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THE GEORGE C. MARSHALL SPACE FLIGHT CENTER HIGH REYNOLDS NUMBER WIND TUNNEL TECHNICAL HANDBOOK

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16. ABSTRACT

This report is a description of the High Reynolds Number Wind Tunnel at the George C. Marshall Space Flight Center and is a handbook for the potential user who may not be familiar with its operation. The following items are presented to illustrate the operation and capabilities of the facility: facility description and specifications, operational and performance characteristics, model design criteria, instrumentation and data recording equipment, data processing and presentation, and preliminary test information required.

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INTRODUCTION

The George C. Marshall Space Flight Center (MSFC) has followed the philosophy that the existence of in-house aerodynamic facilities is essential to the efficient fulfillment of the Center's mission. These facilities are generally small, inexpensive in capital investment and operation, flexible and efficient, and operable by small crews. The capabilities and specifications of these facilities are specially tailored to meet the aerodynamic testing requirements at MSFC. Also, these in-house facilities provide a degree of responsiveness to MSFC requirements which cannot be obtained from outside facilities because of human factors such as familiarity with the problems and motivation. Finally, a very important aspect of these facilities is that they provide to the Center's personnel the opportunity to maintain and advance their technical state-of-the-art capabilities, a necessity in the proper formulation and direction of the Center's programs.

The High Reynolds Number Wind Tunnel (HRWT) facility, one of several such in-house facilities, was designed and constructed during the period 1967-1969 and became operational in 1971. The primary function of this facility is to provide high Reynolds number flow (200×10^6 per foot maximum) for aerodynamic testing in Reynolds number dependent areas.

This handbook is published with the hope that users will gain a better understanding of the operation of the High Reynolds Number Wind Tunnel. This will allow the reader/user to more thoroughly plan and follow through with a test program.

The information presented is subject to change and, therefore, final test programs and schedules must be cleared by the facility staff. Inquiries may be directed to:

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FACILITY SUMMARY

The High Reynolds Number Wind Tunnel at the Marshall Space Flight Center is a Ludwieg tube type tunnel capable of producing high Reynolds number simulation over a range of Mach numbers from 0.25 to 3.50. The tunnel is located in Building 4775 as shown in the area map in Figure 1. The facility is supported by a facility and model design group, a machine shop, an instrumentation group, and a photographic laboratory.

Capabilities of the facility are summarized below:

<u>Tunnel Specifications</u>

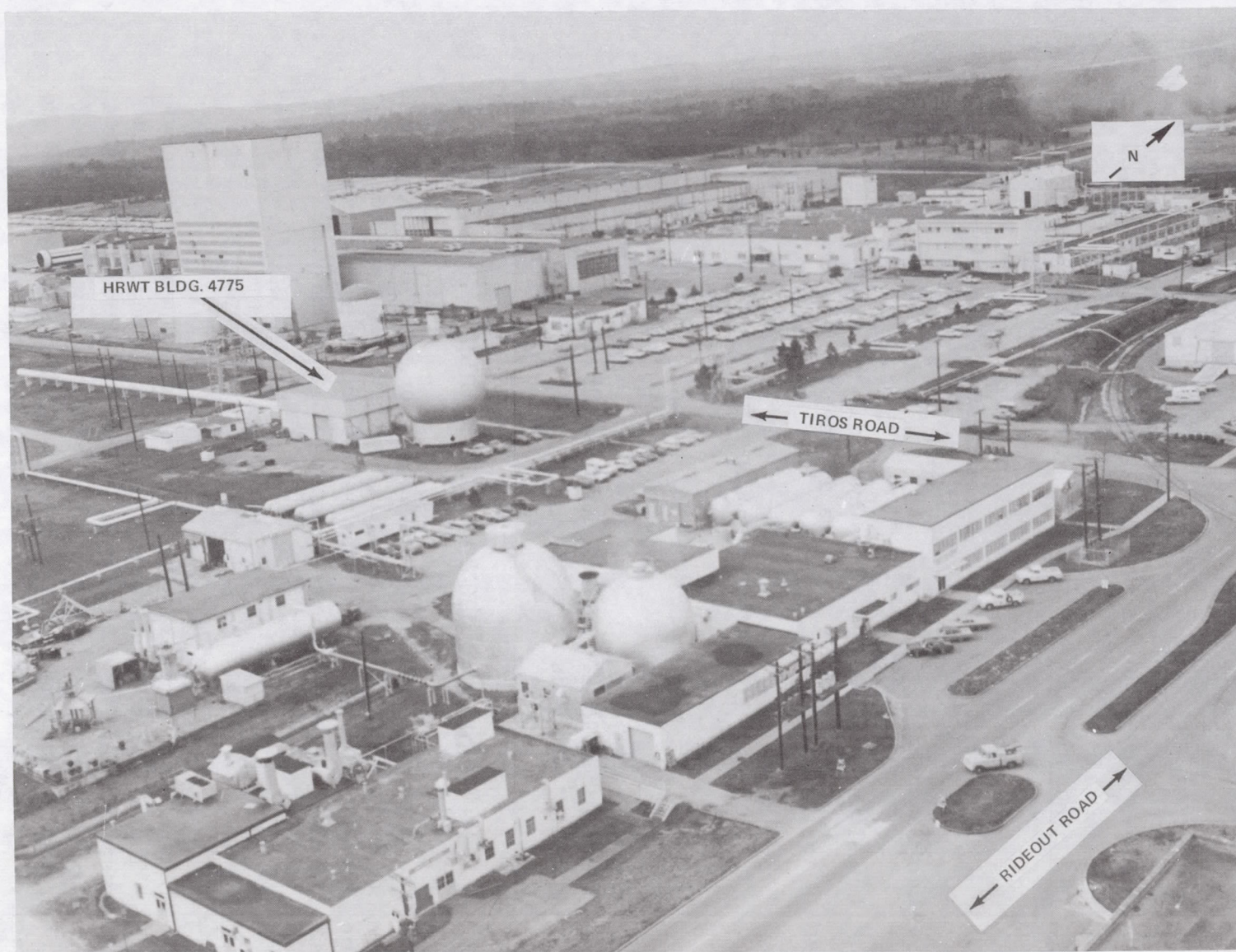|	
Type of Tunnel	Ludwieg tube
Test Section Size	32 in. in diameter by 64 in. long
Mach Number Range	0.25 to 1.30, 1.40, 1.70, 2.00, 2.75, 3.50
Stagnation Pressure Range	45 to 686 psia
Reynolds Number Range	7×10^6 to 200×10^6 per ft
Stagnation Temperature Range	$460°R$ to $560°R$
Run Time	350 to 550 milliseconds

Figure 1. Area map.

Run Rate	12 to 15 per 8 hour shift at charge pressures of 200 psia or less
	5 to 7 per 8 hour shift at charge pressures of 500 psia and above

Data Acquisition and Processing

Angle of Attack	+11 to -18 degrees with added range provided with offset stings
Data Channels	20
Data Computation	Onsite data reduction with pressure and force programs available

DESCRIPTION AND SPECIFICATIONS

Layout

The facility is located on Tiros Road (see Figure 1). The overall layout of the tunnel is shown in Figure 2.

Supply Tube and Stilling Chamber

The supply tube has a 52 in. inside diameter and is 386 ft long. It is terminated on one end with a hemispherical head and on the other end with a stilling chamber. The stilling chamber is 20 ft long and has a maximum diameter of 78 in. The entrance cone has an 8 deg included angle.

Nozzles

The facility utilizes six interchangeable, axisymmetric, contoured nozzles. The diameters at the entrance and exit of each nozzle are 52 and 32 in., respectively. The "sonic" nozzle is used to produce all subsonic and transonic speeds (M = 0.25 to 1.30). The other five nozzles are designed for discrete Mach numbers as follows: 1.4, 1.7, 2.0, 2.75, and 3.5. The general design of the nozzles is shown in Figure 3.

SUPPLY TUBE

322 ft · 1.25 in. THICKNESS · 18 ft · 1.75 in. THICKNESS · 46 ft 10 in. · 1.25 in. THICKNESS

11 ft 6 in. · 13 SPACES @ 23 ft EACH = 299 ft

REINFORCED CONCRETE THRUST BLOCK

STILLING CHAMBER · 20 ft 5 in. · FLOW · 1 ft 6 in.

MODEL SUPPORT SECTION · DIAPHRAGM CLAMP RING · RECEIVER SPHERE

TEST SECTION · DIAPHRAGM CUTTER SECTION · SPACER SPOOL · DIFFUSER

NOZZLE · TENSION ROD SYSTEM

6 ft 7.38 in. · 5 ft 4 in. · 3 ft 10 in. · 3 ft · 4 ft 10.63 in. · 11 ft 8 in. · 14 ft 9.38 in. · 4 ft 2.63 in.

1 ft 6 in. · FLOW · ELBOW
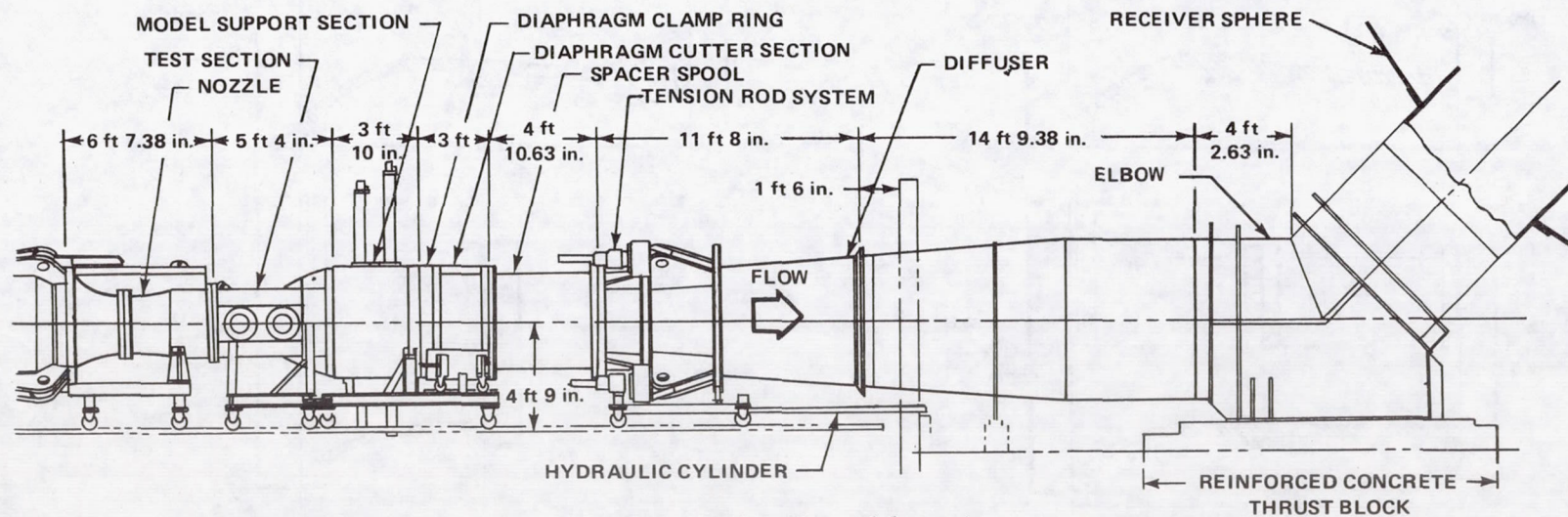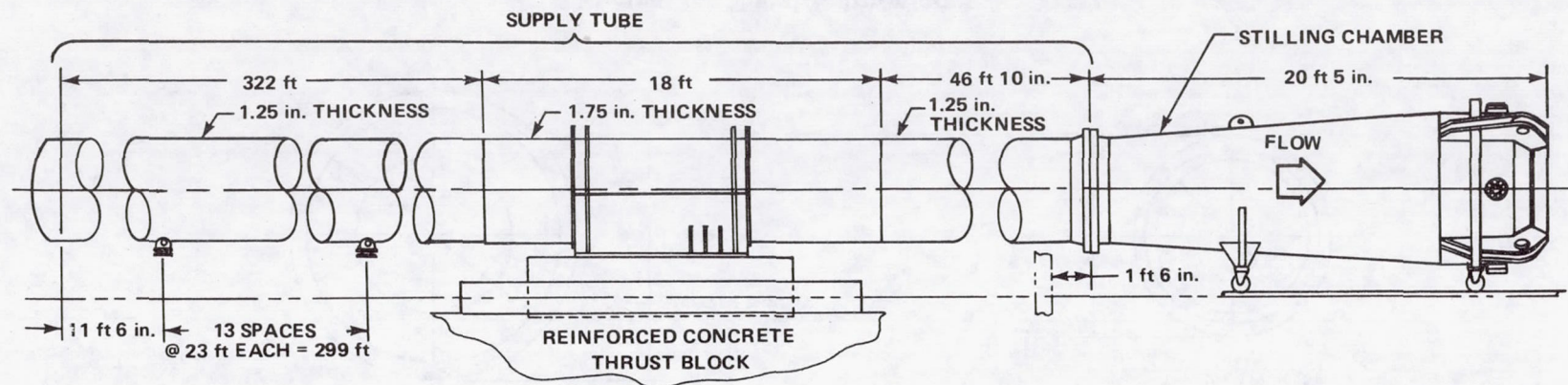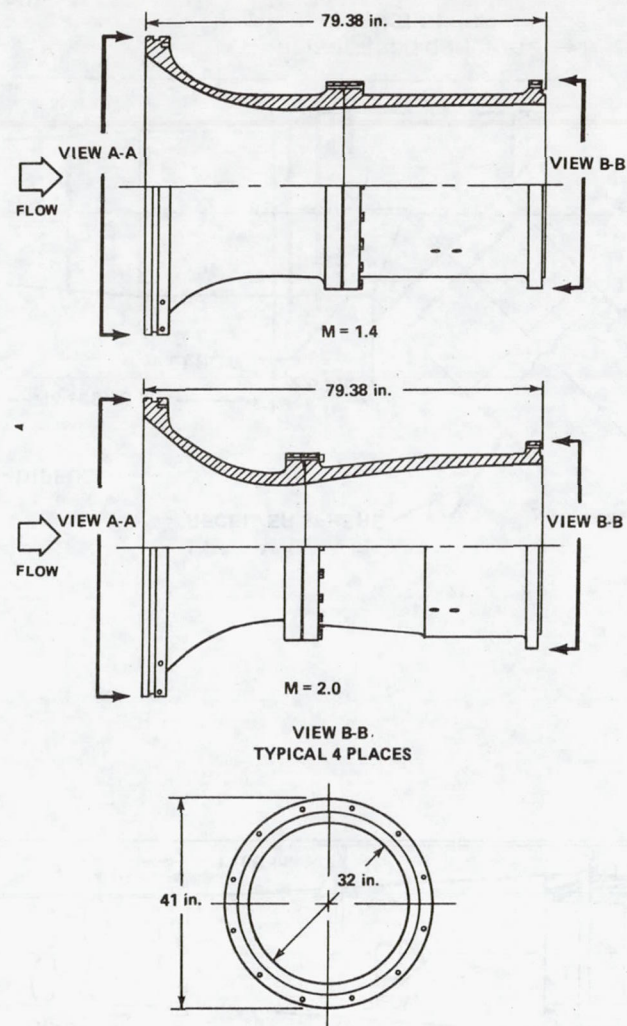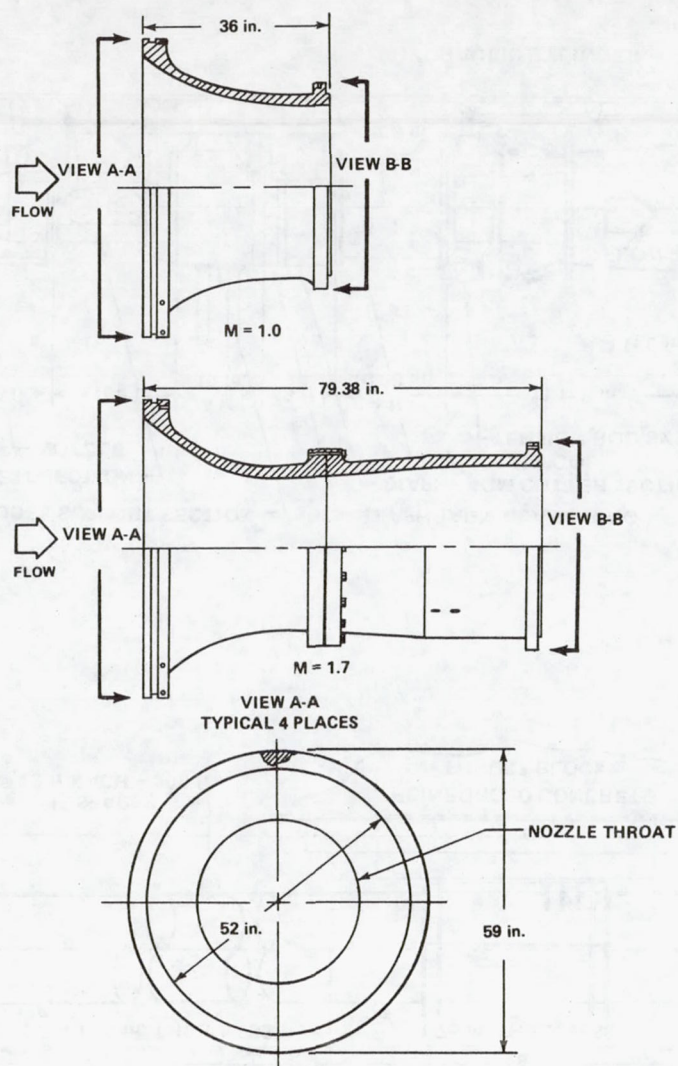
4 ft 9 in.

HYDRAULIC CYLINDER · REINFORCED CONCRETE THRUST BLOCK

Figure 2. Tunnel layout.

Figure 3. Nozzle dimensions.

138 in.

A-A

B-B

M = 2.75

138 in.

A-A

B-B

M = 3.50

NOZZLE THROAT

59 in.

52 in.

A-A
TYPICAL 2 PLACES
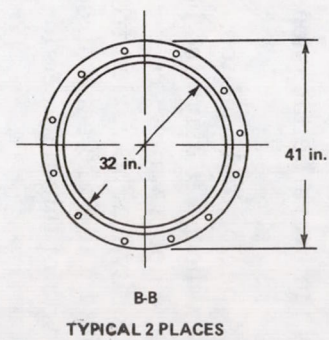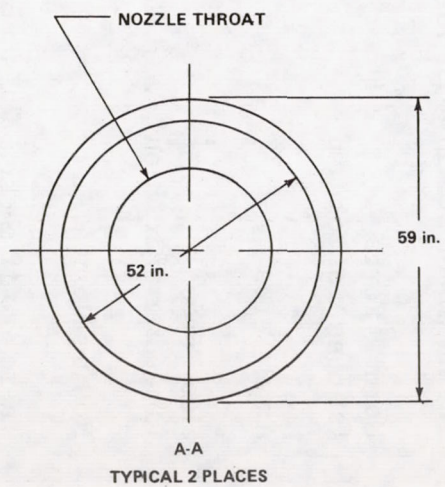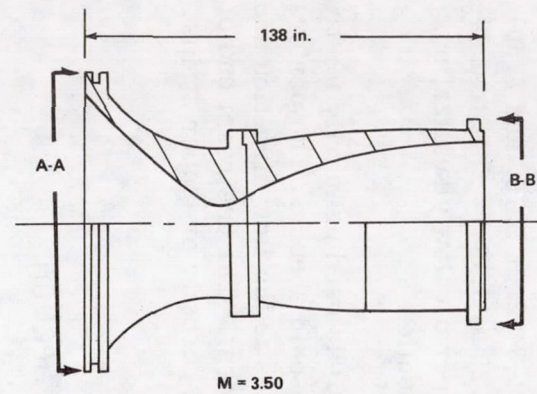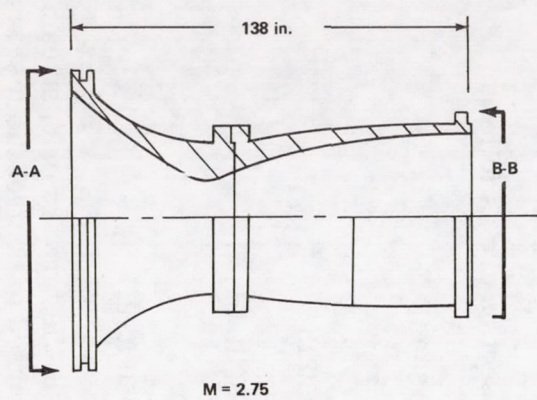
32 in.

41 in.

B-B
TYPICAL 2 PLACES

Figure 3. (Concluded)

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Test Sections

Two interchangeable test sections, each 32 in. inside diameter, are used to cover the full speed range. A solid wall test section, 64 in. in length, is used for all supersonic speeds (M = 1.4, 1.7, 2.0, 2.75, and 3.50) and may be used for the subsonic speeds (M = 0.25 to 0.77). This test section has tandem windows, 10 in. in diameter, to permit flow visualization. Figure 4 shows the overall dimensions of this test section.

A perforated wall test section (Fig. 5) is used primarily for transonic testing, although it may also be used for subsonic speeds. The perforated walls have holes which are inclined 30 degrees to the flow direction and the wall porosity can be varied from 0 to 10 percent. The upstream end of the perforated walls are configured with tapered porosity or "taper strips." The total length of this test section is 100 in.

Model Support Section

The model support section (Fig. 6) plays two important roles at the facility: It contains the model support pitching mechanism and it houses the choking flaps that control the subsonic Mach numbers. This section has a 54 in. inside diameter and is 46 inches long.

The model support pitching mechanism consists of two vertical struts, a sting pod, and a drive assembly. The strut drive assembly is geared so that the sting pod pitches from +11 to -18 degrees about a center of rotation located 38 in. upstream of the model support section.

The maximum design loads for this section are as follows:

Normal Force (at center of rotation)	±13 500 lb
Axial Force	±4050 lb
Side Force (at center of rotation)	±8050 lb
Rolling Moment	±5050 ft-lb

There are 12 choking flaps mounted in the forward or upstream end of the model support assembly. The flaps are used to control the test section Mach number in the subsonic range (0.25 to 0.77).
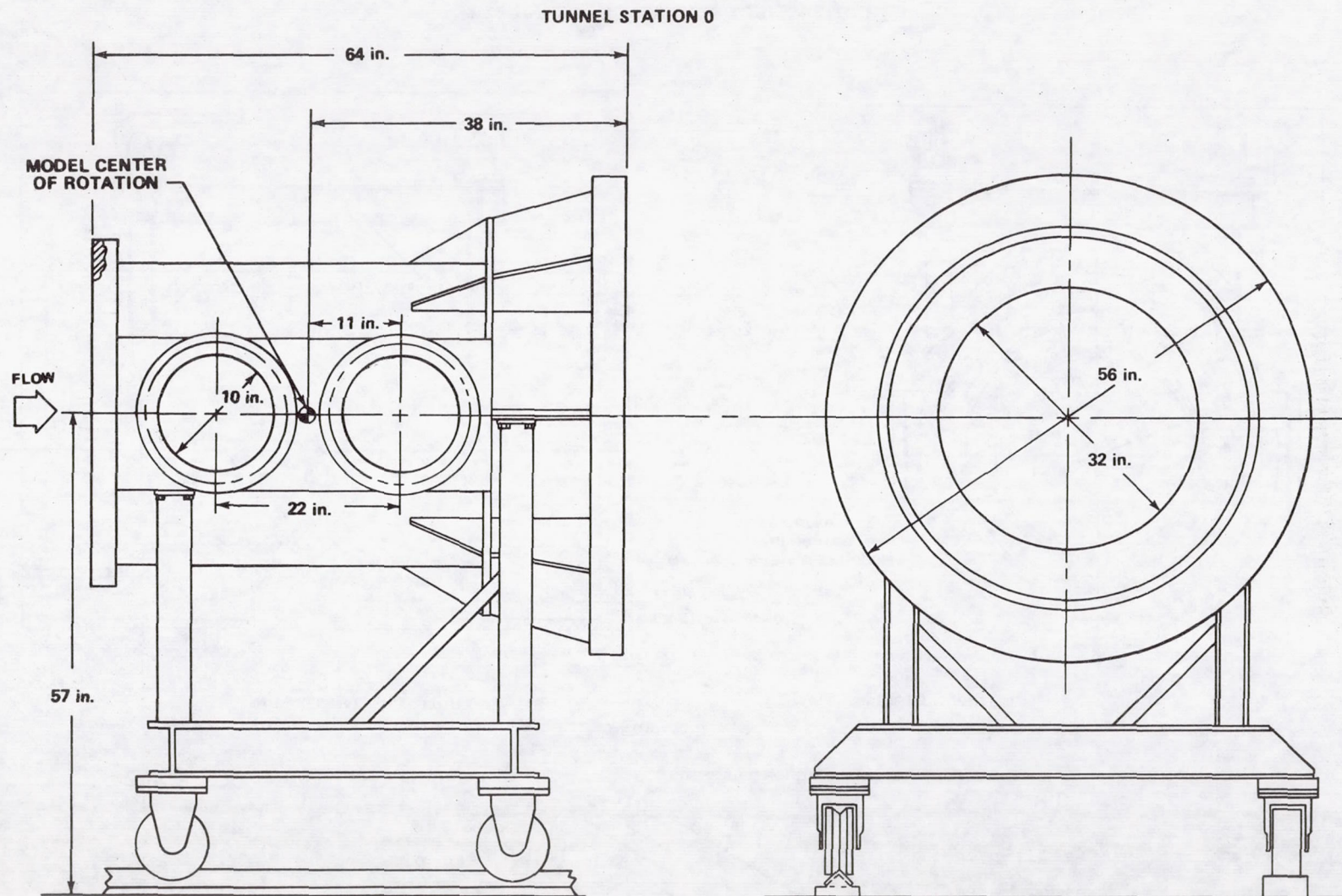
Figure 4. Supersonic test section.

FIXED 0.5 in.
WALL

0.13 in. MOVABLE
WALL

0.5 in. DIA. HOLE INCLINED 30 deg TO FLOW

DETAIL A

MOVABLE WALL ACTUATOR

PLENUM EJECTOR CONTROL PLATE
INNER   OUTER

EJECTOR PUMPED
PLENUM FLOW

VARIABLE POROSITY
PERFORATED WALL
SEE DETAIL A

FLOW

59 in.

32 in.

57 in.

100 in.
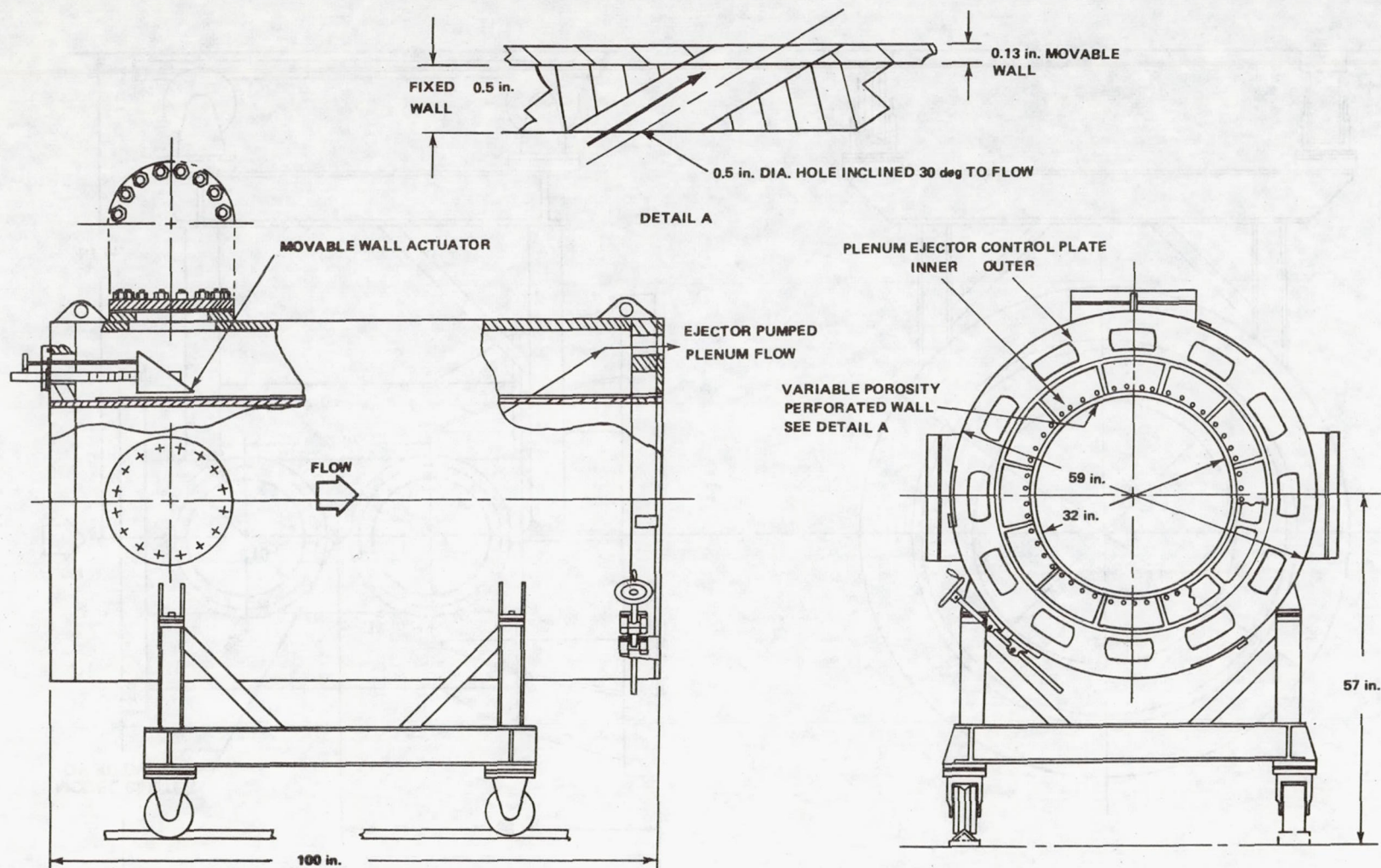
Figure 5. Transonic test section.

MODEL SUPPORT PITCH DRIVE

TUNNEL STATION 0

DIAPHRAGM CLAMP RING

DIAPHRAGM CUTTER SECTION

MODEL CENTER OF ROTATION TUNNEL STATION 38

46 in.

53 in.

2.25 in.

15 in.

84 in.

57 in.

FLOW

18°

11°

NOTE: MODEL CENTER OF ROTATION
MOVES REARWARD 2.25 in.
AT MAX ANGLE OF ATTACK
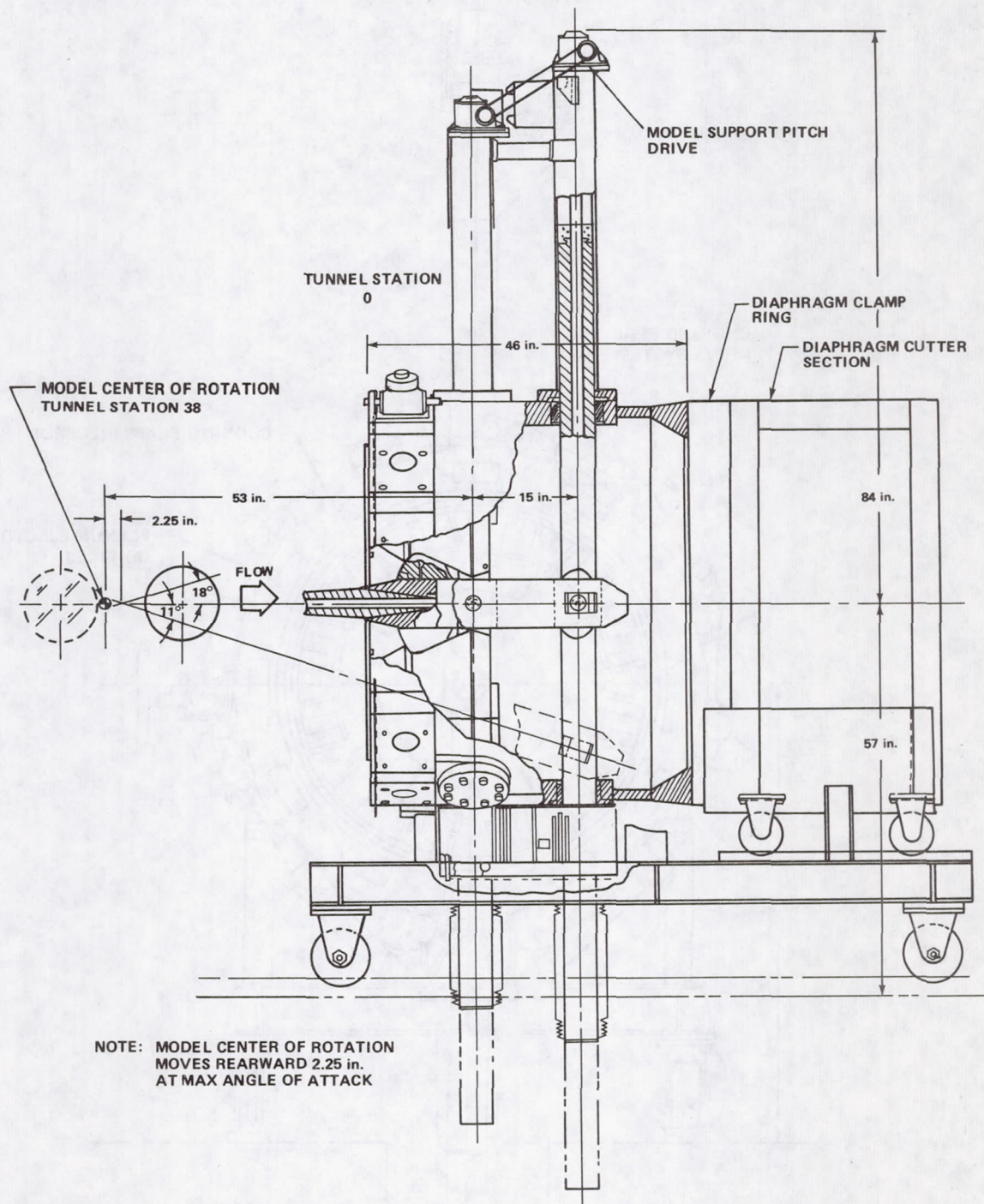
a. Side view.

Figure 6. Model support section.

CHOKING FLAP
DRIVE SYSTEM

CHOKING FLAPS (CLOSED)

PLENUM EJECTOR
ORIFICES

57 in.
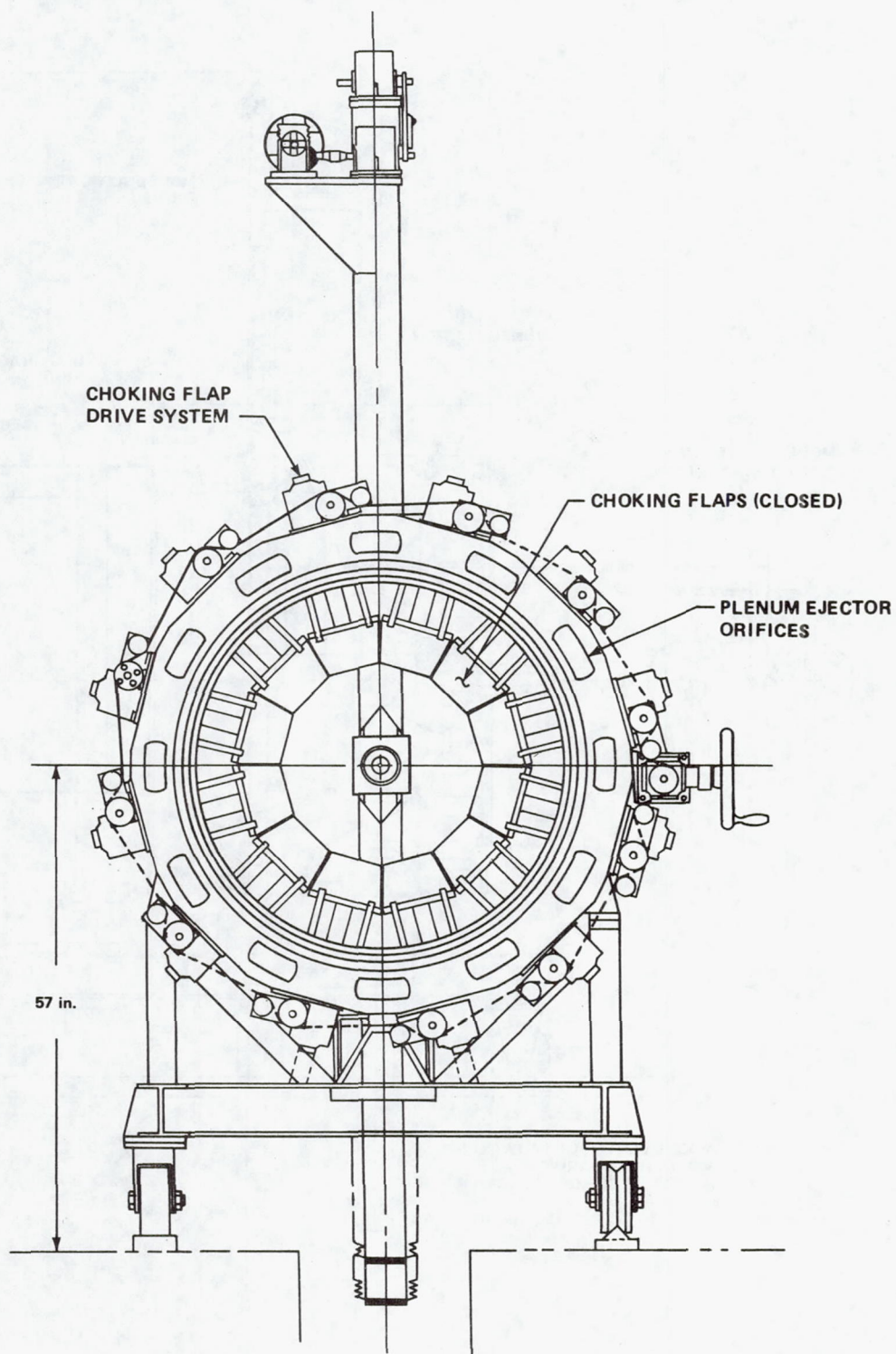
b.   Front view.

Figure 6.   (Concluded)

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Diaphragm Section

A test operation is initiated in the diaphragm section by the rupturing of the diaphragm. This section, shown in Figure 7, consists primarily of a cylindrical vessel 48 in. in diameter and 30 in. long. It contains a four-arm cruciform which partially supports the multilayer Mylar diaphragm. Recessed in the cruciform is a four-blade knife, pneumatically actuated, which ruptures the diaphragm. The diaphragm layers are clamped by a split ring assembly, also shown in Figure 7, with 72 bolts providing the clamping force. The diaphragm material is Dupont Mylar Type A, 0.014 in. thick per layer. The number of layers required is a linear function of charge pressure with each layer capable of holding about 20 psid.

Spools and Diffuser

Several cylindrical spools 48 in. in diameter and of selected lengths are needed to maintain a fixed tension rod length between the stilling chamber and diffuser since nozzles and test sections of different lengths are used in various combinations. Downstream of the spool is an 8 deg included angle telescoping diffuser. The diffuser has an inlet diameter of 48 in., an exit diameter 84 in., and a length of 21 ft. This assembly is built in two pieces, with the upstream section being capable of sliding 6 ft into the downstream section. This feature provides the capability for nozzle, test section, and diaphragm changes, as well as convenient access to the model. Movement is provided by a hydraulic cylinder attached to the upstream diffuser section. Figure 8 shows the layout of the spool and diffuser assembly.

Tension Rod System

Four tension rods, equally spaced about the tunnel centerline, span from the stilling chamber to the upstream section of the diffuser. These 4 in. diameter rods provide the force necessary to clamp the tunnel components together when the tunnel is pressurized. Each of the rods is in two pieces with a clevis and eye connection near the midpoint of the rod to permit quick disconnection after each tunnel run. Each of the rods produces 565 000 pounds of force when loaded by means of a hydraulic piston built into the downstream end of the rod. The system layout is shown in Figure 9.

CLAMP RING

30 in.

4 in.

4 in.

MULTIPLE LAYER
MYLAR DIAPHRAGM

FLOW

59 in.

45°

45°

0.31 in.

48 in.

7

1.5 in.

6 in. DIA. (AIR CYLINDER)

DIAPHRAGM
CUTTER SLOT

55 in.

VIEW DOWNSTREAM
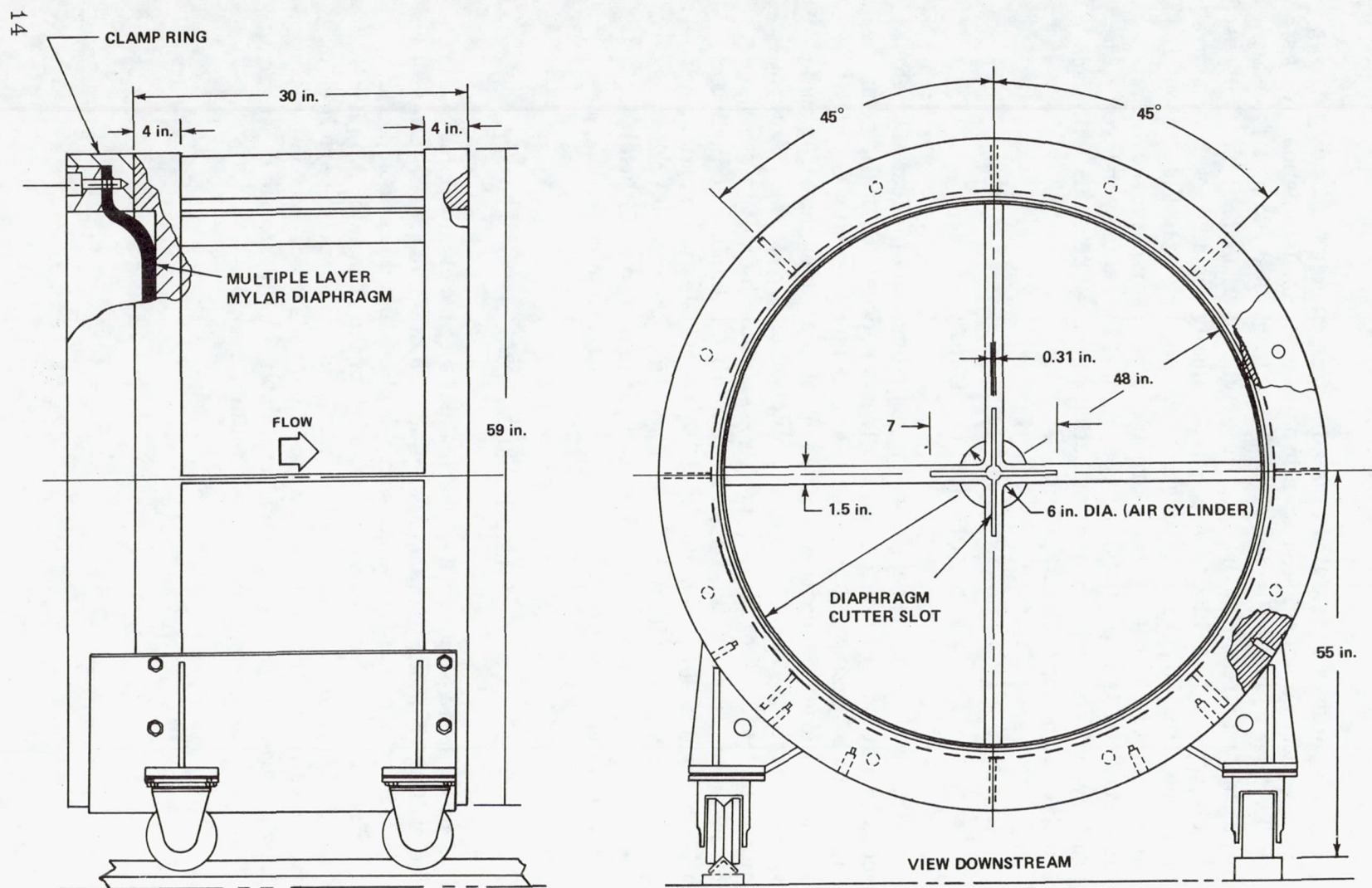
Figure 7. Diaphragm section and clamping ring.

X (in.)	USE WITH
101.13	M-1 NOZZLE, SUPERSONIC TEST SECTION
65.13	M-1 NOZZLE, TRANSONIC TEST SECTION
58.63	M-1.4, 1.7, 2.0 NOZZLE, SUPERSONIC TEST SECTION
22.63	M-1.4, 1.7, 2.0 NOZZLE, TRANSONIC TEST SECTION
0	M-2.75, 3.50 NOZZLE, SUPERSONIC TEST SECTION

Figure 8. Spool and diffuser assembly.

72 in.

a. Top view, open position

250

95.75 in.

STILLING
CHAMBER

NOZZLE

SUPERSONIC
TEST SECTION

MODEL
SUPPORT

DIAPHRAGM

SPOOL

DIFFUSER

FLOW

57 in.

49.13 in.

b. Side view, closed position

Figure 9. Tension rod system.

Elbow and Receiver Sphere

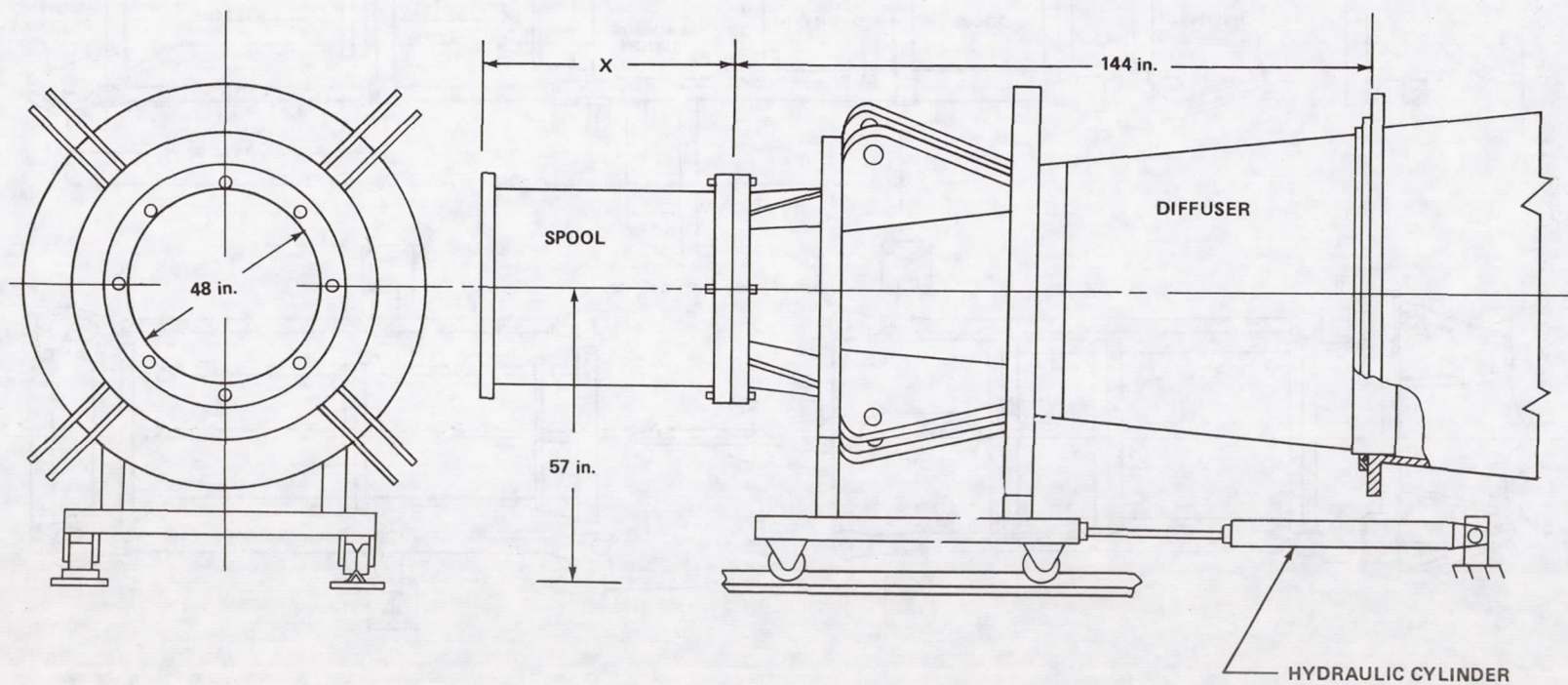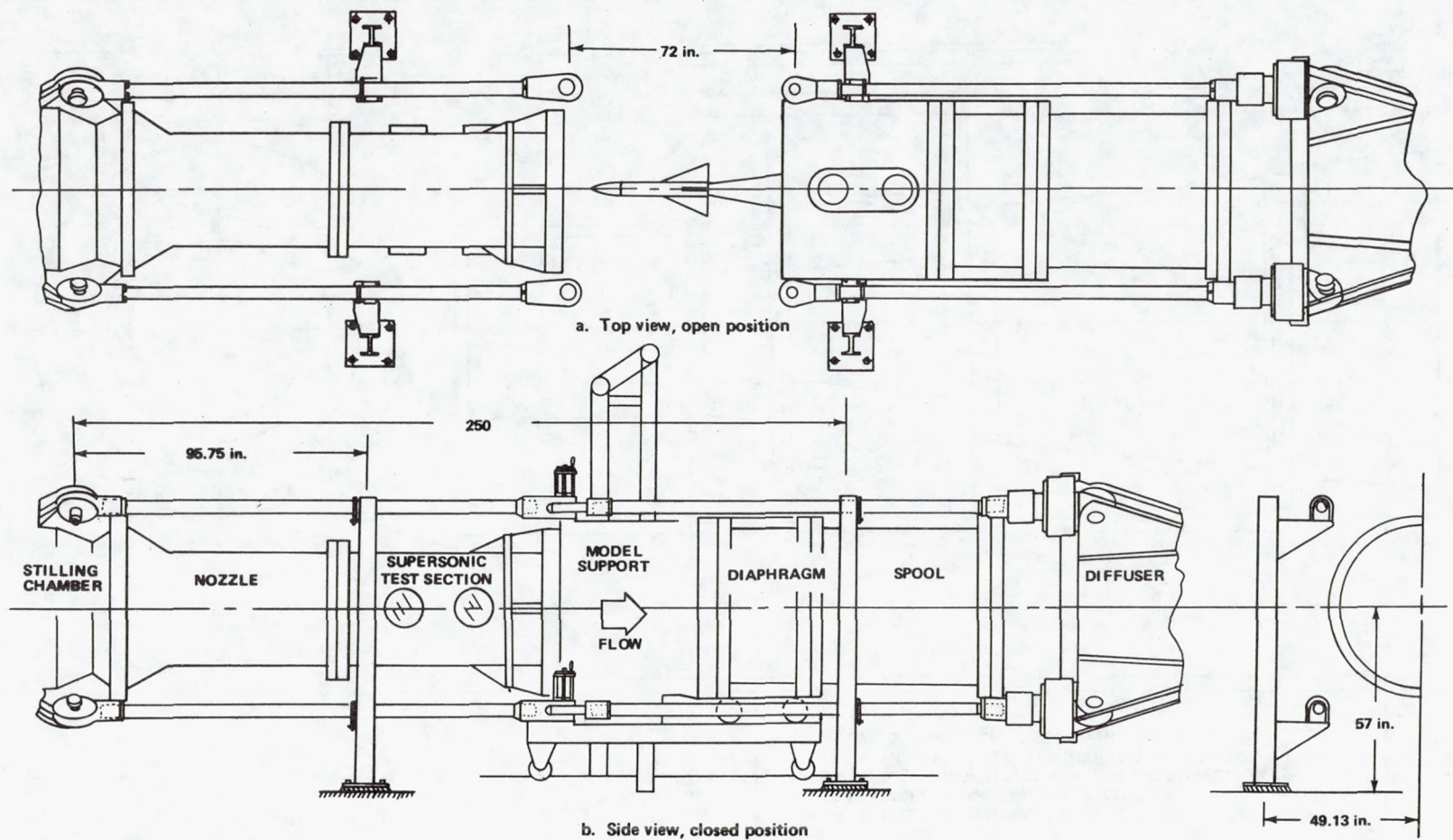Downstream of the diffuser is a reinforced 45 deg elbow which serves to turn the flow upward into a receiver sphere. The elbow is 7 ft in diameter and is mounted on a heavy base plate which is in turn mounted on a reinforced concrete thrust block. This thrust block restrains all aerodynamic and pressure forces on tunnel components downstream of the diffuser, including the receiver sphere. It is designed for a maximum axial force of 572 000 lb.

The 50 ft diameter receiver sphere (Fig. 10) serves as a sound attenuator and a collector for the Mylar debris resulting from the bursting of the diaphragm. The 7 ft diameter inlet duct extends 35 ft into the sphere and has a closed end. The duct is perforated with 198 holes, each 8 in. in diameter, arranged symmetrically about the center of the sphere to produce uniform loading on the sphere. Located at the top center of the sphere is a 12 in. diameter opening with a pneumatically operated on-off valve and a silencer. At the bottom center of the sphere is a second 12 in. diameter opening with a pneumatically operated on-off valve followed by a line connected to a large trash container.

When a tunnel run is completed, a positive equalization pressure is achieved in the sphere (as high as 70 psig). This pressure is bled to the atmosphere by opening the valve at the top of the sphere. When the pressure decays to about 5 psig, this valve is closed and the valve at the bottom of the sphere is opened. This blows the Mylar debris, which collects at the bottom of the sphere, into the trash container from which it is removed periodically.

OPERATING CONCEPT AND PERFORMANCE CHARACTERISTICS

Operating Concept

The tube tunnel concept was suggested in 1955 by Ludwieg [1]. The operating principle is essentially that of a short duration wind tunnel in which the test section is supplied with air from a long, constant diameter, supply tube, similar to the driver tube of a shock tunnel. Air is stored at high pressure (700 psig max) in the supply tube which is sealed downstream of the test section by a diaphragm. When the diaphragm is ruptured, an expansion fan propagates into the test section, nozzle, and supply tube, thus setting the stored air in motion. This fan of expansion waves passes through the test section and nozzle and into the supply tube until sonic velocity is reached at the nozzle throat for the supersonic case or at the choking flaps for the subsonic case. Figure 11 shows this wave process. As soon as sonic velocity is attained (at the nozzle throat or the choking flaps) constant reservoir
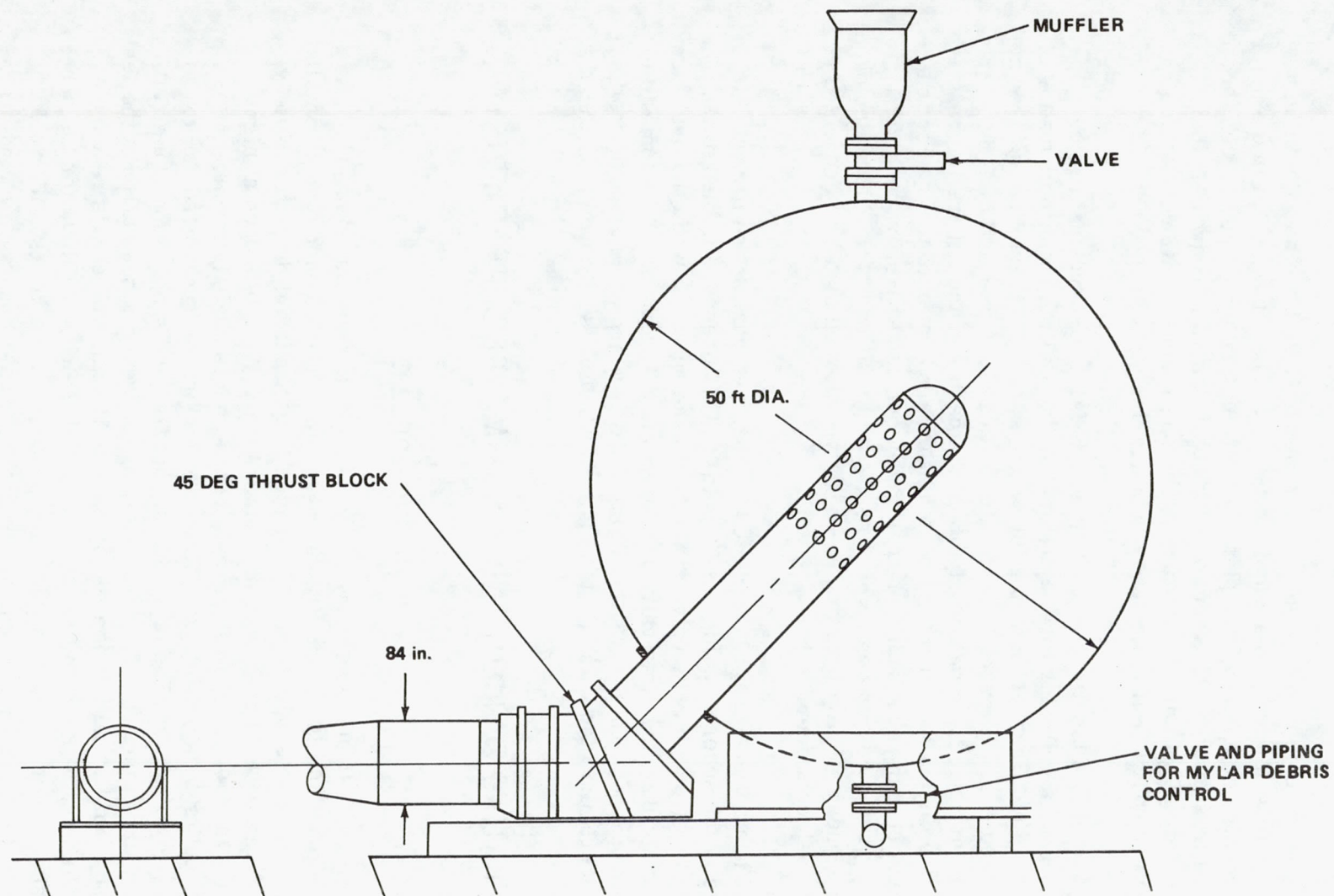
Figure 10. Receiver sphere.
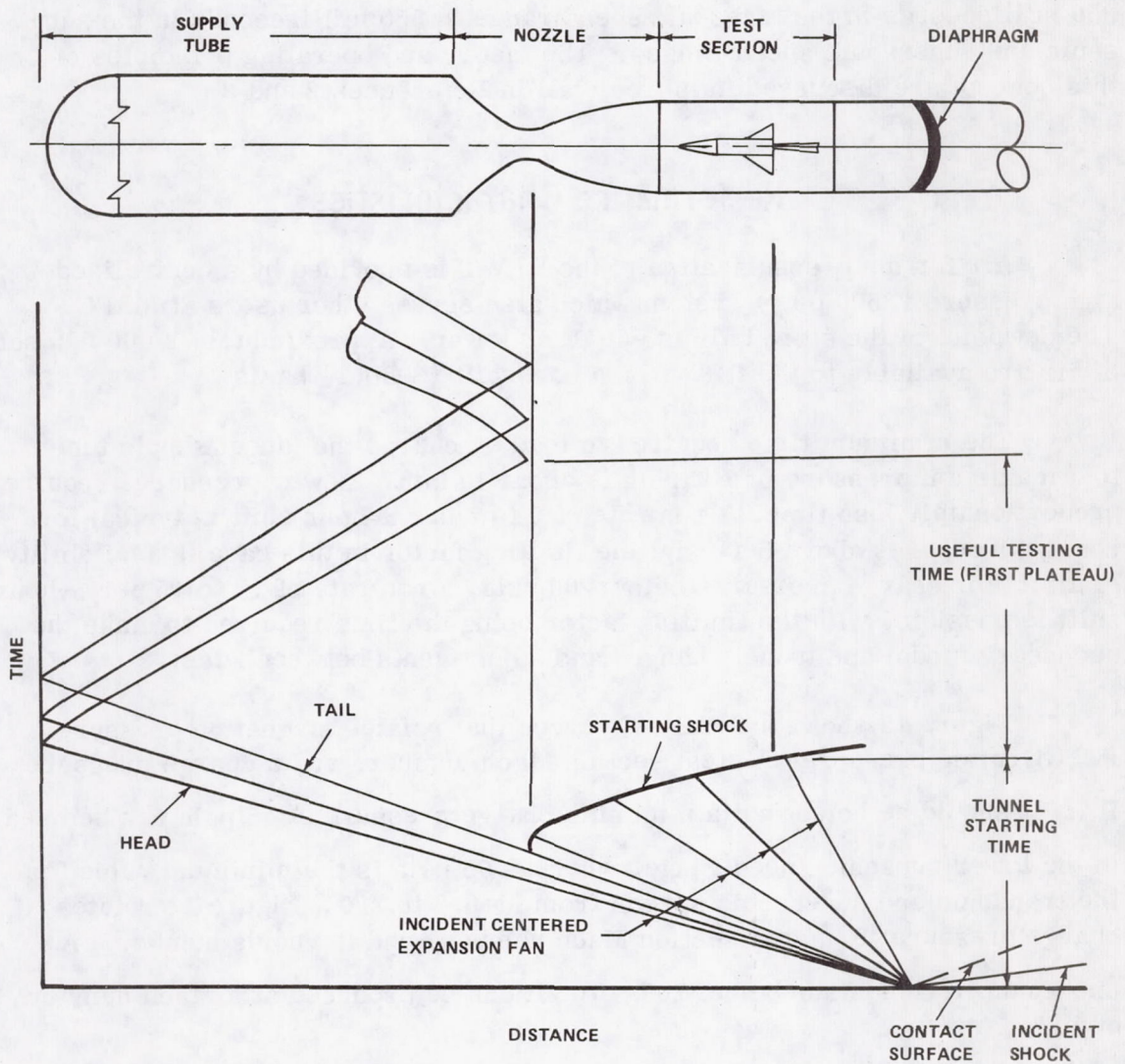
Figure 11. Tunnel wave diagram.

conditions are established upstream of the sonic point. Since energy is not conserved in the expansion process, the stagnation pressure and temperature are somewhat lower than the charge pressure and temperature. This drop in pressure and temperature is a function of the supply tube Mach number. Reservoir conditions remain constant upstream of the sonic point until the head wave of the expansion fan reflects off the closed end of the supply tube

and returns to the nozzle.[1] Useful testing times for the first plateau vary from 350 milliseconds in the transonic speed range to 550 milliseconds in the sub-sonic and supersonic speed ranges. The theory and operating principles of this concept are discussed in more detail in References 2 and 3.

Performance Characteristics

Air for the pressurization of the HRWT is provided by a centralized, high pressure (3500 psig) system which also serves other users at MSFC. The dewpoint of the stored air is $-60°$ F or lower. Approximately 2 000 000 scf of air are available to the HRWT on a one-shift (8-hour) basis.

The minimum time required to load or charge the tunnel supply tube to a maximum pressure of 700 psig is about 10 min. Lower pressures require proportionately less time. A run rate of 5 to 7 per 8-hour shift is typical for charge pressures above 500 psig; the limiting factor in this case is availability of air. For charge pressures below 200 psig, a run rate of 12 to 15 per 8-hour shift is possible, with the limiting factor being the time required to make the necessary model and tunnel changes and adjustments between runs.

Figure 12 shows a family of curves that relates stagnation pressure P_o, dynamic pressure Q, test section Mach number, and a charge pressure P_c. It should be noted that a minimum charge pressure of 45 psia can be used in the lower subsonic speed range, whereas 65 psia is the minimum value for the transonic and supersonic speeds from M=0.8 to 2.0. Figure 13 relates charge pressure P_c, test section Mach number, and Reynolds number. A maximum Reynolds number of 200×10^6/ft can be produced at a Mach number of 1.3.

Tunnel settings are adjusted prior to each run to produce the desired test section conditions (Mach number, stagnation pressure, Reynolds number, etc.). If the measured conditions vary from those desired, tunnel settings are readjusted and a repeat run is made.

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1. Subsequent test periods can be obtained at reduced reservoir conditions between re-reflected wave processes (plateaus) in the supply tube.
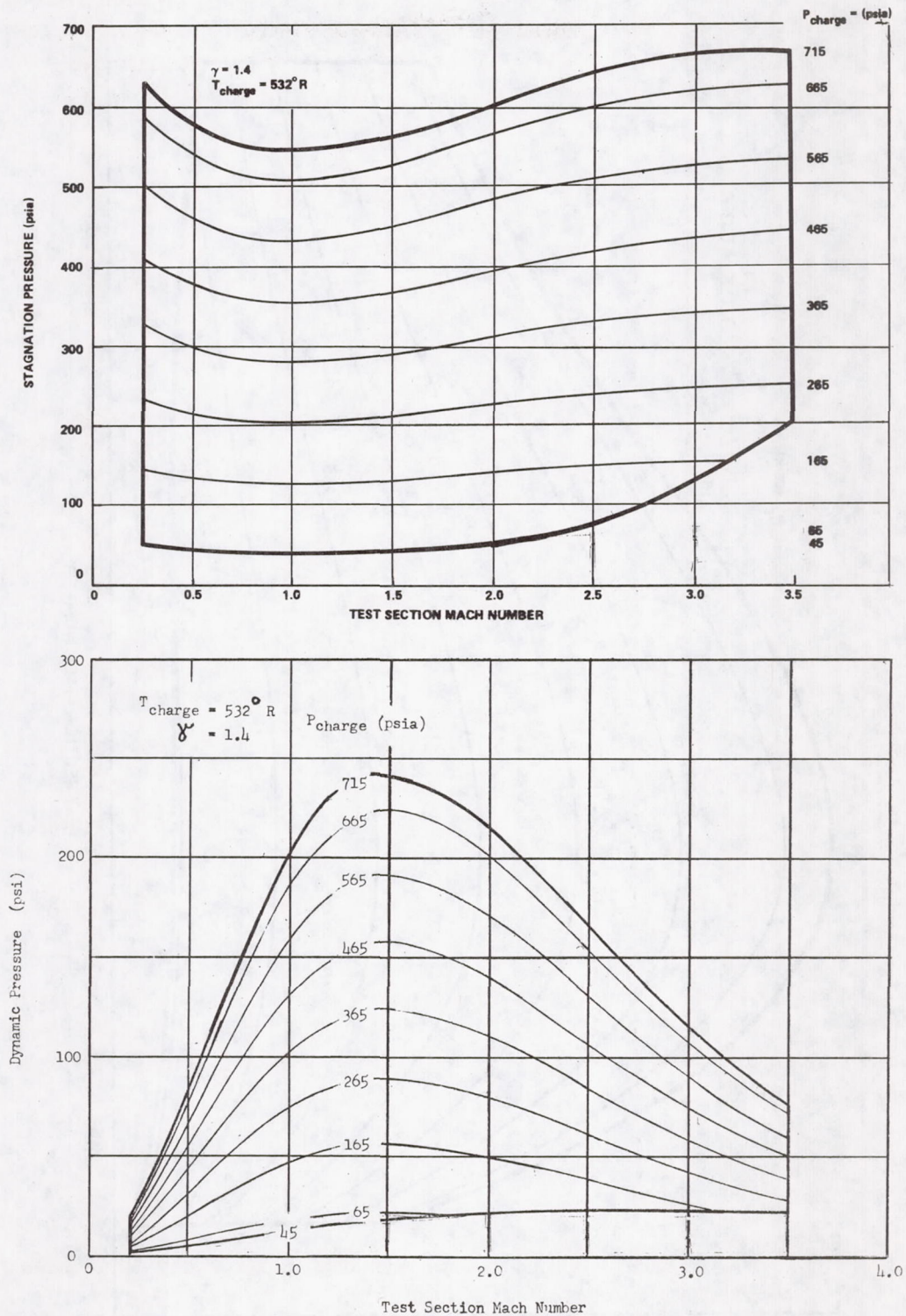
Figure 12. HRWT stagnation pressure and dynamic pressure as a function of test section Mach number and charge pressure.
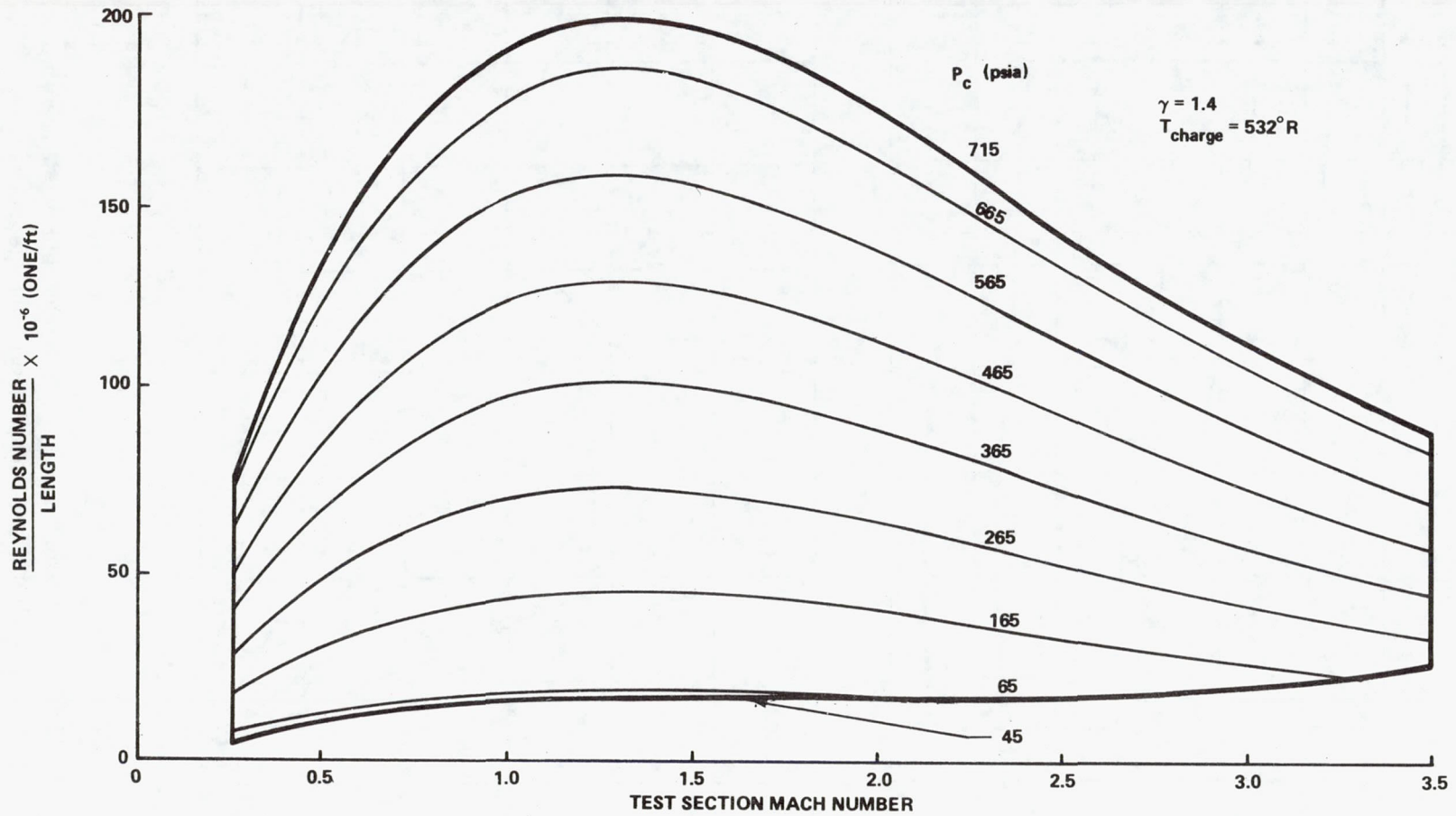
Figure 13. HRWT Reynolds number, test section Mach number, and charge pressure operational envelope.

MODEL DESIGN CRITERIA

Model Sizing

The maximum model size which can be tested is largely dependent on the model geometry and the test conditions such as Mach number, stagnation pressure, and angle of attack. A general rule-of-thumb for model sizing as far as blockage is concerned is 1 percent of the test section cross-sectional area or about 8 in.^{2}. A useable test rhombus of at least 32 in. is possible throughout the test Mach number range, provided the model configuration is such that any wave systems generated by the model can be cancelled at the variable porosity wall when testing in the transonic speed range.

Because of the importance of model and frontal area shapes on the tunnel starting process and wake establishment, it is recommended that any prospective test originator discuss his specific model requirements with the HRWT facility manager.

Starting Loads

The unsteady forces on the model during the tunnel starting process are generally greater than the steady state running loads. The magnitude of this overshoot is dependent on several factors, such as test section Mach number, model geometry, model attitude, and model location in the test section. It has been determined from measurements on models tested to date that the ratio of starting to running loads is 2 or less in all cases. The ratio of starting loads to steady state loads used for model design purposes will be 1.5 for transonic and 2.0 for supersonic Mach numbers. It is recommended that models designed for testing in the HRWT have a safety factor of 4 based on the ultimate strength for maximum expected loads.

Pressure Models

The facility is presently equipped to measure up to 20 model pressures per shot. All pressure measurements are real time; however, a 48-port model pressure trapped volume system is available if desired. Instrumentation requirements in excess of these capabilities may be possible under special circumstances, so requirements should be discussed with the facility manager.

Since all pressure measuring instrumentation is located outside the tunnel, approximately 210 in. of tubing are required to reach from the model to the transducer. In order to insure adequate tubing pneumatic response in the run time available in this facility, the tubing inside diameter must be 0.087 in. for Mach numbers of 2.0 and below and somewhat larger for higher supersonic Mach numbers. It is also required that the model pressure tubing be extended 36 in. beyond the base of the model. Any deviations from these requirements should be discussed with facility personnel. Tubing should be steel with all joints silver-soldered if at all possible.

Static Stability Models

Static stability models are normally tested using NASA-furnished force balances and stings. The appropriate sting-balance combination will be selected by facility personnel based on model criteria furnished by the test requester. Criteria determining the proper sting-balance combinations are:

1. Model forces and moments.

2. Space limitations of the model balance cavity.

3. Model placement in the tunnel.

4. Placement of balance in the model to align the model average center of pressure with the balance center.

Standard "blow down type" balances are utilized in this facility. Although the HRWT is an impulse type facility, the test time is of sufficient duration that conventional balances may be used. The presently available balances and stings are summarized in later sections.

Any internal cavities in a model must be either pneumatically sealed or vented sufficiently so that the internal pressure can stabilize prior to the data-taking period. The model experiences the tunnel charge pressure immediately prior to diaphragm burst. At diaphragm rupture, the test section static pressure drops, in a period of 50 to 350 milliseconds, to a lower level which is dependent on the test section Mach number. If an internal cavity should be still venting during the data-taking period, it could cause an abnormal flow separation, thrust, or other extraneous side effects which would invalidate model force or pressure data.

If base pressure corrections are to be applied to axial force data, provisions will be made to route one or more tubes (0.087 in. ID or larger as a function of Mach number) to the model base area. This tubing will be either rigidly anchored to the sting or flush-mounted in a groove provided for this purpose.

Model Mounting Hardware

A family of compatible model stings, sting extensions, and a 12 deg offset chuck are available for tests in this facility. The center of the model should be located near Tunnel Station 38, which is the normal center of rotation of the support hardware. When the length from the center of the model to the downstream end of the model or balance is known, the required mounting hardware can be selected. Figure 14 is a summary of all stings and offsets presently available at the facility. Also shown in the figure are the standard tapers used to connect the model, balance, and sting to the model support system. An angle of attack range of +11 to -18 deg is available with the straight stings and extensions. The use of the 12 deg offset provides a range from +23 to -6 deg. If the listed model mounting components do not meet the requirements of a specific test, the potential user should contact facility personnel.

INSTRUMENTATION AND DATA HANDLING EQUIPMENT

Control Room

All facility operation, control equipment, and data acquisition equipment are located in the control room (Fig. 15). The tunnel-charging process is controlled from this room by manual operation of a hand loader which operates a dome type control valve. This control valve meters the air into the tunnel from a 3500 psi storage field. The final charge pressure is read and recorded on the digital data acquisition system immediately prior to diaphragm rupture and flow initiation.

Data Acquisition System

All facility and test article data are acquired by a Hewlett-Packard digital data acquisition system. The system consists of 20 channels of input amplifiers with sensitivities of 10, 100, 1000, and 10 000 mV full scale and

selectable filters of 5, 50, 100, and 500 Hz. A variable rate multiplexer scans and converts the outputs of these amplifiers. The scan rate can be varied from one scan every millisecond to any slower scan rate. The digitized (16 bit) data is stored in the memory of the control computer for subsequent processing and display. A cathode ray tube display with a hard copy unit is used to inspect raw data and to plot reduced data. Teletype input/output and punched card output are available. The usual mode of operation is for the system to start loading data with the fire command and scan for the suitable length of time encompassing all plateaus of interest for the specific test. Any data may be displayed on the CRT and if the run is judged to be good, the data are reduced, tabulated, punched, and plotted. The system is quite flexible and can accommodate any reasonable test requirements.

Pressure Instrumentation

Standard 0.5 in. diameter, flush diaphragm, strain gage transducers are used for measuring pressure. Available pressure transducers have ranges from 5 to 1000 psia, and from 5 to 100 psid.
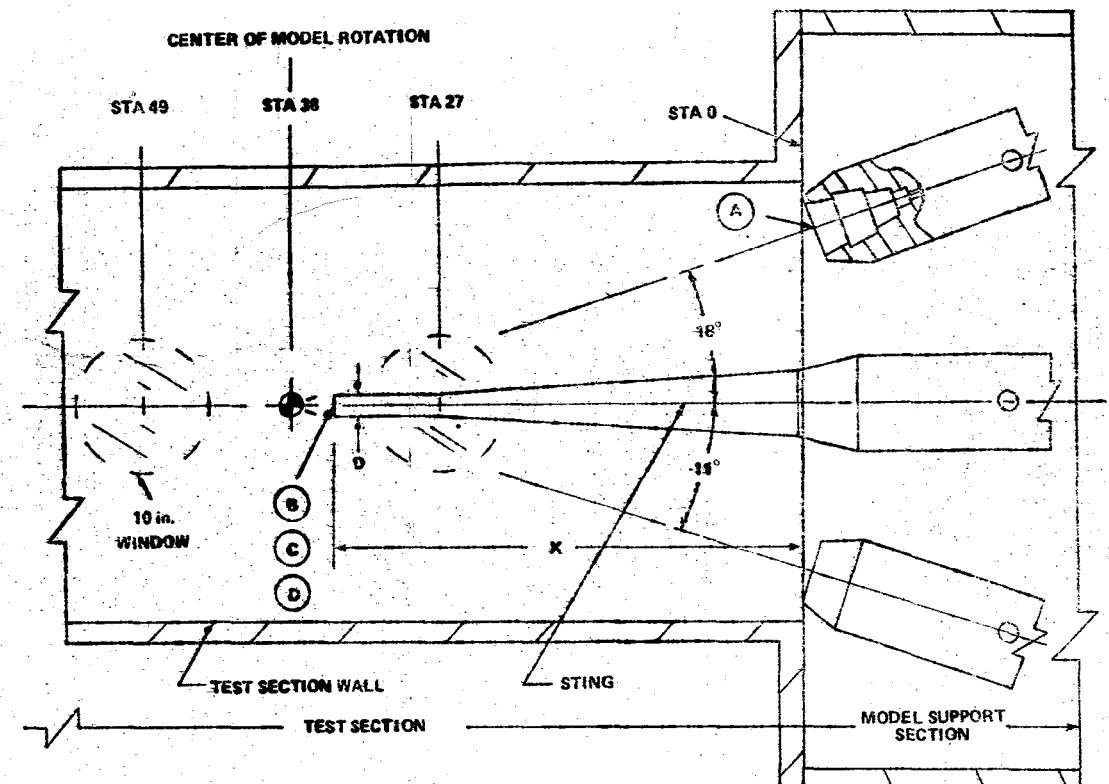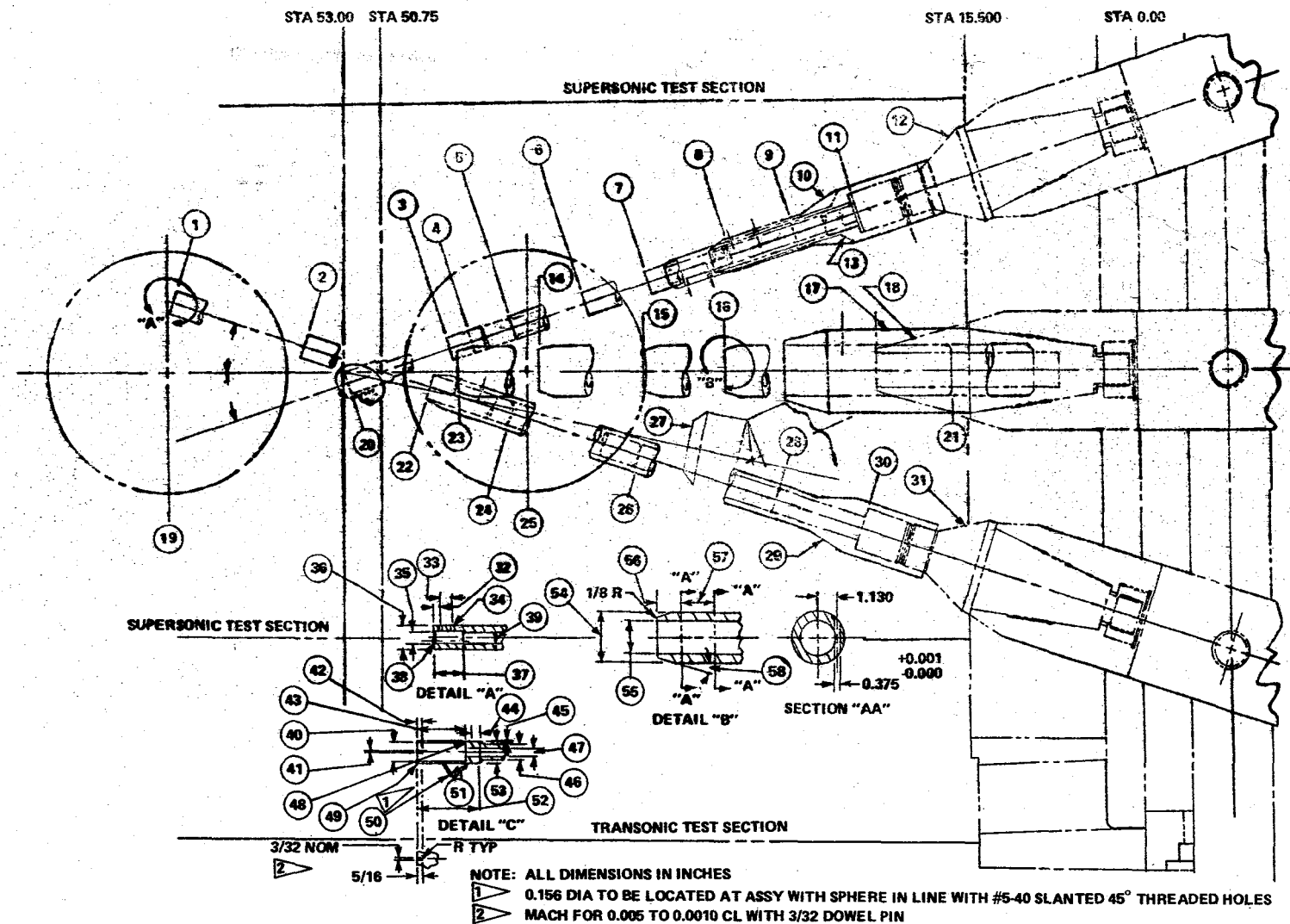
Static Stability Instrumentation

All model force and moment data are measured by internal strain gage balances. A variety of balance sizes and load ranges are available for force model tests. Calibration constants are determined from measurements of the balance outputs resulting from dead weight loadings of the balance in a special calibration stand. Weight tares are measured for all models and corrections applied to the final data.

Check weight loads are applied to the model when installed in the tunnel. This procedure provides an exacting system checkout and serves as a moment transfer distance check. This operation is repeated periodically during each test.

Deflections of the model, sting, and balance system are measured during the dead weight calibration program. Using these deflection constants, the model angle of attack is corrected for the effect of aerodynamic loads throughout the test.

The six-component balance is the type primarily used in this facility. The components measured are normal force, pitching moment, side force,

Figure 14. HRWT sting summary.

NOTE: ALL DIMENSIONS IN INCHES
1. 0.156 DIA TO BE LOCATED AT ASSY WITH SPHERE IN LINE WITH #5-40 SLANTED 45° THREADED HOLES
2. MACH FOR 0.005 TO 0.0010 CL WITH 3/32 DOWEL PIN

STING NO.	X (in.)	D (in.)	NF (lb)	NOTE
91	34.9	2.550	9000	D
92	35.5	1.400	2100	B
109	35.5	1.875	5000	C

NOTE:
A. 3½ in./ft TAPER, 80% MIN CONTACT WITH "RING GAGE" 80M33323.
B. 1 in./ft TAPER, 85% MIN CONTACT WITH "PLUG GAGE" 80M32384.
C. 1 in./ft TAPER, 85% MIN CONTACT WITH "PLUG GAGE" 80M32524.
D. 1 in./ft TAPER, 85% MIN CONTACT WITH "PLUG GAGE" 80M32388.

LEGEND

1. STA 67.09, MAX EXT OF 80M32242 W/80M32244
2. STA 58.46, MAX EXT OF 80M32241 W/80M32244
3. STA 48.97, MAX EXT OF 80M32242 W/80M32240
4. STA 47.57, MIN EXT OF 80M42177 W/80M42176
5. STA 44.94, MIN EXT OF 80M32242 W/80M32240
6. STA 40.34, MAX EXT OF 80M32241 W/80M32240
7. STA 36.31, MIN EXT OF 80M32241 W/80M32240
8. STA 31.08, REAR END POS OF 80M42177 W/80M42176
9. STA 27.09, REAR END POS OF 80M32241 AND 80M32242 W/80M32240
10. STING ADAPTER 80M32240 OF H.R.E. ASSY 80M51065
11. STA 23.06
12. STING-POD ADAPTER 80M42179 OF 80M51063 H.R.E. ASSY
13. STING 80M42176 OF H.R.E. ASSY 80M51063
14. STA 41.19, MIN EXT OF 80M32316 W/80M32313
15. STA 34.94, MAX EXT OF 80M32315 W/80M32313
16. STA 29.94, MIN EXT OF 80M32315 W/80M32313
17. CHUCK 80M32313 OF H.R.E. ASSY 80M51077
18. CHUCK 80M32314 OF H.R.E. ASSY 80M51077
19. STA 64.00 SUPERSONIC TEST SECTION WINDOW
20. STA 55.58, MAX EXT OF 80M42177 W/80M42176
21. STA 16.44, REAR END POS OF 80M32316 AND 80M32315 W/80M32313
22. STA 50.38, MIN EXT OF 80M32241 AND 80M32242 W/80M32244
23. STA 46.19, MAX EXT OF 80M32316 W/80M32313
24. STA 45.22, REAR END POS OF 80M32241 AND 80M32242 W/80M32244
25. STA 42.00 SUPERSONIC TEST SECTION WINDOW
26. MIN END POS OF 80M32241
27. OFFSET STING 12° 80M51081
28. MIN END POS OF 80M32242
29. STING ADAPTER 80M32244 OF H.R.E. ASSY 80M51065
30. STA 23.06
31. STING-POD ADAPTER 80M42179 OF 80M51063 H.R.E. ASSY
32. 3/8
33. 3/4
34. 14-28 UNF-2, 3 PL EQ SP RADIALLY @ 2 STA
35. 0.750 +0.001 -0.000
36. 1.437 +0.000 -0.001
37. 1 3/4
38. 1/32 x 45°
39. 11/16
40. 1.125 DIA
41. 1/8 TYP 3 PL
42. 11/16
43. 1 7/8
44. 1/2
45. 1/16
46. 0.999 +0.0000 -0.0015
47. 1/2
48. 1/8 R
49. 1/32 x 45°
50. 0.156 DIA TYP 3 PL EQ SP FULL DIA
51. 45° REF
52. 2 5/8
53. 1.374 +0.000 -0.002
54. 2.999 +0.000 -0.001
55. 2.000 +0.001 -0.000
56. 1 1/2
57. 2
58. 15°
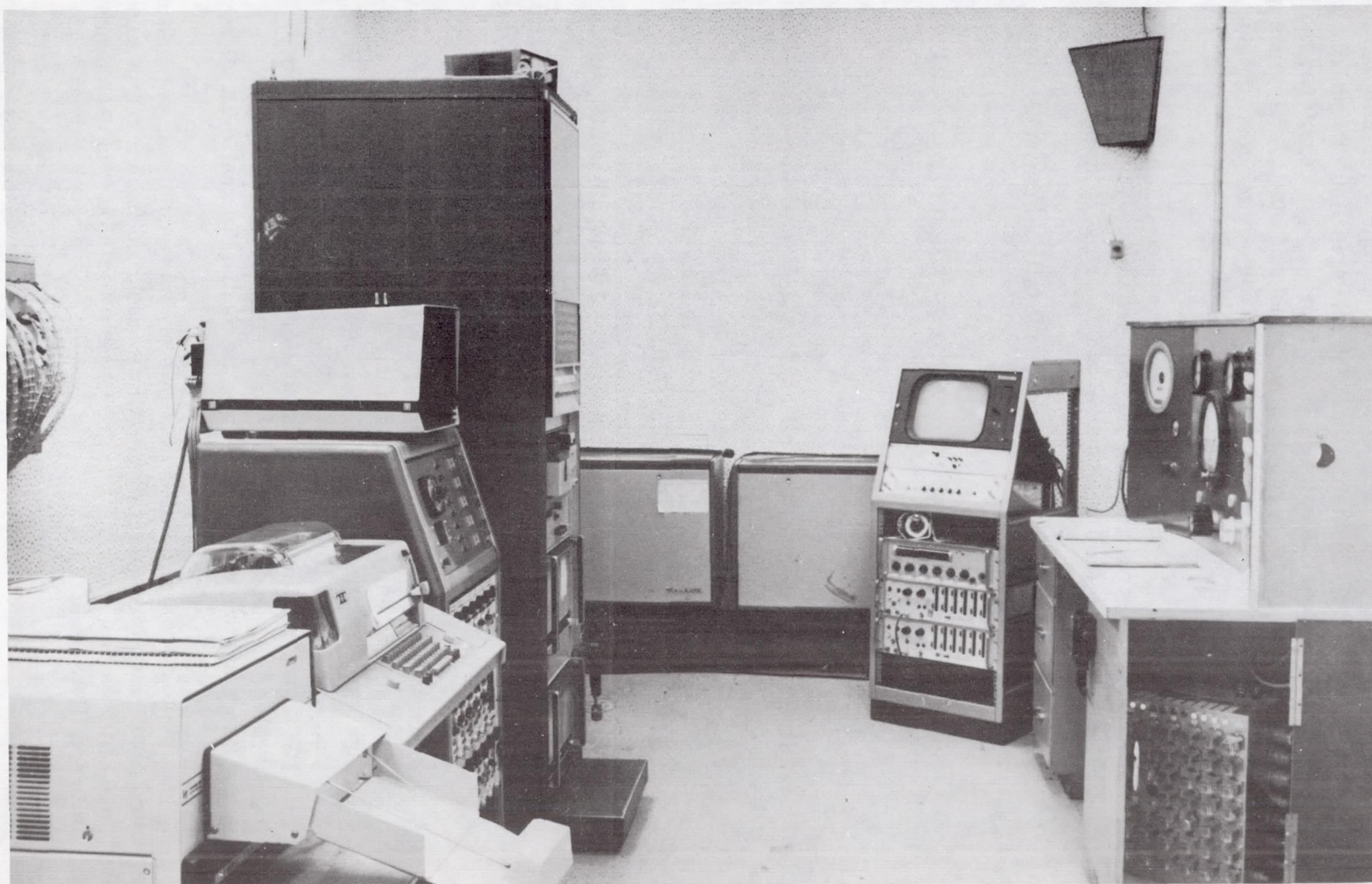
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Figure 15. HRWT control room.

yawing moment, rolling moment, and axial force. Table 1 lists the balances available for use in the HRWT, their capacities and principal dimensions. Additional balances are constructed from time to time and, therefore, the list in Table 1 may be incomplete. It should also be pointed out that balances used in the 14-Inch Trisonic Wind Tunnel are available when lower load ranges are required. Reference 4 includes a list of these balances.

Balances furnished by outside users may be used if they are compatible with existing mechanical hardware and the data acquisition system. In the design of a balance for this facility, several points are very important:

1. Balance gaging must be done very carefully so that no bubbles are trapped under the gages.

2. Balance lead wires must be securely anchored to withstand the loads imposed by the balance cavity venting process.

3. Electrical connectors should be of the positive locking type.

For these reasons it is necessary that all balance design or selection considerations be discussed with HRWT personnel prior to final test planning.

Flow Visualization

The only flow visualization system used to date is the spark shadowgraph. The shadowgraph is recorded on 11 by 14 in. high speed film, the light source being an air spark of duration less than 1 μsec. Clearly, only one shadowgraph per run can be obtained at any preselected time during the run.

A schlieren system is not installed at the facility, but sufficient components are on hand so that one could be installed if a test required it. A variety of schlieren light sources are available, such as xenon arc, mercury arc, flash xenon, and continuous color sources. The extremely high density of the flow at the HRWT may preclude the use of schlieren in that a sufficiently desensitized system may not be feasible. Both still and motion picture cameras, as discussed below, could be used to record the schlieren pictures.

Direct photography of colored oil flows or fluorescent oils can be made with motion picture cameras ranging from a few hundred frames per second up to about 8000 frames per second. However, these techniques have not been tried in this facility to date.

TABLE 1. HRWT BALANCE LISTING[a,b]

Balance Number	Balance Components	Normal Force (lb)	Side Force (lb)	Axial Force (lb)	Pitching Moment (in.-lb)	Yawing Moment (in.-lb)	Rolling Moment (in.-lb)	Balance Diameter (in.)	Balance Length (in.)
228	4	2200	4400		8 800	8 800		1.5	10.7
229	6	750	250	250	1 575	525	400	1.4	11.5
230	6	9200	4600	3000	25 000	12 500	5000	2.6	15.075
234	6	1500	500	500	3 150	1 050	750	1.4	11.5
235	6	5000	2500	1500	10 500	5 250	1500	1.875	11.5

a. These are nominal values.

b. Balances have a forward and aft taper of 1 in./ft and are generally interchangeable for the same diameters.

Calibration Equipment

For pressure testing, standard calibration type mechanical gages of 0.1 percent accuracy are used. They are available in ranges from 15 psia to 1000 psia and are periodically recalibrated by the MSFC Calibration Laboratory.

For force balance testing, the balances are furnished to the facility with their calibrations. These calibrations are performed in a central balance calibration apparatus, as seen in Figure 16, using dead weights for forces and dead weights on long arms for moments. A complete calibration which considers nonlinear terms and cross-product interactions is routinely furnished with each balance. The central calibration apparatus cannot load to the full range required by this facility, however. Balances with force capacities appreciably beyond 3000 lb are loaded in a special high capacity apparatus at the facility, which can load up to 14 000 lb dead weight, with combined moments and axial force loads. Experience with families of balances has shown that the detailed calibration to 3000 lb is sufficient for determination of all interaction terms and only the nonlinearities of the prime terms need be checked to the higher loads. Sting and balance deflections are also recorded at the higher loads. Figure 17 shows the high capacity apparatus. As a final check on the overall system, additional dead weights are loaded when the balance has been installed in the tunnel.

DATA PROCESSING AND PRESENTATION

Data Processing

All data are reduced on site in the computer controlled data acquisition system. Forces and moments are reduced to standard coefficients and pressures are reduced to pressure ratios or pressure coefficients. These coefficients are then punched on cards for subsequent analysis by the user, such as pressure integration or force coefficient slopes. The computer memory is limited and cannot carry over information from run to run for comparative analysis.

Data Presentation

Any data may be plotted on the CRT as a function of run time and at any scale factor desired, and hard copies may be made. Tabulated data are available via the teletype; its relatively slow output dictates judicious selection
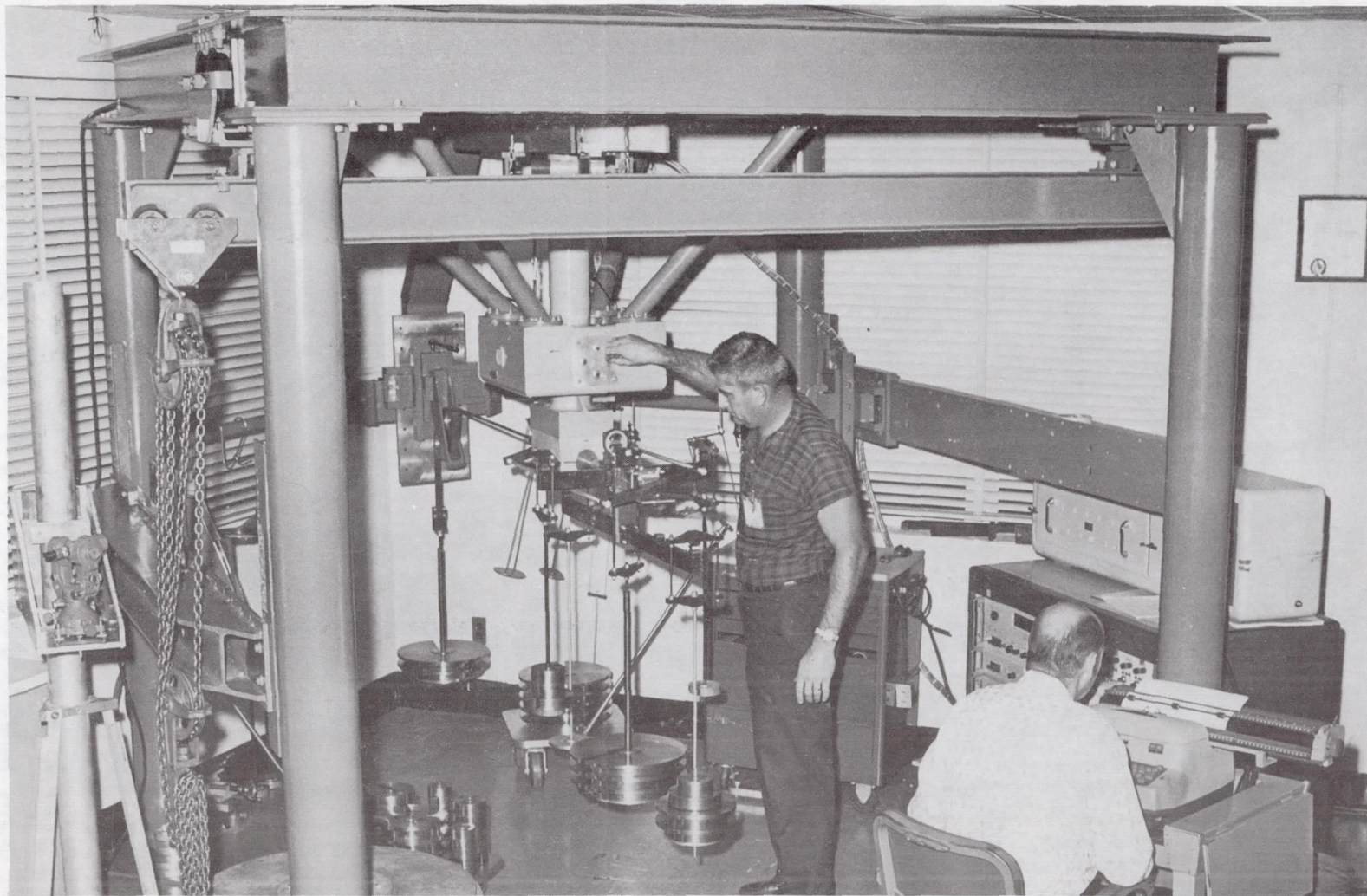
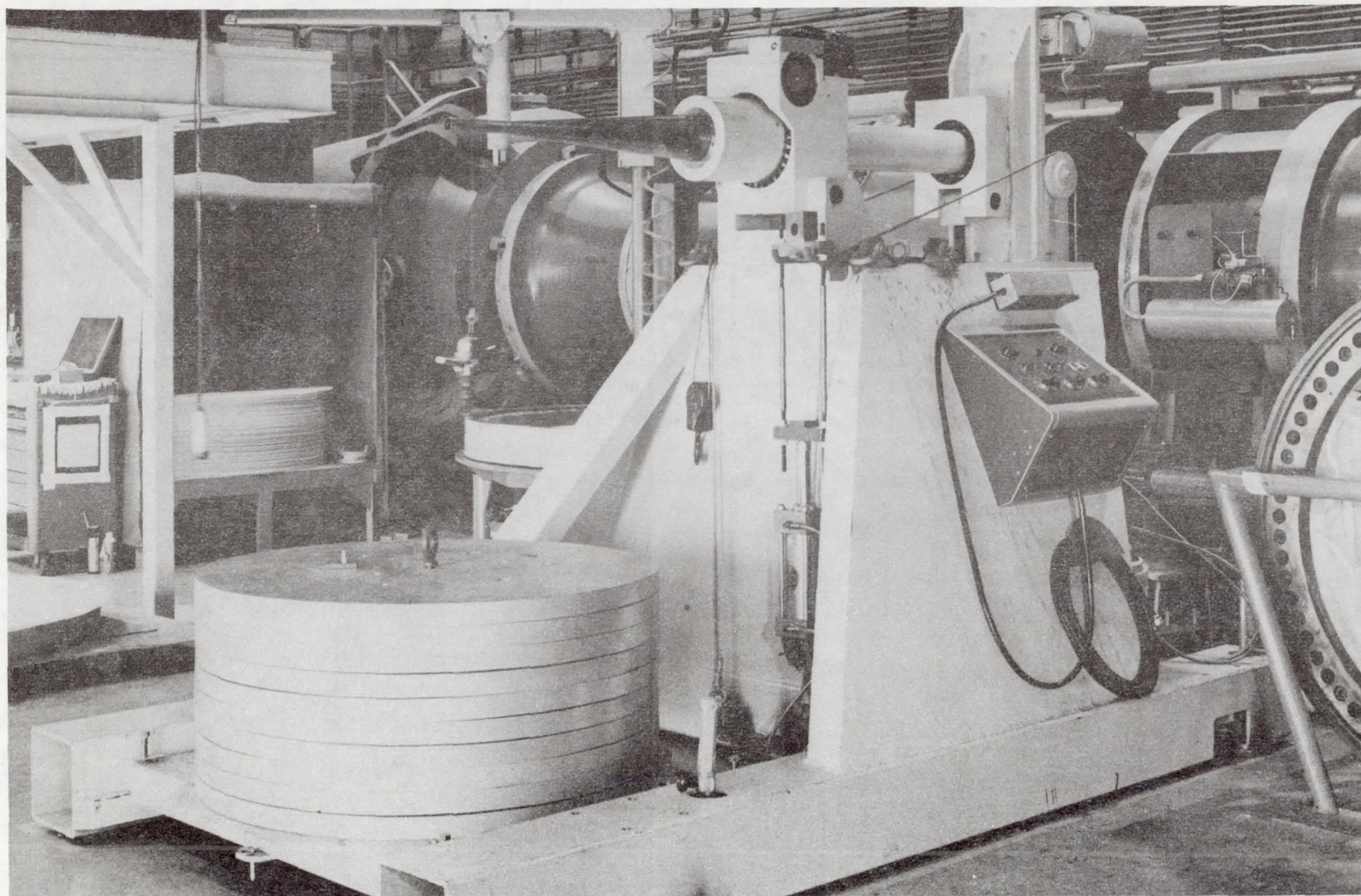Figure 16. Central balance calibration apparatus.

Figure 17.   14 000 lb calibration stand.

of what is to be tabulated. All data reduction is usually finished about 20 min. after the run; this figure varies considerably depending upon how much plotting is done.

PRELIMINARY TEST INFORMATION REQUIRED

Stress Report

The stress report should contain a detailed analysis of the model and model mounting hardware and should be detailed so that critical areas can be located and checked. The ratio of starting loads to steady state loads used for model design purposes will be 1.5 for transonic and 2.0 for supersonic Mach numbers. A minimum factor of safety of 4.0, based on ultimate strength, is required for all test hardware except for HRWT balances and stings where a factor of 3.0 is normally accepted. Requests for deviations from these requirements will be handled by the facility manager on an individual basis.

Responsibility of the User

When initial contact with the facility personnel has been made by the user, a decision for a feasibility conference will be made based on the complexity of the test. When the test has been deemed feasible by the facility manager, the user will be required to submit an MSFC Form 197 "Request for Aerodynamic Testing," a sample of which is shown in Figure 18. This information will enable personnel to establish test schedules and begin the necessary pretest work.

After the test has been firmly scheduled, the user must submit 3 complete sets of model drawings, 2 copies of the stress report, and 10 copies of the test plan. These should be delivered to the facility manager at least 5 weeks prior to scheduled test date.

Model drawing details should include material and heat treatment designations of each model and sting part. Assembly drawings should show the external model shape, the balance and sting attachment, clearances, and the model location in the tunnel.

A test plan shall be submitted with the complete requirements of the test and should include at least the following:

REQUEST FOR AERODYNAMIC TESTING		DATE:	
2. COST CODE:		3. FACILITY TO BE UTILIZED:	
4. PURPOSE AND SCOPE OF TEST:			
5. TYPE OF TEST:	6. MODEL CONFIGURATION:	7. MACH NUMBERS:	
8. STAGNATION PRESSURE, PSIA:	9. STAGNATION TEMPERATURE, °F:	10. ANGLE OF ATTACK RANGE, DEG.:	
11. ANGLE OF YAW RANGE, DEG.:	12. ROLL ANGLES, DEG.:	13. NUMBER & KIND OF MEASUREMENTS:	
14. MODEL LOAD ESTIMATES:	15. LOCAL PRESSURE MEASUREMENTS:	16. PHOTOGRAPHIC REQUIREMENTS:	
17. FLOW VISUALIZATION:	18. BALANCE NUMBER:	19. STING NUMBER:	
20. MODEL NUMBER:			
21. MISCELLANEOUS, INFORMATION:			
22. NAMES OF PERSONS PARTICIPATING IN TEST: TEST PROJECT ENGINEER		ORGANIZATION:	PHONE NUMBER:
23. SIGNATURE OF RESPONSIBLE CIVIL SERVICE PERSON:	DATE:	ORGANIZATION:	PHONE NUMBER:
TO BE COMPLETED BY S&E-AERO-AEG STAFF			
24. TEST NUMBER:		25. ESTIMATED TUNNEL OCCUPANCY:	
26. SCHEDULED TEST DATES:		27. REVISED TEST DATES:	
28. COMMENTS:			
29. APPROVALS			
SIGNATURE OF FACILITY MANAGER:	DATE:	SIGNATURE OF CHIEF, GAS DYNAMICS SECTION:	DATE:
30. TEST COMPLETED:		31. NUMBER OF RUNS:	
32. NOTES:			

MSFC - Form 197 (July 1971)

Figure 18. Request for aerodynamic testing.

1.   Introduction.

2.   Title of the program.

3.   Security information for the model, the test data, and the final data report.

4.   Purpose and scope of the test.

5.   Model description — dimensional details, model installation sketches, references, and configuration nomenclature.

6.   Model load estimates — maximum load conditions, center of pressure, and curves of any similar known configurations or estimated characteristics.

7.   Test requirements — angle of attack range, Mach number, Reynolds numbers, etc.

8.   Facility mounting hardware — to be furnished by the user, to be furnished by the facility.

9.   Special equipment requirements — photographic coverage, flow visualization, model fouling indicators, pressure instrumentation, auxiliary air, auxiliary electrical power, hinge moments, etc.

10.   Estimated facility occupancy — installation, running, model changes, removal, etc.

11.   Data to be recorded during test — Mach number, six- or three-component force data, base pressures, local model pressures, tunnel operating conditions, etc.

12.   Data reduction — model reference areas and lengths, moment reference positions, definition of aerodynamic coefficients, reference axis transfer equation, etc.

13.   Data presentation — data to be tabulated and order of tabulation desired, where and to whom the data should be delivered.

14.   General — names, addresses, phone numbers of the personnel who will participate in the test and their tentative arrival dates, and shipping instructions of return of the model and other hardware.

Pretest Conference

A pretest conference is usually held 2 weeks before the test to resolve last minute test details and to familiarize all personnel with the test. Data reduction requirements will be discussed at this meeting. Conferences will be scheduled by the facility manager.

All pretest coordination will be done through the facility manager or the person he designates. During the testing, the user should coordinate all test requirements through the facility engineer assigned to the test. It is necessary that the user have a qualified project engineer present at all times to monitor results and make necessary decisions concerning the conduct of the test.

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2. Warmbrod, J.D., and Struck, H.: Application of the Characteristic Method in Calculating the Time Dependent, One-Dimensional Compressible Flow in a Tube Wind Tunnel. NASA TM X-53769, August 1968.

3. Davis, J.W., and Gwin H.S.: Feasibility Studies of a Short Duration High Reynolds Number Tube Wind Tunnel. NASA TM X-53571, January 1968.

4. Simon, E.: The George C. Marshall Space Flight Center's 14 × 14 Inch Trisonic Wind Tunnel Technical Handbook. NASA TM X-64624, November 1971.
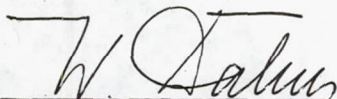
APPROVAL

THE GEORGE C. MARSHALL SPACE FLIGHT CENTER HIGH REYNOLDS NUMBER WIND TUNNEL TECHNICAL HANDBOOK
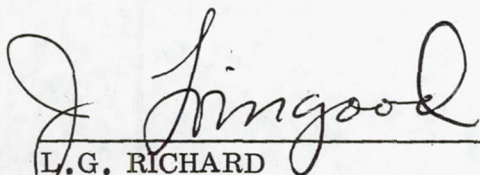
By H.S. Gwin

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense of Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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