Evaluation of High Thermal Stability Fuels
Project 66

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Co-Investigator: Randall Boehm, Washington State University
Project manager: Theodore W. Johnson, FAA

October 15, 2025
Alexandria, VA

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 66 through FAA Award Number 13-C-AJFE-WaSU-036 under the supervision of Theodore W. Johnson. Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the FAA.

ASCENT

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Washington State University

PI: Joshua Heyne

Co-PI: Randall Boehm

PM: Theodore W. Johnson

Cost Share Partner(s): Air Company

Objective:

Inform decisions regarding SATF composition and/or blending, aircraft design, and engine design at early stage of technology maturation

Project Benefits:

Characterize the potential benefits of high thermal stability fuels, both 'drop-in' and 'non-drop-in'

Inform impurity limits as they pertain to thermal stability

Provide insight towards which feedstocks, conversion technologies, and/or end-use products pose potential thermal stability risks

Research Approach:

1. Develop engine performance model to evaluate fuel effects and then optimize fuel composition for energy savings from high thermal stability
   - Completed
2. Characterize impurities in fuel samples to assess areas of risk towards thermal stability
   - Use polar extraction techniques to isolate impurities from fuel
   - Use state-of-the-art methods to characterize fuel impurities
     - For some characterizations, the chosen analytical method may be cutting-edge
3. Evaluate thermal stability of impurity-controlled samples to inform community of risks associated with blending SATF with fossil-derived jet fuel
4. Evaluate risk of fuel-bound-nitrogen (FBN) at levels up to 5x the current specification limit

Major Accomplishments (to date):

EPM introduced: Boehm, Scholla, Heyne: Sustainable Alternative Fuel Effects on Energy Consumption of Jet Engines https://doi.org/10.1016/j.fuel.2021.121378.

Optimized fuel benefits: Boehm, Faulhaber, Behnke, Heyne: The Effect of Theoretical SAF Composition on Calculated Engine and Aircraft Efficiency https://doi.org/10.1016/j.fuel.2024.132049

Gage R & r of JFTOT/ETR method (ILS participant)

Proficiency gained in separations and analytical methods

Future Work:

Additional fidelity in FBN characterizations is in progress

Execution of thermal stability DOE as described in April 2025

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Introduction

Motivated by the industry-wide goals around fuel security, fuel economy, and emissions this project has two main objectives:

- Characterize energy savings of ‘drop-in’ and ‘non-drop-in’ SATF strategies – Published May ‘24
- Evaluation of impurities and thermal stability for current/developing SATF products informs the fuel approval process – In Progress

Practical applications

- Guide fuel producers towards bulk compositions that take advantage of energy savings associated with high thermal stability
- Provide thermal stability risk assessment for approved/developing SATF products based on impurities risk associated with a given pathway

Schedule and Status

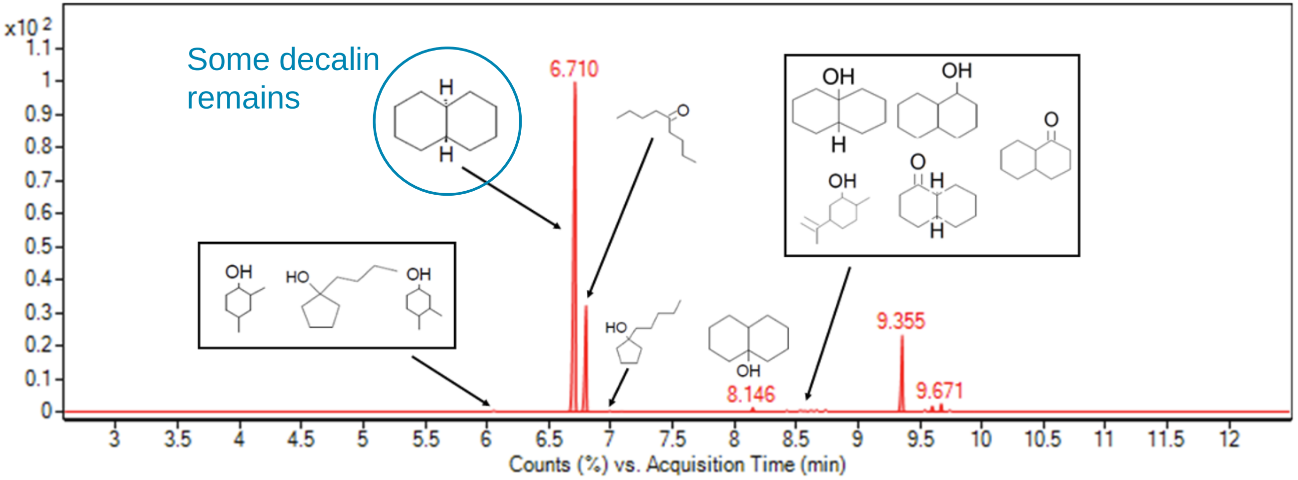
Milestone	Completion Goal	Percent Complete
Producibility evaluation	January 31, 2024	95% - Ongoing
Non-drop-in fuel specification recommendation	March 31, 2024	100%
Materials Acquisition	February 28, 2024	95% - Ongoing
Thermal Stability Testing	September 30, 2024	50%
Report Findings	December 31, 2024	100% to-date

Milestone	Completion Goal	Percent Complete
Thermal Oxidation Test Repeatability and Reproducibility Assessment	January 31, 2025	100%
Detailed & Actionable Test Plan	February 28, 2025	95% - Ongoing
Acquisition of Fuel Samples	April 30, 2025	95% - Ongoing
Gain Proficiency in Analytical Methods	December 31, 2025	75%
Natural Impurities Amplification Method Development	January 31, 2026	65%
Complete 1st Thermal Stability Test Campaign	March 1, 2026	0%
Submit Research Article	May 15, 2026	0%
Detail Follow-up Research Needs and Approach	June 30, 2026	0%

Natural Impurities Amplification Status

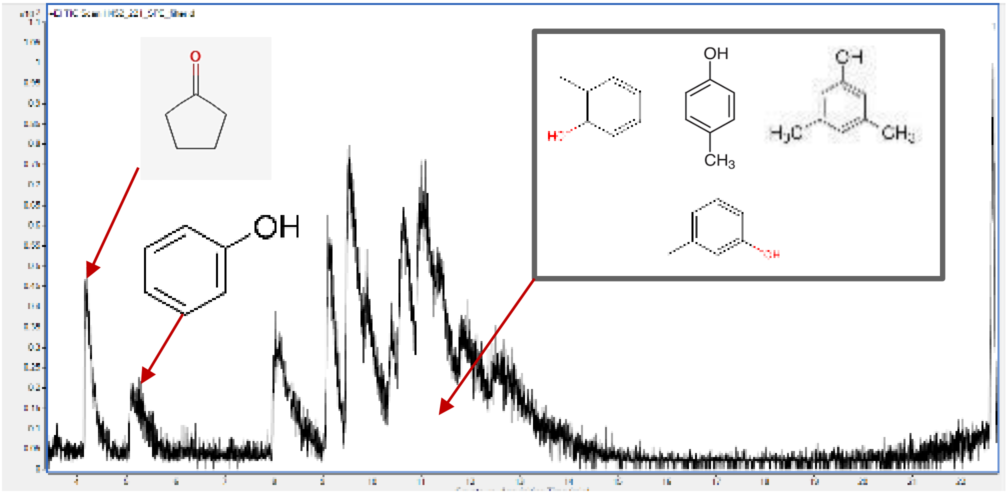
- Demonstrated effectiveness of Solid Phase Extraction (SPE) method in our lab

GCMS of Effluent of Stale Decalin Sample



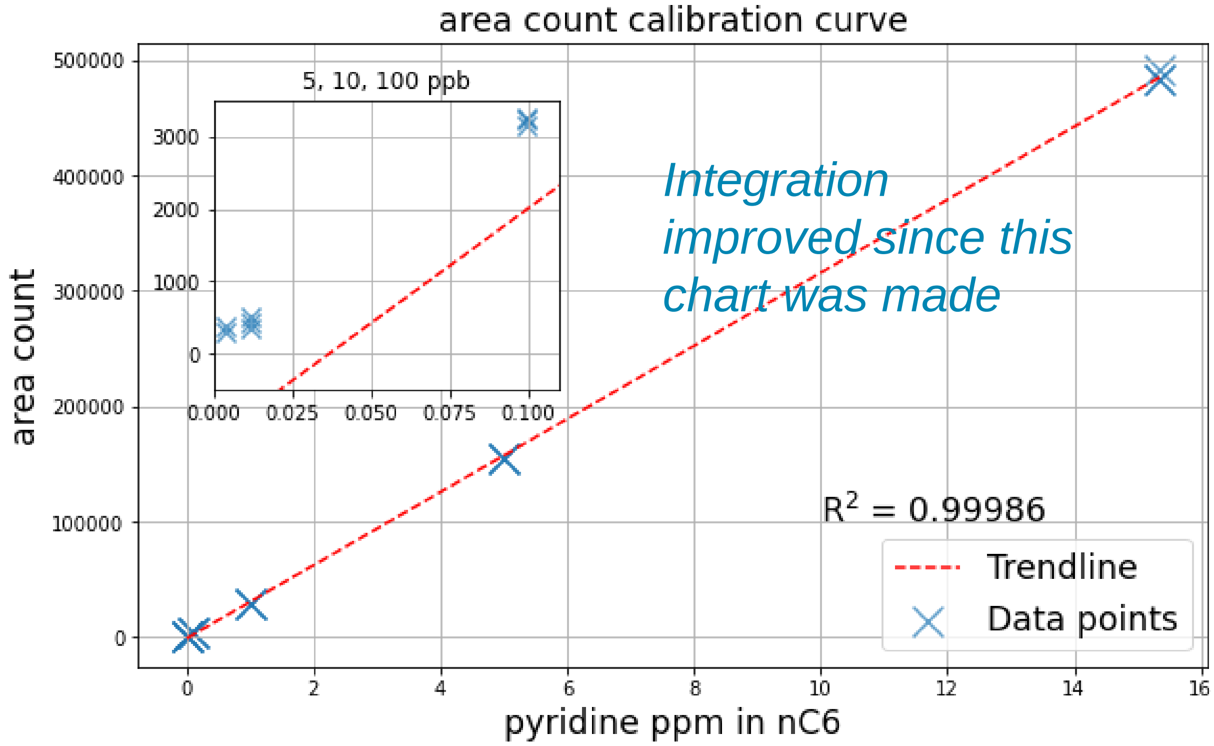
- Plan to employ internal standard(s) to quantify concentrations of impurities
  - at least 2 runs necessary
- Evaluating different GCMS column media for improved isolation of organo-nitrogen compounds
- Required sample volume is suitable for characterization of SATF
  - Recipe for doping cocktail (rqmt)

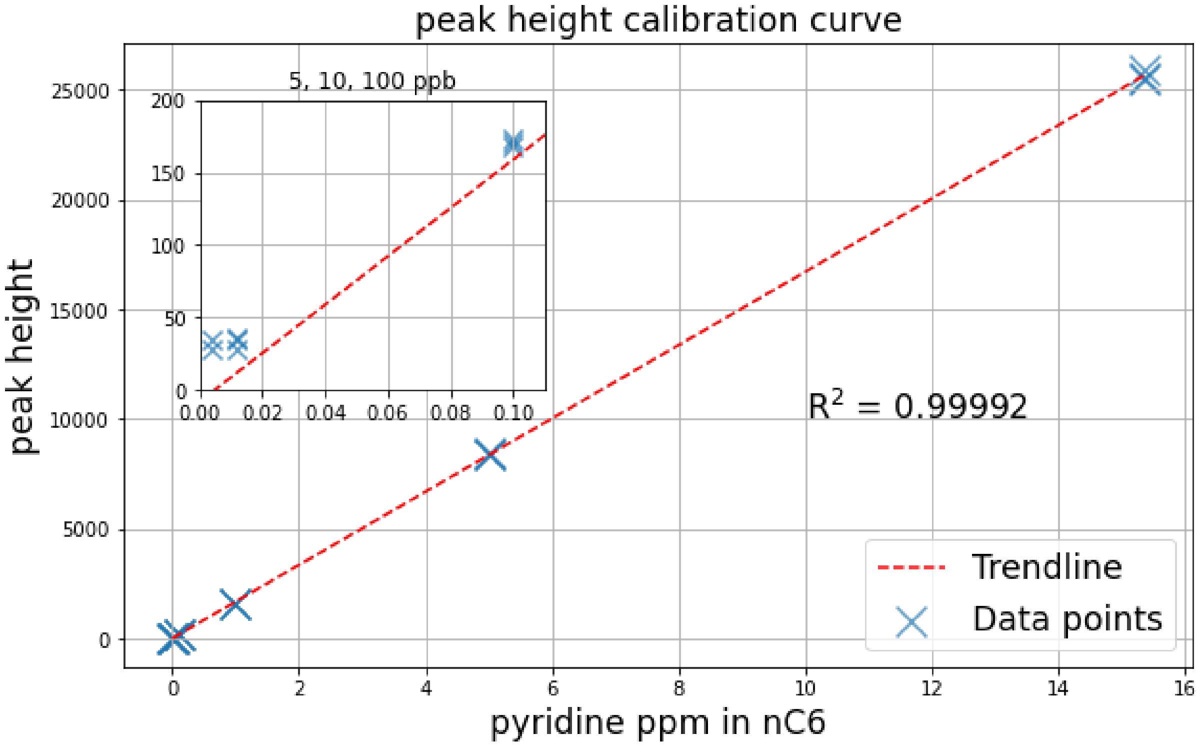
GCMS of Effluent of Fuel Sample



- High-fidelity identification & quantification of impurities in fuel is not critical to our thermal stability design of experiment
- Verification of complete extraction of polar impurities is mission-critical
  - partitioning of aromatics, ethers and sulfides is of particular concern
- Scale-up to 100's ml sample volume is high on priority list
  - Current capability is 10-50 ml sample volume

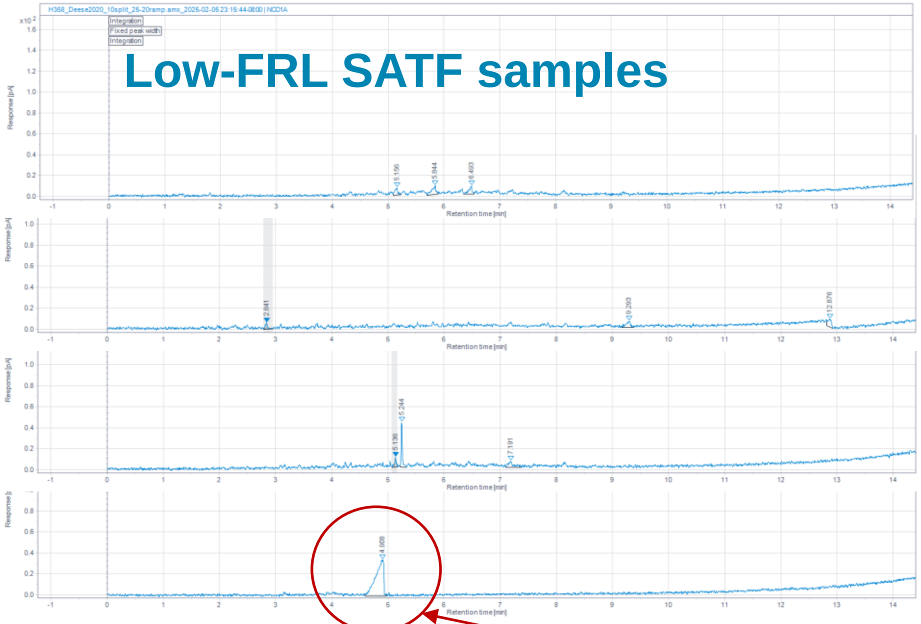
Nitrogen Chemiluminescence Detection (NCD) Calibration

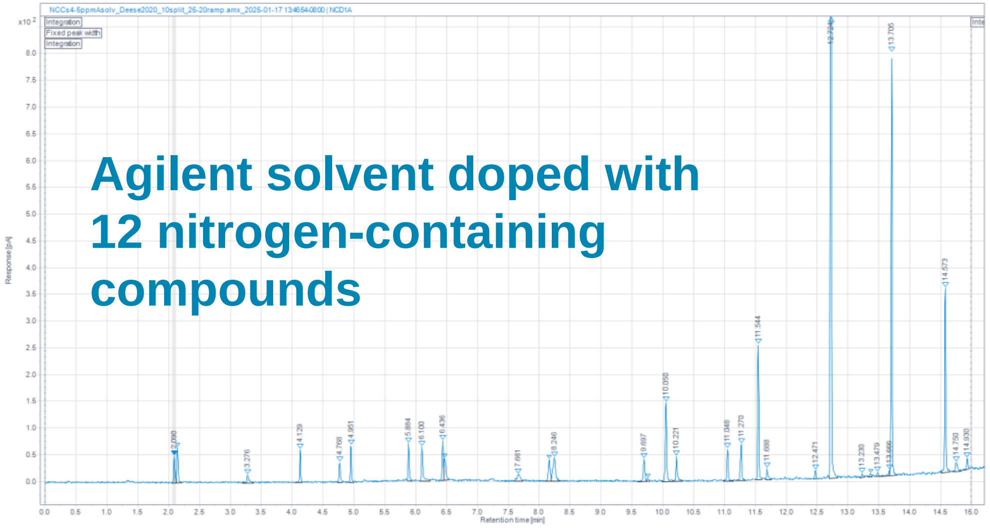




- 7 calibration standards (including "blank") of pyridine in n-hexane made and tested in NCD using method based on Deese et al. 2020.
  - Pyridine concentrations range: 5 ppb to 15ppm
  - Each standard mixture measured in triplicate
  - LOD in the 5-25 ppb range
  - LOQ ~100 ppb
  - Impurity amplification by SPE is necessary prior to GC-NCD analysis to render the organo-nitrogen compounds quantifiable by NCD

Representative NCD Data





This is not an organo-nitrogen compound. Rather it is a single HC molecule at very high concentration: 10^{-7} sensitivity relative to FBN

Analysis Goal: Each peak identified and quantified

Data then serves are target for surrogate dopant to be used in thermal stability testing

ASTM D3241 (JFTOT) Set-Up

> 500mL required for this method

3 ml/min for 2.5 hrs + rinse

Standard test is performed 260C, D4054 Fast Track test is done at 325C

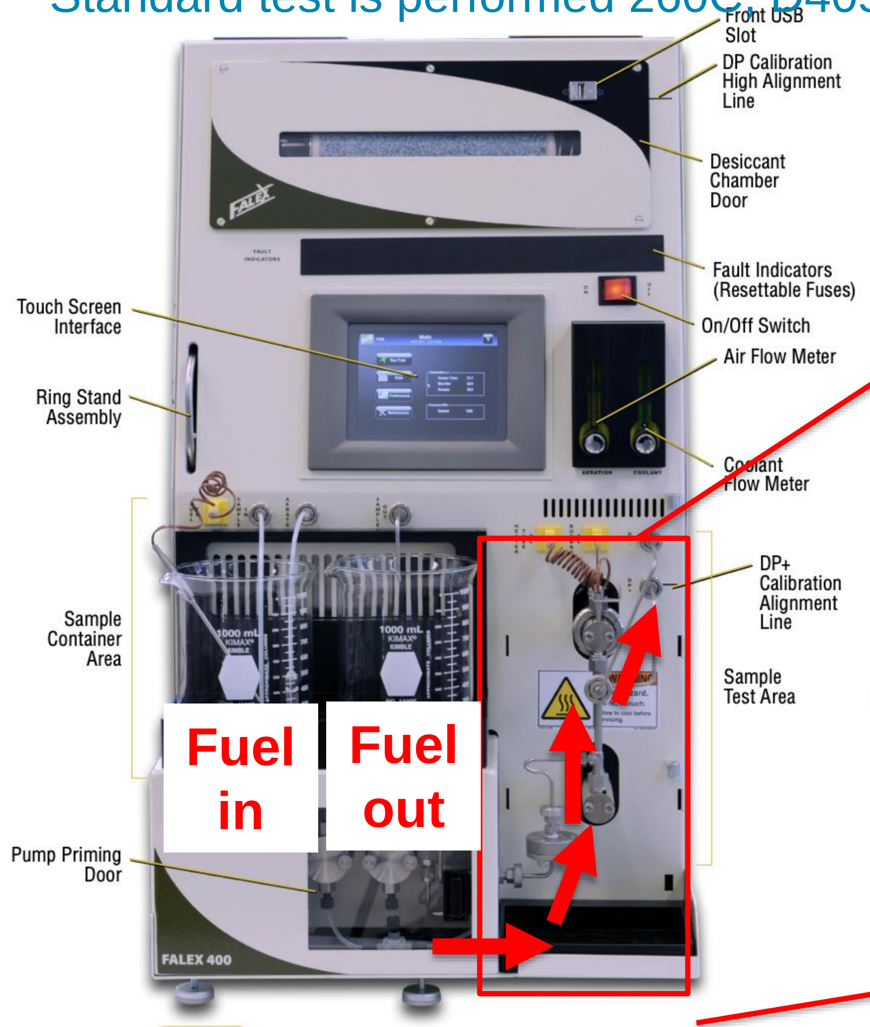
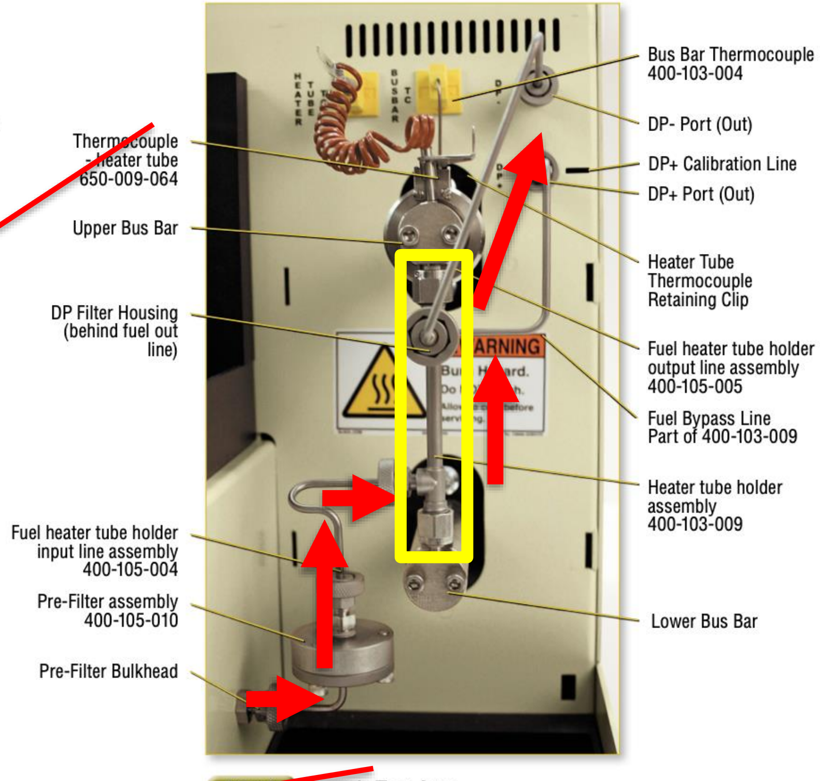


Figure 1 Fuel Thermal Oxidation Tester–Front



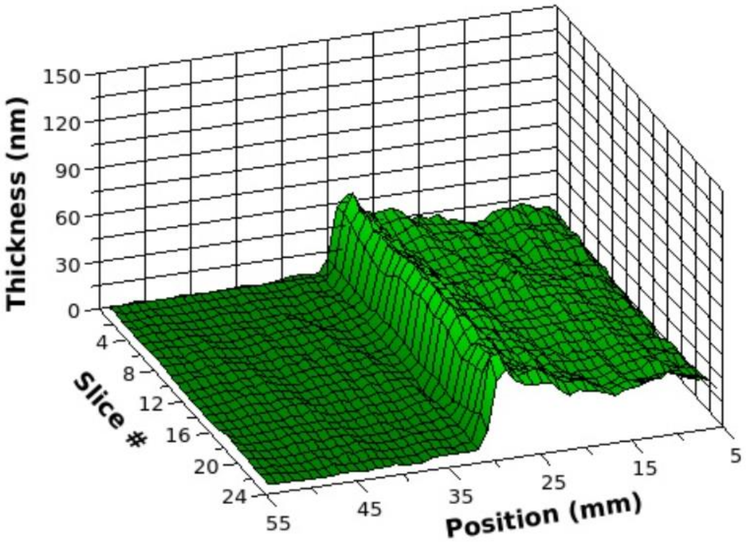
Sample Test Area

Fuel follows path of red arrows across heated sample tube (yellow)

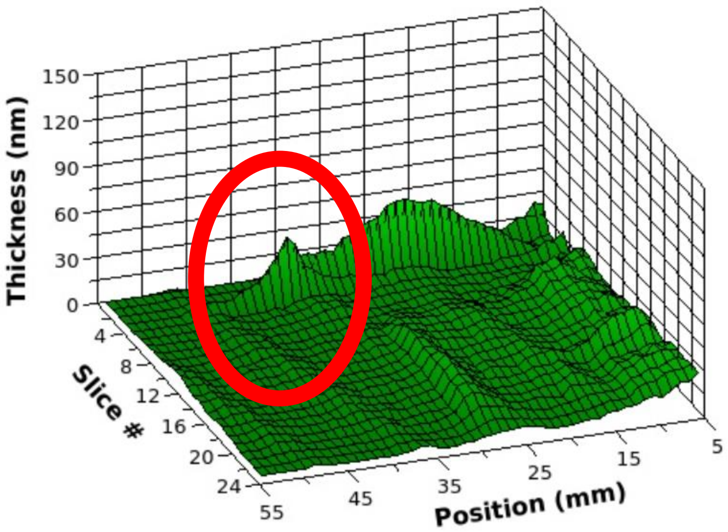
JFTOT/ETR Repeatability Concern

- Examples shown are of the same fuel, same temperature (325 ºC), different days
- Prior to 04/16/2025 we had not observed streaking, since then we've encountered several examples

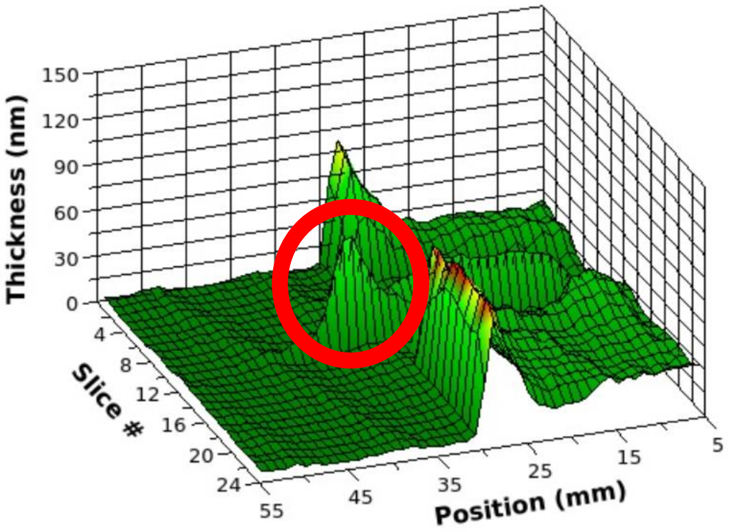
04/09/2025



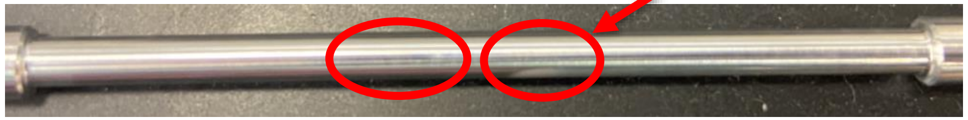
04/22/2025



04/24/2025



Gap in deposit



Different fuel, also 325 ºC

- Streaking occurs in some runs (George Wilson, SWRI & Mark Hopkin, Compass)
- Replication plan must accommodate this contingency

Summary

Programs with overlapping interests leveraged to make progress here

- Analytical methods to characterize oxygenates in SATF
- Analytical methods to characterize total and mercaptan sulfur in any fuel sample (discussed elsewhere)
- Analytical methods to characterize organo-nitrogen content in SATF is progressing
- Upscaled SPE method for impurities separation from conventional fuel is TBD

Discovered repeatability concern with JFTOT -> more runs will be necessary than originally planned (re-plan TBD soon)

Acknowledgements

- U.S. Federal Aviation Administration Office of Environment and Energy

Participants

- Randall Boehm, WSU
- Joshua Heyne, WSU
- Conor Faulhaber, WSU