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Interpretation Of Flow Visualization In Generic Combustor Through Design And Fabrication Of A Traverse System

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Abstract: This research work deals with design, fabrication and assembly of a two axis traverse system to make various non-intrusive planar measurements as applicable to aero propulsion research in the stream wise and span wise direction. The Two axis Traverse system will help enable the investigators to address various types techniques and acquire detailed and comprehensive information about the flow field which may be a single plane flow field where the fuel-air mixing of the gas jets can be studied by acquiring the velocity field of the injected fuel at various stream-wise reactions using Mie scattering technique or alternatively study the liquid penetration and mixing characteristics by the use of appropriate lasers and image acquisition equipment. This traverse will also enable studies on drop size characteristics in a liquid fuel spray and fluorescence studies on the spray for fuel fraction measurements by mixing additional attachments to the image acquisition like an image doubler for SMD studies and image intensifier for fuel fraction measurements. The functionality of the traverse is verified and demonstrated by making planar Mie scattering measurements in subsonic cross flows for spray penetration.

Keywords: traverse system, non-intrusive planar measurement, Mie scattering technique, liquid fuel spray and fluorescence

1.1. INTRODUCTION:

To move an aircraft through the air, we have to use some kind of propulsion system to generate thrust. The most widely used form of propulsion system for modern aircraft is the gas turbine engine. The gas turbine engine is a kind of internal combustion engine. Gas turbine engine consists of three primary section mounted on the same shaft, the compressor, the combustion chamber and the turbine. The compressed air is mixed with the fuel injected through nozzles. The fuel-air mixtures ignite under constant pressure condition and the hot combustion products(gases) are directed to the turbine where it expands rapidly, imparts rotation to the shaft and the exhaust gases leave the nozzle mixes with ambient air outside the engine. A combustor is a component or area of a gas turbine engine where combustion takes place. It is also known as a burner or a combustion chamber. In a gas turbine engine, the combustor or combustion chamber is fed high pressure air by the compressor system. The combustor then heats this air at constant pressure. After heating air passes from the combustor through nozzle guide vanes to the turbine.

From **Achilleas V. Bardakas et al [1]**, the design and development of a pc-controlled three axis traverse mechanism that is used to determine the extensive velocity and temperature into the drying chamber of a laboratory scale convective dryer was studied. From **H. Seyfried, et al [2]**, The application of several optical measurement techniques for the characterization of the combustion behavior of the pilot burner of a gas turbine combustor developed according to the lean premixed pre-vaporized

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concept was helpful in the research. From **Jacob N. Stenzler1, et al [3]**, the results used were increasing the momentum flux ratio increased penetration and increasing the weber number diminished the overall spray penetration by decreasing the average drop sizes of the sprays.

1.2. OBJECTIVES AND SCOPE

The main objectives of this research work are as follows:

1. To design and built a two axis traverse mechanism using modeling software (CATIA V5).

2. Structural analysis of the traverse mechanism to determine its load carrying capability and amount of deformation on application of load using SKYCIV ENGINEERING.

3. Use the traverse setup to study liquid fuel penetration in a subsonic cross flow using planar Mie scattering in a model duct to verify the functionality of the traverse and generate spray data.

2.1. DESIGN AND MODELLING OF 2-D TRAVERSE SYSTEM

The traversing mechanism are classified as 1D, 2D, 3D traverse systems, in which a 2D traverse mechanism was built to determine the different flow phenomenon in a test rig facility.

2.1.1 DESIGN REQUIREMENTS

The basic requirements of the traverse are the designing of the mechanism. The design requirements were to accommodate different image acquisition system and apparatus to carry out measurement of various parameters. Also, rapid movement and precise positioning to acquire large amounts of quantitative data in the given blow down time as accurately as possible. It should be used in other test rigs as well. It was decided to concentrate on the important aspect for mechanism to get the plane of projection at particular location in the test section of rig, as shown in Fig-1.

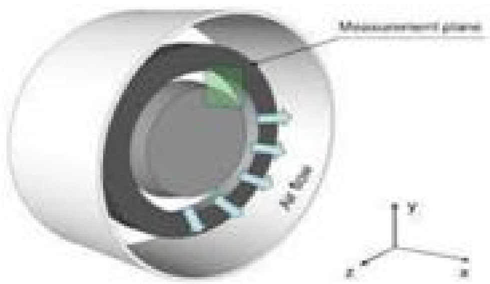

Fig-1- Measurement plane in the combustion chamber

2.1.2 DESIGNING

The 2-axis mechanism is composed of two sliders in two sets of guides. This traverse is powered by three fine-step, stepper motors (800 steps for 1 revolution). The stepper motors which is used in the mechanism has the 22kg-cm torque and 10 kg-cm torque.

The base plate is made of aluminum so that machining could be done easily. Standard ball screws and related nuts are be used to ensure standard movement for all sensors. Linear motion is achieved by linear floating bearings with re-circulating ball channels running on chrome plated steel shafts ensuring smooth operation and low friction coefficient resulting in reduced wear and reduced power requirements. A custom drive system solution has been developed in order to achieve motor control through a personal computer with USB connectivity by employing an external signal generator and a standard stepper motor driver.

2.1.3. MATERIALS SELECTION

Table 1- Comparison of the selected material properties

Materials	Ultimate Tensile Strength (MPa)	Yield Strength (MPa)	Density (Kg/m^3)

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Aluminum	310	276	2700
Stainless Steel	505	215	7700
Mild Steel	370	247	7850

2.1.4. SOFTWARE IMPLEMENATION

Second aspect which we had to think of was how were we supposed to get the motion of the traverse in required planes. We decided to program the mechanism. In order, to program the mechanism basic knowledge of electronics is required. Main controller is based on microchips atmega32 microcontroller board. The controller will generate the necessary signals to rotate the stepper motor. Signals from the micro controller is amplified using driver circuits based on mosfets (for unipolar motor) and L298D IC (for bipolar motor). HEDR 5421EP111, an optical type rotary encoder is used as motion feedback system, which will generate pulses corresponding to the number of rotations made.

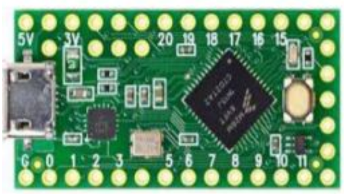

Fig-2-Micro controller

Fig-3-Rotary encoder

2.2. MODELLING OF THE TRAVERSE SYSTEM

Our modelling was classified into 3 stages. The preliminary model consisted of the basic drawing. In secondary model, the preliminary design was improved keeping in mind the requirements as well as working on scope of improvement. In the final model the mistakes were in secondary model were corrected, as well as the model was analyzed.

2.2.1. PRELIMINARY MODEL

A C-section type design met the requirement of getting motion along longitudinal and lateral axis. After preparing a rough sketch it was modelled in the software. The Fig-4 and Fig-5 show the top and the isometric view respectively.

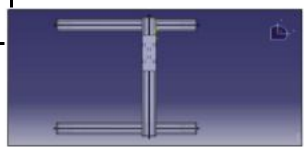

Fig-4-Top view

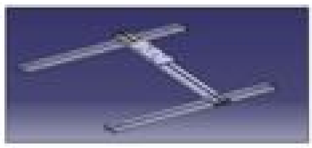

Fig-5-Isometric view

2.2.2 SECONDARY MODEL

The importance of the mirror mounting as the main objective was realized to make the laser beam fall exactly parallel to the flow. This being a challenging task and the design as shown in Fig-6 was drafted. The frame idea was thought to mount the mirrors. On the approval of this concept the next step was to improvise.

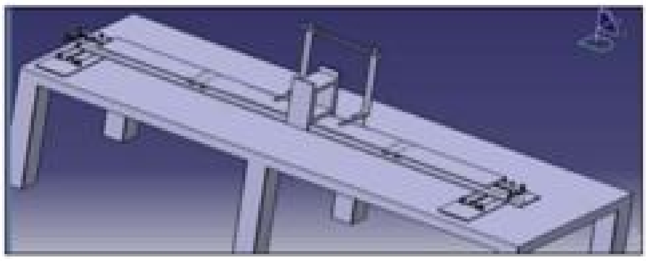

Fig-6- Isometric view of the secondary model

2.2.3 FINAL MODEL

Fig-7 shows the final model with the set-up of the apparatus on the bed. Frame was improvised, made 4 sided so that it could resist vibrations. Methods were thought to reduce weight.

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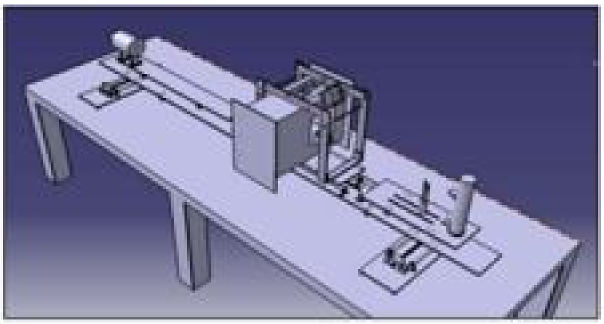

Fig-7-Isometric view of the final model

This model was analyzed for errors and then approved with minor changes to be made before creating the 2-D drawings. The next step was to create 2-D sketches for fabrication of the model. Fig-8 shows the isometric view of the entire final assembly with all the parts labeled.

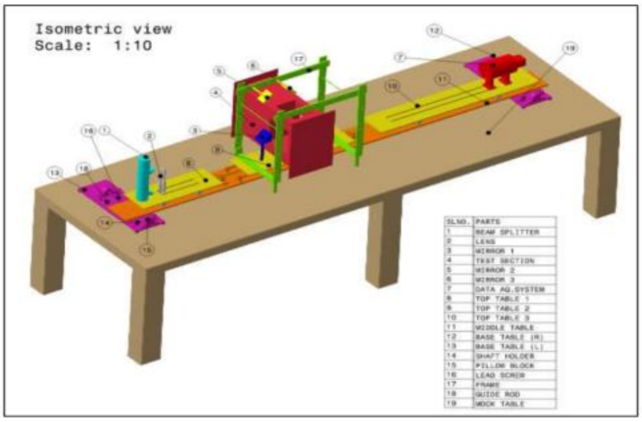

Fig-8-Isometric view of the final assembly

3.1.STRUCTURAL ANALYSIS OF TRAVERSE SYTEM

Structural analysis is important because it can evaluate whether a specific structural design will be able to withstand external and internal stresses and forces expected for the design. A primary reason that structural analysis is beneficial is to determine the cause of a structural failure.

3.1.1 LOAD CALCULATIONS AND DEFORMATIONS

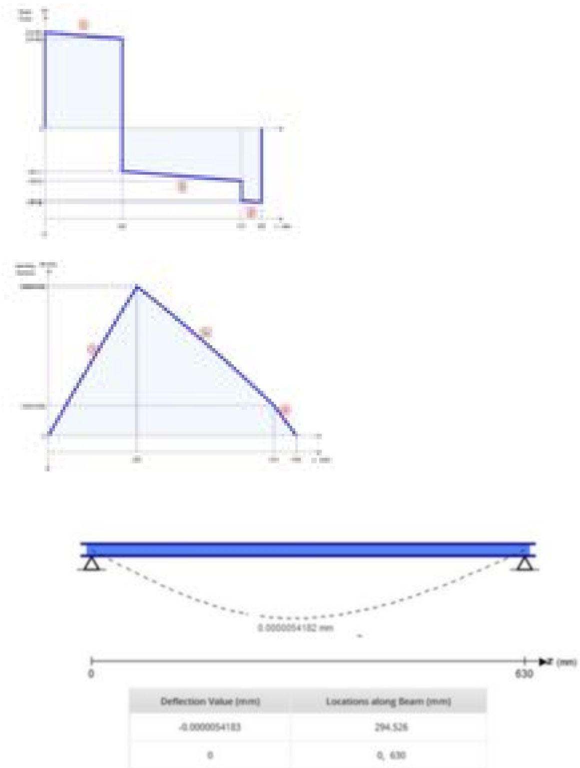

Fig-9- SFD, BMD, and deflection curves of base plate from SKYCIV

As seen from the fig-9 the deflection in the base plate is minimum. So, it was made sure that this plate can take the entire load of the top plates/beds (approx. 40-45 Kg) and thus can be proceeded for fabrication. The theoretical value of the deflection which we achieved was: -0.00000466 which is close to the value obtained from the software.

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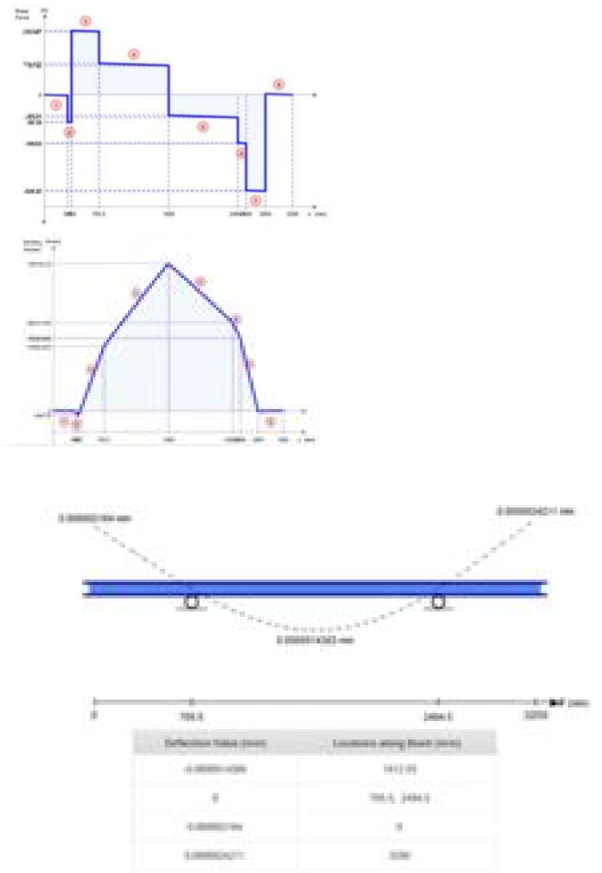

Fig-10-SFD, BMD AND deflection curves for middle plate from SKYCIV

The deflection calculated manually was again approximately very close the value obtained from software. The deflection being minimum, but to avoid bending, which would obstruct the lateral motion we decided to fix wheels under the middle plate so that there is a smoother motion.

4.1. FABRICATION

4.1.1 DRAFTING

The model looked to be free from major errors, so now the next step was producing the 2D drawings for the fabrication. Fig -11 shows the top and font view of the entire assembly.

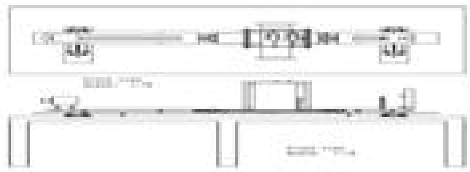

Fig-11-2D Top and front view of assembly

4.1.2 MANUFACTURING AND ASSEMBLY

These 2-D drawings were submitted to the fabricator for manufacturing. The operations carried out to produce the above shown parts required very simple cutting and drilling operations. The plates were cut using CNC machine. After manufacturing the plates, we assembled the mechanism to see for major/minor errors. Fig-12 shows the assembled base plate. The base plate (aluminium) supports 2 plummer blocks, 4 end blocks, 4 linear bearings and 2 guide rods. Since, this plate is the base for the entire setup and as mentioned in the previous chapter that it has to take 40-45Kg load, so upon assembly we checked on the parameters again to make sure the load carrying capacity of the plate so that we don‘t face major difficulty upon final assembly in the test facility.

Fig-12-Traverse assembly

5.1. FLOW VISUALISATION

Experimental flow visualization techniques are applied for several reasons:

1. To get a picture of fluid flow around a scaled model of a real object, without any calculations.

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2. To develop or verify new and better theories of fluid flow or models.
3. If the flow could be made visible by some kind of flow visualization technique, it would be possible to observe flow phenomena which are essentially inviscid (e.g., vortex flows, flows distant from surfaces) as well as those phenomena which are dominated by the effects of viscosity (e.g., boundary layer flows, separation).

5.2. EXPERIMENTAL ANALYSIS

Capturing the image of the point where the jet fuel mixes with the air will help us to understand the fuel injector characteristics on the analysis of which the fuel injector can be further studied. Fig-13- shows a schematic of the droplet breakdown when the fuel mixes with the high velocity air.

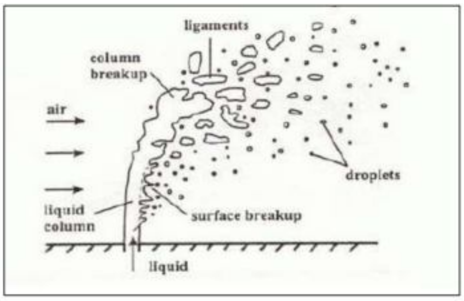

Fig-13-Schematic of droplet breakdown sequence

The experiment to be conducted involves moving the traverse in x and y directions to capture images of the air-fuel mixture flow in different planes with a motion of 2-3mm. The measurement planes along x axis and measurement plane along the y axis is shown in Fig-14.

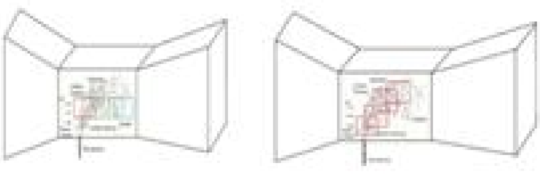

Fig-14-Schematic of measurement plane along X and Y axis

5.3. EXPERIMENTAL SET UP

The traverse was fixed on the test rig. The apparatus required for Mie scattering was set up on the traverse. The arrangement is shown in Fig-15. The laser from the laser source was made to pass through the beam splitter, cylindrical lens, spherical lens, and the 3 mirrors placed at different angles such that the laser beam falls inside the test section and exactly parallel to the flow. The most important parameter kept in mind while setting up the apparatus on the traverse bed are as follows:

1. The laser beam should fall exactly parallel to the cross flow.
2. Intensity of the laser when it falls inside the test section should be sufficient the angles of the two mirrors mounted on the frame were adjusted as per requirement.

Fig-15-Arrangement of apparatus on traverse at combustion test rig

The parts in the combustion rig are test section, 45 deg inclined mirror, spherical lens, cylindrical lens, laser source, top plate-3, base plate and stepper motor. Image acquisition device on the other side of the test section to capture the image. Use of ball screw instead of lead screw gives us more precession in motion, which is vital for the small changes in planes. The setup is a simple arrangement which satisfies our requirement to test the air-fuel mixing characteristics.

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5.4. EXPERIMENTAL DATA

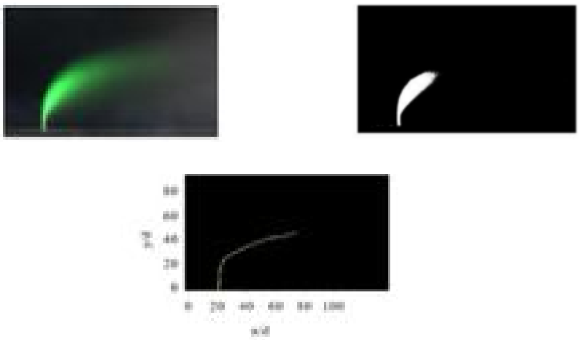

Fig-16- Mie scattering threshold and upper surface trajactory

6.1. CONCLUSION

Momentum flux ratio and Weber number were varied to develop an understanding of their influence on the penetration of the liquid spray. It was found out that increasing the momentum flux ratio increased penetration and increasing the Weber number diminished the overall spray penetration by decreasing the average drop sizes of the sprays. It was also found out that the Planar Mie-scattering images confirmed as the ambient pressure increased, the penetration of the jet slightly decreased and the spray coverage area decreased.

6.2. FUTURE SCOPE

1. Future work might include temporally resolved LIF/Mie measurements using the laser system and the high-speed framing camera. High spatial resolution in combination with temporally resolved images can be used to estimate the length and time scales for evaporation and mixing with air of kerosene for the fuel injector.

2. The present study paves the way to further investigate the interactions between the spray and shock waves generated in the supersonic environment of the flow and can directly extended to the spray interaction with more diverse supersonic flows in terms of different Mach numbers.

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