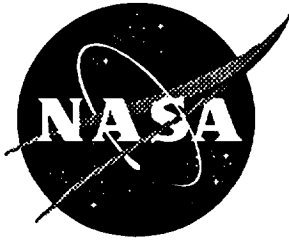NASA Technical Memorandum 110242

User's Guide for the National Transonic Facility Research Data System

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I. INTRODUCTION

The *National Transonic Facility* (NTF) is a complex wind tunnel facility (Figure 1A.). The purpose of this user's guide is to briefly describe the facility, the data system, the instrumentation used to acquire research data and to define some of the acronyms commonly used at the facility. The computational methods and equations will be discussed in detail and references will be listed for the user who needs additional technical information. The customer should find this guide helpful both in preparing for a test and during the operational phase of the test. It is intended that this document answer many of the general questions about how research data is acquired and processed in the National Transonic Facility.

II. FACILITY DESCRIPTION

The NTF is a fan-driven, closed-circuit, continuous-flow pressurized wind tunnel (Figure 1B). The test section is approximately 8.2 X 8.2 feet square and 25 feet long with longitudinal slots in the top and bottom walls (6 slots each, 6 percent open). *Test section* configuration variables are top and bottom wall divergence, reentry flap angle, and initial diffuser angle (i.e. model support wall angle). Refer to Figures 2A-2L for tunnel operating envelopes.

The NTF test gas may be air or nitrogen. For the air mode of operation, *cooling* is obtained by water-fed cooling coils located at the upstream end of the settling chamber. The cooling capacity of this system is 31 MW. For the nitrogen mode of operation, heat is removed by evaporating liquid nitrogen which is sprayed into the tunnel circuit upstream of the fan. By using liquid nitrogen as a coolant, the tunnel test temperature range is variable from -250 to 150 $°F$ (116 to 340 $°K$). The maximum cooling capacity at -250$°F$ is 115 MW. Thermal insulation has been installed internal to the pressure shell to minimize energy consumption.

To facilitate rapid *model access* for configuration modifications during a test series with a minimum loss of nitrogen and time, model access tubes are provided (Figure 3). The tubes are inserted from either side of the plenum and close around the model to form a thermally insulated enclosure. This enclosure can be conditioned for safe personnel entry while the plenum and tunnel circuit remain cold.

The tunnel *drive system* consists of two variable speed induction motors with a combined power output of 35 MW (50 MW short term overload), a two speed gear box, and a synchronous motor with a power output of 31 MW (45 MW short term overload). The compressor consists of a fixed pitch, single stage fan with variable inlet guide vanes. The drive system can be operated in either of two modes: (1) the synchronous mode where the fan is operated at the constant synchronous speed of 360 RPM and the inlet guide vanes are varied to achieve the desired compression ratio ; and (2) the variable fan speed mode where the induction motor(s) are used to drive the fan over a range of rotational speeds (up to 600 RPM) to achieve the desired compression ratio. Different combinations of fan speed, inlet guide vane angle and gear ratio are used by the tunnel operator depending on tunnel pressure and temperature.

III. DATA SYSTEM DESCRIPTION

The NTF operation is centered around energy efficiency, high productivity and safety. It is unique in the aeronautics community because of its ability to produce high quality data at flight Reynolds Numbers. The NTF *data system* plays an important role in achieving the high productivity and high quality data which is so important to our customers, both NASA and industry. Timely dissemination of data to our customers is a goal of this facility, and a reliable and efficient data system is necessary to achieve this goal.

The National Transonic Facility Open Architecture Data System (Figures 4A-4C) consists of three data acquisition/reduction systems in the Real-Time Systems (RTS) group: (1) the Research Computer System (RCS), the Process Computer System (PCS) and the Model Preparation Area (MPA); (2) a Host Computer System (HCS); and (3) sixteen Networked Display System Consoles (NDSC). Together, these computer systems provide the functionality for acquiring, processing, recording and displaying on-line and off-line data from the model, the tunnel and the model preparation areas.

The **RTS** group is based on the MODCOMP REAL/STAR 2000 computer running a real-time operating system called REAL/IX. This operating system is based on the standard Unix (AT&T System V) with real-time extensions and provides a user friendly environment which is modular, scalable and has distributed system components. The use of this open computer architecture allows many commercially available, "off the shelf" hardware and software products to be used for system expansions and upgrades. The CPU functions are handled by four 25-MHz Motorola 88100 CPU's in a tightly coupled, fully symmetrical processor configuration.

The **PCS** data acquisition subsystem is responsible for collecting the data from several different data acquisition units (DAU). The primary analog inputs consist of a Neff 620/500 controller and a Neff 620/600 analog input subsystem with up to 256 analog channels and 16 digital channels. Other analog inputs come over a serial RS-232 interface from a PC-based Temperature Monitor Scanner system which monitors up to 640 temperatures for tunnel safety and structural integrity assessment. Three sequencers, consisting of Programmable Logic Controllers (PLC) which control and sequence tunnel interlocks, transmit up to 4096 discrete digital state inputs to the PCS. The PCS also receives data over a high-speed SCRAMNet reflective memory system. This data comes from three control microprocessors and from the RCS system and is used to control model attitude.

Since safety is a major concern in a high pressure cryogenic environment, the PCS has an elaborate alarm system. This system provides a channel-based alarm processing capability with characteristics which are configurable in the test setup file to provide an independent configuration for each channel. When a channel enters or exits an alarm state, a message is logged to the alarm display window, the system log window and the system log files. A channel can also be configured to activate visual and/or audible annunciators. These annunciators are located on the Test Engineer's panel and their on/off status is controlled by the alarm system software. Each channel has a deadband parameter which reduces unwanted alarms, without affecting safety. Optionally, a response procedure can be displayed for corrective action.

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The PCS system is divided into eight different functional areas as shown in the PCS block diagram (Figure 5A). The functional areas are initialization, test setup, system control, calibration, data collection, computation, alarming and data display. Each is a separate and distinct area of PCS but necessary for the operational success of the total system.

The **RCS** (Figure 5B) data acquisition subsystem is responsible for collecting the data from a similar Neff DAU containing 128 analog channels and 16 digital channels. This system continuously acquires, computes, performs alarm checks and displays model data and tunnel parameters. The RCS computer also receives model and tunnel wall pressure data from an electronically scanned pressure system (ESP 8400) across an IEEE 488 interface. Standard force and moment data are measured with strain gage balances which are calibrated to account for first and second order interactions. Other measurements may be made such as pressures from the model, tunnel walls, boundary-layer rakes, internal flow rakes, and wing gages. Model angles are measured with either an on-board accelerometer package or the accelerometer located in the arcsector. Model roll angle is measured by either a resolver or potentiometer. Since NTF is a cryogenic wind tunnel, temperatures are monitored in many regions of the tunnel and on the model. The RCS computer also processes data from thermocouples, platinum resistance thermometers (PRT) and various other temperature measuring devices. The subsystems used for computing Mach number will be described in a later section (III A). During operation, two tasks run in the RCS computer: (1) *TCYCL* acquires, averages, reduces and displays cyclic or "real-time" data and (2) *TPOINT* acquires, averages, reduces, records and displays static (point-based) data. The RCS system has the same eight functional areas as the PCS system and the block diagram is the same with the exception of the input sources.

To minimize the time required for model installation and instrumentation verification, one of the three model preparation areas can be used for pretest setup. The **MPA** data acquisition subsystem is patterned after the RCS and runs a subset of the RCS software. The computer system is used for accelerometer calibrations, balance loadings, sting bending calculations and pressure orifice leak checks. Following model assembly and ambient temperature checkout, cryogenic models undergo further checkout in the cryogenic chamber located in MPA 3. The data acquired during the cryogenic checkout is later used for temperature corrections during the actual tunnel test. The computer system used in the NTF model bays is very effective in model pretest preparation, instrumentation verification and software checkout.

As stated above, each of the RTS computers interfaces with the Neff 620/500 controller and the Neff 620/600 DAU to acquire analog and digital data. The Neff 620/600 is a high-speed unit that measures multi-point, low-level and high-level analog signals. This unit provides the system with the following features and functions (Reference 14):

- Analog to digital conversion
- 16-bit resolution (including sign)
- Accuracy of 0.02% of full scale ±2 microvolts at constant temperature after autocalibration
- Programmable gain post amps with steps 1,2,4,8,16 and 32
- Autoranging capability with throughput of 50 kHz (currently used on fixed range)
- Maximum throughput of 100 kHz

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- Automatic zero and full-scale calibration
- Precision internal voltage calibration source
- Alphanumeric display for viewing channel values on-line and off-line.

The Neff 600 unit uses the Neff 620650 amplifier/filter circuit cards to signal condition the incoming data signals before they are digitized. Each card contains four channels and has the following features and functions:

- Programmable gain preamps with steps 1,8,64, and 512
- Programmable filter selection, using 4-pole Butterworth low-pass filters, with steps of 1,10,100 and 1000 Hz
- Full scale voltage ranges from 5 millivolts to 10 volts
- Input protection of 100 VDC or peak AC
- Common range rejection ratio of 66 dB to 120 dB depending on gain and filter settings
- Buffered wide band output available for each channel for external use.

As stated above, one of the capabilities of the Neff 620/600 is an automatic internal self-calibration for all data channels (defined in the acquisition setup file) using all gain and filter steps available. Zero and full scale corrections are determined for each channel. This information is stored in the Neff internal calibration memory, written to calibration disk files and written to test recording file if enabled (raw data file). Both the number of scans and the averaging period is configurable. At the present time, the usual scan rate for a discrete data point is 10 scans/sec and the averaging period is one second.

Although the purpose of this document is to provide information about the *research* data system, information has also been included about the PCS because tunnel related information is often used by both the test engineer and the research engineer. Since these computers are on a local area network (LAN), information from the PCS and the RCS can be passed back and forth and also mixed on displays and plots. This is helpful particularly during cryogenic and/or high pressure operations since the tunnel environment affects the quality of the research data. The outputs from pressure gages and thermocouples located throughout the tunnel are recorded on the PCS system and can be displayed along with the model data from RCS if desired.

IV. TUNNEL PARAMETERS

A. Parameter Measurements

The NTF research Mach system was designed to measure tunnel total and static pressures to a high degree of accuracy such that the resulting Mach Number accuracy would be ±0.002 over the range from 0.2 to 1.2. The transducers for this system are fused quartz absolute gages (RUSKA) and are staged to achieve the required accuracy levels. For static pressure measurement there are five gages with the following full scale values: 150, 100, 50, 30, 15 psia. For total pressure there are only four gages with the 15 psia gage omitted since the tunnel is not designed to operate at total pressures less than one atmosphere (14.7 psia). Solenoid valves provide automatic over-pressurization protection at 90% of full scale. The data system monitors the position of these

valves to pick the pressure values from the most sensitive gages.

The gages for this system have a laboratory quoted accuracy of ±0.012 % of reading plus ±0.006 % of full scale. The sensitivities of the transducers are determined by off-site laboratory calibrations. Two point in-place calibrations are made daily with these calibrations consisting of a near vacuum point (< 200 microns) to determine and adjust the gage offset value and a barometric pressure point that is used in combination with the vacuum point as a check on sensitivity deviation.

A correction is made to the total pressure measurement as a result of the transducers and the probe orifice not being located on the centerline of the test section. The orifice is located near the bottom of the tunnel in the settling chamber and the gages are at a lower elevation. This correction is of the form:

$$P_{T, CL} = P_{T, Meas} - (\lambda_2 h_2 + \lambda_1 h_1)$$

where

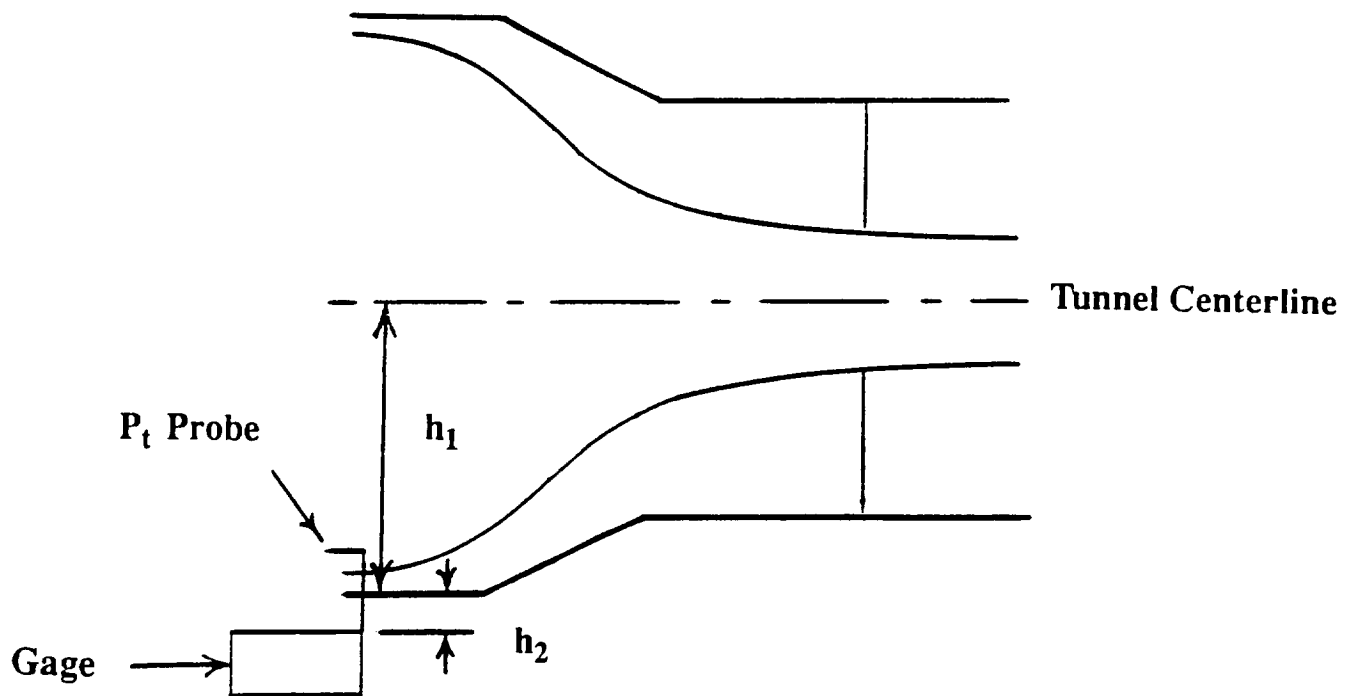λ_1 = specific weight of gas at tunnel test temperature and pressure, $\left(\dfrac{lbs}{ft^3}\right)$

λ_2 = specific weight of gas at ambient temperature and tunnel pressure, $\left(\dfrac{lbs}{ft^3}\right)$

h_1 = 20.58ft, height of column of gas at tunnel temperature and pressure

h_2 = 2.0ft, height of column of gas at ambient temperature and tunnel pressure. See sketch below for details.

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An additional pressure measurement system (Mach system) is currently being verified and will be used as a redundant system. The *flow reference system* (FRS) is based on PSI 8400 pressure system technology. This system consists of four pressure gages (two absolute and two differential). The absolute gages are resonant quartz transducers (Digiquartz) and have a full scale range of 150 PSI. These transducers are accurate to ±0.015 % of full scale. The two differential pressure gages are piezo-resistor micro-machined silicon sensors (HASS) and have full scale ranges of +30 and +15 PSID respectively. The accuracy of these transducers is also ±0.015 % of full scale. One of the absolute gages measures tunnel total pressure, (P_T) from a pressure probe mounted on the wall of the contraction cone at the horizontal centerline of the tunnel. This installation removes the necessity for an elevation correction to the P_T measured by this system. The other absolute gage measures the tunnel reference static pressure, (P_S). Both of the delta pressure gages measure $P_T - P_S$. The most sensitive ΔP gage (within range) is used in combination with P_T to calculate Mach Number. If neither of the ΔP gages is within range, then the pressures from the two absolute gages are used in the calculation. It is anticipated that this system will be as accurate as the Ruska based system now in use. The gages for this system are housed in modules that are sent to the laboratory to be calibrated on a semi-annual basis. This system may eventually be used as the primary Mach system and may also be used for tunnel Mach control.

The prime measurement of tunnel stagnation temperature is made with PRT probe mounted in the the reservoir section of the tunnel near the screens. Currently, there are several of these 1000 ohm probes, two of which are used at any given time. These probes have an accuracy of approximately ±0.05°K and a response time of 1 to 2 seconds.

The data reduction program utilizes the Callender-Van Dusen equation to compute temperature (Reference 1):

$$\frac{R_T}{R_0} = 1.0 + \alpha\left(T - \delta\left(\frac{T}{100} - 1\right)\left(\frac{T}{100}\right) - \beta\left(\frac{T}{100} - 1\right)\left(\frac{T}{100}\right)^3\right)$$

where

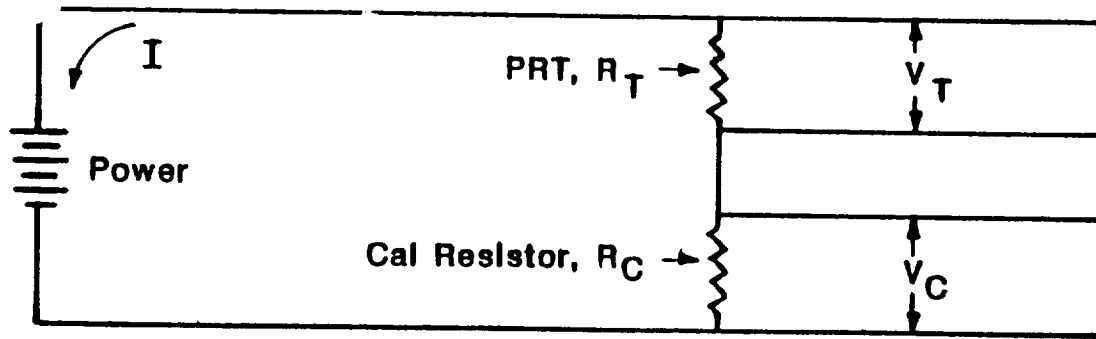α, β, δ are coefficients in the laboratory calibration

R_0 is the resistance at $0°C$

R_T is the resistance at temperature, T.

The tunnel PRT instrumentation system consists of a constant current power supply for the PRT and a high accuracy calibration resistor ($R_C = 1000 ohms$). The PRT and calibration resistor are connected in series as shown on the next page.

With this electrical arrangement, V_T and V_C are measured and $\dfrac{R_T}{R_0} = \left(\dfrac{V_T}{V_C}\right) \times \left(\dfrac{R_C}{R_0}\right)$ because

$R_T = \dfrac{V_T}{I}$, $R_0 = \dfrac{V_0}{I}$, and $R_C = \dfrac{V_C}{I}$. With the resistance ratio determined, the stagnation temperature is calculated from the Callender-Van Dusen equation which is iteratively solved in the data reduction software.

Measurements of tunnel stagnation temperature are also made with a copper-constantan thermocouple which has an accuracy of $\pm 1 \, ^\circ K$ at cryogenic temperatures. The thermocouple has a response time of 1 to 2 seconds. Copper-constantan thermocouples are also used to measure model, balance, and tunnel component temperatures. All these thermocouples are referenced to the ice point $(0^\circ C)$ and the millivolt outputs are converted to temperature by using polynomial fits of the form

$$T = A_0 + (A_1 V) + \left(A_2 V^2\right) + \left(A_3 V^3\right) + \left(A_4 V^4\right)$$

where V is in millivolts and T is in $^\circ K$. Each polynomial covers a specific millivolt range as indicated in the table below.

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COEFFICIENTS FOR COPPER-CONSTANTAN THERMOCOUPLES
(*Reference Temperature*, 273.15°K or 32°F)

MV RANGE	$-6.059 \le -5.587$	$-5.588 \le -3.574$	$-3.575 \le 2.864$	$2.865 \le 20.684$
A0	4020.6970000	97.65544600	273.15000000	274.00707000
A1	1441.7082000	-143.83491000	25.85383400	25.18987600
A2	43.3593140	-62.52461700	-0.71469546	-0.54212165
A3	-34.5629920	-10.01594900	-0.07198166	0.01734062
A4	-3.3589826	-0.63851732	-0.01351040	-0.00025029

B. Calculation of Tunnel Conditions

Gas Properties

In the NTF data reduction software, the gaseous properties for both air and nitrogen are mathematically represented by the Beattie-Bridgeman thermal equation of state which has the form

$$P = \left[\frac{RT(1-\varepsilon)}{V^2}\right](V+B) - \left[\frac{A}{V^2}\right]$$

(Reference 2)

and by ideal-gas (i.e. zero pressure) specific heats of the form

$$\frac{C_P}{R} = \frac{G_1}{T^3} + \frac{G_2}{T^2} + \frac{G_3}{T} + G_4 + G_5 T + G_6 T^2 + G_7 T^3 + \frac{G_8 \mu^2 e^\mu}{(e^\mu - 1)^2}$$

where $\mu = \frac{G_9}{T}$ (Reference 3).

The constants for these two descriptions are given in the following tables. The first table contains the equations of state (Beattie -Bridgeman) constants.

$$A = A_0\left(1 - \frac{a}{V}\right)$$

$$B = B_0\left(1 - \frac{b}{V}\right)$$

$$\varepsilon = \frac{C}{VT^3}$$

where

	NITROGEN	AIR
A_0	1.34450	1.30120
a	0.02617	0.01931
B_0	0.05046	0.04611
b	-0.00691	-0.01101
C	4.2×10^4	4.34×10^4
W	28.01340	28.96000

R (gas constant) = 0.0820539 liter-atm / mole - K
V(specific volume)= $1/\rho$ where ρ is density
W = molecular weight.

The above constants apply when the quantities have the following units: P(atm), T(K), and V(liters/mole).

The second table contains the ideal gas specific heat constants.

	NITROGEN	AIR
G_1	-7.352104012×10^2	0.0
G_2	3.422399804×10^1	0.0
G_3	$-5.576482846 \times 10^{-1}$	0.0
G_4	3.504042283	3.5
G_5	$-1.733901851 \times 10^{-5}$	0.0
G_6	$1.746508498 \times 10^{-8}$	0.0
G_7	$-3.568920335 \times 10^{-12}$	0.0
G_8	1.005387228	0.0
G_9	3.353406100×10^3	0.0

In addition to the equation of state and specific heat representations of the two gases, the NTF software also mathmatically characterizes the viscosity of the gases.

For nitrogen, the equation is $\quad \mu = \mu_0(T) + \mu_\varepsilon(\rho,T) \quad$ (Reference 4)

where

$$\mu_0(T) = \sum_{i=1}^{9} Z_i T^{(i-3)}$$

$$\mu_\varepsilon(\rho, T) = \sum_{i=1}^{7} X_i \rho^i$$

Z_1	7.41653×10^1	X_1	2.30835×10^{-1}
Z_2	-1.58344	X_2	-9.36362×10^{-1}
Z_3	3.85308×10^{-3}	X_3	9.033392
Z_4	8.01337×10^{-4}	X_4	-4.18321×10^1
Z_5	-8.92031×10^{-7}	X_5	1.08976×10^2
Z_6	8.90597×10^{-10}	X_6	-1.29139×10^1
Z_7	-5.37794×10^{-13}	X_7	5.97821×10^1
Z_8	1.73983×10^{-16}		
Z_9	-2.30840×10^{-20}		

These constants apply when the quantities have the following units : μ (10^3 gm/cm-s), T (K),and ρ (gm/cm^3).

For air, Sutherland's equation is $\quad \mu = 1.45820 \times 10^{-6} \left[\dfrac{T^{3/2}}{(T + 110.33)} \right]$.

Thermodynamic Equations

The thermodynamic property equations for entropy, enthalpy, specific heats and speed of sound are as follows:

$$S(\rho, T) = S_{T_0, Amb} + \int_{p'T_0}^{T}\left(\frac{C_p^0}{T}\right)dT - [R \times \ln(\rho RT)] + \int_{T'0}^{\rho}\left[\left(\frac{R}{\rho}\right) - \left(\frac{1}{\rho^2}\right)\left(\frac{\partial p}{\partial T}\right)_\rho\right]d\rho$$

where $S_{T_0, Amb} + \int_{p'T_0}^{T}\left(\frac{C_p^0}{T}\right)dT$ is an arbitrary constant $= 25.5308$ (joules/mole) and is represented by G_{11} in the data reduction software.

$$H(\rho, p, T) = H_{T_0, Amb} + \int_{T'0}^{\rho}\left[\left(\frac{p}{\rho^2}\right) - \left(\frac{T}{\rho^2}\right)\left(\frac{\partial p}{\partial T}\right)_\rho\right]d\rho + \left[\frac{(p - \rho RT)}{\rho}\right] + \int_{p'T_0}^{T}C_p^0 dT$$

where $H_{T_0, Amb} + \int_{p'T_0}^{T}C_p^0 dT$ is an arbitrary constant $= 14.9124$ (joules/mole) and is represented by G_{10} in the data reduction software.

$$Cv(\rho, T) = \left(C_p^0 - R\right) - \int_{T'0}^{\rho}\left(\frac{T}{\rho^2}\right)\left(\frac{\partial^2 p}{\partial T^2}\right)d\rho$$

$$Cp(\rho, T) = \left(Cv + \frac{\left[T\left(\frac{\partial p}{\partial T}\right)_\rho^2\right]}{\left[\rho^2\left(\frac{\partial p}{\partial \rho}\right)_T\right]}\right)$$

$$C(\rho, T) = \left[\left(\frac{Cp}{Cv}\right)\left(\frac{\partial p}{\partial \rho}\right)_T\right]^{\frac{1}{2}}$$

where Amb subscript implies p = 1 atmosphere
^{0} superscript implies p = 0
T_0 subscript implies a constant temperature of 298.15 $^\circ K$.

Since air is only used at near ambient temperature in the NTF, a constant ideal gas specific heat representation is adequate. Previous research (Reference 5) has shown that for the operating temperature and pressure range of NTF, this reasonably simple representation of the properties of nitrogen is in close agreement with much more complex representations that were designed for high accuracy over a much broader pressure and temperature range. In addition, prior research (Reference 6 and 7) has shown that various types of flows (isentropic, normal shock, and boundary layer) are not significantly different from those same flows calculated for an ideal diatomic gas. While the nondimensional flow parameters that characterize these flows are essentially the same, proving that cryogenic nitrogen is a good test medium, it is necessary to retain this more complex representation of the gas properties to calculate the various dimensional flow quantities

such as density, speed of sound, and dynamic pressure.

Procedure

With measurements of free-stream total pressure, total temperature and a static reference pressure, the other important reference conditions such as Mach Number, Reynolds Number, and dynamic pressure can be calculated by using basic thermodynamic equations (Reference 8) which express properties such as entropy, enthalpy, specific heat, and speed of sound in terms of the equation of state, its derivatives and the ideal gas specific heat values. These equations along with the assumption that the flow is isentropic (constant entropy) and adiabatic (no heat transfer) make

possible an iterative solution of the adiabatic energy equation $H_T = H + (V^2/2)$ where H is enthalpy and V is velocity. Once this solution is complete, all of the desired reference quantities can be calculated. The various steps in the calculation procedure are as follows:

1. Input the measured test parameters and the gas type (air or nitrogen).
   a. P_t, stagnation pressure
   b. P_s, plenum static pressure
   c. T_t, stagnation temperature

2. Calculate other stagnation properties.
   a. $\rho_t = \rho_t(P_t, T_t)$, density
   b. $S_t = S_t(\rho_t, T_t)$, entropy
   c. $H_t = H_t(P_t, T_t, S_t)$, enthalpy

3. Iteratively solve for static temperature assuming isentropic flow.
   a. Approximate static temperature, T, using ideal-gas expansion from P_t, T_t to P, T.
   b. Calculate static density, $\rho = \rho(P, T)$
   c. Calculate static entropy, $S = S(\rho, T)$
   d. Obtain incremental variation in entropy with temperature, $\Delta S/\Delta T$, by incrementing T
   e. Check for convergence, $S = S_t \pm \left(S_t \times 10^{-8} \right)$

   (1) If convergence criterion has not been met, adjust T by $T = T + ((S_t - S)/(\Delta S/\Delta T))$ and return to step b.
   (2) If convergence criterion has been met, static temperature, T, and density, ρ, are now known.

4. Determine other tunnel parameters.
   a. $H = H(P, \rho, T)$, enthalpy
   b. $C = C(\rho, T)$, speed of sound
   c. $V = \left[2(H_t - H)^{1/2} \right]$, flow velocity
   d. $M = V/C$, Mach number

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e. $\mu = \mu\,(\rho, T)$, viscosity

f. $R_e = (\rho V l)/\mu$, Reynolds number

g. $q = (\rho V^2)/2$, dynamic pressure

C. Calibration Corrections

A correction is made to the reference Mach Number (M_{REF}) based on the results of centerline static pipe calibration tests in the NTF. The correction is a function of M_{REF} and Reynolds Number per foot (REYNFT). A double interpolation of the following table values is performed and the correction, ΔM , is added to M_{REF} to obtain the free-stream Mach Number (M_∞).

ΔM CALIBRATION CORRECTION

M_{REF}	REYNFT					
	6×10^6	14×10^6	30×10^6	60×10^6	100×10^6	130×10^6
0.0	0.0×10^{-3}	0.0×10^{-3}	0.0×10^{-3}	0.0×10^{-3}	0.0×10^{-3}	0.0×10^{-3}
0.20	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3
0.30	-1.7	-1.9	-2.8	-2.8	-3.5	-4.1
0.40	-2.1	-2.1	-2.2	-2.2	-2.3	-2.3
0.50	-2.3	-2.4	-2.6	-3.0	-3.5	-3.9
0.60	-2.7	-2.7	-2.8	-3.0	-3.3	-3.5
0.70	-2.5	-2.6	-2.8	-3.1	-3.6	-3.9
0.80	-2.5	-2.7	-3.0	-3.6	-4.4	-5.0
0.90	-2.8	-3.0	-3.4	-4.1	-5.0	-5.7
0.95	-2.5	-4.3	-7.6	-4.7	-4.7	-4.7
0.98	-1.9	-4.5	-7.7	-7.8	-7.8	-7.8
1.00	-2.3	-5.1	- 6.0	-7.8	-7.3	-6.7
1.02	-2.6	-3.7	-5.0	-7.5	-7.6	-7.6
1.05	-2.5	-5.8	-6.6	-8.3	-8.3	-8.3
1.10	-2.1	-4.7	-5.7	-7.5	-7.5	-7.5
1.15	-8.4	-8.4	-8.4	-8.4	-8.4	-8.4

Once ΔM has been determined, M_∞ can be calculated as follows:

$$M_\infty = M_{REF} + \Delta M$$

Another correction which is based on the NTF static pipe calibration data is the buoyancy correction (ΔCD_{buoy}) to the drag coefficient (CD). This correction is also a function of M_{REF} and REYNFT. A double interpolation of the following table values is performed to obtain $\frac{dM}{dX}$. For this calculation it is assumed that the top and bottom test section wall angles are zero, the re-entry flap angles are zero, and the initial diffuser angles are -1.76°.

dM/dX CALIBRATION CORRECTIONS

M_{REF}	REYNFT					
	6×10^6	14×10^6	30×10^6	60×10^6	100×10^6	130×10^6
0.0	$0.0 \quad X\,10^{-4}$	$0.0 \quad X\,10^{-4}$	$0.0 \quad X\,10^{-4}$	$0.0 \quad X\,10^{-4}$	$0.0 \quad X\,10^{-4}$	$0.0 \quad X\,10^{-4}$
0.20	-0.989	-0.885	-0.677	-0.287	0.233	0.623
0.30	-1.436	-1.371	-1.241	-0.996	-0.670	-0.426
0.40	-1.849	-1.771	-1.613	-1.317	-0.923	-0.628
0.50	-1.992	-1.914	-1.757	-1.462	-1.069	-0.775
0.60	-1.851	-1.778	-1.634	-1.363	-1.001	-0.730
0.70	-1.506	-1.446	-1.326	-1.100	-0.800	-0.575
0.80	-0.675	-0.628	-0.534	-0.358	-0.123	0.053
0.90	0.184	0.150	0.080	-0.049	-0.222	-0.352
0.95	0.636	-0.550	-2.050	-0.800	-0.800	-0.800
0.98	1.250	-0.300	-4.000	-4.400	-4.400	-4.400
1.00	1.500	-0.200	-3.000	-5.100	-4.200	-3.350
1.02	-0.900	-0.350	-0.900	-2.200	-2.200	-2.200
1.05	3.900	-0.280	-0.500	-0.900	-0.900	-0.900
1.10	12.400	7.800	7.600	7.200	7.200	7.200
1.15	7.940	7.940	7.940	7.940	7.940	7.940

Using $\dfrac{dM}{dX}$ from the table, the buoyancy correction and the corrected drag coefficient can then be computed using the following equations:

$$\Delta CD_{buoy} = -\left(\frac{2}{M_\infty}\right)\left[\left(\frac{1}{1 + 2M_\infty^2}\right)\right]\left(\frac{Vol}{S_{ref}}\right)\left(\frac{dM}{dX}\right)$$

$$CD_{corrected} = CD_{uncorrected} + \Delta CD_{buoy}$$

where

Vol = model volume, ft^3

S_{ref} = model reference area, ft^2

M_∞ = free-stream Mach Number

$\dfrac{dM}{dX}$ = tunnel longitudinal Mach gradient, 1/ft.

This correction is applied directly to the drag coefficient instead of the axial force so that it does not affect any of the other coefficients through Euler rotations.

V. MODEL PARAMETERS

A. Model Orientation

Critical measurements in any wind-tunnel model test are those of model attitude with respect to the gravity axis system. These measurements, along with a knowledge of the tunnel flow direction with respect to gravity, makes possible a determination of the model orientation with respect to the wind axis. Existing techniques at Langley Research Center involve the use of accelerometers to sense the attitude of the model (Reference 9). For the cryogenic environment of NTF, it is necessary to provide heated containers for the accelerometers so that they remain at a constant temperature ($\approx 160\ ^\circ F$). There are many considerations when choosing the proper on-board package to be used at NTF. The space and wiring requirements of a package must be considered.

Another inertial device used in NTF is the electrolytic bubble which detects the angle between its base and local horizontal. This device when installed in an on-board accelerometer package is used to establish "wind-off zero attitude" during the test.

The NTF acceleromenter packages NTF10-X and NTF12-X measure elevation angle of the model. In addition, the NTF12-X package contains two electrolytic bubbles measuring zero elevation both upright and inverted. Since the NTF10-X has no bubbles, it should only be used when the space available prohibits the the use of the "12" package. The output of the accelerometer is a

function of the sine of the angle so it has its best accuracy at small angles. The accelerometers will measure within ±0.01° for small angles.

Prior to a wind-tunnel test, the model support system is assembled in one of the three model preparation areas. Sting and balance deflection constants are determined for normal, side, pitch and yaw loadings. This also provides a good check on the balance and the data system. If the model is to be cryogenically tested, it will either be assembled in or moved to MPA 3 where the model/sting combination will be thermally cycled to cold test temperatures. Once all calibrations are completed in the MPA, the model/sting assembly can be transported to the test section by a model handling cart. The balance is again checked in the tunnel by hand loading.

Once a model has been installed in the tunnel, a reference plate is attached to the model which establishes the model reference axes. The AOA package should then be powered and heated to 160°F for 30 minutes before proceeding with the calibration. The pitch and roll 0° output (model level) for the AOA device is recorded. If an NTF-12 package is being used, the zeroing pot on the bubble readout is adjusted for the upright bubble channel. A second calibration point is recorded at pitch = 0° and roll = 90°. The leveling plate should have provisions for inverted leveling of the model so that a third point can be recorded at pitch= 0° and roll= 180°. At this point, the zeroing pot on the bubble will be adjusted for the inverted bubble channel. Now all the necessary information has been obtained for calculating the calibration constants. The following equations are used for this calculation:

$$Eleva = \text{asin}\left[\frac{(E-Bias)}{Sens}\right] - Omax \times \sin(Az + Roll)$$

where

Eleva	=	elevation angle (usually referred to as "pitch" angle in software)
E	=	output of accelerometer (volts)
Bias	=	electrical bias of accelerometer (volts)
Sens	=	sensitivity of accelerometer (volts/g)
Omax	=	misalignment of accelerometer (deg)
Az	=	roll orientation of misalignment (deg)
Roll	=	roll attitude of model (deg)

The sensitivity of the accelerometer is acquired from the laboratory calibration. Bias, Omax and Az are computed from the in-place tunnel measurements described above. The equations are as follows:

$$Bias = \frac{(E_0 + E_{180})}{2}$$

where

E_{180} = voltage output at 180° roll.

E_0 = voltage output at 0° roll and

Az and Omax are then calculated using this bias.

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$$Az = \text{atan} \left[\frac{\text{asin} \left((E_0 - Bias)/Sens \right)}{\text{asin} \left((E_{90} - Bias)/Sens \right)} \right]$$

and

$$Omax = \frac{\text{asin} \left((E_0 - Bias)/Sens \right)}{\sin (Az)}$$

where

E_{90} = voltage output at 90° roll.

Basic three dimensional model support is provided by an aft-mounted sting. This sting is attached to a vertically mounted arcsector which is driven by a hydraulic cylinder. The roll mechanism provides the interface between arcsector and sting (Reference 10). The pitch range of the the arcsector is from −11° to 19°, but sting knuckles can be used to obtain higher pitch angles. The roll range is −180° to 180°, and sideslip angles are achieved by using pitch/roll combinations. Computer software is available to compute the pitch (θ) and roll (ϕ) angles given input angles of α (model angle of attack) and β, (model angle of sideslip). Design load capabilities of the model support system are discussed in Reference 10.

The measured angles with respect to the gravity axis that are obtained from the primary orientation system are converted to angles with respect to the other axis systems by applying a series of Euler rotations (APPENDIX A and APPENDIX B) The model accelerometer package is always considered the primary system but a secondary system consisting of an accelerometer in the arcsector can be selected by using the angle definition code. See Figures 6A through 6E for descriptions of how these two systems can be used in the software.

B. Model Forces and Moments

In order to measure three dimensional model forces and moments in the NTF, a series of special balances (*APPENDIX C*) have been designed with metals that have acceptable strength and fracture toughness at cryogenic temperatures. These moment-type balances have two sets of strain gages mounted near both ends of a beam section. The sum of the gage outputs is proportional to the force (normal and side) and the difference in the outputs is proportional to the moment (pitch and yaw). There are individual gage outputs for axial force and rolling moment. The gages for these balances were carefully selected, matched and temperature compensated such that sensitivity and no-load output variations are in the order of 1% of full scale output for the temperature range 300 to 100°K. The changes in sensitivity with temperature are measured in a laboratory cryogenic chamber and sensitivity shift constants are calculated for the balance. The zero offset changes with temperature are measured here at the NTF in the cryogenic chamber of MPA 3. The chamber is cycled from ambient temperature to approximately 100 °K. The sensitivity and zero-load voltage is recorded (usually at five minute intervals) during the MPA cryogenic cycle. The data are fit with a second order curve and coefficients are calculated for each gage. These coefficients are included in the standard balance data reduction to further reduce errors due to temperature variations. For ambient temperature testing, the data reduction software is equipped to

handle both force and moment type balances.

The temperature correction philosophy indicates that all balance readings (wind-off zero, weight tare data, and wind-on data) that are taken at a given temperature should be corrected to a reading that would have been obtained at a fixed ambient temperature. This fixed temperature is the temperature at which the balance is calibrated ($295\ °K$). The data for each gage is correlated with balance temperature as measured by the temperature measuring device nearest the gage. All NTF balances have three temperature devices located at the front, middle and rear of the balance. The actual placement of these devices is shown in Figure 7. The zero shift due to temperature level is characterized by the following equation

$$\Delta V_{EZ} = C_0 + C_1 T_i + C_2 T_i^2$$

where:

C_0, C_1, C_2 = temperature compensation coefficients

T_i = temperature from temperature device for ith gage (1-6)

EZ = subscript denoting electrical zero.

The effect of sensitivity shift on load voltage is expressed as

$$V_L = V_{(L,295)} \times SC_i$$

where:

$SC_i = 1 + SS_i (T_i - 295)$

SS_i = sensitivity change per degree change in temperature

= $(S - S_{295}) / (S_{295} \times \Delta T)$

L = subscript denoting load.

Thus, the equation for the measured bridge voltage, V_T is:

$$V_T = V_{(EZ,295)} + \Delta V_{EZ} + (V_{Tare} + V_{Aero})_L$$

where:

$V_{(EZ,295)}$ = bridge electrical zero at T = 295 °K

V_{Tare} = voltage due to model weight

V_{Aero} = voltage due to aerodynamic loads.

Since V_{Tare} and V_{Aero} in the above equation are voltages due to load, they are related to their calibration temperature values as follows:

$$V_{Tare} + V_{Aero} = (V_{Tare} + V_{Aero})_{(L,295)} \times SC$$

The temperature compensation algorithm philosophy is to correct the measured voltage, V_T, to what would have been measured at the calibration temperature (295° K).

$$V_{(T,295)} = V_{(EZ,295)} + \Delta V_{(EZ,295)} + (V_{Tare} + V_{Aero})_L / (SC)$$

where

$\Delta V_{(EZ,295)}$ approaches zero at the calibration temperature.

$$F_i = ((V_{(T,295)})_{(wind-on)}) \times Sens_i - ((V_{(T,295)})_{(wind-off)}) \times Sens_i$$

where $Sens_i$ = balance primary sensitivities.

Even though the data reduction software applies temperature compensation to each of the balance components, test procedures call for taking wind-off zeroes at test conditions. This minimizes the effect of the zero offset correction.

The result of the above procedure is a set of balance forces and moments that have been corrected to a temperature reference of 295 ° K. The forces and moments must now be corrected for 1st and 2nd order interactions, for model weight tares, and other corrections such as base and chamber pressure. Also, these forces and moments must be transferred to the model and wind axis systems and then non-dimensionalized in coefficient form. Although the details of these procedures are very similar for all wind tunnels, the balance data reduction equations including all corrections are given in APPENDIX A.

C. Model Pressures

Steady-state pressure measurements in NTF are made with several different types of instrumentation depending on the accuracy requrements. For multi-channel applications such as measurements on the test section walls and on models with multiple pressure orifices, ESP instrumentation is used.

The ESP system consists of several key components (Figure 8). The multi-transducer modules (available with 16, 32, 48, and 64 ports) are housed in thermal enclosures in the cryogenic environment of NTF and the temperature is maintained at near ambient levels. The modules are interfaced with the system processor which contains the scanner digitizing units (SDU) through the combination of the remote power supply (S81FC) and the scanner junction unit (SJU). The small size of the SJU allows the transducer voltage to be controlled at or very near the model. This unit is also housed in a thermal enclosure. The modules are pneumatically connected to the model orifices, tunnel reference pressure, the local processor with its slot mounted pressure calibrate units

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(PCU) and the bias control unit. This unit biases the control line pressure (shifts module to run/ calibrate position) to valves that are approximately 100 PSI above the tunnel reference pressure.

At NTF, this system is configured such that the host computer commands the ESP system to read/send raw voltage at a prescribed scan rate over a specified period of time. This period of time (nominally, 1 second) is the same acquisition period used for other types of data such as balance data and tunnel parameter data. The maximum scan rate is dependant on the number of ports on each module in the system.

The average voltage from each module is converted to engineering units (PSID) using the following 4th order polynomial equation

$$\Delta P = C_0 + C_1 V + C_2 V^2 + C_3 V^3 + C_4 V^4$$

where

$$\Delta P = P_{orifice} - P_{ref}$$

V = average voltage from a given port/module

C_i = calibration coefficients

P_{ref} = module reference pressure

The calibration coefficients are determined from two types of calibrations. Full calibrations involve the PCU sending out five pressures (0, -FS, -.5FS, +.5FS, FS) where FS indicates the full scale pressure of a module. At certain tunnel conditions, the negative pressures as indicated cannot be achieved. In these cases, there is an algorithm used to predict what the substitute pressure should be . The purpose of this algorithm is to calculate the value of five reasonably spaced calibration pressures when the tunnel pressure drops below the critical pressure for that size module. Then the calibration pressures are calculated internally in the software and operator intervention is not required.

The algorithm is as follows:

(1) Calculate the critical pressure for each size module:

$$P_{crit} = (P_{ref} - P_{min}) \quad \text{where } P_{min} = \text{minimum pressure of the vacuum system } (P_{min} \approx 5 \text{ psi})$$

(2) Calculate pressure interval for module calibration based on comparison of P_{crit} to FS pressure of a module:

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If $(P_{crit} > FS)$ then $P_{min} = P_{ref} - FS$ and $P_{max} = P_{ref} + FS$.

If $(P_{crit} < FS)$ then $P_{min} = P_{min,v}$ and $P_{max} = P_{ref} + FS$

(3) Set calibration pressures based on P_{crit}:

(a) If $(P_{crit} \geq FS)$ then:

P1 = 0
P2 = -FS
P3 = -FS / 2
P4 = +FS / 2
P5 = +FS

(b) If $(P_{crit} < FS)$ then:

P1 = 0
P2 = $(P_{min} - P_{ref})$
P3 = $(P_{min} - P_{ref}) / 2$
P4 = + FS / 2
P5 = +FS

These calibrations take a minimum of 25 seconds per pressure (2.1 minutes total time) and are usually only done at wind-off conditions. Zero calibrations involve the PCU sending a zero ΔP across the transducer. The higher order coefficients are retained from the last full calibration and the offset coefficient (C_0) is updated to satisfy the above equation. During calibration , on-line diagnostics are used to indicate that the system(s) is performing correctly and within expected tolerances. The various diagnostics are given in APPENDIX D. In order to check the ESP system(s) during tunnel operation, at least one port on each module is pneumatically connected such that ΔP will equal zero for that port. When the indicated pressure on that reference port exceeds the accuracy tolerance (±0.19 % FS), a zero calibration is usually performed.

Tunnel wall pressures (16 rows, 352 "good" orifices) can be measured and used to make wall interference assessments. The orifice layout and the standard module hook-up remain essentially the same from test to test.

Pressure data may be presented in coefficient form. The coefficients are calculated by the following equation:

$$CP = \frac{[(\Delta P + P_{ref}) - P_{\infty}]}{q_{\infty}}$$

where

P_{∞} = free-stream static pressure

and

q_{∞} = free-stream dynamic pressure.

VI. OPTIONAL DATA CORRECTIONS AND CALCULATIONS

A. Sting-bending Temperature Corrections

An investigation was conducted at the NTF to document the change in sting-balance deflections from ambient to cryogenic temperatures (Reference 15). A method of reducing the required calibration time is to obtain only ambient temperature sting- balance bending data and to correct for changes in the modulus of elasticity with temperature. The following equation is used to correct the sting bending constants:

$$K_{i_{CRYO}} = K_{i_{AMB}} (A_0 + A_1 T_R)$$

where:

K_1 = yaw deflection due to side force
K_2 = yaw deflection due to yawing moment
K_3 = pitch deflection due to normal force
K_4 = pitch deflection due to pitching moment
K_5 = roll deflection due to rolling moment
K_6 = yaw deflection due to rolling moment
K_7 = roll deflection due to side force
K_8 = roll deflection due to yawing moment

CRYO indicates cryogenic temperatures
AMB indicates ambient temperature
T_R = rear balance thermocouple temperature in $°F$.

Using the above equation over the temperature range from $75°F$ to $-250°F$, a decrease of approximately 3.7% in bending can be expected. For the most prevalent sting material, Vascomax 200, $A_0 = 0.990746$ and $A_1 = 0.0001322$. If other materials are used, these constants can be adjusted in the data reduction set-up file.

B. Tunnel Flow Angularity Correction

Model orientation can be corrected for tunnel flow angularity in the pitch (upflow) direction and/or the yaw (crossflow) direction. Refer to Appendix B for a discussion of the Euler rotation equations. Upflow angle is determined by measuring normal force coefficient, C_N with the model upright and inverted at the same tunnel conditions. The inverted polar angle of attack, α values are multiplied by (-1) and a first order curve fit is performed on both polars over a specified angle range. This angle range is chosen based on the model. The intersection point of these two curves becomes the upflow angle, α_f. The method is shown below.

$$C_{N_{UPR}} = C_{0_{UPR}} + C_{1_{UPR}}\alpha_{UPR} \qquad \text{(1st order fit)}$$

$$C_{N_{INV}} = C_{0_{INV}} + C_{1_{INV}}\alpha_{INV} \qquad \text{(1st order fit)}$$

To determine flow angularity, $C_{N_{UPR}} = C_{N_{INV}}$ and $\alpha_{UPR} = \alpha_{INV}$, therefore:

$$C_{0_{UPR}} + C_{1_{UPR}}\alpha_f = C_{0_{INV}} + C_{1_{INV}}\alpha_f$$

and

$$\alpha_f = \frac{(C_{0_{INV}} - C_{0_{UPR}})}{(C_{1_{UPR}} - C_{1_{INV}})}$$

where

C_0 = offset

C_1 = slope

UPR indicates upright

INV indicates inverted

α_f = upflow angle.

Currently, the Data Analysis System (DAS) software (Reference 13) is used to compute flow angularity. The data is first processed using the off-line data reduction software. A file is created containing the values to be used for computing the flow angle correction. Once the upflow angle has been determined another pass is made throught the data reduction software to correct for tunnel flow angularity. The present method is somewhat awkward and time consuming and a one pass data reduction method is planned for the near future. This method will be self-contained and will not require the use of the DAS software.

In the NTF, there is no mechanism for conducting an angle sweep in the yaw direction, therefore, only two points ($\phi = 90°$ and $\phi = -90°$) can be obtained to determine crossflow. This normally is not done since it would not give an accurate representation of tunnel crossflow angle.

C. Mass Flow Calculation

Mass flow ratio calculations for flow-through nacelles are often made at the NTF. First the average pressure coefficient is calculated from n static pressure orifices in the nacelle.

$$CPIAV = \frac{(CP_1 + CP_2 + ...CP_n)}{n}$$

Using CPIAV, the average internal Mach Number, MIAV can be calculated.

$$MIAV = \sqrt{\left\{5\left[\left(\frac{P_{T_\infty}}{CPIAV \times q_\infty + P_\infty}\right)^{\frac{2}{7}} - 1\right]\right\}}$$

where

P_{T_∞} = free-stream total pressure

q_∞ = free-stream dynamic pressure

P_∞ = free-stream static pressure

The mass flow ratio (nacelle flow/free-stream flow), MFR is then calculated using the following equation:

$$MFR = KV \times \left[\frac{\left\{\frac{MIAV}{\left(1 + \frac{MIAV^2}{5}\right)^3}\right\}}{\left\{\frac{M_\infty}{\left(1 + \frac{M_\infty^2}{5}\right)^3}\right\}}\right] \times \left(\frac{ATF}{AHL}\right)$$

where

M_∞ = free-stream Mach Number

ATF = nacelle flow area

AHL = free-stream reference area

KV = viscous correction parameter (non-dimensional) based on chord Reynolds Number.

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D. Calculation of Model Deformation Parameter

The amount that a model deforms is predicted by the ratio of free-stream dynamic pressure, q_∞ to the modulus of elasticity, E, of the model metal. Aeroelastic studies in the NTF can be performed by holding the Mach Number and Reynolds Number constant and varying the q_∞/E parameter. Studies can also be made with a constant model shape (constant q_∞/E) while varying Reynolds Number. The modulus of elasticity (Young's modulus) for a particular model material is a function of temperature, therefore, this parameter is calculated by the following equation:

$$E = 144.0 \left[E_0 + (E_1 \times T_{T_\infty}) + \left(E_2 \times T_{T_\infty}^2 \right) + \left(E_3 \times T_{T_\infty}^3 \right) \right]$$

q_∞ = free-stream dynamic pressure in PSF

T_{T_∞} = tunnel total temperature in $°F$.

For the two model materials most frequently used in the NTF, the coefficients are as follows:

(1) Vascomax
$\quad E_0 = 26.47 \times 10^6$
$\quad E_1 = -3468.0$
$\quad E_2 = 0.0$
$\quad E_3 = 0.0$

(2) A286
$\quad E_0 = 28.371 \times 10^6$
$\quad E_1 = 754.9$
$\quad E_2 = 22.218$
$\quad E_3 = .025944$

VII. DATA MANAGEMENT

A. Data Acquisition and Reduction

The RCS must be configured for each test program based on the requirements documented in Administrative Instruction Procedure-29 (AIP-29) and the Test Plan developed by the Test Engineer. Once the configuration file has been generated, the system is started through the menu and the process of defining the required configuration environment will automatically be accomplished. One set-up file contains all the necessary information for the acquisition, recording , and

on-line data reduction. This file defines the types of instrumentation to be used, the DAU channels which have been selected, the ESP configuration and in some cases, calibration information for various tunnel devices. It also contains retrieval information for balance calibrations and temperature compensation constants. Model information is contained in the set-up file along with other constants necessary in the data reduction process. There is a capability to do simple calculations within the file which provides a mechanism for meeting unique computational test requirements without having to implement special software. Reference 11 gives detailed information about the research data acquisition and reduction process.

Off-line data reduction is done immediately upon receipt of the data reduction instruction sheet (Figure 9) from the test engineer or the research engineer. Tunnel customers and research engineers will be given a user area on one of the NTF file servers. The test data will be put into /tdata /ntf /testXX as soon as it is reduced. The customers/researchers may "ftp" the data files from the server to any workstation but they will not be given "write" privileges in this area. As previously mentioned, there is a two step process for data reduction in order to calculate the tunnel flow angularity. If the value of the flow angle falls outside of the range 0.13 ±0.05 the researcher will be consulted. The data file name will have the form " rxxx-yyyfp.f" where "xxx-yyy" is the run set," f" indicates the presence of force data, "p" indicates the presence of pressure data and the ".f" appendix indicates that the flow angularity correction has been applied. The customer may have access to both corrected and uncorrected data if desired. Force and pressure data may also be separated into two files if this is necessary. Most research engineers prefer to do their own analysis but some post-run plotting is available at the customers request using the Data Analysis System (DAS) plotting tool (Reference 13) . This service is provided only if time permits and manpower is available. NTF test personnel will always monitor the health of the instrumentation and the quality of the data. Refer to section D for a discussion of data verification.

B. Data Presentation

The research data may be presented in many different ways. The Graphical User Interface (GUI) software (SAMMI) allows for creating schematics and tabular displays. Several different types of plots and menus can be created for easy user interface to these displays. A real-time "snapshot" of selected raw and computed data will be configured pre-test and displayed on the workstation screen or printed to the lineprinter. Cyclic or "real-time" data is presented with the GUI but point-based data is usually displayed through the Research Graphics System (RGS). This system consists of third-party software (RT-WORKS) which provides for both continuous and point data to be plotted and displayed on as many as three Sun workstations. An additional feature of this system allows for previous test data to be plotted along with the current test information. This feature is very helpful in diagnosing problems and also in making "real-time" decisions about the test program. Once the RGS is configured for a test, the research engineer and/or customer will be allowed to change screens, change scales on individual plots and display predefined comparison data during operations. As with most on-line graphics systems, there are certain restrictions.

C. Data Transmittal

The information to be transmitted during the test will be determined pre-test and, if possible, will remain the same during the test. It is important to include all information which might need to be analyzed. The transmittal format is one that has been used at NTF for many years and is based on the standard interface file (SIFT) concept . The format is an ASCII 80 character record which can easily be read on any computer. The data items included in these transmittal files can be changed at any time during the test at the request of the customer through the proper channels.

Each NTFSIFT file contains at least one set of *NAME* records. Following these records, there may be many sets of *DATA* records. There may or may not be other sets of *NAME* records on the file.

NAME records are written with the following FORTRAN statements:

WRITE (IOUT,501) (ARRAY(I),I=J1,J2)
501 FORMAT (2X,6(A8,5X))

where

ARRAY = array of names
J2 =J1 + 5 and *J1* is incremented by *6* until *J2* ≥ *number of names.*
All unused fields are filled with the name "*BLANK*".

DATA records are written with the following FORTRAN statements:

WRITE (IOUT, 502) (ARRAY(I),.I=J1, J2)
502 FORMAT (2X, 6(E12.6, 1X))

where

ARRAY = array of data
J2 = J1 + 5 and *J1* is incremented by *6* until *J2* ≥ *number of data items.*
All unused fields are set to -9990.0.

The final data can be transmitted on 4mm DAT tape, optical disk or electronically transferred. The latter is the preferred mechanism. Flow visualization data may also be transmitted on CD-Rom. All research data generated in the NTF is FEDD restricted and company proprietary.

D. Data Verification

Because data quality is very important in the National Transonic Facility, data verification becomes the task of every individual involved in the test process. The data verification procedures take place not only when a model is being tested in the tunnel but when the model is placed in one of the model preparation areas. Data verification can logically be divided into two catagories:

(1) On-line Verification Procedures

Online Snapshot
A list of items will be predetermined for each test and these values will be saved in a snapshot file and/or printed on the lineprinter. These items are usually a combination of raw data, engineering units and computed data. Since a full set of corrections can be and usually are applied to the data, the values can be compared to the offline values post-run. The wind-off-zero point and tare run used to correct the balance data are also displayed. The snapshot is used to monitor the on-line calculations to insure instrumentation and data system health.

Wind-off Zero Log
A record of balance raw voltages, model angles calculated from the model acceleromenter and the arcsector accelerometer, balance temperatures, and tunnel temperature are recorded for each wind-off zero point. At the present time, this is done by the data system engineer but future plans are to have this stored on a computer file which can be retrieved at any time by test personnel. This log monitors the health of both the balance and model orientation devices.

Diagnostic Messages
For purposes of maintaining the health of various tunnel sytems such as the ESP 8400 system, the NEFF DAU, and the MACH Ruska system, many diagnostic messages are printed either to the Data System Engineer (DSE) workstation or to the lineprinter to indicate a potential problem.

Daily Instrumentation Calibrations/Checks
Calibrations and checks are run each morning by the instrumentation technicians on all of the above mentioned systems. Calibration reports are checked and the test engineer is notified if any of the systems are out of tolerance. If hardware maintenance is needed, it can be done early before testing begins. A report of this activity is given at the morning shift meeting.

OADISP tool
This tool provides a dynamic display of real-time channel data including the raw value, EU value, channel name, description, Neff range and filter setting.

RAWDISP tool
This tool can help provide verification of input data as close to the hardware as possible by displaying raw voltages (μV).

On-line Research Data Plots

Research plots are set-up pre-test by the research engineer and the test engineer. These plots can be a combination of real-time data and point-based data. The requested data is sent across the network from the RCS computer to a Sun workstation. There are three screens available for displays and plots. The RGS allows for historical comparisons (test-to-test), repeatability comparisons (run-to-run within a test), and logical progression checks. By viewing these "real-time" comparison plots, problems can often be found early enough to save nitrogen consumption.

RCS Debug Report

If a problem is suspected, various debug reports can be turned on by the DSE. Many of the intermediate calculations are saved for these reports and problems can sometimes be resolved by displaying these intermediate values. The user should be warned that only those reports that are needed should be initiated because large files and/or large stacks of paper can be created through this process.

(2) Off-line Verification Procedures

Off-line verification of data involves running one or more of the following "check" programs available on the ModComp or the Sun workstations :

RAWANAL

This software is available on the ModComp and can be run by the DSE at the request of the test engineer, research engineer, or other test personnel. The raw data file is read and individual scans of data for a requested point or points can be displayed as well as the average raw data record. Either ESP or Neff data can be displayed.

RAWED

This software is available on the Sun workstation and can be used by the DSE to modify information in the raw data header records such as dataid, run and point. For example, records can be skipped or rearranged to eliminate a bad ESP calibration.

DAUSCAN

This software is available on the Sun workstation and can also be run by the DSE at the request of the test personnel. ESP or DAU channel or channels may be requested and the individual scans are displayed. Statistical information is computed for a particular channel including mean, standard deviation and other information that might be helpful in assessing data problems. This program is particularly useful in detecting noise and lag time problems in the data.

TUNPC

This software is available on the Sun workstation and can be used by any of the test personnel to check tunnel parameters. With minimal instruction from the data quality engineer, this tool is useful in checking the continued veracity of the thermodynamic and equation of state subroutines. This program has an option to correct the total pressure for height difference.

TEMPCOMP

This software is available on the Sun workstation and can be used by any of the test personnel to check temperature compensation. First, the temperature compensation file for this test must be downloaded from RCS to the workstation. The program calculates temperature compensation for the six balance components for any given data point. The wind-off zero data for that point is also necessary.

This software is available on the Sun workstation and can be used by any of the test personnel to check 1st and 2nd order balance interactions. First, the latest balance calibration interaction file must be downloaded from RCS to the workstation. Then the balance forces and moments corrected for interactions can be calculated.

EULER1

This software is available on the Sun workstation for all test personnel. Given input angles in the gravity axis system and rotation information, it provides a check on angle rotations from the gravity axis system to the balance axis system and then the model axis system.

EULER2

This software is available on the Sun workstation for all test personnel. Given forces, moments and angles in the gravity axis system and the rotation information, it provides a check on forces and moments in the body axis, the stability axis and the wind axis systems.

The NTF operations personnel will be happy to assist the tunnel users in data verification using any of the above mentioned procedures. The ultimate product of the National Transonic Facility is high quality research data. The methods for acquiring, reducing and presenting research data in the NTF are highly flexible. Every effort will be made by the NTF staff to honor the requests of our customers when time and manpower are available. All data in the National Transonic Facility are considered FEDD restricted and company proprietary and certain restrictions are necessary to protect the data.

E. Future Plans

Future plans for the data system include:

1. On-line flow angularity calculation and corrections
2. On-line wall corrections
3. On-line research data used by model attitude control algorithm to achieve desired angle of attack (Alpha)and angle of sideslip (Beta)
4. On-line calculation, display and recording of standard deviation for all Neff channels
5. Off-line relational database storage and retrieval of test data for specific programs.

VIII. CONCLUSION

In this document, the users of the NTF are provided with information about the data system, the various instrumentation devices, the data reduction algorithms, the data management system and the data transmittal procedures. This report only briefly describes the design and major characteristics of the tunnel, and it is anticipated that it will be used in conjunction with other documents that fully describe these aspects of the National Transonic Facility. A new version of the National Transonic Facility User's Guide can be found at the following address on the World Wide Web:

http://ad-www.larc.nasa.gov/facility/ntf/ntftb.html

APPENDIX A.

BALANCE DATA REDUCTION EQUATIONS

Three types of data are required to properly compute the loads measured by a strain-gage balance: wind-off reference data, weight tare data, and wind-on data. Wind-on is the term used to refer to data acquired to measure an unknown load due to forces other than the model weight. The processing used to compute the unknown load for wind-on data requires the prior processing of the wind-off and the weight tare data. A detailed mathematical explanation of this procedure will follow.

The processing of a wind-off data point involves the calculation of a set of weight tare factors which are used to compute the initial loads on each balance. These factors are calculated by an iterative procedure. A mathematical explanation of this procedure is included in the following paragraphs.

The model weight is a vector, $\vec{W}$. In the gravity axis system, it is apparent that there are no horizontal components of weight and that the vertical component is directed downward. The weight vector in the gravity axis system, $\vec{W}_g$, is then

$$\vec{W}_g = (W_{gx}, W_{gy}, W_{gz}) = (0, 0, -W)$$

where W is the magnitude of $\vec{W}_g$ at attitude $[R_{gb}]$. This attitude matrix is defined as follows:

$$[R_{gb}] = [R_x \phi_g] [R_y \alpha_g] [R_z \psi_g]$$

where ϕ_g, α_g, ψ_g are rotations about the roll, pitch and yaw axes respectively and the subscript denotes the gravity axis system where:

$$[R_{gb}] = \begin{bmatrix} (\cos\alpha_g \cos\psi_g) & (-\cos\alpha_g \sin\psi_g) & (-\sin\alpha_g) \\ (\cos\phi_g \sin\psi_g - \sin\phi_g \sin\alpha_g \cos\psi_g) & (\cos\phi_g \cos\psi_g + \sin\phi_g \sin\alpha_g \sin\psi_g) & (-\sin\phi_g \cos\alpha_g) \\ (\sin\phi_g \sin\psi_g + \cos\phi_g \sin\alpha_g \cos\psi_g) & (\sin\phi_g \cos\psi_g - \cos\phi_g \sin\alpha_g \sin\psi_g) & (\cos\phi_g \cos\alpha_g) \end{bmatrix}$$

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Because the x and y components of $\vec{W_g}$ are zero, only the third column of $[R_{gb}]$ needs to be considered.

Force Weight Tare Computation

Consider the third column of $[R_{gb}]$, denoted $[R3]$, which is

$$[R3] = \begin{bmatrix} -\sin\alpha_g \\ -\sin\phi_g\cos\alpha_g \\ \cos\phi_g\cos\alpha_g \end{bmatrix}$$

For the wind-off zero point $[R3]$ becomes $[R3_0]$:

$$[R3_0] = \begin{bmatrix} -\sin\alpha_0 \\ -\sin\phi_0\cos\alpha_0 \\ \cos\phi_0\cos\alpha_0 \end{bmatrix}$$

The delta weight tares are defined as the change in balance components due to model weight W, relative to initial loads. Now let

$$[V] = -([R3] - [R3_0])$$

Then the delta force weight tares can be expressed as:

$$\begin{bmatrix} AFTA \\ SFTA \\ NFTA \end{bmatrix} = W\begin{bmatrix} V1 \\ V2 \\ V3 \end{bmatrix} = \begin{bmatrix} W(\sin\alpha_g - \sin\alpha_0) \\ W(\sin\phi_g\cos\alpha_g - \sin\phi_0\cos\alpha_0) \\ -W(\cos\phi_g\cos\alpha_g - \cos\phi_0\cos\alpha_0) \end{bmatrix}$$

Now, recognizing that the force beams of a balance will each sense a different portion of the balance weight as well as the model weight, this equation may be rewritten as:

$$WAF = \frac{AFTA}{V1}$$

$$WSF = \frac{SFTA}{V2}$$

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$$WNF = \frac{NFTA}{V3}$$

provided the denominators are not zero.

In actual practice, several weight tare recordings are made at different balance attitudes which results in an overly defined system of equations. The solution for the force weight tares will be written in the following form for consistency with the moment weight tares.

Assuming n weight tare recordings, the solution is written:

$$WAF = \frac{\displaystyle\sum_{i=1}^{n} (AFTA_i \times V1_i)}{DTAF}$$

$$WSF = \frac{\displaystyle\sum_{i=1}^{n} (SFTA_i \times V2_i)}{DTSF}$$

$$WNF = \frac{\displaystyle\sum_{i=1}^{n} (NFTA_i \times V3_i)}{DTNF}$$

where the denominators are:

$$DTAF = \sum_{i=1}^{n} (V1_i \times V1_i)$$

$$DTSF = \sum_{i=1}^{n} (V2_i \times V2_i)$$

$$DTNF = \sum_{i=1}^{n} (V3_i \times V3_i)$$

Moment Weight Tares

If transfer distances X, Y, and Z are measured in the balance axis system from the balance

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moment center to the model center of gravity, positive in the directions of positive thrust, side force and normal force respectively, then the delta moment weight tares are obtained by transferring moments as follows:

$$\begin{bmatrix} RMTA \\ PMTA \\ YMTA \end{bmatrix} = \begin{bmatrix} SFTA \times Z - NFTA \times Y \\ AFTA \times Z + NFTA \times X \\ SFTA \times X + AFTA \times Y \end{bmatrix}$$

Substituting for AFTA, SFTA and NFTA gives:

$$\begin{bmatrix} RMTA \\ PMTA \\ YMTA \end{bmatrix} = \begin{bmatrix} (WSF \times V2 \times Z) - (WNF \times V3 \times Y) \\ (WAF \times V1 \times Z) + (WNF \times V3 \times X) \\ (WSF \times V2 \times X) + (WAF \times V1 \times Y) \end{bmatrix}$$

Each of the equations can be solved for the weight tare factors by first premultiplying both sides of the equation by the transpose of the row vector on the right containing the V terms. The solution then involves inverting the matrix obtained from the transpose of the row vector times the row vector itself.

Recalling that in actual practice, several weight tare recordings are made (both pitch and roll angles), the solution obtained are then:

$$WZRM = \frac{\sum_{i=1}^{n} (V3_i \times V3_i) \times \sum_{i=1}^{n} (RMTA_i \times V2_i) - \sum_{i=1}^{n} (V2_i \times V3_i) \times \sum_{i=1}^{n} (RMTA_i \times V3_i)}{DTRM}$$

$$WYRM = \frac{\sum_{i=1}^{n} (V2_i \times V3_i) \times \sum_{i=1}^{n} (RMTA_i \times V2_i) - \sum_{i=1}^{n} (V2_i \times V2_i) \times \sum_{i=1}^{n} (RMTA_i \times V3_i)}{DTRM}$$

$$WZPM = \frac{\sum_{i=1}^{n} (V3_i \times V3_i) \times \sum_{i=1}^{n} (PMTA_i \times V1_i) - \sum_{i=1}^{n} (V1_i \times V3_i) \times \sum_{i=1}^{n} (PMTA_i \times V3_i)}{DTPM}$$

$$WXPM = \frac{\sum_{i=1}^{n} (V1_i \times V1_i) \times \sum_{i=1}^{n} (PMTA_i \times V3_i) - \sum_{i=1}^{n} (V1_i \times V3_i) \times \sum_{i=1}^{n} (PMTA_i \times V1_i)}{DTPM}$$

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$$WXYM = \dfrac{\sum\limits_{i=1}^{n}(V1_i \times V1_i) \times \sum\limits_{i=1}^{n}(YMTA_i \times V2_i) - \sum\limits_{i=1}^{n}(V2_i \times V1_i) \times \sum\limits_{i=1}^{n}(YMTA_i \times V1_i)}{DTYM}$$

$$WYYM = \dfrac{\sum\limits_{i=1}^{n}(V2_i \times V2_i) \times \sum\limits_{i=1}^{n}(YMTA_i \times V1_i) - \sum\limits_{i=1}^{n}(V2_i \times V1_i) \times \sum\limits_{i=1}^{n}(YMTA_i \times V2_i)}{DTYM}$$

where the denominators are

$$DTRM = \sum\limits_{i=1}^{n}(V2 \times V2_i) \times \sum\limits_{i=1}^{n}(V3_i \times V3_i) - \sum\limits_{i=1}^{n}(V2_i \times V3_i) \times \sum\limits_{i=1}^{n}(V2_i \times V3_i)$$

$$DTPM = \sum\limits_{i=1}^{n}(V1_i \times V1_i) \times \sum\limits_{i=1}^{n}(V3_i \times V3_i) - \sum\limits_{i=1}^{n}(V1_i \times V3_i) \times \sum\limits_{i=1}^{n}(V1_i \times V3_i)$$

$$DTYM = \sum\limits_{i=1}^{n}(V1_i \times V1_i) \times \sum\limits_{i=1}^{n}(V2_i \times V2_i) - \sum\limits_{i=1}^{n}(V1_i \times V2_i) \times \sum\limits_{i=1}^{n}(V1_i \times V2_i)$$

If the absolute value of the demoninator for either the force or moment equations is less than some predetermined tolerance level, then this is an indication that there is insufficient data in this set of tare points to accurately calculate this particular parameter. The parameter is then set equal to a corresponding parameter for which there is sufficient information to be calculated (Reference 12).

The nine weight tare factors are computed based on corrected balance-axis components, which in turn are based upon assumed initial loads equal to the wind-off zero loads. The newly computed weight tare factors are then used to recompute the initial loads, which are then compared to the original loads. If the new initial loads are sufficiently close to the old initial loads, they are assumed to have converged, and the tare computations are accepted. If the new initial loads are significantly different, the old initial loads are replaced with the new initial loads, which are then used to recompute the corrected balance components to start another iteration. This process continues until the initial loads converge or for a maximum of five iterations. The accuracy required for each component is obtained from the balance calibration. The nine weight tare factors, the six initial loads, and the wind-off zero angles are all saved for future wind-on computations.

Corrections for Balance Interactions

The uncorrected balance components are AF, SF, NF, RM, PM, and YM. These components are referred to as "delta" components because they are relative to a wind-off zero recording of ini-

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tial loads. The components are treated as a 6 X 1 column vector demoted by FU (forces uncorrected), where:

$$FU = \begin{bmatrix} AF \\ SF \\ NF \\ RM \\ PM \\ YM \end{bmatrix}$$

Let the components corrected for interactions be denoted $[F]$

$$[F] = \begin{bmatrix} AFC \\ SFC \\ NFC \\ RMC \\ PMC \\ YMC \end{bmatrix}$$

For first order interactions, the following matrix relationship between correct and indicated components has been established during the balance calibration:

$$[FU] = [C1] [F]$$

where $[C1]$ is a 6 X 6 matrix which is the normalized first order interaction coefficient matrix with main diagonal elements of unity.

Provided $[C1]$ is nonsingular, the correct delta components are found from:

$$[F] = [C1I] [FU]$$

where $[C1I]$ is the inverse of $[C1]$.

Second Order Interactions

For second order interactions, the following matrix relationship between correct and indicated components has been established during the balance calibration:

$$[FU] = [C1] [F] + [C2] [F2]$$

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were $[C2]$ is a 6 X 21 matrix which is the normalized second order interaction coefficient matrix and $[F2]$ is a 21 X 1 matrix of product combinations of $[F]$ as follows:

$$[F2] = \begin{bmatrix} AFC \times AFC \\ AFC \times SFC \\ AFC \times NFC \\ AFC \times RMC \\ AFC \times PMC \\ AFC \times YMC \\ SFC \times SFC \\ SFC \times NFC \\ SFC \times RMC \\ SFC \times PMC \\ SFC \times YMC \\ NFC \times NFC \\ NFC \times RMC \\ NFC \times PMC \\ NFC \times YMC \\ RMC \times RMC \\ RMC \times PMC \\ RMC \times YMC \\ PMC \times PMC \\ PMC \times YMC \\ YMC \times YMC \end{bmatrix}$$

Provided $[C1]$ is nonsingular, The correct delta components are found from:

$$[F] = [C1I] \, [FU] - [C1IC2] \, [F2]$$

where $[C1IC2]$ is the product of the inverse of $[C1]$ and $[C2]$. This equation must be solved iteratively because $[F]$ is expressed in terms of $[F2]$ which is itself a function of $[F]$.

Translation of Initial Loads

Typical balance calibration coefficients as determined in the laboratory have a zero-load reference (i.e., no external weight or load applied to the balance) and, therefore, are based on total applied loads. In the wind tunnel, however, load measurements are made relative to a wind-off zero recording. These loads are delta loads since the weight of the model has already been sensed by the balance when the wind-off zero was taken. Since the 2nd-order interaction coefficients are nonlinear it is necessary to add in the initial loads before correcting for 2nd-order interactions. The following is a mathematical description of the procedure.

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Let $[FU_0]$ denote the indicated initial loads,

$[F_0]$ denote the correct initial loads,

$[FUT]$ denote the indicated total loads, and

$[FT]$ denote the correct total loads

where

$$[FT] = \begin{bmatrix} AFT0 \\ SFT0 \\ NFT0 \\ RMT0 \\ PMT0 \\ YMT0 \end{bmatrix}$$

By definition

$$[FUT] = [FU] + [F_0]$$

and

$$[FT] = [F] + [F_0]$$

The second order interaction relationship between correct and indicated components for the tunnel is then:

$$[FT] = [C1I] [FUT] - [C1IC2] [F2T]$$

where $[F2T]$ is just $[F2]$ based on $[FT]$. This equation must be solved iteratively. Note that for initial loads, this becomes

$$[F_0] = [C1I] [FU_0] - [C1IC2] [F2_0]$$

where $[F2_0]$ is just $[F2]$ based on $[F_0]$.

Now, for the ith iteration, let

$$[\varepsilon_i] = [C1IC2] [F2T]$$

and specifically, for initial loads, let

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$$[\varepsilon_0] = [C1/C2] [F2_0] .$$

The iteration technique is then given by:

Iteration	[FT] Approximation	Error
0	$[C1/] [FU] + [C1/] [FU_0]$	$[\varepsilon_0]$
1	$[C1/] [FU] + [C1/] [FU_0] - [\varepsilon_0]$	$[\varepsilon_1] - [\varepsilon_0]$
2	$[C1/] [FU] + [C1/] [FU_0] - [\varepsilon_1]$	$[\varepsilon_2] - [\varepsilon_1]$
.		.
.		.
.		.

This iteration is continued until $[\varepsilon_i] - [\varepsilon_{i-1}]$ is less than the specified accuracy for all components. The accuracy criteria are obtained for the balance calibration.

The correct delta components are then obtained from;

$$[F] = [FT] - [F_0]$$

Computation of Sting Deflections

Sting deflection (or bending) occurs when loads are applied through the model. Devices used to measure angles which define the balance and model attitude are sometimes located such that they do not record deflections of the sting. Consequently, sting deflection angles must be computed as a function of correct balance loads. The deflection angles are assumed to be small enough so that the sting responds elastically, allowing the angle to be described as a spring constant times a load. The loads used in the bending calculations can be either total loads or delta loads. In the following equations the spring (deflection) constants are SFDF, YMDF, NFDF, PMDF, and RMDF.

For delta loads, the current deflections and initial deflections are:

$$YAWS = (SFC \times SFDF) + (YMC \times YMDF)$$

$$ALPS = (NFC \times NFDF) + (PMC \times PMDF)$$

$$PHIS = (RMC \times RMDF)$$

$$YAWI = 0.0$$

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$ALPI=$ 0.0

$PHII=$ 0.0

For total loads, the current and initial deflections are:

$$YAWS= (SFT0 \times SFDF) + (YMT0 \times YMDF)$$

$$ALPS= (NFT0 \times NFDF) + (PMT0 \times PMDF)$$

$$PHIS= (RMT0 \times RMDF)$$

$$YAWI= -YAWS$$

$$ALPI= -ALPS$$

$$PHII= -PHIS$$

Computation of Balance Attitude

The attitude of the balance with respect to gravity is determined on the basis of a specified input rotation scheme which consists of an ordered set of orthogonal Eulerian transformations (Appendix B). Each transformation rotates the components of a vector through a specified angle about a specified axis. The final result is the transformation of the components of a vector from the gravity axis system to the balance axis system. The axis system used are right-hand Cartesian systems (Figure 10).

The transformation matrix $[R_{gb}]$, as defined on the first page of this appendix, describes the attitude of the balance with respect to gravity and is derived from successive applications of the appropriate individual transformations. This can be summarized as a single yaw rotation YAWG, followed be a single pitch rotation ALPG, followed by a single roll rotation PHIG. That is:

$$[R_{gb}]= [R_x(PHIG)] [R_y(ALPG)] [R_z(YAWG)]$$

Solving for YAWG, ALPG, and PHIG gives:

$$YAWG= \text{atan} [(\cos\alpha_g \sin\psi_g) / (\cos\alpha_g \cos\psi_g)]$$

$$ALPG= \text{asin} [\sin\alpha_g]$$

$$PHIG= \text{atan} [(\sin\phi_g \cos\alpha_g) / (\cos\phi_g \cos\alpha_g)]$$

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Restrictions and special conditions for these calculations are listed in Reference 12. In the NTF data reduction software there can be up to eight gravity to balance rotations with a special code to define the type of rotation. This allows for rotations due to a bent sting (knuckle).

The gravity to balance matrix $[R_{gb}]$ is then further rotated through the sting-bending angles PHIS, ALPS, and YAWS by the method described in APPENDIX B.

Correction for Weight Tares

For the balance at any attitude $[R_{gb}]$, let $[FTARE]$ equal a vector containing weight tare corrections as defined previously.

$$[FTARE] = \begin{bmatrix} AFTA \\ SFTA \\ NFTA \\ RMTA \\ PMTA \\ YMTA \end{bmatrix}$$

Now let $[FBAL]$ denote the aerodynamic loads in the balance axis system where:

$$[FBAL] = \begin{bmatrix} AFBA \\ SFBA \\ NFBA \\ RMBA \\ PMBA \\ YMBA \end{bmatrix}$$

The aerodynamic loads in the balance axis system are computed by subtracting the weight tares from the correct delta balance loads.

$$[FBAL] = [F] - [FTARE]$$

Computation of Model Attitude

Now that the gravity axis to balance axis transformation $[R_{gb}]$ has been fully developed. Similar transformation matrices from balance axis to model axis $[R_{bm}]$ and from wind axis to gravity axis $[R_{wg}]$ may be similarly defined on the basis of specified input rotation schemes.

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The wind to gravity matrix $[R_{wg}]$ describes the tunnel flow angularity and is defined as an upflow or pitch rotation and a crossflow or yaw rotation.

The attitude of the model with respect to the wind can then be described by the transformation matrix $[R_{wm}]$ given by:

$$[R_{wm}] = [R_{bm}] \, [R_{gb}] \, [R_{wg}]$$

The model attitude $[R_{wm}]$ can also be summarized as a single roll rotation PHIW, followed by a single yaw rotation YAWW, followed by a single pitch rotation ALPW. That is:

$$[R_{wm}] = [R_y(ALPW)] \, [R_z(YAWW)] \, [R_x(PHIW)]$$

Substituting the elementary transforms and carrying out the indicated multiplications yields:

$$R_{WM} = \begin{bmatrix} (\cos\alpha_w\cos\psi_w) & (-\cos\alpha_w\sin\psi_w\cos\psi_w - \sin\alpha_w\sin\phi_w) & (\cos\alpha_w\sin\psi_w\sin\phi_w - \sin\alpha_w\cos\varphi_w) \\ (\sin\psi_w) & (\cos\psi_w\cos\phi_w) & (-\cos\psi_w\sin\phi_w) \\ (\sin\alpha_w\cos\psi_w) & (-\sin\alpha_w\sin\psi_w\cos\phi_w + \cos\alpha_w\sin\phi_w) & (\sin\alpha_w\sin\psi_w\sin\phi_w + \cos\alpha_w\cos\phi_w) \end{bmatrix}$$

Solving for YAWW, ALPW, and PHIW gives:

$$PHIW = \operatorname{atan}[\,(\cos\psi_w\sin\phi_w)/(\cos\psi_w\cos\phi_w)\,]$$

$$YAWW = \operatorname{asin}[\sin\psi_w]$$

$$ALPW = \operatorname{atan}[\,(\sin\alpha_w\cos\psi_w)/(\cos\alpha_w\cos\psi_w)\,]$$

The restrictions and special conditions associated with these angle computations are listed in Reference 12.

The angle of attack of the model is ALPW and the angle of sideslip is computed from the definition (Figure 11):

$$BETA = -YAWW$$

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Computation of Balance Components in the Model Axis System

The correct balance axis components can now be rotated into the model axis system by using rotation matrix $[R_{bm}]$. The subscripts are used for clarity in describing the final rotations and corrections to the balance components.

$$\begin{bmatrix} AFMA_1 \\ SFMA_1 \\ NFMA_1 \end{bmatrix} = [R_{bm}] \begin{bmatrix} AFBA \\ SFBA \\ NFBA \end{bmatrix}$$

$$\begin{bmatrix} -RMMA_1 \\ PMMA_1 \\ -YMMA_1 \end{bmatrix} = [R_{bm}] \begin{bmatrix} -RMBA \\ PMMA \\ -YMBA \end{bmatrix}$$

The minus signs in the moment equations result from axis system differences in the conventional wind tunnel balance force and moment sign conventions.

The transfer distances $XBAR$, $YBAR$, and $ZBAR$ describe the transfer from the balance moment center to the model moment reference center (Figure 12). The transfer equations are given by:

$$AFMA_2 = AFMA_1$$

$$SFMA_2 = SFMA_2$$

$$NFMA_2 = NFMA_1$$

$$RMMA_2 = RMMA_1 + (NFMA_1 \times YBAR) - (SFMA_1 \times ZBAR)$$

$$PMMA_2 = PMMA_1 - (NFMA_1 \times XBAR) - (AFMA_1 \times ZBAR)$$

$$YMMA_2 = YMMA_1 - (SFMA_1 \times XBAR) - (AFMA_1 \times YBAR)$$

Base and Chamber Pressures

Letting PB_i denote the ith base pressure, the base pressure coefficients are computed as:

$$CPB_i = \frac{(PB_i - P_\infty)}{q_\infty}$$

where

$$q_\infty = \text{free-stream dynamic pressure}$$

and

$$P_\infty = \text{free-stream static pressure.}$$

The forces and moments to be applied as a correction are computed as:

$$
\begin{bmatrix} AFB \\ SFB \\ NFB \\ RMB \\ PMB \\ YMB \end{bmatrix} = \sum_{i=1}^{NBAS} (PB_i - P_\infty) \begin{bmatrix} -AREA_{AF_i} \\ AREA_{SF_i} \\ AREA_{NF_i} \\ (AREA \times ARM)_{RM_i} \\ (AREA \times ARM)_{PM_i} \\ (AREA \times ARM)_{YM_i} \end{bmatrix}
$$

where the summation i is over all base pressures for which the correction flag is set equal to one. The column vector on the right side and the correction flag are obtained from the input specifications.

If the correction flag is set to zero, the forces and moments (XAFB, XSFB, XNFB, XRMB, XPMB, XYMB) are computed as above but not applied.

The axial force terms are also expressed in terms of axial and drag coefficients as:

$$CAB = AFB / (q_\infty \times S)$$

$$CDB = CAB \times \cos\alpha_w$$

$$XCAB = XAFB / (q_\infty \times S)$$

$$XCDB = XCAB \times \cos\alpha_w$$

Letting PC_i denote the ith chamber pressure, the individual pressure coefficients are computed as:

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$$CPC_i = \frac{(PC_i - P_\infty)}{q_\infty}$$

The forces and moments to be applied as a correction are computed as:

$$
\begin{bmatrix} AFCH \\ SFCH \\ NFCH \\ RMCH \\ PMCH \\ YMCH \end{bmatrix} = \sum_{i=1}^{NCHM} (PC_i - P_\infty) \begin{bmatrix} -AREA_{AF_i} \\ AREA_{SF} \\ AREA_{NF_i} \\ (AREA \times ARM)_{RM_i} \\ (AREA \times ARM)_{PM_i} \\ (AREA \times ARM)_{YM_i} \end{bmatrix}
$$

where the summation of i over all chamber pressures for which the correction flag is equal to one. The column vector on the right side and the correction flag are obtained from the input specifications.

When the correction flag is equal to zero, the forces and moments (XAFC, XSFC, XNFC, XRMC, XPMC, and XYMC) are computed as above but not applied.

Sign Convention for Area (A) and Arm (l) in Base and Chamber Correction

Force/ Moment	Orifice Location	Area (A) Sign	Arm (l)	A*l sign
Axial	Rearward facing	+		
Axial	Forward facing	-		
Normal	Top	+		
Normal	Bottom	-		
Pitch	Top-rear	+	-	-
Pitch	Bottom-rear	-	-	+
Pitch	Top-forward	+	+	+
Pitch	Bottom-forward	-	+	-

The axial force terms are also expressed in terms of axial and drag coefficients as:

$$CAC = AFCH / (q_\infty \times S)$$

45

$$CDC = CAC \times \cos\alpha_w$$

$$XCAC = = XAFC/(q_\infty \times S)$$

$$XCDC = XCAC \times \cos\alpha_w$$

Computation of Model, Stability and Wind Axis Components

The forces and moments are corrected for base and chamber pressures to give the final corrected model axis components:

$$
\begin{bmatrix} AFMA \\ SFMA \\ NFMA \\ RMMA \\ PMMA \\ YMMA \end{bmatrix} = \begin{bmatrix} ARMA_2 \\ SFMA_2 \\ NFMA_2 \\ RMMA_2 \\ PMMA_2 \\ YMMA_2 \end{bmatrix} - \begin{bmatrix} AFB \\ SFB \\ NFB \\ RMB \\ PMB \\ YMB \end{bmatrix} - \begin{bmatrix} AFCH \\ SFCH \\ NFCH \\ RMCH \\ PMCH \\ YMCH \end{bmatrix}
$$

The stability axis components are obtained by rotating the model axis components through minus the angle of attack

$$
\begin{bmatrix} DRAG \\ SFSA \\ LIFT \end{bmatrix} = [R_y(-\alpha_w)] \begin{bmatrix} AFMA \\ SFMA \\ NFMA \end{bmatrix}
$$

$$
\begin{bmatrix} -RMSA \\ PMSA \\ -YMSA \end{bmatrix} = [R_y(-\alpha_w)] \begin{bmatrix} -RMMA \\ PMMA \\ -YMMA \end{bmatrix}
$$

The wind axis components are obtained by rotating the stability axis components through the angle of sideslip:

$$
\begin{bmatrix} AFWA \\ SFWA \\ NFWA \end{bmatrix} = [R_z(\beta)] \begin{bmatrix} DRAG \\ SFSA \\ LIFT \end{bmatrix}
$$

$$
\begin{bmatrix} -RMWA \\ PMWA \\ -YMWA \end{bmatrix} = [R_z(\beta)] \begin{bmatrix} -RMSA \\ PMSA \\ -YMSA \end{bmatrix}
$$

Computation of Coefficients

Let $[FMA]$, $[FSA]$, and $[FWA]$ denote the model, stability and wind axis components and define the 6 X 6 maindiagonal matrix $[C]$ as:

$$[C] = \begin{bmatrix} \dfrac{1}{q_\infty \times S} & 0 & 0 & 0 & 0 & 0 \\[2ex] 0 & \dfrac{1}{q_\infty \times S} & 0 & 0 & 0 & 0 \\[2ex] 0 & 0 & \dfrac{1}{q_\infty \times S} & 0 & 0 & 0 \\[2ex] 0 & 0 & 0 & \dfrac{1}{q_\infty \times S \times B} & 0 & 0 \\[2ex] 0 & 0 & 0 & 0 & \dfrac{1}{q_\infty \times S \times CBAR} & 0 \\[2ex] 0 & 0 & 0 & 0 & 0 & \dfrac{1}{q_\infty \times S \times B} \end{bmatrix}$$

where

S	=	model reference area (ft^2)
CBAR	=	model reference chord (in.)
B	=	model reference span (in.)
q_∞	=	dynamic pressure (psf)

and all of the elements off the main diagonal are zero as shown.

Let $[CMA]$, $[CSA]$, and $[CWA]$ denote the model, stability and wind axis coefficients:

$$[CMA] = \begin{bmatrix} CA \\ CY \\ CN \\ CRM \\ CM \\ CYM \end{bmatrix}$$

$$[CSA] = \begin{bmatrix} CD \\ CYS \\ CL \\ CRMS \\ CMS \\ CYMS \end{bmatrix}$$

$$[CWA] = \begin{bmatrix} CDW \\ CYW \\ CLW \\ CRMW \\ CMW \\ CYMW \end{bmatrix}$$

The model, stability and wind axis coefficients are then computed as:

$$[CMA] = [C] \, [FMA]$$

$$[CSA] = [C] \, [FSA]$$

$$[CWA] = [C] \, [FWA]$$

The lift to drag ratio and lift squared are also computed.

$$L/D = CL/CD$$

$$CLSQ = CL \times CL$$

APPENDIX B.

EULER ROTATION SCHEME

The NTF data reduction software uses a rotation scheme to determine balance attitude, model attitude and also to adjust for flow angularity in the tunnel. This scheme (Figure 10) consists of an ordered set of orthogonal Eulerian transformations. Each transformation rotates the components of a vector through a specified angle about a specified axis.

The following define the three types of rotations that are used:

(1) Roll rotation through some angle ϕ about the X-axis - right wing down is positive.

$$Rx(\phi) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\phi) & -\sin(\phi) \\ 0 & \sin(\phi) & \cos(\phi) \end{bmatrix}$$

(2) Pitch rotation through some angle θ about the Y-axis - nose up is positive.

$$Ry(\theta) = \begin{bmatrix} \cos(\theta) & 0 & -\sin(\theta) \\ 0 & 1 & 0 \\ \sin(\theta) & 0 & \cos(\theta) \end{bmatrix}$$

(3) Yaw rotation through some angle ψ about the Z - axis - right wing aft is positive.

$$Rz(\psi) = \begin{bmatrix} \cos(\psi) & -\sin(\psi) & 0 \\ \sin(\psi) & \cos(\psi) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

The order of the rotations is important since the rotations are noncommutative. An ordered set of codes describing the axes of rotation is included in the data reduction set-up file.

APPENDIX C.

DESCRIPTION OF NTF BALANCES

Force balances for the National Transonic Facility must be specially designed to withstand the extreme temperature and high loads imposed by a cryogenic high-pressure tunnel. If a model or test requires a balance of a different size or load range then those listed in the table below, a minimum of one year is needed to design, fabricate, gage and calibrate the balance for the NTF. However, if testing is to be done only at ambient temperature, the data reduction equations provide for processing output from any type of balance, either force or moment.

At this time all NTF balances are constructed of an 18-percent nickel maraging vacuum-remelt steel with an ultimate strength of 200 KSI. The model balance interface is a diameter fit with a dowel for fixing the longitudinal location of the moment center. The sting balance fit is a taper with set screws at 45° to seat and unseat the taper. In addition to the force and moment gages, each NTF cryogenic balance comes with three type T thermocouples positioned at the front, axial and rear of the balance. The output from these thermocouples is used to temperature compensation the balance during testing. (The NTF113C has three PRT's instead of the type T thermocouples. This balance also provides for wiring for the AOA package and ESP modules through the middle of the balance in order to keep these wires from carrying loads when they are passed over the outside of the balance.)

Most NTF balances have integral wiring 20 feet long. There are eighteen #32 gauge wires and three type T thermocouple wires encased in a sleeving. This wire bundle is approximately 0.25 inches in diameter. The table on the next page lists all of the NTF balances with size and maximum loads.

Size and Load Capacity Information on NTF Balances

BALANCE	SIZE diameter x length	normal (lbs)	axial (lbs)	pitch (in-lbs)	roll (in-lbs)	yaw (in-lbs)	side (lbs)
NTF101A	2.375 X 15.565	6500	700	13000	9000	6500	4000
NTF101B	2.375 X 15.565	6500	700	13000	9000	6500	4000
NTF102	2.000 X 14.281	3000	600	6000	600	600	300
NTF103	2.000 X 14.281	1500	300	3000	300	300	150
NTF104A	2.000 X 14.281	3400	300	10000	5000	5000	1000
NTF104B	2.000 X 14.281	3400	300	10000	5000	5000	1000
NTF105	2.000 X 14.281	2000	175	6000	3000	3000	700
NTF106	1.750 X 12.176	2500	350	5000	2500	4000	1000
NTF107	0.750 X 7.250	160	50	250	100	125	40
NTF108	1.500 X 12.013	1600	125	3000	1500	1500	500
NTF109	Nose Balance	1200	175	3000	900	1500	350
NTF111	1.750 X 12.176	1000	300	2000	1000	2000	500
NTF112	1.250 X 9.400	600	180	1700	1000	400	280
NTF113A	2.375 X 15.565	6500	400	13000	9000	6500	4000
NTF113B	2.375 X 15.565	6500	400	13000	9000	6500	4000
NTF113C	2.375 X 15.565	6500	400	13000	9000	6500	4000
NTF113D	2.375 X 15.565	6500	400	13000	9000	6500	4000
NTF114S*	16.00 X 25.750	6100	1300	70000	353000	75400	-- --
NTF115	2.000 X 14.281	3200	200	6500	4500	2500	1000

* The NTF114S balance is a side-wall balance used for semi-span testing.

APPENDIX D.

ESP 8400 SYSTEM DIAGNOSTICS

The following diagnostic messages are part of the standard RCS ESP calibration software. The requirements apply to full module calibration unless otherwise indicated. (FS = full scale pressure of the module and C_i are the calibration coefficients.)

TEST (1)

$|C_0| \leq 0.25$ X full scale pressure of module

MESSAGE (1)

C_0 out of tolerance ($C_0 \geq 0.25$ X FS)

TEST (2) (zero calibration)

$|C_0| \leq 0.004$ X FS

MESSAGE (2)

ΔC_0 out of tolerance ($C_0 \geq 0.004$ X FS)

TEST (3)

$[C_1 \geq (FS/5) \times 0.7]$ .AND. $[(C_1 \leq FS/5) \times 1.25]$

MESSAGE (3) (if out of these bounds)

C_1 (sensitivity) out of tolerance

TEST (4)
The combined non-linear coefficient test should be based on the maximum calibration pressure voltage for the given port (i.e. V4).

$$|C_2 \times (V4)^2 + C_3 \times (V4)^3 \times C_4 \times (V4)^4| \leq 0.007 \ X \ FS$$

MESSAGE (4)

Combined coefficient calculation out of tolerance

52

REFERENCES

1. Benedict, Robert P.: Fundamentals of Temperature, Pressure and Flow Measurements. John Wiley & Sons, Inc., 1969.

2. Beattie, James A.; and Bridgeman, Oscar C.: A New Equation of State for Fluids. The Journal of American Chemical Society Vol. 50, No. 12, December 1928.

3. Stewart, R. R.; Jacobsen, R. T. ; and Myers, A. F.: The Thermodynamic Properties of Oxygen and Nitrogen - Part 1. Engineering Experiment Station, University of Idaho, August 1972.

4. Jacobsen, R. T.; Stewart, R. B.; McCarty, R. D.; and Hanley, H. J. M.: Thermophysical Properties of Nitrogen from the Fusion Line 3500 R (1944 K) for Pressures to 150,000 psia. NBS Tech Note 648, U. S. Dept. of Commerce, December 1973.

5. Hall, Robert M.; and Adcock, Jerry B.: Simulation of Ideal-Gas Flow by Nitrogen and Other Selected Gases at Cryogenic Temperatures. NASA TP 1901, September 1981.

6. Adcock, Jerry B.: Real-Gas Effects Associated with One-Dimensional Transonic Flow of Cryogenic Nitrogen. NASA TN D-8274, December, 1976.

7. Adcock, Jerry B.; and Johnson, Charles B.: A Theoretical Analysis of Simulated Transonic Boundary Layers in Cryogenic-Nitrogen Wind Tunnels. NASA TP 1631, March 1980.

8. McCarty, R. D.: Determination of Thermodynamic Properties from the Experimental P-V-T Relationship. International Union of Pure and Applied Chemistry; Butterworths, 1975.

9. Cryogenic Wind Tunnel Models, NASA CP-2262, May 1982, pp. 215-256.
   A. Ferris, Alice T.: Strain Gage Balances and Buffet Gages.
   B. Holmes, Harlan K.: Model Deformation System
   C. Kern, Frederick A.: NTF Model Pressure Measurements
   D. Finley, Tom D.: Angle of Attack Systems

10. Fuller, Dennis E.: Guide for Users of the National Transonic Facility. NASA TM 83124, July, 1981.

11. User's Guide of the Product Specification of the Research Computer System of the National Transonic Facility Open Architecture Data Acquisition System, NASA-DID-P600, Langley Research Center, Aerodynamics Division, Research Facilities Branch, June 1995.

12. Fox, Charles H., Jr.: Real Time Reduction Capabilities at the Langley 7-by-10 Foot High Speed Tunnel. NASA TM 78801, January 1980.

13. Graham, A. B.: <u>The Data Analysis System - System Description and User's Guide</u>, Langley Research Center, Aerodynamics Division, Research Facilities Branch, April 15, 1993.

14. <u>Technical Description of the Model Preparation Area Computer System at the National Transonic Facility</u>, Prepared for NASA by Wyle Laboratories, Document Number HD62397-361R0-D8, November, 1995.

15. Popernack, Thomas G. Jr.; and Adcock, Jerry B.: <u>Cryogenic Temperature Effects on Sting-Balance Deflections in the National Transonic Facility</u>. NASA TM 4157, January, 1990.

LN₂ SUPPLY SYSTEM

DRIVE SYSTEM

CONTROL ROOM

MODEL ASSEMBLY BAYS

FAN SYSTEM

TEST SECTION

VENT SYSTEM
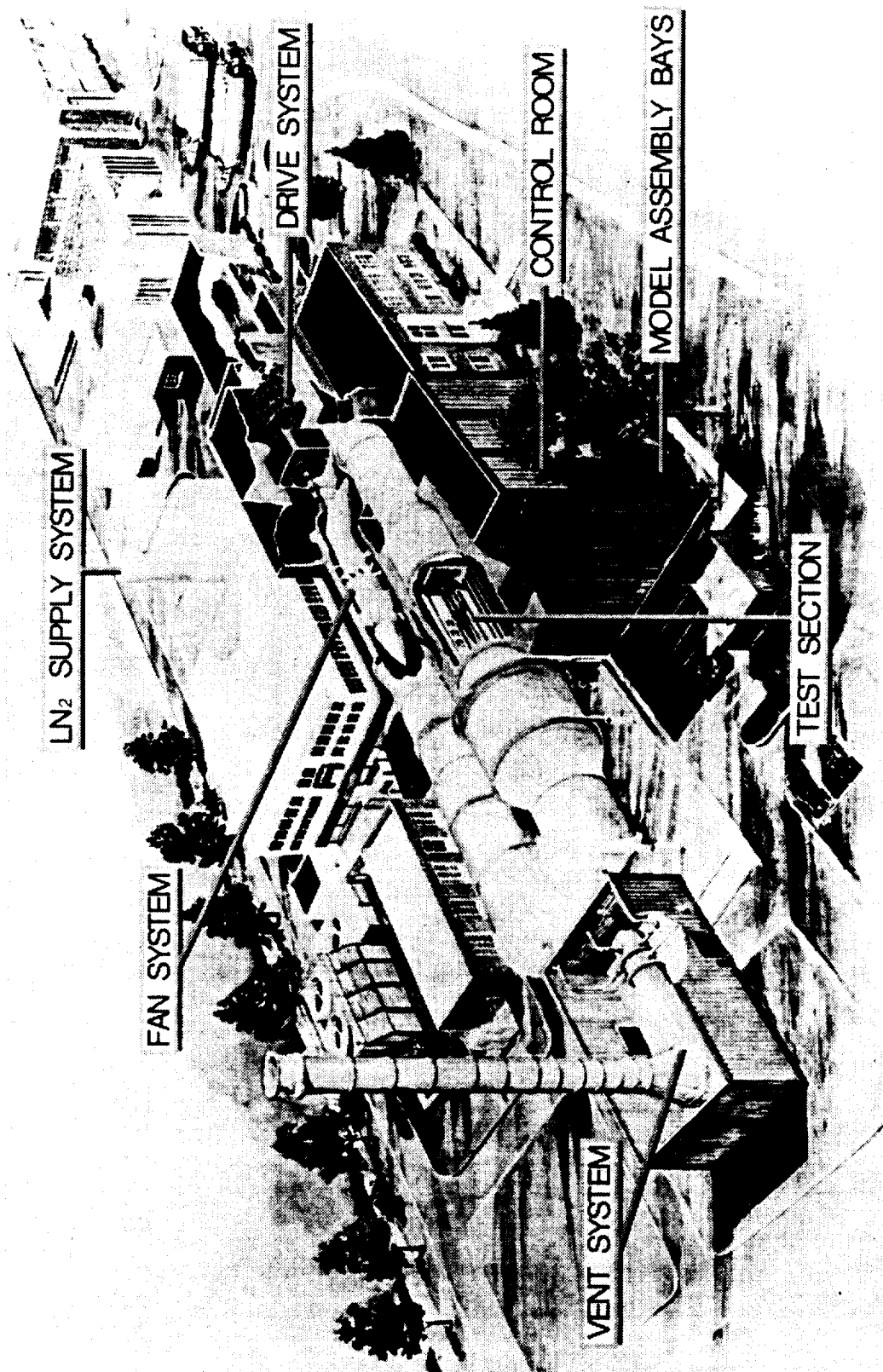
Figure 1–A.   National transonic facility.

FAN

LOW SPEED DIFFUSER

200 ft

15:1 CONTRACTION

SLOTED TEST SECTION

HIGH SPEED DIFFUSER

PLENUM

ANTI-TURBULENCE SCREENS

COOLING COIL

RAPID DIFFUSER

48 ft
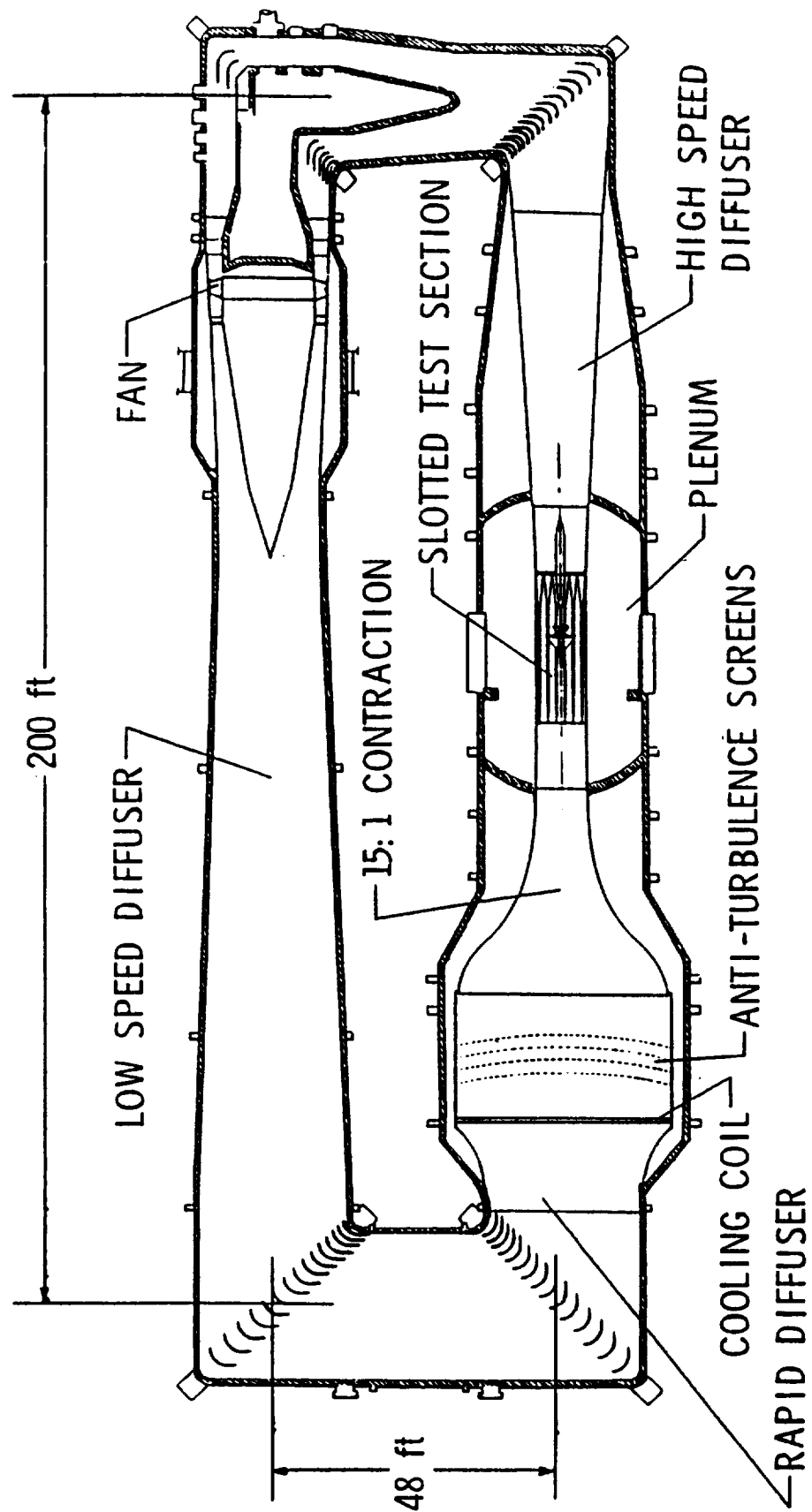
Figure 1–B. Plan of tunnel circuit.

NTF ENVELOPE--MACH=0.100
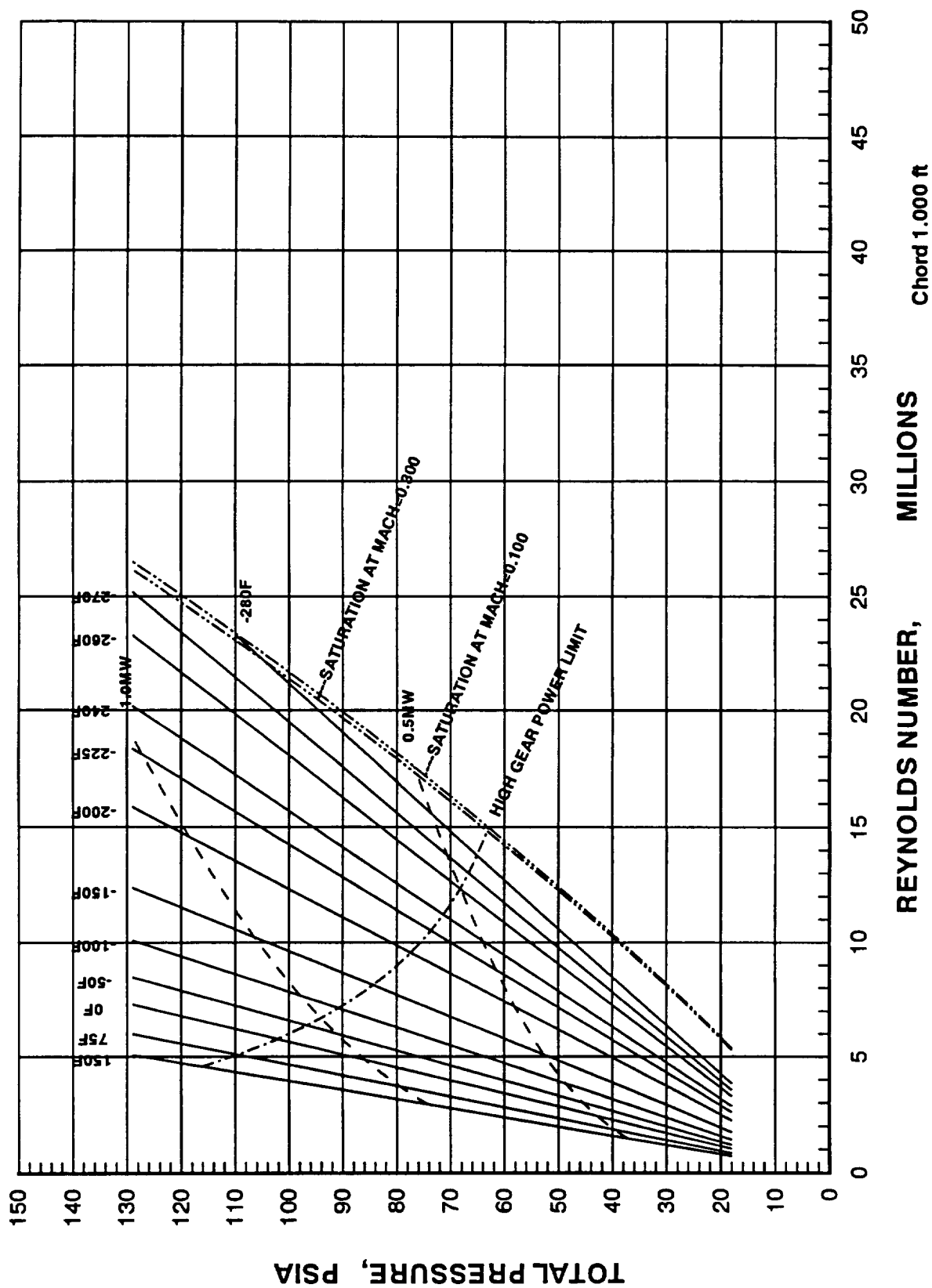
Figure 2-A. Tunnel Operating Envelopes

NTF ENVELOPE--MACH=0.200
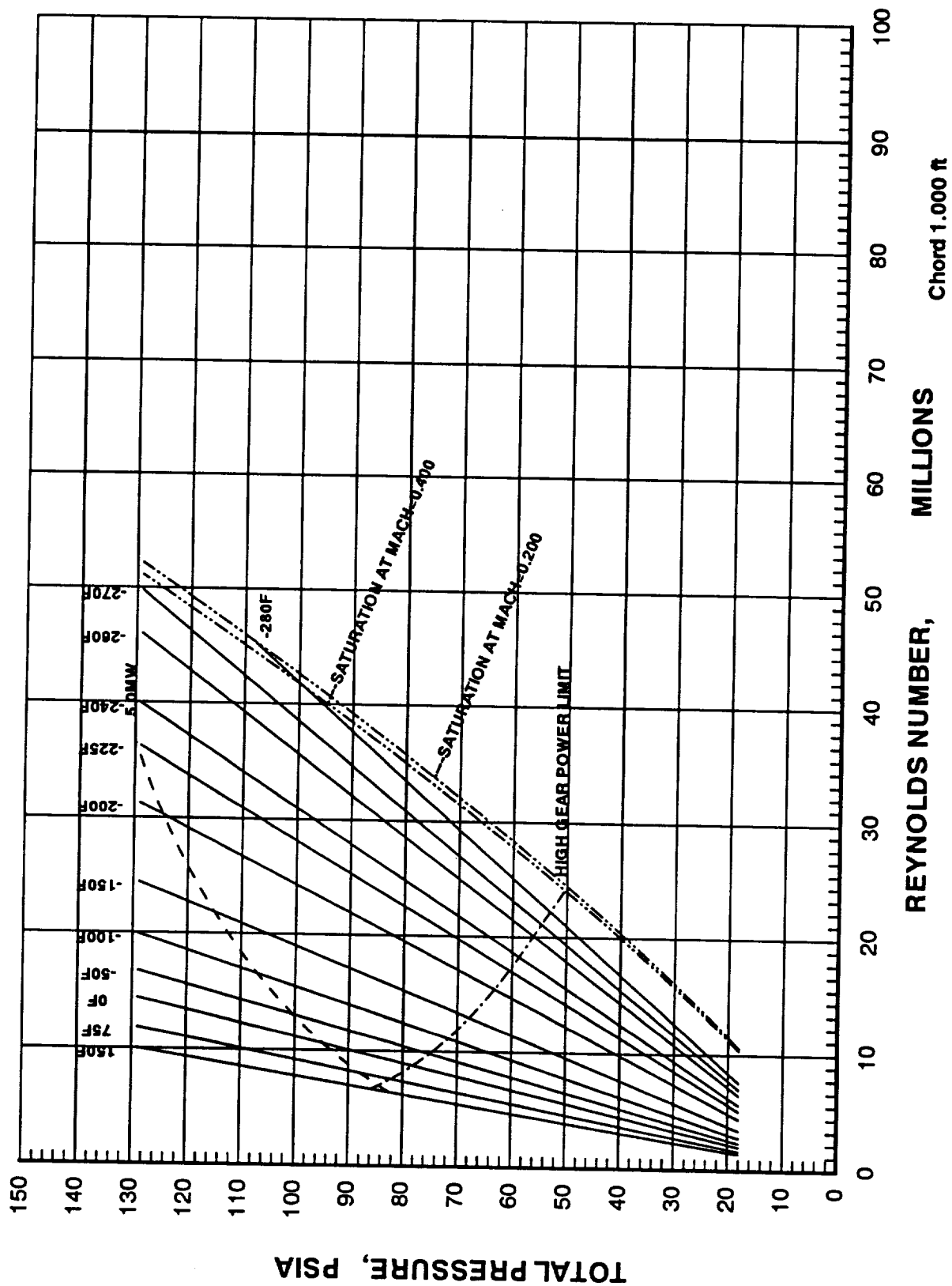
Figure 2-B. Tunnel Operating Envelopes (continued)
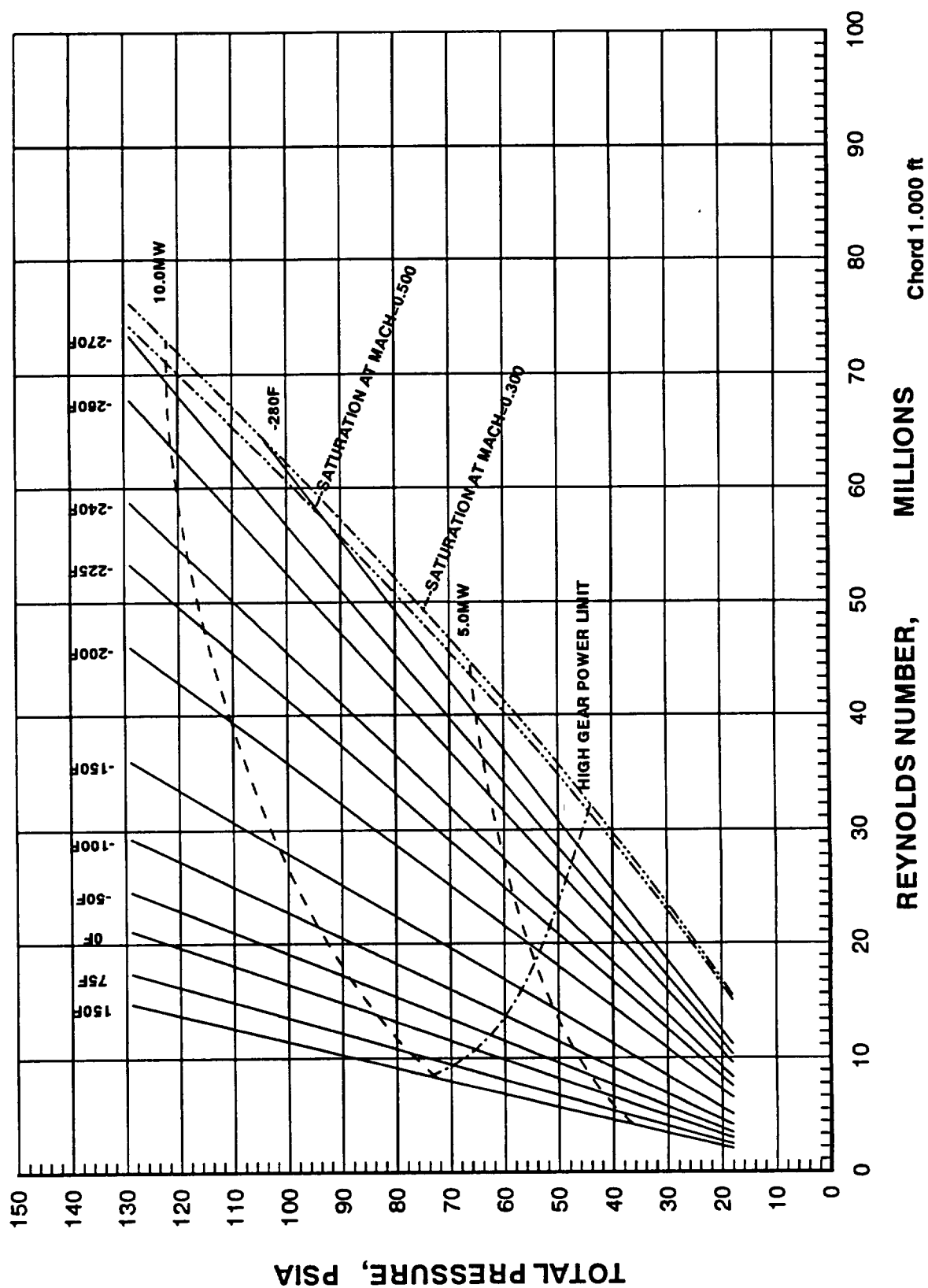
Figure 2.-C. Tunnel Operating Envelopes (continued)
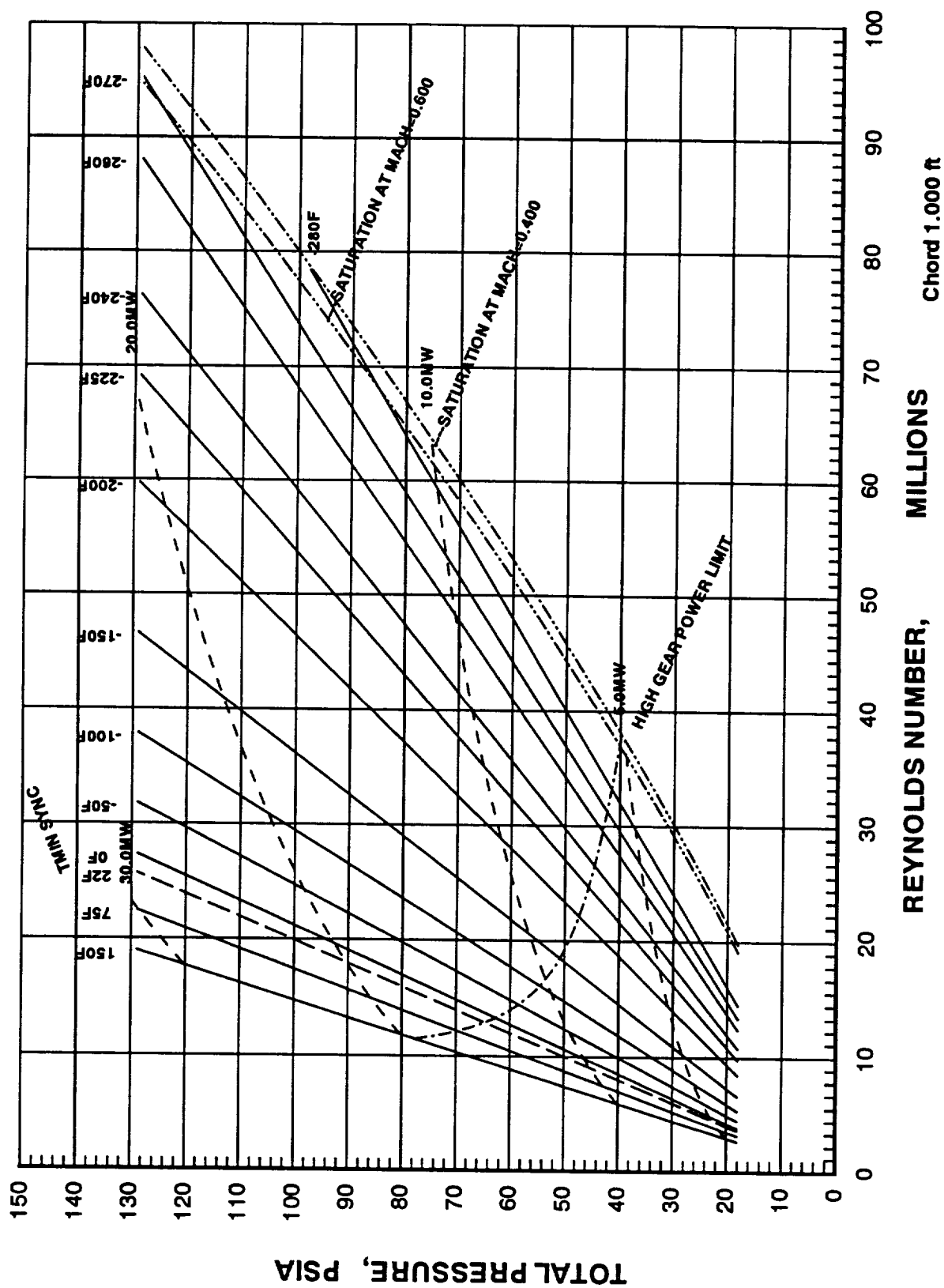
Figure 2-D. Tunnel Operating Envelopes (continued)

60
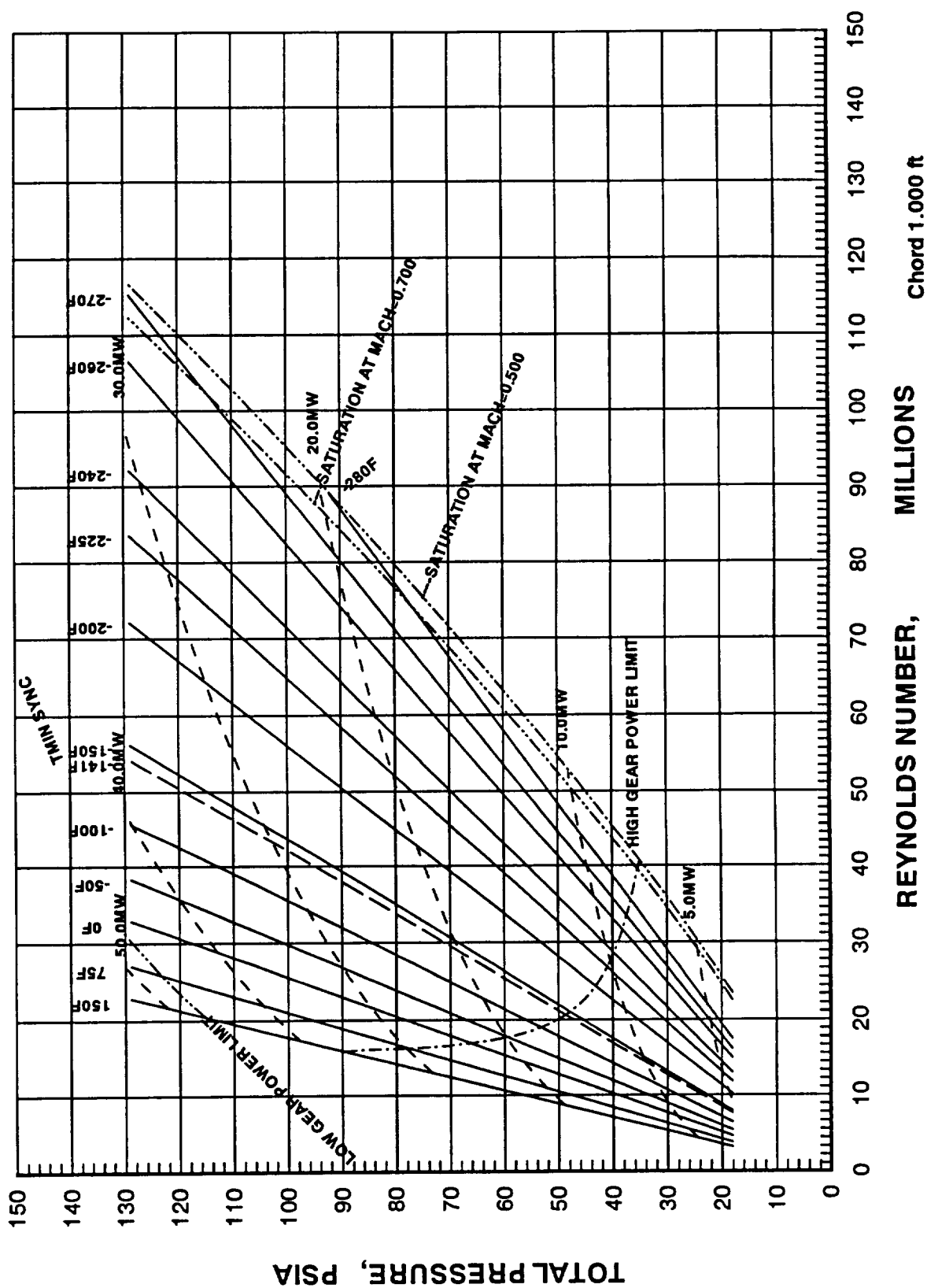
Figure 2-E. Tunnel Operating Envelopes (continued)

61

NTF ENVELOPE--MACH=0.600
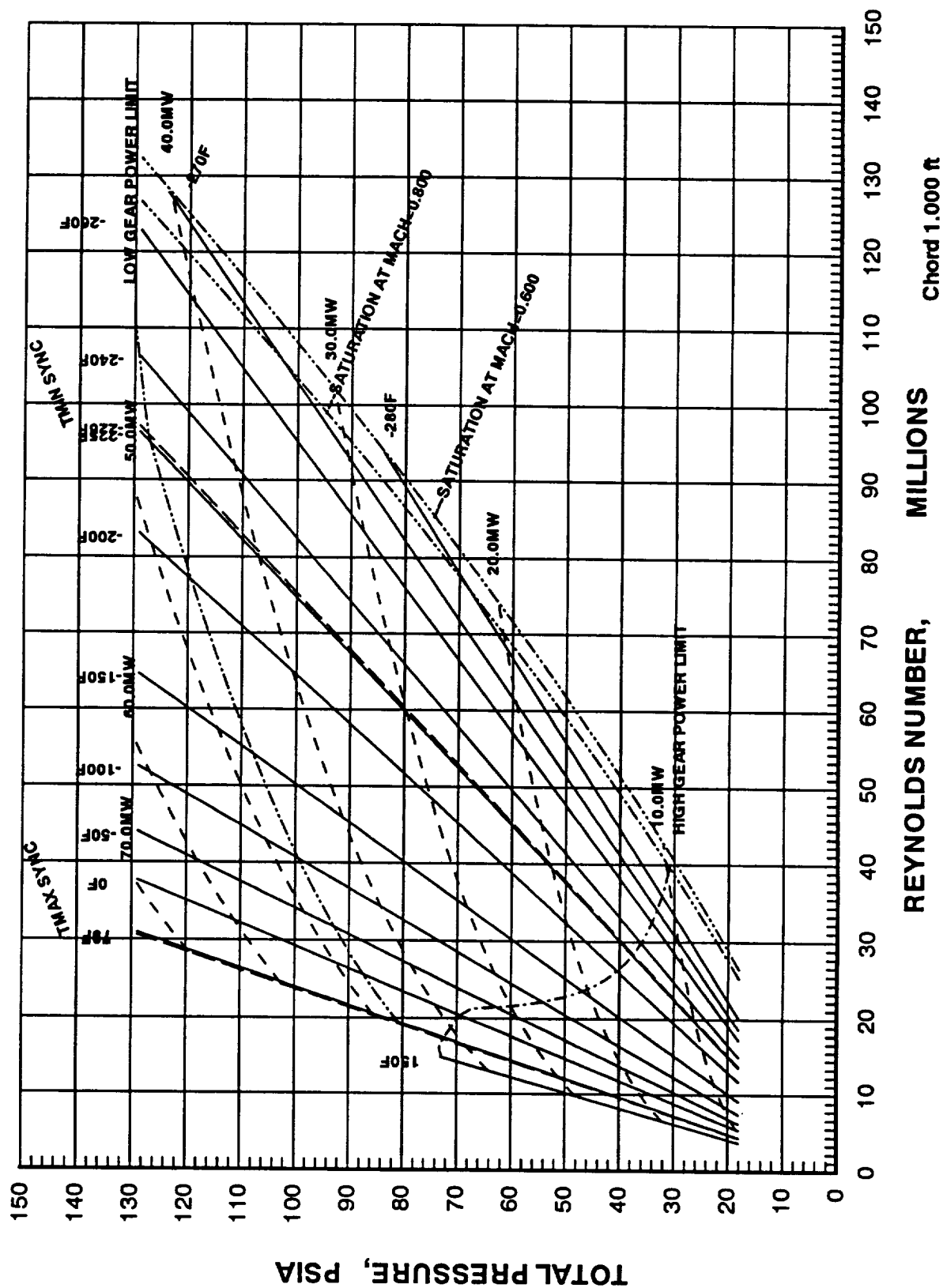
Figure 2-F. Tunnel Operating Envelopes (continued)

62

NTF ENVELOPE--MACH=0.700

REYNOLDS NUMBER,   MILLIONS   Chord 1.000 ft
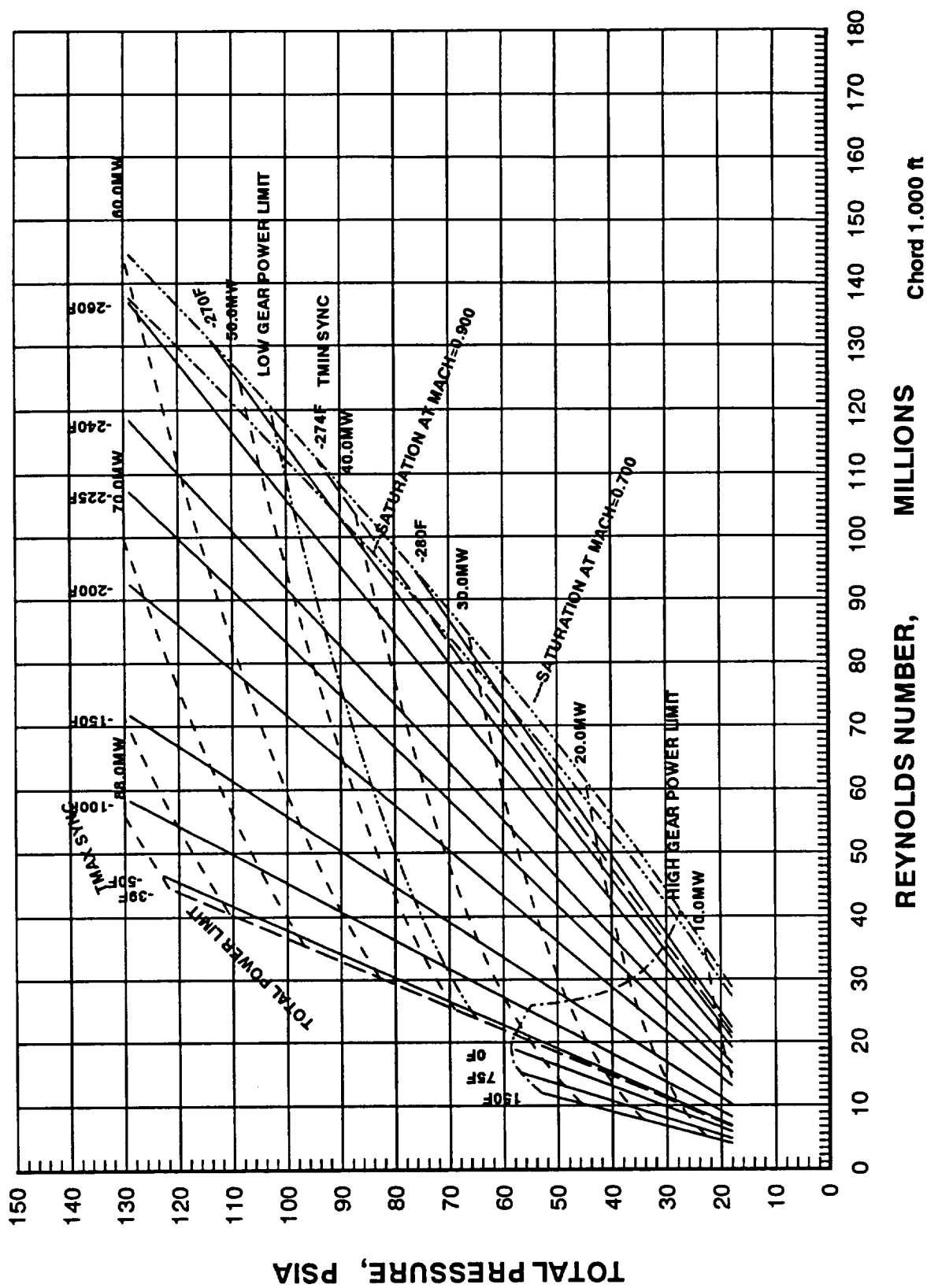
Figure 2-G. Tunnel Operating Envelopes (continued)

NTF ENVELOPE--MACH=0.800

REYNOLDS NUMBER,   MILLIONS

Chord 1.000 ft

TOTAL PRESSURE, PSIA
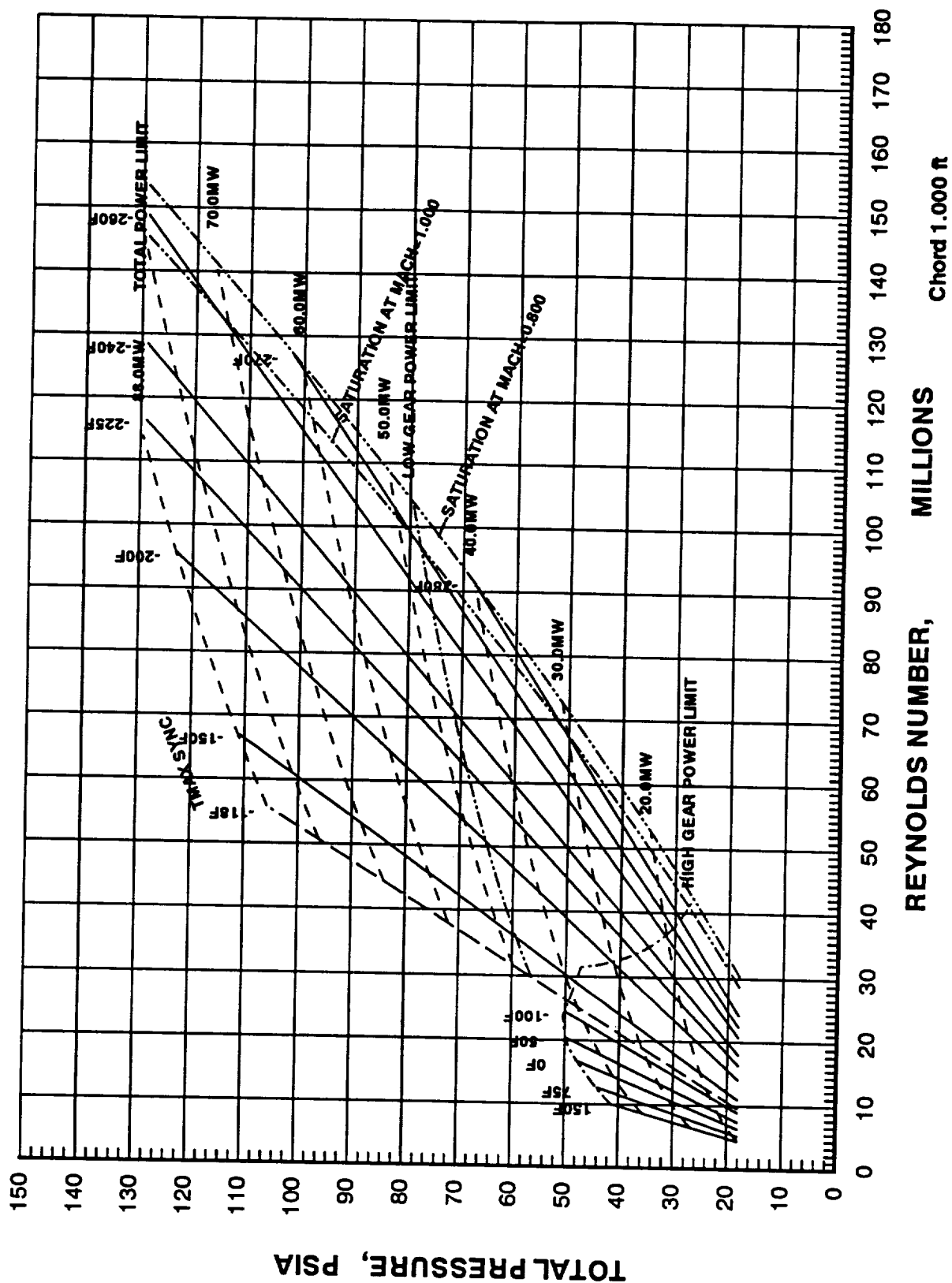
Figure 2-H. Tunnel Operating Envelopes (continued)
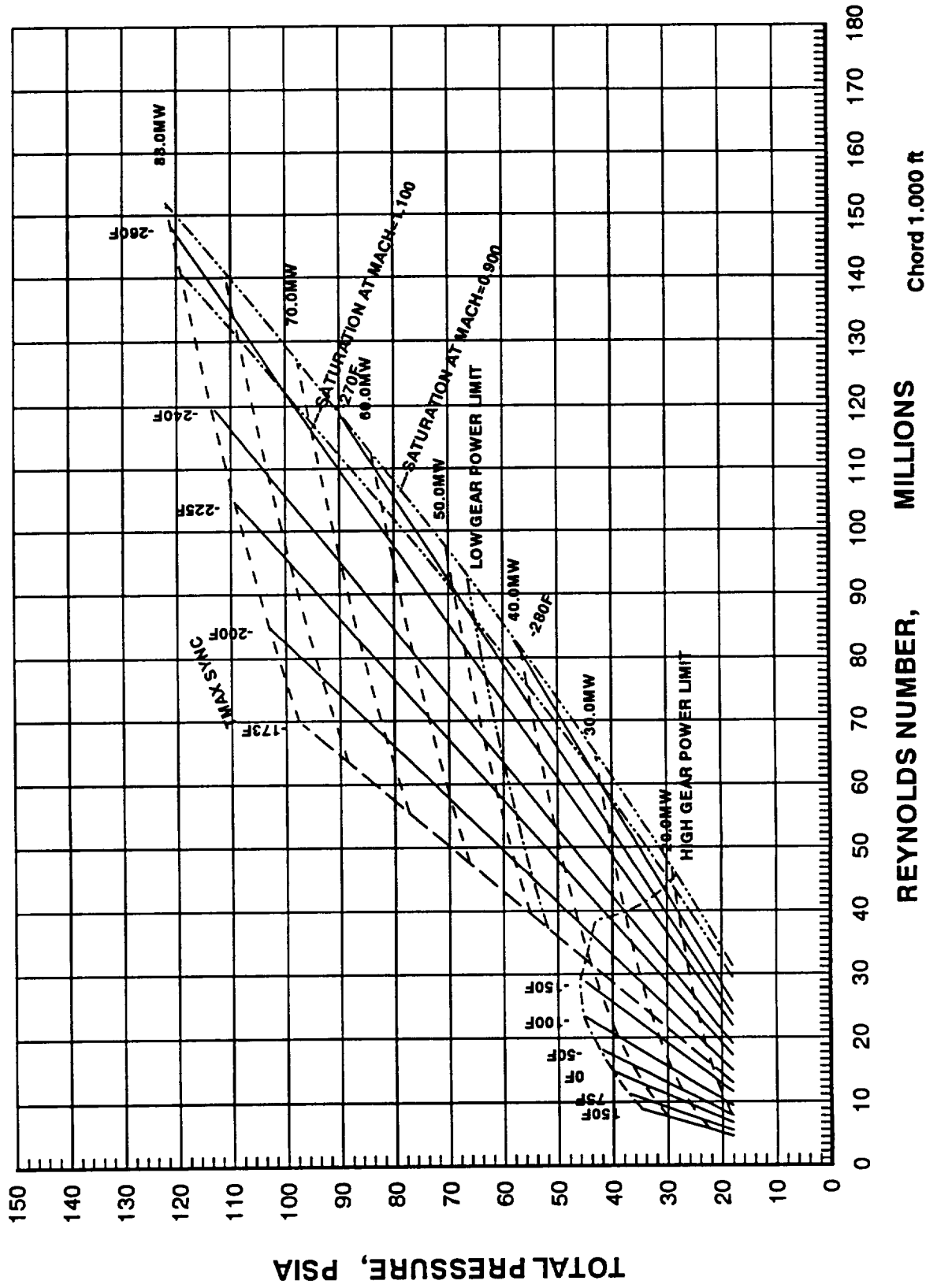
Figure 2-I. Tunnel Operating Envelopes (continued)

65

NTF ENVELOPE--MACH=1.000
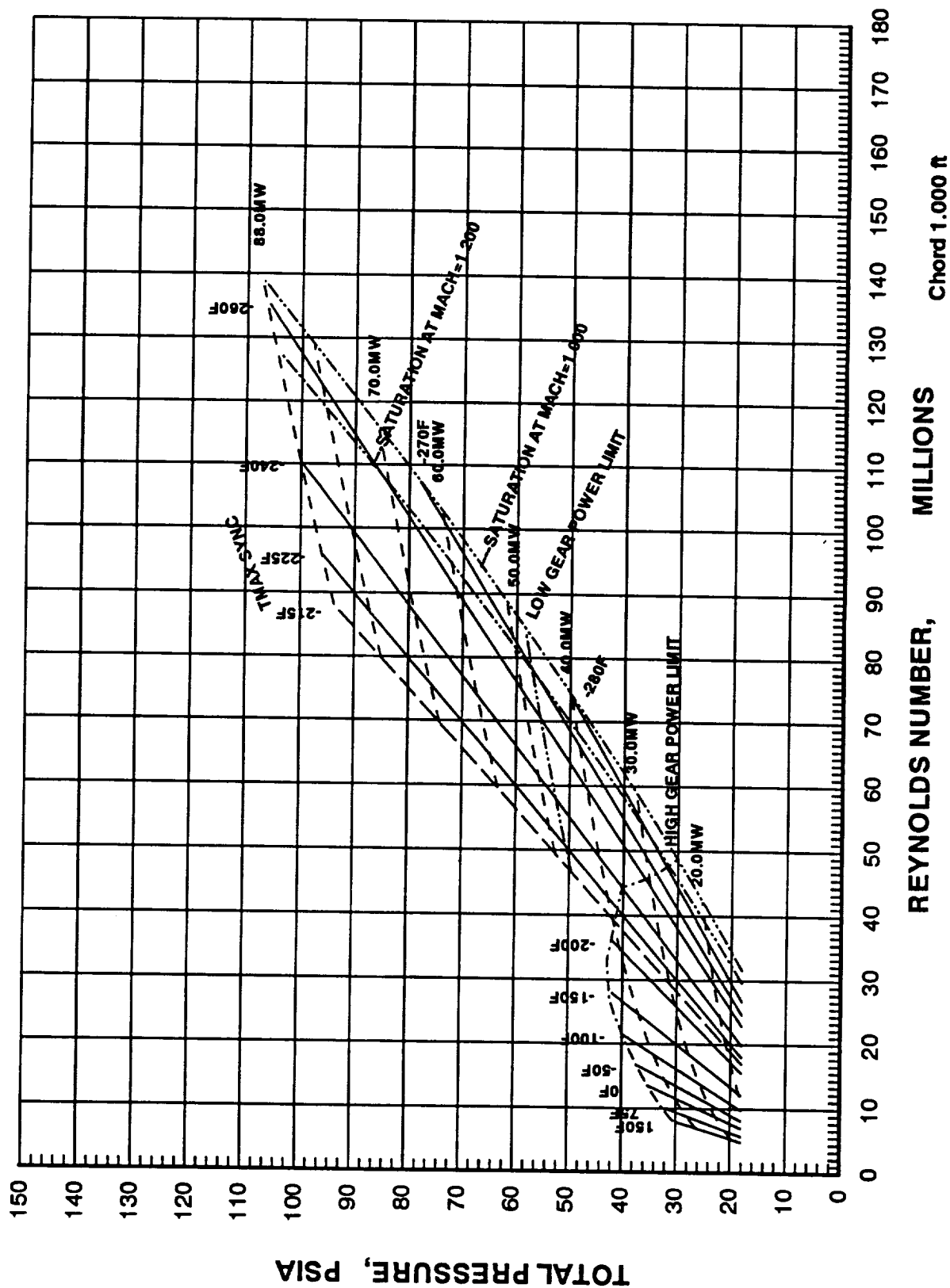
Figure 2-J. Tunnel Operating Envelopes (continued)

NTF ENVELOPE--MACH=1.100
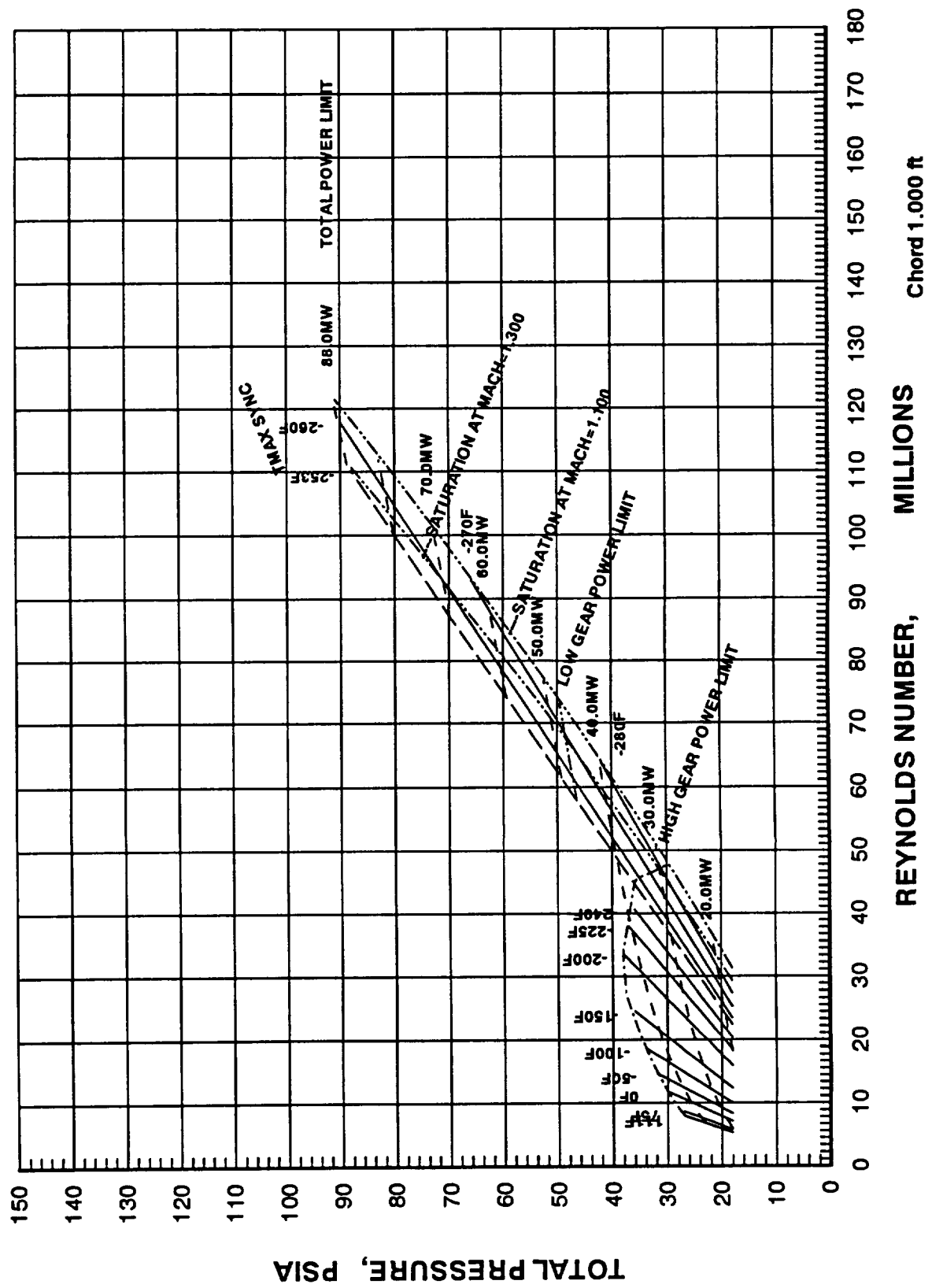
Figure 2-K. Tunnel Operating Envelopes (continued)

67

NTF ENVELOPE--MACH=1.200

TOTAL PRESSURE, PSIA

REYNOLDS NUMBER, MILLIONS

Chord 1.000 ft
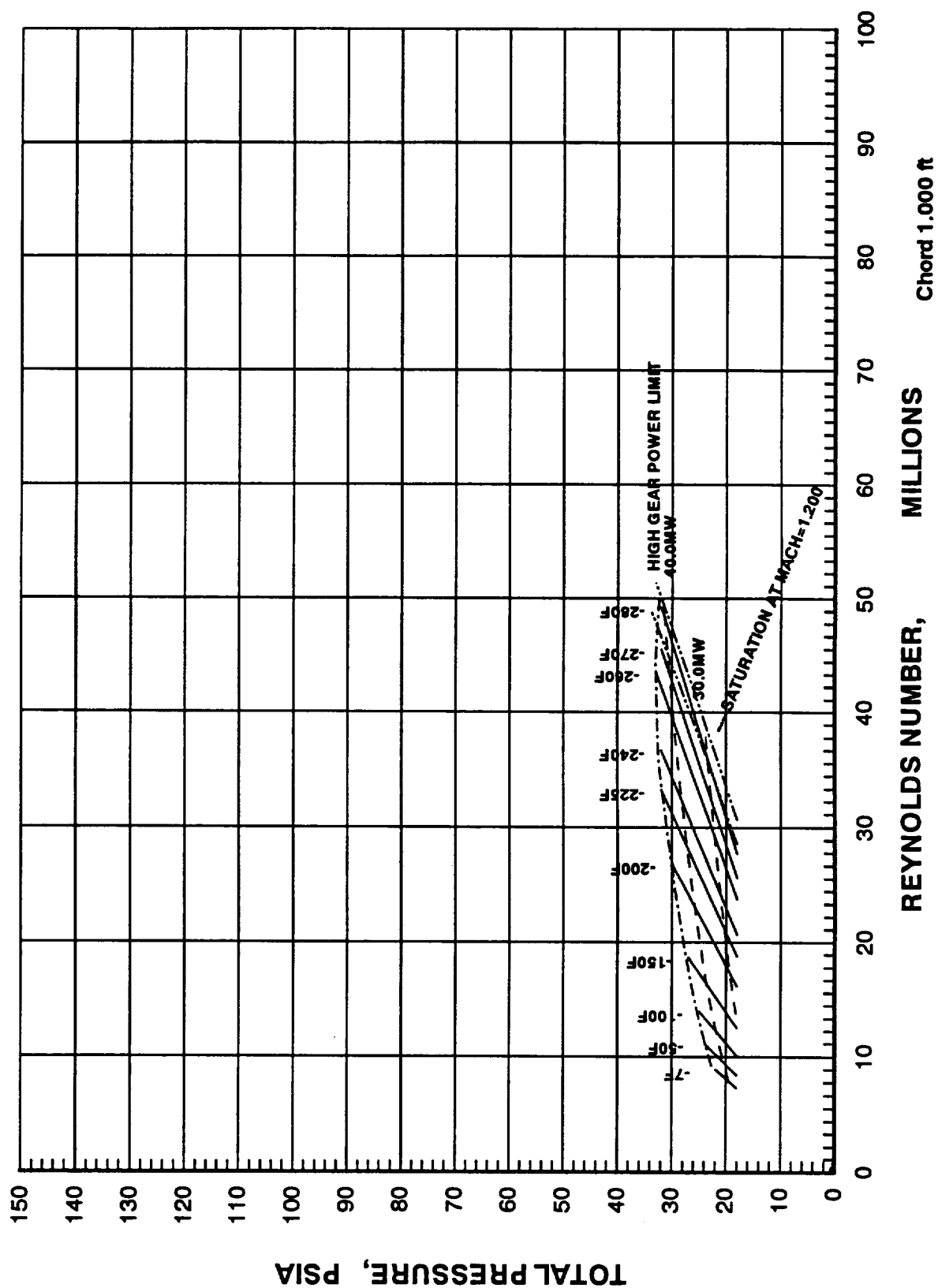
Figure 2-L. Tunnel Operating Envelopes (continued)

TUBE
EXTRACTED

8.5 m DIAMETER

TUBE
INSERTED

SECTION THRU MODEL
PITCH CENTER
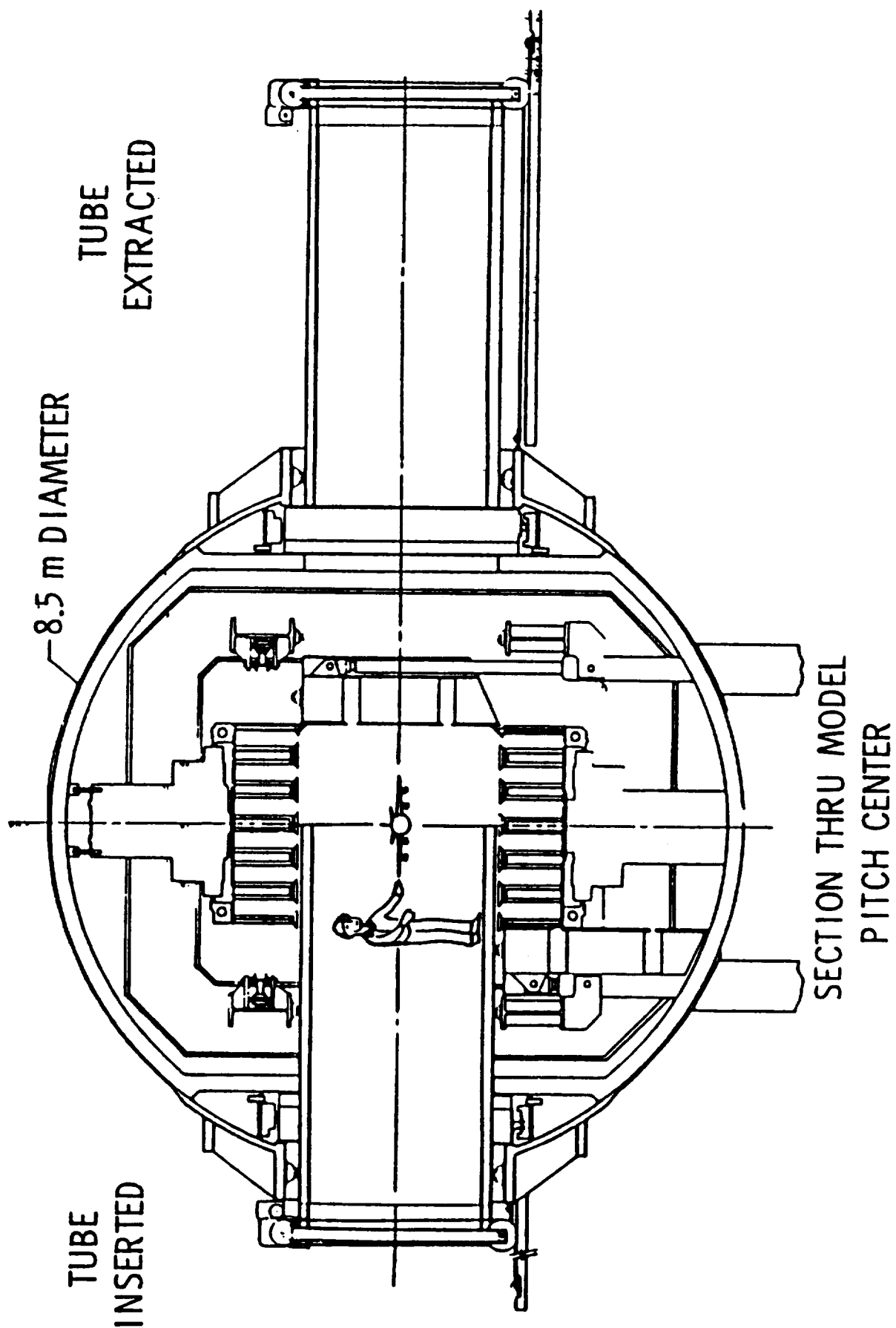
Figure 3.   Model access system.
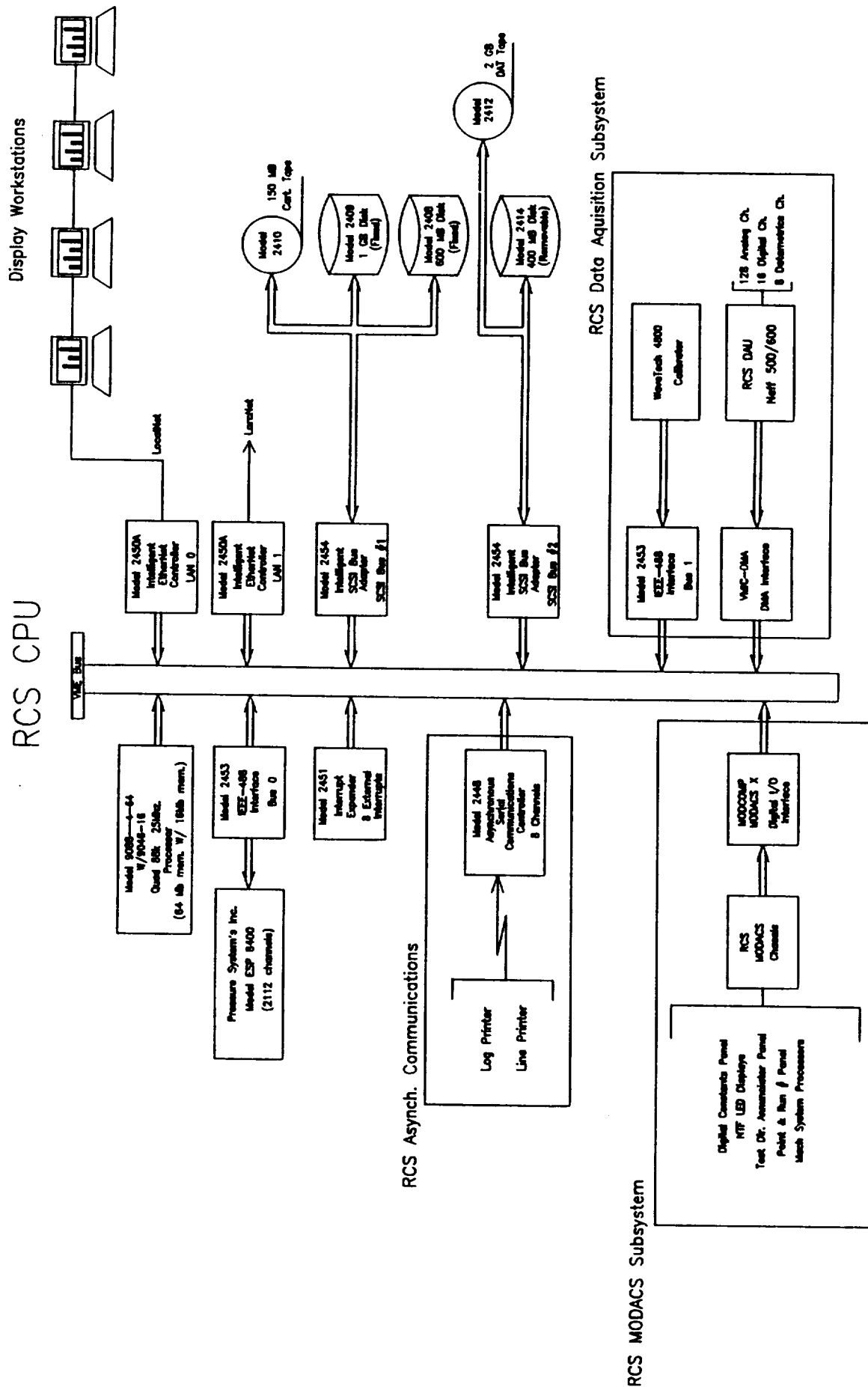
Figure 4-A. Research Computer System Hardware Schematic
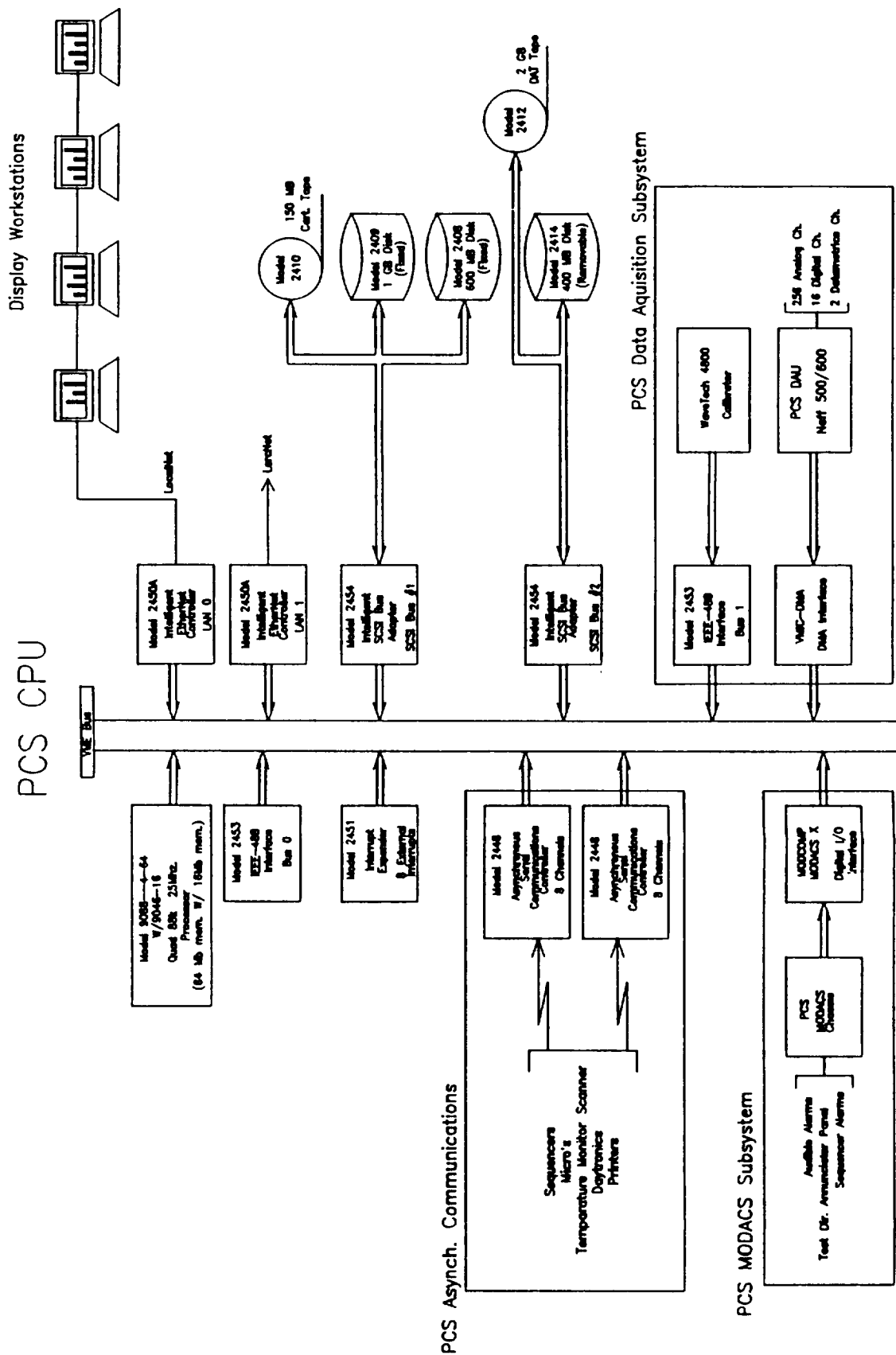
Figure 4-B. Process Computer System Hardware Schematic

71
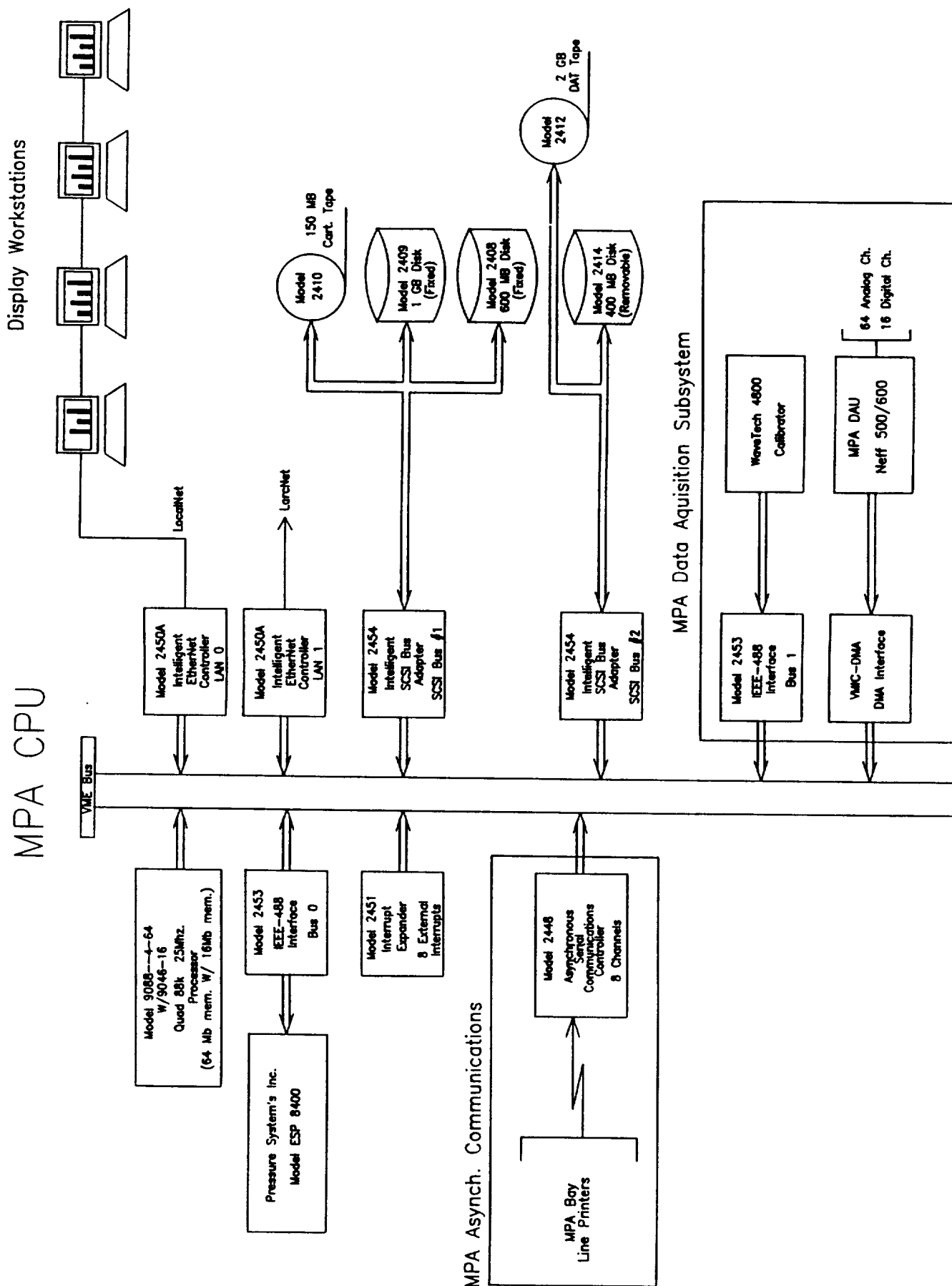
Figure 4-C.   Model Preparation Area Computer System Hardware Schematic
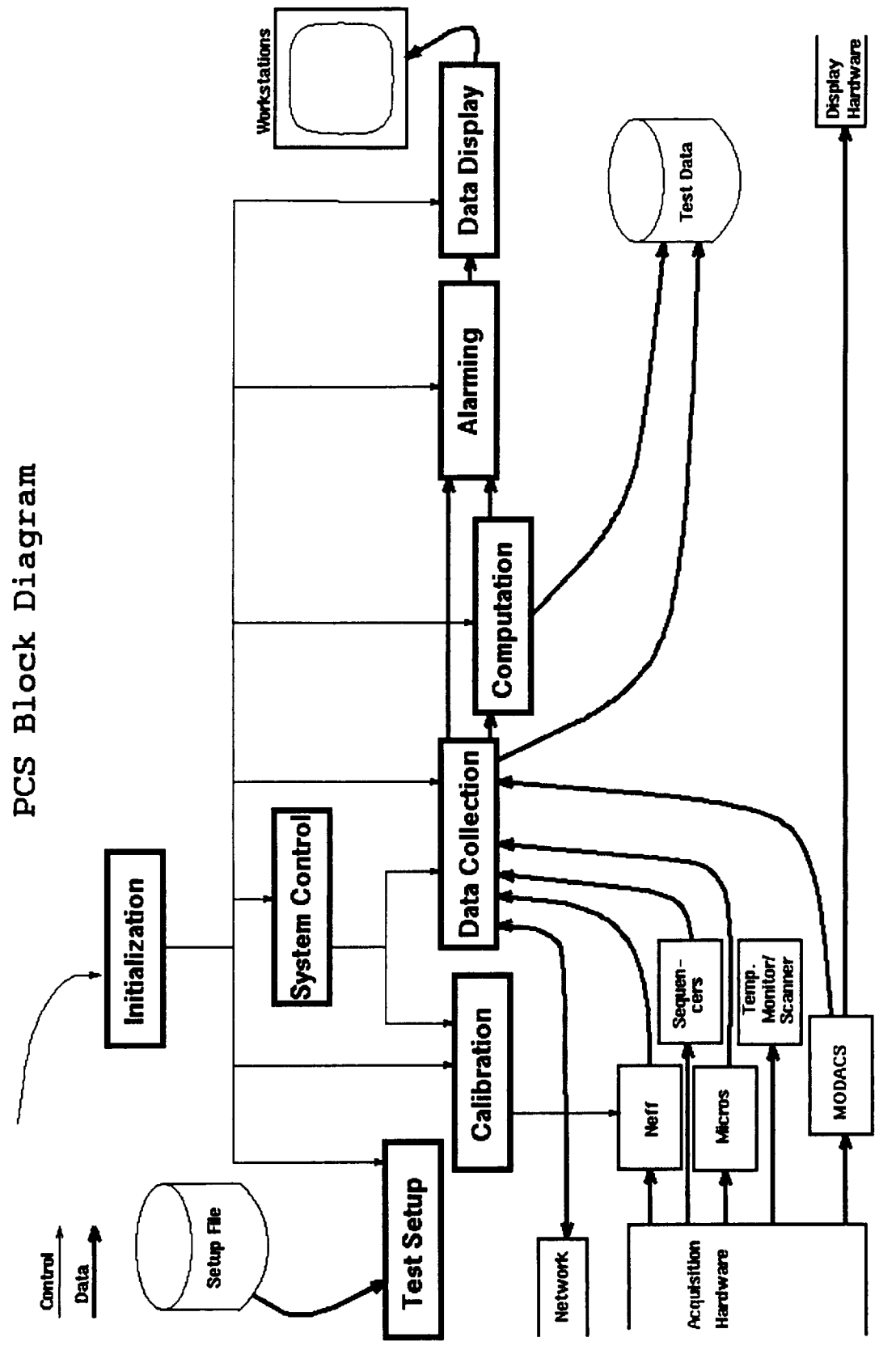
PCS Block Diagram

Figure 5-A. Process Computer System Functionality Diagram

73

RCS Block Diagram
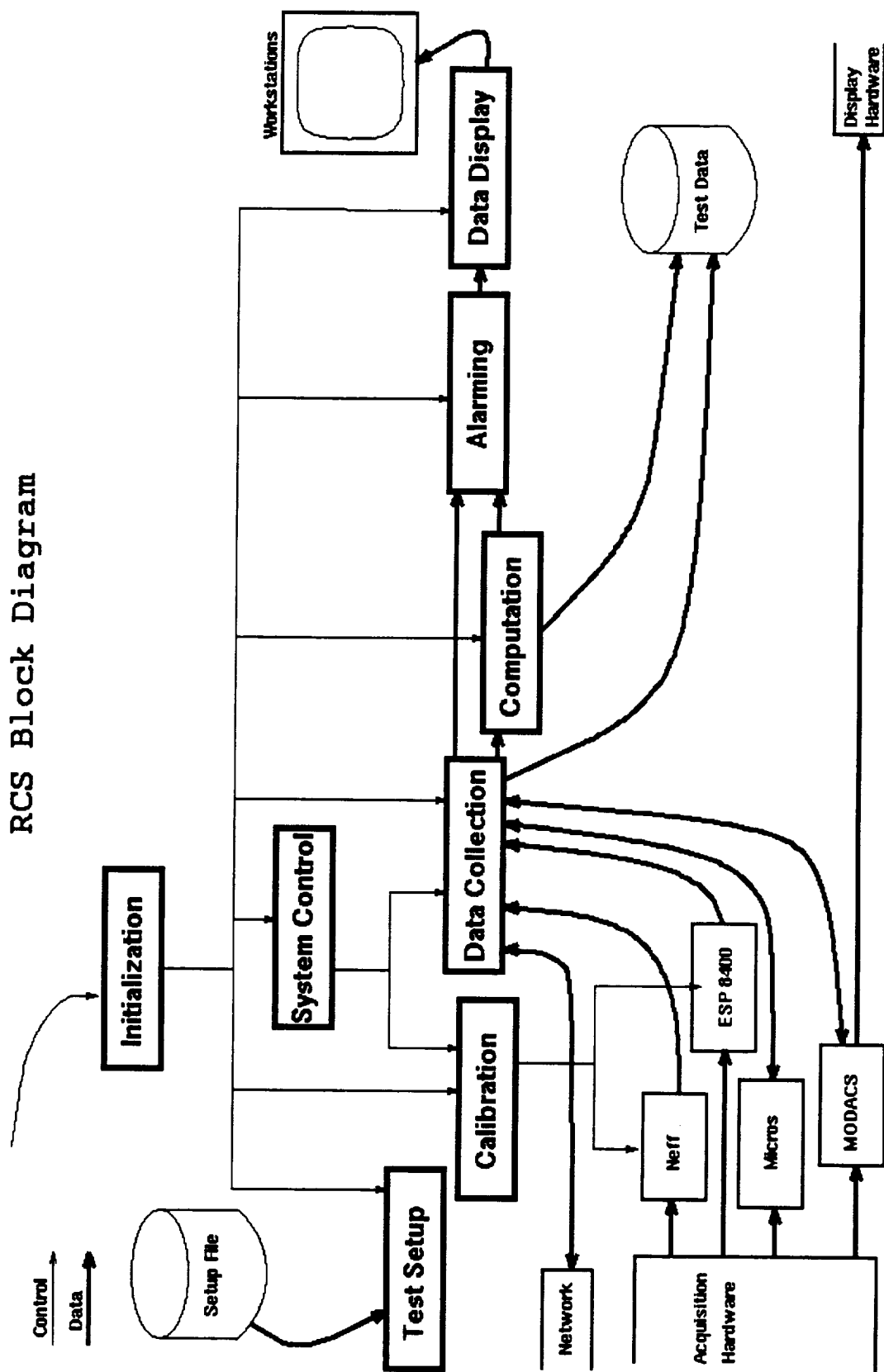
Figure 5-B. Research Computer System Functionality Diagram

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MODEL ACCELEROMETER – CASE I
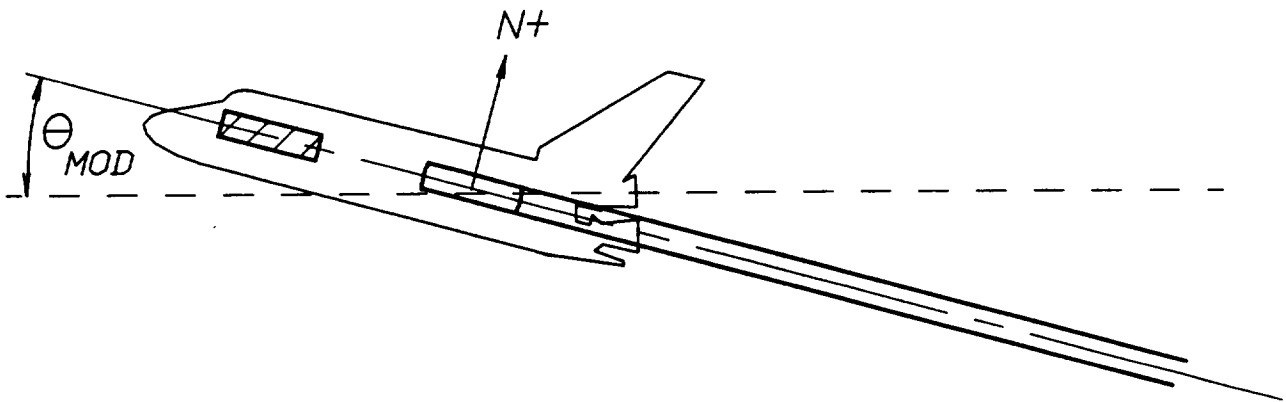
1. BALANCE IN MODEL AXIS SYSTEM, $\Theta_{BM} = 0$

2. BALANCE UPRIGHT, $\phi_{BM} = 0$

Figure 6-A. Model Orientation Definitions using Model Accelerometer

MODEL ACCELEROMETER - CASE II
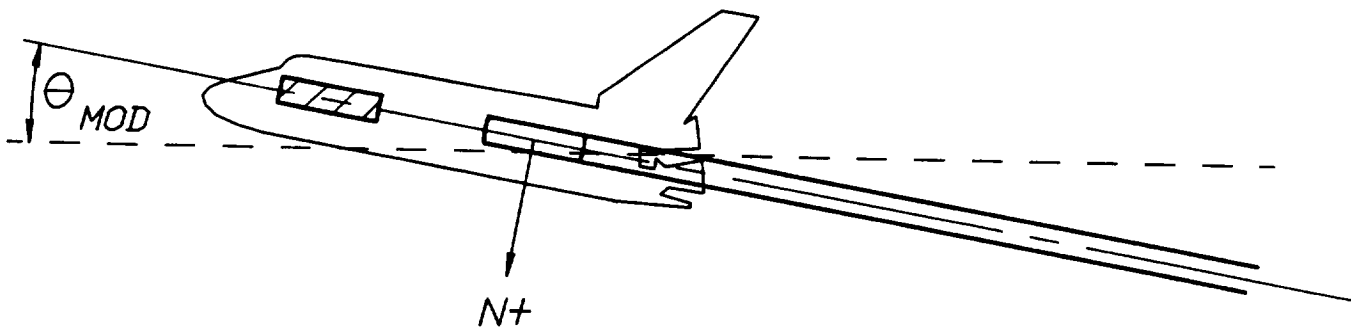
1. BALANCE IN MODEL AXIS SYSTEM, $\theta_{BM} = 0$
2. BALANCE INVERTED, $\phi_{BM} = 180$

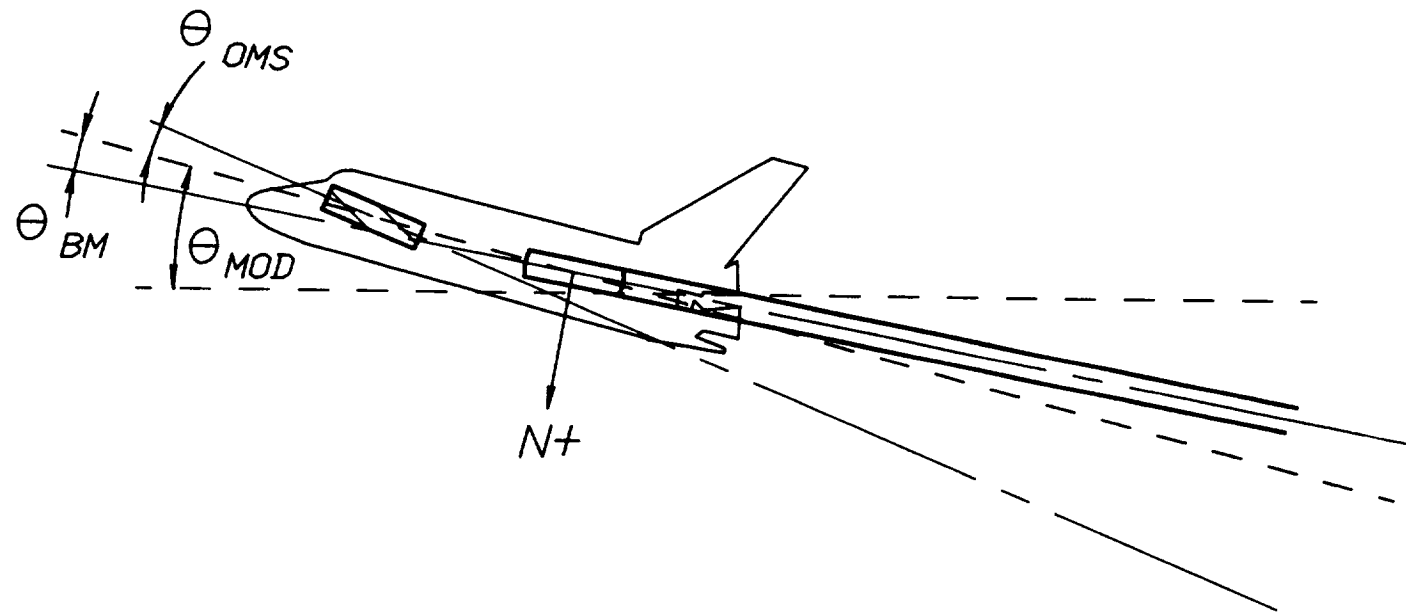**Figure 6-B. Model Orientation Definitions using Model Accelerometer**
(continued)

MODEL ACCELEROMETER - CASE III
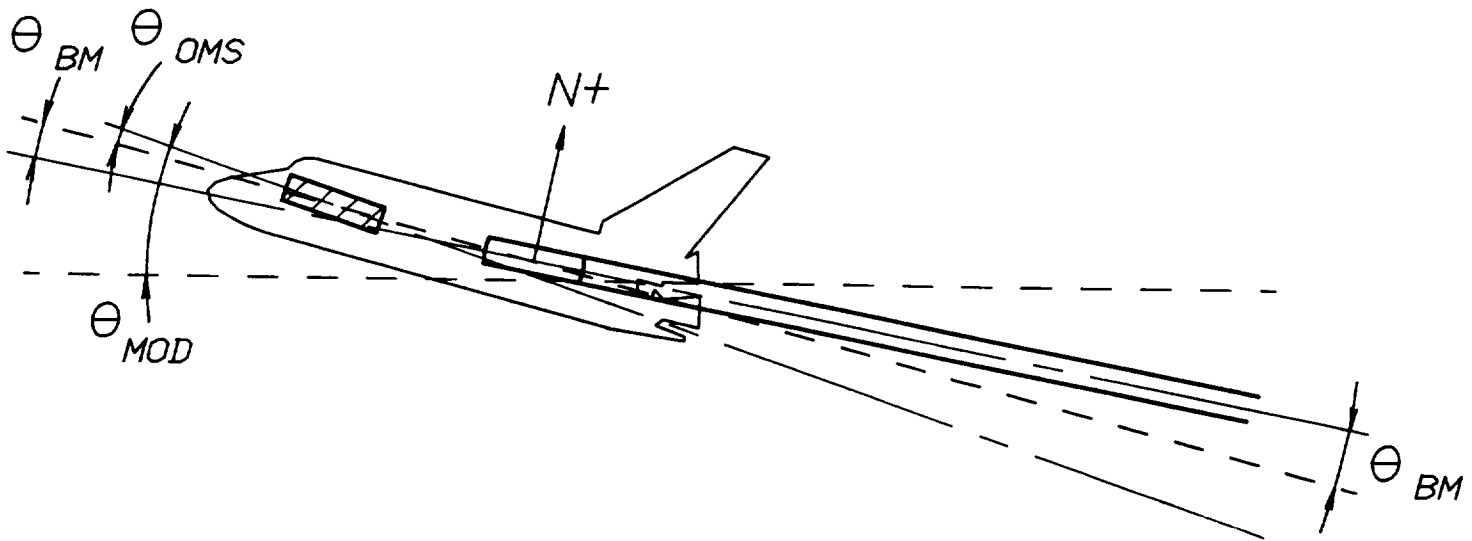
1. MODEL ACCELEROMETER MISALIGNED WITH RESPECT TO MODEL AXIS, Θ_{OMS} (GRAVITY AXIS $\neq$ MODEL AXIS)

2. BALANCE UPRIGHT, $\phi_{BM} = 0$

3. BALANCE MISALIGNED WITH RESPECT TO MODEL REFERENCE AXIS, Θ_{BM} (BALANCE AXIS $\neq$ MODEL AXIS)

Figure 6-C. Model Orientation Definitions using Model Accelerometer
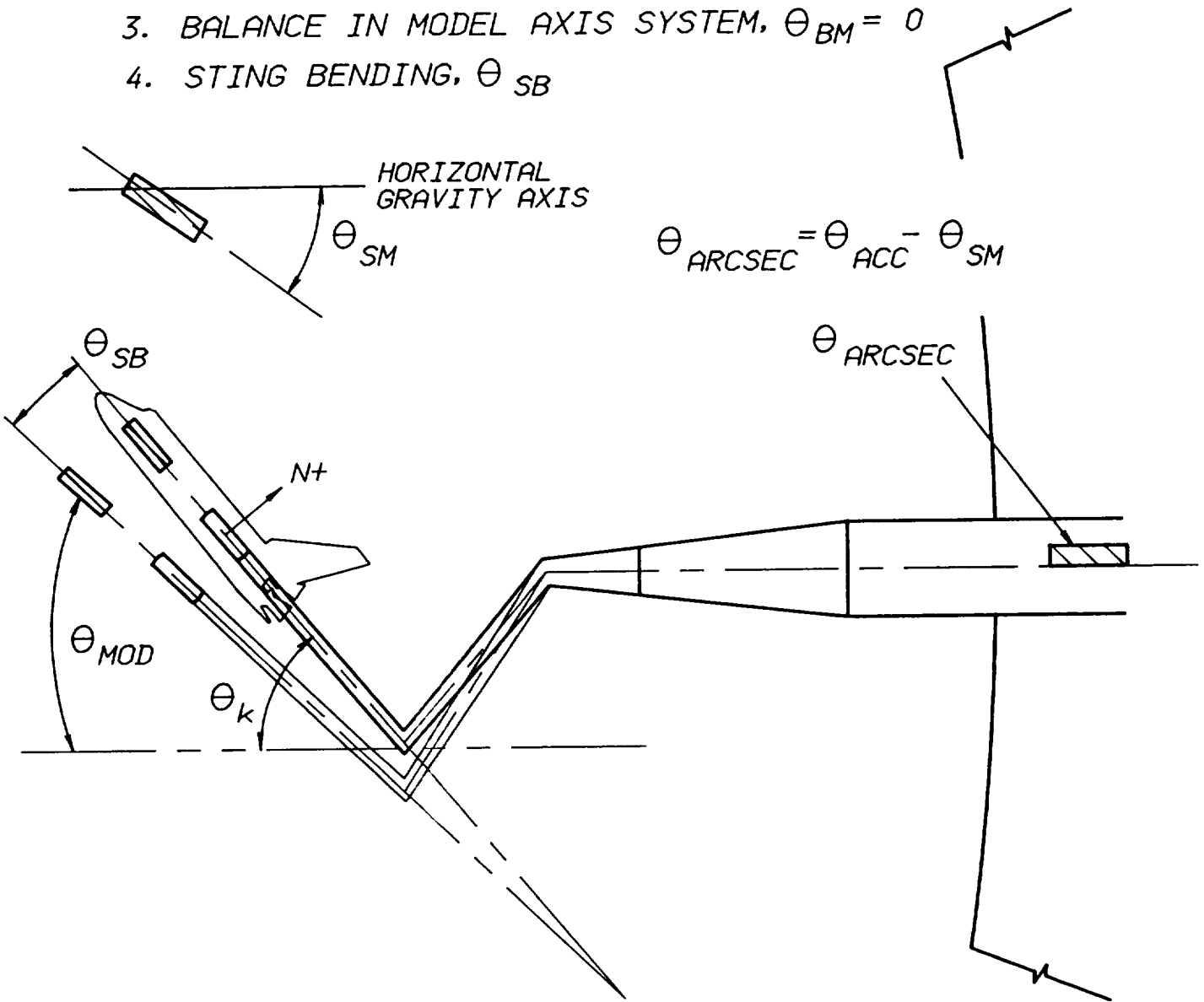
(continued)

MODEL ACCELEROMETER – CASE IV

1. MODEL ACCELEROMETER MISALIGNED WITH RESPECT TO MODEL AXIS, Θ_{OMS} (GRAVITY AXIS $\neq$ MODEL AXIS)

2. BALANCE INVERTED, $\phi_{BM} = 180$

3. BALANCE MISALIGNED WITH RESPECT TO MODEL REFERENCE AXIS, Θ_{BM} (BALANCE AXIS $\neq$ MODEL AXIS)

Figure 6-D. Model Orientation Definitions using Model Accelerometer

(continued)

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ARCSECTOR CASE Ⅴ

1. STING OFFSET, θ_k
2. BALANCE UPRIGHT, $\phi_{BM} = 0$
3. BALANCE IN MODEL AXIS SYSTEM, $\theta_{BM} = 0$
4. STING BENDING, θ_{SB}

HORIZONTAL
GRAVITY AXIS

θ_{SM}

$\theta_{ARCSEC} = \theta_{ACC} - \theta_{SM}$

θ_{SB}

θ_{ARCSEC}

$N+$

θ_{MOD}

θ_k

$$\theta_{MOD} = \theta_{ARCSEC} + \theta_k - \theta_{SB}$$

$$\theta_{MOD} = \theta_{ACC} - \theta_{SM} + \theta_k - \theta_{SB}$$

Figure 6-E. Model Orientation Definitions using Arcsector Accelerometer

ARCSECTOR CASE VI

1. STING OFFSET, θ_k
2. BALANCE UPRIGHT, $\phi_{BM} = 0$
3. BALANCE OFFSET FROM MODEL REFERENCE, θ_{BM}
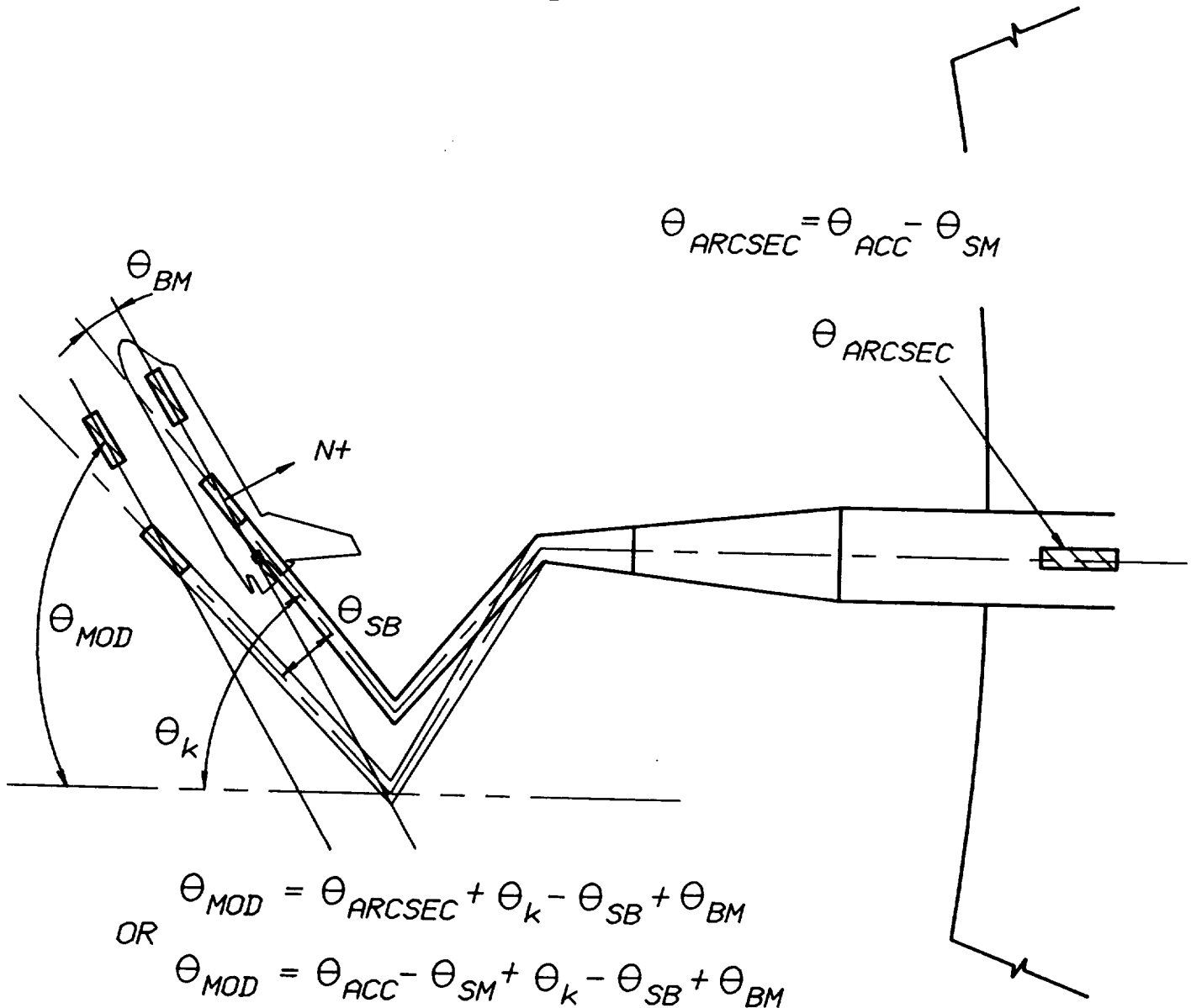4. STING BENDING, θ_{SB}

$$\theta_{ARCSEC} = \theta_{ACC} - \theta_{SM}$$

θ_{BM}

θ_{ARCSEC}

$N+$

θ_{MOD}

θ_{SB}

θ_k

$$\theta_{MOD} = \theta_{ARCSEC} + \theta_k - \theta_{SB} + \theta_{BM}$$

OR

$$\theta_{MOD} = \theta_{ACC} - \theta_{SM} + \theta_k - \theta_{SB} + \theta_{BM}$$

Figure 6-F. **Model Orientation Definitions using Arcsector Accelerometer**

(continued)

80

ARCSECTOR CASE VII

1. STING OFFSET, Θ_k
2. BALANCE INVERTED, $\phi_{BM} = 180°$
3. BALANCE OFFSET FROM MODEL REFERENCE, Θ_{BM}
4. STING BENDING, Θ_{SB}

$$\Theta_{ARCSEC} = \Theta_{ACC} - \Theta_{SM}$$

$$\Theta_{MOD} = \Theta_{ARCSEC} + \Theta_k - \Theta_{SB} + \Theta_{BM}$$

$$\Theta_{MOD} = \Theta_{ACC} - \Theta_{SM} + \Theta_k - \Theta_{SB} + \Theta_{BM}$$
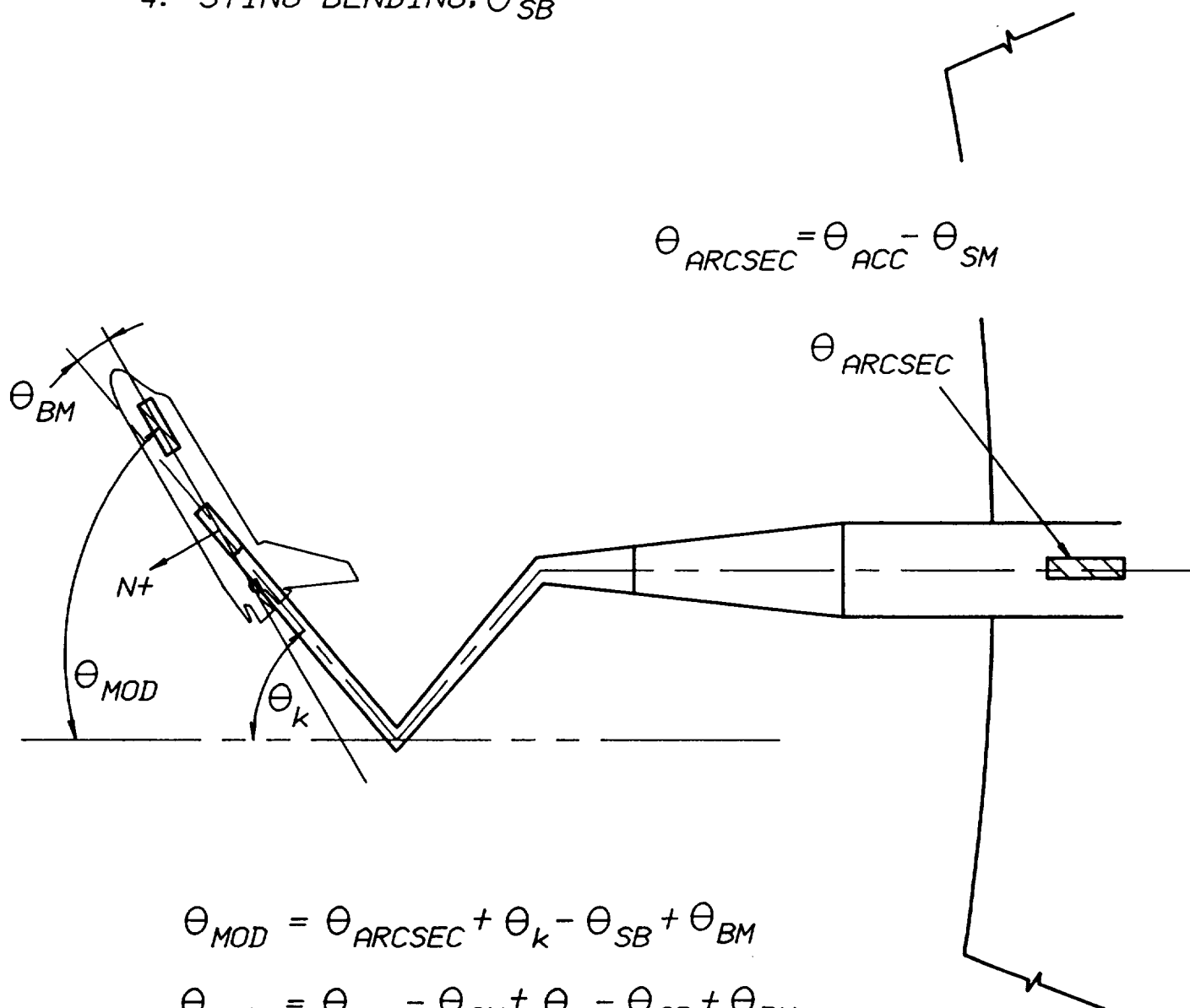
Figure 6-G. Model Orientation Definitions using Arcsector Accelerometer

(continued)

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1. MODEL ACCELEROMETER MISALIGNED WITH RESPECT TO MODEL AXIS, θ_{OMS}

2. BALANCE INVERTED, $\phi_{BM} = 180°$

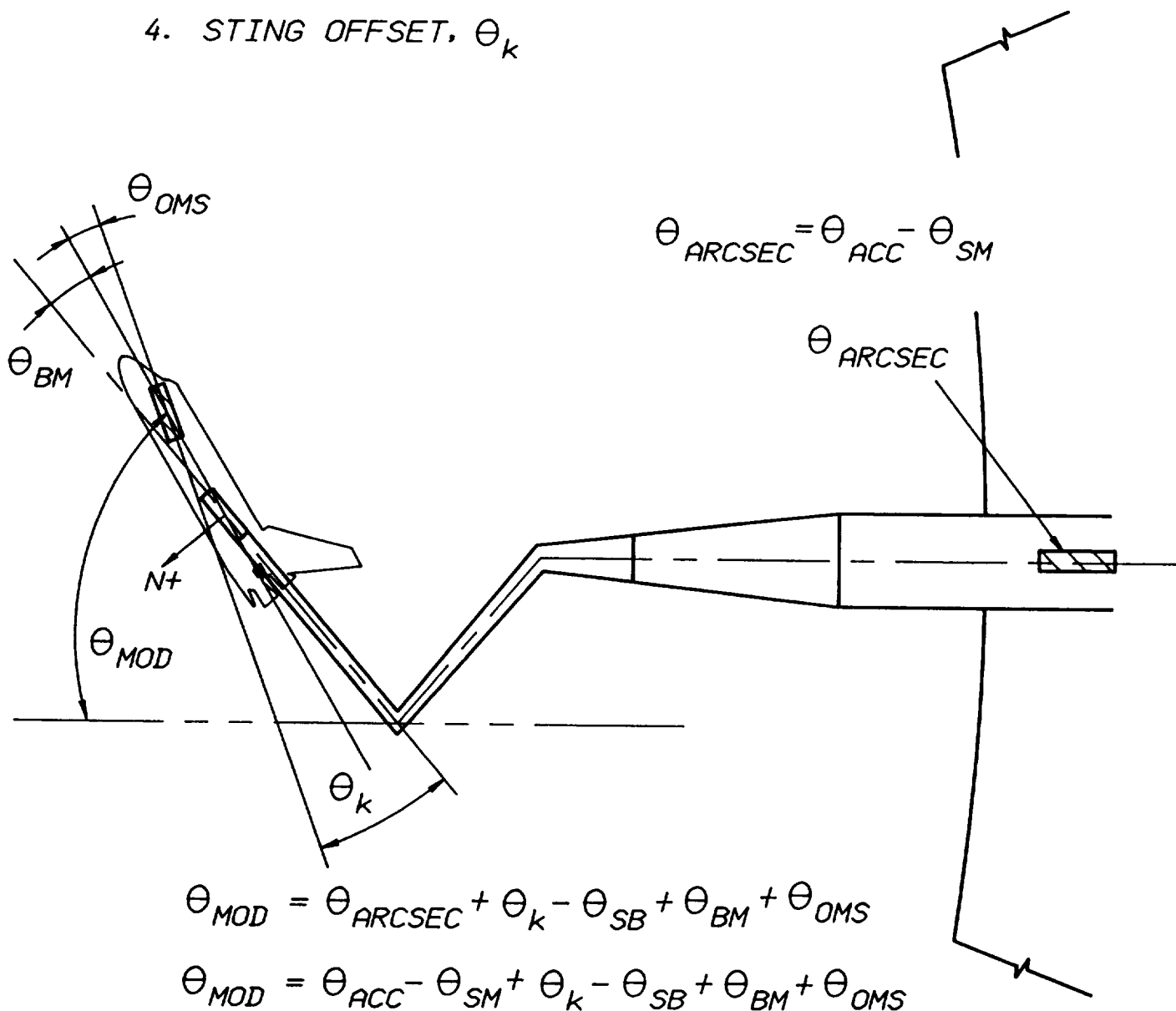3. BALANCE MISALIGNED WITH RESPECT TO MODEL REFERENCE AXIS, θ_{BM}

4. STING OFFSET, θ_k

$$\theta_{ARCSEC} = \theta_{ACC} - \theta_{SM}$$

$$\theta_{MOD} = \theta_{ARCSEC} + \theta_k - \theta_{SB} + \theta_{BM} + \theta_{OMS}$$

$$\theta_{MOD} = \theta_{ACC} - \theta_{SM} + \theta_k - \theta_{SB} + \theta_{BM} + \theta_{OMS}$$

Figure 6-H. Model Orientation Definitions using Arcsector Accelerometer

(continued)
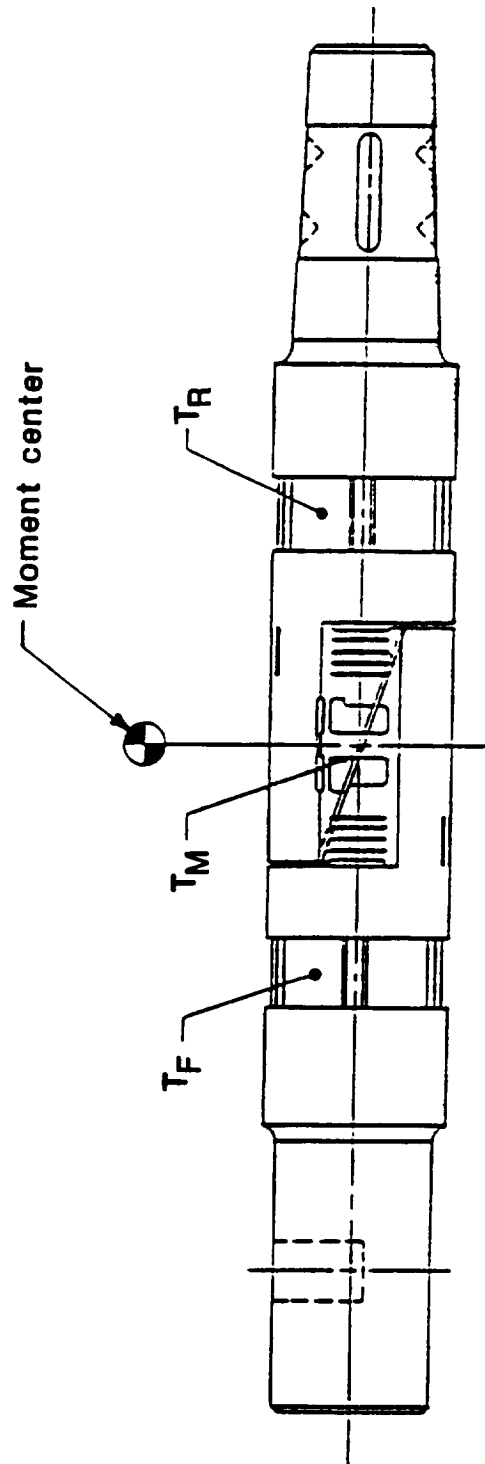
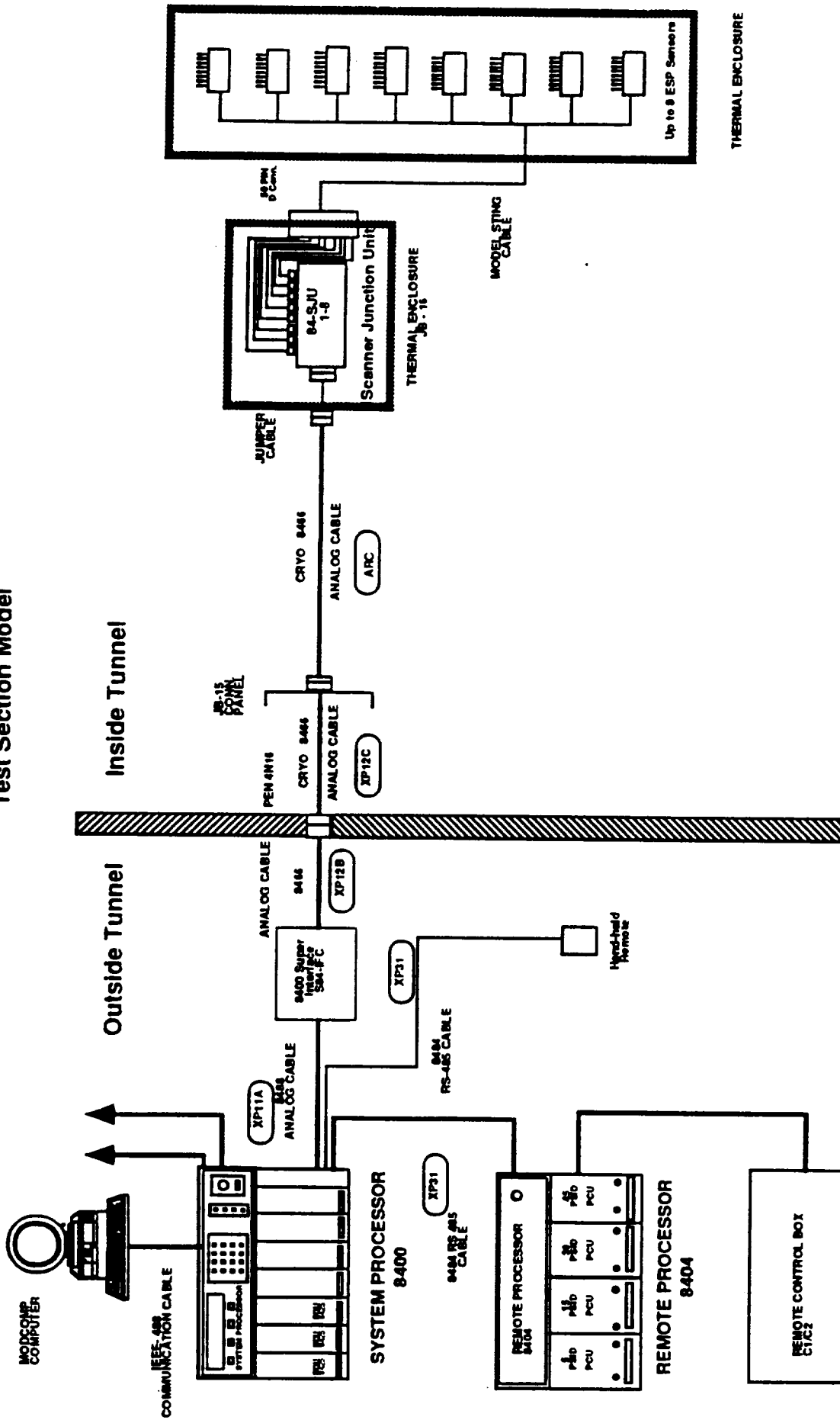Figure 7. NTF balance with thermocouple locations.

Figure 8. ESP System Schematic

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TEST DIRECTOR / RESEARCH ENGINEER
DATA REDUCTION INSTRUCTION SHEET
NTF077 PATHFINDER II

Please fill out this sheet and give to DSE after completion of run set.

DATE _____

INITIALS _____

BegRun	EndRun	Void points / runs	FLWA11 (flow angle)	BWOZ/FWOZ	TARE	CONFIG
___	___	___	___	___	___	___
___	___	___	___	___	___	___

Beta (≠ 0)Run Numbers _____

Angle set-up _____
(A = arcsector) (B = on-board)

	RUN NUMBER (for upflow calc)
AIRGAS	
Air ___	INV ___
LN2 ___	UPR ___

	TIME	DATE	DSE INITIALS
Request received	___	___	___
Data delivered	___	___	___

Figure 9. Sample Data Reduction Instruction Sheet

PSI = ψ = Euler yaw angle = < ABC

THETA = θ = Euler pitch angle = < CBD   (Note θ ≠ α unless φ = 0°)

PHI = φ = Euler roll angle = < CDE
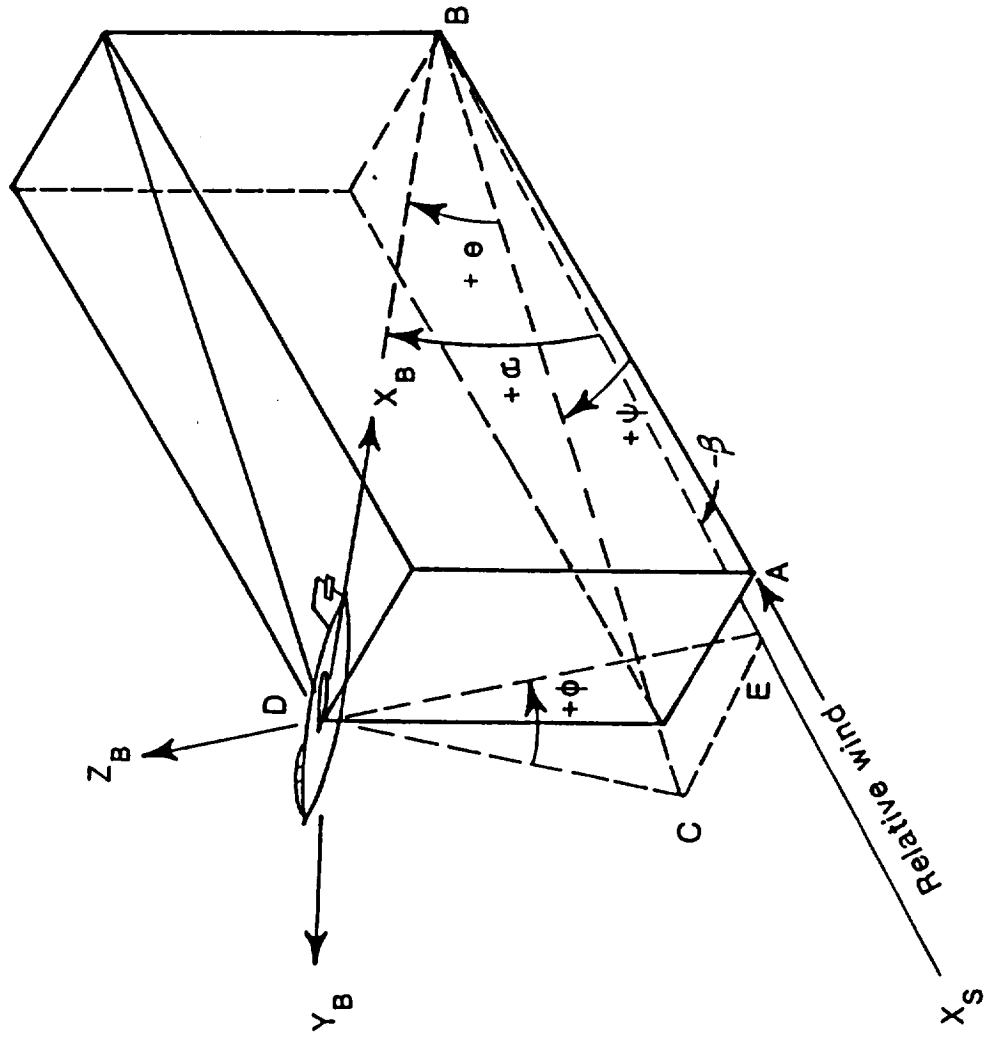
Figure 10. Definition of Euler angles and directions.

Note: Axes shown are for $\phi = 0^\circ$

X_m
X_s
X_w
Z_m
Z_s
Z_w
Y_s, Y_m
Y_w
$+\alpha$
$-\beta$
ϕ
V_∞

Angle of attack $= \alpha =$ angle between stability
X axis and model X axis $= TAN^{-1}$ w/u $=$
θ for special case of $\phi = 0^\circ$,(see figure 9.)

Angle of sideslip $= \beta =$ angle between stability
X axis and relative wind $= SIN^{-1}(-v/V_\infty)$
$-\psi$ for special case of $\phi = 0$, (see figure 9.)
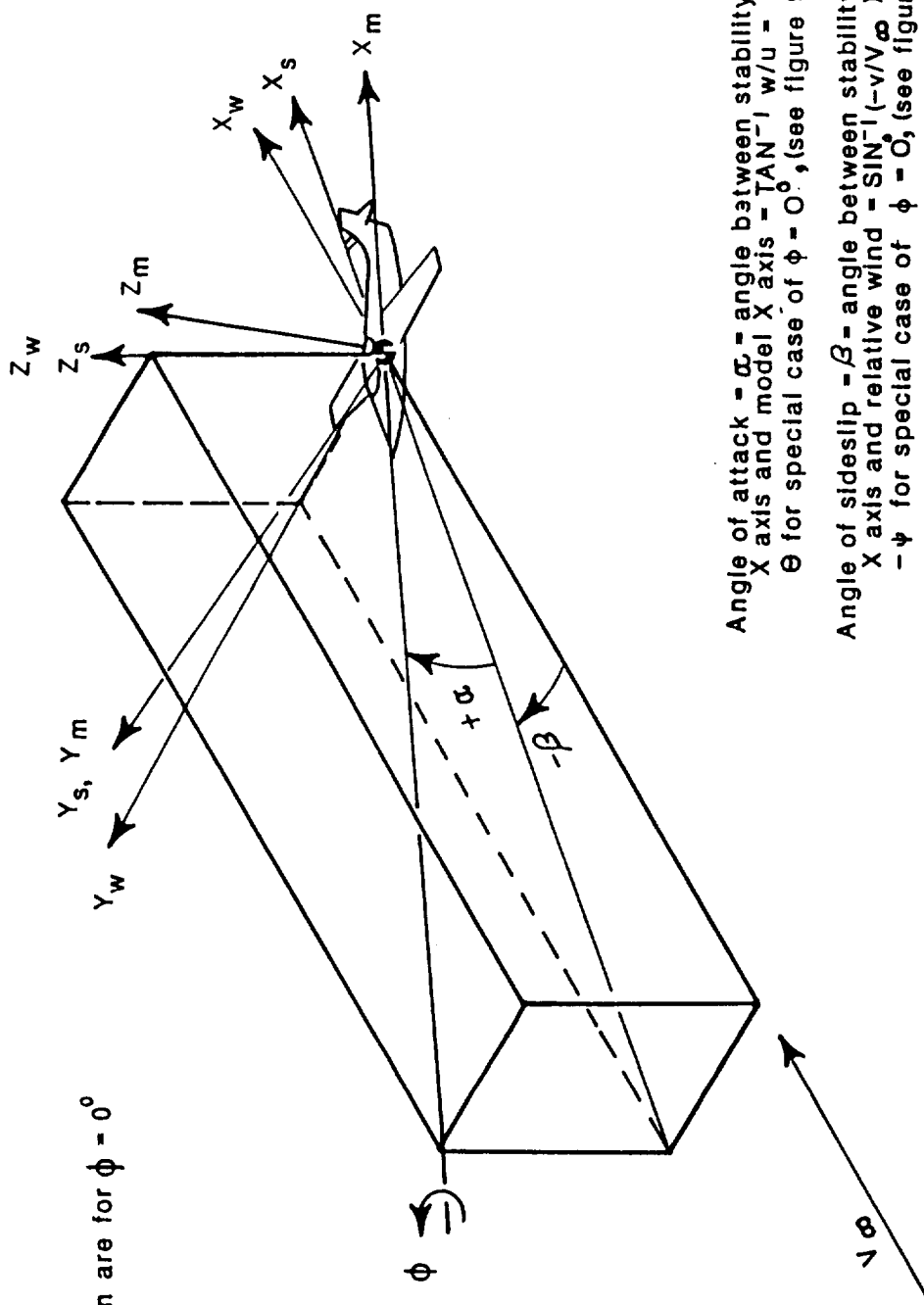
u = X component of relative wind
v = Y component of relative wind
w = Z component of relative wind

Figure 11.   Definition of angle of attack and angle of sideslip.

87
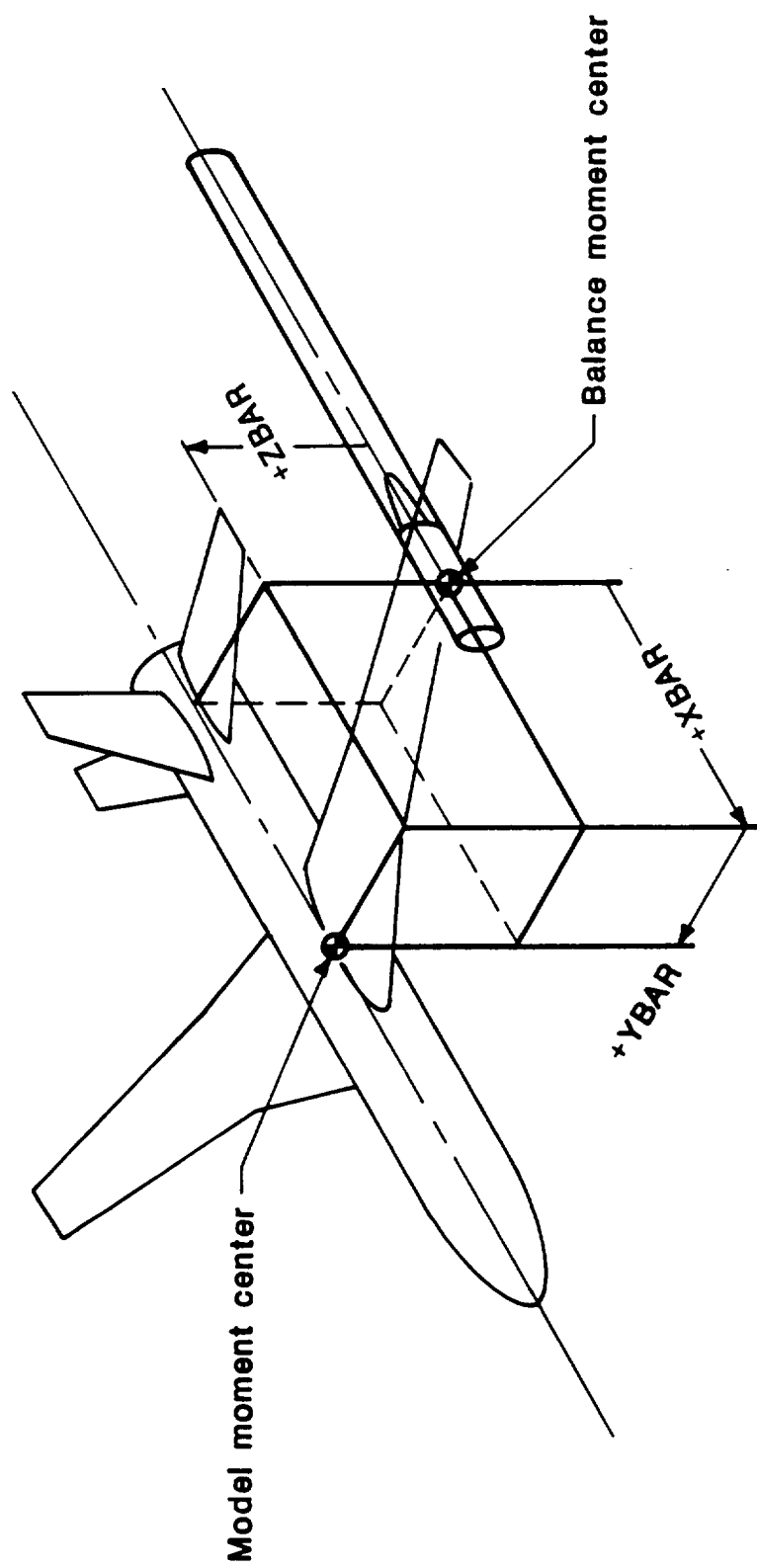
Figure 12. Transfer distance definitions for balance to model moment center translations.

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13. ABSTRACT *(Maximum 200 words)*

The National Transonic Facility is a complex cryogenic wind tunnel facility. This report briefly describes the facility, the data systems, and the instrumentation used to acquire research data. The computational methods and equations are discussed in detail and many references are listed for those who need additional technical information. This report is intended to be a user's guide, not a programmer's guide; therefore, the data reduction code itself is not documented. The purpose of this report is to assist personnel involved in conducting a test in the National Transonic Facility.

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