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CFD Analysis and Improvement of Combustor

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1 Introduction

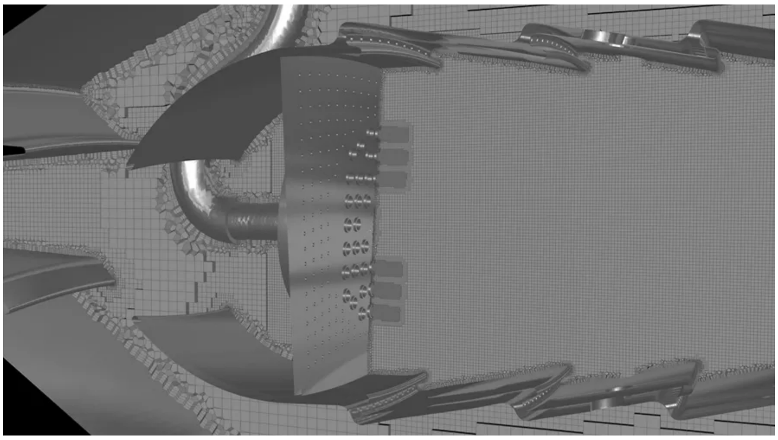

Figure 1: Sample geometry of hydrogen combustor

The combustion chamber of a jet engine is where the energy is generated to drive the entire engine. Air and fuel are supplied to the cylinder of the combustion chamber and are mixed inside. Additional air can flow around the outside to keep the cylinder cool. The air is then introduced through openings along the cylinder according to our design. The main aim of the design is to obtain a constant temperature distribution at the outlet of the chamber.

In gas turbine combustion chambers, fuel is injected into the combustion chamber through a set of nozzles. The shape and direction of the nozzles and the baffles in the combustion chamber are carefully designed to ensure both balanced mixing and a stable flame in the combustion chamber. The fuel-air mixture ignites in the combustion zone, releasing energy in the form of heat.

2 Literature Review

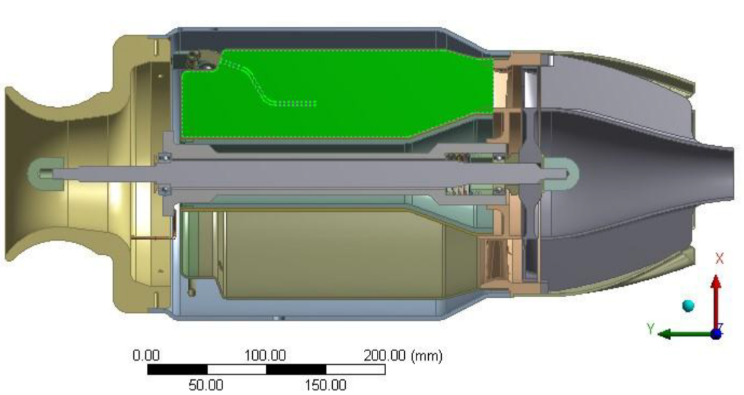

Figure 2: Geometry of the analyzed jet engine

Engine technology has evolved continuously over the past 70 years. The reason for this is the constant drive to minimize fuel combustion. More fuel-efficient engine cycles have led to increased pressure and temperature inside the combustion chamber.

The simulations were inspired by an article describing the effects of the above-mentioned changes in combustion chamber parameters on nitrogen oxide (NOx) emissions. [1] (e-ISSN: 2395-0056)

The method of designing the combustion chamber attracted particular attention. It was found that there is no single and exclusive method for such a simulation, so other possible solutions more oriented towards gas combustion were examined.

3 Model description

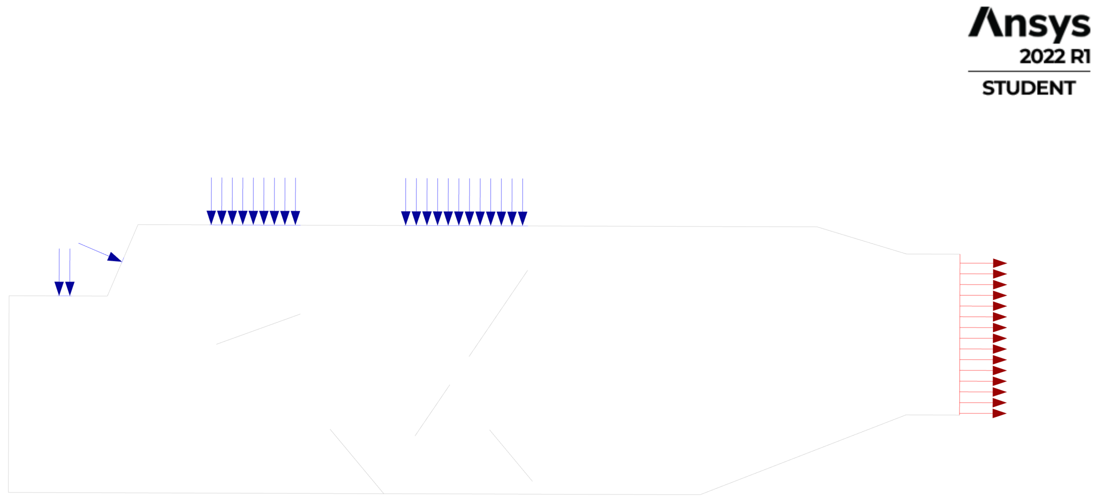

Figure 3: 2D geometry of angular combustor with flame holders

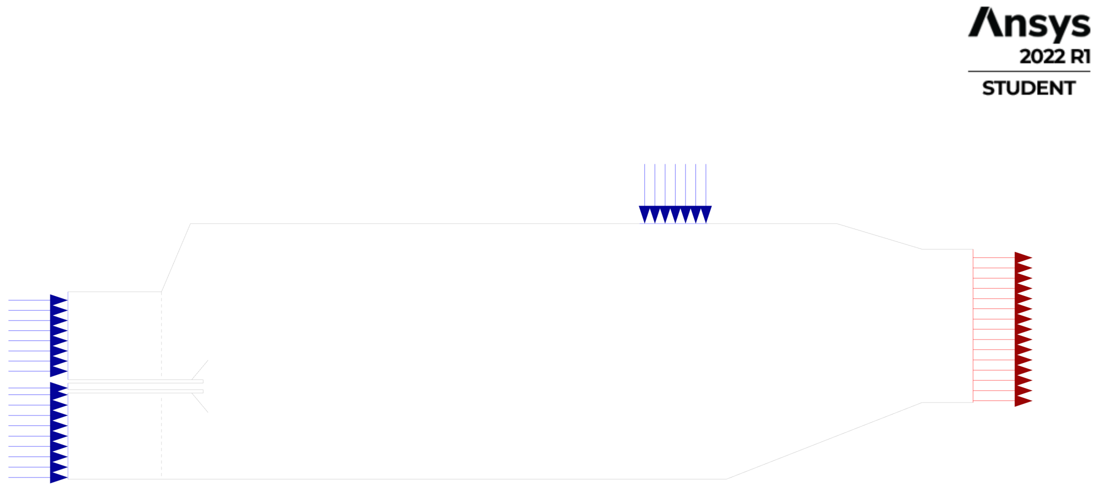

Figure 4: 2D geometry of angular combustor with mesh

In this project two different geometries of combustors were tested. This geometries are shown in Figure 3 and Figure 4. The flame considered is a turbulent diffusion flame. A very small nozzle $(2\ mm)$ introduces methane at calculated mass flow rate about $20\ {}^{g}\!/\!{}_{s}$. Air from the compressor which temperature is $600\ K$ enters the combustor by holes radially or axially. The main assumption is that the air flowing from the compressor through the diffuser has a velocity of about $10\ {}^{m}\!/\!{}_{s}$. The overall air-to-fuel equivalence ratio $\lambda = 1$.The first design is the try to improve geometry used in the article. The second geometry's design is influenced mostly by the chosen fuel Figure 1 (methane) which mechanism of combustion is very different from kerosene.

4 Theoretical background

Model used in this project is generalized eddy-dissipation model. The combustion will be modeled using a global one-step reaction mechanism, assuming complete conversion of fuel to CO_2 and H_2O. The reaction equation is:

$$\mathrm{CH_4} + 2\,\mathrm{O_2} \longrightarrow \mathrm{CO_2} + 2\,\mathrm{H_2O} \tag{4.1}$$

The eddy-dissipation model was chosen because methane is fast burning fuel and the overall rate of reaction is controlled by turbulent mixing. In non-premixed flame, such as in this case, turbulence slowly mixes fuel and oxidizer into the reaction zones where they burn quickly.

$$R_{i,r} = v'_i \cdot M_{w,i} \cdot A \cdot \rho \cdot \frac{\varepsilon}{k} \cdot \min{}_{\mathcal{R}} \left(\frac{Y_{\mathcal{R}}}{v'_{\mathcal{R},r} \cdot M_{w,\mathcal{R}}} \right) \tag{4.2}$$

$$R_{i,r} = v'_i \cdot M_{w,i} \cdot A \cdot B \cdot \rho \cdot \frac{\varepsilon}{k} \cdot \left(\frac{\sum_P Y_P}{\sum_j^N (v''_{j,r} \cdot M_{w,j})} \right) \tag{4.3}$$

where,

$Y_P =$ the mass fraction of any product species, P
$Y_{\mathcal{R}} =$ the mass fraction of a particular reactant,$\mathcal{R}$
$A =$ an empirical constant equal to 4.0
$B =$ an empirical constant equal to 0.5

Equation 4.2 and 4.3 are limiting (the smaller one) the net rate of production of species i due to reaction r. That means the combustion proceeds whenever turbulence is present ($k/\varepsilon > 0$) and an ignition source is not required to initiate combustion which is acceptable for non-premixed flames.

5 Analysis comparison

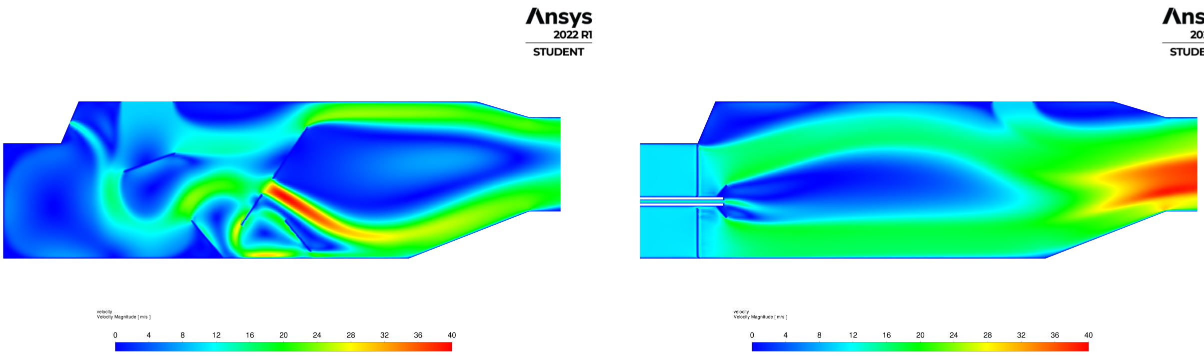

Figure 5: Velocity comparison

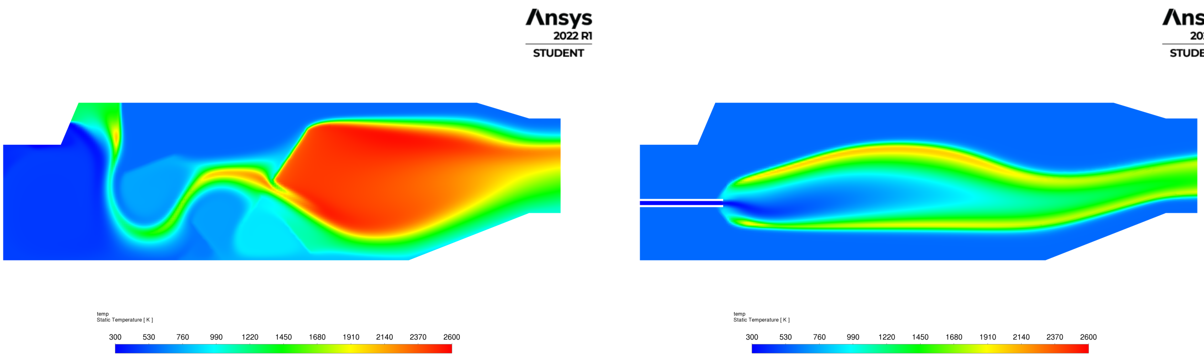

Figure 6: Temperature comparison

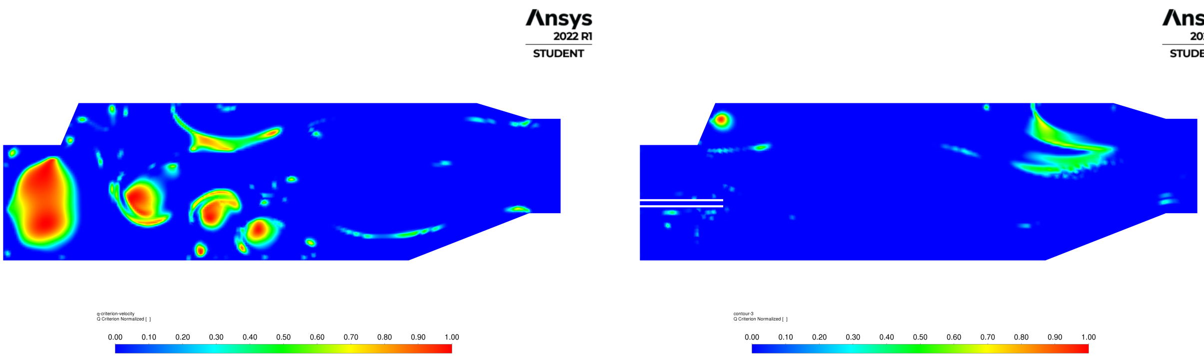

Figure 7: Q-criterion comparison

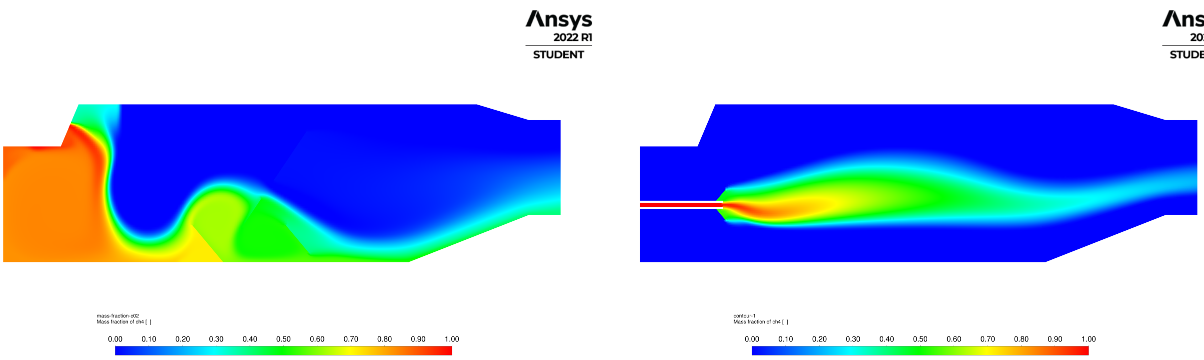

Figure 8: Mass fraction of CH_4 comparison

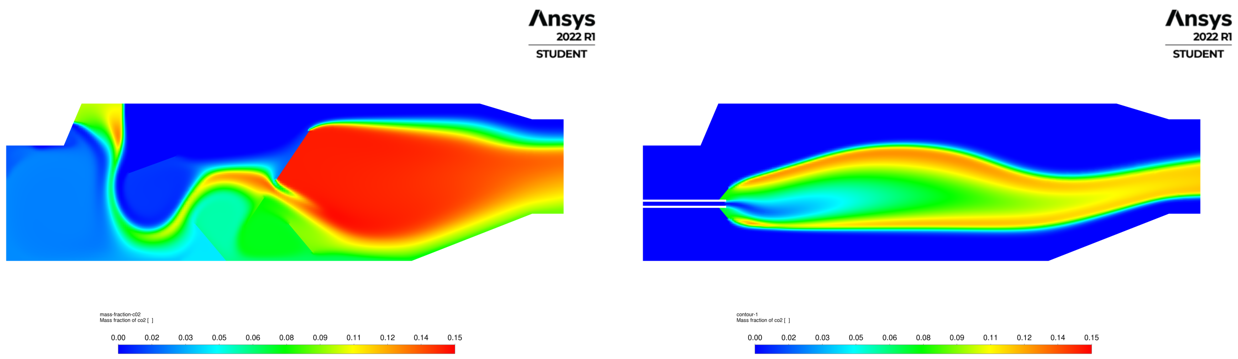

Figure 9: Mass fraction of CO_2 comparison

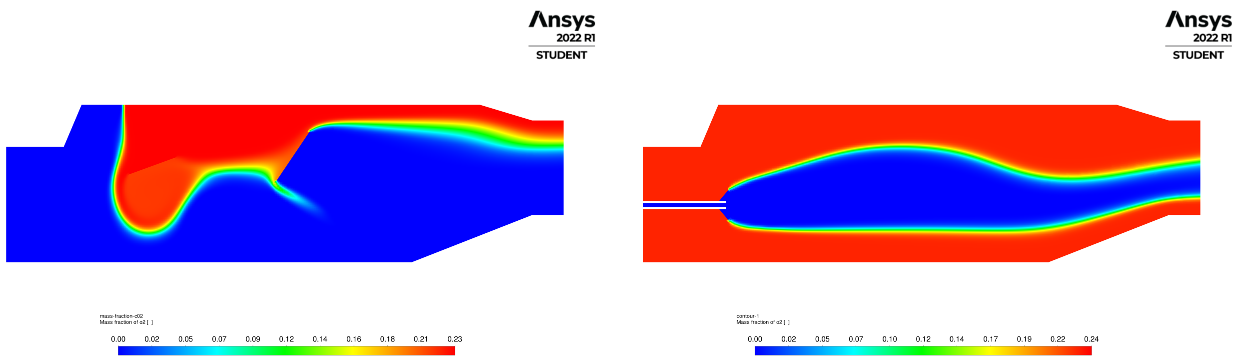

Figure 10: Mass fraction of O_2 comparison

6 Discussion of the results and Conclusions

It has been found that in Design 1, the addition of one-plate flame holders such as those used in the afterburners, resulted in very large vortex structures (Figure 7) and slowed down the flow (Figure 5). These conditions are highly desirable for the combustion. It can be seen in the Figure 6 that in the Design 1 there is large zone of high temperature at the end of the chamber. It can be observed that in Design 2 there is much lower temperature in the combustion chamber. The average value of the temperature at the outlet of the Design 2 is about 900K, while in the Design 1 it is 1400K, which is as much as 500K more.

The higher percentage of pure oxygen in the second Geometry results in a lower combustion chamber wall temperature. That increases the reliability of this engine part.

In conclusion, Design two has better performance due to low pressure loss, which is very desirable in combustion chamber design. Higher temperatures can be obtained by improving the re-circulation zones near the nozzle of the injector. [2]

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