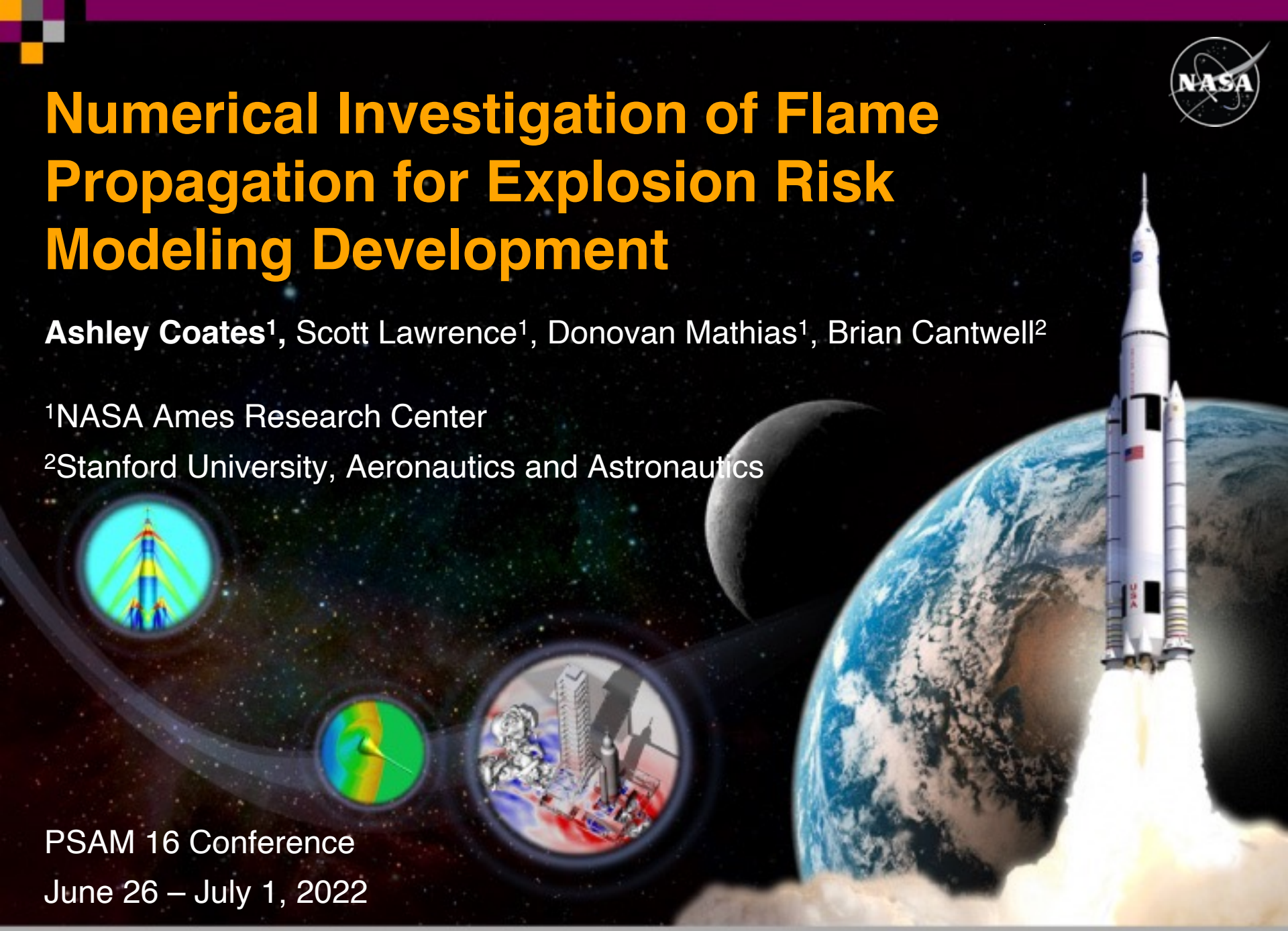
Numerical Investigation of Flame Propagation for Explosion Risk Modeling Development

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[2]Stanford University, Aeronautics and Astronautics

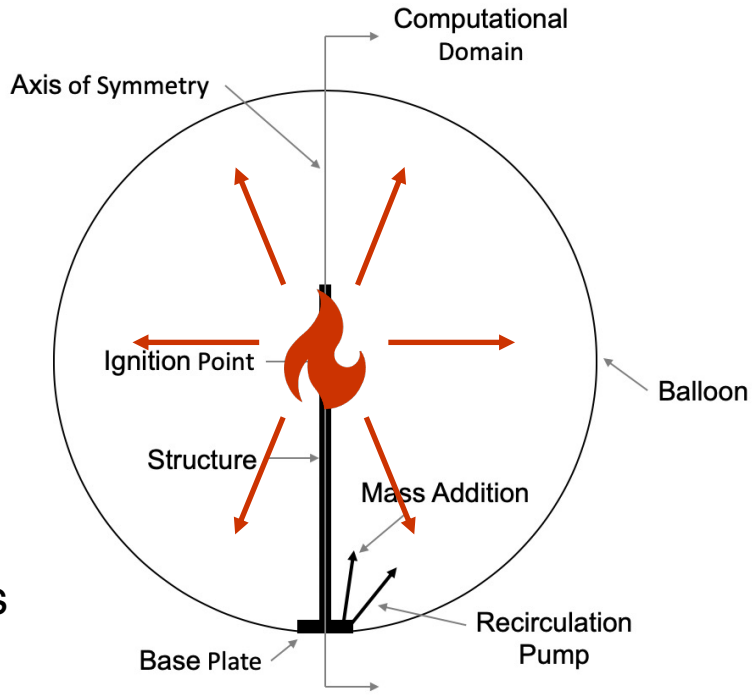


PSAM 16 Conference

June 26 – July 1, 2022

Overview

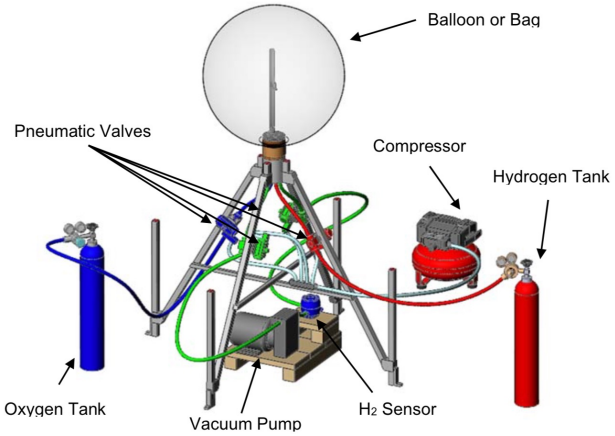
- Introduction and Overview
- Motivation
  - Why investigate flame propagation?
  - Why use computational fluid dynamics?
- Problem Setup
- Parameter Studies 1 and 2
  - Simulation results
  - Comparison with experimental data
- Comparison with Engineering Model Results
- Conclusions and Future Work
- Questions



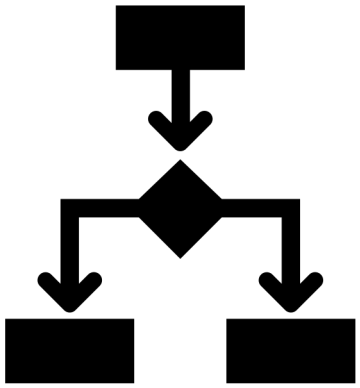
Motivation

Identify risk-driving failure mechanisms and help to evaluate overall design safety using probabilistic failure propagation and abort risk models

Gain understanding through high-fidelity simulations about the complex physics of flame propagation, debris strikes, overpressure, and other factors that could occur after an uncontained launch failure



Experiments →



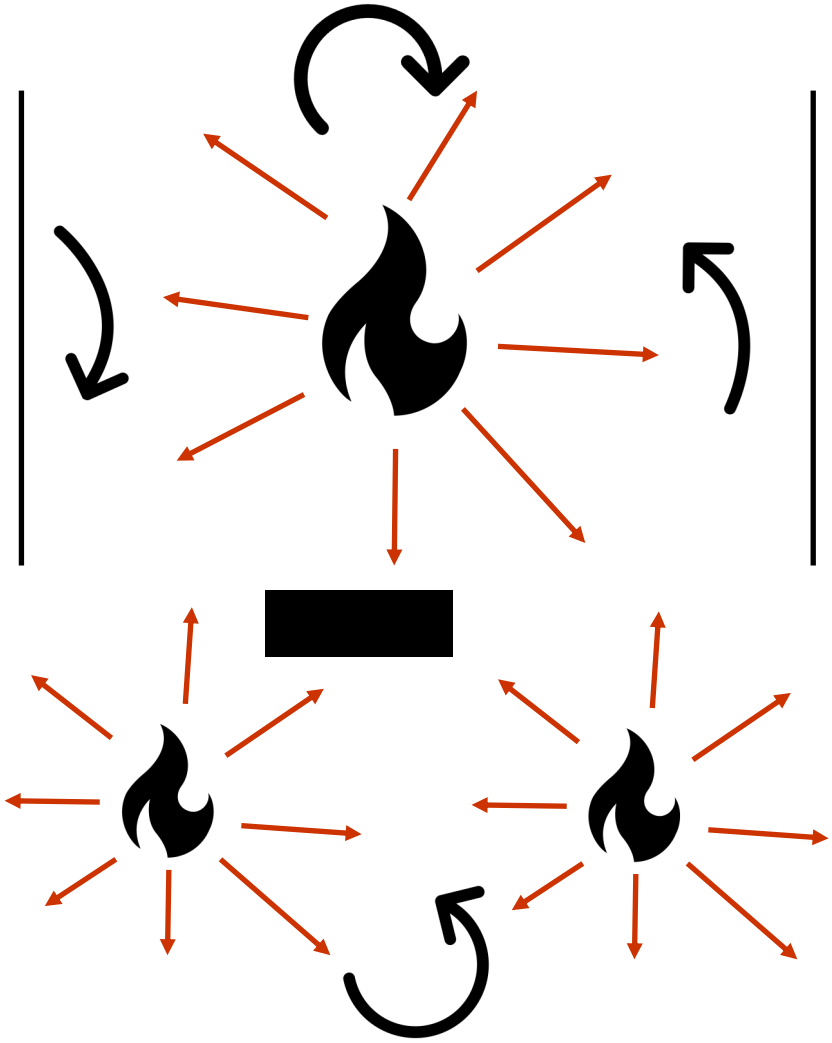
Engineering-level Blast Model

← CFD Simulations



Motivation

Many things can interfere with or change how the flame is propagating

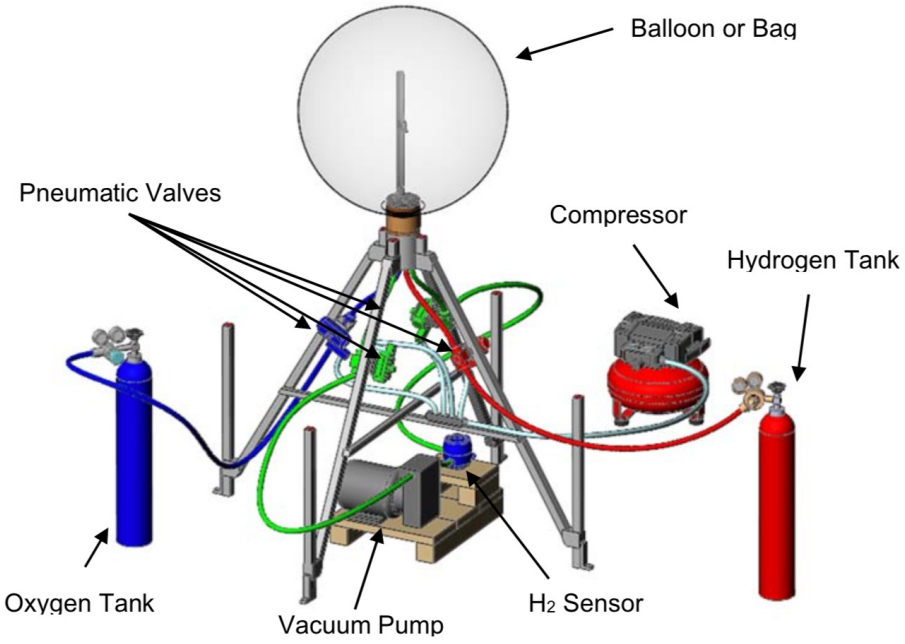


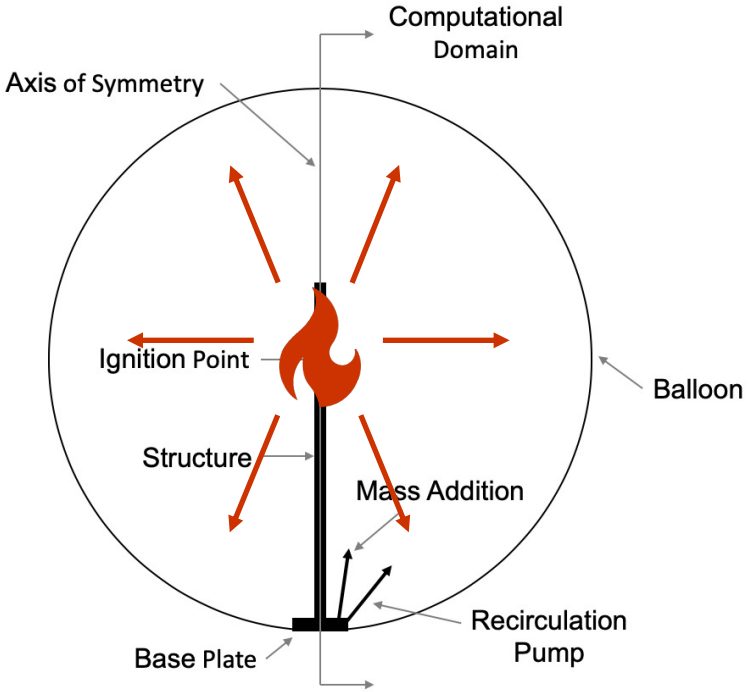
Potential Setup Features

- Initial Pressure
- Initial Velocity Distribution

Problem Setup

Geometry representative of the Hydrogen Unconfined Combustion Test Apparatus (HUCTA) experiments conducted at MSFC

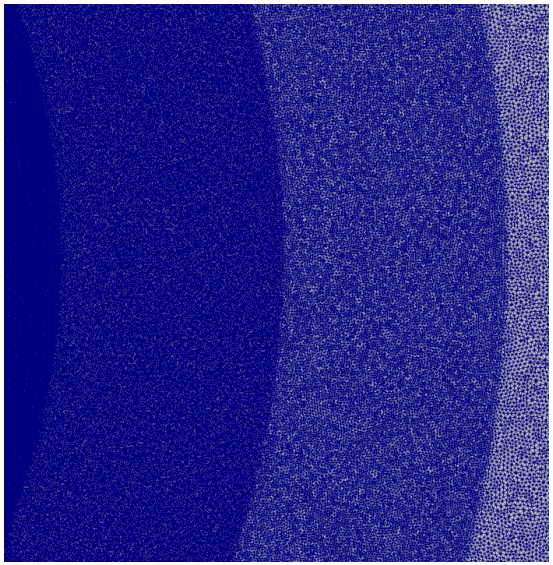




Problem Setup

- Loci-Chem CFD Code
  - Density-based, finite volume, unstructured solver
  - 2nd order accuracy time and space
  - Navier-Stokes in three dimensions
  - Viscous, turbulent, chemically reacting flows
- Mesh
  - Unstructured
  - Grid spacing of 0.254 mm, order of laminar flame thickness
  - Spacing very small in comparison to overall domain, use multiple meshes
  - Assume axisymmetric, 2D mesh
- Models
  - Built-in database for transport and diffusion models
  - Menter's Baseline turbulence model
  - 7-species, 8-reaction H_2-O_2 chemistry model

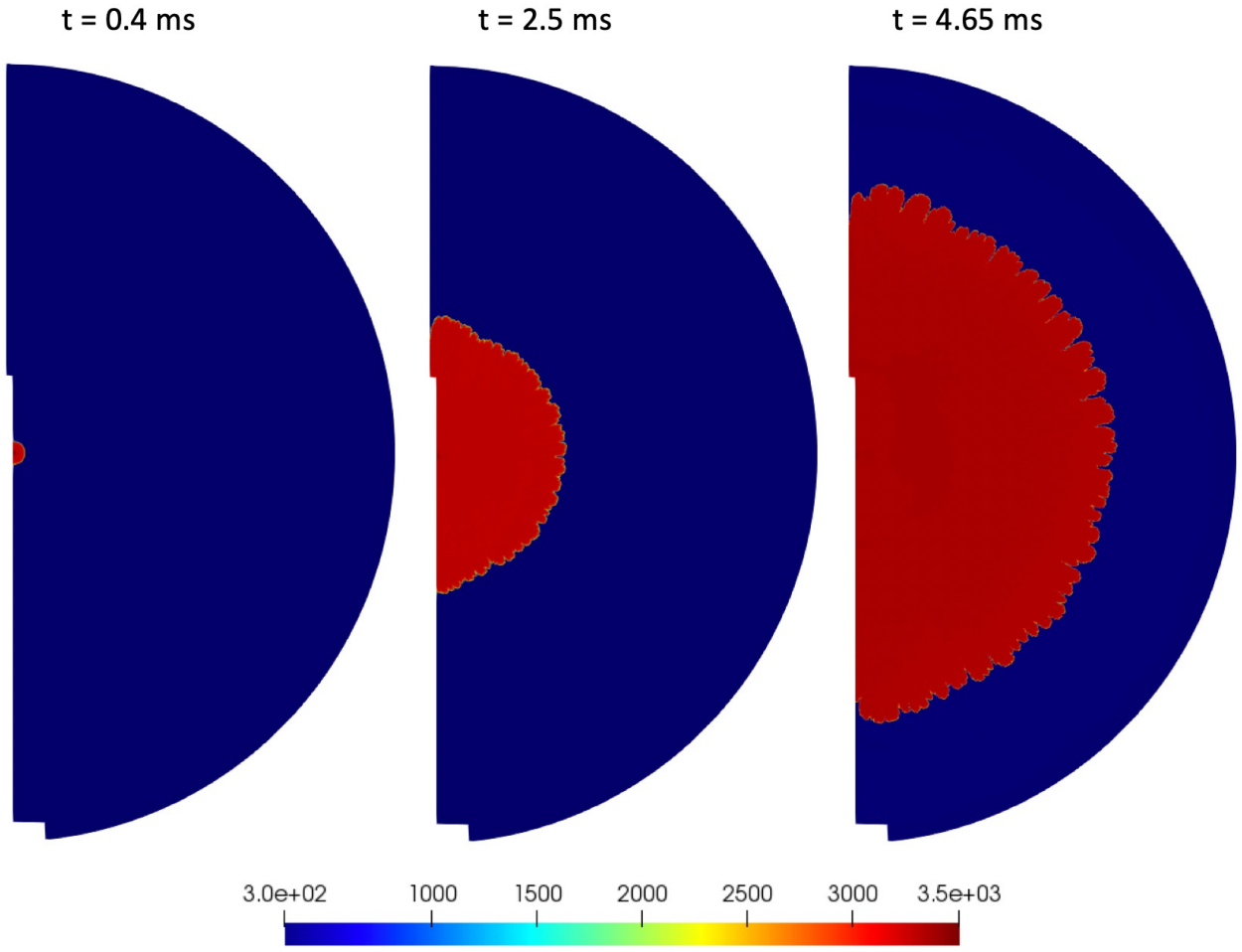
Arrhenius Form
$k=AT^{B}\exp(-C/T)$



RESULTS AND DISCUSSION

Initial Pressure Variation

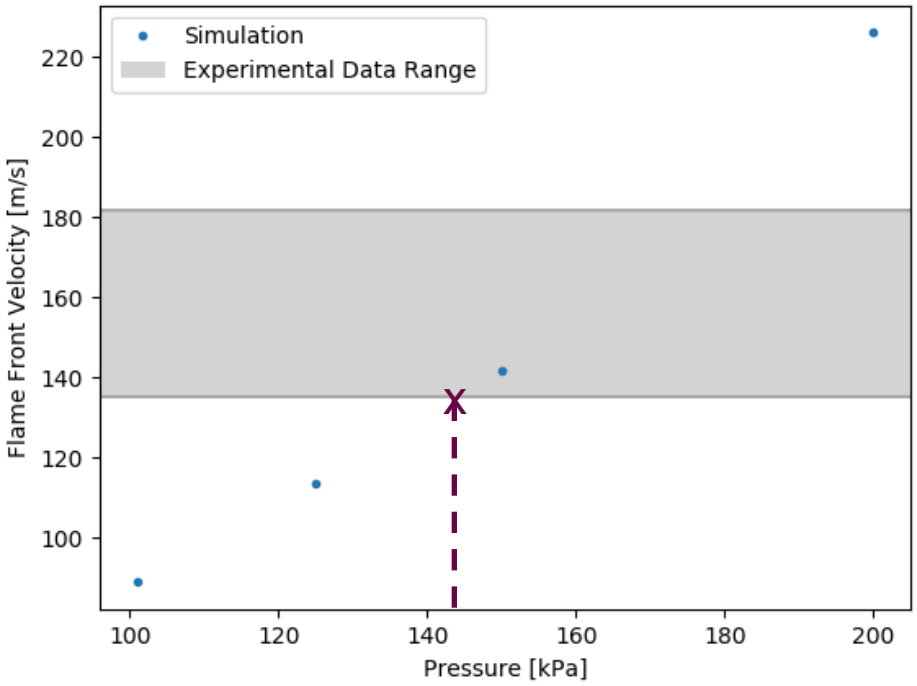
Stoichiometric
Hydrogen-Oxygen
Quiescent
$P_{initial}$ = 125 kPa



Temperature Contours

Compare to Experiment

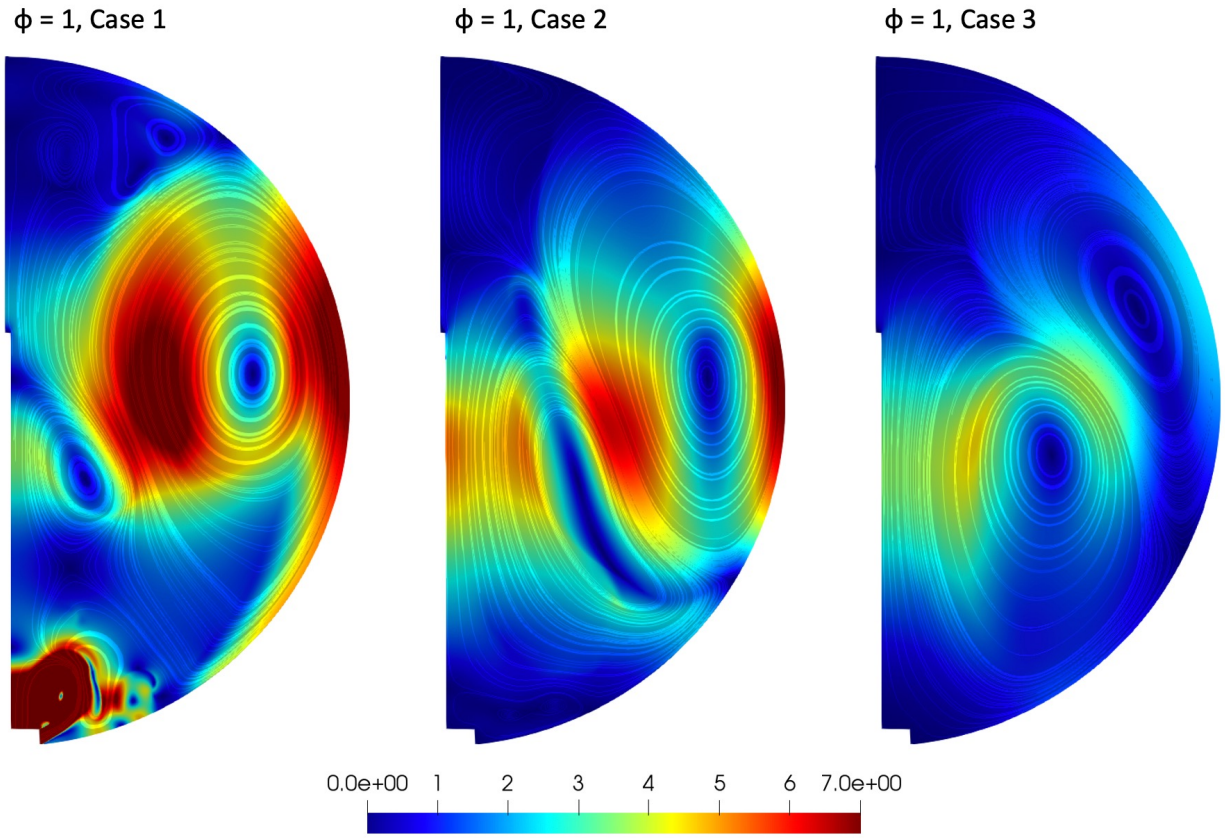
- Temperature held constant, so density varied with pressure in the simulations
- Experimental data range determined from cases with approximately stoichiometric mixtures



Pressure not the driving factor for increased flame speed in experiment

Initial Velocity Variation

Characterize potential effects an initial velocity distribution could have on flame speed, capture filling and recirculating processes

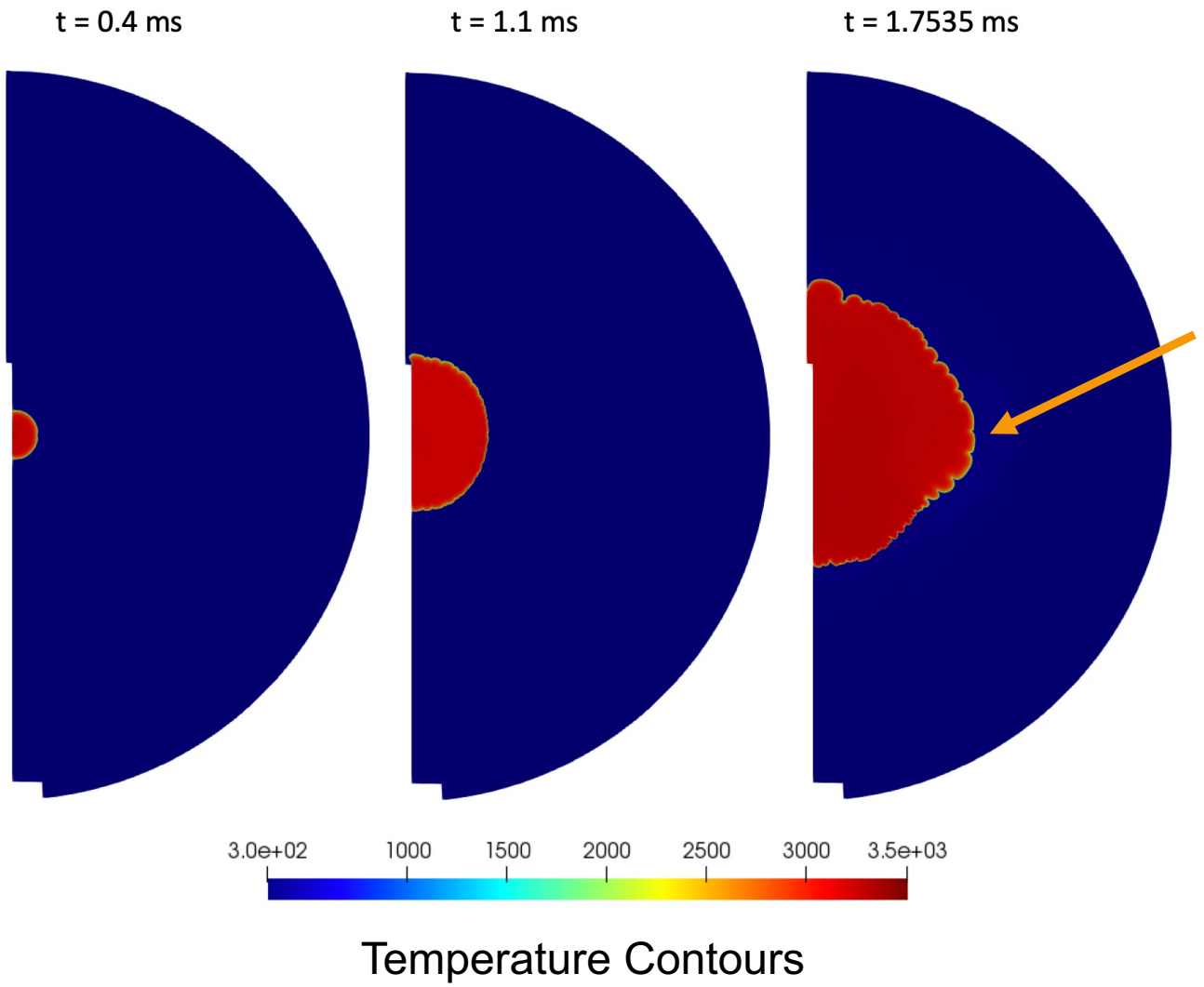


Velocity Magnitude Contours

Wait Time = 2/3 Fill Time

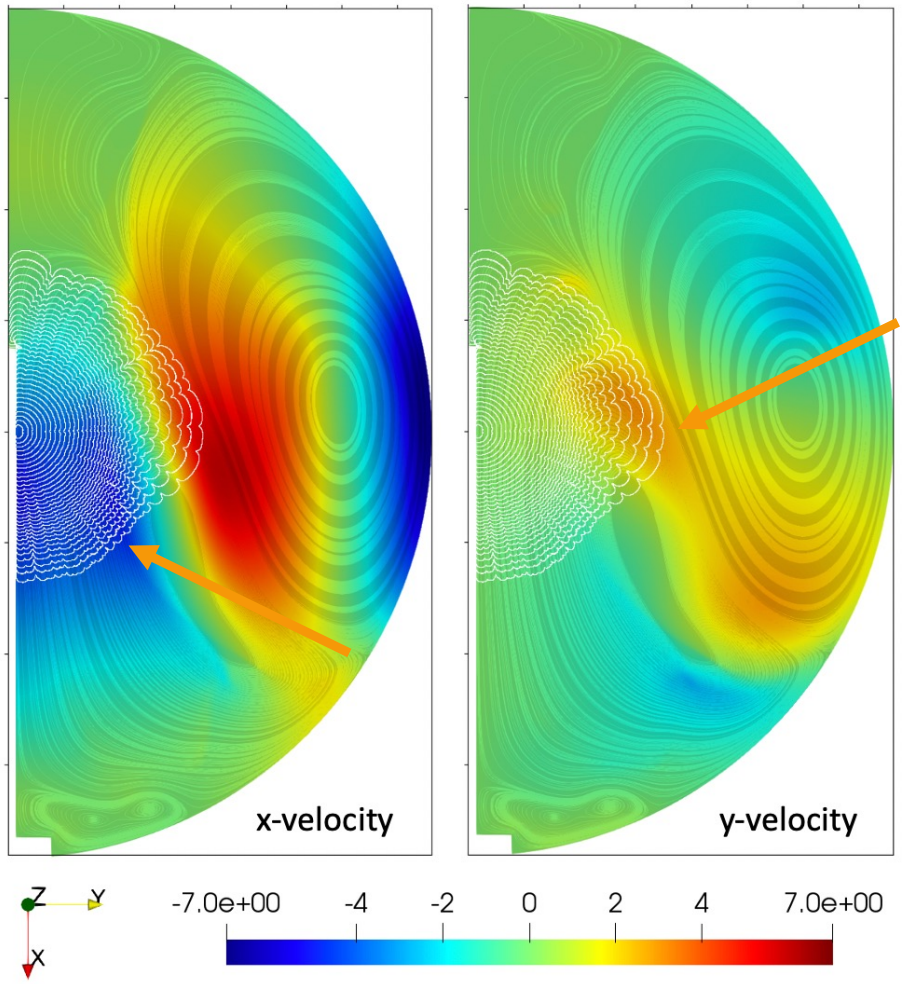
Initial Velocity Variation

Stoichiometric Hydrogen-Oxygen Velocity Distribution Case 2



Initial Velocity Variation

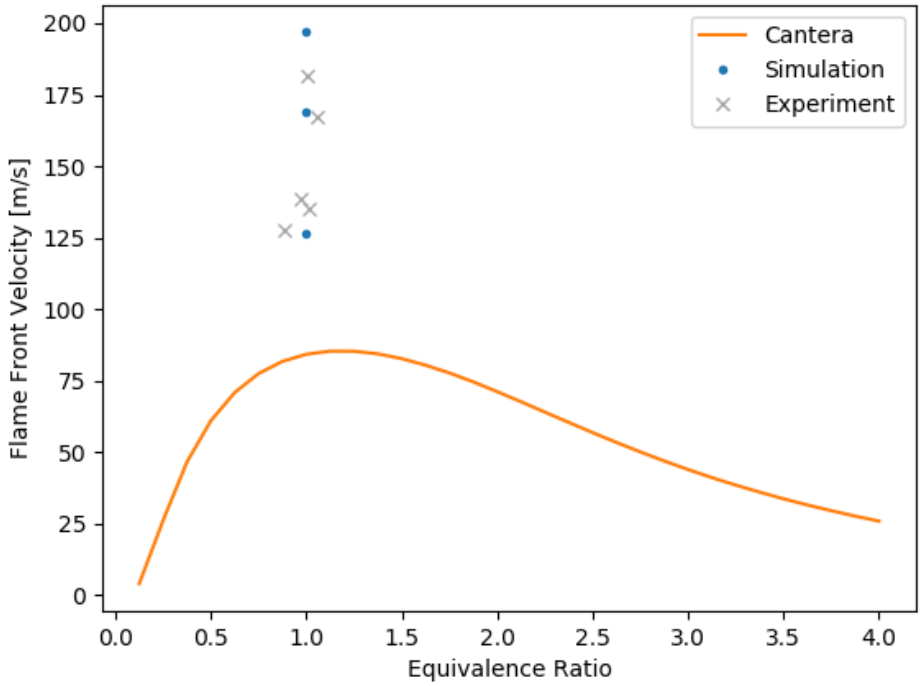
- Flame accelerated and deformed as it interacted with the underlying flow
- Flame generally accelerated with underlying flow in the same direction, decelerated in adverse flow



x and y Component Velocity Contours Propagation Overlaid

Compare to Experiment

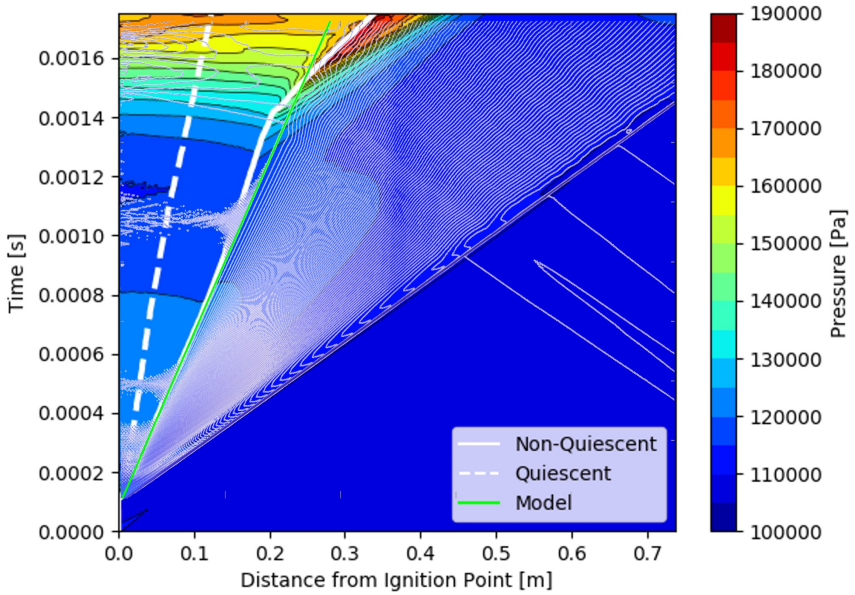
Reminder: Simulations did not model experiments exactly since experimental fill and recirculation process parameters were not reported and likely important

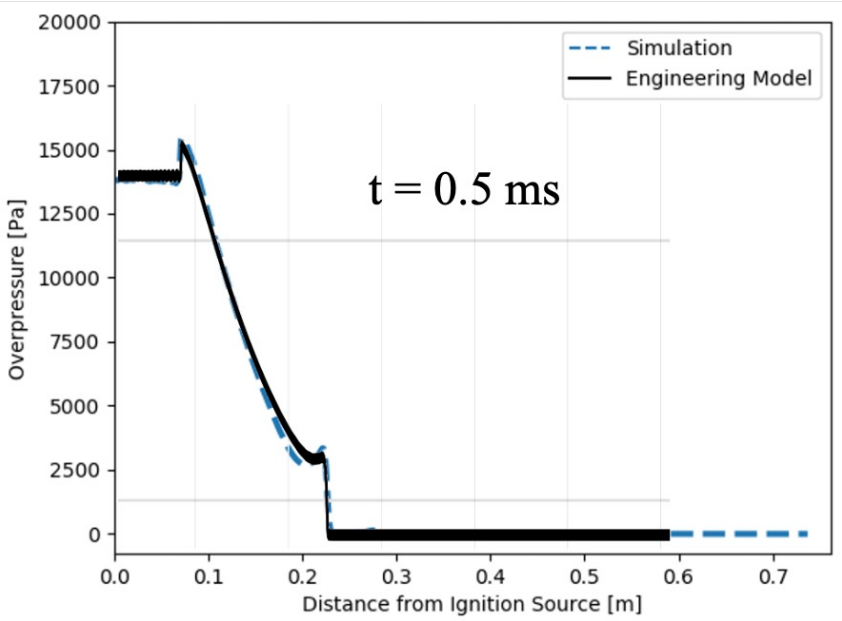


Presence and character of a non-uniform velocity field at ignition can significantly affect flame propagation behavior

Compare to Engineering Model

- Pressure appears to be well resolved by the engineering model if the flame speed is known





Focus for furthering model capabilities should be placed on determining appropriate flame speeds

CLOSING REMARKS

Conclusions and Future Work

- Gained understanding leads to more informed flame speed values

- Setup procedures for both numerical and experimental studies can significantly affect flame speeds results, report information carefully
- Flame speed is sensitive to initial conditions, particularly to interactions with underlying velocity flow features
- Engineering model is well-suited to capture blast waves if flame speed is known throughout propagation
- Important for any relatively confined industrial setting where explosion hazards and potential for flame propagation exists

- Consider 3D effects
- Allow the flame to propagate outside the balloon to capture the blast wave farther from ignition
- Disseminate findings on local flame acceleration study

References

[1] E. Richardson, T. Skinner, J. Blackwood, M. Hays, M. Bangham, and A. Jackson. "*An experimental study of unconfined hydrogen/oxygen and hydrogen/air explosions*", 46th Joint Army- Navy-NASA-Air Force (JANNAF) Combustion Conference, (2014).

[2] Supercomputer Picture, https://images.nasa.gov/details-ARC-2008-ACD08-0272-002

[3] E. Luke and T. George. "*Loci: A rule-based framework for parallel multidisciplinary simulation synthesis*", Journal of Functional Programming, 15, pp. 477–502, (2005).

[4] E. Luke. "*On robust and accurate arbitrary polytope CFD solvers (invited)*", 18th AIAA Computational Fluid Dynamics Conference, (2007).

[5] E.A. Luke, X. Tong, J. Wu, P. Cinnella, and R. Chamberlain. "*CHEM 3.3: A Finite-Rate Viscous Chemistry Solver - The User Guide*", (2014).

[6] Pointwise, Inc., https://www.pointwise.com/.

[7] Cantera, https://cantera.org.

[8] S.L. Lawrence and D.L. Mathias. "*Blast overpressure modeling enhancements for application to risk-informed design of human space flight launch abort systems*", Reliability and Maintainability Symposium (RAMS), (2008).

[9] M.J. Tang and Q.A. Baker. "*A new set of blast curves from vapor cloud explosion*", Process Safety Progress, 18, pp. 235–240, (1999).

- Additional references in full paper

Thank You

QUESTIONS?


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