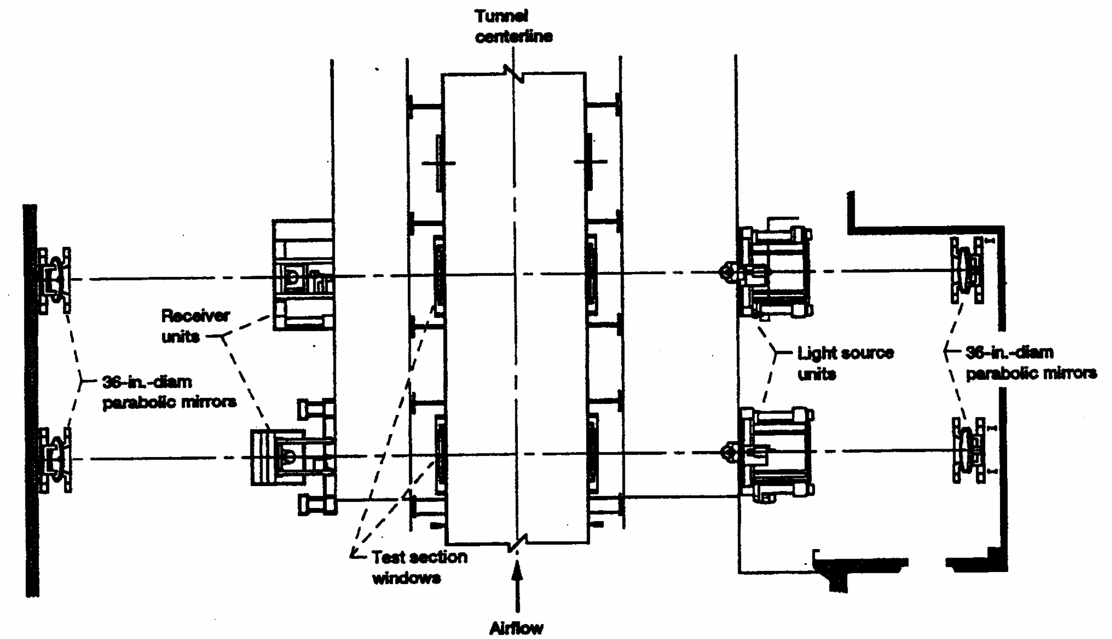


Figure 21. – Schlieren system plan view.

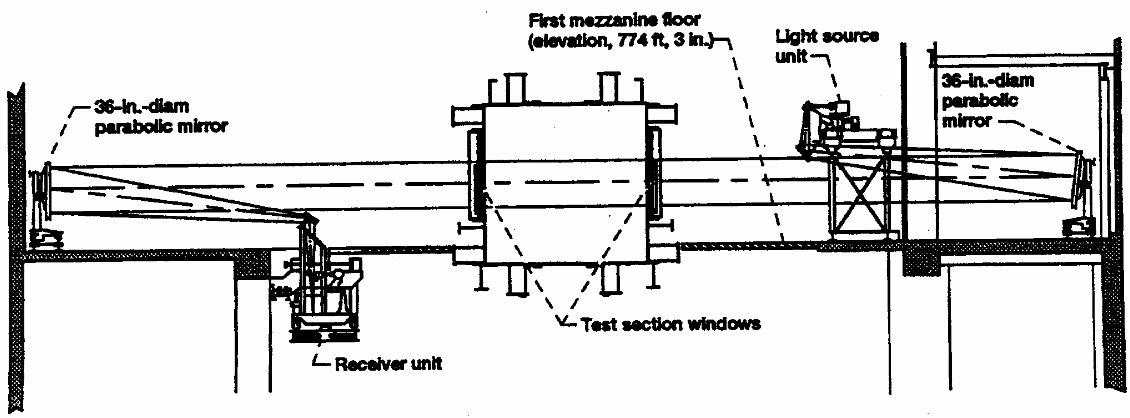
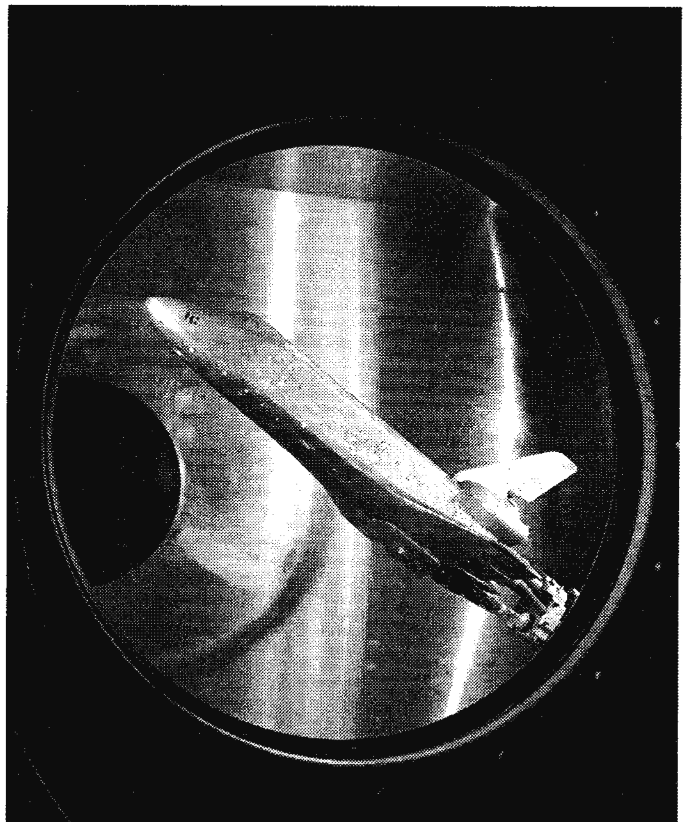
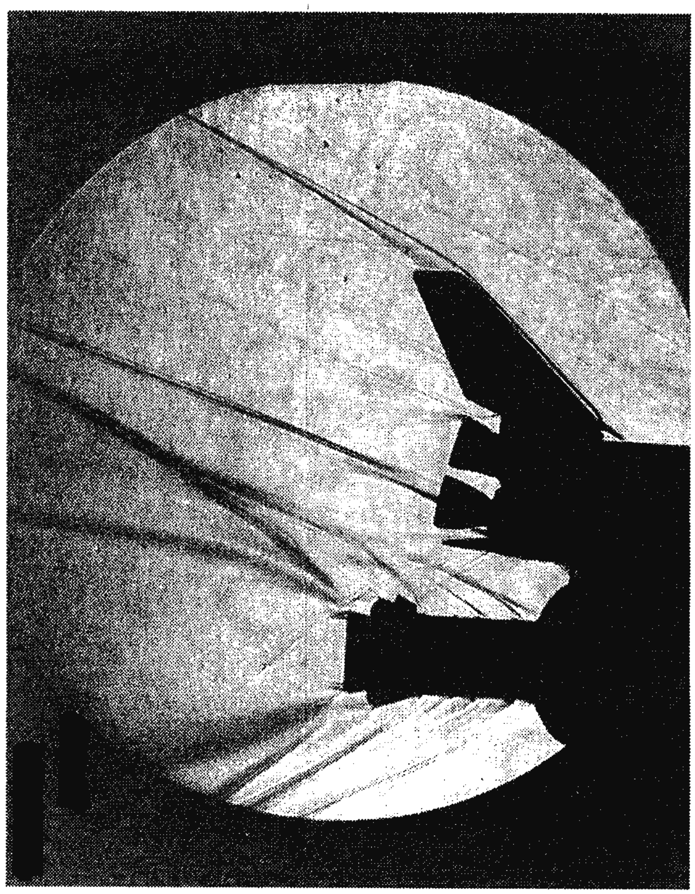


Figure 22. – Schlieren system elevation view (looking downstream).



NASA Glenn photo C-83-5386

Figure 23.-Shuttle model viewed through test section schlieren window.



NASA Glenn photo C-88-03901

Figure 24. – Model photo using schlieren system.

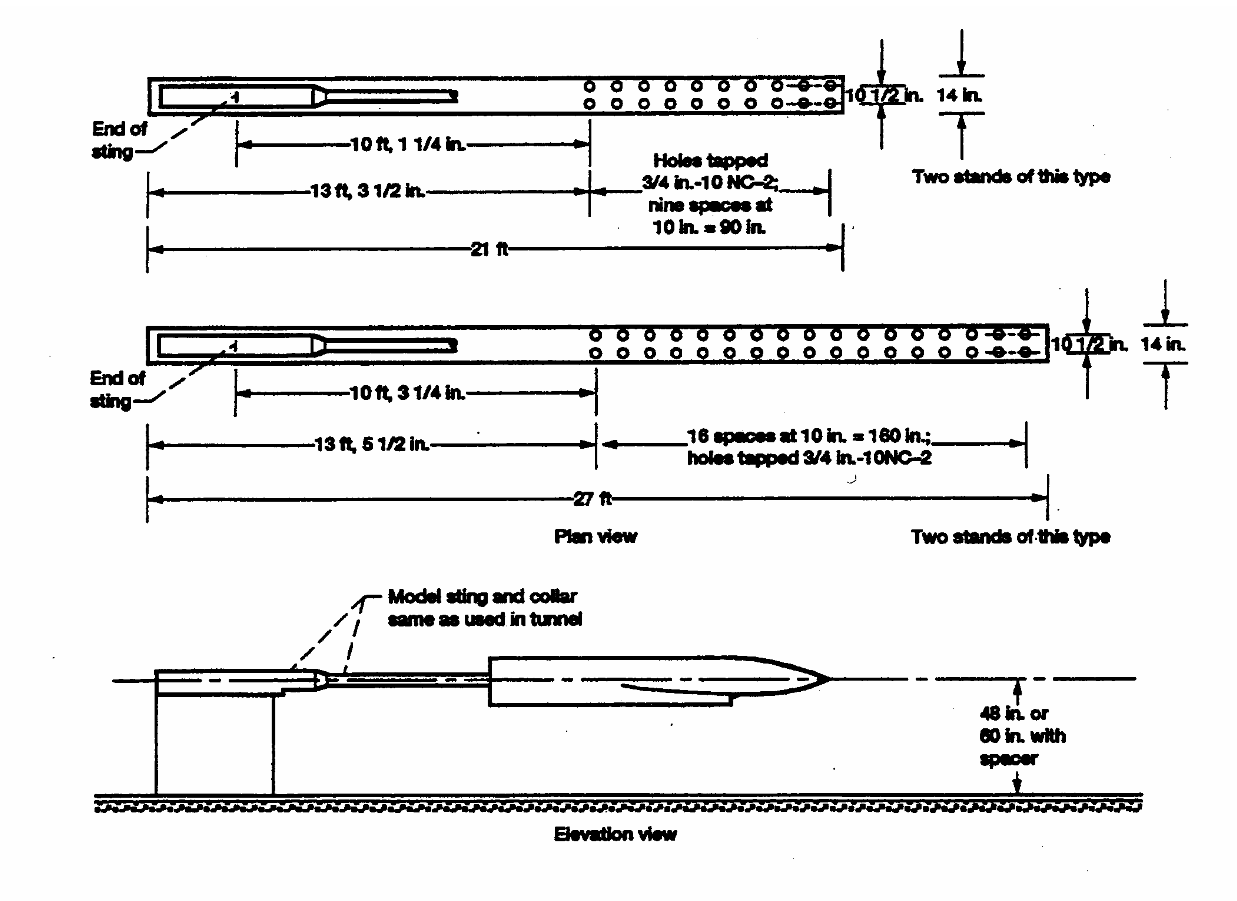


Figure 25. – Shop stands for sting-mounted models

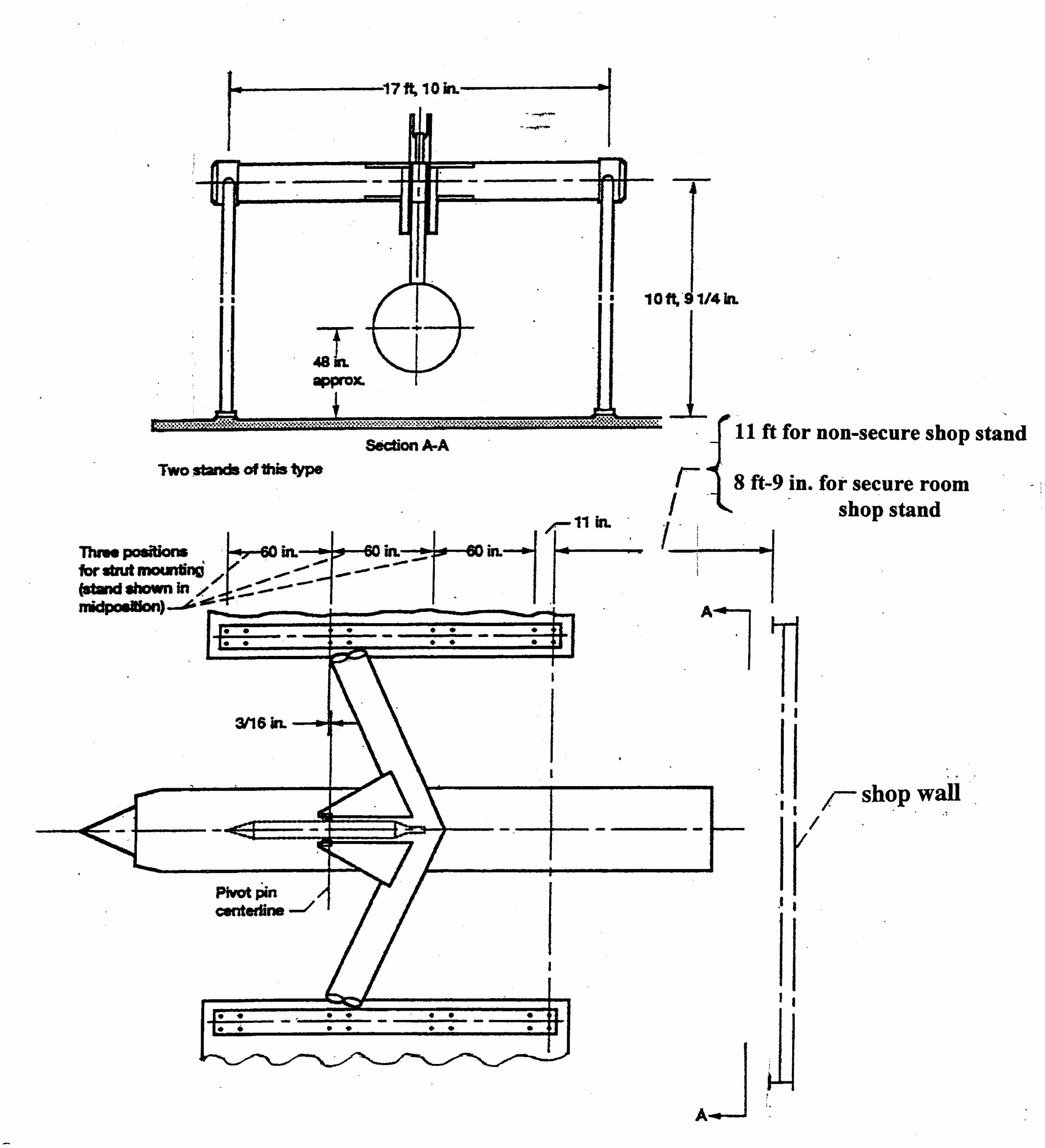


Figure 26. – Shop stands for ceiling-suspended models.

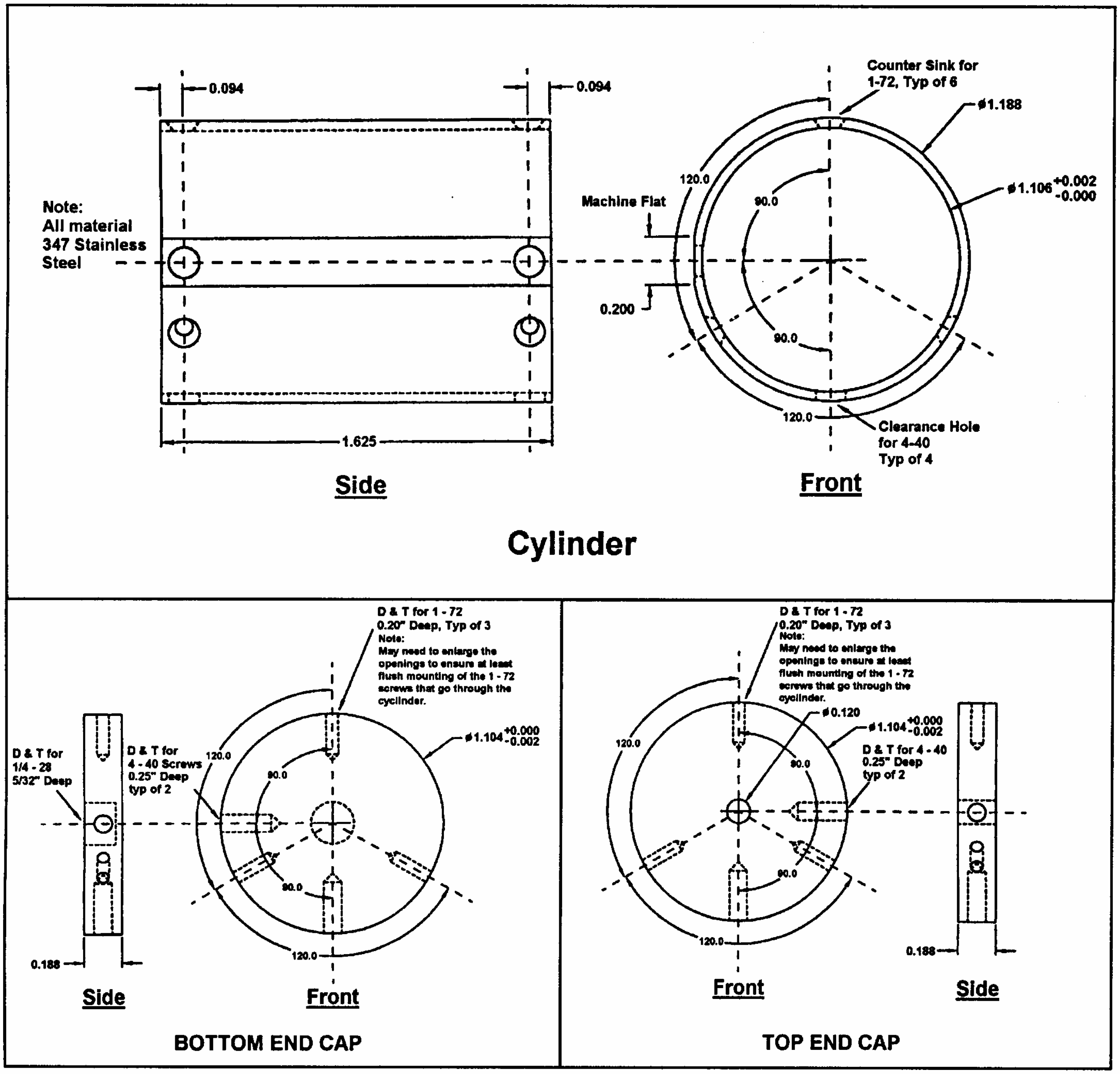


Figure 27. – Wyle Labs Model 0102 Angle of Attack (AOA) Sensor. All dimensions are in inches and angular designations

are in degrees.

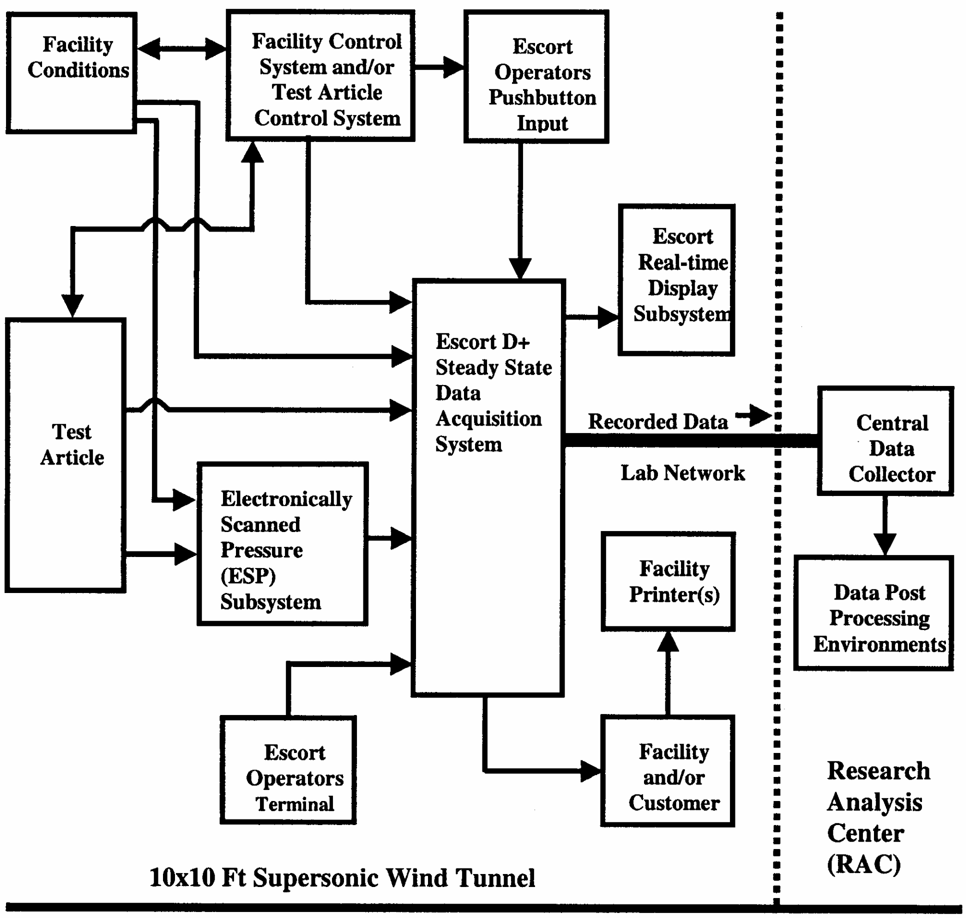


Figure 28. – Schematic Flow Chart of the 10X10 SWT data system.

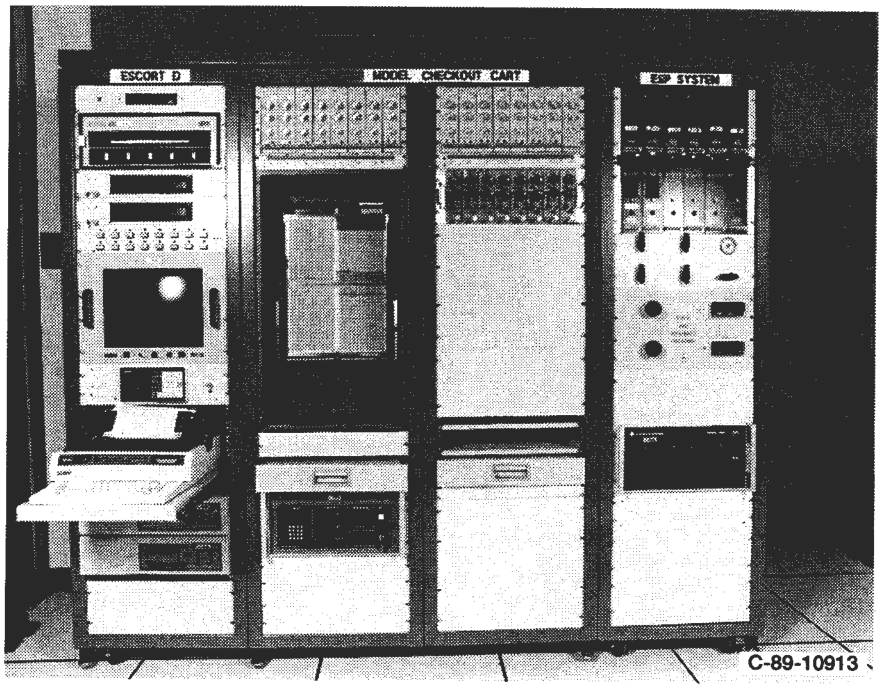


Figure 29. – Model checkout cart.

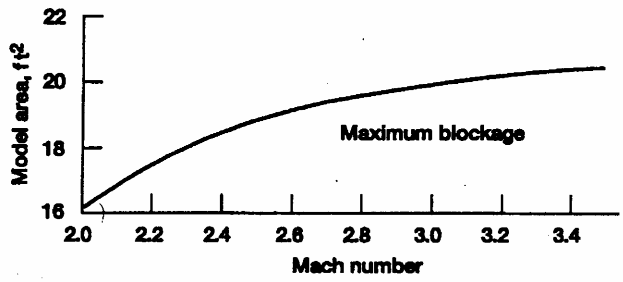


Figure 30. – Starting limitations.

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13. ABSTRACT *(Maximum 200 words)*

This manual describes the 10-by 10-Foot Supersonic Wind Tunnel at NASA Glenn Research Center and provides information for users who wish to conduct experiments in this facility. Tunnel supersonic 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 supersonic aerodynamic (closed) cycle and the supersonic propulsion (open) cycle. Tunnel subsonic operation over a Mach number tange of 0 to 0.36 by using either the facility air dryer air blowers or the primary drive compressor are described. The tunnel test section Mach number range is 0 to 0.36 and 2.0 to 3.5. General support systems, such as air systems, hydraulic system, hydrogen system, oxygen 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			**15. NUMBER OF PAGES**
Supersonic wind tunnels; Subsonic wind tunnels; Wind tunnel tests			**16. PRICE CODE**
17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	

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Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

The following list describes the figures that are presented in this report.

Figure 1. – This figure was extracted from NASA TM 105626 (revised copy), 1995. It is figure #2 in that report.

Figure 2. - This figure was extracted from NASA TM 105626 (revised copy), 1995. It is figure #3 in that report. No changes were made to this figure.

Figure 3. – This figure was extracted from NASA TM 105626 (revised copy), 1995. It is figure #4 in that report. No changes were made to this figure.

Figure 4. – This figure presents a subsonic altitude capability map for tunnel operation and is a new figure.

Figure 5. – This figure presents a subsonic Reynolds No./ft capability map for tunnel operation and is a new figure.

Figure 6. - This figure was extracted from NASA TM 105626.(revised copy), 1995. It is figure #5 in that report. We changed two dimensions on this drawing.

Figure 7. - This figure was extracted from NASA TM 105626 (revised copy), 1995. It is figure #6 in that report. No changes were made to this figure.

Figure 8. - This figure was extracted from NASA TM 105626 (revised copy), 1995. It is figure #7 in that report. We inserted one dimension on this figure in the vicinity of detail A. No other changes were made to this figure.

Figures 9. and 10 - These figures were extracted from NASA TM 105626 (revised copy), 1995. They are figures #8 and #9 in that report. No changes were made to these figures.

Figures 11 and 12. - These figures were extracted from NASA TM 105626 (revised copy), 1995. They are figures #10 and #11 in that report. No changes were made to these figures.

Figure 13. - This figure was extracted from NASA TM 105626 (revised copy), 1995. It is figure #12 in that report. No changes were made to this figure.

Figure 14(a). - This figure was extracted from NASA TM 105626 (revised copy), 1995. It is figure #13(a) in that report. Three new dimensions and two notes have been added to this figure.

Figure 14(b). and 15. - These figures were extracted from NASA TM 105626 (revised copy), 1995. They are figures #13(b) and #14 in that report. No changes were made to these figures.

Figure 16. – This figure was extracted from NASA TM 105626 (revised copy), 1995. It is figure #15 in that report. No changes were made to this figure.

Figure 17. – This figure describes a pitch-yaw sting and is a new figure.

Figure 18. – This figure describes a knuckle sting and is a new figure.

Figure 19. – This figure was extracted from NASA TM 105626 (revised copy), 1995. It is figure #17 in that report. The word ‘rotational’ was added to the note ‘Front adapter sleeve assembly’.

Figure 20. - This figure was extracted from NASA TM 105626 (revised copy), 1995. It is figure #16 in that report. We have added two new notes to this figure.

Figures 21. and 22. – These figures were extracted from NASA TM 105626 (revised copy), 1995. They are figures 18 and 19 in that report. No changes were made to these figures.

Figure 23. - This figure (photo) was extracted from NASA TM 105626 (revised copy), 1995. It is figure #20 in that report. No changes were made to this figure.

Figure 24. - This figure (photo) was extracted from NASA TM 105626 (revised copy), 1995. It is figure #21 in that report. This figure was rotated 90º CW to reflect the correct position of the model in the tunnel test section.

Figure 25. - This figure was extracted from NASA TM 105626 (revised copy), 1995. It is figure #22 in that report. No changes were made to this figure.

Figure 26. - This figure was extracted from NASA TM 105626 (revised copy), 1995. It is figure #23 in that report. Two notes were added to this figure and some minor alterations were made to the wall structure that surrounds the model stand.

Figure 27. - This figure describes the angle-of-attack sensor. It is a new figure.

Figure 28. – This figure is a schematic flow chart of the 10X10 SWT data system. It is a new figure.

Figure 29. – This figure (photo) was extracted from NASA TM 105626 (revised copy), 1995. It is figure #28 in that report. No changes were made to this figure.

Figure 30. – This figure was extracted form NASA TM 105626 (revised copy), 1995. It is figure #29 in that report. No changes were made to this figure.