THE DESIGN OF MODELS FOR CRYOGENIC WIND TUNNELS

Vernon P. Gillespie

NASA Langley Research Center

Wind-tunnel research at cryogenic temperatures has become a reality in the past few years and its advantage and importance are increasing. Cryogenics as a science has been pursued for about 75 years; however, large-scale industrial application of cryogenics is less than 25 years old. Langley Research Center currently has in operation a 0.3-meter transonic wind tunnel that operates with stagnation temperatures in the cryogenic range; it also has in the design phase the National Transonic Facility (NTF) that will operate at cryogenic temperatures. Wind-tunnel testing of models at cryogenic temperatures requires detailed consideration of areas not normally germane to the model designer.

The NTF will operate at Mach numbers from 0.1 to 1.2, stagnation temperatures from 352 K to 80 K and stagnation pressures from 103.4 kN/m^2 (15 psia) to 896.3 kN/m^2 (130 psia). Model design for the NTF will require that detailed technical consideration be given to three unique areas imposed by these operating capabilities. First, consideration must be given to the high model loads imposed by the high operating pressures. Wing root stress on many configurations will be in excess of 0.69 GN/m^2 (100 000 psi). Materials capable of such stress levels, including the customary safety factors that are normally associated with wind-tunnel model design, do not exist.

The second area that must be considered is the thermal environment. Although a vast amount of practical engineering has been accomplished involving cryogenics, only limited experience with the design of wind-tunnel models to operate in the cryogenic environment exists. It is not particularly difficult to design low-temperature apparatus, but attention to the details of the design is required from the outset. There are changes in the physical properties of all materials that must be taken into account. The most striking change in many materials is that of embrittlement. Carbon steel, for example, may fail catastrophically due to embrittlement at temperatures only slightly below ambient. Many materials, however, withstand the low-temperature environment very well and are used extensively in cryogenic applications (most austenitic stainless steels are a good example).

The third and probably the most complex area of consideration for NTF model design is the conflicting requirements imposed by the combination of the aerodynamic loads and the thermal environment. To the wind-tunnel model designer, the most important material properties have been yield and tensile strength. Only on rare occasion did any other material property dictate the material design selection. The yield and tensile strength of most materials increase with decreasing temperature. Figure 1 illustrates the increase in tensile strength with decreasing temperature for three commonly used materials. For polycrystalline face-centered cubic metals, the yield strength at 20 K is between two and three times the room-temperature yield strength. For the designer of models to be tested in the NTF, this increase in strength can be advantageous.

Examination of the candidate materials, however, cannot end with the strength properties alone. Probably the most important and least understood of the mechanical properties at low temperature is that of toughness. The most common methods for inferring toughness are the tensile elongation, impact tests, and notch tests. Generally, material toughness decreases with decreasing temperature. Figure 2 illustrates the decrease in elongation of some commonly used materials with decreasing temperature. The figure demonstrates the classic ductile-to-brittle transition of carbon steel at low temperatures. Materials which have a ductile-to-brittle transition in the operating temperature range must be avoided.

In the short time the Langley 0.3-m transonic cryogenic tunnel has been operational, several types of models have been designed, fabricated, and tested in the facility. (See fig. 3) The models range from simple wooden shapes to support strain-gage balance testing, two-dimensional airfoils fabricated from a commonly used model material (304 stainless steel), to a complex 0.45-percent-scale model of the space shuttle. High wing loads at both cryogenic and ambient temperatures combined with a low deflection requirement resulted in a serious material problem for the space shuttle model. An iron-based, nickel-cobalt superalloy (HP-9-4-30) was chosen for the shuttle wing structure as it had an ultimate strength of 1.7 GN/m^2 (250 000 psi) and excellent toughness throughout the test temperature range.

Experience with the design and fabrication of an early two-dimensional airfoil which spans the jet and is attached to the test-section side walls (fig. 4) illustrates the attention to detail that is required of models to be tested in a cryogenic environment. Design analysis indicated customary mounting procedures were not adequate. If there was too little preload in the mounting, the model would be loose upon tunnel cool down. If there was too much preload, the mounting would be overstressed at room temperature. Model fasteners were a continual problem. When the model was delivered for testing, it was discovered that carbon steel screws (not stainless steel screws as specified) had been supplied with the model, thereby incurring the danger of a brittle fracture at cryogenic temperatures.

Another difficulty arose in the testing of the airfoil shown in figure 4. During the testing at cryogenic temperatures, small droplets appeared and froze along the joint between the solder used to cover the pressure tubes and the parent material. Further examination of the droplets revealed these to be machine oil trapped during the fabrication process. A procedure was subsequently developed to adequately remove the oil so that the airfoil tests could continue.

In recognition of the unique technical considerations which must be given to the design of models for the NTF, the Langley Systems Engineering Division and the NTF Project Office established an NTF Model Task to assemble the technology required to design and fabricate models for NTF. It appears the technology required to design and fabricate models for the NTF generally exists. Engineering design involving cryogenics has been a reality for a number of years, and the task will be to assemble the necessary information into a format easily usable by the model designer. Generally, "the object of the Models Task is to determine and document the requirements for the design of models to be tested in the NTF and, as required, to develop the technology necessary to meet the design requirements."

The specific objectives of the Model Design Task are outlined in table I. The outline also serves as the plan or the order in which the subjects will be addressed during the five-year study. The first objective will be to establish a generalized criteria of information to be supplied for model design. Probably one of the most time-consuming objectives will be the detailed investigation of components for NTF models. It is under this objective that the critical material questions will be addressed. One of the more difficult material problems appears to be the use of fillers. Certainly the "body fillers" commonly used in current wind-tunnel testing are not acceptable in the cryogenic environment. If an acceptable substitute is not found, the cost of models could increase significantly.

Although integration of instrumentation into the model design is an objective of this task, the detail design of research instrumentation such as balances will be accomplished by a separate task. It is anticipated that special fabrication techniques will be required to meet some of the NTF requirements; therefore, an ongoing effort will be used to address these problems as they arise from experience in the Langley 0.3-m transonic cryogenic tunnel or from other objectives of the task. As the NTF is planned to be a high productivity facility, there will be requirements imposed on the model design to accommodate work schedules, high data-acquisition rates, and automated control.

Late in the study it is planned to design and fabricate a "pathfinder" model using the information learned in the study. To conserve resources and evaluate earlier study results on a real problem, the model will be designed for testing in the Langley 8-foot transonic pressure tunnel but will meet NTF requirements. Finally, it is planned to establish and document design guidelines for NTF model design. At the present time it is anticipated that the design guidelines will be published in a format similar to the recently published Langley handbook "User-Furnished Wind-Tunnel Model Criteria," LHB 8850.1. The guidelines and requirements contained in this handbook will allow the model designer maximum flexibility while insuring the integrity of the models to be tested.

It is planned that the results of the NTF Model Design Task will be documented at least one year before the NTF is operational so that all users will have timely access to the study results.

TABLE I

MODEL DESIGN TASK OBJECTIVES

I. Establish a Generalized Criteria of Information to be Supplied for Model Design

II. Establish Specific Representative Design Values for Above Criteria to be Used in Future Studies

   A. Fighter Configuration
   B. Transport Configuration
   C. Space Shuttle

III. Determine Specialized Requirements Associated with NTF Environment

   A. Components
   B. Fabrication
   C. Instrumentation

IV. Investigate (Analytically or Experimentally as Appropriate) Components for NTF Models

   A. Materials
      1. Types
         (a) Metals
         (b) Nonmetals
         (c) Fillers
      2. Properties
         (a) Mechanical
         (b) Environmental Compatibility
         (c) Cost
         (d) Availability
         (e) Others
   B. Instrumentation
      1. Balance
      2. Pressure Techniques
      3. Temperature Techniques
      4. Other as Required
   C. Fasteners
   D. Devices
      1. Motors
      2. Bearings
      3. Others as Required

V. Investigate (Analytically or Experimentally as Appropriate) Special Fabrication Techniques

A. Review Problems with 0.3-Meter Facility and Others
B. Determine Capability to Meet Special Requirements

VI. Study Model Elastic Effects

A. Determine Seriousness
B. Method of Reduction
C. Effect on Model Design
D. Other Factors

VII. Determine Model Handling Requirements

A. Facility Compatibility
B. Time Constraints
C. Model Stability
D. Effect of Sting and Instrumentation
E. Others as Required

VIII. Design and Fabrication of Pathfinder Model and Sting

A. Design to NTF Requirements
B. Design for Testing Langley 8-foot Transonic Pressure Tunnel
C. Should be a Research Model (Not Just an Engineering Test Apparatus)
D. Fabricate to Test System

IX. Establish Design Guidelines for Model Design

A. Design Margins
B. Recommended Materials of Construction
C. Facility Constraints
D. Recommended Construction Techniques

X. Document Requirements and Recommendations as Appropriate

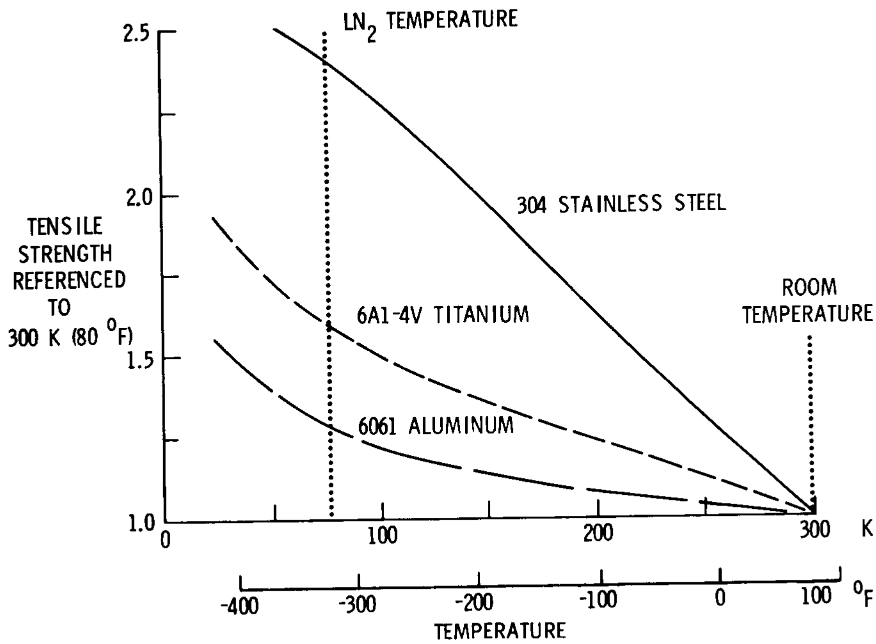

Figure 1.- Change in tensile strength of typical model construction materials.

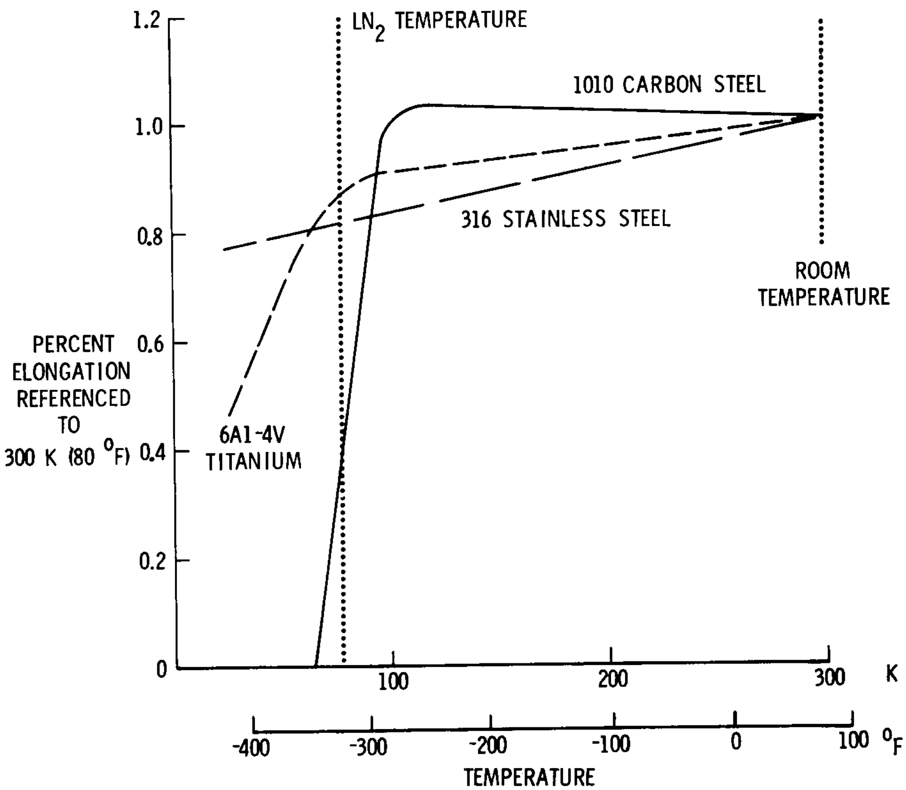

Figure 2.- Change in percent elongation of typical model construction materials.

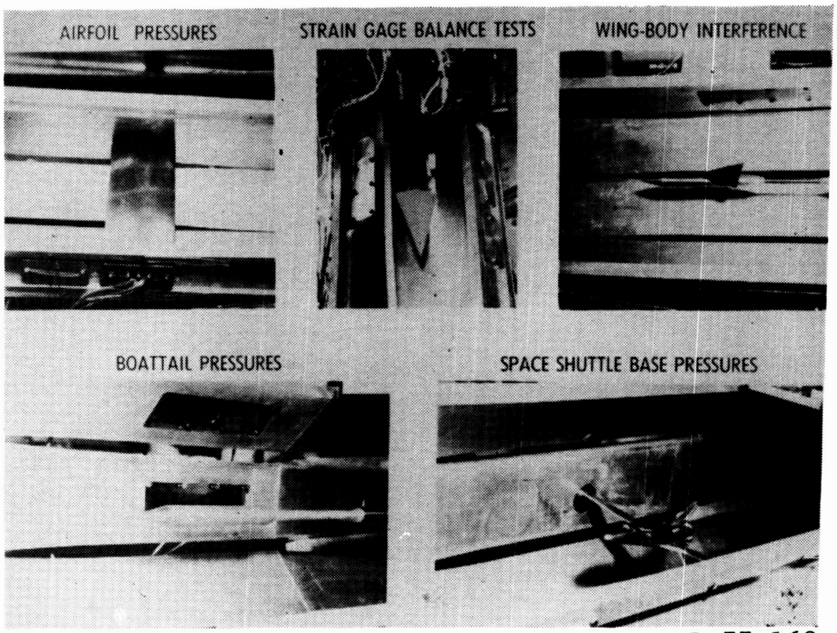

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Figure 3.- 0.3-meter transonic cryogenic tunnel tests.

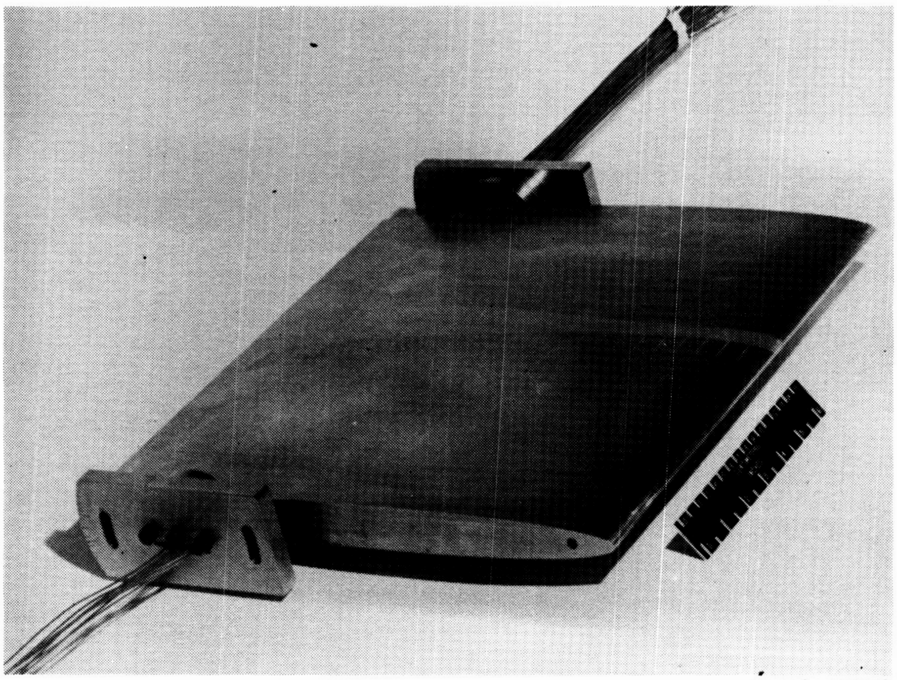

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Figure 4.- Fabrication of airfoil.