

AFOSR – THEORETICAL, NUMERICAL, AND EXPERIMENTAL INVESTIGATIONS OF THE FUNDAMENTAL PROCESSES THAT DRIVE COMBUSTION INSTABILITIES IN LIQUID ROCKET ENGINES

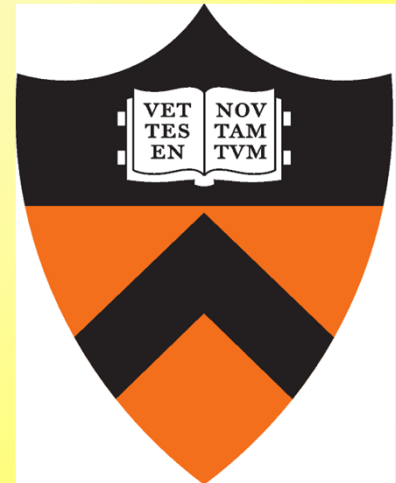
Program Update

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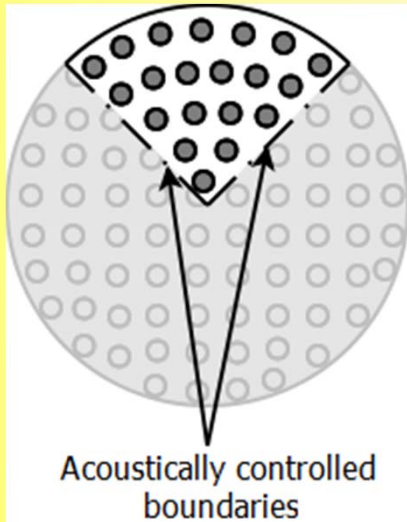
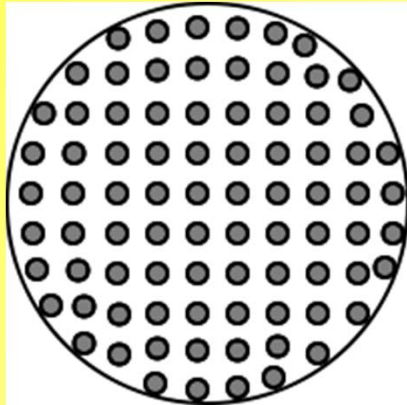
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September 13th, 2012

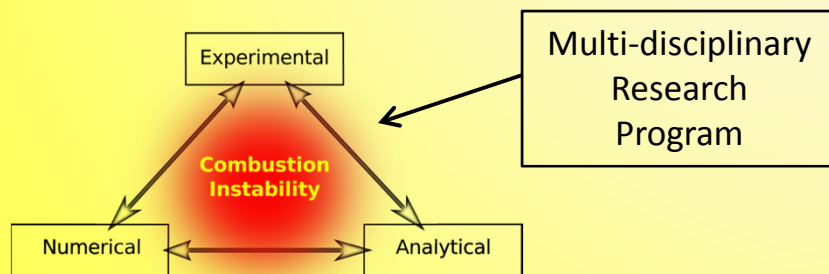
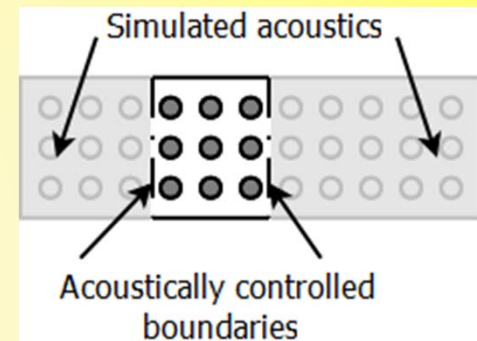
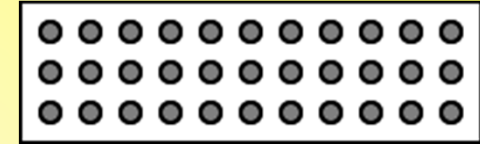


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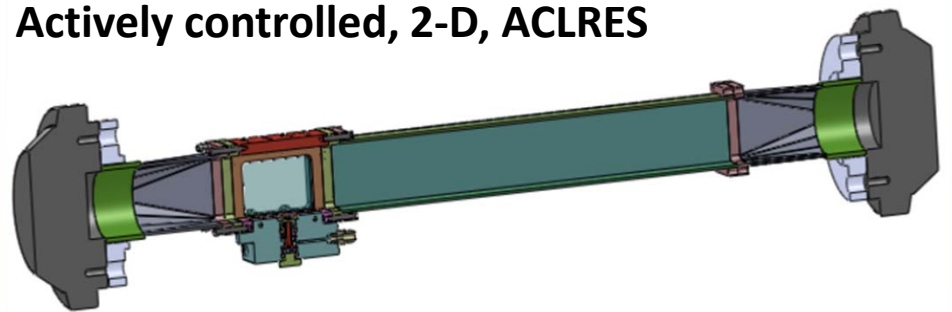
The Actively Controlled LRE Simulator (ACLRES) Concept



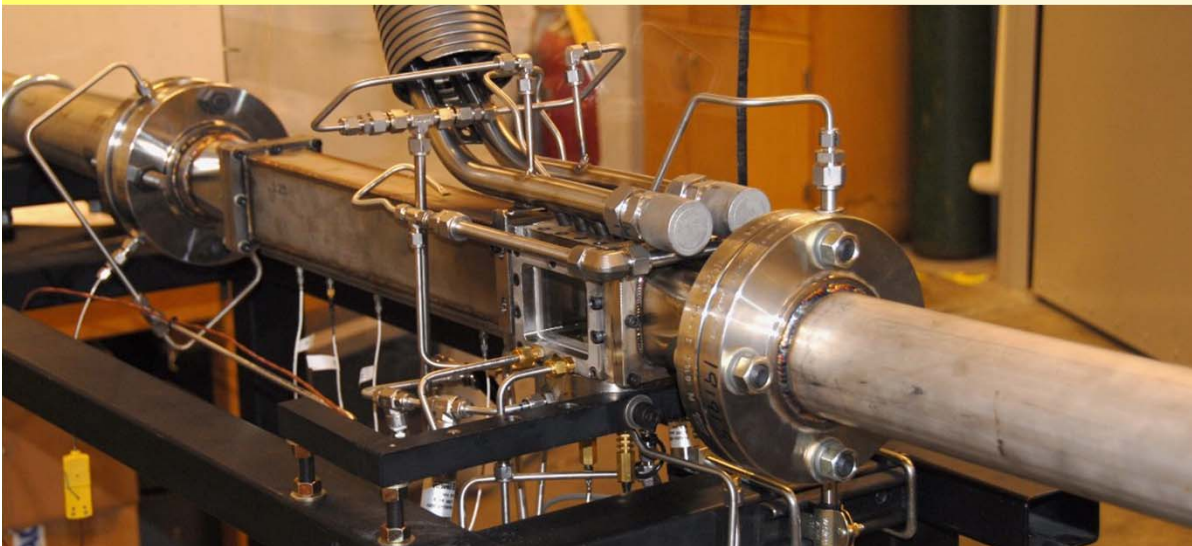
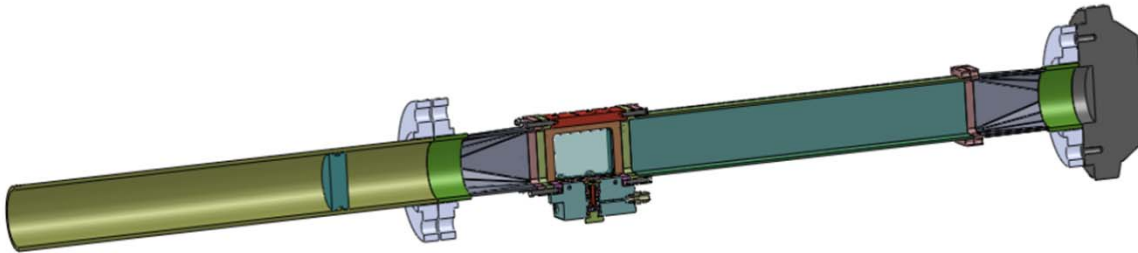
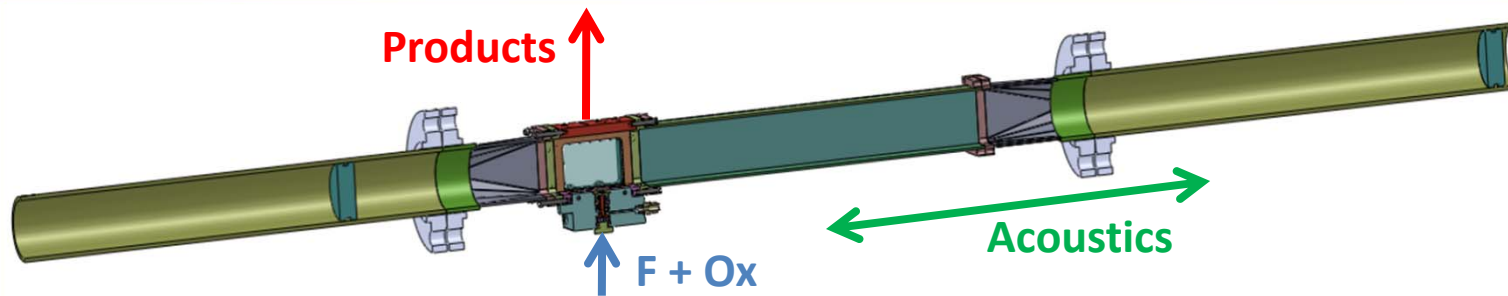
- Testing full scale cylindrical or two dimensional LRE is very costly
- The acoustic environment within any section of a full scale LRE is controlled by the acoustic impedances on its boundaries
- For simplicity, the proposed small scale rig concept is being demonstrated on a 2-D rig that can also experience transverse instabilities
- The boundary impedances in the small scale rig are actively controlled by speakers



Actively controlled, 2-D, ACLRES

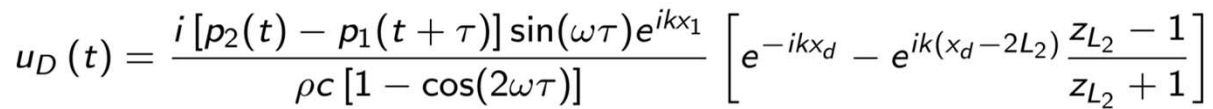


Actively controlled LRE Simulator (ACLRES)



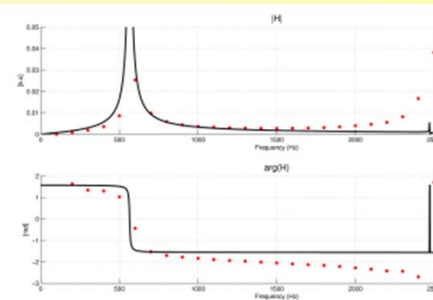
- Active control of boundary impedance capabilities
- Excites transverse acoustics (instabilities)
- Has access for optical diagnostics
- Injector plate may be interchanged to allow investigation of the driving by different injection systems

- The ACLRES system
- Acoustic model



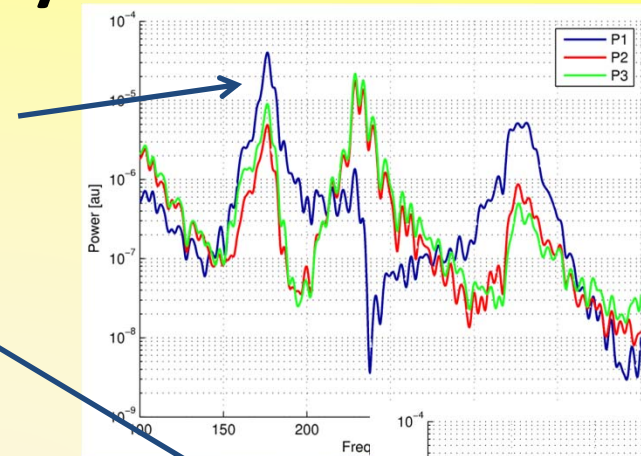
The diagram shows a mechanical system. On the left, a blue rectangular block is connected to a mass-spring-damper system. A spring with stiffness k and a damper with coefficient c are in parallel, connected to a yellow cylindrical mass of mass m . A green arrow labeled F_{coil} points to the right towards the mass. The mass is partially submerged in a fluid, indicated by a horizontal line at the top of the mass. The fluid exerts a pressure $p(t)$ on the right face of the mass, represented by five arrows pointing left. The right face of the mass is at position $x=0$. The fluid extends to the right, ending at a red vertical line at position $x=L$. The top right corner of the fluid region is labeled z_L .

$$I(t) = u_d(t) \frac{\left[i\omega m + \frac{\kappa}{i\omega} + \nu + \frac{(N\pi dB)^2}{Z_{el}} + Z_{Md} \right]}{G_{amp} N\pi dB}$$

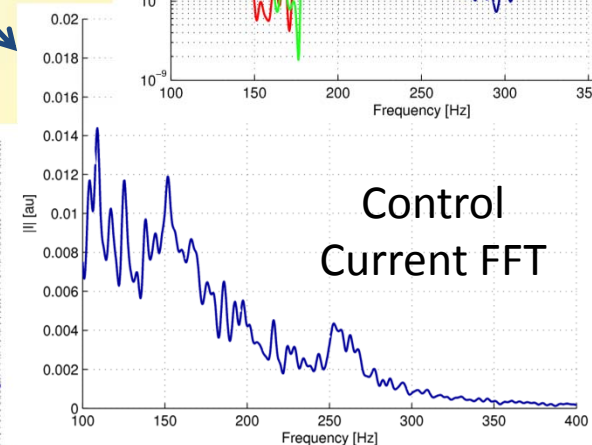
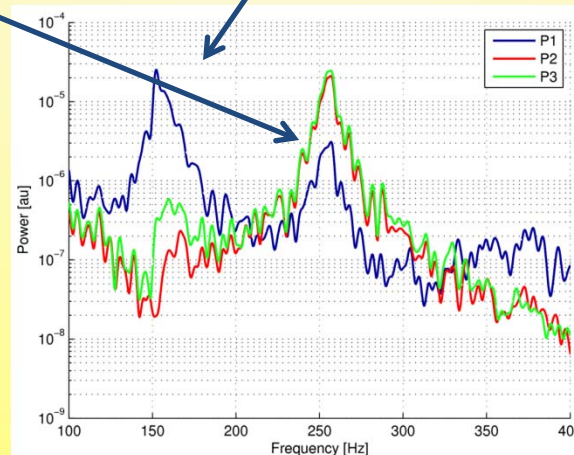
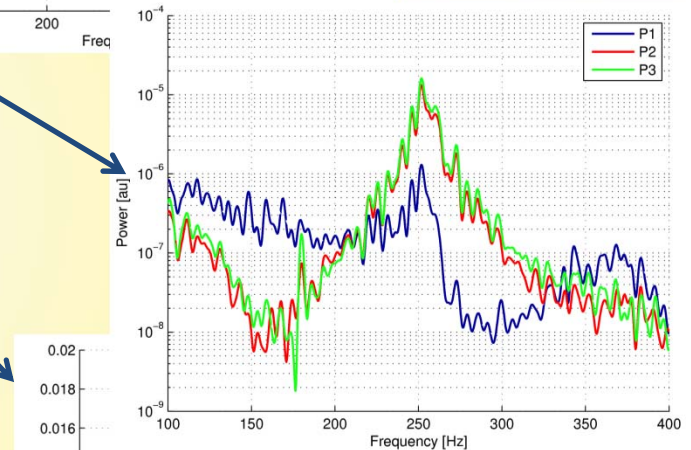


Preliminary Results

- The “Full scale” LRE tested to identify its instabilities (~ 170 Hz)
- Investigated the acoustics of the ACLRES rig (~ 250 Hz)
- The ACLRES (using one injector and combustion) was actively controlled to excite full scale LRE instabilities in the rig
- The “full scale” engine instabilities and the ACLRES natural acoustic modes were excited in the first test
 - Need to “remove” the ACLRES natural modes in future tests
- Modeling efforts show the mean flow controls the spinning instability



Acoustic PSD

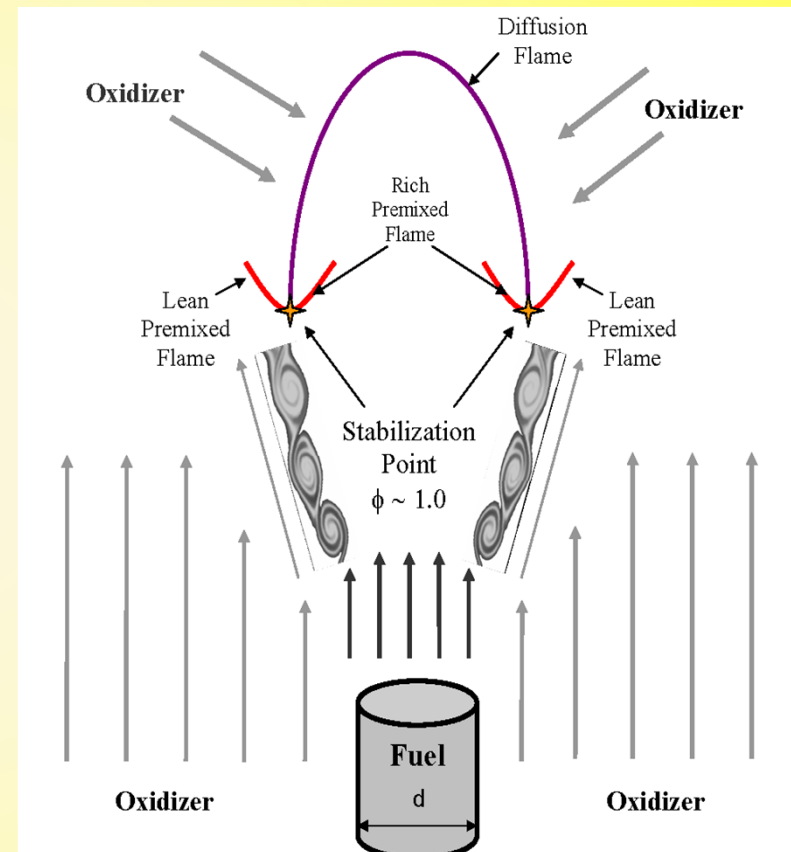


Control
Current FFT

Interest and Governing Physics

Explore role of stability of nozzle-generated triple flame on LRE combustion instability

- Stabilization through premixed flame segment =>
 - Chemistry inherently important
 - Prone to exhibit flamefront instability
- Bulk flame is still diffusion controlled
 - Source of heat release
 - Also prone to flamefront instability
 - Couples to chamber acoustics



Various Intrinsic and Acoustic Flamefront Instability Modes

Instability Mode	Premixed Flame	Diffusion Flame
Rayleigh-Taylor (RT)	Yes	Yes
Diffusional-thermal (DT)	Pervasive, $\downarrow$ as $p \uparrow$	Near-limit situations
Darrieus-Landau (DL)	$\uparrow$ as $p \uparrow$ and $\delta \downarrow$	No
Kelvin-Helmholtz (KH)	?	Yes
////////////////////////////////////	////////////////////////////////////	////////////////////////////////////
Acoustical / Parametric	Yes	Yes

Instability Modes Analyzed

- ❑ Nonpremixed flame segment

- Rayleigh-Taylor, Kelvin-Helmholtz

- ❑ Acoustic-flame interaction

- Resonantly stabilizing but parametrically destabilizing

- ❑ Stability domains

- Landau limit

- Finite flame thickness

High-Fidelity Modeling and Simulation of Liquid-Propellant Combustion at Supercritical Conditions

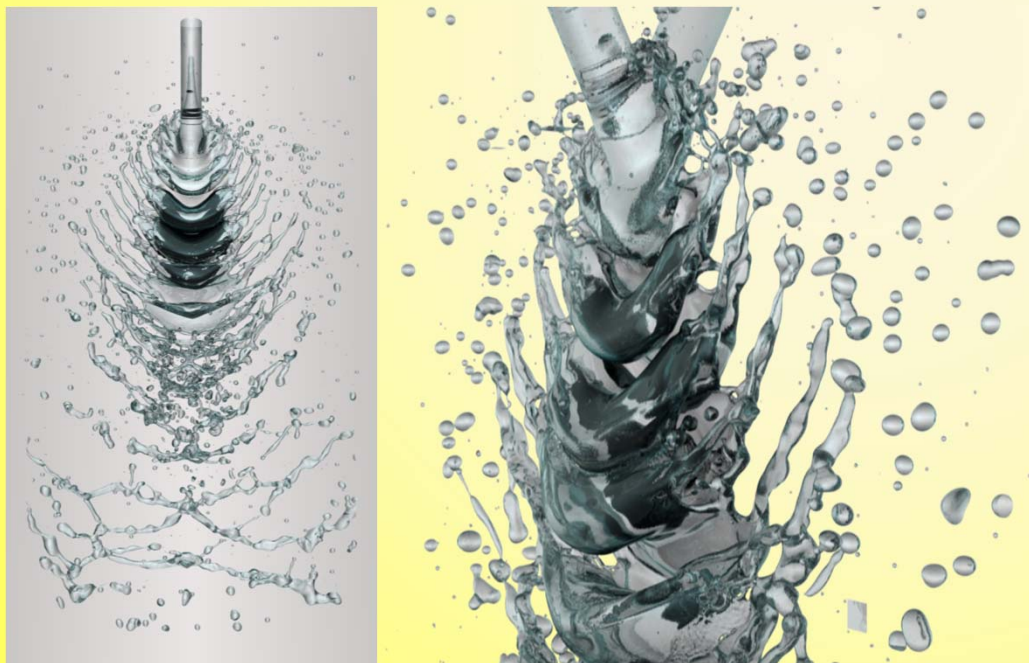
- **Objective of Research:** To develop an integrated theoretical and computational framework for treating combustion dynamics of cryogenic and hydrocarbon propellants under conditions representative of contemporary liquid rocket engines
- **State of the Art of Research:** Limited research on high-fidelity modeling and simulation of (1). turbulence-chemistry interactions at supercritical conditions; (2). supercritical combustion of hydrocarbon propellants (some progress made for cryogenic propellants); (3). swirl injector flow dynamics (only classic theories available); (4). liquid-liquid injector flame dynamics; (5). injector flow response to external forcing.
- **Advancements of Current Research:** (1). Establishment of a unified theoretical-numerical framework for treating supercritical combustion over entire fluid thermodynamic states; (2). study of swirl injector flow dynamics at supercritical conditions; (3). study of swirl injector combustion of hydrocarbons; (4). study of swirl injector flow response to acoustic excitations.

Research is currently undergoing to establish this correction.

ACCOMPLISHMENT 1

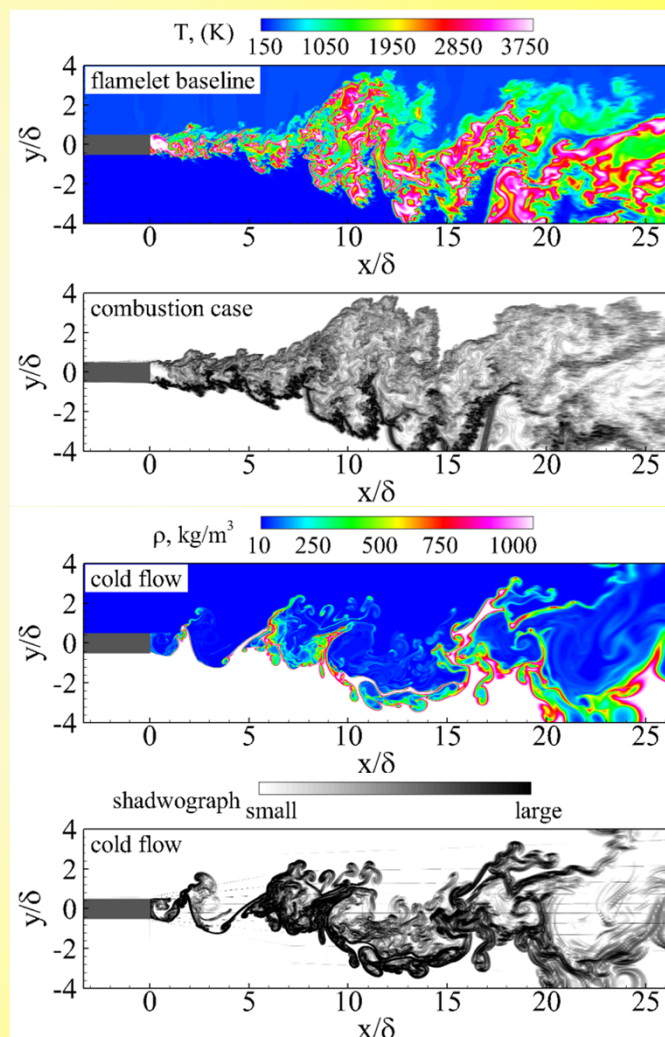
(1) high-fidelity, quantitative knowledge of liquid propellant combustion dynamics at practical engine operating conditions; (2) identification of key design attributes and flow conditions dictating injector behaviors; (3) reduced-base modeling for data presentation and knowledge synthesis.

Multi-Phase Flow Dynamics



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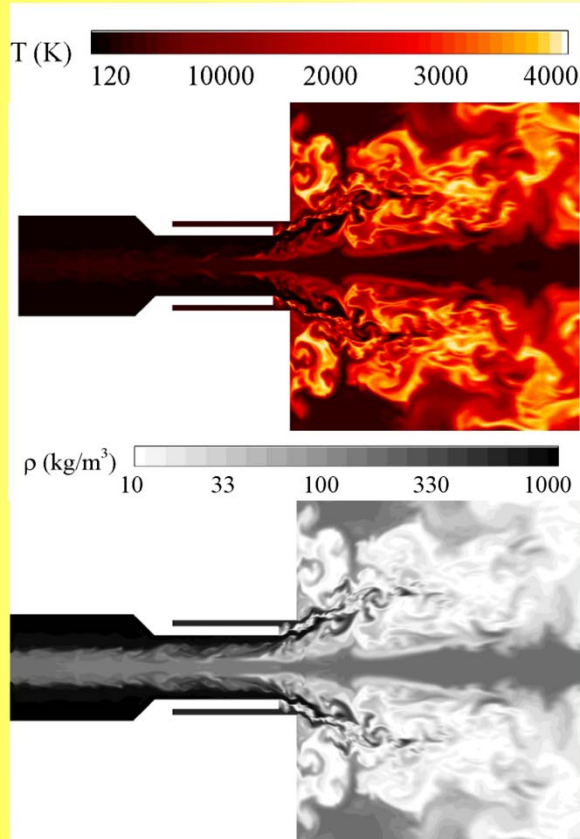
DNS/LES of LOX-Methane Flames



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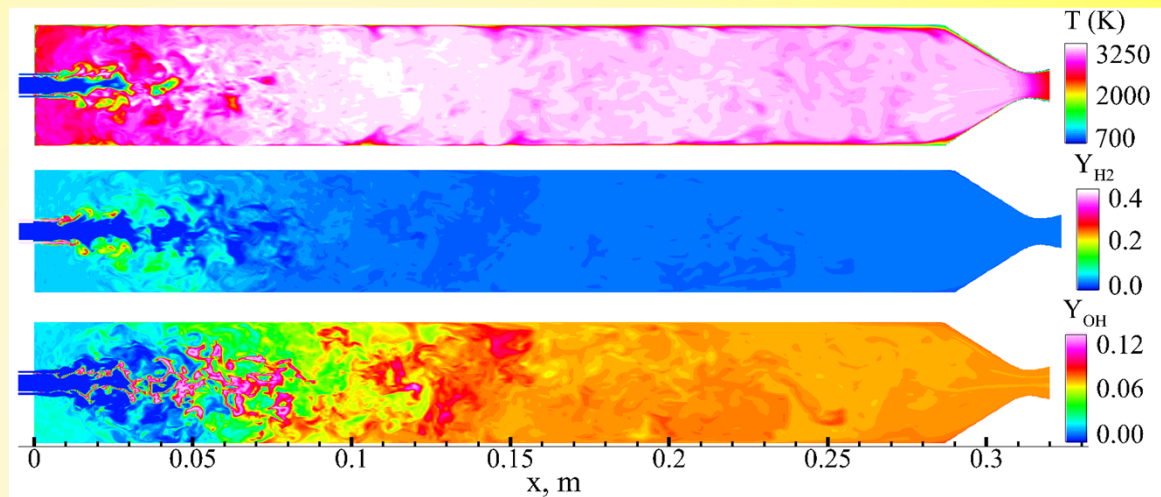
ACCOMPLISHMENT 2

Identification of key injector design attributes and flow conditions for engine performance improvement and combustion instability mitigation



instantaneous temperature and density contours of LOX/kerosene double swirl injector flame

9/13/2012



snapshots of temperature, and mass fractions of H₂ and OH of GO₂/GH₂ shear co-axial injector flames

LES techniques developed to address critical development issues of liquid rocket combustion devices



- injector dynamics
- chamber cooling
- wall compatibility
- combustion instability