Sonic Boom Reduction using an Adjoint Method for Supersonic Transport Aircraft Configurations

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Introduction

THE objective of this work is to develop the necessary methods and tools to facilitate the design of low sonic boom aircraft that can fly supersonically over land with negligible environmental impact. Traditional methods to reduce the sonic boom signature were targeted towards reducing aircraft weight, increasing lift-to-drag ratio, improving the specific fuel consumption, etc. Seebass and Argrow revisited sonic boom minimization and provided a detailed study of sonic boom theory and figure of merits for the level of sonic booms. Recently, with the help of faster computing resources, automatic aerodynamic optimization has been revisited. In particular, automatic design procedures, which use CFD combined with gradient-based optimization techniques, have made it possible to remove the difficulties in the decision making process traditionally taken by a designer. Finding a fast and accurate way of calculating the necessary gradient information is essential to developing an effective design method, since this may be the most time consuming portion of the design algorithm. A computationally efficient option, the control theory approach to optimal aerodynamic design in which gradient information is obtained via the solution of an adjoint equation, was first applied to transonic flow by Jameson[1,2] and has become a popular choice for design problems involving fluid flow.[3,4] The adjoint method is extremely efficient since the computational expense incurred in the calculation of the complete gradient with respect to an arbitrary number of design variables is effectively *independent* of the number of design variables. In this paper, the control theory approach is used to develop an automatic aerodynamic optimization method to reduce the sonic boom signature.

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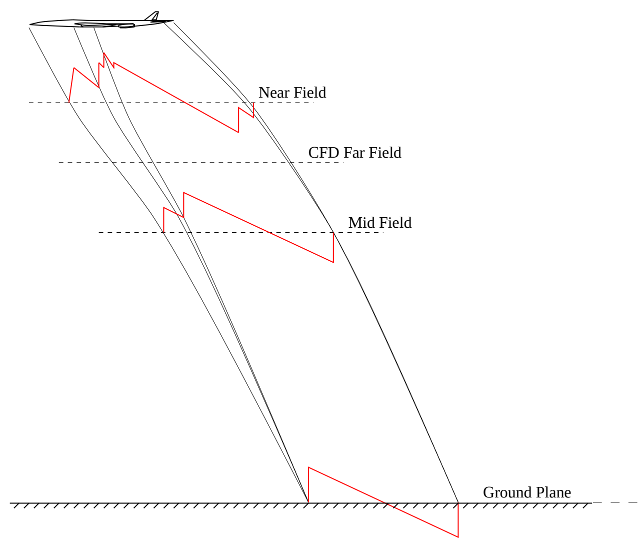

Fig. 1 Schematic of Sonic Boom Minimization

Procedure

For typical cruise altitudes required for aircraft efficiency, the distance from the source of the acoustic disturbance to the ground is typically greater than $50,5000ft$. A reasonably accurate propagation of the pressure signature can only be obtained with small computational mesh spacings that would render the analysis of the problem intractable for even the largest parallel computers. An approach that has been used successfully in the past is the use of near to far field extrapolation of pressure signatures based on principles of geometrical acoustics and non-linear wave propagation. Theses methods are based on the solutions of simple ordinary differential equations for the propagation of the near field pressure signature to the ground.

Figure 1is a schematic of the sonic boom minimization problem. The shape optimization for sonic boom reduction problem can be divided into two separate optimization problems. Firstly, an optimization of near field pressure signature for sonic boom reduction is performed by solving an inverse problem using the cost function:

$$I_1 = \frac{1}{2}\int_{\mathcal{B}} (p_G - p_{Gd})^2 \, dS. \quad (1)$$

Secondly, between the aircraft of interest and the near field pressure signature, another inverse problem for the aerodynamic shape design optimization can be carried out by defining the cost function as:

$$I_2 = \frac{1}{2} \int_{\mathcal{B}} (p_0 - p_{0d})^2 \, dS. \quad (2)$$

which is the difference between the current near field pressure distribution, p_0, and the target near field pressure signature, p_{0d}. Note that here p_{0d} is the designed result from the first optimization problem.

Now the whole aerodynamic shape design for sonic boom reduction is completed by solving the near field pressure signature optimization as a preprocess and by performing the aerodynamic shape design using the cost function which is the function of near field current and target pressure only.

The complete discussions on the implementation will be covered in the final conference paper. The rest of this abstract paper will cover the preliminary results.

Preliminary Results

The near field pressure optimization for an aircraft configuration, the generic Quiet Supersonic Platforms (QSP), are presented in this subsection.

Near Field Pressure Optimization for a Generic QSP

The near field pressure distribution of the generic QSP configuration has been optimized. Note that the generic QSP used in the design example is the configuration which was already designed by the linear method in order to have the ramp shape ground boom with the first shock strength less than 0.3 psf and the second shock strength less than 0.5 psf. The initially designed configuration and the same flight conditions as those of the linear method, which are $M_\infty = 2$, flight altitude $= 55,000 ft$, flight path angle $= 3.5°$ and $R/L = 0.5$, were used for the Euler calculation. As shown in Figure 3, the initial ground boom is no more a ramp shape and the shock strengths are much stronger than the criterion. It is due to that the nonlinear effects are accounted for by the Euler calculation. In this design example, instead of achieving a complete optimization, the current boom has been improved to satisfy the criterion used for the linear method. As shown in Figure 3, the shock strength was reduced and the ramp shape was recovered in 500 design iterations. As shown in Figure , this case has produced the resulting near field pressure signature for the aerodynamic shape design.

Aerodynamic Shape Optimization Using an Adjoint Method

In the last six years the method has been successfully used to optimize complex two and three dimensional configurations including wing-fuselage combinations and complete aircraft by Jameson et al.[3,4] A prove of concept of the remote inverse problem, where the cost function is not collocated at the geometry being modified, has also been demonstrated by Nadarajah et al.[5] Since the length of the abstract paper is limited to two pages, the various design results are not included and the readers can find them in the reference papers.

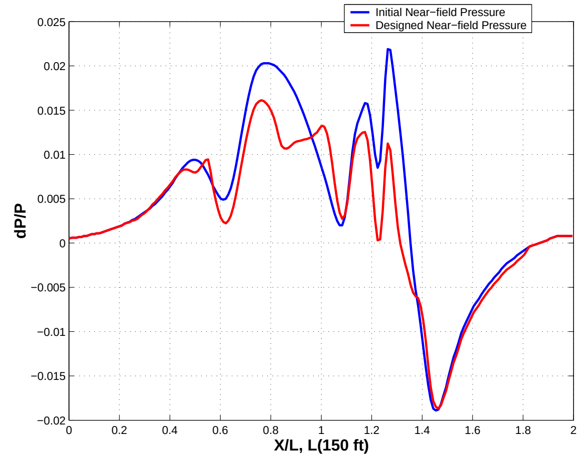

Fig. 2 Near Field Pressure for Generic QSP

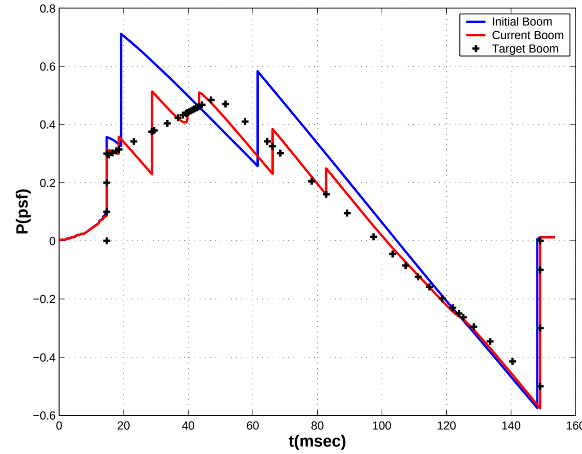

Fig. 3 Ground Pressure for Generic QSP

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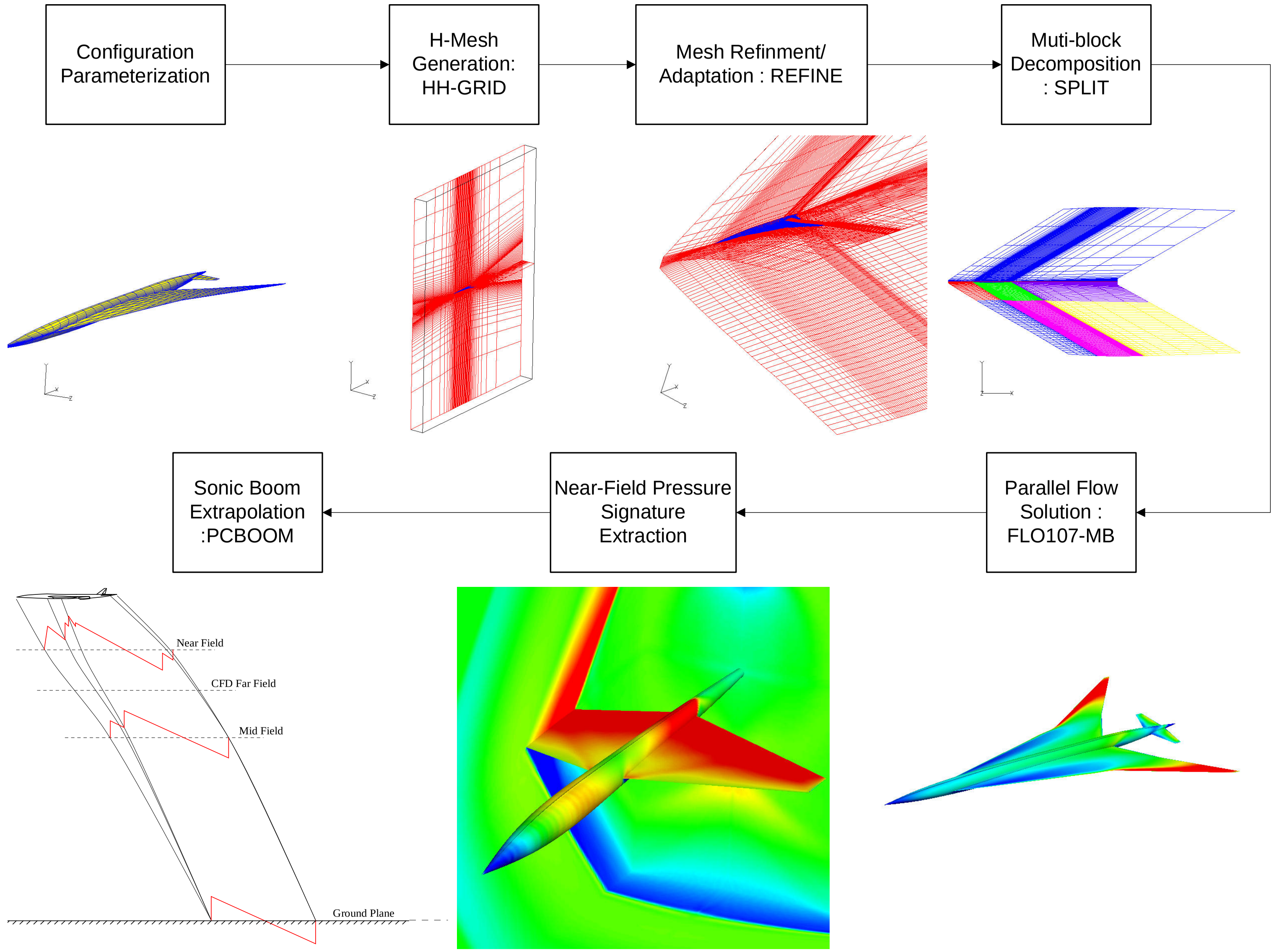

Configuration Parameterization
H-Mesh Generation: HH-GRID
Mesh Refinment/ Adaptation : REFINE
Muti-block Decomposition : SPLIT
Parallel Flow Solution : FLO107-MB
Near-Field Pressure Signature Extraction
Sonic Boom Extrapolation :PCBOOM
Near Field
CFD Far Field
Mid Field
Ground Plane