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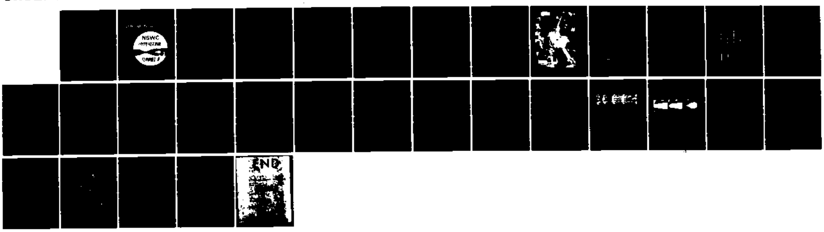

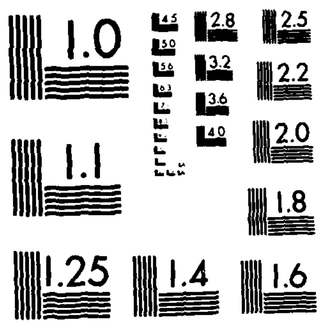

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JANUARY 1984

USERS MANUAL

NSWC HYPERSONIC TUNNEL 8

NAVAL SURFACE WEAPONS CENTER
WHITE OAK LABORATORY
Silver Spring, Maryland

REPORT DOCUMENTATION PAGE

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents information required to plan tests in the NSWC Hypersonic Tunnel. It contains a description of the tunnel and the associated instrumentation, overall performance capability, and some of its unique performance capabilities. It is intended as a guide to potential users.

FOREWORD

This users manual presents information frequently required when planning tests in the Hypersonic Tunnel (T8) located at the Naval Surface Weapons Center (NSWC), White Oak Laboratory. It contains a description of the wind tunnel facility, its outstanding performance capabilities, and the associated instrumentation that is available. This manual is intended as a guide to potential users.

The Hypersonic Tunnel is part of a wind tunnel complex at NSWC and has been in operation since 1960. It provides an exceptional high Reynolds number testing capability in support of Navy and Department of Defense agencies and contractors.

Approved by:

C. A. Fisher

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Weapons Dynamics Division

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INTRODUCTION

This users manual presents information frequently required when planning tests in the Hypersonic Wind Tunnel Facility (T8) located at the Naval Surface Weapons Center (NSWC), White Oak Laboratory. It contains a description of the tunnel and its outstanding performance capabilities, and is intended as an instructional guide for potential users. The associated instrumentation that is available and specialized capabilities that are unique to this facility are also described. This document supersedes NSWC/WOL MP 76-10.[1]

The Hypersonic Tunnel is a high Reynolds number, blowdown-type facility in which accurate aerodynamic and aerothermodynamic measurements can be made within the Mach number range of 5 to 8. Air is the working medium with a maximum supply pressure of 150 atmospheres for all nozzles. However, supply pressure at Mach 5 is normally limited to 100 atmospheres because very high mass flow rates above this pressure level cause run times to become very short. A limit of 100 atmospheres at Mach 5 and 150 atmospheres for Mach 6 through 8 corresponds to a Reynolds number per foot of 50 million at Mach 5 and 10 million at Mach 8. Run times range from several hours to minutes and are dependent on Mach number and supply conditions.

The Hypersonic Tunnel at NSWC is part of a wind tunnel complex consisting of a Calibrations Laboratory; 16 x 16 inch continuous/blowdown Supersonic Tunnel (T2); a 10 x 12 inch Boundary Layer Channel (T7); 23-inch-diameter, Mach 18 Hypervelocity Research Tunnel (T8A), and 5-foot-diameter Hypervelocity Wind Tunnel (T9).

GENERAL DESCRIPTION OF THE FACILITY

The Hypersonic Tunnel is an intermittent blowdown-type facility in which compressed and heated air is used as the working fluid. The air supply system consists of a 42,000-pound capacity, 3,000/5,000 psi maximum pressure storage field. A regenerative pebble-bed heater capable of a maximum temperature of 1050°F is used to heat the air to a temperature which is sufficient to avoid liquefaction in the test section.

Hypersonic flow at Mach numbers 5, 6, 7, and 8 is generated using interchangeable, fixed geometry nozzles having dimensions as shown in Table 1. The nozzles discharge into a large open jet test section which is designed to facilitate access to service test models and instrumentation. A model support system contained in the test section is capable of positioning the model over a wide range of angle of attack, providing axial motion, and injecting the test model into, and retracting it from, the flow. Special roll attachments are also available to permit rotation of test models. The test chamber is equipped with a two-mirror, parallel-path Schlieren system which permits optical coverage of the test model flowfield.

TABLE 1. NOZZLE GEOMETRY DATA

MACH NO.	CROSS-SECTION	THROAT DIMENSIONS IN.	OVERALL LENGTH IN.	EXIT DIMENSIONS IN.	EXIT AREA $IN.^2$	DESIGN PRESSURE PSIA	DESIGN TEMPERATURE °F
5	CIRCULAR	3.150 dia.	139.0	17.0 dia.	227.0	1470	1000
6	RECTANGULAR	0.300 x 16.00	131.4	17.90 x 17.44	312.2	2205	600
7	CIRCULAR	1.962 dia.	144.5	21.78 dia.	372.6	2205	1000
8	CIRCULAR	1.463 dia.	158.0	22.25 dia.	388.8	2205	1000

From the test section, flow proceeds through a fixed geometry diffuser. In addition, the tunnel exhausts to atmosphere or a series of vacuum pumps, and a multiple nozzle air ejector system located at the diffuser inlet can be used to reduce exhaust pressures further. Most tunnel components are fully cooled to maintain dimensional stability and to prevent excessive thermal stresses. A view of the Hypersonic Tunnel working section, and a schematic view of the entire tunnel system are shown in Figures 1 and 2, respectively.

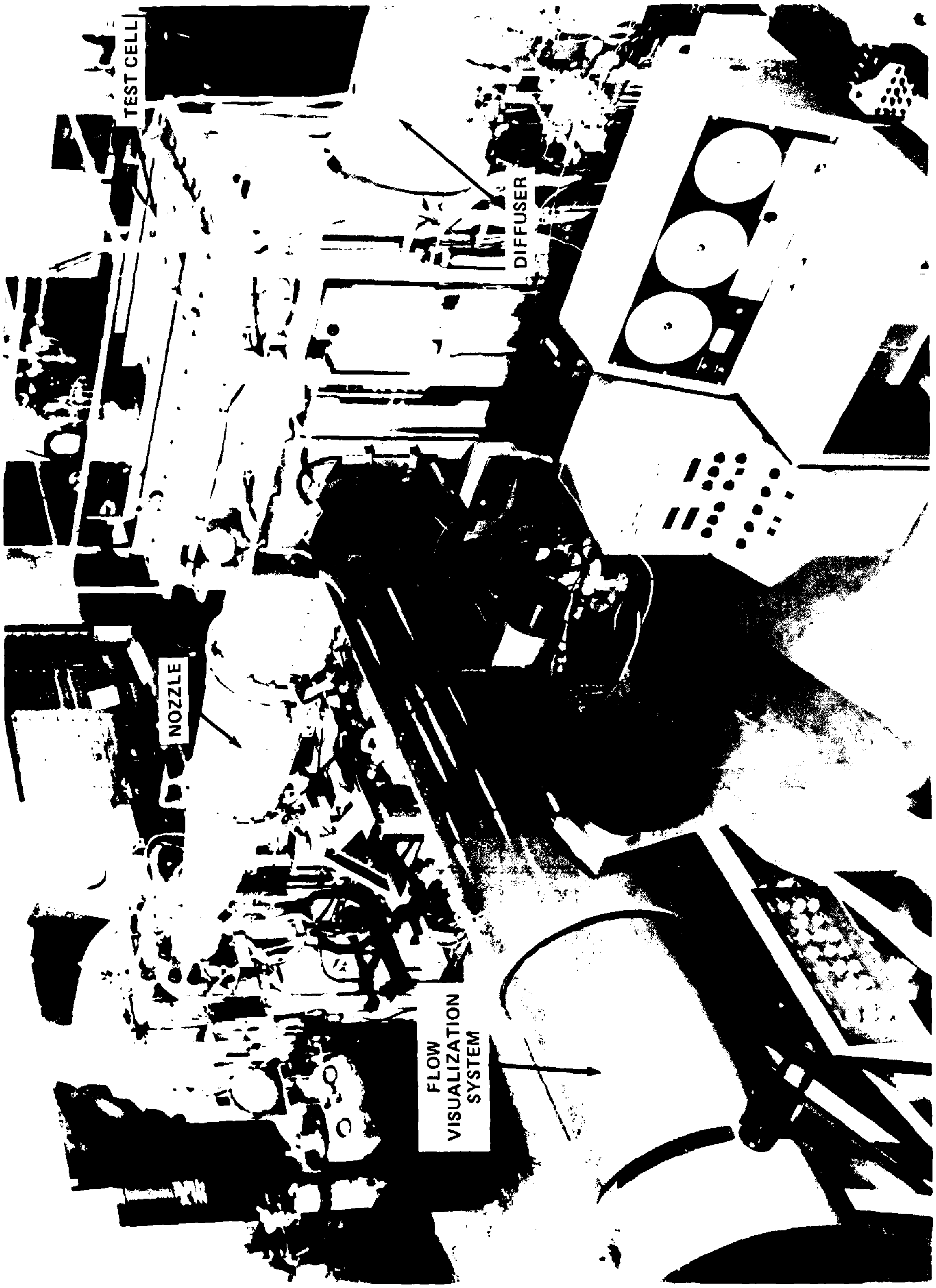

FIGURE 1. HYPERSONIC TUNNEL WORKING SECTION

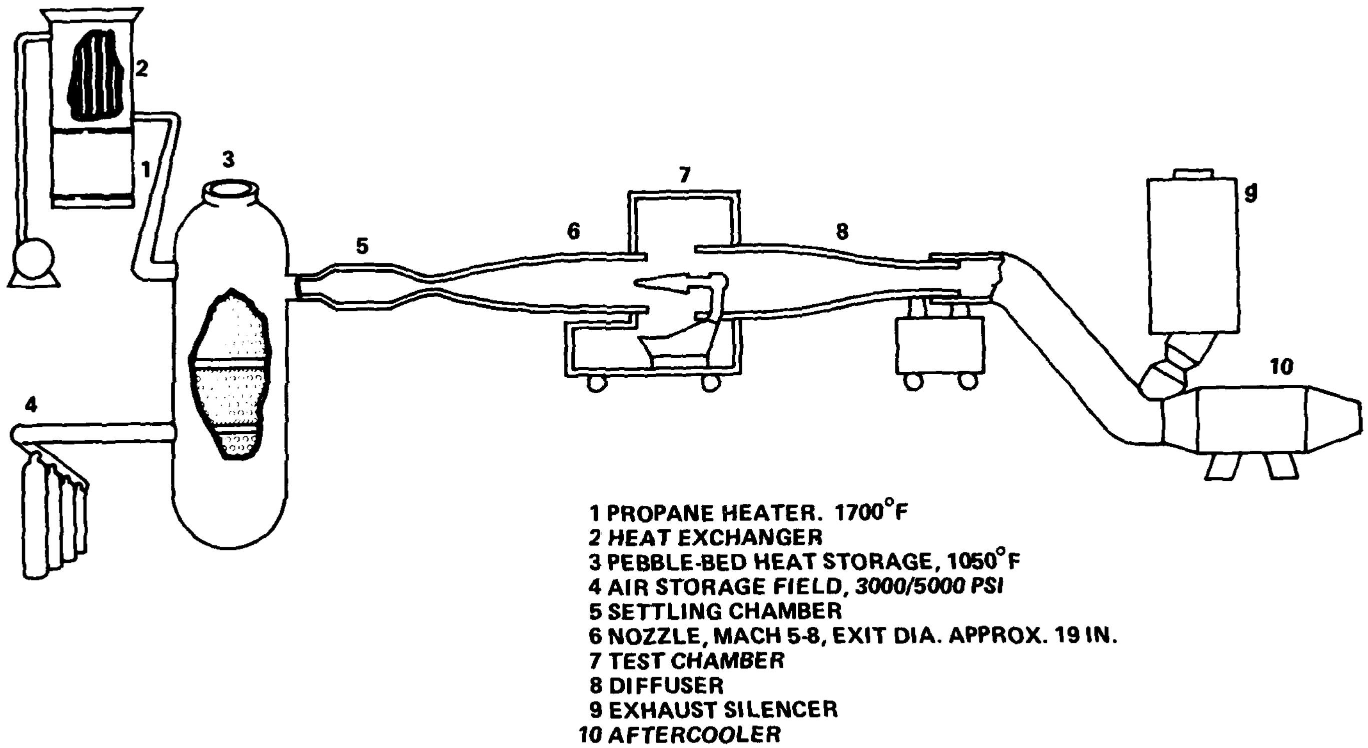

FIGURE 2. SCHEMATIC VIEW OF THE HYPERSONIC TUNNEL

AERODYNAMIC CAPABILITY

A summary of the overall performance capability of the Hypersonic Tunnel is shown in Table 2. This table shows the nominal test Mach numbers, the maximum and minimum available supply pressures and temperatures, the maximum and minimum test Reynolds numbers, and the tunnel run times at maximum and minimum pressures.

TABLE 2. OVERALL PERFORMANCE CAPABILITY

MACH NO.	MAXIMUM SUPPLY PRESSURE (ATM)	MINIMUM SUPPLY PRESSURE (ATM)	MAXIMUM SUPPLY TEMP. (°F)	MINIMUM SUPPLY TEMP. (°F)	MAXIMUM REYNOLDS NUMBER $\times 10^6$	MINIMUM REYNOLDS NUMBER $\times 10^6$	RUN TIME AT MAX. P_o (MIN)	RUN TIME AT MIN. P_o (MIN)
5	100	5	1000	140	50	.96	½	25
6	150	10	600	250	36	2.0	½	40
7	150	10	1000	525	18	.84	1	45
8	150	10	1000	730	10	.61	3	170

PERFORMANCE CAPABILITY

The Reynolds number envelope for the Hypersonic Tunnel is illustrated in Figure 3. Also shown in this figure are the appropriate altitude simulations. The range of Reynolds number for each individual Mach number is shown in Figures 4 through 7. Closed form algebraic expressions of the form given in Equation (1)* represent an approximation of these figures and will compute the required tunnel supply pressure in terms of the Reynolds number and tunnel supply temperature.[2] This expression is derived by using the relations which govern isentropic flow and the definition of Reynolds number. Tabulated values of "a" and "b" for each available Mach number are given in Table 3.

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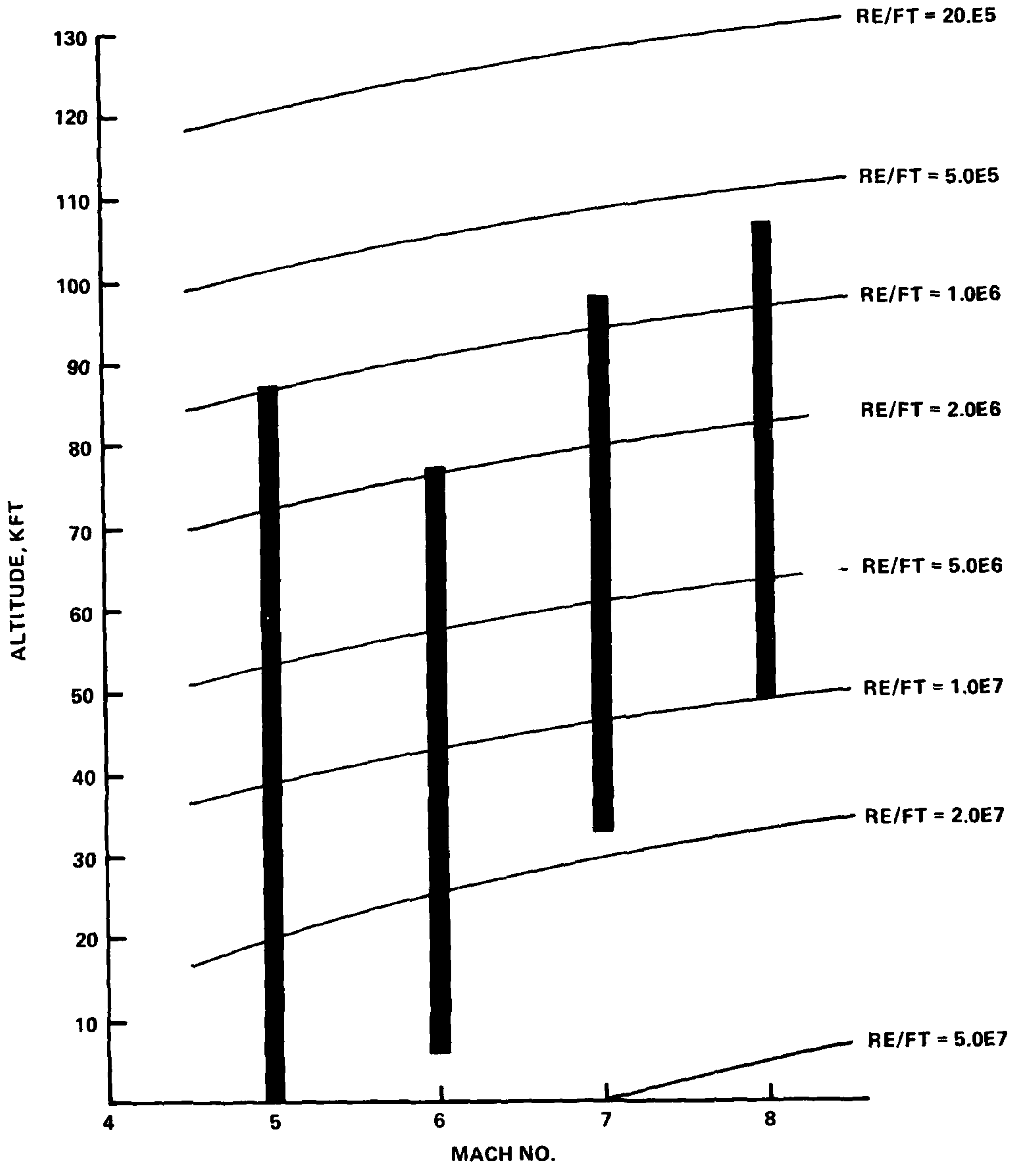

FIGURE 3. OPERATING ENVELOPE OF NSWC HYPERSONIC TUNNEL

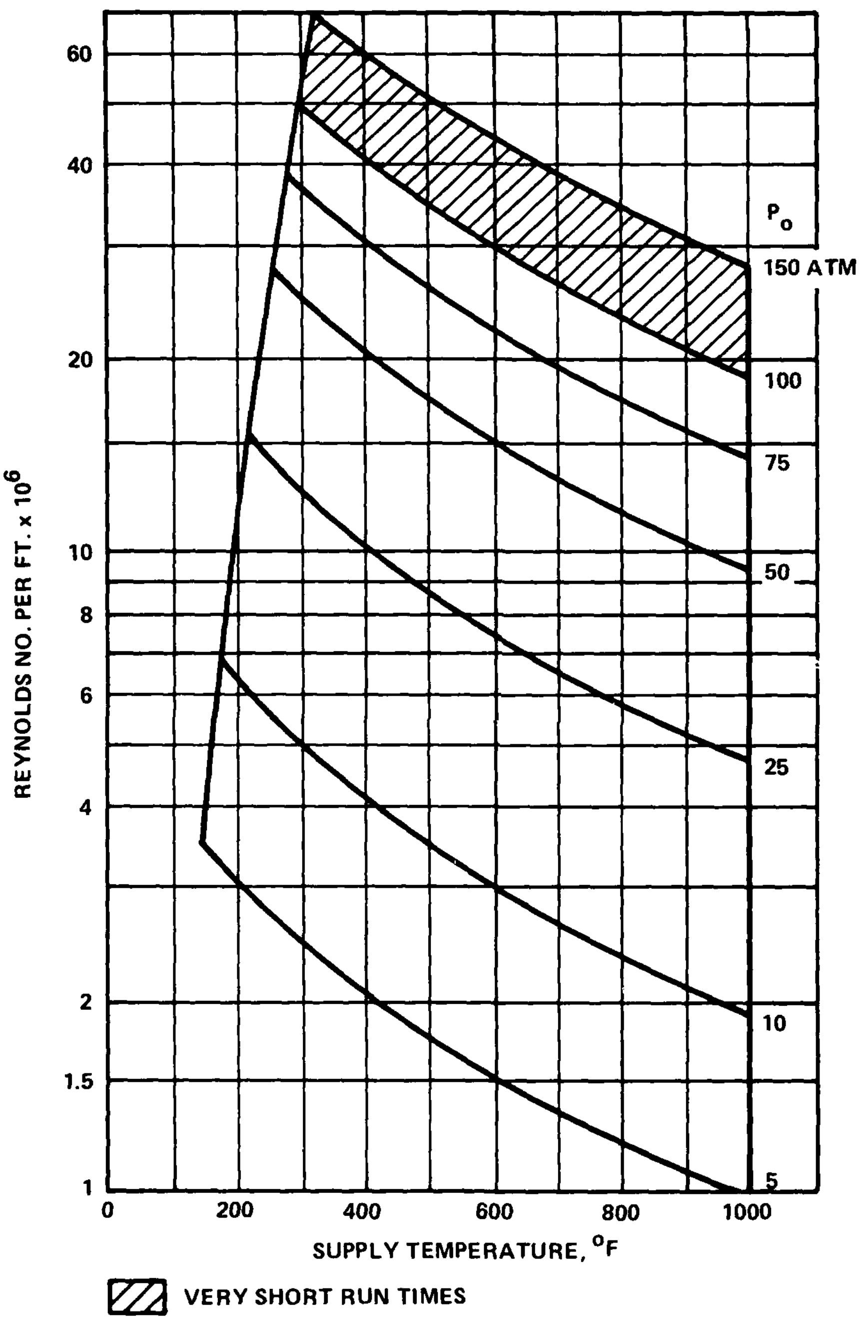

FIGURE 4. FREE-STREAM REYNOLDS NUMBER RANGE AT MACH 5

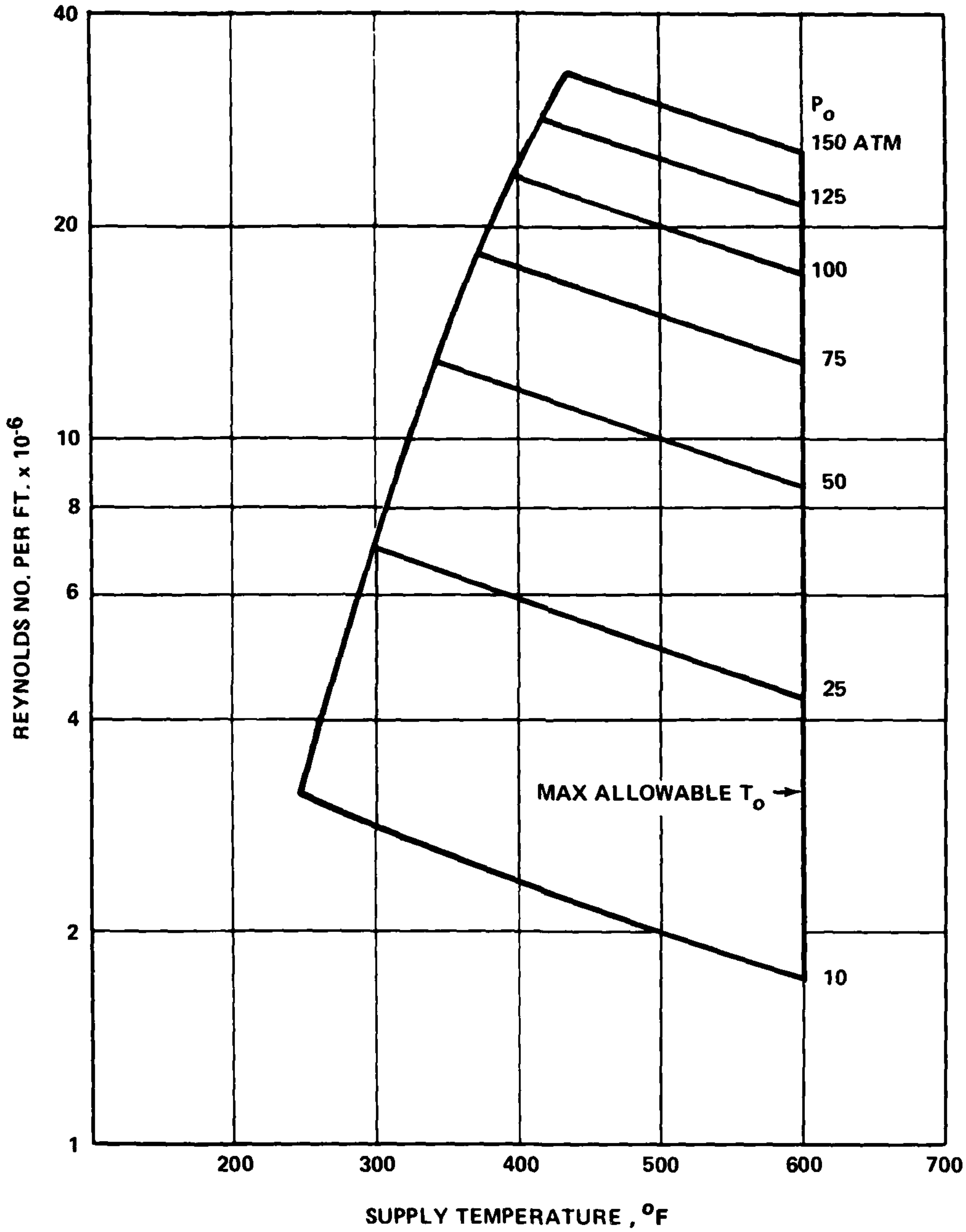

FIGURE 5. FREE-STREAM REYNOLDS NUMBER RANGE AT MACH 6.

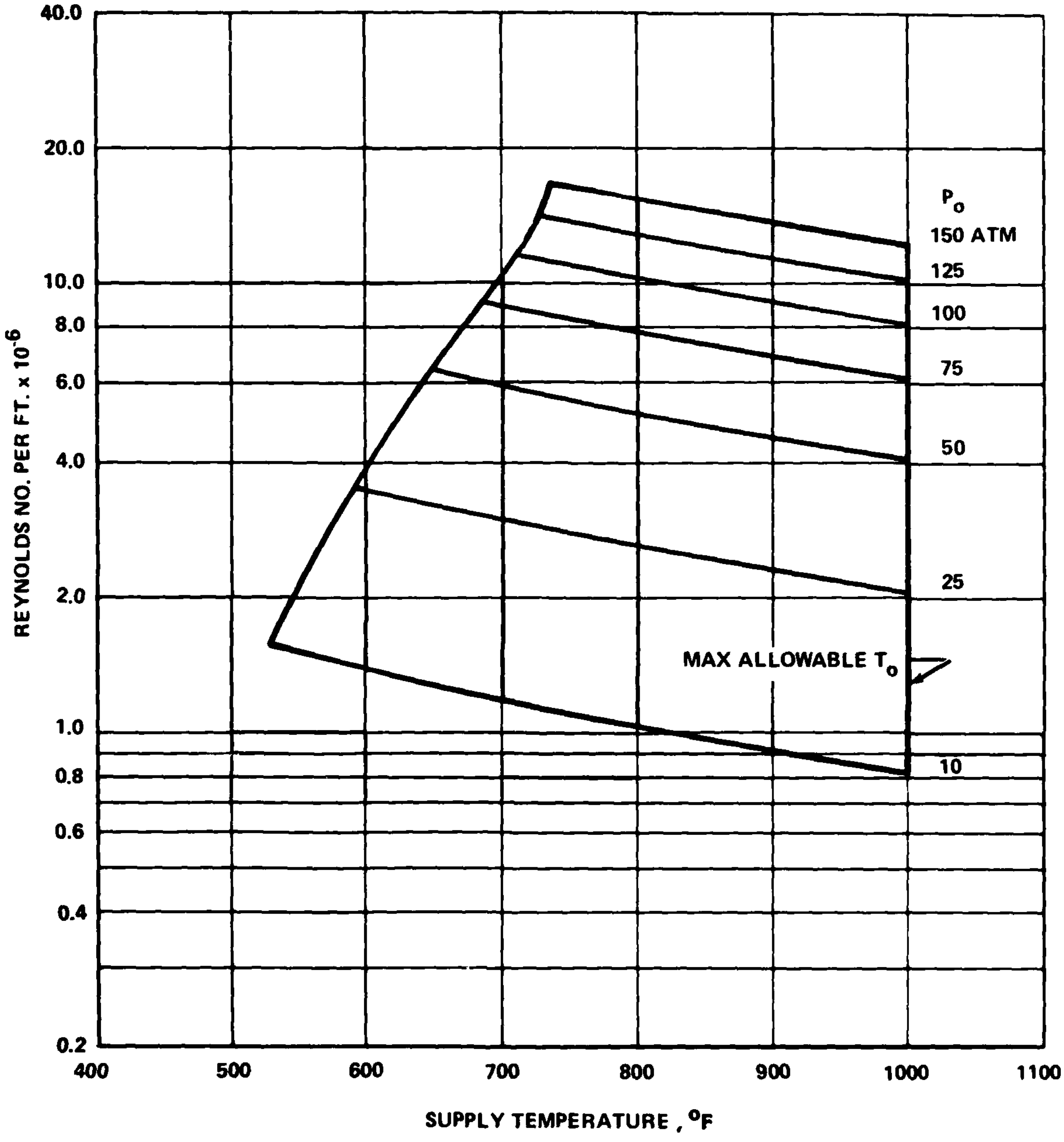

FIGURE 6. FREE-STREAM REYNOLDS NUMBER RANGE AT MACH 7.

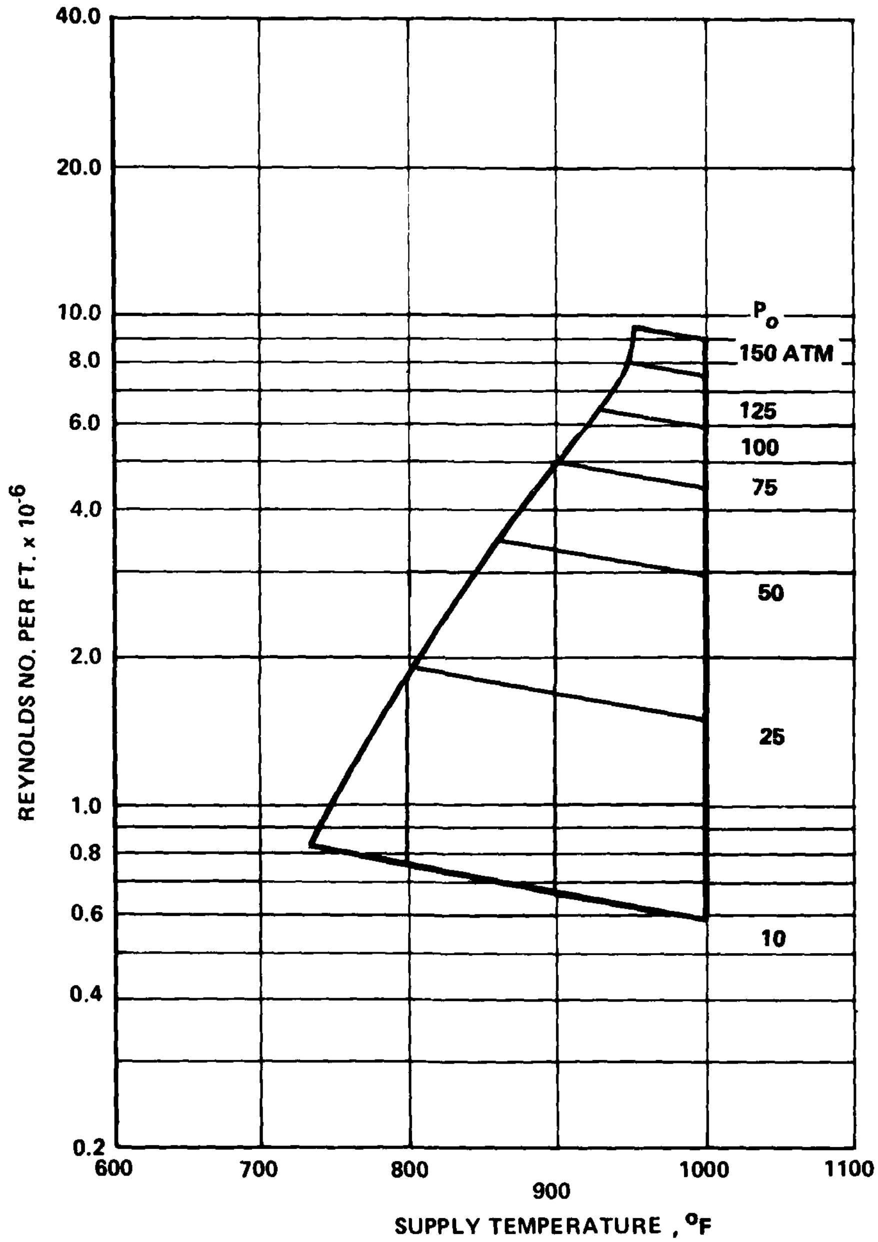

FIGURE 7. FREE-STREAM REYNOLDS NUMBER RANGE AT MACH 8.

$$P_o = \frac{Re * T_o^2}{a * (T_o + b)} \quad (1)$$

where P_o is the supply pressure (psia)

T_o is the supply temperature (deg R)

Re is the tunnel Reynolds number per foot

TABLE 3. TUNNEL PERFORMANCE EQUATION COEFFICIENTS

M	a	b
5	1.027×10^7	1.192×10^3
6	5.649×10^6	1.628×10^3
7	3.309×10^6	2.144×10^3
8	2.048×10^6	2.740×10^3

The upper limit in Reynolds number is determined by the maximum supply pressure allowed for the nozzle and by the minimum supply temperature at which the flow is free of liquefaction effects. The lower Reynolds number limit is dictated by the minimum supply pressure necessary to maintain flow.

Flow quality in the Hypersonic Tunnel has been determined through pitot pressure and total temperature surveys. Typical samples illustrating Mach number uniformity are shown in Figures 8 through 11.

TEST CELL AND MODEL SUPPORT

The test chamber is 40 inches wide, 68 inches long, and 130 inches high and has two doors, one of which is the walk-in type, to permit access to models and instrumentation. The "open jet" distance between the nozzle exit and the diffuser entrance is 16.5 inches. This length may be increased to 22.5 inches by installing a spacer between the nozzle and test cell. Schlieren quality windows, each 16.5 inches in diameter, are located on each side of the test chamber, and there is a 7-inch-diameter window located on top for viewing from above.

Model support and attitude control is provided by the model carriage as shown in Figure 12. This permits model injection and retraction, axial traverse, and angular traverse in the pitch plane. Model roll is also provided by a sector arm equipped with a roll control mechanism. Readout equipment is provided to give position indication for all motions. This information may be read directly or supplied to the data acquisition system.

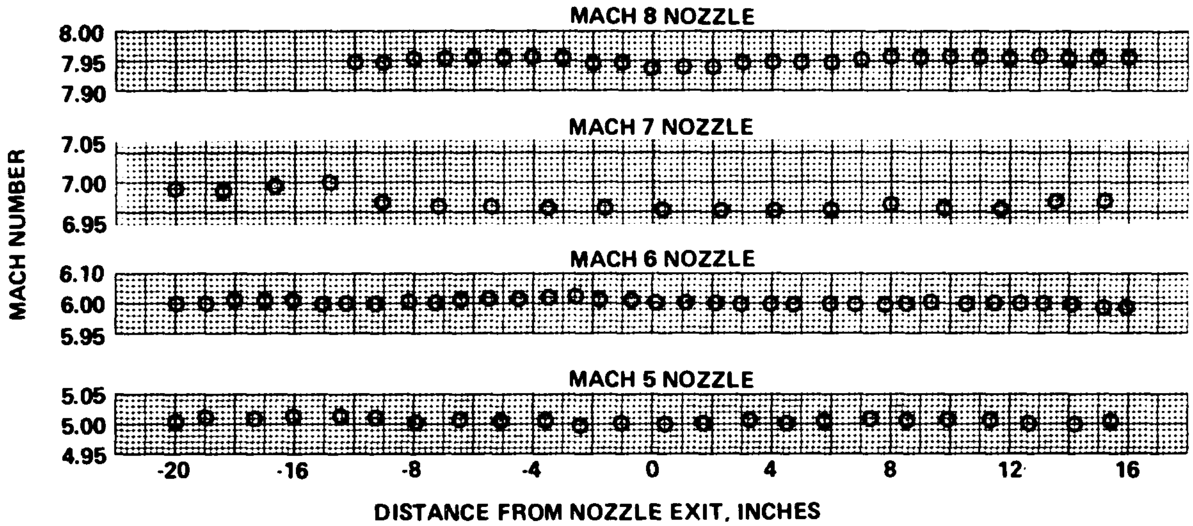

FIGURE 8. AXIAL MACH NUMBER PROFILES

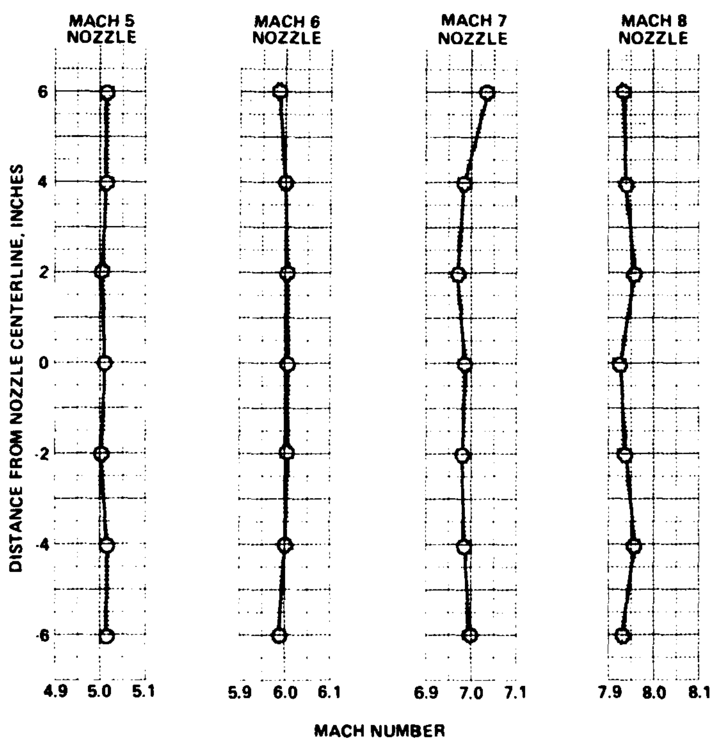

FIGURE 9. RADIAL MACH NUMBER PROFILES

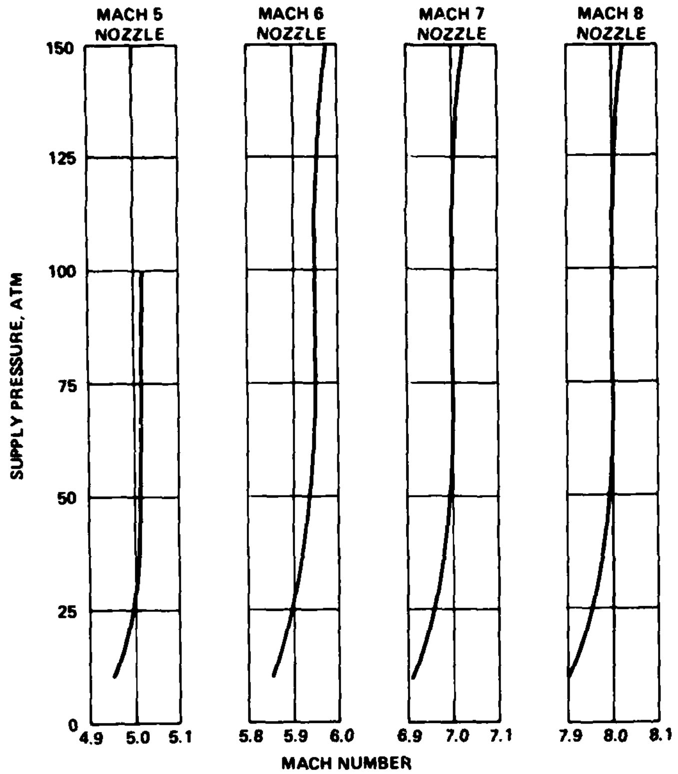

FIGURE 10. TEST SECTION MACH NUMBER VARIATIONS WITH PRESSURE

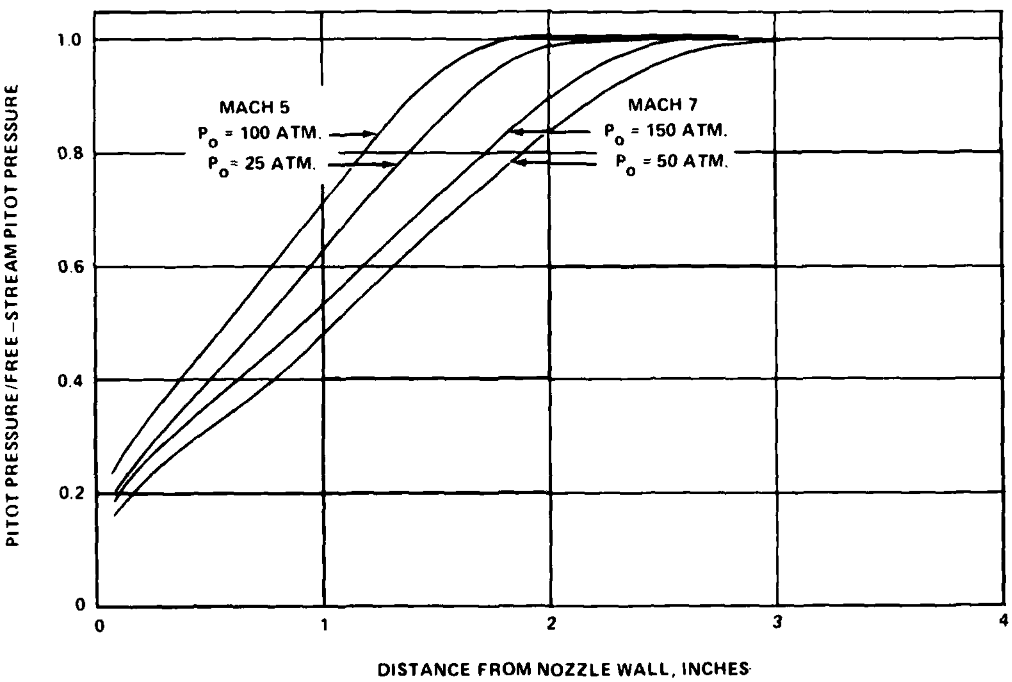

FIGURE 11. NOZZLE EXIT BOUNDARY LAYER THICKNESS

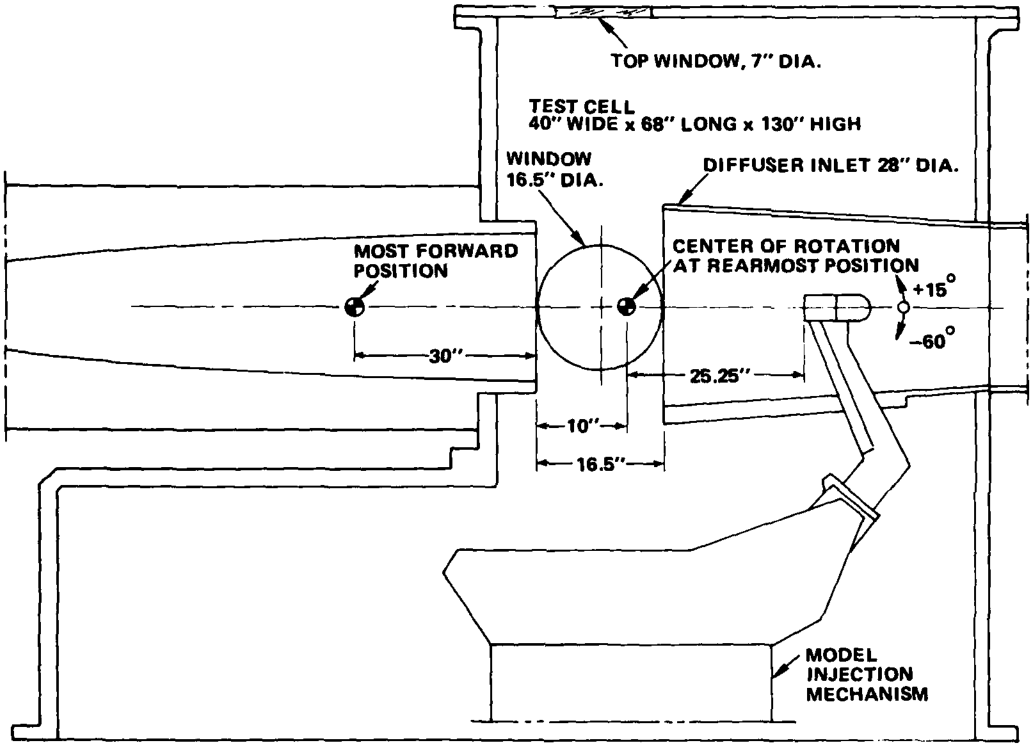

FIGURE 12. HYPERSONIC TUNNEL TEST SECTION

In a normal injection mode, the model enters the test jet at a velocity of 3 feet per second and then decelerates to zero upon reaching the nozzle centerline. When necessary, the injection velocity may be reduced, or the tunnel may be started with the model in the test position. Axially, the model may be traversed for a distance of 40 inches at a rate of up to 1.6 inches per second within the limits shown in Figure 12. Model pitch angle may be varied at a rate of four degrees per second or less within the limits of -15 to +60 degrees. Both axial and pitch traverses can be made during a test, but not simultaneously. Model roll can be attained at a rate of 5 degrees per second using a roll-head attachment.

MODEL SIZE LIMITATIONS

The maximum size of a model generally is limited by one or more of the following factors: (1) tunnel blockage; (2) reflected bow shock; (3) test rhombus length; and (4) length of the opening available for model injection. Blockage problems at hypersonic conditions generally have not been experienced for models having a maximum cross-sectional area equal to or less than 15 percent of the nozzle exit area. Nozzle exit areas have been calculated and are given in Table 1. Larger, more streamlined, models have been tested successfully in the past, and any future inquiries must be considered on an individual basis. Reflected bow shock or test rhombus length at hypersonic conditions do not impose a serious limitation except for large angles of attack. The standard length of the opening for model injection in this tunnel is approximately 30 inches. This distance includes the "open jet" length of 16.5 inches, nozzle spacer length of 6 inches, and a 10 x 10 inch "cut-out" in the bottom of the diffuser inlet. Models longer than 30 inches may be accommodated provided that the model diameter beyond the 30-inch point, as measured from the model nose, is 4 inches or less.

INSTRUMENTATION

The NSWC Hypersonic Tunnel is outfitted with instrumentation systems capable of measuring aerodynamic forces and moments, pressures, temperatures, heat transfer rates, and Schlieren/Shadowgraph flow visualization. A high-speed analog-to-digital data acquisition system is used to record all measurements.

FORCE MEASUREMENTS

Force and moment measurements are made with internal strain-gage balances. Figure 13 illustrates a typical Hypersonic Tunnel balance and Table 4 lists the available balances and their characteristics. Each balance is provided with a matching sting which positions the sensing element at the center of rotation of the model traversing sector. A water-cooled jacket is provided for thermal insulation of the balance from aerodynamic heating. Selection of a particular force balance should be discussed with NSWC project engineers to ensure that the optimum balance is chosen for the expected aerodynamic loads on the test model.

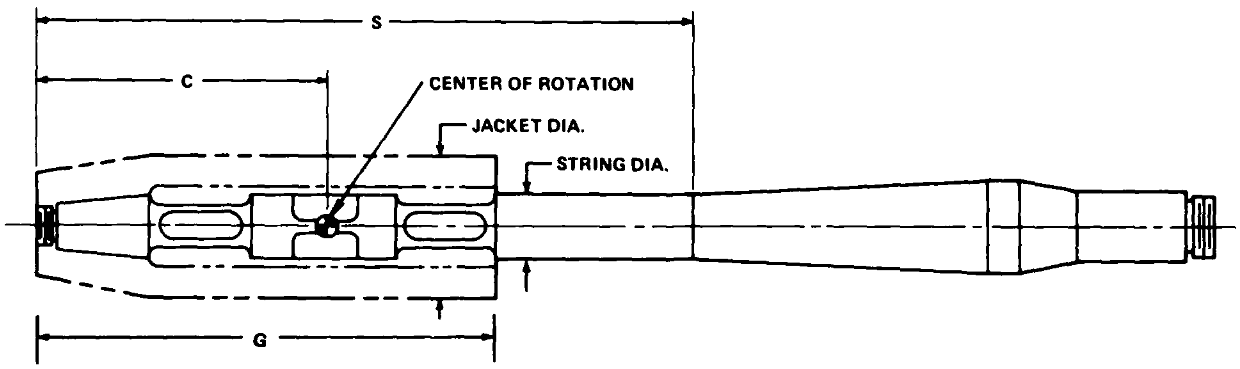

FIGURE 13. FORCE BALANCE SCHEMATIC

PRESSURE MEASUREMENTS

Static pressure measurements are made with strain-gage type transducers which are normally assembled together in a special container equipped with valving to permit calibration as shown in Figure 14. Two containers housing 48 transducers each and two housing 16 transducers each are currently available. The transducers are generally the "absolute pressure" type. A number of

TABLE. 4 NSWC HYPERSONIC TUNNEL FORCE BALANCES

BALANCE NO.	MAX* PITCH LB	MAX* YAW LB	MAX ROLL IN-LB	MAX DRAG LB	STING DIA IN	JACKET DIA IN	G*** IN	S*** IN	C*** IN
8H4-1	44	44	–	–	1.187	1.750	6.000	26.125	1.875
8H5-1	80	80	34	–	1.187	1.250	11.250	28.187	3.875
8H5-4	290	290	–	200	1.375	2.750	7.625	9.250	2.000
8H5-6	105	105	–	32	.937	1.250	5.437	6.500	1.937
8H5-7	240	240	–	78	1.250	1.650	6.250	7.250	2.625
									1.937
8H5-8	450	450	212	–	1.250	1.437	7.000	15.250	4.375
8H5-9	215	215	120	–	1.250	1.580	6.250	11.875	4.250
8H5-10	165	165	–	52	1.250	1.650	6.250	7.250	2.625
5-48	280	280	81	–	1.500	1.750	8.125	16.000	3.062
8H6-2	70	70	87	215	.875	1.125	5.540	11.000	1.375
8H6-3	280	280	250	122	1.000	1.375	7.375	8.000	4.625
8H6-6	460	460	410	146	1.000	1.375	7.375	8.000	4.625
8H6-7	460	460	410	50	1.000	1.312	7.375	8.000	4.625
8H6-8	460	460	410	146	1.000	1.375	7.375	8.000	4.625
8A4-1	12	12	–	–	.765	1.500	5.656	18.25	3.125
8A6-5	41	37	4.5	38	.890	1.500	8.500	20.25	4.000
9H6-1	1050	700	100	350	6.60	2.125	24.75	–	11.886
M-12**	62	7	–	–	.875	1.312	TURBINE DRIVE, WATER COOLED		
M-15**	75	11	–	–	.812	.812	FREE SPINNING, WATER COOLED		
M-19**	71	53	–	–	.750	.812	SOLID-STATE, COPPER		
M-20	71	53	–	–	.750	.812	SOLID-STATE, COPPER		
DTMB-2	260	62	–	–	1.225	1.225	ELECTRIC MOTOR DRIVE 11 H.P., VARIABLE FREQUENCY		

*FORCE APPLIED WITHIN ± ONE-INCH OF CENTER POINT OF GAGE SECTION
**MAGNUS BALANCE
***REFERENCE FIGURE 13

transducers that cover small and large ranges of pressure are available. The transducer containers may be located within the test cabin or outside of it, requiring approximately 8 or 15 feet of tubing, respectively. For some tests which might require only limited pressure data, and model size or internal space is not a problem, transducers can be placed inside the test model.

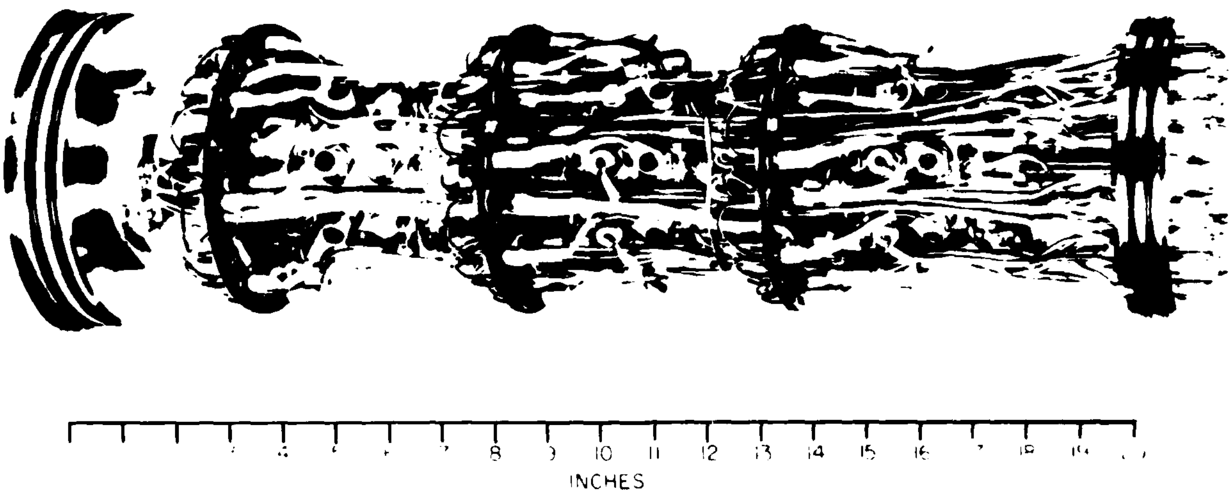

FIGURE 14. PRESSURE TRANSDUCER CONTAINER

TEMPERATURE AND HEAT TRANSFER MEASUREMENTS

Heat transfer rates are normally determined from transient temperature measurements. The model is first lowered into a semi-closed shell where it can be pre-cooled down to -320°F and then injected into the test jet. Except in special cases, the temperature measurements are made with thermocouples. The tunnel is equipped with a thermocouple reference unit (150°F) allowing simultaneous monitoring of 128 thermocouples which may be of chromel/alumel or tungsten/tungsten-rhenium type. A second reference unit for 78 thermocouples of chromel/alumel, chromel/constantan, or platinum/platiunum-rhodium is also available. When instrumenting a model, the thermocouple wires should be at least 18 feet long.

ABLATION STUDIES AND REENTRY REYNOLDS NUMBER SIMULATION

Ablation testing using Low Temperature Ablation (LTA) materials can be accomplished in the Hypersonic Tunnel due to its high temperature capability. Past applications have included studies of reentry body nosetip ablation characteristics,[3,4] investigations of heatshield outgassing effects, and sensor window ablation tests.[5] This tunnel is particularly well suited for reentry body nosetip ablation testing because of the large range in Reynolds number at Mach 5 (up to 50 million per foot). This allows the LTA nosetips to see fully laminar, transitional, and fully turbulent flow environments in one test run by varying the tunnel supply pressure (and therefore Reynolds number) at closely controlled rates. This variable Reynolds number technique, when used in conjunction with boundary layer transition modeling parameters, allows for simulation of reentry trajectories in the wind tunnel. An example of a shape change pattern at a transitional Reynolds number is shown in Figure 15. The maximum supply pressure "ramping" rate is 75 psi per second. Simultaneous variations in model pitch and roll angles are also possible. This variable Reynolds number capability is applicable to other types of testing in the tunnel as well.

FIGURE 15. SHAPE CHANGE PATTERN OF A LOW TEMPERATURE ABLATOR NOSETIP

DYNAMIC MEASUREMENTS

Dynamic testing of models is possible in the Hypersonic Tunnel using a three-degree-of-freedom gas bearing model support system.[6] This type of testing permits the measurement of time-dependent aerodynamic loads. The support allows restricted angular motion in the pitch and yaw planes of ±7 degrees and unrestricted motion in roll. Currently, a spherical bearing with a 75-pound capacity in both the axial and transverse directions is available at NSWC. A schematic of the spherical bearing is shown in Figure 16. Because the model must be dynamically balanced for proper angular response, there should be provisions designed into the model for ensuring that its center of mass is at the point of rotation. The spherical bearing is instrumented with a photo-optical readout system which measures the pitch and yaw angles every 0.5 degree with an accuracy of ±0.05 degree. Model roll angle is measured every 22.5 degrees. A total of 5 data channels are utilized; two for pitch, two for yaw, and one for roll. The analog data signals are recorded on magnetic tape and then digitized. The digitized signal, together with a "readout algorithm" and calibration, provides the angular record in degrees versus time. The spherical bearing also has additional mechanisms for inducing spin, and pitch and yaw oscillations. Cylindrical air bearing support systems have also been used in the past for roll-damping studies.

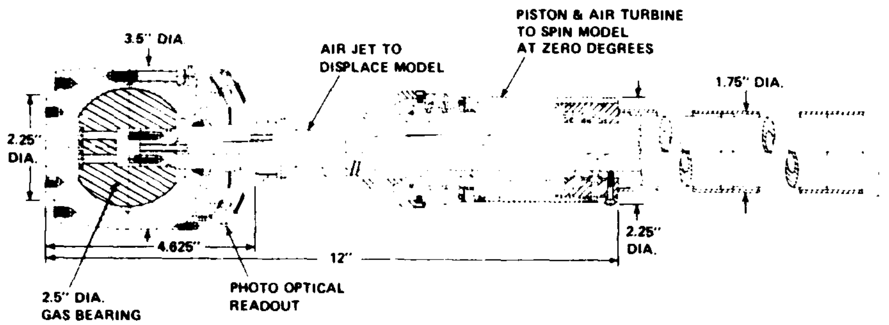

FIGURE 16. THREE-DEGREE-OF-FREEDOM GAS BEARING

This technique for making dynamic measurements is complex, and it is suggested that potential users contact NSWC well in advance for development of a test plan.

FREE-FLIGHT AND FREE-FALL STUDIES

Testing has been conducted in the Hypersonic Tunnel using free-flight techniques for drag and dynamic stability studies, and free-fall techniques for base pressure measurements. These methods are useful because the data are free from interference effects caused by the use of a model support system. The motion of the free-flight model is recorded using high-speed photography in conjunction with the tunnel Schlieren flow visualization system. At hypersonic Mach numbers, model length limitations for free-flight tests is approximately 4 inches; while for free-fall tests, it is approximately 12 inches. These test techniques are not routine, and potential users are encouraged to conduct test planning well in advance.

FLOW VISUALIZATION

Flow visualization is accomplished using a "Z" configuration, parallel-light Schlieren system which can observe and photograph density gradients in the flowfield around the test model. This system can be operated in the Schlieren or the Shadowgraph mode. Illumination is provided by a continuous light or a 10 to 15 microsecond flash for "spark" photographs. Other "spark" sources of longer duration and strobe lights of various frequencies are also available. Flowfields can be photographed using a 70 mm still camera, 4 x 5 inch Polaroids, up to 11 x 14 inch film sheets, pulse-type cameras, movie cameras with framing rates of up to 20,000 frames per second, or a combination of the above. In addition, a special mount and prisms have been provided for closed circuit television which is used for control room monitoring. Special optical requirements such as off-axis viewing and multiple exposure coverage can also be arranged.

DATA RECORDING SYSTEM

Normally, the test data are digitized and recorded on tape using the DARE V analog-to-digital recording system. For special types of tests, e.g., tests involving very high frequency data, analog-type tape recorders are also available. The DARE V system can record up to 128 analog data channels. Full-scale input voltages may range from 2.5 millivolts to 5 volts. The analog data inputs are first connected to the input patch panel located near the test cabin. From there, the inputs are channeled to a low-level multiplexer which distributes these to 16 amplifiers. Amplifier outputs go to a high-level multiplexer and analog-to-digital converter, and then to the computer core memory. Normally, the data are transferred from the core memory to magnetic tape by the operator at the local teletype console. The operator may also transfer the data to the line printer, or to a "quick look" mini-computer for data review and plotting. Direct on-line plotters are available for selected channels. The computer memory capacity is 24,576 words. Within this capacity, the maximum recording time is determined by the number of data channels and the selected sample rate. It may be computed as (24,576)/(Block Size x Sampling Rate). The "Block Size" here is determined by multiplying 20 amplifier channels (16 data amplifiers plus 4 service channels) by the number of scans (maximum of 8). For example, assuming 128 data inputs and a sampling rate of 10 per second, the maximum recording time is 15.36 seconds.

GENERAL INFORMATION

The NSWC Hypersonic Tunnel is located at the White Oak Laboratory, Silver Spring, Maryland. It is within approximately 30 minutes driving time from either Baltimore-Washington International or Washington National airports and approximately 45 minutes from Dulles International airport (Figure 17).

The tunnel is normally operated five days a week from 0730 to 1600. Machine shops are available for model modifications during a test program or for complete model-instrumentation assemblies. Design and engineering support are also available. Whether the models are designed by the contractor or by the Laboratory, an early conference is suggested to ensure adequate integration of tunnel and instrumentation capabilities with program requirements.

Charges are based on test requirements and tunnel occupancy time. A fixed-cost price quotation is made once a test plan is finalized and negotiated. Preliminary estimates may be provided early in the planning stages for budgeting purposes.

Additonal information may be obtained by contacting the AERODYNAMICS BRANCH, K24, at (202)394-1669, Autovon 290-1669, or by writing to:

Naval Surface Weapons Center
White Oak Laboratory
Aerodynamics Branch
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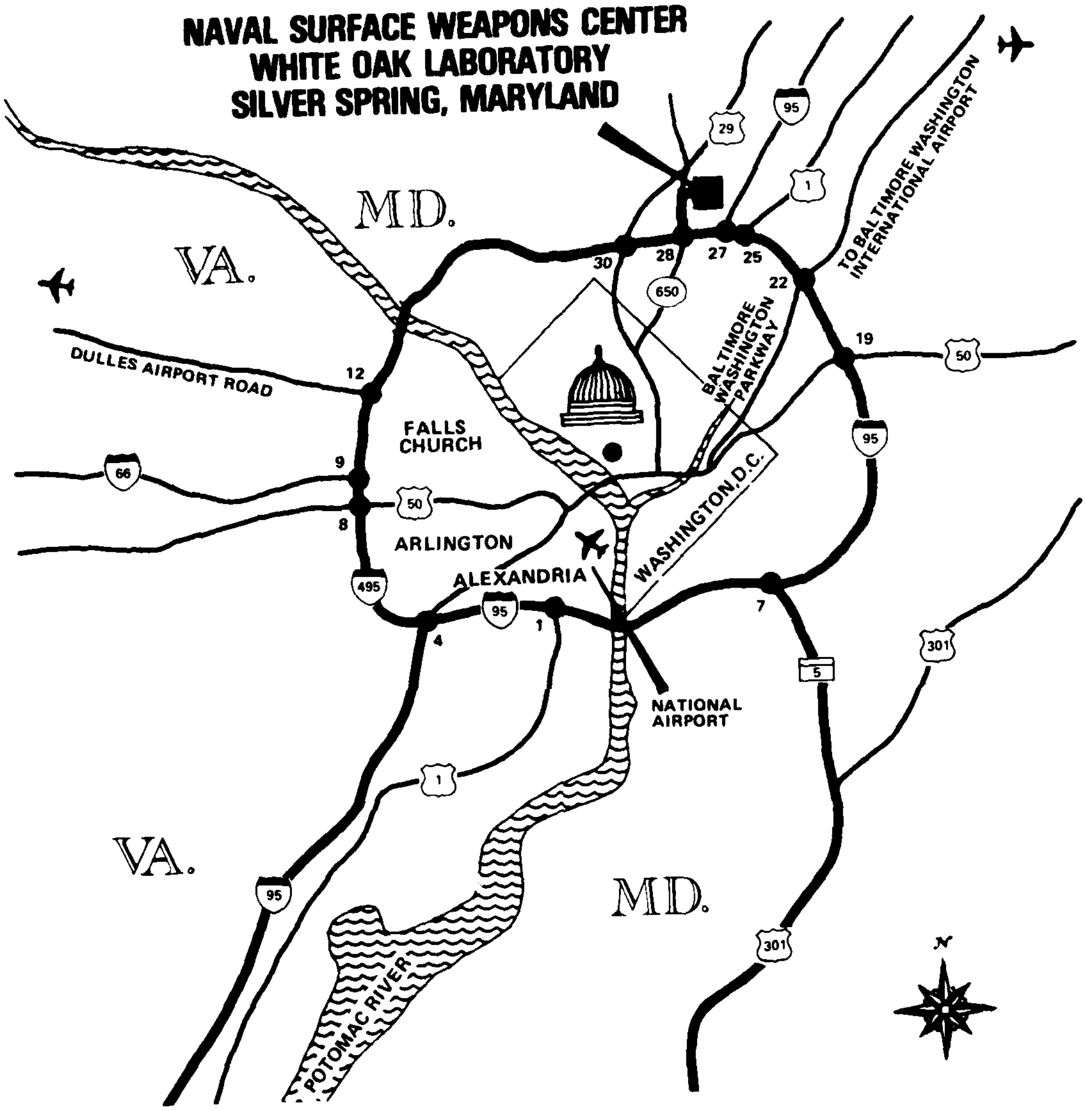

FIGURE 17. WASHINGTON, D.C. AREA MAP

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