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NASA Glenn Wind Tunnel Model Systems Criteria

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March 2004

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Summary

This report describes criteria for the design, analysis, quality assurance, and documentation of models that are to be tested in the wind tunnel facilities at the NASA Glenn Research Center. This report presents two methods for computing model allowable stresses on the basis of the yield stress or ultimate stress, and it defines project procedures to test models in the NASA Glenn aeropropulsion facilities. Both customer-furnished and in-house model systems are discussed.

The functions of the facility personnel and customers are defined. The format for the pretest meetings, safety permit process, and model reviews are outlined. The format for the model systems report (a requirement for each model that is to be tested at NASA Glenn) is described, the engineers responsible for developing the model systems report are listed, and the timetable for its delivery to the project engineer is given.

1.0 Introduction

This report defines the criteria for the design, analysis, quality control assurance, and documentation of wind tunnel models that are to be tested in the following aeropropulsion facilities at the NASA Glenn Research Center: the 1- by 1-Foot Supersonic Wind Tunnel, the 10- by 10-Foot Supersonic Wind Tunnel, the 8- by 6-Foot Supersonic Wind Tunnel, the 9- by 15-Foot Low-Speed Wind Tunnel, and the Icing Research Tunnel. These facilities are managed and operated by the NASA Glenn Research Testing Division (RTD). Customers should contact the facility managers as described in appendix A to schedule tests and use these facilities. Appendix B lists the procedure for obtaining test time in one of the facilities, and appendix C presents tables giving the models loads that are allowed in the wind tunnels.

This report is designed to be used in conjunction with the specific tunnel information presented in each wind tunnel manual (refs. 1 to 4 and Soeder, Ronald H.; Roeder, James W.; and Panek, Joseph W.: User Manual for NASA Glenn 10- by 10-Foot Supersonic Wind Tunnel. NASA/TM—2004-212697, 2004 (to be published)).

2.0 Terminology

Critical speed—A speed of the rotating system that corresponds to a resonant frequency of the model system.

Critically loaded (stressed) component—A component critical to the structural integrity of the model, whose failure can result in model system loss or facility damage.

Customer-furnished model system—A model system to be tested that is provided by a customer who is not from NASA Glenn; this customer (i.e., research engineer) must provide adequate documentation

regarding the structural integrity of the model and ancillary systems under the required loads to the assigned Glenn research engineer and the RTD project engineer for review.

Electronic engineer—The RTD electronic engineer and project engineer are responsible for the development of the project instrumentation manual, which contains both the model and facility instrumentation documentation. The research engineer supplies them with the model research instrumentation requirements for this manual. The RTD electronic engineer is responsible for reviewing and overseeing the installation of all model electrical, electronic, and data equipment and connections needed for particular tests. This engineer also reviews and oversees the installation of all facility instruments that are required by the research engineer and the RTD project engineer.

Facility manager—The facility manager schedules and manages the operation of the facility. The facility manager presents the program to the RTD division chief, who approves all model programs that are to be tested in NASA Glenn aeropropulsion facilities. The procedure for contacting facility managers is outlined in appendix A, and the procedure for scheduling a facility is outlined in appendix B.

In-house-furnished model system—This is a model system that is designed and fabricated with NASA Glenn review and manufacturing control.

Model design engineer—The model design engineer develops the required model stress analysis and engineering drawings per the request of the research engineer (customer) with assistance from the RTD project engineer. The model design engineer keeps the research engineer and the RTD project engineer informed about progress toward model completion (usually on a monthly basis) and consults with them as required. If the model is provided by an offsite customer, the customer's model designer will provide the model systems report (sec. 7.1) to the RTD project engineer for review. If the model is developed at NASA Glenn, the onsite model design engineer will provide the model systems report to the RTD project engineer for review. In cases where the model is designed by a member of RTD, the RTD project engineer produces the model systems report.

Model systems—The model systems and components covered in this report include, but are not limited to, aircraft or parts of aircraft models, turbine engines, turbomachinery components (e.g., fans or compressor rigs), flow survey rakes and arrays, splitter plates, and model support hardware (including force balances, struts, and stings). In this report, "model systems and components" does not apply to

- (1) Model support equipment that is a permanent part of the facility
- (2) Items such as gearboxes, motors, actuators, and instrumentation mounts that are not critical to the structural integrity of the model system and whose failure cannot damage the facility
- (3) Auxiliary equipment, such as tunnel cables and foundations

Pretest meetings—A series of pretest meetings are held to review the schedule and status of the test and to discuss the test plan, instrumentation, facility hardware, and data requirements. The first pretest meeting should be set up as far in advance as is practical, at least 1 year before the tunnel test. The attendees at this meeting are usually the research engineer (customer), the facility manager, and the RTD project engineer. Ensuing pretest meetings are scheduled by the RTD project engineer. These meetings are attended by the facility customers (e.g., the lead research engineer and key research personnel), the RTD project engineer, the RTD electronic engineer, key RTD personnel, and Research Analysis Center (RAC) programmer analysts (if required). The number of pretest meetings is usually a function of test complexity.

Project engineer—The RTD project engineer is responsible for project planning, project management of the test program, identifying any required facility modifications, reviewing all model and support system drawings and stress analyses, and overseeing the installation of model and ancillary equipment into the facility test section. The RTD project engineer can also serve as the RTD test engineer and the research engineer. The RTD project engineer also assists the facility manager in interpreting the requirements of this report.

The RTD project engineer has the overall responsibility for the safe operation of the test but may seek the assistance of other engineers in the NASA Glenn Engineering and Technical Services Directorate to

verify model integrity. The RTD project engineer and the RTD electronic engineer are also responsible for the development of the project instrumentation manual, which contains both the model and facility instrumentation documentation. The research engineer supplies the RTD project engineer and electronic engineer with the model research instrumentation requirements for this manual.

Research engineer—The research engineer (i.e., the customer) may be from NASA Glenn, another NASA center, another U.S. Government agency, or a private corporation. The research engineer oversees the model configuration definition. When the lead research engineer is from NASA Glenn, the responsibilities of model design and fabrication are shared with the RTD project engineer. The research engineer also defines the test matrix and instrumentation requirements for the test program and the engineering parameters and sets of equations that are part of the computing requirements package. This package must be delivered to application programmers in the RAC for implementation on Glenn computing systems (both centralized systems and those dedicated to specific facilities) at least 2 months prior to the start of the test.

When the lead research engineer is from another NASA center, another U.S. Government agency, or a private corporation, a Glenn research engineer is also assigned to the project and usually serves as a point of contact between the customer research engineer and in-house activities at NASA Glenn. The Glenn research engineer obtains the required test matrix, model stress, and load calculations from the customer research engineer and meets with the RTD project engineer to discuss the project instrumentation manual. If assistance of RAC programmers is required for data reduction, the Glenn research engineer also obtains a computer requirements package from the customer research engineer at least two months prior to the start of the test.

Safety permit process—The RTD project engineer determines the need for a safety permit for a given project. This is done by examining the Safety Permit Requestor's Guide which is posted on the NASA Glenn intranet at http://osat-ext.grc.nasa.gov/gso/manual/chapter_01a.pdf. The need for a safety permit is determined by the nature and the extent of the testing that is to be performed and the associated hazards.

Activities at NASA Glenn tunnels which require a safety permit include

- (1) Testing of models or test articles
- (2) Use of fuels or oxidizers
- (3) Use of chemicals or hazardous materials
- (4) Use of compressed gases
- (5) Operation at high temperature (exceeding 140 °F)
- (6) Use of high-voltage electrical power (220 volts or more)
- (7) Use of high-speed turbomachinery equipment
- (8) Use of lasers
- (9) Use of pressurized vessels or piping systems
- (10) Use of vacuum systems
- (11) Modifications to an existing operation

The RTD project engineer meets with the chairperson of the appropriate safety committee to determine if a safety permit is required. The necessary forms that need to be completed are outlined in the Safety Permit Requestors Guide (see previously noted Web site). The Safety Permit package should be submitted for review at least 8 weeks before the start of testing. This time frame is a function of the complexity of the test. The following conditions would require special action to be taken by the appropriate area safety committee:

- (1) Use of radioactive materials or gases
- (2) Use of high-speed rotating test article parts without suitable shrouds
- (3) Ejection of materials or gases into or from an RTD aeropropulsion facility
- (4) Use of toxic materials (a material safety data sheet should be provided by the customer)

- (5) Use of explosive nature fuels in quantities that exceed the separation distances to inhabited buildings and public roads

Test engineer—The RTD test engineer supports the preparation, installation, and testing of the model and auxiliary systems. Usually, a mechanical and electronic engineer are assigned as test engineers to a test program. An RTD test engineer will act as a test conductor who conducts the tunnel test and plans each tunnel run. This engineer is in charge in the tunnel control room during the run and directs the model and facility operators to accomplish the run objectives.

3.0 Background Information

3.1 Model Criteria Implementation

The facility manager has the responsibility and the authority to impose the criteria in this report. The facility manager may elect to seek assistance from the RTD project engineer and the research engineer. The RTD project engineer ensures that the model and system design and fabrication meet the criteria of this report. Any deviations in these criteria must be addressed according to the deviation procedure outlined in section 9.0.

3.2 Model Reviews

Model system reviews allow the RTD engineer to meet with the model installation team and determine the status of a test. Stress calculations will be reviewed. The installation will be monitored as well. The customer may attend, if desired. These reviews take place at the pretest meetings (see definition, sec. 2.0) during the model buildup and installation phase of the program. The schedule and attendees for these meetings are determined by the RTD project engineer. In addition to these regular meetings, during the model buildup and testing phase it may be necessary to have engineering review meetings to discuss problems with the model. These meetings are not scheduled on a regular basis but as required during the program. The RTD project engineer schedules these meetings and contacts the attendees.

4.0 Design and Analysis

4.1 Design Loads

At least 4 months prior to the start of testing at Glenn, the customer must supply the model design loads to the RTD project engineer for review. These loads must be consistent with the safe limits of the RTD facilities (refs. 1 to 4 and NASA/TM—2004-212697), and they must be included in the model systems report (sec. 7.1). The model design engineer and the RTD project engineer must agree with the conclusions originally put forward by the research engineer.

4.2 Material Selection

4.2.1 Standards.—The materials used for the model and the support structure must be selected according to their mechanical properties from experimental test data or from an accepted standard from an organization (i.e., American Society of Mechanical Engineers (ASME), American Society for Testing

and Materials (ASTM), American Welding Society (AWS), Aerospace Structural Metals Handbook Department of Defense, Military Handbook #5 Department of Defense (DOD), etc.).

4.2.2 Adjustments for environment.—All model material properties, design criteria, and allowable stresses must be suitably adjusted for test condition temperature, pressure, and any other environmental effects that may be present when the model material is under stress during tunnel operation.

4.2.3 Galling and galvanic corrosion.—Galling and galvanic corrosion must be considered in selecting materials for all model and auxiliary systems. Tunnel operation resulting in high-frequency vibrations (i.e., the vibrations that accompany a tunnel unstart condition) would aggravate galling. In reference 5 it is suggested that galling occurs where there is a lack of lubrication, a lack of oxide film on metal surfaces, high contact pressure, and high heat. This reference also suggests techniques that have been used to eliminate or reduce galling. It also states that the use of coarse threads is preferred over fine threads and that stainless steel bolts are particularly likely to gall.

Galvanic corrosion occurs when two dissimilar metals are in the presence of an electrolyte such as moisture. A galvanic ranking of some common engineering materials is listed in reference 6. It is suggested that stainless steel can be made passive by oxidizing it in an air furnace or treating it with an acid to cause an oxide film to form.

4.2.4 Nonmetallic materials.—Nonmetallic materials that are used to manufacture models or model support systems require other considerations that are mentioned below. Test section cleanliness is also important. Wood or wood-based materials selected for a model or model support systems should be resistant to warping, easy to work, glue well, and have a clear finish. Tunnel operation at low dew points could dry and crack the woods used in the models or model support systems; therefore, the woods selected should be resistant to such conditions.

Plastics, epoxy resins, and fiberglass materials that are used on a model may soften with elevated temperatures in the tunnel test section and experience loss in strength or other mechanical properties. These topics, if applicable, should be discussed at the first pretest meeting held at NASA Glenn.

Any nonmetallic materials and/or material processes that are used for a critically stressed model component and not covered in section 4.2.1 must have as-built properties (i.e., properties that take into account changes in the model or system material properties due to the fabrication process) verified at test temperature. The nonmetallic material properties should be verified by techniques (e.g., tensile testing techniques) that are developed by the RTD project engineer with input from the customer and any other appropriate organizations.

4.3 Structural Analysis

4.3.1 Stress analysis.—A stress analysis is required as part of the model systems report (sec. 7.1).

(1) The stress analysis should show that allowable stresses are not exceeded for the worst case loads.

(2) For each model section that is analyzed, the customer should prepare a sketch showing the forces and moments on that section. These sketches should list the approximations, assumptions, model section properties, and allowable limits of material strengths.

(3) All general equations and their sources must be listed before numerical values are substituted into the equations.

(4) Model stations should be established along the longitudinal axis of the model, and the cross-sectional area of the model should vary by at least 5 percent from one section to the next. The latter statement insures that a sufficient number of model stations are established in order to give credence to model integrity. Each section should be analyzed to determine the allowable shear, axial load, bending, and torsion of structural members to locate the critical sections of the model.

(5) The model systems report should show that the model, the mounting points (including struts and stings), and the restraints are statically and dynamically stable (not subjected to natural frequencies) within

the model operating envelope. The effects of Reynolds number, Mach number, surface conditions, and other factors in the development of the equations noted in the analysis should be discussed. The range of mass and inertia parameters as well as the stiffness coefficients used in the analysis also should be noted.

(6) Some models that are tested in the tunnels (specifically, in the Icing Research Tunnel and the 9- by 15-Foot Low-Speed Wind Tunnel) are flight hardware, and the allowable stresses are adjusted to reflect this fact. RTD suggests that the aerodynamic category of the model be determined (i.e., normal, transport, rotorcraft, utility, or commuter, etc.) and that the Federal Aviation Regulations for the model category be consulted to determine the allowable stresses (i.e., factor of safety, strength, and deformation). The specific Federal Aviation Regulations manual that is used to determine the allowable stresses on the model should be noted in the model systems report.

(7) If used, finite element analyses documentation must include computer-generated plots of the finite element model or models, a tabular or graphical summary of stress data, and the name of the structural code used. A convergence to a solution by the computer code validates that the finite element model developed represents the model that is to be tested.

(8) When model loading is being established for supersonic startup, an additional 10° flow angle should be added to the maximum positive and negative model angle of attack with respect to the free stream to establish the model design loads. This should be done in both the pitch and yaw directions. The dynamic pressure used should be the maximum tunnel dynamic pressure as given by the facility operating envelope stated in references 1 to 4 and NASA/TM—2004-212697. With this criterion, the allowable stresses should not exceed one-half of the yield stress. All auxiliary parts of the model exposed to the airstream and nominally at 0° angle of attack should be evaluated at +10° angle of attack for supersonic startup loads.

Appendix C contains five tables of information, one for each of the five tunnels that are operated by RTD. These tables discuss supersonic startup conditions, supersonic and subsonic steady-state conditions, supersonic localized unstart conditions, model angle of attack, pressure load, allowable stresses, and auxiliary model parts angle of attack. Models unusual in size, shape, or operation may require special analysis. Steady-state conditions for such models can be discussed with the RTD project engineer.

4.3.2 Thermal analysis.—The model must be analyzed to examine thermal stresses and distortions for both steady-state and transient conditions.

4.3.3 Fatigue analysis.—To the extent that fatigue is a credible failure mode, model components that are subjected to cyclic loadings must be analyzed for fatigue. The fatigue analysis is performed on the premise that no flaws or cracks exist in the structure.

4.4 Mechanical Connections

4.4.1 Structural bolts and joints.—The minimum safety factor at any model stress condition for the fasteners that clamp the model, sting, model auxiliary structure, or model equipment is 3.0 on the basis of yield stress and 5.0 on the basis of ultimate stress for heat-treated hardened bolts. The safety factors are based on bolt cross-sectional area, not on the proof load or proof stress. The proof load and proof stress concept is discussed in reference 7.

The total cross-sectional area of the bolts, based on the required safety factor, is determined by first calculating the load on the joint for the most severe test condition. The joint load is then divided by the allowable stress obtained from bolt material tables at the condition determined above. Note that the allowable stress sometimes has a safety factor figured into its table value (this depends on the reference used). The safety factors noted in this section do not include a bolt preload. Bolt preload is defined in reference 8, and bolt preload uncertainty is presented in reference 9. Bolt preloads as a percentage of yield stress are presented in reference 5. Information on various sizes, types, and materials for bolts in space

flight hardware are addressed in reference 10. Information on gaskets and gasketed joints are discussed in reference 11.

Shear loads should be transmitted through the use of keys, pins, and shoulders; the keys and pins should be prevented from any movement. A joint system where shear loads are minimal in relation to the axial loads are addressed in reference 8. Bolts that are subjected to a combination of tension, shear and bending loads are addressed in reference 8. Bolt material ultimate shear strength for most ductile materials is addressed in reference 12.

All structural weld joints should be designed in accordance with the American Welding Society (AWS) structural codes. A Web site that can be used to locate welding information is <http://www.aws.org/catalogs/>. Catalog code index numbers that refer to specific welding problems encountered in the installation of models in wind tunnels are listed as follows:

- (1) B1.10.1999 Guide for Nondestructive Examination of Welds
- (2) B1.11:2000 Guide for the Visual Examination of Welds
- (3) C3.7:1999 Specification for Aluminum Brazing
- (4) D1.1/D1.1M:2002–D1.1 Structural Welding Code for Steel
- (5) D1.2–97 Structural Welding Code—Aluminum
- (6) D1.3–98 Structural Welding Code—Sheet Steel
- (7) D1.4–98 Structural Welding Code—Reinforcing Steel
- (8) D1.6:1999 Structural Welding Code—Stainless Steel
- (9) D9.1M/D9.1:2000 Sheet Metal Welding Code

All critical joints whose failure could damage the model, model components, or facility must be either radiographed to the requirements of the applicable AWS code or put through an alternate nondestructive evaluation method that satisfies AWS codes. The RTD project engineer may enlist the assistance of the Quality Management Office (8200) to evaluate model welds.

4.4.2 Fastener requirements.—All fasteners must meet the following requirements:

(1) It is recommended that threaded fasteners be torqued to produce a preload equivalent to 75 percent of the proof load of the fastener unless a lower preload is permitted because of a specific application (see ref. 5) or a thermal or mechanical consideration.

(2) The recommended thread engagement of a bolt of one material installed in a tapped hole in a different and frequently lower strength material is discussed in reference 6. Additional information on required tapped hole lengths is given in reference 13.

(3) All critical fastener connections must be provided with positive mechanical locks, such as locking inserts, self-locking nuts, locking-tab washers, interference thread forms, safety wiring and/or chemical locking systems (thread locking adhesives, fillers, etc).

(4) The factor of safety for a fastener is the allowable stress rating for the fastener in accordance with information presented in section 4.5.1. The allowable stress is divided by the actual stress on the fastener and must be greater than or equal to 5 on ultimate stress and 3 on yield stress. The actual stress does not include bolt prestress.

4.5 Metallic Materials Allowable Stress

The allowable stress criteria for metallic materials given in this section are based on well-established design practices. Two methods are discussed for establishing the stress allowable limits. Method 1 is based on conservative approaches that can be used where structural design optimization is not a factor and minimum analysis is needed. Method 2 is a systematic approach that can yield a more optimum structural

design. It is acceptable to design some parts of a model system according to the requirements of method 1 and other parts of the model system according to the requirements of method 2.

4.5.1 Stress computations using method 1.—The allowable stress for maximum loading is the smaller of one-fifth of the minimum ultimate stress or one-third of the minimum yield stress of the material. This corresponds to a safety factor of 5 on ultimate stress and of 3 on yield stress. Shear stress calculations and the relationship between yield stress and ultimate tensile stress are presented in reference 8. Thermal stresses that may occur on the model should be added to the load stresses before determining the factor of safety. The allowable stresses are the value at the operating temperature. The material properties that are used in the calculations should be the expected minimum values. Closed form solutions and standard handbook calculations will in general be sufficient to use this method. The model stress analysis should follow the eight items that are listed in section 4.3.1.

4.5.2 Stress computations using method 2.—This method to determine allowable stresses can be used when the model system cannot be designed to the allowable stresses that are defined by method 1. Before a model system can be designed to the allowable stresses defined in this section, the stress state must be understood to a high level of confidence. If the model system takes the form of a highly indeterminate complex structure, a more in-depth analysis will be required using state-of-the-art structural analysis codes that employ finite-element or finite-difference techniques. If structural computer codes are used, then a safety factor of 1.5 on yield stress and 3.0 on ultimate stress can be used. See the safety factor reduction notes presented in tables I through IV in appendix C.

4.6 Model Stability

When the model system is to be analyzed for stability, rigid body motions shall be considered about all axes; flexibility about pitch, roll, and yaw axes shall be considered for aeroelastic stability. The flexibility and stability issues can be addressed using computer codes.

4.6.1 Model system stiffness.—Model system stiffness verification is a source of concern when the model-sting system is a long, slender, columnar configuration to be tested at an angle of attack. For this type of configuration, the test dynamic pressure must not exceed one-half the model design dynamic pressure. The analysis should be based on the maximum model angle of attack (pitch and yaw) plus 10°.

4.6.2 Model dynamics.—Models to be dynamically tested must be analyzed to verify that the mountings and/or restraints are structurally adequate and dynamically stable. If the model that is to be tested dynamically is a turbomachinery component, the instrumentation requirements (review all of sec. 5.0) and model operation should be addressed in the model stability report mentioned in section 7.1.4.

4.6.3 Model system buckling.—The allowable compressive load in model support columns must not exceed one-half of the Euler critical buckling load.

4.7 Pressure Systems

4.7.1 Model support pressure vessels.—All model internal or external pressure vessels, support systems, and test equipment that operate at pressures exceeding 15 psig or exceed 6 in. in cross section (whether hydraulic, pneumatic, or other type of system) should be designed in accordance with the specifications that are presented in the NASA Glenn Safety Manual, chapter 7.8.1 (Design Requirements for Pressure Vessels). The most current information on pressure vessel design can be found in the latest edition of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 (Pressure Vessels) or Division 2, (Alternative Rules). Division 1 involves “design by rule” (i.e., design formulae) whereas Division 2 involves “design by analysis” (i.e., justification by stress analysis calculations). Subsection A of Division 1 covers the general requirements in terms of design pressure, temperature, and loadings to be considered in the design and indicates the maximum allowable tensile stress values. Subsection B deals

with methods of fabrication and examination. A brief description of these Division 1 and 2 codes can be found at <http://www.hse.gov.uk/hid/land/comah/level3/5C7360E.HTM>.

The customer should provide the following minimum requirements to the RTD project engineer: system volume, temperature range, working pressure, and proof test pressure. The RTD project engineer may stipulate other requirements as needed for model internal or model external support systems. RTD suggests that all components of a pressure system be stored in a clean, dry, and sealed condition after proof testing, prior to delivery to the facility.

4.7.2 Pressure relief devices.—Pressure relief devices may be required in a hydraulic, hydrostatic, or pneumatic system, but not necessarily in the model. If the system is not rated for the pressure emanating from the pressure source, these devices should be capable of relieving the overpressure by discharging sufficient flow from the pressure source under the conditions causing the malfunctions. Review the specifications presented in the NASA Safety Manual, chapter 7.9.2 (Design Requirements for Pressurized Systems) and the latest edition of the ASME Standard Piping Codes B31.1 and B31.3.

4.7.3 Pressure piping systems.—All model and support system piping must be designed, fabricated, inspected, tested, and installed in accordance with information presented in the NASA Glenn Safety Manual, specifically section 7.9.2 (Design Requirements for Pressurized Systems) and the ASME Codes B31.1 (Power Piping) and B31.3 (Process Piping). Pressure vessels that are constructed from standard pipe fittings and standard flanges are also considered pressure piping and use the ASME Standard Piping Codes noted above. Additional ASME Codes that may be helpful are B36.10M (Welded and Seamless Wrought Steel Pipe) and B36.19M (Stainless Steel Pipe).

The welding of pressure piping must follow the procedures that are outlined in the ASME Boiler and Pressure Vessel Code as well as in the ASME Standard Piping Codes B31.1 and B31.3. Additional information is published in Codes B36.10M (Welded and Seamless Wrought Steel Pipe) and B36.19M (Stainless Steel Pipe).

4.8 Force-Balance System

The Icing Research Tunnel is the only Glenn tunnel that maintains a force-balance system. When tests are to occur in other tunnels, the customer must supply the force-balance system if one is needed. The Icing Research Tunnel project engineer can discuss the force-balance system with the customer at one of the pretest meetings (see ref. 4).

4.9 Rotating Systems

The requirements in this section apply to model systems with rotating parts (e.g., propeller, engine, or fan models) that are to be tested in the 8- by 6-Foot Supersonic Wind Tunnel, the 9- by 15-Foot Low-Speed Wind Tunnel, the 10- by 10-Foot Supersonic Wind Tunnel, or the Icing Research Tunnel facilities. In addition, certain parts of this section apply specifically to turbine engines that might be tested in the 10- by 10-Foot or 8- by 6-Foot Supersonic Wind Tunnels.

4.9.1 Propeller model design.—Propeller model systems should be designed to operate at a maximum operating speed of 15 percent above the maximum test speed without model system damage. Propeller model systems must be designed to withstand at maximum operating speed the maximum unbalanced load that could occur due to blade loss. The model system should be equipped with a control system that will sense an unbalanced load and overspeed, then initiate an automatic shutdown of the rig. Provision should be made that the system (i.e., the propeller model and the drive system) is properly balanced.

4.9.2 Fan, compressor, and turbine model design.—Fan, compressor, and turbine model systems should be designed to operate at a maximum operating speed of 15 percent above the maximum test speed without model system damage. Fan, compressor, and turbine model systems must be designed to withstand

at maximum operating speed the maximum unbalanced load that could occur because of blade loss. The model systems should be equipped with a control system that will sense an unbalanced load and overspeed, then initiate an automatic shutdown of the rig. Provision should be made that the systems (i.e., fan, compressor or turbine models, and drive systems) are properly balanced. The RTD project engineer and the customer should discuss the need of using a containment shield around the model based on the risk of the test program.

4.9.3 Rotating model system analysis.—The customer should provide the RTD project engineer with rotating model system resonance points if they exist. Before a rotating model can be tested in a Glenn wind tunnel, the customer must provide the RTD project engineer with a Campbell diagram that shows possible resonance points (i.e., intersection points between rotor blade natural frequency lines and engine order lines (straight lines of frequency as a function of component speed)). Model system excitation frequencies that result during model tests should differ from model system natural frequencies by at least 15 percent. Strain gage instrumentation should be mounted on the model blades in order that resonance points are avoided during testing.

4.9.4 Structural testing of rotating components.—If the structural integrity of a fan, compressor, or turbine rig is to be verified, then one blade from each manufactured set of rotor blades should be tested. This test should be developed by the blade manufacturer with input from the model design engineer. The tests can be performed on a test specimen that simulates the section of the blade that is under critical loading.

Frequency response checks must be performed for a blade in a propeller rig and for one blade from each stage of a fan, compressor, or turbine rig. Each blade should be clamped in a fixture at the root. These frequency checks must be performed by the blade manufacturer to determine the structural similarity of the blades by comparing the first mode (bending or torsion) frequency. The blade manufacturer should specify the acceptable variation in blade frequency response levels and notify the model design engineer, the RTD project engineer, and the customer.

4.9.5 Balancing.—The blade manufacturer should specify the acceptable difference in weight and center-of-gravity between the various blades that comprise a propeller, fan, compressor, or turbine rig and should notify the model design engineer, the RTD project engineer, and the research engineer. The assembled system must be statically and dynamically balanced and should be within drive rig limits.

4.9.6 Prerun testing of rotating models.—Runup sea-level testing of a rotating model system should be demonstrated at the model manufacturer's plant prior to shipping the model to NASA Glenn. These sea-level tests must demonstrate safe operation at the maximum operating speed which is defined in sections 4.9.1 and 4.9.2. A lower speed condition may be approved by the RTD project engineer and the customer if there are aeromechanical stability considerations.

Testing of a rotating model in one of the Glenn tunnels is only permissible after an engineering analysis is performed by either the RTD project engineer using data supplied by the rotating model manufacturer or the Engineering Development Division (EDD) using information stated in their Engineering Design Guide Manual plus computer codes used to predict turbomachinery blade or burst disc containment. In addition approval must be obtained from the appropriate area safety committee.

4.9.7 Inspection.—All components of a rotating model system, including the blades, drive shaft, bearings, hub, and other parts, must be thoroughly inspected at the time of manufacture and assembly by the rotating model manufacturer. Inspections of the rotating model may be required at established intervals during testing at NASA Glenn. The required inspection methods should be developed by the rotating model manufacturer with the concurrence of the RTD project engineer and the customer.

4.10 Electrical Equipment and Components

The flow environment in the test sections of Glenn facilities requires the use only of qualified hardware, equipment, and material that conforms to the National Electrical Code (NEC). If this presents

a problem to the customer then the customer should discuss the problem with the RTD electronic engineer at the first pretest meeting and come to an agreement as to the alternate use of good electrical practices. All wires on pressure transducers, strain gauges, vibration pickups, and other low-voltage devices should be shielded. Design details regarding customer-supplied control panels, the associated wiring to the facility control room, electrical wiring diagrams, and connectors at interfaces located at control boxes or the model exterior should conform to the NEC or good electrical practices. These details should be discussed between the customer, the RTD project engineer, and the RTD electronic engineer at one of the pretest meetings.

4.11 General Periodic In-Service Inspections

All model system components that are critically loaded must be inspected during testing at time intervals that are specified by the RTD project engineer. These inspections may include force balances that are customer supplied, stings, model lifting surfaces, flaps, fasteners, and other items that must be guarded against fatigue failure. When these periodic inspections are required to take place should be documented and included in the model systems report (sec. 7.1).

5.0 Instrumentation Rakes

Instrument rakes placed upstream of or inside of turbine engines, in rotating models, or upstream of a facility compressor are classified as class I instrumentation rakes. The failure of a rake body could result in a catastrophic failure to a turbine engine, propeller model, or facility compressor; therefore a structural integrity check of all class I instrumentation rakes is required (see sec. 5.2.1 through 5.2.4).

Instrumentation rakes and associated probes placed upstream of or inside of static models or that are used to calibrate NASA Glenn wind tunnel test sections or other legs of the wind tunnels are classified as class II because a failure of this type of instrumentation rake will not be catastrophic. The checkout of the structural integrity of this type of instrumentation rake will not be as stringent as for the class I instrumentation rakes. The customer should provide a stress analysis on the class II rake. These calculations should be verified by the RTD project engineer. If the load and stress analysis shows that the rake and associated probes are of sufficient strength to withstand the proposed tunnel test then this is sufficient to verify class II instrumentation rake integrity. After approval a test instrument rake should be fabricated, and tests in the specified tunnel can be initiated.

5.1 Qualification of Instrumentation Rakes

In this section the Aero Power & Propulsion Test Engineering Branch of RTD establishes its policy regarding the classification and recertification of instrument rakes used in NASA Glenn wind tunnels. The vibration tests presented in sections 5.2.1 through 5.2.4 for prototype instrumentation rakes and section 5.4.1 for test instrumentation rakes were obtained from NASA Lewis bulletin CP 644748-1, Dynamic Qualification Testing for Instrumentation Probes. The customer can obtain a copy of this document from the RTD project engineer.

If class I instrumentation rakes are to be placed upstream of or inside of propeller rigs, fan or compressor rigs, or turbine engines as part of facility tests, then the following procedure should be followed to verify instrumentation rake design. It is paramount that instrumentation rake failure does not occur. Severe damage to the facility as well as damage to the model must be averted. For each different class I rake design that is to be used in one of the facility test sections, the current Glenn procedure calls for the manufacture of one additional rake. This prototype or additional rake build of each class I rake

design is rigorously tested. This prototype rake is subjected to sinusoidal sweep vibration and dwell tests (see sec. 5.2.1 and 5.2.2) and random vibration and shock tests (see sec. 5.2.3 and 5.2.4). The information presented in sections 5.2.1 through 5.2.4. is found in the NASA Lewis bulletin CP 644748–1. The testing of final design instrumentation rakes is discussed in section 5.4.1. The test schedule for the prototype rake and the test rakes should be agreed upon by the customer, the RTD project engineer, and a member of the Engineering Development Division. If the instrumentation rake is built at NASA Glenn, the procedures outlined in section 5.1 will be adhered to. If the instrumentation rake is supplied by the customer then the customer must supply the RTD project engineer with the appropriate documentation that ensures that the instrumentation rake was tested in accordance with the stipulations of this section.

5.2 Prototype Instrumentation Rakes

Prior to dynamic testing of a new prototype instrumentation rake, each rake probe as well as the rake body is inspected for surface fabrication flaws with the aid of nondestructive testing (NDT) and a magnified (10×) visual inspection. NDT can include Spotcheck (Magnaflux, Glenview, IL) red dye liquid penetrant, Zyflo (Magnaflux, Glenview, IL) fluorescent penetrant, and/or Magnaflux (Magnaflux, Glenview, IL) magnetic particle inspection. Radiographic inspection may also be required depending on the rake configuration. The areas of the instrumentation rake and the measurement probes that are of concern include (1) the fillet region (i.e., the compound curve) where the rake body intersects the instrument rake mounting pad base and (2) the region where the instrument rake probes intersect the instrument rake body. The RTD project engineer should notify the instrument rake designer of any cracks, pits, or porosity defects that the tests reveal.

The following sections describe the type of tests the class I prototype rakes should undergo. The data obtained are to be evaluated by the customer, the RTD project engineer and the Structural Dynamics Lab vibration test engineer. Prototype instrumentation rakes are not to be used for test article experiments, under any circumstances.

5.2.1 Sinusoidal sweep vibrations.—The purpose of the sinusoidal sweep tests that are conducted on each instrumentation rake body and the associated probes is to determine the flexural and torsional resonant frequencies and the associated amplitudes. During these tests the instrument rake body and measurement probes are subjected to a sinusoidal force of specified amplitude over a given frequency range and a stipulated sweep rate. The sweep rate is constant for RTD instrumentation rake vibration tests, but they may be varied for different segments of a frequency span if required. Class I prototype instrumentation rakes and the associated measurement probes are to be subjected to the following vibration schedule:

(1) A sinusoidal sweep vibration test is performed over the z-axis of the rake (refer to fig. 8 in reference 14 for the axis orientation of the instrumentation rake). If the rake is in the vertical position in the test section, the z-axis is the transverse axis. If the rake is in the horizontal position, then the z-axis is the vertical axis. The vibration schedule for the rake is as follows:

- A displacement test level of 0.26 in. with a double amplitude is used over a frequency range of 5 to 15 Hz, at a sweep rate of 2 octave/min.
- An acceleration level test of 3g peak, over a frequency range of 15 to 500 Hz, at a sweep rate of 2 octave/min.
- An acceleration level test of 3g peak, over a frequency range of 500 to 2000 Hz, at a sweep rate of 1 octave/min.

(2) A sinusoidal sweep over all three axes of the instrumentation rake consists of the following vibration schedule:

- A displacement level of 0.5 in. with a double amplitude is used over a frequency range of 5 to 20 Hz, at a sweep rate of 1 octave/min.

- An acceleration level test of 10g peak, over a frequency range of 20 to 100 Hz, at a sweep rate of 1 octave/min.
- An acceleration level test of 10g peak, over a frequency range of 100 to 3000 Hz, at a sweep rate of 0.5 octave/min.

5.2.2 Sinusoidal dwell tests.—Class I prototype instrumentation rakes and the associated measurement probes are to be subjected to the following dwell vibration schedule over all three axes:

Dwell at an acceleration level of 10g peak at two maximum response amplitudes below 1000 Hz for a period of 30 min for each axis. During this part of the vibration test schedule, record any changes in frequency to maintain amplitude. If the frequency change is continuous or more than 50 Hz, then extend the test time to 60 min. This is a severe test and subjects the instrument rake body and associated measurement probes to a high strain level. This dwell vibration test may consume a considerable amount of the instrumentation rake life.

5.2.3 Random vibration tests.—Class I prototype instrumentation rakes and the associated measurement probes are to be subjected to the following random vibration schedule over all three axes:

The instrumentation rake is to be subjected to a frequency range of 20 to 2000 Hz. The amplitude level of the random vibration test is expressed in terms of acceleration density (i.e., white noise, $0.05 \text{ g}^2/\text{Hz}$). The root-mean-square (r.m.s.) acceleration is determined by multiplying the acceleration density by the frequency range (Δf) and taking the square root of this product. All three axes of the instrumentation rake and the associated probes should be subjected to a white noise level equal to $0.05 \text{ g}^2/\text{Hz}$ for a period of 15 min/axis.

5.2.4 Shock tests.—Class I instrumentation rakes are subjected to a shock test procedure that applies three pulses to each of the three test axes. The shock pulses are applied through computer control of the shaker head which results in better control of amplitude and pulse shape. The amplitude of the shock wave is 20g and the shape is a half sine wave. The pulse duration is based on frequencies f_1 and f_2 , of the largest two peaks below 1000 Hz obtained from the sinusoidal sweep tests (sec. 5.2.1). The pulse duration = $500/f_i$, in milliseconds (where i equals either 1 or 2).

5.3 Prototype Rakes Posttest Inspection

After a prototype class I instrumentation rake has satisfactorily completed sinusoidal sweep vibration tests, sinusoidal dwell vibration tests, random vibration tests, and shock tests, the measurement probes on the instrument rake are inspected for fatigue cracks with the aid of Spotcheck red dye liquid penetrant, Zyglo fluorescent penetrant, or Magnaflux magnetic particle inspection. A magnified (10×) visual external inspection of the rake will also be conducted. It is the responsibility of the RTD project engineer to ensure that a prototype rake is not used on a test program with either a static or rotating model system. It is suggested that a prototype rake be etched with identification in order to prevent improper use.

5.4 Final Design Instrumentation Rakes

The Class I instrumentation rakes used in NASA Glenn wind tunnel experiments are to be subjected to a sinusoidal sweep over the z-axis of the rake (sec. 5.2.1). The vibration schedule is as follows:

- A displacement test level of 0.26 in. with a double amplitude is used over a frequency range of 5 to 15 Hz, at a sweep rate of 2 octave/min.
- An acceleration level of 3g peak, over a frequency range of 15 to 500 Hz, at a sweep rate of 2 octave/min.

- An acceleration level of 3g peak, over a frequency range of 500 to 2000 Hz, at a sweep rate of 1 octave/min.

5.5 Acceptance of Final Design Instrumentation Rakes

The acceptance or rejection of a final design instrumentation rake scheduled for use in a test program is based on agreement of resonant frequencies and response shapes of the final design rake (from the vibration tests, sec. 5.4) with that of the prototype rake (sec. 5.2.1, pt. (1)).

6.0 Project Procedures

This section describes procedures to be followed by RTD project engineers to monitor hardware of the models to be tested at NASA Glenn. These procedures are intended to assure that the as-built model hardware meets the model design specifications.

6.1 Purchase Requests

Purchase requests for model hardware must identify appropriate procurement requirements. Only NASA- or customer-approved drawings and specifications are used to purchase parts or materials. The RTD project engineer is encouraged to review the Glenn procedure document, GRC-P3.9, Acquisition Process, current revision.

6.2 Receiving Inspection

The RTD project engineer ordering the model hardware must inspect the hardware upon receipt. When requested, this inspection may be performed by a designee of the RTD project engineer placing the order. The documentation that is received with the model hardware may include purchase order number, purchase order item number, contract number (if applicable), supplier name, part number, raw material information, and the inspector's signature.

Evidence of the following supplier inspections and tests, as defined in the purchase documentation, must be verified during the receiving inspection by the RTD project engineer or a designated representative:

- (1) Material certification test document
- (2) Evidence of supplier inspection acceptance
- (3) Certification of heat treatment process if applicable
- (4) Certification that the end item is from the material specified
- (5) Test data
- (6) Inspection reports
- (7) Other documentation as specified on the purchase order

After receiving inspection of the model hardware, supplier data and documentation delivered with the hardware showing the manufacturer's traceability will be maintained. The inspection forms and reports can be retired to Records Management after the hardware becomes inactive.

6.3 Model Hardware Fabrication

The model design engineer is responsible for developing the engineering drawings used for model fabrication and installation. The model design engineer keeps the customer and the RTD project engineer informed as to the progress towards completion of the engineering drawings. The RTD project engineer will assist the model design engineer if requested to do so. The model design engineer tasks may be the responsibility of the RTD project engineer. The RTD project engineer is responsible for monitoring the proper fabrication and installation of the model hardware for in-house models that are fabricated at NASA Glenn or offsite. The RTD project engineer is also responsible for the proper installation of models that are supplied by the customer to NASA Glenn.

6.3.1 Traceability and control.—Raw materials and parts used in the fabrication and assembly of a model and its associated systems (i.e., oil system, hydraulic system, etc.) must be controlled to maintain identification and traceability. The RTD project engineer should require the customer to provide model identifiers (including its components) and associated subsystems. The identification system may take the form of part numbers, serial numbers, etc. and should be agreed to by the customer and the RTD project engineer at one of the pretest meetings. The RTD project engineer should follow the Glenn procedure document, GRC–P2.13, Product Identification and Traceability, current revision.

6.3.2 Controlled storage.—Raw materials, model hardware, and fasteners must be stored in a dedicated, controlled-access storage area. The RTD project engineer and the applicable facility lead mechanic should come to an agreement as to an appropriate facility storage area.

6.3.3 Configuration control.—The RTD project engineer maintains the model hardware configuration by controlling drawing and specification changes. The customer and the RTD project engineer assure that obsolete drawings and specifications are withdrawn and destroyed. If model nonconformance occurs (sec. 6.4), the RTD project engineer and the customer are required to agree to revisions in procedures, specifications, and/or requirements. The RTD project engineer should review the Glenn procedure document, GRC–P4.7, Corrective and Preventive Action, current revision.

The RTD project engineer is to follow the instructions below to ensure model system hardware are controlled and kept to current specifications:

Identification: When necessary, model hardware is identified by electrolytic etch or another method on a surface (see SAE Aerospace Standard, AS 478G–3063A) that will not affect flow or structural integrity. The model identification is posted on the model's container.

Drawing and specification control: Drawings and specifications define the completed model configuration and provide a record of the design. The model design engineer provides the research engineer and the RTD project engineer with a copy of all revised drawings upon request.

Red-line changes: Red-line changes may be used to change drawings temporarily during the fabrication process. Red-line changes are initiated and approved by the RTD project engineer. These changes are initialed and dated on the face of the fabrication drawings by the RTD project engineer prior to implementation. They are incorporated into the next revision of the drawing.

6.3.4 Fabrication planning.—For in-house models the RTD project engineer may coordinate the fabrication and inspection effort with the Engineering Development Division. Inspection records are maintained as long as deemed necessary by the RTD project engineer.

6.4 Control of Nonconforming Models and Hardware

A model and its associated hardware are identified as nonconforming if they do not meet a specified requirement. The RTD project engineer should review the Glenn procedure document, GRC–P4.4, Control of Nonconformance Product, latest revision, for these requirements. The RTD project engineer, after

consulting with the other project team members (e.g., the research engineer, the model design engineer, and other RTD test engineers), decides if a model must be reworked. Model rework is supervised by the model design engineer or RTD project engineer. All engineering drawings are updated to reflect model changes, and the revised model must be approved by the safety committee. The RTD project engineer should review Attachment 1 of the Glenn Work Instruction GRC–W7600.007, Test Engineering Non-conformance Identification and Reporting System, current revision. The RTD project engineer may enlist the assistance of the Quality Management Office (8200) in the resolution of a nonconforming model.

6.5 Inspection Control

The inspection instruments (i.e., gages and calibration meters) that are used to verify model compliance to engineering drawing specifications must be in current calibration, and a calibration sticker must be displayed on all these instruments.

6.6 Handling, Packing, and Shipping

Model hardware must be protected from damage during all phases of manufacturing and shipping. The model design engineer or the RTD project engineer will document any special handling, packing, and shipping requirements for model hardware. Shipping containers are to be designed to ensure safe arrival and ready identification. Containers for finished hardware must identify individual parts and should contain a complete set of as-built drawings and assembly procedures.

6.7 Records

The records and forms generated by the RTD project engineer are presented in the Business Management System document, Aero Test Engineering, GRC–P7600.003, current revision.

7.0 Documentation

7.1 Model Systems Report

A model systems report is required for all model systems that are to be tested at NASA Glenn. The model systems report is to be a complete, comprehensive stand-alone document. The customer must submit the model systems report to the RTD project engineer at least 2 months prior to tunnel entry, but the RTD project engineer may request an earlier delivery date for the report. The RTD project engineer establishes the content of the model systems report from the information outlined in the following sections.

7.1.1 Model system drawings.—The model system drawings include the as-built drawings of the model system configuration to be tested and (where applicable) assembly drawings, installation drawings, electrical sketches, and wiring diagrams.

7.1.2 Model design loads.—The design load calculations must take into account model specifications and requirements. Derived loads must consider aerodynamic, mechanical, and thermal effects. Life-cycle requirements must also be addressed.

7.1.3 Model stress analysis.—The model stress analysis must summarize all the safety factors that are developed in model engineering calculations. General equation sets, terms, and computer programs must be referenced. Any assumptions that are used in equation set development must be properly noted. The model stress analysis should also specify material data for all components that comprise the model system as well as for fasteners that are used to secure model components together. The material data should include standard and adjusted properties (i.e., pressure, temperature, or other environmental effects).

Stress calculations must be supplemented by model section sketches that show the appropriate forces and moments at an adequate number of model system stations (see sec. 4.3.1). Detailed shear and moment diagrams for the model system must be presented along with a stress analysis for a worst-case loads scenario.

A structural joint analysis for the model system components must be performed if applicable. This analysis considers bolted, welded, brazed, and bonded joints. A model system component analysis must also be performed for pressurized systems, hydrostatic systems, and specialized model systems that are subjected to fatigue and thermal effects.

7.1.4 Model stability report.—In cases where the model consists of a fan rig, compressor, or turbine rig, or turbine engine and the test program is dynamic, a report may be required that addresses such specialized topics as blade flutter and rotating stall dynamics. The customer should discuss this requirement with the RTD project engineer at one of the pretest meetings.

7.1.5 Inspection report.—The customer may be required to supply the RTD project engineer with an inspection report. The RTD project engineer initiates this request and specifies the content of the inspection report. The inspection report may contain material certification information (supplier documentation), fabrication planning information (sec. 6.3.4), and material or nonconforming hardware control information (sec. 6.4).

7.1.6 Qualification report.—The RTD project engineer initiates the request for a model pretest qualification report, if required. This qualification report may include model material properties, model load information, static and dynamic balancing of the model, and model runup tests (sec. 4.9.6).

7.1.7 Hazard analysis.—A hazard analysis is required for the model test. The decision as to the content of this analysis should be made at the first pretest meeting of the customer and RTD project engineer (at least 1 year before the actual tunnel test time). The hazard report can discuss possible damage to the model and the facility if a model failure occurs due to stress, thermal effects, fatigue, instrumentation malfunction, facility power loss, or some other factor. The report is a joint effort of the RTD project engineer and the customer.

7.2 Assembly, Installation, and Configuration Change Procedures

A model system assembly, installation, and configuration change procedure should be established as early as possible, preferably at the first pretest meeting. The format for this procedure should be agreed upon by the customer and the RTD project engineer by the time the model is delivered to the facility for buildup in the selected tunnel test section. Typical procedures or drawings should contain sequential assembly steps, torque values, alignment criteria, and other information necessary to assemble, install, and check out the model and associated hardware in the test section of the Glenn facility selected to test the model.

8.0 Model Delivery Schedule

Most of the models tested in the facilities at NASA Glenn are complex; therefore, the model buildup time in the facility model preparation areas and facility test sections varies greatly. RTD suggests that the customer discuss with the RTD project engineer the appropriate arrival time for the model and any auxiliary equipment that is customer supplied.

9.0 Deviations

Customers who consider it necessary to deviate from the requirements in this manual should submit a written request for approval through the RTD project engineer to the appropriate facility manager. Approval or denial of the request will be documented by the RTD project engineer and retained in the RTD facility files.

9.1 Deviation Requests

The RTD project engineer with the concurrence of the facility manager provides or obtains an evaluation from the proper Glenn authority for the model and/or facility deviation request. The facility manager and the RTD project engineer may request the assistance of the RTD chief, appropriate RTD branch chiefs, the Glenn Office of Safety and Assurance Technologies, members of the appropriate area safety committee, or other Glenn committees or organizational groups as required. A copy of the deviation request should be sent to the chairman of the appropriate area safety committee and then the chief of the Office of Safety and Assurance Technologies Directorate at NASA Glenn.

The customer drafts the deviation request, which should contain the following information:

- (1) The component or model system under consideration
- (2) The test plan requirement that calls for a deviation in standard operation of the facility or model
- (3) The reason why this plan requirement cannot be achieved under normal operating procedures
- (4) Technical information supporting the claim that a deviation from normal facility or model system operation is acceptable

9.2 Approval Authority

If a customer model failure could result in damage to the model and minor damage to a Glenn aeropulsion facility, the facility manager and the RTD project engineer must seek the approval of the appropriate area safety committee and RTD management before a deviation in test procedures is permitted. The Glenn chief counsel will be notified, and before testing begins, an agreement between the customer and RTD management will be made regarding model and facility liability.

Appendix A Glenn Contacts

The name of the appropriate facility manager can be obtained from the Web site <http://facilities.grc.nasa.gov/>. This site is accessible for customers that are either onsite or offsite. On this home page under Test Information in the left hand column, click on the Contact Information link. The names and the phone numbers of the facility managers are listed on this page. The above noted URL is valid for customers that are either offsite or onsite. Mail correspondence to a facility manager can be addressed as follows:

NASA Glenn Research Center at Lewis Field
Attn: (Name of person), ___*___ Facility Manager
Mail Stop 6–8
21000 Brookpark Road
Cleveland, Ohio 44135

*Insert appropriate tunnel name before Facility Manager: 10×10 SWT, 8×6 SWT, 9×15 LSWT, 1×1 SWT, or IRT.

Appendix B

Procedure for Obtaining Test Time in Wind Tunnel Facilities

(1) The customer contacts the appropriate RTD facility manager at least 1 year prior to the test (more advance notice is usually required).

(2) The appropriate RTD facility manager and key facility personnel review the request (at least 1 year prior to the test).

(3) For non-NASA requestors only, the customer submits a formal letter of request (at least 1 year in advance of the test) to the appropriate facility manager at NASA Glenn.

(4) For non-NASA requestors only, if the project is accepted, a test agreement is prepared and signed.

The test agreement outlines the legal responsibilities of NASA Glenn and the customers during the time that the project is at NASA Glenn. The customer is required to sign the test agreement and return it to NASA Glenn. The four types of test agreements follow:

(a) NASA test program

(b) NASA-industry cooperative program (nonreimbursable Space Act agreement)

(c) Other U.S. Government agency programs (reimbursable or nonreimbursable interagency agreement)

(d) Industry proprietary or noncooperative program (reimbursable Space Act agreement)

Appendix C

Model Allowable Conditions in RTD Wind Tunnels

The following five tables describe the model conditions that are acceptable in the 1×1 Supersonic Wind Tunnel, 10×10 Supersonic Wind Tunnel, 8×6 Supersonic Wind Tunnel, 9×15 Low-Speed Wind Tunnel, and the Icing Research Tunnel.

TABLE I.—1×1 SUPERSONIC WIND TUNNEL

Test section size, in.	12 high by 12.2 wide by 53.25 long
Mach range (discrete Mach numbers)	1.3, 1.6, 2.0, 2.5, 2.8, 3.0, 3.5, 4.0, 5.0, 5.5, 6.0
Total pressure range, psia	7.5 to 165
Total temperature range, °R	530 to 1110
Dynamic pressure range, psi	0.848 to 21.467
Reynolds number/ft range	0.361×10^6 to 20.999×10^6

	Supersonic startup conditions	Supersonic steady-state conditions	Supersonic localized unstart conditions
Model AOA ^a	Maximum model AOA ±10° (pitch and yaw)	Maximum model AOA (pitch and yaw)	-----
Pressure load	Facility maximum dynamic pressure	Facility maximum dynamic pressure	Static pressure rise across a normal shock
Allowable safety factors ^b	2 based on yield strength	Smaller of 5 based on minimum ultimate strength or 3 based on minimum yield strength	Smaller of 5 based on minimum ultimate strength or 3 based on minimum yield strength
Auxiliary model parts AOA	If nominally at 0°, add 10° for analysis	-----	-----

^aAOA is angle of attack.

^bThe safety factors for all of the above can be reduced to 3 on minimum ultimate stress and 1.5 on minimum yield stress if the customer provides finite element codes or if the model loads and model stress analysis techniques used are agreed to by the customer model designer and the RTD project engineer.

TABLE II.—10×10 SUPERSONIC WIND TUNNEL

Test section size, ft..... 10 high by 10 wide by 40 long
 Subsonic Mach range..... 0 to 0.36 (see refs. 15 and 16)
 Altitude, ft..... 0 to 48 000 for subsonic operation

Parameters listed below are for tunnel supersonic operation

Mach range for aerodynamic cycle (closed loop) and propulsion cycle (open loop) 2.0 to 3.5
 Altitude, ft..... 50 000 to 150 000
 Total pressure range, psf
 closed loop 235 to 5000
 open loop..... 1382 to 4920
 Total temperature range, °R
 closed loop 550 to 750
 open loop..... 525 to 1140
 Dynamic pressure range, psf
 closed loop 24 to 735
 open loop..... 500 to 600
 Reynolds number/ft range
 closed loop 0.110×10^6 to 3.42×10^6
 open loop..... 2.15×10^6 to 2.72×10^6

	Supersonic startup conditions	Supersonic and subsonic steady-state conditions	Supersonic localized unstart conditions ^d
Model AOA ^a	Maximum model AOA ±10° (pitch and yaw)	Maximum model AOA (pitch and yaw)	Model dependent
Pressure load	Facility maximum dynamic pressure	Worst case pressure difference across the model	Static pressure rise across a normal shock
Allowable safety factors ^b	2 based on yield strength ^c	Smaller of 5 based on minimum ultimate strength or 3 based on minimum yield strength	Smaller of 5 based on minimum ultimate strength or 3 based on minimum yield strength
Auxiliary model parts AOA	If nominally at 0°, add 10° for analysis	If nominally at 0°, add 10° for analysis	Model dependent

^aAOA is angle of attack.

^bSafety Factor Reduction: The safety factors for all of the above can be reduced to 3 on minimum ultimate strength and 1.5 on minimum yield strength if the customer provides finite element or finite difference codes. If finite difference codes are used, and it is difficult to obtain correct analytical expressions for partial derivatives, numerical approximations to the partial derivatives can be used by implementing a forward differencing finite-difference approach (ref. 17).

^cThis safety factor on yield strength (stress) cannot be reduced.

^dThe “localized unstart conditions” refers to the situation where one side of the model hardware is unstarted (subsonic) and the other side is started (supersonic). This condition can occur when large flat plates are installed in the test section. All model hardware does not need to be designed for this condition. The model geometry will dictate whether the localized unstart condition applies. The project engineer and research engineer should determine if this condition exists.

TABLE III.—8×6 SUPERSONIC WIND TUNNEL

Test section size, ft.....	8 high by 6 wide by 23.5 long
Low Mach range (using air dryer fans).....	0.0 to 0.01
Mach range (see ref. 18 for low Mach number range).....	0.25 to 2.0

Parameters listed below are for tunnel supersonic operation

Altitude, ft.....	1400 to 36 300
Total pressure range, psf.....	2320 to 3500
Total temperature range, °R.....	575 to 660
Dynamic pressure range, psf.....	220 to 1264
Reynolds number/ft range.....	2.6×10 ⁶ to 4.8×10 ⁶

	Supersonic startup conditions	Supersonic and subsonic steady-state conditions	Supersonic localized unstart conditions ^d
Model AOA ^a	Maximum model AOA ±10° (pitch and yaw)	Maximum model AOA (pitch and yaw)	Model dependent
Pressure load	Facility maximum dynamic pressure	Worst case pressure difference across the model	Static pressure rise across a normal shock
Allowable safety factors ^b	2 based on yield strength ^c	Smaller of 5 based on minimum ultimate strength or 3 based on minimum yield strength	Smaller of 5 based on minimum ultimate strength or 3 based on minimum yield strength
Auxiliary model parts AOA	If nominally at 0°, add 10° for analysis	If nominally at 0°, add 10° for analysis	Model dependent

^aAOA is angle of attack.

^bThe safety factors for all of the above can be reduced to 3 on minimum ultimate strength and 1.5 on minimum yield strength if the customer provides finite element or finite difference codes. If finite difference codes are used and it is difficult to obtain correct analytical expressions for partial derivatives, numerical approximations to the partial derivatives can be used by implementing a forward differencing finite-difference approach (ref. 17).

^cThis safety factor on yield strength (stress) cannot be reduced.

^dThe “localized unstart conditions” refers to the situation where one side of the model hardware is unstarted (subsonic) and the other side is started (supersonic). This condition can occur when large flat plates are installed in the test section. All model hardware does not need to be designed for this condition. The model geometry will dictate whether the localized unstart condition applies. The project engineer and the research engineer should determine if this condition exists.

TABLE IV.—9×15 LOW-SPEED WIND TUNNEL

Test section size, ft.....	9 high 15 wide by 28.6 long
Low Mach range (using wing blowers), kn.....	5 to 23
Mach range	0.05 to 0.23
Total pressure.....	Atmospheric
Total temperature range, °R.....	530 to 550
Dynamic pressure range, psf.....	3.7 to 75.6
Reynolds number/ft.....	0.34×10 ⁶ to 1.47×10 ⁶

	Subsonic steady-state conditions
Model AOA ^a	Maximum model AOA ^a (pitch and yaw)
Pressure load	Facility maximum dynamic pressure
Allowable safety factors ^b	Smaller of 5 based on minimum ultimate strength or 3 based on minimum yield strength
Auxiliary model parts AOA	If nominally at 0°, add 10° for analysis

^aAOA is angle of attack.

^bSafety factors for all of the above can be reduced to flight type safety factors on ultimate and yield stresses if the customer can provide finite element or finite difference codes; other codes may be used to compute model loads and stress values provided that there is agreement for its use by the customer model designer and the RTD project engineer.

TABLE V.—ICING RESEARCH TUNNEL

Test section size, ft.....	6 high by 9 wide by 20 long
Speed range, kn (mph)	50 to 300 (58 to 346)
Total pressure, psia	Atmospheric (avg 14.4)
Total temperature range, °R.....	438 to 493
Dynamic pressure range, psf	
at 58 mph	9.3
at 346 mph	316.2
Reynolds number/ft	
at 58 mph	0.59×10 ⁶
at 346 mph	3.58×10 ⁶

Allowable stress: To determine the allowable stresses, first establish the aeronautical category of the model to be tested (i.e., military, normal, transport, rotorcraft, utility, commuter, etc.). Then consult the Federal Aviation Regulations for the model.

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13. ABSTRACT (<i>Maximum 200 words</i>) This report describes criteria for the design, analysis, quality assurance, and documentation of models that are to be tested in the wind tunnel facilities at the NASA Glenn Research Center. This report presents two methods for computing model allowable stresses on the basis of the yield stress or ultimate stress, and it defines project procedures to test models in the NASA Glenn aeropropulsion facilities. Both customer-furnished and in-house model systems are discussed. The functions of the facility personnel and customers are defined. The format for the pretest meetings, safety permit process, and model reviews are outlined. The format for the model systems report (a requirement for each model that is to be tested at NASA Glenn) is described, the engineers responsible for developing the model systems report are listed, and the timetable for its delivery to the project engineer is given.				
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