HIGH SPEED WIND TUNNEL FACILITY HANDBOOK

FORCE AND MOMENT • INLET • JET INTERACTION • CAPTIVE TRAJECTORY • IR THERMOGRAPHY

AFFORDABLE TEST PLANNING • INNOVATIVE MODEL DESIGN • PRECISE FABRICATION • FLAWLESS TEST EXECUTION • EXCEPTIONAL DATA QUALITY

LOCKHEED MARTIN

Contents

Table of Figures

1 Introduction

This handbook aims to provide customers of the Lockheed Martin Missile Fire and Control (MFC) High Speed Wind Tunnel (HSWT) with information necessary for planning, scheduling and model design in support of testing efforts. The HSWT facility can accommodate a wide variety of high-speed tests including aerodynamic force measurements, flutter, store separation, inlet performance evaluation, jet engine base-flow simulation and dynamic stability. Detailed descriptions of the wind tunnel circuit capabilities, data acquisition and processing capabilities, model support system, special test systems and techniques and model design considerations are provided in this handbook. Information for planning and scheduling testing is also included.

The services of the high-speed wind tunnel are available to the commercial aerospace industry, educational institutions, military and other government agencies requiring controlled high speed (nominally M = 0.2 to 5.0) wind tunnel testing conditions. The facility is physically located at 9301 Skyline Road in Dallas, Texas, and it is within a 30-minute drive of the Dallas/Fort Worth International Airport.

As a military contractor, government-approved policies and procedures are in place for protecting proprietary and classified information. Wind tunnel customer data is handled with the utmost security. Tunnel access during a test is controlled in accordance with the customer's instructions. A well-equipped model setup room is provided to the customer for pretest and post-test support. Experienced personnel are available for model assembly and checkout.

A fixed-price rental rate is charged for tunnel occupancy time. The rental rate includes all labor, indirect costs and data processing. The occupancy charge policy is presented in more detail in Section 2.0

An on-site Test Systems Design Group is available for support during testing and can be separately contracted for any of the following services:

- Calibrations of Balances and Transducers
- Strain Gage Installation
- Force Measurement Consulting
- Design and Fabricate Support of Six-Component Internal Strain Gage Force Balances, with or without Flow-through Capability
- Design and Fabricate Support of Special Purpose Balances
- Calibration Equipment
- Design and Fabricate Support of Complete Models, Components and Modifications
- Design and Fabricate Support of Stings and Support Equipment
- Design and Fabricate Support of Thrust and Test Strands

The HSWT is independently operate by a dedicated staff of highly trained Engineers and Technicians whose responsibilities are focused on the execution of customer test efforts. The Lockheed Martin MFC Aerodynamics Group can be contracted separately to provide any combination of the following services for your test program:

Design Definition	Preliminary Through Final Configuration	Surface Sizing Analysis
Drag Predictions	Trade Studies	Air load Predictions
Model Design Support	Model Requirements	Design oversight
Empirical	Analytical	CFD
Test Support	Planning	Conduct

The services of all groups are available, and information concerning capabilities may be obtained by contacting the manager or facilities engineer of the High Speed Wind Tunnel.

We invite potential customers to visit our HSWT facility. Further information related to visits, testing scheduling or rental rates is available through either of the following:

Manager, High Speed Wind Tunnel (972) 603-2751

Test Systems Design (972) 603-0545

Security / Sub-Contracts (972) 603-3234

Mailing Address:

Lockheed Martin Missiles and Fire Control

P.O. Box 650003, MS LJS-05

Dallas, Texas 75265-0003

2 High Speed Wind Tunnel Facility Overview

The High Speed Wind Tunnel is a blowdown-to-atmosphere, tri-sonic, adjustable-Mach-number facility. The general arrangement of the facility is shown in an aerial photograph in Figure 2-1. A schematic drawing indicating wind tunnel circuit layout is provided as Figure 2-2.

Figure 2-1 High Speed Wind Tunnel General Arrangement

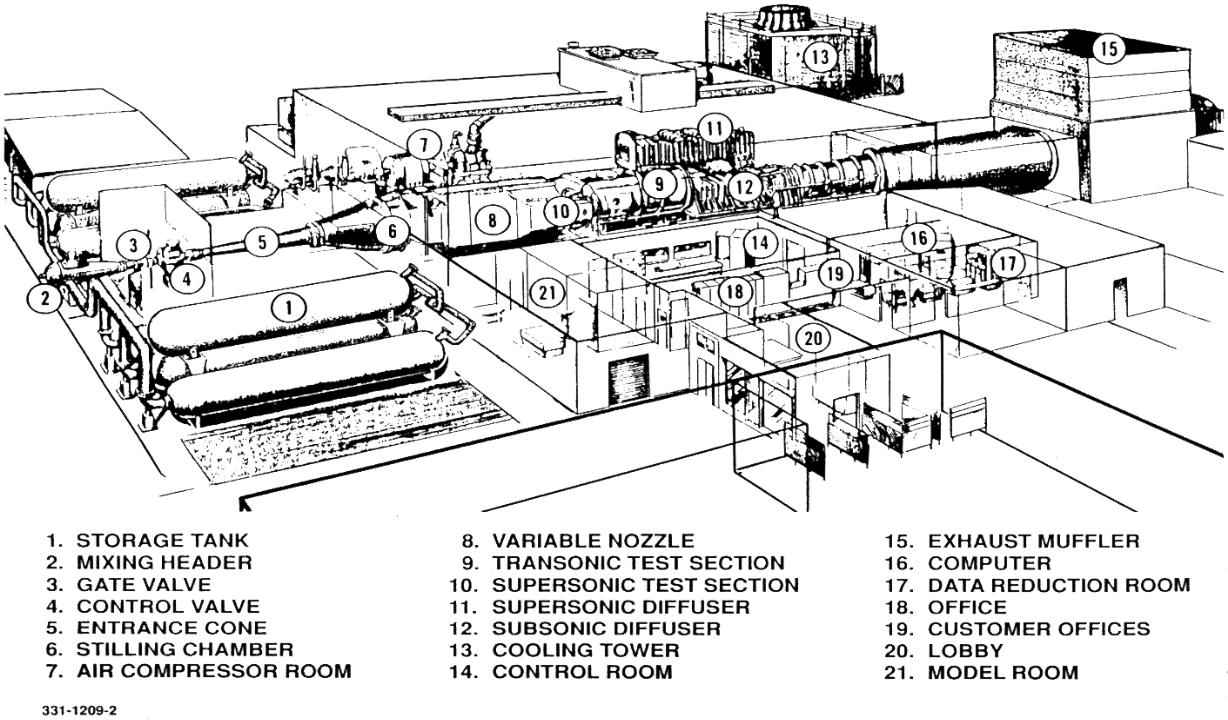


Figure 2-2 High Speed Wind Tunnel Circuit Layout (Old Layout)

Table 2-1 High Speed Wind Tunnel Operating Parameters and Descriptive Details

Type of Tunnel	**Blowdown-To-Atmosphere**
Air Storage Capacity	40,0000 Cubic Feet
Maximum Storage Pressure	520 psia
Air Compression Rate	7 to 26 lb/sec
Nominal Tank Temperature	100°F
Temperature Change During Run	10° to 20°F Nominal
Run Time	15 to 110 Seconds
Nominal Supply Air Dew Point	0°F at 100 psia
Nozzle	Flexible Plate (38 ft long)
No. of Nozzle Adjustable Jacks	28 Upper, 28 Lower
Test Section Size (Transonic)	4X4X6 Feet
Test Section Size (Supersonic)	4X4X5 Feet
Mach Number Range	0.2 - 5.0
Transonic Section Range	0.2 - 1.8
Supersonic Section Range	1.6 - 5.0
Reynolds number Range	4 - 34 Million per Foot
Equivalent Airspeed	145 - 1,200 kt
Transonic Section Porosity	22.5 % (Normal-to-Surface Holes)
Model Cart Range (Straight Sting)	-12° to +22°
Model Cart Range (8° Offset Roll Sting)	-4° to +30°
Model Cart range (High Alpha Roll Sting)	30° to +60°, 60° to +90°
Number Data Channels	64 Analog, 256 Pressure
Data Acquisition System	Digital Data Processor
Maximum Voltage	+/- 10 VDC
Input Signal Range Per Channel for Maximum Output	2.5 to 10,000 Millivolts
Digital Data Sampling Rate	50 Hz Simultaneous
Data Availability	5 Minutes After Run

2.1 Facility Description

The wind tunnel facility is divided into eight areas:

- Offices
- Model Machine Shop
- Control Room
- Data Reduction and Processing Area
- Instrumentation Assembly and Repair Area
- Instrumentation Calibration Area
- High-bay Area
- Compressor Building

Office Space for wind tunnel customers is located adjacent to the wind tunnel circuit and is equipped with personal computer connections as shown in Figure 2-3. Customers may bring laptops or personal computers provided arrangements are made in advance. Separate office areas are maintained for data reduction/computer operations and test operations. Print and copy capabilities, wireless networking and secure file storage capabilities are conveniently located within the facility. All offices, shops and the high-bay area are environmentally controlled.

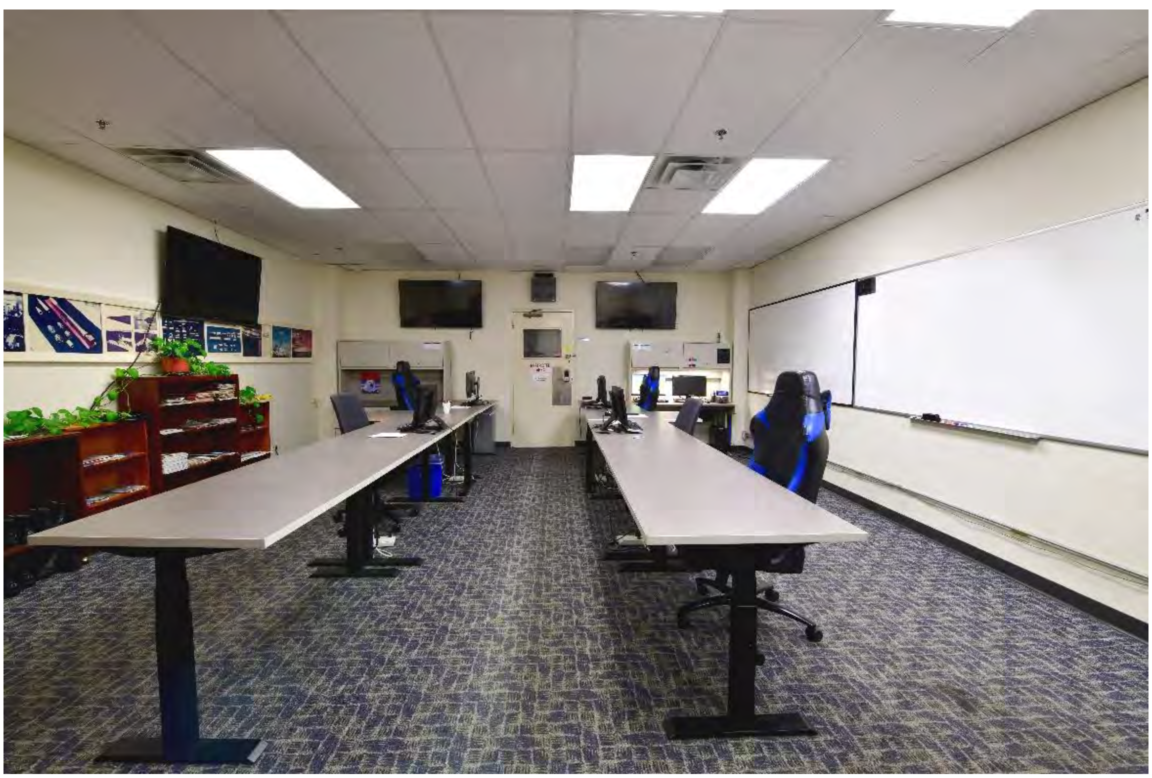


Figure 2-3 Customer Area

The machine shop is located west of the office areas, and it contains machine and hand tools for model repairs and parts fabrication. The machine shop consists of CNC and conventional lathes and mills along with a model setup area as shown in Figure 2-4.

Figure 2-4 Machine Shop

The control room, which provides instrumentation and controls for operation of the wind tunnel and certain remotely controlled model parameters. Data signal amplifiers, electronic pressure scanners and a 64-channel high speed digital data system are located here as well. The control room is shown in Figure 2-5.

Figure 2-5 Control Room

The data reduction area is located adjacent to the control room. This area contains the data acquisition server, the data reduction computer and is where the final data package is generated. Data reduction and processing capabilities are described in more detail in section 4 of this handbook.

An instrumentation assembly and repair room is also situated adjacent to the control room. This instrumentation room is well equipped to service electrical and electronic devices such as thermocouples, strain gauges and small circuits.

High quality digital cameras are available for immediate photo coverage at the wind tunnel site. All runs are recorded on HD video recording equipment. High speed video coverage and Infrared Thermal Imaging are also available upon request. Protection of customer proprietary data, photographs and videos is ensured for all tests.

The high bay area, shown in Figure 2-6, houses parts of the wind tunnel circuit downstream of the entrance diffuser. Two 40-ton overhead cranes can traverse the length of the high bay area for maintenance and interchange of heavy equipment.

Figure 2-6 High Bay

The compressor building shown in Figure 2-7, was built in 2018 and is located on the south side of the HSWT complex adjacent to the administration building. The three compressors were designed in parallel to allow them to be run one, two or all three at a time.

Figure 2-7 Compressor Room

2.2 Occupancy Charge Policy

Test efforts vary widely and the HSWT staff begin coordination of efforts with our customers four months or more in advance to ensure costs and charging policy during testing is clear prior to test start. The information provided here is intended to provide the reader with a general understanding of some test charging factors. Section 9 covers the test planning and scheduling process which is intended to provide the customer with a detailed estimate of expected occupancy hours required based on their testing needs defined in the customer provided Request for Quote. Tunnel occupancy time is charged for model installation, tank recharging after a valid run, test section changes, Mach number changes, model and/or instrumentation changes during the test, non-standard data acquisition requirements and model removal. Most model changes can be accomplished during the tank recharging time, thus avoiding additional charges during air-on testing. Occupancy time charge limits are normally imposed for model installation, test section changes and model removals. Installation charges are based on system complexity and typically range from four to 12 occupancy hours. The installation charges are agreed to by the customer and the assigned HSWT representative prior to the test.

Occupancy charges for the HSWT are calculated based on actual tunnel time used. Testing times are determined based on the Certificate of Service, which is maintained by the assigned test engineer. The test engineer is responsible for recording test operations on a daily basis for each individual testing period. The customer representative reviews the certificate and verifies the entries with his signature. Daily occupancy charges begin at the start of the first valid run. In the event of a void run due to company equipment failure or personnel error, time charges are ceased until the next valid run. An estimated pump-up time is charged after the final run of the day based on known pump rates.

Occupancy is not charged when the tunnel is unavailable for customer testing due to maintenance of equipment, or due to delays and check runs requested by HSWT personnel. Repeat runs requested by the customer or model repair time is chargeable. Uncharged time is itemized, and the reason is entered in the certificate of service.

2.3 Security

Lockheed Martin MFC facility is approved by DCSA for handling of materials and data at a range of classification levels. Further details as it relates to a customer's specific testing needs can be coordinated upon request. The High Speed Wind Tunnel (HSWT) is located separate from the primary Lockheed Martin MFC Dallas campus and completely enclosed within perimeter fencing to fully control access and maintains a separate facility clearance granted by DCSA. During classified and customer proprietary testing, external access is strictly controlled at a gated entry point. A Restricted Area is established inside the building. Access to the Restricted Area is granted by a written access list controlled by HSWT designated personnel. The access list is approved prior to posting by both the customer and the designated HSWT representative to verify persons with a need to know and proper clearance. Clearances are verified by the Lockheed Martin MFC security department through the Defense Information Security System (DISS) prior to any access to classified material. Clearance levels for all HSWT personnel can be vetted and verified though appropriate customer and DCSA security channels.

2.4 Additional Facilities and Services

The facility has a fully operational machine shop on sight consisting of lathes, mills, drill presses, grinders and is available to repair or modify existing models. The facility can provide a machinist to the customer for immediate repairs or model changes at no additional charge in most cases. In addition, the Test Systems Design group is available for any model design changes or consultations that may be desired at an additional charge.

Design and fabrication of both wind tunnel models and test support equipment can be provided on a suitable contractual basis either in conjunction with testing at the HSWT or in support of testing at other facilities.

2.5 Wind Tunnel Operating Capabilities

In order to properly prepare for testing activities, the remaining sections of this handbook provide technical information addressing key wind tunnel operating capabilities. These capabilities and discussions include:

- Wind Tunnel Circuit
- Data Acquisition and Processing
- Model Support System
- Special Test Systems and Techniques

Subsequent sections address specific considerations associated with model design, preparation, test planning and scheduling.

3 Wind Tunnel Circuit Capabilities

A description of the High Speed Wind Tunnel circuit is provided to introduce potential customers to its capabilities and operating parameters. A summary of the wind tunnel's operating parameters and descriptive details is in included in Table 2-1.

3.1 Compression and Storage

In 2018, a new compressor building was added to the HSWT campus and supplies compressed air to the storage tanks. There are three compressor trains working in parallel to deliver 18,000 SCFM of air to the storage tanks. Each compressor train consists of two three-stage compressors. Air flows through intake filters before passing through the first three-stage compressor with two stages of intercooling, reaching a pressure of 100 psig. The uncooled air passes through a desiccant dryer system that uses the waste heat to assist in regeneration of the dryer before being cooled and dried. The dryers reduce the pressure dew point to -40˚F (-70˚F at 1 ATM). The cool, dry air then passes through another filter before entering the second three-stage compressor (booster). This second compressor, with two intercoolers, achieves a final pressure of 520 psia and 250˚F. This description details one compressor train, with two others able to run in parallel with it. A back-pressure valve admits air to the storage tanks while keeping optimized conditions for the compressors. The compressor system was designed such that a train can be any combination of primary-dryer-booster arrangement thus allowing for flexibility and maximizing operational redundancy.

The compressor system is connected to eight tanks with a storage capacity of 40,000 ft^3. The tanks are pressurized to a maximum pressure of 520 psia. As the compressors reach 520 psia, they will throttle down to not exceed 520 psia and maintain the set pressure. The compressor control system automatically resumes loading the compressors, reaching full output by the end of the blowdown. An alumina pebble bed in each tank absorbs heat during pump up and dissipates heat during discharge to maintain a near-constant supply temperature, nominally 100° F.

The time required to recharge the air storage tanks following a run varies from 15 to 75 minutes, depending n the final tank pressure. A nominal tank pressure increase rate is seven and a half pounds per square inch (psi) per minute when operating all three compressor trains in parallel.

3.2 Flow Control

Airflow through the wind tunnel is controlled by three valves between the storage tanks and test section. A pneumatically actuated safety valve located in the mixing header is preset to close automatically if the stilling chamber pressure exceeds a preset level. Two axial plug valves isolate and control the airflow through the tunnel circuit with minimal disturbance. Both valves are actuated hydraulicly with a spring return to automatically close in the event of hydraulic or power failure, maximizing safety to the wind tunnel, models and personnel. The isolation valve is a simple on/off control and is opened immediately before a blowdown. The control valve is a similar design but includes internal flow conditioning to allow for variable flow control. The control valve is actuated with a servo control system that is commanded to maintain the pressure in the stagnation chamber, which can be a constant or computer-controlled variable depending on test requirements.

Downstream of the control valves are the entrance diffuser and stilling chamber. The entrance diffuser reduces the air velocity from the supersonic control valve exit to low subsonic at the stilling chamber entrance. Flow control devices inside the entrance diffuser are designed to produce uniform flow at the stilling chamber entrance and reduce valve noise.

Turbulence screens and a honeycomb sound attenuation structure are located in the stilling chamber. Large vortices are broken down by these devices into uniform, low-intensity, isotropic turbulent eddies. Stagnation pressure and temperature are measured downstream of these devices.

3.3 Variable Contour Nozzle

The variable contour nozzle consists of two steel plates that are 48 inches wide and 453 inches long with a thickness of 0.75 inch. They are contoured to produce a uniform test section flow using 28 nozzle jacks on each plate spaced at 10-to-18-inch intervals. During nozzle changes, the plates are hydraulically extended to permit positioning of the threaded nozzle jacks. After the nozzle jacks are properly set, the plates are retracted against the nozzle jack stops. Microswitches on the stops indicate plate contact. Strain indicators at each jack position protect the nozzle plate from excessive stresses.

During each run, the hydraulic cylinders are charged with high pressure to hold each plate support rigidly against the nozzle jack stops. Nominal Mach number changes can be completed in approximately 15 minutes.

3.4 Test Sections and Diffusers

Because of the different operational requirements for the transonic and supersonic testing, two test sections are available. The Mach number ranges for each test section overlap somewhat, although the supersonic test section is recommended for Mach numbers of 1.8 or higher.

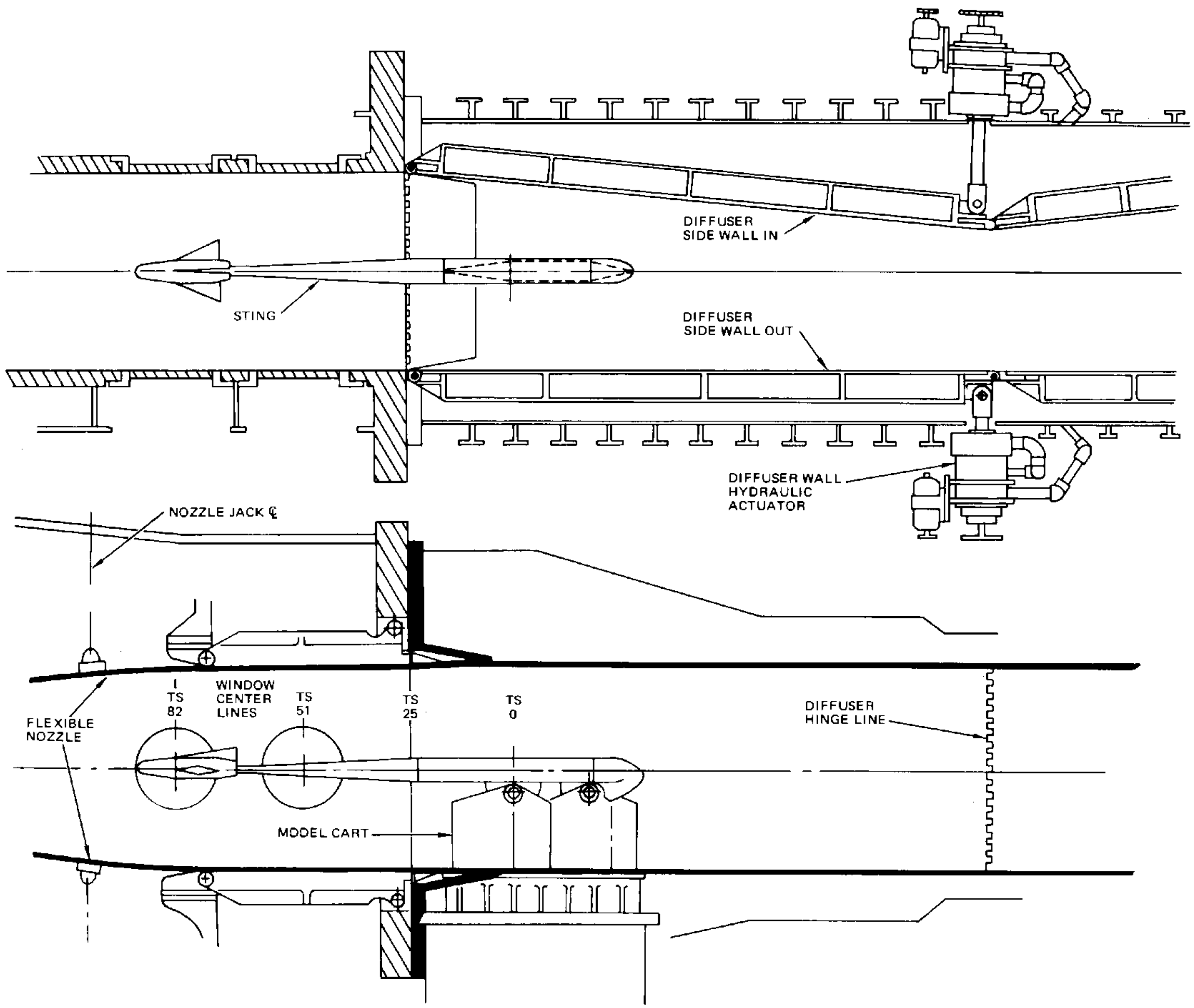


Figure 3-1 Supersonic Test Section with Diffuser in Place

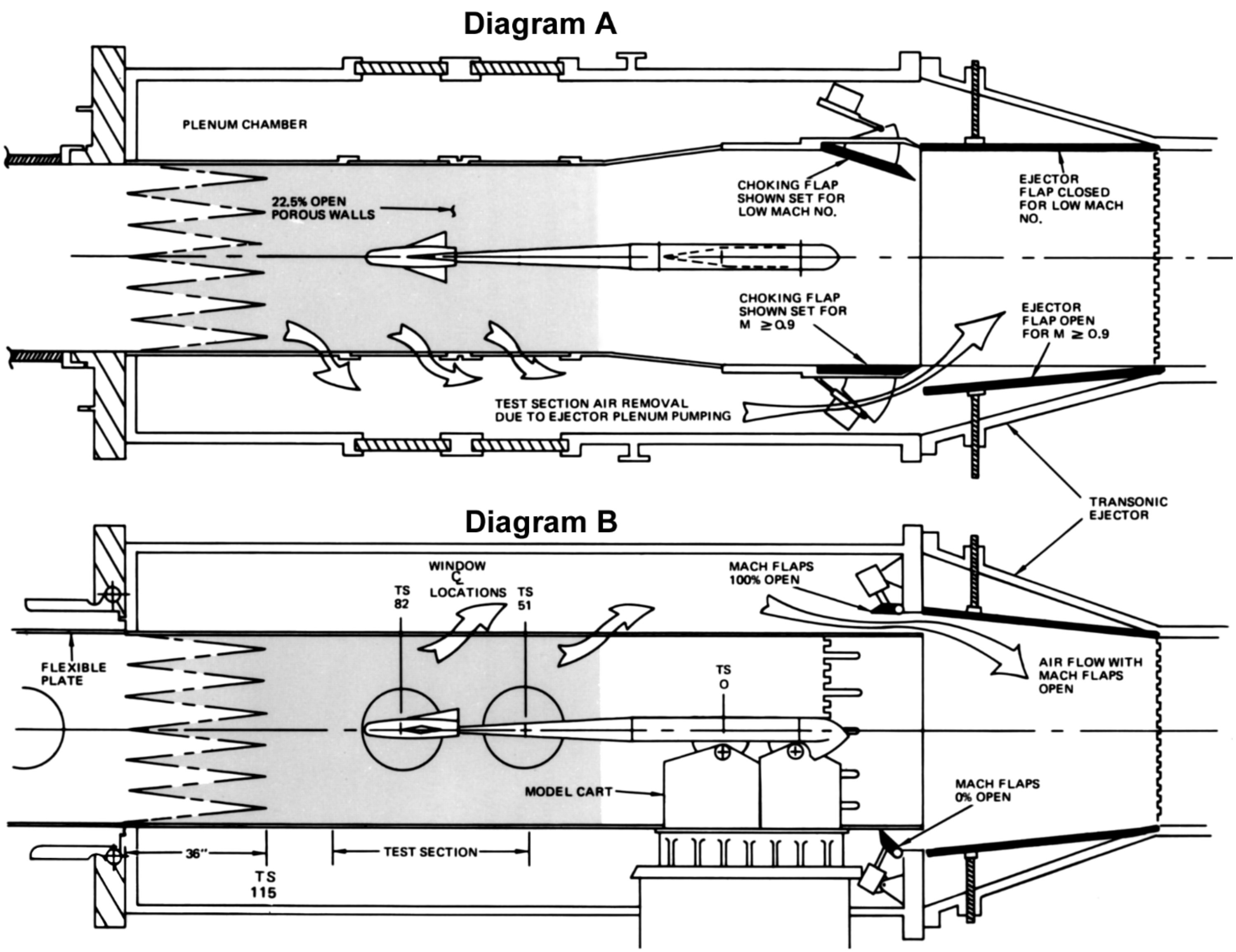


Figure 3-2 Transonic Test Section and Ejector

3.4.1 Supersonic Test Section

The four foot by four foot supersonic test section is located in the last five feet of the flexible nozzle. Two optical quality glass windows, 20 inches in diameter and 31 inches between centers, are located on each side of the test section for photographic flow visualization studies. Downstream of the supersonic test section is a symmetric, single-peak, variable geometry diffuser, which permits operation at lower stagnation pressures than is possible with a fixed geometry diffuser. Diffuser geometry is varied within preset mechanical limits with hydraulically positioned walls. Cross-sectional diffuser area at the single peak is varied from that required for starting to the minimum required for sustained operations. Figure 3-1 provides cross-sectional diagrams of the supersonic test section and diffuser.

3.4.2 Transonic Test Section

For transonic operation, the supersonic diffuser is removed and the transonic test section and ejector section are set in place. Conversion time from supersonic to transonic configuration is nominally one hour.

Figure 3-2 provides cross-sectional diagrams of the transonic test section and ejector. The transonic test section has normal hole-perforated walls with 22.5 percent porosity. Test section size is nominally four by four by six feet, with floor and ceiling convergence of 25 minutes. Subsonic Mach number control is accomplished with hydraulic, servo-actuated choking flaps downstream of the test section, as illustrated in Diagram A in Figure 3-2.

A control system maintains the preset ratio of static to total pressure during each run by causing small changes in choking area. Above Mach number 0.89, the choking flaps are fully open and Mach control is switched to a set of plenum-chamber bleed-control flaps. These hydraulically actuated, servo-controlled "Mach Flaps" remove test section air through the porous walls by ejection-pumping of the plenum chamber. A maximum Mach number of 1.15 can be attained with a sonic nozzle. To obtain Mach numbers greater than 1.15, nozzle plates are contoured in addition to using plenum pumping. A maximum Mach number of 1.8 is possible in the transonic test section. Continuously variable Mach ramps are possible between Mach 0.3 and 1.15.

As Diagram B in Figure 3-2 illustrates, the model cart is relocated downstream approximately 11 feet into the transonic test section. Test section window locations relative to the model cart are the same for either section.

3.5 Performance and Operational Characteristics

The High Speed Wind Tunnel covers a Mach number range of 0.2 to 5.0 using test sections, as described in the preceding paragraphs. The perforated wall transonic test section operates of the Mach range of 0.2 to 1.8. The supersonic test section and diffuser operates between Mach 1.6 and Mach 5.0.

To provide potential customers with sufficient data for determining the applicability of the HSWT to test requirements and for preliminary test planning, the following are presented:

- Performance parameters
- Mach number and flow angularity calibration data
- Operational characteristics

3.5.1 Performance Parameters

One dimensional, isentropic, compressible flow relations for air (Technical Reference 2 & 3, Appendix A) were used to develop the performance charts presented in Figure 3-3 through Figure 3-10. These charts present wind tunnel parameters for:

- Variation of Reynolds Number for To = 100°F, Transonic Section (Figure 3-3)
- Variation of Reynolds Number for To = 100°F, Supersonic Section (Figure 3-4)
- Static Pressure as a Function of Mach Number (Figure 3-5)
- Dynamic Pressure Variation as a Function of Mach Number, Transonic Section (Figure 3-6)
- Dynamic Pressure Variation as a Function of Mach Number, Supersonic Section (Figure 3-7)
- Test Section Density Variation as a Function of Mach Number (Figure 3-8)
- Maximum Run Time as a Function of Mach Number (Figure 3-9)
- Pressure Altitude Versus Equivalent Air speed (Figure 3-10)

The calculations are based on the assumption of a nominal stagnation temperature of 100˚F. Operational limits shown on each chart are based on theoretical mass flow maximums, stagnation pressure limits and model size considerations.

Figure 3-9 show calculated run time as a function of Mach number and stagnation pressure. The maximum run time is based on an initial pressure of 520 psia and calculated pressure losses during stabilization. This chart can be used as a guide during test planning to match the time required to obtain the desired data within the maximum available run time. Run output can vary significantly (from 1.2 to 5 per hour) as a function of tunnel operating conditions and pitch or roll range and rate. Estimates of occupancy time for a particular program may be obtained by contacting the manager of the High Speed Wind Tunnel.

Figure 3-10 presents pressure altitude versus equivalent airspeed with lines of constant Mach number and stagnation pressure. Operating limits of the wind tunnel are noted above an equivalent altitude of 10,000 feet. A stagnation temperature of 100˚F was assumed and a ARDC model atmosphere was used to obtain pressure altitude equivalence. For convenience, equivalent airspeed is shown in ft/sec.

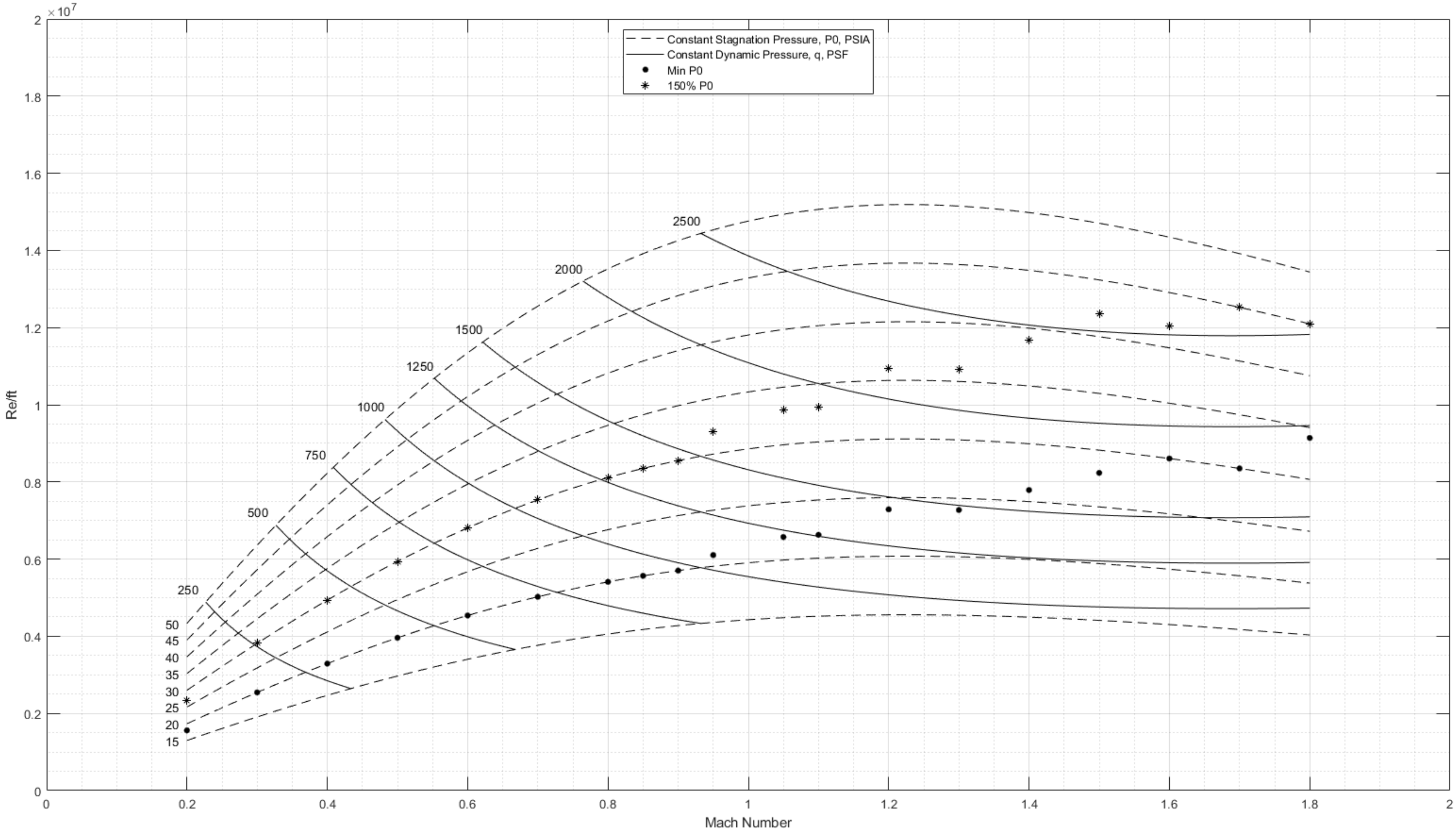


Figure 3-3 Variation of Reynolds Number for T_o = 100°F, Transonic Section

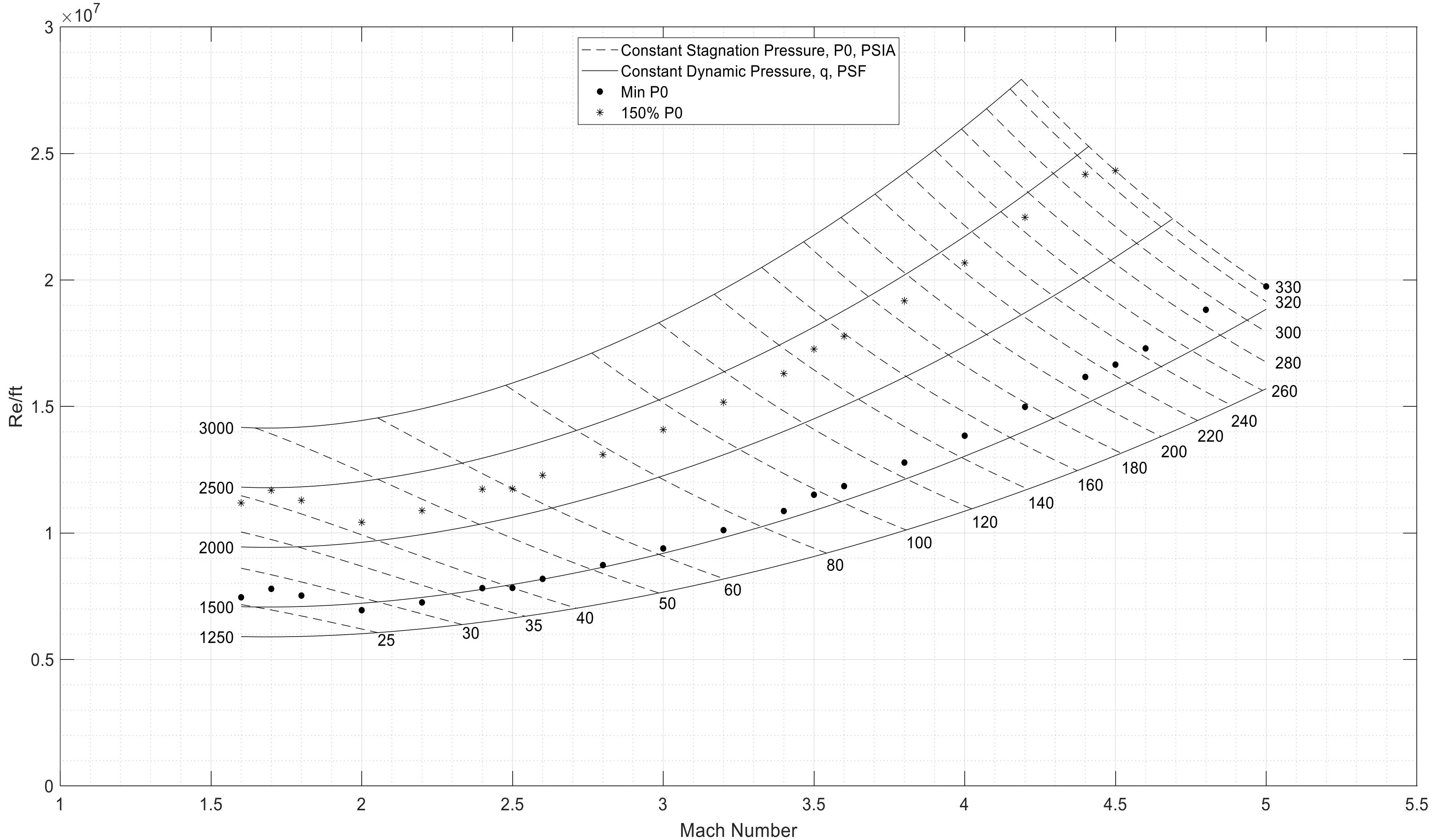


Figure 3-4 Variation of Reynolds Number for T_o = 100°F, Supersonic Section

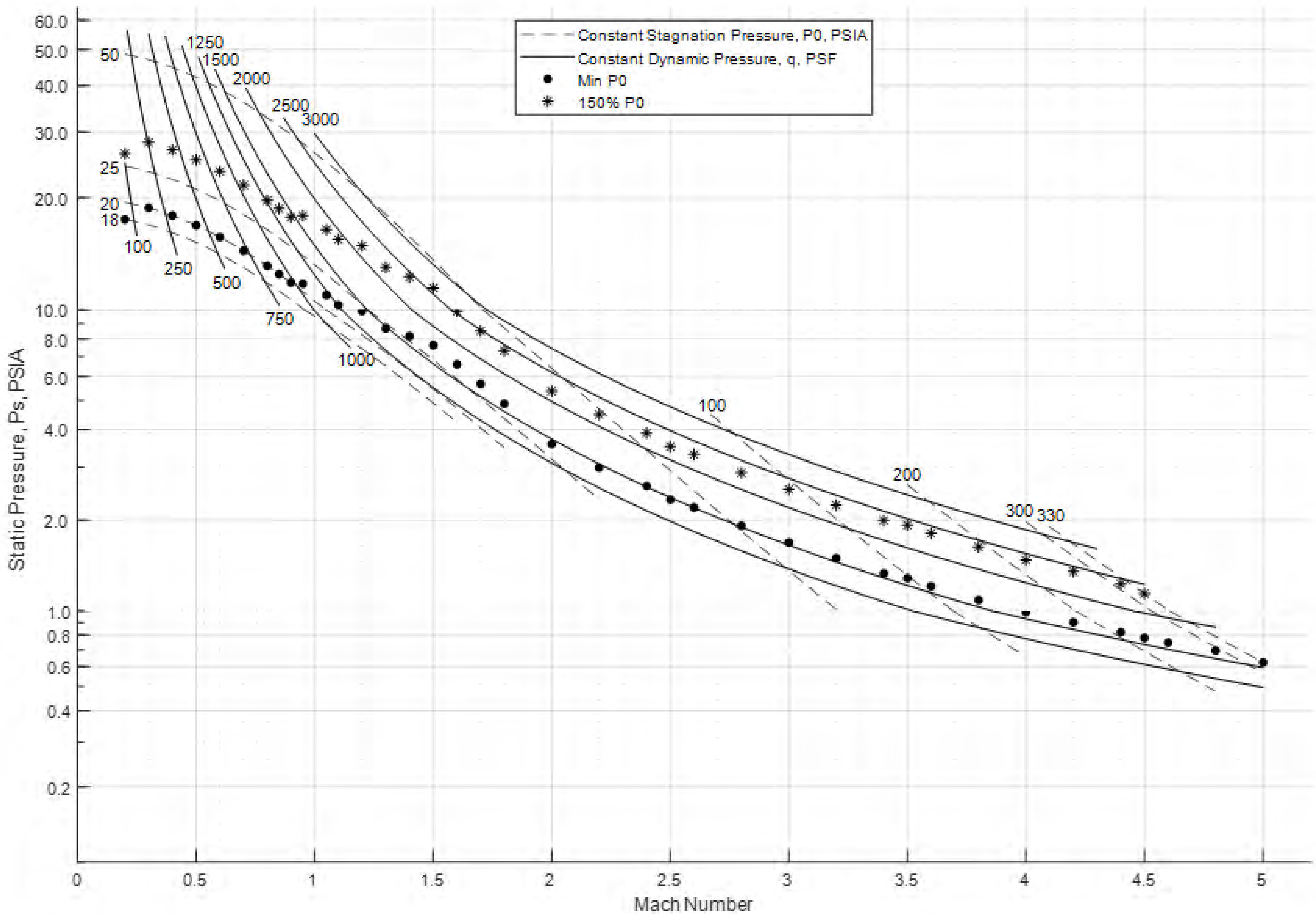


Figure 3-5 Static Pressure as a Function of Mach Number

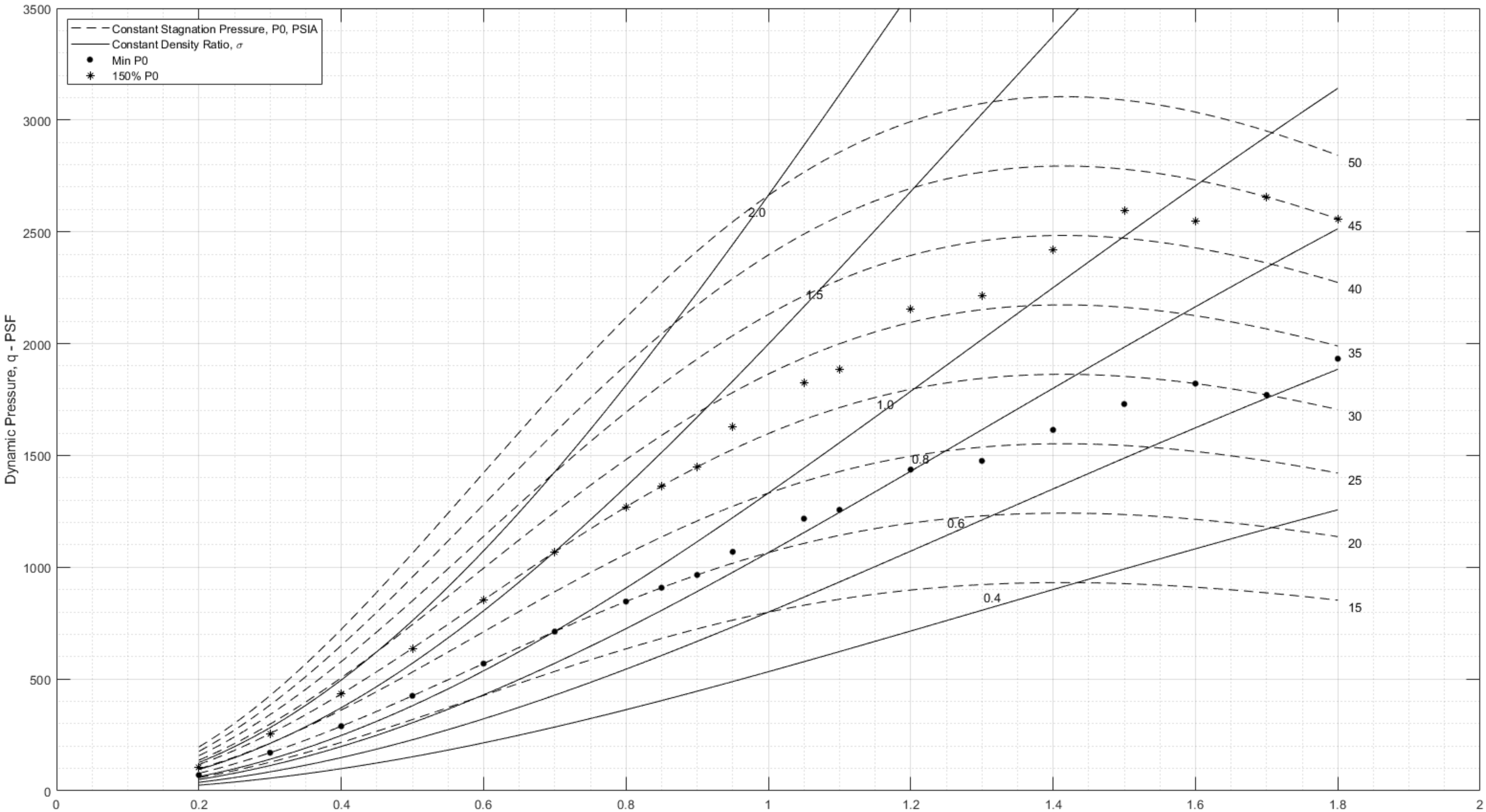


Figure 3-6 Dynamic Pressure Variation as a Function of Mach Number, Transonic Section

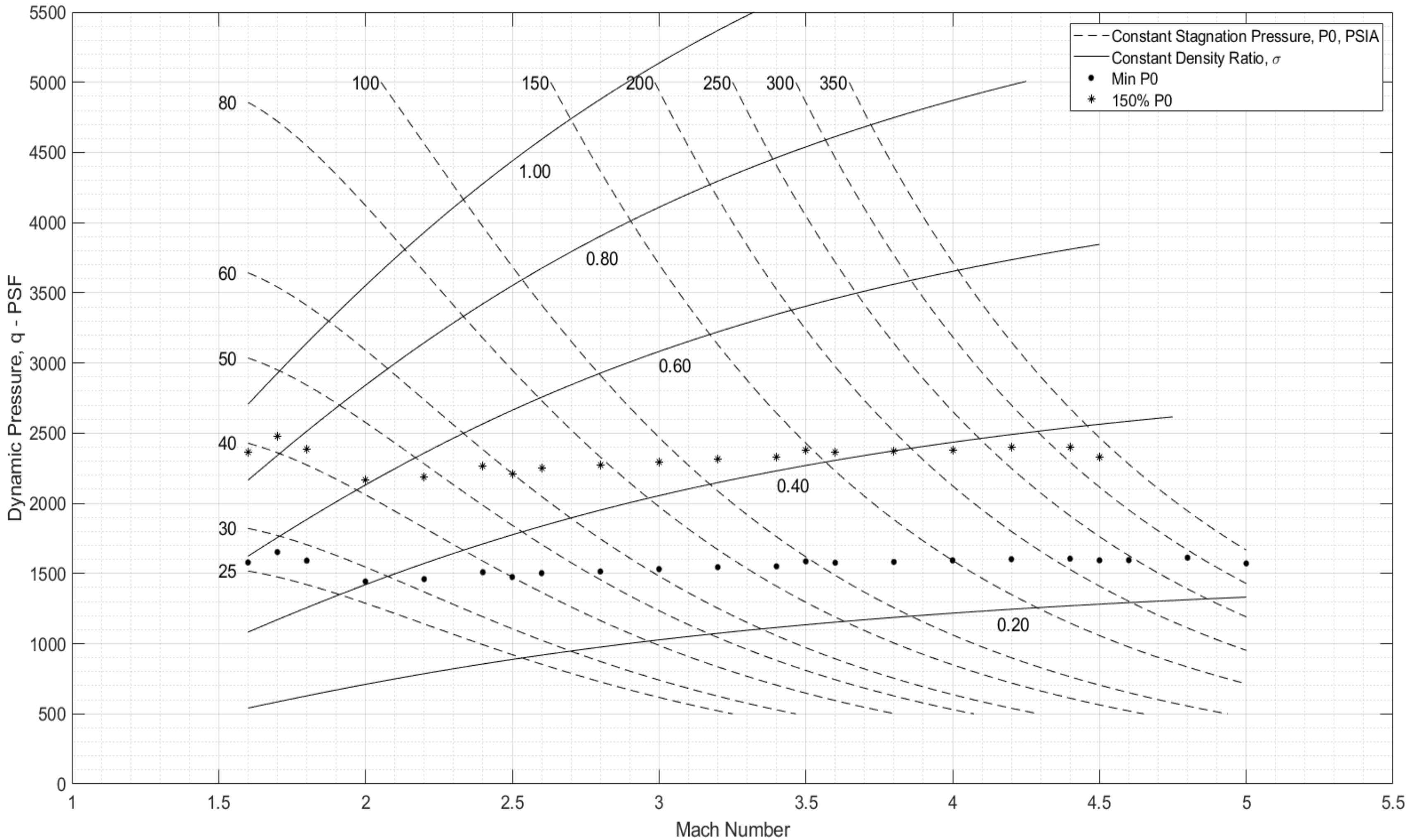


Figure 3-7 Dynamic Pressure Variation as a Function of Mach Number, Supersonic Section

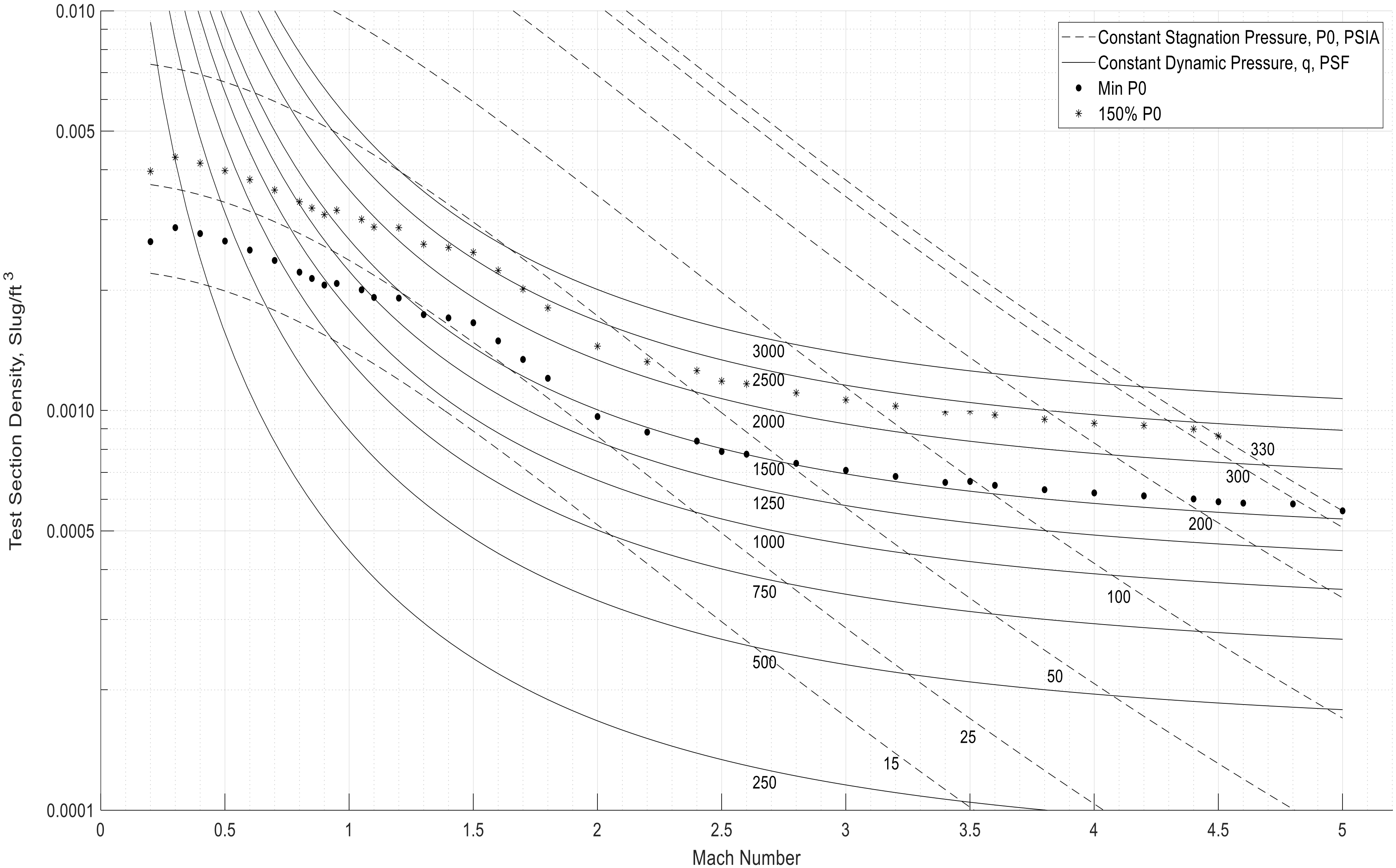


Figure 3-8 Test Section Density Variation as a Function of Mach Number

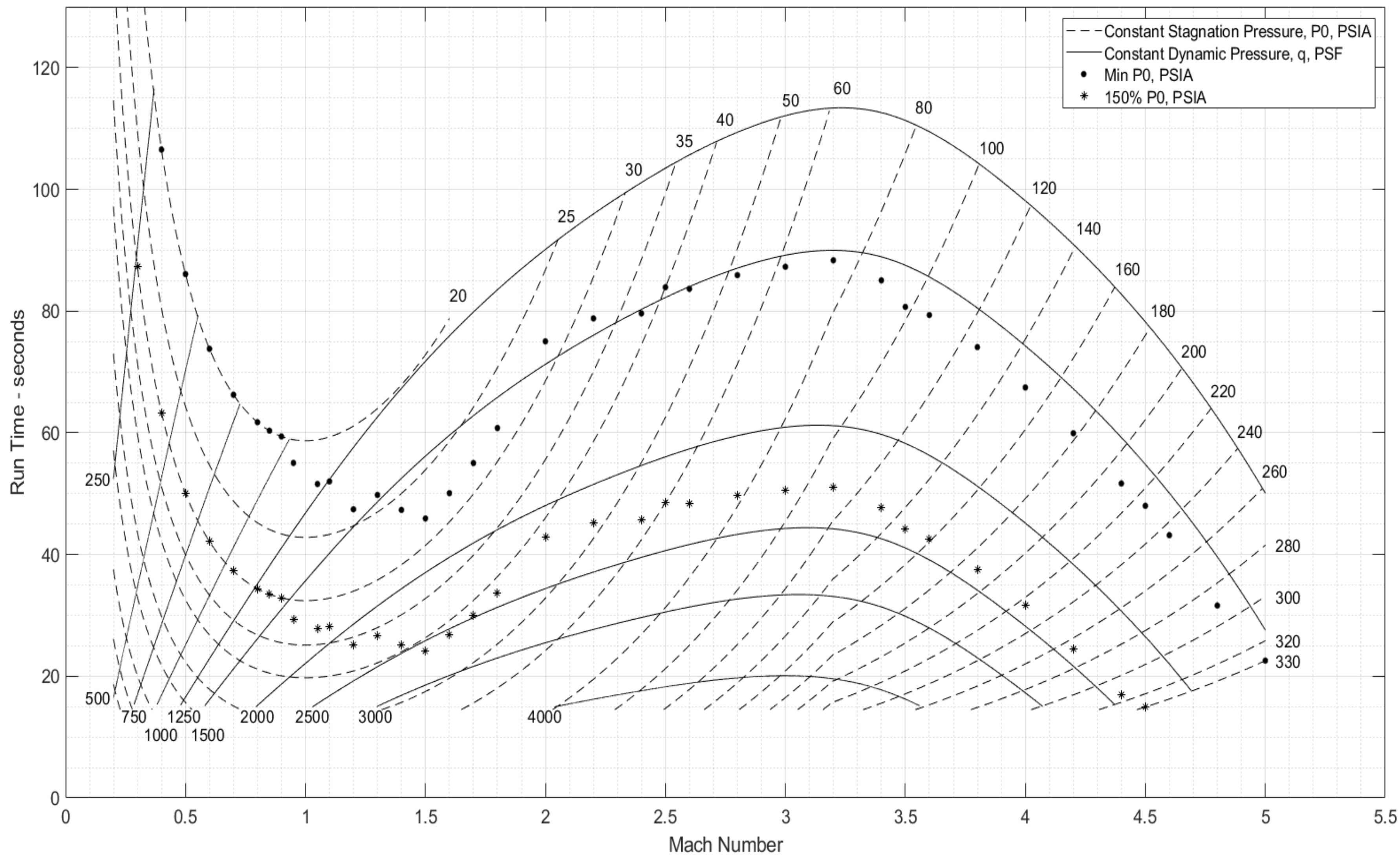


Figure 3-9 Maximum Run Time as a Function of Mach Number

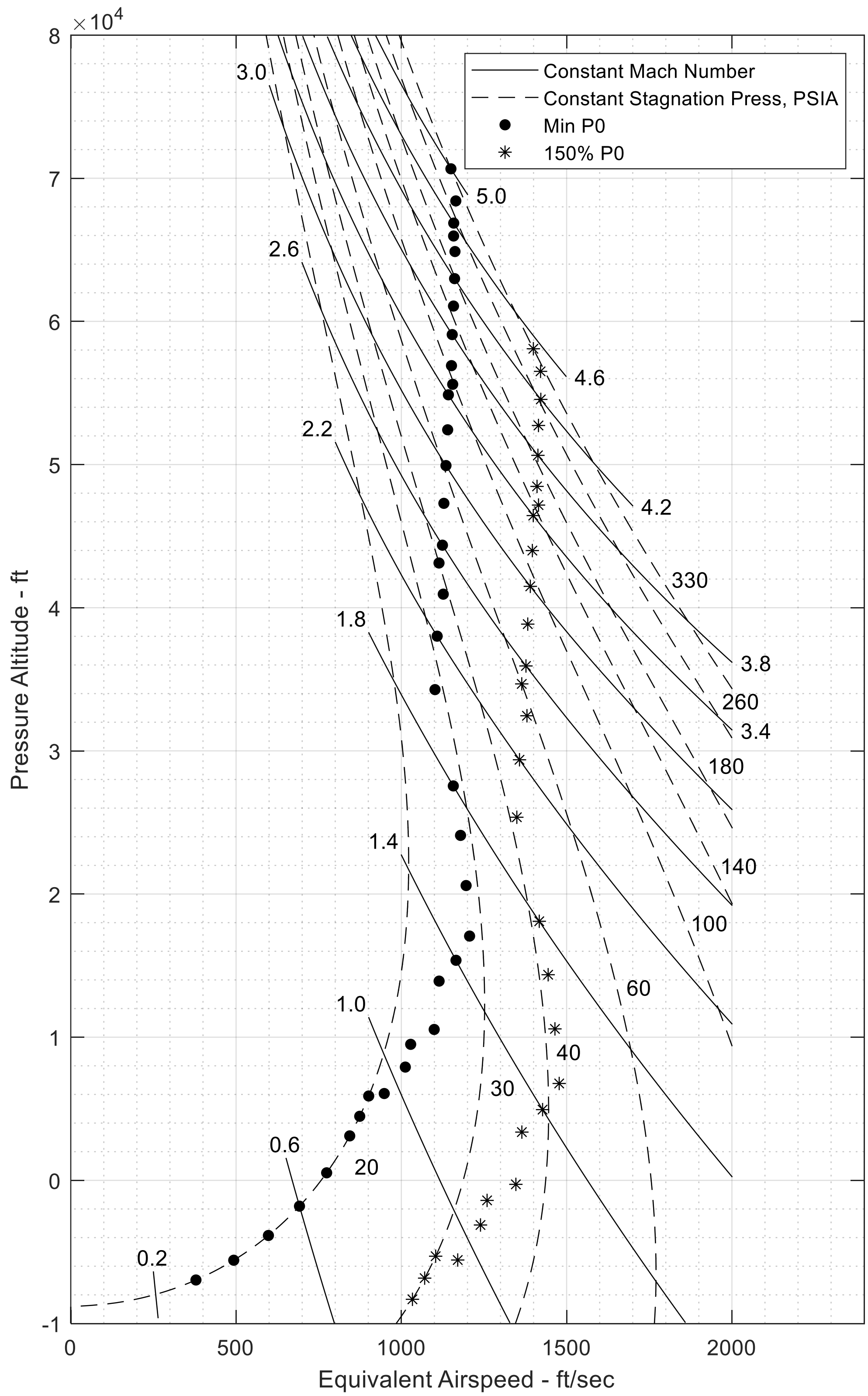


Figure 3-10 Pressure Altitude Versus Equivalent Air speed

LOCKHEED MARTIN

3.5.2 Calibration Data and Operational Characteristics

Mach numbers for the High Speed Wind Tunnel are repeated from time to time as a check on tunnel flow quality. Calibrated supersonic Mach numbers, presented in Table 3-1, were determined from an average pressure distribution in the test section. Table 3-2 presents nominal transonic Mach numbers and appropriate pressure ratios. Transonic Mach numbers are determined from static pressure on the tunnel wall upstream of the model location and stagnation pressure measurements in the stilling chamber.

During a test run, the stagnation pressure and Mach number are normally held constant. Unit Reynolds Number increases slightly due to a 20˚F (approximate) drop in stagnation temperature. The primary variable during a run is model attitude or other remotely controlled test parameter.

Table 3-1 High Speed Wind Tunnel Supersonic Mach Numbers and Mach Functions

CALIBRATED MACH NO.	P_s/P_0	q/P_s	q/P_0	T/T_0	$P_s/P_{0'}$	$P_{0'}/P_0$
1.616	0.229751	1.828019	0.41999	0.656905	0.258386	0.889178
1.712	0.198956	2.051661	0.408191	0.630442	0.233869	0.850719
1.810	0.171398	2.29327	0.393061	0.604149	0.212064	0.808234
2.002	0.127408	2.805603	0.357455	0.555062	0.17697	0.719939
2.203	0.093084	3.397246	0.316228	0.507449	0.148513	0.626771
2.407	0.067656	4.055554	0.274382	0.463235	0.125943	0.537196
2.506	0.057984	4.396025	0.254899	0.443261	0.116758	0.496617
2.603	0.049883	4.742926	0.236592	0.424606	0.10868	0.458992
2.793	0.037244	5.460594	0.203376	0.390599	0.095066	0.391774
2.998	0.027305	6.291603	0.171795	0.357449	0.083018	0.328909
3.209	0.019962	7.208377	0.143894	0.326847	0.072833	0.274082
3.398	0.015168	8.082483	0.122596	0.30218	0.065203	0.232629
3.494	0.013223	8.545625	0.113	0.290562	0.061774	0.214057
3.590	0.011546	9.02167	0.104161	0.279515	0.058606	0.197006
3.788	0.008772	10.04426	0.088107	0.258412	0.05279	0.166167
4.011	0.00649	11.26168	0.073091	0.2371	0.047211	0.137474
4.204	0.005036	12.37153	0.062301	0.220521	0.043062	0.116944
4.400	0.003918	13.552	0.053092	0.205255	0.039381	0.099481
4.506	0.003429	14.21283	0.048743	0.197597	0.037582	0.091253
4.604	0.003038	14.83777	0.045071	0.190863	0.036026	0.084315
4.813	0.002357	16.21548	0.038225	0.177525	0.033013	0.071405
4.938	0.002032	17.06869	0.034691	0.170162	0.031387	0.064754

Table 3-2 High Speed Wind Tunnel Transonic Mach Numbers and Mach Function

NOMINAL* MACH NO.	P_s/P_0	q/P_s	q/P_0	T/T_0	$P_s/P_{0'}$	$P_{0'}/P_0$
0.20	0.97250	0.02800	0.02723	0.99206	0.97250	1.00000
0.30	0.93947	0.06300	0.05919	0.98232	0.93947	1.00000
0.40	0.89561	0.11200	0.10031	0.96899	0.89561	1.00000
0.50	0.84302	0.17500	0.14753	0.95238	0.84302	1.00000
0.60	0.78400	0.25200	0.19757	0.93284	0.78400	1.00000
0.70	0.72093	0.34300	0.24728	0.91075	0.72093	1.00000
0.80	0.65602	0.44800	0.29390	0.88652	0.65602	1.00000
0.90	0.59126	0.56700	0.33524	0.86059	0.59126	1.00000
1.00	0.52828	0.70000	0.36980	0.83333	0.52828	1.00000
1.10	0.46835	0.84700	0.39670	0.80515	0.46886	0.99893
1.20	0.41238	1.00800	0.41568	0.77640	0.41537	0.99280
1.30	0.36091	1.18300	0.42696	0.74738	0.36852	0.97937
1.40	0.31424	1.37200	0.43114	0.71839	0.32795	0.95819
1.50	0.27240	1.57500	0.42903	0.68966	0.29297	0.92979
1.60	0.23527	1.79200	0.42161	0.66138	0.26281	0.89520
1.70	0.20259	2.02300	0.40985	0.63371	0.23675	0.85572
1.80	0.17404	2.26800	0.39472	0.60680	0.21416	0.81268

* Actual Mach Numbers are computed from measured static and stagnation pressure

For special requirements, certain tunnel or model parameters can be controlled with an analog or digital computer program. Examples of operational capabilities involving computer-controlled variables during a run include:

- Mach number variation from 0.2 to 1.15, with stagnation pressure, lift coefficient or Reynolds number constant
- Reynolds Number variation, with Mach number constant
- Stagnation pressure variation (to compensate for temperature drop), with Reynolds Number constant

Additional capabilities can sometimes be added for a specific requirement if sufficient lead time is available to develop a computer routine before the test.

4 Data Reduction and Processing Capabilities

The data acquisition and processing system is the heart of the HSWT data gathering and computation capability. The system's capabilities covers:

- State of the art data acquisition and processing system
- A wide assortment of dynamic data equipment
- Steady state force instrumentation
- Steady state pressure instrumentation
- Data processing and reporting

4.1 Data Acquisition and Processing System

Operated from the tunnel's control room, the data acquisition and processing system accommodates up to 64 analog voltage signals from the model and tunnel transducer components. Signals are amplified through a Precision Filters 28000 Chassis using 28124 conditioner cards. Signals can be conditioned though selected low-pass filters to minimize high frequency noise generated by model vibrations or random pressure pulses.

Amplifier outputs may be used in any or all of three recording modes.

- Filtered outputs digitized and stored for use in final data processing
- Unfiltered outputs recorded on a high-response digital recording device
- Filtered or unfiltered outputs used in analog computations and displayed on strip charts during each run

During each wind tunnel test run, the signals from the signal conditioners are digitized simultaneously at a rate of 1kS/s and stored on the DAS server at 200 Hz. Since the server acquires all signals continuously during the test run, the desired digitized signals are parsed and down sampled to 50 Hz. The data is then saved on the data reduction computer.

After each test run, complete and final coefficient data are reduced in a customer provided ASCII format. Tabulated data are also provided digitally to the customer and if desired hard copy tabulated data can be provided. Digital coefficient data plots of customer selected parameters are provided immediately following each run for quick appraisal of model performance.

4.2 Dynamic Data Recording Equipment

The HSWT is equipped with a wide assortment of high frequency response instrumentation for recording dynamic data from various sources. Available equipment include:

- 30 Channel Dewetron DEWE2-M13 chart recorder
- 48 Channel VibBox high speed digital data acquisition system

- High Speed Video

The full complement of dynamic data recording equipment or any combination of selected instrumentation may be employed in dynamic tests such as flutter evaluation, dynamic stability, roll damping, buffet, store ejection and transient or impulse phenomenon studies. Techniques for such dynamic tests are described in Section 7 of this handbook.

4.3 Data Processing and Reporting

The HSWT strives to provide customers with real-time test results to minimize wind tunnel time and maximize substantive test data. HSWT personnel are dedicated to meeting specific customer data requirements. We can accommodate virtually any data requirement or reporting need if notified ahead of time. Complete data reduction information should be included in the customer's test plan or pretest report. Reference area, reference lengths, moment reference points, base drag correction areas, desired coefficient data and other pertinent parameters used in data reduction (input or output) should be included for each configuration in the test plan prior to scheduled wind tunnel testing dates. Further information concerning test planning and scheduling notification required for wind tunnel testing is provided in Section 9 of this handbook.

Final tabulated data are available within five minutes following a run, depending on file size. A digital copy of the data is provided for customer use. The tabulated data format can be arranged to suit the customer if such requirements are provided no later than one week prior to the test. Special data reduction equations, techniques and methods can be programmed if sufficient lead time is allowed.

Preliminary plotted digital data are usually available within two to five minutes following a run. If hard copies are required, a laser printer is used to plot the desired coefficients.

Final data reports can be prepared by HSWT personnel when requested by customers at a nominal charge. All the information pertinent to the test, methods of data reduction, model sketches, tabulated data and plotted data are included in the data report. Data analysis will not be included unless this requirement is stipulated prior to testing, and it will incur an additional charge. The final data report is provided to the customer within 90 days of test completion. One copy of the final data report will be retained in the HSWT files, subject to any contractual or proprietary information agreements.

5 Instrumentation

5.1 Steady State Force Instrumentation

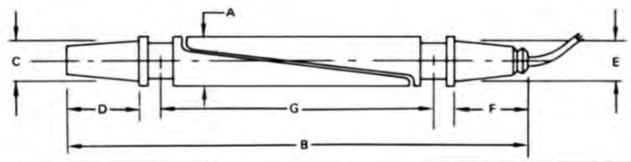
Over 30 six component internal strain gauge balances are available for customer use in measuring forces and moments. Theses balances were designed, fabricated and calibrated by the Test Systems Design group and are furnished as a standard customer service. A typical, one-piece six-component internal strain gauge balance is shown in Figure 5-1.

Figure 5-1 Typical One-Piece, Six-Component Balance

Balances are available in several sizes, as described in Table 5-1. For the best results, the balance maximum-rated load should be approximately the maximum expected model loads. However, full-scale data system output can be obtained for much smaller loads by using higher signal amplifier gain. Special force balances or other instrumentation can be designed and fabricated by the Test System Design group.

The Test Systems Design Group also has extensive knowledge with strain gages and can gage, wire and calibrate devices in house. Typical uses are three component tail fins or canards measuring normal force, hinge moment and bending moments. We have the capability to modify hardware to ensure the device does not foul due to limited clearance from wires and gages to achieve maximum outputs. Custom instrumentation design and fabrication are available for customer purchase under contract. It should be noted that design requires planning and test system design approval before fabrication of hardware.

FWD END



AFT END
NOTE TAPER CODE REFERS TO DIMENSIONS ON AFT END TO FIT STING FRONT END SEE TABLE V

BAL NO.	DIMENSIONS, INCHES							TABLE OF MAXIMUM LOADS						AFT END TAPER CODE	REMARKS
	A	B	C	D	E	F	G	N	PM	Y	YM	RM	AF		
VB-5	1.20	10.0	1.20	2.0	1.00	2.1	4.8	550	825	350	525	-	-	B	
VB-7	2.75	16.2	2.75	3.5	2.75	3.5	8.0	5,000	8,500	3,500	7,700	2,500	4,000	C	
VB-10	0.75	6.1	0.75	1.0	0.54	1.0	3.6	340	330	290	3155	70	-	D	
VB-14	2.00	13.8	1.25	2.5	1.25	3.0	7.0	2,000	4,200	1,400	2,400	1,200	100	A	LARGE AF INTERACTIONS
VB-17	1.20	10.0	1.20	2.0	1.00	2.1	5.0	750	1,000	400	650	500	250	B	
VB-18	1.50	12.7	1.25	2.5	1.25	3.0	6.0	1,800	2,250	1,800	2,250	1,250	300	A	
VB-20	1.20	10.0	1.20	2.0	1.00	2.1	5.0	400	500	300	375	200	400	B	
VB-21	1.50	12.7	1.25	2.5	1.25	3.0	6.0	1,000	1,000	800	1,200	400	200	A	
VB-28	1.85	14.2	1.50	3.0	1.50	3.0	6.9	2,800	4,460	2,100	3,350	1,800,1,500	400,150	E	INTERCHANGEABLE RM/AF ELEMENTS
VB-36*	1.50	12.7	1.25	2.50	1.25	3.00	6.0	2,000	3,000	800	1,200	1,200	200	A	INTERCHANGEABLE WITH VB-18
VB-38*	1.25	10.0	1.20	2.00	1.00	2.10	5.0	800	2,000	440	1,100	600	125	B	INTERCHANGEABLE WITH VB-17
VB-40	0.60	5.13	0.50	1.00	0.50	1.00	2.78(2.8)	125	160	100	120	60	15	-	
VB-42*	0.75	6.1	0.75	1.00	0.54	1.00	3.6	175	185	150	160	100	75	D	INTERCHANGEABLE WITH VB-11
VB-44*	1.50	12.7	1.25	2.5	1.25	3.00	6.0	1,800	2,250	1,800	2,250	1,250	300	A	INTERCHANGEABLE WITH VB-18
VB-46*	1.25	10.0	1.20	2.0	1.00	2.10	5.0	640	1,600	640	1,600	600	125/400	B	SYMMETRICAL VB-38
VB-48*	1.85	14.2	1.50	3.0	1.50	3.00	6.9	2,800	4,460	2,100	3,350	1,800	400	E	INTERCHANGEABLE WITH VB-28
VB-50*	0.46	4.0	0.375	0.72	0.375	0.72	2.21	35	35	35	35	27	10	A	
VB-51	1.25	10.00	1.20	2.00	1.00	2.10	5.20	875	1,112	875	1,112	-	—	B	FOUR COMPONENT
VB-52	1.00	8.22	0.80	1.66	0.80	1.66	4.30	600	750	600	750	350	125	F	
VHB-2	0.50	3.75	0.50	0.25	0.37	0.68	2.5	10	13	5	6	5	10		
VHB-5	0.50	3.11	0.50	0.25	0.37	0.68	2.0	6	8	2	2	2	7		
VHB-7*	0.46	3.36	0.46	0.50	0.37	0.68	2.0	35	35	18	18	27	10		
VHB-11	0.37	4.0	0.30	0.37	0.30	0.61	2.5	10	10	10	10	3	5		TWO (2) AVAILABLE
VTB-4	1.20	10.0	1.20	2.0	1.00	2.1	4.9	740	950	740	950	400	-	B	0.5 DIA HOLE ON ℄
VTB-12	1.50	15.65	1.25	2.62	1.25	3.12	6.0	1,600	2,000	1,600	2,000	500	-	A	0.68 DIA HOLE 2000 PSI
VSB-1	0.75	4.1	0.625	0.19	0.54	0.97	2.4	6	6	3	3	2.5	11	D	SEMICONDUCTOR BRIDGES
VSB-3	0.30	7.9	0.30	0.38	0.30	0.61	2.0	5	2	2	2	-			
VSB-4	1.80	34.8	1.25	2.5	2.50	3.75	6.0	1,500	2,250	700	1,050	1,390	250		INTEGRAL STING-BALANCE
VSB-10	0.30	7.6	0.30	0.50	0.326	0.80	2.4	34	34	34	34	3	-		
VSB-12	0.325	2.99	0.25	0.375	0.325	0.485	1.8	15	14	15	14	4	-		SEVEN (7) AVAILABLE
VSB-13	1.50	12.7	1.25	2.5	1.25	3.0	6.0	1,800	2,250	1,800	2,250	-	-	A	0.5 DIA HOLE ON ℄
VSB-24	0.35	10.68	0.30	0.40	0.46	1.0	2.3	35	40	20	23	19	-		INTEGRAL STING-BALANCE
VSB-42	0.25	8.37	0.25	0.37	0.30	0.61	1.3	20	10	20	10	3			INTEGRAL STING-BALANCE

*one-piece design

Table 5-1 Internal Force Balance Load and Dimensional Information

A sketch of a typical balance adapter with an integral insulated taper for a model fouling indicator is shown in Figure 5-2.

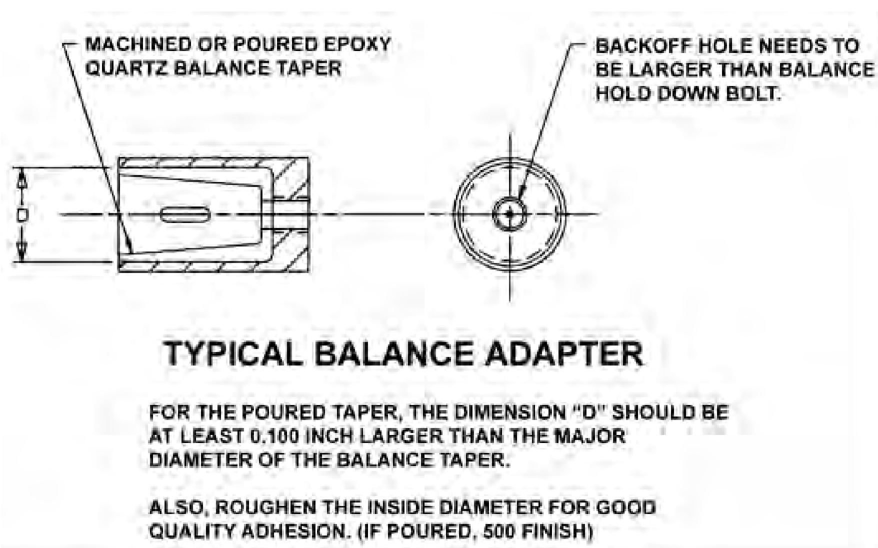


Figure 5-2 Typical Balance Adapter

5.2 Pressure Instrumentation

The wind tunnel is equipped with several different systems for taking pressure measurements on a model. They include:

- Individual pressure transducers
- Dynamic response pressure transducers
- Miniature pressure scanner module

Pressure calibration instrumentation is also available to verify pressure system data accuracy. The miniature pressure scanner modules are manufactured by Scanivalve.

The HSWT maintains an inventory of individual pressure transducers with a wide range of measurement capabilities from ±5 to ±50 pounds per square inch differential (psid) and 0-5 to 0-5,000 pounds per square inch absolute (psia) are available. Most individual transducers are 0.25 and 0.5-inch flush-diaphragm, strain-gauge pressure transducers.

Pressure requirements above approximately 15 pressures are measured using miniature pressure scanner modules. The HSWT uses the MPS4232 modules from Scanivalve. There are two different MPS4232 modules available with different pressure ranges as follows: two 0-15 psid modules and six 0-50 psid modules. The two types of modules are available as shown in Figure 5-3. Both modules can be back pressured to bring their ranges to 0-30 psid and 0-100 psid respectively.

Pressure calibration instrumentation is available using a precision NIST traceable digital pressure gauge. The digital pressure gauge is capable of setting pressures from 0 to 100 psia to an accuracy of 0.001 psia.

Figure 5-3 Miniature Electronically Scanned Pressure Modules

6 Model Support System

The HSWT model support system includes a specially designed model cart, remotely controlled roll stings and a wide variety of support stings and adapters.

6.1 Model Cart

The model cart is mounted on rails and can be rolled some distance away from either test section to facilitate test section or major model changes. During a test run, the model cart is secured with hydraulically operated locks. The model cart position relative to the test section window is the same for either the supersonic or transonic section.

Sting-supported models are usually mounted on the model cart. The servo-controlled, hydraulically actuated cart can sweep through an angle range of -12 to +22 degrees while the center of rotation remains on the tunnel centerline. Figure 6-1 illustrates model cart kinematics. Sweep rates up to six degrees per second are possible, as well as pitch pause runs. The cart can be used to pitch the model and can be mechanically rolled for yaw sweeps. Knuckle stings can provide fixed offset model pitch, yaw angles or can extend the cart angle range. A remotely controlled roll sting can be added to provide multiple pitch, roll and yaw sweeps.

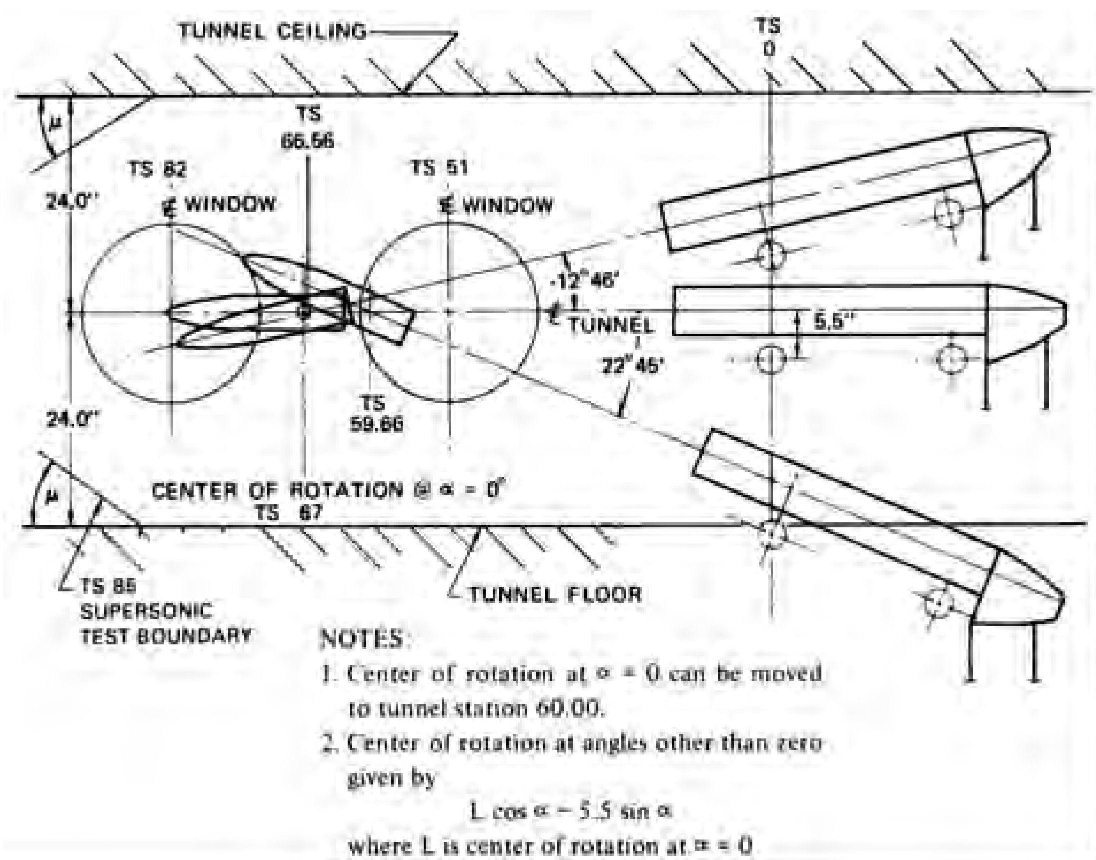


Figure 6-1 Model Cart Kinematics

System performance for all three remotely controlled stings is summarized in Table 6-1.

Table 6-1 Roll Support System Performance Parameters

Roll angle range, A9 and A10	**270 degrees**
Roll angle range, A15 and A16	**355 degrees**
High Alpha Roll Sting	**355 degrees**
Maximum Stall Torque	**2500 inch-pounds**
Maximum roll rate, 100 inch-pounds torque	**100 degree/second**
Normal force and side force	**4000 pounds – 42 inches forward of front face of roll pod**
Roll positioning accuracy	**±0.15 degree**

6.2 Remote Roll Sting

Three remotely controlled roll stings are available to cover an angle-of-attack range of -12 to +22 degrees (A_9, A_{15}), -4 to +30 degrees (A_{10}, A_{16}) and +30 to +90 degrees High Alpha Roll Sting(HARS). The A9 and A10 have a roll range of 270 degrees while the A_{15} and A_{16} have a roll range of 355 degrees. Roll rates up to 90 degrees per second are possible. These remote roll stings serve as roll support systems and were designed primarily for missile testing to increase run output by allowing pitch sweeps at several roll angles or roll sweeps at several pitch angles during a run. A special software routine allows computer control of a roll sting to achieve either a pitch sweep at a constant yaw angle or a yaw sweep at a constant pitch angle. Figure 6-2 illustrates the geometrical relationships offered by the roll support systems.

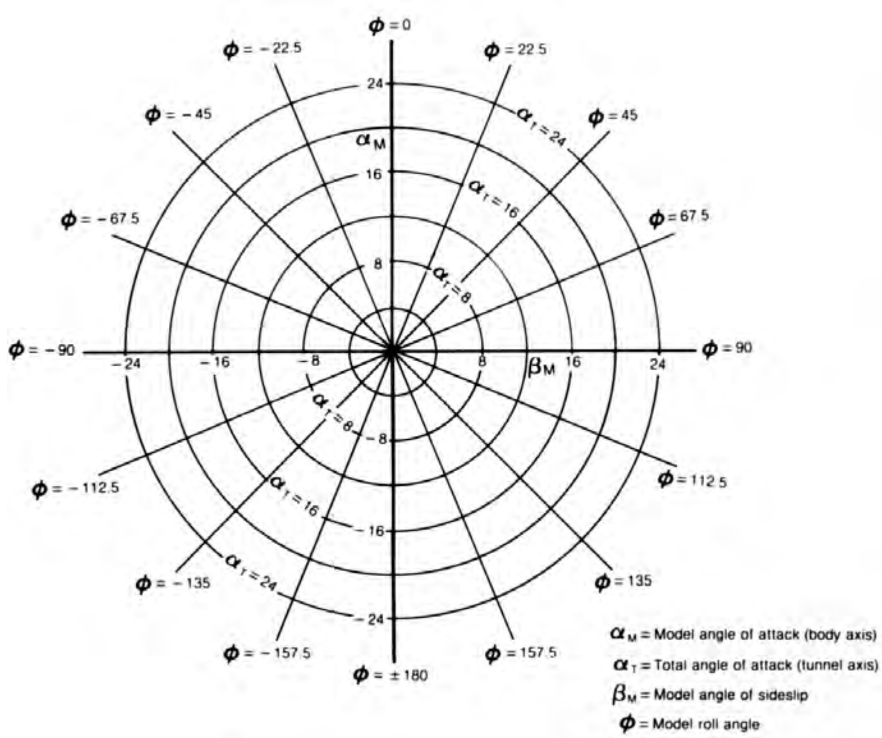


Figure 6-2 Roll Support System Geometrical Relationships

6.3 Support Stings and Adapters

Models are normally mounted from the rear on a sting and model cart assembly, as described in paragraph 6.1 above. To accommodate accurate model mounting, a number of sting configurations are available as standard wind-tunnel-furnished equipment for customer use. Each sting's forward end and aft end is coded to match the taper dimensions with mating parts. The mating part may be a balance (as described in Section 4), a sting extension or a special adapter. Figure 6-3 and Figure 6-4 are examples of available stings. Customers may also use their own with necessary adapters. See the HSWT Instrumentation Handbook for more detailed information on available model support stings, sting extension and adapter information.

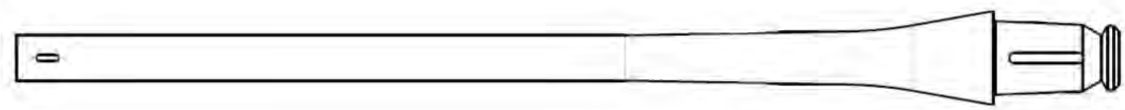


Figure 6-3 E-31 Sting (Technical Reference 4, Appendix A)

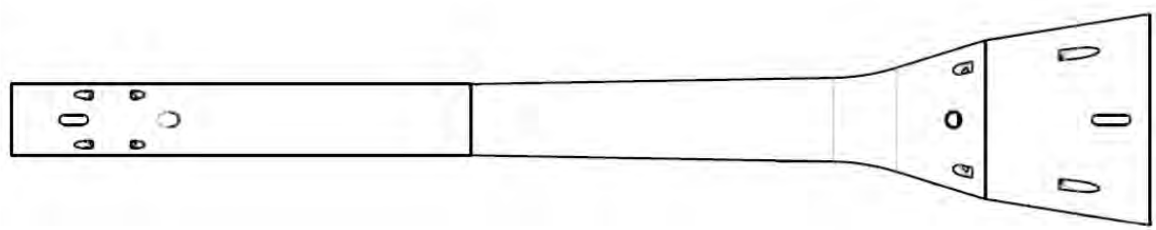


Figure 6-4 F-23A Sting (Technical Reference 4, Appendix A)

7 Special Test Systems and Techniques

In addition to basic force and pressure test capabilities, the High Speed Wind Tunnel group has accumulated considerable experience in a number of testing specialties. Descriptions of the special hardware and techniques offered are provided in the paragraphs which follow.

7.1 Inlet and Propulsion Tests

Inlet and propulsion tests can be conducted using a computer-controlled inlet test system which can control the mass flow throttle plug position and angle-of-attack sequencing. The system can also record up to 256 channels of individual pressure transducers, temperatures or other instrumentation devices.

Up to 50 combinations of throttle plug (TP) position and angle of attack can be programmed for any run. A typical run may use all or only a portion of this capability. An example of setup combinations might be 10 discrete throttle plug settings at each of five angles of attack for a total of 50 data points. A manually initiated abort procedure can be used in the event of buzz or other occurrence for which data is not required. The plug sequence can subsequently be reset to move the model's pitch to the next angle of attack or returned to zero to terminate the run.

In addition to computer control of throttle plug position and angle of attack, several additional servo-controlled functions are available in the computer program. Time on point, data sampling rate, number of data points, throttle plug and angle-of-attack rates of change are all selectable as desired for each test.

Several inlet and throttle plug-mounting systems are available. The customer may adapt their configuration to these or may furnish a complete system adaptable to the tunnel pitch cart. Each system has been calibrated using ASME sharp-edge orifice meters in the wind tunnel high-pressure test facility.

Below is the example of an available throttle plug-inlet support assembly at the HSWT. The Air Flow Parameter $\left(AFP = \frac{\dot{w}}{p}\sqrt{T} \right)$ range for the 3.81" is from .8 to 4.8. The pitch range assembly is from -10 and -15 degrees. See the HSWT Instrumentation Handbook for more detailed information available mass flow plugs at the HSWT.

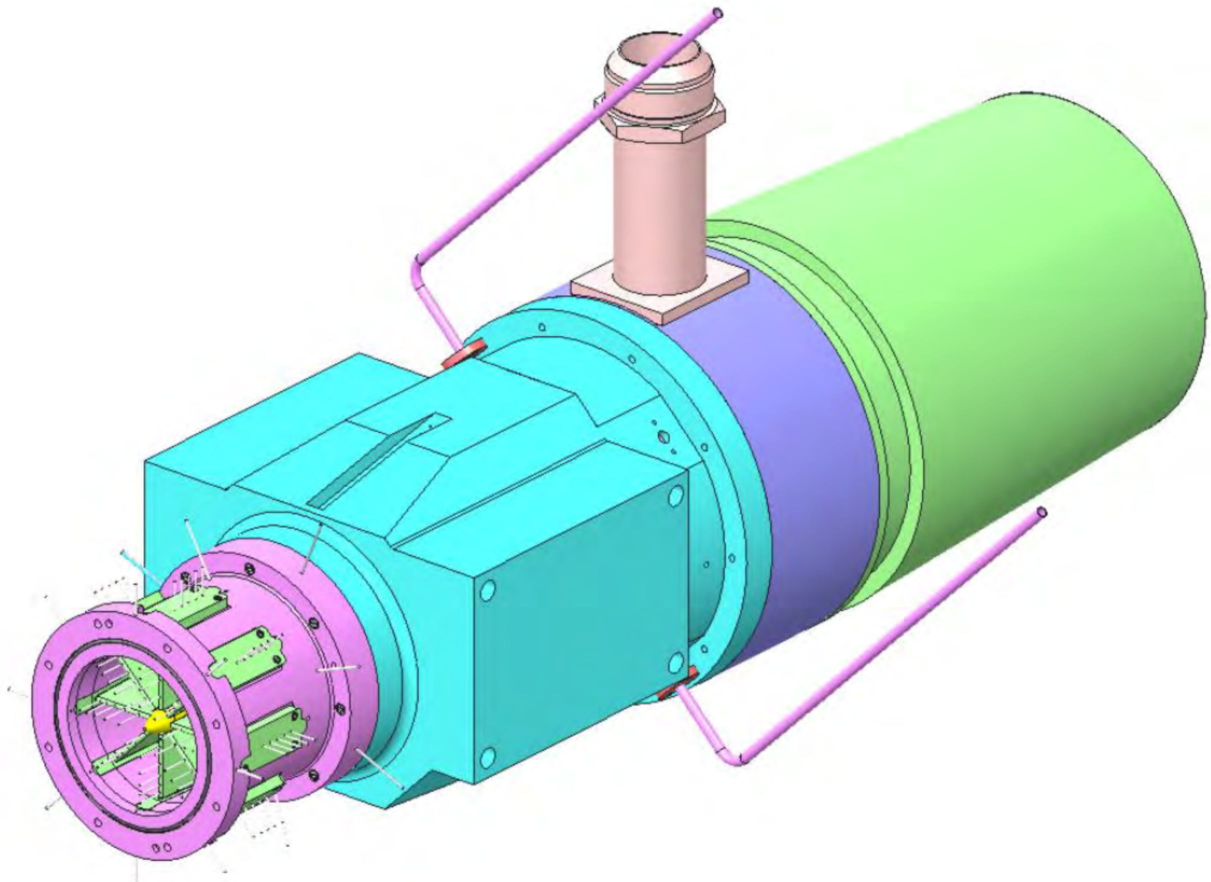


Figure 7-1 3.81-Inch Mass Flow Plug (Technical Reference 4, Appendix A)

7.2 Captive Trajectory Simulation (CTS)

The captive trajectory simulation, shown in Figure 7-2, has been developed to provide solutions to problems involving aerodynamic interactions between a parent vehicle and separating stores.

Aerodynamic forces and moments measured by the store balance are processed by the digital computer. The computer commands the model support to move the store in response to these forces and moments. Dynamic stability derivatives, ejection forces, variable model mass, static and variable moments of inertia, altitude and gravity terms are included in the equations of motion. Special simulation parameters requested by a customer can be included if sufficient lead-time for programming is permitted.

Components of the system form a closed loop starting with store-model balance signals, as shown in Figure 7-2. The signals are digitized and processed to obtain non-dimensional aerodynamic coefficients to be used in the complete equations of motion. Solutions of the equations of motion result in body axes linear and angular accelerations from which linear and angular positions may be obtained by double integration and axes transformation. Sting positions are then converted from digital to analog voltages and sent as command signals to each servo linkage of the model support.

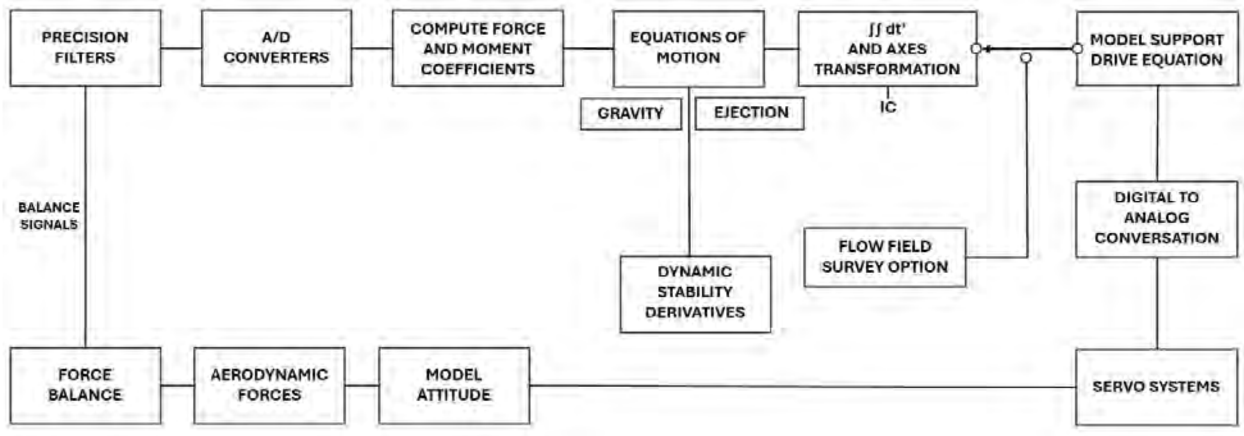


Figure 7-2 Servo Control Flow Diagram

New command signals are generated 25 times each second, resulting in a smooth, continuous, time-scaled store separation. Time scales can be selected depending on the speed of separation. A 30-second run, for example, will yield a complete time history of all the angular and linear velocities and displacements equivalent to one second of real time.

The two-part model support system comprises of six independent hydraulic servos, shown in Figure 7-2. The parent model actuator attaches to the ceiling of the tunnel and provides an axial displacement of 36 inches. The remaining five actuators are located in the store support mechanism. All six motions are controlled simultaneously, and any degree of freedom may be changed independently of the others. Translation boundary limits, which are programmed in the computer, protect the store against movement into the tunnel sidewalls.

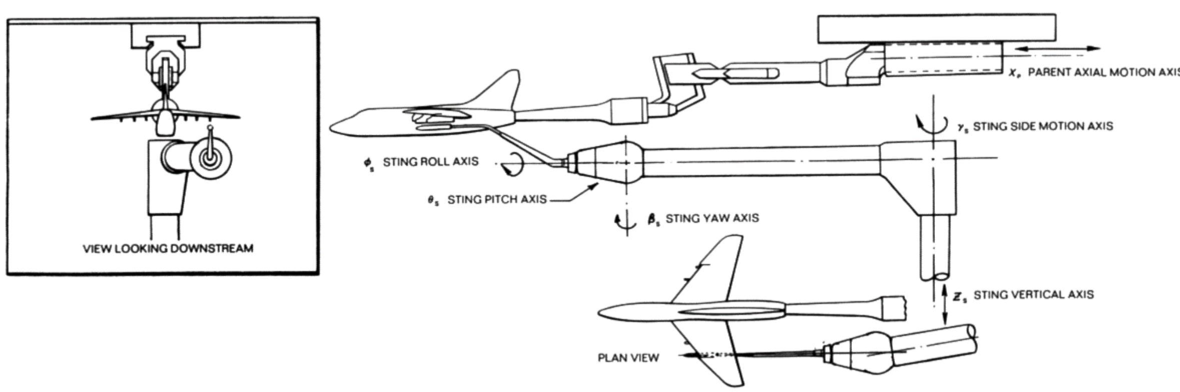


Figure 7-3 Flight Dynamics Simulator Components

Positioning errors under no-load and maximum driving rates will not exceed ±0.02 inch on linear displacements and ±0.05° on angular displacements. Linear and angular driving rate and load limits are presented in Table 7-1.

Table 7-1 CTS References

Store Model	**Rate**	**Load**	**Range**
Pitch and Yaw	10 deg/sec	500 lb	±22-1/2˚*
Roll	20 deg/sec	84 in-lb	±170˚
Axial		600 lb	
Vertical	0.22 ft/sec	1500 lb	14 in
Lateral	0.22 fr/sec	500 lb	±14 in
*Range can be changed up to 0-45˚ by clevis change			
Parent Model			
Axial	0.33 ft/sec	1000 lb	36 in.
Pitch angles - Fixed Increments			Nom ±10˚

7.3 Dynamic Stability

A free-oscillation dynamic-stability rig has been developed using a ball-bearing support and a torsion flexure. Hydraulically operated deflect and pinlock mechanisms permit release from deflect angles of 0° to 10°. Interchangeable torsion spring elements vary the mechanical restoring moment from almost 0 to over 60 ft-lb/rad.

Dynamic and static stability derivatives about the center of rotation can be obtained as a function of oscillation amplitude. Nonlinear tare damping effects can also be obtained using a free-oscillation data reduction program.

7.4 Spin and Magnus Testing

The steady rolling velocity which an aerodynamic body will attain in free flight may be determined by static force and free-spin testing. The rolling moment produced by various deflections of the roll control surfaces of an aerodynamic model restrained in roll can be obtained in static force tests. By allowing the model to spin freely about its longitudinal axis, the rolling moment due to roll velocity (roll damping) may be obtained. Side force increments due to roll velocities (magnus effect) may be determined by forcing the model spin rate above the steady-state value and measuring these effects as the model coasts back to steady-state roll conditions. A six-component internal balance is usually used to support the model. The support system consists of a bearing mount to allow free rotation of the model about the longitudinal axis. A motorized unlocking device may be used to permit tunnel flow establishment before the model is released to spin. The angular velocity of the model can be precisely measured by a digital frequency counter which directly counts the impulses from a tachometer system (Figure 7-4) mounted in the model. An air turbine built into the model can provide spin rates higher than steady-state rates. Figure 7-5 shows a typical spin model roll mechanism assembly. Three bearing mount systems are available. Wind tunnel personnel can determine which system best suits a customer’s requirements.

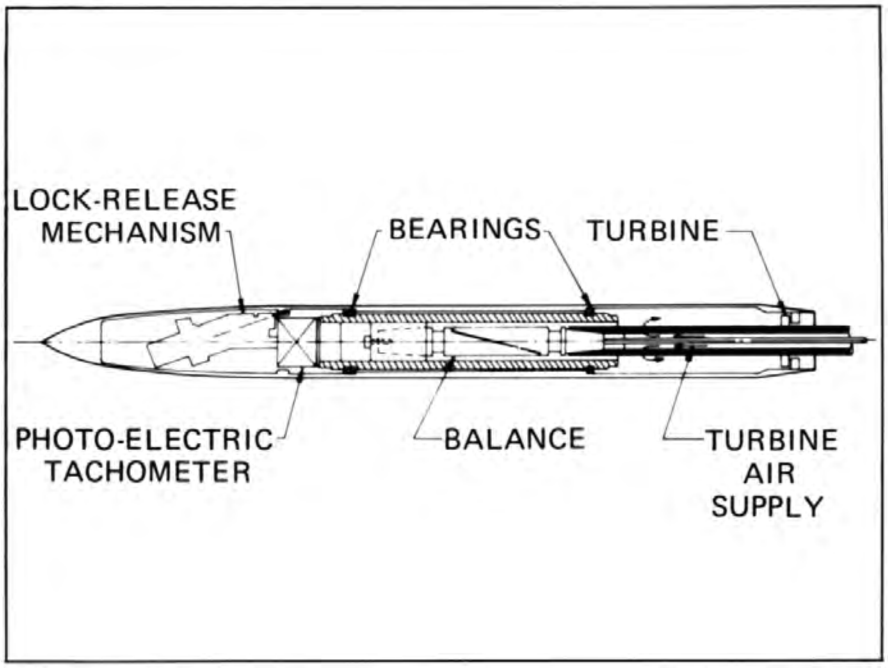


Figure 7-4 Photoelectric Tachometer System

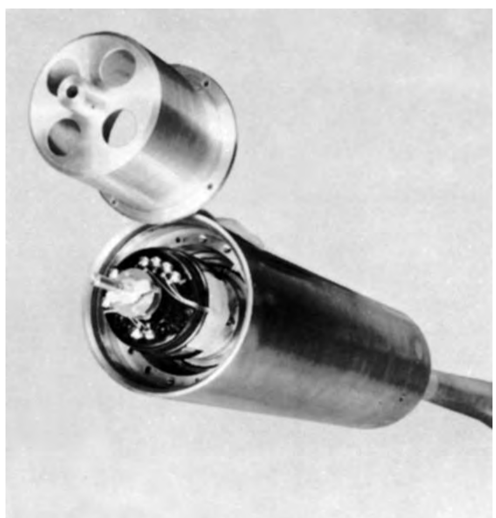


Figure 7-5 Typical Model and Roll Mechanism Assembly

7.5 Instrumented Stores Testing

The relatively small scale of models tested in the High Speed Wind Tunnel results in minimal space available for store force-measuring systems. Specialized instruments have been developed to measure the aerodynamic forces on aircraft individual stores or groups of stores. Miniature five-component balances with quick-disconnect features are available for individual store loads testing. The balances are interchangeable, and the store/balance assemblies can be readily added to or removed from multiple stores carriage systems. Pylon balances to measure total loads on groups of stores have been designed and tested on particular aircraft models. Multiple fouling indicator circuits are available to monitor each store or pylon balance for model-to-model or model-to-balance grounding. Improved design, calibration and operational techniques have been developed through experience gained while testing aircraft multiple-carriage stores systems.

7.6 Flow Visualization

Techniques that use visual aids to obtain a qualitative understanding of flow phenomena have been used extensively. Among the more commonly used visual aids are shadowgraph, fluorescent oil, pigmented oil and sublimation techniques.

Shadowgraphs are normally recorded live on a HD Camera for the entire run. A high-intensity mercury Xenon light source is directed through the test section's optical-quality glass windows onto an opaque Mylar sheet. Shadowgraphs in the transonic section are taken through solid Plexiglas windows, which replace the perforated windows normally used. A high-quality digital camera can also be used simultaneously to obtain still shots of the shadowgraph. Typical shadowgraphs are shown in Figure 7-6.

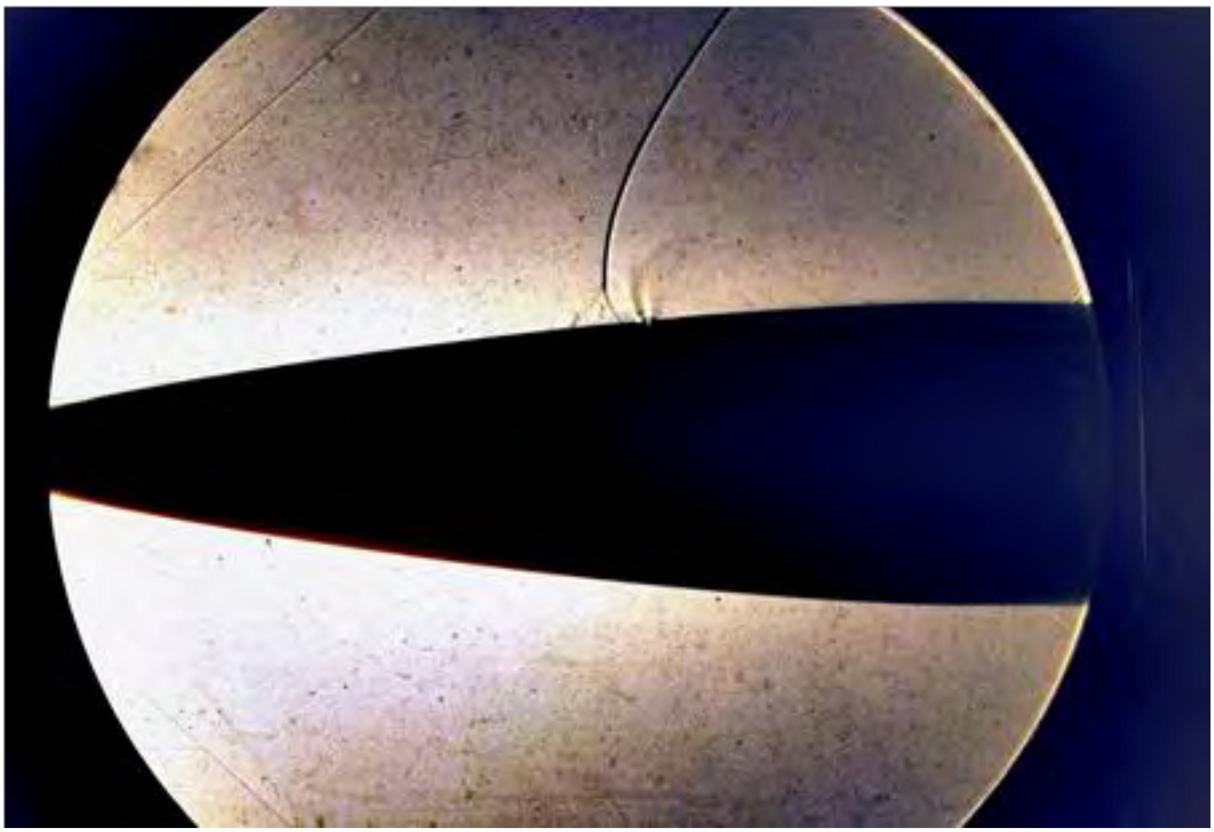


Figure 7-6 Typical Shadowgraph

Fluorescent or pigmented oils have been used successfully to study surface streamline directions and separated flow regions. Mixed to the proper consistency, pigmented oils will spread and "set" in approximately five seconds so that no pattern distortion occurs during shutdown. Dual-color pigmented oils can be photographed in normal light, as shown in Figure 7-7. Normally, such pictures are taken with a high-quality digital camera for greater clarity and detail. Fluorescent oils are observed and photographed under ultraviolet light.

Sublimation techniques are used to detect boundary-layer transition and flow separation regions. A slow-drying, supersaturated solution of naphthalene dissolved in toluene is sprayed on the model immediately before each run. During a short run, turbulent areas are made visible by higher sublimation rates. Photographic records of the patterns may be taken immediately after the run.

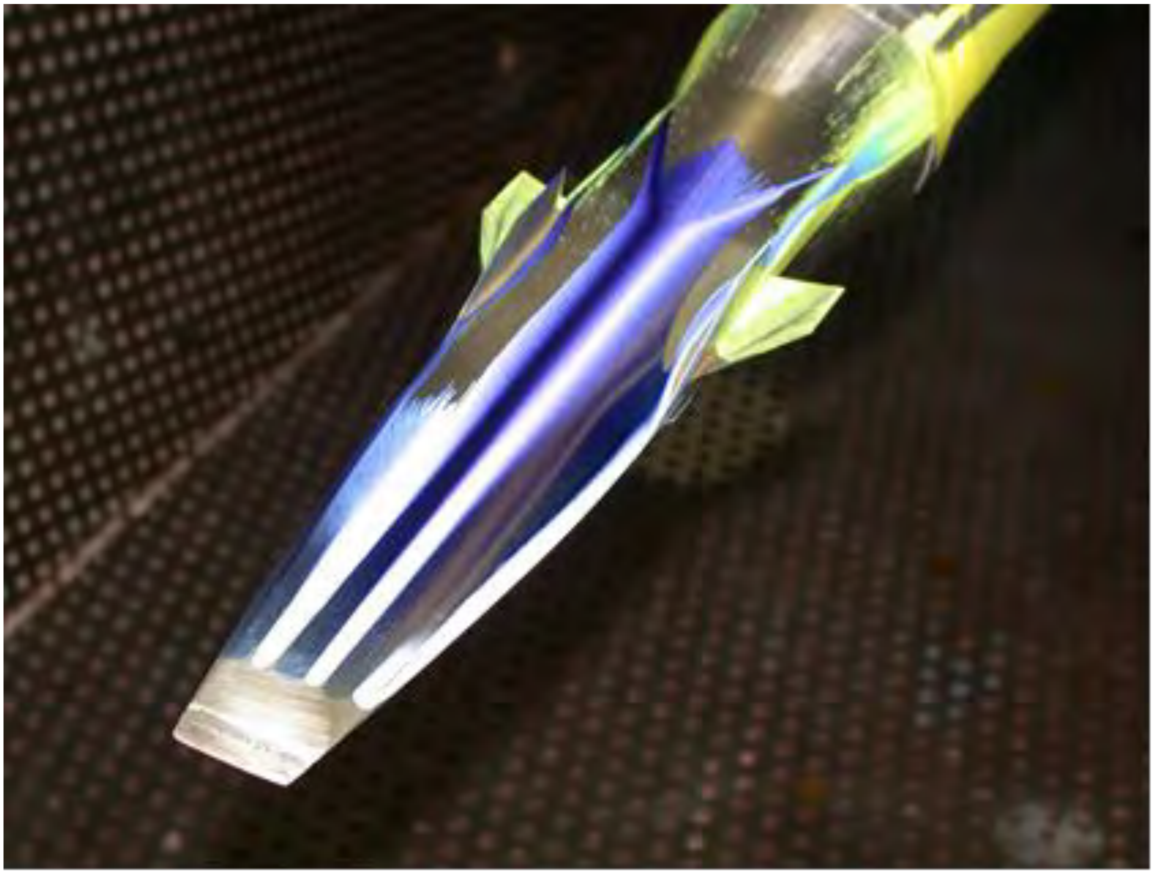


Figure 7-7 Dual Color Pigmented Oil Flow

7.7 Bench Test Facility

A compressed-air static test facility is available as a supply source for a variety of tests in the tunnel and for inlet, duct and cascade bench tests outside the tunnel. Compressed air can be provided from the main storage tanks.

Flow meters and control valves regulate air supply at the airline exits. Supply-line and orifice-meter sizes can be selected to obtain flow rates up to 40 pounds per second with 500 psia supply pressure

7.8 High Pressure Nitrogen Gas Facility

Figure 7-8 High Pressure Nitrogen Gas Facility

A high-pressure nitrogen gas supply system has been added to the HSWT. The system can provide nitrogen gas at a pressure up to 5000 psi at a flow rate of 15 pounds per second. Currently, the gas can be supplied to a wind tunnel model via a flow-through balance (five component only) mounted on a sting with remote roll capability. The present system configuration allows for the pressure to be varied during a test run. For adequate run times in the tunnel, the model chamber pressure needs to be 3000 psi or less.

Advanced technology missiles are utilizing transverse flow jet thrusters as a primary control system or to augment the missiles aerodynamic surface control system. Even though a significant amount of data concerning the effectiveness of transverse jets has been published, highly nonlinear force and moment variations due to transverse jet flow interactions require the investigator to rely on experimentally obtained data.

7.9 Additional Test Support Equipment

The following is a partial list of test support equipment available at the High Speed Wind Tunnel. Equipment described in detail elsewhere may not be included here.

- Phantom high-speed video recorder system – full screen to 2,000 frames/sec; up to 1,000 frames/sec with split screen; two cameras available.
- VibBox 48 channel high speed digital data recorder

- Dewetron DEWE2-M13
- High Quality Digital Cameras
- HD Video Recorder
- Barometer - Druck Pace 1000
- Inclinometer – WylerCLINO Frame ±60° (Calibrated), Digipas Two Axis Digital Level (Calibrated) and Wixey Digital Angle Gauge (Reference only)
- Various 3D Printing Capabilities available on site & off site
- FARO Quantum X.S FaroArm – Portable 3D CMM metrology system

8 Model Design Considerations

The following guides may be used in the design of models to be tested in the High Speed Wind Tunnel. Since testing of a model is normally at the risk of the customer, exceptions may be made at the customer's discretion. The wind tunnel staff is available for consultation involving any phase of the wind tunnel program.

8.1 General Design Considerations

- Model weight should be kept low to minimize dynamic effects
- Aluminum models should be anodized to obtain a hard surface for abrasion resistance
- All models should incorporate some means for alignment in roll and pitch (leveling plate)
- Complex model designs should be avoided to minimize lost time during model changes
- Pressure and electrical leads should be routed to provide convenient accessibility when the model is mounted in the tunnel.

8.2 Model Size

In general, model cross-sectional area at any station should be limited to approximately 23 square inches (1% of test section area). This limit is imposed by transonic testing considerations and may be relaxed for supersonic testing. Figure 8-1 presents maximum allowable blockage areas as a function of supersonic Mach number. In addition to frontal area limits during transonic tests, model span and length limits of 30 and 50 inches, respectively, are needed to minimize wall interference effects.

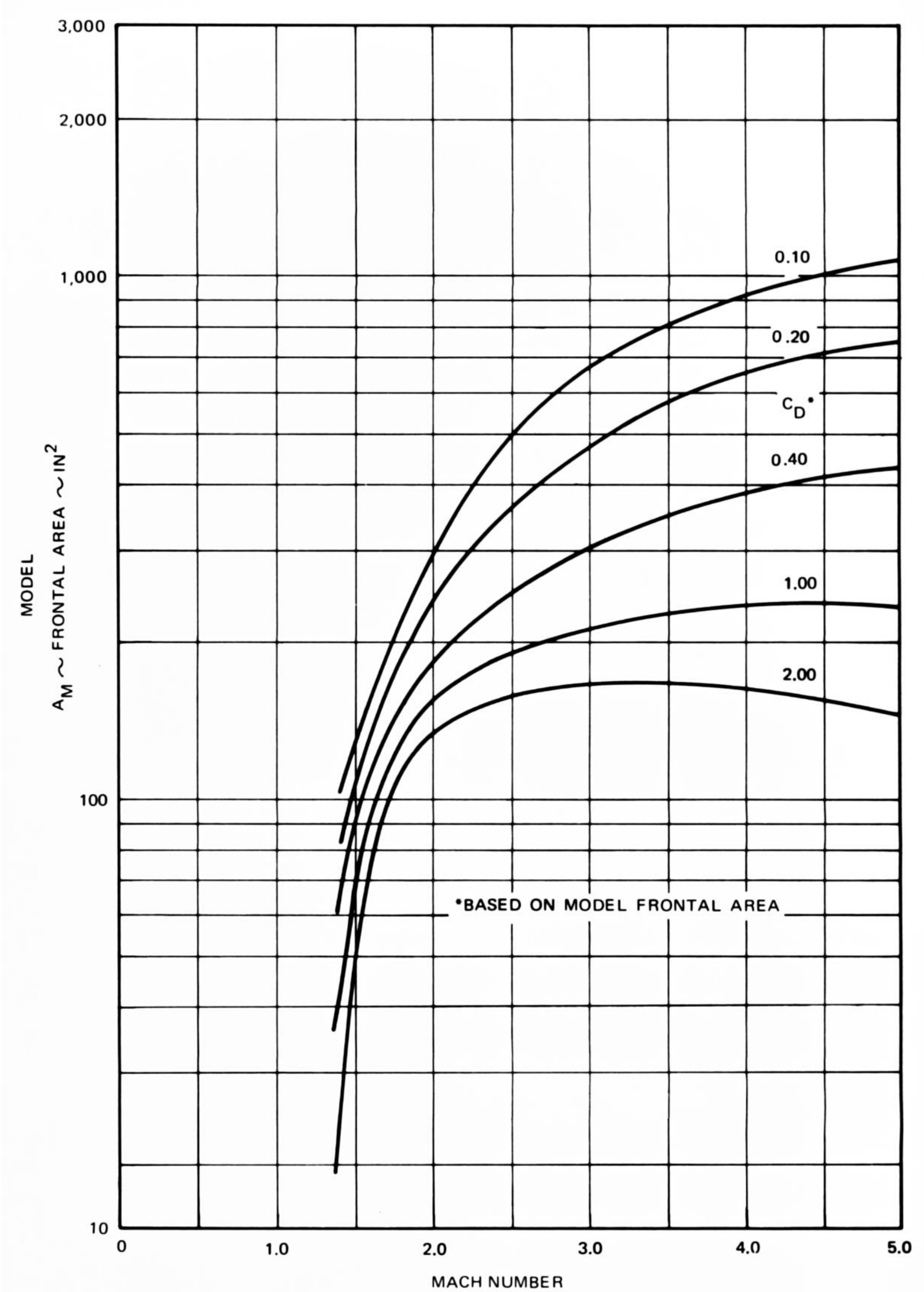


Figure 8-1 Allowable Model Frontal Area as a Function of Mach Number and Drag Coefficient (Technical Reference 1, Appendix A)

8.3 Model Placement

Under certain conditions of transonic operation, the centerline Mach number can vary downstream of station 51 (aft window centerline). For this reason, it is recommended that the model base be positioned no farther downstream than station 56 for any transonic test. It is also recommended that the model nose extend no further forward than tunnel station 102 to keep the model in acceptable flow conditions in both the transonic and supersonic test sections.

8.4 Pressure and Internal Flow Models

Model pressures are normally measured using individual pressure transducers or a modular pressure scanning system from Scanivalve located in the model or mounted downstream on the model support sting. Details of the Scanivalve system were presented in a previous section.

All pressure orifices should be flush with the surface, without burrs and not less than 0.040 inch in diameter. Pressure tubing should be 0.0625 or 0.04167 inch o.d. quarter-hard stainless steel, and long enough to reach the transducer or Scanivalve. Connections are usually made with short lengths of flexible tubing.

8.5 Static Stability Force Model Design Considerations

Static stability models will normally be mounted on a wind-tunnel-furnished sting/balance combination. Model installation hardware will be selected based on the maximum forces and moments expected, space limitations of the model balance cavity and model placement considerations in the test section.

A model-to-balance adapter is normally supplied by the customer to adapt the model to a wind tunnel balance as seen in Figure 5-2. Construction of an adapter may be accomplished by the High Speed Wind Tunnel on a time-and-materials basis, if desired. Ring and plug gages are available from the wind tunnel for use in fabricating such an adapter.

If possible, the adapter should be constructed so that the balance center is approximately at the same location as the midpoint of the center-of-pressure range.

Base pressure corrections are normally made from pressure measurements taken inside the balance cavity and/or from a pressure manifold located at the model base. Pressure measurements on the model are possible during a force test for a limited number of pressures if pressure tubing is installed without interference with force measurements.

Measurement of model control surface hinge moments, wing root bending etc., during a force test can normally be done if the gages or lead wires are accessible for instrumentation hookup. When necessary, a fouling circuit can be provided to indicate when contact is made between model and sting.

8.6 Starting Loads and Factors of Safety

Tunnel starting and stopping loads during supersonic operation may be the highest loads to which wind tunnel models are subjected. Figure 8-2 presents the modified normal-shock method of determining maximum starting load coefficients at various Mach numbers. This method assumes that supersonic flow could be established on one side of a model and subsonic flow behind a normal shock could exist on the other side, resulting in a large normal load. The normal-shock method, which assumes an infinite-aspect-ratio, thin-flat-plate model, is inconsistent with the flow field about a body of revolution during a tunnel start. Cross flow would reduce the pressure difference, resulting in reduced starting loads. The modified normal-shock method predicts more reasonable loads at lower Mach numbers and takes into account the ratio of the lifting surface area to the total planform area.

A model design safety factor of 3.0 based on nominal starting or maximum running loads, is recommended wherever possible. Under no circumstance should the safety factor be less than 1.5 based on yield strength.

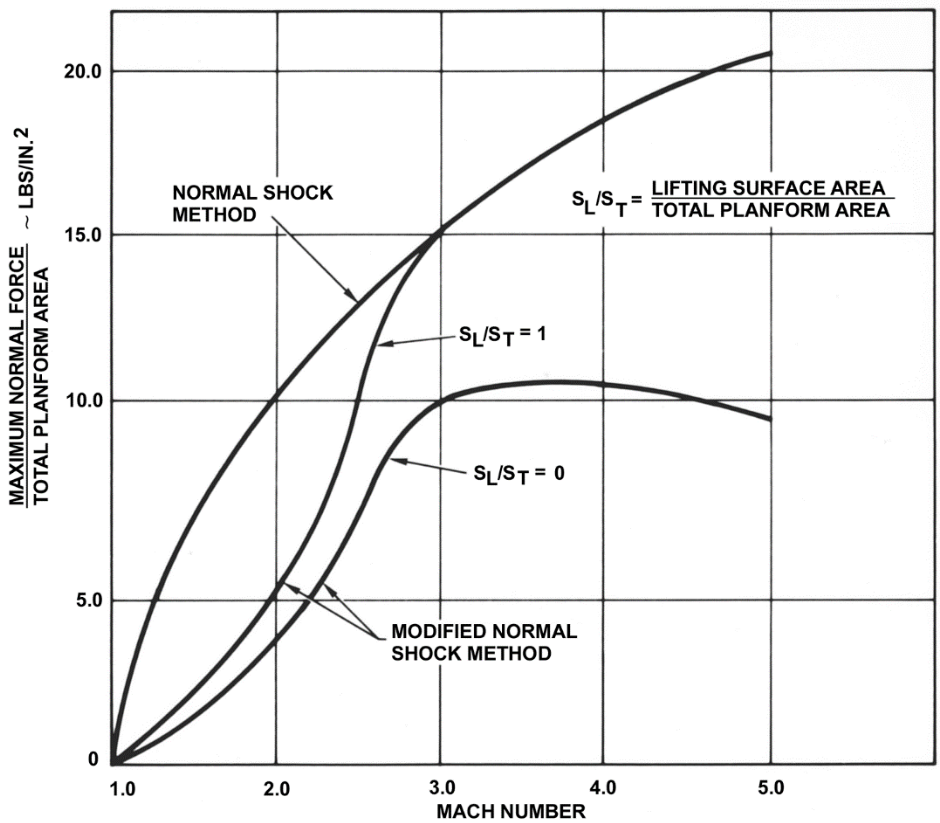


Figure 8-2 Modified Normal-Shock Method of Evaluating Maximum Starting Loads

9 Test Planning and Scheduling

9.1 Test Scheduling

An executed nondisclosure agreement must be in place before any exchange of proprietary information. Contact should be made with the Manager of the High Speed Wind Tunnel early in the design phase of the program to insure compatibility of model size, balances and support hardware. When the anticipated test date is known, the High Speed Wind Tunnel Manager can tentatively schedule a test. Test dates are confirmed by the issuance of a Purchase Order.

A Request for Quote (RFQ) or Request for Proposal (RFP) should be sent to the Contracts Representative and/or High Speed Wind Tunnel Manager as soon as definite program requirements are known. Non-official ROMs can be provided upon request.

The Request for Quote or Request for Proposal document should contain as much of the following information as is available:

a. Names and phone numbers of contractual and technical representatives
b. Anticipated test date
c. Purpose, scope and classification of test program
d. Description of model including dimensional details, installation sketches and configuration nomenclature
e. Expected maximum running loads
f. Test requirements (a run matrix or schedule)
g. Test conditions required (Mach numbers, angle-of-attack ranges, angle of yaw ranges, dynamic pressure, etc.)
h. Tunnel mounting hardware requirements. What will be customer furnished and what should be furnished by the wind tunnel
i. Special equipment requirements (photographic coverage, model fouling indicators, pressure instrumentation, auxiliary air, auxiliary electrical power, auxiliary hydraulic power, etc.)
j. Special engineering support (model design, vendor site model buyoff support, etc.)
k. Data to be recorded during test (force, lift, drag, pitching moment, pressure, tunnel operating conditions, etc.). Plot requirements while test is in progress (components most desired for "quick look" situation, sample plotting scales).
l. Data presentation requirements (components to be tabulated and order of tabulation desired, data report plots, components desired showing sample scale and axes arrangements, model reference areas and lengths, moment reference positions, definition of aerodynamic coefficients i.e. $C_N = N/qS$ body axes and others)
m. Shipping instructions for return of the model and other equipment
n. Specific contractual requirements and information.

A Letter Quote or Proposal will be provided. (Dates for testing cannot be guaranteed until a purchase order is in place).

After contract award and not less than two weeks prior to test date, a Pre-test document should be provided to the Manager of the High Speed Wind Tunnel containing an up-to-date Statement of Work detailing the information listed in the 3rd paragraph of this section.

A customer led Test Readiness Review (TRR) is recommended at least three business days prior to the scheduled start of test.

9.2 Model Delivery Information

Models should be received by the wind tunnel at least two weeks prior to the scheduled starting test date. When special instrumentation or calibration is necessary, additional lead-time should be allowed.

The following instructions are presented for shipment of models, test support equipment, materials, etc., to the facility.

Address models and other bulk materials to:

Lockheed Martin Missiles & Fire Control
High Speed Wind Tunnel
1701 W. Marshall Drive
Grand Prairie, TX 75051
Attn: HSWT Manager, (972) 603-2751

Classified models and other classified materials to:

External Label:

Lockheed Martin Missiles & Fire Control
1701 W. Marshall Drive
Grand Prairie, TX 75051
Attn: Security

Internal Label:

Lockheed Martin MFC
1701 W. Marshall Drive
Grand Prairie, TX 75051
Attn: HSWT Security Coordinator, (972) 603-3234

Two copies of a packing list containing a detailed description of each item should be enclosed with the shipment. Classified models are to be shipped in accordance with proper security directives.

The High Speed Wind Tunnel Manager or Test Operations Engineer should be notified by email of the date and time of shipment, waybill number, mode of transportation and carrier, the tracking number and the estimated time of arrival. This notification is mandatory if the shipment is classified.

Appendix A – Technical References

1. Czysz, P.A., "*Correlation of Wind Tunnel Blockage Data*," ASD-TDR-63333333230, April 1963.
2. NASA, "*U.S. Standard Atmosphere, 1976*", October 1976.
3. Anderson, John, "*Fundamentals of Aerodynamics*", March 2016.
4. Caruth, Chase, "LOCKHEED MARTIN HIGH SPEED WIND TUNNEL INSTRUMENTATION HANDBOOK", October 2025