ASCENT Project 65B

Fuel Testing Approaches for Rapid Jet Fuel Prescreening

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Cost Share Partner: Convergent Sciences

Objective:

Develop a new compact test rig (M1 combustor) which can complement ASTM D4054 evaluation and qualification guidelines for prescreening of fuels prior to Tier 3 & 4 tests.

- The M1 combustor has the potential to carry out these tasks at much reduced fuel volumes (~gallons vs. ~hundreds of gallons) in a simplified and open architecture.

Project Benefits:

- Assess the combustor performance of SAF using small volumes prior to fuel intensive Tier 3 & 4 tests
- Accelerate fuel certification process for SAF
- Provide well characterized combustor to community for SAF combustion performance evaluation

Research Approach:

- Development of a compact prescreening combustor (M1)
- X-ray diagnostics at Argonne's Advanced Photon Source
- Carry out advanced laser & optical diagnostics
- Support numerical simulations (Argonne team)
- OEM and national laboratory buy-in and collaboration

Establish a common and accessible combustor to

- enable fuel producers and OEMs to individually predict confidence levels using low quantities of fuel
- enable access to combustor performance data without a centralized combustor with large operational overhead
- contribute to various fast track processes for fuel certification
- provide platform for other combustor tests of SAF (i.e., emissions, etc.)

Major Accomplishments (to date):

Accomplishments in Year II

- Collaboration with numerical simulation team at Argonne
- Measurements of cold-start ignition performance to investigate effects of nozzle geometry
- Argonne APS measurement campaign – completed September 2021
- Initial analysis of x-ray spray imaging data collected at Argonne's APS
- Implementation of spray injector characterization into combustor simulation (using x-ray spray data)

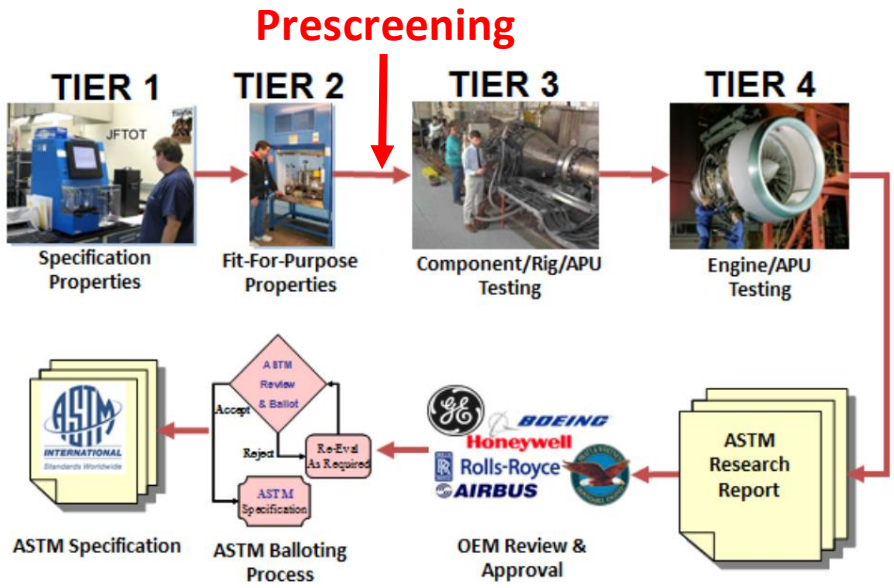
Future Work / Schedule:

Continued Characterization of M1 combustor

- Analysis of x-ray spray imaging data taken at Argonne's APS
- Perform lean blow out testing with small nozzles to characterize shift in combustion behavior
- Simultaneous PLIF and PIV to study flame behavior near lean blow out
- Continued collaboration with numerical simulation team at Argonne
- Additional X-ray diagnostics at Argonne's APS (multiple fuels)

This research was funded by the U.S. Federal Aviation Administration Office of Environment and Energy through ASCENT, the FAA Center of Excellence for Alternative Jet Fuels and the Environment, project 65B through FAA Award Number 13C-AFJE-UI-030 under the supervision of Anna Oldani. Any opinions, findings, conclusions or recommendations expressed in this this material are those of the authors and do not necessarily reflect the views of the FAA.

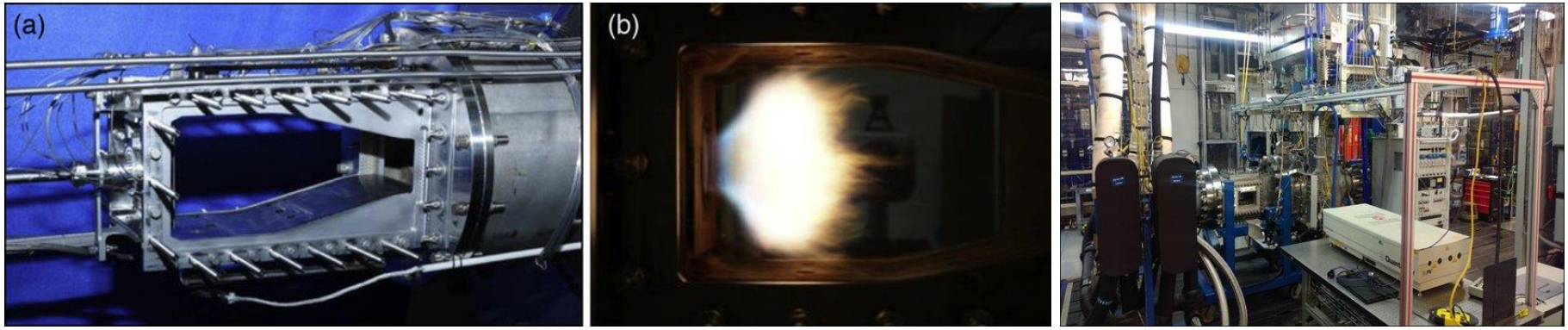
Combustor Prescreening



Fuel & Additive Approval Process

Combustor Prescreening

- Referee Combustor at AFRL was suggested as an effective tool for combustor performance pre-screening through the NJFCP program
- The Referee Combustor is in a secure military facility and requires large amount of fuel (~100s of Liters)



Referee Combustor – National Jet Fuel Combustion Program (AFRL, WPAFB)

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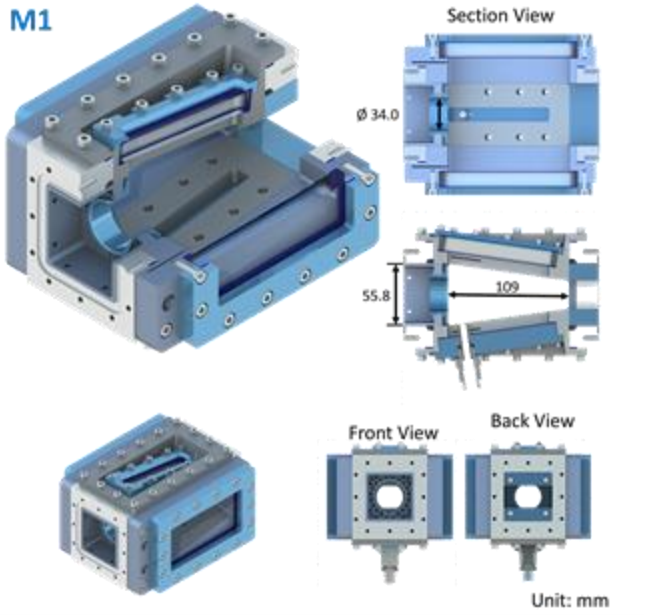
M1 Combustor: Prescreening and Research

M1 Combustor Overview

- M1 is a well-characterized, compact test combustor environment
- Low startup and infrastructure costs
- Ample optical access for characterization
- Portable architecture for transport to different testing locations

Fuel Prescreening

- Prescreening with limited fuel quantities (~5 gallons vs. hundreds of gallons)
- Investigation of technologies for integration of SAF
  - Study of combustion physics, liquid-gas interaction, emissions, etc.
  - Application of new diagnostics not possible on other rigs



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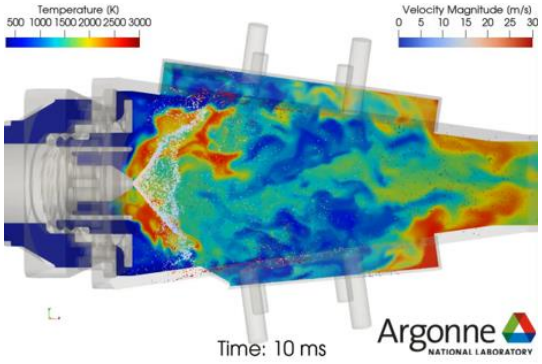
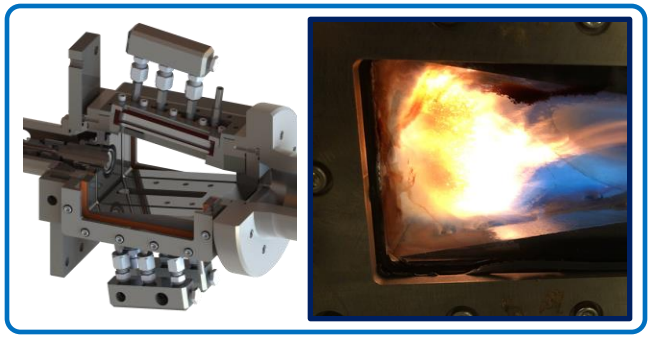
M1 Combustor Program Overview

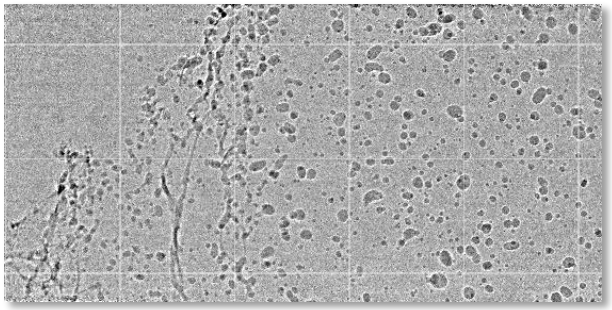


High Performance Computing (Argonne)



M1 Combustor

High Altitude Chamber (ARL)

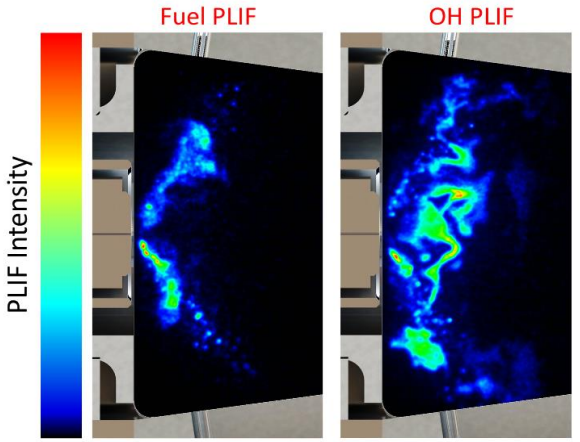


High-Speed X-Ray Imaging (Argonne)

Argonne NATIONAL LABORATORY

Support from Argonne, ARL, and FAA

- Open architecture available for the community
- Diagnostics & computation support from federal labs for characterization of combustor behavior



High-Speed Diagnostics (UIUC)

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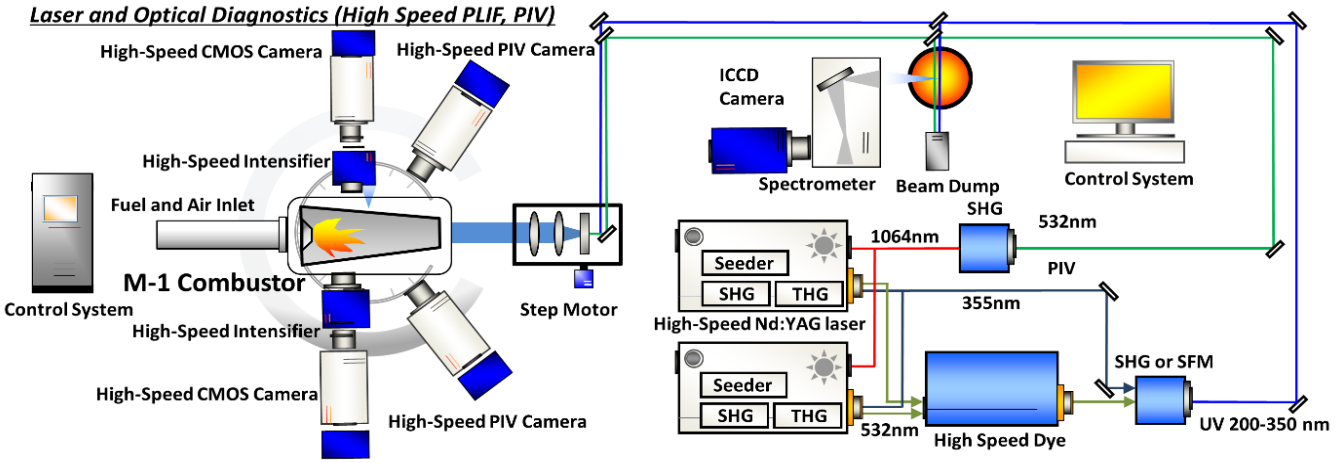
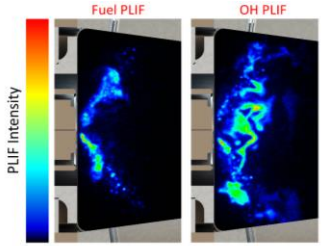
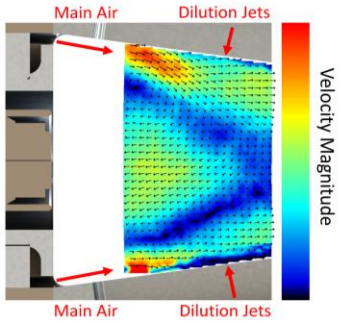
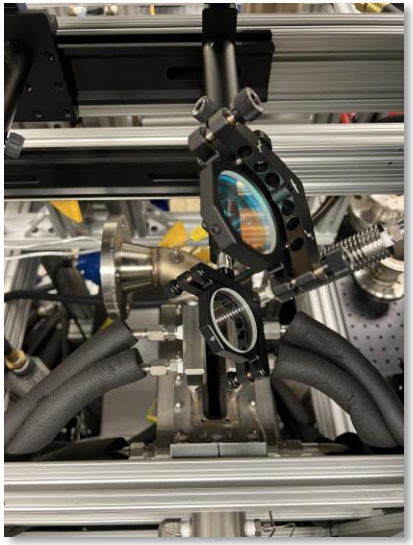
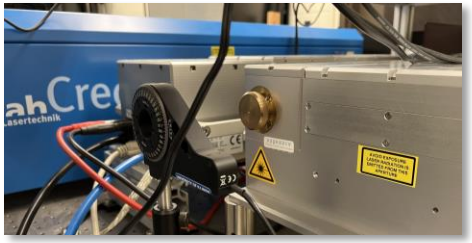
Laser & Optical Diagnostics: UIUC

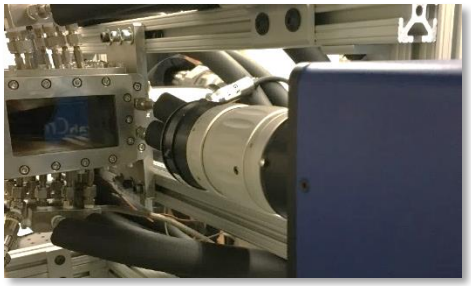


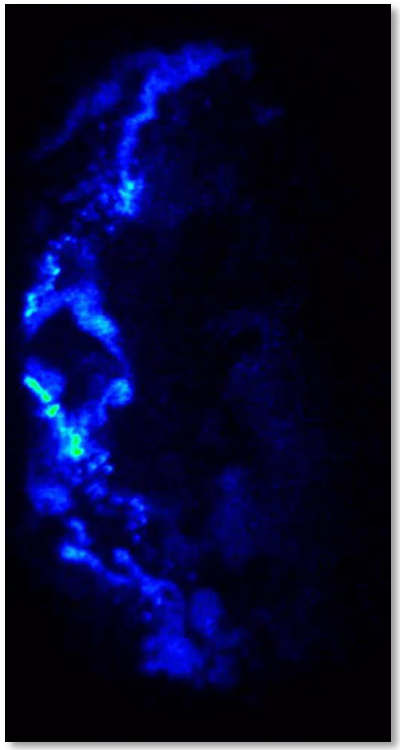












OH PLIF (UIUC)

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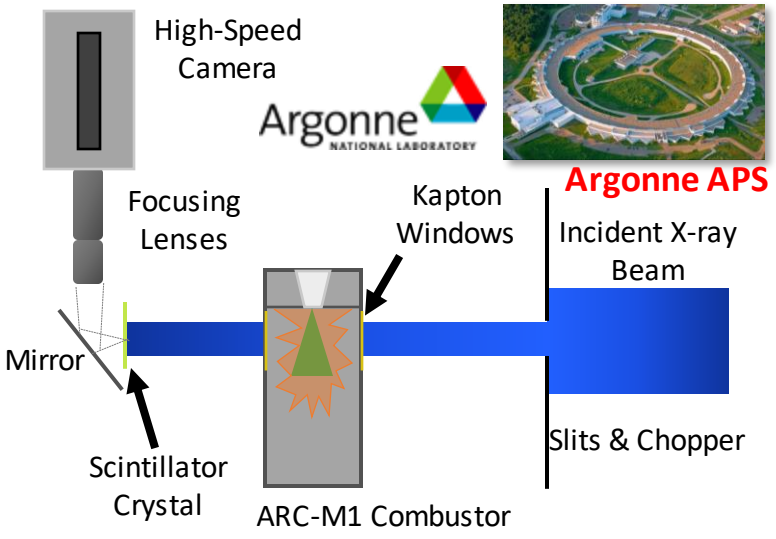
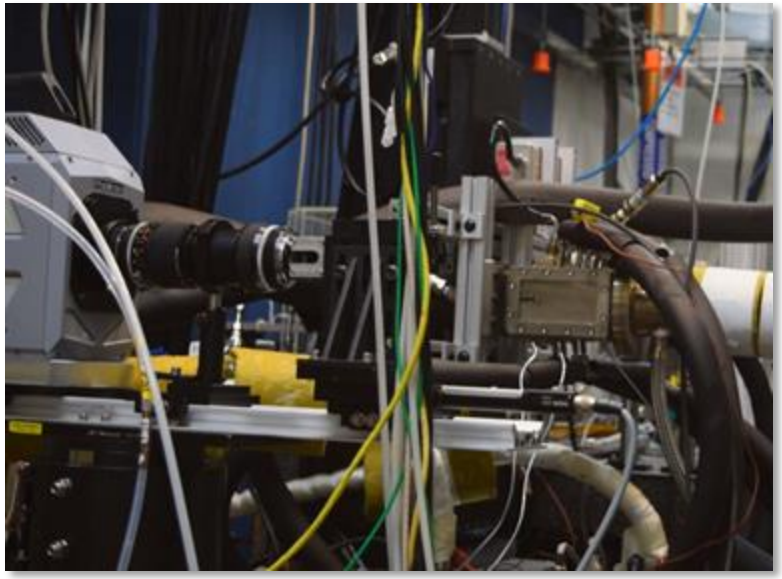
Argonne APS X-Ray Imaging Campaign

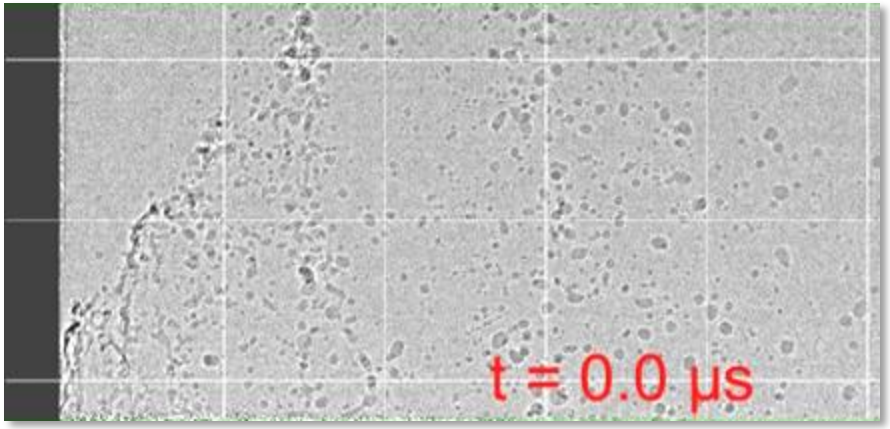
X-Ray Phase Contrast Imaging (PCI)

- Argonne's Advanced Photon Source (APS) employed to study liquid spray breakup in M1 M1 combustor and supporting infrastructure able to be transported to Argonne's APS for imaging
- Phase Contrast Imaging (PCI) applied to operating M1 at 90,517 Hz to visualize liquid spray behavior





ARC-M1 Combustor Installed at APS



Example Spray Breakup Imaging

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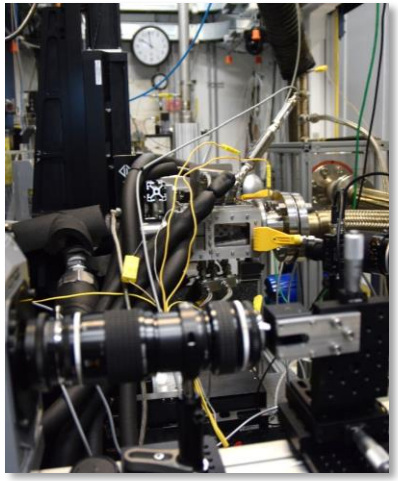
Argonne APS X-Ray Imaging Campaign

Fall 2021 APS Imaging Campaign

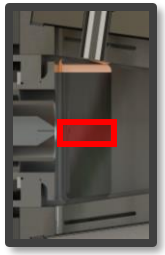
- M1 combustor and infrastructure brought to APS for 10-day experimental campaign (Sept 2021)
- Chilled air and fuel systems developed at UIUC and transported to APS beamline
- Roots-blower vacuum pump system installed at APS for sub-ambient pressure testing
- Combustor testing performed at cold-start and altitude relight conditions investigating fuel spray
- Imaging performed near-nozzle exit and near igniter to investigate difference

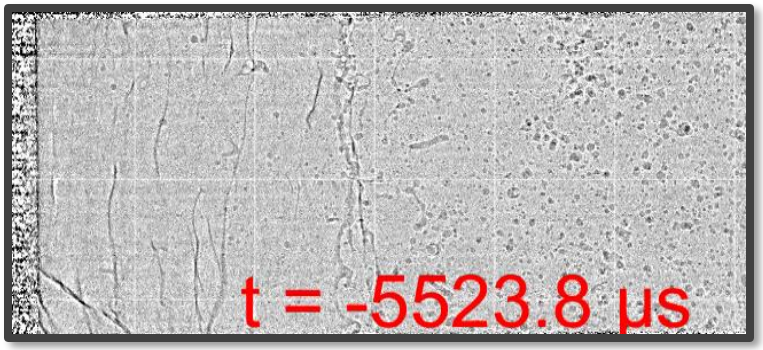


ARC-M1 Combustor Installed at APS

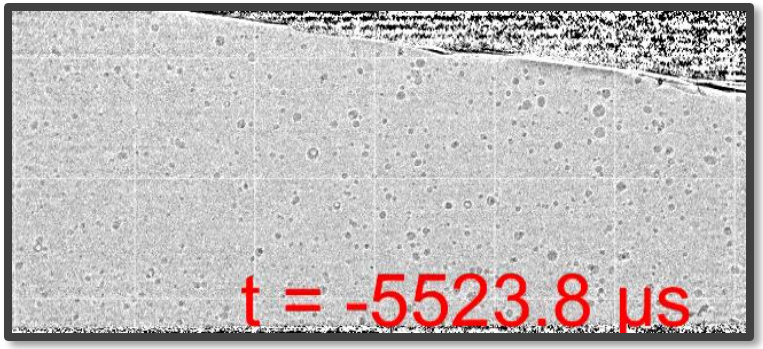
Chilling System

Near Nozzle





Near Igniter



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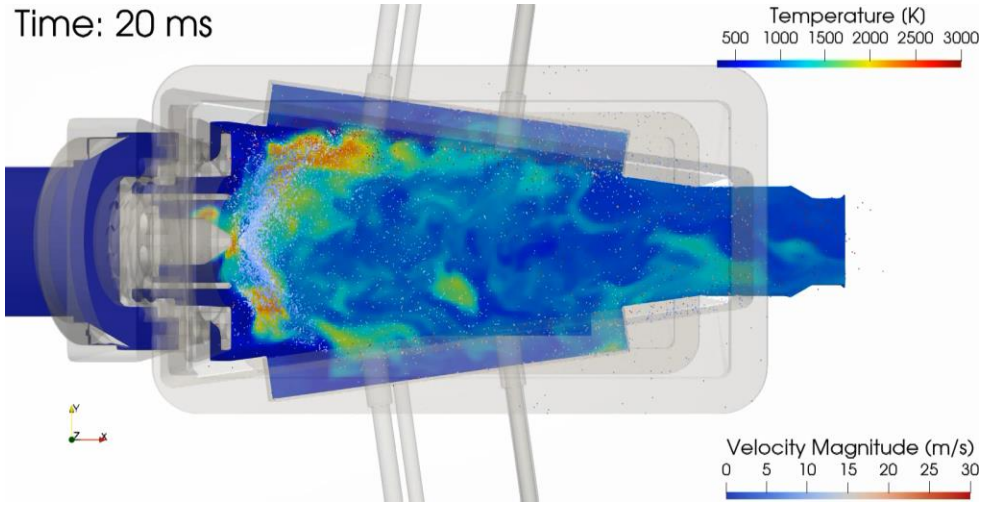
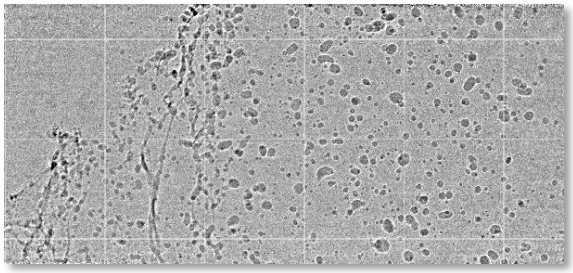
Argonne ARC-M1 Simulation Efforts



Center plane temperature contours w/ spray droplets

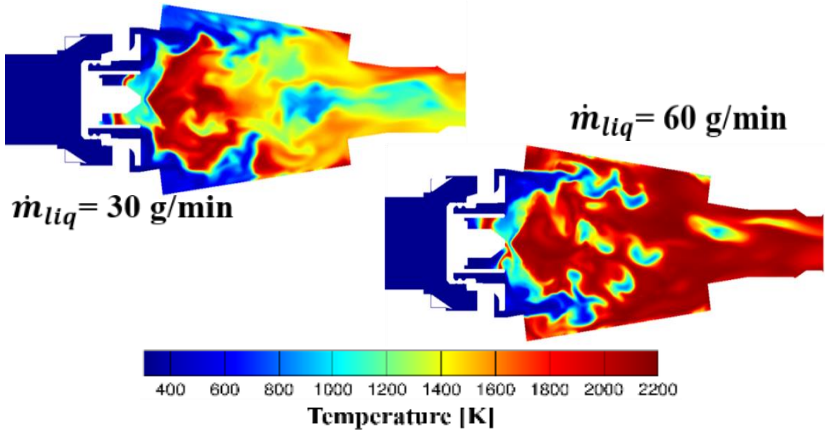


X-ray Data used to Initialize Liquid Spray

Title	Description
Software	CONVERGE 3.0
Fuel	Jet-A, F-24
Fuel flow rate	29 – 70 g/min
Dilution flow rate	4 - 12 g/s
Main air flow rate	17 - 45 g/s
Pressure	0.7, 1, 2 atm
Inlet Temperature	268 – 394 K

Title	Description
Spray breakup model	Taylor-Analogy Breakup
Combustion model	Finite rate chemistry
Turbulence model	Large-eddy simulations, Dynamic structures
Mechanism	48 species, 254 reactions
Base Grid	4 mm
Minimum grid size	0.25 mm
Cell count	~24 million

- Collaboration with Argonne National Laboratory team (Debolina Dasgupta, Sibendu Som) to develop computational model of ARC-M1
- APS x-ray data for spray initialization critical for accurate results
  - Droplet distribution and velocity measured directly
  - No interpolation required for data near nozzle exit
- Understanding flame shape change due to different operating conditions
- Testing of fuel property dependence for critical scenarios including lean blowout, cold start, and altitude relight



Flame shape for two fuel flow rates

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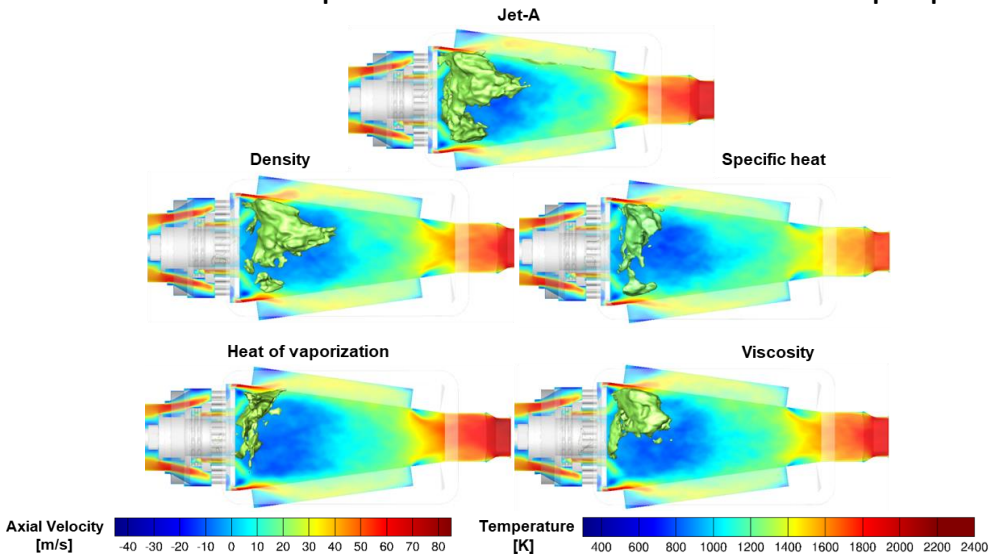
Argonne ARC-M1 Simulation Efforts

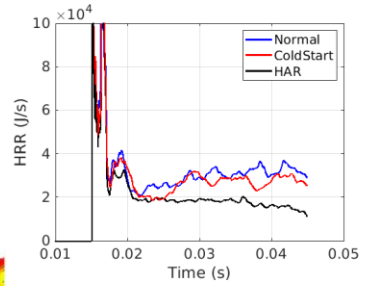
- Current simulations have focused on testing of fuel property dependence for lean blowout and stable operating condition for cold start and high-altitude relight-like conditions
- For fuel property effects, selected Jet-A properties are varied to assess the change in flame shape and LBO liquid flow rate. Increase in these properties pushes LBO towards higher flow rates

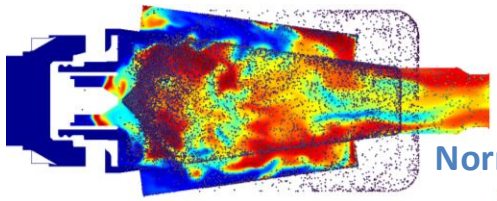


Property/ Fuel	Change in property value	LBO Flow rate
Jet-A	-	35.9 g/min
Density	9% at 15.56°C	36.6 g/min
Viscosity	11% at 40°C	37.4 g/min
HOV	8% at 208°C	37.8 g/min
Cp	15% at 150°C	38.9 g/min

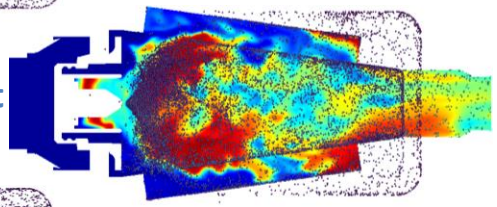
Center plane axial velocity contours 1200 K iso-surface to show fuel property impact on flame shape

	Normal	Cold Start	HAR
Pressure	1 atm	1 atm	0.7 atm
Inlet Temp	322 K	268 K (-5°C)	268 K (-5°C)

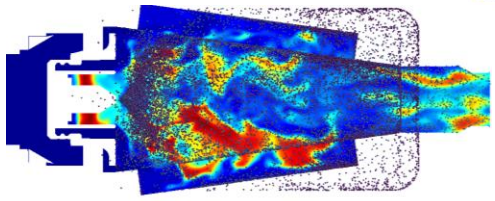




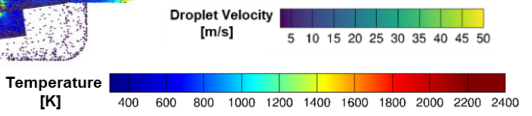
Normal



Cold Start



HAR



Center plane Temperature contours and heat release rate profile for the three conditions

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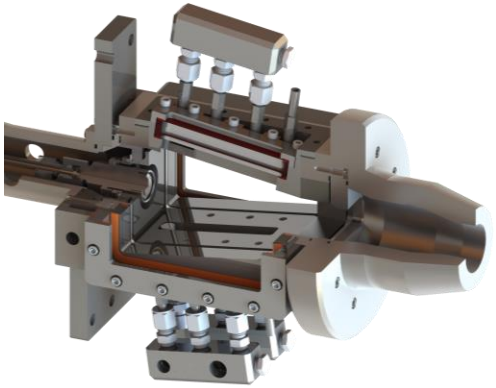
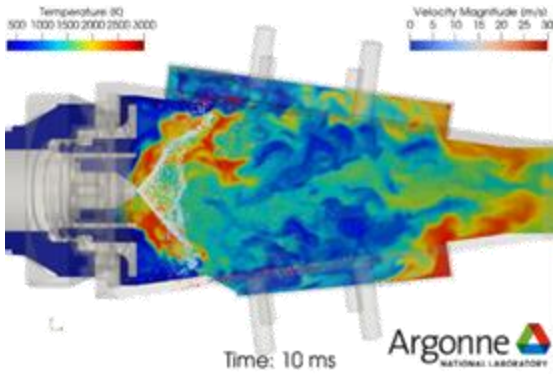
Future Work & Vision

Continued Characterization of M1 Combustor

- Further collaborations with Argonne, ARL, and FAA towards understanding combustion behavior
- Perform lean blow out testing to characterize different operating regimes in M1 combustor
- Simultaneous high-speed PLIF and PIV to study flame behavior near lean blow out
- Additional X-ray diagnostics at Argonne's APS at cold-start and altitude relight conditions (multiple fuels)
- Boundary condition data will continue to be provided to ANL numerical simulation team
- Work will allow small-scale combustor to become valuable tool for prescreening of SAF





Standard testing platform for fuel and combustion community.

Geometry and test data will be distributed to the community.

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