Project 65B

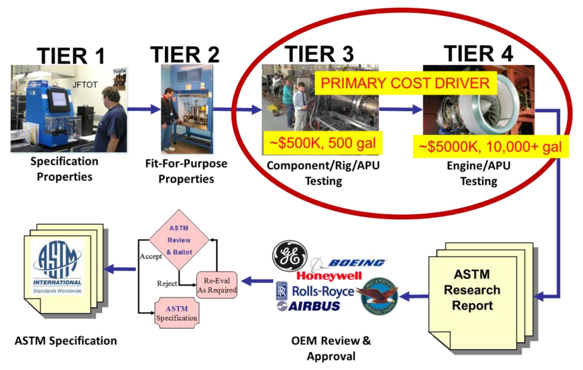
Fuel Testing Approaches for Rapid Jet Fuel Prescreening

Summary

Small scale combustor (M1) to study alternative fuel combustion physics. Standard combustion tests have been and will be performed for prescreening evaluation.

Motivation

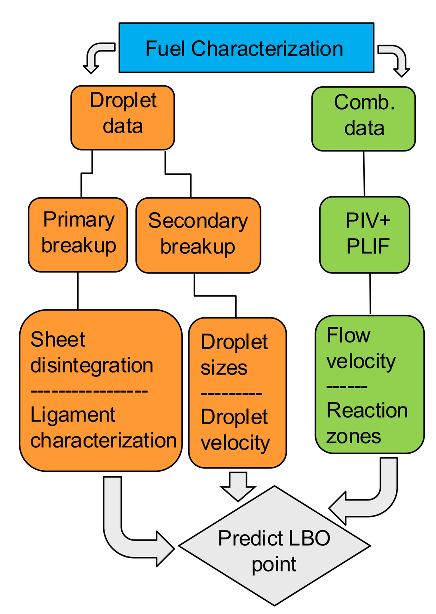
- Prescreening can give increased confidence to fuel manufactures before scaling up production
- Prescreening of fuel using small scale combustor requires only a few gallons of fuel
- Small scale combustor testing can significantly save time and money in SAF integration



ASTM D4054 Approval Process, NJFCP 2018

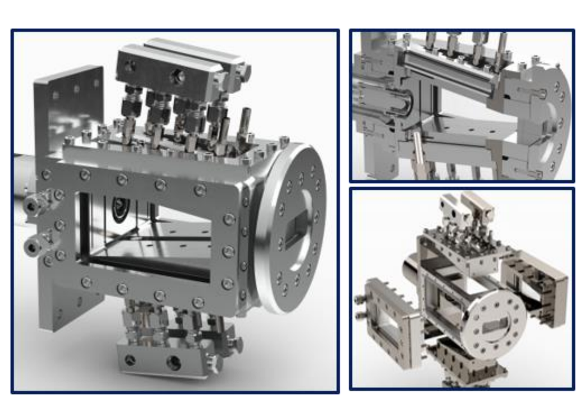
Objectives

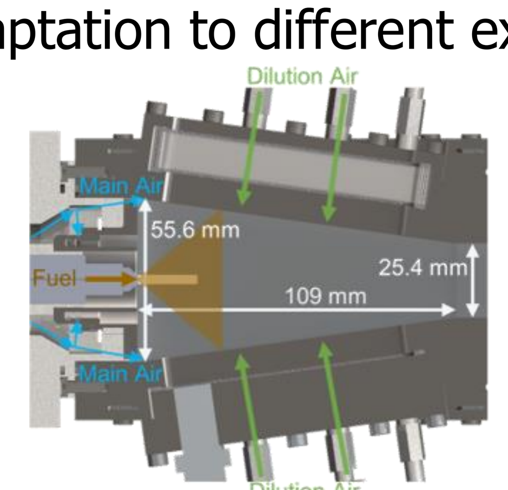
- Develop a new compact test rig to complement ASTM D4054 evaluation and qualification guidelines for prescreening of fuels prior to Tier 3 & 4 tests
  - Utilize small scale combustor to **prescreen** new fuels
  - **predict** results of different standard combustion tests (ignition, LBO, combustion efficiency, etc.) at different conditions and fuels
  - Utilize **simulations** for new fuels to supplement/bypass experimental testing



Methods: M1 Combustor

- The ARC-M1 simulates a single swirl cup of compact gas turbine combustors currently in-service
- Designed in collaboration with ARL and engine OEMs to replicate airflow patterns from relevant engines
- Designed with 4-sided optical access for advanced diagnostics such as PIV and PLIF
- Modular construction for adaptation to different experiments





OEM Collaboration

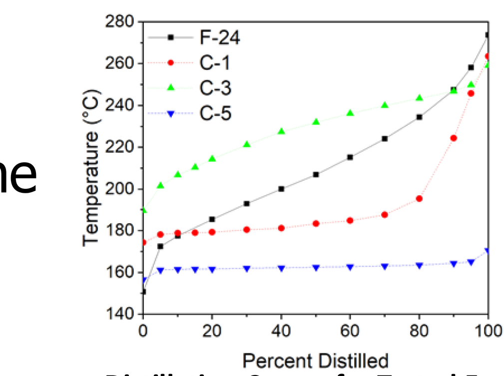
Honeywell
Raytheon Technologies

Unique Fuels for Testing

Four fuels are tested to study how specific extreme fuel properties affect combustion performance

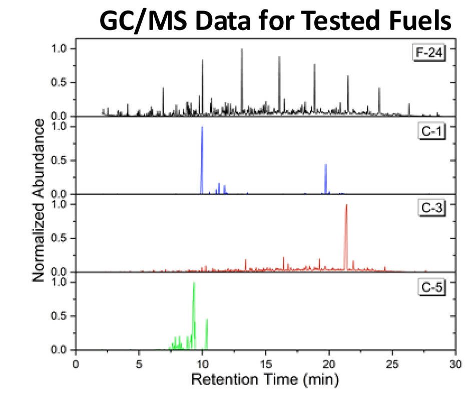
- F-24: Jet-A with US Military Additives – chosen as baseline
- NJFCP Category C Fuels – developed to target extreme properties
  - C-1: Low Cetane Number, alcohol-to-jet fuel
  - C-3: High Viscosity, high boiling curve
  - C-5: Low Viscosity, Narrow Boiling Range

Fuel Name	Key Features	Cetane Number	Viscosity (mm^2/s) @ 40°C	50% Distillation Temp. (°C)
F-24	Jet-A w/ Military Additives	48.6	1.36	207
C-1	ATJ	17.1	1.53	185
C-3	High Viscosity	47.0	1.78	232
C-5	Flat Boiling Curve	39.6	0.83	163



Distillation Curves for Tested Fuels

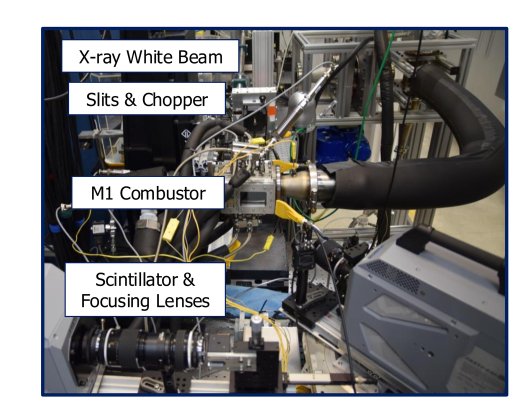
GC/MS Data for Tested Fuels

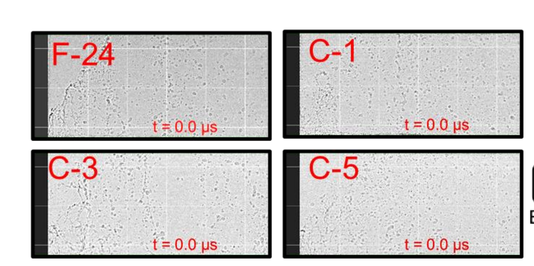


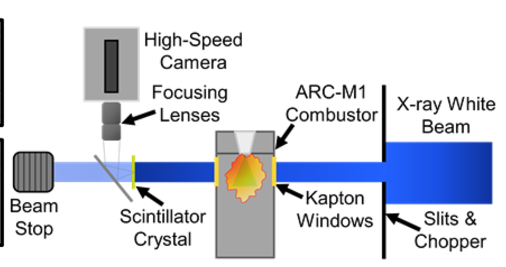
Results and Discussion

Spray Characterization

- X-ray PCI gives high resolution temporal images of fuel spray at combusting conditions
  - Quantitative comparison performed using subpixel-based image processing algorithm
  - Low-viscosity C-5 fuel showed smallest droplets; high-viscosity C-3 fuel had largest droplets

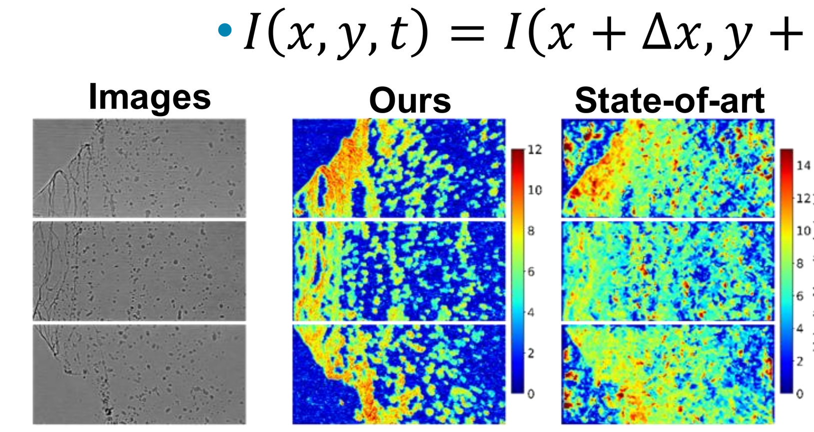


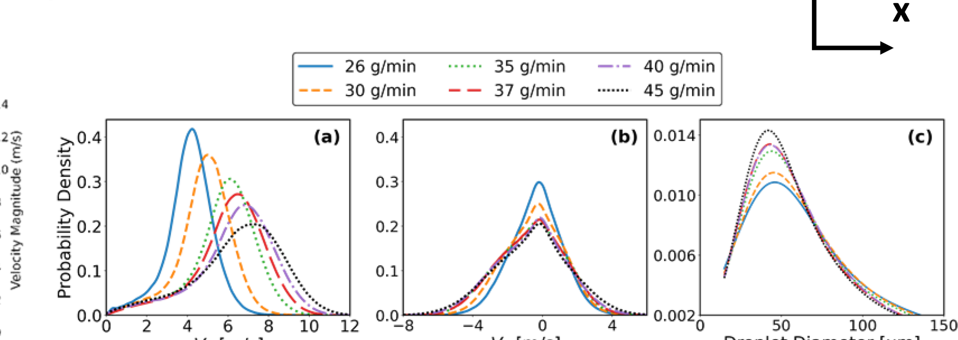




ML Applications: Velocity Prediction

- Predicting velocity between image pairs based on feature correspondence
  - $I(x, y, t) = I(x + \Delta x, y + \Delta y, t + \Delta t)$





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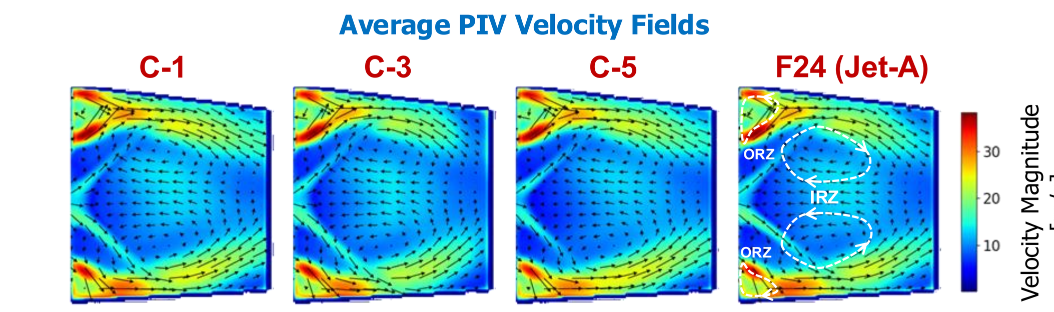
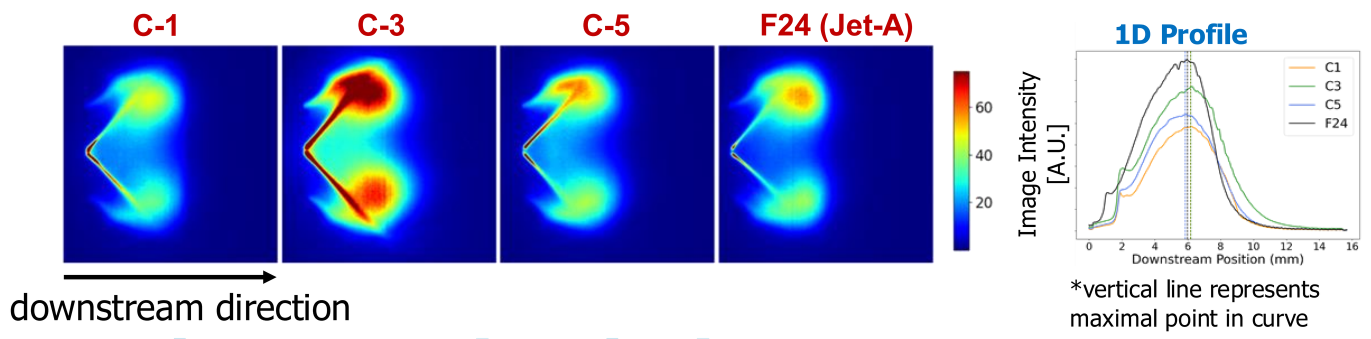
Characterization of Flame/Mixing

Simultaneous PLIF/PIV

- Analyze combustion dynamics near blowout in small-scale gas turbine engines (10 kHz imaging)
- Recirculation zones bring hot product gases back to central region of combustor
- Strong OH signal initiated further upstream in low viscosity C5 fuel; C3 fuel displayed larger instability in outer reaction zone



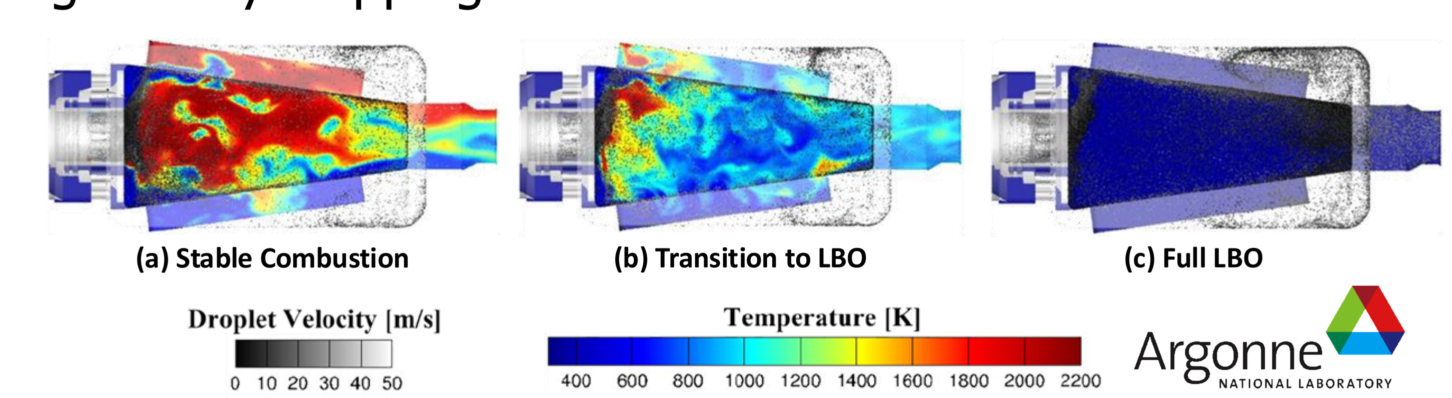


downstream direction

*vertical line represents maximal point in curve

Lean Blowout Simulations

- Collaboration with Argonne National Laboratory team to develop high-fidelity computational model of ARC-M1
- X-ray data used directly to initialize spray in numerical simulations
- Simulations replicated LBO test procedure through gradually stepping down fuel flowrate



Conclusions/Future Work

Conclusion

- Detailed near-nozzle spray analysis:
  - Nozzle geometry is a critical performance driver
  - Variations in fuel composition directly impact atomization efficiency.
  - Viscosity was found to be the most significant in determining droplet sizes and velocity statistics
- Time-resolved PLIF/PIV quantification:
  - Low-viscosity C-5 fuel enables a stable, upstream reaction zone.
  - High-viscosity C-3 fuel results in a delayed and detached downstream reaction zone
  - fuel viscosity is a controlling parameter for flame stabilization mode behavior

Future Work

- Develop a standardized testing framework to link fuel properties to spray and combustion behavior
- Use experimental data to inform and validate predictive models for combustion stability

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