ENGINEERING AND FABRICATION COST CONSIDERATIONS FOR CRYOGENIC WIND TUNNEL MODELS

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DESIGN

To date NASA Langley has very little real experience on which to base an objective comparison of cryogenic wind tunnel model costs versus conventional model costs. Most of the experience gained over the past year or two contains significant development costs, such as material characterizations, developmental testing to understand the effects of the cryogenic environment on subsystems, and additional analyses that would not normally be required. This discussion, then, presents a more philosophical look at the main cost drivers, and considers primarily models for the National Transonic Facility (NTF). Both design or engineering costs and fabrication or manufacturing costs will be addressed.

Models for NTF testing are basically characterized by high-precision requirements, such as operation in an extremely low temperature environment and under relatively high loads. These are not new to model design individually, but collectively they require additional and special considerations. The requirement for high precision in terms of surface finish and tolerances adds very little to the engineering or design costs, but may be a significant factor in the manufacturing manpower or cost.

The cryogenic temperatures require the use of materials with relatively high fracture toughness but at the same time high strength. Some of these materials are very difficult to machine, requiring extensive machine hours which can add significantly to the manufacturing costs. Some additional engineering costs will be incurred to certify the materials through mechanical tests and nondestructive evaluation (NDE) techniques, which are not normally required with conventional models because of the high safety factors and insensitivity to flaws or cracks when operating at normal temperatures. When instrumentation such as accelerometers and electronically scanned pressure (ESP) modules is required, temperature control of these devices will have to be incorporated into the design, which will require added effort. Additional thermal analyses and subsystem tests may be necessary, which will also add to the design costs.

The largest driver to the design costs is potentially the additional static and dynamic analyses that will be required to insure structural integrity of the model and support system. The depth of analysis, and therefore the cost, will be a function of the margins of safety existing in the hardware. A handbook approach should first be used to examine the problem, and if high margins are indicated then additional analyses may not be required.

In summary, the largest impact to the design costs of cryogenic or NTF models is due to the analyses required to obtain confidence in the design. The tendency in the early stages of developing such models is to take a conservative approach. As more experience is gained and better analysis techniques are developed, these costs should come down.

FABRICATION

In general, the discussion given herein is valid for any wind tunnel model for the cryogenic transonic high Reynolds number tunnel. This is not to say that models for the National Transonic Facility will not cost more than models for conventional transonic tunnels; rather, the cost factors for the two classes of models are the same. The major cost factors for wind tunnel models are model complexity, tolerances, surface finishes, materials, material validation, and model inspection. To provide the maximum influence on model cost, it has been found that fabrication personnel should be involved early in the design process. Manufacturing processes must be determined in advance and attention must be directed toward processes that induce minimum stresses in the metal components. Since there will be a variety of types of models, the cost of cryogenic model fabrication must be determined on a case-by-case basis.

ENGINEERING COST CONSIDERATIONS

- LITTLE REAL EXPERIENCE EXISTS
  - EXPERIENCE TO DATE INCLUDES SIGNIFICANT "DEVELOPMENT" COSTS

- WHAT ARE PRIMARY COST DRIVERS AFTER DEVELOPMENT WORK IS DONE?

CRYO MODEL CHARACTERISTICS

- NTF MODELS CHARACTERIZED BY:
  - HIGH PRECISION
  - CRYO TEMPERATURES
  - HIGH LOADS

- NOT NEW TO MODEL DESIGN - INDIVIDUALLY

- COLLECTIVELY - CREATE SOME SPECIAL CONSIDERATIONS

FACTORS AFFECTING THE INCREASE IN NTF MODEL COST AS COMPARED TO CONVENTIONAL MODEL COST (Δ COST)

- PRECISION - TOLERANCE & SURFACE FINISH
  - MINOR DESIGN COST FACTOR
  - SIGNIFICANT FABRICATION COST FACTOR
- CRYO TEMPERATURES
  - MATERIALS
    - SPECIAL MATERIALS REQUIRED - STRENGTH, STABILITY, FRACTURE TOUGHNESS
    - ENGINEERING COSTS - MINOR
    - CAN BE SIGNIFICANT FABRICATION COST FACTOR
  - INSTRUMENTATION
    - ESPs, ACCELEROMETERS - TEMPERATURES NEED TO BE CONTROLLED
    - ADDITIONAL EFFORT - DESIGN, ANALYSIS, TEST - MAY BE REQ'D
- HIGH LOADS
  - GENERALLY MORE DETAILED ANALYSES REQUIRED
  - DEPTH OF ANALYSIS DETERMINES COST
  - DEPTH REQUIRED IS FUNCTION OF FACTOR OF SAFETY
  - USE HANDBOOK APPROACH TO DETERMINE IF PROBLEM EXISTS AND FURTHER ANALYSIS IS REQUIRED

SUMMARY

- LARGEST POTENTIAL ENGINEERING Δ COST OCCUR IN THE STATIC AND DYNAMIC ANALYSES REQUIRED TO OBTAIN CONFIDENCE IN DESIGN.
- SHOULD ONLY REPRESENT SIGNIFICANT Δ COSTS WHEN FACTORS OF SAFETY ARE LOW.
- EACH MODEL IS DIFFERENT - CAN'T GENERALIZE.
- FREQUENT COMMUNICATION IS IMPORTANT TO KEEP COSTS DOWN.

MANUFACTURING COST FACTORS

- o COMPLEXITY OF MODEL
- o TOLERANCES
- o SURFACE FINISHES
- o INSTRUMENTATION
- o MATERIALS
- o SPECIAL PROCESSING
- o QUALITY ASSURANCE REQUIREMENTS

COMPLEXITY OF MODEL

- o CONSTRUCTION METHOD
  - A. UNITIZED
  - B. STRONG BACK
- o SHAPE AND ASPECT RATIO OF AIRFOIL.
- o NUMBER OF INTERCHANGEABLE ELEMENTS; FLAPS, SLATS, ETC.
- o TYPE, NUMBER, INSTALLATION METHOD, AND ROUTING OF INSTRUMENTATION.
- o COVERPLATES AND ACCESS HATCHES TO INSTRUMENTATION.
- o ATTACHMENT METHODS FOR CONTROL SURFACES.

TOLERANCES - AIRFOIL SECTIONS

- o TOLERANCE AND SURFACE FINISH MUST BE CONSIDERED JOINTLY TO DETERMINE MANUFACTURING COSTS.

- o TIME REQUIRED TO MACHINE AND HANDWORK TO A GIVEN TOLERANCE INCREASES PROPORTIONALLY TO THE INCREASE IN TOLERANCE REQUIREMENT.

- o FACTORS INFLUENCING COST OF ACHIEVING SPECIFIC TOLERANCE

  A. STABILITY OF MATERIAL

  B. MACHINING AND FINISHING METHOD

  C. PROPORTIONAL AMOUNT OF HAND FINISHING VERSUS MACHINE TIME

  D. REQUIRED SURFACE FINISH OF COMPLETED COMPONENT

SURFACE FINISHES - AIRFOIL SECTIONS

- o TOLERANCE AND SURFACE FINISH MUST BE CONSIDERED JOINTLY TO DETERMINE MANUFACTURING COSTS.

- o TIME REQUIRED TO MACHINE AND HANDWORK TO A GIVEN SURFACE FINISH INCREASES GEOMETRICALLY TO THE INCREASE IN FINISH QUALITY.

- o FACTORS INFLUENCING COST OF ACHIEVING SPECIFIC SURFACE FINISH:

  A. FINISHING QUALITY OF MATERIAL

  B. MACHINING AND FINISHING METHODS

  C. PROPORTIONAL AMOUNT OF TIME REQUIRED FOR HANDWORK VERSUS MACHINE WORK

  D. REQUIRED TOLERANCE OF FINISHED COMPONENT

MATERIALS

- o COST OF MATERIALS
- o SPEEDS AND FEEDS
- o MANUFACTURING SEQUENCE
- o EQUIPMENT AND TOOLING

FABRICATION COST COMPARISON OF THREE TWO-DIMENSIONAL CRYOGENIC AIRFOILS OF SIMILAR DESIGN

MODEL	% THICKNESS	MATERIAL	FABRICATION COSTS IN MANHRS.	FABRICATION COST INCREASE	FACTORS IN INFLUENING COST INCREASE	% OF COST INCREASE BY FACTOR
#1	12%	15-5 S.S.	862	-	-	-
#2	14%	13-8 MO	948	10%	● QUALITY ASSURANCE	6%
					● CRYOCYCLING OF MATERIAL DURING FABRICATION	4%
#3	12%	VASCOMAX-200	1172	36%	O INCREASED MACHINING TIME DUE TO MATERIAL AND INCREASED NUMBER OF OPERATIONS	21%
					O QUALITY ASSURANCE	11%
					O CRYO CYCLING OF MATERIAL DURING FABRICATION	4%

SUMMARY

- o FABRICATION COST DRIVERS
  - A. COMPLEXITY OF MODEL
  - B. TOLERANCES AND SURFACE FINISHES
  - C. MATERIALS
  - D. INSPECTION AND VALIDATION
- o DESIGN/ANALYSES, FABRICATION AND TESTING COSTS MUST BE EVALUATED JOINTLY TO DETERMINE MOST COST EFFECTIVE APPROACH.
- o MODEL FABRICATION PERSONNEL SHOULD BE INVOLVED EARLY IN DESIGN STAGE TO PROVIDE MAXIMUM COST EFFECTIVE INFLUENCE.
- o COST OF CRYOGENIC MODEL FABRICATION MUST BE DETERMINED ON A CASE BY CASE BASIS DUE TO VARIETY OF COST INFLUENCING FACTORS.
- o MANUFACTURING PROCESSES MUST BE DETERMINED IN ADVANCE AND ATTENTION MUST BE DIRECTED TOWARD PROCESSES THAT INDUCE MINIMUM STRESSES IN METAL COMPONENTS.