Algorithmic Improvements to a High-Order Space Marching Method for Sonic Boom Propagation

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Abstract: Algorithmic improvements to a high-order space marching method enabling an efficient strategy for sonic boom propagation by coupling near-field Computational Fluid Dynamics (CFD) solutions to an efficient space marching solver are described. The space marching solver is based on a high-order accurate finite-difference discretization of the 3D Euler equations on a specially designed curvilinear grid to enable a single sweep space marching solution. The improvements to the existing space marching method include improvements to the automatically generated grid, elliptic hole cutting, generalization of the coupling to both structured and unstructured CFD grids, and implementation of a zonal marching algorithm which significantly reduces the memory footprint. The coupled approach is shown to improve efficiency and accuracy by reducing the necessary domain size of the CFD grid and generating mid-field solutions from coarse CFD grids equivalent to those obtained using fine grid CFD. This is demonstrated using test cases from the AIAA Sonic Boom Prediction Workshops and four different CFD solvers.

Keywords: Numerical Algorithms, Aeroacoustics, Sonic Boom.

1 Introduction

The National Aeronautics and Space Administration (NASA) in collaboration with industry partners is currently developing the X-59, a supersonic aircraft which is shaped to reduce the loudness of the sonic boom. It was established in Housman et. al. [1] that a three-step procedure consisting of near-field CFD, high-order space marching, and far-field acoustic propagation resulted in an efficient and accurate method for ground level noise predictions. Moreover, it was shown that including the three-dimensional azimuthal velocity effects to several body lengths (more than 4) was necessary before transferring the propagation to a traditional far-field propagation code in order to remove sensitivity to the ground level noise prediction. In addition, it was demonstrated in Duensing et. al. [2] that the radial extent of the CFD domain size could be significantly reduced to approximately half a body length with no loss of accuracy in ground level noise prediction when coupled to the high-order space marching solver, which resulted in approximately fifty percent reduction in overall computational resources, see Figure 1 (a)-(d).

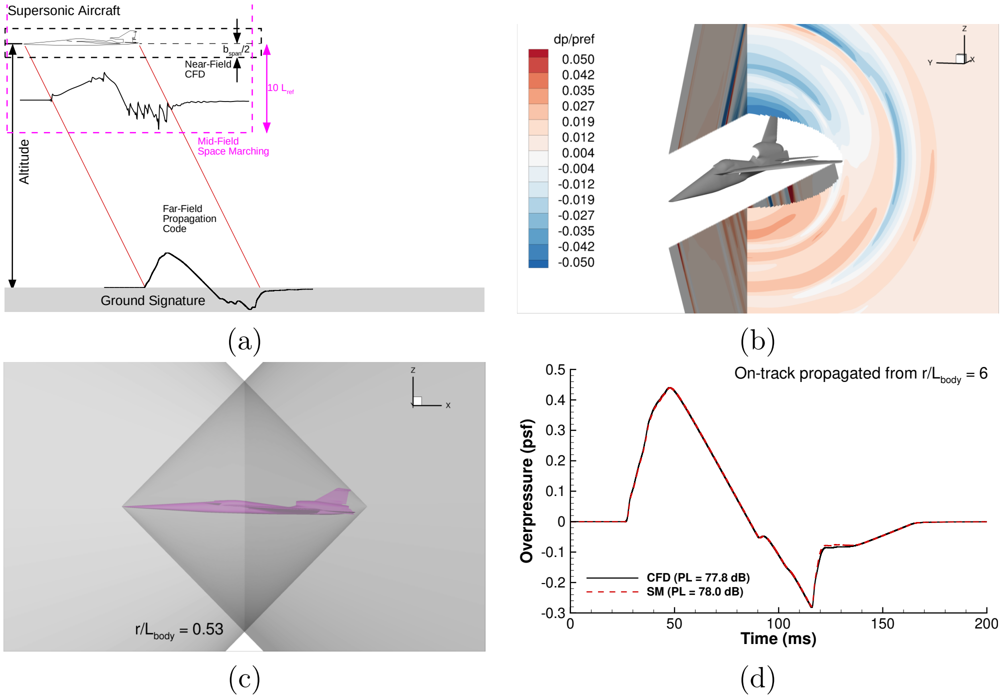

Figure 1: (a) Diagram of three-strep procedure to ground level noise prediction. (b) Solution on the space marching domain showing elliptical hole cutting procedure. (c) Diagram illustrating the domain of dependence of the CFD domain. (d) Comparison of ground level signature using CFD versus CFD on truncated radial domain coupled to the space marching solver.

2 Description of the Work

In this work, algorithmic improvements to a high-order space marching method to enable accurate and efficient sonic boom propagation by coupling to both structured and unstructured CFD near-field solutions are described. First, the automatically generated grid is improved to retain a valid space marching mesh as the local Mach number approaches unity. Second, an elliptic hole cutting procedure is introduced to allow the coupling with the CFD solution closer to the aircraft. Third, a generalization of the coupling code to allow the space marching solver to couple with both structured and unstructured grid CFD solvers is added. Finally, the single sweep space marching solution algorithm is extended to a zonal marching algorithm. This reduces the memory footprint of the space marching solver allowing it to be run on reduced computational resources. Demonstrations on AIAA Sonic Boom Prediction Workshop problems coupling to LAVA, USM3D, FUN3D, and HALO3D will be included in the final paper.

References

[1] J. Housman, G. Kenway, J. Jensen and C. Kiris. Efficient Near-Field to Mid-Field Sonic Boom Propagation Using a High-Order Space Marching Method. *AIAA Aviation Conference*. June, 2019, AIAA-2019-3487.

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