Turbulence modification of particle-laden flow in model of rocket motor

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1. Abstract

Experiments with two-phase flow were investigated in a model of rocket engine using Particle Image Velocimetry (PIV). The high mass loading (up to 120) of dispersed inertial alumina particles \( (St \approx 10^{10^3}) \) creates two way coupling flow regimes. In particle-laden flows the Turbulence Kinetic Energy (TKE) can increase or decrease in presents of dispersed particle phase. The results showed that with increasing of mass loading the TKE increasing respectively. The magnitude of TKE modification has high impact on the design and performance of the rocket motor.

Keywords: Rocket motor, Particle-laden flow, Turbulence modification, Particle image velocimetry

2. Introduction

Particle-laden turbulent flows are ubiquitously present in nature and industrial applications, such as transportation of pollutants or desert storms. In this research the application is dispersed alumina particles \( (350 \mu m) \) in a model of a rocket motor, the particles are added to the combustion chamber in order to encourage and control the burning process [1]. The high mass loading of the particles creates two way coupling and even four way coupling in some regions of the motor. Understanding of the turbulent flow fields, particle-flow and particle-particle interactions in the rocket motor has impact on the design, operation and performance of the motor.

Previous studies have shown that dispersion of particles can either increase ([2], [3], [4]) or decrease ([5], [6], [7]) turbulent kinetic energy (TKE) and the dissipation. Gore and Crowe [8] have proposed the parameter \( dp/L \), this parameter is the ratio of the particle diameter to the large length scale and it is categorized the turbulence into increasing and decreasing. Tanaka and Eaton [9], extended this work by proposing the momentum parameter \( Pa=Re^2St(\eta/L)^3 \) that involves also density dependency.

The physics of turbulence modification by particles is still not well understood in simple-isotropic turbulent, And the problem becomes even more complex in environment of rocket motor chamber when the problem also involves fuel droplets, non-sapphire particles, high burning temperatures, heat transfer, acceleration of the flow and particles in the motor's nozzle, complex geometry and more. In this research the aim is to experimentally investigate the laden flow in simplified model of rocket motor, in simple environment (at atmospheric conditions) and geometry (2D model). when the goal is to acquire knowledge and database that will hopefully contribute to the development of a physical model of turbulence modification with
diluted particles and then to incorporation it to computational simulation of fluid dynamic in the rocket motor and other industrial applications.

3. Experiments and Methods

The experiments setup consist of 10 times reduced model of the rocket engine, see figure 1. The flow is assumed to be two-dimensional since the width of the model is 35 mm, the maximum length is 245 mm and the nozzle throat is 35 mm. A blower pumps air through the model at flow rate up to 0.2 m³/s, while the flow is seeded simultaneously with olive oil tracers particles (1 µm) via laskin nozzle and inertial alumina particles (St≈10·10³). A double-head Nd:YAG laser (120 mJ/pulse, New Wave Solo) illuminating the flow while 11 Mp CCD digital camera (TSI Inc) taking pairs of images within short time interval (10 µs). The continuous phase velocities were analyzed by Particle image Velocimetry (PIV) with Insight3G and the dispersed phase with Particle Tracking Velocimetry (PTV).

Figure 1- In the left sketch of the system, in the right the system at PTV experiment

In order to calculate the particle mass loading and for the PTV analysis there is a need to segment the alumina particles from tracers [10], [11]. We use the difference in their image size and intensity. Binarization of the images with intensity threshold of 107/255 and elimination of particles with size less then 14 pixels produced the images in figure 2, showing the image before and after the image prepossessing. The image analysis of particle images created by laser light scattering does not allow determining their sizes; therefore, we approximate the local mass loading using a representative value from separate microscope measurements.

Figure 2- Images before (left) and after (right) image prepossessing on PIV data that combined tracers and alumina particles at two different locations (organized by rows)
4. Results

From the two-phase analysis, we get that the particle mass loading (ϕ) is increasing along the centerline of the nozzle, shown in figure 3. When y/Lt is normalized distance coordinate from the nozzle along the centerline, starting (y=0) at the entrance to the nozzle. Notice that the plateau in $\phi$ form y/Lt=0.5 is result of saturation in illumination at the area near the nozzle entrance, we predict from mass conservation that $\phi$ continue to grow until the throat.

From the PIV measurements, we get the velocities of the air flow surrounding the particles. The mean velocity magnitude of the continuous flow didn’t changed from the un-laden to the laden case. In contrast the Urms is increasing with the increasing of the mass loading resulting to increase in Turbulent Intensity (TI) which is the ratio of Urms to Uaverage.

![Figure 3- Urms, Uav, TI and the mass loading as function of the distance from the nozzle](image)

5. Conclusions

The interaction of turbulence in high Re with high mass loading of inertial alumina particles results an increase in turbulence intensity. When the mean flow is not affected by the particle present even in high mass loading. We assuming that the particles transferring their kinetic and potential energy to the TKE which increasing the velocity fluctuations. Also the high stokes particles generates wakes which increasing the fluctuations. This finding are matching Tanaka and Eaton [9], the results of the flow produced Pa>10⁵ which categorized as increasing region in TKE.

It is seems to be that particle mass loading have an important role on the magnitude of the modification. And this correlation and interaction needs to be study further more in future research.

6. References


