Numerical Predictions of Sonic Boom Signatures for a Straight Line Segmented Leading Edge Model.

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Abstract: A sonic boom wind tunnel test was conducted in October 2011 on a straight-line segmented leading edge (SLSLE) model in the NASA Langley 4- by 4- Foot Unitary Plan Wind Tunnel (UPWT). The primary purpose of the test was to ascertain whether the sharp pressure peaks in the sonic boom signature could be measured while moving the model continuously instead of the move/pause mode of operation used in earlier wind tunnel tests. In the proposed paper, numerical simulations of the SLSLE model will be presented as a contribution to NASA's Supersonics Project under Fundamental Aeronautics Program. Numerical simulations will be conducted for a free-stream Mach number of 2, angle of attack of 2.3° and Reynolds number of 1.5×10^6 based on the model reference length. The effects of turbulence modeling on the computed sonic boom signature will be presented and discussed. Computational results will be compared with wind tunnel data from the recent Langley Research Center 4- by 4- Foot Unitary Plan Wind Tunnel, and the Glenn Research Center 10- by 10- Foot Wind Tunnel using conventional move/pause data acquisition.

Keywords: Sonic Boom, Supersonic flow, Numerical Algorithms, CFD, SLSLE.

Introduction

Over the past few decades, the primary method used to measure the sonic boom signature of aircraft in wind tunnels was a single survey probe. Pressure rails were also used with varying degrees of success [1]. A wind-tunnel test (WTT), UPWT Test 1998, was recently conducted on SLSLE model at NASA Langley. The WTT was conducted at free-stream Mach numbers of 2 corresponding to Reynolds number of 1.5×10^6 based on the model reference length. Sonic-boom pressure signatures, model forces and pitching moments were measured. The test was conducted as part of the Supersonic Cruise Efficiency – Airframe element of the NASA Fundamental Aeronautics Program Supersonics Project. The objective of the Supersonic Cruise Efficiency element is to improve aerodynamic design and analysis capability for highly efficient, supersonic vehicles. The primary technical challenge of the Supersonic Cruise Efficiency element is to develop robust CFD-based methods for rapid design and analysis of supersonic cruise aircraft that are highly efficient, and have low sonic boom.

In the Langley UPWT Test 1998 single probe pressure data was acquired continuously as the aircraft model was steadily moved past the survey probe. The primary purpose of the test was to ascertain whether the sharp pressure peaks in the sonic boom signature could be measured while moving the model continuously. In the proposed paper, numerical simulation of the flow around the SLSLE will be conducted; near field sonic boom signatures will be extracted and compared with WTT data. Accurate numerical predictions of near field sonic boom signatures remains quite challenging. Specialized grid generation process that places points within the zone of influence of the sonic boom disturbance or solution-adaptive methods are required to obtain accurate solutions [1]. Two widely used NASA CFD codes, USM3D and CART3D-AERO, will be used for the computational analysis of the flow around SLSLE model [2]. USM3D will be used to provide inviscid, laminar and turbulent flow simulations of SLSLE. The CART3D-AERO module will use the adjoint-based mesh adaptation method to guide refinement and control discretization errors in the inviscid simulations.

Application and Results

Computational and experimental methods for accurate sonic boom prediction will be presented in the proposed paper. A brief description of the WTT will be provided. A sketch of the model showing overall dimensions and a model photograph is shown in Figure 1. Preliminary computational grids for SLSLE were generated by the Mach Cone Aligned Prism (MCAP) approach [1]. Fine, stretched, and shock aligned grids are a key parameter in capturing low boom signature. A refined unstructured grid within a cylinder in the near field is followed by projection of the surface faces on the cylindrical boundary in the radial direction with a series of prism layers to the far field. Figure 2 shows a sample of USM3D computed pressure coefficient for the SLSLE model at M=2, $\propto = 2.3^{\circ}$ degrees on a 48 million-cell grid. Figure 3 shows laminar and turbulent sonic boom signatures at a distance of 1.5 body lengths from model.

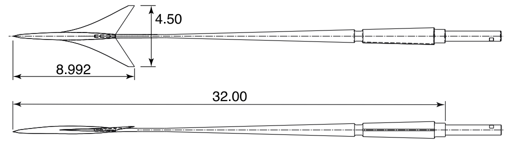
Summary and Proposed Work

In the proposed paper, USM3D and CART3D-AERO will be evaluated for their ability to accurately capture near field sonic boom signatures. The near field sonic boom signatures will be propagated to the ground and the variations in ground signature strength and loudness will be evaluated. The results of this study will help address the issue of viscous modeling on the measured supersonic boom signature. Computational results will be compared with sonic boom data from the recent Langley UPWT Test 1998 using the aforementioned continuous model translation acquisition method and data from NASA Glenn 10- by 10- Foot wind tunnel using conventional move/pause data acquisition.

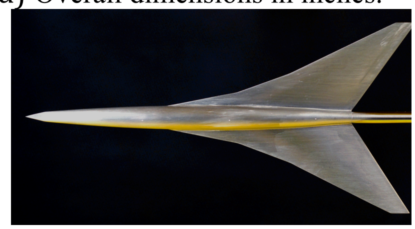
References

[1] S. Cliff, A. Elmiligui, R. Campbell, and S. Thomas, "Evaluation of Refined Tetrahedral Meshes with Projected, Stretched and Sheared Prism Layers for Sonic Boom Analysis," AIAA Paper 2011-3338, June 2011.

[2] Elmiligui, A. A., Cliff, S. E., Aftosmis, M. J., Nemec, M., Parlette, E. B., Wilcox, F. J., and Bangert, L. S. "Sonic Boom Computations for a Mach 1.6 Cruise Low Boom Configuration and Comparisons with Wind Tunnel Data," AIAA-2011-3496, June 2011.

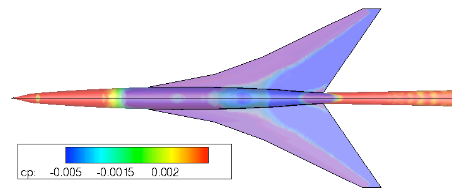


(a) Overall dimensions in inches.

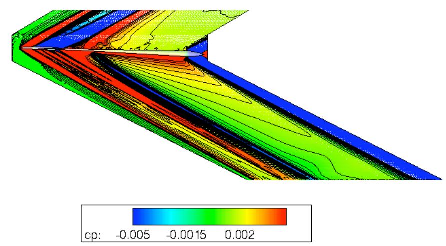


(b) Photograph of SLSLE model.

Figure 1 SLSLE model.



(a) Surface Cp



(b) Symmetry Plane Cp

Figure 2 SLSLE, Coefficient of Pressure Contours, USM3D Code, Mach=2, α=2.3° on a 48 Million-cell Grid

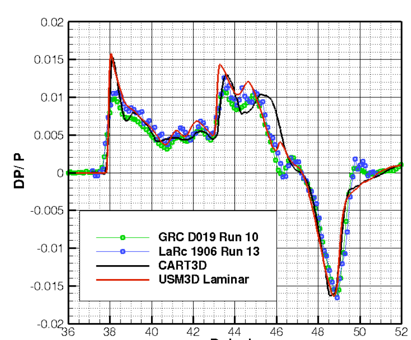


Figure 3 SLSLE USM3D Sonic Boom Signatures.