511-05

HSR

High Speed Research - Configuration Aerodynamics

Langley Research Center

Aftbody Closure Model Design

Lessons Learned

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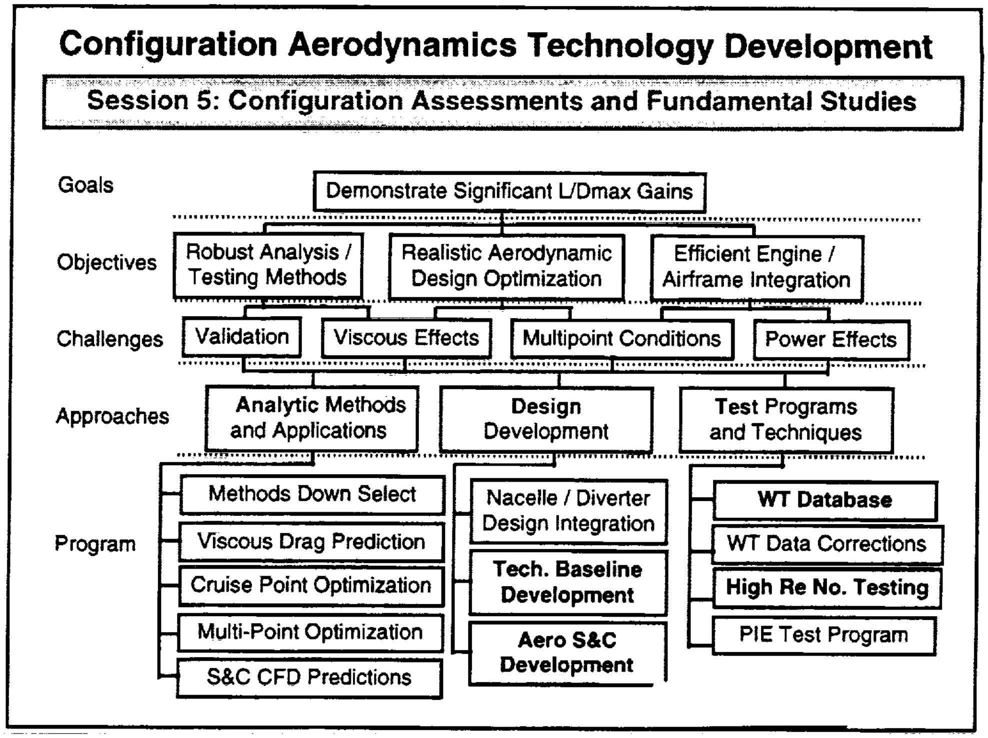


This figure shows the Configuration Aerodynamics "Program on a Page".

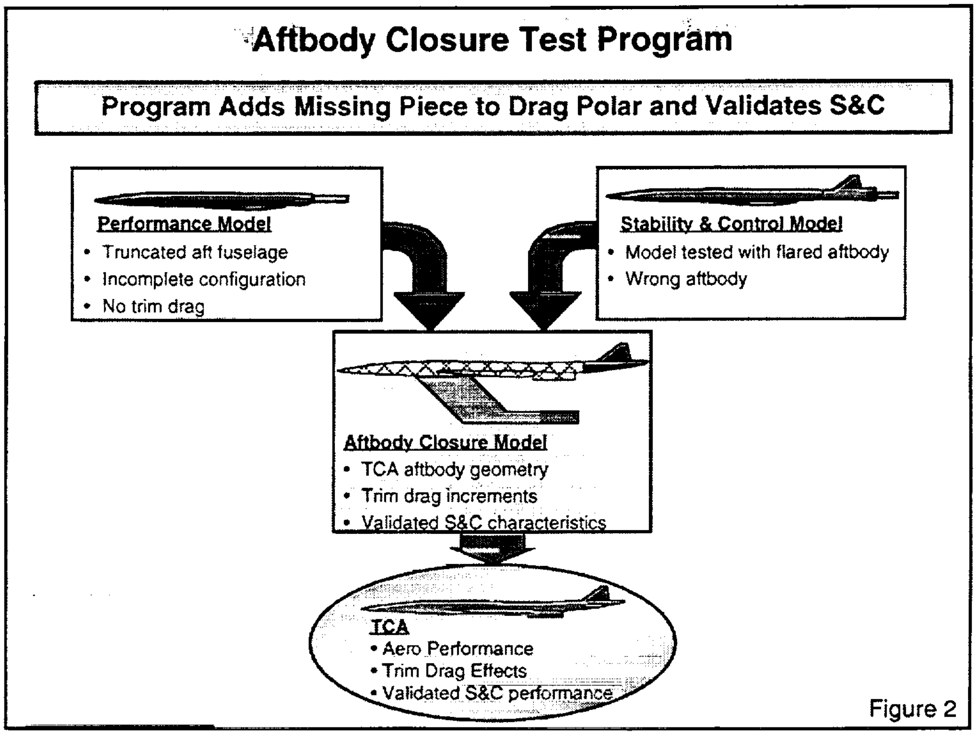


Figure 2

An Aftbody Closure Test Program is necessary in order to provide aftbody drag increments that can be added to the drag polars produced by testing the performance models (models 2a and 2b). These models had a truncated fuselage, thus, drag was measured for an incomplete configuration. In addition, trim characteristics cannot be determined with a model with a truncated fuselage.

The stability and control tests were conducted with a model (model 20) having a flared aftbody. This type aftbody was needed in order to provide additional clearance between the base of the model and the sting. This was necessary because the high loads imposed on the model for stability and control tests result in large model deflections. For this case, the aftbody model will be used to validate stability and control performance.

Overall Program Objectives

Program Combines Performance and S&C Objectives

- **Establish and validate aftbody closure test techniques**
- **Determine drag characteristics for various aftbody geometry's**
- **Determine trim drag increments**
- **Provide data base for correlation of CFD predictions of aft-body drag and stability and control characteristics**
- **Validate longitudinal and directional stability levels**
- **Validate control effectiveness**
- **Assess effects of nacelle nozzle external shape on aftbody drag**
- **Provide data base for correlation of data to other models**
- **Assess inlet unstart characteristics**

Figure 3

The aftbody closure overall program objectives are a combination of both the performance and stability and control objectives. One prime objective of this program was to establish and validate aftbody closure test techniques. This paper will present the results of study in which the basic model would be wing-tip supported in the wind tunnel. As such, it will show why this particular system was chosen and some of the resulting issues and problems associated with the design of a wing-tip supported model.

Overall Program Requirements

Program Combines Performance and S&C Requirements

Performance Requirements:
- $M = 0.9, 0.95, 1.2, 2.4$
- $-4° \leq \alpha \leq 8°$
- $\beta = 0°$
- $\delta_t = -6°, -2°, 0°, 2°, 4°, 6°$
- ± 1.5 ct accuracy - Transonic
- ± 1/2 ct accuracy - Supersonic
- Aftbody configurations
  - Baseline TCA aftbody
  - Modified baseline
  - Flared aftbody
- Nacelle shapes

S & C Requirements:
- $M = 0.6, 0.90, 0.95, 1.2, 1.8, 2.4$
- $-4° \leq \alpha \leq 12°$
- $-6° \leq \beta \leq 6°$ - Transonic
- $-3° \leq \beta \leq 3°$ - Supersonic
- $-9° \leq \delta_t \leq 9°$ - Transonic
- $-6° \leq \delta_t \leq 6°$ - Supersonic
- $\delta_r = 0°, 10°, 20°$ - Transonic
- $\delta_r = 0°, 10°$ - Supersonic
- Aftbody configurations
  - Baseline TCA aftbody
  - Flared aftbody
- Nacelle inlet plugs

Figure 4

As with the overall test objectives, the program requirements were also a combination of the performance and stability and control requirements. Note that a wider range of test conditions are necessary for stability and control whereas, one of the more important performance requirements is both a transonic and supersonic accuracy requirement. Model scale was essentially fixed by the need for stability and control data at Mach 1.8. Obtaining data at this Mach number is desirable because of nonlinearites that occur in the various stability parameters. The model scale chosen was 1.5-percent which was the same as Model 20 that was used for stability and control tests. The resulting model length is the longest model that can be tested at mach 1.8 in the Unitary Plan Wind Tunnel (UPWT) at Langley. Tests were also planned for the 16-FT Transonic Tunnel.

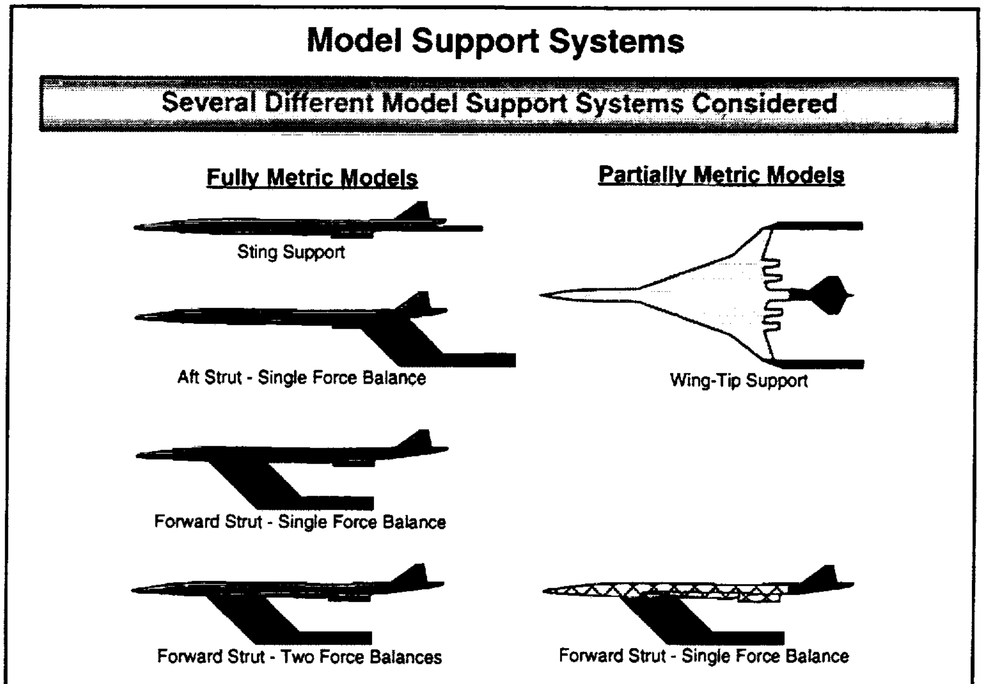
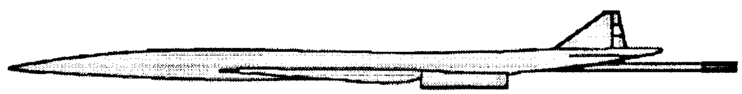


Figure 5

The combination of test objectives and requirements generally will have a strong impact on the type of model support chosen for the test. Several support systems can be used for an aftbody closure type test and a study was conducted to determine which support system was best suited to meet the overall test objectives and requirements. For the current test, several support systems were considered and are shown above. These support systems generally fall into two classes; those that are fully metric in which total configuration forces are measured, and partially metric in which forces are measured only on the configuration aftbody. Figures 6 to 11 list the advantage and issues associated with each of the support systems considered in this study.

Fully-Metric Model Support Systems

Sting-Support WithSingle Force Balance



ADVANTAGES

- Complete aerodynamics measured
- Model can be sized for UPWT
- Could test with truncated fuselage (similar to model 2)
- Could test with extended aftbody (similar to model 20)
- Can test at sideslip

ISSUES

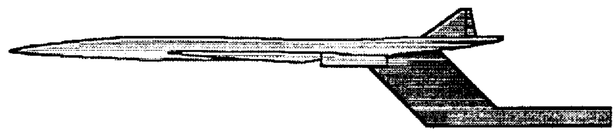
- Aftbody always in presence of sting
- Aftbody increment is difference of two large numbers
- Large balance forces
- Sting interference needs evaluation
- Seal at metric break
- Large internal pressure correction to normal and axial force (corrections based on inaccurate area measurement)
- Cannot be used for HSCT type configurations

Figure 6

Figure 6 shows a sting-supported model. Although this type of support system cannot be used for a HSCT slender configurations, it was included to show advantages and issues for this type support system.

Fully-Metric Model Support Systems

Aft Strut-Support WithSingle Force Balance



ADVANTAGES

- Complete aerodynamics measured
- Sting/Strut shock induced interactions minimized at supersonic speeds
- Could use existing sting/strut support
- Model can be sized for UPWT

ISSUES

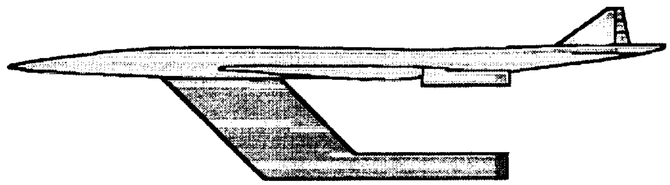
- Aftbody always in presence of strut
- Aftbody increment difference of two large force balance measurements
- Strut interference needs evaluation
- Seal at metric break
- Large internal pressure correction to normal and axial force (corrections based on inaccurate area measurement)
- Potential for major fouling problems
- Testing at sideslip may be limited
- Determination of tunnel flow angularity

Figure 7

Figure 7 shows a model with an aft strut-support system. This support system was eliminated because the aftbody would always be in the presence of the strut. It was felt that the strut interference effects could not be determined

Fully-Metric Model Support Systems

Forward Strut-Support WithSingle Force Balance



ADVANTAGES

- Complete aerodynamics measured
- Aftbody not in presence of strut
- Model can be sized for UPWT
- Testing at sideslip may be easier for forward strut

ISSUES

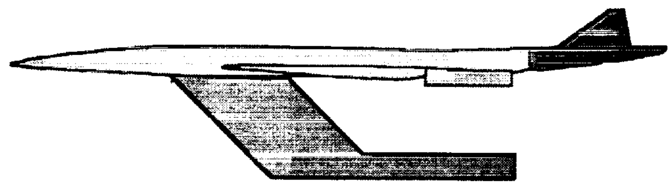
- Aftbody increment is difference of two large force balance measurements
- Strut interference needs evaluation
- Seal at metric break
- Large internal pressure correction to normal and axial force (corrections based on inaccurate area measurement)
- Sting/strut/model shock interactions may be problem at supersonic speeds
- Potential for major fouling problems
- Determination of tunnel flow angularity

Figure 8

This figure shows a model with an forward strut-support system. This support system was eliminated because of the need to determine strut interference effects. A large portion of the model fabrication budget would have to devoted to making alternate position and dummy supports that would be needed to determine support interference. Also, determining support system can take up to 25-percent of the time available to test.

Fully-Metric Model Support Systems

Forward Strut-Support With Two Force Balance



ADVANTAGES

- Complete aerodynamics measured with main force balance
- Aftbody drag measured directly by aftbody force balance
- Can duplicate geometry of Models 2 and 20 in order to provide increments to adjust data to full configuration
- Model can be sized for UPWT
- Testing at sideslip may be easier for forward strut

ISSUES

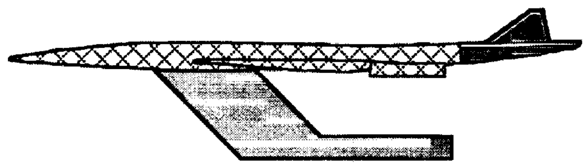
- Strut interference needs evaluation
- Seals at metric breaks
- Large internal pressure correction to normal and axial force (corrections based on inaccurate area measurement) for main balance
- Sting/strut/model shock interactions may be problem at supersonic speeds
- Potential for major fouling problems
- Determination of tunnel flow angularity

Figure 9

This figure shows a model with an forward strut-support system and a second force balance to measure aftbody forces. While this may be the best support system to use because bot total and aftbody forces would be measured, it was also eliminated because of the need to determine strut interference effects.

Partially-Metric Model Support Systems

Forward Strut-Support With Single Force Balance



ADVANTAGES

- Aftbody drag directly measured
- Low balance forces
- Strut interference does not need to be evaluated
- Can duplicate geometry of Models 2 and 20 in order to provide increments to adjust data to full configuration
- Testing at sideslip may be easier for forward strut
- Determination of tunnel flow angularity not critical

ISSUES

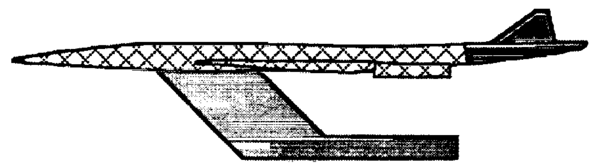
- Performace based on sum of measurements from two or more tests
- Potential for large internal pressure correction to axial force (correction based on accurate area measurement)
- Seal at metric break
- Sting/strut/model shock interactions may be problem at supersonic speeds

Figure 10

This figure shows a model with a partially-metric, forward strut-support system in which the force balance measures only aftbody forces. This support system was eliminated because of the uncertainty in sting/strut shock interactions at supersonic speeds that could occur if the same support strut was used in both facilities that tests were to be conducted.

Partially-Metric Model Support Systems

Forward Strut-Support With Single Force Balance



ADVANTAGES
- Aftbody drag directly measured
- Low balance forces
- Strut interference does not need to be evaluated
- Can duplicate geometry of Models 2 and 20 in order to provide increments to adjust data to full configuration
- Testing at sideslip may be easier for forward strut
- Determination of tunnel flow angularity not critical

ISSUES
- Performace based on sum of measurements from two or more tests
- Potential for large internal pressure correction to axial force (correction based on accurate area measurement)
- Seal at metric break
- Sting/strut/model shock interactions may be problem at supersonic speeds

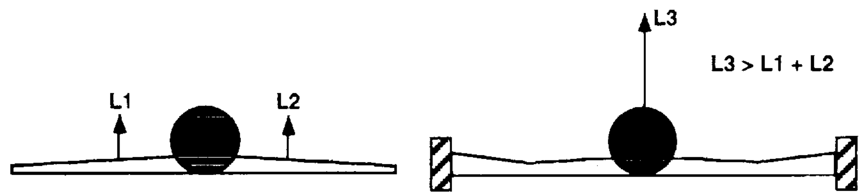
Figure 11

This figure shows a model with a partially-metric, wing-tip support system in which the force balance measures only aftbody forces. Although this support system has more issues than the forward strut support shown in figure 10, it was chosen because it was felt that this support system would have the least support interference effects on the aftbody.

With the support system and model scale chosen, model requirements were issued to designers to proceed with a design of a wing-tip supported model.

The Wing-Tip Design Problem

Total Model Loads Now Tranmitted Through Wing Tips



Sting - Supported Model

- Load from each wing panel transmitted through wing root
- Control surface loads typically transmitted through fuselage structure
- Instrumentation leads routed out through sting

Wing - Tip Supported Model

- Total model load, including wing plus control surfaces, now transmitted through wing-tip
- Wing-tip subjected to shear load plus bending and torsion moments
- Instrumentation leads now routed out through wing tips

Figure 12

This figure has been included to illustrate the main structual problem associated with a wing-tip support model. For a conventional sting-supported model, the main loads are developed on the wings. Typically, the lift load on each wing panel is transmitted through the wing root to a fuselage strongback. The wing root chord generally is longer and thicker than any other wing chord. In addition, control surface loads are transmitted through the fuselage structure. Instrumentation leads are routed out through the sting or a support strut.

For the wing-tip supported model, total model loads including control surface loads now must be transmitted out through the wing tips. The wing tip is also subjected to shear loads plus bending and torsion moments, the latter which can be quite high. In addition, additional thickness must be made available in order to route instrumentation leads through the wing-tips. These load conditions imposed on the wing tip will result in increases to both the length and thickness of the wing tip chord.

Wing-tip supported model have been in use for many years. Such systems have been used for fighter type configurations at the 16-Ft Transonic Tunnel since 1955. For a fighter type configuration, wing thickness ratio can usually be maintained out to about 50-percent semispan after which the wing is designed to have constant thickness. In addition, a modest increase (15 to 20 percent) in wing tip chord may be required. However, fighter configurations generally have wings with greater aspect ratio and thickness ratio than HSCT configrations. None the less, previous experience in the design of wing-tip support systems had a large influence on the decision to proceed with this type support.

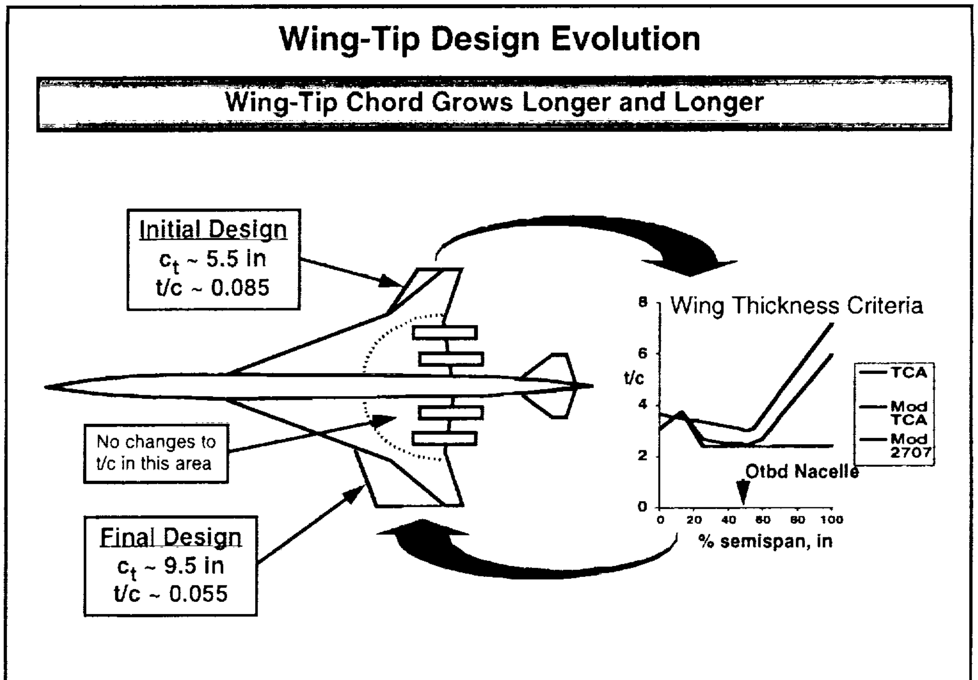


Figure 13

As stated earlier, model design was initiated once the support system, model scale and preliminary loads were known. However, there were no requirements or guidance given to the model designers on how wing thickness ratio may vary along the wing semispan. As a result, the initial design of the wing-tip support model had a tip chord of about 5.5 inches with a thickness ratio of 8.5 percent. This design did however, maintain the thickness ratio of the chord at the break in the wing leading edge. The tip chord for the 1.5-percent model is about 2.2 inches. Thus this first design had a new tip chord that was just over twice as long as the unmodified tip chord.

The model designers were then given wing thickness criteria as shown on figure 13. It was desired that the tip chord thickness ratio not exceed 6 percent. For reference, the wing thickness ratio of a very early supersonic configuration that was tested with a wing-tip support had a 7-percent thick tip chord is also shown in figure 13. As can be seen, the final design that emerged was one that had a tip chord of about 9.5 inches with 5.5-percent thick airfoil. This design also maintained the thickness ratio of the chord at the break in the wing leading edge.

Wing-Tip Support Model Design for 16 FTT

Some Major Design Concerns Still Existed

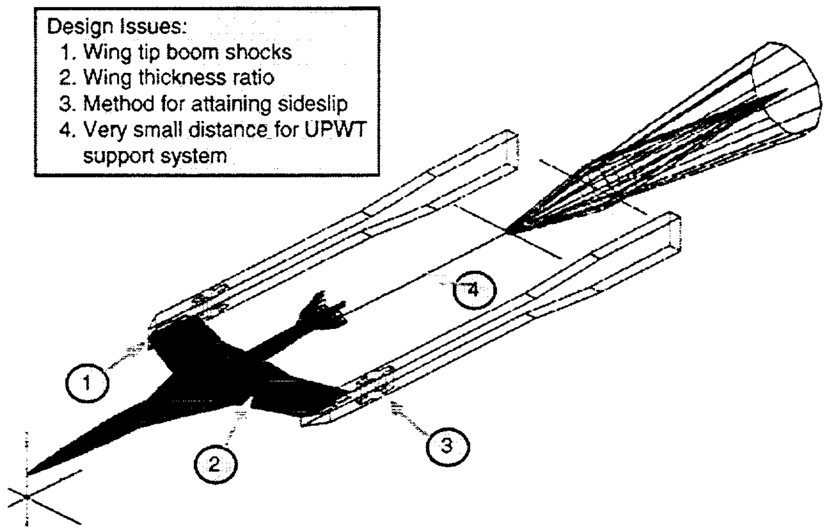


Figure 14

This figure shows a schematic of the wing-tip model as it would installed in the 16-Ft Transonic Tunnel. Basically, all the hardware shown would have to be built. The wing-tip booms would be about 5 feet long. Sideslip would be accomplished by using incidence blocks in the booms. At this point, the structural design of the support booms did not consider any side loads that would be generated by the forward part of the boom that effectively was at an angle of attack.

Also shown on this figure are some of the issues that still remained with the wing-tip support that were shown earlier on figure 11. These included wing-tip boom shock interactions on the aftbody portion of the model, wing thickness ratio at about 50 to 60-percent semi-span and the method of attaining sideslip. In addition, there was a concern of the distance between the end of the model and the main tunnel support in UPWT. For the 16 FTT, this distance was fixed at 30 inches whereas in UPWT this distance would be about 6 inches.

Wing-Tip/Boom Shock Interactions

Shock Interactions on Model Unacceptable

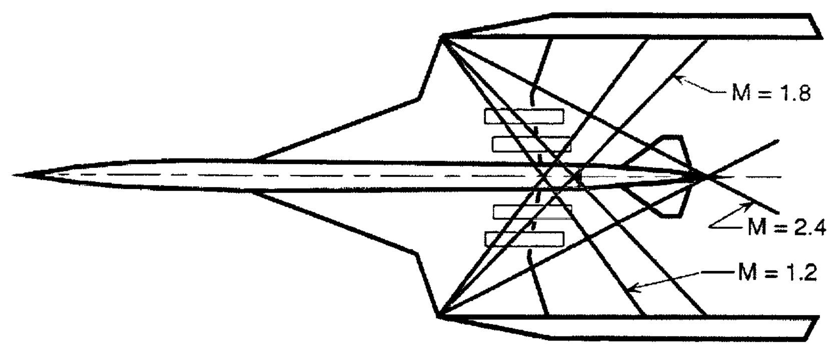


Figure 15

The predicted wing-tip/boom shock intersections on the model at Mach numbers of 1.2, 1.8 and 2.4 are shown in figure 15. At Mach 2.4, shocks from the wing-tip booms can be seen impinging on the aftbody portion of the model which is unacceptable. At Mach 1.8, the shocks intersect on the model near the metric break which also is unacceptable. This is because the shocks may affect the pressure measurements made at the metric break. These pressure measurements are used to correct force data similar to cavity and base corrections for a sting-mounted model. At Mach 1.2, the intersection of the shocks forward of the metric break was also considered marginally unacceptable.

One means of eliminating the effect of the wing-tip boom shock problem is to extend the booms such that the shocks intersect on the nonmetric portion of the model far upstream of the metric break. This has method has previously been used. However, this was deemed impracticable for the Mach 2.4 case because the booms would have to be extended forward of the location where the wing leading edge intersects the fuselage. Boom extensions of this length would have resulted in very large loads in the side direction on the booms. The booms would then have to be much thicker to take these loads. In addition, there could be extensive support interference from the flow field of the deflected booms.

The proposed solutions to the above wing-tip boom shock problems are shown in the next figure.

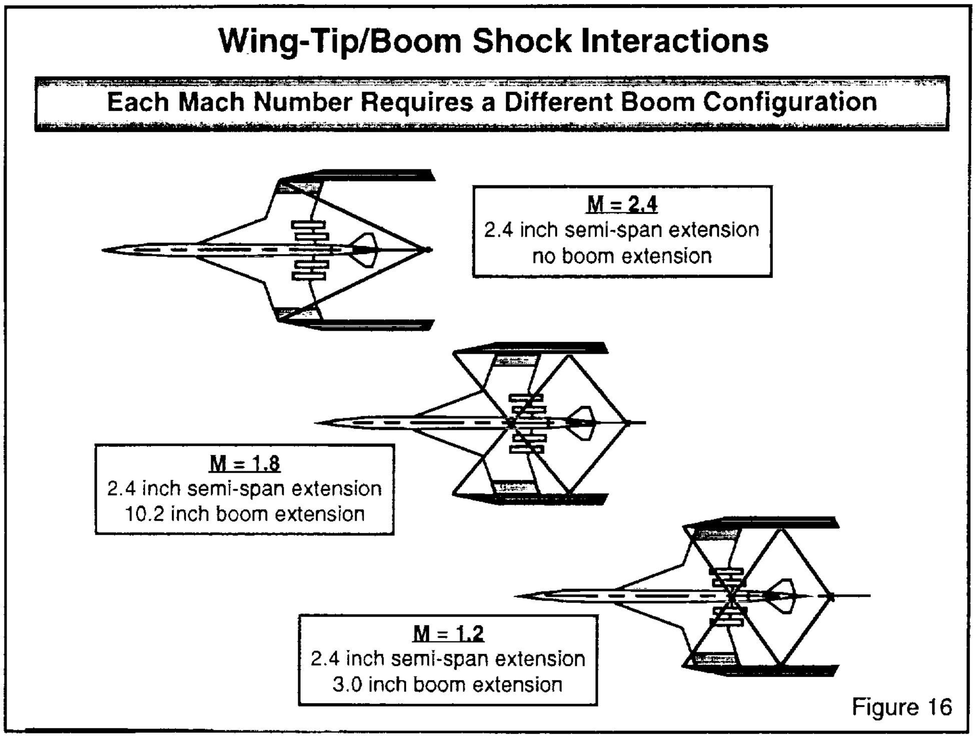


Figure 16

At Mach 2.4, the wing-tip boom shock intersections were moved far downstream of the model by extending the wing semispan by 2.4 inches. A boom extension of 10.2 inches was then required at Mach 1.8 in addition to the span extension in order to move the shock intersections forward on the nonmetric portion enough where the effects of the shocks were considered minimal. At Mach 1.2, a 3.0 inch boom extension was needed. Note, that at these two Mach numbers, no consideration was given to the extra loads imposed on the support booms when the model would be tested at sideslip.

Wing Thickness Issues

Growth of Inboard Wing Thickess Ratio Becomes Unacceptable

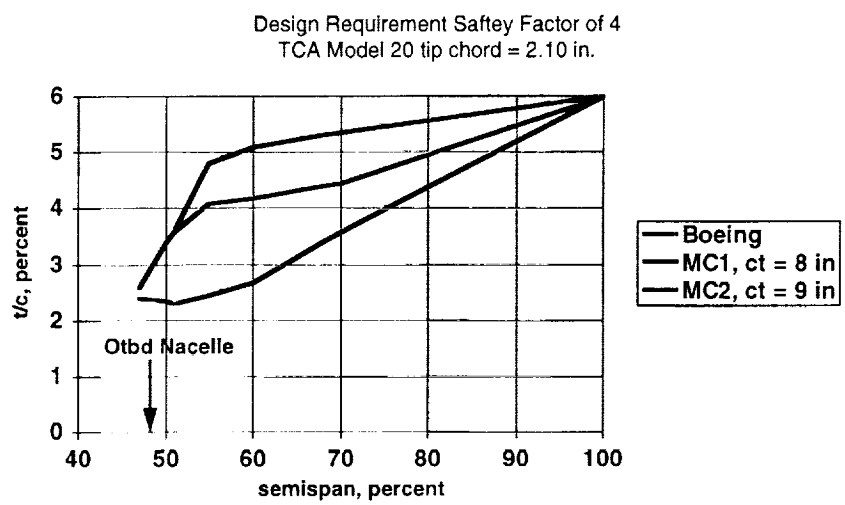


Figure 17

Additional structural analysis were being performed on the wing since the previous analysis shown in figure 13 was done only on the wing tip. The results of this analysis shown on the above figure indicated that the wing thickness ratio had to be at least 4-percent at the 55 to 65-percent semispan stations in order to facility strength and safety factor requirements. This thickness ratio was much higher than the desired thickness of 2.5 percent. This was for the wing with the 9-inch tip chord. The maximum thickness for this portion of the wing that could be tolerated was thought to be about 3 percent.

Wing Thickness Issues

Large Model Deflections Predicted by FEM Analysis

1. Overall deflection was 2.185 in.
2. Max stress denoted in red 56,713 psi
3. Analysis performed on Microcraft wing loft
4. VASCOMAX C-250 required for saftey factor 4

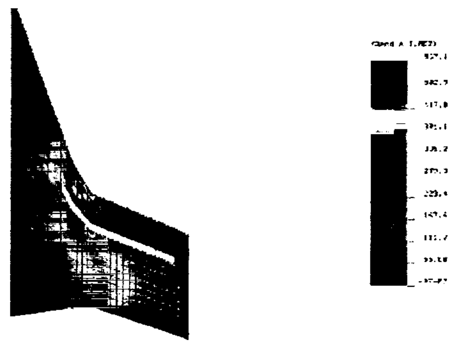


Figure 18

Figure 18 shows the results of a finite element analysis (FEM) that was conducted on the wing-tip support model for the wing identified as MC2 on figure 17. As can be seen, the maximum stresses were about 57 kpsi. This result did check the handbook analysis. However, one factor the handbook analysis could not show were the two areas of high stress concentrations located at the break in the wing leading edge and inboard on the wing at about 25-percent of the chord. Stress concentrations of this type are generally not desirable for primary structure for wind tunnel models. This analysis also showed that the minimum material required was VASCOMAX C-250 which is also a steel that is not generally desirable for fabricating wind tunnel models. However, the most disturbing result from the FEM analysis was the very high predicted model deflection of over 2 inches. This high model deflection was not acceptable.

Summary -- Wing-Tip Design Study

Basic Support System Changed Based on Study Conclusions

- Extreme modifications to baseline TCA outboard wing necessary to carry loads imposed by wing-tip support system
- Wing thickness ratio imposed by structual requirements at mid span locations of the modified wing unacceptable
- Finite analysis of modified wing with greater thickness ratio showed
  - Undesirable stress concentrations at break in wing leading edge
  - Max stress of ~57,000psi requires VASCOMAX
  - Large deflections on the order of 2 inches
- Uncertainty in wing/wing-tip-boom shock interference
- Close proximity of end of fuselage to UPWT main support system
- Lack of CFD analysis

Wing-Tip Support Abandoned in Favor of Forward Strut-Support

Figure 19

A thorough review was made of all of the results from the wing-tip supported model design. These results are summarized in figure 19. At this point, the wing-tip support was abandoned in favor the forward-strut-support with a partial metric model in which only aftbody forces would be made. This type support system was previously described in figure 10.

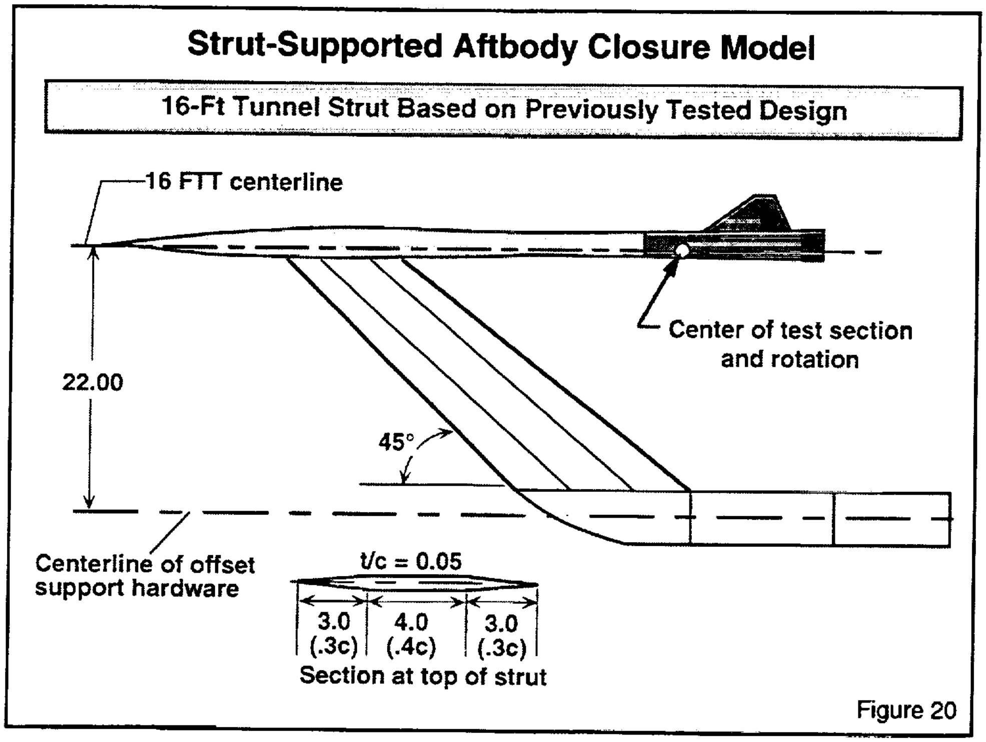


Figure 20

Figure 20 shows a schematic of the model as it will be installed the 16-Ft Transonic Tunnel. The support strut airfoil section characteristics at the top of the strut were similar to a support strut used at 16FTT. The model will be located on the wind tunnel centerline. The aftbody is located basically in the center of the test section.

Strut-Supported Aftbody Closure Model

UPWT Strut Profile Based on Previous Design

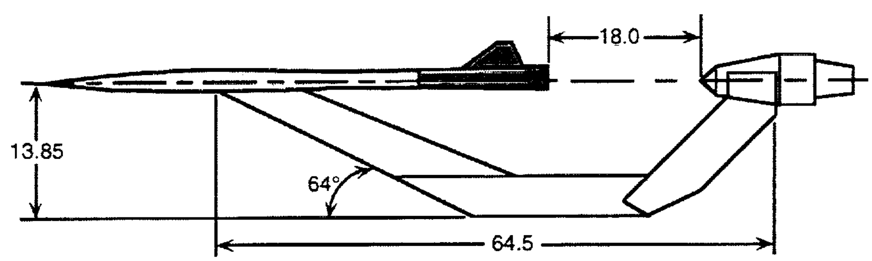


Figure 21

Figure 20 shows a schematic of the model as it will be installed the UPWT. The support strut profile was based on a previous support strut that was tested in UPWT. The blockage characteristics of the current aftbody test are similar to the model previously tested.

Strut-Supported Aftbody Closure Model

A Significant Amount of Existing Hardware Usable

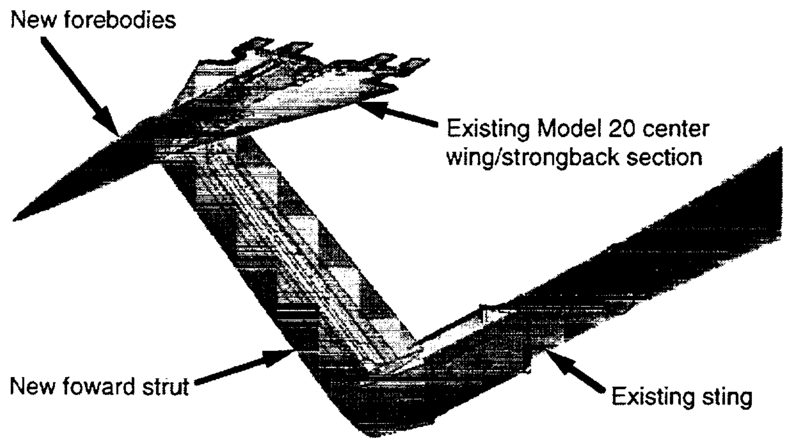


Figure 22

Figure 22 shows another view of the installation for the 16-Ft Transonic Tunnel. One thing to note is that the existing wing/strongback section of model 20 will be used for this investigation. This results in substantial savings in model fabrication time.

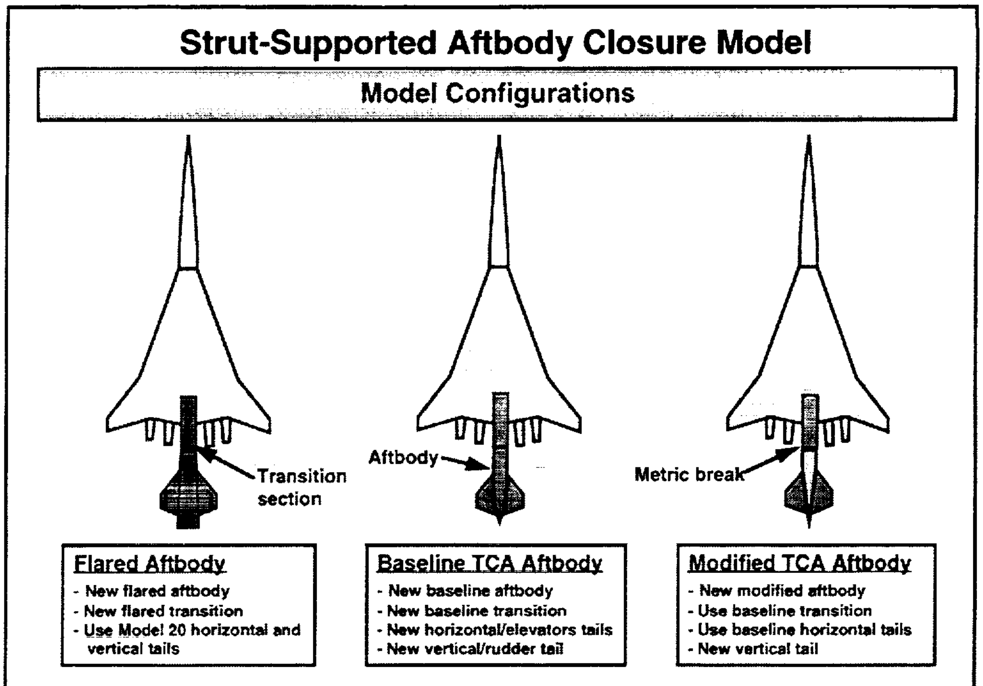


Figure 23

Figure 23 presents the three basic model configurations to be tested. The configuration with the flared aftbody is similar to model 20. The model part labled transition section will be part of the nonmetric model on which no forces are measure.

The middle sketch shows the baseline TCA aftbody. It has its own transition sections. As can be seen, all new control surfaces need to be built in order to test this configuration.

The configuration with the the modified TCA aftbody will be used primarily to determine trim characteristics. This aftbody allows the leading edge of the horizontal to remain ported with a +7° setting. The horizontal tail remained ported for the baseline aftbody only to about 2.5°.