NATIONAL FULL-SCALE AERODYNAMICS COMPLEX

OPERATIONS MANUAL

PART IV

TEST PLANNING GUIDE

FOR INVESTIGATIONS IN

40- BY 80-FOOT WIND TUNNEL FACILITY

NFAC

Revised: September, 1989

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This document is a revision of the 1984 Planning Guide and replaces and supersedes the 1984 "Guide for Planning Investigations in the Ames 40- by 80-Foot Wind Tunnel Operated by the Low Speed Wind Tunnel Investigations Branch (FHW)."

Every effort has been made to incorporate the most up-to-date information about the systems, functions, and operations of the tunnel in this manual. The systems and procedures are continually updated and revised. A User should check the revision level of this manual and request a new revision through the Project Director or the NFAC office before initiating a project.

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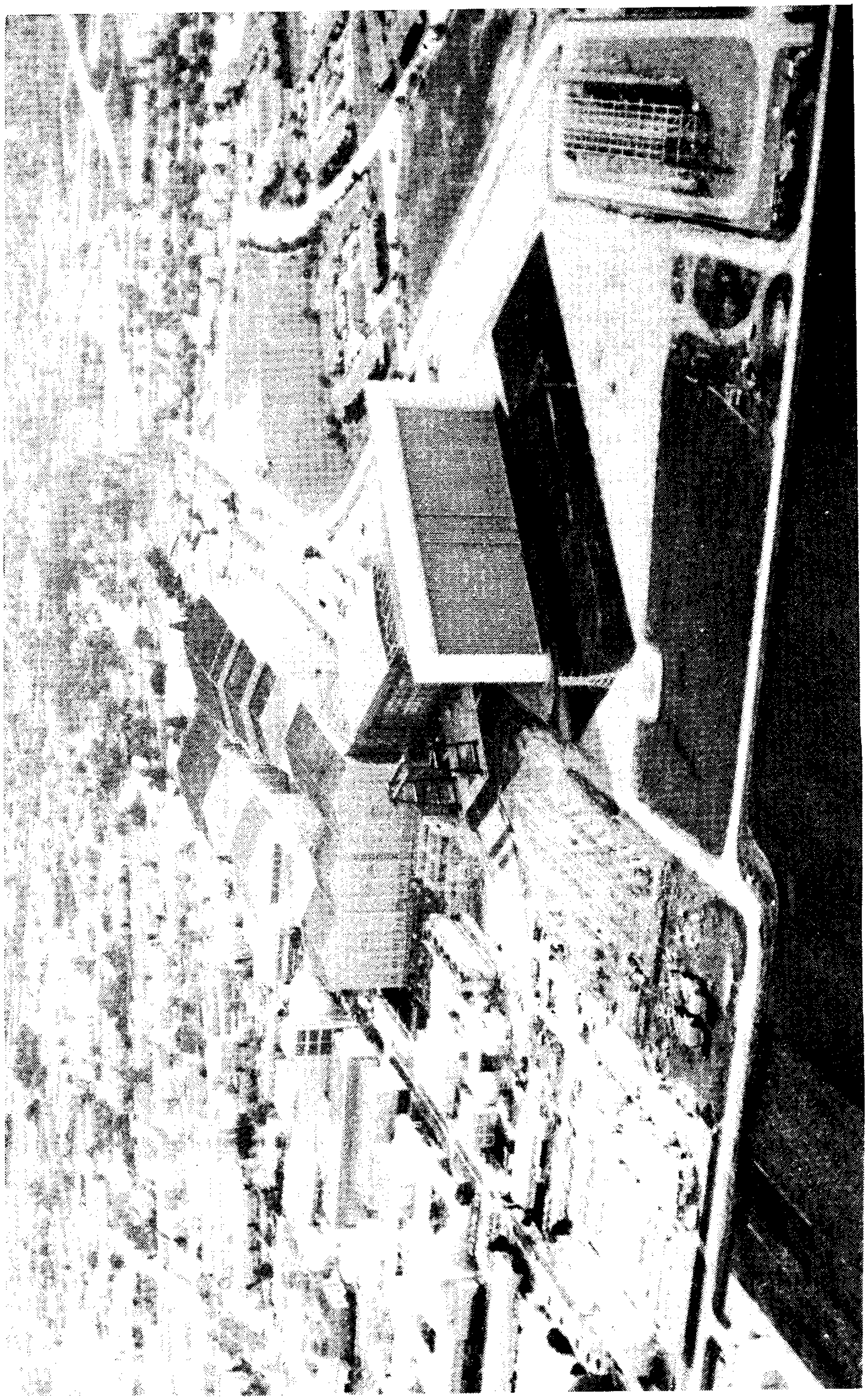

The 40- by 80-Foot and the 80- by 120-Foot Wind Tunnel

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TEST PLANNING GUIDE

FOR INVESTIGATIONS

IN THE AMES 40- BY 80-FOOT WIND TUNNEL

1.0 INTRODUCTION

The National Full Scale Aerodynamic Complex (NFAC) consists of the 40- by 80-Foot Wind Tunnel, the 80- by 120-Foot Wind Tunnel, and the Outdoor Aerodynamics Research Facility (OARF). The Full-Scale Aerodynamics Research Division of Ames Research Center operates this complex. These facilities are used primarily for aerospace research, developmental work for industry, and, when it is in the national interest, non-aerospace testing.

The National Aeronautics and Space Administration personnel and its contractors staff and operate the NFAC facilities. The engineers, technicians, electricians, and mechanics that make up the NFAC staff are available to support every test.

Although NFAC consists of three facilities, this particular manual provides information specific for the use of the 40- by 80-Foot Wind Tunnel and the specific requirements for the design and fabrication of models that are tested in that tunnel. In the manual, Sections 3 through describe the tunnel and the available equipment in the tunnel while Sections 2, 6, 7, and 8 set forthe the requirements and procedures for conducting tests in the tunnel. The appendices contain more detailed guidelines for instrumentation, software, safety, model design. Due to the continual evolution of techniques and test equipment, the information contained in this manual is subject to change without notice.

The requirements of this manual apply to all tests that are to be conducted in the facility including the following categories of tests: those initiated and constructed in-house by NASA personnel or by a construction contractor, those initiated by the Department of Defense and/or other government agencies, and those initiated by private industry. In this manual the word "User" designates any of the above.

All tests will follow the procedures outlined in the *NFAC Operations Manual.* Before model and test acceptance, all Users must meet with the appropriate NFAC operations and research personnel to discuss the justification of the test. To facilitate test preparations, NFAC personnel should be consulted as early as is possible during the planning phase of a test program. To insure model compatibility with NFAC requirements, this consultation should occur before model design is initiated.

Throughout this manual the following letter designations are used to identify the NFAC Division staff and the various Branches within the Division:

- FF Full-Scale Aerodynamics Research Division
- FFN NFAC Research Operations Branch
- FFD Instrumentation and Data Systems Branch
- FFF Fixed-Wing Aerodynamics Research Branch
- FFR Rotorcraft Aeromechanics Branch

The FF Division is primarily responsible for the operation and safety of all personnel and equipment in the division. Under the FF Division each of the four branches have specific responsibilities: FFN conducts all test operations, and operates, maintains, and upgrades all NFAC equipment; FFD is responsible for all data acquisition, data verification, data storage, and data security for all test programs; FFF conducts research on conventional and powered-lift aircraft; while FFR is responsible for rotorcraft-related research activities. Figure 1 shows the basic Division organization.

Following FF Division acceptance of a test, a member of the staff is appointed Project Director. The Project Director for a test is generally the individual most concerned with the research aspects of the test and is usually involved in the early development and justification of the test. The Project Director's main responsibility is to oversee the research requirements of the test. The Project Director is the User's point of contact for the coordination of all test requirements, meetings, and correspondence with NFAC personnel.

Following the approval of the formal Test Request, a Test Director is also appointed from the division staff. The Test Director is responsible for the operational conduct of the test. Safety is a Test Director's prime concern: safe operation of the tunnel and safe operation of the model.

FULL-SCALE AERODYNAMICS RESEARCH DIVISION (FF)

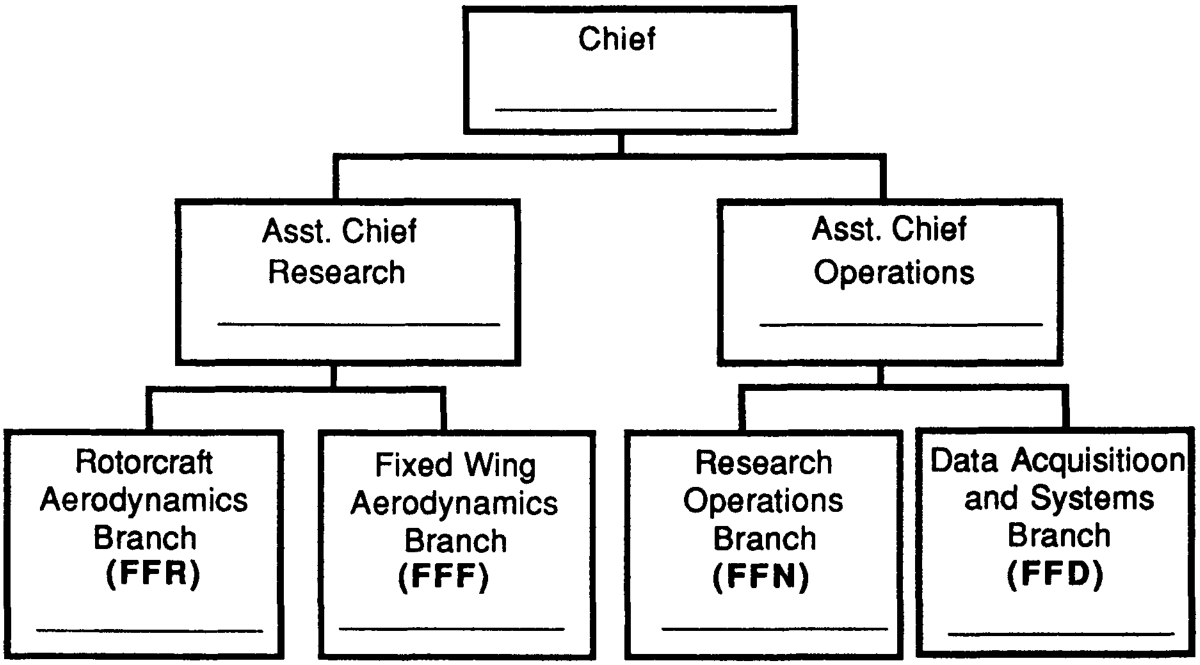


FIGURE 1 - NFAC Organization Chart

2.0 TEST PLANNING REQUIREMENTS

The following sections specify the required preparations and documentation that a User must complete before a model enters the tunnel. The four appendices provide more detailed guidelines.

The NFAC *Operations Manual* details management procedures and the configuration management plan for all tunnel testing. Both the Project Director and the Test Director are responsible for assuring that the *NFAC Operations Manual* guidelines are met in every test.

2.1 TEST APPROVAL

An informal telephone call to the Assistant Division Chief of Operations is the usual form for the initial inquiry for tunnel testing. This inquiry should address the suitability of the facility and the desired schedule for the proposed test. If it appears that the test is appropriate, the User must submit a formal written request to the Director of Aerospace Systems.

Following the receipt of the Formal Request, the NFAC Division Chief will schedule a Test Justification meeting with the requestor and the appropriate operations and research personnel. At this meeting the discussion topics will be the justification for the test and the technical requirements of the test. Before this meeting the requestor must furnish NFAC with the following information:

- The name of the agency and/or contractor supporting the test
- A prioritized list of test objectives including the minimum requirements needed to meet the basic objectives
- The appropriate drawings of the test model
- A tentative run schedule
- The general requirements for instrumentation, equipment, and data display
- The earliest and latest acceptable test dates

All proposed tests must have a Test Justification Meeting that will determine the acceptability of the proposed test. Following this meeting, a decision on the acceptability of the test will be made, and a formal written response will be given. Once Formal Approval is given, tunnel time will be committed to the test, and an NFAC Project Director will be appointed.

The NFAC Division management reviews monthly the priority list of scheduled tests. Priorities are set based on the importance of the test to aeronautical research, the importance to the national interest, and the urgency of the test.

Scheduling of tests is based on this priority list and the availability of resources, equipment, software, and testing time. Testing time is based on a calendar day basis and includes model installation and model removal time.

2.2 DESIGN REVIEWS

The design activity typically starts very early in the test planning process, and reviews are held periodically throughout the design process. These reviews examine suitability of the design, loads, status and progress, analyses, detailed drawings, fabrication procedures, and installation procedures.

All designs for the NFAC require a Conceptual Design Review and a Critical Design Review. Additional interim reviews may be scheduled for specific test programs. The number and schedule of such reviews will be based on the complexity of the test and the risk the program presents to the safety of NFAC personnel and facilities. Critical Design Reviews shall be completed before the start of fabrication, and all phases of the design process shall be fully documented. See Appendix C, for further information.

2.3 NFAC OPERATIONS TEST REQUEST

The Project Director submits this document to NFAC Operations so that resources can be assigned to a specific test.

2.4 DOCUMENT OF PRELIMINARY REQUIREMENTS

The Project Director prepares the Document of Preliminary Requirements in written form. This document develops, in reasonable detail, the requirements necessary for each aspect of the test. It must be available four weeks before the first Test Planning Meeting, but it may be modified as a result of discussions at that meeting. NFAC personnel will plan their activities based on the requirements in this document. The document deals with all elements of the test to whatever extent is possible at this early stage. Each item should answer the following questions:

•Test Objectives	What are the primary and secondary objectives of the test?
•Test Approach	What approach will be used to attain the objective?
•Test Budget	What is the project budget? How much money is allocated for each element of the test?

•Test Schedule	What is the schedule for completion of the test, and where do the major milestones of each element fit into the schedule? In particular, the Design Reviews and the Test Planning Meetings should be part of this schedule.
•Hardware and Controls	What is the model geometry? In particular, include the planform, control surfaces, power engine arrangement, control ranges, engine thrust range, and speciality hardware.
•Model Utilities	Which model utilities will be required to support this test? What are the specific requirements for electrical power, hydraulics, fuel, and high pressure air? Are there any unusual requirements for capacity?
•Instrumentation and Data	What type of data is required? What are the number of sensors, their location , and the special arrangements needed, dynamic or static, the frequency response, the accuracy, the on-line data, the display needs, the raw data needs?
•Software	What is the scope of test dependent computations? What plots are required? Describe the scope of the software in sufficient detail so that a time estimate for development can be established.
•Test Parameters	What is the range of the angle-of-attack, the yaw angle, the velocity/dynamic pressure, and the engine power? What special configurations or special equipment is needed?
•Safety	What are the anticipated areas of greatest risk that require proper controls e.g. fuel, rotating equipment, high pressure air unknown dynamics, and flutter?
•Training	What are the requirements for crew training and certification? Is any special operating equipment involved? Are there any unique circumstances, emergencies, or operational requirements for which special preparations must be made?

2.5 TEST PLANNING MEETINGS

The Test Planning Meetings review the specific plans for the test and the associated documentation. The first Test Planning Meeting will discuss the basic elements of the test using the document of Preliminary Requirements. This meeting should occur approximately one (1) year before the scheduled tunnel entry date. Subsequent test planning meetings should include, as a minimum, meetings at six (6) months and three (3) months before tunnel entry.

2.6 DOCUMENTATION REQUIREMENTS

All tests must include the documentation described in this section. All documents will include both a draft and a final submittal version for each separate document. Draft Documentation documents, submitted four weeks before the Six Month Planning Meeting, are to be complete documents that contain all the necessary information; they do not have to be reviewed or in final form. Final documents are to be submitted four weeks before the Three Month Planning meeting.

2.6.1 Test Plan

The Test Plan is a comprehensive document that guides all the anticipated aspects and activities for the test and includes the following:

Test objectives

Run schedules with priorities assigned

Overall test equipment with a full listing of -

- description and priorities
- monitoring requirements
- redline limits, warning limits, and priorities

General description of data requirements covering acquisition, reduction, and plotting

Predicted operational envelope

Predicted model/rotor loads that coincide with the operational envelope

Manpower requirements

- Crew assignments
  - NASA personnel
  - Contractor personnel
- Crew training plan and certification requirements
- Maintenance procedures
- Inspection procedures -
  - After each run
  - Daily
  - Additional
  - Checklists
- Test operation procedures -
  - Preflight
  - Starting and stopping
  - Data run
- Emergency procedures
- Operational surveillance
- Security requirements
- Special communication requirements
- Installation and removal -
  - Model transportation requirements
  - Lifting procedures

2.6.2 Instrumentation Requirements

These requirements completely document all of the instrumentation necessary to conduct the test. Well organized Instrumentation Requirements give the NFAC staff adequate information to develop and implement the desired instrumentation. The plan includes the following:

A full description and listing of all measurements -

- Location
- Priorities
- Monitoring requirements
- Safety of flight items
- Steady and dynamic limits
- Filtering and signal conditioning requirements
- Complete calibration data

Interface schematic drawings -

- Electrical
- Mechanical
- Signal Flow diagram

A guide to the planning and preparation of the Instrumentation Requirements is given in Appendix A.

2.6.3 Software Plan

This plan completely documents all of the software necessary to conduct the test. It is important that the User clearly understands and meets the data requirements, so that the results more nearly match the User's expectations. Special details for data reduction, equations, and plotting give the NFAC staff adequate information to develop the needed software. The Software Plan includes the following:

Full description and listing of all measurements

- Priorities
- Static data and dynamic data

Test configurations

Tare requirements

Real-time display requirements

Data reduction requirements

- Reduced data
- Formatting
- Plotting requirements

A guide for software planning is also given in Appendix A.

2.6.4 Design Analysis Report

The Design Analysis Report documents all required engineering calculations and plans for the fabrication and testing of parts and models. The Design Analysis Report consists of the following documents:

Design Loads Document

Stress Analysis Document

Description and drawings of the hardware

Inspection Requirements Document

A full description of these document requirements is given in Appendix C.

2.6.5 Safety Analysis Report

This report documents all of the safety analyses required for tunnel entry. It includes the following:

Gross Hazards Analysis

Dynamic Stability Analysis

Fragmentation Analysis

Operations Safety Requirements

A full description of these analyses and requirements is given in Appendix B.

2.7 MODEL ASSEMBLY, CHECKOUT, AND TESTING

Delivery of the model is dependent on the amount of assembly and checkout that must be performed at Ames Research Center. The assembly of models and the checkout of systems must be complete before the Test Readiness Review, four weeks before tunnel entry. All systems and instrumentation must be functionally checked out, completely verified, and any needed corrections made.

2.8 THE TEST READINESS REVIEW

The Test Readiness Review is a formal review that ensures that all of the test documentation and preparation activities are complete. This review occurs four weeks before tunnel entry. A Test Readiness Report must be compiled for this review: it should consist of all of the final documentation for the test.

The Test Readiness Review Guide and Sign-off Sheet (See Appendix D) will be completed and signed off at this meeting.

2.9 TUNNEL ENTRY

The model will be installed in the tunnel as scheduled only when the Test Readiness Report Guide and Sign-off Sheet is completed and all issues or actions have been properly addressed. The model lift-in is the event that initiates tunnel occupancy.

2.10 SUMMARY OF MILESTONES AND REQUIRED DOCUMENTS

These milestones are typical for a standard test in the facility. The usual schedule is indicated in the right hand column in months before tunnel entry.

1. Test Approval
   - Initial telephone inquiry
   - Formal Written Request
   - Test Justification Meeting
   - Formal Approval of test
2. Start design activity (Section 2.2)
3. NFAC Operations Test Request
4. Document of Preliminary Requirements (Section 2.4) — 13 months
5. First Test Planning Meeting (Section 2.5) — 12 months
6. Draft Documentation — 7 months
   - Test Plan
   - Instrumentation Requirements
   - Software Requirements
   - Design Analysis Report
   - Safety Analysis Report
7. Six Month Planning Meeting — 6 months

8.	Final Documentation	4 months
	• Test Plan • Instrumentation Requirements • Software Requirements • Design Analysis Report • Safety Analysis Report	
9.	Three Month Planning Meeting	3 months
10.	Model Assembly	
11.	Model Checkout and Testing	
12.	Test Readiness Review	1 month
13.	Tunnel Occupancy	

3.0 THE 40- BY 80-FOOT WIND TUNNEL

The 40- by 80-Foot Wind Tunnel is a closed circuit, single return wind tunnel. Its general arrangement is shown in Figure 2. The tunnel is driven by six 40 foot diameter fans that are powered by six 22,500 horsepower motors.
The 40- by 80-foot test section and the 80- by 120-foot test section share this fan drive system. By adjusting the position of the vane sets three and four, the airflow can be directed through one test section or the other. When the 40- by 80-foot test section is in operation, work may simultaneously continue in the 80- by 120- foot test section. However, work may not continue in the 40 by 80 test section when the the 80 by 120 foot test section is in operation.

Air is exchanged in the 40- by 80- circuit by the air exchange system at rates of ten, five, and zero percent. The ten percent rate is used for normal operation. The five percent rate can be used whenever required. The zero percent rate is not normally allowed.

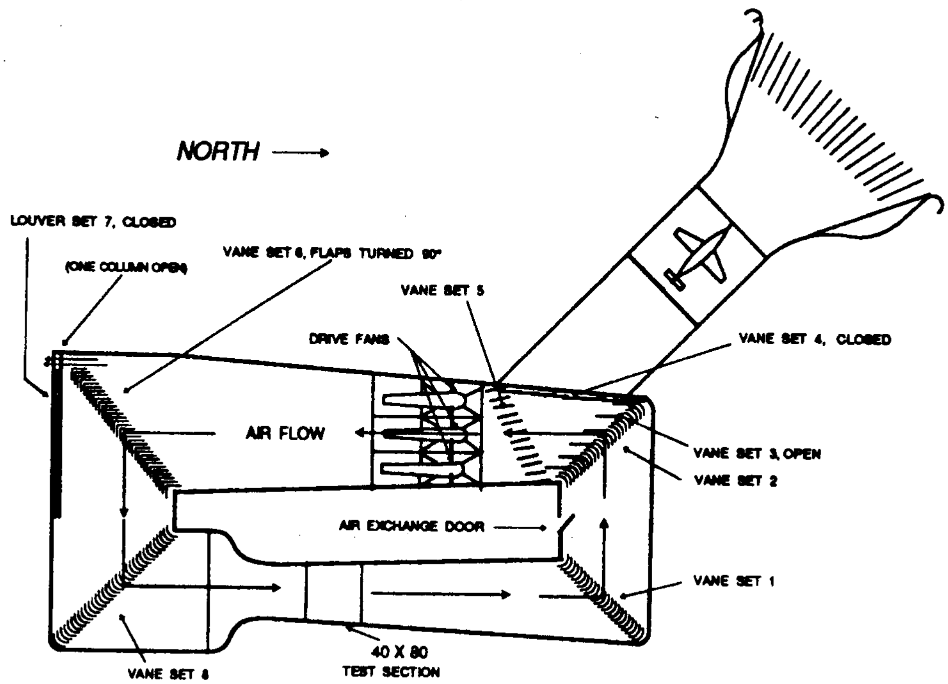


Figure 2 40-X 80-Foot Wind Tunnel

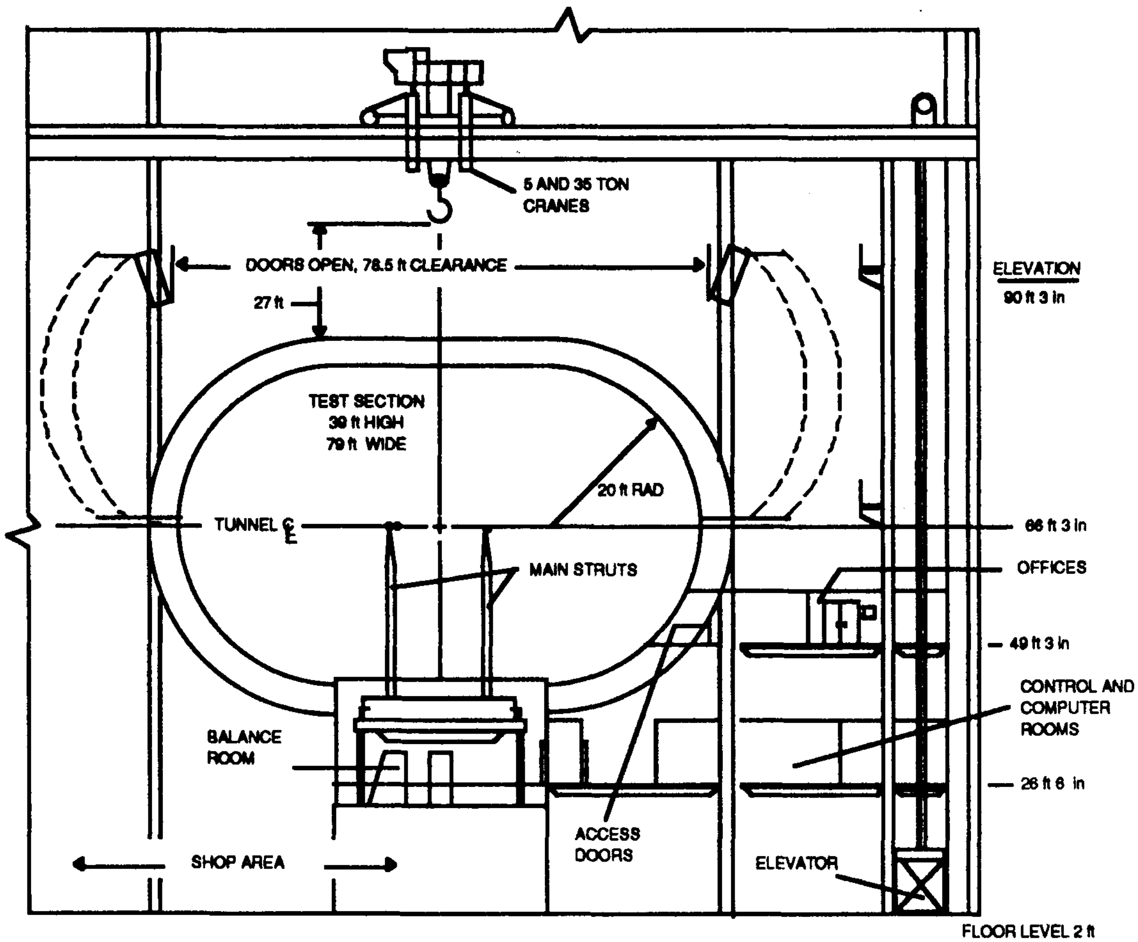


Figure 3 Cross Section of the Test Section

3.1 TEST SECTION

The 40- by 80-foot test section is 39 feet high, 79 feet wide, and 80 feet long. It is lined with a six inch acoustic lining used for acoustic research. A cross section of the 40- by 80-foot test section and control room is illustrated in Figure 3. Figure 4 is a photograph of the test section.

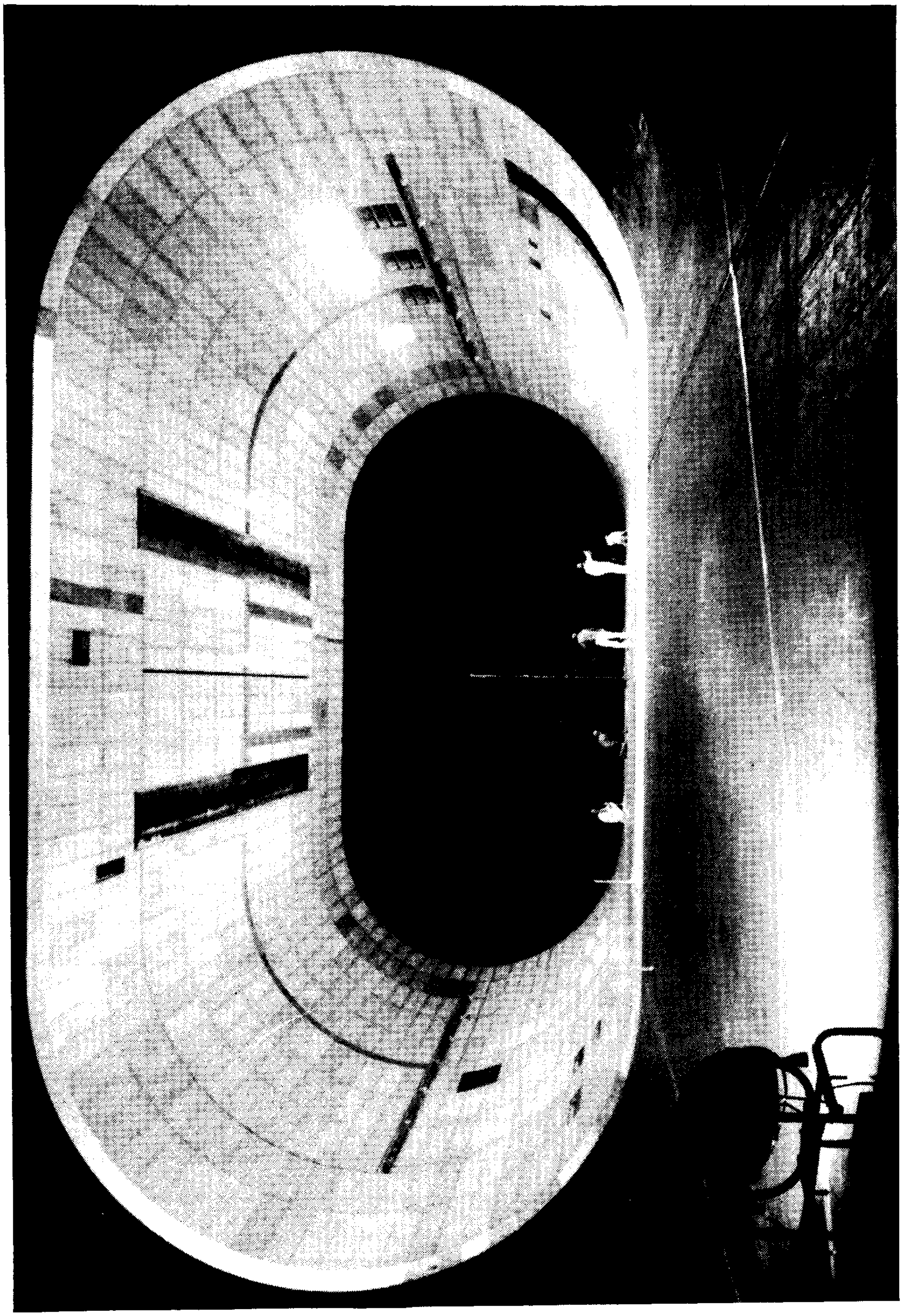


Figure 4 40- by 80-Foot Wind Tunnel Test Section with the Acoustic Lining

SECTION

3.2.1 Performance

Speed Range	0 to about 300 knots, continuously variable
Stagnation Pressure	Atmospheric
Dynamic Pressure	262 pounds per square foot, maximum allowed
Reynolds Number	0 to about 3 x 10^6 per foot with standard atmospheric conditions (see Figure 5)

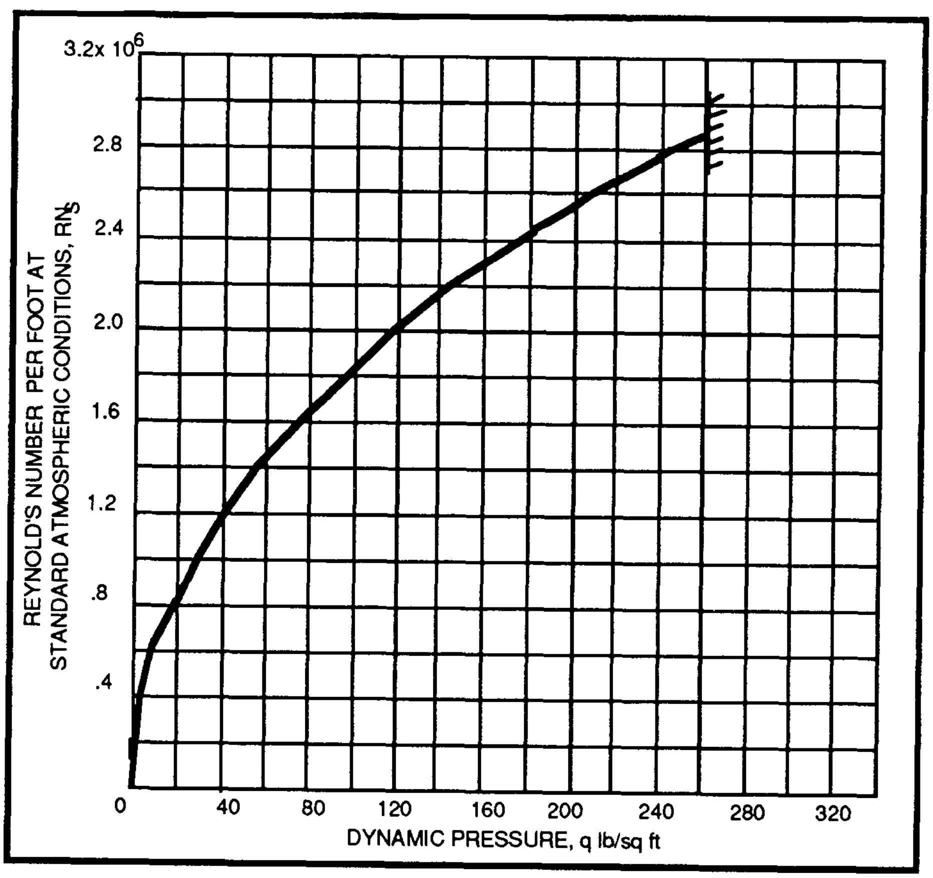


Figure 5 Variation on the Reynolds Number

3.2.2 Operating Envelope

The operating envelope for the 40- by 80-foot test section pressure or velocity is controlled in two ways: by changing the speed of the six tunnel drive motors and by changing the pitch angle of the tunnel drive fan blades.

The speed of the tunnel drive motors can be operated in two modes. The first operating mode is with the Induction Frequency Control (IFC) system. This system is used to start the six tunnel motors and to synchronize them at a starting speed of 36 revolutions per minute (rpm).

The IFC mode can be used to control the tunnel drive motors at a lower rpm for special tests that require low background noise. The fan blade pitch may be varied in this mode to control the operating envelope. The IFC is limited in power to about 20 megawatts. Figure 6 presents the operating envelope available in the IFC Mode.

The second and normal operating mode of the tunnel is the Utility Mode where power is drawn directly from the utility grid. Then the six drive motors are run at a constant 180 rpm. Changes in the test section pressure or velocity are controlled by varying the fan blade pitch of the six fan drives from a blade angle of -18° to +52°. The maximum available power for the drives is 106 megawatts. The maximum operating pressure on the 40- by 80-foot test section is 262 pounds per square foot. Figure 7 presents the operating envelope available in the Utility Mode.

Wind tunnel operations permit continuous running of the IFC and Utility Mode for a total running period of 2 hours per tunnel run.

Tunnel temperature is dependent upon seasonal atmospheric variations and is also affected by the operation of model aircraft engines. Air temperatures from about 30°F to 125°F are generally within safe limits. Figure 8 presents information which can be used to establish the wind tunnel temperature rise at various rates of air exchange.

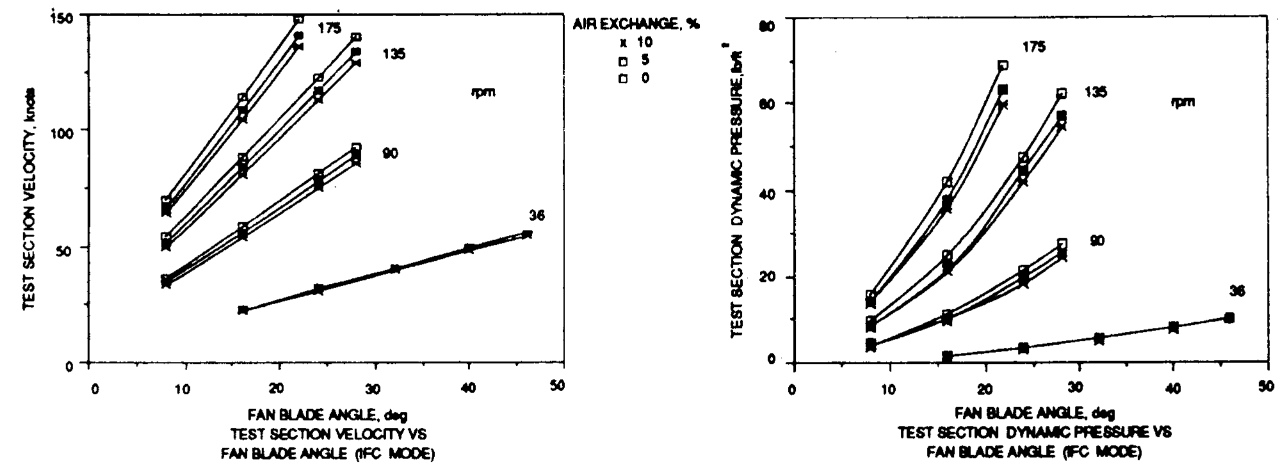


Figure 6 Operating Envelope in the IFC Mode

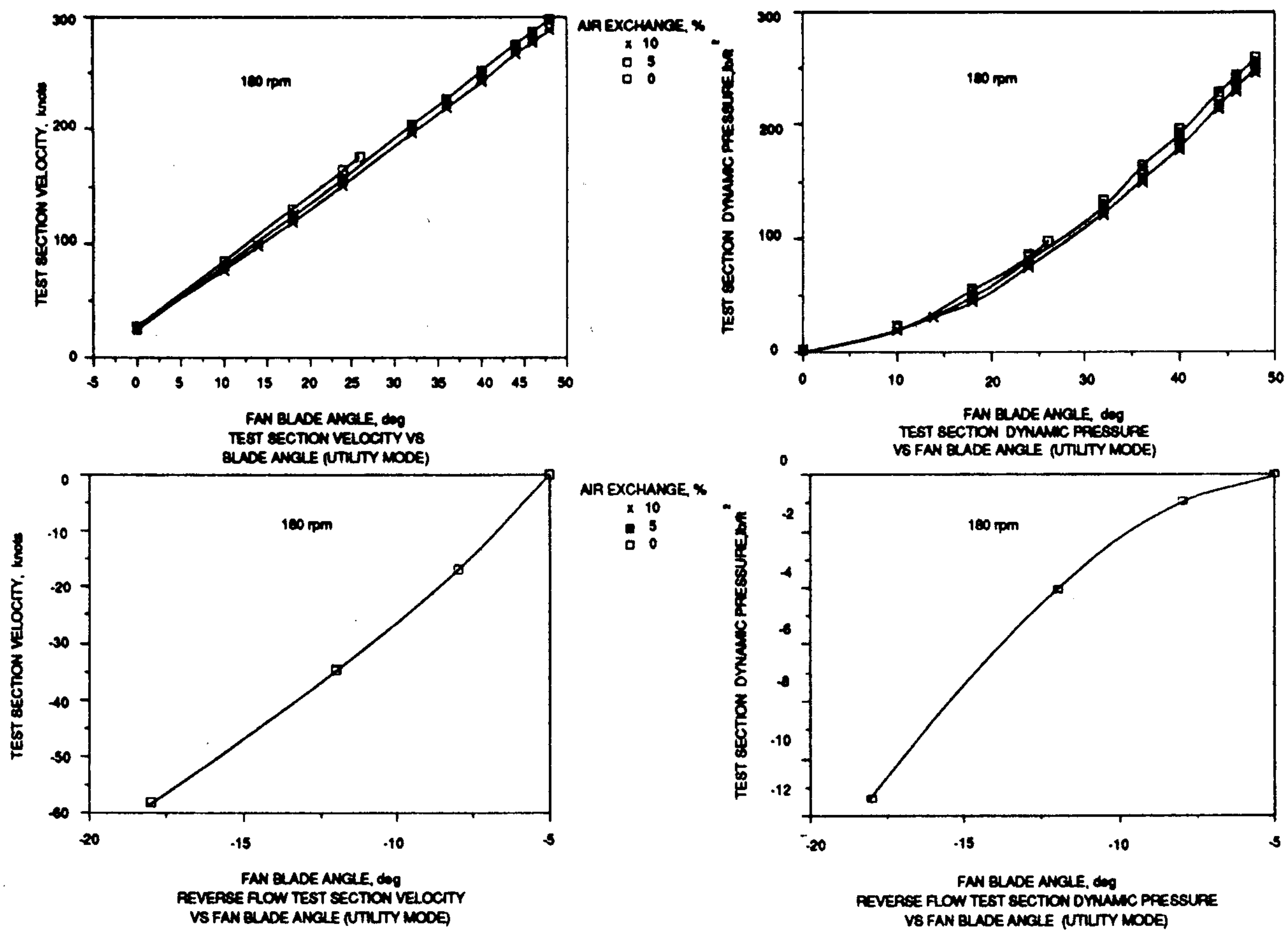


Figure 7 Operating Envelope in the Utility Mode

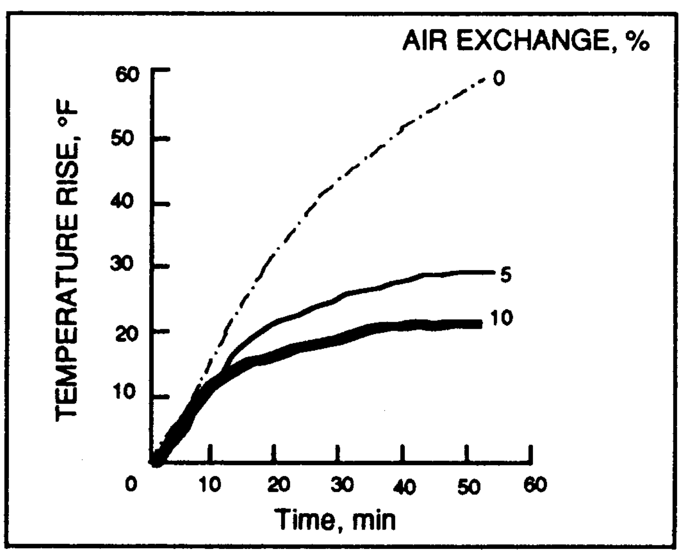


Figure 8 Temperature Rise at Maximum Air Velocity and Tunnel Empty

3.2.3 Critical Test Mode

In the wind tunnel there are numerous protective devices that initiate warnings and automatic shutdowns. Most tests will be run in the "Normal" test mode: this allows the functioning of all automatic stop circuits. The "Critical" test mode places a five minute delay in selected - not all - automatic stop circuits. This delay is intended to provide time, between the alarm and the actual shutdown, for the test crew to prepare for the impending shutdown.
Since not all automatic shutdown circuits are included in this "Critical' mode, a model must be able to withstand a spontaneous shutdown whether it ever occurs or not. The Test Director, with review with the Test Readiness Review Board, makes the decision whether to use the "Critical" mode. The test documentation should include the rationale and need for use of the "Critical" mode. NFAC management must approve each specific use of this mode.

3.2.4 Emergency Stop Circuit

The tunnel drive system is equipped with an emergency stop circuit. Examples of the rate of reduction of dynamic pressure for normal and emergency stops from various tunnel speeds are shown in Figure 9. While the drive system itself cannot be damaged by making an emergency stop, there is the possibility of doing significant damage to models during such a stop. This possibility though, depends on the type of model being tested. Specific procedures for emergency stops must be developed for each test and reviewed at the Test Readiness Review. These approved procedures must be followed closely during tests.

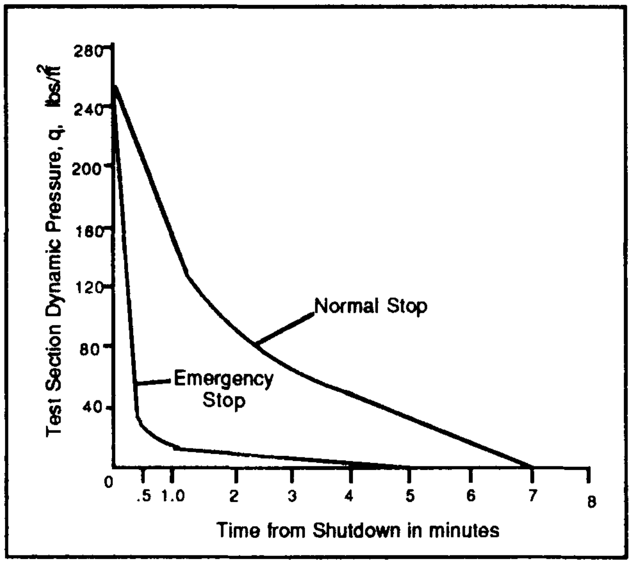


Figure 9 Time for Flow Decay In the Test Section on Normal and Emergency Shutdown

3.3 PRIMARY MODEL SUPPORT SYSTEM

The primary model support system in the 40x80 test section consists of two mechanical systems. They are operated from the control room during a test and can change either the angle-of-yaw by rotating the turntable systems, or the angle-of-attack by moving the nose/tail strut.

3.3.1 Description

The model support system has two major elements. The first is used to support the model and consists of three model struts, a lower turntable, the floating frame, and the balance system. The three moveable model struts are mounted on the lower turntable which is a "T Frame". This lower turntable "T Frame" is mounted on a floating frame that is connected to the balance system.

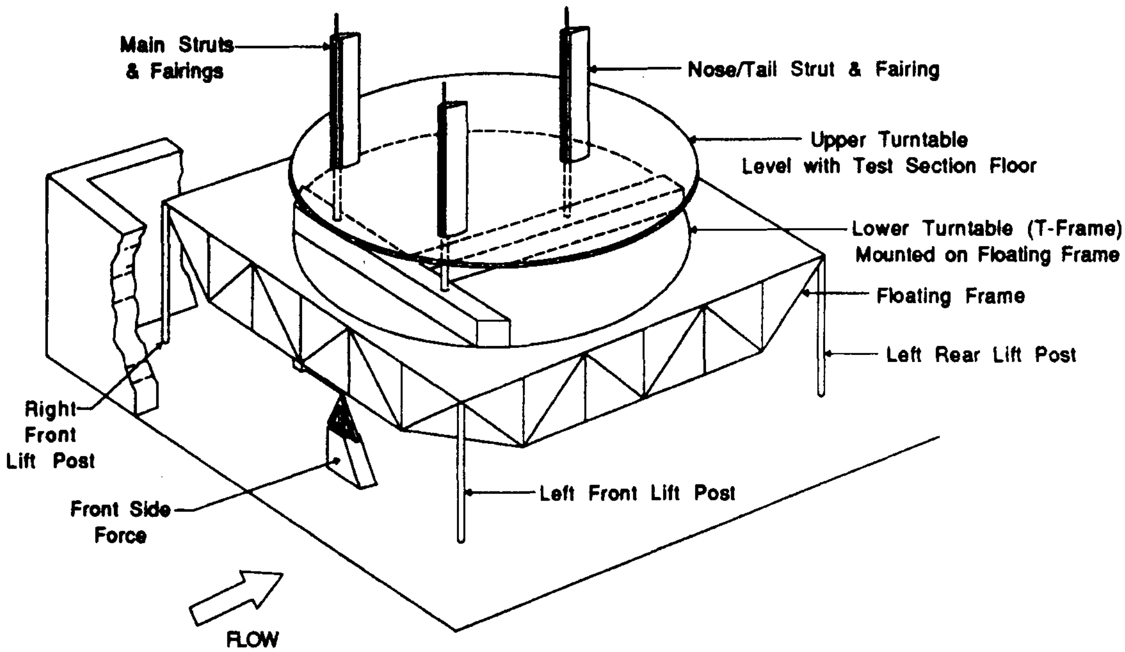


Figure 10 Schematic View of the Model Support System

The second major element is the upper, floor turntable and strut fairings. Each model strut is shielded from the air stream by a fairing that is mounted to the upper, floor turntable independent of the model struts. The two turntables, upper and lower, are separately supported to isolate fairing aerodynamic loads from model aerodynamic loads. Figure 10 presents a schematic view of the 40x80 Model Support System. When the upper turntable is yawed, the fairings also rotate so that they remain aligned with the tunnel air stream.

The upper turntable, the floor, and the fairings are identified as a *non-metric* system because they are isolated from the *metric* system, which consists of the struts, the lower turntable "T Frame", the floating frame, and the balance system. This isolation permits separation of model loads from the fairing aerodynamic loads, and it also provides a system for detecting a "foul" during a test run. If during a test, any part of the *non-metric* system contacts the *metric* system, a warning light flashes in the control room indicating that the measured aerodynamic loads for the model may be in error or "fouled".

3.3.2 Model Support Struts

The model is mounted in the tunnel on two main struts and a single telescoping nose/tail strut. The struts can be moved to accommodate models of different treads (widths) and different tail or nose lengths. Figure 11 presents the range of tread and tail lengths available.

The model may be mounted in the tunnel at variable heights through a system of different main struts and tip extensions. The main strut configuration can vary from a minimum of 2' 0" to a maximum of 19' 7" above the tunnel floor. The aerodynamic fairings, which shield the struts, also vary in height. Table 1 presents the different struts, tips, and fairing arrangements available. Other arrangements may be fabricated for special tests.

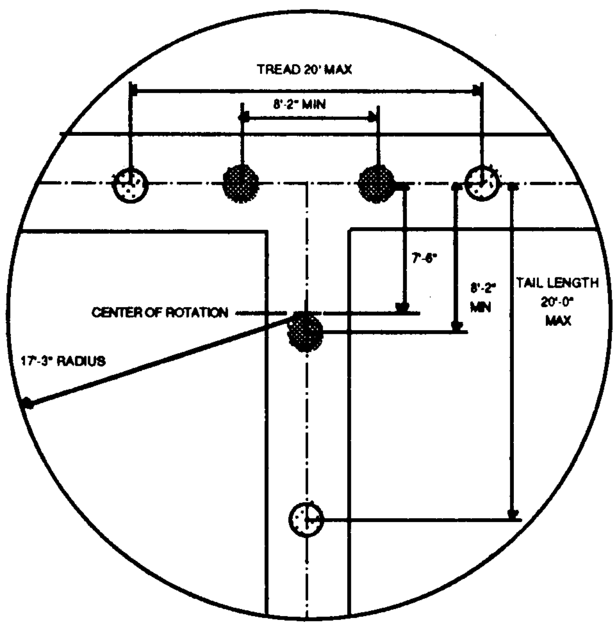


Figure 11 Available Tread and Tail Lengths

Configuration Strut + Tip (ft, in)		Fairing Height Above Acoustic Floor, less cap (ft, in)	Ball Height Above Floor* (ft, in)
Strut	Tip		
1' 6"	6"	No Fairing	1' 11.7"
1' 6"	2' 9"	3' 6"	4' 0.7"
1' 6"	5'	6'	6' 3.7"
8'	6"	6' 5"	8' 5.25"
8'	2' 9"	8' 8"	10' 6.25"
8'	5'	9' 9"	12' 9.25"
15'	6"	13' 1"	15' 2.25"
15'	2' 9"	15' 5"	17' 3.25"
15'	5'	15' 5"	19' 6.25"

* Notes: For pitch and roll calculations the critical dimension is from the top of the acoustic floor to the center of the ball.

Table 1 Arrangements for the Main Strut and Fairing Heights

Tail Strut Height Range (ft, in)	Extension Length (ft, in)	Tip (ft, in)	Faalring Height Range w/ Cap (ft, in)
2' 0" - 13' 0"	0	1' 0"	0
3' 0" - 14' 0"	0	2' 0"	0
5' 0" - 16' 0"	0	3' 0"	0
6' 0" - 17' 0"	0	4' 0"	0
7' 6" - 18' 6"	0	5.6"	0
10' 0" - 21' 0"	7' 0"	1'0"	9' 9" - 21' 0"
11' 0" - 22' 0"	7' 0"	2' 0"	9'9" - 21' 0"
12' 0" - 23' 0"	7' 0"	3' 0"	9'9" - 21' 0"
13' 0" - 24' 0"	7'0"	4' 0"	9'9 - 21' 0"
14' 6" - 25' 6"	7' 0"	5.6"	9'9" - 21' 0"

All measurements are made from the top of the turntable acoustic lining.

Table 2

Available Travel for the Tail Strut Tip and Fairing Arrangements

The telescoping nose/tail strut uses a ball screw and tip extensions to achieve variable heights. Nose/tail strut configurations can vary from a minimum of 2' 6" to a maximum of 24' 6" above the tunnel floor. The ball screw has an extension length of 11' 6" from the fully retracted to the fully extended length. The maximum tilt of the gimbal for the nose/tail strut is ±15°. Table 2 presents the available tail strut travel for different tip and fairing arrangements. Figure 12 illustrates the strut limits for tilt.

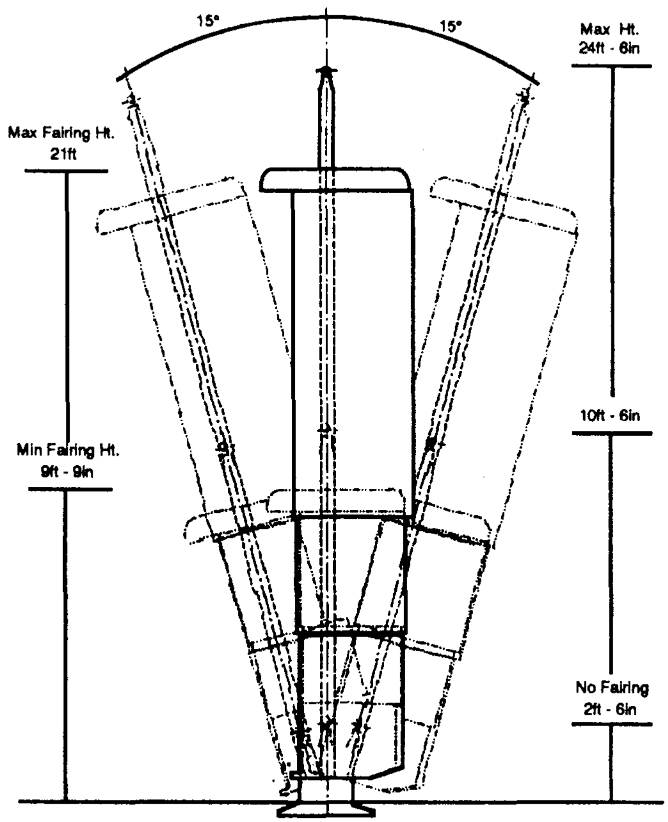


Figure 12

Tail Strut Tilt Limits

3.3.3 Allowable Strut Loads

The two main struts are "fixed" at their base and carry model dead weight, lift, side, and drag forces, and all rolling, yawing, and pitching moments. The

nose/tail strut is mounted in a gimbal and can carry only pure axial loads from model dead weight and lift forces.

The different load combinations for anticipated aerodynamic forces and model dead weight must be developed for the variable test configurations for angle-of-attack and angle-of-yaw. These load combinations must be examined to calculate the resultant loads on the supporting struts.

Strut & Tip Configuration		Max. Horizontial Resultant Load Drag + Side	Maximum Down Load *	Maximum Up Load **	Maximum Deflection of Strut (in)
Strut	Tip				
1.5'	No tip	20,300	100,000	-47,000	.01
1.5'	6	20,300	100,00	-45,500	.02
1.5'	33	20,300	9,500	-38,000	.37
1.5'	60	18,600	7,000	-30,500	.44
8'	No tip	17,750	65,000	-27,500	.21
8'	6	16,800	65,000	-28,500	.22
8'	33	12,800	65,000	29,500	.52
8'	60	9,000	65,000	-33,000	.45
15'	No tip	13,000	35,000	-15,000	.35
15'	6	12,700	35,000	-15,000	.41
15'	33	11,000	35,000	-15,000	.66
15'	60	9,400	35,000	-15,000	.84
Tail/Nose Strut		NA	18,000	18,000	NA

* Model weight included
** Model weight excluded

Table 3

Maximum Allowable Load For Each Main Strut

and For the Nose/tail Strut

The horizontal resultant force acting on the two main struts include side forces, drag forces and yawing moments. The vertical resultant force acting on the two main struts include model dead weight, lift forces, pitching moments and rolling moments.

Table 3 presents for each of the two main struts, the allowable resultant loads for the different strut height and tip configurations, and the maximum allowable axial load for the tail strut.

3.3.4 Model Support Connections

The model connections to the main struts and nose/tail strut are made with ball socket mounting assemblies. These joints are a potential single point failure, and therefore, are critical to structural safety and to model support. Through-bolting for these joints is desirable whenever possible, however, a drilled and tapped configuration is also acceptable. To obtain the maximum load capacity of the system with a drilled and tapped configuration, the mounting pad from the ball socket to the model interface must be a 1-1/4" thick, 4130/4340 steel plate, welded to the model's structural frame. Figure 13 presents the drilled and tapped configuration of the ball and socket arrangement.

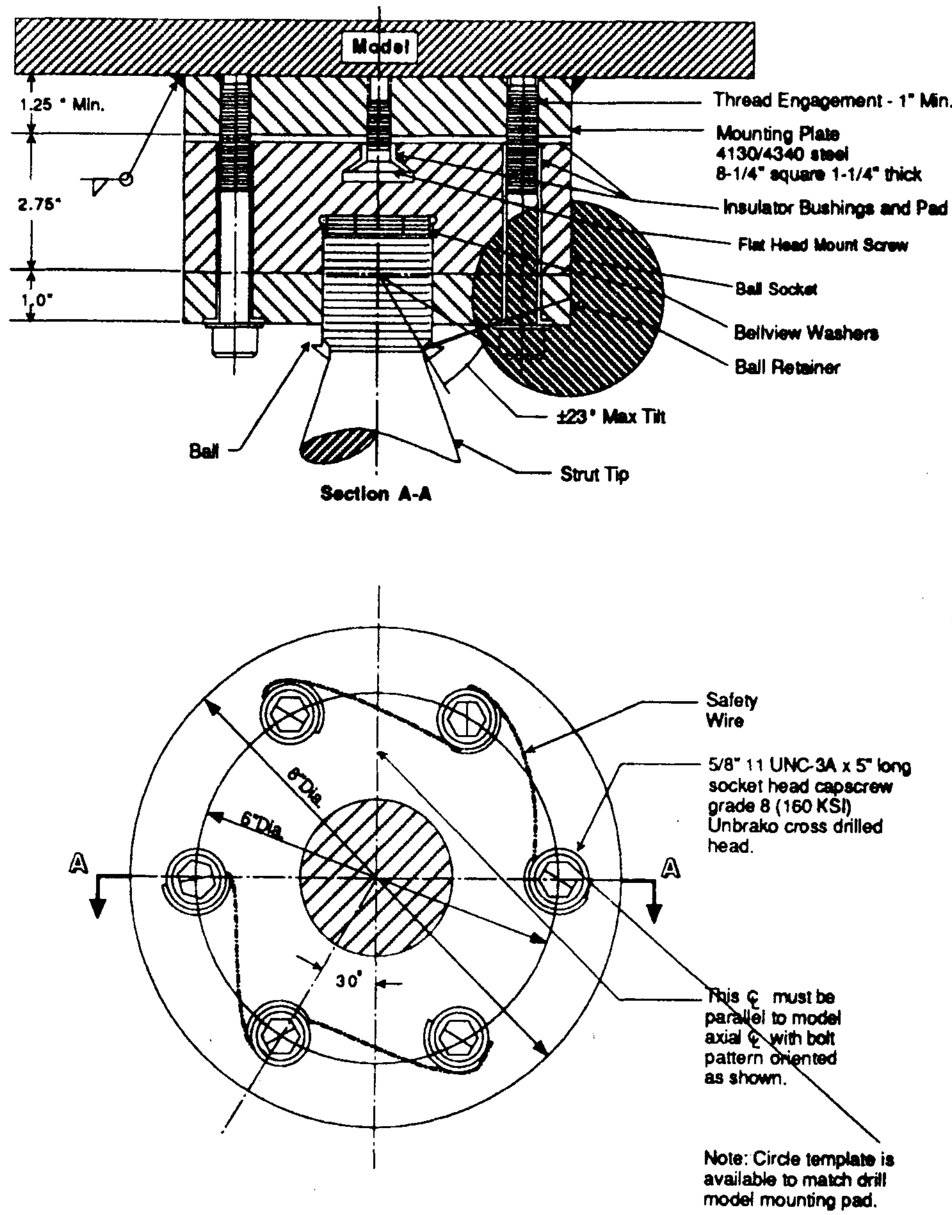
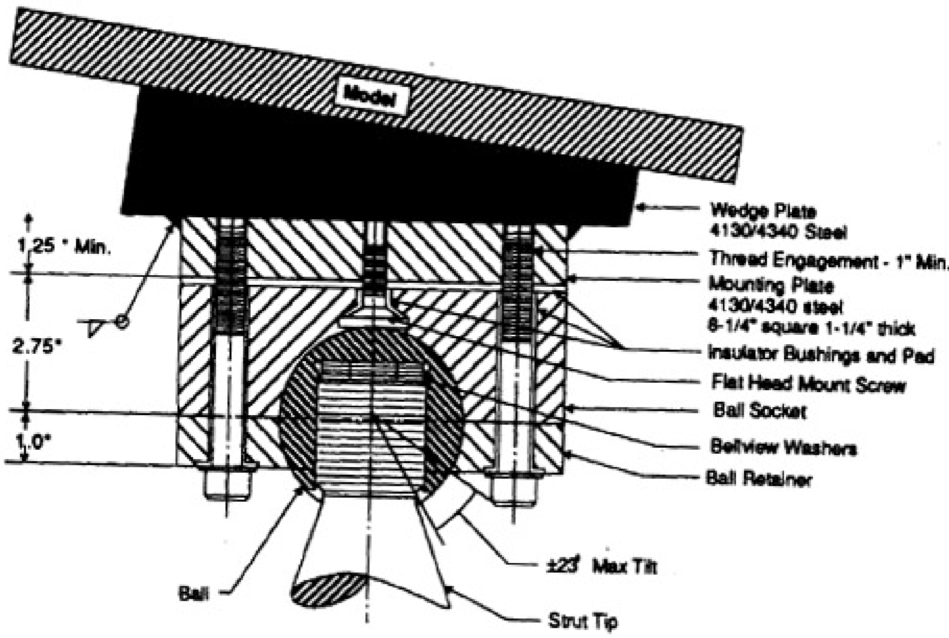


Figure 13 Main Strut Mounting Assembly



Section **A-A**

Figure 14 Main Strut Model Mounting Assembly

3.3.5 Angle-of-Attack Range

The angle-of-attack range for the model support system is ±23°. However, specific requirements for each model vary and may limit the angle-of-attack by any one of four conditions:

1) The range of the Nose/tail strut tilt and height (See Figure 12 and Table 2)

2) The angular limitations of the ball sockets which is ±23° (See Figure 13)

3) The interface of the strut fairings with the model

4) The capacity of the model support and balance system for reacting aerodynamic loads (See Tables 3, 4, & 5 and Figure 18)

The insertion of wedges at the model attachment pads can offset the strut ball and socket angular limits by any amount up to ±20° (See Figure 14).

3.3.6 Angle-of-Yaw Range

The total angle-of-yaw range is 290° and is adjusted by rotating the turntable in a clockwise or counterclockwise direction. The angle-of-yaw range is limited by the travel of the "stem" of the T Frame. The area between +14° and +84° in the upper right quadrant of the turntable circle is inaccessible to the stem of the T Frame. When the stem is oriented with the tail strut in the down stream position, the angle-of-yaw is +194° in the clockwise direction and -96° in the counterclockwise direction. Figure 15 illustrates the angle-of-yaw range.

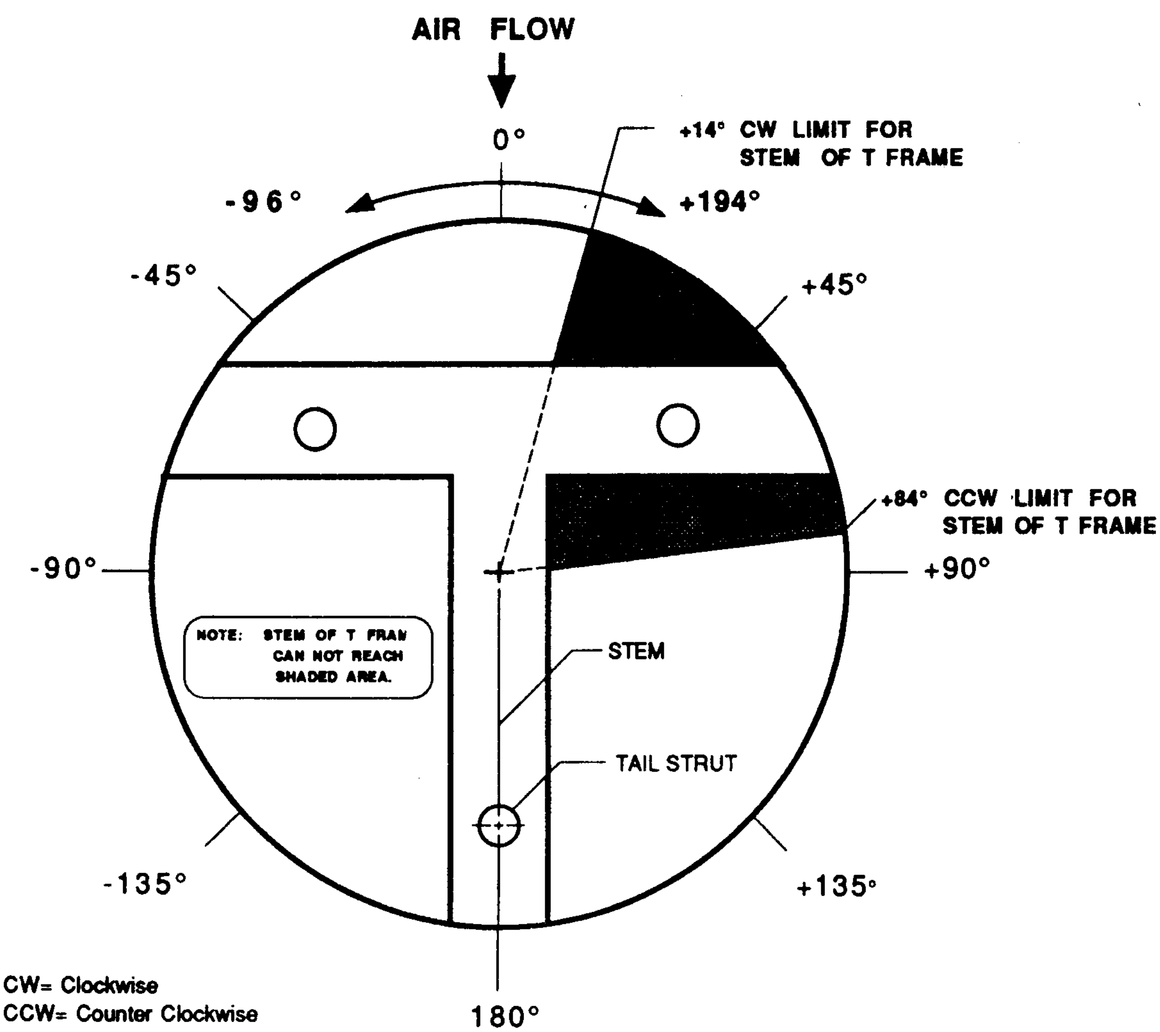


Figure 15 Angle-of-Yaw Range

3.3.7 Balance System

The balance system supports the test model, model struts, lower turntable "T Frame", and the floating frame. The floating frame is rectangular and is supported by an independent balance systems or scales at seven separate locations.

The balance system is designed to measure the forces for the six degrees of freedom transmitted from the model to the floating frame. These forces include the dead weight of the model, lift, roll, side and drag forces, and rolling, pitching, and yawing moments.

Each of the four corners of the floating frame is supported by a lift post which carries pure axial load to four separate scales. The front and rear center locations of the floating frame are each supported by independent front and rear side force scales. Additionally, the center of the floating frame is supported by a drag link connected to the drag scale. This drag link support is directly under the center of rotation of the lower turntable "T Frame". Figures 10 &16 presents a schematic view of the floating frame and balance systems.

The front roll and rear roll scales are lever arms which are interconnected to the two front lift scales and the two rear lift scales. These resolve roll measurements directly from these lift scales.

This balance system with its digitizers and computer interface is referred to as the Static Force System for recording instrumented test data referenced in Section 5.2.5.

3.3.8 Balance System Capacities

The different load combinations used for model strut capacities must be examined to calculate the expected loads that will be transmitted into the balance system.

The calculations must include the moments due to drag and side forces acting above the drag and side force links. The drag moments must be included in the calculations for the front and rear lift scales, and the side force moments must be included in the calculations for the front and rear roll scales. Table 4 presents the different scale capacities.

The dimensions for calculating the maximum scale loads for a test are shown in Figure 16. Moments are summed about the front and center of the floating frame. The NFAC has the equations for equilibrium developed in a computer software program. This program may be used to evaluate scale requirements for a known test configuration and test envelope. See Appendix A, Section 2.2.7, for moment arm parameters required when using the program to compute scale loads.

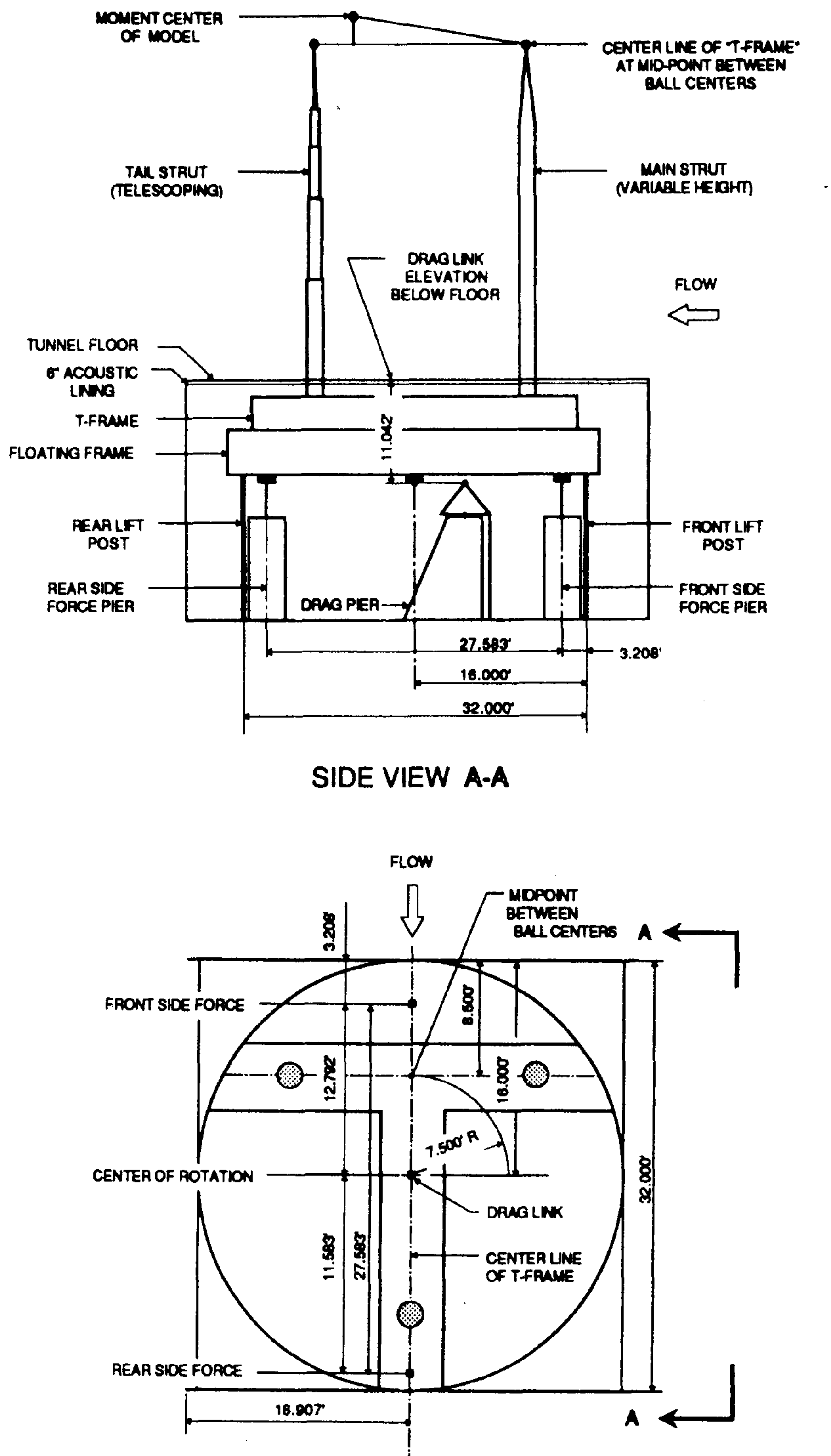


Figure 16 Dimensions for Computing Scale Capacities

SCALE FUNCTION	MAXIMUM CAPACITY LBS	MEASUREMENT
Front lift	± 50,000 per lift post *	2 Lift Posts: Front lift is total of left plus right front lift posts
Rear lift	± 50,000 per lift post *	2 Lift Posts: Rear lift is total of left plus right rear lift posts
Drag	± 16,000	Drag link
Front side force	± 8,000	Front side force link
Rear side force	± 8,000	Rear side force link
Front roll	± 20,000 **	Left minus right front lift post
Rear roll	± 20,000 **	Left minus right rear lift post

* Includes model weight
** Can be biased to either +40,000 or -40,000

Table 4 Scale Capacities

Model geometry and model support configuration both have a significant effect on balance system capacities. Care should be taken to evaluate both of these parameters when evaluating balance system requirements. For example, the side force capacity is ±8000 pounds for each of the front and rear side force scales. If the total side force is applied at the center of rotation of the T Frame, the total side force capacity of the balance system may be ±16,000 pounds.

The capacities of these scales may limit the test envelope of some tests. If required, the balance system can be locked out to use the higher allowable loads of the model struts. Note that the higher loads on the two main struts will result in larger deflections at the tip of the struts. Table 3 presents the maximum allowable strut loads with the various strut and tip configuration with the balance system locked out.

3.4 ALTERNATE SUPPORT SYSTEMS

A variety of alternate support systems exist, and others can be fabricated for use on specific tests. Where the primary system described above does not appear suitable, contact the NFAC staff regarding the alternate systems available. The existing alternate systems are:

- A floor-mounted turntable for semi-span models
- A sting mount with high pressure air capacity.

4.0 AUXILIARY FACILITIES

4.1 UTILITIES

The following utilities are available in the test section.

4.1.1 Electric Line Power

- 120 volt, 60 cycle, single phase
- 208 volt, 60 cycle, single and three phase
- 440 volt, 60 cycle, three phase

4.1.2 Jet Engine Starting

Electric - Intermittent use 28-32 volt DC, 1500 amps normal with up to 1800 amps for 3 minutes.

Air Start - High Pressure Air

Shop Air

Standard Aircraft Portable Start Units

4.1.3 Variable Frequency Power Supplies

- 0 to 150 cycles, 2120 KVA. Two sets are available. See Figure 17 for the operating limits on this equipment.

  1) 40 x 80 Set

     Maximum Continuous - 2500hp @ 150 Hz
     Maximum 1. 3000hp @ 150 Hz
     2. 2350 A, M.G. Set Loop Current
     3. 90°C (194°F) M.P. Set Stator Temp

     NOTE: Maximum limit is whichever occurs first of items 1, 2, or 3 listed above. Special arrangements must be made before operating above 2500hp.

  2) 14-foot Set 150 cycle set ; maximum 2500hp for 1 hour @ 150 Hz.

- 0 to 400 cycles, 706 KVA. Two sets are available. See Figure 18 for the operating limits on this equipment.

Arrangements for use of these variable frequency power supplies must be made early in the test planning process.

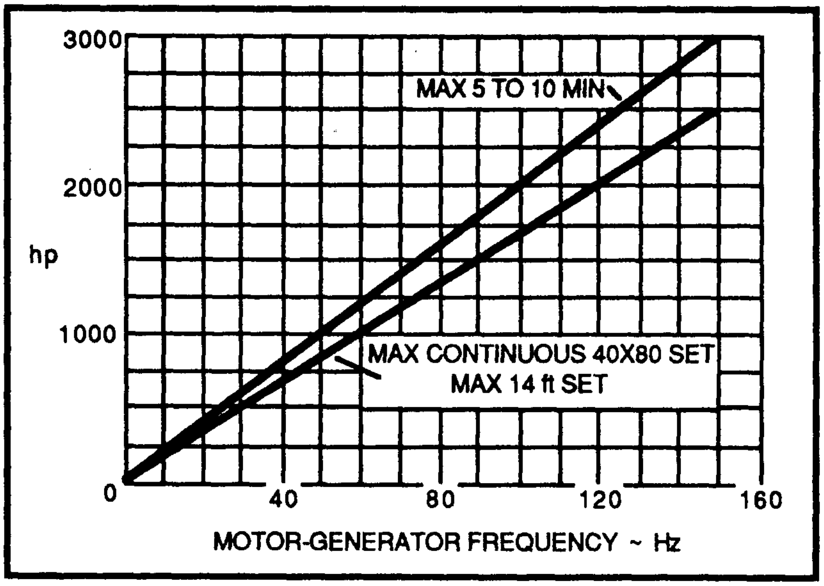


Figure 17

Operating Limits for the 150 Hz Variable Frequency Power

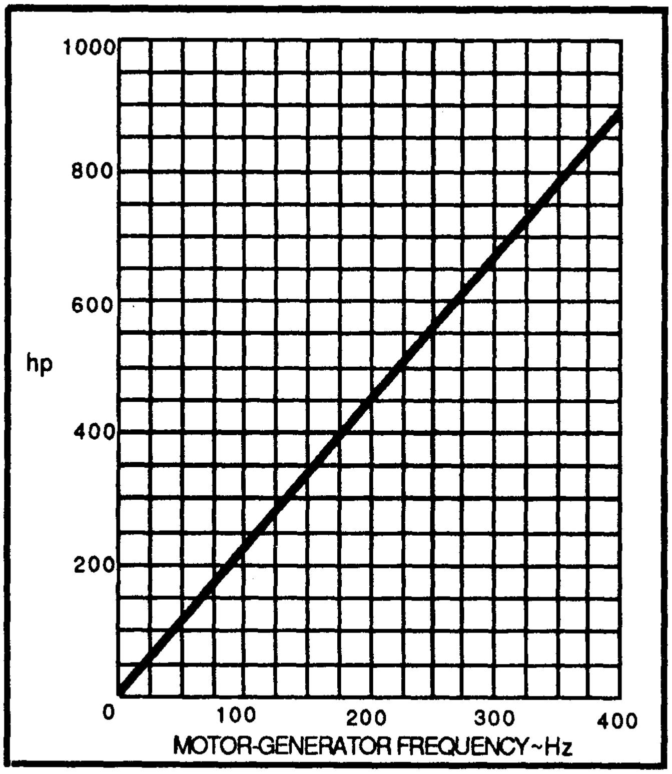


Figure 18

Operating limits for the 400 Hz Variable Frequency Power

4.1.4 Compressed Air

- High Pressure Air - 0 to 3000 psi at temperatures from ambient to 204°C (400°F).

  Unheated flow rates to 40 lbs/sec

  Heated to 400°F flow rates to 12 lbs/sec

- Shop air - 125 psi, sufficient for hand tools.

- Instrumentation Air - 125 psi, 50 cfm, dry air for instrumentation cooling requirements.

4.1.5 Hydraulic Fluid:

Hydraulic fluid is available at 32 gallons per minute maximum output at regulated pressures of up to 3000 psi continuous and 5000 psi intermittent use.

4.1.6 Treated Cooling Water

A closed circuit cooling water system supplies water to the model in the test section and also on the ground floor of the High Bay. This water is filtered and treated with a corrosion inhibitor. The water pressure on the ground floor is 70- 80 psi with a 60 gallons per minute flow rate. At the model the pressure is 30- 50 pounds per square inch.

4.1.7 Fuel Supply

JP-5 fuel can be supplied in the test section for the operation of turbojet or turbofan engines. While the upper limits of the flow rate are 50 gallons per minute at a pressure of 100 psi, system controls can create pressure and flow rate reduction. Arrangements for fuel requirements should be made at the time the test request is made. The User or Sponsoring Agency must bear the cost of fuel used in the test.

The use of on-board aircraft or model fuel tanks is not allowed. Direct hook-up to the NFAC fuel system is required. All model fuel tanks must be purged and pressurized with an inert gas.

4.1.8 Electric Model Motors

Electric model motors that range from 3 to 1500 horsepower and run on 150 cycle or 400 cycle variable frequencies are available at the tunnel. Users must verify the availability of these motors well in advance of the proposed test date.

4.2 HELICOPTER ROTOR TEST BEDS

There are currently six test beds available at the NFAC for testing helicopter rotors of various diameters and tip speeds. Arrangements for use of these test beds must be made well in advance of the desired test date because of the heavy use of the equipment and the complexity of the individual model system installation, checkout, and test requirements.

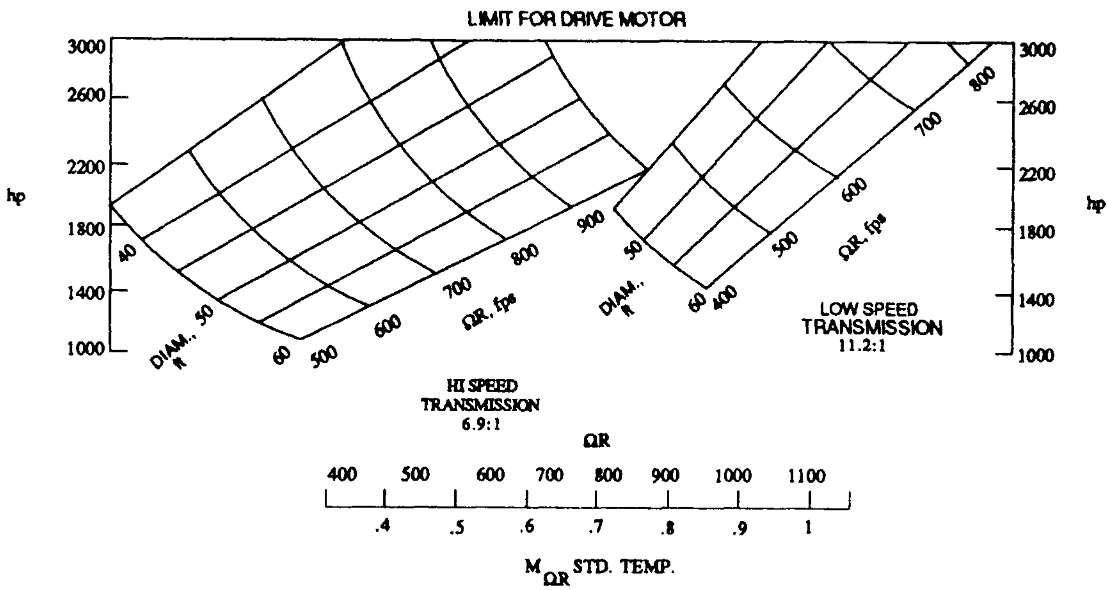


Figure 19 Rotor Test Apparatus Power Capacity

4.2.1 Rotor Test Apparatus (RTA)

The RTA is used for testing large-scale main rotor systems. The design flexibility of this apparatus allows for the accommodation of a variety of rotor diameters and tip speeds. The power capability of the RTA is presented in Figure 19.

The RTA is powered by two tandem-mounted, variable-speed electric motors, which can provide up to 3000 horsepower at either 437 or 268 rpm. The RTA control system provides collective, longitudinal, and lateral control with a direct display of resolved blade-flapping and pitch-angles. Using the dynamic control option of the RTA console, time-dependent control motions are entered into the primary control system.

The RTA is currently being modified to allow the direct measurement of rotor forces and moments independently from the RTA structural frame and fairing.

4.2.2 Model 576 Test Stand

This stand was designed to accept two-bladed main rotors and has been retro-fitted to operate a Bell Helicopter Model 412 rotor. The stand is powered by a single, variable-speed electric motor that can provide up to 1266 horsepower at the Model 412 rotor speed of 324 rpm.

The test stand fairing shell is mounted on load cells that allow shell lift, drag, and pitching moment to be measured independently of the rotor forces and moments.

4.2.4 Hover Test Rig (HTR)

The HTR is designed to test small-scale rotors in the hover mode only with collective pitch control. The stand is powered by a variable-frequency electric motor that can provide up to 600 horsepower at a rotor speed of 2866 rpm.

The HTR incorporates the capability of measuring rotor forces and moments.

4.2.5 Propeller Test Rig (PTR)

The PTR is designed to test large-scale propeller systems and tilt-rotor-type configurations. The PTR incorporates the capability of measuring rotor forces and moments. The PTR is powered by two tandem-mounted, variable-speed electric motors that can provide up to 3000 horsepower at 750 output shaft rpm, using the existing 4:1 gear box. For the tilt rotor configuration, the rotor is provided with collective and cyclic pitch control.

4.2.6 Tail Rotor Test Rig

This test bed consists of a right-angle gearbox powered by a 250 horsepower variable-frequency electric motor that is encased in a pod. The pod is mounted on a faired, vertical post and can be translated in the X, Y, and Z directions. The blade collective pitch is manually adjustable.

4.3 MODEL HANDLING EQUIPMENT

4.3.1 Test Section Doors

The test section doors are 40 feet wide by 49 feet long, and there is one on each side of the tunnel center line on top of the test section. When fully open, a clear opening 78.5 feet by 49 feet is provided. Figures 20 A and B show one test section door fully opened (20 A) and partially closed (20 B). Figure 4 shows the test section with both doors completely closed.

4.3.2 Main Hoist

A 35-ton hoist and a 5-ton hoist, mounted on a common bridge at the top of the test chamber, are available to hoist models into the test section from the floor of the High Bay.

4.3.3 Gantry Crane

A 10-ton hoist and 6 1/2-ton hoist are available for handling large components for model assembly in the High Bay shop area before installation in the test section. The completed model is hoisted into the test section by the 35-ton hoist mentioned previously.

4.3.4 Elevators

Two elevators are available for transporting personnel and equipment from the street level to various levels in the High Bay. The first elevator, the personnel elevator, operates between the street level and the control/computer room, the test section, and the top of the tunnel. Its load capacity is 2500 pounds with a 5.6-by 7.0-foot area.

The second elevator, the freight elevator, operates between the street level, the control/computer room, and the test section. Its load capacity is 6000 pounds with a 10- by 10-foot area. The clear door opening is 9 feet 8 inches wide and 10 feet high.

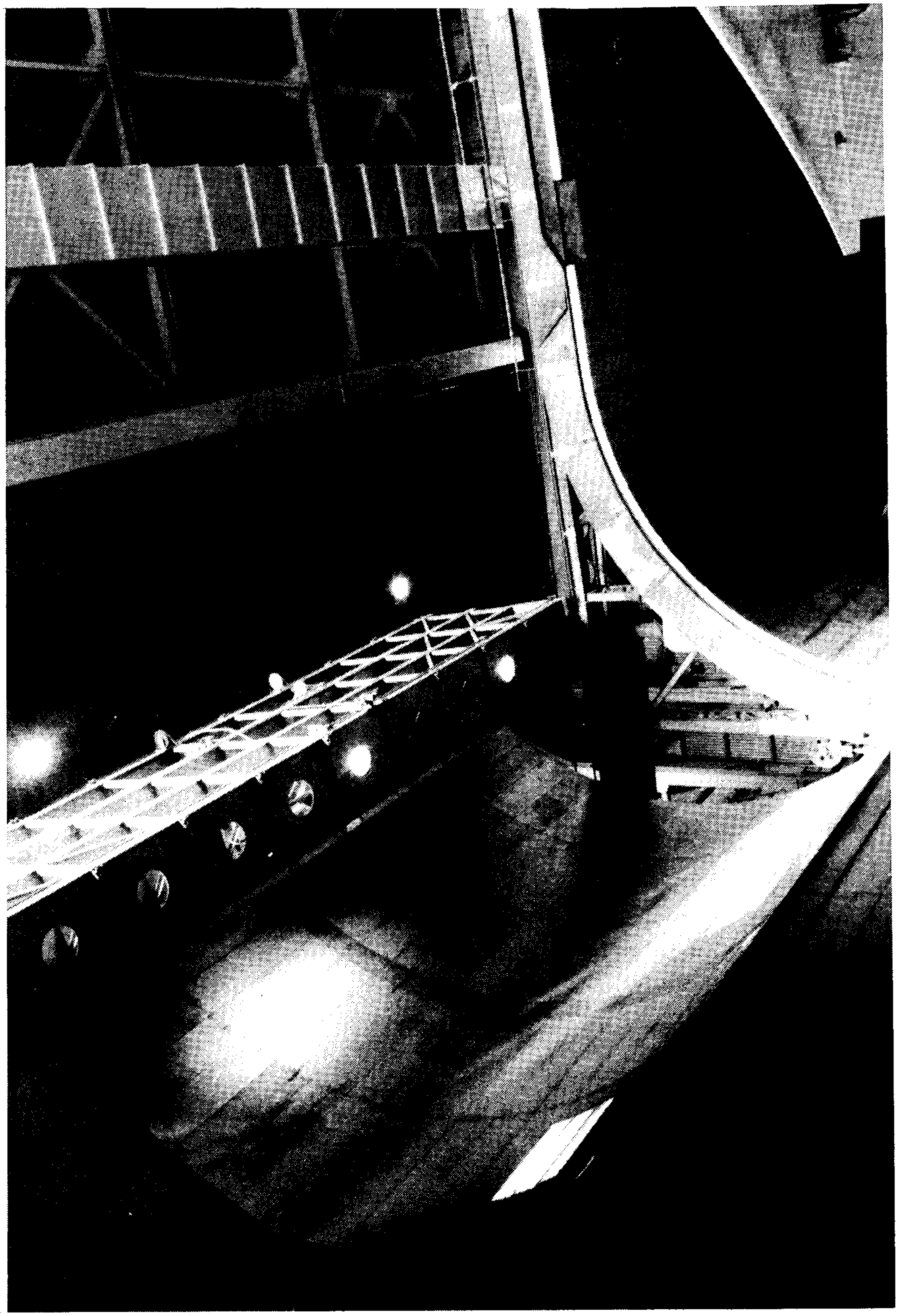


Figure 20A Test Section Doors Open

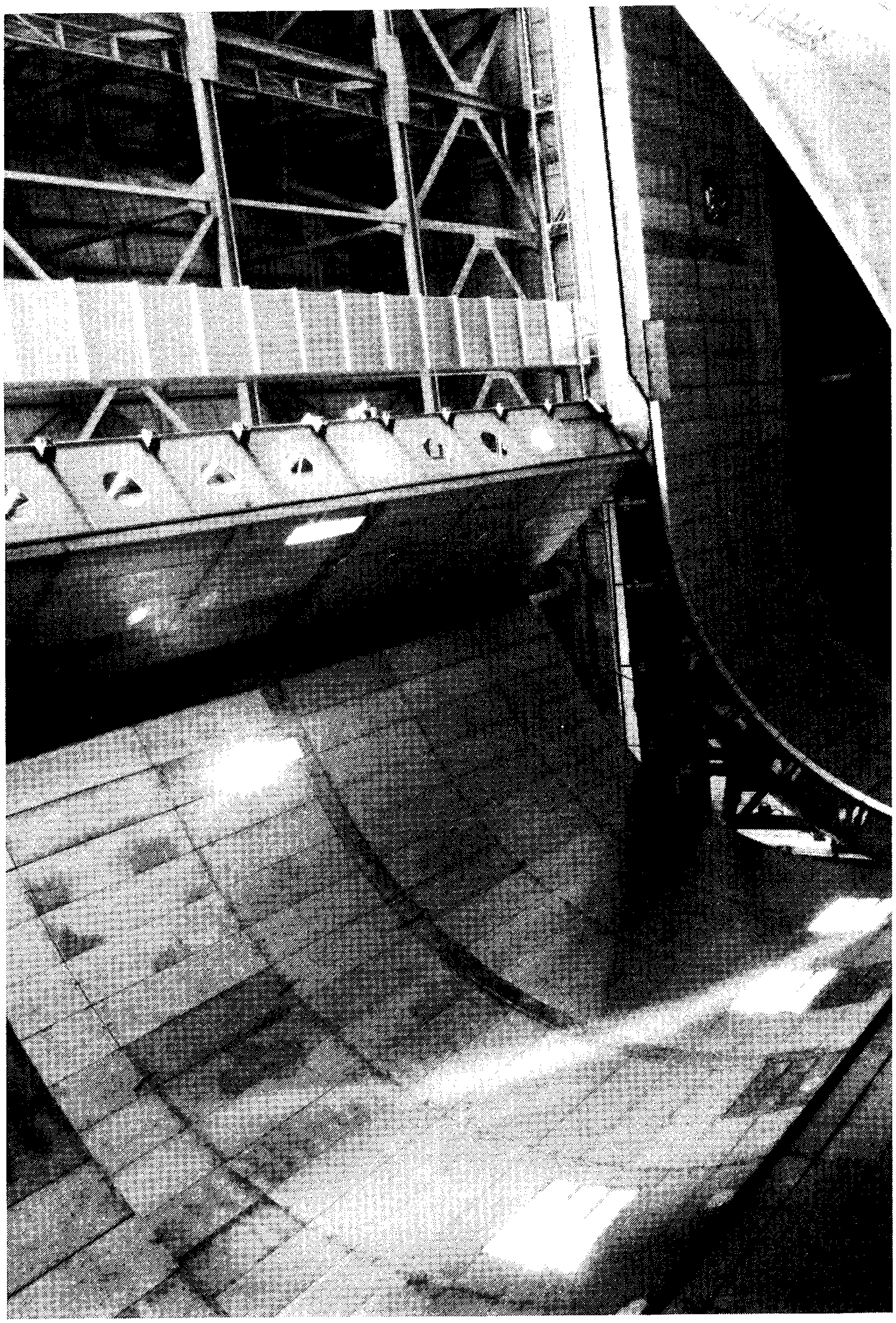


Figure 20B Test Section Doors Partially Closed

4.4 SHOPS AND OFFICES

4.4.1 Model Preparation Building

Final model assembly, instrumentation, and check-out is typically conducted in the Model Preparation Building adjacent to the 40- by 80-Foot Wind Tunnel where adequate floor space is available for this purpose. Most utilities available at the wind tunnel are available in this building. This building is also equipped with a 25-ton bridge crane.

4.4.2 Office Space

Limited office space is available for test participants during tunnel occupancy if arrangements are made with the NFAC staff.

4.4.3 Wind Tunnel Shop Area

A shop area is located on the ground floor in the High Bay (See Figure 5). This area is used primarily for attaching the hoisting cables to the model prior to lifting it into the test section. This area is also used to store model parts for configuration changes while the model is in the test section. A small shop containing a limited number of machine tools is also located in this area directly under the test section.

4.4.4 Shop Services Available at NASA Ames

An extensive on-site shop fabrication capability, the Ames Technical Services Division, exists at NASA-Ames, which supports on-going research programs. While a detailed listing of Center capabilities and equipment is available upon request, below is a summary of each Branch's capability.

<u>Model Development Branch</u>

The Model Development Branch provides for all non-metallic fabrication of aerospace models and experimental equipment including wood, plastics, and composite materials. The branch has developed techniques and procedures for applying materials such as thermal control coatings, structural plastics, and ablative materials to models and equipment.

Metals Fabrication Branch

The Metals Fabrication Branch provides heavy-metal fabrication and assembly of models, experimental equipment, and facility repairs. ETF also provides aircraft and spaceflight precision sheet metal fabrication and is responsible for all aircraft modification work done at Ames.

Model and Instrument Machining Branch

The Model and Instrument Machining Branch provides all general and precision machine, instrument, and glass fabrication services. It machines and assembles new and modified research models, aircraft parts, mechanical and electromechanical instruments, and other experimental research equipment.

Manufacturing Inspection Office

The Manufacturing Inspection Office ensures that the hardware furnished by the Technical Services Division or contractors conforms to specifications before acceptance and delivery.

5.0 DATA ACQUISITION

5.1 GENERAL

In order to ensure compatibility between instrumentation methods and equipment, it is essential that the NFAC staff be consulted early in the planning of test instrumentation. Implementation of an instrument plan should not be started before such a consultation.

Appendix A is a guide to the preparation of software and instrumentation for tunnel testing; necessary forms are available from the NFAC staff. The staff needs the configuration form returned as early as is possible. For contractor instrumented models, a complete model instrumentation book or document must be prepared showing, in detail, the components of the model that will be instrumented, the instruments that will be used, the circuit diagrams, and the calibrations for the instruments. This Instrumentation Documentation should be ready for presentation to the NFAC staff with the Draft Documentation as listed in Section 2.10.

5.2 DATA ACQUISITION

The 40 by 80 Real-Time Data Acquisition System is a distributed computer-based data system. It consists of the following major subsystems:

- REP (Real-time Executive Processor)
- DGP (Data Gathering Processor)
- Kernel System
- Static Force System
- Control Console
- DIO (Digital I/O)
- Transducer Conditioning System
- High-Speed Data Acquisition System
- Reference Pressure System

The data system block diagram is shown in Figure 21. The equipment is located in the control room and the computer room on the second floor of the test chamber. In addition to this system, general purpose instrumentation is available for model installation or for special test requirements.

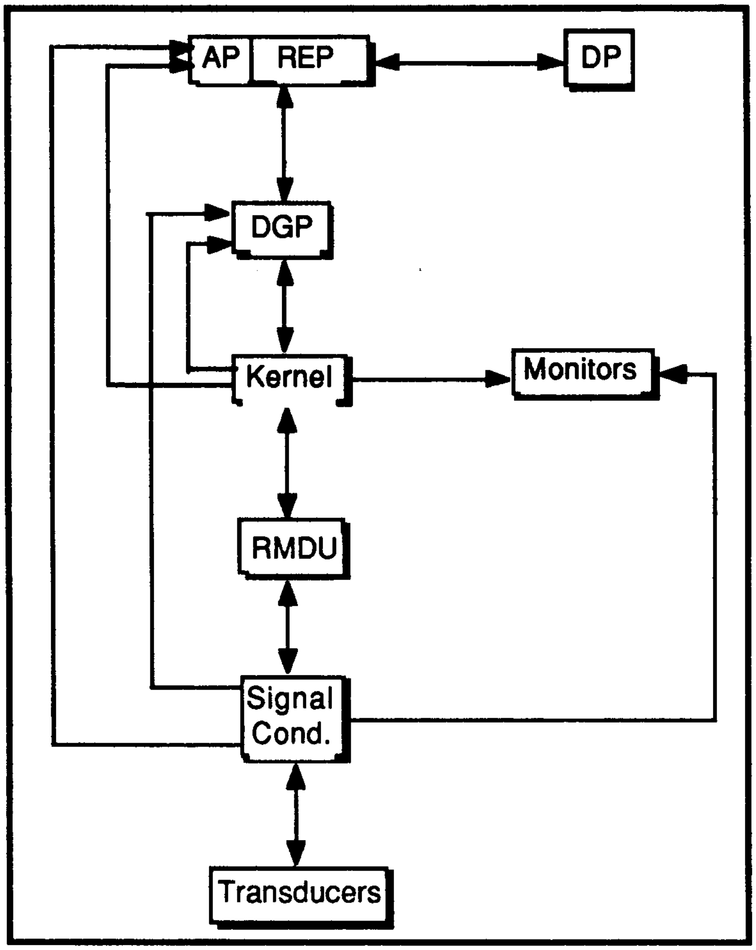


Figure 21 Data Acquisition

The instrument subsystems in the control room are connected to the model through a general patch panel to the permanently installed cables in junction boxes on the tunnel balance frame and from there to the model. Connectors identical to those in the junction boxes are located in the model preparation building, so that the same model cabling can be used during model checkout and tunnel testing. Using the patch panel, both in preparation and in tunnel hookup, reduces setup time when the model is installed in the tunnel.

5.2.1 REP (Real-time Executive Processor)

This processor is part of a working trio composed of the REP, the Array Processor (AP), and the Display Processor (DP). The REP component performs real-time computations on data recorded during data points. It also performs real-time computations on data entered through the AP. The AP accepts data from the Kernel and performs array computations on this data; the AP then transfers the results to the REP. The DP, also part of this trio, accepts data from the REP and produces post-run plots; it can also monitor on-line data. The salient components of the REP are the following:

- VAX 11/780 CPU
- 6 Megabyte Semiconductor Memory
- 2 each, 9 track, 800 or 1600 bits per inch magnetic tape unit
- 2 each, 205 Megabyte RA 60 disk
- 1 each, 456 Megabyte R 481 disk
- 2 each, line printer

5.2.2 DGP (Data Gathering Processor)

The DGP accepts data from the Kernal and records it on disk and magnetic tape for later data reduction. The DGP also performs computations in real-time for displays on the monitors used to control the tests. Lastly, it provides the interface with the data technician, so that the system can be initialized. The DGP components are the following:

- PDP 11/70 CPU
- 512 Kiloword core memory
- 2 each, 9 track, 800 or 1600 bpi magnetic tape unit
- 1 each, 176 Megabyte RP06 disk
- 1 each, VT-29 real time display driver
- 1 each, Line printer

5.2.3 Kernel System

The Kernel controls the sampling of data from the RMDUs (Remote Multiplexor/Demultiplexor Unit), and then controls the distribution of the data to output devices which include the DGP, the AP, the DAC (Digital to Analog Convertor), and the PCM (Pulse Code Modulator).

The RMDUs are capable of accepting analog and digital signals, providing transducer excitation, bridge balancing, and calibrating resistor insertion. The RMDU amplifies, digitizes, encodes, and transmits data to the RCU (RMDU Control Unit) in the form of a serial bit stream. The RCU then de-multiplexes the serial bit stream and routes the data to various output ports that include processors, recorders, and minicomputers.

A PAG (Portable Address Generator) is also available. This unit allows the calibration and checkout of all data channels in the model preparation area using the exact instrumentation and cabling that is used in wind tunnel testing.

5.2.4 Dynamic Monitor System

This system consists of the trio mentioned in Section 5.2.1 coupled with the appropriate software. The AP of the trio is a CSP Inc. MAP (Macro Arithmetic Processor) and uses the REP for computations and the DP system for graphic output. This allows dynamic parameters to be monitored in either the time or frequency domain.

5.2.5 Static Force System

This Static Force system consists of the Balance System (described in Section 3.3.7), digitizers, and a computer interface. A floating frame system of beam balances is used to measure the six components of forces and moments on the model. A schematic representation of the general arrangement is shown in Figure 10. The component forces and moments include the following:

- Lift
- Drag
- Side Force
- Pitching Moment
- Rolling Moment
- Yawing Moment

The Static Force System records and monitors these aerodynamic forces and moment data. These data are normally obtained from the scale-beam balance system. Output data are digitized and recorded in the DGP.

5.2.6 Data System Control Console

The operation of the data acquisition system is centered at the control console. The following functions are incorporated in this console:

- Display System
- DGP Terminal
- Scanivalve Position Control and Display
- Scale Displays

- CRT Display
- Movie/Still Camera Control
- Function Key Pad
- Video Tape Recorder Remote Control
- Run and Data Point Number

5.2.7 DIO (Digital Interface System)

The components of the DIO are the following:

- Computing Counters
- Digital Panel Meters
- Inclinometer
- Yaw Readout
- Barometer

Some of the characteristics for this system are the following:

- Computing Counter

Model Number	Anadex 1600R
Frequency Range	2 Hz to 20 Hz
Input Sensitivity	From .01v to 150v rms
Periods Averaged	1, 10, 100, 100

- Digital Panel Meters

Model Number	Newport Labs 2000A
Voltage Ranges	0.4v, 4v, 40v, 400v
Resolution	4 3/4 Digits (± 10μv greatest resolution)

- Inclinometer

Range	±30°
Resolution	4 1/2 digits
Accuracy	± 0.01%

- Yaw Readout

Range	0 to 360°

Resolution	0.01°
Accuracy	± 0.15% of reading

• Barometer

Reads in	psia
Resolution	4 1/2 digits
Accuracy	± 0.15% of reading

5.2.8 Transducer Conditioning System

This system supplies excitation (DC), bridge completion, bridge balancing, shunt resistor calibration (Rcal), and external excitation. The characteristics of the system are as follows:

Model	Moxon 2545
Excitation Range	0-20v and 20-40v
Rcal 4 Position Switch	50KΩ, 75KΩ, 125KΩ, 250KΩ, or 100KΩ, 150KΩ, 200KΩ,500KΩ
Balance	± .01v for 10v Excitation
Six Wire Capability	

The transducers are connected to this conditioning system through the system patch panel. Normally, internal sense is used for the power supplies; however, the remote sense capability exists.

5.2.9 High-Speed Data Acquisition System

This system consists of sixty Newport 70A-4 amplifiers, with a Xerox Data Systems (XDS) sample and one hold amplifier per channel, an XDS 64 channel multiplexer, and an XDS ±14 bit analog to digital converter. This system, while interfaced to the computer cannot operate in a stand alone mode. The characteristics of the system are as follows:

Input-

Guarded, Differential, and Isolated

Impedance	30mΩ
Range	±10v
Gain	1, 2, 5, 10, 20, 50, 100, 200, 500, 1000, 2000
Accuracy	0.05% Full Scale

Output-

Unfiltered	±10v, 100 ma, 0.1Ω, and
4 Pole Bessel Low Pass	1, 10, 30, 100, 300, 1K, 10K, 100KHz

5.2.10 Reference Pressure

The Pressure/Vacuum Console is a system that produces a combination of controlled pressures and vacuums to the transducers. A pressure or vacuum, once set, is automatically maintained indefinitely by a system of regulators. Features of this Console include pressure relief valves to protect against damaging sensitive components and digital read outs that are interfaced to the DIO.

The Console consists of three basic subsystems: Cal 1, Cal 2, and Back Pressure. These three subsystems may be operated independently or simultaneously.

5.2.11 Real-Time Monitoring

This system is used for real-time display. Inputs are through the HSDAS amplifiers, the Kernel Digital to Analog Converter (DAC), and the Kernel serial bit stream. The system components include:

Oscilloscope:

Model	Tektronix 5A26 Amplifier & 5223 Oscilloscope
Input Impedance	1MΩ
Accuracy	±1.0%

Channels	8
BW	DC to 12 MHz

Visicorder (2 Each):

Model	Honeywell 1858
Channels	18
Chart Speed	1, 2, 4, 8, 16 in/sec.
Multiplier	0.1, 1, 10
Inputs	High Gain and Medium Gain

Bar Chart Monitor (BCM)

Display channels	50
Inputs	2 channels PCM & 32 channels analog
Functions	
• Max	• Average
• Min	• Vector
• RMS	•Peak to Peak

5.3 ACOUSTIC RECORDING SYSTEM

Several portable analog 14-track tape recorders, one 32-track intermediate band tape recorder, several B & K capacitance microphones, and supportive instruments are available to record acoustic data.

5.4 AUXILIARY INSTRUMENTATION

In addition to the systems previously discussed, a number of portable instruments are available. These include oscillographs, frequency counters, digital voltmeters, strain gage power supplies, and bridge balance boxes.

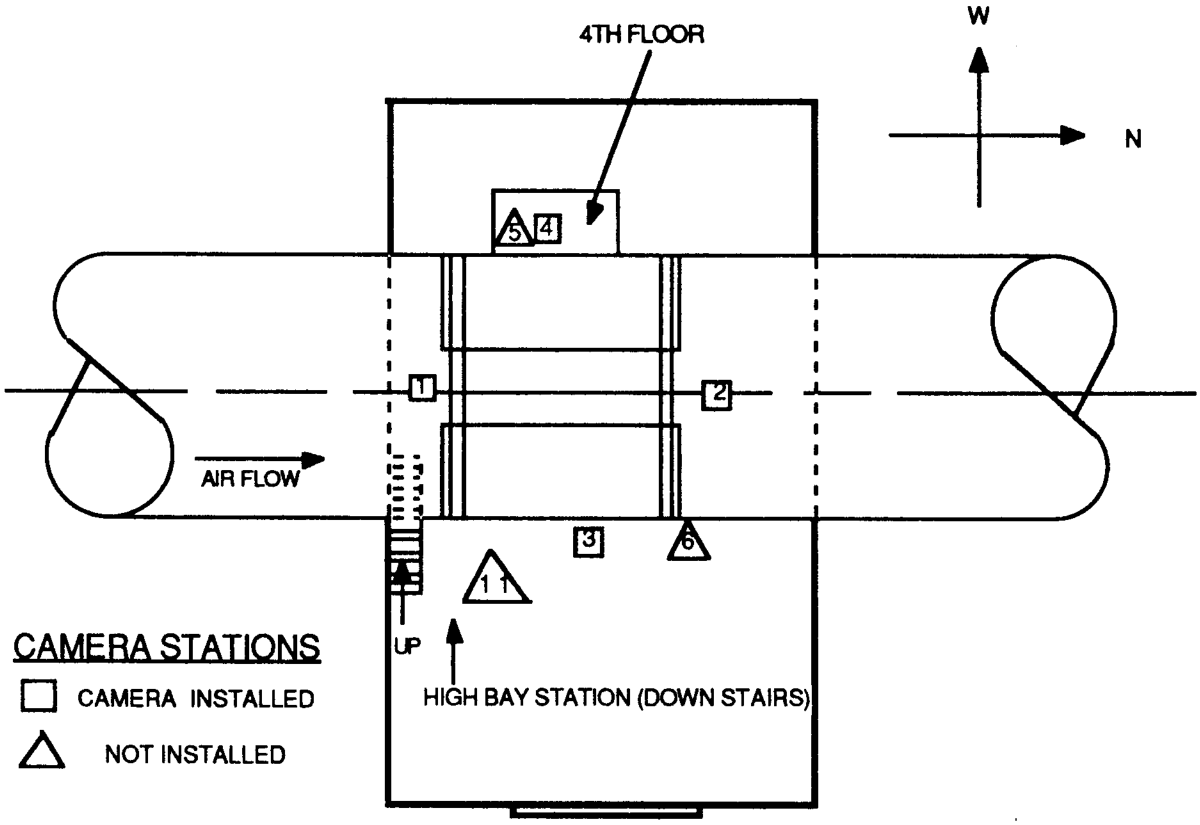


Figure 22 Camera Locations, Top View

5.5 CLOSED CIRCUIT TV SYSTEM

This system consists of four remote-control TV cameras, four video recorders, five permanent monitors, and an additional monitor drive capability. There are seven locations for cameras on the tunnel skin (See Figure 22). The cameras have tilt, pan, and zoom capability. This system is for safety and visual monitoring of the model during testing.

5.6 MODEL AND FLOW VISUALIZATION

Facilities for model illumination are provided. Normally, oil film or tuft studies on the model can be observed during tests from either side and from above the test section. When safety demands it, most of the direct viewing windows will be covered with armor plate. During such a time, up to four closed circuit television circuits will be provided for visual monitoring of the model. These cameras can continuously record test section activity on video tape.

5.7 SPECIAL REQUIREMENTS FOR INSTRUMENTATION INSTALLATION

Special instrument power outlets in the control room furnish instrumentation and control system power. If these systems are grounded to equipment that is not connected to the model, the mounting-strut/fairing foul system will not operate. A User should consult with the NFAC staff over any concerns regarding the ground system.

Wires from the model to the tunnel junction box must be 80 feet long, depending on which main strut is used. No lead wires are used in the tail strut fairing: instrumentation leads run down the right strut and power leads run down the left strut. Shielding against electrical noise is very important in such long wires. The NFAC staff should be contacted regarding shielding requirements; they should also be contacted regarding the length of wires. In general, data wires should consist of twisted, shielded pairs with the shields insulated. Then each shield can be grounded at its appropriate point.

5.8 TRANSDUCERS AND SCANNERS

The NFAC instrumentation shop has an inventory of transducers, scanners, and other measuring devices that are used on the various models.

Pressure transducers -	primarily differentiated from 1 psid to 25 psid full-scale; compatible with the scanivalve scanners. Some absolute to several hundred psid full-scale.
Accelerometers -	a "top hat" strain gage form of transducer, range from 1 g to 10 g full-scale and from 0 Hz to 60 Hz response.
Thermocouples -	Standard probes and test specific (Type J, K, and T).
Microphones -	a frequency response to 20 kilohertz and 40 kilohertz.
Load cells -	range from 100 to 20,000 pound full-scale using from one to three axes.
Pressure scanners -	Mechanical and electronic measure from 16 to 48 pressures per module.
Mechanical scanners -	up to 48 voltages for such measurements as thermocouples.

5.9 DATA ACQUISITION MODES

The Real-Time Data Acquisition System, as outlined in Section 5.2.1, is composed of subsystems under the control of the DEC 11/70 DGP computer. The system acquires data in three modes of on-line operation: hardware verification, monitor, and record.

- Hardware Verification Mode -

  Data is acquired and displayed in raw counts. This assists the technicians in problem identification, problem solving, and system end-to-end checkout.

- Monitor Mode -

  Data is acquired from the static force system balances, special instruments, miscellaneous analog signals, and keyboard entries. This data can be reduced and displayed without a hard copy.

- Record Mode -

  Data is obtained from all on-line subsystems from which it is written to a disk. For efficiency of wind tunnel operation, certain selected data (force, moment, pressure, and special instruments) can be reduced and printed at a particular time and it can also displayed in monitor mode. Dynamic data is recorded, but not reduced on-line.

5.10 DATA REDUCTION PROGRAMS

Force and moment data are normally reduced on-line by the VAX 11/780 REP computer. When data must be transferred to another computer it is done via magnetic tape. Located in the office area of the building are two VAX computers that are connected to the Central Computer Facility network.

Data reduction programs for the force and moment data applicable to aircraft, helicopter, and propeller test models are available. These programs produce tabulated aerodynamic coefficients, and may be computed about any of the commonly used axes. Pressure data can be reduced to P/q or $(P-P_S)/q$ type coefficients, and integrations of these can be performed by available programs. Data reduction, other than pressures and dynamic data, beyond existing programs must be provided by the User or as specified in Appendix A. All User furnished data reduction programs must be completely debugged and checked out on the computer to be used at least one week before tunnel test date.

Rotor data is first reduced on the wind tunnel VAX, then transferred by magnetic tape to another VAX 11/780 in the office area that has an extensive data reduction system.

Guidelines for preparing test write-ups for software support can be found in Appendix A.

6.0 MODEL REQUIREMENTS

6.1 RELIABILITY

The 40- by 80-Foot Wind Tunnel backlog of work is always extremely long, therefore, everything possible should be done to avoid run delays and repetitious runs. Model reliability and instrument reliability are crucial in making the best use of the testing time each model has in the tunnel.

6.2 ENVIRONMENTAL EFFECTS

Tunnel temperature, test section dynamic pressure, and tunnel air speed all may effect the model.

The ambient temperature in the tunnel is uncontrolled and varies with the seasons; temperatures range from as low as 30°F to as high as 120°F. During test runs using un-powered models, the tunnel temperature may increase as much as 30°F. In test runs with models that have operating engines, tunnel temperature increases are often greater than 30°F. The temperature ceiling for testing is 125°F; test runs are terminated when tunnel temperatures exceed 125°F. The model structure and the mechanisms and instrumentation within the model must function reliably over this temperature range. Particular attention must be given to methods of protecting the instrumentation and wiring that are in the proximity of engine combustion and exhaust systems. Tunnel total temperature is recorded from a resistance thermometer located in the entrance cone and is considered constant throughout the tunnel test section.

The dynamic pressure in the test section continuously varies from a minimum of 0 pounds per square foot to a maximum of 262 pounds per square foot: the total pressure of the air stream is near atmospheric at all speeds.

The tunnel air speed is determined from the pressure difference between a static pressure ring at the entrance of the contraction cone and a second static pressure ring 10' 2" upstream of the test section. The pressure difference is measured as uncorrected dynamic pressure on a force scale. The test data is then corrected according to the tunnel calibration by a standard computer program.

6.3 MODEL SIZE LIMITATIONS

Span	72 feet (maximum test-section width, 79 feet)
Wing area	Approximately 600 square feet
Length	60 feet

Weight	70,000 pounds (additional restrictions when using alternate support systems)

The maximum available vertical clearance for the rigging equipment and the model is 27 feet. But because of the various processes used in opening the test sections doors and the maneuvering of the model, clearance may not be limited by the 27 foot clearance (See Section 4.4.1). The NFAC staff must be consulted for all unusual rigging requirements.

The maximum span and wing area are governed by the reliability of wind tunnel-wall corrections: certain corrections may be necessary for the reduction of the data if these limits are reached. If these limits are exceeded, results will be questionable. The NFAC should be contacted for advice for any models which would exceed the above stated limitations.

6.4 MODEL POWER AND CONTROL LEADS

Models are controlled from the control room located on the second floor of the wind tunnel test building. Provisions have been made to house within the primary support system struts the power cables, the fuel lines, and the control leads. NFAC will supply all fuel lines and heavy electrical power leads up to the model. The User shall supply the leads to he test specific control panels. These leads must be 80 to 90 feet long (as specified in section 5.7). Because the space available for leads within the struts is limited, all proposals for use of fuel, power, and control, together with the needs for instrumentation, should be forwarded to the NFAC staff for approval before the fabrication of the lines and cables. Early and continuous consultation with the NFAC staff is mandatory to assure the resolution of interface problems. Leads are generally divided between the two main struts, and this should be considered when designing the points of entry into the model (Refer to Section 5.7). Because of strut and fairing mobility needs, there shall be no leads in the tail strut fairing. For safety reasons, fuel lines and electrical leads carrying any significant voltage must be well separated within the model and shall enter the model via different struts.

Starter requirements for models using jet engines should be discussed with the NFAC staff as early as possible. Electric starter power is available for moderate starting torque requirements. Special arrangements must be made in each case for air-start systems.

6.5 MODEL CONTROL SYSTEMS

Models tested in the tunnel are monitored and remotely controlled from the test section control room. The information displayed on the control console ensures the technician that the model is operating within the model's safe operating limits, and that it is operating properly. The console does not monitor the aerodynamics of the model or other test information that would distract the operator from his single task of proper, safe model control. In addition, the control console must have an abort button that will lock the model control system, and the console must also have a key switch that disables the control system. See Appendix C, Section 8.0 Model Control Systems.

6.6 PRESSURE DATA LEADS

Plans for obtaining pressure data from surface orifices, rakes, and probes should be discussed with the NFAC staff at the earliest possible date. NFAC can usually supply the required scanivalves and leads to the model. The User will be required to provide pressure tubing to the mating points. This tubing must be compatible with NFAC scanivalve equipment. The mating points shall be either inside the model or at least 80 feet from the model. Connections to the scanivalve units require 0.063-inch O.D. flexible tubing.

.6.7 ANGLE-OF-ATTACK CALIBRATION REFERENCE

The User shall install an angle-of-attack reference that is rigidly attached to the frame of the model.

6.8 ANGLE-OF-YAW CALIBRATION REFERENCE

The User is responsible for informing NFAC on the procedures necessary to zero out the angle-of-yaw.

6.9 FIRE PROTECTION

In models with operating engines, the User shall supply an on board fire extinguishing system, or they may contact the NFAC staff for advice regarding the use of the tunnel fire extinguishing systems. Details for this requirement can be found in Appendix B, Section 6.1.

6.10 DELIVERY

Models, with all the associated equipment and information, shall be delivered well in advance of the scheduled test date. This advance time allows the NFAC staff to check the model and assemble, install, and check the connections of electrical wiring and pressure leads. Typically model quality assurance check-out will take place in the model preparation building or occasionally at the OARF. The length of time needed for this process varies with the complexity of the model. The burden of shipments to and from the NFAC facility rests with the User.

Users shall ship models and component accessories in crates or pallets of adequate strength to withstand unloading by fork lift or crane. If the model is shipped by truck, a flat-bed or open top trailer style should be used: these styles allow overhead crane access. If the model is shipped to the NFAC facility in parts and assembled in the model preparation building, the User must provide for the transport of the model from that building to the tunnel.

Instrumentation must be delivered on, or preferably, before the model delivery date. The NFAC staff will calibrate and check out for function all devices before the model is installed in the tunnel. The User shall furnish all loading yokes, gages, or other equipment needed to facilitate such checking.

6.11 LIFT-IN

For lifting the model into the test section, the User shall supply lifting points on the model. These lifting points must contain the model center-of-gravity. The User shall also furnish suitable attachment hardware and special slings, if required, to provide a safety factor of 5 on ultimate stress for the lifting system. The lifting points, the supporting structure, and the slings shall have appropriate Stress Analysis, documentation, and review prior to NFAC approval. General hoisting gear, cables, and slings may be provided by NFAC and should be discussed with the staff before shipment.

6.12 POWERED MODELS

Models that incorporate power systems for primary lift, thrust, or auxiliary purposes, such as for boundary-layer-control, must be functionally checked before tunnel entry. If electric motors are used, the functional checks will be made in the model preparation area. If operating engines are used, the model will be mounted at the OARF where engine operation will be thoroughly checked out. In the latter case, consideration will be given to the advisability of mounting the model on load cells and recording test data at near zero airspeed conditions. While the OARF is an NFAC facility, it is a separate facility and preparations for any tests conducted there must be as complete and as extensive as preparations made for the tunnel. Thrust calibration, ground effects, noise measurements, and control effectiveness data that may be obtained at this facility can usefully supplement the wind-tunnel test program and reduce the test time required in the wind tunnel. The time required to perform functional checks on powered models will be at least three weeks, but this will be determined for each model.

7.0 TEST PROGRAM

7.1 GENERAL

There is a continual demand for wind tunnel testing time, and test programs are scheduled at least six months in advance. Testing time for each program is assigned on a calendar-day basis, not by tunnel operating time. Tunnel occupancy includes model installation, model check-out, model testing, and model removal. Hook-up time, calibration time, time to make model configuration changes, possible delays associated with the model, tunnel equipment malfunctions, and instrumentation problems all reduce the amount of time available for testing. The wind tunnel normally operates one nine-hour shift per day, nine days per two weeks. Because of these demands, it is necessary to plan each test and program carefully so that the allotted time is used productively.

7.2 RUN SCHEDULE

At the approval of the test request, the User shall submit a run schedule of proposed tests as part of the Test Readiness Report for review by the NFAC staff. Priorities should be assigned to each proposed test condition. These priorities aid in formulating the final test schedule. Priorities also assure an efficient chronological scheduling of test runs if there are unusual delays or a failure of the model before the tests are completed. All proposed test runs must meet with NFAC staff approval before the final test schedule is arranged.

7.3 AUTHORITY DURING TEST OPERATION

During the actual test operation, the NFAC Test Director or the Deputy Test Director shall supervise the testing. Authority to deviate from the approved test schedule rests with the Test Director alone. The Test Director, the Deputy Test Director, or the User, on a contractor supported test, shall have the authority to limit or terminate a test run should the safety or the integrity of the model appear to be in danger.

7.4 DISCLOSURE OF DATA

There shall be a continual, free exchange of data gathered by NFAC and by the User during the tests. NFAC will assume technical ownership of all data, including photographic coverage, and the rights to publish the data through the usual NASA procedures. Specific agreements limiting publication must be made before test approval. The intent of this statement is to place the burden of disclosure of all proprietary data and/or classification restraints upon the User. Early discussions of such restraints will assure preparations for any requirements for special handling of the data and allows NFAC time to properly assess its position in support of the proposed program.

7.5 CLASSIFIED TEST SECURITY

Classified testing in the 40- by 80 Foot Wind Tunnel is very difficult. Maintaining security in the facility is a major effort because of the size of the wind tunnel and size and type of the models being tested. The Ames security force is not staffed to accommodate the large number of security personnel needed to maintain close surveillance of the test section or the numerous entry ways into the tunnel. The data gathering systems in the wind tunnels are not secure, and at present, there are no firm plans to make the existing computers or software secure.

Because of these concerns, any anticipated programs requiring classification of the hardware and/or data must be discussed and procedures agreed upon at the time of test approval. At present, two Center conference rooms are fully secure.

8.0 HEALTH AND SAFETY OF PERSONNEL

It is important that the User know and understand the hazards associated with the wind tunnel facility. In this section, these hazards are defined, and procedures and protective equipment needed to reduce the risks from these hazards are specified. All aspects of the *Ames Health and Safety Manual* apply to all NFAC facilities.

8.1 PERSONAL ILLNESS

For all personal illnesses, medical facilities in the local communities are available. El Camino Hospital (415-940-7000) in Mountain View offers both 24 hour emergency service and a referral service. The telephone number for the referral service is 415-962-7503.

8.2 TREATMENT OF INJURIES

To receive emergency treatment for injuries occurring at Ames Research Center, dial 911. If ambulance service is not required, the injured person can be driven to El Camino Hospital Emergency Room on Grant Avenue in Mountain View. During the day shift, first aid treatment is available at the Ames Health Unit located across the street from the north entrance of the cafeteria. In addition, first aid kits can be found at many strategic locations throughout the work areas at the facility.

8.3 HAZARDS

User personnel should be aware of the following hazards.

- Noise levels in the control rooms may be high during powered model operation, and levels in adjacent areas are at times greater than 100 db (A). Environmental Protection Agency approved earmuffs are required when entering a designated noise hazard area.

- Models installed in wind tunnels may have sharp cutting edges. These should be covered when the model enters the wind tunnel.

- Wind tunnels are considered hazardous areas. NFAC personnel control entry into the wind tunnel. User personnel entry is limited to the test section only.

- The senior User representative, assigned to the shift, is responsible for ensuring that all User personnel have left the tunnel before the test section is closed.

Hazards peculiar to a test facility or a particular test shall be discussed with all personnel at a pre-run safety meeting before the beginning of wind tunnel testing; they must also be addressed in the Gross Hazards Analysis.

8.4 HAZARDOUS MATERIAL

Hazardous materials are defined as any materials that have properties that may result in a risk to health or injury or the destruction of life. Materials that may cause damage or the destruction to the facilities are included in the hazardous material category. Hazardous materials include toxic, flammable, corrosive, asphyxiant, and explosive materials. Use of all hazardous materials must be discussed in the Gross Hazard Analysis.

Individuals using such materials must have an adequate understanding of the specific hazards of the material, the specific precautions to be taken in using it, and the specific procedures for handling any emergencies. Before the start of operations, plans must be available that include identification of the material and precautions and procedures for handling it. Two procedures must be followed:

- every operation must be thoroughly screened for safety
- all personnel must be made aware of the hazards, the precautions, and the procedures for handling accidents and other emergencies.

The Material Safety Data Sheets (MSDS) for hazardous materials are available from the Project Director. The User will provide the MSDS for any hazardous material he supplies. In this way, protection is guaranteed for the personnel in the area and for the equipment for which the User is responsible. For more specific information regarding hazardous materials, see the *Ames Health and Safety Manual*, AHB 1700-1, Chapter 24.

8.5 PROTECTIVE EQUIPMENT

All User personnel are expected to observe the posted requirements for protective equipment. User personnel should be equipped with protective earmuffs, safety glasses, safety shoes, gloves, and any other protective equipment justified by the nature of the wind tunnel test. Fire blankets and fire extinguishers are available in all work areas. Emergency eyewash fountains are also located in the facility.

8.6 EMERGENCY PROCEDURES

The wind tunnel has a documented set of Emergency Operating Procedures which contain specific procedures for specific situations. For each test the NFAC Test Director develops a specific set of emergency procedures.

8.7 WORKING ALONE

Working alone is not permitted without specific approval of the Test Director. Working alone is defined as the performance of work by a person who is out of audio or visual contact with a co-worker, a "buddy", for more than five minutes at a time. Working alone at hazardous heights or while using hazardous systems or materials is not permitted.

8.8 LASER SAFETY

The use of lasers at Ames is governed by two documents:

- *A Guide for Control of Laser Hazards,* issued by the American Conference of Industrial Hygienists
- Chapter 8 of the *Ames Health and Safety Manual* (AHB1700-01).

The Ames Radiation Safety Officer must approve all laser installations and operations. Approval must be coordinated through NFAC. The authorized laser User is responsible for compliance with these regulations in the operation of his equipment.

The authorized laser safety eye wear is designed to filter out the specific wavelength characteristics of the laser. It affords adequate protection only if properly prescribed and used. Safety eye wear should be evaluated periodically to ensure its integrity. Eye wear designed for protection from specific lasers should not be mistakenly used with lasers of different wavelengths. The specific optical density at appropriate laser wavelengths of the filter plate should be printed on the eye wear.

All personnel who work with lasers, or who are permitted by an authorized laser User to be in a designated laser control area must receive a thorough ophthalmological examination before work begins.

APPENDIX A:

DATA ACQUISITION

and

SYSTEMS INFORMATION

1.0 INTRODUCTION

Appendix A is a guide to the planning and preparation of the software and instrumentation required for wind tunnel testing. It is important that the User clearly understands and meets the data requirements, so that test results more nearly match the User's expectations. A well organized set of data specifications gives the NFAC staff adequate information to develop and implement instrumentation plans and software.

Many data functions that a User requires may already exist in the NFAC software library as standard software modules. Early in pretest planning discussions, those modules that match User needs will be identified to minimize the amount of work needed to prepare the required software documents.

New Users are supplied with document #FFD-SG-DOC, *NFAC Guidelines for the Preparation of Software and Instrumentation Test Requirements.* This document details instrumentation requirements, software requirements, and information on installed instrumentation. The forms in the document should be filled out, in as complete a condition as is possible, and then returned to the NFAC staff by the appropriate milestone date.

2.0 SOFTWARE

.2.1 LEAD TIME REQUIREMENTS

When considering lead time for software development, two test categories exist:

- simple tests - those procedures that require approximately 3 months lead time

- average tests - those that require 6 months for preparation (See Section 2.6.2 and 2.6.3)

The lead time requirements are intended to allow sufficient time for all phases of software development. Normally, the actual coding of a program proceeds quickly, but there are a number of other time-consuming processes that must be accommodated. Those include: program design, software testing, test case preparation, documentation preparation, computer down-time, and all hand checks of computational algorithms. Adequate lead time is, therefore, crucial to quality software development. In addition, any schedule changes or program requirement revisions can result in a delay in testing.

2.2 SUBMITTAL OF SOFTWARE DOCUMENTS

Each User must prepare a Software Requirements document. The NFAC staff will review the document for accuracy and completeness. If appropriate, a formal review will be held. Since this document serves as the sole basis for all functional specifications for the assigned programmer, it should be complete and well organized, and it should contain all the information that the programmer will need in order to complete the software development task.

This User's document should always begin with a narrative description of the research project and include the test objectives, a description of the model under consideration, the facilities that will be used, the data systems that will be used, and any other background material that could aid the programmer in conceptualizing the experiment. Such a description helps arrange a common basis for future discussions between the User and programmer.

Software requirements should first be outlined using a topic sequence as illustrated in Figure A - 1. This outline serves the programmer as a system overview. Within each outline section, there should be a unique number assigned to each item or equation. Furthermore, that unique number must be constructed so that the first digit corresponds to the first digit of the section number in which it is initially defined. For example, item number 152 would indicate that it is an item in Section 100, as shown in Figure A - 2.

TABLE OF CONTENTS

ITEM	SECTION
Parameter Identification	100
Tunnel Conditions	200
Model Surface Deflections	300
Wind Tunnel Balance Loads	400
Engine Parameters	500
Auxiliary Balances	600
Pressures and Temperatures	700
Resolution and Combination of Forces	800
Data Presentation	900

FIGURE A -1 Sample Table of Contents for the Software Requirements Document

ITEM	TITLE	DESCRIPTION
150	CONFIG	Configuration
151	FLP1	Flapping angle #1
152	FLP2	Flapping angle #2
153	GAP	Gap between wing and flap

FIGURE A - 2 Examples of Section 100 Items

Additionally, every page of the Software Requirements document should be numbered sequentially. This insures the NFAC staff that the document is complete, and it also aids in revising the specifications if that is necessary.

Because of the similarities among all rotor wind tunnel tests, there are a number of existing data reduction programs that process the six-component force data from the wind tunnel scale system and the dynamic data from the high-speed data acquisition system. These standard programs have been completely documented in the *Rotor Data Reduction System* manual. That manual guides the User in a step by step process through the computations, so that the User need not provide the equations for these standard computations. Copies of the manual are available from the NFAC staff.

Whenever possible, the User should use a computer when composing the Software Requirements document. This allows the programmer to use the write-up as comments and as actual code, since many Users write their equations in FORTRAN. The software staff has access to IBM PC's, Macintoshes, and the VAX computer. Documentation can be transferred between any of these processors, and if needed, help is available in transferring the requirements to the computer.

2.2.1 Parameter Numbering

Throughout the documentation, item numbers are assigned to each parameter (See Figure A - 3a) and each equation (See Figure A - 3b). In each instance, the new item is defined; the definitions also indicate the units of measure and the range of the value.

Statistical measurements are also available to the Users. Maximum, minimum and half peak to peak values can be obtained. Standard deviation is also available, but it should be used sparingly, since it impacts the performance of the computer used for data acquisition. The User should append "MX", "MN", "PP" and "SD" to mean channel names. The User is allowed no more than 8 characters for the name of the measurements. The statistical measurements should be listed with item numbers.

200	TUNNEL CONDITIONS ITEM	
201	V	Tunnel Velocity, XXX.X. Knots
202	RNFT	Unit Reynold's Number, XX.X Million per Foot
203	Q	Corrected Tunnel Dynamic Pressure, XXX.X PSF
204	TT	Tunnel Total Temperature, XXX.X °R
205	PTO	Tunnel Total Pressure, XX.XXX PSIA
206	PSO	Tunnel Static Pressure, XX.XXX PSIA = PTO - QCV/144

Figure A - 3a Parameter Numbering

514 PTFAR Fan Inlet Average Total Pressure Recovery, X.XXXX

$$= \frac{PTFAV}{PTO} \qquad \begin{matrix} \text{(PTFAV from 513)} \\ \text{(PTO from 205)} \end{matrix}$$

Figure A - 3b Equation Numbering

Generally, the programmer will attempt to code the software so that the software is as consistent with the original document as is possible . Whenever possible, a programmer will use the same name for an item in the program as is used in the document.

.2.2.2 Equation Numbering

Each equation in the test document is to be sequentially numbered for identification and set in the proper sequence in which it is to be evaluated. Each term in the equation, whether a previously identified parameter, a constant, or a calculated quantity, must use a unique name. The "from" notation is not required, but it is useful for cross referencing components and should be seriously considered in a complex test.

In setting up a Rotor test, the standard quantities listed in Section 3 of the *Rotor Data Reduction System* manual may be used as inputs to the non-standard computations and to the output specifications, and may be referenced by name. These may also be used in non-Rotor tests. A list of standard computations may also be obtained from the programming staff.

The examples included in this section (See Figure A - 4) show a series of equations each with an assigned item number, a name for the variable, and a short description.

Cross-referencing the instrumentation is illustrated in Figures A - 4, A - 5, and A - 6. In Figure A - 4, the measurement numbers for Items 507 and 511 are shown. The measurement number for Item 507, TNC, is labeled 592 - 600 in the instrumentation Input I/O List form (See Figure A - 5). Refer to the *Project Engineer/Director Input Guide for Instrumentation Test Plan Programs* for instructions and sample forms.

500 ENGINE PARAMETERS (CONT) ITEM

507	TNC(X)	-	Core Exit Rake Temperature, XXXX.X°R; X = Measurement Numbers 592 - 600
508	TNCAV	-	Core Engine Nozzzle Average Total Temperature, XXXX.X° R $= \frac{1}{12} \sum_{N=1}^{12} \text{TNC(X) N}$
509	DELTAT	-	Total Pressure Reference = $\frac{\text{PBAR}}{14.696}$
511	PTF(X)	-	Fan Inlet Total Pressures, PSIA X = Tube Numbers 122 - 161

Figure A - 4 Cross Referencing of Terms in an Equation

Note: Data Systems Control Console entries do not usually appear on any instrumentation documentation and must be noted in Section 100 (See Figure A - 2.).

TEST: ____________ DATE: ____________

Measurement No.ID	Measurement Descripton	PRI	DYN STC	TSP	ACC	APS	PCM	SAS	BPF	BCM	CGR	CRO	DPM	CTR	DI	OTHER	Additional Hookup Control Panel

INIOLIST.RES011487kb
Rev:

Figure A - 5 Sample Input for 40- by 80-Foot I/O List

Project Title:
Engineer:
Transducer Mfg and Model:
Serial Number :
SV Assembly Number

REF Pressure:
Calib. Pressure:
Pressure Range:
SV Module Number:

Date:
Revision Number:
Index Code:
SWTS Channel No:
SV Meas Number:

Port No.	Location	Tube No.	Meas No.	Description	Port No.	Location	Tube No.	Meas No.	Description
1					24				
2					25				
3					26				
4					27				
5					28				
6					29				
7					30				
8					31				
9					32				
10					33				
11					34				
12					35				
13					36				
14					37				
15					38				
16					39				
17					40				
18					41				
19					42				
20					43				
21					44				
22					45				
23					46				

Figure A - 6 Scanivalve Setup Sheet

2.2.3 Added Equations

Additional equations may be inserted by adding a, b, c, etc. to the item number. Figures A - 7 and A - 8 illustrate a "before and after" situation in which delta PTC and delta TIC have been inserted as Numbers 567a and 569a. Optionally, gaps may be left between item numbers to facilitate additions.

2.2.4 Standard Names

Standard names for parameters are shown in Section 2.5 of this Appendix. All users are encouraged to use these names in the Software Requirements as much as is possible.

500 Engine Parameters (Cont.)

Item		
567	PTC(X)	Compressor Face Rake Total Pressure, psi Measurement Numbers 844 to 858
568	PSC(X)	Compressor Face Static Pressure, psia Measurement Numbers 859 to 861
569	TIC(X)	Compressor Face Rake Temperatures, °R Measurement Numbers 862 to 876
570	PBLL(X)	Inlet Boundary Layer Rake, Left Engine, psia Measurement Numbers 834 to 838

Figure A - 7 Parameters before Additions

500 Engine Parameters (Cont)

Item		
567	PTC(X)	Compressor Face Rake Total Pressure, psi Measurement Numbers 844 to 858
567a	ΔPTC(X)	PTC/PBAR
568	PSC(X)	Compressor Face Static Pressures, psia Measurement Numbers 859 to 861
569	TIC(X)	Compressor Face Rake Temperatures, °R Measurement Numbers 862 to 876
569a	ΔTIC(X)	TIC(X) - TTO
570	PBLL(X)	Inlet Boundary Layer Rake, Left Engine, psia Measurement Numbers 834 to 838

Figure A - 8 Parameters After Additions

2.2.5 Arithmetic Constants

Arithmetic constants, wherever used, should be clearly indicated as shown in the examples of this section. Often a summary list of all the constants used in the equations is helpful for reference and should be included in the document.

If constants are to be changed during a test, then that fact should be noted. Often such cases need special handling. Figures A - 9 and A - 10b are sample tables of such lists. Figure A - 10a illustrates the use of a table of constant information.

On those systems where a VAX is available, constants that are subject to change are entered into a file that can be updated for any range of runs or points. These values can be printed out whenever there is a request for them. This system minimizes the amount of constant information that needs to be included in output specifications.

N	PTFN(X)	R_F(in)	PSNF(X1)	PSNF(X2)	RFS1	RF	AF
1	412	24.47	484	485	24.09	2.401	13.96
2	413	23.71					
3	414	22.92					
4	415	21.11					
5	416	21.27	485	486	21.69	2.846	
6	417	20.39					
7	418	19.74					
8	419	18.82					
9	420	24.47	487	488	24.09	2.401	14.45
10	421	23.78					
11	422	22.92					
12	423	22.11					
13	424	24.47	488	489	21.69	2.864	
14	425	23.71					
15	426	22.92					
16	427	22.11					
17	428	23.47	490	491	24.09	2.401	14.42
18	429	23.71					
19	430	22.92					
20	431	22.11					
21	432	21.27	491	492	21.69	2.864	
22	433	20.39					
23	434	19.47					
24	435	18.82					
25	436	23.87	493	494	23.51	2.269	15.86
26	437	23.15					
27	438	22.41					
28	439	21.64					
29	440	20.84	494	495	21.24	2.691	
30	441	20.02					
31	442	19.15					
32	443	18.55					
33	444	27.96	496	497	27.84	2.689	14.55
34	445	27.33					
35	446	26.67					
36	447	26.60					

Figure A - 9

A Sample Table

513 PTFAV -- Fan Inlet Average Total Pressure, XX.XXX psia

$$= \frac{1}{SINL} \sum_{N=1}^{80} [PTF(X)_N \; AI_N$$

Where: PTF(X) is from 511

AI_N = Area Weighing Factor

SINL = Area of Fan Inlet, 1416.6 in^2 at Rake Measuring Station

N	AI (in^2)	PTF(X)
1	See Table II	PTF (122)
2		PTF (123)
|		|
|		|
80		PTF (201)

FIGURE A - 10a Sample Use of Tables

Table II - Fan Inlet Area Weighing Values

N	PROBE NO.		AI,in ^{2} (Each Probe)
1 - 8	PTF (122) (132) (142) (152) (162) (172) (182) (192)		16.8
73 - 80	PTF (131) (141) (151) (161) (171) (181) (191) (201)		25.88
	Remainder of Pressures		
9 - 16	PTF	123 - 130	16.8
		133 - 140	16.8
		143 - 150	16.8
		153 - 160	16.8

Figure A - 10b Sample Use of Tables

2.2.6 Conversion Constants

The Instrumentation Test Plan (ITP), which is prepared by an NFAC instrumentation engineer, shows the conversion constants. The programmer will assume first order conversions for all instrumentation. Zero subtraction will be assumed for all items except those entered through the keyboard and items such as temperatures and angles. If the ITP specifies an Rcal Equivalence for a channel, it will be used in converting the data, but any exceptions to first order conversions must be noted. Such exceptions might be: a) higher order conversions, or b) no zero subtraction conversions.

When converting thermocouple data, careful attention should be given to the range of the data. If the range is relatively small, a first order conversion is adequate. If it is not adequate, the programming staff maintains a set of higher order conversions related to the thermocouple and hot box types that can be used. The ITP will specify which type of instrumentation is being used, so that the programmer may select the proper type of conversion. Conversion constants, RCAL equivalences, and offsets are supplied by the Instrumentation group. Offsets are always in engineering units.

Figure A - 11 illustrates the use of the measurement number and special conversion information.

The Standard Wind Tunnel System (SWTS) notation that will apply is described on the following page. In the description, K1 is the RCAL equivalence for those channels that have Rcals. For those that do not have them, it is the first order conversion constant. K0 is the offset.

Special Conversion Information

Meas. No.	Name	Comment
512	A6	Do not subtract zero
540	TT8	Copper-Constantan 150° hot box Range - 20 to 400
550	AX9	Second order conversion, subtract zero, do not apply cal. $C_0 = 2.5$ $C_1 = 1.5$ $C_2 = 2.0$

Figure A - 11 Itemization of Conversion Constants

TYPE	DESCRIPTION	EQUATION
1	1st order polynomial conversion: Do not subtract zero, do not apply RCAL.	K1 * Data + K0
5	Same as 1	
7	Simple multiplication : Do not subtract zero, do not apply RCAL	K1 * Data
8	Multiplication with zero subtract, do not apply RCAL	K1 * (Data - Zero)
10	1st order polynomial conversion: Subtract zero, do not apply RCAL.	K1 * (Data-Zero) + K0
13	1st order polynomial conversion: Subtract zero, apply RCAL	K1*(Data-Zero)/(Cal-Zero) + K0
16	Conversion for channels that require statistical data. If Cal is not used, the (Cal-Zero) term is set to 1.0.	K1*(Data-Zero)/(Cal-Zero) + K0

Either Electronic Pressure Scanners (ESPs) or Scanivalves are used in measuring pressure data. The usual setup of pressure data taken with scanivalves is illustrated in Figure A - 6. This data is converted to either pounds per square inch or pounds per square foot by the following equation:

$$Pressure_n = \frac{Port_n - Pa}{Pcal - Pa} * PCAL$$

where PCAL is the calibration pressure from a separate measurement in engineering units and n is the port number (Pt in Figure A - 6).

When ESP pressure data is acquired, a series of calibration points are taken at the beginning of a run and repeated during the run if conditions change. The SWTS software performs a least square fit on this data resulting in coefficients of whatever order the User selects. These coefficients are then used to convert the data to pounds per square inch or pounds per square foot.

For a test requiring Load Cells, the "Load Cell Information" form must be completed. For a test requiring Task Balances, the "Task Balance Parameter" form must be completed.

For further information that may assist the User in furnishing Load Cell parameters refer to the NASA Technical Memorandum 86693, *Experimental Techniques for Three-Axis Load Cells Used at the National Full-Scale Aerodynamics Complex* by Michael R. Dudley. If the test requires a Task Balance, refer to the *Description of the Standard Wind Tunnel Balance Program* document by Johannes Van Aken.

At this time the VAX system is available at the 40- by 80-Foot Wind Tunnel. Using the VAX, conversion constants are entered into a special file that may be updated for each run or changed for any range of points. Reports of these constants can be printed for any run.

2.2.7 Model Information and Toledo Scale Parameters

Model specific information must be provided to the NFAC staff. When the Toledo scale is used for load measurement, moment arm information must also be provided. The forms used are shown in Figures A - 12 and A - 13. As with conversion constants, these values may be changed for any range of runs or points.

MODEL INFORMATION

MODEL PARAMETERS:

CHORD -- Wing Chord (ft.) ____________

SPAN -- Wing Span (ft.) ____________

SWING -- Wing Reference Area (sq. ft.) ____________

ROTOR PARAMETERS:

R -- Rotor Radius (ft.) ____________

SR -- Reference area for calculation of rotor coefficients, normally the total blade area (sq. ft.) ____________

SIGMA -- Rotor Solidity Ratio ____________

SWC -- Wind Tunnel cross section areas (sq. ft.) ____________

40 X 80 with acoustic treatment:	2754.59
80 X 120:	9600.0

FHEL -- Equivalent helicopter drag area for descent velocity calculation (sq. ft.) ____________

FEE -- Helicopter drag to be simulated ____________

QLIM -- Value of Q which establishes the break point between high & low Q tares ____________

WALL CORRECTION:

CAT -- Wall Correction for Alpha ____________

Figure A - 12 Model Information Parameters

MOMENT ARM PARAMETERS

H -- Vertical distance from drag link elevation to midpoint between strut tip ball centers (positive up, ft.) ____________

J -- Lateral distance from balance frame center line to midpoint between strut tip ball centers (positive west, ft.) ____________

K -- Stream-wise distance from lift wire to midpoint of ball centers (positive downstream, ft.) ____________

X -- Stream-wise distance from midpoint between strut tip ball centers to model moment center, for zero angle of attack (positive downstream, ft.)

____

Y -- Vertical distance from midpoint between strut tip ball centers to model moment center, for zero angle of attack (positive up, ft.)

____

DX -- Stream-wise moment center shift (ft.) ____________

DY -- Vertical moment center shift (ft.) ____________

PBPSI -- Base portion of turntable, degrees ____________

MOMARM -- Specifies model orientation: ____________

0=Non-semispan
1=Semispan, upper surface west;
-1=Semispan, upper surface east.

Figure A - 13 Scale Parameters

2.2.8 Revisions of Software

Minor revisions to the specifications can easily be implemented by insertions and additions as noted in the previous sections of this appendix. Major revisions affecting large groups of parameters or equations may, in some cases, require the rewriting of one or several pages of the document. Then changed pages should contain the revision number and date of the revision. In all cases, revised specifications must be dated and forwarded to the programmer.

The Instrumentation Group furnishes the programmer with all instrumentation revisions.

Any revisions that are required after the Software Requirements documents have been approved by the Computation and Data Analysis Group Leader are implemented through the normal change procedure outlined in Section 6.3.7 of the NFAC *Operations Manual.*

During a test many changes can be made without changing the program. Where a VAX is used for data reduction, software updating procedures exist that allow modification of constants, engineering unit instrumentation readings, raw data readings, and conversions. To do this the same change procedures as noted above must be used.

2.3 DATA PRESENTATION

Well specified output requirements and layouts provide the programmer with an exact proposal for the presentation of tabular or graphic program output. Print and plot layouts are followed precisely by the programmers, and are assumed to be the exact requirements of the engineer.

2.3.1 Printer Output

The desired outputs must be specified thoroughly and clearly, and the range and the number of decimal places to be printed must be stated. When line printer data layouts are set up on the computer, the maximum number of spaces used across the page are 132, while there are 45 lines of print per page (See Figure A - 14).

Whenever possible, output for a rotor test should include standard items in a fixed format. The non-standard output will be appended to the standard output and will have the appropriate header lines added. The user should follow the above guidelines for the specification of non-standard output. Figure A - 15 is an example of a typical test output format. The *Rotor Data Reduction System* manual contains other examples of rotor test output.

```
                    FULL SCALE INTERACTIONAL AERODYNAMICS I -- TEST XXX                                PAGE XXX

RUN XXX.XX    DATE ACQUIRED 12/02/87  14:26:37    DATE PRINTED 12/02/87  10:47:53    CONF X  WIND - X.  ROTATE - X.    VER. XX

ROTOR TERMS           WING TERMS           BALANCE & MOMENT CENTERS            Q COEFFICIENTS          WALL EFFECTS

AREA   -    XX.XX     AREA  - XXXX.XX      H - XX.XXXX      X  - XX.XXX        X.XXXXE-XX CONST        CAT - X.XXXXE-XX
RADIUS -    XX.XX     CBAR  - XXX.XXX      J - XX.XXXX      Y  - X.XXXX        X.XXXXE-XX QU           SWC - X.XXXXE-XX
SIGMA  - X.XXXXX      SPAN  - XXX.XXX      K - XX.X         DX - XX.XXX        X.XXXXE-XX QU**2
PB     -   XXX.XX                                           DY - XX.XXX        X.XXXXE-XX QU**3
                                                                               X.XXXXE-XX QU**4

AERODYNAMIC TARE COEFFICIENTS:

               --------TUNNEL LOADS--------       ------FUSELAGE LOADS------        --FUSELAGE - TUNNEL LOADS---
                      TARE SET - XX                     TARE SET - XX                      TARE SET - XX

               LIFT      DRAG      PITCH          LIFT      DRAG      PITCH          LIFT      DRAG      PITCH
LOW Q TARES:
CONSTANT       X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX
ALFS,C         X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX
ALFS,C**2      X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX
ALFS,C**3      X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX
Q              X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX
Q**2           X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX
HIGH Q TARES:
CONSTANT       X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX
ALFS,C         X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX
ALFS,C**2      X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX
ALFS,C**3      X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX
Q              X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX
Q**2           X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX        X.XXXXX   X.XXXXX   X.XXXXX

STRUT COEFFICIENTS:
                      C0        C1        C2        C3
          LIFT      X.XXXX    X.XXXX    X.XXXX    X.XXXXX
          DRAG      X.XXXX    X.XXXX    X.XXXX    X.XXXXX
          PITCH     X.XXXX    X.XXXX    X.XXXX    X.XXXXX
```

Figure A - 14 Printer Output

2.3.2 Graphics Output

A simple sketch of each plot requested should be included in requests. The sketches should include the following information:

1) the title of plot

2) the test parameter information such as test number, the angle of attack etc.

3) the X and Y axis labels and units

4) the minimum, maximum and increment values of the X and Y axis.

Automatic scaling may be requested for off-line plots.

There are basically two types of plots available: pressure plots that are produced for a point; or standard plots which are produced for one or more runs or for sequences of points within one or more runs. A pressure plot may also be made for non-pressure data. The only requirement for pressure data is that the plot must apply to only one point. There are many options for plotting and the programming staff can be consulted for further details.

2.3.3 Monitor Mode Program and Display

The monitor mode program should include only that data that is required for test guidance and safety. The real-time aspect of the program severely limits the memory space and CPU time. Standard items are calculated and displayed if requested. In addition, a special routine can be written to compute and display items that are test dependent.

NFAC uses a VT-29 monitor for the real-time display. The VT-29 has a limit of 2 columns with 16 lines in each screen. The VT-100 monitor can display data in 3 columns with 23 lines in each screen. Test heading requires one line in all columns. Also, the run, the sequence number, the time, and the date require a line in all columns. These items do not necessarily need to be at the top of the screen. Data will be displayed with a 1 to 4 character name and with 4 significant digits in the E format. Figures A - 15 and A - 16 can be used as guides for the monitor mode display screen setup. The User must be sure that all the equations are supplied. Also note that scanivalve data cannot be displayed in real time.

It is important to supply the program and display information as early as is possible, since it may impact the manner in which the instrumentation engineer arranges the hardware. When necessary, the software staff communicates any special needs to the instrumentation staff. For instance, if a test dependent computation is to be displayed, the software staff must supply the instrumentation engineer with a list of the channels that are components of that computation.

Because this software is a subroutine or a set of sub-routines that fits into a standard program, it is very difficult to provide the capability of reading constant files.

2.3.4 Rotor Data Reduction System (RDRS) and Dynamic Data

If the RDRS is required as a part of data reduction, an RDRS form must be submitted. The Dynamic Data programs are described in the manual entitled *Rotor Data Reduction System.* The Project Director must complete the "Static Data Parameter Initialization Information", the "Dynamic Data Parameter Initialization Information," and the "Dynamic Data Reduction Parameters" forms to use these programs. These forms are available upon request from the NFAC staff.

2.4 PROGRAM CHECKOUT AND TEST CASES

All tests undergo extensive software checkout before tunnel entry. The programming staff builds a test case from the available information and then tests the interaction between modules, the input and output, and the results. User input is very helpful and often aids in this process.

2.5 STANDARD NAMES

MEASUREMENTS

ALPHA	Model angle of attack
ATEM	Atmospheric temperature, degrees F
AVEL	Atmospheric wind velocity, knots
AWDR	Atmospheric wind direction, degrees

BARO	Barometric pressure, psi
PCALi	PCAL source #i
PS	Tunnel static pressure, psf or psi as defined by engineer
PSI	Turntable yaw angle, degrees
PT	Tunnel total pressure, psf or psi as defined by engineer
RH	Relative Humidity, %
TT	Tunnel temperature, degrees F

Note: On instrumentation sheets Q from the Scale system is referred to as Q. In a test write-up it is referred to as QU (Uncorrected Q) to distinguish it from corrected Q (QS).

2.6 STANDARD COMPUTED VALUES

CS	Speed of sound, feet per second
MTUN	Tunnel Mach number
QS	Tunnel Q adjusted for scale errors
RHO	Density computed from PS, TS, HUM, BARO
VFPS	Tunnel velocity, feet per second
VKTS	Tunnel velocity, knots

IDENTIFICATION PARAMETERS

DATAQ	Date point was acquired
TIMAQ	Time point was acquired
DATE	Date output was produced
TIME	Time output was produced
RUN	Run number
POINT	Point number

COLUMN 1 COLUMN 2

RUN XXX SEQ XXX	DD-MM HH:MM:SS

Maximum number of characters for the title is 32.
Maximum number of characters for each variable is 4.

Figure A - 15

VT - 29 Real-Time Display

Column 1	Column 2	Column 3
RUN XXX SEQ XXX	DD-MM	HH:MM:SS

Maximum number of characters for the title is 32.
Maximum number of characters for each variable to display is 4.

Figure A - 16

VT - 100 Real-Time Display

3.0 INSTRUMENTATION

3.1 INSTRUMENTATION LEAD TIME

Instrumentation Requirements must be provided to the NFAC staff no later than seven months prior to the scheduled test date. In some cases, this date will be earlier than the date when the Software Requirements are needed. Delays in submittal may result in test date slippage especially if long lead time items are involved.

3.2 INSTRUMENTATION REQUIREMENTS SUBMITTAL

The completed Instrumentation Requirement documents are to be submitted to the NFAC staff. The staff will review the requirements and assign the project to an instrumentation engineer. This engineer will initially establish man loading requirements, hardware assignments, calibration requirements, and long lead time procurement (See the *Project Engineer Input Guide for Instrumentation Test Plan Programs* available from the instrumentation engineer for specifics). The instrumentation engineer then schedules meetings with the User and programmer to coordinate the pre-test preparations.

3.3 INSTRUMENTATION DOCUMENTS AND FORMS

To assist the User and the instrumentation personnel, a separate document entitled *Project Engineer Input Guide for Instrumentation Test Plan Programs* provides for format, organization, and presentation of Instrumentation Requirements. In order to ensure compatibility of instrumentation methods and equipment, a copy of this document is available from the NFAC instrumentation engineer. This document should be used as early in the planning of test instrumentation as is possible.

3.4 REVISIONS OF INSTRUMENTATION

In the normal process of test preparation, the Instrumentation Requirements are modified for numerous reasons including model fabrication restrictions, changes in research objectives, and availability of equipment. Any revisions that are required after the measurements and requirement documents have been approved by the NFAC staff, shall be implemented through the normal change procedures outlined in Section 6.3.7 of the NFAC *Operations Manual*.

APPENDIX B:

SAFETY ANALYSIS REPORT

APPENDIX B:

SAFETY ANALYSIS REPORT

1.0 GROSS HAZARDS ANALYSIS

The User shall conduct a Gross Hazard Analysis of the proposed test. This analysis must be a comprehensive, qualitative, and non-mathematical assessment of the hazards and safety features of the test system. Areas to be considered may include, but should not be limited to, the following:

Model Design	Energy Sources
Fuel and Propellants	Human Factors
Environmental Restraints	Test Model Hazards
Material Compatibility	Sequential failures
Toxic and Hazardous Gasses and Materials	Procedural change hazards

While this analysis is not required until the Test Readiness Review, the sooner in the preparation process that it is completed, the more likely that the critical and catastrophic hazards can be identified and eliminated.

1.1 MODEL DESIGN

The complete model design should be reviewed to identify all critical elements or single point failures who's failure might cause damage to the model or the facility or injury to personnel. See Appendix C for model design guidelines.

1.2 ENERGY SOURCES

All energy sources which, if uncontrolled, may be hazardous to personnel, equipment, or the facility must be identified. These energy sources should include, but may not be limited to, the following:

- High Pressure Air
- Jet engine turbines or compressors
- Propellers and rotors
- Liquid or gaseous fuels
- Rotating electrical machinery
- Electrical power and auxiliary power supplies

- Explosive devices

1.3 FUELS AND PROPELLANTS

The characteristics of fuels and propellants must be identified, and the hazard level handling procedures, the methods of control, and the requirements for safe use of these materials must be listed.

1.4 TOXIC AND HAZARDOUS GASES AND MATERIALS

In addition to piston and jet engine exhaust gasses, other gasses may be released into the wind tunnel to aid in flow visualization. The fluids, used in measuring pressures, may also be hazardous. These include mercury, TBE, Alkzene, and alcohol. Other toxic liquids may include solvents, cleaning fluids, lacquers, glues, and paints, as well as fiber glass, asbestos, sawdust, and grinding dust; these too should be considered.

1.5 ENVIRONMENTAL RESTRAINTS

The environmental restraints imposed on the test system may include the following:

- Remote control of power and controls
- Response time of various parameters
- Limited visibility of the test model

1.6 HUMAN FACTORS

A successful test depends largely on human factors. Therefore, the following points should be evaluated carefully.

- The familiarity of operators with the test system
- How well NFAC personnel and User personnel interact
- How well the various personnel disciplines, such as operator, aerodynamicist, and technicians interact. Technical language barriers should also be considered
- The assignment and division of responsibility and authority especially under emergency situations

- The personnel training for safe operation and maintenance of the system

1.7 HAZARDS TO THE TEST MODEL

Hazards to the test model that result from tunnel equipment failure must be considered. These hazards include the following:

- Loss of the tunnel drive system
- Loss of model power or control on rotor or propeller tests
- Power failure to or failure of monitoring instrumentation
- Failure of model attitude control
- Loss of cooling water or lubrication to electrical model motors
- Failure of high-pressure air or hydraulic systems
- Divergent oscillations or instabilities of the model in conjunction with the model support system
- Loss of instrument cooling air
- Jet fuel leak
- Loose objects that may cause model or tunnel damage

1.8 MATERIAL COMPATIBILITY

Compatibility of material includes such considerations as:

- The proximity of fuel and electrical wiring
- The effect of the temperature environment on instrumentation sensors and lead wires
- The deleterious effects of leakage of fuels or lubricants throughout the system.
- The identification and safety provisions for toxic materials

1.9 PROCEDURAL CHANGE HAZARDS

Hazards may develop due to procedural changes. These situations include the following:

- Deviation from the specified test schedule
- Deviation from a specified test start or stop procedure
- Any deviation from the monitoring of specific test parameters, such as instrumented stresses, loads, positions, speeds, and powers that are required for safe operation
- Any changes in the operating crew such as altering the number of operators or monitors, changing crews while a test is in progress, crew changes at shift change time, or using temporary substitutes for specific tasks
- Any improper procedural action by operators

1.10 SEQUENTIAL FAILURES

When there is an assumed initial failure, the system shall be analyzed for hazards in the failed system and in the interfacing subsystems. This analysis shall include the effects of the operator's reactions to the initial failure.

1.11 ENVELOPE OF TEST OPERATIONS

The limits of conditions for safe test operations must be determined, and the criteria for each limit must be defined. The predicted test parameters for both the tunnel and the model conditions closest to these limits shall be presented in plots. These plots will be used to define the safe operating envelope of the test operations.

2.0 DYNAMIC STABILITY ANALYSIS

A Dynamic Stability Analysis Report shall be submitted for tests that involve aeroelastic or dynamic instabilities. The Report will document the analysis being used, the assumptions employed, and the predicted results for the complete test envelope under the proposed Test Plan. All critical dynamic modes of potential instability will be identified and shown to be completely stable throughout the test envelope.

Longitudinal Modes							Lateral Modes						
Mode	ω Hz	H g/1000 lb	H in/1000 lb	C lb/fps	C_L lb/fp	M lb	Mode	ω Hz	H g/1000lb	H in/1000 lb	C lb/fps	C_L lb/fps	M lb
****** No Dampers *******													
Balance	1.81	0.19	0.57	1600	690	6400	Balance	2.23	0.45	0.88	630	380	55000
Strut	3.21	0.30	0.28	2000	1400	49000	Strut	3.73	0.45	0.32	1500	1400	41000
Bal. Vert.	7.3	0.15	0.03				Mast	23.3	3.2	0.06			
Mod. Vert.	10.0	0.90	0.09				Mast	27.7	2.6	0.03			
XB Vert.	14.1	0.70	0.03										
Mast	25.5	3.2	0.05										
****** Balance Locked ******													
Strut	2.45	0.47	0.77	685	640	53000	Strut	2.72	0.99	1.31	310	250	29000
Mod. Vert.	10.0	0.60	0.08				Mast	23.2	2.0	0.04			
XB Vert.	15.3	0.50	0.02				Mast	27.7	1.9	0.02			
Mast	25.5	2.5	0.04										
****** 8 Balance Dampers ******													
Balance	2.04	0.14	0.33	2900	2600	35000	Balance	2.41	0.34	0.57	14000	760	17000
Strut	3.46	0.09	0.07	7900	5700	49000	Strut	4.01	0.17	0.10	4600	3100	33000
Bal. Vert.	7.3	0.15	0.03				Mast	23.2	3.2	0.06			
Mod. Vert.	10.0	0.90	0.09				Mast	27.7	2.6	0.03			
XB Vert.	14.1	0.70	0.03										
Mast	25.5	3.2	0.05										

Table B - 1

Dynamic Characteristics of the Rotor Test Apparatus of the 8-ft Struts/60-in Tips

Module Weight 305000, 12-in Tail Strut Tip

Longitudinal Modes						Lateral Mode					
Mode	ω Hz	H g/1000 lb	C lb/fps	C_L lb/fps	M lb	Mode	ω Hz	H g/1000 lb	C lb/fps	C_L lb/pfs	M lb
****** No Balance Dampers, No Snubbers ******											
Balance	1.77	0.01	2659	1246	7000	Balance	2.34	0.19	1946	787	5100
Strut	4.02	0.50	742	891	3400	Strut	4.49	0.76	1050	904	23000
Bal. Vert.						Mast	23.80	1.34	3441		
M od. Vert.	9.17	0.19	9391								
XB Vert.	13.77	0.20	13467								
Mast	26.70	0.73	7076								
****** Balance Locked, No Dampers ******											
Strut	3.11	0.58	592	883	22000	Strut	3.43	0.91	465	417	31000
Mod. Vert.	9.26	0.16	1144			Mast	23.80	1.36	3418		
XB Vert.	14.60	0.10	27119								
Mast	26.99	0.40	13070								
****** 8 Balance Dampers Engaged *****											
Balance	2.24	0.05	8192	7672	58000	Balance	2.71	0.15	3555	2815	26000
Strut	4.17	0.24	3367	2726	40000	Strut	4.64	0.37	2462	2336	27000
Mod. Vert.	9.32	0.20				Mast	23.81	1.36	3408		
XB Vert.	13.98	o.17	15323								
Mast	26.91	0.77	6813								

Table B - 2

Dynamic Characteristics of the Rotor Apparatus of the 15-foot Struts/6-inch Tips

Module Weight 30500 lb, 12-inch Tall Strut Tip

Longitudinal Modes						Lateral Modes					
Mode	ω Hz	H g/lb	C lb/fps	C_L lb/fps	M lb	Mode	ω Hz	H g/lb	C lb/fps	C_L lb/fps	M lb
****** No Balance Dampers and 4 Pylon Dampers ******											
Balance	1.98	0.0003	2030	832	51520	Balance	3.19	0.0005	36440	14375	1951320
Strut	3.91	0.0055	130	158	6086	Pylon Roll	5.10	0.015	75	103	1706
Pylon Pitch	5.45	0.01	92	120	1546	Strut	7.68	0.01	298	782	5538
****** Balanced Locked and 8 Pylon Dampers ******											
Strut	3.40	0.01	140	298	7052	Strut	4.80	0.01	92.1	105	1829
Pylon Pitch	5.38	0.0085	124	145	1185	Pylon Roll	5.40	0.0045	700		27756
****** 8 Balance Dampers and 4 Pylon Dampers******											
Strut	4.04	0.0023	413	261	5345	Balance	3.20	0.0005		29150	1951320
Pylon Pitch	5.42	0.01	119	126	1610	Pylon Roll	5.07	0.01	90	104	1223
						Strut	7.65	0.003	460	864	4670

Table B - 3

Dynamic Characteristics of B412/576 Test Stand with 8-foot Struts/60-Inch Tips

Module Weight 15,000, 24-Inch Tall Strut Tip

Yaw Modes					
Mode	w Hz	H g/lb	C lb/fps	C_L lb/fps	M lb
****** No Balance Dampers and 4 Pylon Dampers******					
Model/Strut Balance	2.03 2.71	0.0005 0.0004	832 5425	2581 2101	65688 284970
****** Balanced Locked and 8 Pylon Dampers ******					
Model Strut	2.13		988.3		89677
****** 8 Balance Dampers and 4 Pylon Dampers ******					
Model Strut Balance	2.08 2.70	0.0002 0.0004	1250	2300	59248 284970

Table B - 3 continued

Dynamic Characteristics of B412/576 Test Stand with 8-foot Struts/60-inch Tips

Module Weight 15,000lb, 24-inch Tail Strut Tip

3.0 FRAGMENTATION ANALYSIS

The total system shall be reviewed to identify all energy sources, especially those that might be released in the event of a model failure. Examples of such energy sources include rotors, propellers, fans, jet engines, pressure vessels, and explosive cartridges. During testing, the primary dangers to personnel arise from high energy fragments being released as a result of model failures. The energy level and the range of fragment directions possible at the time of release shall be documented. The energy level shall be expressed as:

$$e = \frac{W}{A}\left(\frac{V}{1000}\right)^2$$

where:

W = weight of unit, lb.
V = velocity at instant of separation, ft/sec.
A = minimum cross-sectional area, in^2

Details of the calculations, and the quantities W, V, and A shall be included in the documentation.

The data will be judged in terms of the likelihood of injury to personnel. Figure B -1 presents a chart that should assist in making these decisions. The 40- by 80-foot Wind Tunnel test section is lined with armor plating: the plate is 1-1/4" thick on the west wall and 5/8" thick on the east wall.

Corrective measures may be required to assure a satisfactory level of personnel safety. Some acceptable measures are modifying the model, the facility, or the removal of personnel from the plane of predicted projectile path.

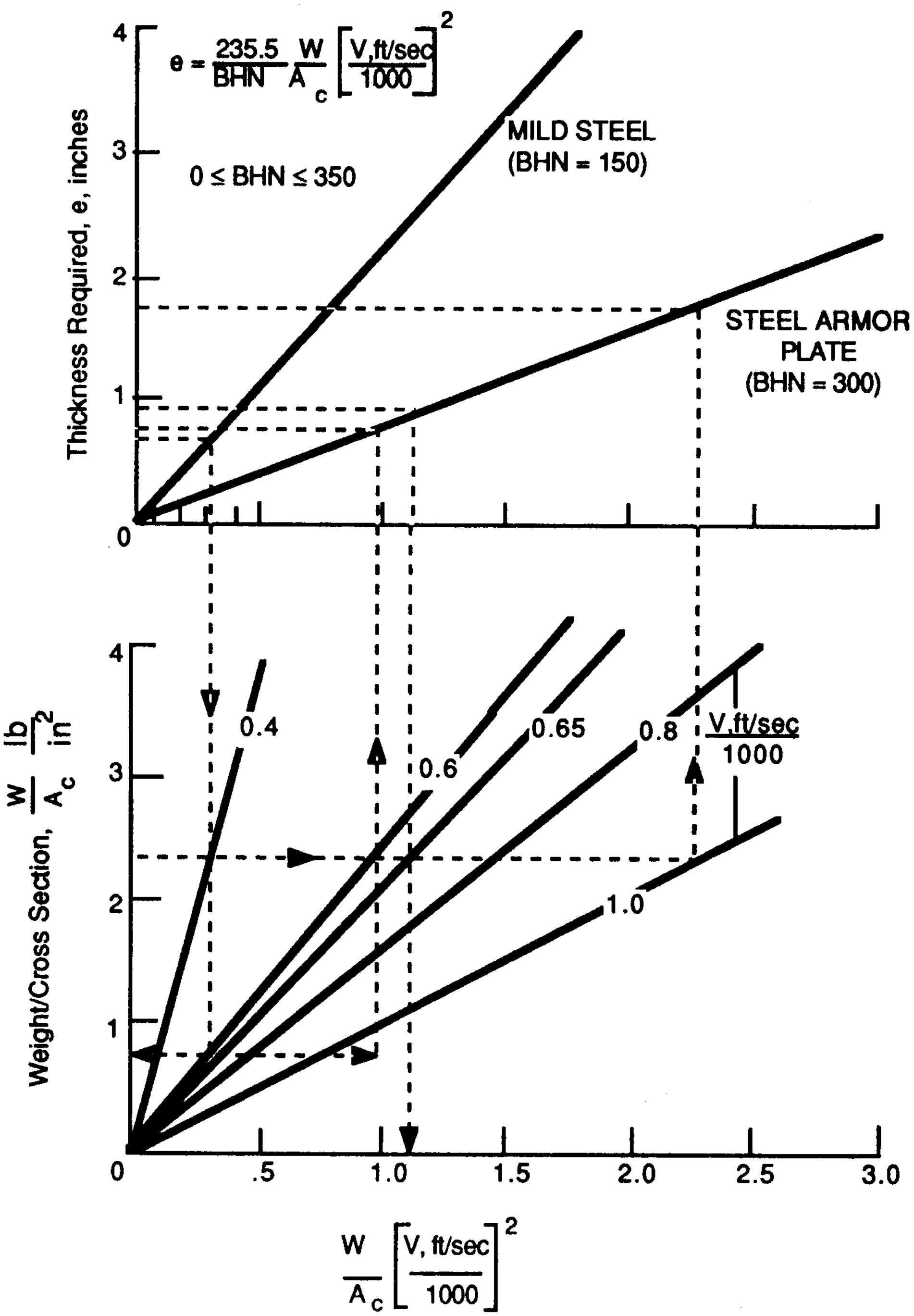


Figure B - 1

Chart for Determining Fragmentation Protection

4.0 OPERATIONS SAFETY REQUIREMENTS

4.1 FIRE PROTECTION SYSTEMS

In fueled models, the User shall supply the total fire-extinguishing system, or the User may contact the NFAC staff for advice regarding the use of the tunnel fire-extinguishing system. A third alternative is to use an on-board system for this purpose. The tunnel system is a carbon-dioxide type. It is designed to protect the balance room and test section of the tunnel against fuel fires. Auxiliary fittings are provided for attachment to model lines when necessary. An on-board system is a self-contained system that uses bromotriflouromethane as an extinguishing agent; this system is mounted on the model. The normal detection device used with the on-board system is a combustible gas alarm with a manually released extinguishing agent. If the User wants to use fire or temperature detectors, then the User must furnish these devices.

If the model is an aircraft with integral fuel tanks, these tanks must be filled with an inert gas under pressure during wind tunnel tests. The user shall install remote reading pressure sensors to detect any gas leakage from the tanks.

4.2 FAIL SAFE CONTROLS

Loss of primary power, electrical or hydraulic, to model controls can precipitate failures unless fail-safe systems are used. Mechanical screws with a preventive back-driving device, check valves, or closed circuit hydraulics may be used as a fail-safe system. Such fail-safe features are required unless the User can prove that testing will be safe without such features.

4.3 THE ENVELOPE OF TEST OPERATIONS

The limits of conditions for safe test operations must be determined and plotted in a graphic format (See Gross Hazards Analysis, Section 1.0).

4.4 CREW TRAINING

Test systems, where the safety of the test operations may at times be dependent upon the experience or reaction times of the operating crew, require simulation training before the start of the tests. The need for such training and the nature and extent of the training will be established in consultation with the NFAC staff.

4.5 SAFETY AIDS

All components and equipment associated with possible system failures shall be considered for re-design or considered for supplementary aids to enhance test safety. The following methods shall be considered:

- Redundancy, such as parallel servos or hydraulics for critical controls either of which has sufficient power to do the job.
- Fail-safe features (see Section 6.2 of this Appendix).
- Automatic warnings such as panel warning lights that sensor-actuate on limits to loads, stress, speed, or temperature of critical components.
- Automatic lock-out of personnel in lieu of warning.
- Instrumentation duplication, such as sensors or readout displays for measuring critical parameters.

APPENDIX C:

DESIGN AND ACCEPTANCE REQUIREMENTS

APPENDIX C:

DESIGN REQUIREMENTS

The intention of Appendix C, Design Requirements, is to give Users a design guide compatible with NFAC Operation's practices and the desired approach to solving problems. Alternate design methods preferred by a User organization are acceptable provided that they are thorough, they follow accepted engineering practice, and they demonstrate sound judgement and engineering prudence. The Design Analysis Report format shall be followed for Design Analysis documents submitted to the NFAC for review.

1.0 DESIGN

1.1 CRITICAL AND NON-CRITICAL STRUCTURES

All designed parts shall meet the requirements for either critical or non-critical structures according to their classification by the definitions given below.

NOTE: The design engineer should review all structures and parts as if they were critical. All calculations and decisions should be documented to show the engineer's thought process.

1.1.1 Critical Structures

Critical structures include all designs and parts whose failure would lead to a significant hazard to personnel and/or facilities if they failed or if they contributed to an accident.

Existing structural supports for designs are not included as critical structures provided that their documentation can be referenced to show that the supports have adequate strength for the applied loads. For example: model designs may use rated loads for existing struts.

All critical potential failure modes and effects from static, dynamic, and fatigue loads acting on critical structure parts shall be considered for evaluation in the stress analysis and shall be documented in the Stress Analysis Report.

All critical parts shall require 100% inspection. Inspection requirements shall be annotated on the design drawings.

1.1.2 Non-Critical Structures

Non-critical structures are those parts that are not classified as critical, and whose premature failure would be acceptable since it leads to no hazard to the personnel of the facility. In order to determine the non-criticality of a structure, a failure modes and effects analysis is required for hazardous designs.

Non-critical parts do not have to meet the analysis documentation or the inspection requirements used for critical parts. However, non-critical parts are expected to have the same safety factors as those required for critical parts.

1.2 DESIGN REVIEWS

Reviews are held periodically to evaluate various aspects of the design. These reviews examine loads, concepts, status and progress, analysis, detailed drawings, fabrication procedures, and installation procedures.

All designs for the NFAC require a conceptual and critical design review. Additional interim reviews (typically preliminary, 60%, and 100%) will be scheduled for specific test programs. Their number and schedule will be based on the complexity of the test and the risk the program presents to the safety of NFAC personnel and facilities.

Design reviews consist of the following basic elements:

- Overview of the test program and objectives
- Design loads
- Statements and definitions of design problems
- Facility utility requirements
- Load paths to react loads
- Detailed solutions to design problems.
- Calculated stresses vs. allowable stresses; safety factors.
- Discussions of specific comments on analysis and drawings.

Note: "Percent complete" for design refers to the percent of the drawing that is complete as compared to the final fabrication and installation drawings.

1.2.1 Conceptual Design Review

At the Conceptual Design Review, the work is about 10% complete. Initial design concepts are underway and in concrete form. Review at this point allows NFAC to determine if the right course of problem solving has been taken. Changes at this point avoid unnecessary work if initial concepts need revising.

1.2.2 Preliminary Design Review

When scheduled, the Preliminary Design reflects a 30% completion. Preliminary drawings, analysis, and other studies necessary for a satisfactory design are complete. Minor changes can still be incorporated, but the design clearly expresses the finished configuration.

60% Design Review

When scheduled, the 60% Design Review requires that all fabrication drawings be in progress and sufficiently defined to determine all materials and components. All interfaces are resolved, properly defined, and detailed. Model utility requirements are finalized. Rigging analysis is complete, and rigging hardware are identified. Member and joint analysis is complete with safety factors addressed. Problem areas are discussed, in detail, to ensure that the design meets NFAC requirements for analysis and safety. Request for waivers from specific requirements are finalized and approved.

100% Design Review

When scheduled, the 100% Design Review shall have all drawings, totally complete and ready for fabrication and installation of the model. All analysis is complete and ready for submission to the NFAC Document Control.

1.2.3 Critical Design Review

The Critical Design Review is scheduled for all designs to ensure that all aspects of hardware design and model design meet the NFAC design and safety requirements. This review also verifies that each design is complete and ready for fabrication and installation. The review may be combined with the 100% Design Review, or it may be held afterward so that it can follow-up on critical comments and problems that surfaced during the 100% Review. The Critical Design Review typically addresses the final status of the items covered in the conceptual design review in addition to the following:

1. Review of Analysis
    a. Major load paths
    b. Critical connections
    c. Allowable stresses
    d. Safety factors
    e. Risk assessment
2. Review of Design Drawings

a. Completeness

b. Verification that drawings and analysis are compatible

c. Constructibility

3. Final approval for fabrication

a. Close out of any action items from previous reviews

b. Final signature on drawings

c. Drawing submittal to Document Control

2.0 DESIGN ANALYSIS REPORT

A Design Analysis Report is required for all projects and designs. The report shall document all required engineering calculations and plans for the fabrication and testing of the parts and models. The report shall be clear, concise, and self-explanatory.

The Design Analysis Report shall consist of the following sections:

- Introduction
- Stress Analysis Document
- Inspection Requirements Document
- Testing Procedures

2.1 DESIGN LOADS DOCUMENT

The Design Loads Document is developed by the User as a formal compilation of all loads and forces used for engineering design. Its contents include the detailed derivation and justification for various loads used in the design of components, hardware, models, or rigging will be installed in or attached to the NFAC facilities.

The critical element of this document is to ensure that the loads are formally developed, reviewed and approved by the User organization before design activities begin. Loads developed for preliminary designs or conceptual studies shall also be reviewed, documented and identified so that design activity can be effectively focused on the correct level of effort. When load revisions are required, they are made by the User organization and incorporated as a change to the Design Loads Document.

2.2 STRESS ANALYSIS DOCUMENT

The Stress Analysis Document should be complete and should be written in a clear and concise narrative fashion. The analysis shall demonstrate that allowable stresses/loads are not exceeded for worst case loading, and that the part's service life meets or exceeds the required service life. All potential failure modes should be considered for analysis and addressed in the Stress Analysis Document. Safe operating conditions for each mode should be clearly specified.

The design stress analysis shall include all structural components up to those that interface with the existing model support systems including the strut pad mounting points. The analysis may stop at this point if it can be shown that the loads imposed on the model support system do not exceed the allowable loads listed for the support system and balance system in the main text in Sections 3.3.3.

2.3 DEFINITION AND INSPECTION REQUIREMENTS DOCUMENT

Inspection, as used in this document, refers to the detection by Nondestructive Examination (NDE) of cracks and flaws in parts. Shape and dimensional checks can be critical in ensuring the strength and functionality of the designed parts; however, requirements for this type of inspection are left to the User to define for each application.

Inspection requirements shall be defined for each test. The requirements shall appear or be referenced in the Inspection Requirements Document and used during fabrication and tunnel operation to ensure that required inspections are performed. Fabrication inspection requirements should also be referenced in written specifications and on individual part drawings. A description of the inspections conducted and the results of the inspections shall be included in the documentation.

3.0 LOADS CRITERIA

3.1 RESPONSIBILITY OF THE USER

The User shall be responsible for establishing the design loads for the test vehicle. These loads must be consistent with the safe operating limits of the facility. The design loads may be determined from user design requirements, from past data of similar designs, from published or well-known theories or formulas, or from pertinent manuals and codes. The Design Load documentation shall cite all sources and references. All design loads and their derivations are subject to review and approval of the NFAC staff.

3.2 MAXIMUM LOADS

Loads and load combinations used to compute stresses for comparison to allowable stresses shall be the maximum loads that are likely to occur during testing. For statistically defined loads, maximum loads are defined as those loads that occur within three standard deviations of the mean loads.

3.2.1 Loads On Surfaces Misaligned with the Air Stream

In the absence of any other more specific aerodynamic guidance, a flow deviation of plus or minus two degrees (2°) from the nominal operational envelope should be considered. Similarly, where upstream turbulence or eddies may induce larger disturbances, plus or minus five degrees (5°) is used.

3.2.2 Starting and Stopping Loads

Starting and stopping loads must also be considered independently for the wind tunnel and for the models and their interaction under operating conditions.

3.2.3 Yawed Models and Combined Loads

If an airplane or model is to be tested in a simulated sideslip maneuver, the load data documentation must show the augmentation of combined loads due to yawing of the model.

3.2.4 Dynamic Loads

Dynamic load data shall describe driving forces, accelerations, model and structure resonant frequencies, damping assumptions, and dynamic load amplification effects. The analysis shall consider all possible sources of dynamic loads including resonances in rotating systems, worst case blade loss, and aerodynamic excitations. When direct analysis is not practical, monitoring of the critical parts during a test is acceptable.

3.2.5 Damping Assumptions

Damping assumptions should relate to testing experiences on similar models or structures or published references such as:

- AGARD Conference Proceedings No. 277 (See reference 2)

- Phillips' article on aircraft structures (See reference 2) -

  aircraft wings - data ranges from 2 to 4%

  engine pods - 0.5% to 3% or more depending the suspension system

- Wada's article on spacecraft (See reference 2) -

  0.5% to 2% is the typical range

  1% is used on STS payload analysis under 50 lbs

  2% for payloads over 50 lbs

The User must decide which damping to use in an analysis. Where the damping is critical to the structural integrity of the system, testing to demonstrate a model's operational safety may be required.

3.2.6 Load Monitoring Requirements

When there are uncertainties with steady or unsteady loads or when stresses are expected to approach or exceed allowable design stresses, the User must implement suitable monitoring of loads during initial testing to ensure that the design stresses are not exceeded. Load monitoring may have to continue throughout the test program to ensure safe operation of the model and the safety of the facility.

3.2.7 Fatigue and Design Life and Loads

The design life shall be determined and used in the fatigue analysis. Usually the application determines the design life. The preferred design approach is the "infinite life" design.

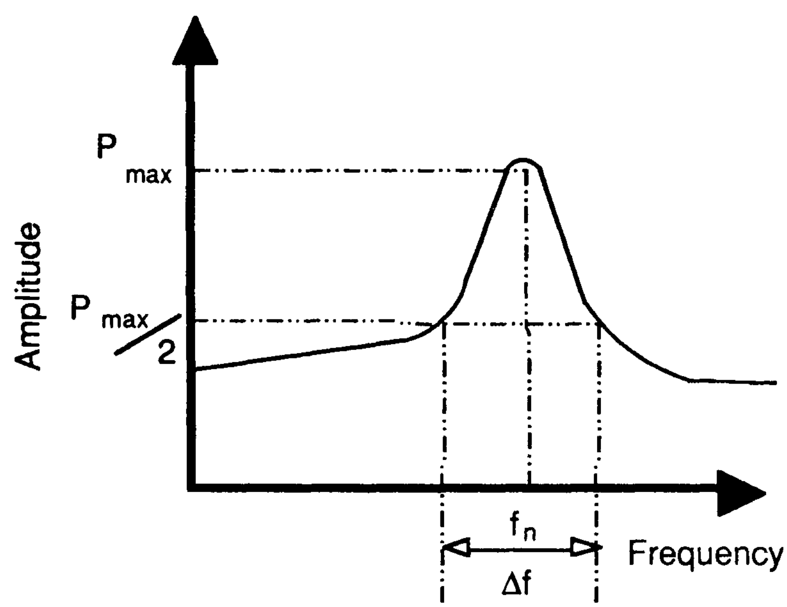
When an estimate of design life and fatigue loading must be determined, the following guidelines may be used when other data are not available.

- Peak Load Cycles - Estimate the life as three times the number of times the design will experience near-maximum steady-state load conditions during the service life.

- Unsteady Loads - For loads induced by aerodynamics or similar turbulent processes, a significant unsteady load may exist and must be accounted for in the analysis.

- Resonance Vibrations - For conditions involving vibration, including propellers, rotors, and rotating machinery parts, extreme load amplifications may occur when operating at or passing through resonances. Fatigue calculations must include the resonant-amplified loads. These loads may be estimated with the number of cycles equal to the resonant frequency (f_n) multiplied by the time spent at loads greater than or equal to one-half of the resonant peak load (P_{max}) (See Figure C - 1). Assume the peak load occurs for all of these cycles.

- When resonant vibrations can not be predicted, the User can make the decision to avoid resonance vibrations. In this event, provisions must be made to monitor and avoid resonant vibrations during the test. Any decisions to operate near or at resonance during the test requires the fatigue calculations as stated above and a formal change to the Test Plan.



Number of Cycles = t x at Amplitude = P_{max}

t = time spent within frequency range Δf

Figure C - 1 Calculation of Fatigue Cycles

3.3 LOADS FOR PROPELLER AND ROTOR DESIGN

3.3.1 Balancing

The design for propellers and rotors shall be balanced so that the individual components of the test bed, model and propeller, or rotor system will have "infinite fatigue life" for any imbalanced force imposed from blade rotation.

The blade design should provide a means of balancing the rotating system. Engineer's notes for fabrication shall require rotational blade balancing before tunnel testing.

The static imbalance force may be calculated using the following formula:

$$F = S\Omega^2 / g$$

Where: F = the imbalance force (lbs).
S = the maximum static imbalance about the rotational axis (in lbs.).
Ω = the maximum design rotational speed (Radians/sec.).
g = the acceleration due to gravity (in/sec^2).

NOTES: Measure the dynamic response of the system directly from the operating propeller or rotor over the maximum speed range to ensure that there are no resonate frequencies at the desired operating speed.

3.3.2 Drive Systems

Natural frequencies for rotor and propeller drive train systems shall be designed so that the lowest natural frequency is at least ten percent (10%) above the design operating frequency. Twenty five percent (25%) is preferred when practical. Damping shall be addressed for these systems.

Design rotor and drive systems shall be designed to operate at a minimum of ten percent (10%) over speed. Design propeller drive systems shall operate at a minimum of twenty percent 20% over speed.

Run up testing will be required for the acceptance of the entire drive train and the control system before tunnel entry. This testing shall demonstrate safe operation over all speed ranges and blade angle settings, including over speed requirements stated above. Run up testing is performed without the propeller or rotor.

Dynamic Shake Tests shall be performed when necessary to ensure safe operation of the total system with regard to natural frequencies and principal modes in the longitudinal and lateral directions. The total system includes the propeller or rotor, model or test apparatus (test bed), model support struts, balance frame, and scale system.

3.3.3 Blade Fatigue Design

Fatigue testing and allowable test cycles for a propeller or rotor are critical to both the development of hardware and the safety of the NFAC. Material selection and fatigue testing for developing allowable stresses should follow requirements stipulated in Section 5.3, Fatigue Requirements. A fatigue testing program should be developed for identical parts that will be used in the tunnel to validate analysis, endurance limits, and total fatigue life, (See the guidelines of Section 4.6, Fatigue Analysis and Testing). The program should address all loads and combined loads the test part will experience in actual service. The test program shall be submitted to the NFAC for review.

The allowable number of fatigue cycles permitted in the wind tunnel is one half (1/2) of the fatigue life of the critical part. Exceptions to this rule are negotiable and require a planned detailed surveillance program for monitoring the parts. The parameters to be considered include, but are not limited to, the developmental technologies of the part, past experience, cracking, crack propagation, delamination characteristics, re-stability, ability of the part to be inspected, stress levels, and research test parameters.

The major objective of the planned program is to prove why it is safe to proceed with wind tunnel testing. Proprietary information may be required to substantiate certain engineering analysis and justification. Proprietary rights for technology, materials, parts, fatigue life characteristics, and design are held in strictest confidence and are treated as classified material with a need to know basis .

4.0 STRESS ANALYSIS

4.1 DOCUMENT FORMATS AND REQUIREMENTS FOR CALCULATIONS

The analysis shall be based on or derived from stated fundamental principles and assumptions. Formulas shall be first given in symbolic form with all the symbols defined before the substitution of numerical values is shown. Each part analyzed shall include the following:

- A problem statement and a summary of the results
- A sketch of the part
- Material specifications including heat treatment specifications
- Pertinent drawing numbers used to develop the sketch
- Material and section properties relevant to the analysis

- Results compared to allowables

Sketches must show sufficient detail to illustrate the analysis and provide the following data where applicable:

- Orientation and references and/or axes
- Pertinent dimensions
- Location and magnitude of the resultant loads and weights
- Shear and moment diagrams for worst case loading conditions
- Airflow direction

Section properties for varying cross sections shall be computed at an adequate number of stations to show that the worst case, in terms of resulting stresses, has been analyzed.

4.2 PRIMARY, INCREMENTAL PEAK, AND SECONDARY STRESSES

Categorize general static stresses for comparison with the allowable stresses.

Primary stresses are due to externally applied loads that are required for equilibrium and that typically would cause the parts to move if they fractured. Primary loading produces bending or other higher order stress gradients that act across a large section of a part. Thermal stresses and stress concentrations shall be considered as appropriate.

Incremental Peak stresses are defined as the additional incremental stresses that are added to primary stresses to give the total stress concentration areas: examples include a fillet or a hole. The basic characteristic of this stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture.

Secondary stresses are those that are self-limiting in nature: a failure of one application of these stresses acting on a ductile material is not expected. They are local and their distortions could relieve the loading mechanism. These include thermal stresses and structural discontinuity stresses such as fit-up stresses and local weld yield stresses.

4.3 COMPUTER PROGRAMS

Analyses using computer programs shall follow the same documentation requirements as hand calculations, with sketches, except that formula descriptions are not required when comprehensive program manuals can be available to the NFAC staff. The complete final printout should be included in the report.

4.4 COMPUTER GENERATED FINITE ELEMENT ANALYSIS

Finite Element Method (FEM) analyses, using a computer program, should be performed using the MSC/NASTRAN program. If other FEM programs are used, then the stress analysis report shall contain a description of the model and the results using MSC/NASTRAN terminology. When requested, a copy of the FEM program manuals shall be made available for use by the NFAC staff.

The FEM analysis shall be documented by plots of the model, tabular or graphic summaries of stress data, and a copy of relevant input data describing model assumptions, boundary conditions, loads, and material and section properties. Where feasible, this information should be shown on sketches or plots.

FEM analyses must show the correct overall results using any of the following methods:

- by showing agreement with other theory for simplified loading
- by comparisons to solutions from other FEM models
- by broad agreement with known analytic solutions
- by FEM model convergence comparisons

Additionally, checks on model results, such as total weight and equilibrium checks, should be made. When requested, dynamic models, such as propeller and rotor, should have the first few modal frequencies checked by testing before tunnel entry.

The degree of refinement of a FEM mesh will vary to suit the analysis purpose. A measure of the accuracy of a FEM model is the difference in stresses computed at the same grid point from the adjacent elements. A coarse mesh may be used for approximate stress results providing that other models or stress concentration factors are used to estimate local stresses from the FEM results for fatigue analyses.

4.5 STATIC TESTS TO SUPPLEMENT STATIC STRESS ANALYSIS

The User may use static tests to supplement a static stress analysis and design when such an analysis is not feasible because of the structural complexity or non-linearity of the model. To make this substitution, a request for a waiver must be submitted to the NFAC Operations Branch Chief. The User must clearly define the need for the waiver in the Design Analysis Report. In addition, the design package must include a description of all necessary fixtures and equipment needed to perform the test.

The test shall meet the requirements for static acceptance tests described below and in Section 4.8 of this appendix with the exception that the test load factor shall be determined as follows:

- Verified Service Loads - When primary loads are verified by instrumentation during initial system loading, the test loads shall be carried to twice the predicted operating load.

- Service Loads Not Verified - When primary loads will not be verified by instrumentation, the static test shall be carried to three times the predicted load. This loading should be carefully monitored to prevent permanent set during the test. Failure to meet this criterion may result in the need to verify service loads as stated above.

Fatigue strength of metallic materials cannot be validated by static test. Therefore, a static test cannot be substituted for a fatigue analysis or for prototype fatigue analysis.

Fatigue strength of some composite materials can be substantiated with static testing. Composite materials and equivalent static testing proposed will be considered on an individual basis for specific applications.

4.6 FATIGUE ANALYSES AND TESTING

All critical structural parts that have oscillating or unsteady loads exceeding the endurance limit shall be analyzed or tested for fatigue.

Designs that provide for "infinite life", which is usually taken as 10 million cycles for steel, are favored over other designs.

The fatigue analysis is performed with the peak, mean, and alternating stresses. This is the sum of the primary, secondary, and incremental peak stresses as defined in Section 3.2.7 of this appendix.

A fatigue analysis as described here is performed with the assumption that no cracks exist in the structure. However, if a life analysis for crack propagation that meets the requirements of Section 4.8 is performed, then a conventional fatigue analysis is not required.

NOTE: Aluminum does not have a well defined endurance limit; therefore, materials with longer fatigue lives may need to be considered.

Some parts have complex fatigue loadings that are beyond the capability of current analysis methods. For these cases, testing of prototypes is highly recommended. Also, it may be necessary to test prototypes when no data can be found to adequately represent the material condition, the surface condition, the stress/strain concentrations, or the non-linear structure responses.

When performed, fatigue testing shall demonstrate the integrity of the part and that the service life exceeds the service lifetime by safety factors specified in Section 5.3 of this Appendix.

Parts similar to the tested parts shall be strain gaged and closely monitored for cracking during wind tunnel testing. Inspection intervals shall be at a minimum of one eighth of the fatigue testlife of the part.

4.7 STATIC ACCEPTANCE TESTS

A static acceptance test is especially recommended for complex parts or structures that present higher than normal hazards to personnel or the facilities. The test is a quality control test used to demonstrate the design adequacy and the structural strength of as-fabricated parts or structures.

The test loading should be carried to a minimum of 1.5 times the maximum service loading.

The static loads shall simulate those developed in the critical sections of the part during actual operation. The manner of loading and the required monitoring measurements, such as deflection measurement points, shall be described in the Design Analysis Report.

Measured deflection should not indicate a permanent set during the test. Plots of loads versus deflections for a complete loading cycle, including the starting and ending zero points, shall be provided in the test report.

A post-test inspection, in addition to a pre-test inspection, of critical weld joints using the methods discussed is recommended for new structures.

4.8 CRACKED PARTS AND SPECIAL REQUIREMENTS

Ordinarily, critical parts that are flawed or cracked parts are not acceptable for use in models. However, it is recognized that all fabricated parts potentially can have flaws, some of which will do no harm in service. Flaws in parts, which exceed the acceptance criteria given earlier or which cannot be repaired, may be used if a fracture evaluation, as described in Section 12, demonstrates that the part will be safe. To use this option, the User must clearly define the need for this approach in the Design Analysis Report and during review. When a critical part develops a crack during testing, the User must, in addition to performing the analysis, request a waiver from the NFAC Operations Branch Chief before continuing use of the part.

5.0 MATERIAL DATA

5.1 MECHANICAL PROPERTIES

Where applicable, obtain the material properties for fabricated parts from the latest issue of acceptable standards and codes listed below. Other sources, such as the Handbooks listed for other specification sources, may be used if the material data are not available in the standards. Minimum specified strength data shall be used if available. Otherwise, 99% reliability minimum values, which may be estimated as 80% of the mean data, shall be used. For fatigue values, use the minimum value data.

All the mechanical properties used shall be corrected for temperature and other significant environmental effects.

The following standards and codes are acceptable:

- American Society of Testing and Materials (ASTM) Specifications (These give minimum strength data.)
- MIL-HDBK-5, "Metallic Materials and Elements for Aerospace Vehicle Structures," (Use the S or the A strength values in this reference.)
- "ANSI/AWS D1.1 Structural Welding Code - Steel," Sections 9.4 and 10.7 for steel weld fatigue data, and Table 4.1.1 for filler metal data.
- "Specifications for Aluminum Structures, Construction manual series, Section 1," Table 3.3.1a for aluminum alloys, Table 3.3.2 for welded aluminum alloys, and Section 4.8 for weld fatigue data.

Other specification sources are:

- *Structural Alloys Handbook*, Volumes 1 and 2
- *Aerospace Structural Metals Handbook*, Volumes 1, 2, and 3
- Damage Tolerant Design Handbook, A Compilation of Fracture and Crack Growth for High-Strength Alloys, MCIC-HB-01R.

To avoid failures from continually stressed parts that operate in aggressive environments, such as those with residual stresses, materials that are insensitive to stress corrosion should be selected. A useful compilation of acceptable and unacceptable materials is in MSFC-SPEC-522A (See 27).

Recommended Materials

The following is a list of materials that the NFAC staff use regularly for model design and facility modifications. The User is not limited to these materials, however, these are generally available for use when problems arise at the NFAC Facilities and quick response is desired from our fabrication shops.

MATERIAL	USE
LOW CARBON STEEL	
ASTM A36	Structural Sections.
Mild Steel	General Structural (low strength) applications.
ALLOY STEEL-HIGH STRENGTH	
AISI 4130	Weldments, and small machined parts.
AISI 4340	General structural, forgings, and machined parts.
AISI 9310	Carburized parts, gears, journals, high hardness for wear. 18% Nickle maraging for extra high strength applications.
AISI 1095	Springs
STAINLESS STEEL	
301	Sheet, spot weld only.
302	Machined parts, springs, no welding.
321	Elevated temperatures, welded applications.
304	Tubing for hydraulic system.
4400	High hardness, heat treatable for wear applications.

17-4PH	Heat treatable (at Ames) weldable.
TITANIUM	
Unalloyed TL	Fire walls
6AL-4V	High Strengths, sheet, forgings, machined parts.
ALUMINUM ALLOYS	
2024	General structural, machined parts, spot weld only.
6061	Weldments, machined parts, hydraulic tubing (weldable).
7075	High strength, machined parts, spot weld only.
3003	Drawing, spinning.

NOTE: For material suggestions for high pressure piping and pressure vessels see Section 7.0.

5.2 STATIC LOAD ALLOWABLE STRESSES

5.2.1 Ductile Materials

The allowable stress for tension, shear, bending, torsion, and buckling shall be computed as the lesser of the following stresses.

- Use the tensile yield strength divided by a safety factor of three (3.0) to calculate the allowable stress factor.
- Use the ultimate tensile strength divided by a safety factor of five (5.0) to calculate the allowable stress factor.
- The applied Primary stresses shall not exceed the allowable material stress, and the sum of the Primary plus the Secondary stresses shall not exceed three (3.0) times the allowable stress.

NOTE: The Incremental Peak Stresses due to stress concentration effects and fatigue analysis are not included in the evaluation of allowable stress.

For multi-axial stresses, use either the Von Mises-Hencky theory, the Maximum Shear theory, or the Tresca theory to compute an equivalent uniaxial stress to use in comparison to the allowable stress. NFAC can furnish these references if they are needed.

For an alternative to the static allowable stresses of three (3.0) for yield and five (5.0) for ultimate strength, refer to the Alternative Design Guide in Section 12.0.

5.2.2 Brittle Materials

The ultimate strength divided by a safety factor of ten (10.0) yields the allowable stress. For the applicable stress, total the Primary, the Secondary, and the Incremental Peak stresses including those due to stress concentration. This total must not exceed the allowable stress.

For calculating the multi-axial stress conditions of uncracked parts, use the Coulomb-Mohr Theory. When calculated, the principle stresses shall not exceed the failure line reached when using the ultimate stresses divided by the safety factor of ten (10.0).

5.2.3 Bearing

Bearing allowable stresses may be used for those cases where the stresses are dissipating as they extend into the material, such as a pin loading hole or for simple compression where stability is not a concern. Bearing stress computations assume the projected areas are in surface contact with machined tolerance surfaces.

The allowable primary stress for materials loaded by bearing, with or without stress types, shall be computed as either the bearing strength divided by a safety factor of 1.5 or, when the bearing strength is not known, the yield strength with a safety factor of one (1.0).

5.2.4 Buckling

<u>Standard Shapes</u>

Standard shapes with buckling loadings described by the AISC publication, *Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings*, shall not exceed the AISC allowable stress values. Aluminum shapes subject to buckling shall not exceed the allowable stresses listed in the *Specifications for Aluminum Structures Construction* manual series, Section 1.

Fabricated Shapes

The primary compressive stress in flat plates, columns, and beam columns shall be computed in one of two ways:

- Using the allowable stress for an equivalent structure with the design formula from the manuals referenced above
- Using the critical linear theory of Buckling stress divided by a safety factor of two (2.0).

The critical, linear-theory, buckling stress may be derived by using the linear finite element analyses or by formulas. The *Guide to Stability Design Criteria for Metal Structures* 3rd or 4th edition contains general compilation of formulas and is an authoritative text.

Shells

The buckling behavior of shells is very different from that of the shapes covered in the previous paragraph because shells typically show a precipitous drop in strength after the instability point is reached. Therefore, use both the primary and the significant displacement secondary loadings for shell buckling calculations. Additionally, many shell loadings show a large decrease in actual or theoretical critical loading as a result of initial imperfections and other, lesser factors. For example, the "knockdown" factors for axial compression of intermediate length cylinders, and for spheres under external pressure, may be larger than 5 to 1. Several of the listed references contain useful summaries that should help define the elastic buckling load and the required knockdown factor.

Shells that are designed in conformance to the American Society of Mechanical Engineers (ASME) Code are acceptable provided that these shells are fabricated to meet the ASME shell imperfection tolerances. Loadings or structures that are not covered by this code must be designed to meet the criteria defined in the following paragraph.

The allowable load for shells not covered by the ASME code shall be the estimated buckling load divided by a safety factor of three (3). The estimated buckling load is the linear theory value times the appropriate knock-down factor on the linear theory as given in the shell buckling references cited above. For combined types of loads, a suitable stress interaction formula shall be used such as the ones discussed in reference 17.

To predict the linear theory buckling load use the linear finite element analysis of shells provided that similar modeling procedures have been shown to produce accurate results for similar problems with known solutions. Apply appropriate knock-down factors to the finite element results to obtain the estimated buckling load. If the analysis method produces lower bound estimates of the linear buckling load, then the allowable buckling load shall be the estimated buckling load divided by a safety factor of 2.5.

Nonlinear, finite-element analyses are more complex, and also require verification by analysis of known problems. The analysis must include the effects of all significant factors which may include the following:

- the worst tolerance imperfections to be allowed during fabrication
- the residual stresses
- the nonlinear material behavior
- the analysis of large displacements and rotations

Analyses that predict lower bound estimates of buckling load may use a safety factor of 2.5 to obtain the allowable load.

5.3 FATIGUE REQUIREMENTS FOR MATERIAL TESTING

This section specifies the fatigue values allowed; it does not include those values for welded structures. Those are treated separately in Section 5.5.

To perform a material fatigue strength analysis, use the lower bound or minimum fatigue strengths given in the references listed in Section 4.1 or use test data that uses the allowable limits specified below. The "Rules of Thumb" relating tensile strengths to endurance limits are frequently wrong and should not be used without supporting evidence to show that the ratio used matches known data for a similar material. For example, the use of Se = 0.5 x UTS will be in error for many steels. A conservative lower bound is 0.3 x UTS as shown in reference 16 page 70.

If no data on fatigue strength can be found after an exhaustive search, there are three alternatives:

- make a conservative comparison with data for similar material
- test the material
- use another material.

A safety factor of 2.5 on alternating stress is required. No safety factor is applied to the mean stress since it is a secondary factor in the fatigue failure. For finite life, fewer than 10 million cycles design, use the more conservative result from either a safety factor of 20 on the calculated life or a safety factor of 2.5 on alternating stress. Fatigue calculation details are given in Section 11.2 of this document.

For cases where prototype test data representing the actual material, surface condition, stress concentrations, and mean stress are available, the required safety factors are given below. The use of at least three tests is encouraged. A smaller number of tests should be used only when sufficient parts to complete the test are not available or if an extreme cost is involved in producing the test parts.

The more conservative result shall be used when applying either the safety factor on stress or the factor on life to the lowest value of the test data. The required factors are listed in Table C - 1.

No. Fatigue Tests	1	2	3	4	5 or more
Stress safety factor	1.50	1.40	1.35	1.30	1.25
Life safety factor	10.0	7.0	6.0	5.0	4.0

Table C-1

Required Safety Factors

To reach the desired levels for a single test, the test should be performed with the actual mean stress, and 1.50 times the alternating stress. It should also demonstrate a life equal to or greater than ten (10) times the required life.

For multiple tests, perform the test at an elevated loading level that is as high or higher than the required safety factor. The test shall show a life equal to or greater than the required safety factor times the required life for all of the tests. If low values are obtained in multiple tests, then the low value results shall be used to determine the allowable stresses and life using the appropriate safety factors for the number of tests.

Accelerating testing, where the stress safety levels are increased to reduce life and shorten testing time, may only be used in cases where the fatigue mechanisms are well known and test data for similar conditions is well established to allow accurate prediction of the equivalent stress safety factor.

5.4 THREADED FASTENER REQUIREMENTS

Allowable stresses in threaded fasteners shall be based on the requirements for ductile materials given in Section 5.2.1 of this appendix, regardless of the fastener material category. Static strength calculations shall show that the fastener meets the required safety factors on operating loads without consideration of pre-load. Fatigue is usually not a consideration and is not a required calculation for "rigid" metal-to-metal joints due to the effect of the required pre-load. However, flexible, soft joints may include pre-load effects.

Secondary loads, such as bending from nonparallel surfaces, should be eliminated by proper design or beveled washers and are not considered since it is expected that the bolt will fail from secondary stresses during application of the pre-load rather than in service. See Section 6.4 of this appendix for other fastener requirements on pre-load, design, and required fastener material grades.

5.5 WELD ALLOWABLE STRESSES

The static load allowable for primary and secondary stresses of welded joints shall not exceed the allowable stresses for the base metals or the filler materials. Incremental stresses are not included since the weld contour stress concentrations usually dominate any other stress risers, and because the joint shape effects are covered by the weld categories in the fatigue tables.

NOTE: For some materials, such as aluminum, the weld strength may be reduced when compared to the parent material. For these materials, use the strength data referenced in Section 5.2 to compute allowable static stresses.

The stress areas are defined in detail for complex welds in Section 2.3 of the ANSI/AWS d.1.1-xx, *Structural Welding Code - Steel.* For most welds, the stress area is the minimum throat size times the weld length regardless of the direction of the applied load.

The weld-fatigue allowable stresses for steel shall be those supplied in the AWS code:

- Section 9 for Bridges
- Section 10.7 for Tubular Structures, but with the AWS stresses divided by a safety factor of two (2.0)

NOTE: The AWS code uses the stress range, equal to the maximum minus the minimum stress, as the design fatigue stress. The applied mean stress is not considered, since the residual weld stress dominates any applied mean stress.

The allowable fatigue stresses for Aluminum shall be those specified in the ANSI/AWS D1.2 - xx, *Structural Welding Code - Aluminum*, Sections 9 and 10 that refer to the *Specifications for Aluminum Structures Construction Manual* series Section 1 and Section 4.8 except where the allowable stresses shall be the tabulated stress ranges divided by a safety factor of 2.0.

NOTE: This information is based on 95% lower confidence bounds data presented in reference 34.

No specific weld fatigue requirements are made for other materials due to the lack of qualified data or codes. However, a comparable approach shall be used based on available weld test data. A lower confidence limit at 95% of the test data shall be defined and a safety factor of two (2.0) shall be applied to this lower boundary to compute allowable stresses.

5.6 REDUCED SAFETY FACTORS

For specialized models, weight critical structures, cases where a larger structure is unacceptable, cases where model size increases the risk of structural failure, alternative design classifications with lower safety factors are available from the NFAC Operations Branch. To use these options, the User must justify the need for reduced safety factors in the design analysis report and during Design Reviews. In addition, the consent of the NFAC Operations Branch Chief is required, and the requirements for the design class that is used must be met (See Section 11, Supplemental Design Guide).

6.0 STRUCTURAL JOINTS

6.1 MECHANICAL STRUCTURAL JOINTS

The following design requirements apply to bolted structural joints .

- Joint Pre-loads - A sufficient number of bolts shall be provided with pre-loads so that the net joint pre-load for all loadings shall be at least two (2) times the operating loads.

- Bolt Pre-loads - A pre-load of 75% of the bolt proof load is recommended for metal-to-metal structural joints. For "soft" joints a pre-load of 50% of the bolt proof load is recommended. These pre-loads are not included when computing the allowable bolt stresses as defined in Section 5.4.

- Fastener Strength - All steel threaded fasteners shall have a tensile strength of 105 ksi (SAE Grade 5) or higher. All fasteners shall have strength identification markings. The National Aerospace Standards (NAS) and Military Standards (MS) fastener specifications are preferred for all critical applications because they have specifications to material and dimensional control, inspections, and strengths.

- Thread - If fasteners other than NAS approved are used, then coarse threaded fasteners are recommended for most structural applications over one half (1/2) inch in diameter.

- Torque - Torque values used to generate the required bolt pre-loads shall be computed and shall appear on assembly drawings.

NOTE: Some hexagonal-socket head screws are not suitable for applying torque from the head side. An example of these are the NAS 333 thru 340, 100 degree close tolerance hexagonal-socket head screws. Use NAS 2803-2810 "Torque" set type of fasteners instead.

- Galling - To prevent galling stainless steel, mating threaded parts should have different hardness levels.

- Locking Devices - All fasteners that will be subjected to vibration shall be provided with mechanical locking devices such as castle nuts with cotter keys, safety wiring, and mechanical staking. Locknuts with deformed threads are acceptable provided that they are replaced after each use. Use of plastic insert locknuts and chemical locking compounds are subject to NFAC staff approval.

Calculations for thread pull out strength (shear) shall assume that all of the load is resisted by the thread engagement equivalent to one bolt diameter and that seventy-five (75%) of the load is carried by the first three threads. The acting stress is calculated as follows:

(Bolt circumference) x (thread depth) x .50 x (load) = Stress

The allowable stress is calculated as follows:

(Yield Stress of weaker material) x 1/3 x .57. = Allowable Stress

A safety factor of 3 on yield is required. Allowable thread shear during torquing is calculated as follows:

(Yield Stress of the weaker material) x .57 = Allowable Stress

No safety factor is required for this stress.

- Tapped Holes - The thread engagement in tapped holes shall be a minimum of one bolt diameter. Thread pullout strength should be at least 1.33 times the bolt strength (See below). Thread inserts are recommended for "soft " materials such as aluminum and plastics to improve pullout strength and wear resistance in repeated use applications. Nuts shall engage bolts for the full thickness of the nut with two or more threads exposed.

- Documentation - Assembly drawings and specifications shall list the grade, part number, pre-load torque, and locking method for all fasteners.

- Shear Loads - All shear loads shall be transmitted by keys, pins, pilots, or bolts. Shoulder bolts are preferable when bolts are used. Joints in critical structures that use friction to transfer loads are allowed, provided that the fasteners are designed to carry the full shear load. The load includes safety factors, without any friction, without elongated holes, or oversized holes beyond the usual clearance size. Friction slip joints are not allowed on any critical structural joint.

- Alignment - Mating surfaces shall be aligned or modified by counterbores, spot faces, countersinks, or spacers to eliminate bolt bending and prying.

6.2 WELDED STRUCTURAL JOINT REQUIREMENTS

Welded structural joints shall meet the welding design requirements for the applicable code such as the AWS or ASME codes. Stress relief of joints is recommended wherever possible. Welding of materials not covered by a code require special welding and joint design.

6.3 ADHESIVE JOINT REQUIREMENTS

The use of adhesives for structural joints is not recommended. Specific applications of adhesives for joining materials to model surfaces are acceptable for many applications. Joints should be designed to transmit loads in shear with no tension perpendicular to the glued joint.

Those applications that may require adhesives for structural joints will be addressed on an individual basis. Materials, adhesive characteristics, and empirical testing of joint design shall be submitted for review by the NFAC staff.

6.4 RIVETED JOINT REQUIREMENTS

6.4.1 Solid Rivets

Solid one piece rivets shall be designed in accordance with *Mil Handbook Five (5)*. Protruding head rivets are preferred over flush-head rivets for structural applications. Tensile and shearing strength of the rivet and bearing and tearing strength of the sheet must be addressed in the Design Analysis Report. Increased attention should be given to flush-head and machine countersunk joints because of the uncertainty of empirical testing data and the difficulty in predicting service life.

The User shall give careful consideration to, and annotate on the drawings, specific hole diameters for rivet installation. The diameter of the upset rivet head should be at least 1.3 times the maximum shank diameter, and head heights are to be a minimum of 0.3 times the diameter.

6.4.2 Blind Fasteners

The only means of insuring proper installation when using blind fasteners is the inspection of the rivet head and the stem. Careful consideration should be given to the details of the mechanical clamping mechanism of the rivet, the hole diameter, and the rivet's interaction with the materials being fastened.

Tensile and bearing values used for design of riveted connections shall be developed empirically for each type of rivet, each material fastened, the stacking heights, and the configuration of each stack used.

Proper grip length shall be specified for each stacking height. Stacking heights shall be determined from the actual gauge thickness of materials used in the installation.

Tests shall be conducted in accordance with the *Mil Handbook Five (5).* Values used shall be developed from the maximum hole size permitted for each installation. Test results for all connections shall be made a part of the engineer's calculations for determining the capacities of the rivet and parent materials.

The manufacturer's existing test reports for rivet capacities may be used if tests performed comply with *Mil Handbook Five (5).*

<u>Rivet Installation</u>

The User must annotate installation procedures on drawings that give specific instructions for installing the rivets. Manufacturers specifications may be used to develop the specification, but these should not be referenced as the only specifications i.e. install per manufacturers specifications, is not acceptable.

Items of concern include the adjustment of the pulling tool, the installation of the proper rivet for grip length, the maximum diameter of hole permitted for installation, the break off point of the rivet, and the variance between manufacturing lots of identical rivets.

Manufacturer's fabrication tolerances for rivets are somewhat lenient between fabrication lots, and these tolerances have a direct effect on the adjustments of the pulling tool and the break off point of the rivet.

Inspection instructions on the drawings should give explicit acceptance criterion for the break-off tolerance, the hole alignment, the rivet alignment, and the pull up between sheets.

The drawings shall be annotated to indicate that all inspections should be performed before painting over the rivet head.

7.0 MECHANICAL DESIGN PRACTICES

7.1 ROTATING MACHINERY

Rotating Machinery should meet the following requirements:

- When practical, vendor parts such as motors, gearboxes, and shafting should all be selected for 200% of maximum operating torque.
- Self aligning bearings and couplings should be used whenever possible.
- Taper-lock type shaft mountings are preferred in lieu of press-on mountings due to their ease of disassembly. Typical taper angles are 8°; keys are relied upon for torque transfer.
- All mounting surfaces should be designed to accommodate alignment. Machined surfaces shall be specified on the design drawings.

7.2 DESIGNS WITH MOVABLE PARTS

Designs with movable parts should meet the following requirements where they are applicable.

- Designs with movable parts that can impact other structures, or that can effect the loads acting on other parts, should have positive mechanical stops provided at each end of the planned travel.
- Provisions should be made for lubrication of all mechanisms, and a suitable lubricant should be specified.
- Mechanisms should have provisions for adjustments through the use of shims or adjusting screws.

8.0 PRESSURE SYSTEMS

Pressure systems include models, support equipment, and pressure vessels that use hydraulics, pneumatics, propulsion, and other liquids and gasses at pressures greater than 15 psig. The pressure systems shall be designed to the *ASME Boiler and Pressure Vessel Code* (ref.1), the *ANSI Code for Threads, Flanges, Fittings, Fasteners, Power Piping, etc.* (ref. 15), and the

Ames Health and Safety Manual, AHB 1700-1, Chapter 10 (ref. 7). These design codes serve best as a guide in the design process, and their use should be standard practice. However, there are situations and specific applications where a design can not meet code; in those situations waivers can be requested from the NFAC Operations Branch Chief.

The intent of the Pressure Vessel Code is to protect personnel and facilities in the event of a pressure vessel failure. Protection of personnel is paramount to NFAC. Three measures accomplish this: adhering to code requirements; using the model for containment by limiting damage to the model; removing personnel from the test area.

A major design factor to consider in preventing catastrophic failures is material ductility. Materials with higher ductility characteristics will fail in tearing. The vessel will tend to remain intact without the emission of shrapnel.

When the User has a specific design that deviates from code guidelines, the reasons for deviation must be discussed during Design Reviews, and the documentation must include the design engineering logic in the Design Analysis Report. A request for waiver is required from the NFAC Operations Branch Chief and, in some cases, the Chairman of the Pressure Systems Safety Committee at Ames.

8.1 DEFINITION OF PRESSURE VESSELS VERSUS PIPING

Pressure vessels may take a wide variety of shapes and forms. Components that are shells, chambers, tanks, ducts, or pipes whose inside diameter is greater than six inches are considered pressure vessels. In addition to standard pressure piping, internal supply tubing for models shall also be considered to be pressure piping.

8.2 MATERIALS

There are a number of materials that can be used and are acceptable for ductile design. Recommended materials and allowable stresses are given in the ASME Boiler and Pressure Vessel Code in Section 8, Division 1, Subsection C, and the ANSI Code for Pressure Piping, B31.1, Tables A1 through A7.

The NFAC preferrers the following for Piping:

- For High Pressure Air > 500 psi, use A106B Seamless
- For Low Pressure Air < 500 psi, use A53B Seamless or Welded
- For Shop Air 150 psi or less, use A120 Welded

Tube materials should be Stainless Steel TP 304 or 316. Swage Lock fittings are the only tube swaged fittings acceptable to NFAC.

8.3 DESIGN AND ALLOWABLE STRESSES

Code allowable stress shall be used for all designs. Deviations shall be addressed through the waiver process.

8.4 PRESSURE TESTS

Pressure systems shall be hydraulically tested in accordance with *The Ames Health and Safety Manual,* Chapter 10. Basic requirements are for service inspection and testing of the system hydraulically to 1.5 times the relief valve pressure setting. Gas testing requires the waiver process but permits testing of the system to 1.25 times the maximum allowable working pressure.

8.5 RELIEF DEVICES

Relief devices are required on all pressure vessels. These devices shall be capable of discharging the full flow of the pressure source under all conditions. Valve closures may not isolate relief devices from protecting the system.

8.6 SERVICE LINE IDENTIFICATION

Service lines shall be identified for working pressures, flow direction (in or out), and the substance carried (fluid or gas). Color coding is required for complex and multiple piping. Loose lines for installations separate from models and lines for interfacing with NFAC systems shall be coded and identified with metal tags that are attached with wire.

All system components shall be identified with part numbers, working pressures, volumes, operating temperature ranges, pressure test data, and date of pressure test.

9.0 MODEL CONTROL SYSTEMS

Models tested in the tunnel are monitored and remotely controlled from the test section control room. The information displayed on the control console ensures the technician that the model is operating within the model's safe operating limits, and that it is operating properly. The console does not monitor the aerodynamics of the model or other test information that would distract the operator from his single task of proper, safe model control. In addition, the control console must have an abort button that will lock the model control system, and the console must also have a key switch that disables the control system. The following sections delineate the model control console and control system.

9.1 GENERAL GUIDELINES

All systems will be designed to "fail safe" or identified and protected by some other means (See Appendix B, Section 4.2).

The model will be operating in a vibrating, oil mist, dusty, and some times high humidity environment. The system must be designed to function in this environment safely and with minimal failure rate (See Sections 6.1 and 6.2 of the Test Planning Guide main text).

Control systems with a simple and straight forward design should be considered first. Complex circuits or systems will be considered only if needed to meet the requirements of the tunnel test.

9.2 MODEL CONTROL SYSTEMS ERROR DETECTION

When appropriate, the system shall have, as a minimum for error detection, an automatic lock up with the following error detection:

- Position error (position vs position)
- Following error (Command vs position)
- Velocity error (high speed)
- Hydraulic or electronic/electrical system failure
- Hardover command error

The cause of any lockup shall be announced and identified, and the error bands shall be adjustable. The tolerance and span of adjustability will be calculated by the User and approved by the NFAC staff.

9.3 CALIBRATION AND VERIFICATIONS

All calibrations and verifications will be subject to MIL-STD-45662 Calibration Systems Requirements.

Calibrations minimize and determine the error of the system being calibrated. Verifications assure that a system works correctly, and in addition they determine whether the system meets the pre-defined specifications. The NFAC staff will review all calibrations and verifications of control systems.

9.4 CONTROL SYSTEM REVIEW

Final control system design shall be submitted, with all other documentation, at the Critical Design Review. The NFAC staff shall review the total system with a complete set of documentation. Part of this documentation must include an operations manual that presents the required control and safety interlock information needed to provide a safe and practical control system.

9.5 DOCUMENTATION REQUIREMENTS

Documentation must include the following items:

- A system description
- A hardware theory of operation
- A complete functional block diagram of the system that shows the essentials of the mechanical and the electrical system with a clear explanation of the system operation
- A complete set of schematics and wiring diagrams of the system
- A failure analysis of all systems, and a component failure analysis if a system failure is single point and a critical function
- A wiring diagram of each unit of equipment supplied by the User
- An interconnecting drawing that links all equipment and shows the connections at all connectors or terminal strips.
- A complete set of set-up, calibration, and verification procedures for the total system and the individual components
- Copies of all test procedures, test data, and results of tests
- The calibrations and verifications results
- A review of system stability
- A list of all parameters on the control system
- Identification of all alarms and value alarm limits
- A listing of the maximum limits of all parameters
- A listing of the operating range of all parameters

9.6 CONFIGURATION CONTROL

A configuration change is defined as any change to equipment that deviates from the original design. Minor circuit changes such as the insertion of instruments for measurements are not generally considered configuration changes. All configuration changes to any circuit or system are subject to a change request and will be critically reviewed by the NFAC staff. Refer to Section 2.6 of the main text for further information on Documentation.

9.7 OTHER APPLICABLE STANDARDS

The model control system must meet the following standards and guidelines as applicable:

- Underwriters Laboratory (UL)
- National Electrical Code (NEC)
- Aircraft standards as applicable
- NFAC Configuration Management Plan
- OSHA and the *Ames Health and Safety Manual*
- Grounding and shielding methods as defined by NASA
- All control systems wiring shall conform to MIL-Std 454

Electromagnetic interference (EMI) must not effect adjacent lab instrumentation, so appropriate EMI shielding must minimize EMI levels.

All interconnecting wiring should be twisted-shielded pairs that meet Belden 87xx series specifications or equal.

9.8 INSPECTIONS AND TESTS

NFAC reserves the right to perform any inspections or tests necessary to assure that all systems conform to prescribed requirements.

User quality assurance personnel shall perform or verify all inspections, tests, calibrations, and verifications.

10.0 INSPECTION REQUIREMENTS

10.1 INSPECTION REQUIREMENTS

NFAC shall specify the type of inspection and the acceptance criteria for all designs to meet the requirements stated in Section 9.0 of this Appendix.

All finished parts, critical and noncritical, shall receive a visual inspection as defined below.

All critical structural parts, except as noted below, shall be inspected for cracks and other possible defects using the appropriate NDE method described in Sections 9.3.2 or 9.3.3 in this appendix.

10.1.1 Welds

Except as noted below, 100% of all critical welds shall be inspected. Fillet welds and welds in thin materials, 1/4 inch or less, may use only a surface inspection method. Welds in thick materials, more than 1/4 inch, shall use both a surface NDE and an NDE for internal defects. Additionally, all critical welds shall meet the requirements for visual inspection in the appropriate ANSI/AWS codes.

The 100% weld inspection rule may be relaxed where a large amount of welding is involved and a proven, quality controlled process is used. In this case, the amount of inspection should be determined by the User, and this should be discussed during a Design Review on a case by case basis to ensure that every welding process has adequate inspection. However, in no case shall less than 10% of the welds be inspected. Also, if the inspections used demonstrate that an unreliable welding technique is being used, then 100% of the welds shall be inspected.

10.1.2 Raw Materials and Finished Parts

NDE inspection of the raw materials or finished critical parts is not a general requirement. The need for this type of inspection is left for the User to define depending on the material source and the criticality of the application.

As a guideline, it is advisable to inspect castings, forgings, and very thick plates that may have such defects as porosity, forging laps, delaminations, or cracks. Critical parts made from thin rolled materials are less likely to contain hidden cracks, but it may be advisable to inspect the critical regions of these parts also.

Also, inspection for internal defects is usually best performed on a raw material due to the simpler shapes involved. In addition, raw material inspection allows rejection of bad materials before any costly operations are performed on them. Surface inspection of a finished product is useful to detect fabrication-induced flaws as well as previously buried flaws.

10.2 INSPECTION METHODS

A useful discussion of NDE methods is given in the Marshall Space Flight document MSFC-STD-1249. The ASME code Section V also describes NDE methods.

10.2.1 Visual Inspection

Visual inspection of welds shall meet the requirements in the appropriate ANSI/AWS codes.

Also a visual inspection shall check the overall quality of a part in relation to its function in addition to checking for defects.

Visual inspection of raw materials and finished parts has a definite value in overall quality control. While visual inspection is not a reliable method for crack detection in metallic parts; nevertheless, it has been known to detect large cracks in parts that were not otherwise inspected.

10.2.2 Internal Defects

The types of NDE to use for the detection of internal, volumetric defects include radiographic and ultrasonic straight beam and angle beam inspection techniques.

NOTE: Standard radiographic inspection will not reliably detect cracks. However, radiography is effective in characterizing volumetric defects such as porosity or lack of weld penetration that may lead to cracking.

The procedures are discussed in Section V of the *ASME Boiler and Pressure Vessel Code*. Also, refer to the ASME code Section VIII, Division 2. Military specifications are also available and are useful for special cases.

10.2.3 Surface Defects

The types of NDE used most for detection of defects that intersect the surface are magnetic particle for ferromagnetic materials and liquid penetrant methods. These procedures are discussed in Section V of the ASME code. Radiographic techniques are not usually reliable for the detection of surface cracks.

Penetrant methods should not be assumed to be effective on machined or mechanically disturbed surfaces unless any potential cracks have been opened by sufficiently large loading. The surface of the material must be chemically etched before inspection.

Special inspections that are used sometimes include eddy current and ultrasonic angle beam inspection methods. These methods require application-specific, calibration standards and procedures to be effective.

10.2.4 Inspection Reliability

The use of multiple inspections is recommended for non-destructive testing when it is imperative to locate cracks to a high reliability.

A properly conducted inspection performed by qualified inspectors may find 90% of the crack's that are detectable. These inspections give a 95% confidence level for very small surface cracks which are up to 1 1/2 inches long.

The size determination of cracks is also difficult. The use of calibration standards for predicted crack sizes and known geometry should be used to improve inspection results.

10.3 ACCEPTANCE CRITERIA

The acceptance criteria for all methods of inspection shall be as specified in a code such as the following:

- The American Welding Society's *Structural; Welding Code*. For steel use the steel version, ANSI/AWS D1.1-87, chapter 9 (Design of New Bridges) or chapter 10 (Tubular Structures).

  For Aluminum, use the aluminum version, ANSI/AWS D1.2-87, chapter 9 (Non-Tubular Dynamically Loaded Structures) and chapter 10 (Tubular Structures).

NOTE: No criteria or procedures for ultrasonic testing are given in this code.

  Ultrasonic testing of aluminum structures shall meet comparable criteria as used for steel structures as referenced above, or shall meet special acceptance criteria supplied by NFAC.

- *The ASME Boiler and Pressure Vessel Code,* Section VIII, Division 2, Article 1 - 5 and Appendices 8 and 9.

- Other acceptable references include military specifications.

NOTE: Some cracked parts may be allowed as special cases even though they would be rejected by these types of codes. Refer to Section 4.8 for the conditions that must be met for cracked parts.

10.4 SPECIAL INSPECTIONS

For some parts the standard inspection methods may not work. For these cases special inspections may be developed or provided by a manufacturer or defined through other documentation such as military standards. When this occurs, the inspection should be reviewed to ensure it is adequate and was calibrated by the detection of known defects that are of an acceptable size.

Nonmetallic material, such as composite structures, shall be inspected. No specific requirements for the inspection are made except that the inspection shall include all critical structural parts. It shall evaluate the structural parts and the structural integrity of the part using the best available methods.

11.0 SUPPLEMENTAL DESIGN GUIDE

The following sections are supplemental to the main body of this document. They provide elaboration of terms and/or methods referenced in this appendix.

11.1 MULTI-AXIAL STRESS FAILURE THEORIES

The following multi-axial failure theories are described here for reference. They are used elsewhere in the document to define allowable stresses.

11.1.1 Ductile Materials Multi-Axial Yielding

For multi-axial stresses, the following theories can be used to compute an equivalent uniaxial stress, S. When the equivalent stress, S, is equal to the yield stress in uniaxial tension, yielding is predicted.

- Von Mises-Hencky Theory:

  Equivalent Von Mises-Hencky stress S in terms of the principal stresses S_1, S_2, S_3 are:

$$S = \sqrt{\frac{(S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2}{2}}$$

  Or, in terms of the triaxial xyz stress subscripts:

$$S = \sqrt{\frac{(S_{xx} - S_{yy})^2 + (S_{yy} - S_{zz})^2 + (S_{zz} - S_{xx})^2 + 6 \times (S_{yz}{}^2 + S_{zx}{}^2 + S_{xy}{}^2)}{2}}$$

- Maximum Shear (or Tresca) Theory:

  Yielding occurs when the maximum shear stress reaches a critical value. So:

  $S = (S_1 - S_3)$

  where $S_1 > S_2 > S_3$ are the principal stresses, with tension positive, compression negative.

11.1.2 Brittle Materials Failure Theory

The best failure theory for predicting failure of brittle materials with multi-axial stresses is the Coulomb-Mohr Theory. This theory requires both tensile (S_{ut}) and compressive (S_{uc}) ultimate strength data. Typically, the compressive strength is much greater than the tensile strength for these materials, so it is conservative to use the tensile strength for compression if no data is available.

This theory is discussed on pp 240-242 of Shigley (ref. 35). The Coulomb-Mohr Theory, with failure data points, is shown by Figure 6-22 in reference 35. A representation of the figure is provided here as Figure C-2.

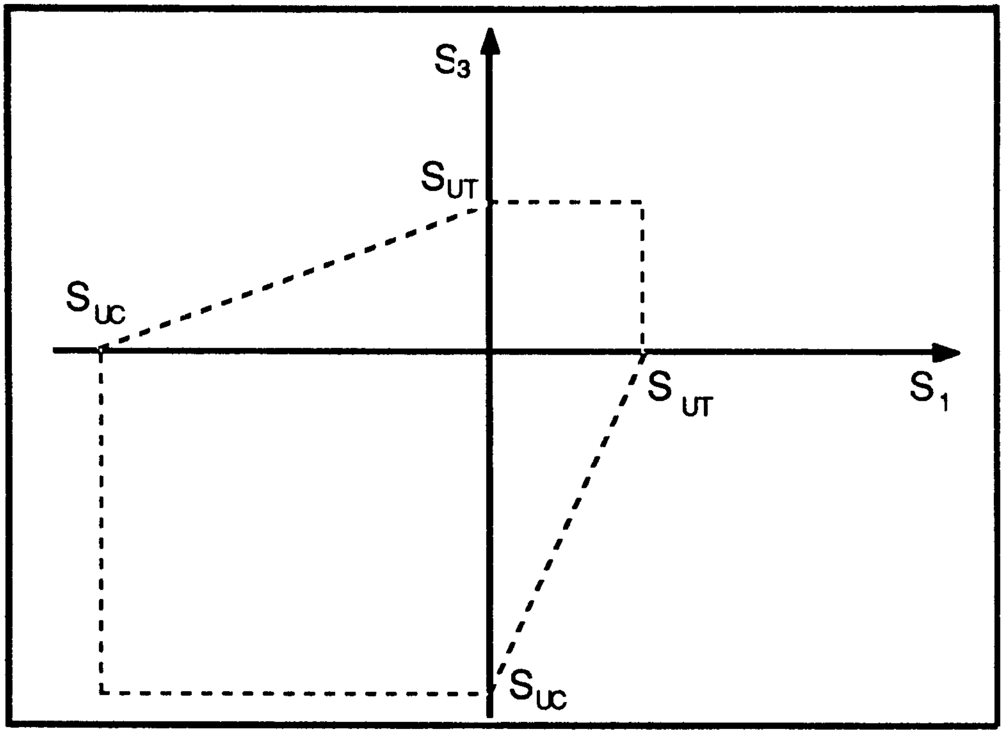


FIGURE C - 2

COULOMB-MOHR FAILURE LINE

The Coulomb-Mohr Theory is identical with the Maximum Normal Stress Theory for the first and third quadrants where the stresses are all tensile or all compressive. However, in the second and fourth quadrants, it is seen that the Coulomb-Mohr Theory is both more conservative and a better match to existing data. For the fourth quadrant, if the principal stresses are ordered so that $S_1 > S_2 > S_3$, then the failure line is given by the equation:

$$\frac{S_1}{S_{ut}} - \frac{S_3}{S_{uc}} = 1$$

which is simply the linear interpolation of the edges of the figure.

11.2 FATIGUE CALCULATIONS

This section provides the recommended methods of performing fatigue analyses. Other methods may be acceptable, provided that they can be shown to be at least as conservative as the procedures defined here. For designs near the endurance limit, the fatigue life may be computed by either the "S-N" approach, or the strain-life method. However, for the very low cycle fatigue regime where notch strains exceed the yield level, the strain-life method is the only viable method.

11.2.1 Definitions

The following terms are used in the discussion:

- S_{min} = the minimum stress of a cycle
- S_{max} = the maximum stress of a cycle
- S_{mean} = mean stress = $\frac{(Smax + Smin)}{2}$
- S_{alt} = alternating stress = $\frac{(Smax - Smin)}{2}$
- R ratio = stress ratio = $\frac{Smin}{Smax}$
- S_y = Uniaxial tensile yield stress
- UTS = Uniaxial ultimate tensile stress
- SCF = Stress Concentration Factor = Ratio of peak theoretical elastic stress to nominal elastic stress.
- S_e = endurance limit (For steels, S_e is typically at 10 million cycles; for aluminum, S_e may be 100 million or more)
- S_f = fatigue strength at a particular cyclic life
- S_f' = fatigue strength corrected for size effect, surface condition, and SCF effect.
- S_f'' = fatigue strength corrected for mean stress effect.

11.2.2 Constant Amplitude S-N Fatigue Life Design

This Fatigue Life calculation while being the oldest is also the best known, and most used method available. It is recommended as a simple method for high cycle or '"infinite life" fatigue design. To perform a calculation, the following information is needed:

- S_{mean} and S_{alt} stresses
- Cyclic service life requirement
- Material S-N curve
- Fatigue modifying factors to account for:
  * Surface Finish Factor
  * Size Factor
  * SCF (Stress Concentration Factor)

It is assumed that the stresses, SCF, and service life are known.

NOTE: No "reliability factor" is used, since this is included in the safety factor requirement.

The procedure sequence is:

1. Determine the fatigue strength, S_f, at the required life from the S-N data. The effect of any special conditions, such as elevated temperatures and/or damaging chemical environments, must be considered when selecting the relevant fatigue data. Typically, the S-N data are for fully reversing stress, i.e., R = -1. However, data for other R values may be used as discussed later.

2. Surface Effect - Correct the S_f for strength reduction due to surface finish that may be a significant factor in fatigue. The following factors affect the surface effect:
   - Surface roughness
   - Residual stresses induced into the surface by finishing processes
   - Changes in surface material such as work hardening of the surface and/or special coatings.

The best approach is to locate data that matches the material and finishing being used. Since these are rarely available, approximations may be used.

For steels up to 100 UTS, the factor for machined surfaces may be bounded by using a factor of 1.5. For more precise data on steel refer to references such as Shigley (ref. 35), pp. 288-291.

Data on aluminum are scarce. Data in reference 36 show a very strong effect of induced surface residual stresses. Other data by Frost (ref. 19), page 50, show a definite surface effect. The largest factor given by Frost is 1.2 for rough machined aluminum.

3. A size effect correction is also possibly needed. The size effect correction is mainly due to differences in stress fields between test specimens and parts. For axial loading fatigue test data, no size effect correction is needed.

   A conservative approximation to use for correcting rotating bending fatigue test data is given in reference 5 as:

$$\text{Size Factor} = 1.5 - 0.5 \times (LT/LP)$$

   (but is not less than 1.0)

   where the size ratio, LT/LP, is the ratio of test sample linear size, LT, to the part linear size, LP. For example, for the usual rotating beam test data, LT is .505 inch diameter, so the size ratio is .505/LP. LP may be taken as the smaller diameter in a part at a stress concentration due to a shaft shoulder.

4. SCF Effect. - Next, the SCF is used to further reduce the endurance strength. If S_f test data are available with a similar or larger SCF value, these data should be used instead of making this calculation correction . Reference 32 is a good source for theoretical SCF for many geometries. The resulting modified fatigue strength is computed as:

$$S_f' = S_f / [(\text{surface factor}) \times (\text{size factor}) \times (\text{SCF})]$$

NOTE: The SCF to be used is the theoretical elastic SCF. NO REDUCTION in the SCF is to be taken due to "material notch sensitivity effects" that are discussed in many references on fatigue, including references 35 and 32. These notch sensitivity factors are only useful with high cycle fatigue because at low cycle fatigue they give incorrect predictions. Also, for a well designed part, these factors yield only a minor advantage, and so it is conservative to ignore them. Furthermore, very sharp notches, where these factors do affect the predictions, should be analyzed by fracture mechanics methods since they are likely to quickly produce a crack.

5. Mean Stress Effect - The final correction to be made to S_f' is the mean stress effect. If test fatigue data are available for the same or larger mean stress with a similar or larger SCF, then it is best to use the test data instead of making this calculation.

   To compute the mean stress effect, a modified Goodman diagram is used as shown below in Figure C-3. When S_f' is derived from S_f data at R = -1, the ordinate is S_f' and the abscissa is the UTS. For calculations using other R, ratio test data, plot S_f' to match the test data S_{mean} value. Then the S_{mean} x SCF stress is used to enter the diagram abscissa and project over to the S_f'. This is given in equation form as:

$$S_f'' = S_f' \times \left(1.0 - \frac{SCF \times S_{mean}}{UTS} \right)$$

   where SCF x S_{mean} is never larger than $(S_y - S_f')/(1.0 - S_f'/UTS)$

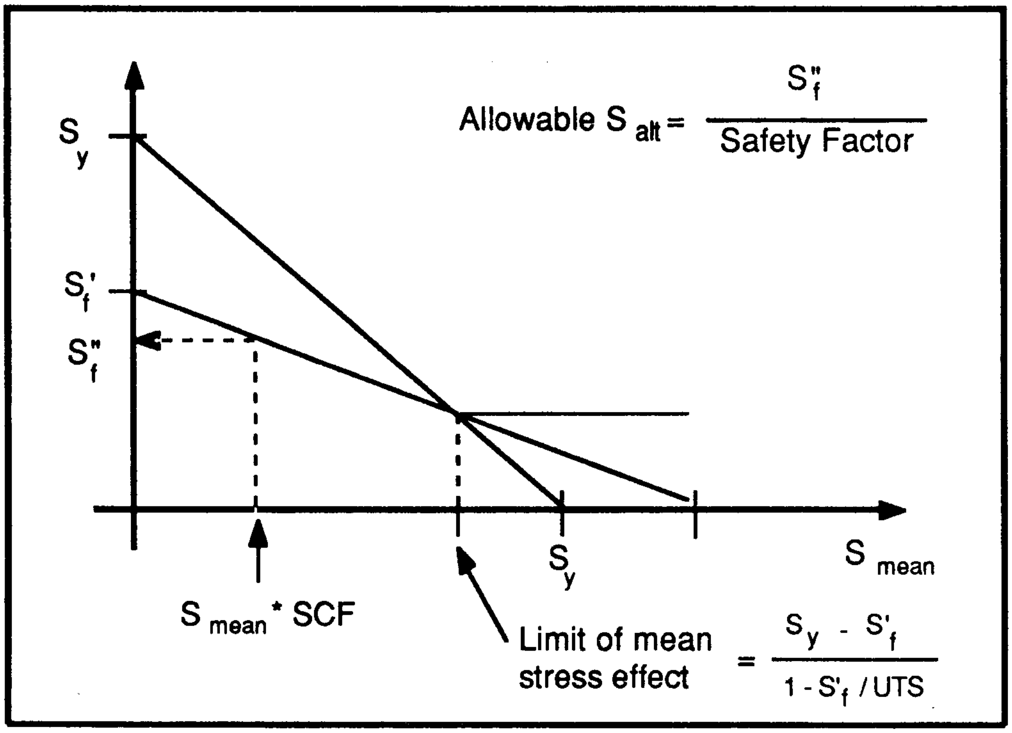


Figure C - 3

Modified Goodman Diagram Calculation of S"f due to Mean Stress Effect

As shown above, the mean stress times the SCF is never larger than a limiting value of the yield stress minus the S_f" value due to the plastic shakedown effects.

6. Allowable Fatigue Alternating Stress. - To compute the allowable S_{alt}, divide S_f" by the required fatigue safety factor as defined in Section 5.3.

11.3 VARYING AMPLITUDE FATIGUE CALCULATIONS

For situations where the applied loading varies during the life of a part, a means of defining the cycle amplitude and frequency is needed. Several methods are described by Fuchs (ref. 20), page 196. The preferred method is the rain flow method, but other methods are acceptable.

To sum the effect of the cycles at varying amplitudes, the Palmgren-Miner linear damage accumulation rule should be used. This approach is described in the Fuchs reference on pages 190-192.

For infinite life design, only the largest amplitude cycles will contribute significant fatigue and may be used directly to define the required design part sizes.

11.4 STRAIN LIFE FATIGUE DESIGN

A more accurate method of computing fatigue life for finite life design is based on the strain-life equation. This methodology has been described in references 20, 35 and 37, which also provides fatigue data.

To perform this analysis, the local strain is required, which may be computed by an elastic-plastic finite element analysis, or estimated by a Neuber or a linear rule strain analysis. The best way to perform the Neuber analysis for low cycle fatigue, where extensive plasticity may be involved, is with a computer program that performs piecewise linear representations of the material cyclic stress-strain curve as described somewhat in reference 20, and to be covered more fully in a 1988 revision of reference 36.

If a strain-life analysis is performed, tension fatigue data are usually used, so that no size effect is required. Also, the SCF effect is built into the local strain computation, as is the computation of the local mean stresses that are input to the life calculation. The surface effect still needs consideration, but unfortunately is not yet well documented. Therefore, conservative estimates such as are used for S-N methods should be applied to the material fatigue strengths to account for surface effects.

12.0 FRACTURE EVALUATION REQUIREMENTS

Fracture evaluations are required for all parts which meet any of the following definitions. Any part to be used at a stress levels high enough to give a finite fatigue life for that part. Critical and/or single point failure parts that are stressed over 95% of their allowable stress. Parts that are found to be cracked during a test, but where it is determined that testing should continue under close monitoring.

Nearly all fabrication processes introduce cracks into a part. The problem is knowing where the cracks are located and the size of each crack. Inspections supply this information. However, inspection procedures are imperfect and often fail to find even large cracks. Therefore, fracture evaluations assume that a crack is present at a critical location and that the crack is of a size which would not be reliably detected by the particular inspection process used.

A fracture evaluation is an analysis of a cracked part or structure that can determines whether the structure can still perform its intended service. This section specifies the minimal requirements for fracture evaluations of materials susceptible to failure by crack propagation that can be analyzed by fracture mechanics.

However, due to the practical limitations on inspection reliability, a finite failure probability still exists even after a part meets the requirements of this section. The magnitude of the remaining failure probability depends on the inspection, the probability functions for cracks in the part, and the material toughness properties. In some cases, the NFAC staff may choose not to accept this residual risk and may reject a part even though it meets the requirements of this section.

This section provides the performance requirements for a fracture evaluation. It is not intended to be a tutorial.

12.1 DEFINITIONS

Terms used in this section are defined as follows:

- Unstable Crack Growth - A rapid crack growth that typically continues without limit when the material fracture resistance is unable to sustain the applied loading.
- Sub-critical Crack Growth - The growth of a crack in a stable manner by mechanisms such as fatigue, stress corrosion cracking, and ductile tearing.

- Stress Corrosion Cracking (SCC) - The sub-critical crack growth in a stressed part due to chemical attack from the surface environment. SCC is a time-dependent process, that requires the presence of a sustained tensile stress, a chemically active environment, and a metallurgically susceptible material.

- Ductile Tearing - A process of sub-critical crack extension that occurs during static loading of cracks in ductile materials when the initiation fracture toughness is exceeded.

- Stress Intensity Factor (mode I, II, or III) - A measure of the intensity or the stresses at the tip of a crack that is opened by tension (mode I), in-plane shear (mode II), or out-of-plane shear (mode III).

- Initiation Fracture Toughness - The material property that defines the.point where crack growth begins under static loads. It is designated herein as K_c or K_{Ic}. K_{Ic} is defined by E399 (ref. 19) for brittle materials where the subsequent crack growth becomes unstable. For ductile materials several designations are used including J_c and J_{Ic}, (see ref. 5); it is the point where ductile tearing begins.

12.2 ACCEPTANCE BY STATIC TESTS

The part may be accepted for use without a fracture evaluation if it is statically loaded and the following conditions are met:

- The stress distribution due to loading will be representative of the worst case service conditions.

- Sub-critical crack growth will not occur in the part during service.

- The completion of a static load test which is at least twice the operating load. Also, there must be no observed crack growth or obvious failure of the part, and measured deflection must not indicate a permanent set during the test. Plots of loads versus deflections for a complete loading cycle shall be included in the Fracture Evaluation analysis.

12.3 ACCEPTANCE BY FRACTURE MECHANICS ANALYSIS

A fracture mechanics analysis shall show that the part meets the following requirements:

- The material fracture toughness and crack growth rate representation shall meet the requirements in Section 12.3.1 of this document.

- The calculations shall be based on initial crack sizes as defined in Section 12.3.2 of this document.

- The stress intensity factor calculations shall meet the requirements in Section 12.3.3 of this document.

- Fracture evaluations for static loadings shall meet the requirements of Section 12.3.4 of this document.

- For parts where Sub-critical crack growth can occur due to fatigue or stress corrosion cracking, a crack life calculation shall show that the part meets the requirements of Section 12.3.5 of this document.

- To reuse parts that have been in service for the computed safe lifetime, the requirements of Section 12.3.6 of this document shall be met.

12.3.1 Material Property Requirements

The material property data used in the analysis shall be identified in the analysis documentation, and this data must meet the following requirements:

In general, the plane strain fracture toughness value should be used. However, for thin sheet analyses appropriate plane stress fracture toughness data may be used.

- The crack growth rate data and equations used in the analysis shall describe the upper bound crack growth rate data within a factor of two (2) on crack growth rates.

  The data and the equations shall be representative of the effects of service conditions including mean stresses, chemical environmental factors such as humidity, and corrosive environments.

- Except for proof-test analyses, the material fracture toughness to use shall be a lower bound initiation fracture toughness. The lower bound shall be computed as follows:

  When two or more data points are available, the lower bound is defined as two standard deviations below the mean.

For a single test value, the lower bound is estimated by either multiplying the value by 80%, or by multiplying by the ratio of the lower bound to the mean for the same material at another, comparable condition.

- For proof test analyses, the fracture toughness to use in computing both the initial crack size and the life shall be the upper bound fracture toughness. The upper bound shall be computed as follows:

  When two or more data points are available, the upper bound is defined as two standard deviations above the mean.

  For a single test value. the upper bound is estimated by either multiplying the value by 1.25, or by multiplying by the ratio of the upper bound to the mean for the same material at another, comparable condition.

  See the Reference List for other acceptable data sources , provided that the data is selected to meet the requirements as stated herein.

Note: The material data in the NASA/FLAGRO (ref. 25) computer program must meet the crack growth rate data requirements, but NOT the lower/upper bound fracture toughness data requirements. Therefore, the User must be careful to truncate a life analysis when the usable fracture toughness is reached in the output.

12.3.2 Initial Crack Size Requirements

The analysis shall be a conservative computation for the crack(s) and the conditions which produce the largest stress intensity factor and/or the shortest crack life. The cracks selected for analysis shall include consideration of:

- The most unfavorable location in the part for a crack to exist.
- Cracks found during inspections. Use conservative size estimates since the sizing or cracks by most inspection methods is not precise.
- The possible presence of cracks which were NOT found by the inspection. The crack size to consider is that which is detected at least 90% of the time with a 95% confidence level.

The basis for the crack size used must be justified by reference to published studies or standards. References which provide crack size data are the NASA documents NHB 8071.1 (ref. 31) and MSFC-STD-1249 (ref. 28).

Proof Testing - Proof testing may be used to define the initial crack size for relatively brittle materials which do not exhibit significant ductile tearing. The proof test loading must simulate the actual service loading and stress distribution in the critical sections of the parts. The calculation shall be based on the upper bound initiation fracture toughness as defined in Section 4.1 of this document.

Proof testing to define initial crack size for tough materials that exhibit ductile tearing is not encouraged since the calculation of the crack that survives the proof test must include the amount of ductile tearing that could occur by means of an elastic plastic fracture mechanics analysis. Since the ductile tearing calculation is not well defined with present technology, the computations must be extremely conservative.

Alternatively, if a bound on the initial crack size can be defined by inspection or other means, then a simulation of the proof test in a similar geometry test specimen may be used to establish the amount of ductile tearing and also the maximum crack size remaining in the structure.

Post proof test inspection of parts is always encouraged since the proof test tends to open up defects and make them more detectable.

12.3.3 Stress Intensity Calculation Requirements

The calculation of the stress intensity due to cracks shall meet the following requirements:

- Analyses shall preferably use the NASA/FLAGRO computer program (ref. 24) for linear elastic fracture mechanics analyses. If another program is used, that program must produce results for the particular problem being analyzed that are at least as accurate as the NASA/FLAGRO program.

- Analyses for elastic plastic fracture mechanics problems shall use the most current and relevant analysis technology that has been shown by experimental verification to be applicable to the particular problem.

- For parts subjected to varying load envelopes, the peak loads shall be used for comparing the computed stress intensity factor to the usable fracture toughness.

- The effect of stress concentration factors shall be included in the calculations through the appropriate stress intensity factor solution.

- The effect of residual stresses shall be included in the analysis if they are present. Welding residual stresses usually have complex distribution,usually reach yield strength in magnitude, and usually require use of assumptions that are different in order to remain conservative for different applications. If the part experiences a proof loading, the residual stress may be reduced in accordance with local strain shakedown calculations.

12.3.4 Fracture Evaluation Requirements

A fracture evaluation of a cracked part that will be subjected to a static stress shall demonstrate that a safety factor of 1.5 exists between the applied stress intensity and the lower bound fracture toughness. This requirement does not apply to proof-test analyses that are covered under the Crack Life Requirements Section 12.3.5 of this document.

12.3.5 Crack Life Requirements

A crack life analysis computes a safe estimate of the minimum time or cycles required for sub-critical crack growth to extend an initial crack to the size where the fracture toughness defined in Section 12.1 of this appendix is reached.

Crack Life Safety Factors - There are two types of safety factor requirements. They are:

- The life analysis shall show that the computed safe life is at least four times the required service life. Proof test analyses must meet this requirement.

- Except for proof test applications, there must be at least a safety factor of 1.5 between the stress intensity at the end of the computed safe life and the lower bound fracture toughness.

  The part shall not be used for a longer time than one safe life without an evaluation for reuse of the part.

The crack life analysis shall also include consideration of the following items to arrive at a conservative calculation of the crack life:

- Sub-critical crack growth due to stress corrosion cracking.

- Use of the maximum possible stresses for computations. For example, if strain gage data or a stress analysis is accurate to 10% then use 1.1 times the estimated stress values for the calculation.

Load-sequence, interaction effects, such as crack retardation and acceleration, may be ignored or included in the life calculation; however, if included, the method used must be documented and shown to give results that are accurate to within a factor of two (2).

12.3.6 Reuse of Part

After the computed crack life of a part has been used, the part may still have additional life left due to possibly conservative initial crack size assumptions. To determine the additional life, a reevaluation of the part is required.

For cases where the loading and environment have not changed during the operational life of a part, a reevaluation may be as simple as a repeat inspection of the part that does not find any cracks larger than those used as initial cracks in the original analysis. The resulting new service life is then the same as the initially calculated service life.

For cases where changes have occurred in the loading or environment, or the repeat inspection is of inferior quality than the original inspection, then a revised analysis shall be prepared in accordance with this appendix.

13.0 ALTERNATE DESIGN GUIDE

13.1 INTRODUCTION AND INPLEMENTATION

This guide provides alternative design stress requirements for all of Section 5.2, and parts of Sections 5.3 and 5.5 of this appendix.

The Alternate Design Guide is to be used for design situations where the usual safety factor requirements cannot be met; such as for specialized models, weight critical structures, or other cases where a larger structure is unacceptable or increases the risk of structural failure.

To implement these options the engineer must: justify the need for reduced safety factors in the Design Analysis Report and during design reviews; obtain the consent of the NFAC Operations Branch Chief; and meet all of the requirements for the design class used.

13.2 DESIGN CLASSIFICATION AND SAFETY FACTORS

The allowable stresses are defined in terms of the design class. A particular design may have different parts with different design classifications. In order to utilize the safety factors for any design class, all of the requirements for that class as detailed below must be met.

One major requirement for all design classifications is that the design is one that meets the requirements of Appendix C and a highly accurate stress analysis; such as a good Finite Element Model (FEM) analysis. Other (i.e.

closed form) analysis types are allowed provided that their assumptions closely match the actual problem.

The design class definitions and the respective requirements to qualify for the design class are as follows:

13.2.1 Class 1: Redundant or Damage Tolerant Structure - No Acceptance Test

A class 1 design requires that the analysis requirements and that either of the (A) or (B) requirements given below be met.

(A) Redundant load paths exist and structural analyses demonstrate that the loss of one load path with any attendant load increases will not result in an immediate major failure of the structure. In addition, it must demonstrate that the load path failure is detectable by planned inspections or instrumentation;

(B) A Fracture Evaluation which meets the requirements of Section 11 shall be performed for critical structural parts. If this fracture evaluation is performed, then a F_B factor of 1.0 may be used to compute F_{Ult} regardless of the material ductility.

Note: No acceptance test is required for Class 1 designs, but one is required for Class 2, 3, and 4 designs.

13.2.2 Class 2: No Damage Tolerant Qualified, Acceptance Test Performed

An static acceptance test as defined in Section 4.7 is required. The magnitude of the test load shall be the maximum loading condition multiplied by the T_{Load} factor for the design class as given below instead of the load factor listed in Section 4.7.

13.2.3. Class 3: Class 2 plus Load and Stress Verification

A class 3 design requires that the Class 2 requirements be met, and additionally that the applied maximum loads be verified by measurement of strains at appropriate places on the structure, and that the stresses in the most critical section of the structure be verified by strain measurements during the static acceptance test or during a simulated system load tests.

The actual loads and/or stresses shall not exceed analysis values by more than 25%. If larger deviations occur, a reevaluation of the analysis to locate the source of the inaccuracy is required. Also, the allowable loads shall be adjusted downward so that the stresses will not exceed the allowables.

13.2.4 Class 4: Redundant or Damage Tolerant Structure -With Acceptance Test

A class 4 design requires that the Class 3 requirements be met, and, additionally, that the structure meet the Redundant or Damage Tolerance requirements of Class 1. If a fracture evaluation according to Section 12 is performed, then an F_B factor of 1.0 may be used to compute F_{Ult} regardless of the material ductility.

There is one test load factor, T_{Load}, and four safety factors, F_{Yield}, F_{Ult}, F_{Cycle}, and F_{Life} which are used as described in Section 13.3. The test and safety factors for the four design classes are as follows:

Design Class	1	2	3	4
T_{Load}	none	1.50	1.25	1.10
F_{Yield}	2.0	2.0	1.5	1.25
F_{Ult}	3.0*F_B	3.0*F_B	2.5*F_B	2.0*F_B
F_{Cycle}	1.5	2.0	1.5	1.25
F_{Life}	10.	20.	10.	4.

where the factor F_B used to compute F_{Ult} is described in Section 12.4.

13.3 ALLOWABLE STRESSES

The following sections define the maximum allowable stresses for ductile and low toughness materials for static and fatigue loadings. Brittle materials must still meet Section 5.2.2 criteria with a safety factor of ten (10.0).

Primary, Secondary, and Incremental Peak Stresses. - These stresses, referenced below are defined in Section 4.2.

13.3.1 Fatigue

This section modifies only the stress and life fatigue safety factors based on data references given in Section 5.3 and the stress safety factor for welds in Section 5.5 The remaining provisions of Sections 5.3 and 5.5 still apply.

The required safety factors shall be F_{Cycle} for alternating stresses and F_{Life} for finite life design as specified in Section 11.2 for the respective design class used.

13.3.2 Static Stress

This section is an alternative replacement to Section 5..2.

Allowable Stress. - The allowable stress shall be computed as the lesser stress obtained by dividing the tensile yield strength by the F_{Yield} factor, or the ultimate tensile strength by the F_{Ult} factor.

Applicable Stress. - The applied Primary stresses shall not exceed the allowable material stress. Also, the sum of the Primary plus Secondary stresses shall not exceed the allowable stress multiplied by the F_{Yield} factor. (Note that the
Incremental Peak Stresses due to stress concentration effects are not included in the evaluation against static allowable stress of materials with some ductility.

Plastic Collapse - For ultimate strength evaluations only, it is permissible to divide the bending stress by the plastic section factor before comparing the sum of applicable stresses to the allowable stress (UTS divided by F_{Ult}). The plastic section factor is the first moment of the cross section area about the neutral axis. Sample values are:

Rectangular sections:	1.50
Circular sections:	1.70
Thin wall tubes:	1.27
W12x36:	1.12

For multi-axial stresses, either the Von Mises-Hencky theory or the Maximum Shear (or Tresca) theory shall be used to compute an equivalent uniaxial stress to compare to the allowable stress. These theories are given in Section 11.1.

13.4 F_B FACTOR DEFINITION

Some hardened materials are especially susceptible to fracture from cracks. They require extra safety margins to give the same protection against catastrophic failures that more ductile, tough materials provide. The F_B factor as defined below is used in Sections 13.2 and 5.2.2 to increase the safety factor on ultimate strength to provide the needed extra safety margin.

For ductile materials, with an elongation of 15% or more in a .5 in. diameter, 2 in. tensile specimen, the F_B factor may be taken as 1.0.

For other materials, the F_B factor is computed as a function of the material minimum ultimate tensile strength fracture toughness, and the probable crack size in a part as follows:

$$F_B = \text{the larger of } \frac{\text{Ultimate Tensile Strength}}{\text{Fracture Stress}} \text{ or } 1.0$$

where Fracture Stress (ksi) 2.8 * K_{ic}

The Fracture Stress calculation depends on the assumed crack size factor, F_{Crack} , which is usually 2.8 as described later, and the material lower bound initiation fracture toughness [K_{ic} or K_c for thin sheets in ksi*√(in.)], as defined in Section 11.3.1. The symbol, "√" means the square root function.

Be advised that toughness data for materials in a semi-ductile, tough condition may be difficult to find. The fracture toughness of these materials is not defined well by the usual K_{ic} or K_c measurements. Equivalent K_{ic} data from J_{ic} measurements may be used but these are scarce also. To bound the F_B ratio for these situations, locate data in the references and compute the F_B ratio for the same material in a less ductile condition. The F_B ratio for a thinner, and/or more ductile, and usually lower yield strength, material condition of interest will be lower than the F_B value at the known condition.

The value of F_B is usually 2.0 or less which may be used as an upper bound for most high strength steels and aluminums as shown in the table below. There are exceptions as shown in the table where ultra high strength materials require a larger F_B factor.

The crack size factor, F_{Crack}, assumes that a quality inspection was performed and only those cracks which are likely to have escaped detection remain in the part. The crack size is based on the 90% probability of detection, at a 95% confidence level, inspection data provided in the NASA Marshall Space Flight Center document MSFC-STD-1249 or the NASA/FLAGRO computer program distributed by NASA Johnson Space Center.

For computing the F_B factor, the crack size may be assumed to be a surface crack which is .075 in. deep and .15 in. long in a 1 in. thick by 10. in. wide part stressed in tension. This produces a value of F_{Crack} of 2.8/√(in.). Although it is not required to do so, F_{Crack} may be computed for other crack geometries and sizes by the NASA/FLAGRO computer program as the inverse of the maximum stress intensity factor for a 1 ksi tension stress.

Example 1: Vascomax 300 forging has a minimum specified ultimate of 280 ksi, 5% elongation, and a lower bound fracture toughness of 56 ksi*√(in.) The fracture stress for the .075 in. deep crack is 2.8*56. =157 ksi. This gives a value for F_B = 280/157 = 1.78, so the material is classified as a low toughness material and the F_B = 1.78 is used to obtain F_{Ult} factors.

Example 2: 17-4 PH Stainless Steel, in H1025 condition, has a minimum specified ultimate of 155. ksi, 12% elongation, and a lower bound fracture toughness of 58. ksi*√(in.). The fracture stress for the .075 in. deep crack is 2.8*58 =162 ksi. This gives F_B =155/162 or .95 which is less than 1.0 so F_B =1.0. This material is classified as a ductile material.

Material Data and F_B Factor Table. - A listing of minimum strength and fracture toughness data for several materials is provided in table C-1 below. The mechanical strength data was selected to meet the requirements of Section

5.1. The fracture toughness data presented was computed to meet the requirements of Section 12 of this appendix.

Several heat treatments are available for most materials. The data shown were those of most frequently used. Data for other heat treatments and material orientations may be found in the references. To use the data shown, the fabrication heat treatment must match the condition referenced in table 1.

The references noted in table C-1 are used for the source of the K_{ic} data. Reference 41 was used the most because it contained the most reliable data. The primary reference for the mechanical strength data is reference 46. However, some values were obtained from manufacturers minimum specified strength data, and some were obtained from references 44 and 45.

Table C - 2 Material Data and FB Factors

Material and Condition	no.	Ref. (ksi)	Syd (ksi)	Sult % in 2"	Elong ksi√in	Min. K_{ic} factor	FB
Steels:							
13-8 Mo PH S.S. Bar	H950	1	205.	220.	10.	60.	1.31
Same except	H1000	1	190.	205.	10.	67.	1.09
Same except	H1050	1	165.	175.	12.	79.	.79 ->1.0
15-5 PH S.S. Bar	H900	1	170.	190.	10.	64.	1.06
" but Vac. Arc Melted (VAM)		1	"	"	"	76.	.89 ->1.0
" VAM but H925	2	155.	170.	10.	101.	.60 ->1.0	
17 4 PH S.S. Plate at H900		3	170.	190.	8.	31.	2.19
" but Bar material		3	170.	190.	10.	40.	1.70
" but at H975		1	150.	162.	11.	65.	.89 ->1.0
" but at H1025		1	145.	155.	12.	58.	95 ->1.0
18% Ni Maraging Steel, VM, heat treat 900 F for 6 hr except as shown:							
Vascomax 350	Billet, 8 hr	3	324.	332.	5.	36.	3.29
" " .5"	Plate,	5	"	"	"	44.	2.69
" 300	Forging or Plate	1	270.	280.	5.	56.	1.78
" 250	Billet, 3 hr	1	242.	255.	6.	56.	1.63
" "	Plate,6-24 hr.	1	"	"	"	73.	1.25
" 200	Plate or Forging	1	220.	224.	6.	99.	.81 ->1.0
AF 1410 10Ni-8Co-2Cr-Mo-.11C Steel	1	215.	235.	12.	122.		.69 ->1.0
9Ni-4Co-.20C 1650 F, AC, 1525 F, Oil Q, T 1025 F or double Temper 1025 F + 1060 F (best method)		1	180.	190.	10.	90.	.75 ->1.0
9Ni-4Co-.30C 1650 F, AC, 1525 F, Oil Q, T 1000 F or double Temper 1000 F (best method)	1	190.	220.	10.	103.		.76 ->1.0
HY 140 (5Ni-Cr-Mo-V)							
Forgings A579 Gr 12		4	140.	150.	13.	>100.	<.5 ->1.0
Plate Mil-S-24371A (Ships)		4	130.	140.	15.	>100.	<.5 ->1.0

Table C - 2 Material Data and FB Factors Continued.

Material and Condition	Ref. no.	Syd (ksi)	Sult (ksi)	Elong. % in 2"	Min.K_{ic} ksiVin	FB factor	
HY 100 Mil-S-16216H (Ships)	5	100.	110.	17.	>60.	<.6 ->1.0	
HY 80 " "	5	80.	100.	19.	>50.	<.7 ->1.0	
D6AC (a modified 4340 steel):							
1650 F Aus-Bay Quench, 975 F Salt Q. 375 F, 1000F 2+2 hr	1	215.	260.	10.	34.	2.73	
1700 F Aus-Bay Quench, 975 F Oil Q. 140 F, 1000 F 2+2 hr	1	215.	260.	10.	76.	1.22	
HY-TUF (a tougher 4340 steel): 1700 F 1 hr AC, 1600 F 1 hr, Oil Q, 550F 2 hr	1	185.	220.	10.	107.	.73 >1.0	
300M (a modified 4340 steel, .42C _ Spec. AMS 6419): Plate with heat treat of 1700 F 1 hr, AC, 1600 F 1 hr, Oil Q, 600 F 2 hr, AC	1	230.	280.	7.	50.	2.00	
AISI 4340, Q. and T. to give	1	230.	280.	14.	44.	2.27	
"	1	220.	255.	14.	47.	1.94	
"	1	200.	219.	13.	55.	1.42	
"	1	180.	191.	14.5	80.	.85 ->1.0	
"	1	160	172.	16.	>140.	.44 ->1.0	
AISI 4140,							
Forged Bar, Q, T at 400 F	1	220.	260.	7.	32.	2.90	
535 F	1	203.	240.	8.	40.	2.14	
745 F	1	175.	200.	11.	40.	1.79	
Plate, Q, T at 800 F	1	165.	190.	12.	47.	1.44	
900 F	1	150.	170.	14.	68.	.89 ->1.0	
Aluminum:							
2014-T6 1" Forging (L-T)	1	56.	65.	6.		26.	.89 ->1.
" " " (T-L),(S-L)	1	55.	64.		3.	14.	1.63
" " Plate (all dir.)	1	60.	66.	6.		18.	1.31
.13" Plate (T-L)	1	60.	66.	7.	52.		.45 ->1.

Table C - 2 Material Data and FB Factors: Continued.

Material and Condition	Ref. no.	Syd (ksi)	Sult (ksi)	Elong. % in 2"	Min.K_{ic} ksi√in	FB factor ß
2024-T351 Plate 1" thk. (S-T)	1	47.	62.	7.	20.	1.11
" " (L-T),(T-L)	1		"	"	25	.89 ->1.0
" -T3 Plate .25" thk. (T-L)	1	47.	64.	12.	99.	.23 ->1.0
6061-T651 Plate >1" (all dir)	1	35.	42.	8.	21.	.71 ->1.0
." " " 25" "	1	36.	42.	10.	87.	.17 ->1.0
7075 Extrusions						
-T6, -T651 >.2" thk (T-L)	1	72.	81.	7.	20.	1.45
-T7351 >.4" thk "	1	60.	70.	8.	19.	1.32
-T6 .12" Sheet "	1	70.	78.	8.	50.	.56 ->1.0

Note: Per ASTM E399 (which are also shown in ref. 46). Typically, loading results in fracture in L-T or T-L directions, with T-L being the less tough direction. Through the thickness loading for the S-T condition is less common.

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APPENDIX D:

SAMPLE OF TEST READINESS REVIEW FORMS

NATIONAL FULL-SCALE AERODYNAMICS COMPLEX	TEST READINESS REPORT GUIDE & SIGN-OFF SHEET			T.R. NO __.
PART 1-ITEMS REQUIRED FOR TEST READINESS REVIEW PRIOR TO MODEL LIFT-IN				
TEST TITLE	FACILITY		JOB ORDER	
PROJECT DIRECTOR	SPONSOR			
TEST DIRECTOR	CONTRACTOR			

TEST PLAN	INITIAL WHEN COMPLETED NASA	CONTR	SPONSR
Test Objectives Developed and Reviewed			
Run Sequence Developed and Reviewed			
Operating Envelope and Constraints Developed amd Reviewed			
Dynamic Stability Boundary Calculations Approved			
Limits of Angle of Attack and Yaw Established			
Have "Model Effects" on Facility Limits Been Documented			
Other Test Limits Identified and Included as Constraints			
Safety Instrumentation Determined and Documented			
Mandatory Instrumentation Identified and Available			
Warning and Redlines Documented for Safety Instrumentation			
Critical Mode Justified and Use Included in SOPs			
Required Personnel and Their Duties Documented			
Model Specific SOPs Documented Including All Control Systems			
Integrated Starting and Stopping SOPs Documented			
Emergency Procedures Written and REviewed			
Pre-run and Post-run System Checklists Prepared			
Operational Checklists Prepared			
Communication Procedures Documented			
CRew Training Plan Prepared and Reviewed by Security Office			
Acoustic Impact Plan Prepared and Reviewed			
Model Installation and Rigging Plan Preared and Reviewed			
Model Weight and C.G. Determined			
Model Weight Within Crane Capacity			
Hoisting Sling Loads Determined			
Hoisting Clearances Determined and Verified			
Certified Hoisting Sling Available when Required			
Model Installation and Rigging Plan Accepted By Gen'l Foreman			

NATIONAL FULL-SCALE AERODYNAMICS COMPLEX	TEST READINESS REPORT GUIDE & SIGN-OFF SHEET	T.R. NO _.

PART 1 - CONTINUED

TEST TITLE	FACILITY

	INITIAL WHEN COMPLETED NASA	CONTR	SPONSR
TEST PLAN - CONTINUED			
Post-run Inspection Plan Developed and Checklist Reviewed			
Data Recording Plans Complete and Forms Available			
Plan For Logging and Closing TDrs and TCRs			
All Log Sheets and Forms Prepared and Available			
Pre-run and Post-run Meetings Planned and Checklists Ready			
FINAL REQUIREMENTS DOCUMENT COMPLETE AND APPROVED			
INSTRUMENTATION AND SOFTWARE			
Instrumentation Plan Reviewed and Approved			
Software Plan Reviewed and Approved			
Instrumentation Hardware Available and Ready			
Data Reduction Program Complete and Operable			
MODEL DESIGN			
Aerodynamic Loads Document Reviewed and Approved			
All Critical Structural Items Identified			
Stress Analyses Complete and Reviewed			
Steady State Stresses Are Within Approved Allowables			
Dynamic Loads and Fatigue Limits are Within Approved Allowables			
Any Independent Design Analysis Reviewed and Response Given			
Design and Drawings Signed-off and In Change Control			
As-Built Drawings Updated and Current			
Design Reviews Complete, Documented, and All Action Items Closed			
MODEL SUPPORT			
Aerodynamic and Model Loads On Strut Documented and Reviewed			
Stress and Loads Analyses of Strut and Balance Complete			
Maximum Combined Forces and Moments Determined			
Resulting Analyses of Struts Within Approved Allowables			
Resulting Analyses of Balance Within Approved Allowables			
ALL MODEL SYSTEMS FUNTIONALLY TESTED AND DOCUMENTED			
ALL ACTION ITEMS LEVIED AGAINST TEST DEVELOPMENT CLOSED			

NATIONAL FULL-SCALE AERODYNAMICS COMPLEX	TEST READINESS REPORT GUIDE & SIGN-OFF SHEET	T.R. NO

PART 1 - CONCLUDED

TEST TITLE	FACILITY

CONTROL SYSTEMS	INITIAL WHEN COMPLETED NASA	CONTR	SPONSR
Critical Controls Identified and are Fail Safe			
Operating Procedures Documented and Reviewed			
All Checklists Prepared and Reviewed			
All Log Sheets and Data Forms Prepared and Available			
All Systems Operationally Tested and Documented			
Design Drawings Signed-off and In Change Control			
As-Built Drawings Updated and Current			
SAFETY			
Gross Hazards Analysis Complete and Reviewed			
Dynamic Stability Analysis Complete and Reviewed			
Fragmentation Analysis Complete and Within Approved Limits			
Model and Strut Grounding "Fault/Foul" System Reviewed and Ready			
Fire Extinguishing Systems Installed and Functioning			
Fire Detection Systems Installed and Functioning			
Fuel Supply System throughly Checked and Ready			
On-board Fuel Tanks Purged and Filled With Dry Nitrogen			
Hydraulic Systems Thoroughly Checked and Ready			
All High Pressure Air Systems Tested and Ready			
Toxic Materials Documented and Safety Provisions Prepared			
REQUESTS FOR OPERATIONAL WAIVERS REVIEWED AND APPROVED			

RMEB REVIEW OF POTENTIAL HAZARDS COMPLETED WITH A DETERMINED HAZARD LEVEL OF ________ AND A PROBABILITY OF ________

SIGNATURE ________
RMEB CHAIR

TEST READINESS APPROVALS

TEST DIRECTOR		
PROJECT DIRECTOR		
CHIEF, RESEARCH BRANCH (FFF OR FFR)		
CHIEF, NFAC OPERATIONS BRANCH		
ASST DIVISION CHIEF FOR OPERATIONS		
CHIEF, FULL-SCALE AERO. RESEACH DIV		
DIRECTOR, AEROSPACE SYSTEMS		

NATIONAL FULL-SCALE AERODYNAMICS COMPLEX	TEST READINESS REPORT GUIDE & SIGN-OFF SHEET	T.R. NO __.

PART 1 - ITEMS REQUIRED FOR MODEL/TUNNEL PRE-TEST PRIOR TO FAN START

TEST TITLE	FACILITY

	INITIAL WHEN COMPLETED		
	NASA	CONTR	SPONSR
TRAINING			
Test Crew Organized, Trained, and Briefed			
All Pre- andPost-run Checklists Prepared and Satisfactory			
Complete Simulated Test Runs Conducted With Full Crew			
Test Crew Trained for Emergency Situations			
Emergency Situations Practiced with Full Crew			
All console Operators have Current Certification			
Communications Procedures Practiced and Fully Understood			
INSTRUMENTATION			
All Monitoring Instrumentation Calibrated and Functioning			
All Monitoring Procedures Posted and Personnel Trained			
Critical Measurement Warning and Red-line Limits Posted			
Data Systems End-to-End Check Completed			
Data Systems and Software Functioning Properly			
All Test Section Instrumentation Hardware Properly Installed			
SAFETY			
Over-temperature Warning Systems Fully Tested and Ready			
Vapor Detection Systems Fully Tested and Ready			
"Fault-Foul" System Working Properly			
Model Support System With Model Working Properly			
Noise Monitoring Equipment Calibrated and Functioning			
Community Noise Limits Viewed andPosted			
All Outstanding TDRs and TCRs Cleared and Closed			
Wind Tunnel Emergency Stop Mode ☐ Normal; Critical☐ Reviewed			
SERVICE REQUEST SUBMITTED FOR MODEL PHOTOGRAPHS			

TEST READINESS APPROVALS

	Signature	Date
Test Director		
ProjectDirector		
Chief, Research Branch (FFF or FFR)		
Chief NFAC Operations Branch		
Ass't Division Chief for Operations		
Chief, Full-scale Aero. Research Div.		