Towards an Aircraft-Crash-Fuel Spill-Fire-Suppression (ACFFS) Simulation Framework

Progress in Aircraft Pool Fire and Agent Application CFD Modeling

by

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Roadmap

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2. Background
3. Aircraft pool fire modeling
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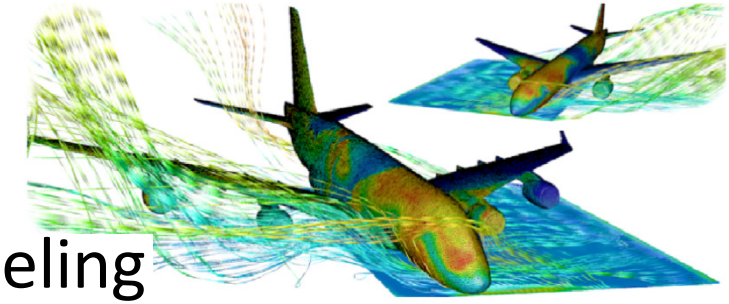
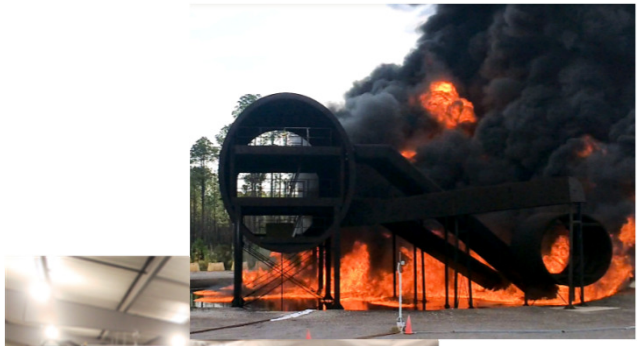
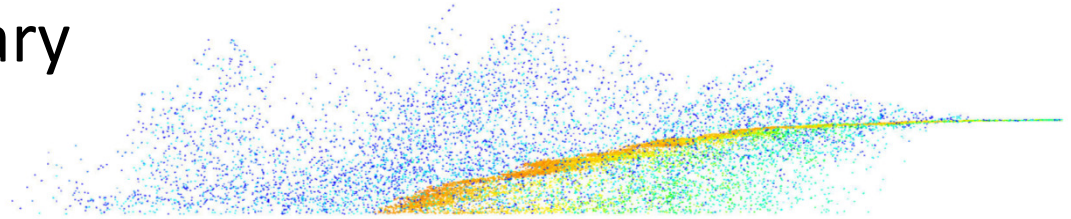
   - NLA mockup experimental support
   - NLA mockup simulations
4. Firefighting agent application modeling
   - Firefighting jet experimental support
   - Firefighting jet simulations
5. Work Summary
6. Future work

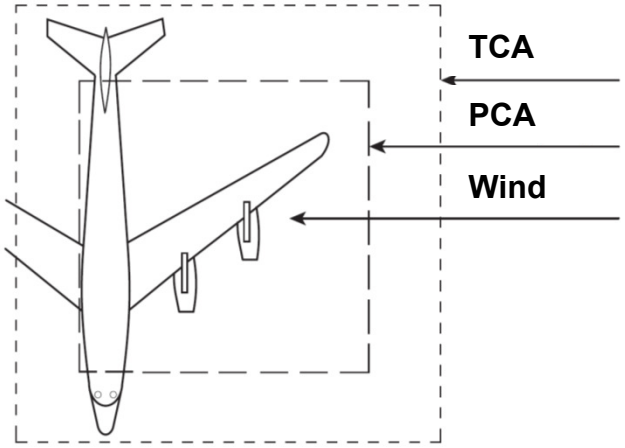




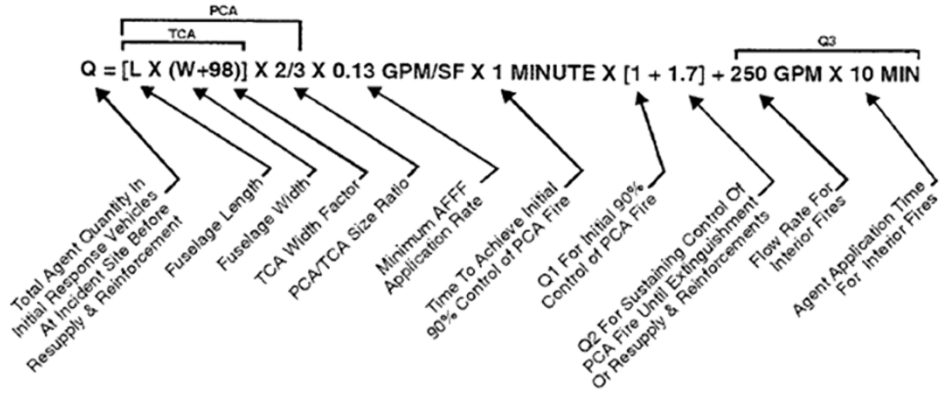


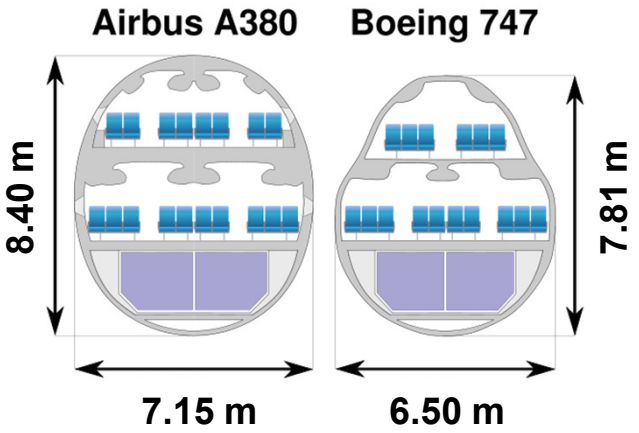
TCA/PCA Method to Determine ARFF Emergency Response Requirements for Transport Aircraft

- Used for nearly 40 years
- Questionable validity when applied to new transport aircraft
- Does not account for physical, 3-D aircraft crash fire dynamics or modern aircraft designs



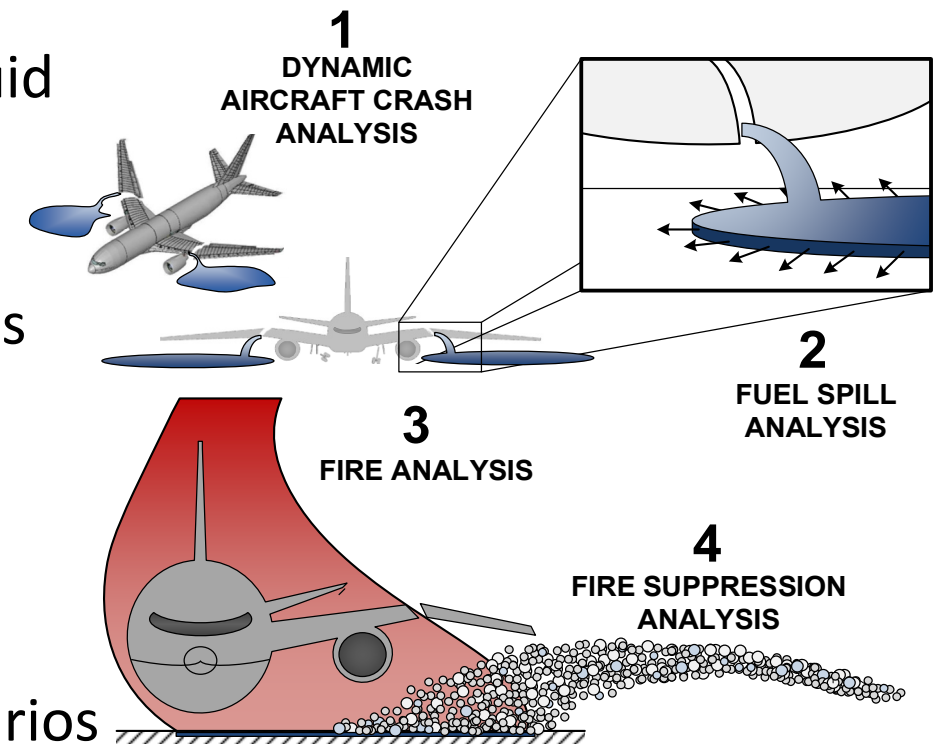
Fixed-Wing Aircraft





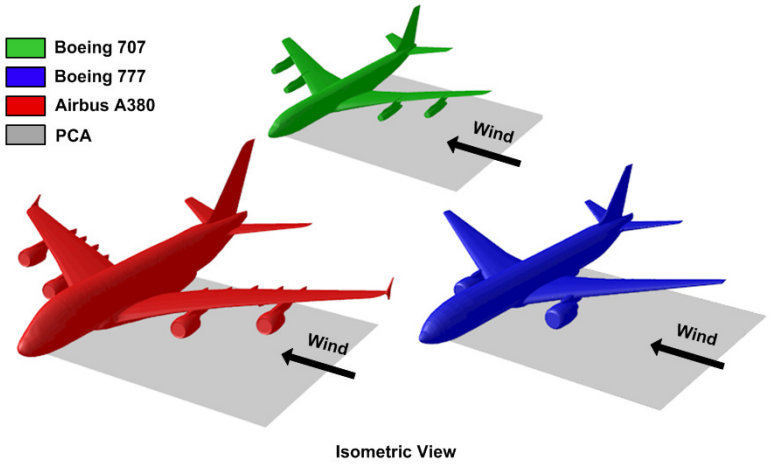
Aircraft-Crash-Fuel Spill-Fire-Suppression (ACFFS) Modeling

- Alternative approach to TCA/PCA method using finite element analysis and computational fluid dynamics (CFD)
- Enables the consideration of actual ACFFS physical dynamics
  - Post-crash geometry and fuel distribution
  - Wind velocity effects
  - Fire suppression techniques
- Allows end-to-end ACFFS scenarios to be considered beyond the scope of practical experiments

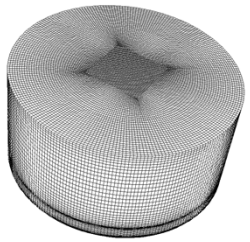


New Large Aircraft (NLA) Pool Fire CFD Simulations

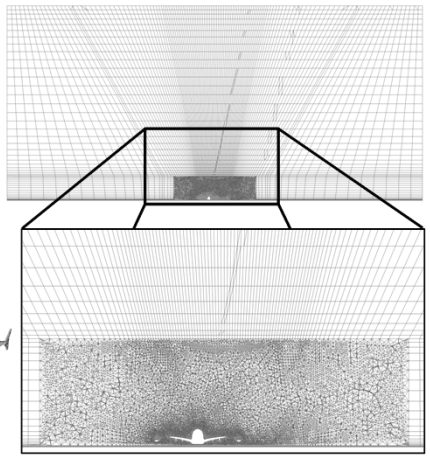
- Characterization of full-scale NLA PCA pool fire model environments
  - Initially Developed using ANSYS Fluent v13.x with SANDIA experimental support
    - Chemical Kinetics – Non-premixed combustion PDF
    - Turbulence – RANS
    - Radiation – Discrete Ordinates
    - Soot – Moss-Brookes
    - Reliable predictions for zero to moderate (5 $m \cdot s^{-1}$) wind conditions
    - Solved using DoD Supercomputing resources



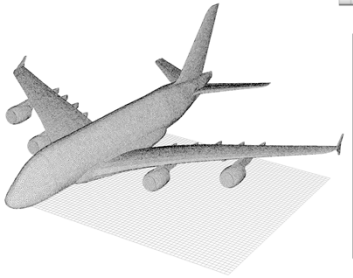
Isometric View



Far Field



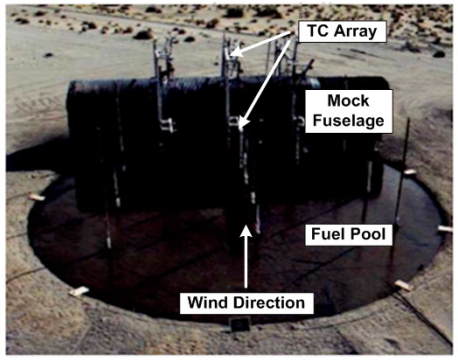
Far Field Centerline Cross-Section

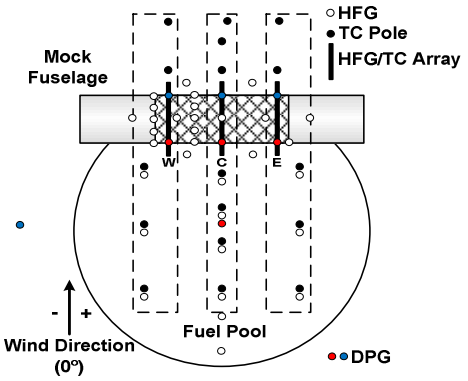


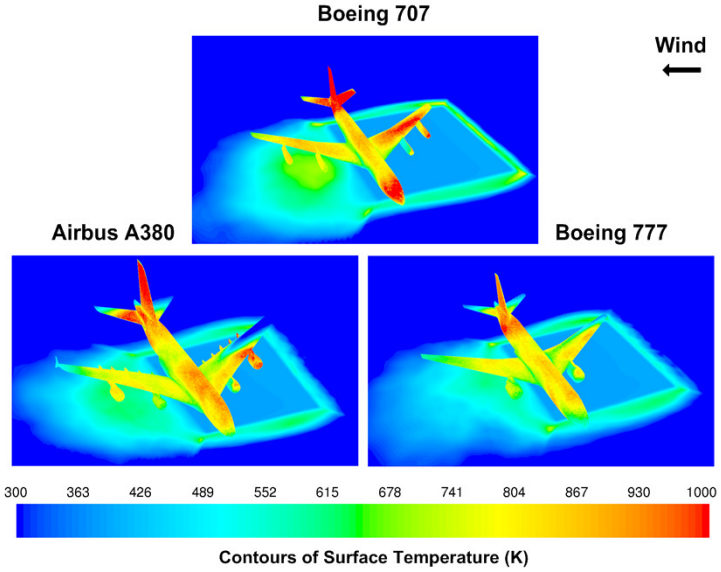
Aircraft and Fuel Pool Surface Mesh

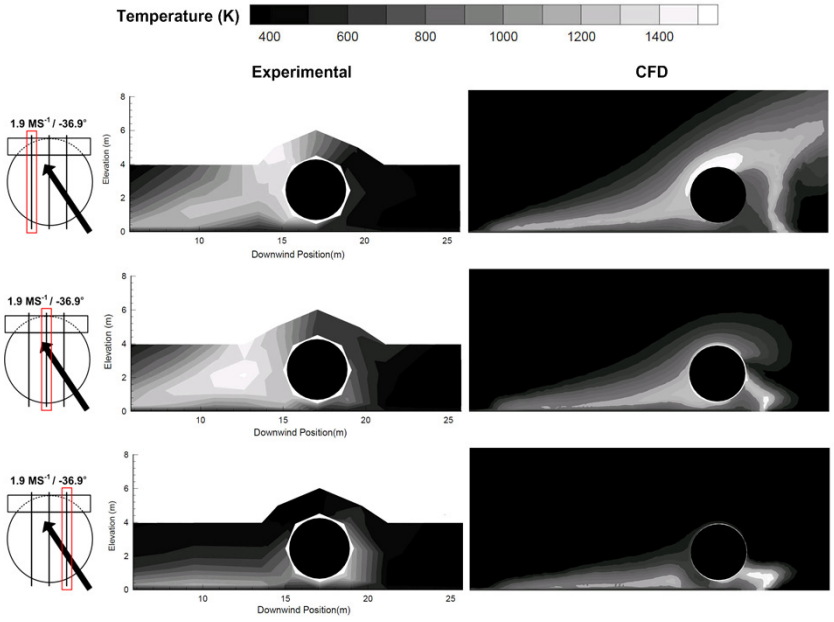
Aircraft and Fuel Pool Near Field

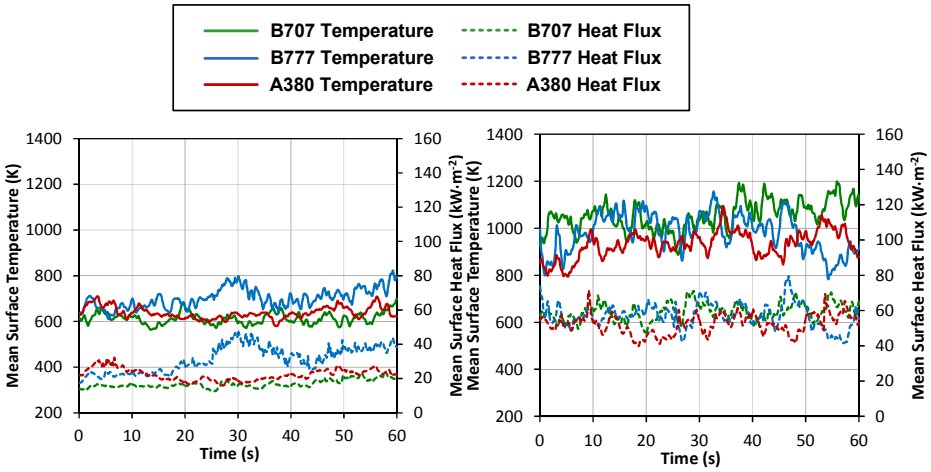
New Large Aircraft (NLA) Pool Fire CFD Simulations











NLA Mockup Pool Fire Experimental Support

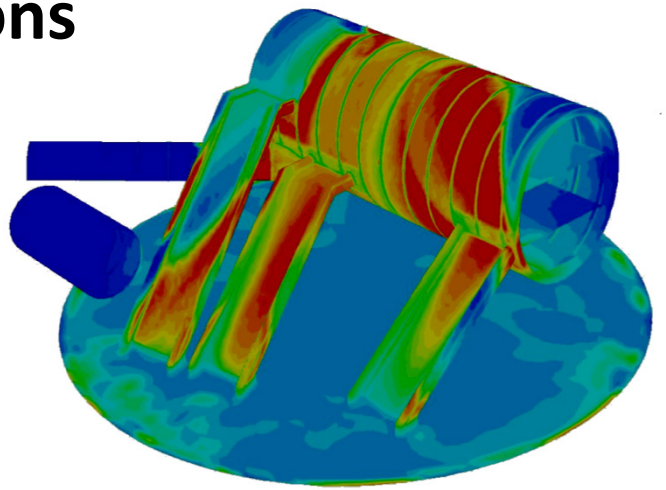
- Characterization of multiscale NLA mockup pool fire environments
  - Full-scale NLA mockup
    - Outdoor, realistic conditions
    - Provides ARFF vehicle performance, egress exercises, and firefighting technique evaluation
  - 1:10 scale NLA mockup
    - Indoor, controlled conditions
    - Provides a repeatable, cost-effective test environment to support CFD model development

Full-scale NLA Mockup

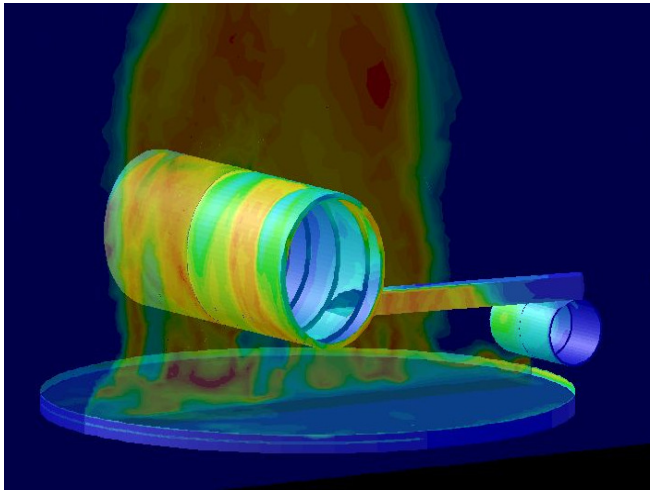
1:10 Scale NLA Mockup

NLA Mockup Pool Fire CFD Simulations

- Characterization of multiscale NLA mockup pool fire environments
  - Based on the established NLA pool fire CFD modeling strategy with improved model accuracy and performance
  - Developed using ANSYS Fluent v14-15.x
  - Increased turbulent, combustion, and wall heat conduction model fidelity
  - Enhanced material property definition
  - Provides an auxiliary engineering approach to analyzing NLA-ARFF related scenarios of interest



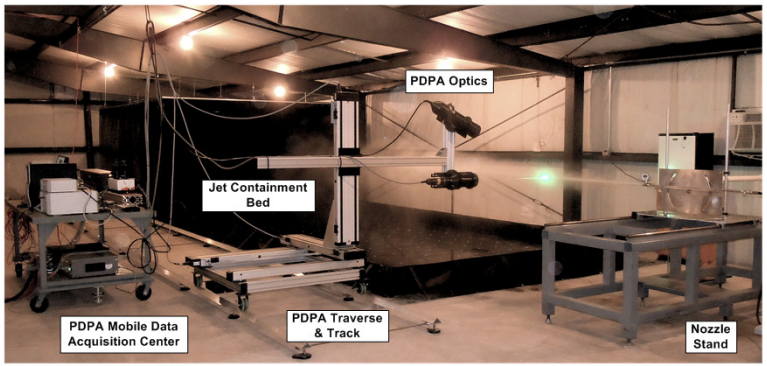
Fuel Temperature Contours and Mockup Surface



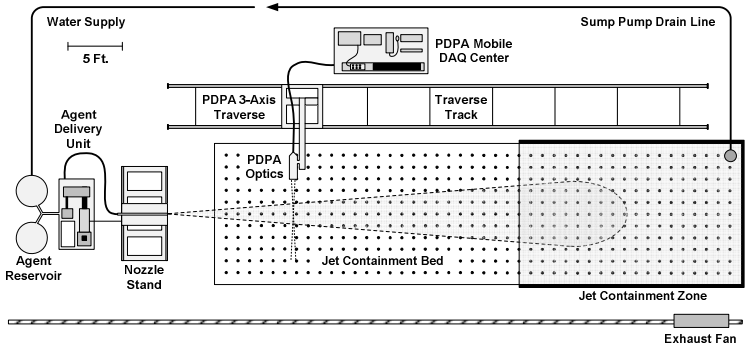
Flame and Mockup Surface Temperature Contours

Firefighting Agent Application Experimental Support

- Characterization of aqueous film-forming foam (AFFF) firefighting jet transport
  - Aqueous firefighting agent application laboratory built to provide experimental support to firefighting agent application model development
  - 2-D phase Doppler particle analyzer (PDPA) to measure agent velocity and droplet size
  - Jet containment area to quantify agent ground pattern shape and foam quality
  - High-fidelity flow visualization

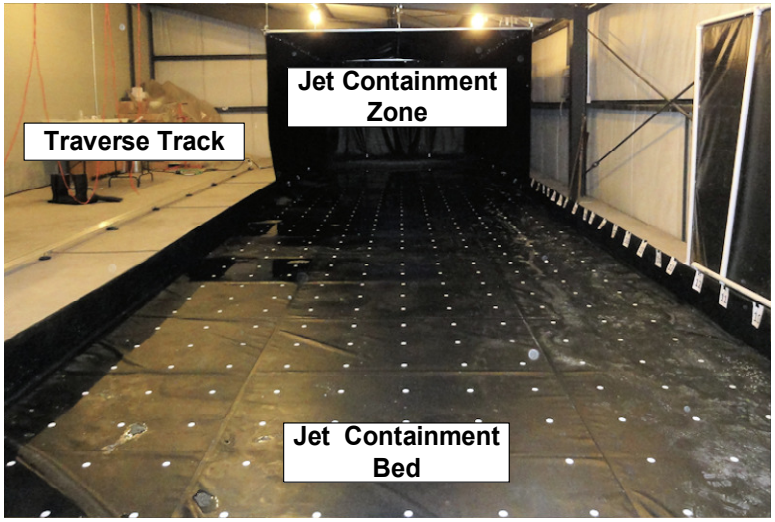


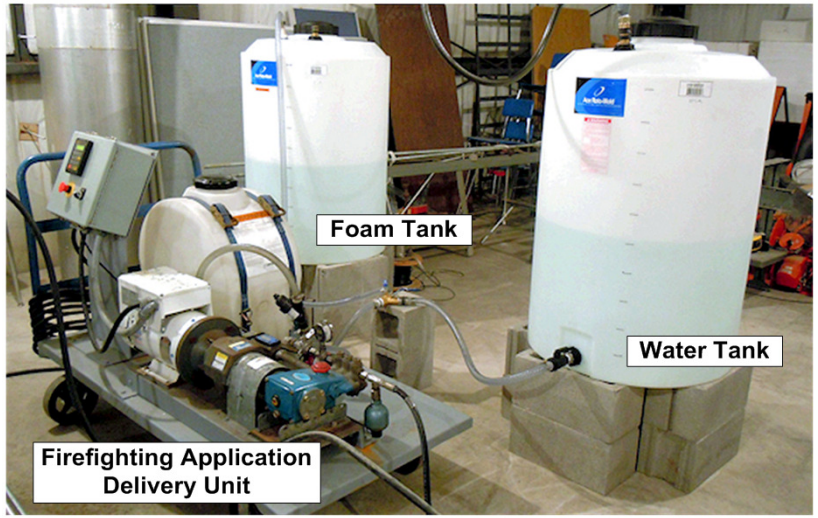
Aqueous Firefighting Agent Application Laboratory

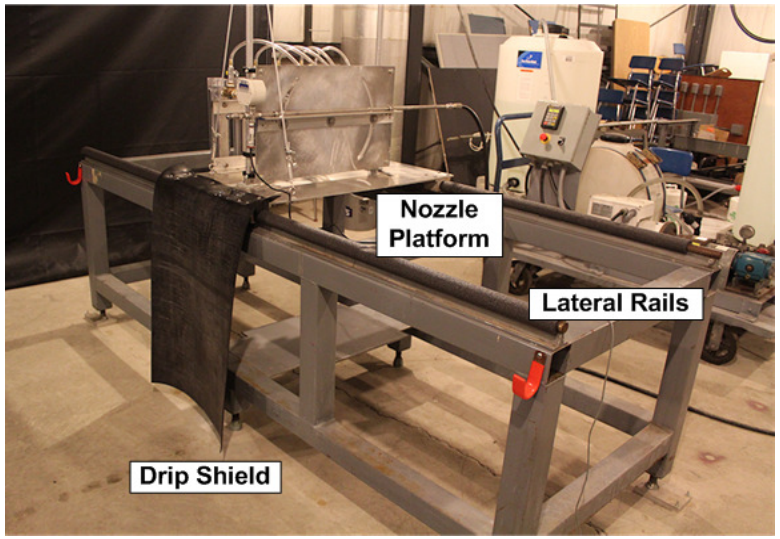


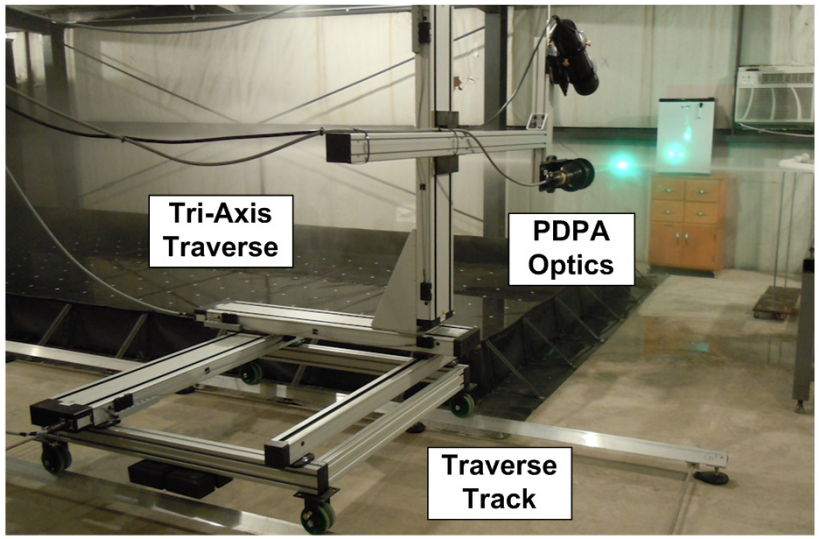
Laboratory Top View Schematic

Firefighting Agent Application Experimental Support

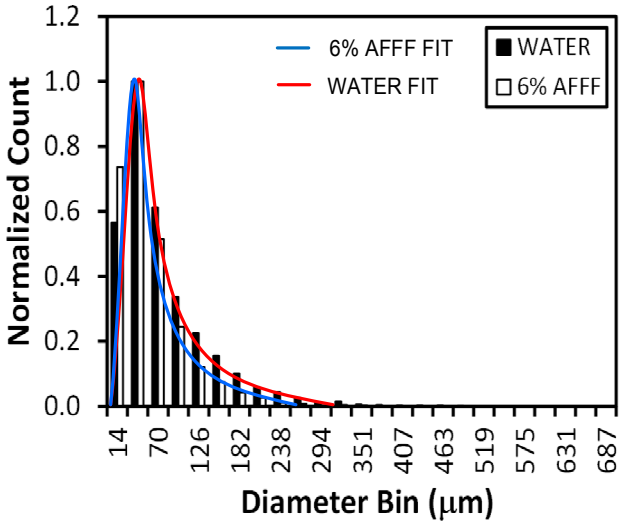




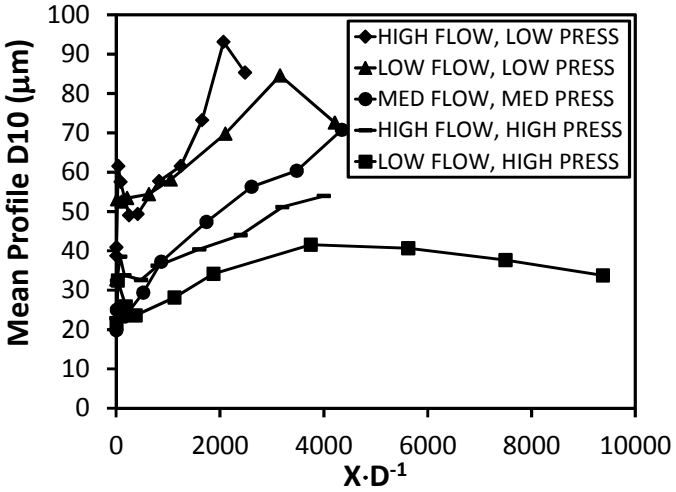




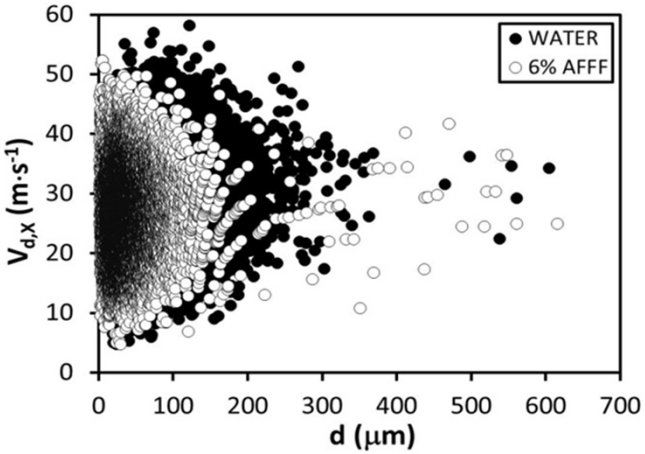
Firefighting Agent Application Experimental Support



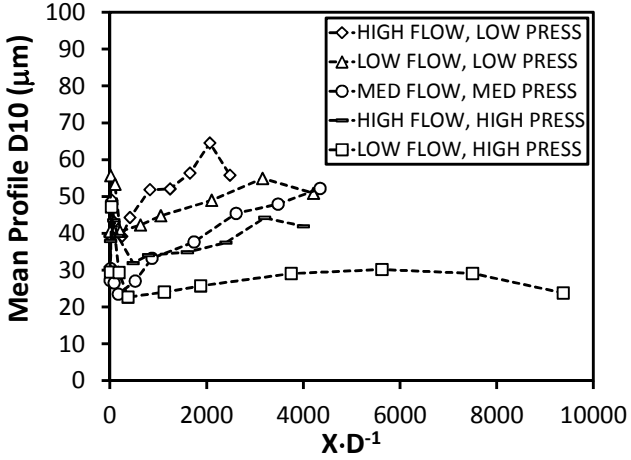
Characteristic Droplet Size Distribution



Water Jet Droplet Diameter vs. Distance Downstream



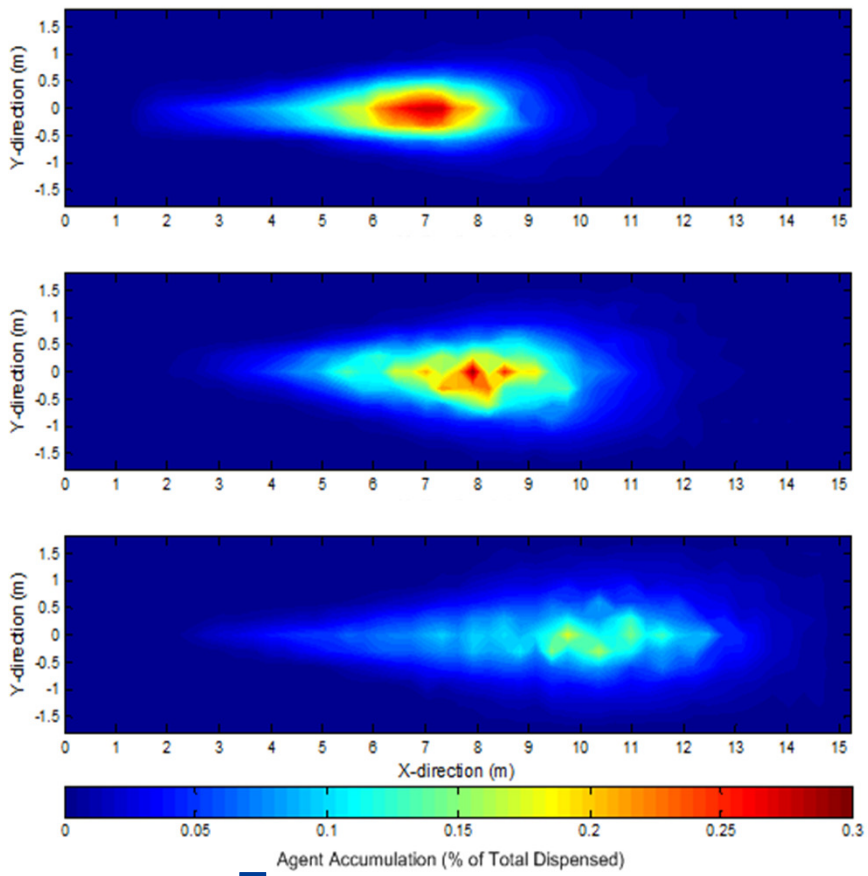
Axial Droplet Velocity vs. Droplet Diameter



AFFF Jet Droplet Diameter vs. Distance Downstream

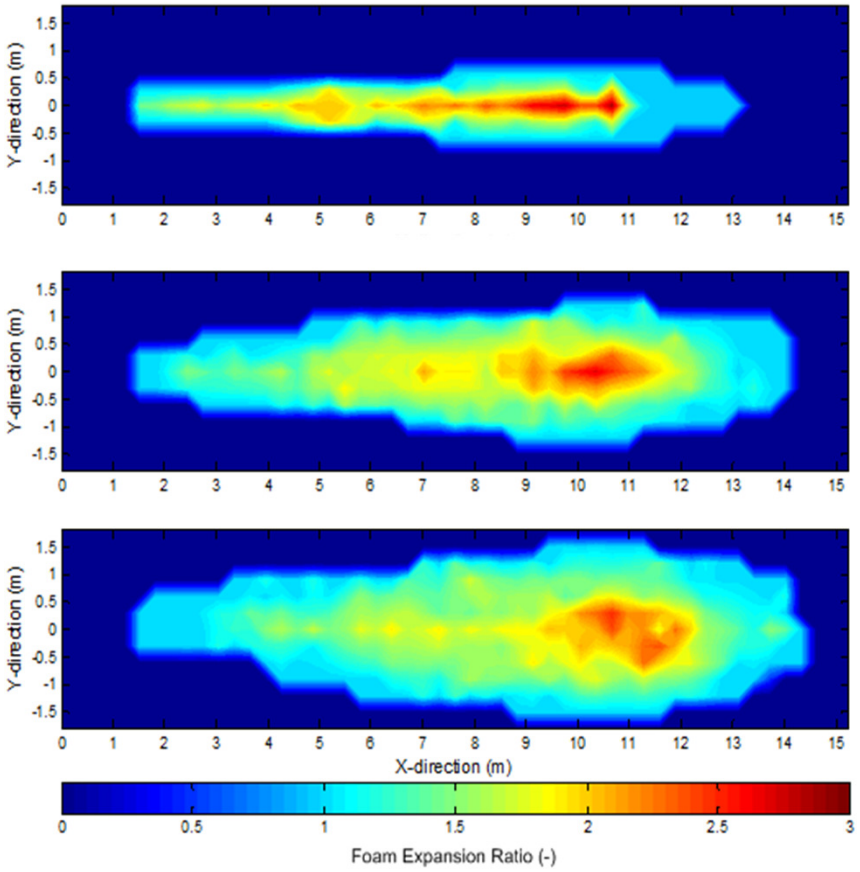
Firefighting Agent Application Experimental Support

Water Jet Accumulation



Constant High Pressure / Increasing Flow Rate

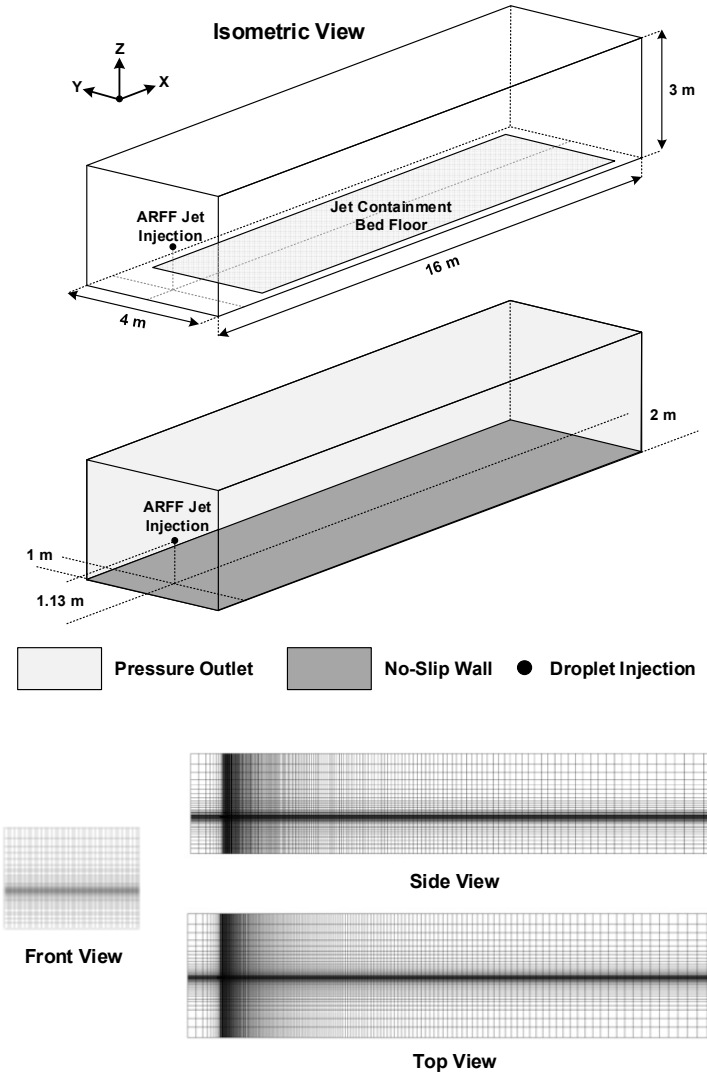
AFFF Jet Foam Quality



Constant High Flow Rate / Increasing Pressure

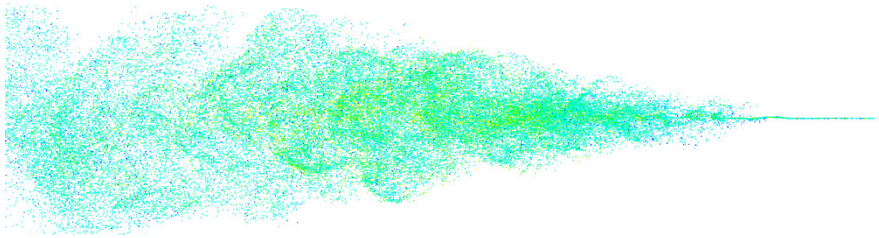
Firefighting Agent Application CFD Simulations

- Characterization of water and AFFF-based firefighting jet model environments
  - Developed using ANSYS Fluent v14.x with concurrent experimental support
  - Droplet Representation – Lagrangian Discrete Phase Model with coalescence, TAB breakup, and collision
  - Turbulence – LES
  - Material properties differentiate water and AFFF

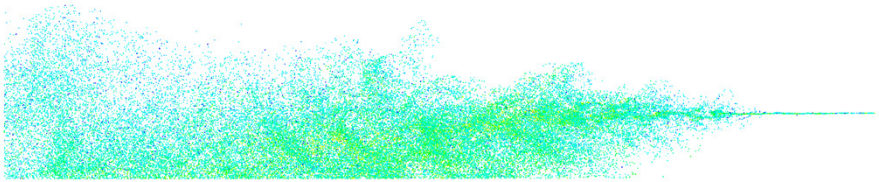


Firefighting Agent Application CFD Simulations

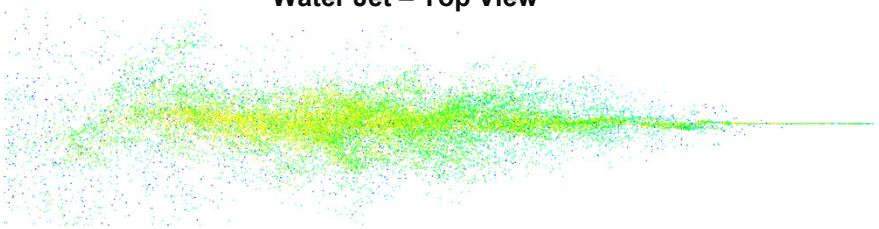
AFFF Jet – Top View



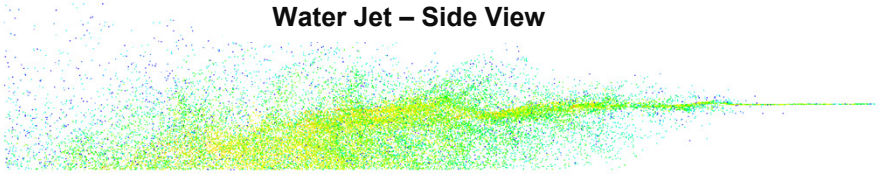
AFFF Jet – Side View



Water Jet – Top View



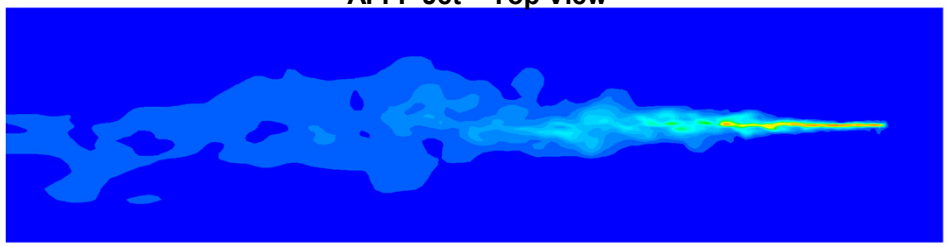
Water Jet – Side View



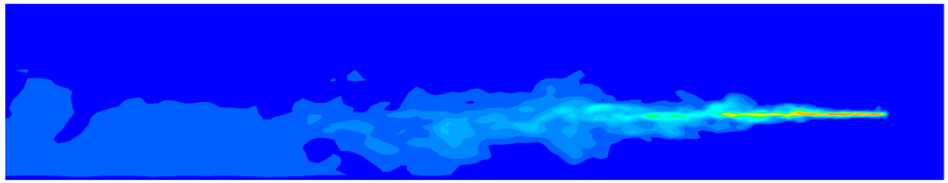
Particle Traces Colored by Particle Diameter (μm)

Max 3.3 mm

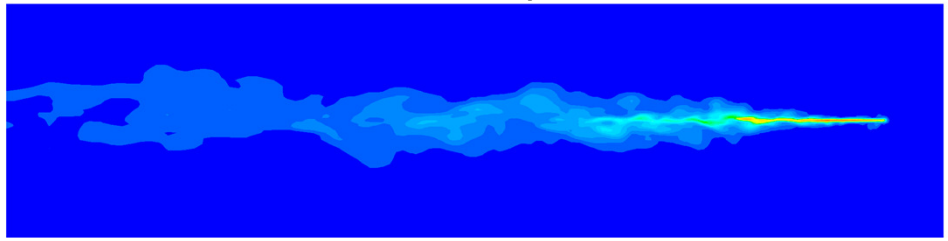
AFFF Jet – Top View



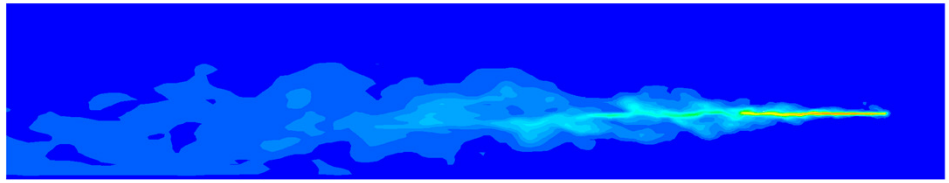
AFFF Jet – Side View



Water Jet – Top View



Water Jet – Side View



Gaseous Contours Colored by Velocity Magnitude ($m \cdot s^{-1}$)

Max 65

Aircraft Pool Fire Model Work Summary

- An aircraft pool fire CFD modeling strategy was developed and validated for low to moderate wind environments.
- Model fidelity was enhanced and applied to multiscale NLA pool fire environments, exhibiting similar or better accuracy to past work. Final model performance evaluations over an extended set of operating conditions are currently in progress.

Firefighting Agent Application Model Work Summary

- An aqueous firefighting agent application laboratory was especially constructed to quantify jet transport characteristics that included the effects of AFFF.
- A firefighting agent application CFD modeling strategy was validated for a wide range of nozzle exit pressure and flow rate conditions.

Future Work and Associated Challenges

- Complete the pool fire model extended parameter study.
- Experimental support is needed to determine the performance of the combined aircraft pool fire-suppression aspect of the ACFFS simulation process.
- CFD sub-model integration challenges exist and must be conquered to ensure the ACFFS simulation effort stays numerically robust and reliable (.e.g. competing time scales).
- Once the ACFFS simulation strategy is defined, it will be applied to crash scenarios of interest to hopefully provide a more favorable method of determining firefighting agent application requirements compared to TCA/PCA methods.