Modelling & Thermal analysis of pulse jet engine using CFD

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Abstract - *The pulsejet engines are used as propulsion systems in various types of rockets, missiles, and pilotless aircraft. The objective of current research is to investigate the combustion characteristics of pulsejet engines using finite rate chemistry and an eddy dissipation combustion model using under pseudo-static state conditions. The combustion analysis is conducted on a pulsejet engine using techniques of "Computational Fluid Dynamics" (CFD). The research findings have shown that proper selection of combustion model is essential for proper evaluation of exit pressure and thrust force generated from pulsejet engine. The pulsejet engine with the eddy dissipation model is found to generate higher thrust force as compared to the finite rate chemistry model.*

Key Words: *Fuel Inlet, Pulsejet, Combustion, CFD, Thrust generation.*

1. INTRODUCTION

Pulsejet Engines are hollow tubes that use sound waves to drive fluid flow and generate thrust. One of the most basic types of air-breathing propulsion that has been created to date is the pulsejet engine. Pulsejet engines are inexpensive to build and maintain since they have few moving components. There is no such thing as a "misfire" in a pulse jet, which makes them lightweight, scalable, affordable, and somewhat effective in converting fuel into heat and thrust. The fundamental benefit of pulsejet engines is their simple design, which has no moving parts. Due to these benefits, they are perfect for utilization in unmanned aerial vehicles (UAVs). These benefits of the pulse jet engine over an internal combustion or Stirling engine include:

- Extremely low-tech, manufactured with few or no moving components [1].
- Due to the fuel's deflagration, it burns highly effectively.
- Unlike Stirling engines and internal combustion engines, it can run on virtually any kind of fuel.
- It creates a substantial amount of power while only weighing a very tiny amount, making it superior to internal combustion engines and Stirling engines in terms of its power-to-weight ratio.
- It can function at a high altitude. Due to extremely thin air at high altitudes, propeller aircraft are typically required to keep below a certain altitude. Commercial passenger airplanes typically travel at high altitudes, for instance, since it is more efficient (the thin air has relatively little air resistance). Additionally, high-altitude engine performance is required for aerospace vehicles (and also demands an engine that doesn't breathe air; this second requirement is difficult but might be resolved by changing fuel) [2,3}

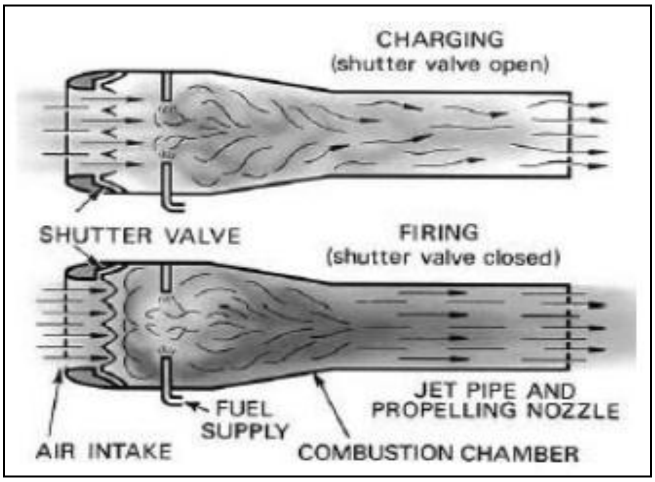


Figure 1: Pulsejet Engine

2. LITERATURE REVIEW

Ordon et al. [4] Researchers at University of Texas at Arlington constructed a numerical model of a valveless pulsejet that involves combustion in order to assess the effectiveness of a pulsejet with a synchronised injection ignition system.

Kiker et al. [5] Post-World War II, the United States Navy conducted research on pulsejets as part of Project Squid. Engineers at SNECMA in France conducted substantial studies on pulse jets. Lockwood of Hiller Aircraft, with the assistance of French engineers, researched operation of pulsejets. This is a significant achievement due to the fact that it is first study of its kind that has been extensively recorded and is rigorous.

Geng et al. [6] E. Tharratt's The next significant advancement in analytical assessment of pulsejets was heuristic method by linearization of a highly nonlinear issue. At the University of Calgary, Kentfield and his colleagues created the first computer simulations of cyclic processes of valveless pulsejets.

Sayres et al. [7] Since2004, North Carolina State University, has conducted a significant amount of research on pulsejets. This study has included analytical, experimental, and numerical studies. These studies have proved that it is possible to operate pulsejets that are as little as 8 centimeters in length.

Titova et al. [8] Consider that the principle underlying their technique is, to begin with relatively simple chemical systems and then progressively advance to more complex ones. This is analogous to the work done by Warnatz in that both make an effort to limit the number of species and reactions which are required to model combustion. Numerous reactions known to alter ignition time are highlighted in the mechanism's revisions. These include the addition or modification of numerous processes that create to combat OH radicals from fuels and intermediates species and need for additional reaction steps, particular examples such as methanol autoignition at high temperatures. In reality, since its initial release in 2001, the update notes have detailed continuous incremental advances in matching ignition data quickly it has been provided.

3. OBJECTIVE

The purpose of this study is to apply finite rate chemistry & eddy dissipation combustion models to the problem of analyzing the combustion characteristics of a pulsejet engine. The combustion analysis is conducted on pulsejet engine using techniques of Computational Fluid Dynamics.

- CAD modeling of new designs with multiple fuel inlets.
- CFD analysis using ANSYS-CFX software using new design with multiple fuel inlets.
- Determining thrust generated, pressure plot and velocity plot for new design with multiple fuel inlets.

4. METHODOLOGY

The CFD analysis is based on Navier's stokes equation which involves the conservation of momentum, mass, and energy. Figure 2 illustrates how the design of the pulsejet engine was created utilizing design software. The developed model is converted in a compatible file format, i.e., iges. This file format .iges makes this file compatible to be opened in ANSYS simulation package.

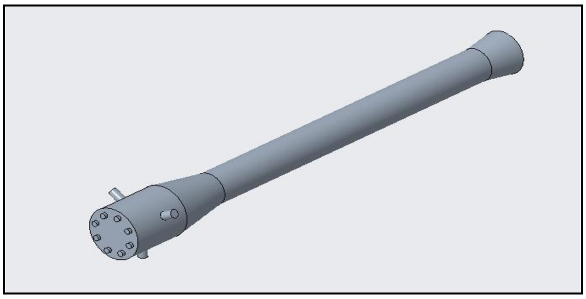


Figure 2: Design of pulsejet engine

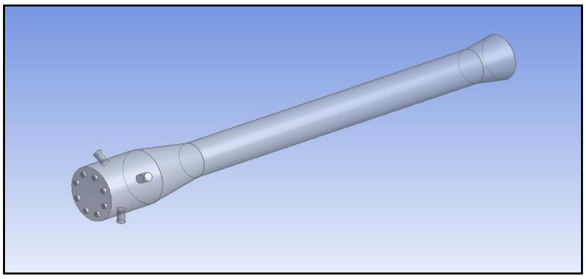


Figure 3: Imported design of pulsejet engine

Pulsejet engines are depicted in figure 3 above, which depicts the imported design. Pulsejet design is checked for geometric errors, imperfections etc. The model of pulsejet engine is discretized with fine relevance and adaptive meshing type. The meshing is done with tetrahedral element type and fine

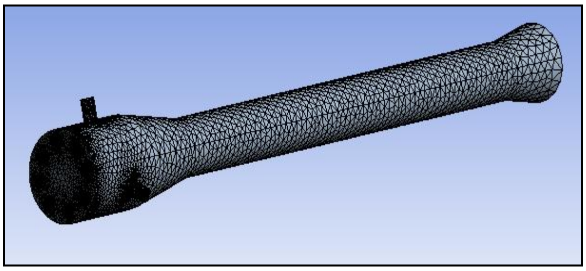


Figure 4: Meshed design of pulsejet engine

After meshing, the loads and boundary conditions are applied on pulsejet engine, which involves air inlet condition, fuel inlet condition and air outlet conditions.

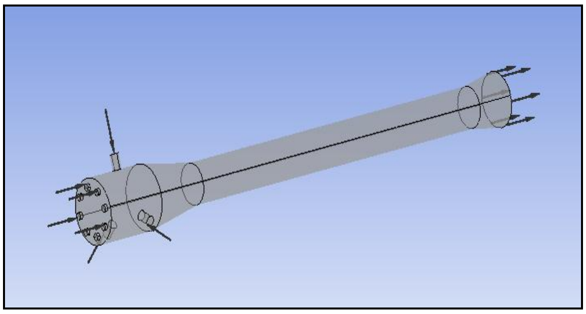
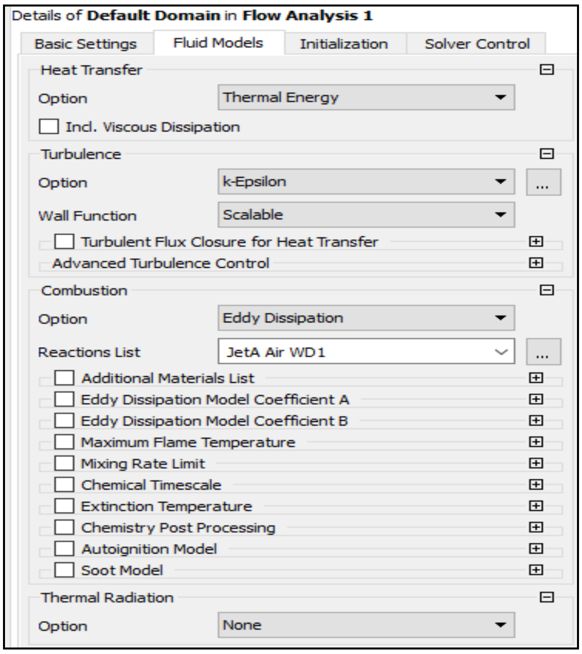


Figure 5: Boundary condition of pulsejet engine

The air inlet boundary condition is defined as shown in figure 8. The inlet air is defined with different mass fractions of CO_2, H_2O, Jet A fuel and O_2. These conditions of mass fractions are shown in figure 7.



Details of **Default Domain** in **Flow Analysis 1**

Heat Transfer

Option: Thermal Energy

☐ Incl. Viscous Dissipation

Turbulence

Option: k-Epsilon

Wall Function: Scalable

☐ Turbulent Flux Closure for Heat Transfer

Advanced Turbulence Control

Combustion

Option: Eddy Dissipation

Reactions List: JetA Air WD1

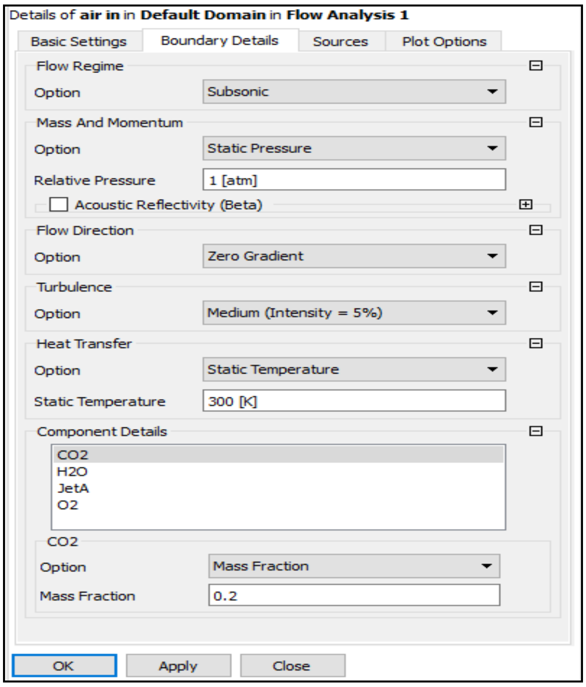
☐ Additional Materials List
☐ Eddy Dissipation Model Coefficient A
☐ Eddy Dissipation Model Coefficient B
☐ Maximum Flame Temperature
☐ Mixing Rate Limit
☐ Chemical Timescale
☐ Extinction Temperature
☐ Chemistry Post Processing
☐ Autoignition Model
☐ Soot Model

Thermal Radiation

Option: None

Figure 6: Eddy dissipation combustion model of pulsejet engine

The combustion model is defined for the analysis as shown in figure 6 and is set to eddy dissipation and finite rate chemistry for subsequent analysis.



Details of **air in** in **Default Domain** in **Flow Analysis 1**

Flow Regime

Option: Subsonic

Mass And Momentum

Option: Static Pressure

Relative Pressure: 1 [atm]

☐ Acoustic Reflectivity (Beta)

Flow Direction

Option: Zero Gradient

Turbulence

Option: Medium (Intensity = 5%)

Heat Transfer

Option: Static Temperature

Static Temperature: 300 [K]

Component Details

CO2
H2O
JetA
O2

CO2

Option: Mass Fraction

Mass Fraction: 0.2

Figure 7: Mass fraction of each gases and fuels

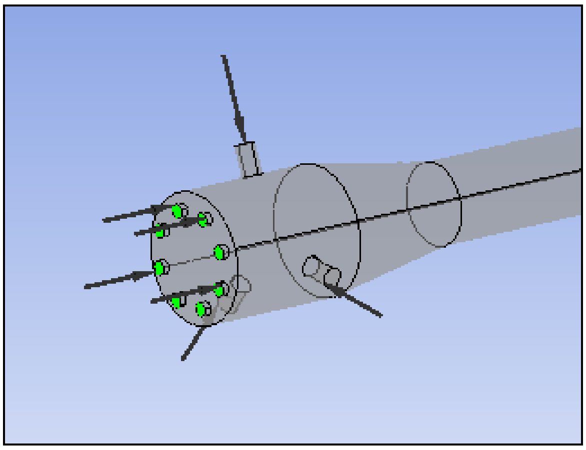


Figure 8: Air inlet boundary condition

The fuel inlet boundary conditions are defined for the pulsejet domain, as shown in figure 9. The fuel inlet involves definition of normal speed, and mass fraction of JetA fuel is set to 1.

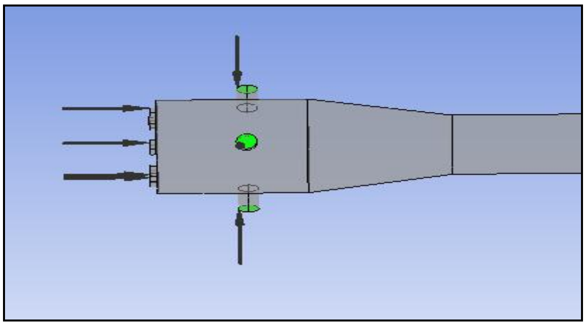


Figure 9: Fuel inlet boundary condition

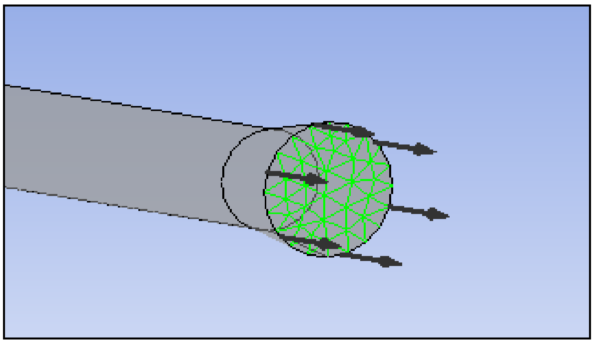


Figure 10: Air outlet boundary condition

The air outlet boundary conditions are defined for the pulsejet engine, as shown in figure 10 above. The outlet boundary condition is defined with 0 relative pressure difference.

5. RESULTS AND DISCUSSION

The pressure distribution plot is generated for the pulsejet engine, as shown in figure 11. The plot shows higher pressure values at the air inlet valves and in the region between fuel inlet and air inlet. In a pulsejet engine, pressure rises towards the combustion zone and falls further away from it.

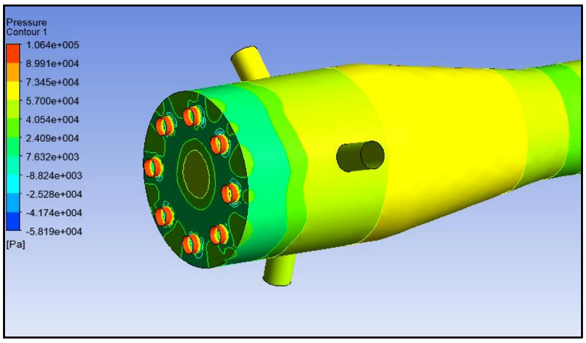


Figure 11: Pressure distribution plot for eddy dissipation combustion model

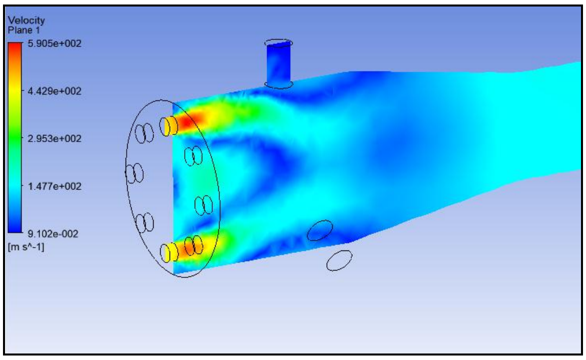


Figure 12: Velocity distribution plot for eddy dissipation combustion model

The velocity distribution plot is generated for the pulsejet engine across the plane, as shown in figure 12. The velocity distribution plot shows a higher magnitude of deformation near the air inlet and reduces along the combustion zone. The velocity is uniform along the exit of the nozzle. The maximum velocity magnitude obtained is 590.5m/s.

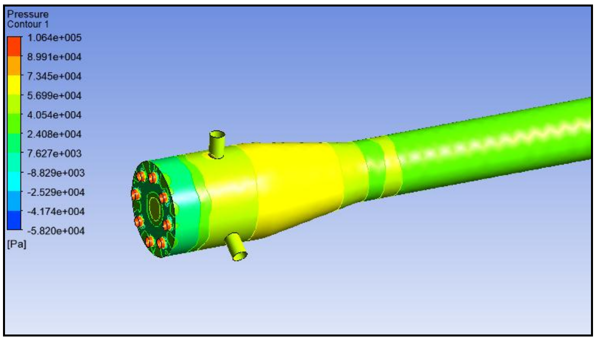


Figure 13: Pressure distribution plot for finite rate chemistry combustion model

The pressure distribution plot is generated for the pulsejet engine with a finite rate chemistry model, as shown in figure 13. The plot shows higher pressure values at the air inlet valves and in the region between the air inlet & fuel inlet. In a pulsejet engine, the pressure is highest at the combustion zone and decreases as the engine gets longer.

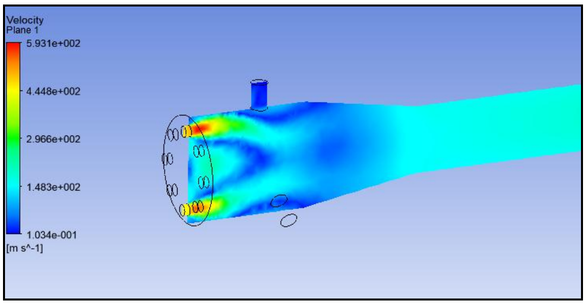


Figure 14: Velocity distribution plot for finite rate chemistry combustion model

The velocity distribution plot is generated for the pulsejet engine across the plane, as shown in figure 14. The velocity distribution plot shows a higher magnitude of deformation near the air inlet and reduces along the combustion zone. The velocity is uniform along the exit of the nozzle with a maximum magnitude of 593.1m/s.

6. CONCLUSION

The CFD simulation enabled to investigation the combustion characteristics of pulsejet engines with different combustion models. The research findings have shown that proper selection of combustion model is essential for proper evaluation of exit pressure and thrust force generated from pulsejet engine. The pulsejet engine with the eddy dissipation model is found to generate higher thrust force as compared to the finite rate chemistry model.

- For all the design configurations of the pulsejet engine the combustion zone is observed to have maximum pressure and static enthalpy which reduces along the exit of the pulsejet engine.
- Among the several fuel inlets designs for pulsejet engines, the design with three fuel inlets demonstrated the highest pressures and thrust

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