High Speed Wind Tunnel and Test Systems Design Handbook

PUBLICATION NUMBER AER-EIR-13552-E

LOCKHEED MARTIN

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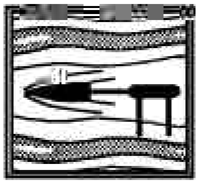
List of Terms, Acronyms and Abbreviations

M	Mach Number, VT/a
μ	Mach line inclination, degrees
q	Dynamic pressure, PSF unless noted otherwise
P_O	Isentropic stagnation pressure, psia
a	Angle of Attack, degrees
s	Density ratio, test section density/sea level density
V_{EAS}	Equivalent airspeed, V_{EAS} = VTvs, knots or feet/second
P_S	Static test section pressure, psia
T	Static test section temperature, °R unless noted otherwise
T_O	Stagnation temperature, °R unless noted otherwise
$P_?$	Stagnation pressure behind normal shock, psia
N	Normal force, pounds
PM	Pitching moment, inch-pounds
Y	Side force, pounds

1.0 INTRODUCTION

The purpose of this handbook is to provide customers of the Lockheed Martin Missiles and Fire Control (LMMFC) High Speed Wind Tunnel (HSWT) and related services with information necessary for planning and scheduling model design or testing. Our HSWT facility can accommodate a wide variety of high-speed tests including aerodynamic force measurements, flutter, store drop trajectories, 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



Aerodynamic Support Services

The Aerodynamics Group can provide any combination of the following services for your test program:

- Design Definition
  - Preliminary Through Final Configuration
  - Surface Sizing Analysis
  - Drag Predictions
  - Trade Studies
  - Airload Predictions
- Model Design Support
  - Model Requirements
  - Design Oversight
- Aero Prediction
  - Empirical
  - Analytical
  - CFD
- Test Support
  - Planning
  - Predictions
  - Conduct
- Post Test Data Analysis
  - Results Presentation
  - Aerodynamic Database Creation
    - Support 3-DOF Simulation
    - Support 6-DOF Simulation

The services of all groups are available, and information concerning capabilities may be obtained by contacting the manager of the Wind Tunnel Laboratories.

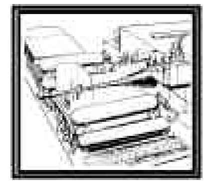
We invite potential customers to visit our HSWT facility. Further information related to visits, testing, scheduling or rental rates is available through either of the following:

Manager, Wind Tunnel Laboratories (972) 946-2751

Test Systems Design (972) 946-8208

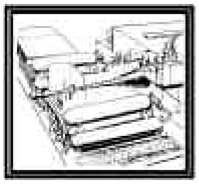
Lockheed Martin Missiles and Fire Control
P. O. Box 650003, MS LJS-05
Dallas, Texas 75265-0003

2.0 HIGH SPEED WIND TUNNEL FACILITY OVERVIEW



The High Speed Wind Tunnel is a blowdown-to-atmosphere, transonic-supersonic, 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



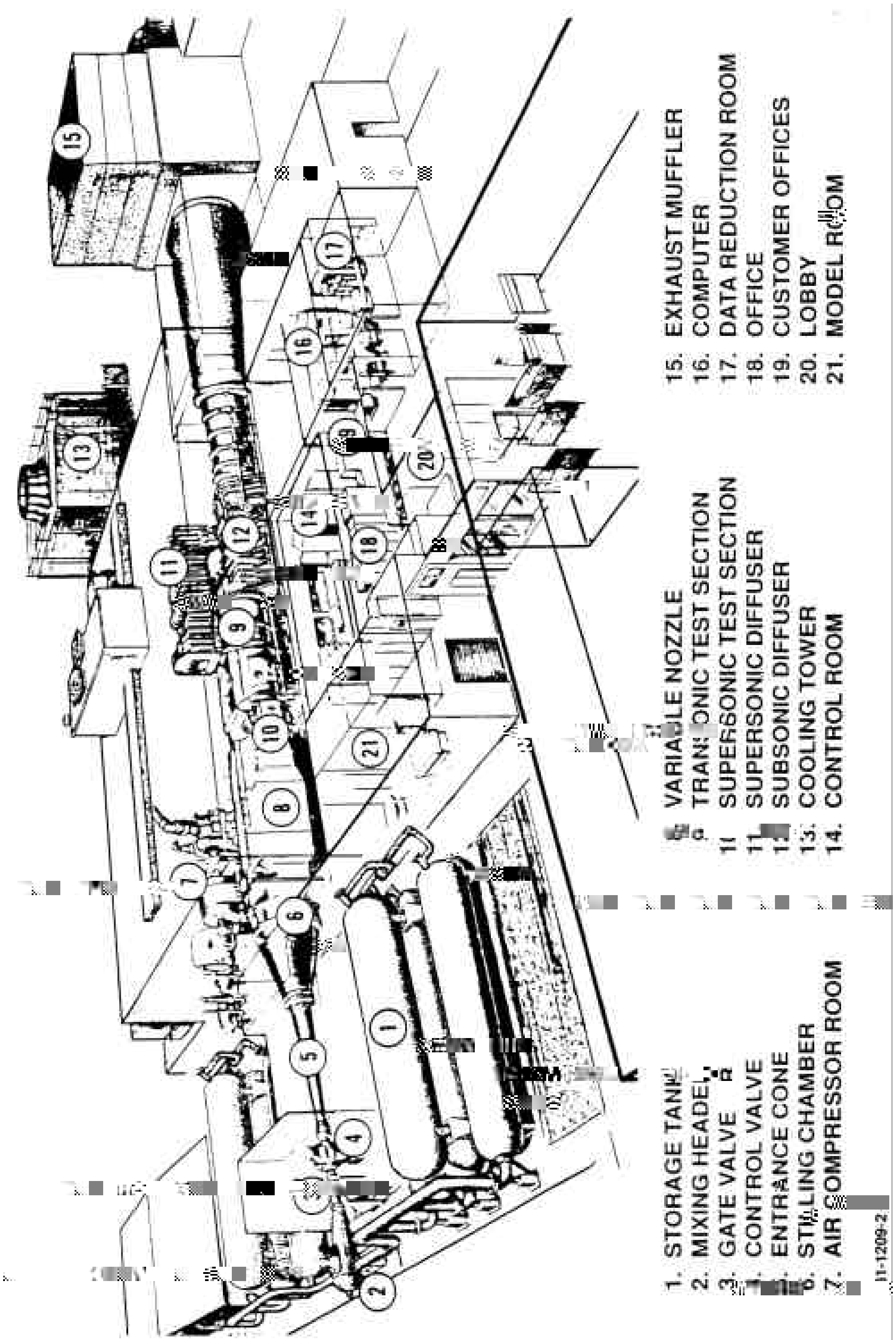
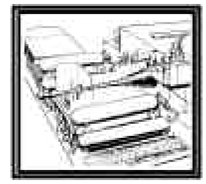


Figure 2-2 High Speed Wind Tunnel Circuit Layout

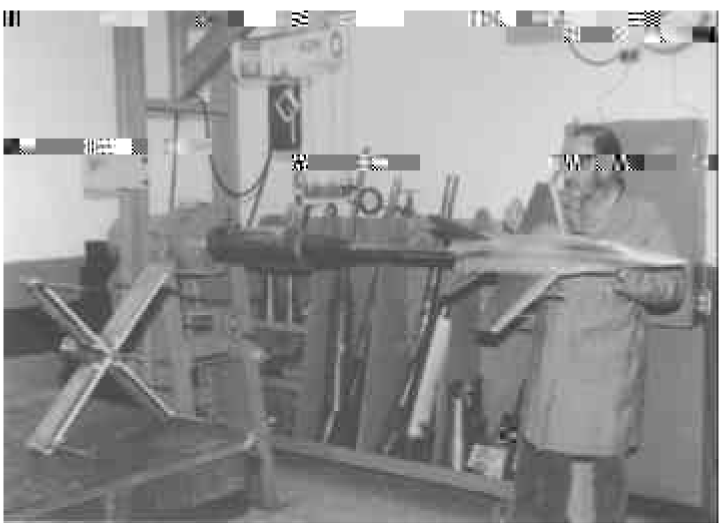


2.1 FACILITY DESCRIPTION

The wind tunnel building is divided into eight areas:

- Offices
- Model setup room
- Control room
- Data acquisition and processing system
- Instrumentation assembly and repair room
- Instrumentation calibration area
- High-bay area
- Compressor room.

Office space for wind tunnel customers is located adjacent to the wind tunnel circuit and is equipped with personal computer connections and a laser printer. Customers may bring laptop or personal computers provided arrangements are made in advance. Separate office areas are maintained for data reduction/computer operations and test operations. Reproduction facilities, classified storage files, and secretarial services are also conveniently located within the facility. All offices, shops and the high-bay area are air-conditioned.



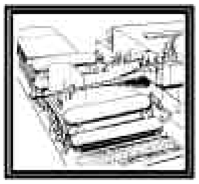
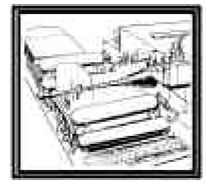


Figure 2-4 Model Setup Room Machine Shop Tools for Model Repairs and Modifications

Figure 2-5 shows 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 scanner, and a 16-channel high speed digital data recorder are also located in the control room.

Figure 2-5 Control Room and Data Signal Conditioning and Acquisition System

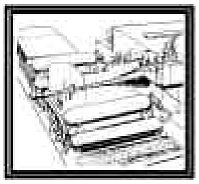


Adjacent to the control room is an area containing the data acquisition and processing system, as shown in Figure 2-6. This system computes final data listings and generates digital plots of selected parameters within a few minutes of each run. System operation and capabilities are described in more detail in Section 4.0 of this handbook.

Figure 2-6 Data Acquisition and Processing Equipment

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 transistor circuits.

An instrumentation calibration area is located on site for calibration of main balances as well as special balances such as for Fin or Wing loads data. Calibration of customer-supplied balances is



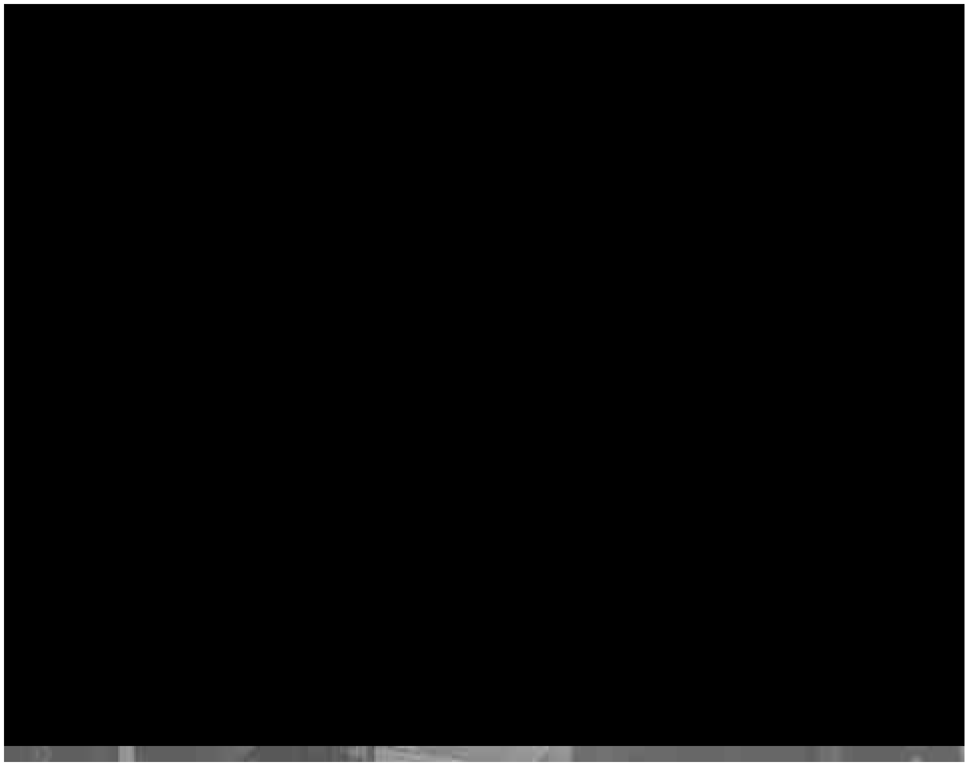


Figure 2-7 High-Bay Area with Transonic Test Section in Place

The compressor room, shown in Figure 2-8, is located north of the high bay area behind sound-absorbing concrete walls. Compressor, tunnel and building foundations are mutually independent to minimize transmission of vibration among the three units.

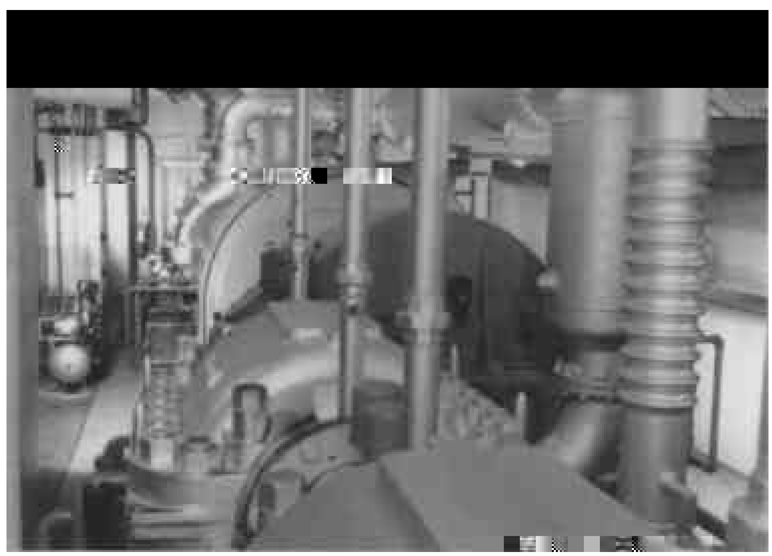


Figure 2-8 Compressor Room

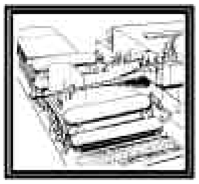
Tunnel occupancy time is charged for model installation, tank recharging after a valid run, test section changes, Mach number changes, model and/or instrumentation changes during the test, data acquisition changes, and model removal. However, most changes can be accomplished during the tank recharging time, thus avoiding additional charges. Occupancy time charge limits are normally imposed for model installation, test section changes, and model removals. Installation charges are based on system complexity and may range from 4 to 12 occupancy hours. The installation charges are agreed to by the customer and the assigned HSWT representative prior to the test. A maximum of 1 hour is charged for a test section change.

Occupancy charges for the HSWT are calculated based on actual tunnel time used. Testing times are determined based on the occupancy log sheet which is maintained by the assigned test operations engineer. The engineer is responsible for recording testing operations on a daily basis for each individual testing period. The customer representative reviews the log 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 cease 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 company equipment, lunch periods (except when the tanks are being filled), 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 an occupancy time log.

2.1.2 Security

Lockheed Martin Missiles and Fire Control has a Top Secret facility clearance granted by the Defense Investigative Service, St. Louis, Missouri, on 30 September 1992. The HSWT facility is completely enclosed within perimeter fencing to fully control access. During classified and customer proprietary testing, access is granted by means of written lists prepared by customer and assigned HSWT representatives and administered by LMMFC Security. All wind tunnel personnel have Secret clearances from the Department of Defense. In addition, the facility proper, including the computer, has been cleared by the Department of Defense for the storage of models and data of the same classification.



2.2 ADDITIONAL FACILITIES AND SERVICES

Wind tunnel customers can use any and all onsite capabilities in support of model and testing activities. Our machine shop, consisting of lathes, mills, drill presses, and grinders, is available to repair or modify models. The customer is invited to use this equipment with qualified operators or the facility can provide a machine operator for immediate repairs or model changes at no additional charge. In addition, the Test Systems Design group is available for any model design changes that may be desired.

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. Nominal costs combined with short schedules and availability make these services quite attractive for support of wind tunnel testing contracts or proposal work.

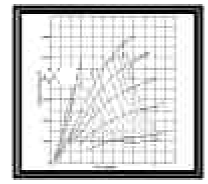
2.3 WIND TUNNEL OPERATING CAPABILITIES

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 and preparation and actual test planning and scheduling.

3.0 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 included in Table 3-I.

3.1 COMPRESSION AND STORAGE

An 8,000-horsepower electric motor drives three series-connected, multistage, centrifugal compressors with an exit pressure of 600 pounds per square inch absolute (psia). Intake volumetric flow rate is constant at 18,000 cubic feet per minute (ft^3/min). Moisture is removed from the compressed air by refrigeration and desiccant dryers to achieve dew-point temperatures of approximately –60 degrees Fahrenheit (°F). The air is then reheated to 350°F before delivery to the storage tanks.

Eight tanks with a total of 40,000 cubic feet of air storage capacity receive the reheated air until a maximum storage pressure of 520 psia is reached. The compressor discharge is then vented to atmosphere until the tank pressure is reduced to below 400 psia. An alumina pebble bed in each tank absorbs heat during pump-up and dissipates heat during air discharge to maintain a near-constant supply temperature.

The time required to recharge the air storage tanks following a run varies from 15 to 75 minutes, depending on the final tank pressure. A nominal tank pressure increase rate is 5 pounds per square inch (psi) per minute.

3.2 FLOW CONTROL

Airflow through the wind tunnel is controlled by three valves between the storage tanks and test section. A squib-fired safety valve located in the mixer header is preset to close automatically if the stilling chamber pressure exceeds a preset level. A pneumatic gate valve, located upstream of the control valve, is normally closed and is opened only during a run.

Flow is controlled by a hydraulically operated, servo-controlled, rotating plug valve located just upstream of the entrance diffuser. This control valve maintains a stagnation pressure in the stilling chamber that matches a set point pressure selected in the control room. The set point pressure can be either constant or a time variable, depending on the type of test run desired.

Downstream of the control valve are the entrance diffuser and stilling chamber. The entrance diffuser reduces the air velocity from supersonic at the 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.

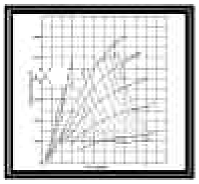
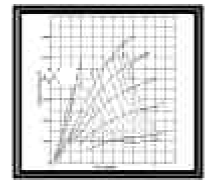


TABLE 3-I HIGH SPEED WIND TUNNEL OPERATING PARAMETERS AND DESCRIPTIVE DETAILS

TYPE OF TUNNEL	**BLOWDOWN-TO-ATMOSPHERE**
Air Storage Capacity	40,000 Cubic Feet
Maximum Storage Pressure	520 psia
Air Compression Rate	16 to 18 lb/sec
Nominal Tank Temperature	100°F
Temperature Drop During Run	



3.3 VARIABLE CONTOUR NOZZLE

0.75-inch thick, 48 inches wide and 453 inches long, 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.

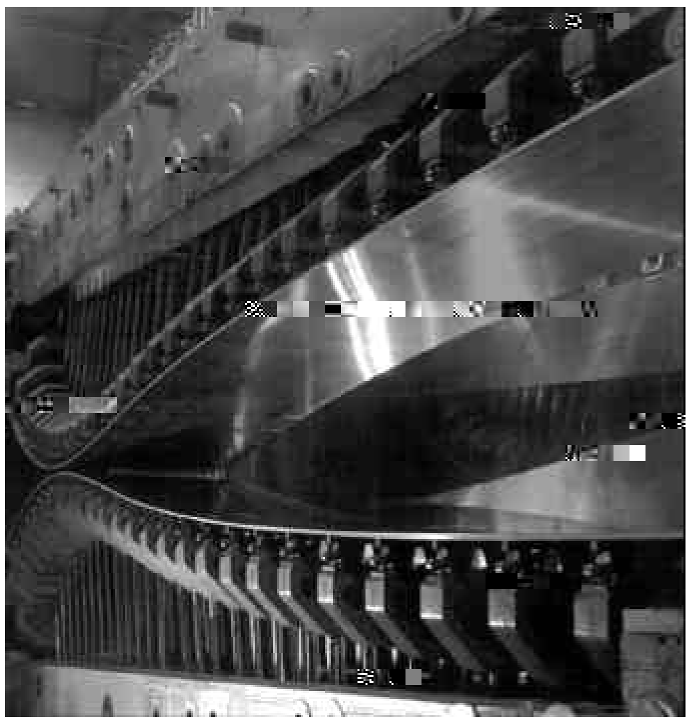


Figure 3-1 Variable Contour Nozzle and Flexible Nozzle System With Side Wall Removed

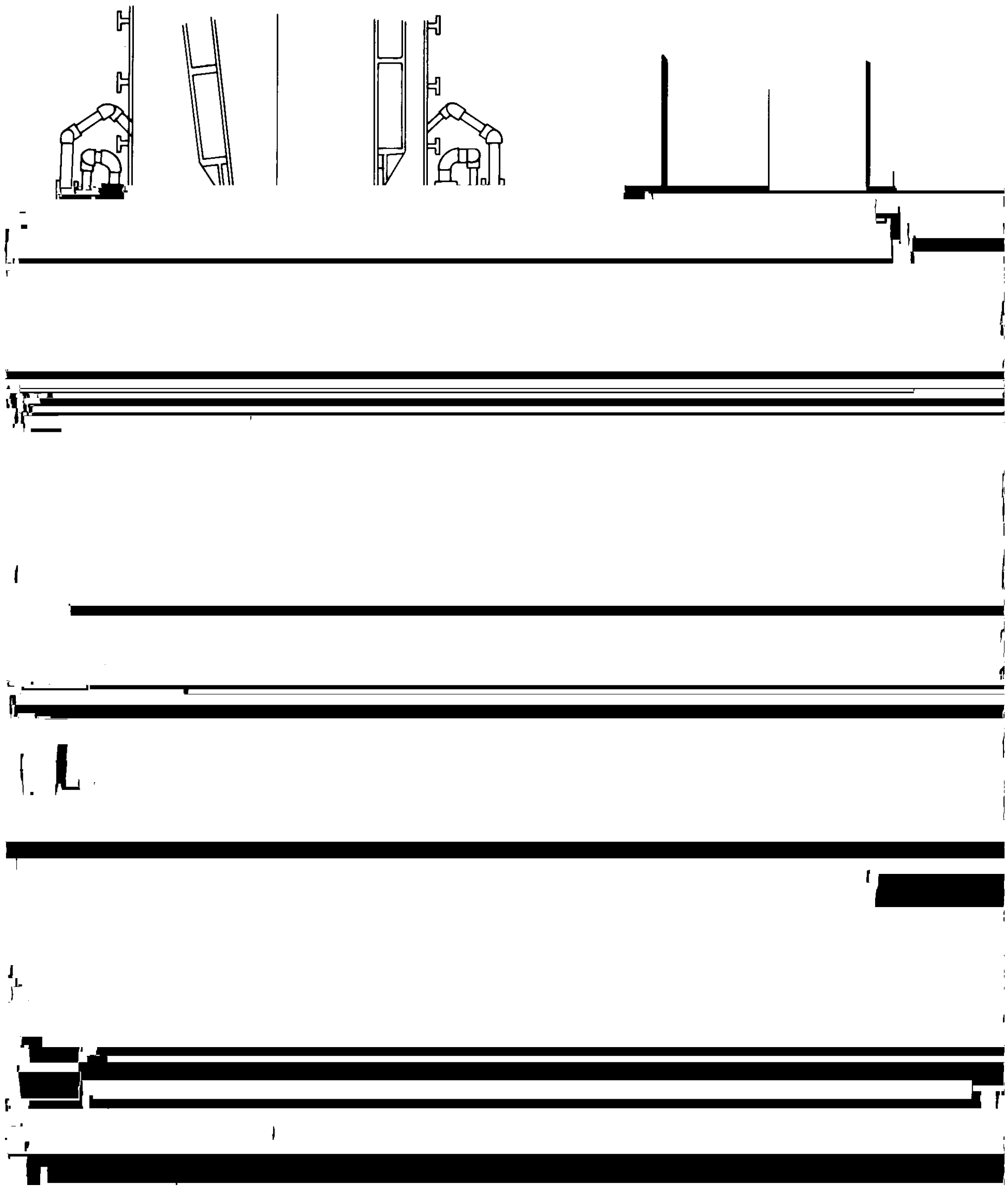
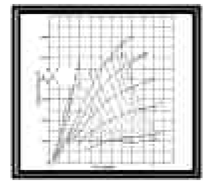


Figure 3-2 Supersonic Test Section With Diffuser in Place



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

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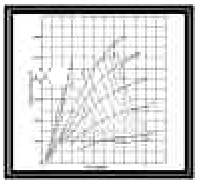


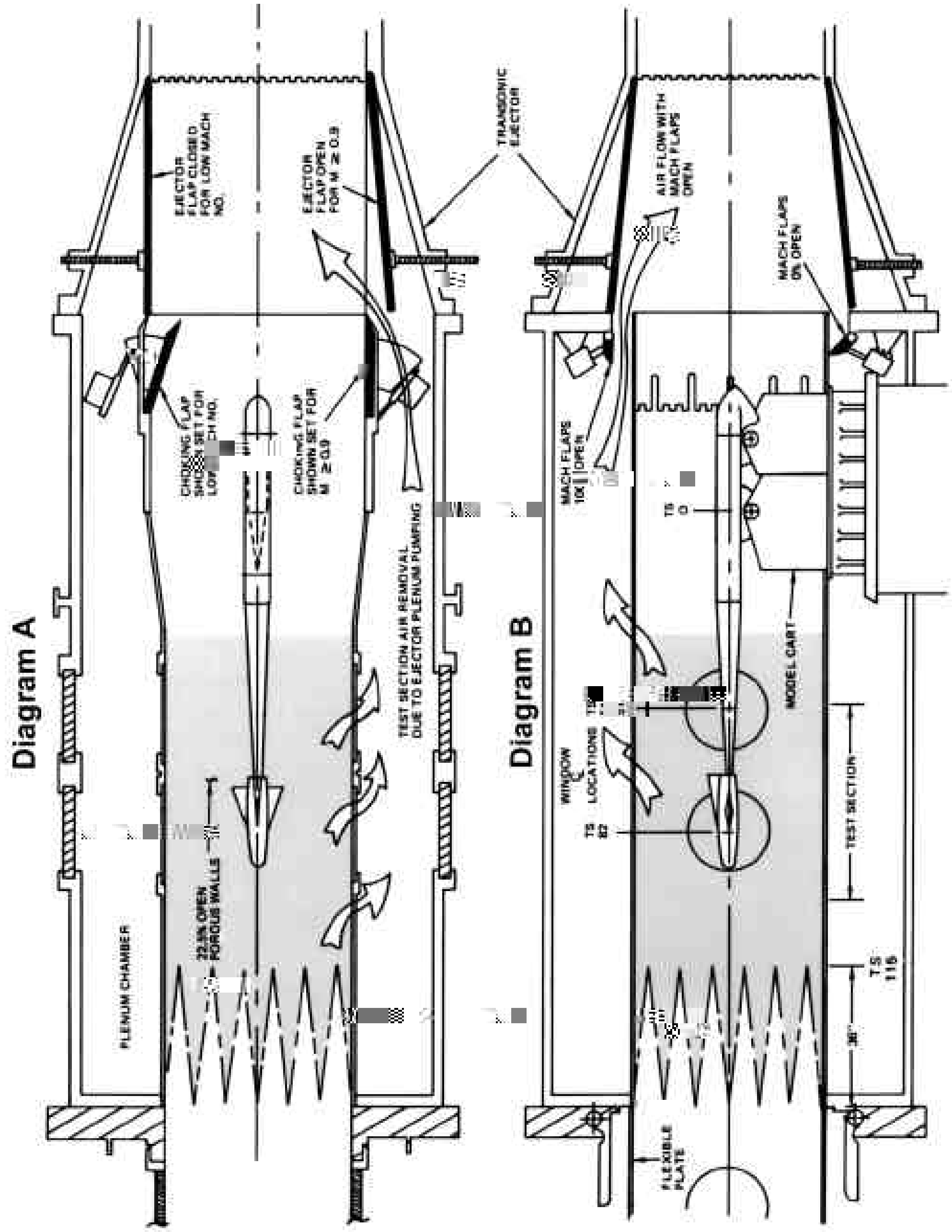
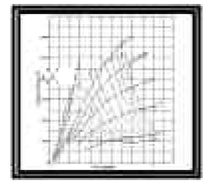


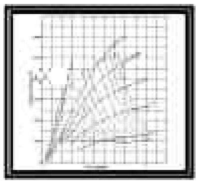
Figure 3-3 Transonic Test Section and Ejector



3.5 PERFORMANCE AND OPERATIONAL CHARACTERISTICS

The High Speed Wind Tunnel covers a Mach number range of 0.3 to 4.8 using two test sections, as described in the preceding paragraphs. The perforated-wall transonic test section operates over the range of Mach 0.3 to Mach 1.8. The supersonic test section and diffuser operates between Mach 1.4 and Mach 4.8.

To provide potential customers with sufficient data for determining the applicability of the HSWT



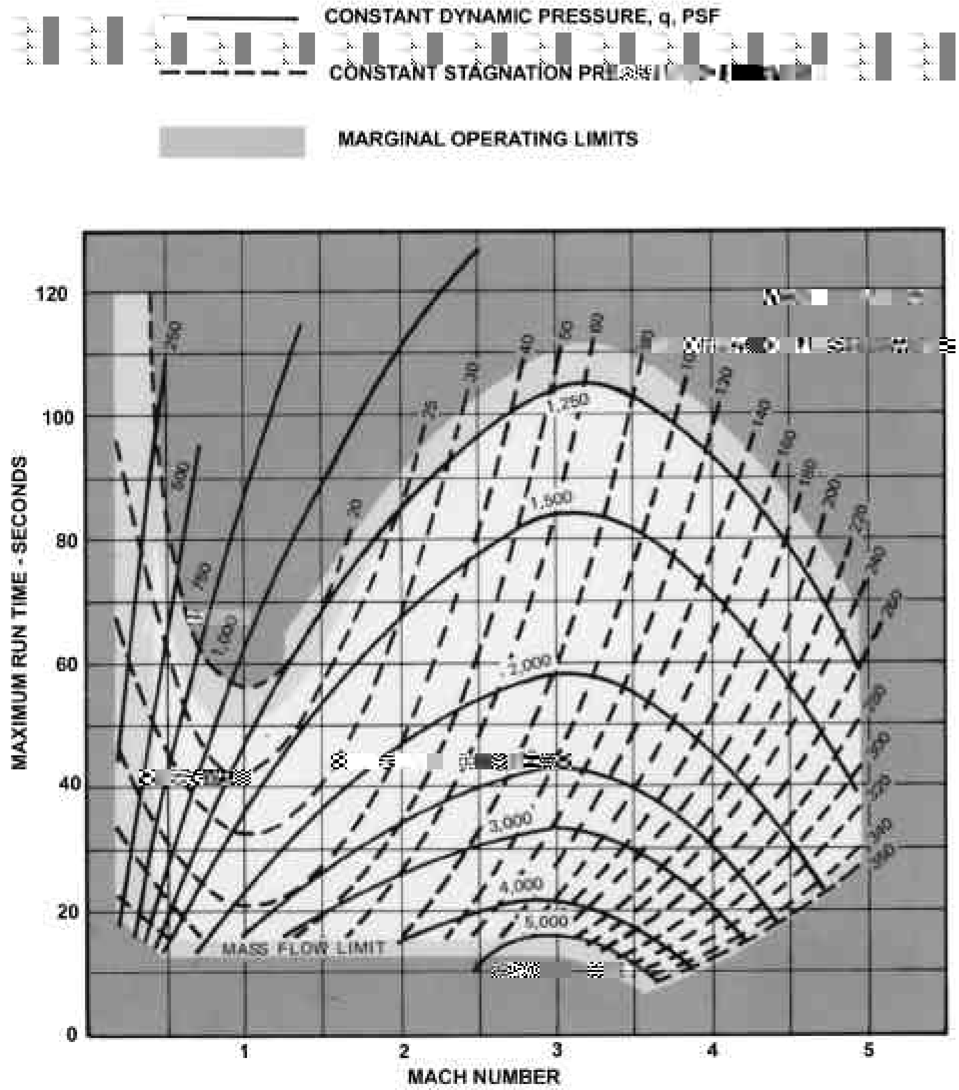
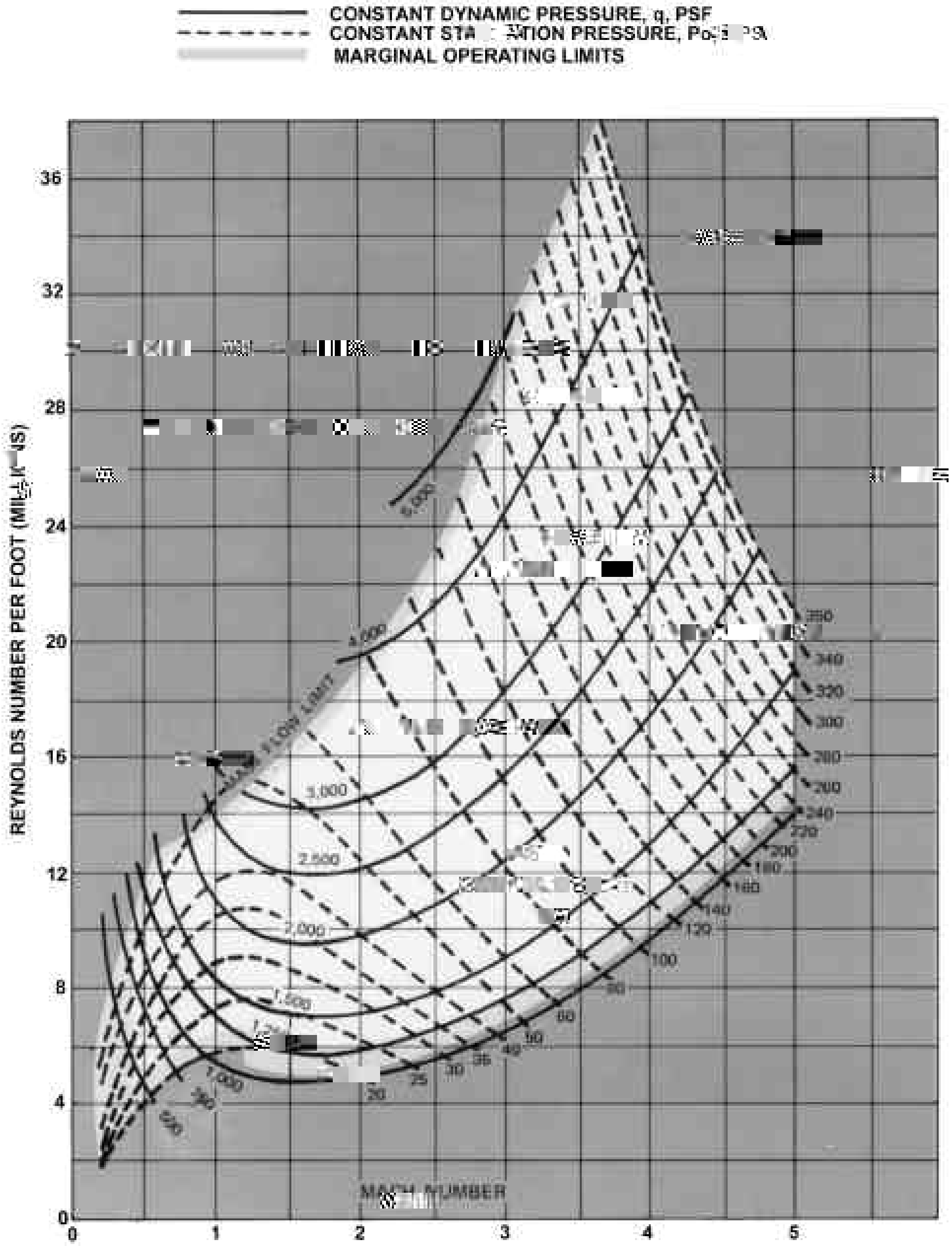


Figure 3-4 Maximum Run Time as a Function of Mach Number



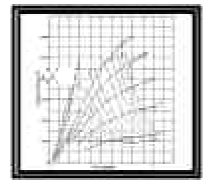
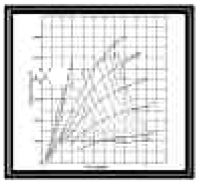


Figure 3-5 Variation of Reynolds Number With Mach Number for T_O = 100°F



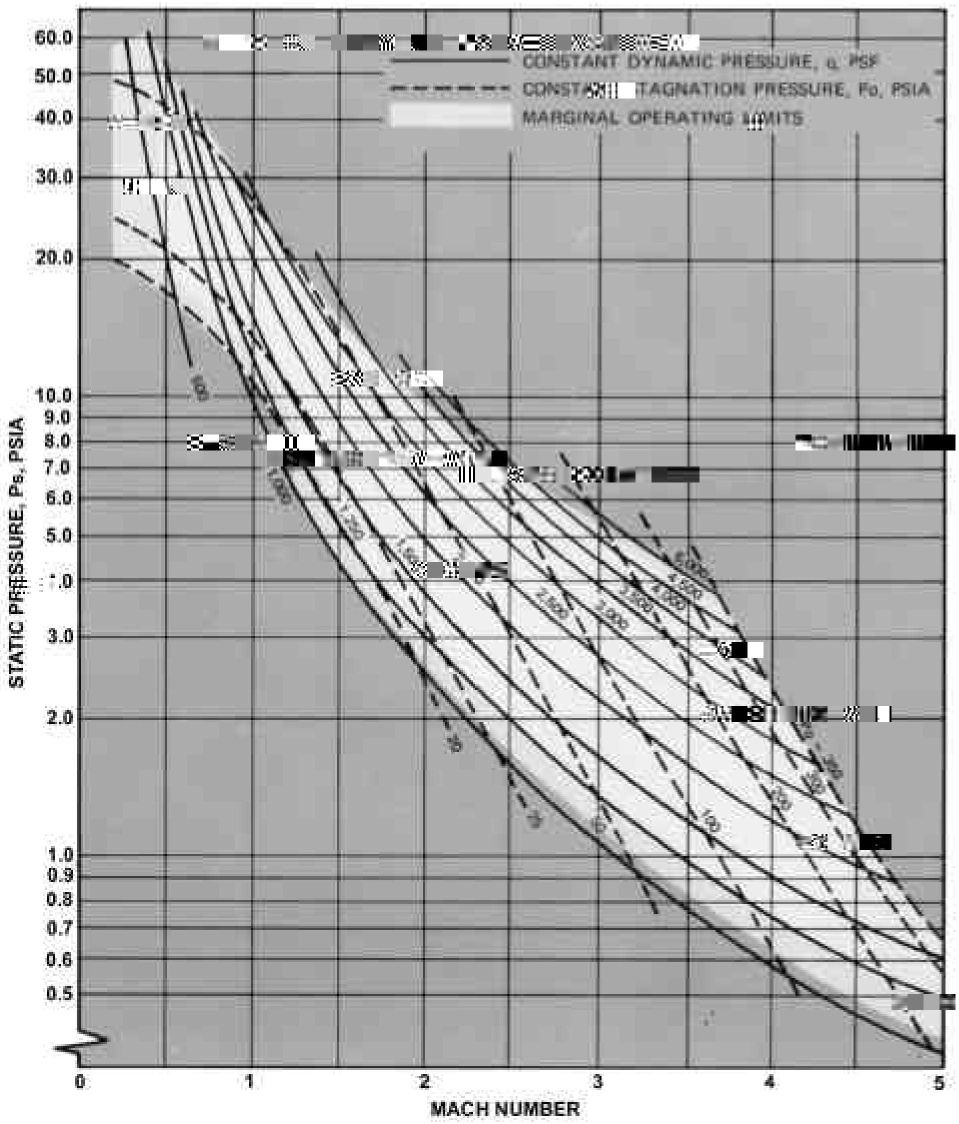


Figure 3-6 Static Pressure as a Function of Mach Number

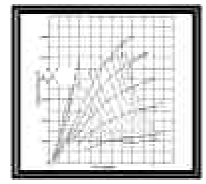
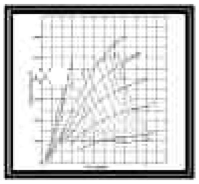


Figure 3-7 Dynamic Pressure Variation as a Function of Mach Number



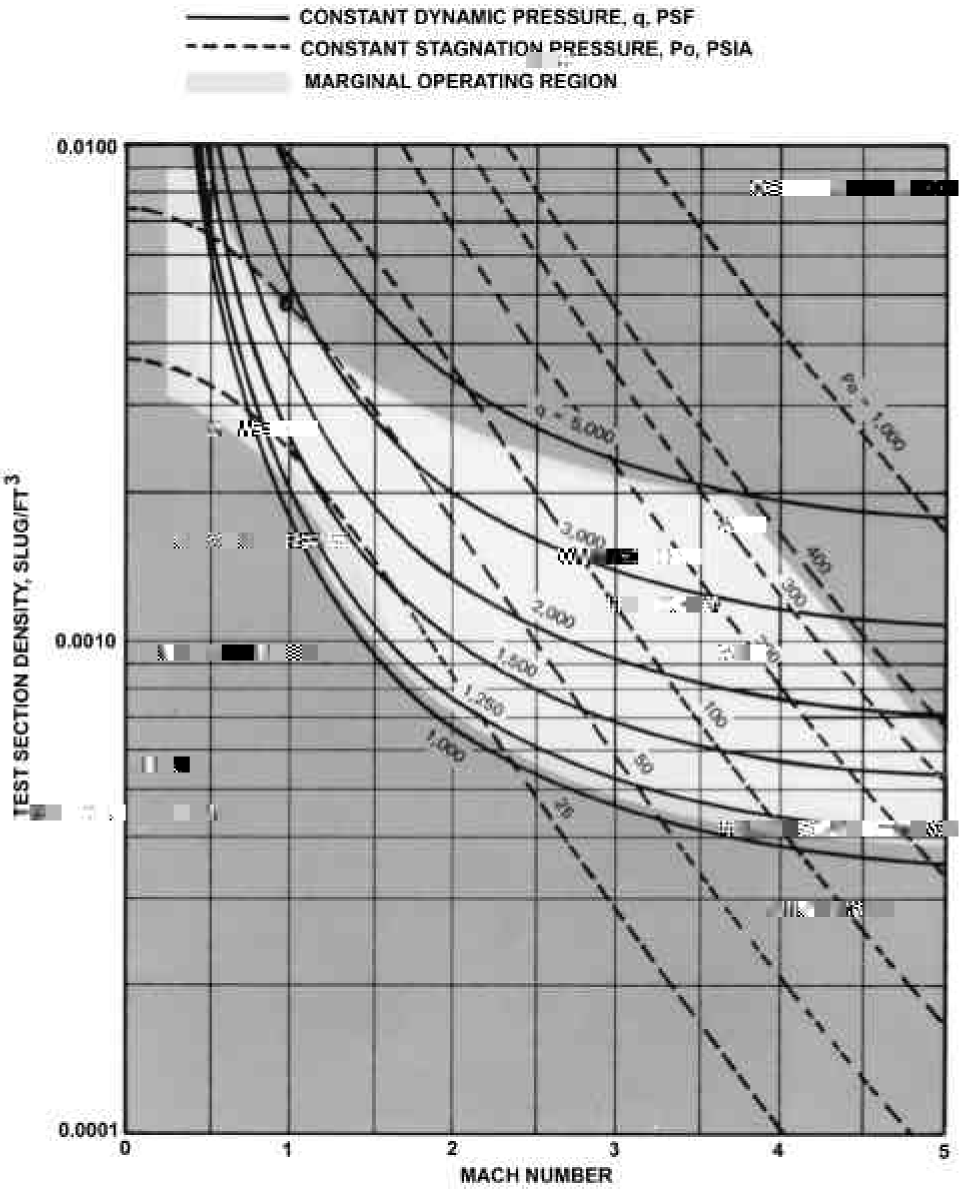


Figure 3-8 Test Section Density Variation as a Function of Mach Number

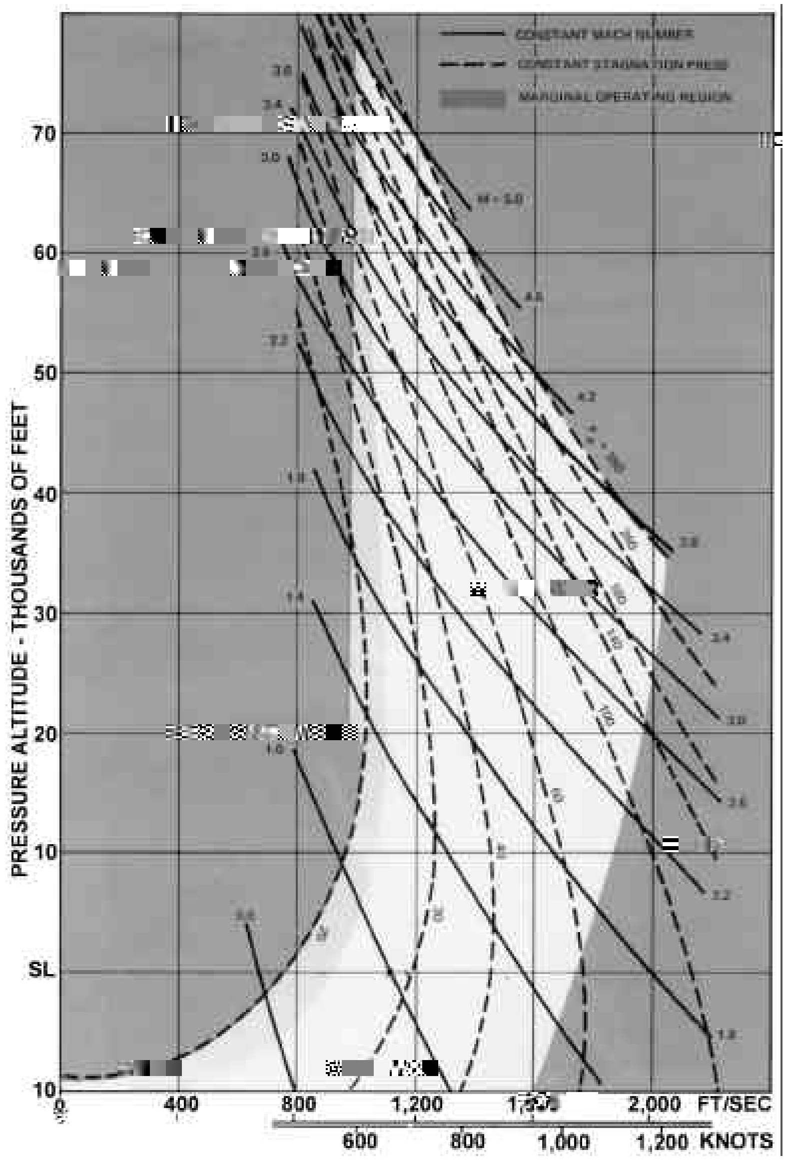
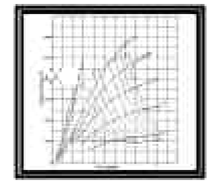


Figure 3-9 Pressure Altitude Versus Equivalent Airspeed



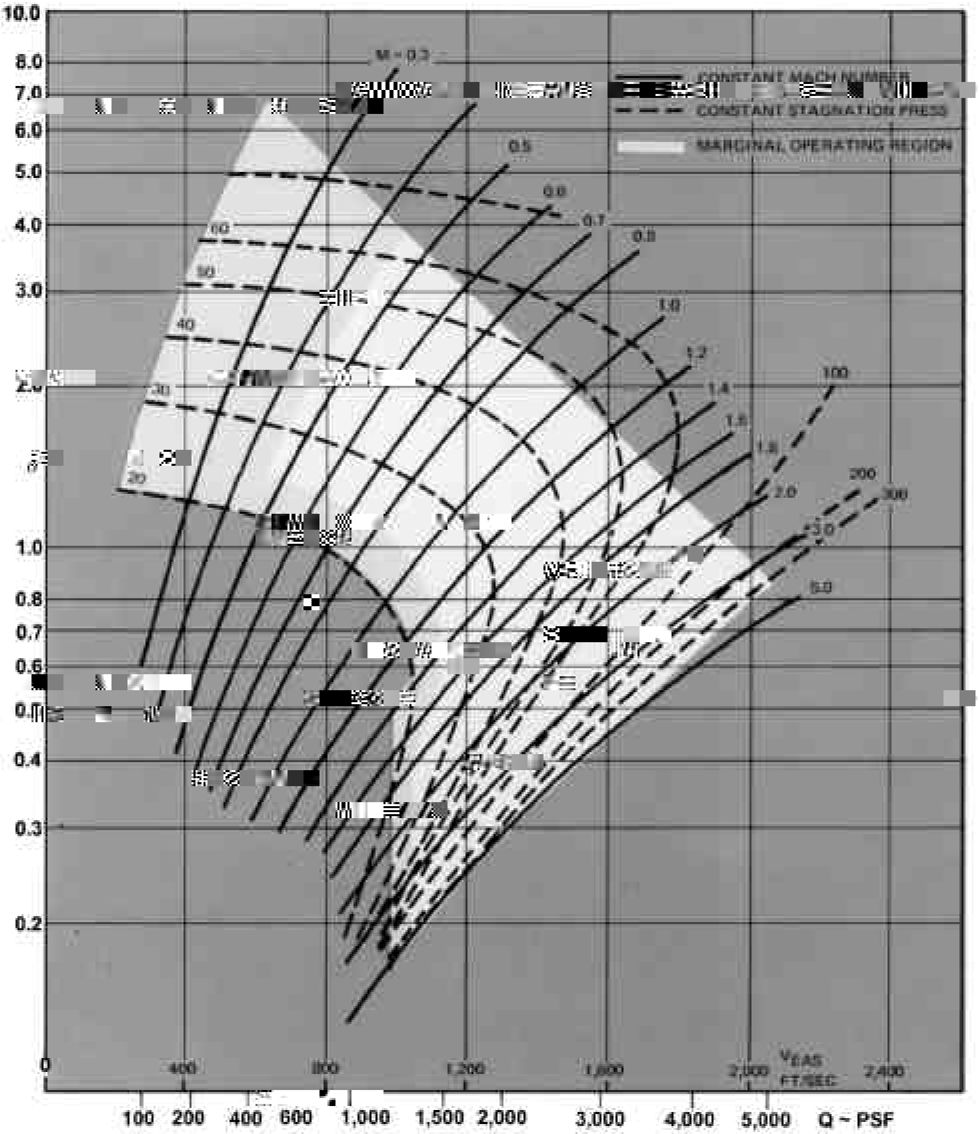
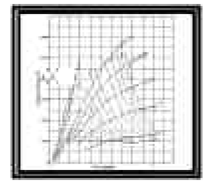


Figure 3-10 Density Ratio Versus Equivalent Airspeed and Dynamic Pressure



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 3-4 shows calculated run time as a function of Mach number and stagnation pressure. The maximum run time is based on an initial tank 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 3-9 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 an ARDC model atmosphere was used to obtain pressure altitude equivalence. For convenience, equivalent airspeed is presented in both feet/second and knots. Density ratio versus dynamic pressure and equivalent airspeed is shown in Figure 3-10.

3.5.2 Calibration Data

Mach number and flow angularity calibrations for the High Speed Wind Tunnel are repeated from -9

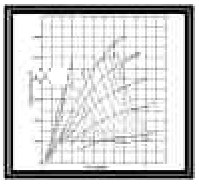


TABLE 3-II HIGH SPEED WIND TUNNEL TRANSONIC MACH NUMBERS AND MACH FUNCTIONS

NOMINAL* MACH NO.	P_S/P_O	q/P_S	q/P_O	T/T_O	$P_S/P_?$	$P_?/P_O$
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

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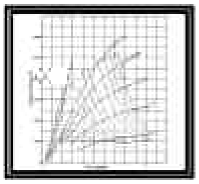


For special requirements, certain tunnel or model parameters can be controlled with an analog or

4.0 DATA ACQUISITION AND PROCESSING CAPABILITIES

LMMFC HSWT offers comprehensive data acquisition and processing capabilities to meet a wide variety of testing requirements. Capabilities include:

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

TABLE 4-I HIGH SPEED WIND TUNNEL DATA PROCESSING EQUIPMENT

EQUIPMENT ITEM	QUANTITY
16-BIT CENTRAL PROCESSING UNIT (CPU) WITH 6-MEGABYTE (MB) MEMORY	1
404-MB MOVING HEAD DISK	1
650 MB CDROM WRITER	1
STANDARD CATHODE RAY TUBE (CRT) DISPLAY DEVICES	3
GRAPHIC CRT DISPLAY DEVICES	2
LASER PRINTER (HEWLETT-PACKARD) LASERJET FOR PLOTTING REDUCED DATA	2
ANALOG-TO-DIGITAL CONVERTER WITH 15-BIT, 64-CHANNEL MULTIPLEXER	1
DIGITAL-TO-ANALOG CONVERTER WITH 4 CHANNELS	2
UNIVERSAL COUNTER	1

During each wind tunnel test run, the system's computer multiplexer terminal receives filtered analog outputs from the instrumentation amplifiers. All inputs are sampled at a commutation rate of 125,000 (variables) per second at intervals of 5, 10 or 20 times per second. The maximum voltage output of ±10 volts is converted to ±32,768 counts. After analog-to-digital conversion, the data are stored on a disk file.

After each test run, complete and final coefficient data are tabulated and printed out on 8½ x 11 paper in customer-specified format. Digital coefficient data plots of selected parameters are produced using the LaserJet printers. Requested plots are immediately available 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 includes:

- 8 channels of wide-band direct current (dc) amplifiers
- 16-channel Astro-Med MT9500 chart recorder
- 8-channel Astro-Med DASH 8 portable chart recorder
- 16-channel Iotech high speed digital data acquisition system
- Spin physics and high-speed film (up to 3,000 frames per second).

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 6.0 of this handbook in paragraphs 6.2 and 6.3.

4.3 STEADY-STATE FORCE INSTRUMENTATION

Over 30 internal strain gauge balances are available for customer use in measuring model forces and moments. These 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 4-1.

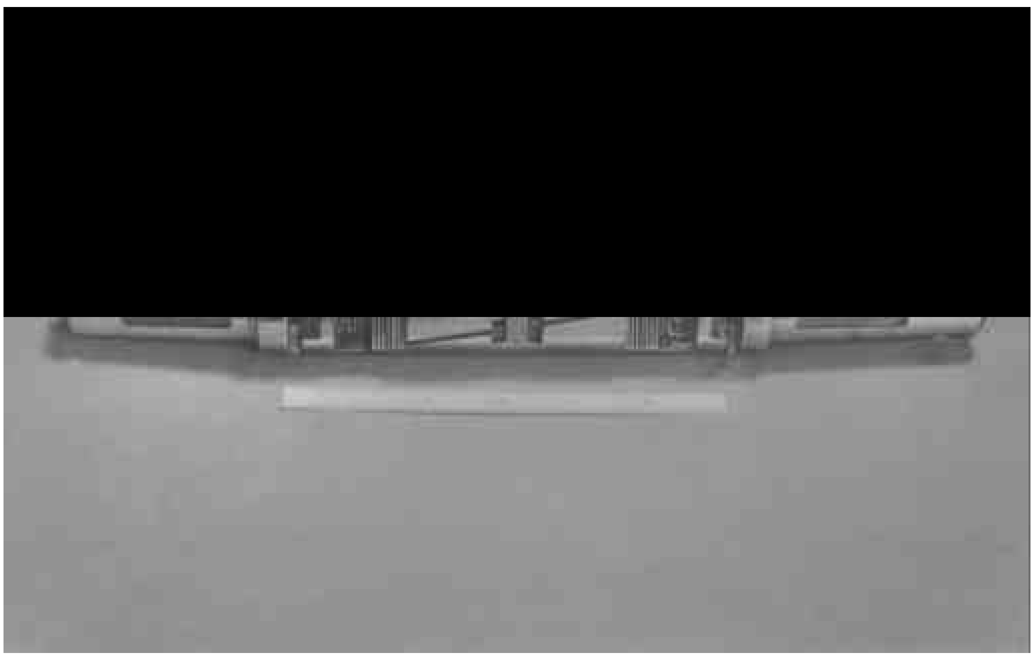
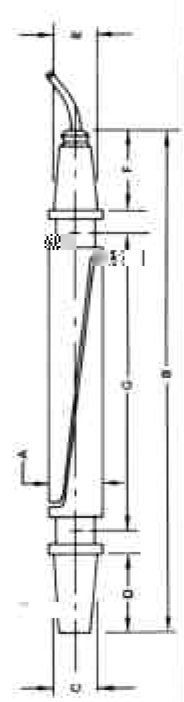


Figure 4.1 Typical One-Piece, Six-Component Strain Gauge Balance

Balances are available in a number of sizes, as described in Table 4-II. For best results, the balance maximum-rated load should approximately equal 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 Systems Design group. Custom instrumentation design and fabrication are available for customer purchase under contract.

TABLE 4-II INTERNAL FORCE BALANCE LOAD AND DIMENSIONAL INFORMATION



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

BAL NO	DIMENSIONS, INCHES A	B	C	D	E	F	G	TABLE OF MAXIMUM LOADS N	PM	Y	YM	RM	AF	AFT END TAPER CODE	REMARKS
VB-5	1.20	10.0	1.20	2.0	1.00	2.1	4.8	550	[illegible]	350	525			B	
VB-7	2.75	16.2	2.75	3.5	2.75	3.5	8.0	5,000	[illegible]	3,500	7,700	2,500	4,000	C	
VB-10	0.75	8.1	0.75	1.0	0.54	1.0	3.6	340	[illegible]	290	3155	70		D	
VB-14	2.00	13.8	1.25	2.5	1.25	3.0	7.0	2,000	[illegible]	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	[illegible]	400	850	500	250	B	
VB-18	[illegible]	12.7	1.25	2.5	1.25	3.0	6.0	1,800	[illegible]	1,800	2,250	1,250	300	A	
VB-20	[illegible]	10.0	1.20	2.0	1.00	2.1	5.0	400	[illegible]	300	375	200	400	B	
VB-21	1.50	12.7	[illegible]	2.5	1.25	3.0	6.0	1,000	[illegible]	800	[illegible]	400	200	A	
VB-28	[illegible]	14.2	[illegible]	3.0	1.50	3.0	6.9	2,800	[illegible]	2,100	[illegible]	1,800 1,500	[illegible]	E	INTERCHANGEABLE RM / AF ELEMENTS
VB-36*	[illegible]	12.7	[illegible]	2.50	1.25	3.00	6.0	2,000	3,000	800	[illegible]	1,200	100	A	INTERCHANGEABLE WITH VB-18
VB-38*	1.25	10.0	1.20	2.00	1.00	[illegible]	5.0	800	2,000	440	[illegible]	600	[illegible]	B	INTERCHANGEABLE WITH VB-17
VB-40	0.60	5.13	0.50	1.00	[illegible]	[illegible]	2.75(2.8)	125	160	100	[illegible]	60	15	[illegible]	
VB-42*	0.75	8.1	0.75	1.00	[illegible]	1.00	3.6	175	185	150	[illegible]	100	75	D	INTERCHANGEABLE WITH VB-11
VB-44*	1.50	12.7	1.25	2.5	[illegible]	[illegible]	6.0	1,800	2,250	1,800	[illegible]	1,250	300	A	INTERCHANGEABLE WITH VB-18
VB-46*	1.25	10.0	1.20	2.0	[illegible]	[illegible]	5.0	640	1,600	640	[illegible]	600	125/400	B	SYMMETRICAL VB-38
VB-48*	1.85	14.2	1.50	3.0	[illegible]	3.1	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	[illegible]	0.72	2.21	35	35	35	35	27	10	A	
VB-51	1.25	10.00	1.20	2.00	[illegible]	[illegible]	5.30	875	1,112	875	1,112			B	FOUR COMPONENT
VB-52	1.00	8.22	0.80	1.68	[illegible]	[illegible]	4.30	800	750	300	700	350	125	F	
VHB-2	0.50	3.75	0.50	0.25	[illegible]	0.68	2.5	10	13	5	8	5	10		
VHB-5	0.50	3.11	0.50	0.25	[illegible]	0.68	2.0	6	8	2	2	2	7		
VHB-7*	0.46	3.36	0.46	0.50	[illegible]	0.68	2.0	35	35	18	18	27	10		
VHB-11	0.37	4.0	0.30	0.37	[illegible]	0.61	2.5	10	10	10	10	3	5		TWO (2) AVAILABLE
VTB-4	1.20	10.0	1.20	2.0	[illegible]	2.1	4.9	740	950	40	950	400		B	0.5 DIA HOLD ON ℄
VTB-12	1.50	15.65	1.25	2.62	[illegible]	3.12	6.0	1,800	2,000	[illegible]	2,000	500		A	0.88 DIA HOLE 2000 PSI
VSB-1	0.75	4.1	0.625	0.19	[illegible]	0.97	2.4	6	8	3	3	2.5	11	D	SEMICONDUCTOR BRIDGES
VSB-3	0.30	7.9	0.30	0.38	[illegible]	0.61	2.0	5	2	2	2				
VSB-4	1.80	34.8	1.25	2.5	[illegible]	3.75	6.0	1,500	2,256	700	1,050	1,380	250		INTEGRAL STING-BALANCE
VSB-10	0.30	7.6	0.30	0.50	[illegible]	0.80	2.4	34	34	34	34	3			
VSB-12	0.325	2.99	0.25	0.375	[illegible]	0.485	1.8	15	14	15	14	4			SEVEN (7) AVAILABLE
VSB-13	1.50	12.7	1.25	2.5	[illegible]	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	[illegible]	1.0	2.3	35	40	20	23	19			INTEGRAL STING-BALANCE
VSB-42	0.25	8.37	0.25	0.37	[illegible]	0.61	1.3	20	10	20	13	3			INTEGRAL STING-BALANCE

*one-piece design

A sketch of a typical balance adapter with an integral insulated taper for a model fouling indicator is shown in Figure 4-2.

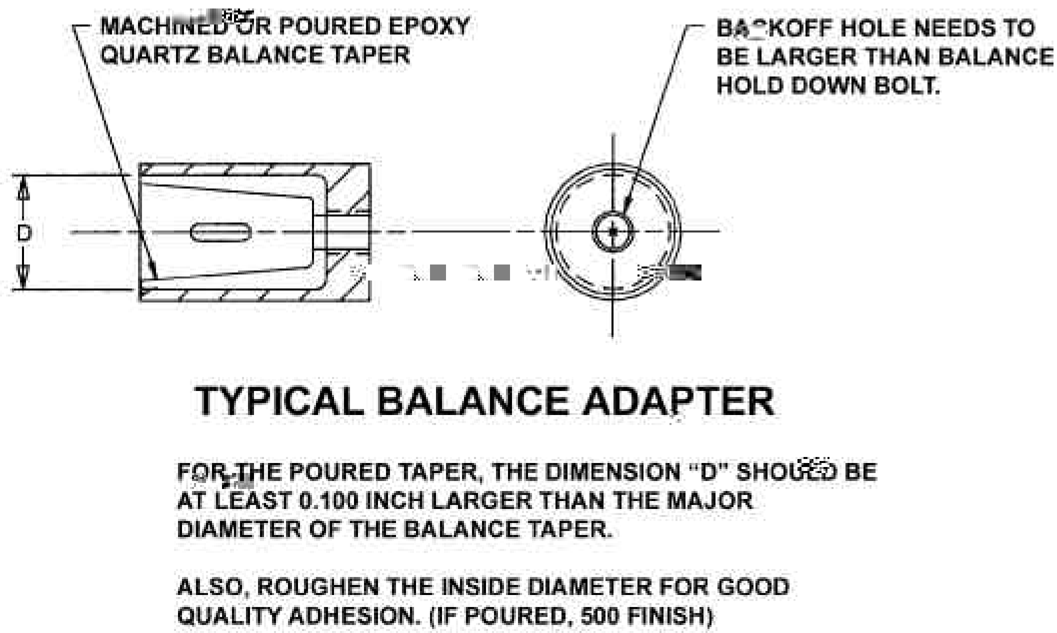


Figure 4-2 Typical Balance Adapter

4.4 STEADY-STATE PRESSURE INSTRUMENTATION

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

- Individual pressure transducers
- Electronically scanned pressure modules

Pressure calibration instrumentation is also available to verify pressure system data accuracy.

The electronic system is manufactured under the trade name, Scanivalve.

We maintain 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 25 pressures are measured using the electronically scanned pressure modules. Two types of modules are available, as shown in Figure 4-3. The ZOC 14 and ZOC 22 modules have 32 ports. One model ZOC 12 module has 16 ports. These modules are used for pressures up to 50 psid. The maximum reference pressure for the ZOC 12 and 22 is 50 pounds per square inch gauge (psig). The ZOC 14 modules are used for pressures up to 100 psid. The maximum reference pressure for the ZOC 14 is 100 psig.

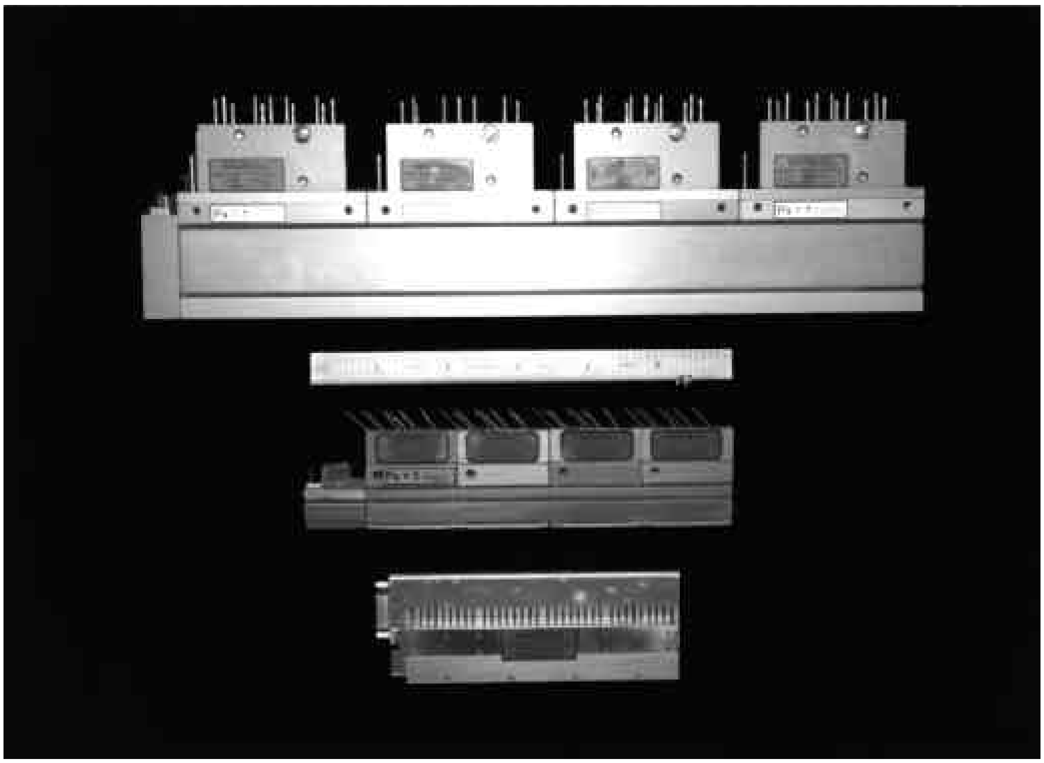
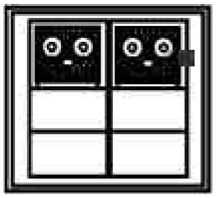


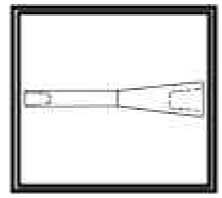
Figure 4-3 Electronically Scanned Pressure Modules and Range Specifications

Pressure calibration instrumentation available includes two dead-weight calibration systems as well as 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.



If a formal data report is requested for tests resulting from less than 30 occupancy hours, the customer incurs 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.

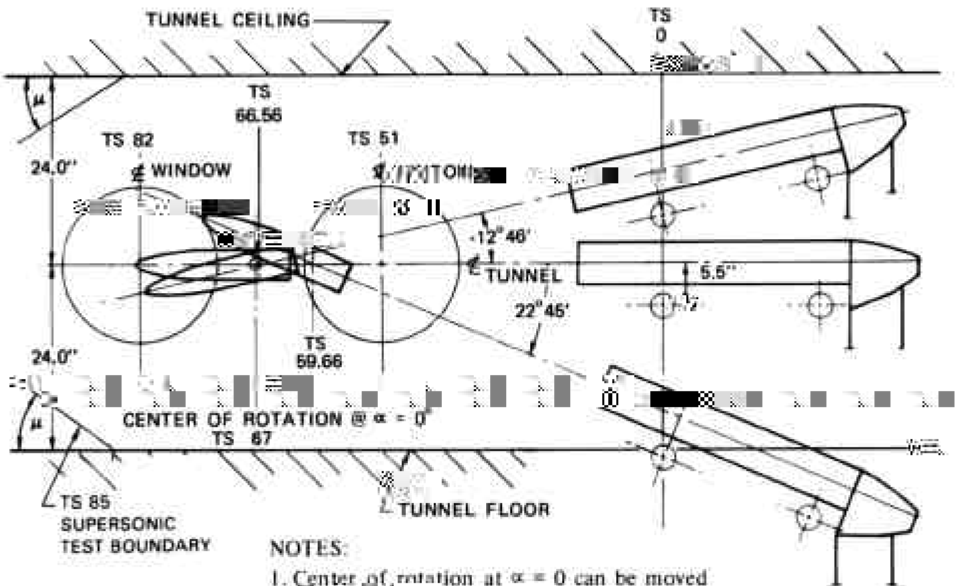
5.0 MODEL SUPPORT SYSTEM



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

5.1 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



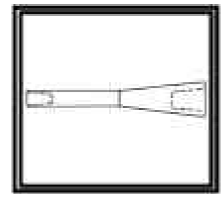
NOTES:

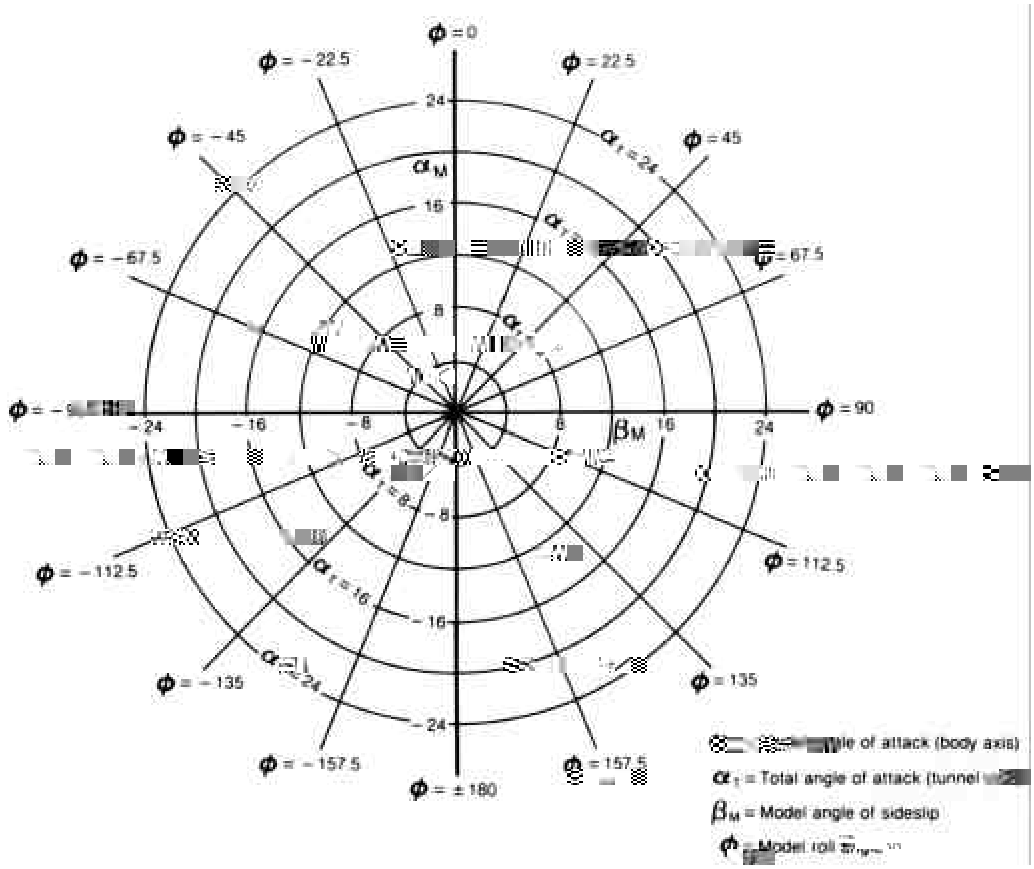
1. Center of rotation at α = 0 can be moved to tunnel station 60.00.
2. Center of rotation at angles other than zero given by

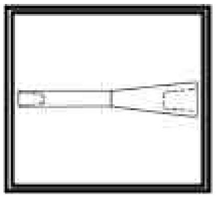
$$L \cos \alpha - 5.5 \sin \alpha$$

where L is center of rotation at α = 0

Figure 5-1 Model Cart Kinematics



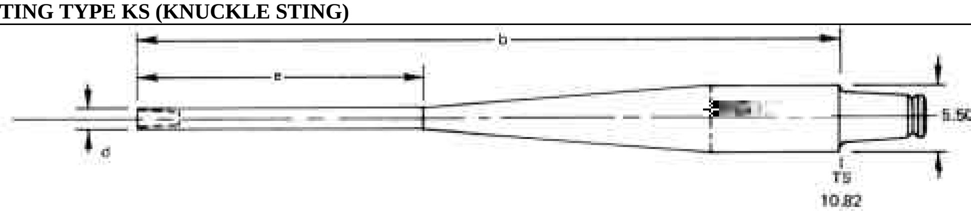

φ = 0
φ = −22.5
φ = 22.5
φ = −45
φ = 45
φ = −67.5
φ = 67.5
φ = 90
φ = −112.5
φ = 112.5
φ = −135
φ = 135
φ = −157.5
φ = 157.5
φ = ±180
αM
βM
αt = 8
αt = 16
αt = 24
24
16
8
−8
−16
−24
αt = Total angle of attack (tunnel
βM = Model angle of sideslip
Model roll



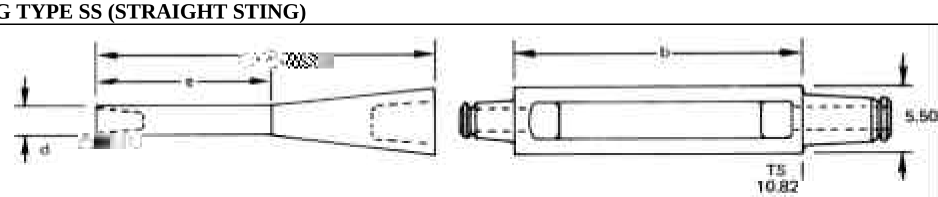
5.3 SUPPORT STINGS AND ADAPTERS

Models are normally mounted from the rear on a sting and model cart assembly, as described in paragraph 5.1 above. To accommodate accurate model mounting, a number of sting configurations are available as standard wind-tunnel-furnished equipment for customer use. Available sting types include knuckle stings (KS), straight stings (SS), pressure stings (PS) or roll stings (RS). Each sting's forward end is coded to match the taper dimensions with mating parts. The mating part may be a balance (as described in Section 4.0), a sting extension or a special adapter Available model support stings are described in Table

STING TYPE KS (KNUCKLE STING)



STING TYPE SS (STRAIGHT STING)



STING TYPE PS (PRESSURE STING) OR RS (ROLL STING)

CONFIG NO.	STING TYPE	MAX LOAD LB	FWD TAPER CODE	DIMENSIONS (INCHES)					TS FWD END
				a	b	c	d	e	
1	SS	2,000	A	-	52.10	-	1.75	36.00	62.92
2	PS	5,000	C	-	24.05	28.28	3.00	21.28	63.20
3	KS	4,000	A	4.13	26.00	22.00	1.75	17.00	62.95
4	KS	750	B	4.13	26.00	30.70	1.20	25.42	71.65
5	KS	750	B	4.13	20.00	30.70	1.20	25.42	65.65
6	KS	4,000	A	4.13	20.00	22.00	1.75	17.00	56.95
7	KS*	2,000	A	4.13	26.00	29.05	1.75	18.96	69.99
8	KS*	2,000	A	4.13	20.00	29.05	1.75	18.96	63.99
11	PS*	2,000	A	-	24.05	34.12	1.75	18.96	69.04
12	PS*	2,000	A	-	24.05	28.12	1.40	14.50	63.04
13	KS	750	B	4.13	26.00	23.52	1.20	18.25	64.47
14	KS	750	B	4.13	20.00	23.52	1.20	18.25	58.47
15	KS*	2,000	B	4.13	20.00	23.05	1.40	14.50	57.99

(CONTINUED NEXT PAGE)

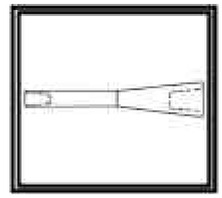


TABLE 5-II AVAILABLE MODEL SUPPORT STING CONFIGURATION
(SHEET 2 OF 2)

CONFIG NO.	STING TYPE	MAX LOAD LB	FWD TAPER CODE	DIMENSIONS (INCHES)					TS FWD END
				a	b	c	d	e	
16	KS*	2,000	B	4.13	26.00	23.05	1.40	14.50	63.99
17	PS	2,000	A	-	24.05	31.88	1.60	21.75	66.80
18	PS*	1,500	A	-	24.05	34.12	1.50	18.00	69.04
19	KS*	1,500	A	4.13	26.00	29.05	1.50	18.00	69.99
20	KS*	1,500	A	4.13	20.00	29.05	1.50	18.00	63.99
21	KS	3,380	A	4.13	26.00	29.83	1.50	23.67	70.77
22	KS	3,380	A	4.13	20.00	29.83	1.50	23.67	64.77
23	SS	1,000	THREADED	-	32.14	-	3.00	4.41	43.06
24	SS	2,000	THREADED	-	20.76	-	3.92	0	31.58
25	SS	1,000	A	-	67.26	-	2.00	3.75	78.08
26	SS	1,700	B	-	55.60	-	1.20	10.50	66.42
27	SS	3,100	THREADED	-	52.68	-	2.50	25.50	63.50
28	PS	1,200	B	-	24.05	36.30	1.40	18.00	71.22
29	KS	1,200	B	4.13	26.00	31.77	1.40	18.00	72.05
30	KS	1,200	B	4.13	20.00	31.77	1.40	18.00	66.05
31-35	SPECIAL SWEPT-BACK SIDE SUPPORT STINGS								
36	PS	300	D	-	24.05	35.00	0.96	18.96	69.92
37	KS	300	D	4.13	26.00	29.71	0.96	18.96	71.10
38	KS	300	D	4.13	[illegible]	29.71	0.96	18.96	65.10

4.13

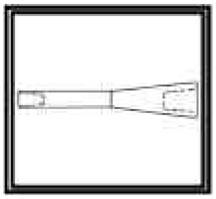


TABLE 5-III AVAILABLE MODEL STING EXTENSION AND ADAPTER CONFIGURATIONS

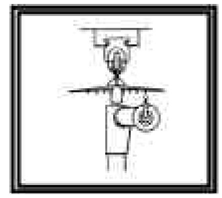
CONFIG NO.	DIMENSIONS – INCHES			FWD TAPER CODE	AFT TAPER CODE
	DF	DA	L		
X1	0.75	1.20	4.00	D	B
X4	1.75	1.75	2.75	B	A
X5	1.40	1.40	8.00	B	B
X6	1.50	1.50	3.00	B	A
X7	1.20	1.50	8.23	B	A
X8	1.75	1.75	4.85	A	A
X9	1.75	1.75	2.75	B	A
X11	1.00	1.00	10.90	D	D
X12	1.75	1.75	6.00	A	A
X13	1.75	1.75	8.00	A	A
X14	1.75	1.75	10.00	A	A
X15	1.85	1.85	3.60	E	A
E1	1.20	1.25	25.40	B	A
E2	1.20	1.25	15.25	B	A
X16	1.50	1.25	16.12	A	A
X19	1.50	1.12	3.50	A	TASK BALANCE

NOTES:

(1) Fwd and aft taper codes match codes in Tables IV and V.
(2) Use of sting extensions reduces the maximum allowable normal load noted in Table V.

Customers may use one of the available stings or use his own with necessary adapters. Detailed drawings of all available

6.0 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.

6.1 INLET AND PROPULSION TESTS

Inlet and propulsion tests can be conducted using a computer-controlled inlet test system which is capable of controlling 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.

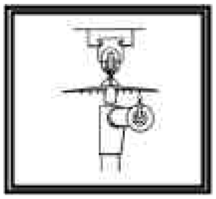
Up to 99 combinations of throttle plug position and angle of attack can be programmed for any run. A typical run may use all or only a portion of this capability. An example of setup combinations might be 15 discrete throttle plug settings at each of five angles of attack for a total of 75 data points. 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.

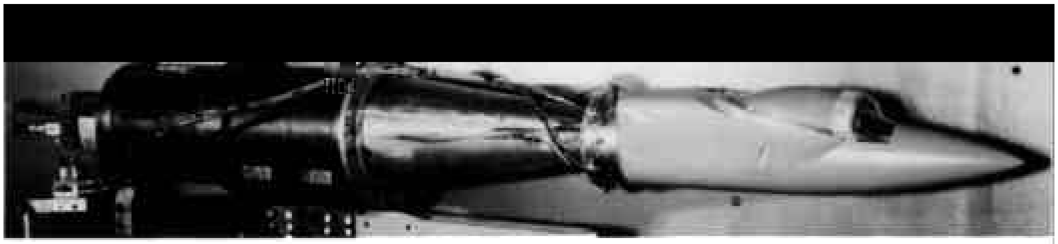
In addition to computer control of throttle plug position and angle of attack, one additional servo-controlled function, two on-off controls, a camera and Scanivalve controls are available in the computer program. Time on point, data sampling rate, number of data points, and throttle plug and angle-of-attack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

Several inlet and throttle plug-mounting systems are available. The customer may adapt his 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.

The primary system used is the 9.2-inch throttle plug-inlet support assembly, shown in Figures 6-

1 and 6-2. The Air Flow Parameter





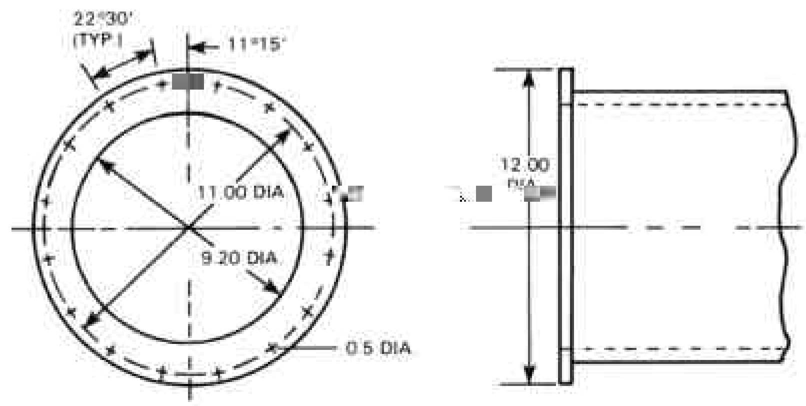


Figure 6-

6.2 FLIGHT DYNAMICS SIMULATOR

The flight dynamics simulator, shown in Figure 6-4, 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 6-3. 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.

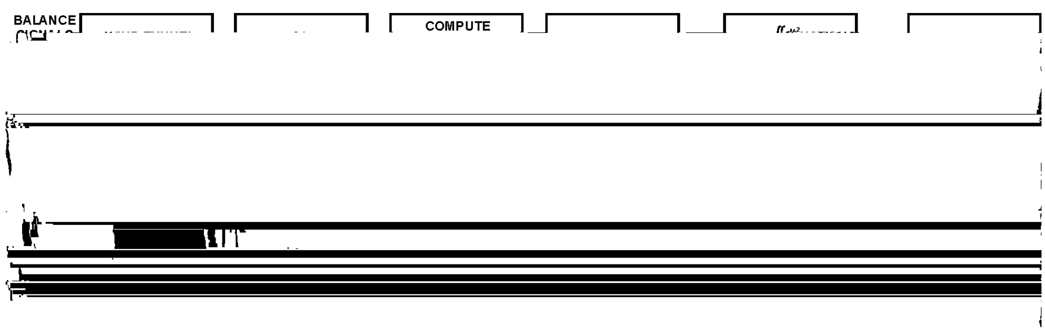
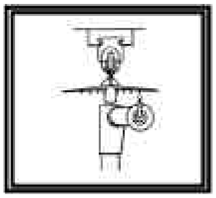


Figure 6-3. Servo Control Flow Diagram



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 1 second of real time.

The two-part model support system comprises six independent hydraulic servos, shown in Figure 6-4. 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
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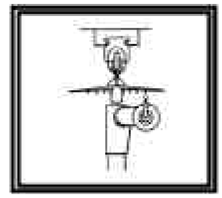

Positioning errors under no-load and maximum driving rates will not exceed ±0.02 inch on linear displacements and ±0.05° on angular displacements. Linear and angular driving rate and load limits are as follows:

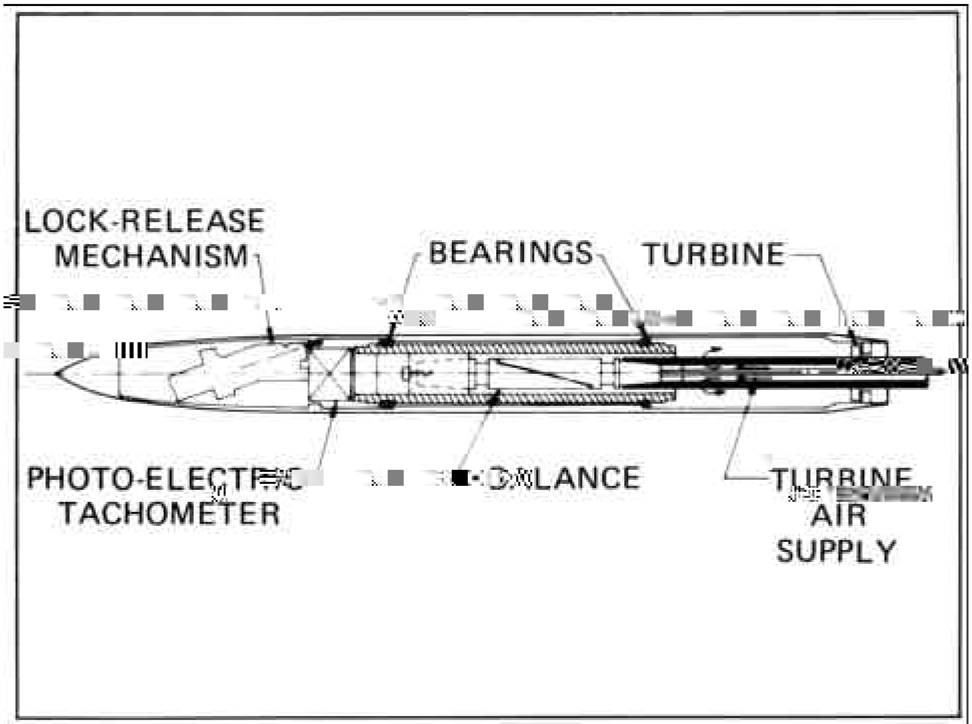

Figure 6-5 Photoelectric Tachometer System

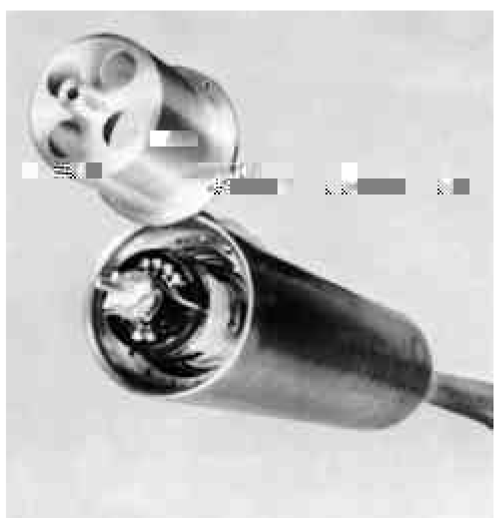

Figure 6-6 Typical Model and Roll Mechanism Assembly

6.5 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.

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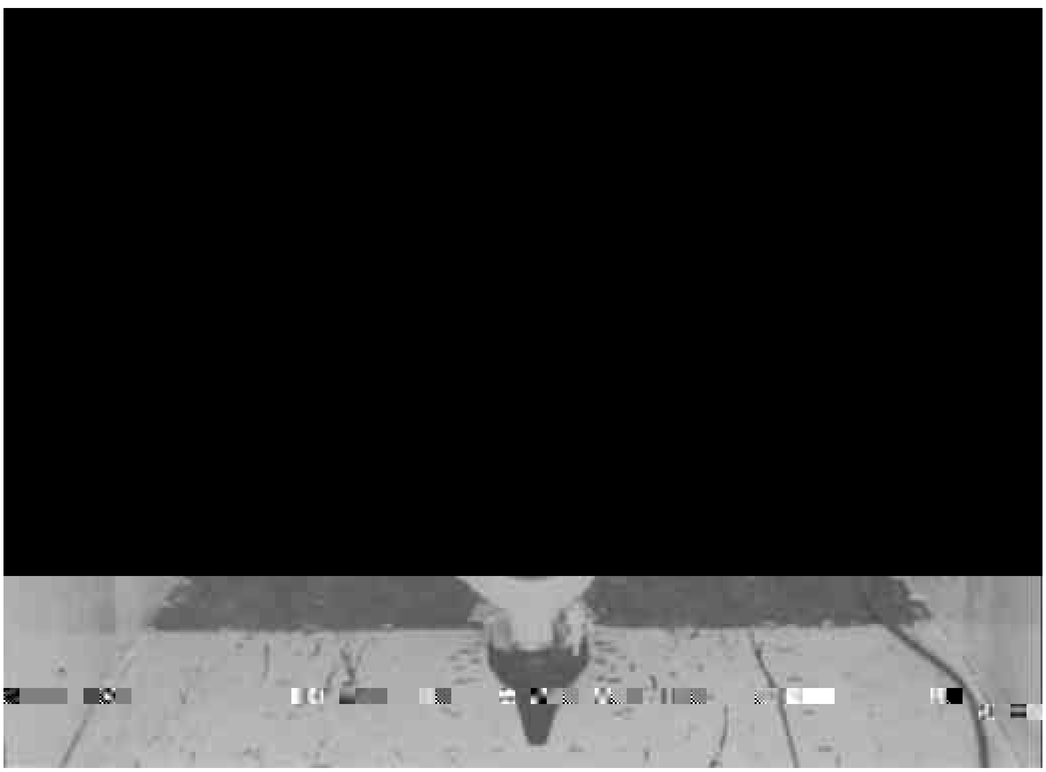


6.6 FLOW VISUALIZATION

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 VHS Videotape recorder 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 6-8.

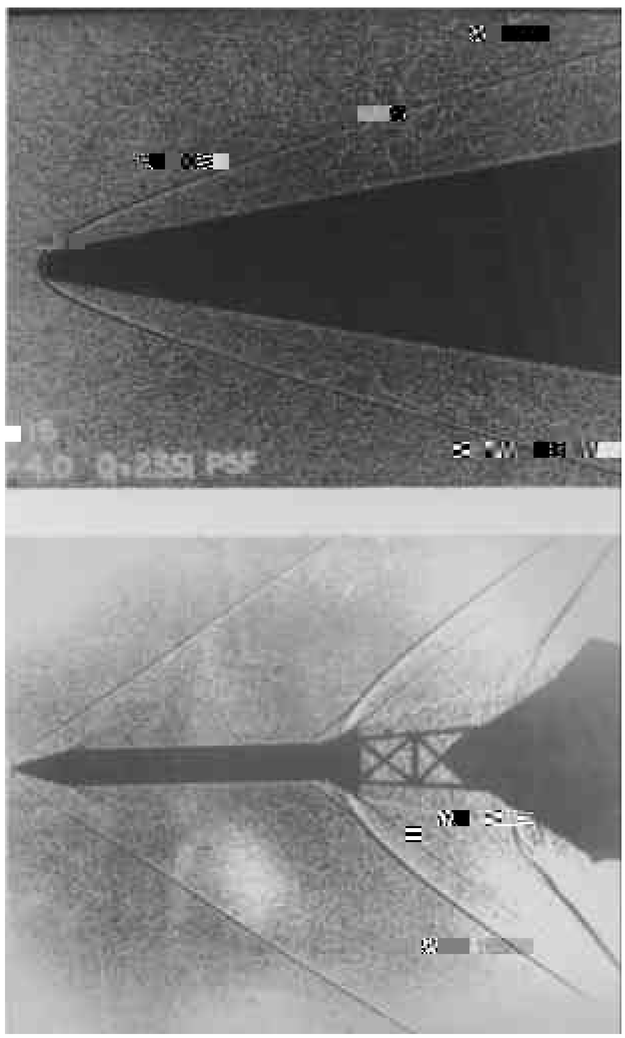


Figure 6-8 Typical Shadowgraphs

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 5 seconds so that no pattern distortion occurs during shutdown. Dual-color pigmented oils can be photographed in normal light, as shown in Figure 6-9. 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.

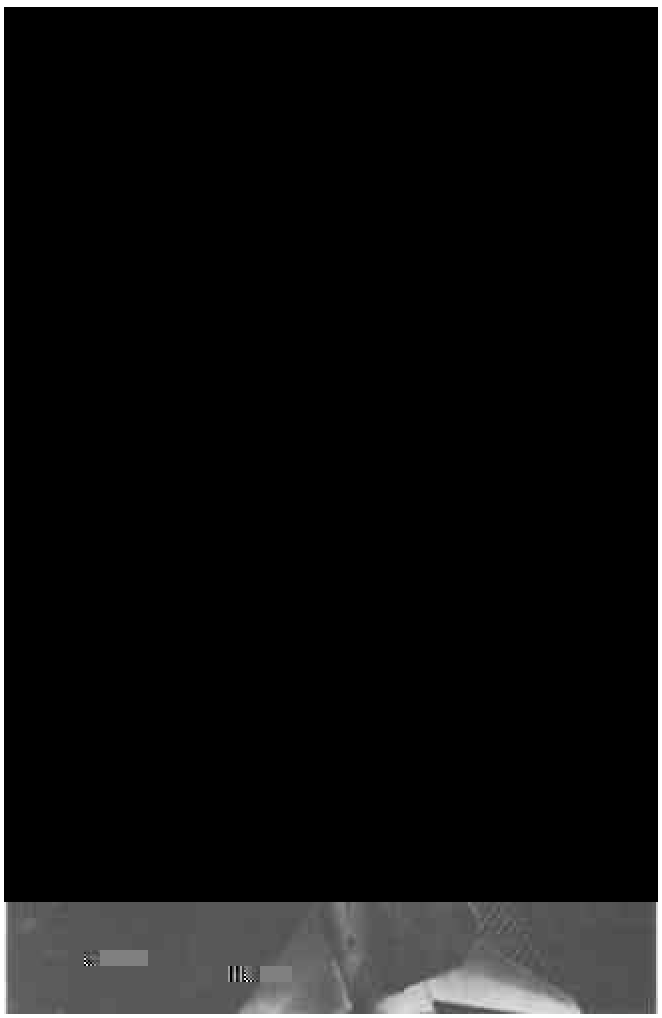
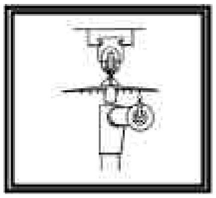
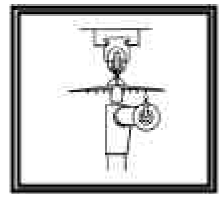


Figure 6-9 Dual-Color Pigmented Oil Flow – Typical Results

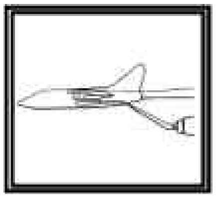




6.9 ADDITIONAL TEST SUPPORT EQUIPMENT

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.

- Spin Physics high-speed video recorder system – full screen to 2,000 frames/sec; up to 1,000 frames/sec with split screen; 2 cameras available.
- IOtech 16-channel high speed digital data system
- Hewlett Packard 3852-A Spectrum Analyzer
- Austron 8152 timecode generator-recorder IR16 A, B
- Astro Med MT 95000, 16 channel chart recorder
- Astro Med DASH 8, 8 channel portable chart recorder
- Hyscan electronic pressure scanner
- Cameras, still – 35 mm single-lens reflex and a high quality digital camera
- VHS Recorder and Camera (Panasonic #3250)
- Pressure standard – Ruska 6200 Pressure Gage
- Clinometer – Hilger-Watts 360° (±0.5’), ±90° (±0.5’)
- Electronic equipment – oscilloscopes (3); oscillographs (6-inch and 12-inch); digital voltmeters (2); signal generators (3); electronic counter; RMS voltmeter, sensitive research AC-DC Polyranger
- Power supplies – 0 to 250 volts dc 3 amp; 0 to 43 volts dc 4 amp (4); 0 to 20 volts 1.5 amp Dual complimentary (2); 0 to 48 volts dc 8 amp (3); 12 volts dc; 0 to 40 volts 300 amp; 115 volts 400 cycle
- Power machine tools – engine lathes (14-inch and 11-inch); band saw; drill press; surface grinder; universal mill; sander; Digital 3-axis LAGUN milling machine
- Surface table – 3 by 6 feet
- Vacuum pumps – Four available
- Reproduction machines – copier that accommodates originals up to 11 by 17 inches
- Fluid flow meters – orifice type (5)
- Thermocouple reference junction (2) – 1500; iron, Chromel, copper, Constantan, and Alumel connections
- Static Flow Facility data acquisition system



7.0 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.

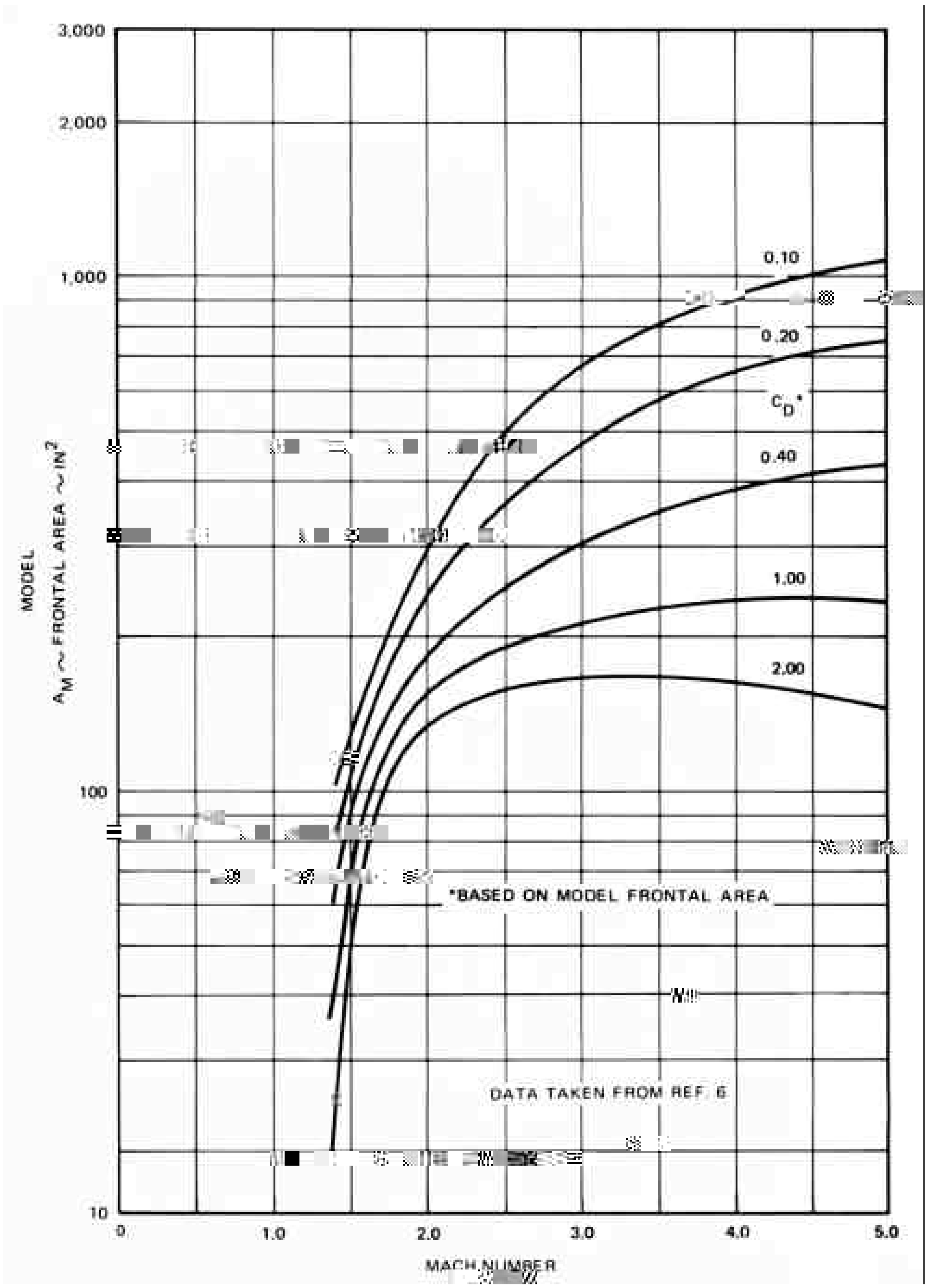


Figure 7-1 Allowable Model Frontal Area as a Function of Mach Number and Drag Coefficient

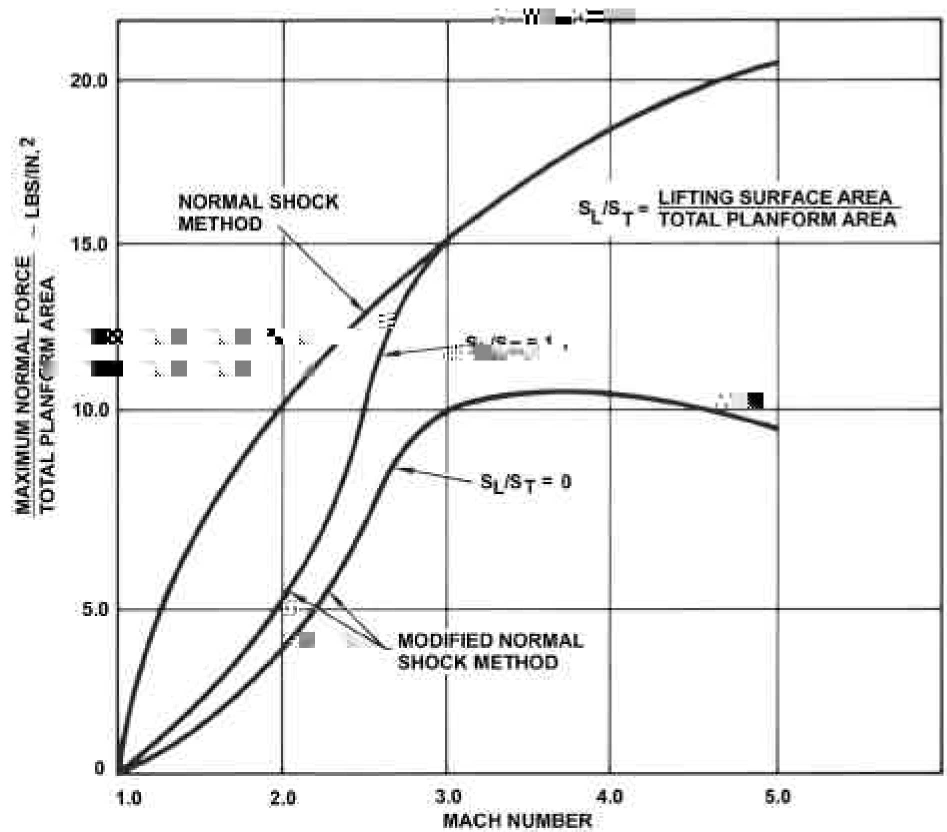


Figure 7-2 Modified Normal-Shock Method of Evaluating Maximum Starting Loads

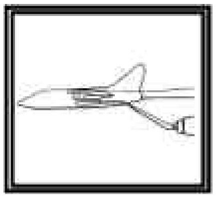
Model pressures are normally measured using individual pressure transducers or a modular pressure scanning system (Scanivalve ZOC) located in the model or mounted downstream on the model support sting. Details of the Scanivalve system were presented in a previous section.

All pressure orifices should be flush with the surface, without burrs, and not less than 0.040 inch in diameter. Pressure tubing should be 1/16 or 1/24 inch o.d. quarter hard stainless steel, and long enough to reach the transducer or Scanivalve. Connections are usually made with short lengths of plastic tubing.

7.5 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. 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 ava

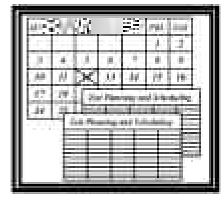


7.6 STARTING LOADS AND FACTORS OF SAFETY

Tunnel starting and stopping loads during supersonic operation may be the highest loads to which wind tunnel models are subjected. Figure 7-2 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 5, 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.

8.0 TEST PLANNING AND SCHEDULING

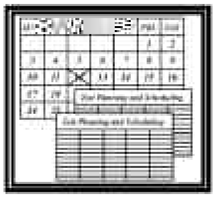


8.1 TEST SCHEDULING

Telephone 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 as soon as definite program requirements are known. Prior to sending an RFQ, contact should be made with the wind tunnel subcontracts coordinator at (972) 946-3234 to obtain the name, mailing address and telephone number of the current Contracts Representative, and to alert the wind tunnel that an RFQ will be forthcoming.

The Request for Quote or Request for Proposal document should contain as much of the following



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 paragraph 3 above.

8.2 MODEL DELIVERY INFORMATION

Models should be received by the wind tunnel at least 2 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.

1. Address models and other bulk materials to:

   High Speed Wind Tunnel
   Lockheed Martin Missiles and Fire Control
   1701 W. Marshall
   Grand Prairie, Texas 75051
   Attn: Manager, HSWT, (972) 946-2751, PDQ

2. 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.

APPENDIX A
Visitor Information

An area map showing the location of the HSWT and some local hotels and motels is presented in Figure A-1.

A Park Inn Suites
700 Ave H East
Arlington, TX 76011
Reservations: 1-800 670-7275
PH: 817-

AREA HOTELS

Figure A-1 Area Map Showing the Location of Local Hotels and Motels

Figure A-2 Map Showing the Location of Lockheed Martin High Speed Wind Tunnel

APPENDIX B
Technical References

1. Ziegler, C.E., "*High Speed Wind Tunnel Instrumentation Handbook,*" LTV Report 2-59710/3R-50929, Nov. 1973, Revised September 1976.
2. Baker, T.M., "*Tables of Mach Functions,*" LTV Report 2-59710/4R-50225, December 1964.
3. Simon, E.H., "*Mach Number Calibration Tests of the CVC High Speed Wind Tunnel,*" LTV Report AER-E1R-13493, June 1961.
4. Fletchtner, J.A., "*Mach Number Calibration Tests of the LTV High Speed Wind Tunnel Transonic Test Section,*" HSWT TEST C-63-3, May 1964.
5. Baker, T.M., "*Data Acquisition, Reduction, and Presentation for Typical Force Tests at the LTV High Speed Wind Tunnel,*" LTV Report 2-59710/OR-50732, July 1970.
6. Czysz, P.A., "*Correlation of Wind Tunnel Blockage Data,*" ASD-TDR-63333333230, April 1963.
7. Maydew, R.C., "*Compilation and Correlation of Model Starting Loads from Several Supersonic Wind Tunnels,*" SC-4691 (RR), June 1962.