Center for Exascale Simulation of Hybrid Rocket Motors

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Rozie Zangeneh: Toward Modeling Turbulent Reacting Boundary Layers with Atomization

**Onboarding for SNL summer internship*

Toward Modeling Turbulent Reacting Boundary Layers with Atomization

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Introduction

Hybrid rocket motors have a unique flow regime, since solid, liquid, and gaseous states are simultaneously present during operation. One of the key aspects affecting thrust generation in a paraffin-based motor is the atomization of liquid fuel in the oxidizer flow. The focus of these simulations is the accurate simulation of surface instability and droplet entrainment to optimize future hybrid rocket motor designs.

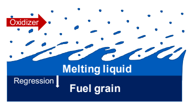


Figure 1. Schematic for fuel surface in hybrid rocket motor.

Ablative Boundary Layers At The Exascale (ABLATE) is the software being developed for the direct numerical simulation of these multiphase flows. The primary goal is to create a scalable solver to simulate these complex multiphase flows.

Objectives

- Ability to analyze shear flow instability growth between various fluids.
- Modeling turbulent reacting boundary layers with atomization.
- Multi-phase LES framework for Sounding Rockets.

Methods

- Large-eddy Simulation (LES) Paradigm
- Direct Numerical Simulation (DNS) of blowing surfaces to develop a wall-model
- Volume of Fluid (VoF) with Stratified Flow
- Multi-phase LES Sounding Rockets

LES Paradigm

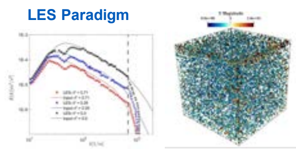


Figure 2. Large eddy simulation of Isotropic Turbulence Box with periodic BCs, L=0.09×2π m

DNS of Turbulent Boundary Layer

•**DNS** of turbulent boundary layers with blowing, $B = \frac{\rho_w V_w Ue}{\tau_w}$, to scale the BL profile:

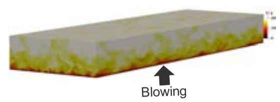


Figure 3. Simulation domain with synthetic turbulent inlet and blowing at wall

- We propose a new scaling law for blowing boundary layers:

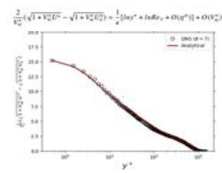


Figure 4. The analytical model compares very good with DNS

- Detailed budgets of turbulent kinetic energy, its production, and dissipation rate, compared to the model predicted budgets approximate boundary conditions for the blowing surfaces.

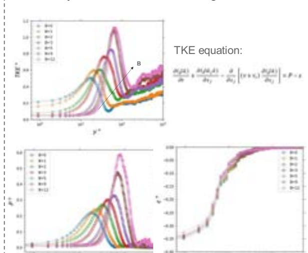


Figure 5. Budget of Turbulent Kinetic Energy, Production, and Dissipation.

Instability Analysis

- Kelvin-Helmholtz Instability (KHI), 2D
  - Initial interface: $|y| = 0.25 + 0.01\sin(10\pi x)$

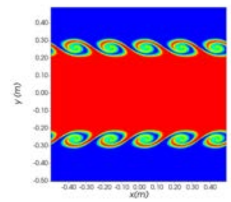


Figure 6. Volume fraction for 2D KHI simulation at t=0.5s.

- KHI, 3D with crosswise perturbation.
  - Initial interface:

$$|y| = 0.25 + 0.01\sin(10\pi x) + 0.01\sin(10\pi z)$$

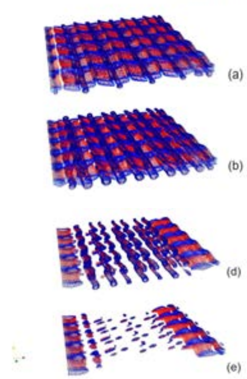


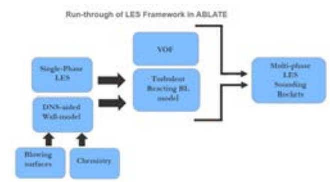
Figure 5. Q-criterion contours for 3D KHI simulation with crosswise perturbation at time (a) 0.1s, (b) 0.2s, (c) 0.3s, (d) 0.4s, and (e) 0.5s.

Summary

1. VoF solver integrated into ABLATE, enabling scalable multiphase flow simulations.
2. New scaling law is introduced for modeling boundary surfaces with blowing, applied to most hybrid rocket configurations.
3. 3D KHI analysis for shear flows shows increased instability growth with crosswise perturbation.

Future Work

Ultimate goal is to develop a multiphase LES framework .



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