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Nacelle-Wing Integration

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Topics of Discussion

The Aerodynamics Division at NASA Ames Research Center is participating in the propulsion airframe integration phase of the High Speed Research Program. The two areas of research being pursued include an experimental program and analysis using computational fluid dynamics. The Applied Aerodynamics Branch is conducting the experimental program, which will involve a nacelle airframe model that was tested in the Ames 11- by 11-Foot Transonic Wind Tunnel in 1973. This branch will also assess various Euler codes in predicting nacelle airframe interference effects. The goal is to provide industry with the necessary data and tools to design a high speed civil transport with favorable propulsion airframe interference.

Topics of Discussion

- Experimental Program
- Computational Fluid Dynamics Research

Figure 1

Background

A nacelle-airframe interference test was conducted in the Ames 11- by 11-Foot Transonic Wind Tunnel in 1973, reference 1. The purpose of the test was to measure detailed interference force and pressure data on a representative supersonic wing-body-nacelle combination at transonic speeds, $0.9 \leq M \leq 1.4$. The basic aerodynamic model was of the final Boeing supersonic transport configuration (Boeing model SA1150). Four independently supported nacelles were positioned beneath the model. The nacelle support system provides the flexibility of varying the nacelle positions relative to the wing-body and to each other and controls the mass flow through each nacelle. The primary variables examined were Mach number, angle of attack, nacelle position, and nacelle mass flow ratio. Four configurations were tested: isolated nacelles, four nacelles as a unit, isolated wing-body, and wing-body-nacelle combination. The data acquired from this test is used extensively by industry. In preparation for phase II of the High Speed Research Program, there has been a high interest in expanding the drag interference database on this model to a higher supersonic regime.

Background

- Test conducted in 1973 in the NASA Ames 11 ft Transonic Wind Tunnel
- SA1150 wing-body and axisymmetric nacelles independently supported
- Current database of wing-body and nacelle interference forces and pressures at $.9 \leq M \leq 1.4$
- Database is used extensively by industry

Figure 2

Nacelle-Airframe Interference Model

Figure 3 is a photo of the nacelle-airframe model installed in the Ames 11- by 11-Foot Transonic Wind Tunnel in 1973. This figure illustrates how the nacelles are mounted separate from the the wing-body. The nacelles are attached to stings where the mass flow plugs are housed. The nacelle stings are attached to the nacelle support system, which is attached to the main sting of the wing-body.

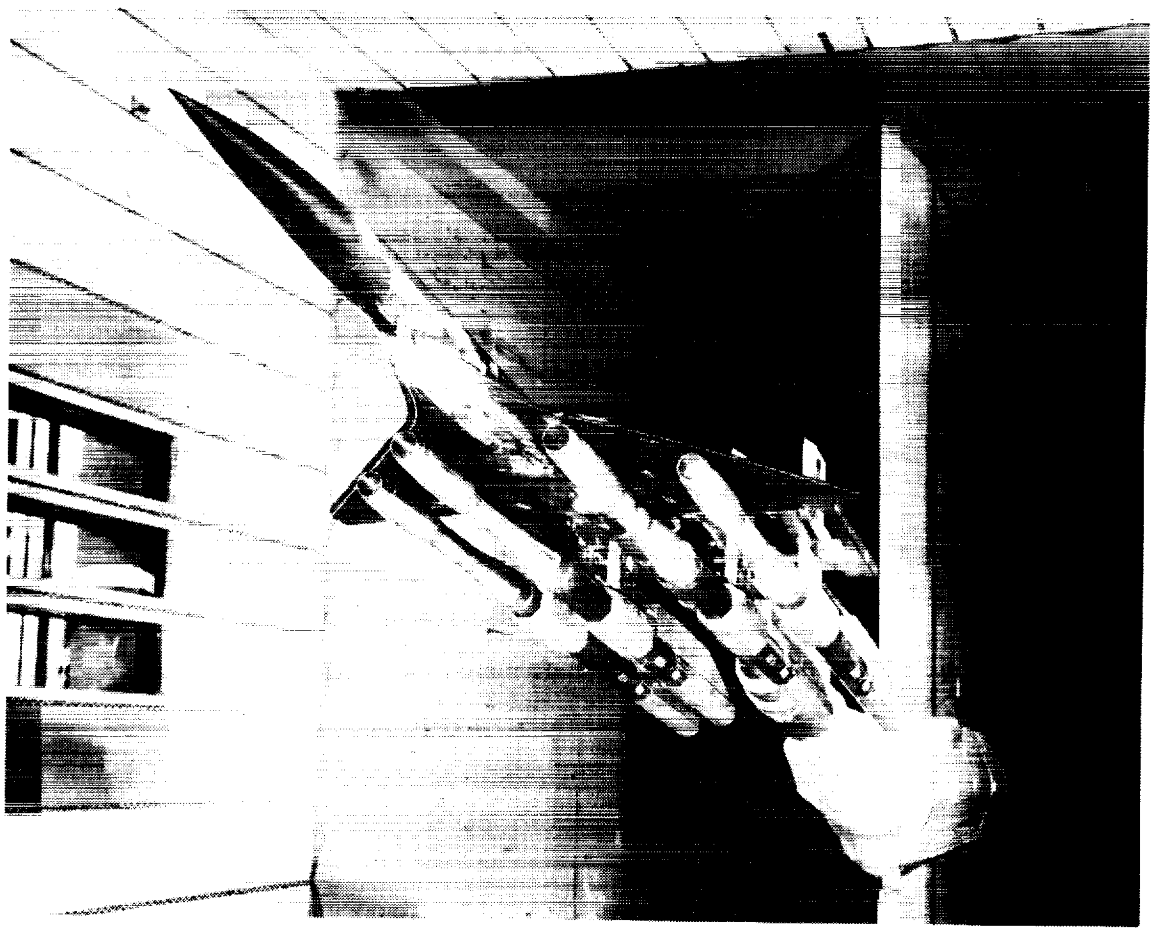

Figure 3. Nacelle-Airframe Model Installed in the Ames 11- by 11-Foot Transonic Wind Tunnel

Nacelle-Airframe Interference Test
Current Program Objectives

The data acquired during the 1973 nacelle airframe interference, NAI, test has been extensively used by both Boeing and Douglas in their development of a high speed civil transport. The NASA Lewis Propulsion Airframe Integration, PAI, meeting in June 1990 showed strong support from Boeing and Douglas for an expanded program. It has also been identified at the Non-Advocate Review as a key technology and is also strongly supported by NASA Lewis and Langley. There are three main objectives for the planned NAI test. This test will be conducted in the Ames 9- by 7-Foot Supersonic Wind Tunnel June 1992. The first is to expand the current database to $1.5 \leq M \leq 2.5$ for the SA1150 model with the existing axisymmetric nacelles. The second objective is to assess the integration characteristics for more representative nacelles for an advanced high speed civil transport. This will be accomplished by using nacelles that are derived from the PAI tasks, which Boeing and Douglas have with NASA Lewis, or other representative nacelles needed in supersonic flows. We feel that this test can provide industry with very important data. In addition, recent sonic boom tests have indicated that nacelles have an impact on aircraft sonic boom signature. The third objective is to use the SA1150 model to study nacelle influences on sonic boom in terms of nacelle position, shape, number, and mass flow ratio. This would require developing a sonic boom measuring technique on large scale models and assessing the adequacy of data taken relative, within on span length, to the configuration.

Nacelle-Airframe Interference Test
Current Program Objectives

- Expand database to $1.5 \leq M \leq 2.5$ of the SA1150 model with existing axisymmetric nacelles in Ames 9 x 7 Supersonic Wind Tunnel
- Assess the integration characteristics for nacelles derived from NASA Lewis propulsion airframe inlet tasks with Boeing & Douglas or other representative nacelle shapes for a high speed civil transport
- Study nacelle influences on sonic boom
  - * position
  - * shape
  - * number (2 to 4)
  - * mass flow ratio
- Develop sonic boom measurement techniques for large models
  - 7 feet of probe travel is required for this model

Figure 4

Hardware

The SA1150 is a delta wing-body model with an axial length of 62.2 inches and a wingspan of 40.8 inches. The model is mounted on a six-component force balance and the left hand wing is pressure instrumented with a total of 126 static pressure orifices, 95 on the lower surface and 31 on the upper surface. The SA1150 model is being refurbished which has included checking all the pressure instrumentation. To this point all pressure instrumentation is intact and flow through except for three orifices. The wing-body model is in the process of being put back together and an interrogation will be performed to obtain a computer definition of the model. This will become the documented definition of the SA1150 model. Two different nacelle geometries were tested. Both nacelle geometries were axisymmetric. One set of nacelles had sharp inlet lips while the other had slightly blunt inlet lips. The two left-hand side nacelles were pressure instrumented and the two right-hand side nacelles were force instrumented. Each of the pressure instrumented nacelles had 48 static pressure orifices located in four rows equally spaced around the nacelles. The six component force balances used to support the right-hand nacelles were housed in the thickness of each nacelle. These nacelles, balances and balance calibration equipment are available and need to be assessed for any damage incurred over the past 18 years. The nacelle support system, control box that controlled all remotely controlled movements of the nacelles and mass flow, nacelle and wing-body stings, and pylons have all be located and are in storage at Ames. All hardware that was used in the previous test will be available for the planned NAI test. New hardware and modifications to old hardware will be made as appropriately needed.

Hardware

- Wing-Body configuration of Boeing model SA1150
  - All but 3 pressure orifices of the left-hand wing (126 orifices: 95 lower, 31 upper) are intact and flow-through
  - In the process of being cleaned up and put back together
- Axisymmetric nacelle geometries
  - 4 sharp and 4 blunt inlet lip nacelles
  - Left hand side pair- pressure instrumented (48 orifices)
  - Right hand side pair - force instrumented (6 components)
- Axisymmetric nacelle balances and calibration equipment
- Nacelle support system fully intact
- Control box
- Sting assembly
- Pylon installation available

Figure 5

The nacelle balances are basically a two-shell flow through force balance using four instrumented flexures located 90° apart at two axial locations, for a total of eight flexures. The balances were intended to measure only the aerodynamic forces on the external surface of the nacelle, however, for mechanical reasons it became necessary to include the aerodynamic forces on the initial 2.30 inches of the internal surface as indicated in figure 6. To prevent flow through the balance cavity, the metric and nonmetric components were bridged by a flexible rubber seal. The metric part of the force instrumented nacelles include the external contour and internal lip surface on the balance. Incorporated into each nacelle sting is a mass flow control plug and appropriate pressure instrumentation to measure the flow through each nacelle. Each plug is remotely controlled. The pressure instrumentation consists of a 16-tube total pressure rake (4 radial rakes, 4 probes per rake) and 4 exit static pressure orifices in each nacelle sting.

Nacelle Flow Through Balance

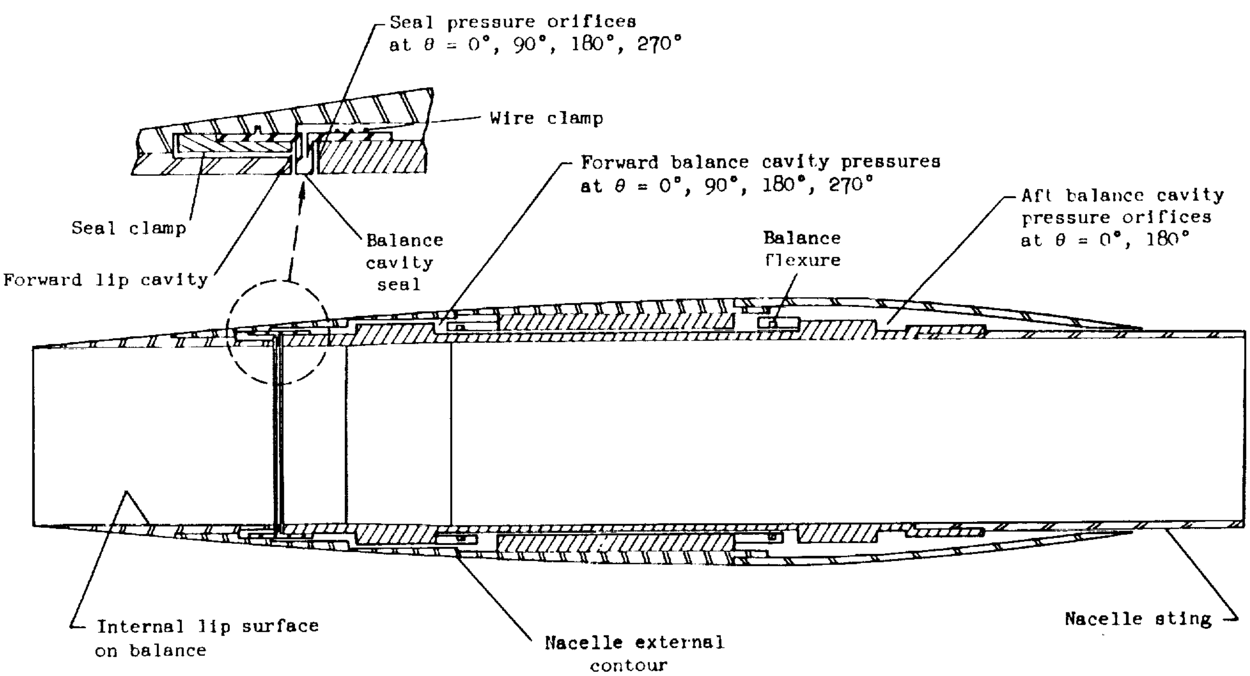

Figure 6. Nacelle Flow Through Balance

SA1150 Configuration with Nacelle Support System

The nacelle support system, figure 7, can independently support four nacelles beneath the wing-body and provide flexibility of positioning the nacelles relative to both the wing-body and to each other. The nacelle support system can also provide for the independent control and measurement of the mass flow through each nacelle. The major components of the nacelle support system consists of the main cross support, four vertical support and positioning units, and four flow through nacelle stings and flow metering units. Eleven independent drives provide a three-dimensional nacelle positioning capability. They include 2 lateral drives, which position the inboard and outboard nacelle pairs symmetrically about the vertical centerline; 4 vertical drives to control the vertical position of the four nacelle stings; and the axial position of each nacelle is controlled by two independent axial drive units: the main drive controls the position of the main cross support (position of all four nacelles as a single unit) and each nacelle sting has its own individual drive unit which allows the position of each nacelle to be varied relative to the other three nacelles. Of the eleven drives all were remotely controlled except the four vertical drives, which were manually operated.

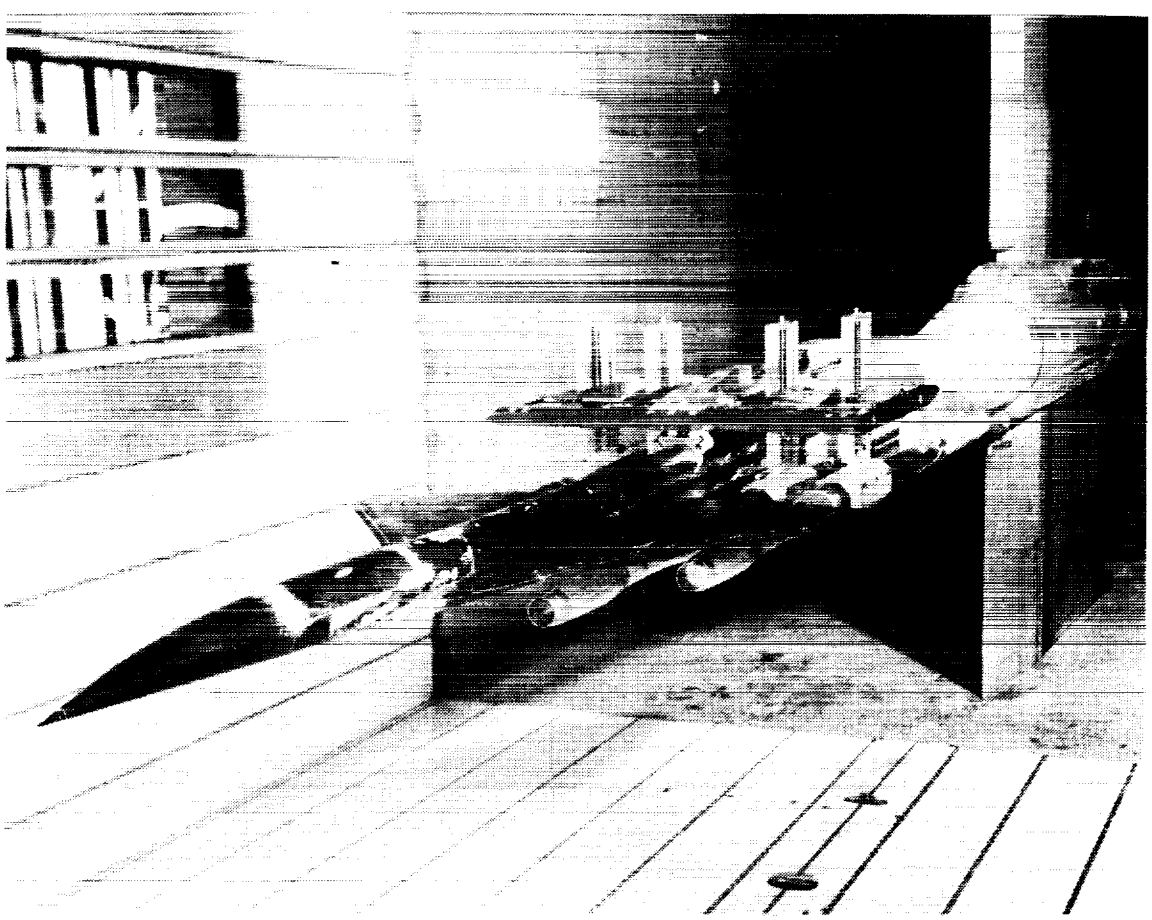

Figure 7. Wing-body-nacelle Configuration with Nacelle Support System

Nacelle-Airframe Interference Wind Tunnel Model
Schedule and Milestones

The NAI test is planned for June 1992, as outlined in figure 8. The refurbishment of the SA1150 model has begun and will continue to be refurbished. Work to refurbish the nacelle support system and the existing axisymmetric nacelles and balances will begin soon under the Precision Model contract at Ames. The representative nacelles to be tested are going through the aerodynamic designs and will be designed and fabricated during the second half of calender year 1991. Design and fabrications for sonic boom measurement equipment will also be worked this year. Model and Test preparations will be an ongoing process for such a complex wind tunnel test. The test will be a cooperative effort between NASA Ames, Boeing, and Douglas.

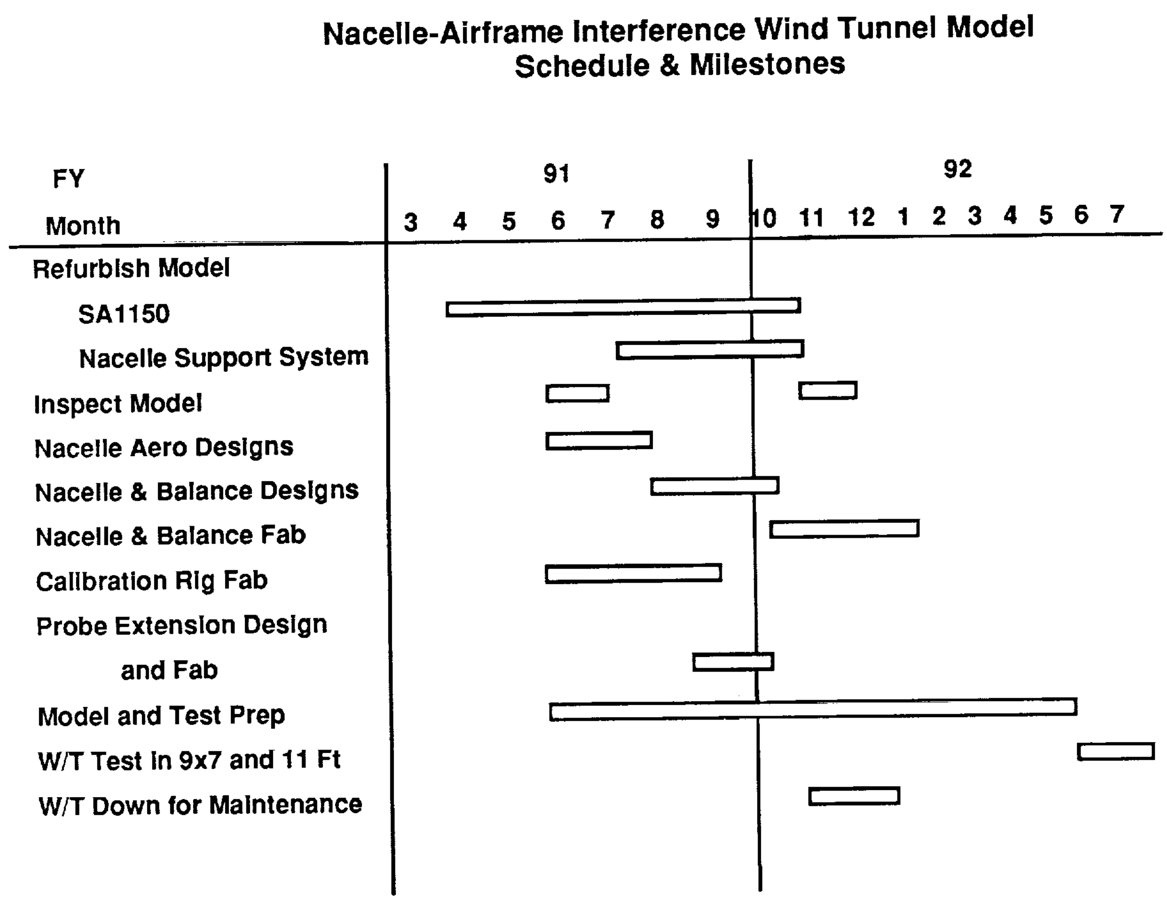

Figure 8. Schedule and Milestones for Nacelle-Airframe Test

CFD Analysis

In addition to preparing for a nacelle airframe test, Ames has begun assessing computational fluid dynamic,CFD, methods for calculating nacelle-airframe interference effects on a high speed civil transport. The SA1150 model with the axisymmetric nacelles serves as the CFD validation model. The SA1150 wing has been modeled based on data in reference 1. The sharp inlet lip nacelles have also been modeled. Euler calculations have been made on this configuration using TEAM, Three-dimensional Euler/Navier Stokes Aerodynamic Methods. TEAM is a multi-block code based on FLO57 and was developed by Lockheed under contract to the Air Force, reference 2. The case run was for Mach 1.4 and an angle of attack of 3 degrees. Sonic boom signatures have also been calculated based on the TEAM solution at 0.3 body lengths away. The CFD data was then extrapolated to 3.6 body lengths away. A comparison was made to wing alone, wing with flow through nacelles, and blocked nacelles.

CFD Analysis

- Modeled SA1150 wing and axisymmetric sharp inlet lip nacelles
- Euler solution at M=1.4, α=3°, and flow through nacelles
- TEAM code
- Sonic boom calculations based on TEAM solution at h/l=0.3 and extrapolated to h/l=3.6 for wing alone, and flow through and blocked nacelles

Figure 9

Wing and Nacelle Surface Grid
&
Symmetry Grid Plane

GRIDGEN, reference 3, was used to generate the grid for the TEAM code. A total of 38 blocks were needed to define the flowfield grid in an efficient and flexible way. The internal duct of the nacelles were modeled for the flow through case, while a solid face boundary condition was placed at the hilight of the nacelles for the blocked nacelle case. Figure 10 illustrates the surface grid of the SA1150 wing and the axisymmetric sharp inlet lip nacelles. Included is the symmetry plane.

Wing and Nacelle Surface Grid
&
Symmetry Plane

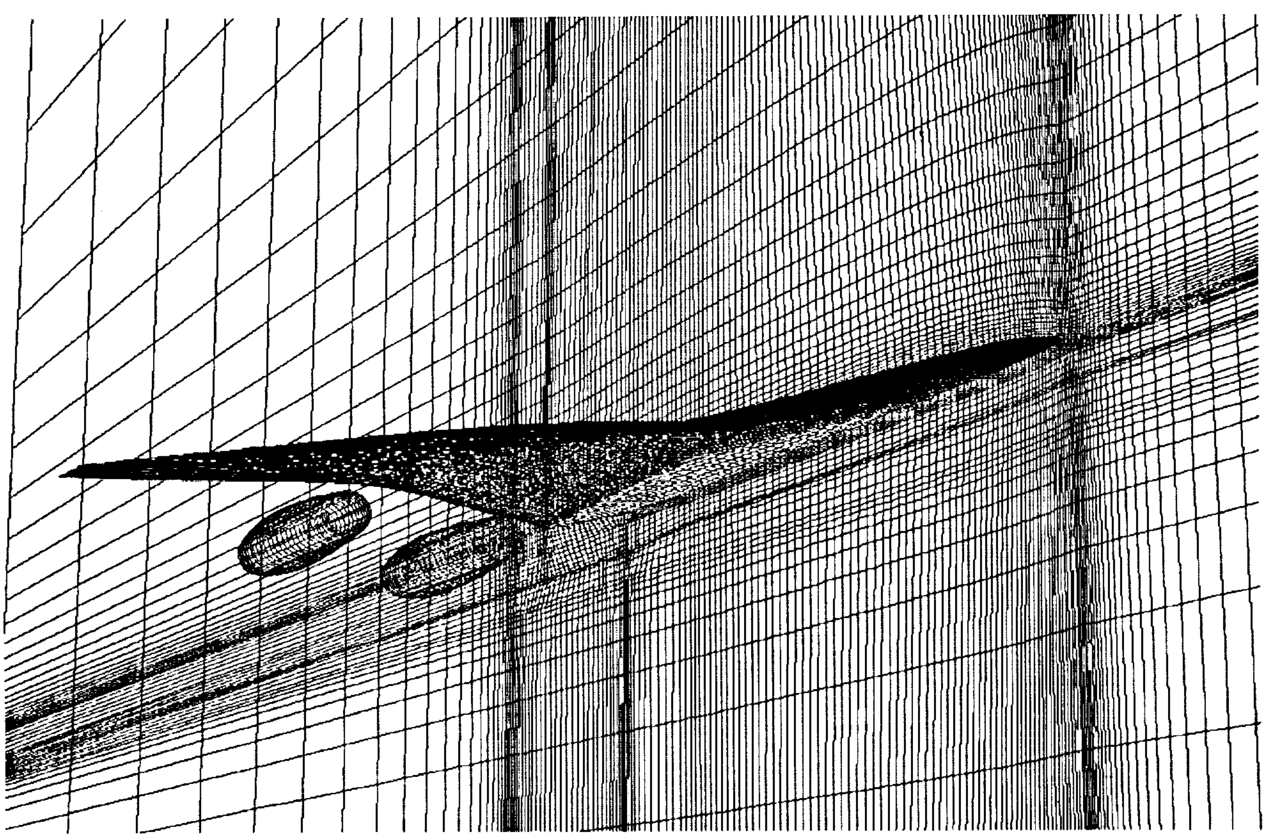

Figure 10. Wing and Nacelle Surface Grid Including the Symmetry Plane

Grid Plane Through Wing and Nacelles

Figure 11 illustrated a grid plane that intersects the wing and nacelles just ahead of the trailing edge of the wing. An H-H grid is used everywhere except in the internal nacelle ducts where an O-H grid is used. A total of approximately 725,000 grid points exists in the entire flowfield which is considered coarse for an Euler grid.

Grid Plane Through Wing and Nacelles

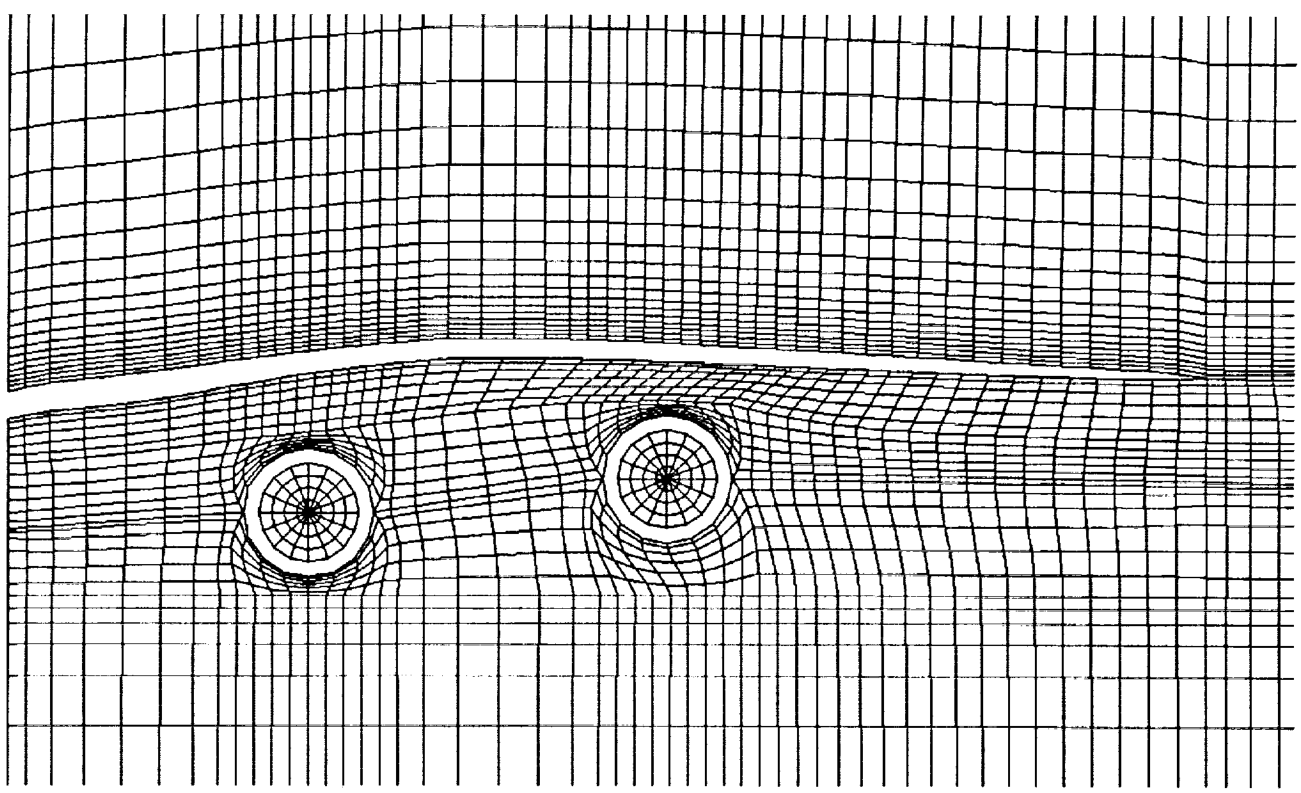

Figure 11. Grid Plane Through Wing and Nacelles

Lower Surface Mach Number Distribution
SA1150 Model
Nacelle-Wing Combination

Figure 12 illustrates the Mach number distribution on the lower surface of the wing. Outlines of the nacelles are placed to point out the interference effects on the wing due to the nacelles.

Lower Surface Mach Number Distribution

SA 1150 Model

Nacelle-Wing Combination

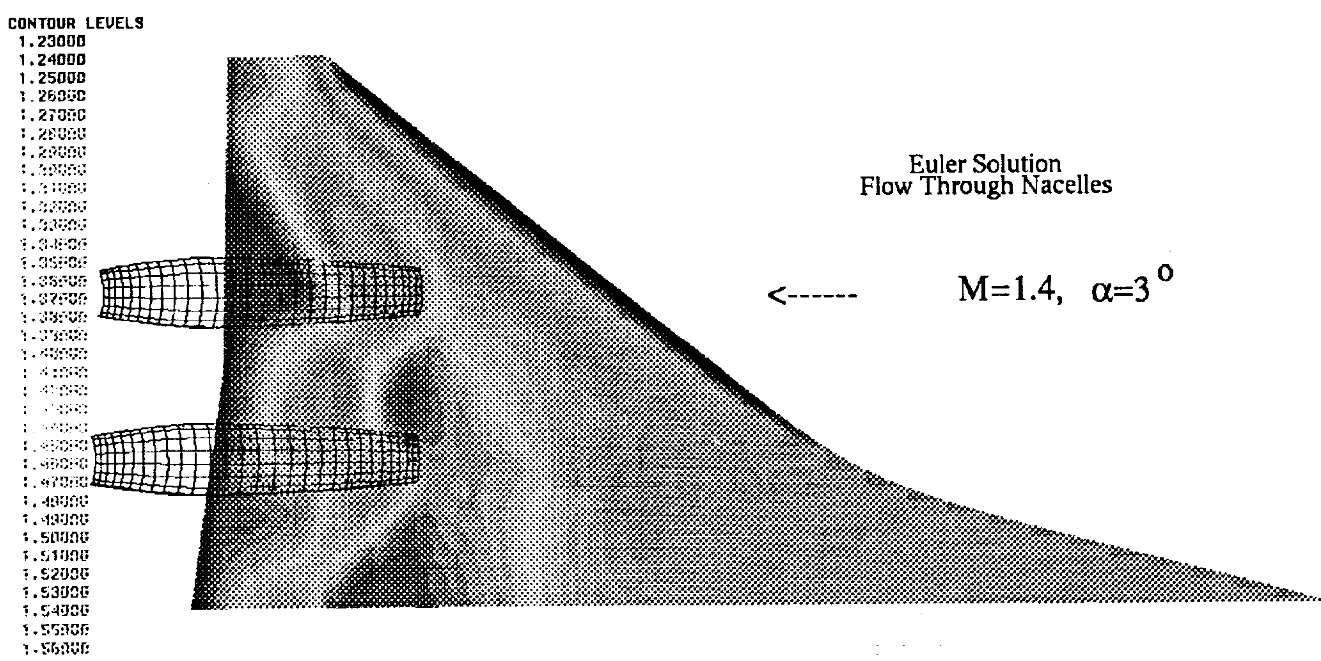

Figure 12. Lower Wing Surface Mach Number Distribution, TEAM Solution

Upper Nacelle Surface Mach Number Distribution
SA1150 Model
M=1.4, α=3°

Figure 13 is the Mach number distribution on the upper external half of the nacelles as well as that plane that intersects the nacelles parallel to the wing surface. This illustrates the wing effects on the nacelles as well as the nacelle-nacelle interference effects.

Upper Nacelle Surface Mach Number Distribution
SA 1150 Model
M=1.4, α=3°

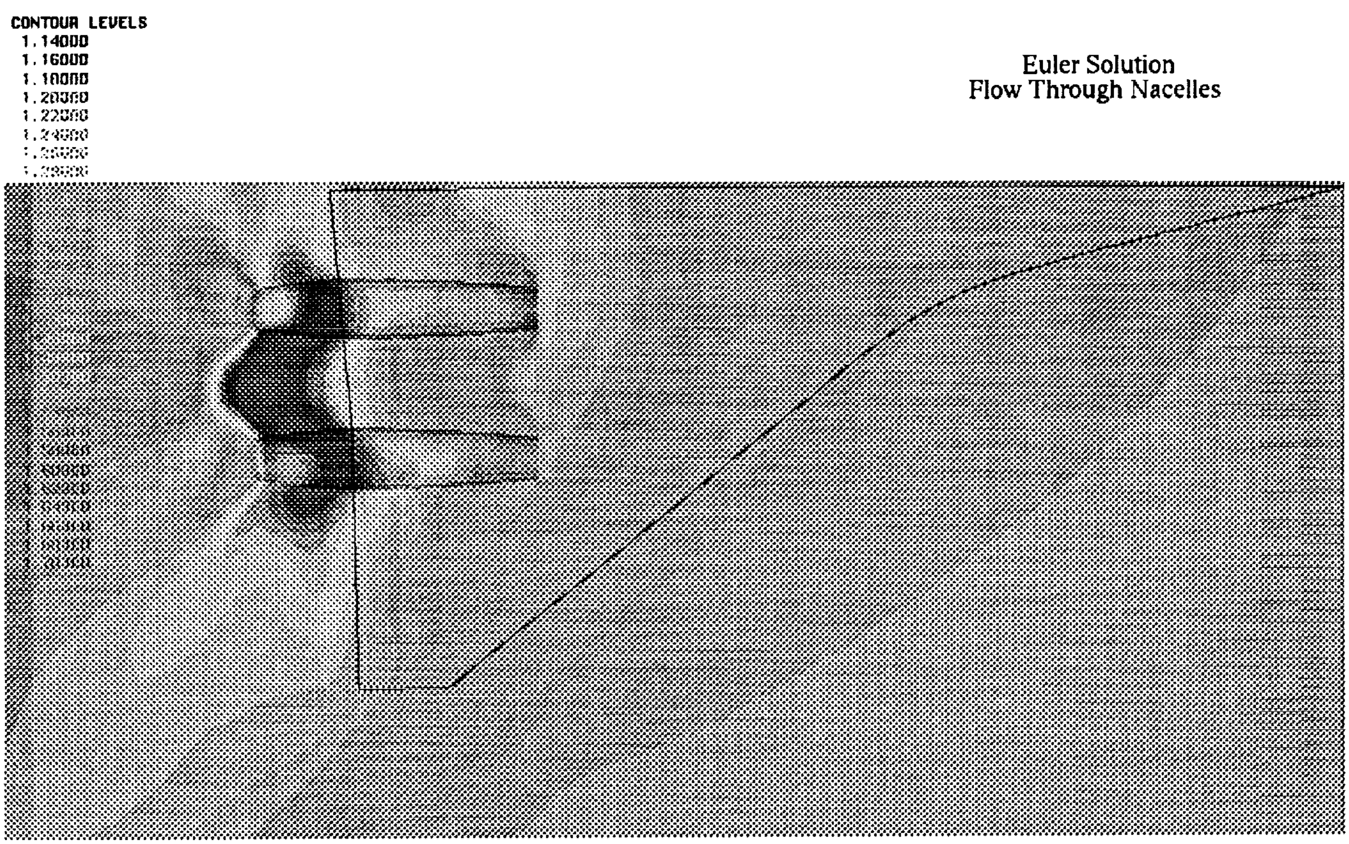

Figure 13. Upper External Nacelle Surface Mach Number Distribution, TEAM Solution

Sonic Boom Signature for SA1150 using TEAM CFD Solutions

Figure 14 shows the difference in the sonic boom signature for wing alone, wing with flow through nacelles, and wing with blocked nacelles.

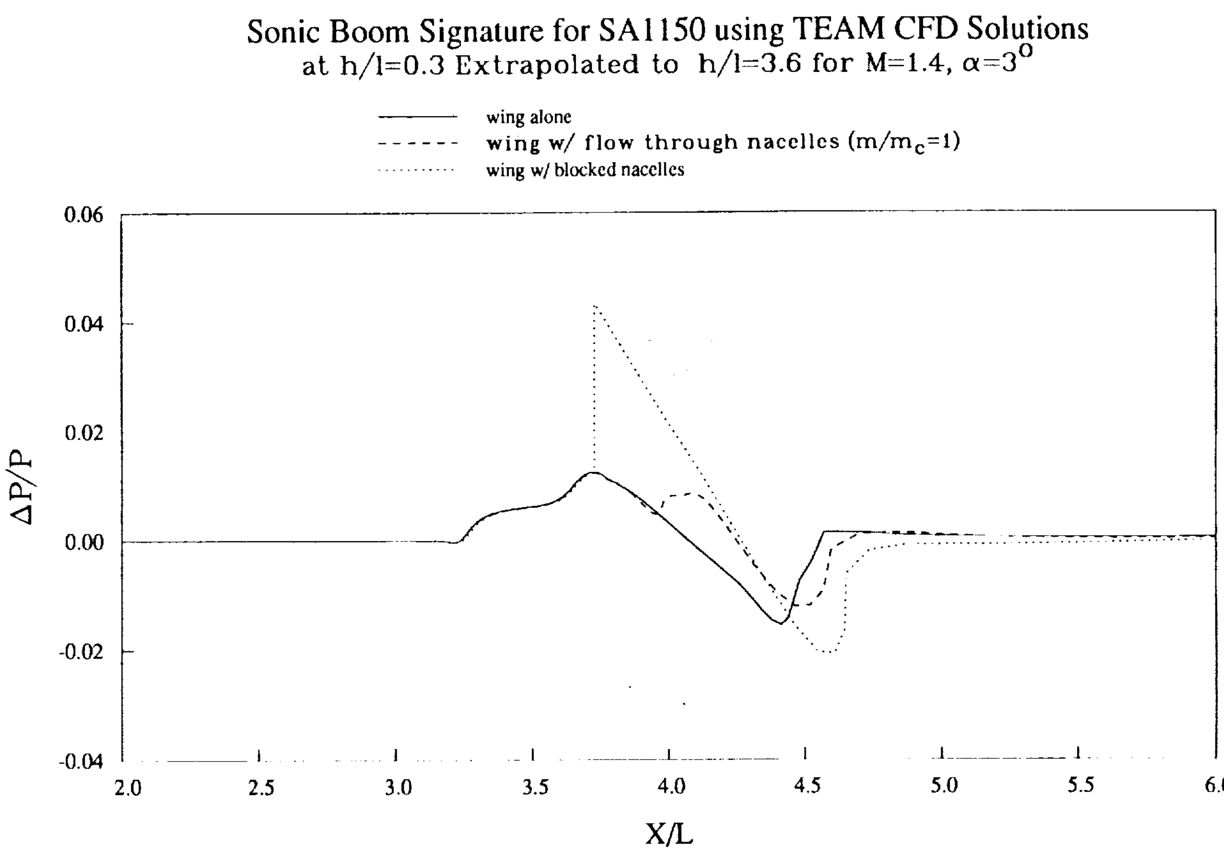

Figure 14. Sonic Boom Signature for SA1150 using TEAM CFD Solutions

Future CFD Analysis

Three Euler codes will be evaluated for predicting nacelle airframe interference effects. These codes are TEAM, TIGER, and AIRPLANE. TIGER is a NASA Ames developed hexahedral unstructured Euler code with grid refinement capabilities, reference 4. AIRPLANE is a tetrahedral unstructured Euler code developed by Antony Jameson and Tim Baker, reference 5. They are all based on FLO57, a four stage Runge-Kutta scheme developed by Jameson.

The SA1150 wing-body with nacelles will be modeled and run for various cases to be compared to experimental data. An assessment of the three codes will be made on how they can predict nacelle airframe interference effects.

Future CFD Analysis

- TIGER, Ames developed hexahedral Euler unstructured code with solution grid refinement
- AIRPLANE, Jameson and Baker's tetrahedral Euler unstructured code
- Model SA1150 wing-body with nacelles
- CFD vs experiment
- Assessment of codes in predicting nacelle airframe interference effects

Figure 15

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