SONIC BOOM MINIMIZATION IN CONCEPTUAL DESIGN - EXTENDED ABSTRACT

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ABSTRACT

Sonic boom reduction in supersonic aircraft places a requirement on the distribution of lift and volume along the length of the aircraft. A framework combining open source libraries OpenVSP, SUAVE, SU2 and Gmsh using Python was built to explore the integration of sonic boom requirements into the conceptual phase of design. Using SU2, the sonic boom equivalent area is calculated using CFD and compared to a target distribution, based on which a differential evolution algorithm searches a design space for optimal candidates.

NOMENCLATURE

F Whitham's.

F function.

S EquivalentArea.

ρ Density.

U_∞ Free streamVelocity.

INTRODUCTION

Future supersonic aircraft must meet noise regulations before being allowed to fly over land. The most common method for sonic boom minimization is aerodynamic shaping, where the aircraft is shaped such that the flow field around it does not cause a loud noise on the ground. This is normally achieved by modifying a baseline configuration chosen after conceptual design, done using linearized aerodynamic methods or CFD. However, the improvements obtained this way are minor. The objective is to build sonic boom minimization into conceptual design, and the next few sections discuss the framework created using Opens [1], SU[2], SUAVE [3], and Gmsh [4] todoso.

THEORETICAL BACKGROUND

Whitham's F-Function The first step in sonic boom prediction is the determination of the near-field pressure distribution, from which the equivalent area can be obtained. This is mostly done using linear theory, however corrections need to be applied to account for inherent non-linearity. Whitham [5] first published the corrections, and defined the F-function, directly proportional to the pressure as follows –

$$F(\tau) = \frac{1}{2\pi}\int_0^{\tau} \frac{S''(t)}{\sqrt{(y-t)}}dt \qquad (1)$$

The area function S(x) used to calculate the F-function has a Volume component, and a lift component proportional to the integral of the chord wise lift distribution.

$$S = S_V + S_L \qquad (2)$$

$$S_L(t,\theta) = \frac{\beta}{\rho U_\infty^2}\int_0^t L(x,\theta)dx \qquad (3)$$

SONIC BOOM PROPOGATION

Since the propagation of sonic booms is non-linear, a purely linear-acoustical treatment of the problem would fail as it cannot capture distortion of the signal and shock waves, as written in See bass [6]. It can be shown that the propagation equation can be transformed into an in viscid form of Burgers' Equation. Once the distortion is accounted for, geometrical acoustics can be used to propagate the disturbance along ray tubes. This integration is then carried out for the ISA to find the amount of distortion in a signal.

SONIC BOOM MINIMIZATION

Sonic Boom is caused by the distortion of the pressure signature of the aircraft leading to shock wave formation. Although the boom due to the volume can be eliminated, the boom due to lift cannot be. The shape of the aircraft is exploited to minimize the annoyance caused by the sonic boom, which can mean the overpressure caused by the shock waves, or the loud sound caused by the sudden change in pressure. A general class of F-functions which can minimize either of the above was conceptualized by See bass, George, and Darden [7, 8], represented by Eqn. 4.

$$F(y) = \begin{cases} \frac{2yH}{y_f} & : 0 \le y < y_f/2 \\ C\left(\frac{2y}{y_f}-1\right) - H\left(\frac{2y}{y_f}-2\right) & : y_f/2 \le y \le y_f \\ B(y-y_f)+C & : y_f \le y < \lambda \\ B(y-y_f)-D & : \lambda \le y \le l \end{cases} \qquad (4)$$

The parameters H, C, D, λ and y_r are found from the length, weight and cruise conditions, by numerically solving the constraint equations using methods given in Rallabhandi's Ph.D. thesis [9]. The equivalent area is obtained by inverting Eqn. 1 through an Abel transformation as follows –

$$S(x) = 4\int_0^x F(y)(l-y)^{1/2}dy \qquad (5)$$

This equivalent area is used as a target to match the aircraft configuration to. The aircraft equivalent area is evaluated using CFD and the objective function to be minimized is the least squares error, evaluated at a set number of points.

FRAMEWORK FORMULATION

Geometry Parameterization

Once the target equivalent area is found, the geometries to be compared against it must be generated. This is done by using 11 parameters to describe a wing-fuselage configuration. The wing is a cranked arrow shape described by 7 parameters, shown in Fig. 1, and the fuselage is a generalized area ruled fuselage described by 4, shown in Fig. 2.

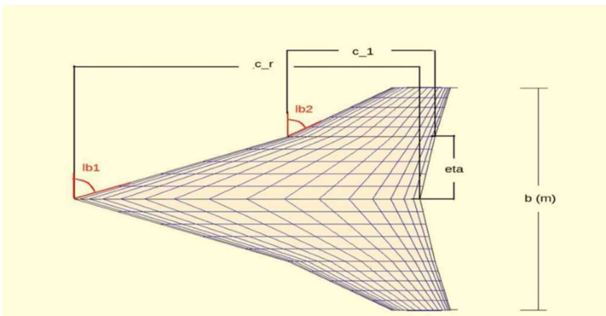

FIGURE 1: WING MODEL WITH PARAMETERS

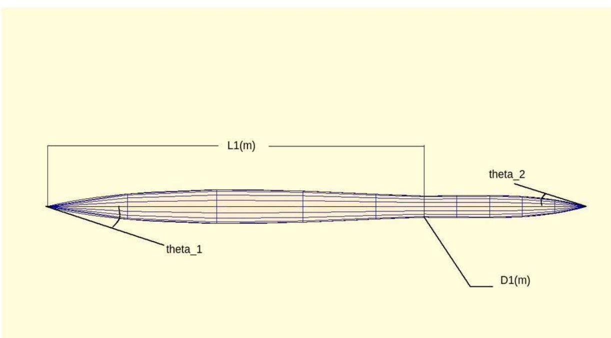

FIGURE 2: FUSELAGE MODEL WITH PARAMETERS

An aircraft geometry is defined in SUAVE using the values of the parameters, and the 3D model is created in OpenVSP. The 3D model is then turned to a surface mesh and sent to Gmsh.

MESHING AND CFD

The surface mesh is transformed into a volume mesh using Gmsh. Aside from the far-field boundary, a near-field boundary must also be defined to evaluate the equivalent area on. SU2 then uses the generated mesh and the flight conditions to run a CFD analysis, calculating the equivalent area and lift at two angles of attack, and then linearly interpolates to find the cruise angle of attack and the equivalent area at that angle. SU2 solves the Euler equations on an unstructured multigrid, using the JamesonSchmidt-Turkel scheme.

OPTIMIZATION

Once the equivalent area of the aircraft is obtained, it is compared to the target area and the least squares difference of the two is taken as the objective function. The current framework uses the differential evolution algorithm available in the Skippy library to find the best candidates in a specified design space.

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