Forced Ignition of Fuel-Stratified Flow

Sheng Wei, Brandon Sforzo, Jerry Seitzman
Ben T. Zinn Aerospace Combustion Laboratory
Daniel Guggenheim School of Aerospace Engineering, Georgia Institute of Technology

Experimental Methods

Flow facility[1]:

- Ejected plasma kernel (into crossflow) generated by aircraft type igniter
- Fuel-air stratification allows initial kernel evolution before encountering fuel
  - achieved by splitter plate; premixed fuel-air in main, air only in kernel flow
  - also creates nearly uniform velocity in cross-flow

Pre-vaporizer:

- Fuel sprayed into heated carrier air; vaporized mixture injected into main flow air (440 K)

Diagnostic methods:

- Integration of broadband emission for ignition probability
- High frame rate mode for schlieren imaging of kernel growth and chemiluminecense

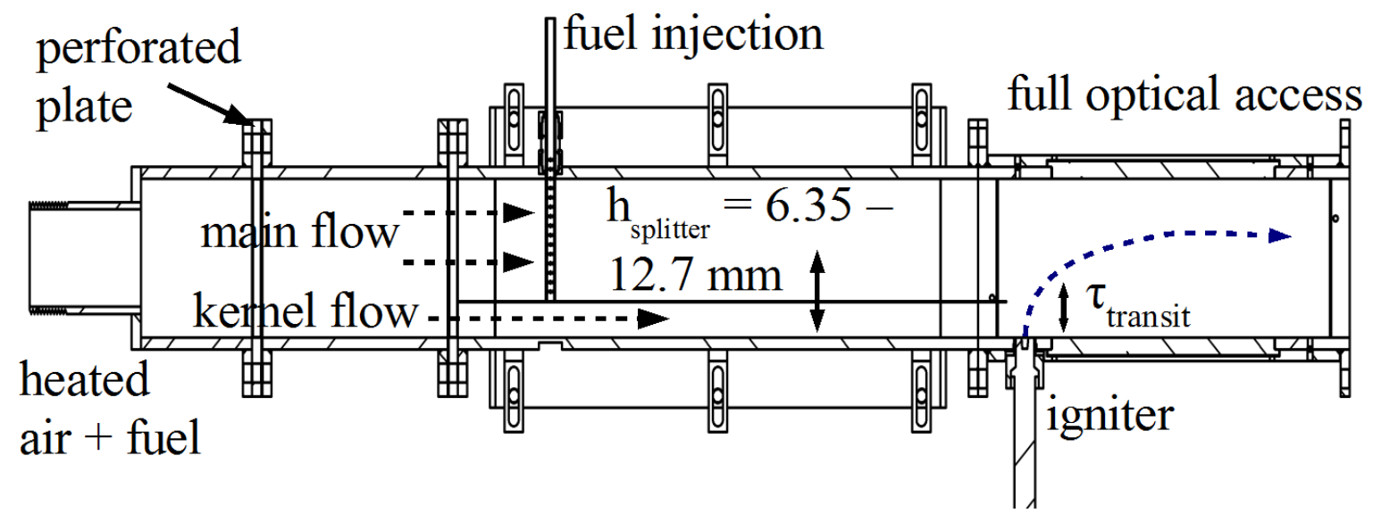

Figure 1. Schematic of stratified flow setup

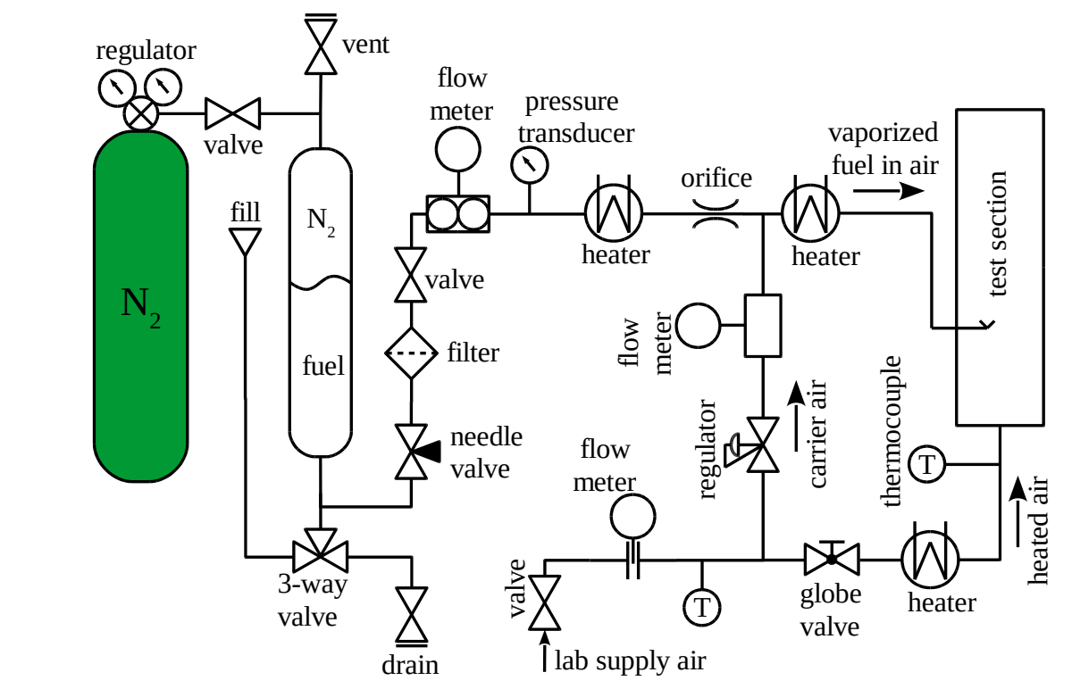

Figure 2. Schematic of the liquid fuel vaporization setup

Ignition Probability:

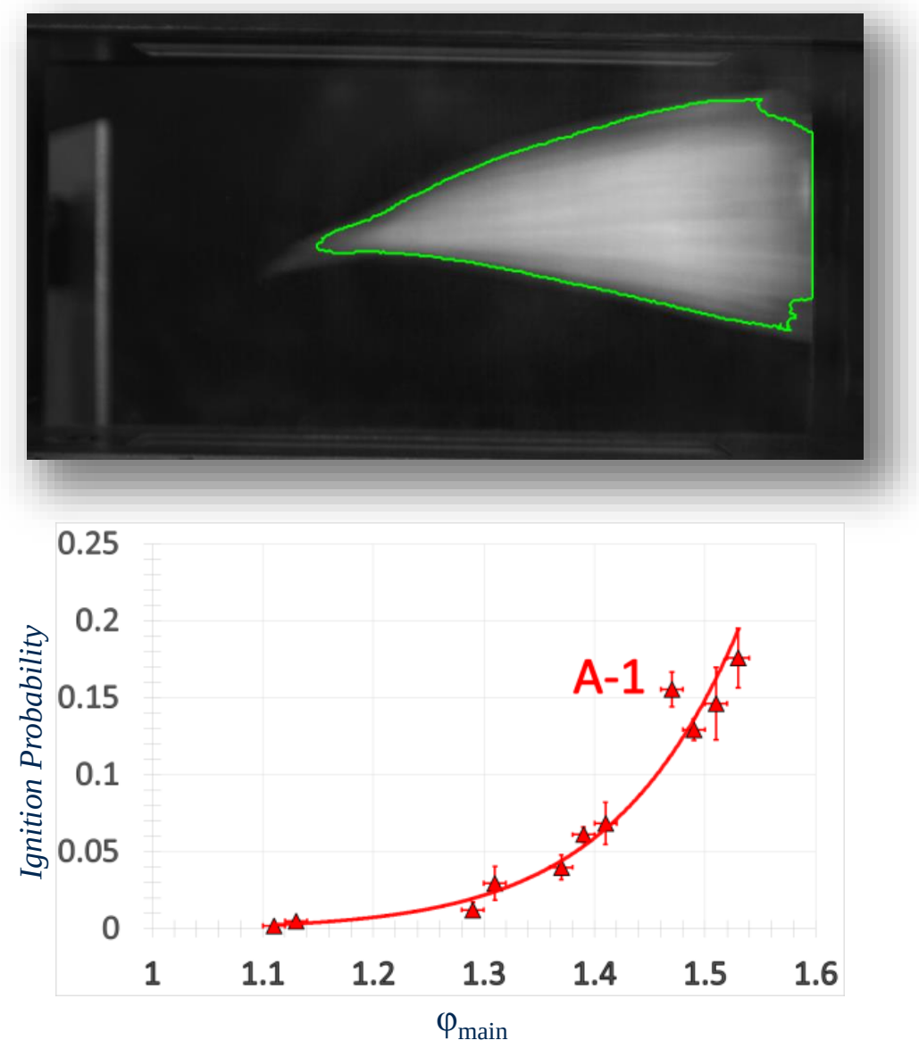

Figure 5. Time-integrated image of successful ignition (top); ignition probability variation with main zone equivalence ratio (bottom)

- Equivalence ratios φ~1.0–1.6
- Ignition probability defined as

$$P(ign) = \frac{N_{success}}{N_{total}}$$

- Fuels ranked at φ=1.5

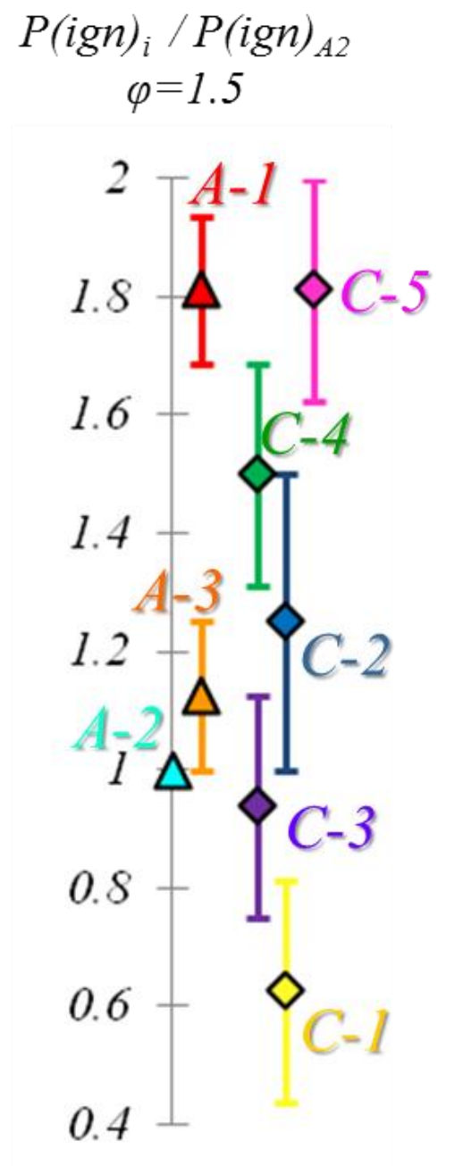

Figure 6. Ranking of ignition probability for φ = 1.5.

Observations:

- Statistically meaningful variation between fuels
- Three fuels selected for further study
  C-5 (high), A-2 (med), C-1 (low)

High Speed Imaging:

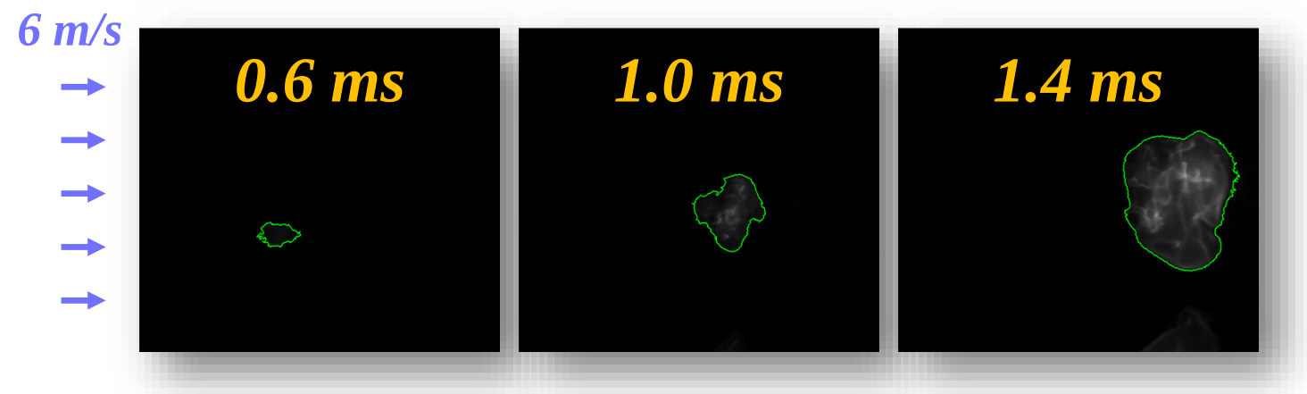

Figure 7. Visible chemiluminescence movie frames of forced-ignition kernel growth with edge tracking (φ = 1.5)

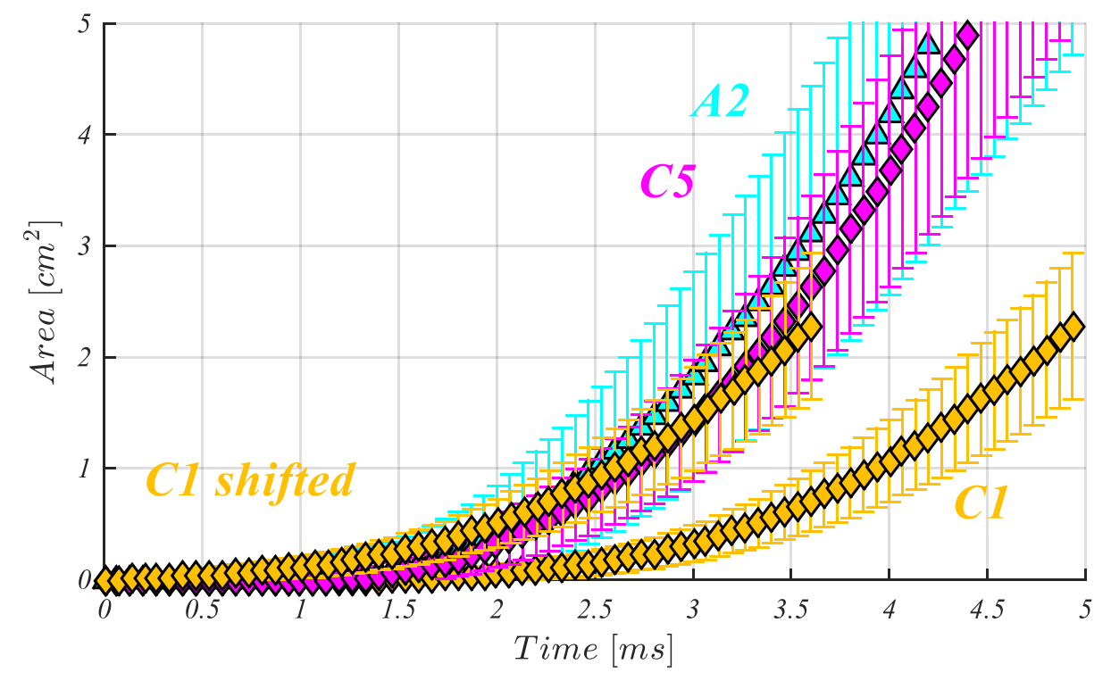

Figure 8. Chemiluminescence area growth from edge tracking; C-1 results also shown shifted in time

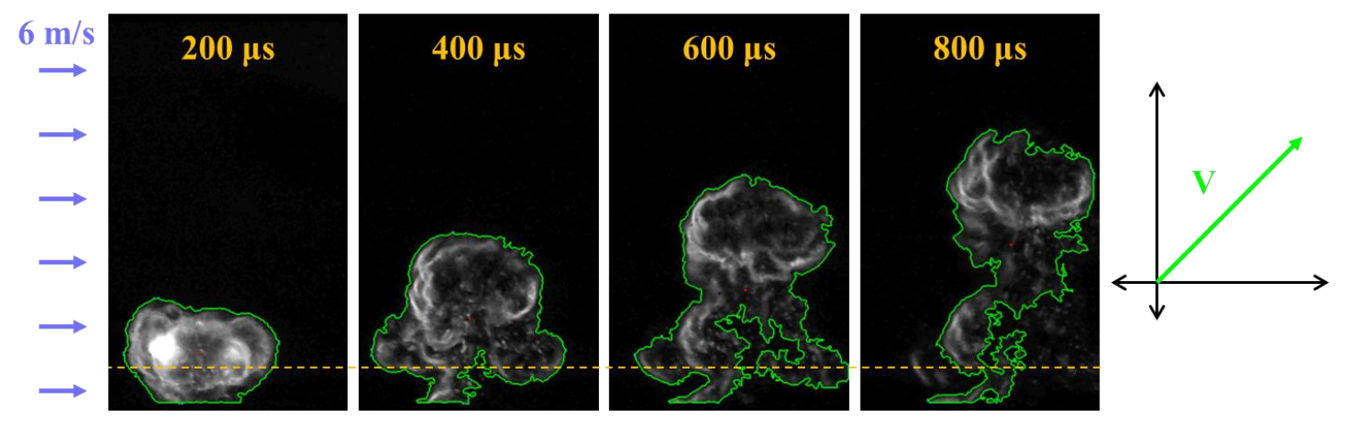

Figure 9. Initial air-plasma kernel growth from high speed schlieren

Observations:

- Similar turbulent flame speed (growth) for all fuels, but delayed growth for low ignition probability fuel
- Growth in initial plasma kernel due to entrainment of ambient fluid, ~60 mg/s from estimated volume growth rate

Objectives

1. Measure ignition probabilities for a number of fuels in a flow that can be easily modelled
2. Initial focus on chemical effects by prevaporizing fuels
3. Develop reduced order model that captures important physics

Motivation

- Reliable ignition is critical for turbine engine operation
- Most forced ignition studies are for premixed/uniform conditions, e.g., SI engines
- Need better understanding of forced ignition in turbine engine relevant flow; for example, lack of fuel near igniter
- Previous work examined natural gas fuel systems, current focus is jet fuels and fuel composition effects

Conclusions

- Significant difference in probability among fuels observed
- Ignition probability is strong function of equivalence ratio
- Flame growth rate (from chemiluminescence) indicates similar flame speeds for all fuels but with delayed beginning
- Bifurcation in temperature from reduced-order modeling demonstrates ability to classify successful vs. unsuccessful ignition

Future Work

- Investigate non-vaporized liquid droplet ignition and develop parameters to characterize ignition
- Compare simulation results of all fuel models. Incorporate two-phase into current model

Reduced-Order Modeling

Modeling tool:

- Cantera[2]: Open-source object oriented software tools for solving problems involving chemical kinetics, thermodynamics, and transport process

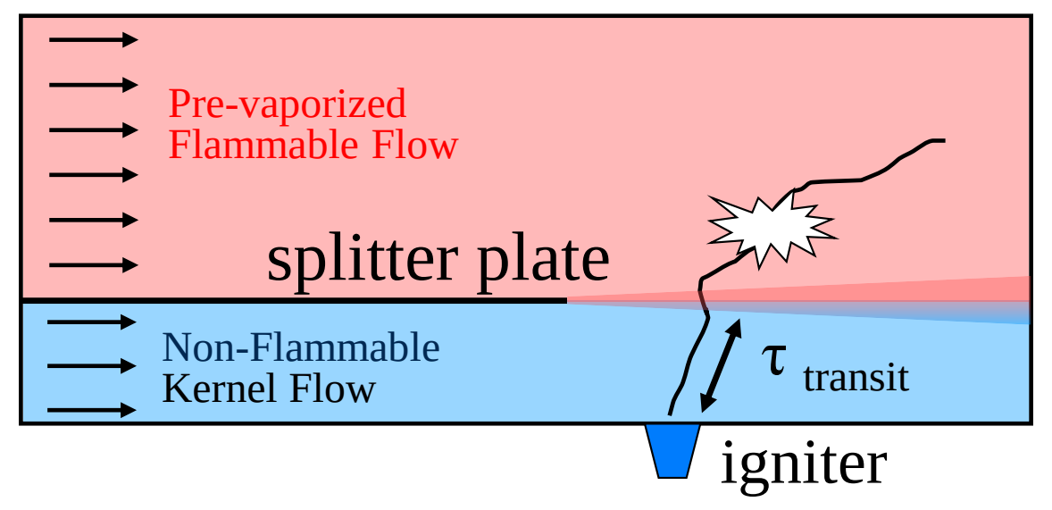

Figure 3. Travel Path of an air-plasma(spark) kernel

Two-staged Perfectly-Stirred Reactor(PSR)[1]:

- First stage simulates entrainment of dry-air into air-plasma(spark) kernel
- Second stage simulates entrainment of fuel-air mixture at certain equivalence ratios after the first-stage air-plasma kernel
- Mass entrainment rate obtained from schlieren imaging

Mechanisms:

- Stage 1: SforzoairNASA9.cti[1] – dry air plasma
- Stage 2: POSF10264.cti[3] – A2 fuel mechanism

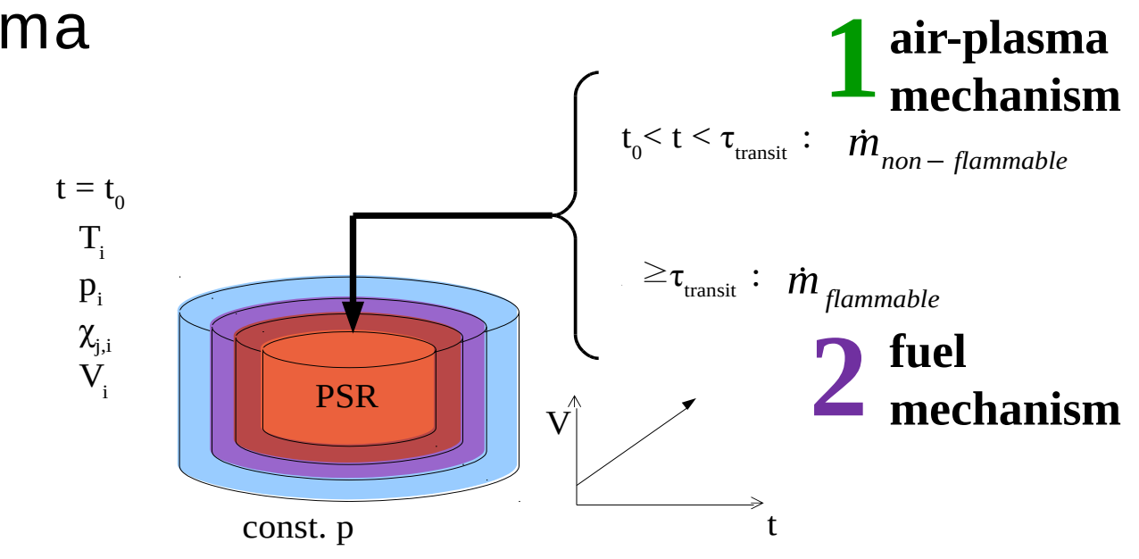

Figure 4. Conceptual representation of a Perfectly-Stirred Reactor(PSR)

Kernel Temperature History:

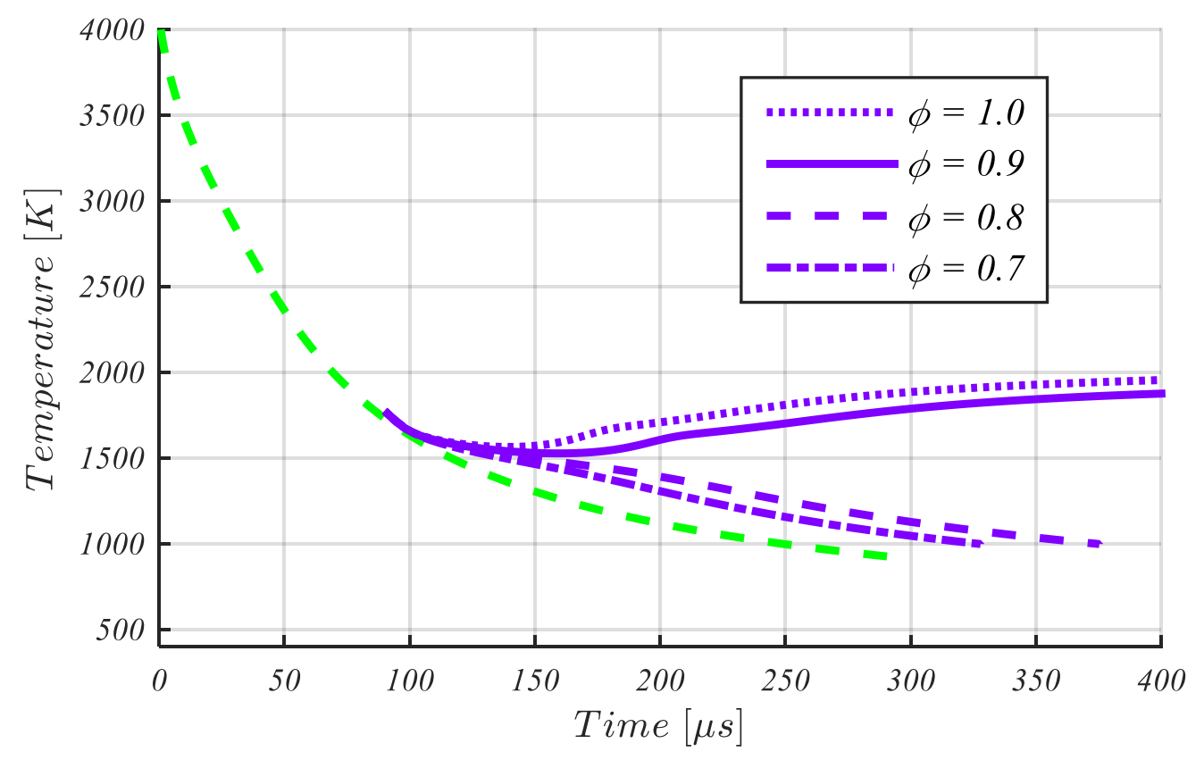

Figure 10. Kernel temperature for 90µs transit time, 400K cross-flow and various main equivalence ratios

Kernel Species Histories:

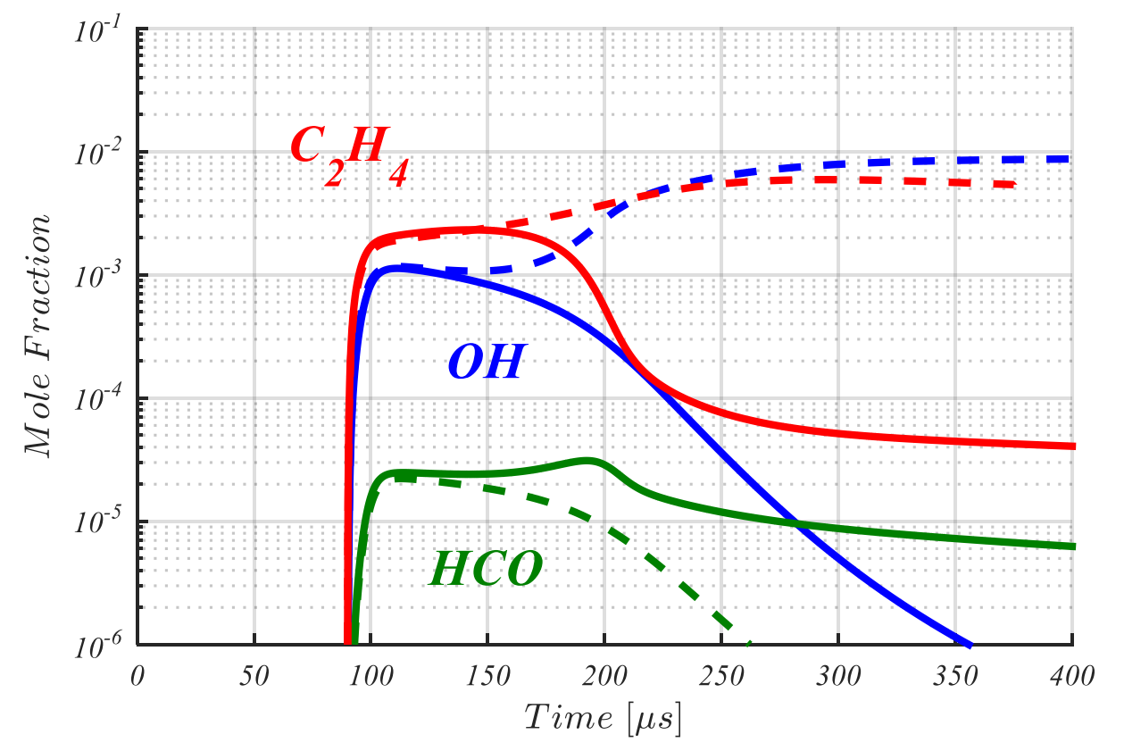

Figure 11. Kernel species mole fractions for successful (solid) vs. unsuccessful (dashes) ignition cases

Ignition Boundaries:

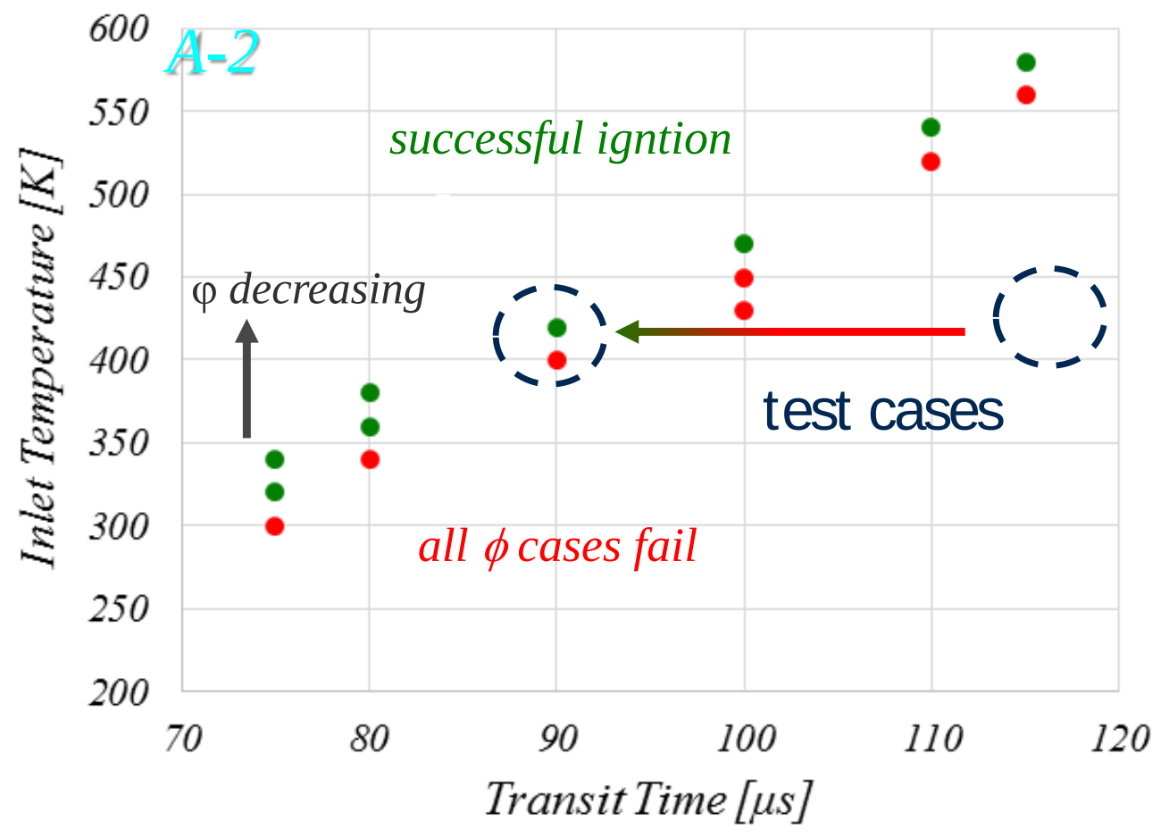

Figure 12. Boundary map of cross-flow temperature and transit time for successful ignition

Observations:

- Kernel temperature when fuel-air mixture entrainment begins and amount of available heat release (higher equivalence ratios) key to successful ignition
- Fuel decomposition occurs in µs, oxidation of decomposition products occurs in 10's µs
- Successful ignition requires initial heat release rate to outweigh kernel cooling from dilution (entrainment)
- Modeling matches experimental trends

Acknowledgements:
This work was funded by the US Federal Aviation Administration (FAA) Office of Environment and Energy as a part of ASCENT Project 13-C-AJFE-GIT-008 under FAA Award Number: 27A. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the FAA or other ASCENT Sponsors.

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[3] Wang, H., Xu, R., Hanson, R. K., Davidson, D. F., Bowman, C. T., "A HyChem Model of Jet Fuel Combustion," Personal communication, 2015.