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AAE 550, Final Project Report

Geometry Optimization of a Scramjet Combustor

**Objective**

This project aims to optimize the geometry of a rectangular profile scramjet combustor for maximum thrust by varying the contour of one of the combustor walls. For simplification purposes, it is assumed that the nozzle perfectly and isentropically expands the resultant flow, producing the maximum thrust possible for a given combustor design.

**Scramjet Combustor Model**

The scramjet combustor model is given by Shapiro [1] as a 1-D analysis, of which the main relations are given below in equations (XXX)

The changing values of *cp* and are calculated using NASA’s Chemical Equilibrium with Applications (CEA) program, which is a chemical property solver developed for determining the thermodynamic properties and physical state of complex mixtures of reactants. The effects of cooling at the wall and wall friction were ignored for simplification purposes.

**Constraints**

Constraints were placed on the model to keep the solution feasible and practical. First, and consecutive wall segments along the contour must be angles within 5 degrees of each other to prevent large changes in combustor geometry that could cause flow separation or strong shocks in the flow. Second, at any point in the flow, the Mach number must be greater than or equal to 1.05. Perturbations in the upstream flow could cause the Mach number to drop, and if Mach 1 is reached, the flow chokes and risks unstarting the inlet system, causing a dramatic loss of thrust and, most likely, a failed mission. Third, the exit Mach from the combustor must be at least 1.15 so that afterburning remains feasible without running a great risk of thermally choking the flow. Finally, the maximum temperature in the combustor is limited to 3000 K in order to keep heat loads manageable.

The constraint functions derived from the physical constraints above are as follows:

**Methodology**

The Sequential Quadratic Programing (SQP) optimization algorithm was used for a multitude of reasons. With the combustor taking significant computation time to solve, the fast and relatively efficient nature of SQP will make the problem more feasible in the allotted time. There is a significant chance the optimization procedure will venture into unfeasible territory easily, which SQP can handle. Additionally, the non-linear nature of the flow field constraints will be better represented by SQP than other strictly linear methods. There was a risk of stepping outside of the continuous domain of the objective function, which occurs when the Mach number in the combustor drops below 1, but the constraints put in place due to the physical ramifications of this scenario prevent such discontinuities from occurring. Matlab’s “fmincon” function with the SQP algorithm was used in practice.

The scramjet combustor model was also developed in Matlab. Calculating the gradients of the objective and constraint functions was practically impossible to do analytically, and extremely time consuming when done numerically. To make gradient calculations more feasible, a significant amount of effort was put into making the model more computationally efficient as well as parallelizing numeric gradient calculations. All gradients were calculated using the forward difference method in order to minimize the number of objective function calls. The model was also developed to have flexible integration fidelity so that, should optimization become intractable within the allotted project time, a low-fidelity solution could be found.

**Results**

**Final Remarks**

Works Cited

Ascher H. Shapiro, “The Dynamics and Thermodynamics of Compressible Fluid Flow”, Vol. 1

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