Large Eddy Simulation of Kerosene/LOx Supercritical Mixing Characteristics of a Swirl Injector using Various Cubic Equations of State

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Abstract

Advanced liquid rocket engines operate at supercritical conditions exceeding the thermodynamic critical state. Hence, the study for the mixing and combustion process of the propellants is indispensable at supercritical conditions. Because of the peculiarities of substances at supercritical conditions, the ideal conventional methods for property analysis are inappropriate so that the applicable thermodynamic relationships for a wide range of pressure must be employed. Among the propellants, kerosene fuels are quite unwieldy in theoretical and numerical analysis because of a large number of hydrocarbons, reactions, and thermophysical parameters. Therefore, kerosene surrogate models are considered for the abbreviation of real fuel components.

In this study, the turbulent mixing of a kerosene/liquid oxygen coaxial swirl injector under supercritical pressures has been numerically investigated. The n-dodecene model and two surrogate models of JP-8/Jet-A are proposed for the kerosene thermodynamic properties. Turbulent numerical model is based on LES (Large Eddy Simulation) with real-fluid transport and thermodynamics over the entire pressure range; Cubic Equations of State (SRK, PR, and RK-PR), Chung's model for viscosity/conductivity, and Fuller's theorem for diffusivity to take account Takahashi's compressible effect. The effects of operating pressure and equations of state on thermodynamic properties and mixing dynamics inside an injector and a combustion chamber are investigated. Power spectral densities of pressure fluctuations in the injector at various chamber pressures are analyzed.

Figure 1 shows coaxial swirl injector geometry: the swirl number of liquid oxygen is 1.598 while that of kerosene is 6.548. Operation conditions are listed in Table 1. The surrogate models of JP-8/Jet-A are applied to kerosene mixing simulation using the mixing and combining rules. For model 1, n-dodecene, which is used to replace the kerosene in a conventional view point as modeling simplicity, is considered as baseline property of kerosene while models 2 and 3 are surrogate kerosene applied for this study. The model 2 (Montgomery, 2002) was considered to check if the predictions using a smaller number of components are suitable. The determination of model 3 is based on the similarity of volatility and the phase change behavior of JP-8/Jet-A and the well-known components for the detailed thermodynamic characteristics (Tucker, 2005). Figure 2 and 3 represent 2D and 3D computational domains, respectively. The characteristics of a typical swirl injector flow structure are presented in Figure 4. As shown in Figure 5, the higher chamber pressure is, the faster fluid density decreases during the mixing and heating process and the earlier burst of vortices since central toroidal recirculation zone (CTRZ) penetrates into the liquid oxygen injector. Figure 6 shows that surrogate models

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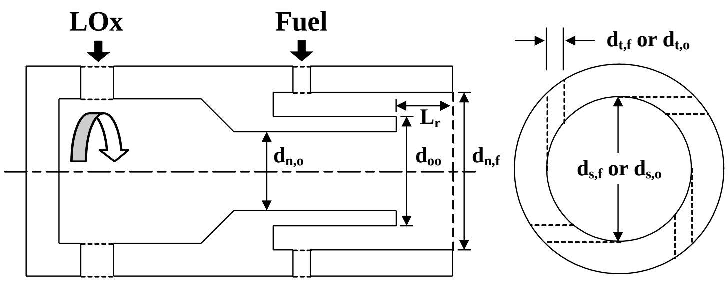
1 and 3 undergo a phase change in a relatively narrow range as compared with model 2. Also, the mixing dynamics is investigated by the analysis of power spectral densities of pressure fluctuations.

The observations for the full 3D injector model will be more specifically discussed and compared with 2D results on the full paper.



$$S_o = \frac{4 d_{s,o} d_{n,o}}{\pi n_{n,o} d_{t,o}^{2}} = 1.598$$

$$S_f = \frac{4\left(d_{n,f} - d_{o,o}\right) d_{s,f}}{\pi n_f d_{t,f}^{2}} = 6.548$$

Fig.1 Injector geometry and swirl number

Table 1. Operation conditions

Injector		Coaxial Swirl
Chamber Pressure		5.25, 8.0, 10.0 MPa
Oxidizer		Liquid Oxygen; 103 K
Fuel		Kerosene; 350 K
Mass Flow Rate	Fuel	0.232 kg/s
	Oxidizer	0.084 kg/s

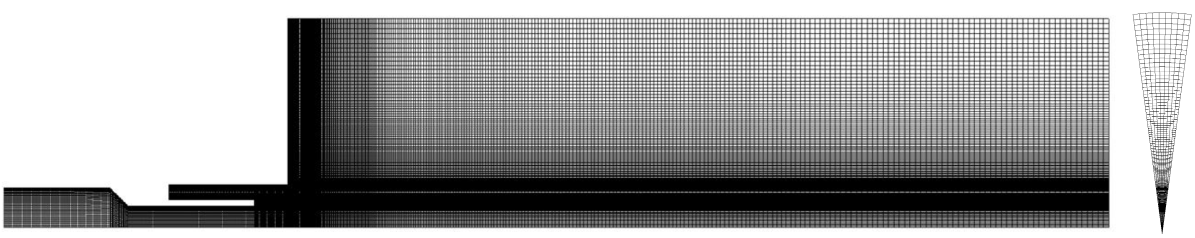


Fig.2 Computational domain (2D)

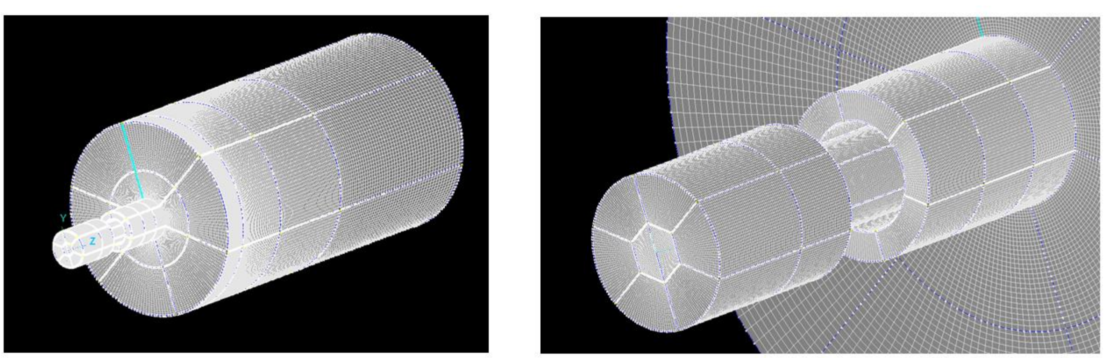


Fig.3 Computational domain (3D)

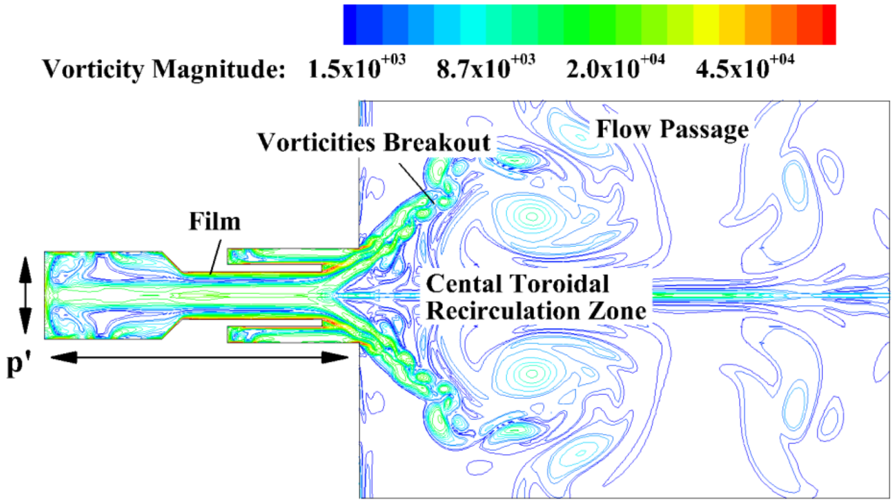


Fig.4 Flow structure of coaxial swirl injector

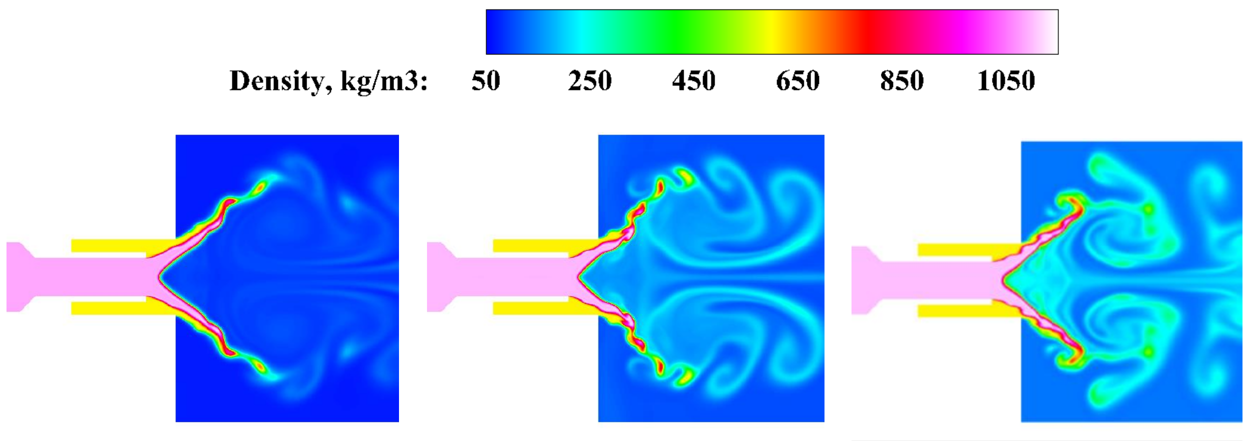


Fig.5 Density contour under various chamber pressure; 5.25 MPa, 8 MPa, 10 MPa

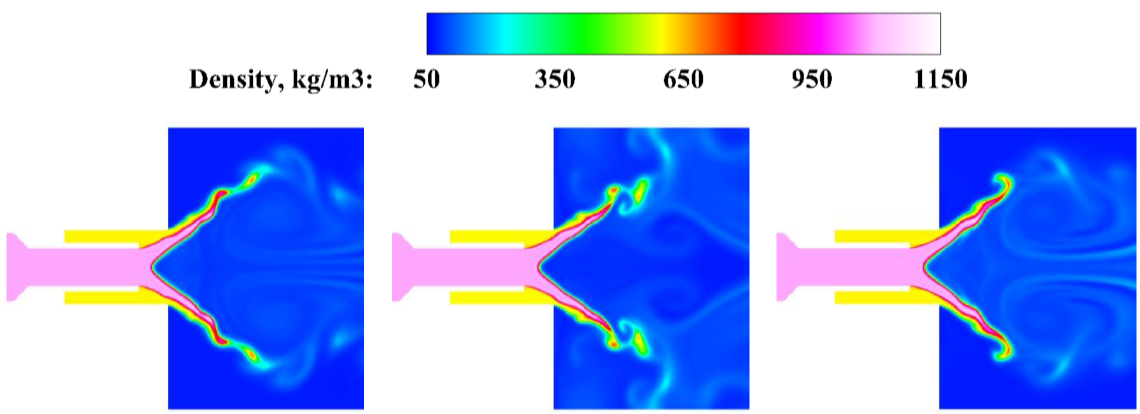


Fig.6 Density contour for kerosene models; Model 1, 2, 3