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Numerical Simulation and Experimental Validation of Air-Assisted Fuel Atomization for Aviation Applications

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Abstract—

The project deals with an attempt of developing an advanced atomizer concept to control the spray formation for mixed spray combustion is examined. The aim is to improve the spray structure that preserves the flame height and modifies the width of the flame. The atomizer concept for development of a modified spray combines a swirling liquid film generation that is atomized by an external swirling gas flow. To investigate the main characteristics of the combined atomizer, experiments and numerical simulations of the flow operation with different geometric nozzle parameters (number of gas holes) and process parameters (flow rate of fuel and air) as well as fuel properties are carried out to produce a modified, enlarged and steady spray of small droplets. In this work, fuel (kerosene) is used as the liquid phase and air as the gas phase. In the simulations, the multiphase flow is modelled using k-epsilon model with transient flow and the turbulence of the gas phase is 10% and fluid is used as dispersed medium and gas as constant fluid at Standard Temperature and Pressure (STP). The goal of the numerical simulations is to investigate the cone angle and flow behaviour of the fuel injector, impingement of surrounding air on the fuel is noticed and the morphology of the spray is examined and the fuel injector is made as prototype design and fabrication work is carried and tested in the laboratory and compared with the CFD analysis..

Keywords— Swirling k-epsilon, Transient flow, Impingement.

I. INTRODUCTION

Research conducted by the Intergovernmental Panel on Climate Change (IPCC) have found that aircraft will produce as much as 3.5% of the total anthropogenic radioactive energy caused by all human doings and activity, as per 2005. Specified the anticipated growth of the aerospace sector, the fundamental body that controls emissions for aerospace - International Civil Aviation Organization (ICAO), has employed a set of regulations meant by restraining the impact of the aerospace sector on the earth's weather, while permitting it to continue to be an important vehicle for economic growth.

The different emissions that are currently regulated by ICAO for aircraft are Carbon Monoxide (CO), Nitrogen Oxides (NOx), Unburned Hydrocarbons (UHC) Particulates etc. Developments to a number of different factors such as air traffic management, engine efficiency and aircraft design, are all desired to help attain lower emissions levels in the future. Modern demands for improvement in combustor performance, has generally been accomplished over a number of technologies.

Technologies such as innovative cooling technologies, higher engine pressure ratios, and fuel nozzles. The term "Atomization" is defined as a process of surface dispersion by the kinetic energy of liquid itself, or by means of high gas velocity impingement, or through the mechanical energy like rotation and vibration means, in which the bulk liquid such that the sheet or jet is disintegrated into a number of small droplets. In our daily life, the atomization process is seen in many forms such that in form of nature itself and industries. For example, the atomization process found in nature as rain, mist, waterfalls or ocean sprays caused during the crashing of waves to the rocky sea shore. In the industrial application atomization is used widely where sprays plays main role.

II. LITERATURE REVIEW

The purpose of this literature review is to provide background information on the issues to be considered in this thesis and to emphasize the relevance of the present study. This concept embraces various aspects of fuel injector nozzle atomization and nozzle efficiency and in turn enhances the combustion efficiency of aircraft.

Lizoel Buss et al [1] proposes a work on Influence of Geometric Nozzle And Process condition on the Spray behavior in a double swirl atomizer. In this effort an advanced atomizer idea to control the spray formation for varied spray combustion is examined. The aim is to address the spray structure that preserves the flame height and changes the width of the flame. The atomizer concept for development of a changed spray combines a swirling liquid film generation that is atomized by an outside swirling gas flow.

Pipatpong Watanawanyoo et. al [2] investigated on the study of a fuel injection system in constant combustor. Air atomizing nozzle is established to good efficiency injection and used for low air pressure (67.95288.79kPa) to assist the atomizing nozzle. Progressive palm oil and motorized diesel oil were the fuels for the experiment for the system of atomization. The atomizer was designed in a way that air could flow through the small sized hole nozzle. Therefore, the low-pressure airflow could induce fuel by siphoning and break oil into small fine droplets that were delivered over the outlet. The aim of design and develop a continuous combustor is emphasized on simplicity for construction, inexpensive, good stability and reduce import fuel for continuous combustor.

Arya Pirooz [3] presented a paper on Effects of Injector nozzle geometry on spray characteristics, Analysis. Aimed at all diesel engines the maximum geometrical factor that affects engine performance would be the hole diameter, it is also the utmost delicate and restricted factor. For diesel engines the main objective in injector design would be to have to uppermost injection pressure without having large damages of increased injector hole number. The number of holes needs to remain higher than unoriginal engines as to have the best in cylinder mixtures, but a need for efficiently creating pressure is also required as the increase in holes will create less pressure. The solution then would be to increase the nozzle sac diameter and needle seat angle importantly. The increase in both these parameters will not only convert the temperature in the injector tip to pressure successfully, but will also help with chilling the injector itself. This method would justify the usage of higher holes in the injector design.

Vimal Kumar Pathak and Sumit Gupta made a study Of Nozzle Injector Performance Using CFD[4]. The purpose of this paper is to study the performance of nozzle injector by fluctuating its shape and fuels. Diesel injector vent shape has an important role in describing the performance and discharge characteristics of a diesel engine. It supports in adequate amalgamation and atomization of the fuel.

Caio Nunes Pereira [5] study focuses on atomization and combustion of liquids. Firstly, the performance of a plain-jet air blast atomizer running on water has been investigated. Sauter mean diameter (SMD) was assessed through a light scattering technique. In addition, spray quality was evaluated using a Phantom V4.2 high speed camera. The results showed a decrease of SMD with increasing values of the atomizing air to fuel ratio (AFR) up to a given value, beyond which spray quality improved marginally.

H.K. Suh et al [6] propsed a paper on Experimental and Numerical Analysis of Diesel Fuel Atomization Characteristics of a Piezo Injection System and this paper determine the characteristics of the fuel spray, injected through a piezo injection system, and to compare the experimental and numerical results to that obtained using a solenoid injection system. In order to investigate the effect of a fuel injection system and spray angle on fuel spray performance such as fuel injection profile, evolution of fuel spray, and atomization characteristics, different nozzle driven systems with the same nozzle specifications were used. For the numerical approaches, a modified nozzle flow model and a breakup model was applied to the simulation of spray atomization using the same calculated conditions as the experiments. It was found that the piezo injection system rapidly reaches the peak injection rate and had uniform injection profiles. The experimental and calculated spray tip penetration of both injection systems showed good agreement as the ambient pressure increased. The microscopic atomization characteristics of the high-pressure piezo injection system indicated that the outstanding injection performance of the piezo injector promoted droplet atomization.

Pankaj Dwivedi et al [7] made Design and Experimental Investigation of Internally Mixed Pressure Swirl Atomizer. To reduce emissions, it is critical to design fuel atomizers that can produce spray with a droplet size and drop distribution at the desired combustor location. The present work is an attempt to design and experimentally investigate the

internally mixed pressure swirl atomizer for Micro Gas Turbine application.

Rick Feddema [8] proposed paper on Effect of Aviation Fuel Type and Fuel Injection Conditions On the Spray Characteristics of Pressure Swirl and Hybrid Air Blast Fuel Injectors. Fuel injector spray atomization performance is affected by the type of fuel injector, fuel liquid properties, fuel injection pressure, fuel injection temperature, and ambient pressure. One objective of this thesis is to contribute spray patternation measurements to the body of existing drop size data in the literature. Fuel droplet size tends to increase with decreasing fuel injection pressure, decreasing fuel injection temperature and increasing ambient injection pressure. The differences between fuel types at particular set conditions occur due to differences in liquid properties between fuels. Liquid viscosity and surface tension are identified to be fuel-specific properties that affect the drop size of the fuel.

Feras Z. Batarseh [9] presented a thesis on Spray generated by an air blast atomizer: atomization, propagation and aerodynamic instability. This thesis presents a study that has been performed to investigate different phenomena exhibited by a spray generated by an air blast atomizer.

B. Sumer et.al [10] made investigation on Numerical Investigation of a Pressure Swirl Atomizer. The flow structure inside a pressure swirl atomizer is investigated using high-speed shadowgraphy techniques and computational fluid dynamics tools. The hollow cone spray properties are detected using Phase Doppler Particle Analyzer. The experimental and numerical results are analyzed and compared. The air core inside the pressure swirl atomizer is visualized at high temporal and spatial resolutions with the high-speed shadowgraphy system. The images captured are analyzed quantitatively with a developed image processing tool. The analyses reveal strong fluctuations of the air core diameter.

Pipatpong et al [11] written a paper on Development of an Air Assisted Fuel Atomizer (Liquid Siphon Type) for a Continuous Combustor. There has been substantial understanding to the operational features of a practical air blast atomizer expanded from this study. Though, further work need to be done before a full understanding of the combustion features of a practical continuous burning combustor can be determined. In summary, low pressure air atomization of refine palm oil fuel with air pressure in the range of 69 - 620 kPa can be used to develop air blaster or burners. The polished palm oil is measured as a renewable source of fuel for it can bear formed domestically is used as fuel.

Hongtao Zheng et al [12] worked on effect of dual fuel nozzle structures on combustion flow field in CRGT combustor. Three different structures of a new dual fuel nozzle design concept (inner swirl nozzle, double swirl nozzle, and outer swirl nozzle) were developed for the chemically recuperated gas turbine (CRGT) combustor.

III. METHODOLOGY

We have followed two approaches to find the solution for our stated problem

1) Numerical Simulation Approach
2) Experimental Approach

1) First Approach [Numerical Simulation Method]

- Detailed study of fuel injectors, working procedure and formula based calculation involved.
- Selecting the necessary CAD modelling software.
- Verifying the Theoretical design calculation with the cad model.
- Selection of efficient CFD Analysis software.
- Selecting the domain.
- Applying the necessary boundary condition.

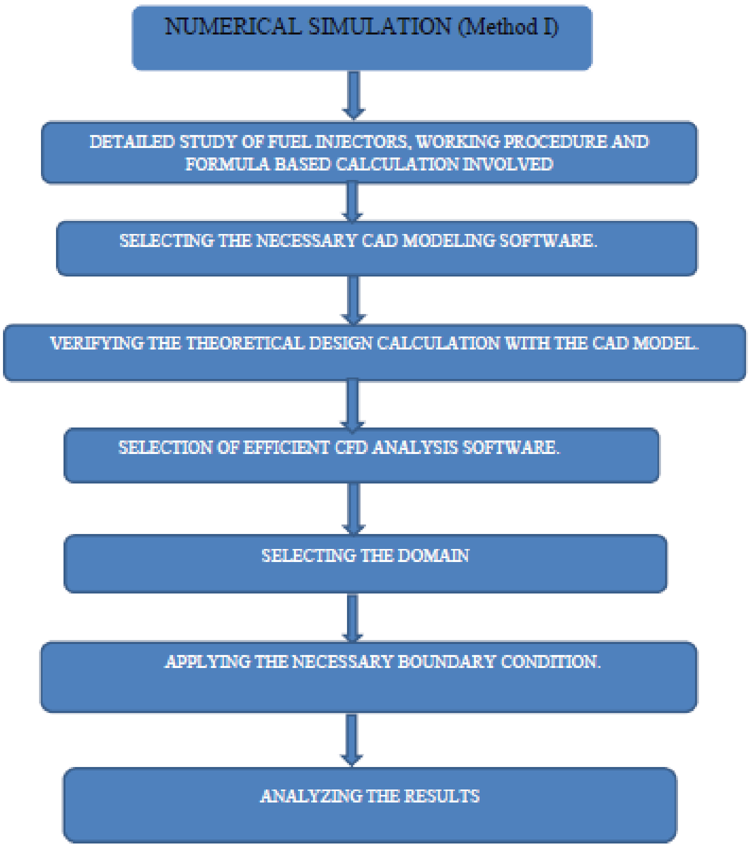

Fig 1 Numerical Simulation Method Flow Chart

1) Second Approach [Experimental Method]

- Selection of Material to be used.
- Selection of operating and machining tool.
- Testing the model in a laboratory condition.
- Verifying the result with the numerical simulation method.

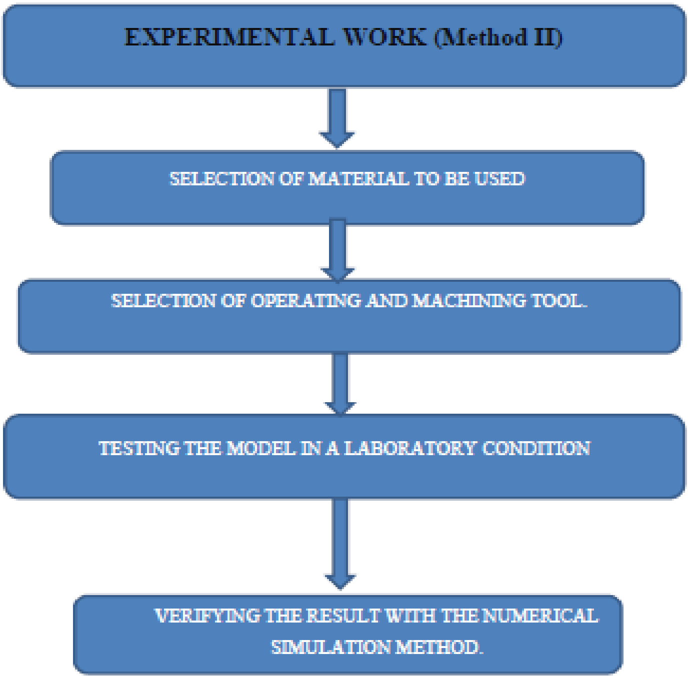

Fig 2 Experimental Method Chart

IV. NUMERICAL SIMULATION

ANSYS CFX is a high-performance computational fluid dynamics (CFD) software tool that delivers reliable and accurate solutions quickly and robustly across a wide range of CFD and multi-physics applications. CFX is recognized for its outstanding accuracy, robustness and speed with rotating machinery.

a) Applying Boundary Conditions

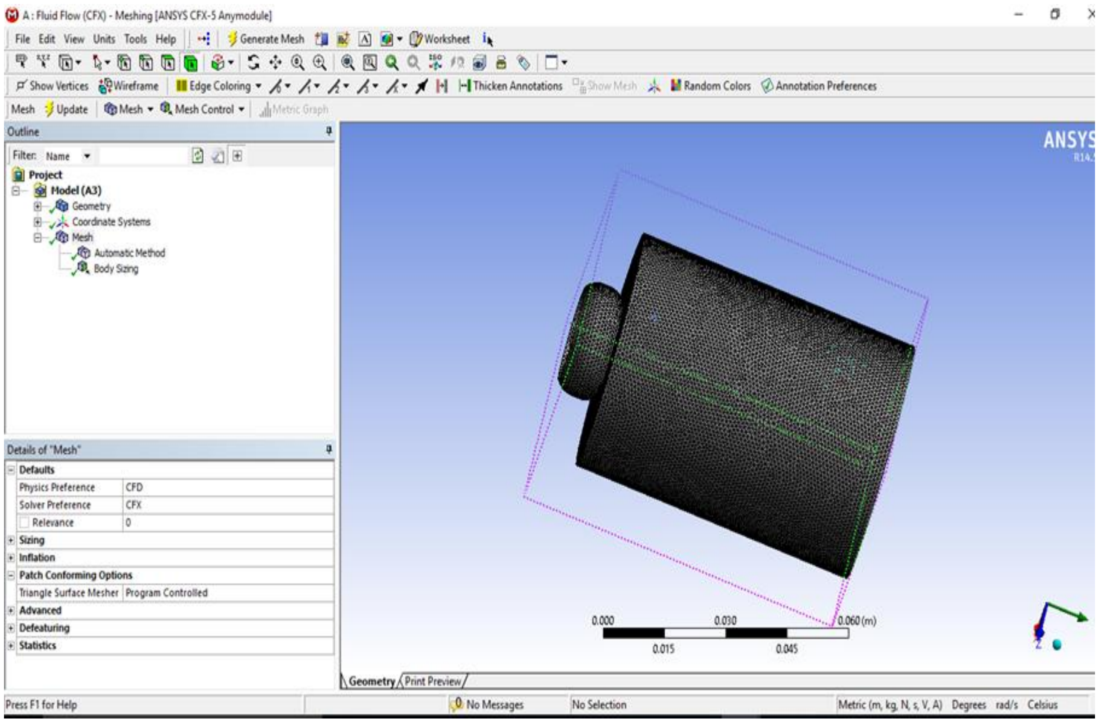

Fig 3 Mesh generation

b) Superficial Fuel Velocity

Superficial velocity (or superficial flow velocity), in engineering of multiphase flows and flows in absorbent media, is a hypothetical (artificial) flow velocity calculated as if the given phase or fluid were the only one flowing or present in a given cross sectional area. Other phases, particles, the skeleton of the porous medium, etc. present in the channel are disregarded. Superficial velocity is used in many engineering equations because it is the value which is usually readily known and unambiguous, whereas real velocity is often variable from place to place, its mean not readily available in complex flow systems, and subject to assumptions. Superficial velocity can be expressed as:

$$\mathbf{Us = Q/A}$$

Where

U_S - superficial velocity of a given phase, m/s
Q - Volume flow rate of the phase, m^3/s
A - Cross sectional area, m^2

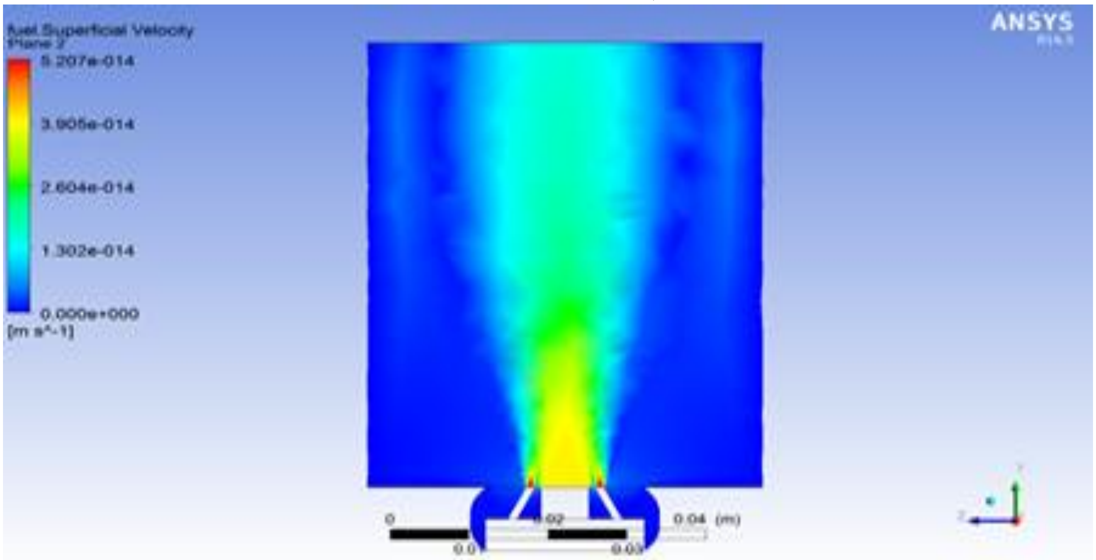

Fig 4 Fuel superficial velocity

It is observed that the maximum fuel superficial velocity shown in red color which is about 5.207m/s and minimum fuel superficial velocity shown in light blue color which is about 1.302 m/s

V. FABRICATED MODEL

This the complete fabricated model after all the above mentioned process, Brass material was chosen because it has a better machining property and available in comparatively less expensive and commonly available. Hence our project mainly deals with the spray angle prediction and atomization, so we are not considering the thermal behavior of the material.

Table 1 Properties of materials

Material	Density (g/c.c)	Thermal conductivity(W/m K)
Brass	8.73	109
Aluminium	2.7	205
Steel	8.05	50.2

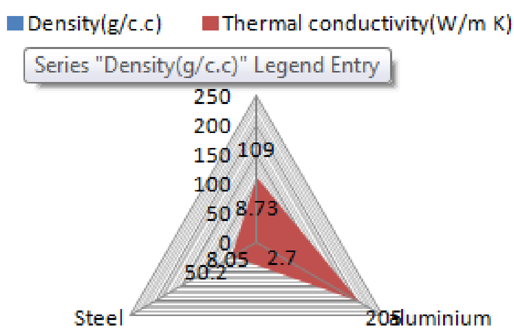

Fig 5 Final fabricated model

A. Testing Of Fabricated Model

The Fabricated fuel injector nozzle is tested in the nozzle testing centre, by connecting the two hose pipes one for fuel and another for air. Then the pipes are clamped with the clips in order to stop the pressure leakage and then the experiment was carried out in the Laboratory conditions.

B. Laboratory Setup

- Fuel (kerosene) was pressurized to 5 bar pressure with a Fuel pressure gauge.
- Air from the air compressor was pressurized to 10 bars.

VI. TESTING RESULTS

After giving above mentioned boundary conditioned, we can observe the atomization process of liquid kerosene, the fuel, it was observed that the variation of pressurized air had a greater influence on the entrainment rate than the liquid flow rate while the droplet viscosity variation did not disturb significantly the behaviour of the gas flow. Entrainment of air and Fuel was observed the cone angle was predicted

From the following test we have noticed that cone Angle is formed till 50 degree from the centre and, we have also noticed another angle of 30 degree were maximum liquid is sprayed with better atomization of the fuel was observed with tiny numbers. The liquid was atomized and disintegrated into smaller number of particles of keroseneand it was noticed when, air strikes at the fuel ejecting out and air is swirled by an angle β of 120 degree to the fuel and at that strike zone of air and fuel the liquid atomization process began and cone angle formation was noticed. However we cannot check the diameter of the liquid in testing process, and this is our future scope of the project and we would like to carry it further. Whereas we have proved by numerical simulation process where it showed the mean diameter of 5 microns.

VII. CONCLUSION

The main scope of this paper is to propose and develop a novel fuel nozzle design that can help reduce emissions of Carbon monoxide, unburnt hydrocarbons, and particulate matter (soot).

In order to achieve this the nozzle needs to meet certain design criteria:

- Consistent and low droplet sizes from idle and low power conditions.
- Demonstrate good atomization over a wide liquid flow rate.
- Achieve uniform circumferential fuel distribution for varying power conditions.
- Improve mixing at idle and low power conditions.
- Low susceptibility to coking

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