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Studies on Igniter Jet Turbulence Effect on the Ballistics of Solid Rocket Motors

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ABSTRACT

A diagnostic investigation is carried out to examine the igniter jet turbulence effects on the internal ballistics of solid rocket motors with divergent port. The numerical studies have been carried out with the help of a two dimensional k-omega turbulence model. It was inferred that increasing the igniter jet turbulence intensity is a possible way to decrease the pressure spike and pressurization rate, marginally during the ignition transient, by altering the location of the secondary ignition in solid rocket motors with non-uniform port.

Key Words: Igniter, Solid Rocket, Turbulence Separation, Reattachment

1. Introduction

Solid rocket motor (SRM) ignition consists of a series of complex rapid events, which start on receipt of a signal and include heat generation, transfer of the heat from the igniter to the motor grain surface, spreading the flame over the entire burning surface area, filling the chamber free volume with gas, and elevating the chamber pressure without serious abnormalities. The igniter in a solid rocket motor generates the heat and gas required for motor ignition. The satisfactory attainment of equilibrium chamber pressure and gas flow in SRMs with non-uniform port is dependent on many factors including the characteristics of the igniter and the transient features of the separated flow and its bubbles. Albeit substantial progress in the experimental and numerical studies on the internal flow features, many intrinsic details of the cause and effects of the turbulent separated and reattaching flows in solid rocket motors with sudden expansion/steep divergence of ports are still remain ineptly inferred [1-2].

This research topic, although interesting in its own right, has been motivated by several practical problems. The static test results and the actual flight data of identical solid motors with divergent port geometry have shown variations in ignition transient features [3]. Authors hypothesized that the slight variation in the igniter jet turbulent intensity will alter the flow separation, reattachment and the location of the secondary

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ignition in certain class of SRMs with non-uniform ports. This might lead to the difference in internal ballistics of identical solid rockets [4]. In this companion paper a diagnostic investigation has been carried out to examine the igniter jet turbulence effect on the internal ballistics of solid rocket motors with divergent ports.

2. Overview of the Numerical Methodology

Theoretical studies have been carried out with the help of a standard k-omega turbulence model. This model uses a control-volume based technique to convert the governing equations to algebraic equations, which can be solved numerically. The viscosity is determined from the Sutherland formula. The initial wall temperature, inlet total pressure and temperature are specified. At the solid walls no-slip boundary condition is imposed. At the nozzle exit a pressure profile is imposed. The transient mass additions due to propellant burning are deliberately suppressed in this study to examine the intrinsic flow features discretely in SRMs with divergent ports. The baseline values are selected based on typical motor configurations.

3. Results and Discussion

A typical grid system in the computational region is selected after the detailed grid refinement exercises. The grids are clustered

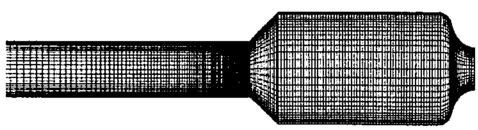


Fig. 1 Grid system in the computational region of a low-velocity transient motor

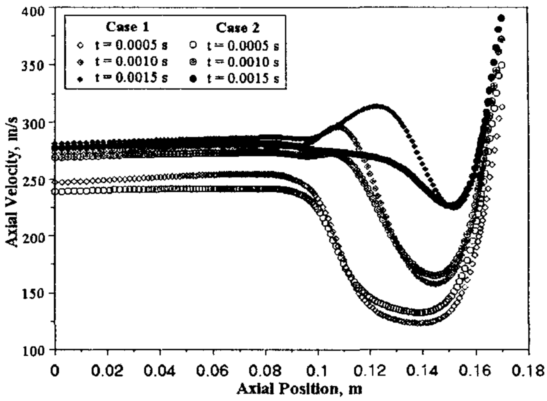


Fig. 2 Comparison of the velocity variation along the axis of a LVT motor with two different igniter jet turbulence levels (Case 1 with 5% JTI and Case 2 with 40% JTI)

appropriately using suitable stretching functions (see Fig.1).

Figure 2 shows the comparison of the axial velocity variation along the port of a low-velocity transient (LVT) motor (At/Ap< 0.56, L/D < 10) with divergent port. In the first case initial igniter jet turbulence intensity (JTI) is selected as 5% and in the second case 40%. All the results reported are anticipated and giving corroborative evidences of the previous experimental and theoretical findings[2-4]. It can be seen from Fig. 2 that when the initial igniter turbulence level is relatively high there is no velocity peak observed at the transition location. It shows that at high turbulence level the tendency of flow separation will be less even with large inlet length.

Figure 3 shows the turbulence intensity variation along the axis of a LVT motor and Fig.4 (a-b) shows the corresponding velocity vectors. Note that the development of the wall boundary layer in turbulent flow is more complicated than in wholly laminar flow. Initially it takes the form of a laminar layer, but at some position along the rocket motor port there is a transition to a turbulent layer, where

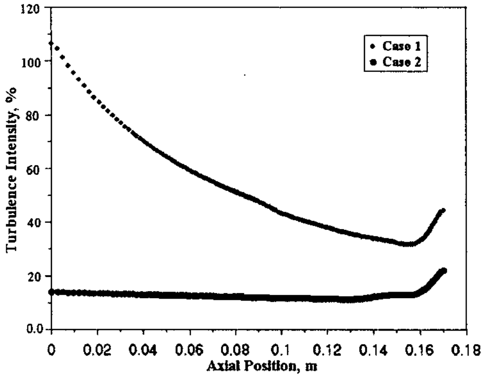
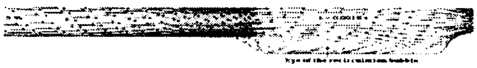


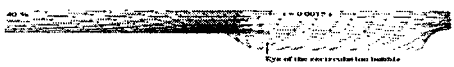
Fig.3 Comparison of the turbulence intensity along the axis of a LVT motor (t = 0.0015 s)

a sudden increase in axial velocity can be discerned (see Fig. 2) The actual position of transition depends on a number of factors including Reynolds number, surface roughness, and the turbulence level of the igniter jet flow entering the motor port. At higher turbulence levels we observed the tendency of shifting of the reattachment point and the location of the eye of the bubbles (see Fig. 4) towards the step location.

In another attempt, the influence of igniter jet turbulence intensity on flow separation has been examined in a high-velocity transient (HVT) motor



(a)



(b)

Fig. 4(a-b) Demonstrating the variation of the size of the recirculation bubble and the location of its eye at different jet turbulence levels.

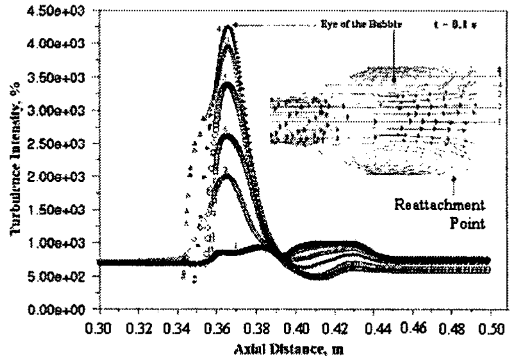


Fig. 5 Demonstrating the variation of the turbulence intensity along the axial direction of an HVT motor; and pinpointing that the turbulence intensity is maximum at the eye (not the center point!) of the recirculation bubble (Velocity vectors are shown in inset)

(At/Ap> 0.56, L/D > 10). A case with high-turbulence intensity shows less possibility of flow separation and reattachment in HVT motor cases too.

We also observed that in all the cases the maximum turbulence intensity falls at the eye of the recirculation bubble (see Fig. 5) because within the separation bubble, the mean turbulent intensity rises highly especially near the centre of the bubble due to high mixing and large-scale unsteadiness, and it reduces as one move to the reattachment point and over the boundary layer development region.

4. Concluding Remarks

The present study leads to say that the reproducibility of igniter jet turbulence intensity is one of the sensitive tasks for any rocket motor igniter designer for getting the repeatability of the ignition/thrust transient of identical launch vehicles with confidence. Note that the turbulent flows are more able than laminar flows to negotiate regions of adverse pressure gradients. Whether or not separation actually takes place, the general effect of the adverse pressure gradient is to give rise to a localized region of slow moving fluid stretching away from the wall. The separated flow characteristics such as size of the separation bubble, flow redevelopment and heat transfer in the recirculation region are known to depend on Reynolds number upstream of the divergent region, its height and the inflow turbulence intensity. In the HVT motor cases considered here the reattachment point is found to lie around 1.5 - 3 times of the divergent height, as estimated, which is relatively higher than the LVT cases considered in this study. In the real motor test cases the exact location of the secondary ignition will possibly be altered from the reattachment point due to the additional influence of the igniter ballistics, ignition delay and the propellant combustion. Therefore, for pinpointing the exact location of the secondary ignition one has to consider the intrinsic fluid dynamics and combustion aspects of the rocket motor and its allied igniter. Note that the secondary ignition occurs inside the initial recirculation bubble. An error pin pointing the turbulence intensity will lead to significant errors in the prediction of the location of the secondary ignition, which in turn alter the internal ballistics of solid rocket motors.

It is inferred that, without altering the basic grain configuration, by inducing high turbulence level (practically by using igniter nozzle wire screens, or by creating artificial roughness to the grain wall without affecting the ballistics!), the position of transition could be brought closer to the entry region, or indeed the laminar layer could be entirely eliminated! Separation is mostly an undesirable phenomenon because it entails large energy losses. Further study of igniter jet turbulence effect on ignition transient is warranted.

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