DESIGN OPTIMIZATION OF A 2-D SCRAMJET INLET

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Summary. *A generic 2-D scramjet inlet is analyzed with SU2 software. Accuracy of three turbulence models are compared and a mesh dependence study is performed for the case. Results are compared favorably with experimental data from Idris et al. (2014). The geometry is planned to be optimized by using the adjoint method in the full paper.*

1 INTRODUCTION

The development of aircraft and guided missiles make the hypersonic flow one of the most interesting subjects for the last 50 years' aerospace industry. Scramjets are the key technology needed to make hypersonic flight possible[1]. Scramjet (supersonic combustion ramjet) is a variation of ramjet engine. While it decelerates the freestream hypersonic air to supersonic speeds before combustion, burning occurs at subsonic speeds in a ramjet. Scramjets consist of three main components; inlet, combustor, and nozzle. A diagram of scramjet is seen in Figure 1.

The purpose of the inlet is compressing the air by normal and oblique shocks with as low as possible pressure losses. The performance of the scramjet inlets can be evaluated by two basic parameters. First one is the compression level and the second one is the efficiency[2]. Two main parameters related to inlet efficiency are the kinetic energy efficiency and pressure recovery[3]. Since inlets are one of the most vital components of the engines, their designs and efficiencies are very effective on the overall performance of the engine.

Design optimization of propulsion systems has always been of great interest[1]. Previously, inlet design optimizations were carried out using wind tunnel facilities. However, they are very costly, and it is hard to make an examination on the entire design space via this method[4]. In recent years, developments in computing systems have completely changed the design process. In order to reduce the duration and cost of the design process and to improve the quality of the designed product, automatized optimization with numerical simulation is now widely used in the industry[5]. However, the CPU time required for high-fidelity optimization with numerous design variables is still notable. Decrease in the calculation time of the gradient of the objective function(s) can significantly minimize the time required for optimization. The adjoint method is efficient in this respect[7].

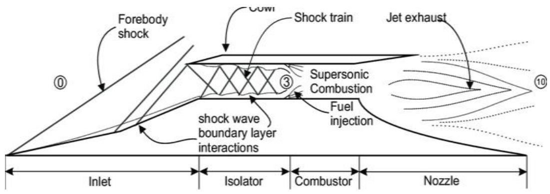

Figure 1: Generic diagram of a scramjet engine[6]

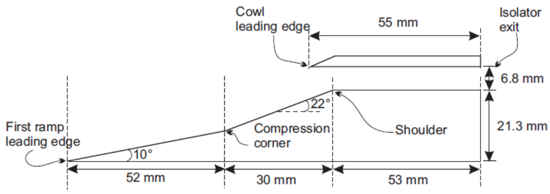

Figure 2: Generic scramjet inlet and its dimensions[6]

2 METHOD

In the current study, a generic 2-D scramjet inlet is analyzed with SU2 software. 3 turbulence models, Spalart-Allmaras with / without Edwards Correction and Menter Shear-Stress Transport are compared in terms of whether the supersonic flow features inside the inlet are captured or not, and a mesh dependence study is done for the case. This work is the preliminary for the inlet geometry optimization by using the adjoint method; that is planned to be given in the full paper.

2.1 Geometry Model

A generic scramjet inlet, given in Figure 2, is used as baseline geometry. This geometry has experimental data on the ramps and isolator surface[6]. The inlet has two ramps. The first one has 10°, and the second one has 22° deflection angle. The total length of the inlet is 155 mm, and the isolator height is 6.8 mm.

2.2 Numerical Approach

Flow solutions and adjoint solution for the current research can be obtained by using the open-source CFD suite SU2, developed in the Aerospace Design Lab at Stanford University. SU2 is a Reynolds-averaged Navier-Stokes (RANS) solver as well as it provides gradient information for optimal shape design by using adjoint method[8].

In this work; in order to calculate the convective fluxes, JST centered spatial discretization[9] was used. The results of three different turbulence models available in SU2 (Spalart-Allmaras (SA), Spalart-Allmaras with Edwards Correction (SA_E), Menter shear-stress transport (SST)) were compared with the experimental data[6]. Turbulence initialization parameters are adjusted according to values given in the Reference [6]. The computational domain is surrounded by inlet, adiabatic wall, supersonic outlet and characteristic far-field boundary conditions (Figure 3). Freestream conditions are given in Table 1. Air was simulated as ideal gas. Sutherland method was chosen as the viscosity model with default settings of SU2. The first layer thickness was set to 2 microns to ensure that y+ value is smaller than 1. The grid dependency analysis was performed by using 3 different grid refinement levels. The number of cells of these grids are given in Table 2.

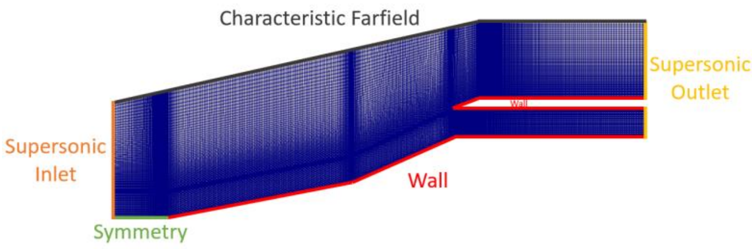

Figure 3: Boundary conditions

Mach number	5.0
Angle of attack [°]	0
Freestream pressure [Pa]	1228.5
Freestream Temperature [K]	62.5

Table 1: Freestream conditions

Grid Type	Number of Cells
Coarse	36800
Medium	79382
Fine	154080

Table 2: Number of cells of three different grid

3 RESULTS

3.1 Comparison of Turbulence Models

The results of 3 different turbulence models are compared with experimental data. Idris et al. (2014) used pressure sensitive paint and pressure transducers on ramps and isolator surface to investigate the shock structure of the baseline geometry of the current study. They also compared their results with CFD analysis. Their numerical and experimental data and SU2 results for the pressure distribution on the ramps and isolator surface are given in Figure 4.

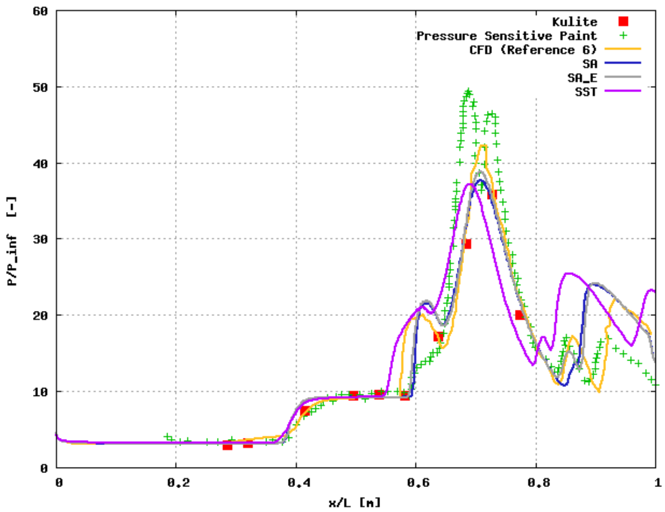

Figure 4: Turbulence model comparison

The behavior of SST turbulence model results differs from that of other turbulence models and the experimental results. Both SA and SA_E turbulence models compares favorably with the experimental data. SA model could not capture the pressure increase near x=0.85 seen in pressure sensitive paint result, whereas SA_E captures this pressure jump. Therefore, the continuation of the study is planned to be carried out with SA_E turbulence model.

3.2 Comparison of Different Grid Refinement Levels

SU2 flow analyses were performed with 3 different grid refinement levels, and the comparison of their results are given in Figure 5.

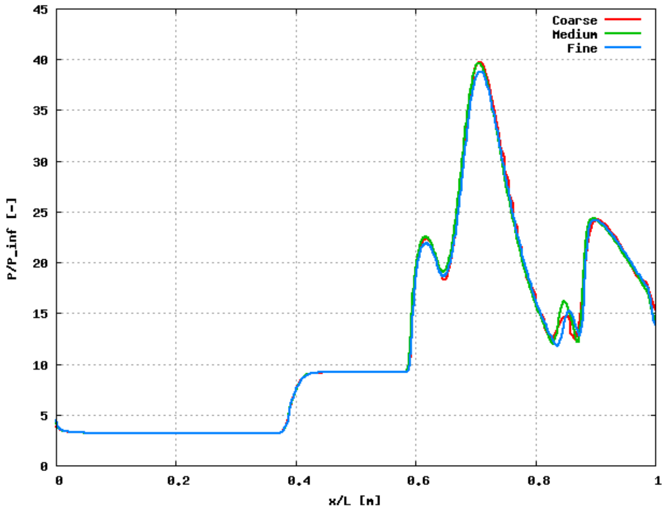

Figure 5: The comparison of different grid refinement levels

It was observed that the refinement level of grids did not have a significant effect on the ramps. However, a grid independent solution for the inside of the isolator could not be obtained at this stage. The cause of this behavior will be investigated further in the full paper.

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