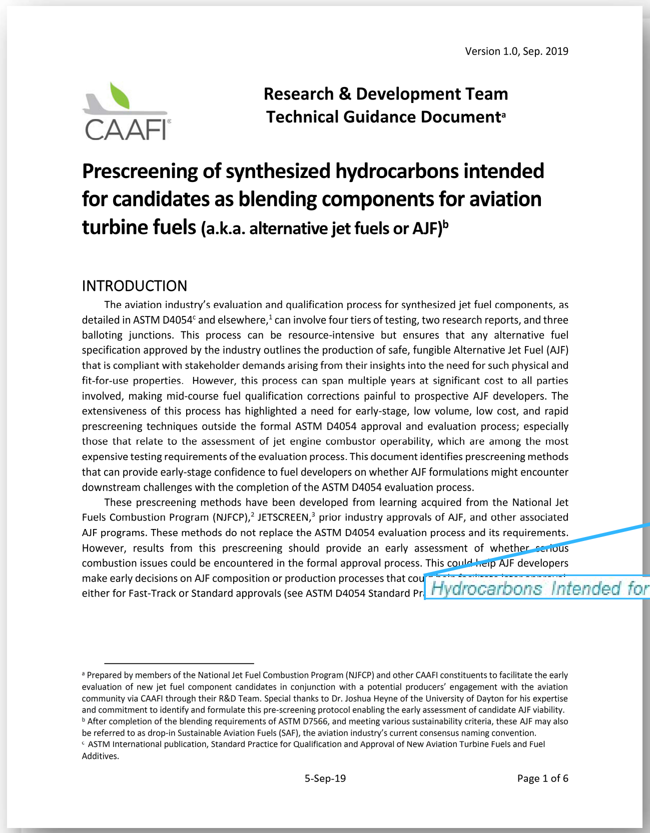
Prescreening Resources

1. **Guidance posted on the CAAFI website**
    1. Prescreening Guidance Page
       http://caafi.org/tools/Prescreening_Guidance.html
    2. Guidance Document
       http://caafi.org/tools/docs/CAAFI_RD_Prescreening_Guidance_Document_v1.0.pdf
2. **CAAFI R&D Team is available for *consultation* (info@caafi.org)**
3. **Labs are available for *testing and evaluation* at low cost**



Version 1.0, Sep. 2019

Research & Development Team
Technical Guidance Document[a]

Prescreening of synthesized hydrocarbons intended for candidates as blending components for aviation turbine fuels (a.k.a. alternative jet fuels or AJF)[b]

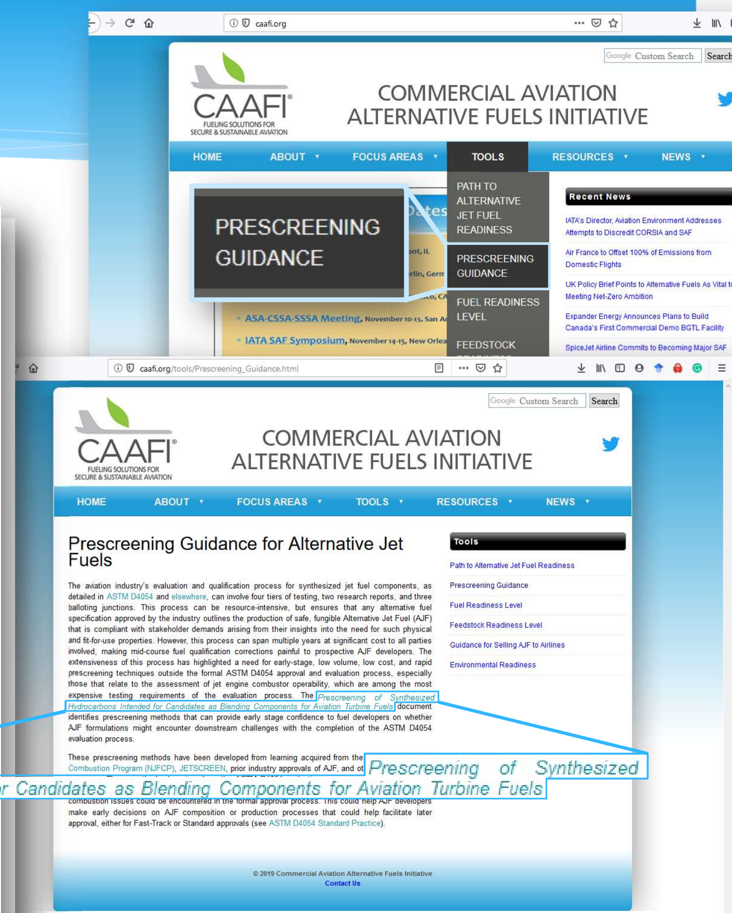
INTRODUCTION

The aviation industry's evaluation and qualification process for synthesized jet fuel components, as detailed in ASTM D4054[c] and elsewhere,[1] can involve four tiers of testing, two research reports, and three balloting junctions. This process can be resource-intensive but ensures that any alternative fuel specification approved by the industry outlines the production of safe, fungible Alternative Jet Fuel (AJF) that is compliant with stakeholder demands arising from their insights into the need for such physical and fit-for-use properties. However, this process can span multiple years at significant cost to all parties involved, making mid-course fuel qualification corrections painful to prospective AJF developers. The extensiveness of this process has highlighted a need for early-stage, low volume, low cost, and rapid prescreening techniques outside the formal ASTM D4054 approval and evaluation process; especially those that relate to the assessment of jet engine combustor operability, which are among the most expensive testing requirements of the evaluation process. This document identifies prescreening methods that can provide early-stage confidence to fuel developers on whether AJF formulations might encounter downstream challenges with the completion of the ASTM D4054 evaluation process.

These prescreening methods have been developed from learning acquired from the National Jet Fuels Combustion Program (NJFCP),[2] JETSCREEN,[3] prior industry approvals of AJF, and other associated AJF programs. These methods do not replace the ASTM D4054 evaluation process and its requirements. However, results from this prescreening should provide an early assessment of whether serious combustion issues could be encountered in the formal approval process. This could help AJF developers make early decisions on AJF composition or production processes that cou
either for Fast-Track or Standard approvals (see ASTM D4054 Standard Pr

[a] Prepared by members of the National Jet Fuel Combustion Program (NJFCP) and other CAAFI constituents to facilitate the early evaluation of new jet fuel component candidates in conjunction with a potential producers' engagement with the aviation community via CAAFI through their R&D Team. Special thanks to Dr. Joshua Heyne of the University of Dayton for his expertise and commitment to identify and formulate this pre-screening protocol enabling the early assessment of candidate AJF viability.
[b] After completion of the blending requirements of ASTM D7566, and meeting various sustainability criteria, these AJF may also be referred to as drop-in Sustainable Aviation Fuels (SAF), the aviation industry's current consensus naming convention.
[c] ASTM International publication, Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives.

5-Sep-19 Page 1 of 6



Low-Cost, Low-Volume Prescreening of Novel SAF

Fit-for-purpose properties to Tier 3 and 4 Operability Limits

Joshua Heyne (jheyne1@udayton.edu) | 17 Oct. 2019 | CAAFI Webinar

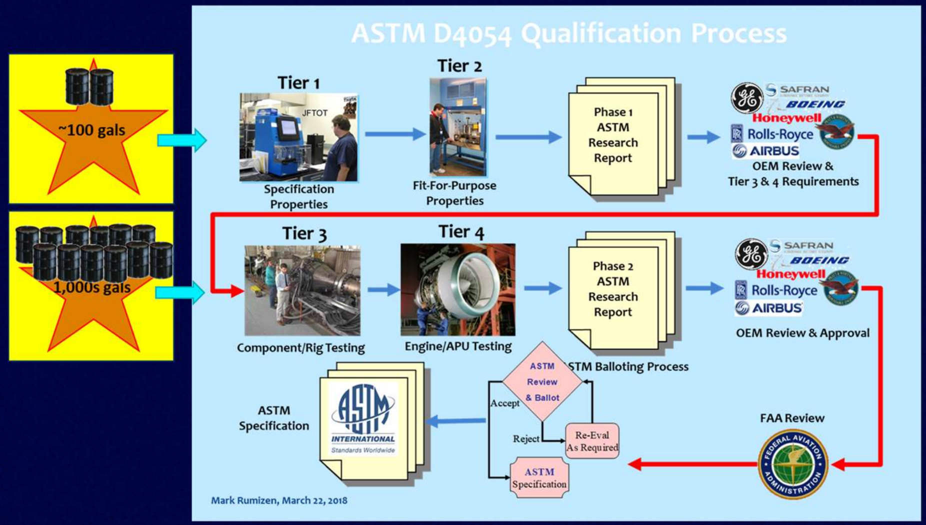
University *of* Dayton
HEAT Lab

The Problem: *High Volume, Cost, and High Uncertainty*

- Potentially high volume and cost requirements, particularly Tier 3 and 4 level.
- Some Tier 3 and 4 Tests focus on Figures of Merit (FOM) Operability limits

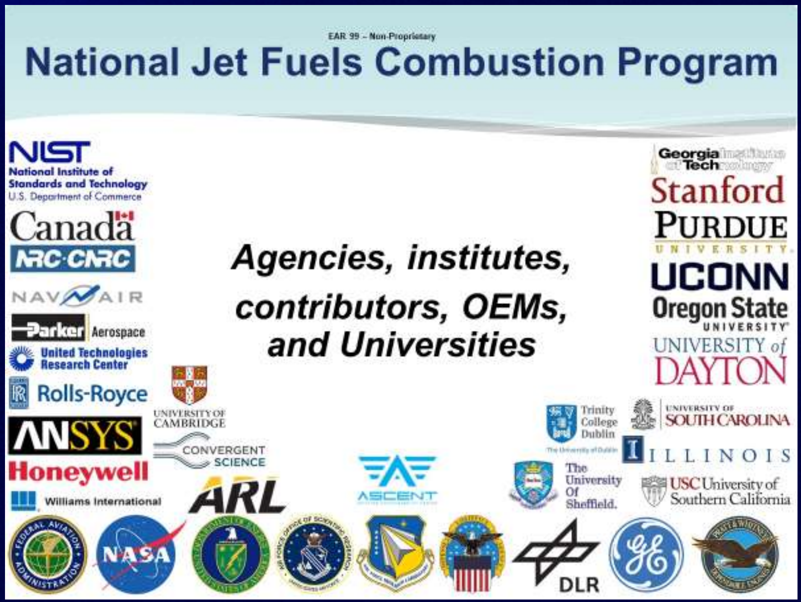
Item	Task	Unit Cost ($K)	Qty	Total Cost ($K)	Fuel Vol (gals)
Tier 1	Fuel Lab Testing	$5	N/A	$5	5
Tier 2	Fuel FFP Testing	$50	N/A	$50	100
Phase 1 Re Rpt	OEM Review	$50	7	$350	N/A
	Phase 1 Sub-Total			$405	105
Tier 3	Fuel Nozzle Spray Rig	$100	2	$200	60
	Fuel System Simulator	$150	1	$150	5,000
	Atomizer Pipe Rig	$50	1	$50	50
	Combustor Rig (Sector)	$250	3	$750	300
	Comb Rig (Full Annular)	$350	1	$350	1000
	APU Combustor Rig	$100	1	$100	50
	APU Cold/Alt Starting	$250	1	$250	50
Tier 4	Engine Oper/Perf Testing	$500	3	$1500	1800 – 9,000
	Engine Emissions	$50	1	$50	100
	Engine Endurance Test	$750	1	$750	20K – 100K
Phase 2 Re Rpt	OEM Review	$150	7	$1050	N/A
	Phase 2 Sub-Total			$5200	28,110 – 115,110
	Grand Total			$5605	28,215 – 115,715

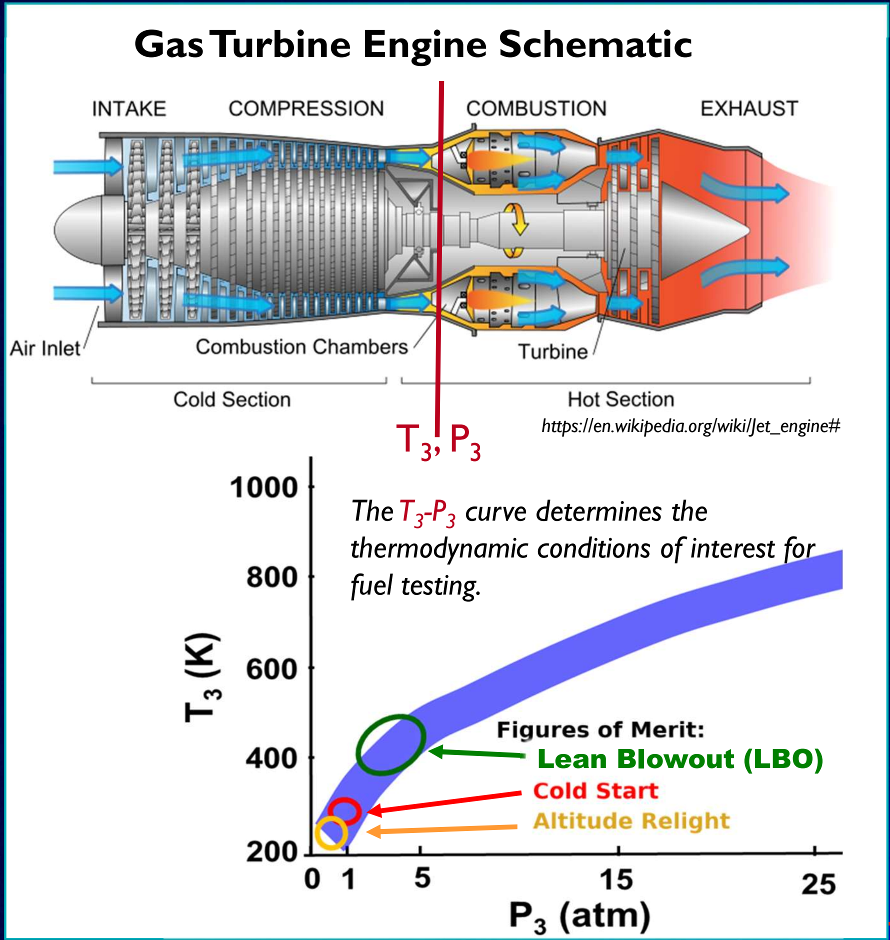
Mark Rumizen
March 24, 2016



National Jet Fuels Combustion Program (NJFCP):

Tier 3 and 4 Operability Focused Testing





- All 5 domestic Engine OEMs
- ~40 institutions, 150 members
- ~12 fuels (3 conventional and 9 alternative)

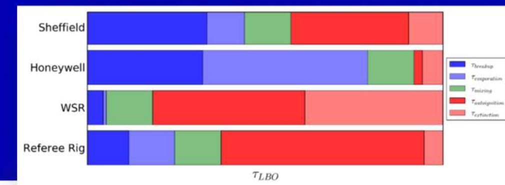
jheyne1@udayton.edu

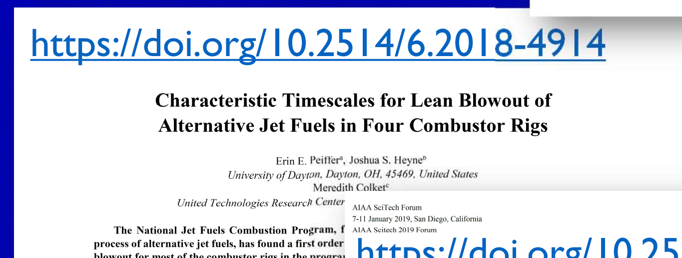
NJFCP Major Take-aways

1. **Conventional Fuel Specifications are Insufficient for Alternative Fuel Characterization**

2. **Referee Rig demonstrates fuel sensitivity for all three FOMs**
   - *Referee Rig fuel sensitivity is larger than other rigs for which we have test data*

3. **Approximately 8 properties are able to account for all observed variance.**
   - *These results are summarized in part with several publications.*
   - *Can be measured with 500 mLs*

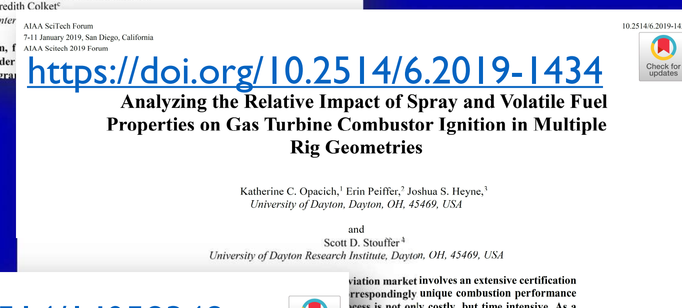



https://doi.org/10.2514/6.2018-4914

Characteristic Timescales for Lean Blowout of Alternative Jet Fuels in Four Combustor Rigs

Erin E. Peiffer[a], Joshua S. Heyne[b]
University of Dayton, Dayton, OH, 45469, United States
Meredith Colket[c]
United Technologies Research Center

The National Jet Fuels Combustion Program, f… process of alternative jet fuels, has found a first order … blowout for most of the combustor rigs in the progra…



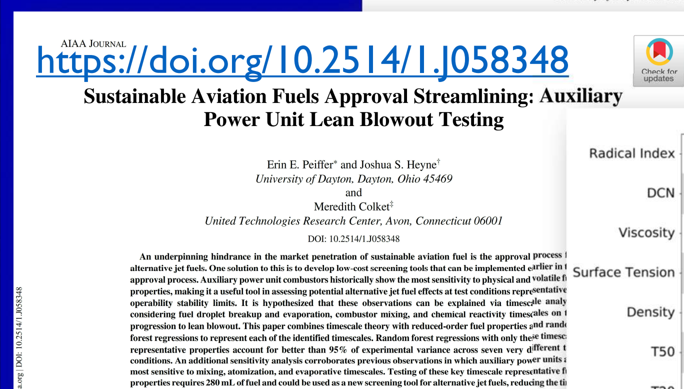
AIAA SciTech Forum
7-11 January 2019, San Diego, California
AIAA Scitech 2019 Forum
10.2514/6.2019-1434

https://doi.org/10.2514/6.2019-1434

Analyzing the Relative Impact of Spray and Volatile Fuel Properties on Gas Turbine Combustor Ignition in Multiple Rig Geometries

Katherine C. Opacich,[1] Erin Peiffer,[2] Joshua S. Heyne,[3]
University of Dayton, Dayton, OH, 45469, USA
and
Scott D. Stouffer[4]
University of Dayton Research Institute, Dayton, OH, 45469, USA

…viation market involves an extensive certification …rrespondingly unique combustion performance …cess is not only costly, but time intensive. As a



AIAA Journal

https://doi.org/10.2514/1.J058348

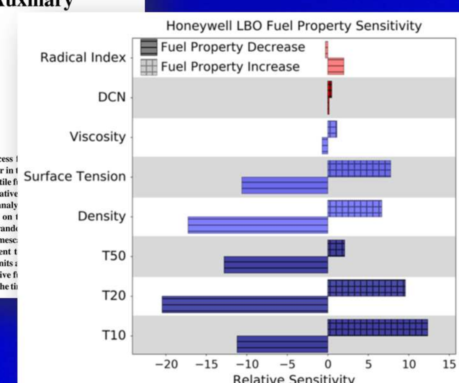
Sustainable Aviation Fuels Approval Streamlining: Auxiliary Power Unit Lean Blowout Testing

Erin E. Peiffer* and Joshua S. Heyne†
University of Dayton, Dayton, Ohio 45469
and
Meredith Colket‡
United Technologies Research Center, Avon, Connecticut 06001

DOI: 10.2514/1.J058348

An underpinning hindrance in the market penetration of sustainable aviation fuel is the approval process … alternative jet fuels. One solution to this is to develop low-cost screening tools that can be implemented earlier in … approval process. Auxiliary power unit combustors historically show the most sensitivity to physical and volatile f… properties, making it a useful tool in assessing potential alternative jet fuel effects at test conditions representative … operability stability limits. It is hypothesized that these observations can be explained via timescale analy… considering fuel droplet breakup and evaporation, combustor mixing, and chemical reactivity timescales on … progression to lean blowout. This paper combines timescale theory with reduced-order fuel properties and rand… forest regressions to represent each of the identified timescales. Random forest regressions with only these timesc… representative properties account for better than 95% of experimental variance across seven very different … conditions. An additional sensitivity analysis corroborates previous observations in which auxiliary power units a… most sensitive to mixing, atomization, and evaporative timescales. Testing of these key timescale representative f… properties requires 280 mL of fuel and could be used as a new screening tool for alternative jet fuels, reducing the ti… and cost for their approval.

iaa.org | DOI: 10.2514/1.J058348



NJFCP Major Take-aways

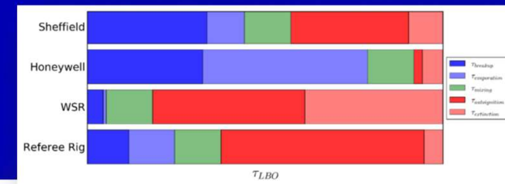
1. Conventional Fuel Specifications are Insufficient for Alternative Fuel Characterization

2. Referee Rig demonstrates fuel sensitivity for all three FOMs
   - Referee Rig fuel sensitivity is larger than other rigs for which we have test data

Tier 2.5 Testing
(Referee Rig AFRL/UDRI)

3. Approximately 8 properties are able to account for all observed variance.
   - These results are summarized in part with several publications.
   - Can be measured with 500 mLs

Prescreening
with mLs of fuel



https://doi.org/10.2514/6.2018-4914

Characteristic Timescales for Lean Blowout of Alternative Jet Fuels in Four Combustor Rigs

Erin E. Peiffer[a], Joshua S. Heyne[a]
University of Dayton, Dayton, OH, 45469, United States
Meredith Colket[c]
United Technologies Research Center…

The National Jet Fuels Combustion Program, f… process of alternative jet fuels, has found a first order… blowout for most of the combustor rigs in the progra…

AIAA SciTech Forum
7-11 January 2019, San Diego, California
AIAA Scitech 2019 Forum
10.2514/6.2019-1434

https://doi.org/10.2514/6.2019-1434

Analyzing the Relative Impact of Spray and Volatile Fuel Properties on Gas Turbine Combustor Ignition in Multiple Rig Geometries

Katherine C. Opacich,[1] Erin Peiffer,[2] Joshua S. Heyne,[3]
University of Dayton, Dayton, OH, 45469, USA
and
Scott D. Stouffer[4]
University of Dayton Research Institute, Dayton, OH, 45469, USA

…iation market involves an extensive certification …rrespondingly unique combustion performance …cess is not only costly, but time intensive. As a

AIAA Journal

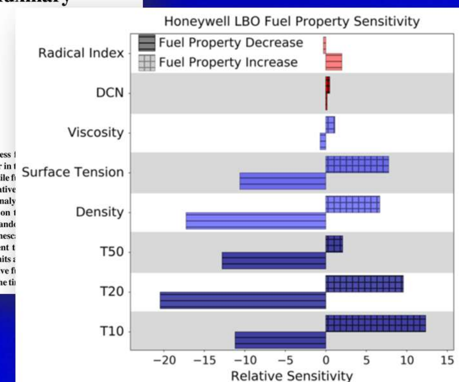
https://doi.org/10.2514/1.J058348

Sustainable Aviation Fuels Approval Streamlining: Auxiliary Power Unit Lean Blowout Testing

Erin E. Peiffer* and Joshua S. Heyne†
University of Dayton, Dayton, Ohio 45469
and
Meredith Colket‡
United Technologies Research Center, Avon, Connecticut 06001

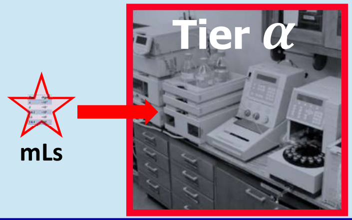
DOI: 10.2514/1.J058348

An underpinning hindrance in the market penetration of sustainable aviation fuel is the approval process … alternative jet fuels. One solution to this is to develop low-cost screening tools that can be implemented earlier in … approval process. Auxiliary power unit combustors historically show the most sensitivity to physical and volatile f… properties, making it a useful tool in assessing potential alternative jet fuel effects at test conditions representative… operability stability limits. It is hypothesized that these observations can be explained via timescale analy… considering fuel droplet breakup and evaporation, combustor mixing, and chemical reactivity timescales on … progression to lean blowout. This paper combines timescale theory with reduced-order fuel properties and rando… forest regressions to represent each of the identified timescales. Random forest regressions with only these timesc… representative properties account for better than 95% of experimental variance across seven very different t… conditions. An additional sensitivity analysis corroborates previous observations in which auxiliary power units a… most sensitive to mixing, atomization, and evaporative timescales. Testing of these key timescale representative f… properties requires 280 mL of fuel and could be used as a new screening tool for alternative jet fuels, reducing the ti… and cost for their approval.



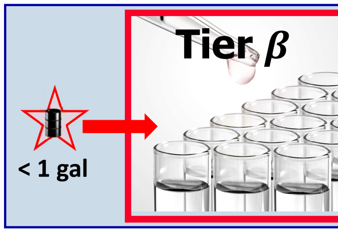
Proposed Three Tiered Screening and Approval

Prescreening



Property Predictions & Blend Estimations

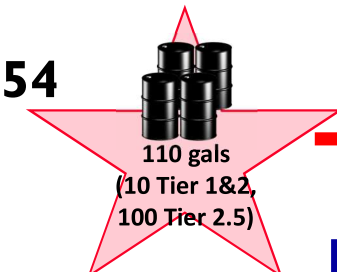
- GCxGC,
- IR absorption, and/or
- NMR

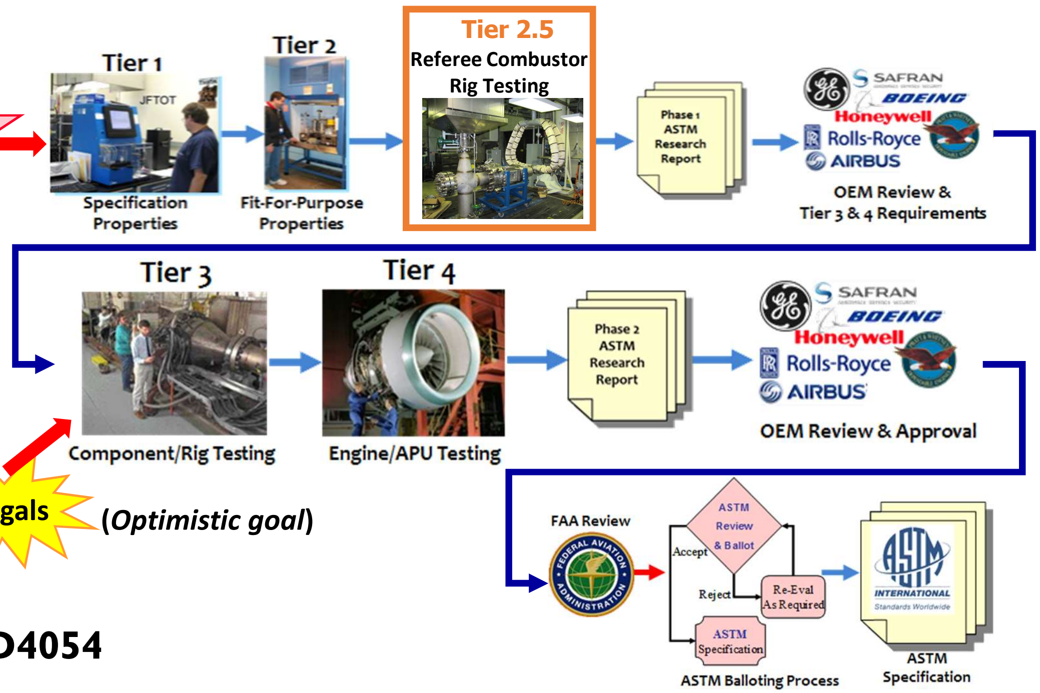


Critical Properties & Blend Limits

- DCN
- Density
- Distillation Curve
- Viscosity
- Surface Tension

Proposed ASTM D4054





0? gals (*Optimistic goal*)

Tier	$\mathcal{O}$(gal)
α	~10^{-4}
β	~10^{-1}
1 & 2	~10^{2}
2.5	~10^{2}
3 & 4	~10^{3}

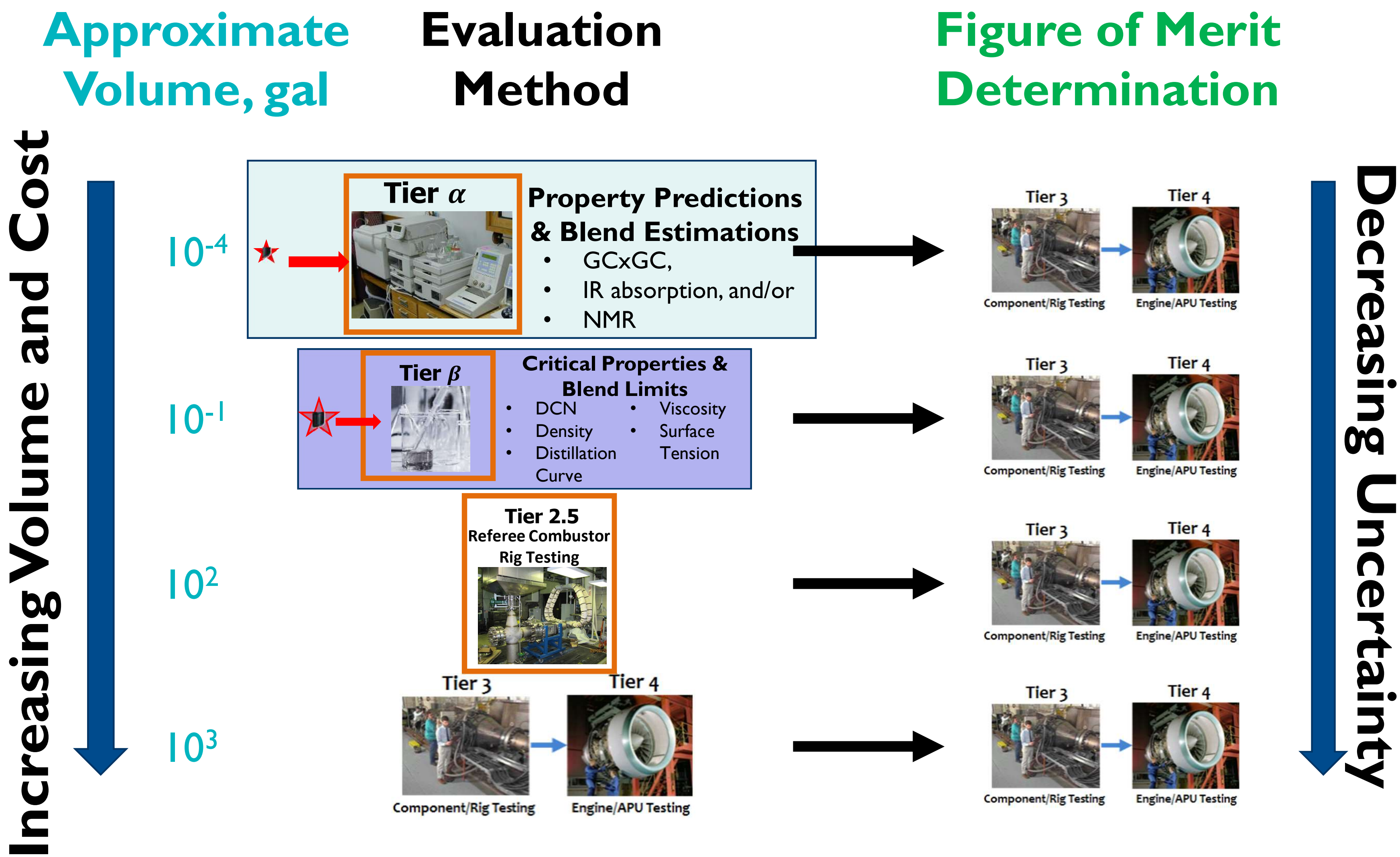
Prescreening (α, β)

Proposed, Tier 2.5 no 3&4 → 2.5

D4054 (1 & 2; 3 & 4)

jheyne1@udayton.edu

Evaluation Methods Volume, Cost, and Uncertainty

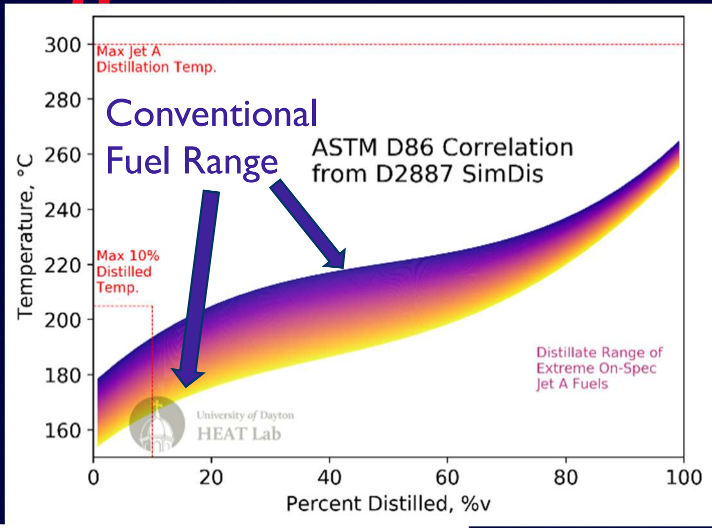


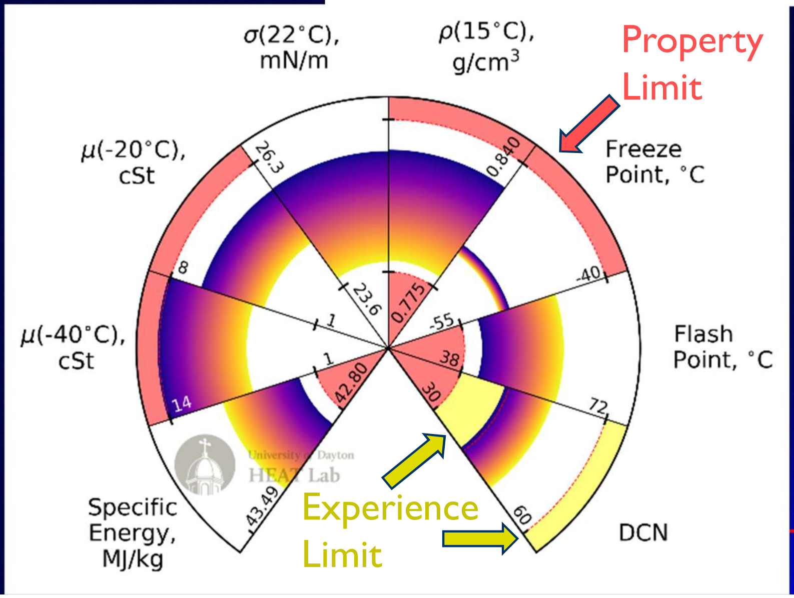
Conventional Fuel Specifications are Insufficient for Alternative Fuel Characterization

- *Conventional Fuel Specification (ASTM D1655) does not account for all the variance.*
  1. No Derived Cetane Number or DCN w.r.t. distillation curve) requirement
  2. No maximum volatility requirements throughout distillation range
  3. No maximum flash point
  4. No maximum surface tension
  5. No -40°C viscosity requirement*

- *To first order, bounding properties within experience range reduces risk.*

- *Non-linear effects can be important. Incorporating models to incorporate FOM effects.*





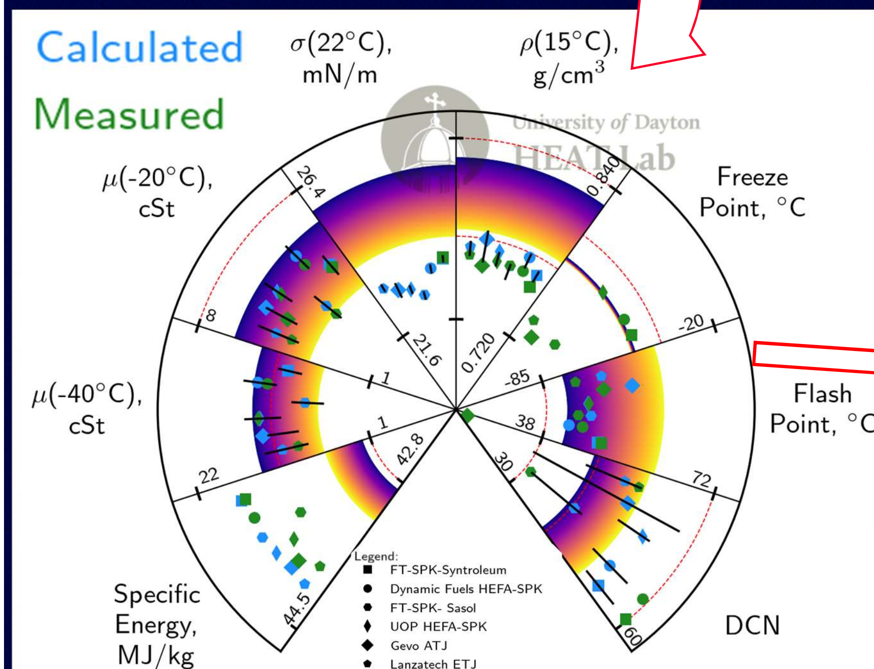
*previous approvals

jheyne1@udayton.edu

Prescreening Evaluation Overview

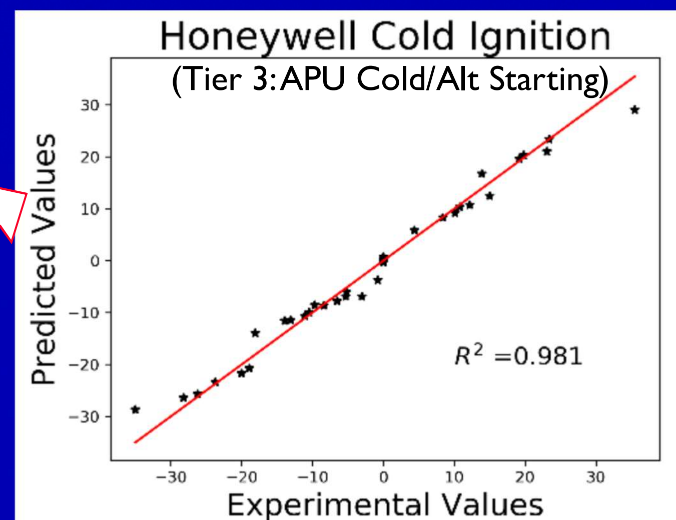
Tier α, mLs

- GCxGC
- ASTM D2887



Tier β, 500 mL

- Tier α
- Viscosity
- Density
- DCN
- Flash Point
- Surface Tension
- O-ring Swelling*



*Optional test dependent on fuel developer's objectives

This Prescreening *isn't (doesn't)*

- Required
- Affect the formal approval process
- Comprehensive
  - Additional properties that alternative fuels are sensitive to are not additionally evaluated.
    - thermal stability
    - contaminates, metals, or olefins
  - Not all Tier 1 & 2 properties are included in the evaluation

This Prescreening *does*

- Give a producer the cheapest and current highest fidelity evaluation of potential Tier 3 and 4 effects
- Communicate what molecules and/or properties are leading to the potentially deleterious behavior
- Give a producer the opportunity to modify a fuel, feedstock, or process *early* in development

Item	Task	Unit Cost ($K)	Qty	Total Cost ($K)	Fuel Vol (gals)
Tier 1	Fuel Lab Testing	$5	N/A	$5	5
Tier 2	Fuel FFP Testing	$50	N/A	$50	100
Phase 1 Re Rpt	OEM Review	$50	7	$350	N/A
	Phase 1 Sub-Total			$405	105
Tier 3	Fuel Nozzle Spray Rig	$100	2	$200	60
	Fuel System Simulator	$150	1	$150	5,000
	Atomizer Pipe Rig	$50	1	$50	50
	Combustor Rig (Sector)	$250	3	$750	300
	Comb Rig (Full Annular)	$350	1	$350	1000
	APU Combustor Rig	$100	1	$100	50
	APU Cold/Alt Starting	$250	1	$250	50
Tier 4	Engine Oper/Perf Testing	$500	3	$1500	1800 – 9,000
	Engine Emissions	$50	1	$50	100
	Engine Endurance Test	$750	1	$750	20K – 100K
Phase 2 Re Rpt	OEM Review	$150	7	$1050	N/A
	Phase 2 Sub-Total			$5200	28,110 – 115,110
	Grand Total			$5605	28,215 – 115,715

Mark Rumizen
March 24, 2016

Summary

- Give a producer the cheapest and current highest fidelity evaluation of what could happen in Tier 3 and 4 testing
  - What molecules and/or properties are leading to the potentially deleterious behavior.
- Tier α ~ mLs
- Tier β ~ 500 mL
- Other efforts are also working towards Prescreening Protocols
  - JETSCREEN
  - Stanford
  - Purdue
  - USC

- Guidance posted on the CAAFI website
  1. Prescreening Guidance Page http://caafi.org/tools/Prescreening_Guidance.html
  2. Guidance Document http://caafi.org/tools/docs/CAAFI_RD_Prescreening_Guidance_Document_v1.0.pdf
- CAAFI R&D Team is available for *consultation* (R&D@caafi.org)

jheyne1@udayton.edu

QUESTIONS?

Joshua S. Heyne, Assistant Professor

School of Engineering

Kettering Labs, Rm 345D

937-229-5319

jheyne1@udayton.edu

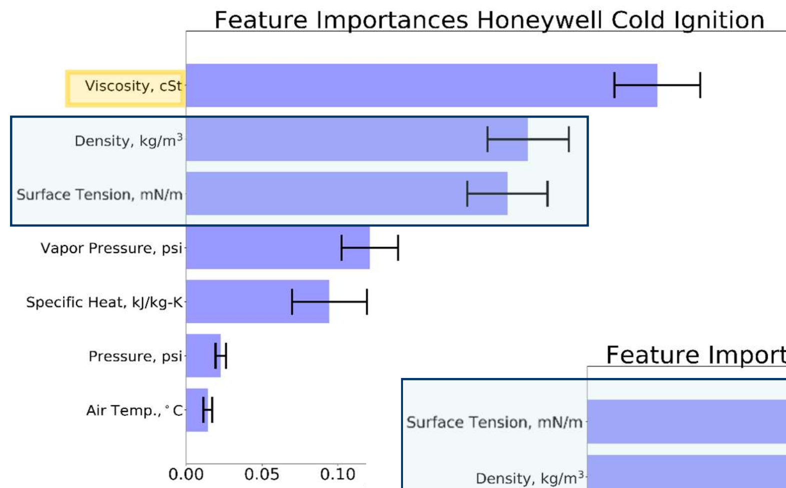
Ignition: *All rigs are consistent qualitatively consistent*

Major Results:

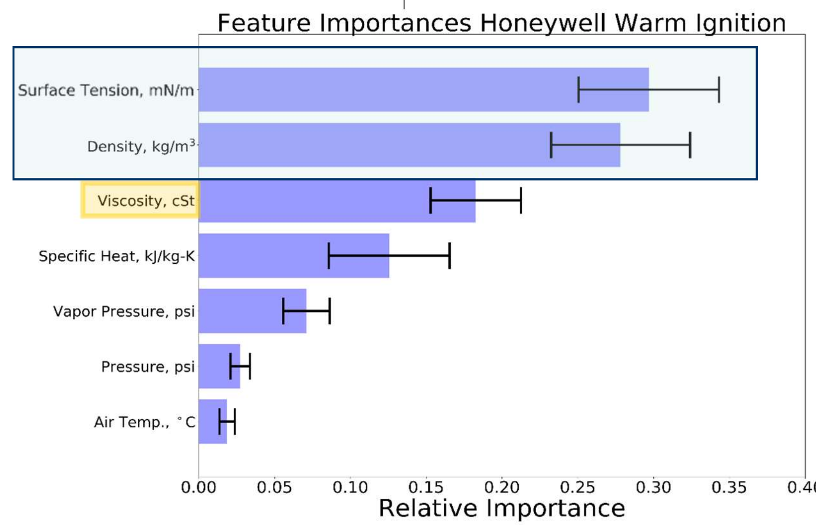
1. All rigs show similar trends
2. Viscosity, surface tension, density, and volatility are *potentially* all important.
   - Collectively more than 96% of variance is captures with these properties.
   - Only one 'odd' fuel (C5) and condition (alt. relight)are identified to date. It remains unexplained.
3. The relative importance of these properties is not currently definitive and may not be universal.

Implications:

1. A maximum flash point.
2. A maximum surface tension.



Fuel temperatures have the largest affect on relative importance of fuel properties.



LBO: *All rigs are qualitatively consistent*

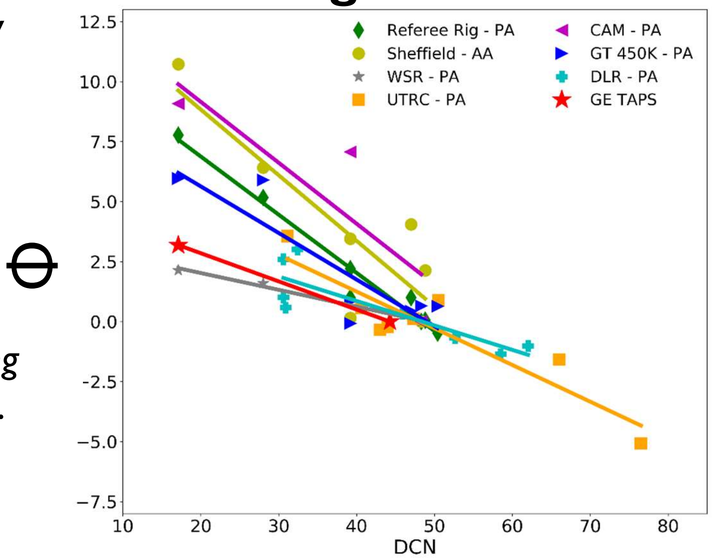
Major Results:

1. All rigs are qualitatively consistent.
2. Warm and cold LBO regimes.
3. Statistical high level models account for more than >89% of all variance, *when neglecting preferential vaporization.*

Implications:

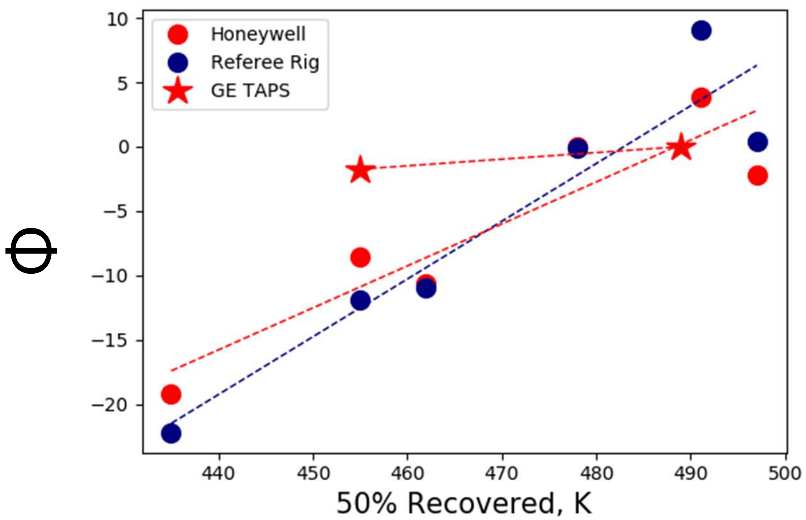
1. A minimum DCN
2. A minimum volatility requirement

Chemical Dominated LBO Regime



$$\text{Normalized LBO } \Phi = \frac{\Phi(LBO_i) - \Phi(LBO_{A-2})}{\Phi(LBO_{A-2})}\ x\ 100$$

Spray/Evaporative Dominated LBO Regime



The distillation curve (D2887 or D86) is a determination of droplet evaporation timescales.

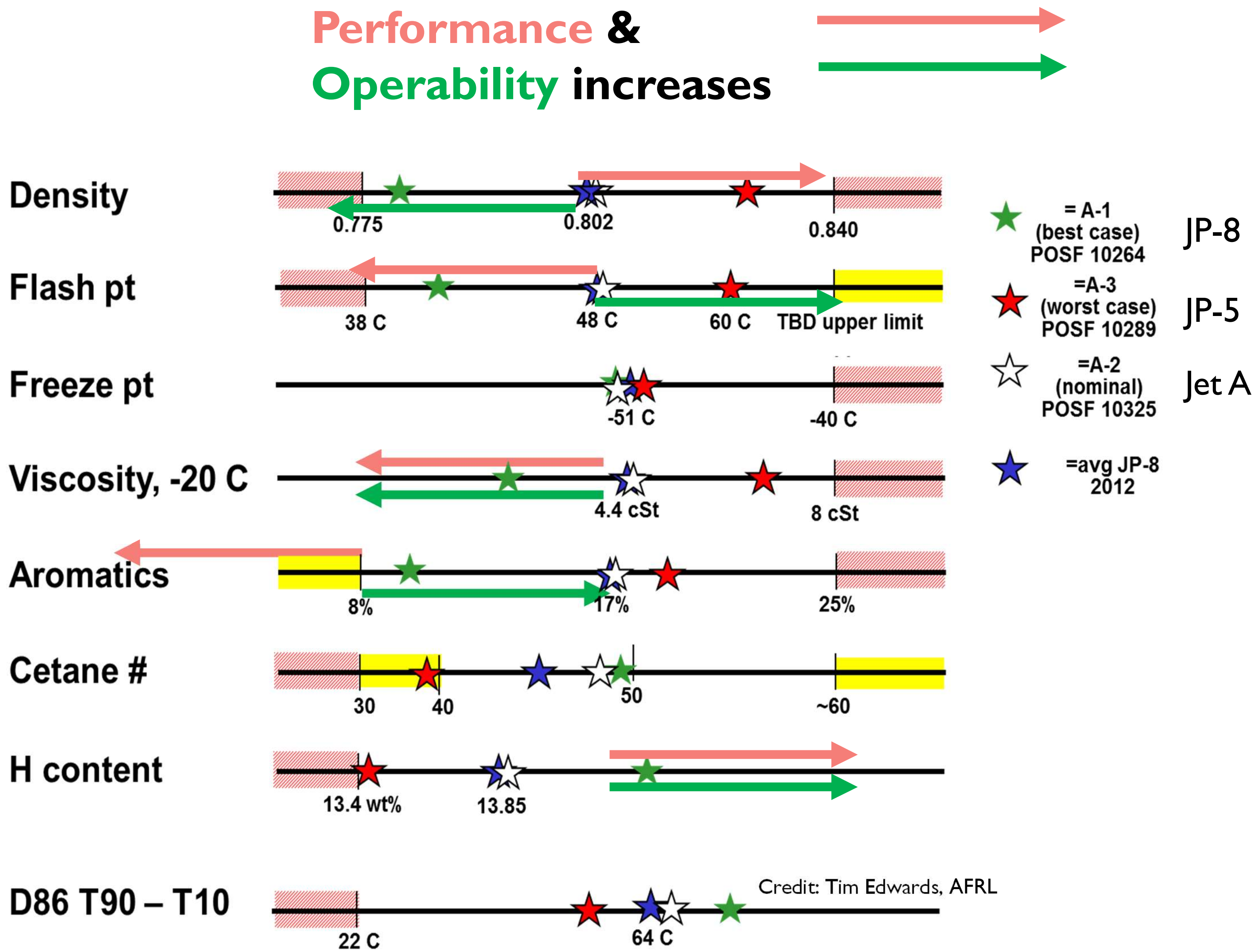
	T_{fuel}, °F	T_{air}, °F
Referee Rig	5	5
Honeywell	59	124
GE (2.5 dP/P)	175	175

Conventional Fuel:

Operability Properties

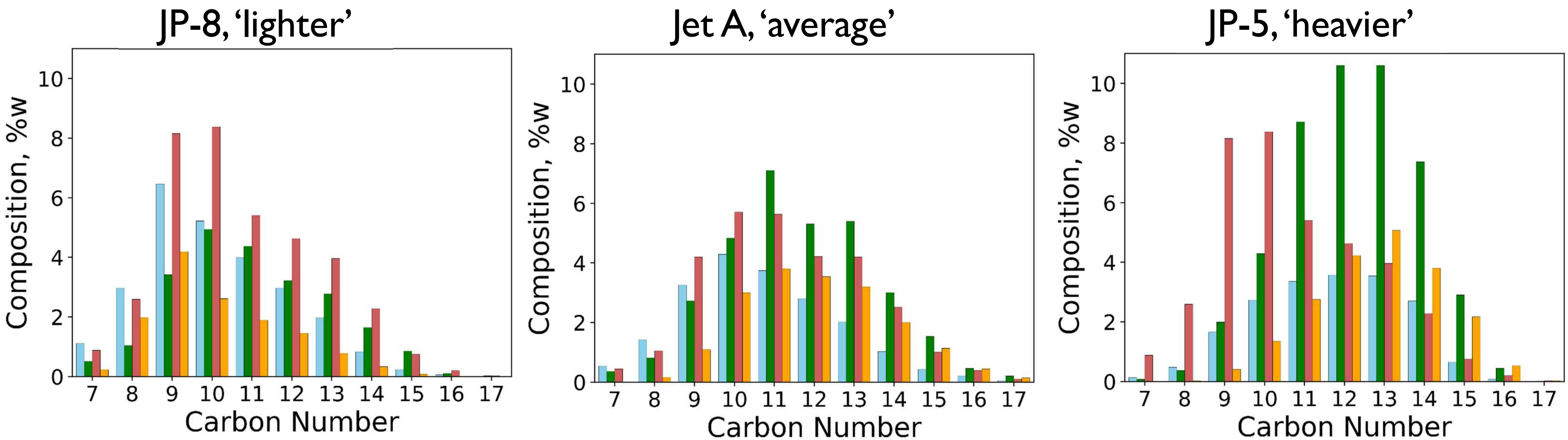
Operability properties enable increased:

- combustion stability with increased propensity to hold a flame and ignite
- safer handling
- lower freeze point



Conventional Fuel: *Composition changes affect operability*

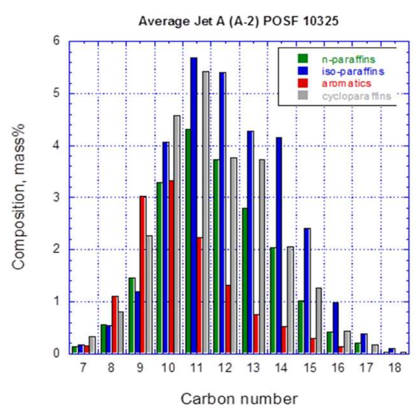
- *There is significant flexibility in jet fuel composition*
- *Molecular weight/average molecule carbon number decreases with increasing operability*
- *Some molecules appear off with properties but still make a great blend with jet fuel*

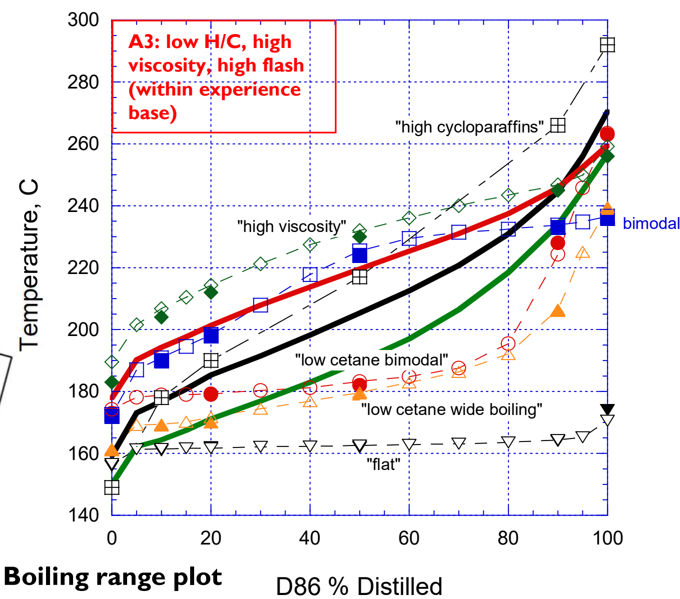


Fuel Candidates and Screening

- Reference Fuels Required to Characterize Rig and Engine Fuel Response
- Category A: Three Conventional (Petroleum) Fuels

  --"Best" case (A-1) --"Average" (A-2) --"Worst" case (A-3)
- Category C: Six "Test Fluids" With Unusual Properties
  - **C-1: low cetane, narrow boiling (downselected)**
  - C-2: bimodal boiling, aromatic front end
  - C-3: high viscosity
  - C-4: low cetane, wide boiling
  - **C-5: narrow boiling, full fuel (downselected)**
  - **C-6 and C-6a: high cycloparaffins**



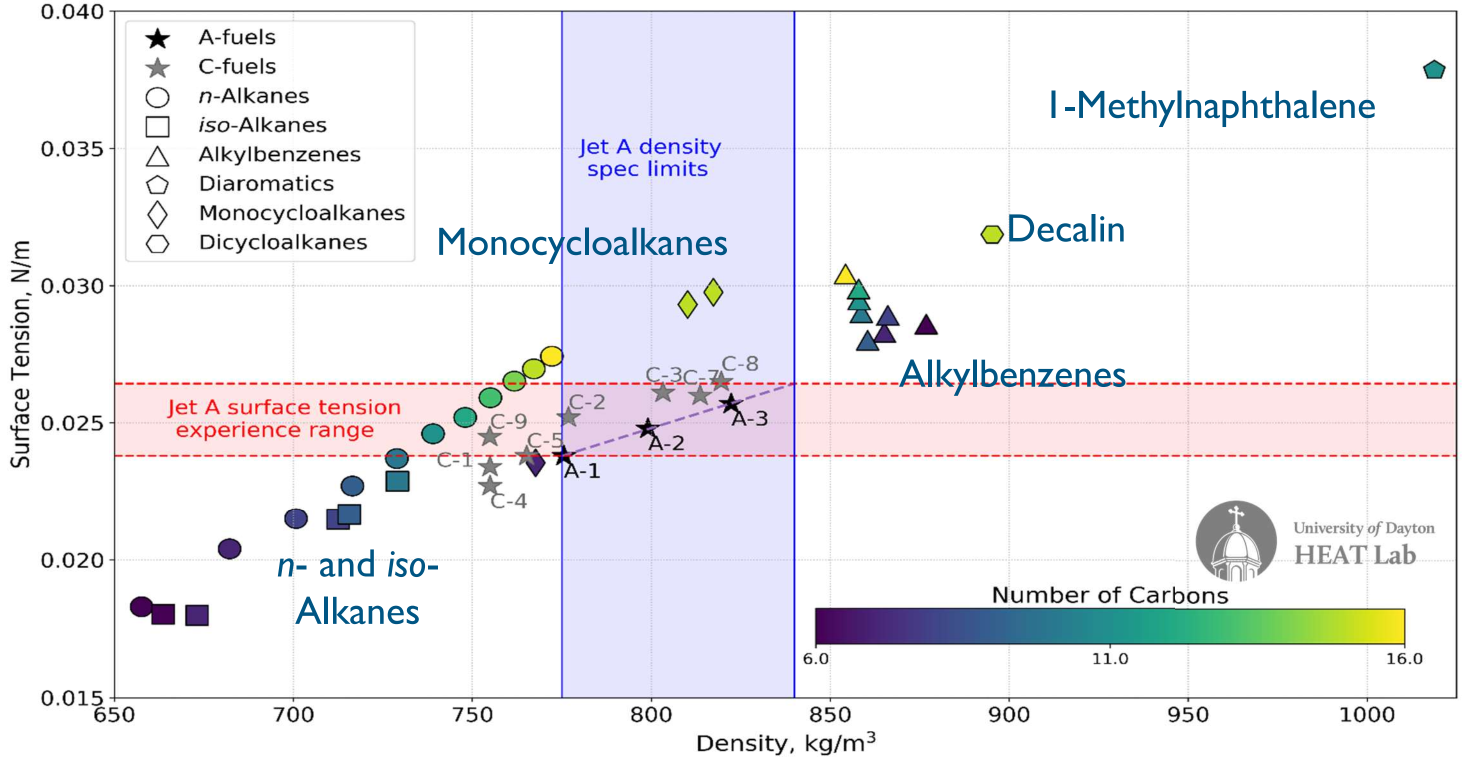


Boiling range plot

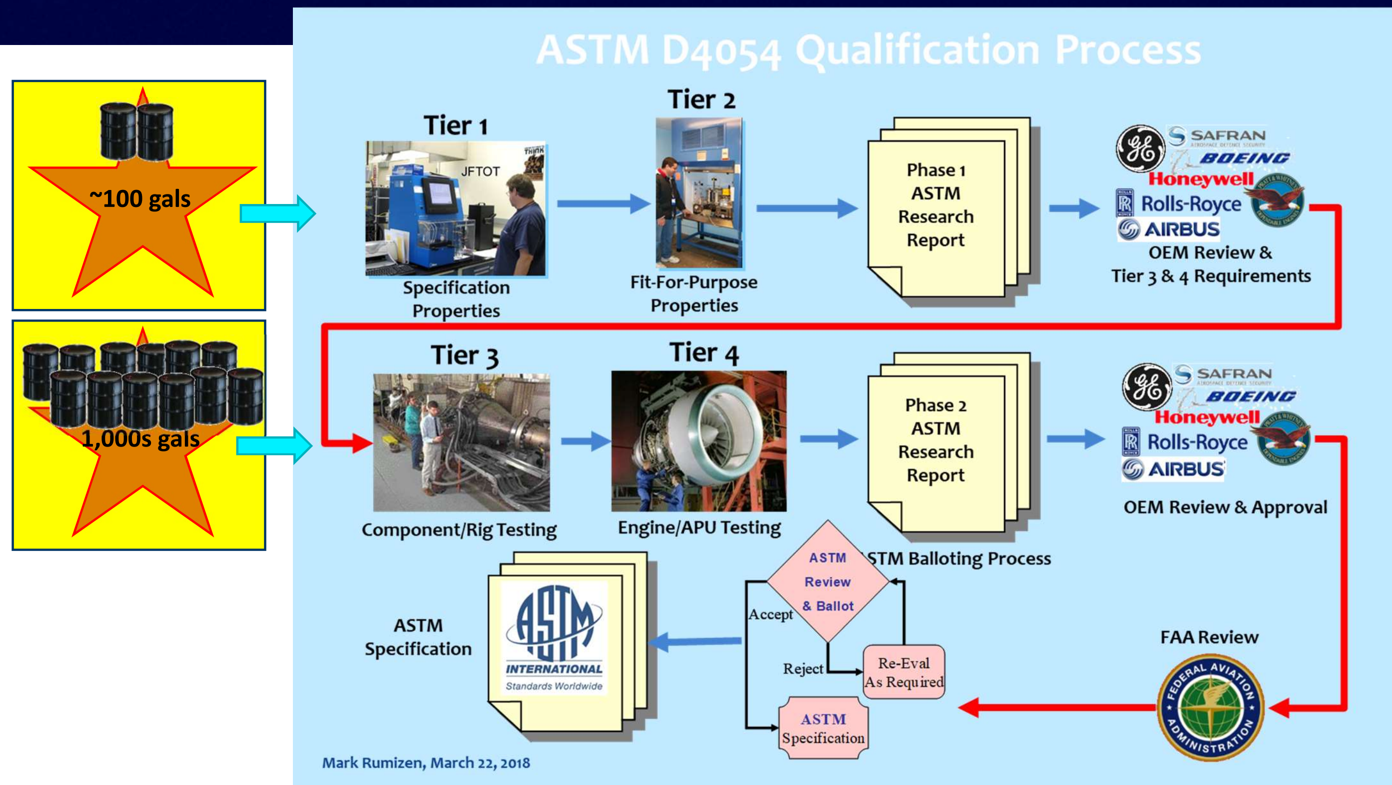
C-1 and C-5 were selected for detailed study in Year 1.

C-6 and C-6a not available

Surface Tension vs. Density at 22 °C



Density specification limits: 775 – 840 kg/m^3


~100 gals
1,000s gals
ASTM D4054 Qualification Process
Tier 1
JFOTOT
Specification Properties
Tier 2
Fit-For-Purpose Properties
Phase 1 ASTM Research Report
SAFRAN
BOEING
Honeywell
Rolls-Royce
AIRBUS
OEM Review & Tier 3 & 4 Requirements
Tier 3
Component/Rig Testing
Tier 4
Engine/APU Testing
Phase 2 ASTM Research Report
SAFRAN
BOEING
Honeywell
Rolls-Royce
AIRBUS
OEM Review & Approval
ASTM Balloting Process
ASTM Review & Ballot
Accept
Reject
Re-Eval As Required
ASTM Specification
ASTM Specification
INTERNATIONAL
Standards Worldwide
FAA Review
FEDERAL AVIATION ADMINISTRATION
Mark Rumizen, March 22, 2018