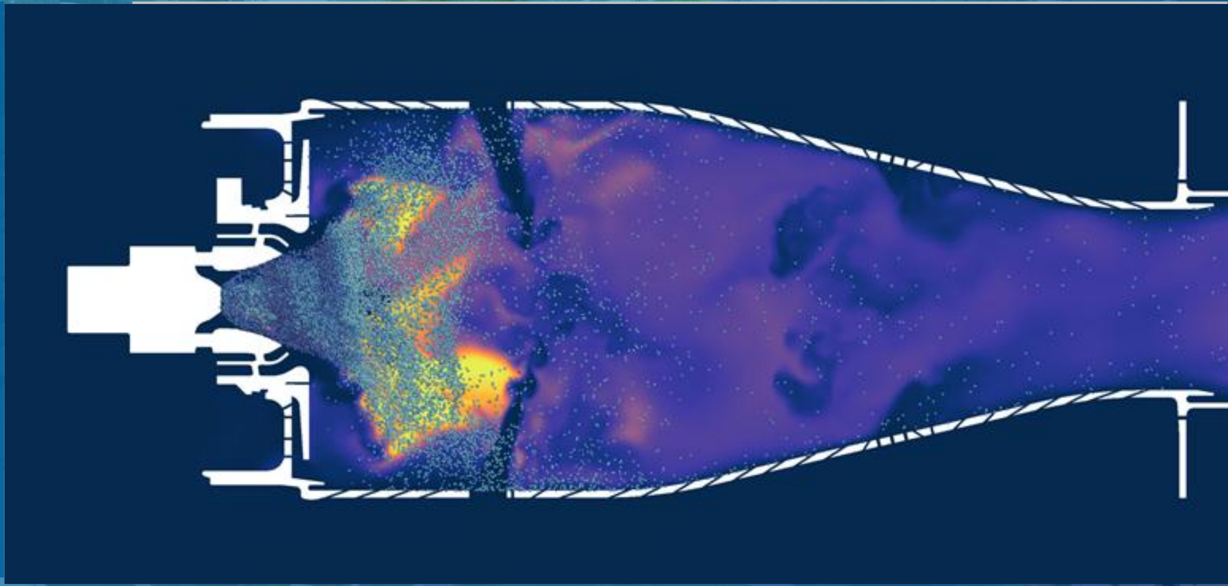
IEA AMF SAF webinar
April 29th, 2026

ASSESSING FUEL PROPERTY IMPACTS ON COMBUSTOR PERFORMANCE FOR AVIATION FUELS



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ACKNOWLEDGEMENT

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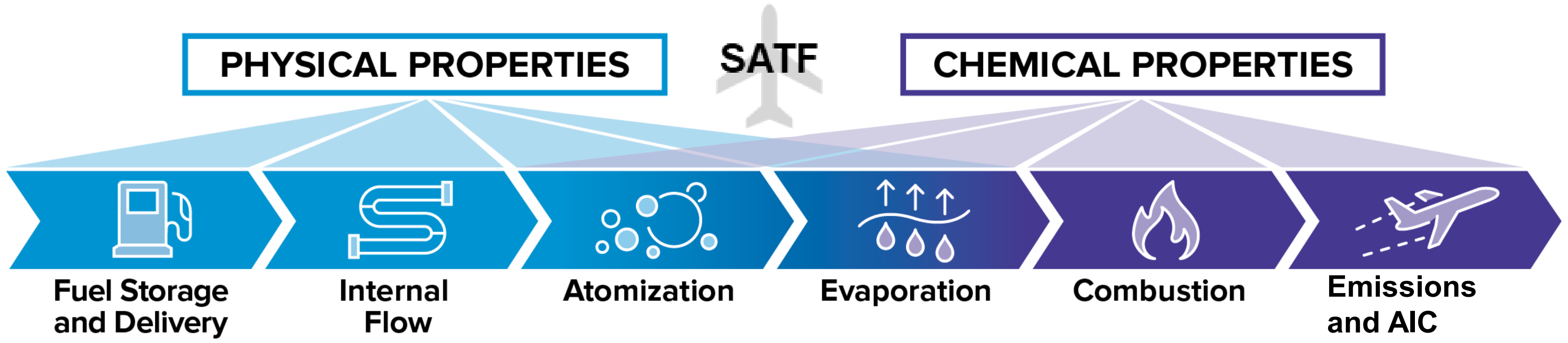
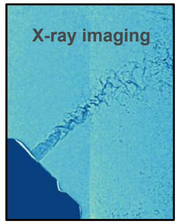
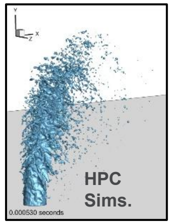
MOTIVATION: OPEN QUESTIONS



MULTIPHASE FLOWS

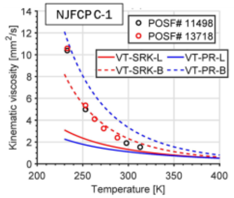

Non-proprietary atomizer

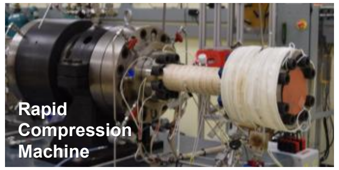




- Impact of fuel properties on spray behavior
- Change in behavior with different operating conditions
- Generation of high-quality data for model validation?

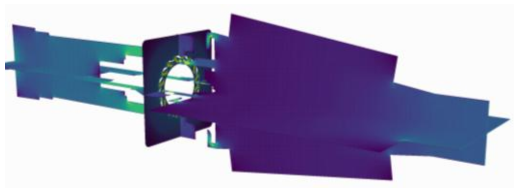
REAL FLUID BEHAVIOR AND CHEMISTRY DYNAMICS





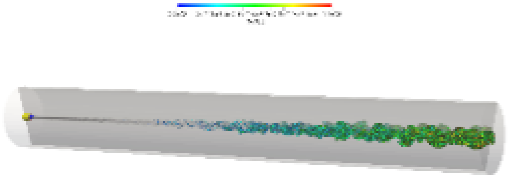
- Development of engineering models for real fluid modeling applicable for the flight map.
- Development of surrogate to mimic the multi-component fuel and predicting properties accurately
- Data generation for validating chemistry models for new fuels

HIGH-FIDELITY SIMULATIONS


Mid-size combustor CFD simulation

- Influence of fuel properties on combustor performance
- Accurately capture the physics and understand the change in figures of merit such as lean blow out and ignition change with fuels
- Utilization of data from high-fidelity simulations to develop improved sub-models

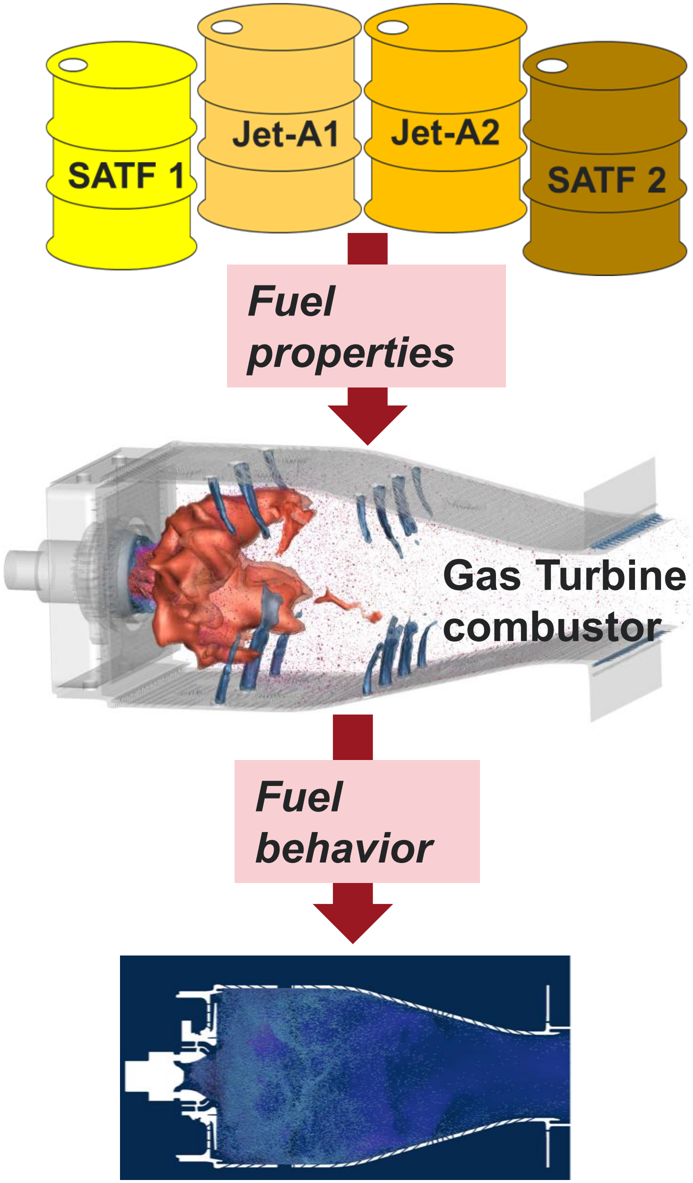
SOOT AND EMISSIONS


Soot interaction with atmosphere

- Impact on emissions (soot, NOx, water vapor) with fuel changes
- Understanding the interaction between these emissions and the atmosphere
- Development of improved models that can support prediction of aviation induced cloudiness

RELEVANCE

- Synthetic Aviation Turbine Fuels (SATF) possess properties analogous to Jet-A
- Between nominal Jet-A and C-category (alternate) fuels, 5 – 10 μm change in SMD are noted with property changes between -2% and +6% for density, +20% and +50% for dynamic viscosity, and -4% and +13% for surface tension [1, 2]
- Essential to compare their performance with Jet-A in engines as variations in fuel properties alter:
  - Combustion Dynamics,
  - Flame stability,
  - Combustor efficiency
- To measure the performance of these fuels, metrics are evaluated.
  - **Lean Blow Out (LBO)**: minimum global equivalence ratio to sustain a flame



LBO: No flame

[1] Shin, D., Bokhart, A.J., Rodriguez, N., et al., 2020, Journal of Propulsion and Power, 36(3).
[2] Wood, E. J., McGann, B., Motily, A., et al., 2020, AIAA SciTech 2020 Forum

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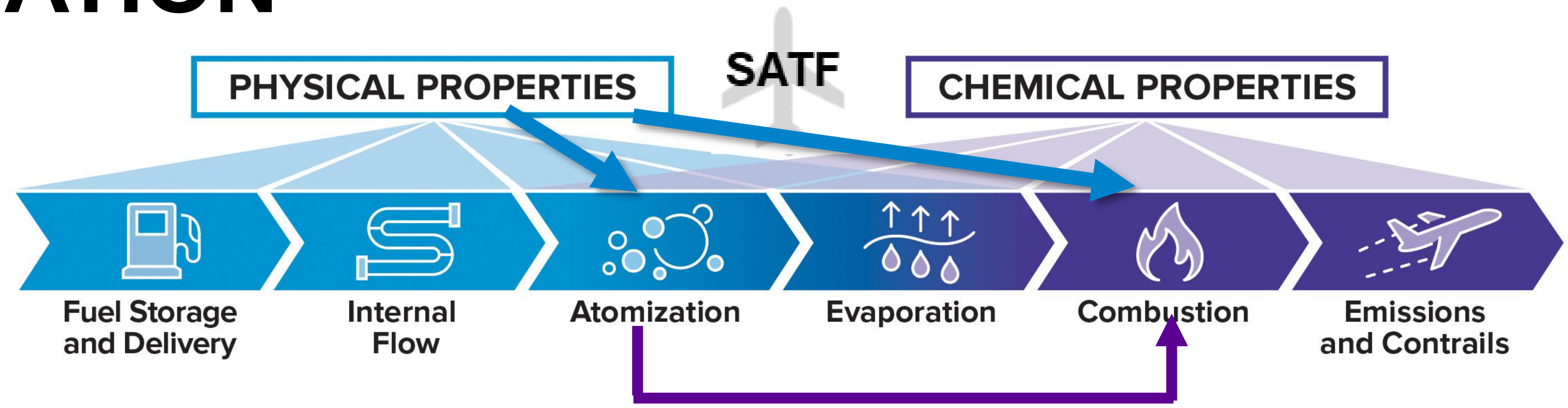
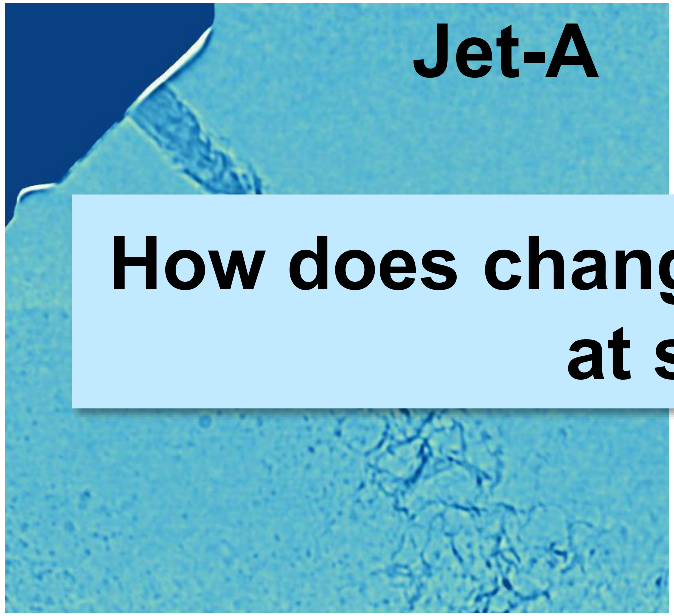
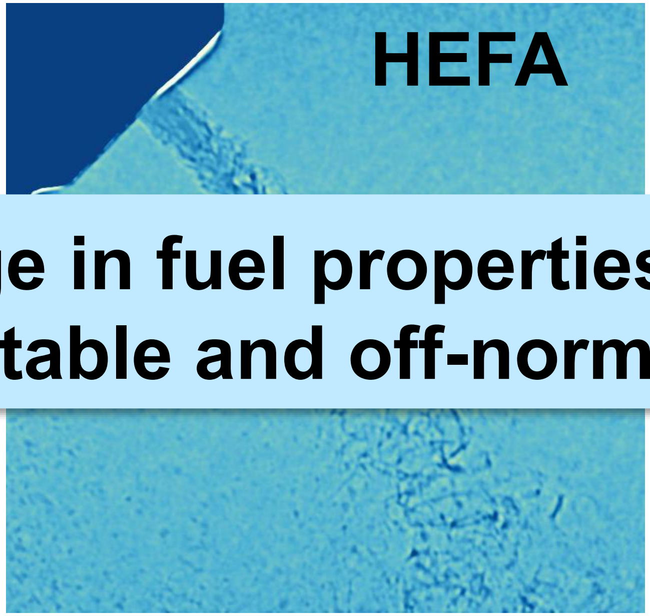
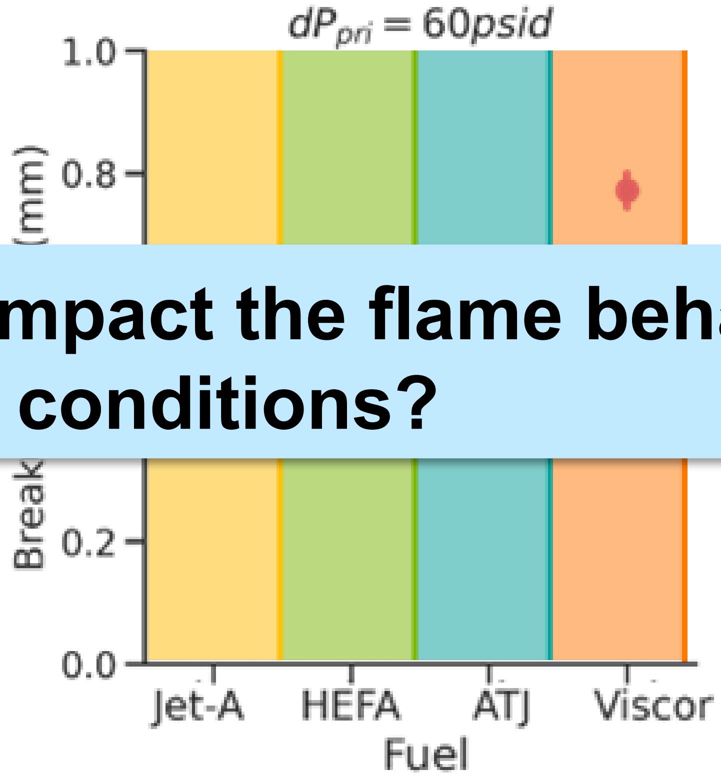
MOTIVATION









How does change in fuel properties impact the flame behavior at stable and off-normal conditions?

Videos and plots courtesy Argonne X-Ray Spray Team

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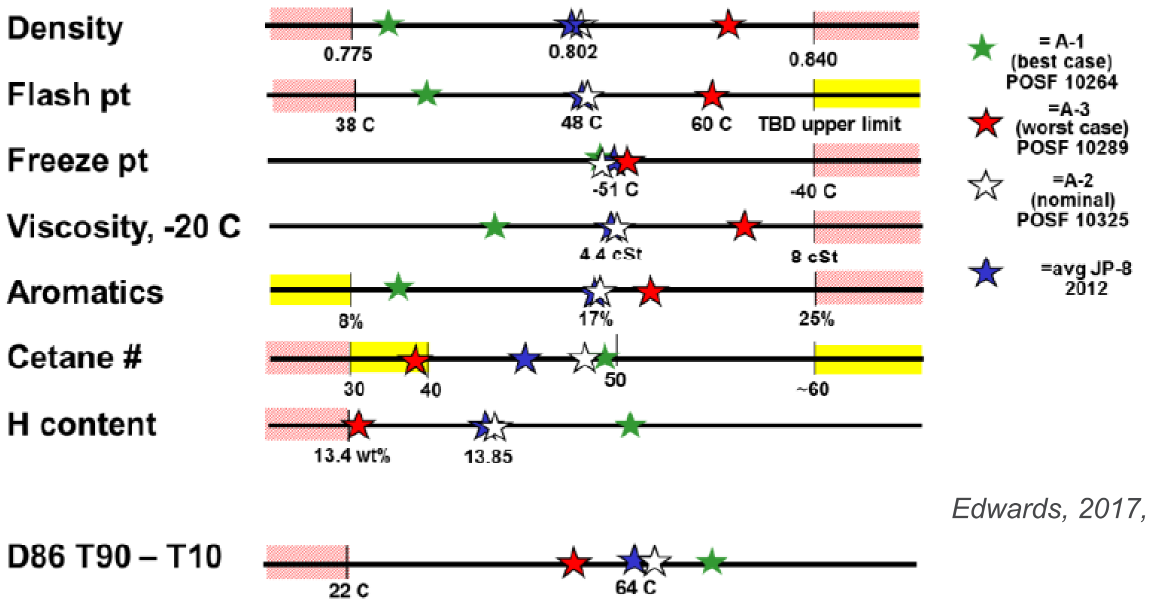
MOTIVATION

Drop-in fuels



Edwards, 2017, AIAA SciTech Forum, AIAA 2017-0146

Figure 1. Property Range of the Category A Conventional Fuels with Respect to Allowed Limits (Red Established, Yellow Proposed)

- Limits on properties to be defined as drop-in fuels
- Property variation considered here include:
  - Density: ± 3%
  - Kinematic Viscosity: ± 3%
  - Heat of combustion: ± 3%

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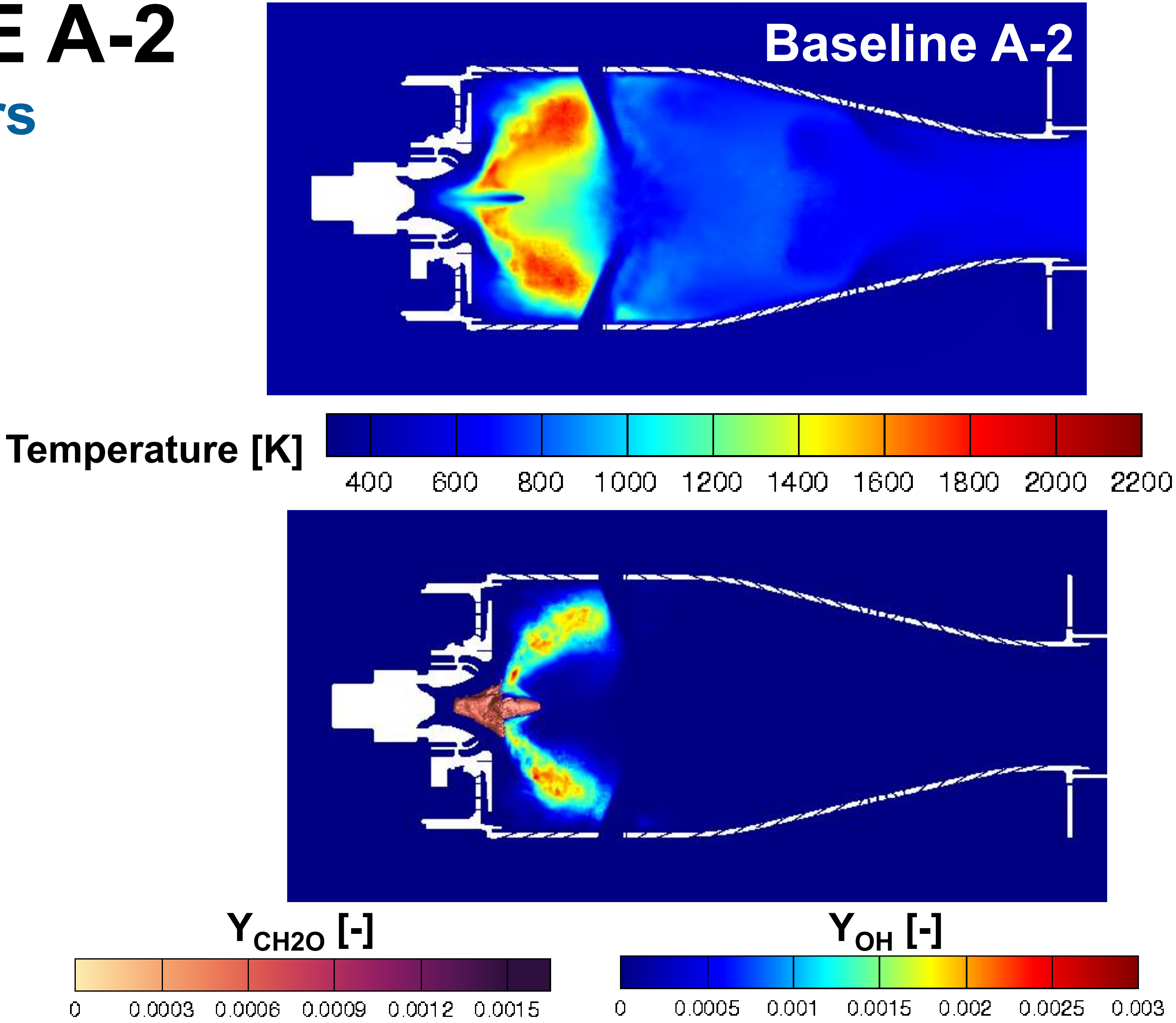
RESULTS: BASELINE A-2

Temperature and OH Contours

- Stable condition for A-2
  - $\Phi_{global} = 0.096$
- For the baseline A-2 case, the high temperature regions can be seen for a typical flame.
  - There is a slight asymmetry in the two branches of the M-flame, with a greater downstream penetration of the top branch.
  - This can be seen with the slightly higher temperature pocket downstream of the dilution air compared to the lower branch.



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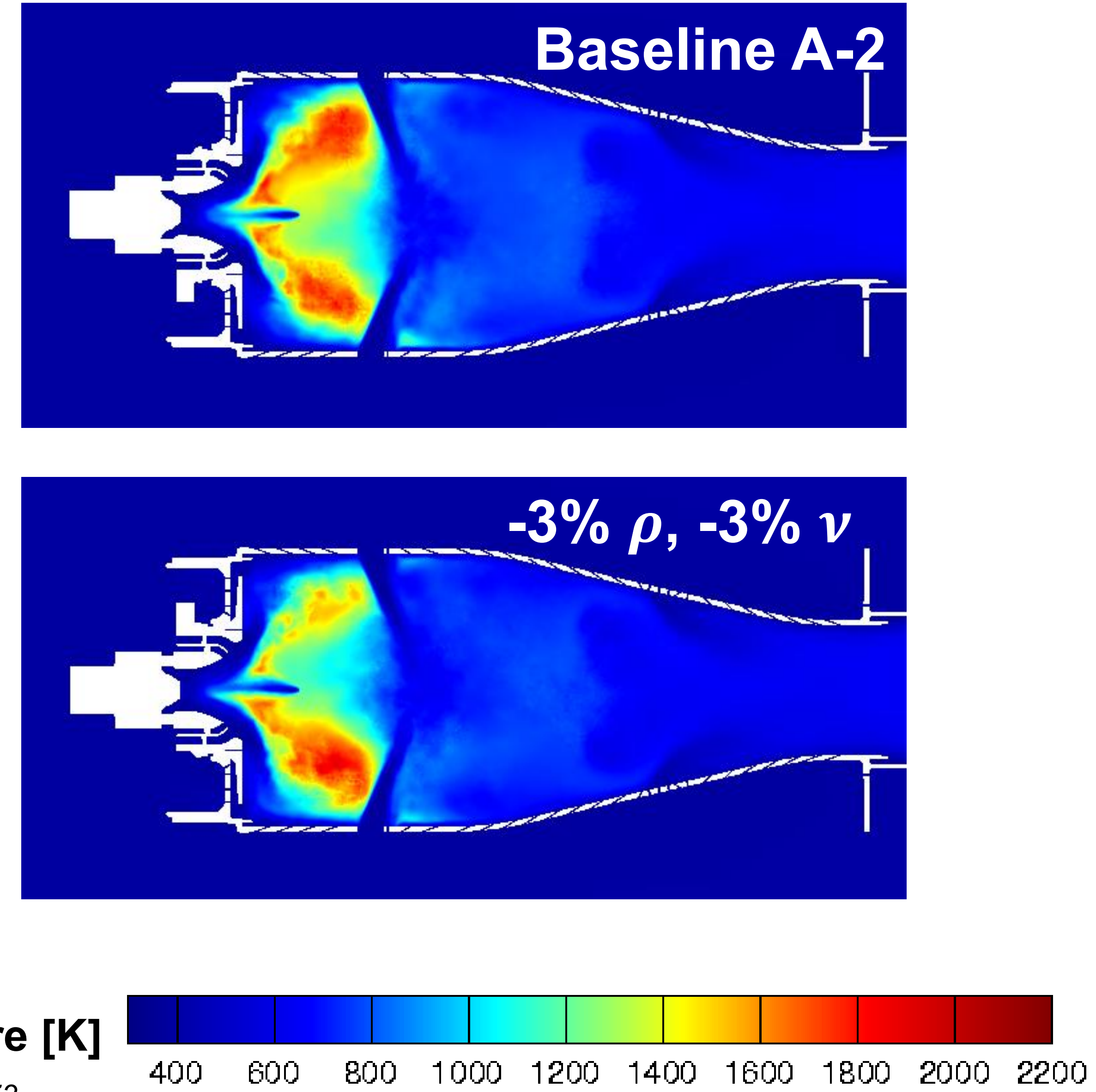
RESULTS: COMBINATIONAL CHANGES

Temperature Contours

- With a reduction in density and kinematic viscosity, enhanced asymmetry is seen
- Higher temperatures in the lower branch compared to the upper branch.
- A reduction in the density and more prominently the kinematic viscosity leads to changes in secondary atomization leading to smaller droplets.
- A potential reason to observe the enhanced flame asymmetry could be the asymmetry in fuel vapor distribution pronounced by the flow-field.



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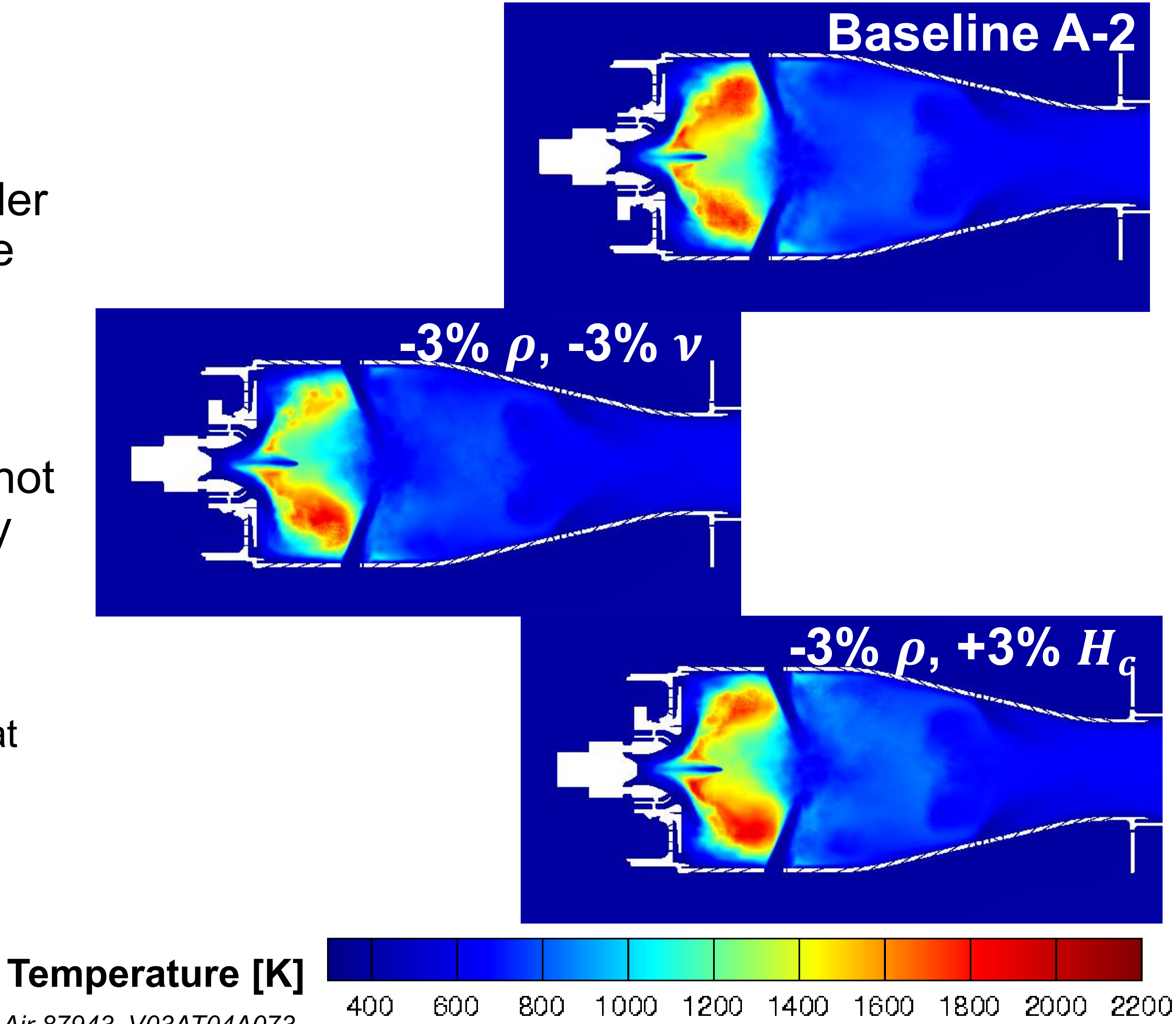
RESULTS: COMBINATIONAL CHANGES

Temperature Contours

- With a reduction in density and an increase in heat of combustion, broader and wider regions of high temperature are noted.
  - This can be attributed to the increased energy release per kg of fuel.
- It can also be noted that the flame is not as asymmetric as the reduced density and kinematic viscosity case.
  - This could be due to the higher temperatures leading to improved vaporization everywhere and the fact that density plays a less significant role in secondary atomization compared to kinematic viscosity.



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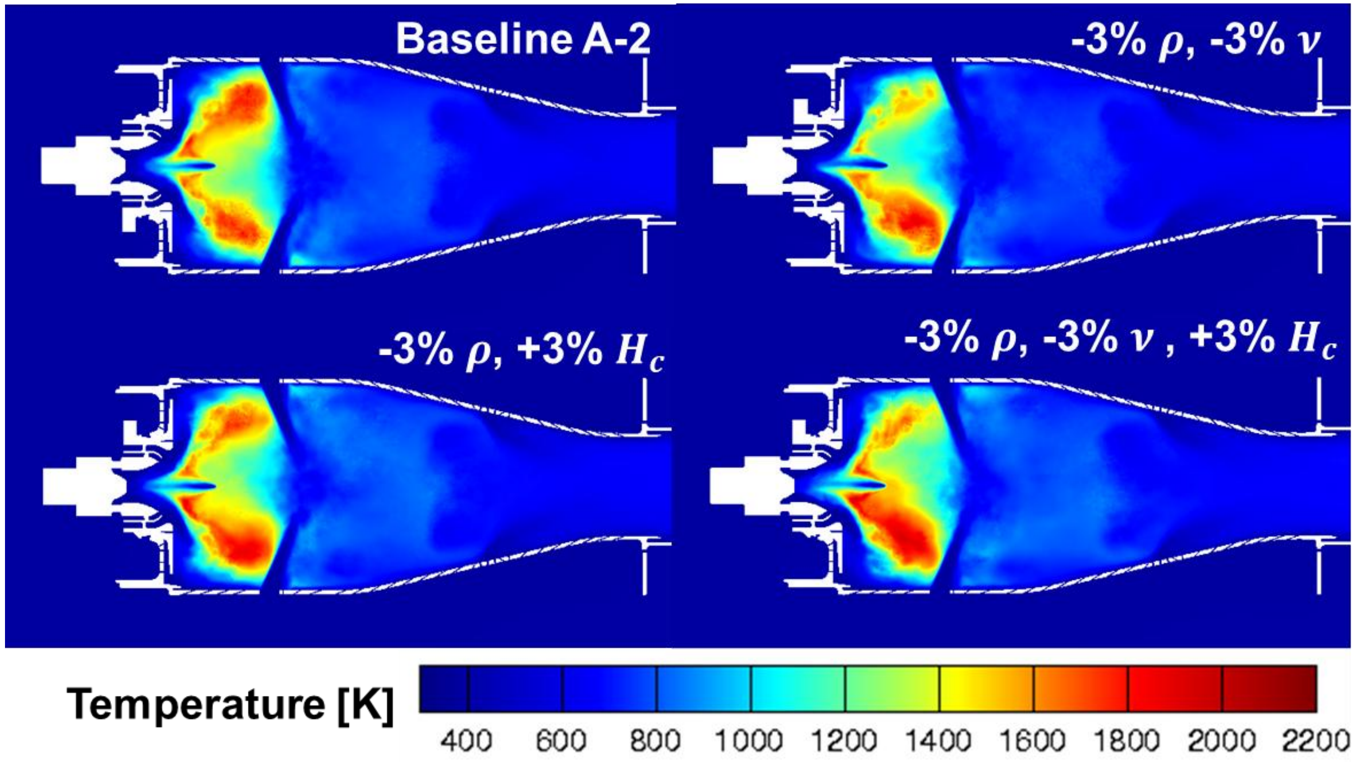
RESULTS: COMBINATIONAL CHANGES

Temperature Contours

- With a reduction in density, kinematic viscosity, and an increase in heat of combustion:
  - The temperature distribution is more asymmetric compared to the previous case
  - Continues to have wider regions of higher temperatures.
- The asymmetry is similar to what was observed with the reduced density and kinematic viscosity.



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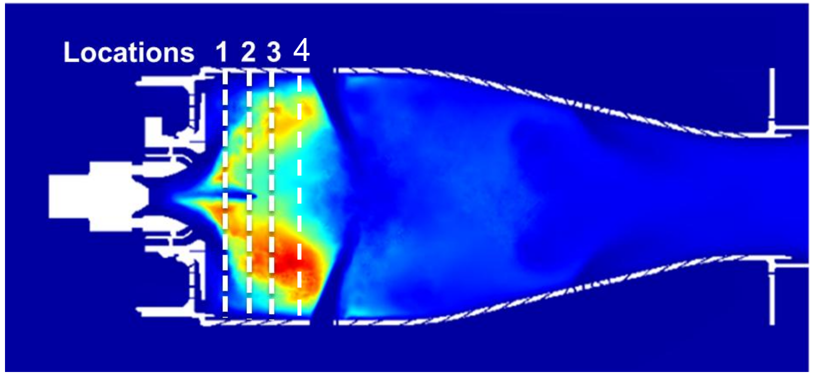
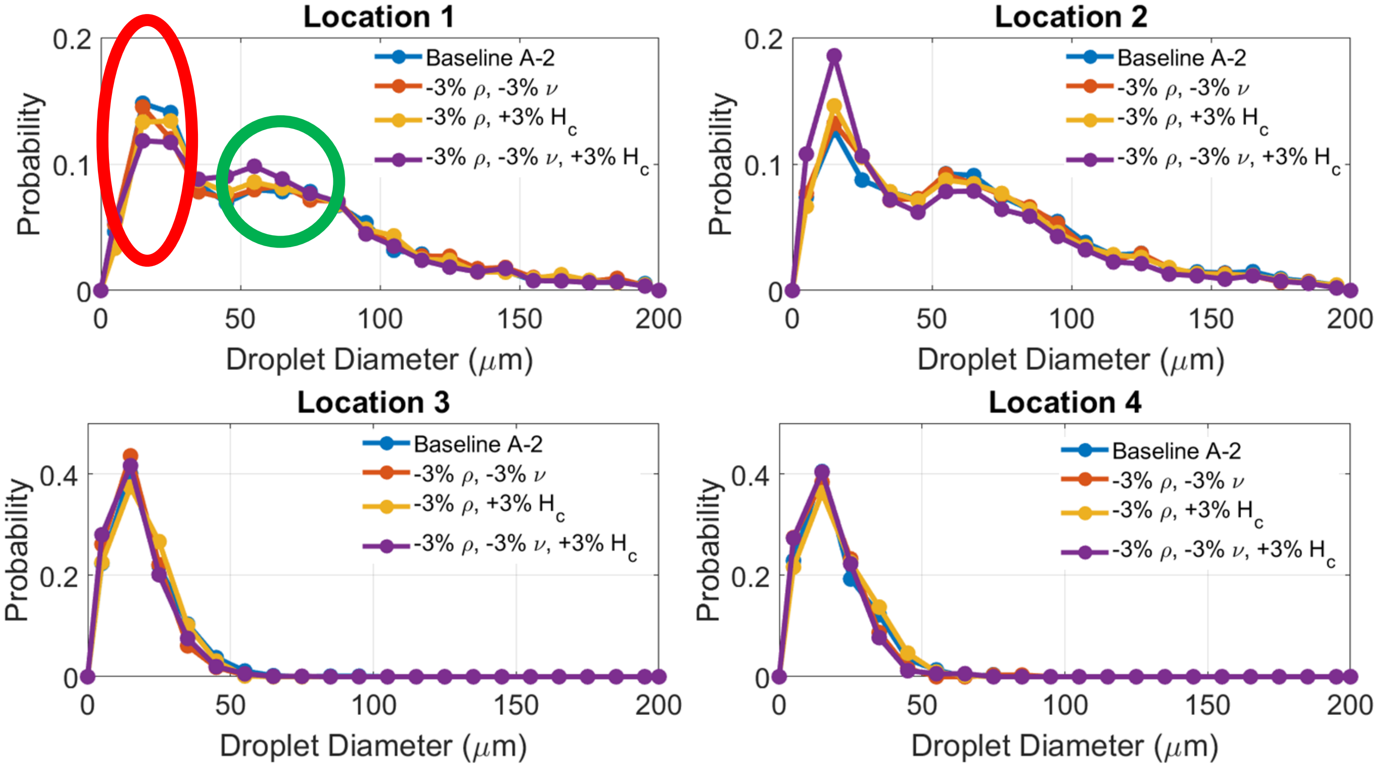
RESULTS: COMBINATIONAL CHANGES

Droplet distribution

- The droplet distribution is not significantly impacted at downstream locations.
- However, differences are observed in distributions closer to the flame anchoring location.
- For the baseline A-2, at location 1, a first peak is seen at around 20 µm. A second peak is observed at ~50 µm.
- For all the combinational changes, the peaks are seen at similar values.





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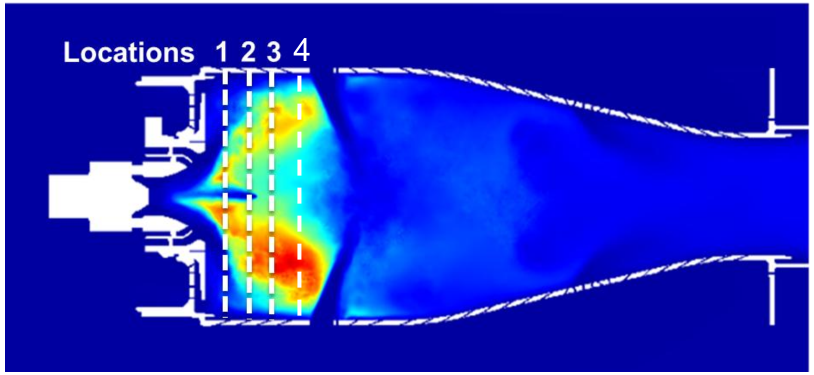
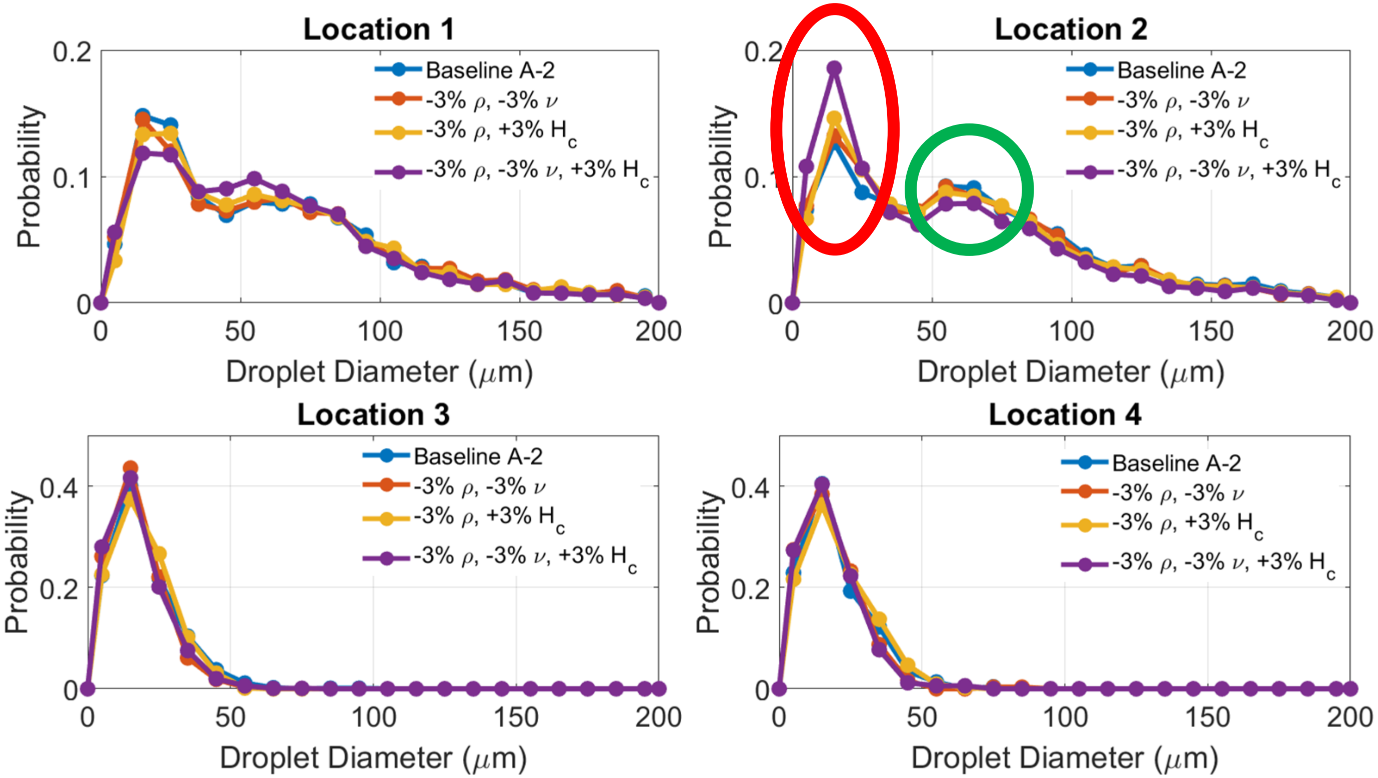
RESULTS: COMBINATIONAL CHANGES

Droplet Distribution



- At location 2, the probability of the peak at ~20 µm increases.
  - This can be attributed to improved secondary atomization for the case where density and kinematic viscosity change.
  - A bigger change is seen with an increase in Hc due to improved vaporization.



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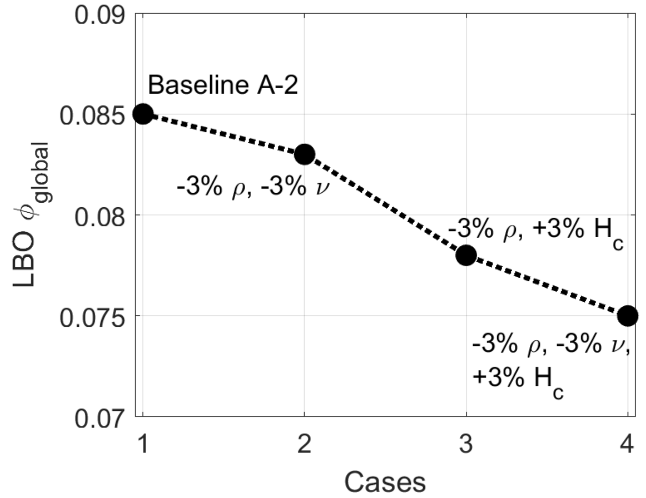
RESULTS: COMBINATIONAL CHANGES

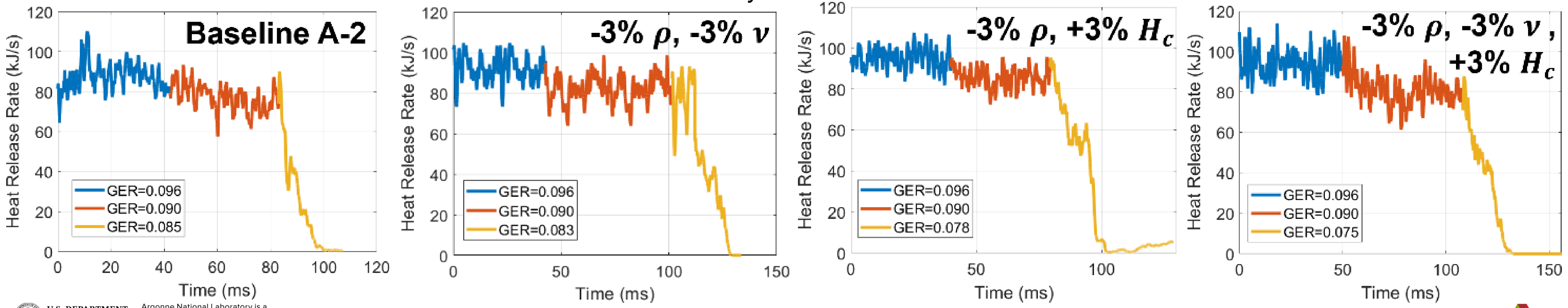
Lean Blow Out

- For finding the Lean Blow Out (LBO) Global Equivalence Ratio (GER), the GER is reduced in steps starting from 0.096 GER.
  - For every step-down, the initial condition is the previous steps last time step.
  - Every GER operating condition is run for 30 ms (~2 flow-through times)
  - The heat release rate is continuously monitored. During the step-down process, beyond a certain GER, the heat release rate starts decreasing rapidly towards zero. This GER is the LBO GER.
  - After the 0.005 GER step-down, for the combinational change cases, additional simulations were run to delineate the LBO GER for each case
  - Every case is re-rerun with GER = 0.096, then GER = 0.09 and LBO GER



LBO equivalence ratio for combinational changes

Heat release rate variation with time to identify LBO GER



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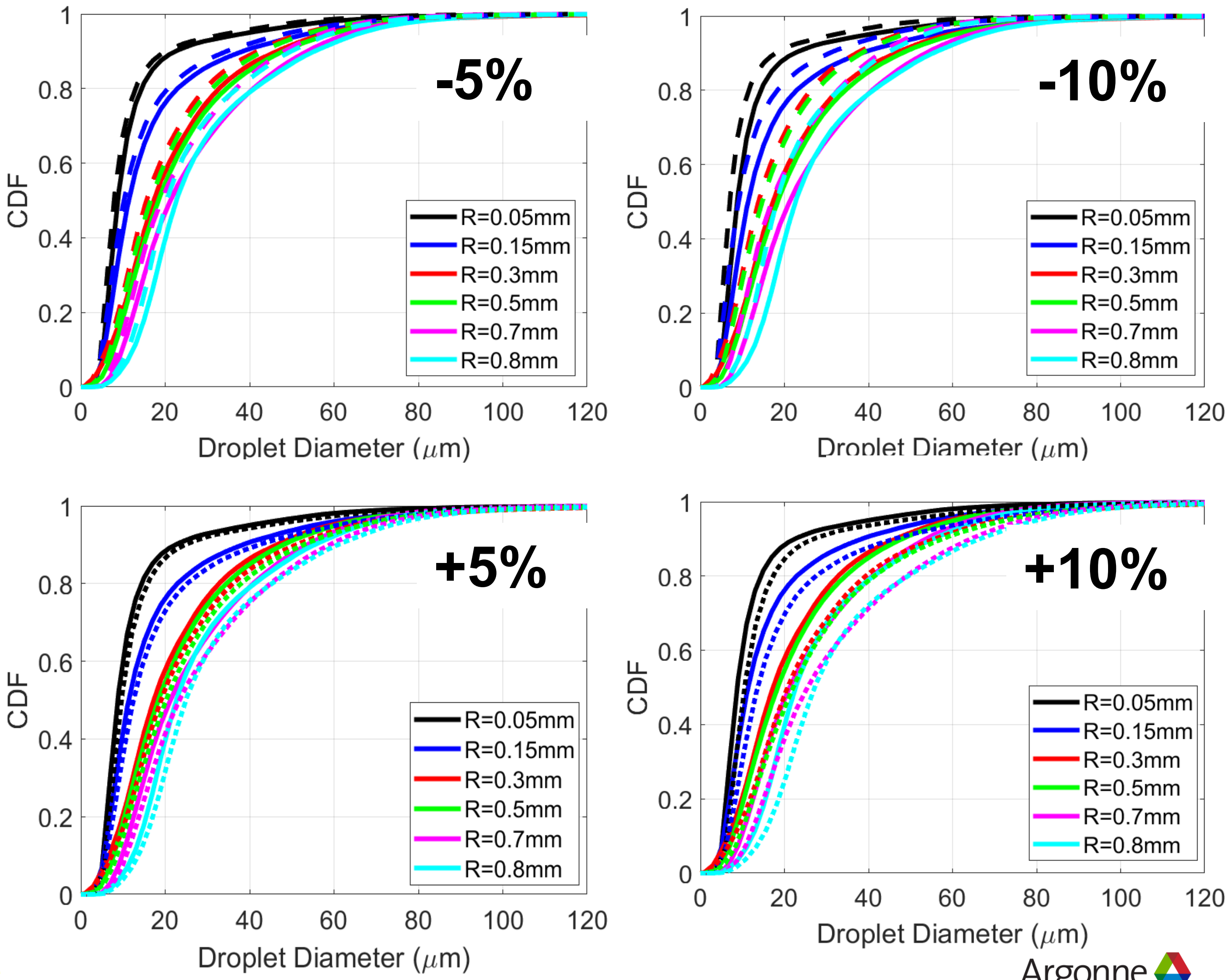
CFD MODEL DEVELOPMENT

Droplet size initialization for the current study

- Changing the mean of the droplet diameter by ±5% and ±10%, retaining the same distribution
- No changes to:
  - Fuel physical properties
  - Spray velocity initialization
  - Chemical properties
  - Chemical mechanism
  - Fuel mass flow rate



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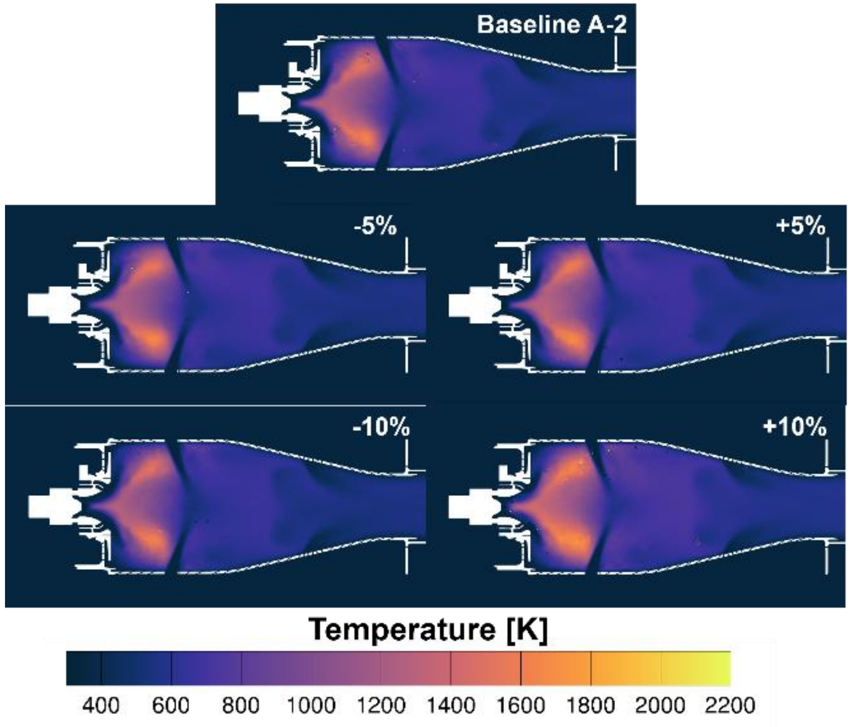
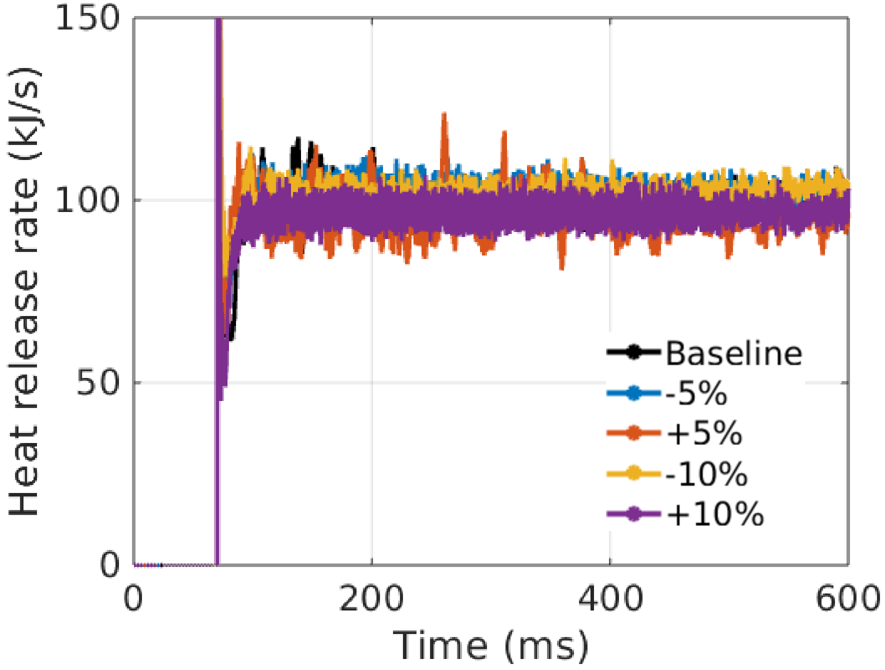
GLOBAL CHARACTERISTICS

Temperature distribution and heat release rate

Center plane slice with temperature contours



Heat release rate variation with time for all cases



- Center plane temperature distributions qualitatively look similar for all cases.
- The asymmetric behavior is seen from all the temperature distributions.
- The heat release rate, which is a global metric, shows no significant differences
  - Global behavior may not be significantly impacted by the change in droplet sizes used in this study

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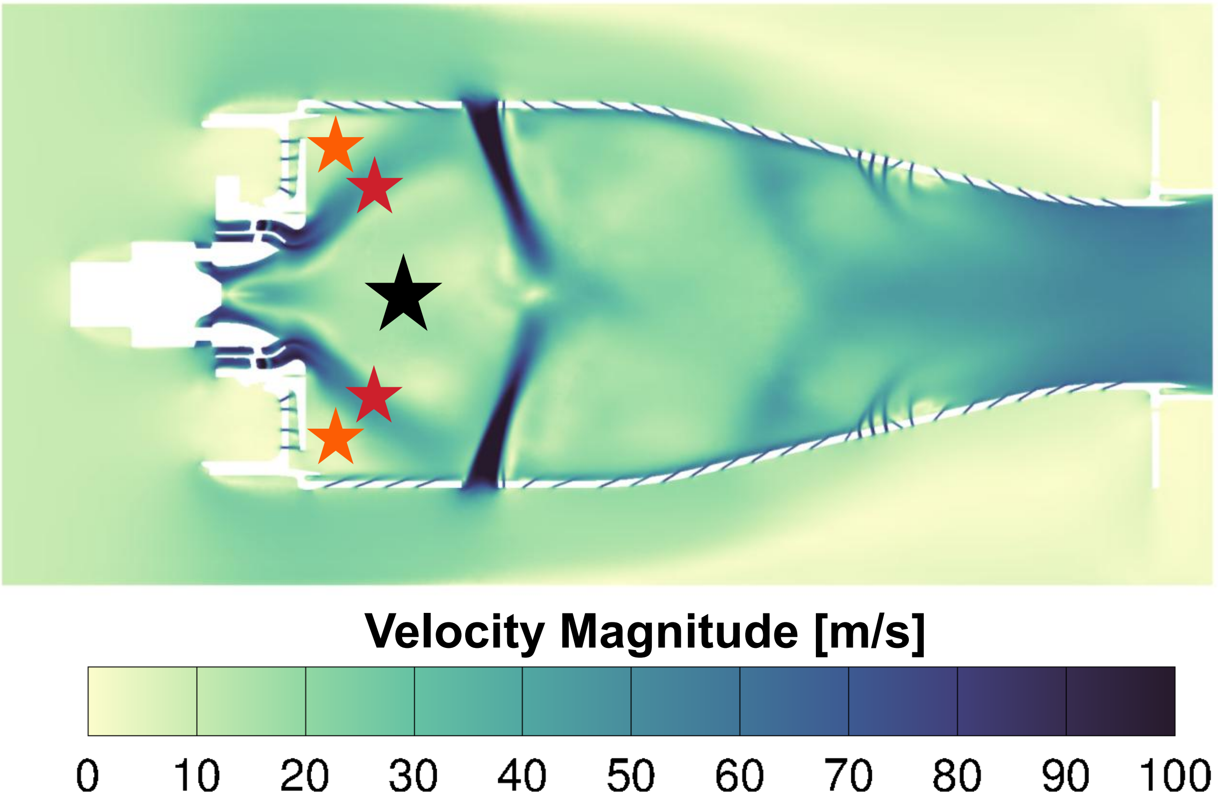
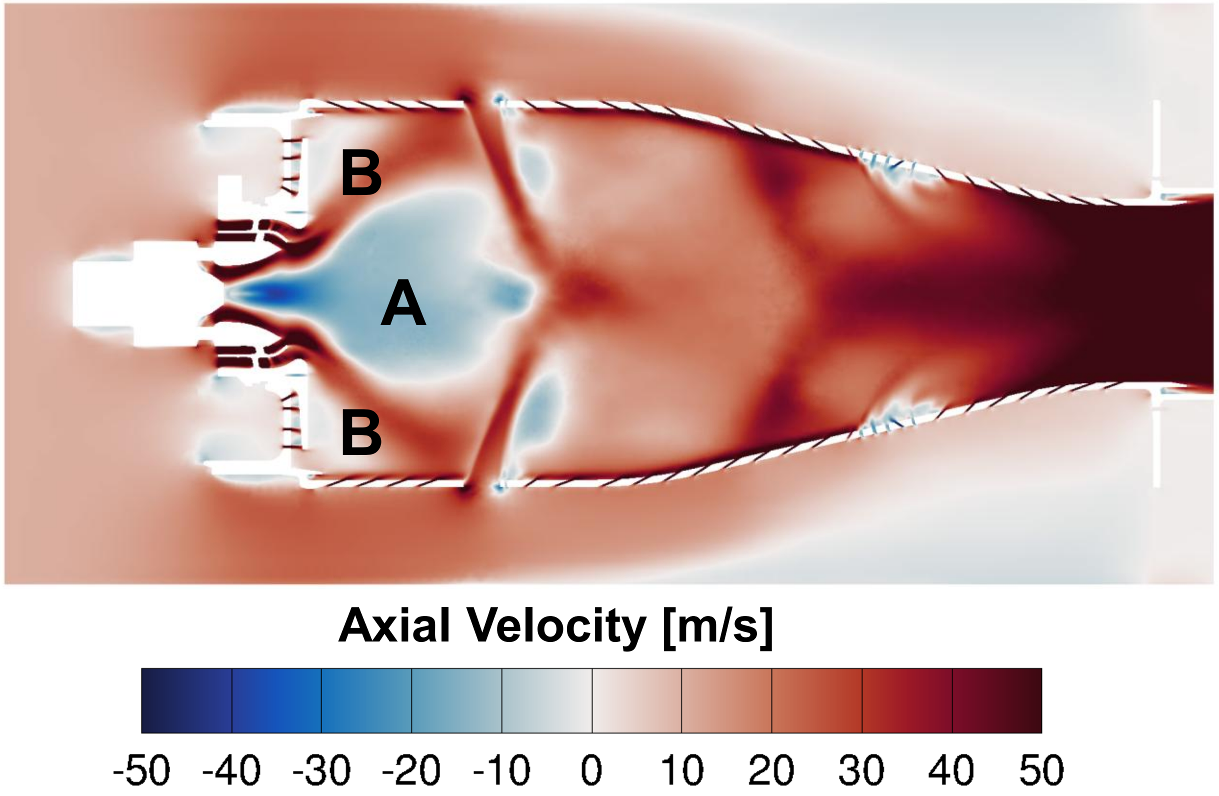
BASELINE A-2 CASE

Flow-field and region identification





★ Central recirculation zone

★ Swirling flow shear layers

★ Corner recirculation zones

Region A ★

Region B ★★

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DROPLET SIZES – REGION A (CRZ)

Comparison between baseline and ±5%, ±10%

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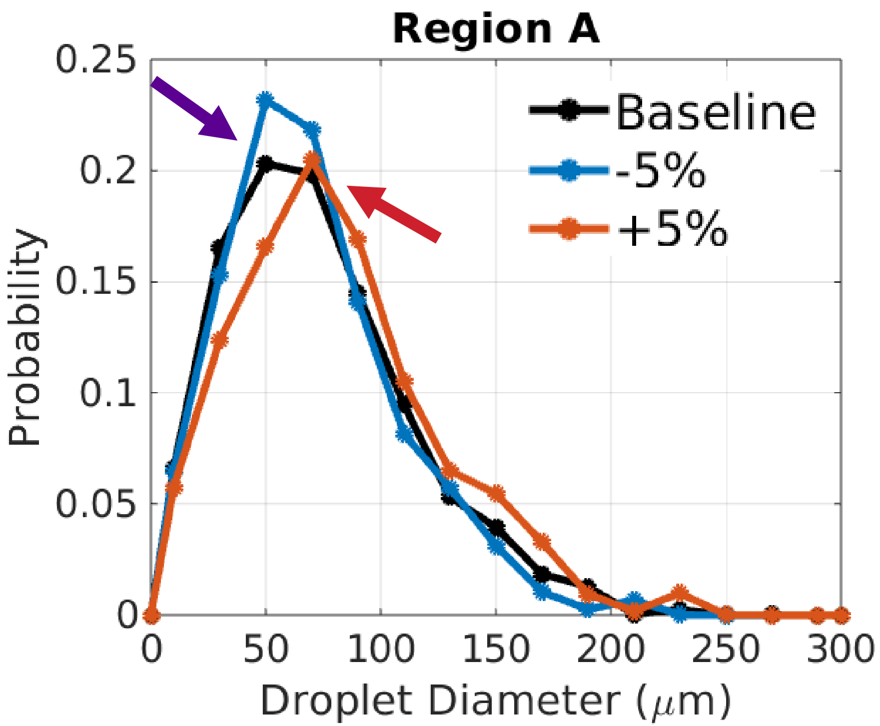

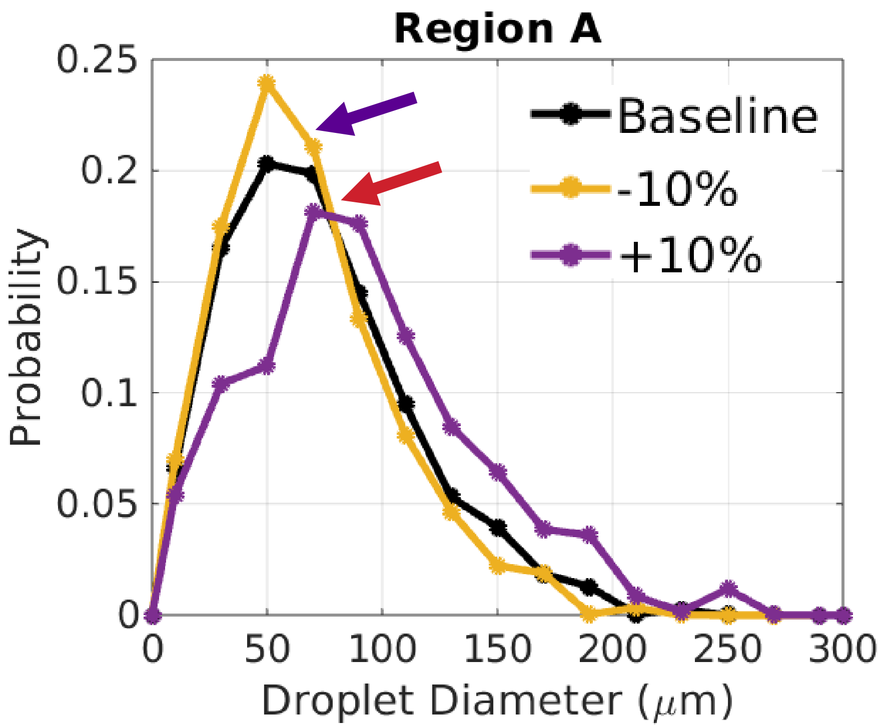

- The peak of the baseline, -5% and -10% occur at 50μm.
- For the +5%, +10%, the distribution and peak move towards a higher value
  - The larger unevaporated droplets survive the flame
  - For the -5%, -10% and baseline, smaller droplets may not survive the flame.

DROPLET SIZES – REGION B

Comparison between baseline and ±5%, ±10%

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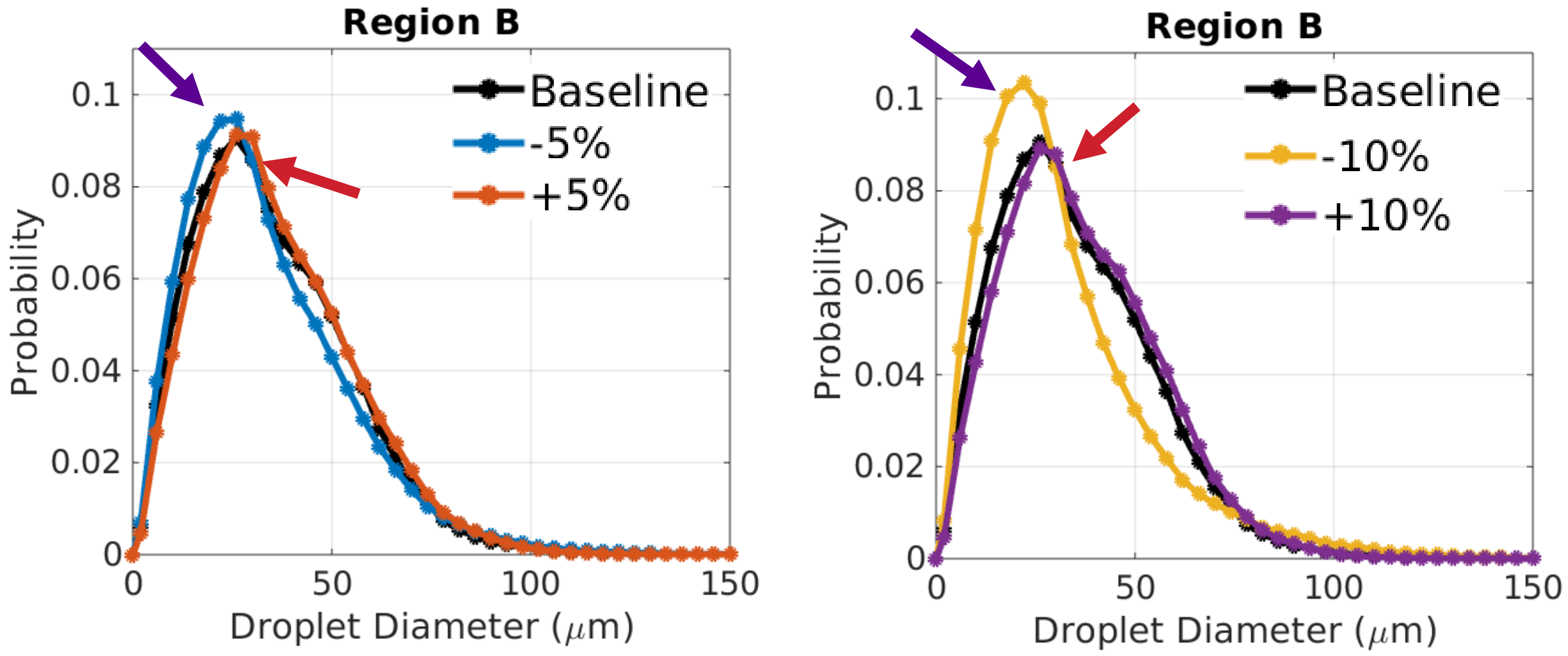
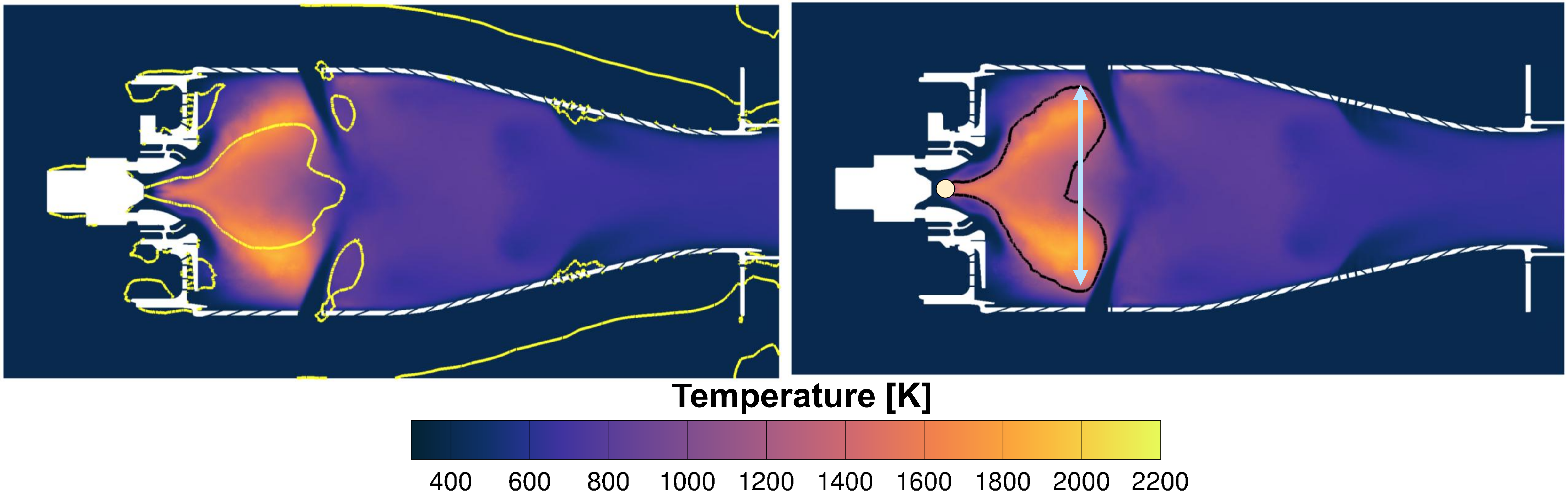


- +5% and +10% distributions are similar to the baseline
- The distribution of the -5% and -10% can be seen to move towards smaller sizes, the deviation is low.
  – The smaller droplets vaporize and reach an equilibrium between new droplets entering this region and vaporization of the droplets.

BASELINE A-2 CASE

Temperature, flame anchoring, flame spread



Zero axial velocity iso-contour

1200 K iso-contour – defining the flame shape

Flame anchoring location – axial location of the 1200 K iso-contour closest to the nozzle

Flame spread – maximum distance in the radial direction of the 1200 K iso-surface

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FLAME BEHAVIOR

Comparison between baseline and ±5%, ±10%

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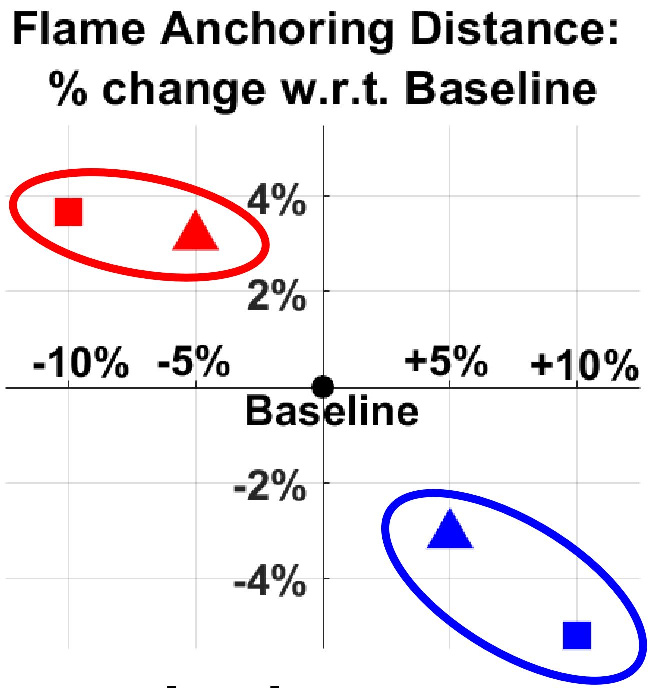
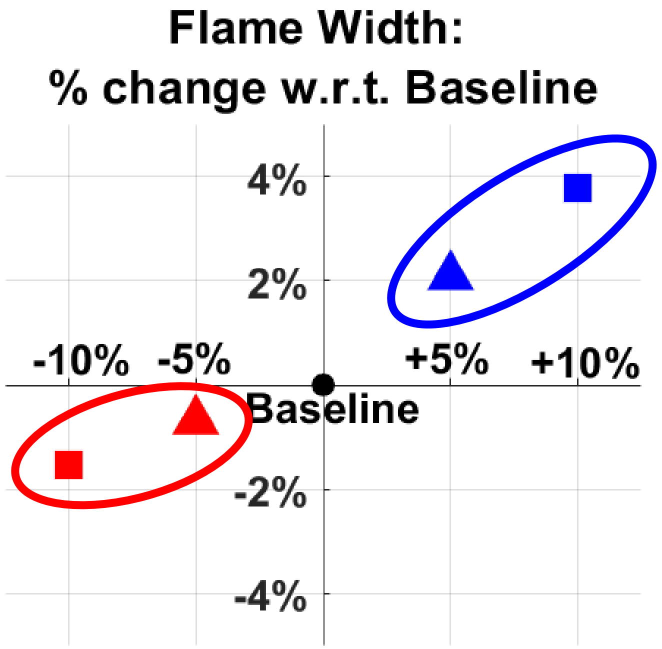




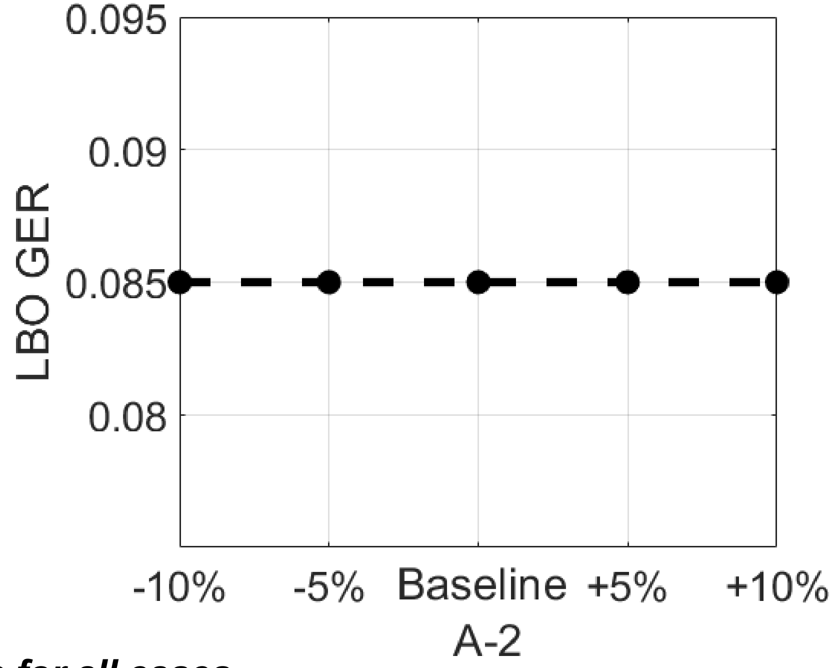
- **For flame anchoring:**
  - —Decrease in droplet sizes -> the location moves slightly downstream
  - —Increase in droplet sizes -> the location moves slightly upstream.
- **For flame width:**
  - —Decrease in droplet sizes -> the spread is lower -> slightly more compact flames
  - —Increase in droplet sizes -> the spread is higher

LEAN BLOW OUT SIMULATIONS

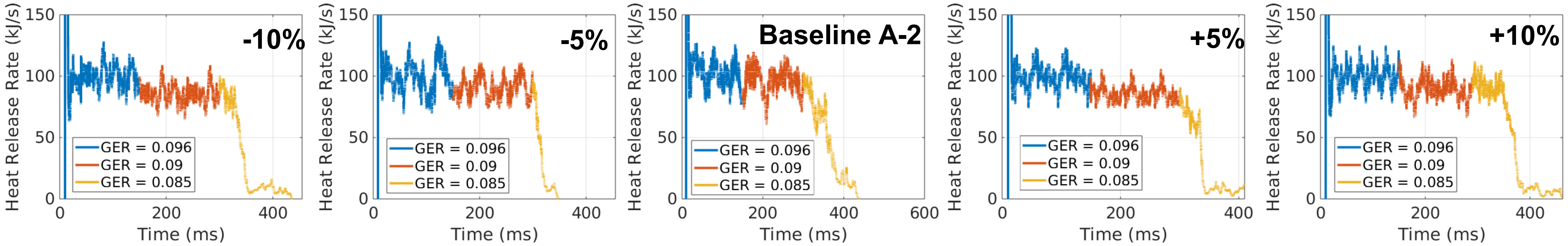
LBO prediction for all cases

- To ascertain the LBO GER, the GER is systematically reduced as 0.096 -> 0.09 -> 0.085.
- All five cases experience LBO at the same GER step of 0.085.
  - The LBO range for these cases is 0.085<=GER<0.09
- Localized variations noted for spray droplets and flame shape; the global behavior is not impacted by the change in the droplet sizes studied here.

LBO GER for all cases



Heat release rate variation with time for all cases



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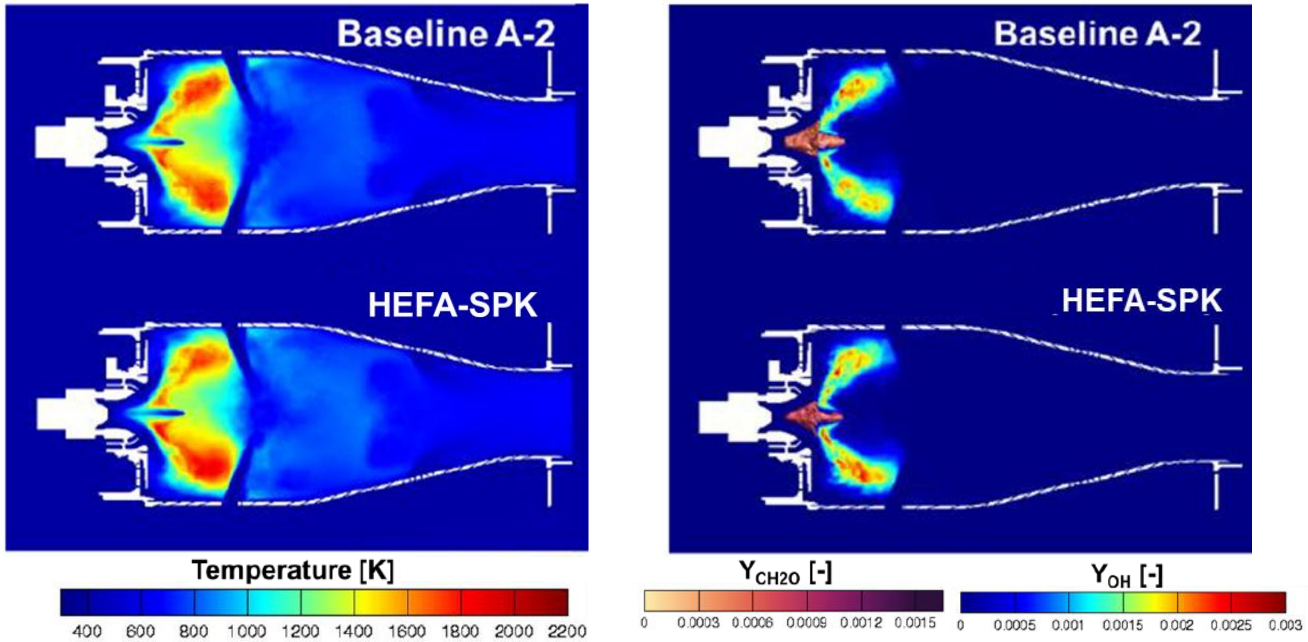
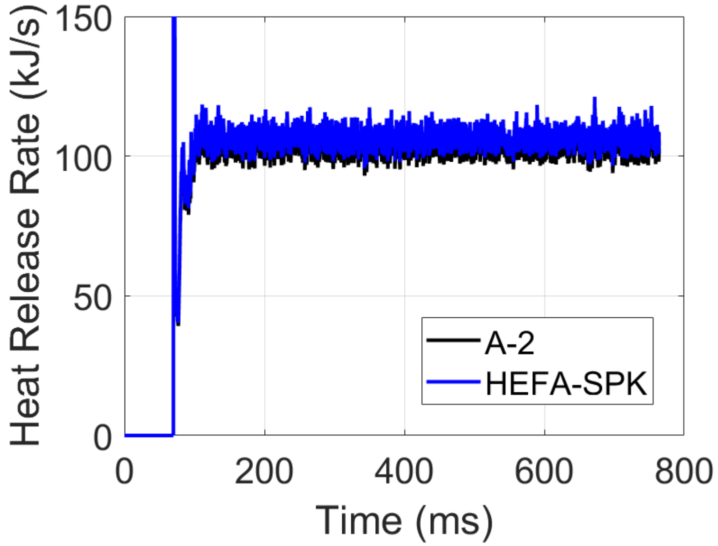
COMPARISON BETWEEN FUELS

Similar flow-fields and global behavior between HEFA and Jet-A

- Operating condition: T_{air} = 394 K, P = 2 atm
- Two fuels compared: Jet-A, HEFA-SPK
- Center plane temperature distributions qualitatively look similar.
- The heat release rate, which is a global metric, shows no significant differences
  - The mean heat release rate for HEFA-SPK is 3.6% higher than Jet-A
- The species' distribution (OH, CH_2O) is similar for both fuels.





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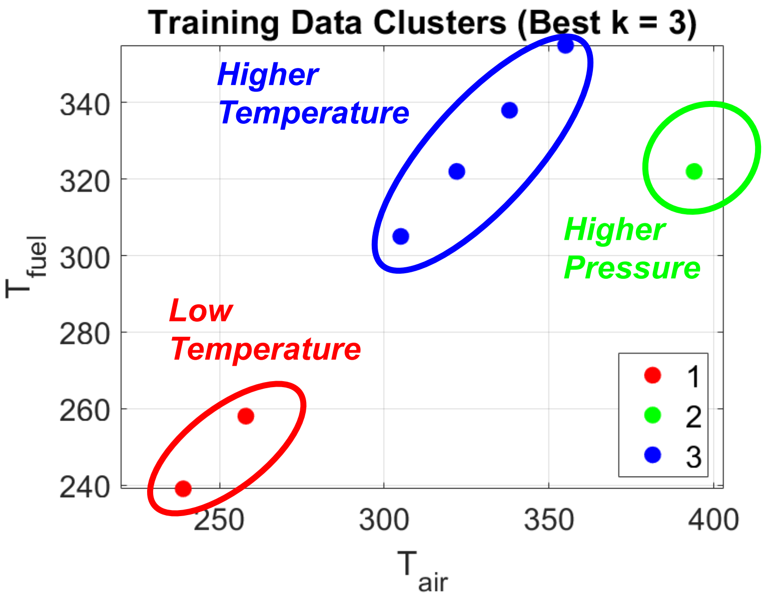
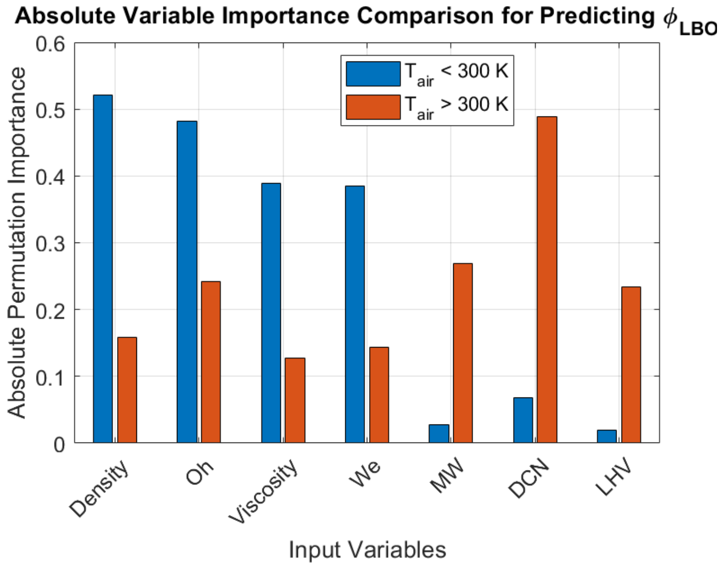
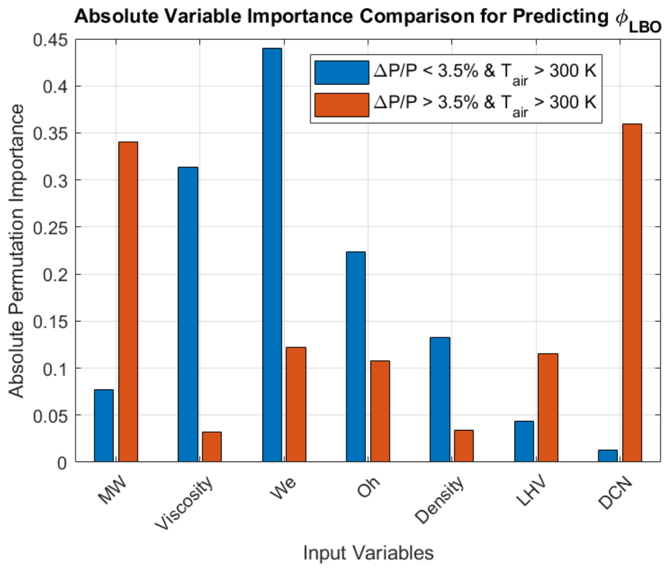
UNRAVELING UNDERLYING PHYSICS

Model development for LBO behavior at varying operating conditions

- Model for assessing the importance of different parameters on LBO
  - Cluster the input space (k-means) to train one regression model (random forest) for each cluster
  - Compute permutation importance to assess which parameters have a stronger influence on each cluster
- Identified clusters separate the operating space based on air temperature and pressure drop within the combustor.
- Comparing clusters 1 and 2+3
  - At lower air temperature, fuel physical properties and atomization influence LBO.
  - At higher temperature, chemical properties influence LBO
- Comparing clusters 2 and 3
  - At lower pressure drop, fuel physical properties and atomization influence LBO.
  - At higher pressure drop, chemical properties influence LBO







MW = Molecular Weight   Oh = Ohnesorge Number   We = Weber number   LHV = Lower Heating Value   DCN = Derived Cetane Number   LBO = Lean Blow Out

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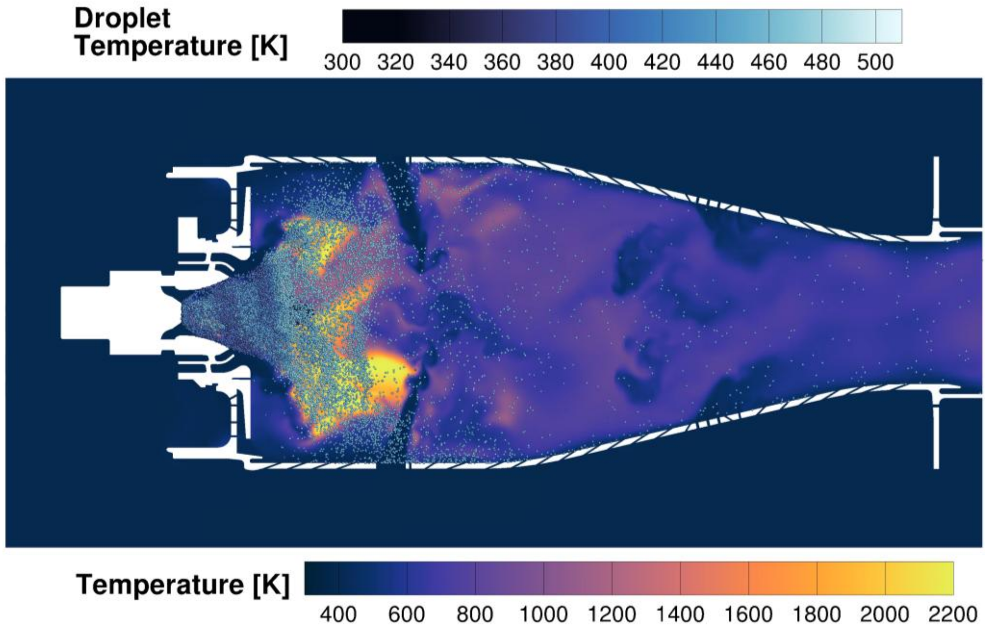
KEY TAKE-AWAY AND FUTURE WORK

How does change in fuel properties impact the flame behavior at stable and off-normal conditions?

- Fuel property impact flame behavior
- Changes in droplet sizes may or may not lead to significant changes
- Global behavior such as heat release rate and lean blow out behavior along with local behavior shed light into dynamics
- Future Work:
  - Expand the analyses to operating conditions where pronounced impact of atomization is observed
  - Create an operability map relating fuel properties to lean blow out global equivalence ratio



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THANK YOU!

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