USING LASER-BASED INSTRUMENTATION TO GIVE STUDENTS EXPERIENCE IN ADVANCED INSTRUMENTATION TECHNOLOGY

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The experimental design instrumentations are critical for engineering students to understand the design procedure and its application with hands-on experience. This project objective is to develop the advance experimental design and instrumentation for analysis/experimental validation and an empirical transient model which is for flow in the Space Shuttle Main Engine (SSME) exhaust duct while exposing students to new instrumentation at the same time. The experiments carried out were done on the scale model space shuttle main engine (SSME) exhaust-duct at the Center for Advanced Energy Systems & Environmental Control Technologies (CAESECT) at Morgan State University using Particle Image Velocimetry (PIV). This scale model is part of NASA's research on the behavior of exhaust flow from the space shuttle while on the launch pad.

The Space Shuttle Main Engine (SSME) is the most reliable and highly tested large rocket engine ever. The SSME uses a mixture of liquid hydrogen and liquid oxygen that can enable it to attain a maximum thrust level of 5.13×10^5 pounds in a vacuum, which is equivalent to greater than 1.2×10^7 horsepower. Expansion of all hot gases through a high-area-ratio exhaust nozzle is allowed by ultra-high-pressure operation of the pumps and combustion chamber to achieve efficiencies never previously attained in a production rocket engine [1].

The purpose of this experiment is to comprehend and test how the exhaust flow from the space shuttle into the exhaust-duct behaves according to fluid dynamics and show students how relevant courses relate to this experiment. In order to understand how fluid flows in a closed environment at different speeds, angles and concentration, engineering tests were conducted, not just to be observe but also collect data to be analyzed. This is where students developed experience in collecting data and conducting data-analyzing. This experiment shows the advantages of the Particle Image Velocimetry (PIV) test method used in the simulation of the space shuttle main engine (SSME) exhaust flow. PIV instrumentation was chosen as a new approach to monitor and test this behavior of fluid flow and give students exposure to something new for carrying out certain engineering testing [2-3]. PIV is an extension of visualization technologies, where velocity vectors are measured simultaneously at thousands of points with high accuracy and resolution [4-5]. PIV is able to measure particle flow without disturbing the flow; therefore students were able to collect useful data.

Humidified particles were used to represent the exhaust flow from the SSME into the exhaust-duct. The humidified particles are moderately convenient to generate and they flow easily through the duct with the aid of air from a blower to increase the airflow rate because the humidifier generating the steam would not be powerful enough to push the steam through the scale model. During the experiment students realize that having ideas and sharing them with each other allowed them to solve different problematic scenarios, for instance by added the blower to get the flow all the way through the model. In addition, fog particles were used to simulate the exhaust flow in the SSME exhaust duct model also to test if results would coincide with each other. The fog particles were relatively easy to generate using a fog generator, which works on the principle of heating oil then passing cold air over it. A voltage regulator was used on the blower to control variable airflow, so that the most suitable flow can be selected. Students were able to gasp the idea that when carrying out experiments try and have the testing as close to the real situation as possible but with very little or no hazards, in this case using steam and fog instead of burning rocket fuel. Undergraduate class like Ergonomics and Workplace Design teaches student what are safe conditions to work in and how they can be safe and they were able to use this knowledge in this experiment.

Experiments were carried out on the scale model and data was collected, this is where some students were able to use data from this experiment to use for a class project in Design and Analysis of Experiments. The data show what results were obtained and how the particle flow varied in each section of the scale model with difference in velocity, circulation and main streamline flow.

The apparatuses involved were a scale model (about 1:100) of the space shuttle main engine (SSME) exhaust-duct, a humidifier and a blower, which students were involved in designing. The scale model reintroduced concepts and ideas to students from classes such as Manufacturing Processes, Product Design, Materials Engineering and Solid Modeling & Design which are required courses for industrial engineering majors. Students brought knowledge from these courses to select appropriate material and design for the test model. Also used was the Particle Image Velocimetry (PIV) equipment, which is composed of a laser power supply, 2 Yag lasers, a laser pulse synchronizer, a camera and a computer to collect the data acquired as shown in Figure A.

Figure A. The Pictorial View of the Experimental Model of the SSME Exhaust Duct along with the Laser-based PIV Instrumentation

The procedure to carry out testing acted as a tool to see how well the students followed instruction and if they were able to carry out some testing on their own. Even when attempted to do so on their own graduate students from the lab were there for safety issues and undergraduate students were always supervised.

Figure 1 shows a meshed diagram of the SSME exhaust duct model to describe particle velocity profiles of PIV instrumentation at different locations. There are eleven (11) sections of laser-based PIV instrumentation as shown in Figure 1.

Figure 1 A Meshed Diagram of the SSME Exhaust-Duct Model & Tested Sections.

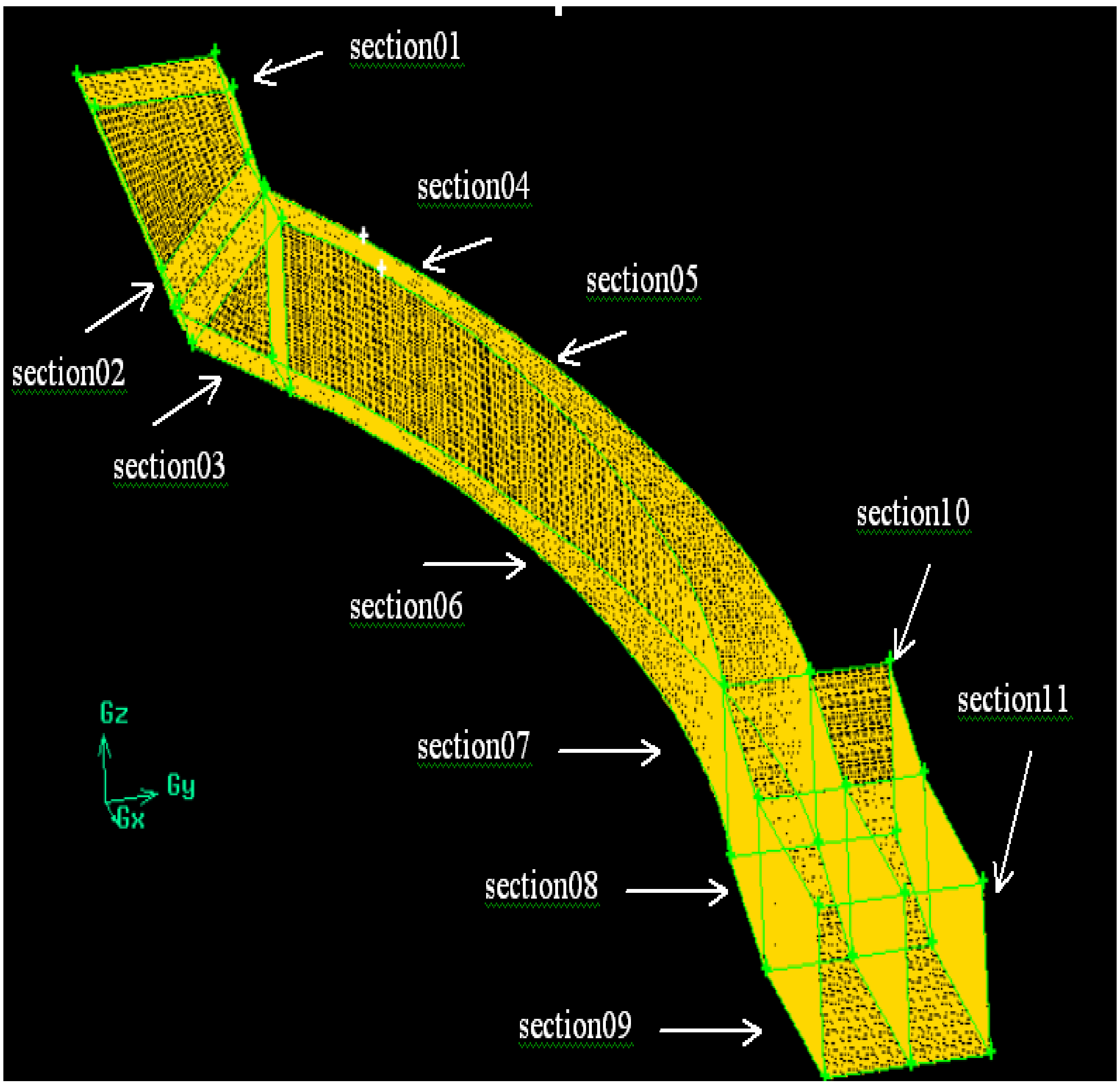
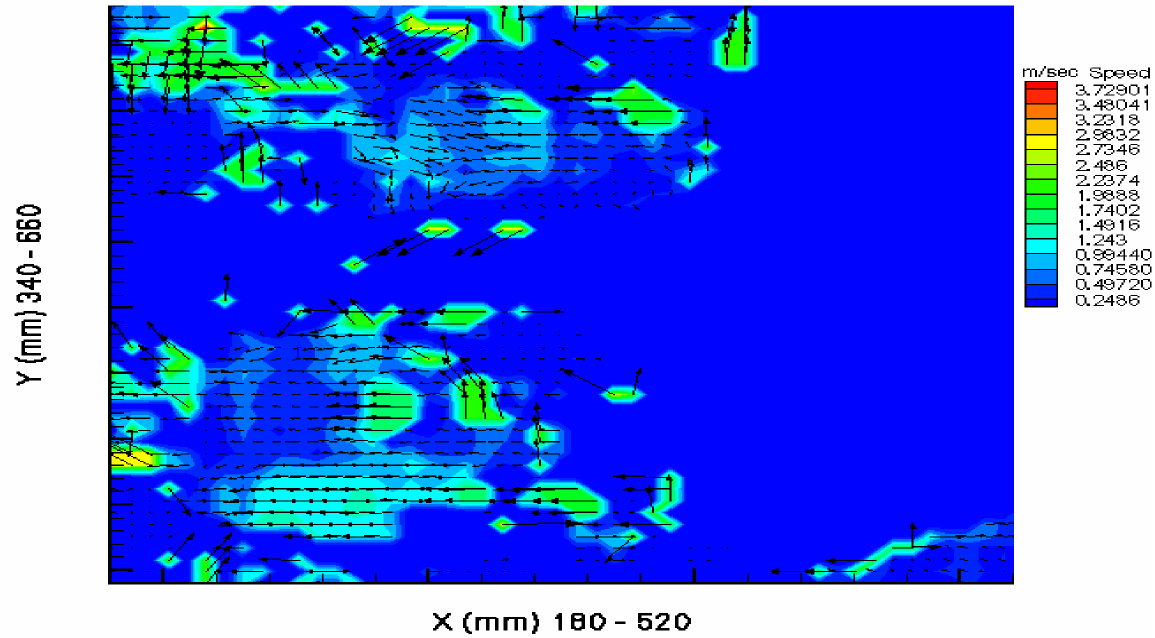


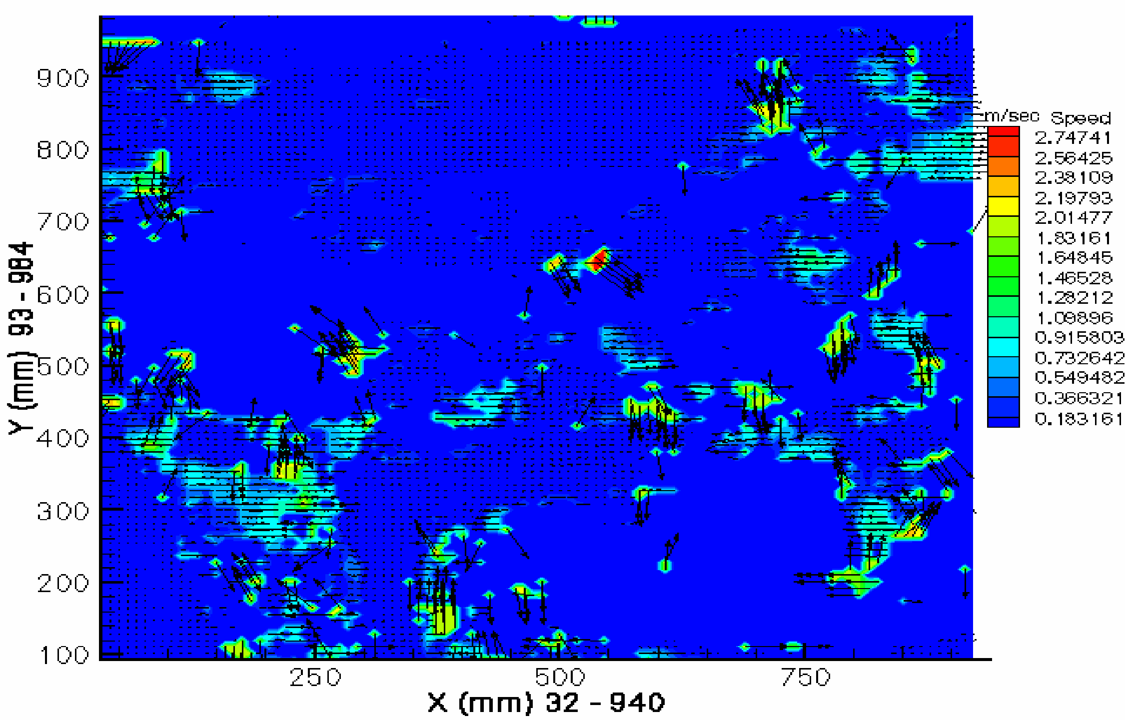
Figure 1 is a meshed diagram, which is used for reference when looking at the velocity profiles in the other figures and some of the results collected.

Figure 2 Velocity Profiles of Humidify Particles at the Top Section of Model



The humidify particles in the top sections on the SSME exhaust duct model shows a cluster of turbulent behavior. The flow illustrates particles moving in various directions with the main clusters showing vortex motion where the higher velocities particles are moving. There is not much high velocity particles in the figure, the greater number of particles were at velocity 2.5 m/sec and lower. The velocities of the particles range from approximately 0.248 m/sec to 3.729 m/sec.

Figure 3 Velocity Profiles of Fog Particles at the Top Section of Model



The Figure above shows the velocity profiles of fog generated particles in the top sections of the SSME exhaust duct at 30 %. The fog was generated from heating oil (Shell Ondina oil) then passing cold air over it. Although the initial velocity of the fog particles were measured at 0.65m/sec PIV instrumentation captured particles exceeding that velocity. The velocity range captured by the laser-based PIV instrumentation is approximately 0.183 m/sec to a maximum velocity captured at 2.747 m/sec. A high flow of fog particles was captured moving in the in downward motion from the point of injection at the top. Most of the particles continued with mainstream flow while some exhibit a backflow behavior and even small areas of vortex flow.

Figure 4 Velocity Profiles of Fog Particles at the Top Section of Model

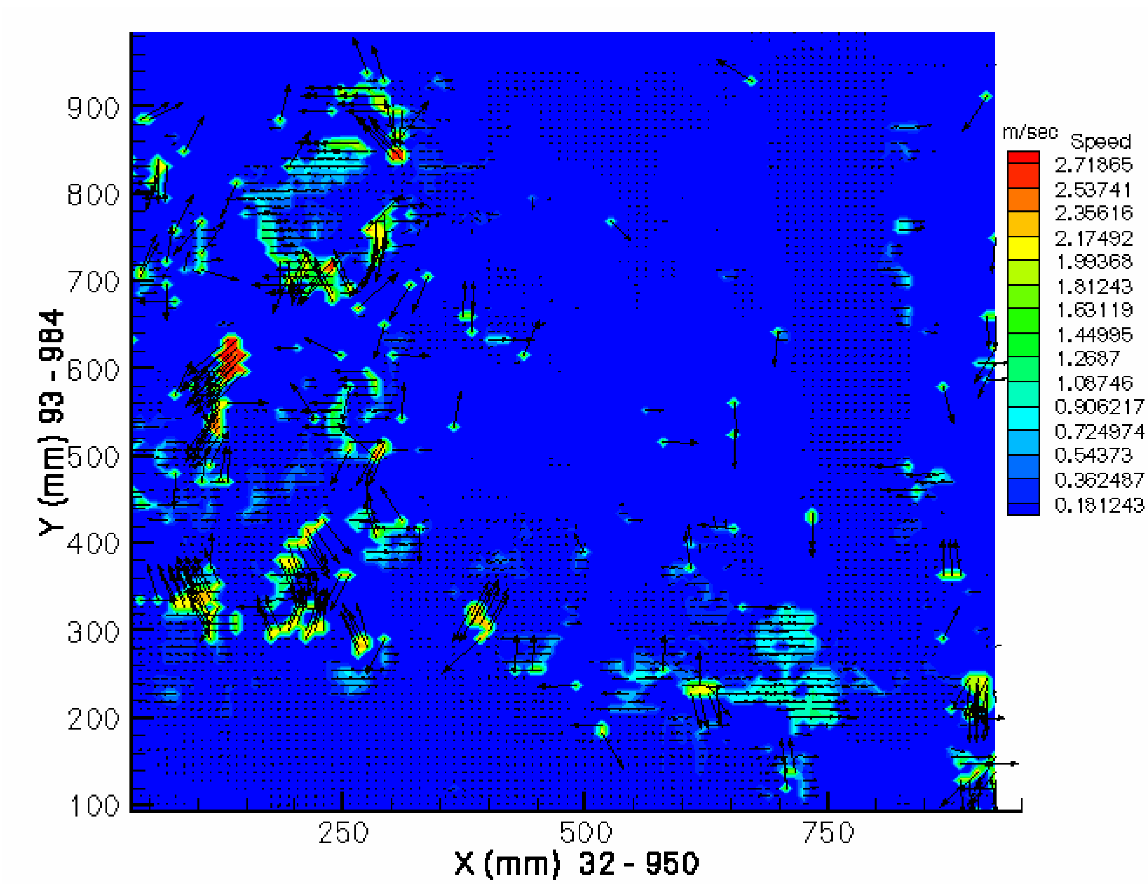


Figure 4 shows the velocity profiles of fog-generated particles in the middle sections of the SSME exhaust duct at 30 %. The velocity range captured by the laser-based PIV instrumentation is approximately 0.181 m/sec to a maximum velocity captured at 2.719 m/sec. Majority of the greater velocity particles were showing vortex behavior with some circulation occurring mainly on the left side in the figure. They were not moving the way they were expected to flow, but rather in little pockets of odd circulation. Some were flowing downwards, while some were in a backflow direction. Most of the lower velocity particles continued with mainstream flow leaving the higher velocity particles to exhibit small areas of vortex flow [6]. Fog particles were use to see if there was a similar flow pattern as in the case of water vapor. It was relatively easy to generate and would be looked at more closely for substituting it for future research.

The accomplishments for this were students were able to observe how humidified particles in the top sections on the SSME exhaust duct model show a cluster of turbulent behavior. They saw how the flow illustrates particles moving in various directions with the main clusters showing vortex motion where the higher velocities particles are moving from the collection and analysis of the data. The velocities of the particles range from approximately 0.248 m/sec to 3.729 m/sec, while those in the middle sections were widely scattered and the velocities of the particles range from approximately 0.177 m/sec to as high as 2.661 m/sec. The fog particles were selected for simulating PIV images in the SSME exhaust duct model and the laser-based PIV instrumentation so students would have other test results other than humidified particles in which they were able to compare results to, and this was conducted successfully. Although the velocity profiles of fog generated particles in the top sections of the SSME exhaust duct were measured at 0.65m/sec, PIV instrumentation captured particles exceeding that velocity. The velocity range captured by the laser-based PIV instrumentation is approximately 0.183 m/sec to a maximum velocity captured at 2.747 m/sec. The velocity profiles of fog-generated particles in the middle sections of the SSME exhaust duct range captured by the laser-based PIV instrumentation is approximately 0.181 m/sec to a maximum velocity captured at 2.719 m/sec. Students observed that most of the greater velocity particles were showing vortex behavior while the lower velocity particles continued with mainstream flow leaving the higher velocity particles to exhibit small areas of vortex flow. This experiment was able to help student appreciate their undergraduate classes more and they were able to apply knowledge learnt from these classes.

REFERENCES

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