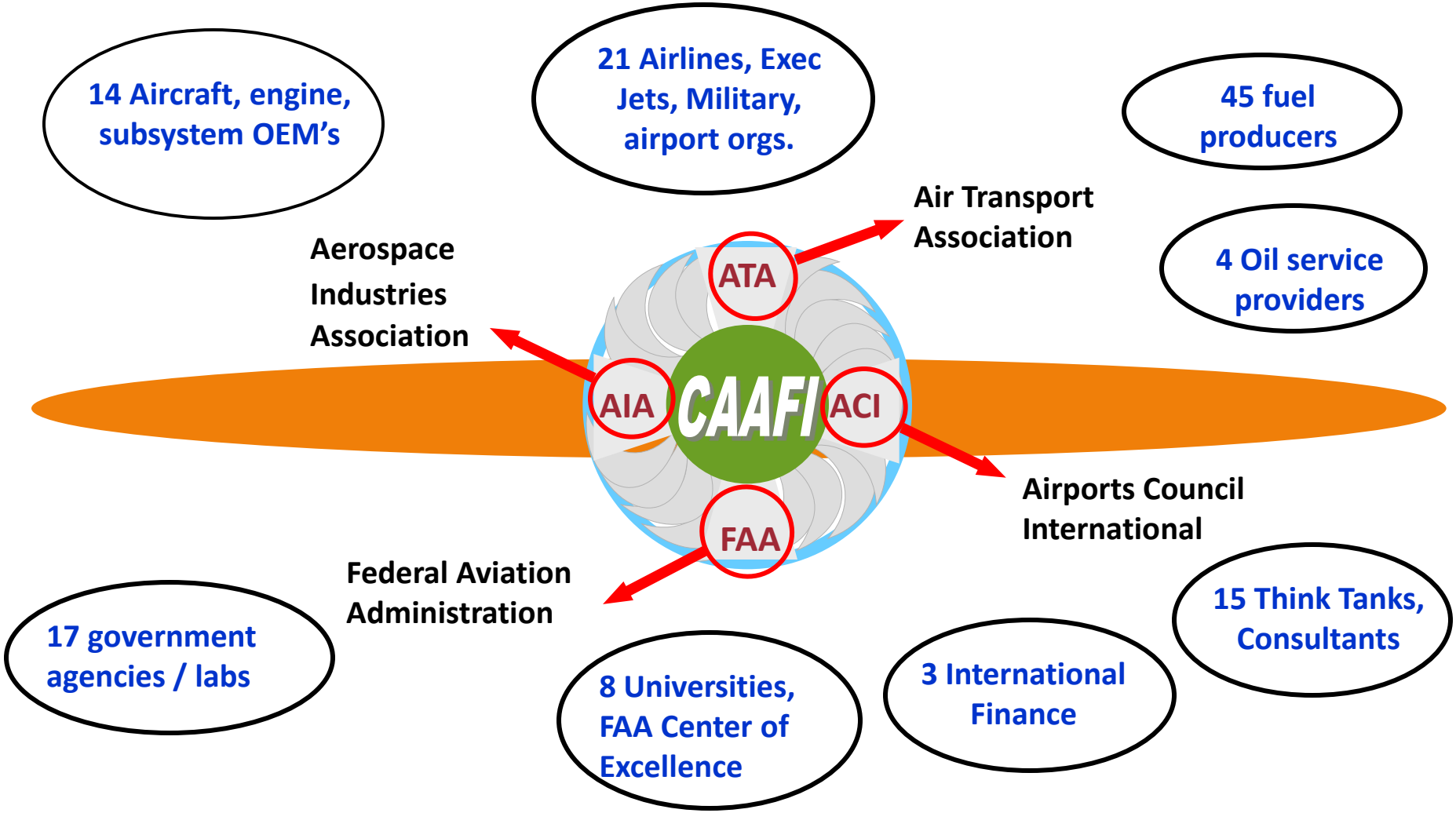
THE AIR FORCE RESEARCH LABORATORY
LEAD | DISCOVER | DEVELOP | DELIVER

Alternative Aviation Fuels Evaluation to Support Certification

July 27, 2011

Tim Edwards
Air Force Research Laboratory
Propulsion Directorate

CAAFI's Global Supply Chain Reach*



350 Sponsors/Stakeholders From All Continents

* *Actual attendance at 9/30/09 annual meeting 230 people, 125 entities*

Aviation Biofuels Supply Chain

Economic and environmental sustainability analysis across entire supply chain

Feedstock Production → Feedstock Logistics → Biofuels Conversion → Fuel Testing & Approval → Large Scale Deployment

USDA	✓	✓	✓	---	✓
Commerce	---	---	---	---	✓
DOE	✓	✓	✓	---	---
DoD - Services	---	---	---	✓	✓
DARPA	✓	✓	✓	---	---
EPA	---	---	---	✓	✓
FAA	---	---	---	✓	✓
NASA	---	---	---	✓	---

Alternative Fuel Evaluation (ASTM D4054, MIL-HDBK-510)

Specification Properties

Fit-For-Purpose Properties

Component/Rig Testing – operability, durability

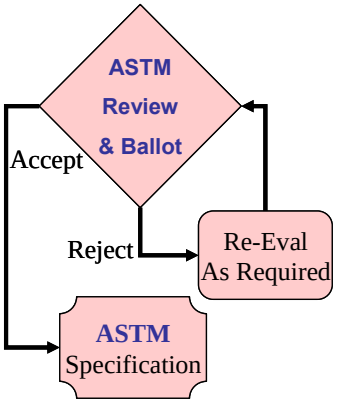
Engine/APU Testing

R&D

Cert.

ASTM Research Report

FAA & OEM Review & Approval



ASTM Balloting Process

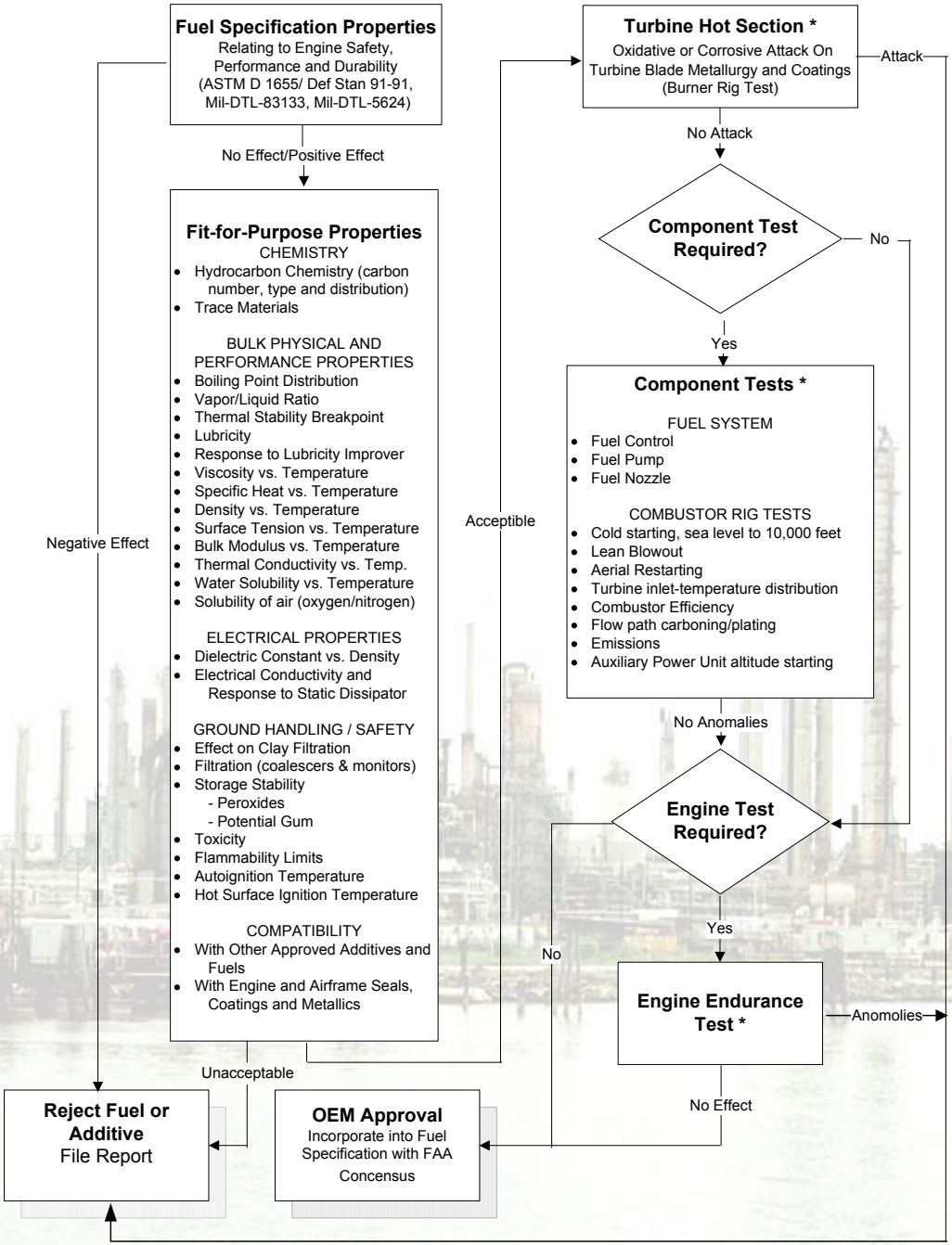
ASTM D7566 Revision

Alternative Aviation Fuels

FEEDSTOCK

PROCESS	coal/NG large volume	plant oils/ animal fat	sugars/ starches	ligno-cellulosic large volume
Fischer-Tropsch	certified, demonstrated at full scale	n/a	n/a	certified, demonstrated at small scale
HEFA/ HRJ	n/a	certified (almost), demonstrated at scale	n/a	n/a
Alcohol-to-jet	n/a	n/a next cert target	ASTM Task Force, FRL 3?	difficulty is sugar/alcohol production
Pyrolysis	demonstrated at small scale	n/a	n/a	upgrading difficult
Direct fermentation	n/a	n/a	FRL 3 (?)	difficulty is direct production from cellulosics

Revised 12/24/07



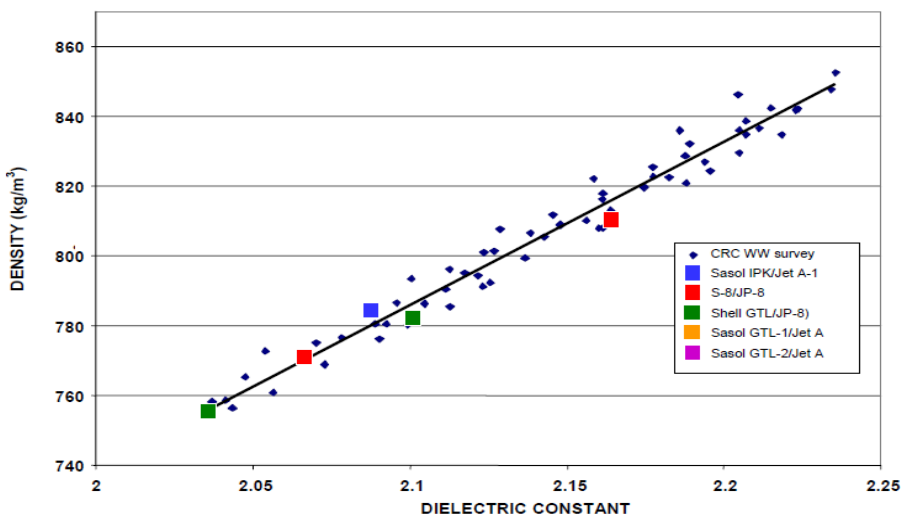
* Testing must be performed at P&W, GEAE , RR or Honeywell due to proprietary concerns

ASTM Standard Practice D4054– Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives

Evolving…

Data Collected in Research Reports

- Used to support commercial specifications (data also used for military certification)
  - Some DOD-unique: diesel engines, afterburners…
- Addresses whether "drop-in" fuels fall within experience base
- Coordinated with Commercial Aviation Alternative Fuel Initiative



COMPARATIVE EVALUATION OF SEMI-SYNTHETIC JET FUELS

FINAL REPORT

Prepared for
Coordinating Research Council, Inc.
3650 Mansell Road, Suite 140
Alpharetta, GA 30022

Universal Technology Corporation
1270 North Fairfield Road
Dayton, OH 4432

Prepared by
Clifford A. Moses
Consultant
New Braunfels, Texas

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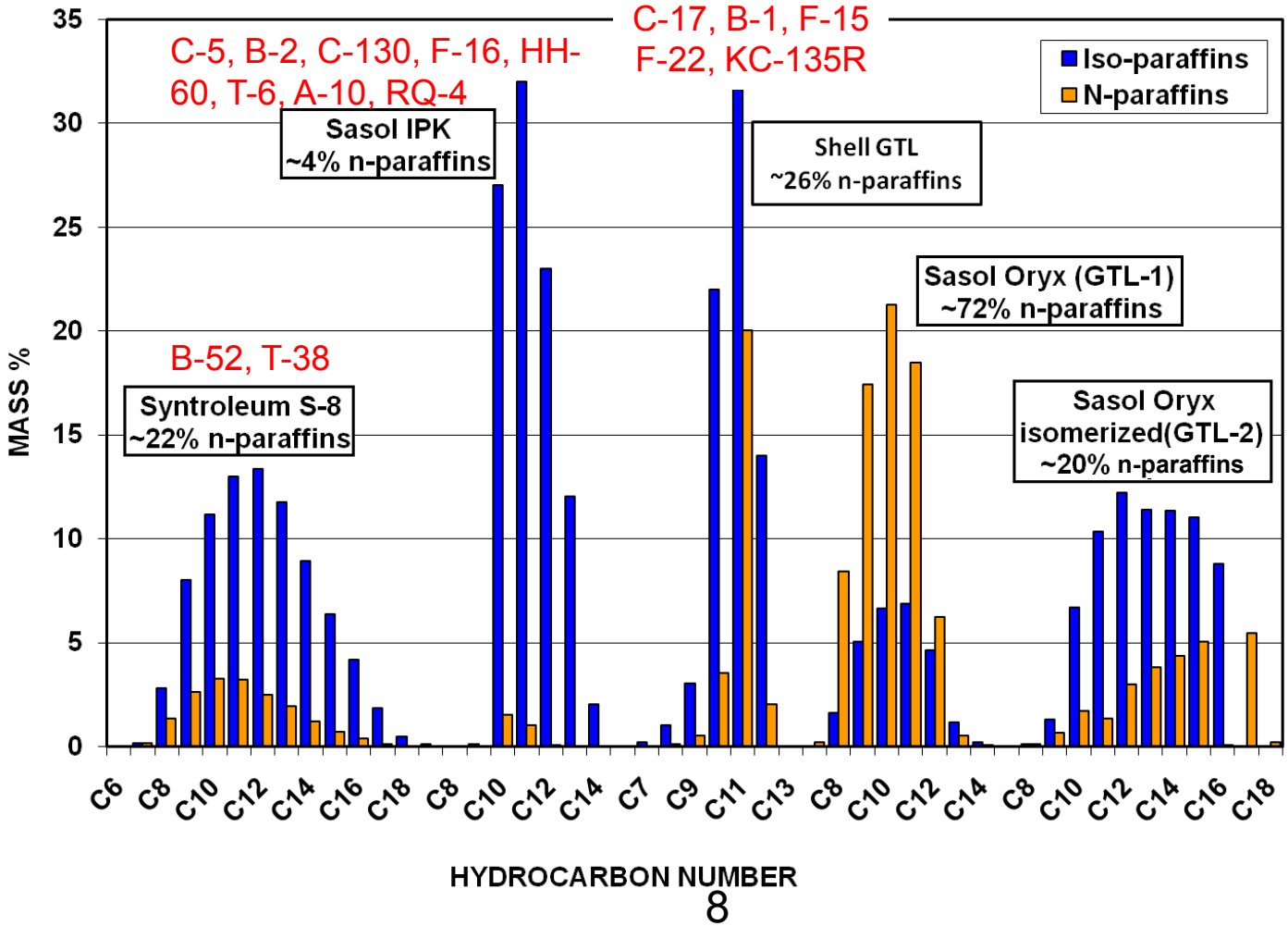
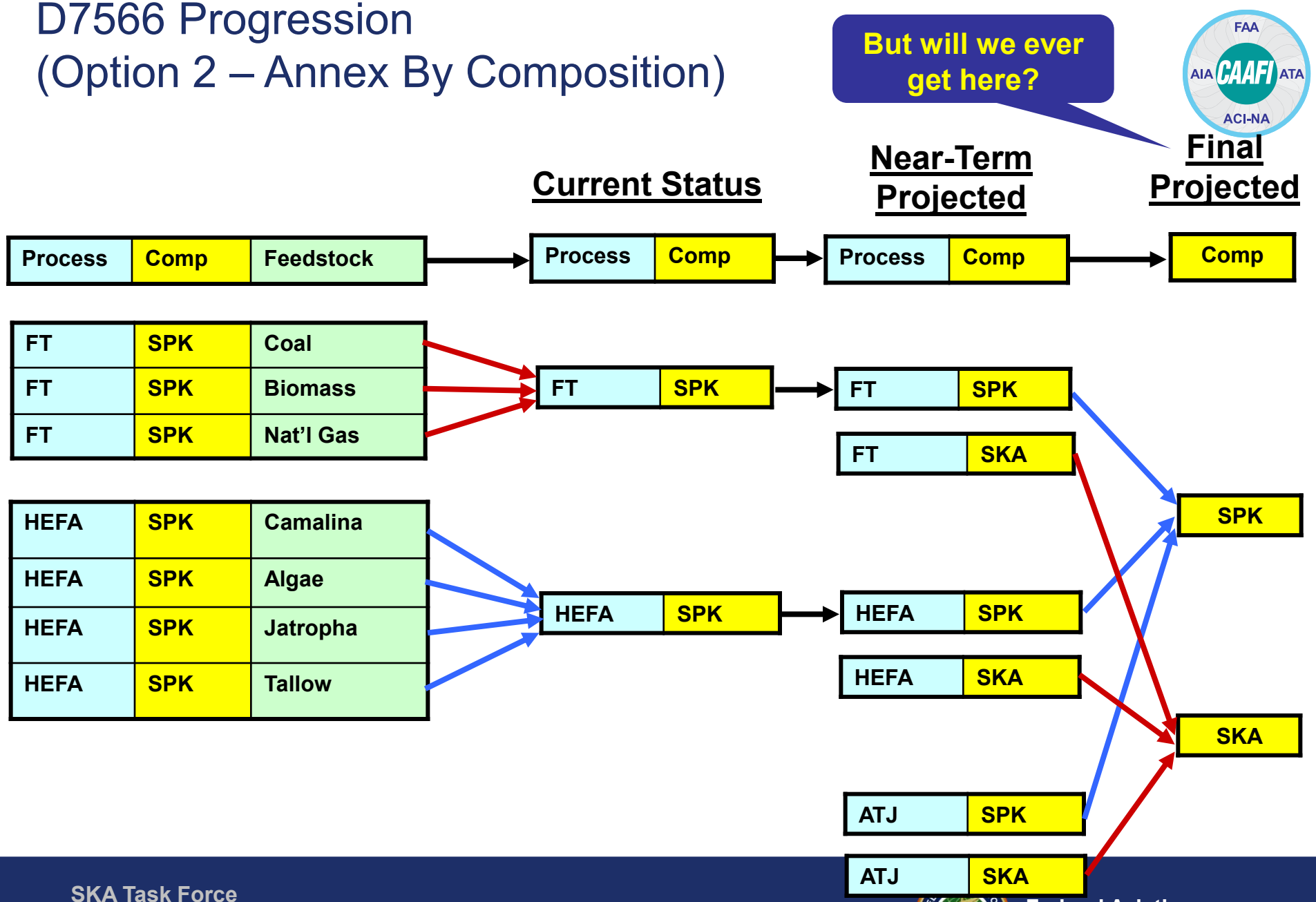
Baseline Fischer-Tropsch Fuels

- Form basis of Research Report to support specification



D7566 Progression
(Option 2 – Annex By Composition)

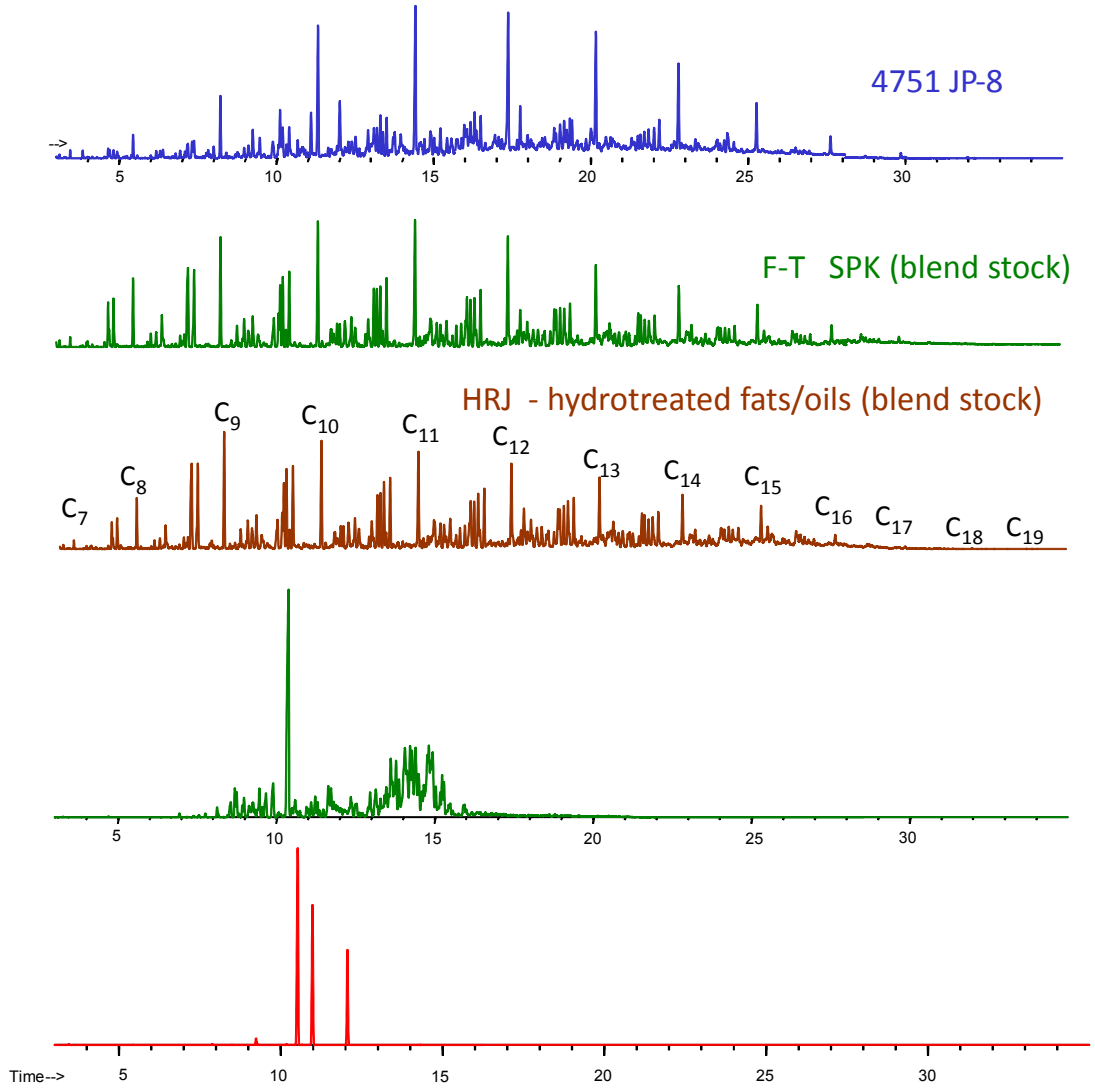


Barriers to 100% Synthetic Jet

- Baseline – 100% SPK/HRJ (n-paraffins + iso-paraffins)

Currently Outside of Experience Base	Aircraft Impact	Potential Solutions
density (low) seal swell (low)	range, fuel gauging, fuel leaks	synthetic cycloparaffins and/or aromatics
synthetic aromatics (except Sasol) and cycloparaffins	known issues: seal swell, density potential issue: lubricity	expand seal swell and lubricity experience base to include synthetic aromatics and cycloparaffins
boiling range (narrow), synthetic aromatics and cycloparaffins	potential issue: combustor operability	expand combustion experience base to include narrow boiling/single component fuels, synthetic aromatics and cycloparaffins

Not All Fuels Look Like SPK…..



current fuels JP-8, Jet A

generic F-T SPK

HRJ

Biofuel A

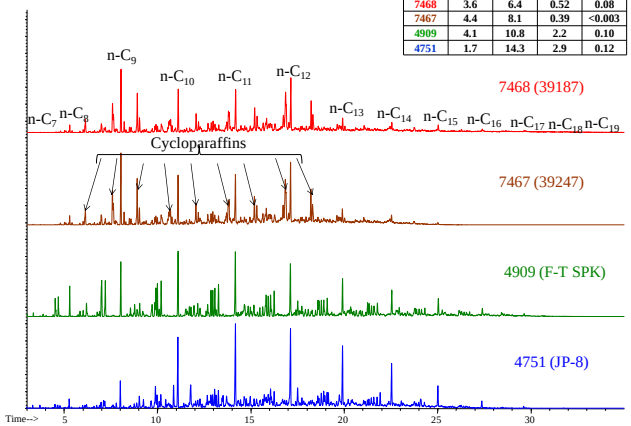
More Challenging!

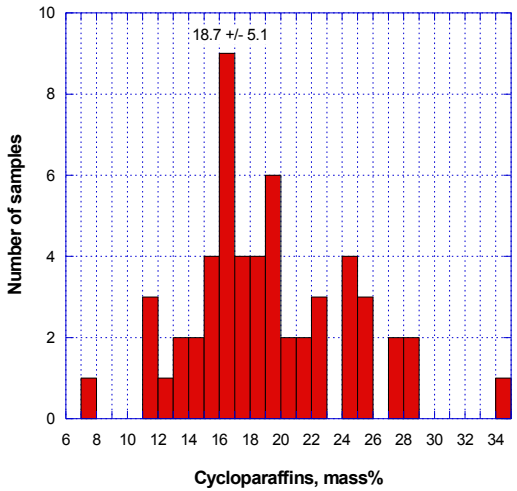
Biofuel B

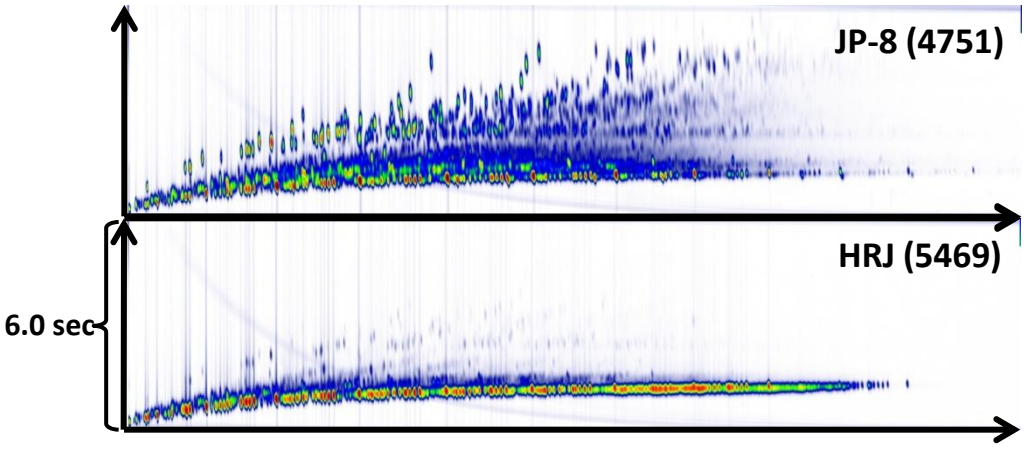
Fuel Compositional Evaluation

- Kerosene fuel characterization by compound class req'd for alt fuel evaluation
  - ASTM D2425 (mass spec): AF/industry results led to inclusion in spec
  - GC X GC (2-D GC) holds promise for better results
  - Collaborations with SwRI, NIST, NRL, UOP

Weight % n-Paraffins				
	C_7-C_9	C_{10}-C_{13}	C_{14}-C_{16}	C_{17}-C_{19}
7468	3.6	6.4	0.52	0.08
7467	4.4	8.1	0.39	<0.003
4909	4.1	10.8	2.2	0.10
4751	1.7	14.3	2.9	0.12



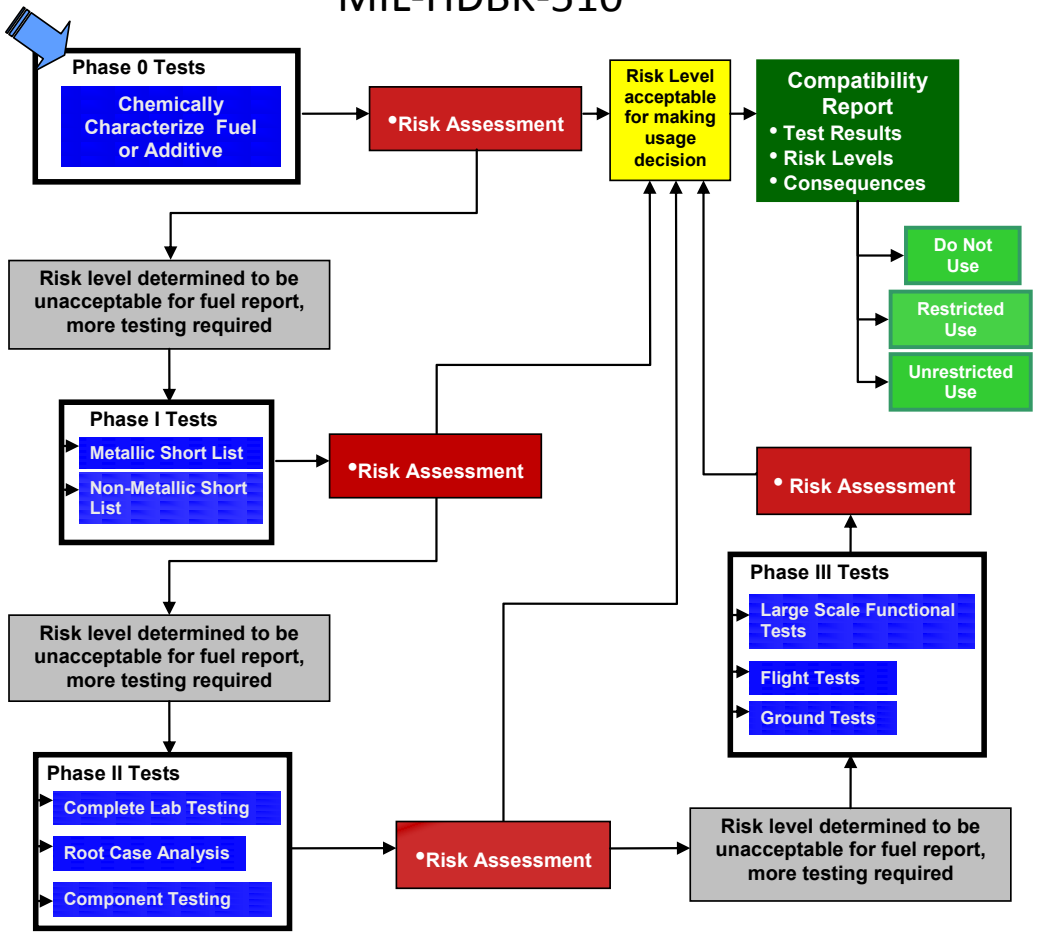


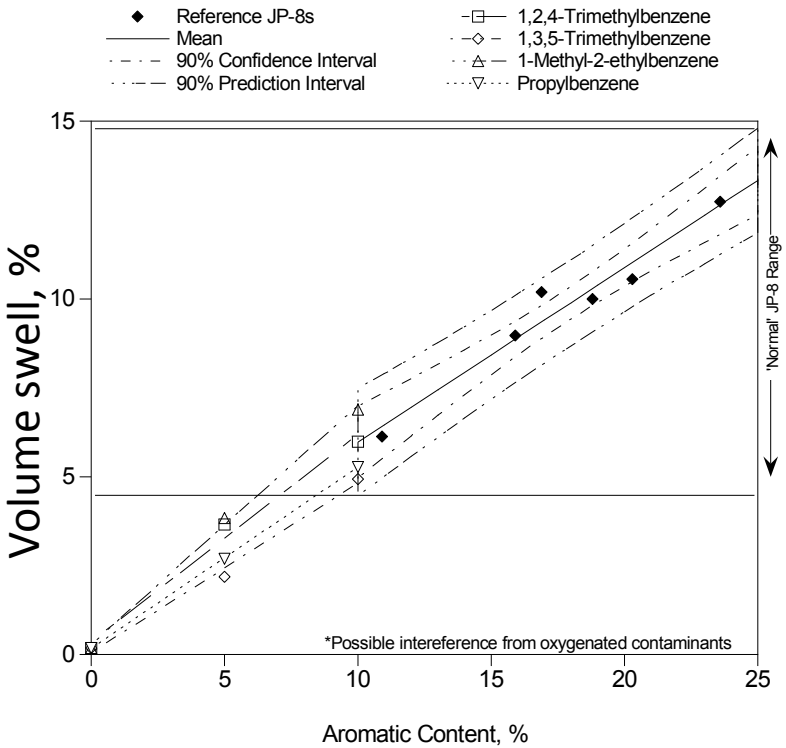


Elastomer Compatibility

- **Extensive investigation of SPK fuels indicates performance of elastomers with alt fuels primary issue – key to specifying composition of fully-synthetic fuels**

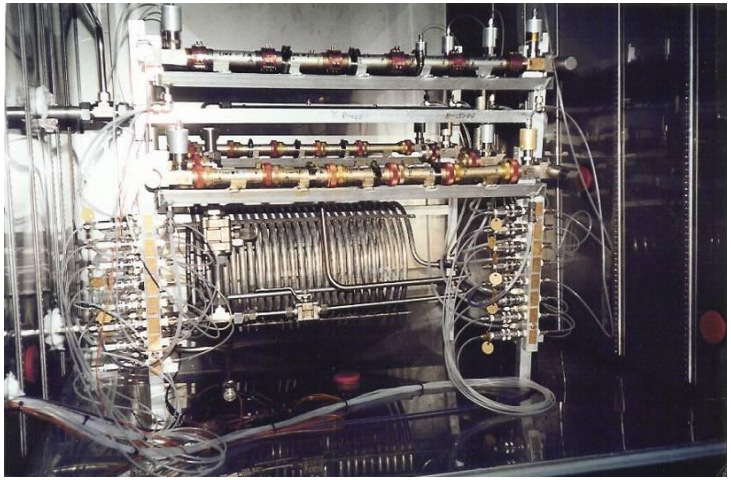
MIL-HDBK-510





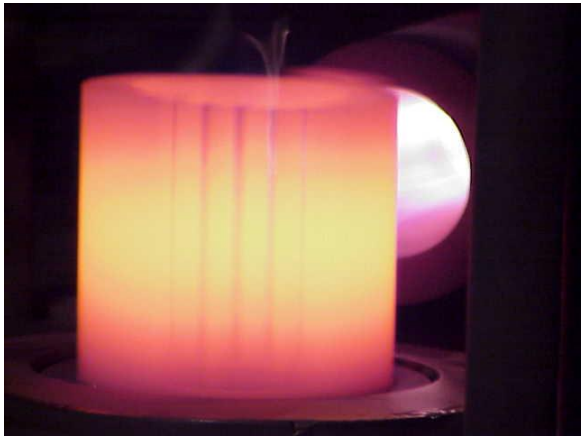
Flow Rig Testing

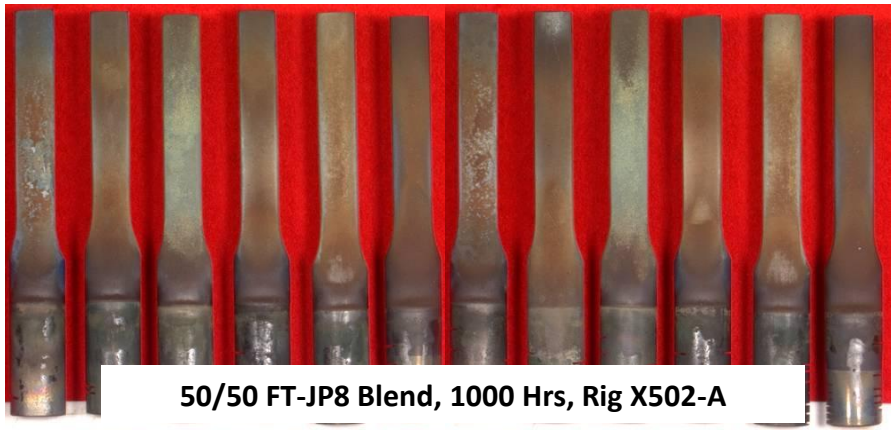
- Functional test used to analyze potential for fuel line leaks with 100% SPK and blends of JP-8 and SPK
- Rig allows for flowing of fuel through 1-inch lines containing both variable and fixed cavity couplings
- High-temp. aging + low temp. leak-checks



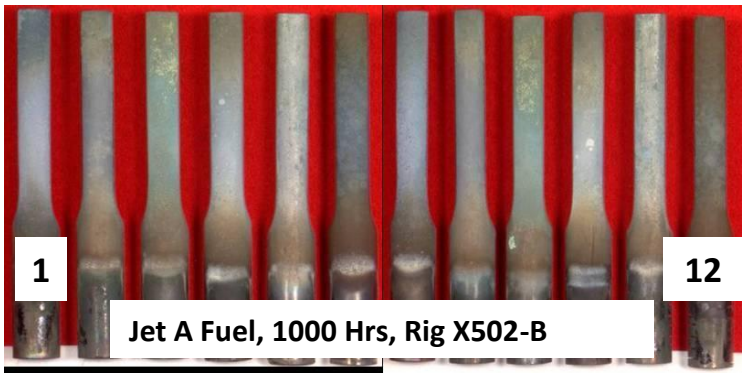
Hot Section Materials Compatibility

- Similar testing by RR/LW, GE, P&W
- P&W oxidation results (1850 F): “Utilization of FT Either as a Blend or 100% Demonstrated No Observable Debit in Materials Performance”
- RR/LW: “no significant difference was evident for all materials tested in the two fuel environments”

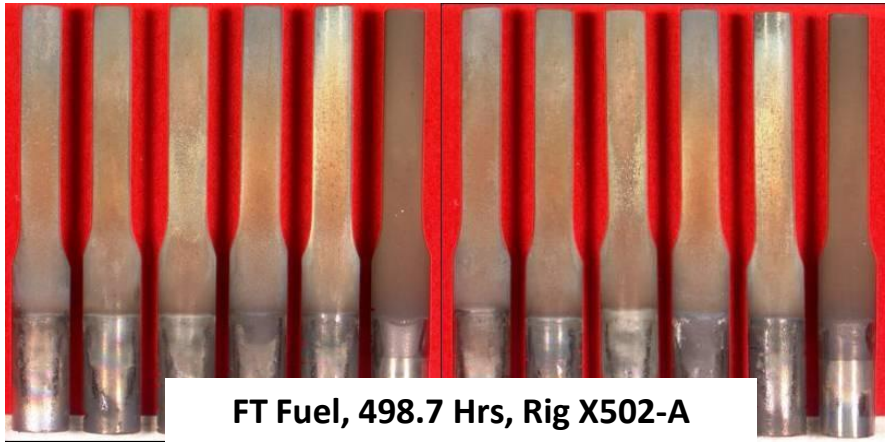




50/50 FT-JP8 Blend, 1000 Hrs, Rig X502-A



Jet A Fuel, 1000 Hrs, Rig X502-B

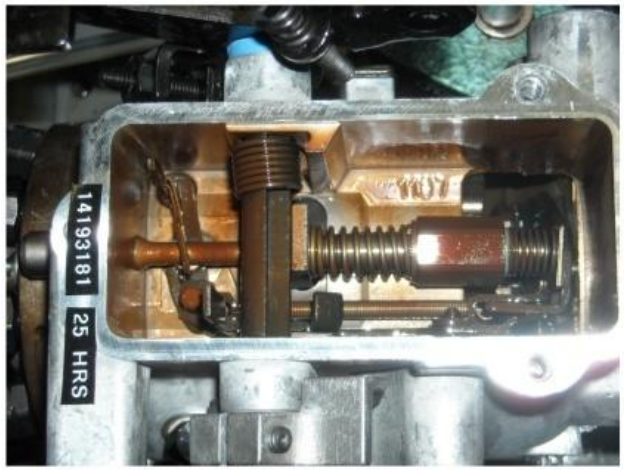


FT Fuel, 498.7 Hrs, Rig X502-A

Lubricity/Fuel Pump Evaluation

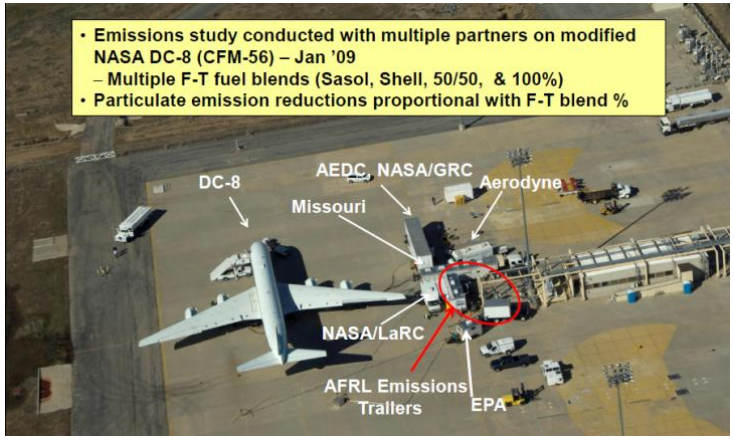
- Alternative fuels typically have low lubricity – potential issue for aircraft fuel pumps
  - Questions about standardized test's (ASTM D5001 BOCLE) applicability to current pumps
  - Need for lubricity additive during transition to Jet A?
- Initial data with ground fuel pumps appears to indicate 50/50 blends not an issue

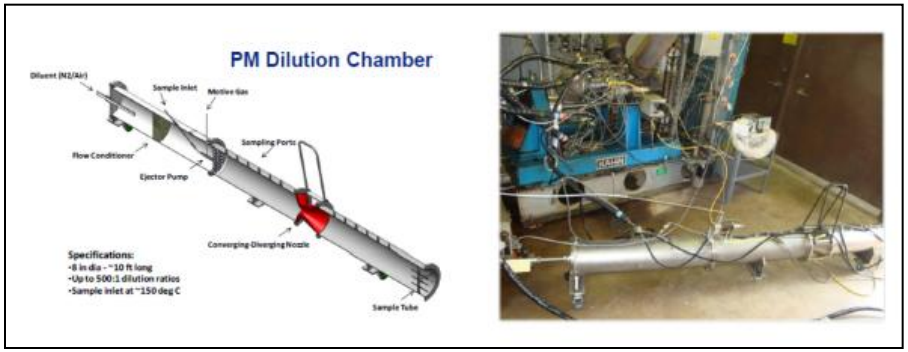
500 hr Stanadyne (HMMWV pump) at SwRI – 50/50 and 100% HRJ pass with CI/LI; HRJ w/o additive fails at 25 hours



Combustion Emissions

- Improved aircraft engine particulate measurements, through SAE E31 and ICAO collaborations:
  - NASA AAFEX, WPAFB campaigns
  - AEDC, UTRC/P&W, NASA
  - EPA
  - ORNL
- Estimate: 80% of health effects near bases and airports due to particulates
- Alternative fuel emissions
  - F-T, HRJ for CAAFI, AFCO
  - Developmental fuels to support R&D

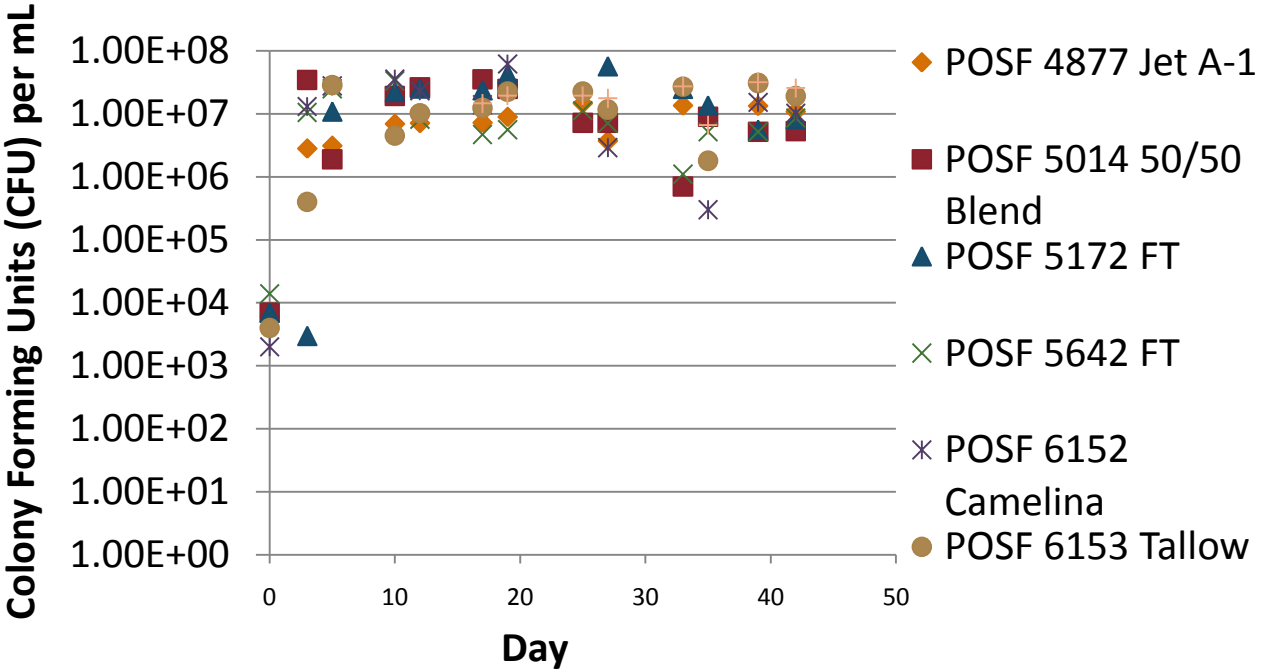




Microbiological Growth Assessment

- **Microbiological growth a problem in field**
- **In-house program characterizing field "bugs" expanded to compare effect of alt fuels**

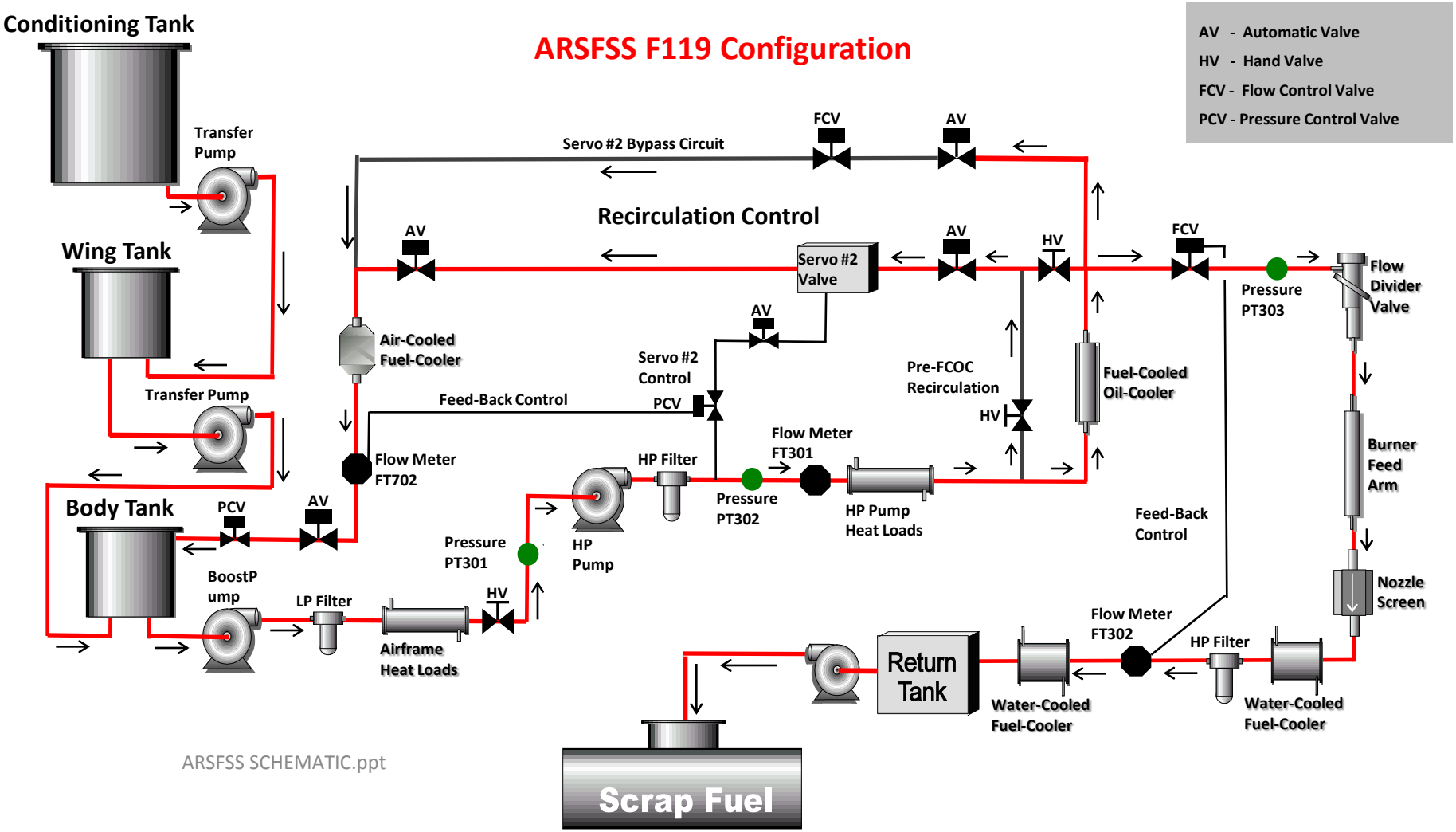
Cladosporium resinae



Toxicology Evaluation (AFRL/RH lead)

- Develop appropriate study design for each toxicity test proposed:
  - Dermal irritation test
  - *In vitro* genotoxicity tests
  - Acute inhalation study
  - *In vivo* genotoxicity test in tandem with inhalation rangefinder study
  - 90-day inhalation toxicity study
  - Sensory Irritation Assay (RD_{50})
- Test 100% in each study except for dermal

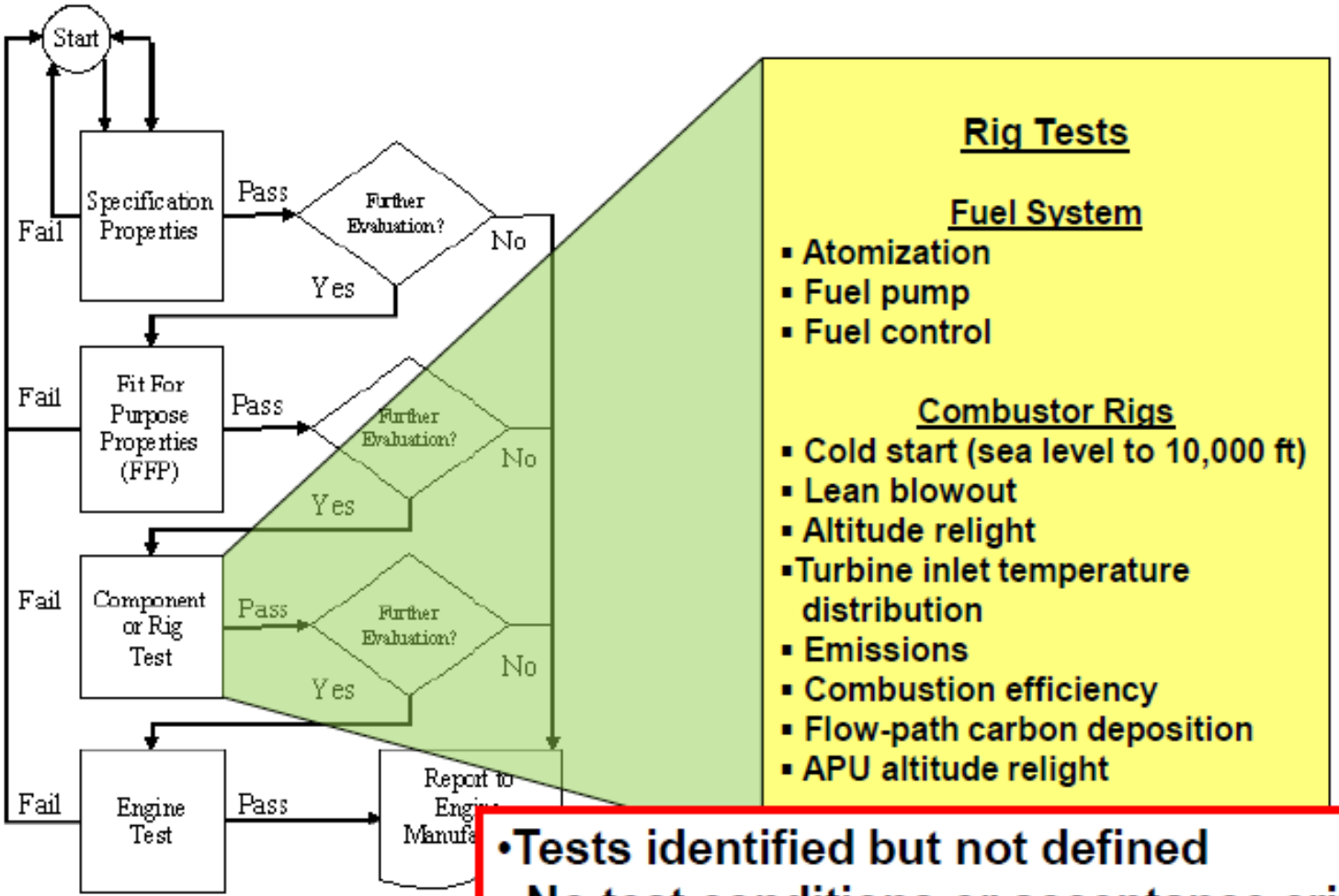
Thermal Stability



ARSFSS SCHEMATIC.ppt

Combustor Operability

Test Program



Rig Tests

Fuel System

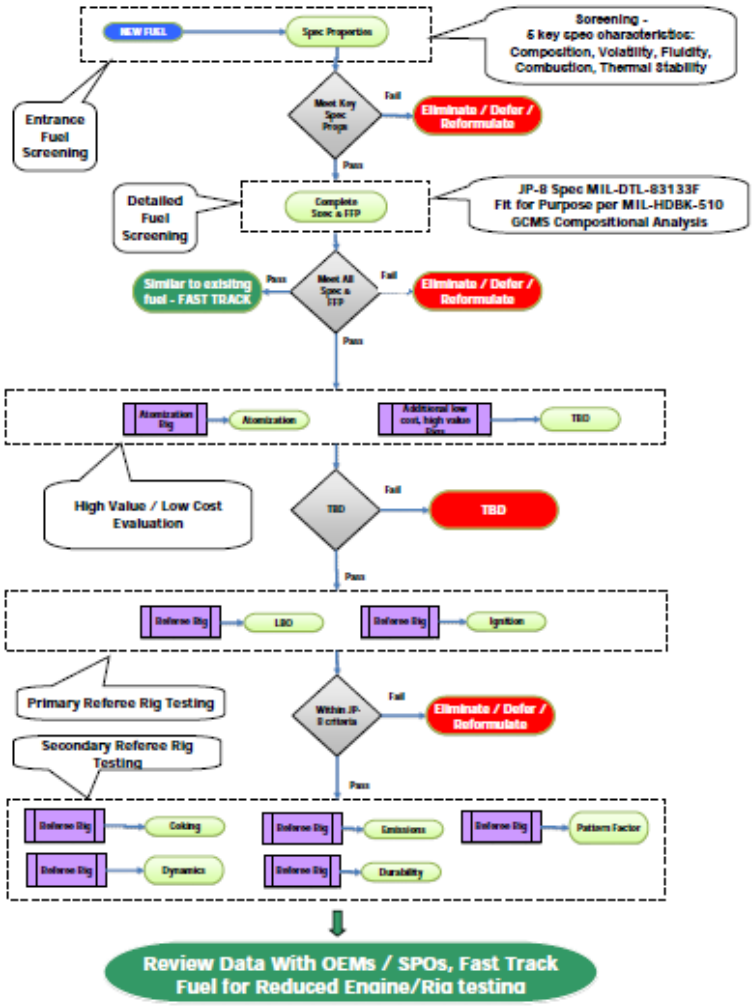
- Atomization
- Fuel pump
- Fuel control

Combustor Rigs

- Cold start (sea level to 10,000 ft)
- Lean blowout
- Altitude relight
- Turbine inlet temperature distribution
- Emissions
- Combustion efficiency
- Flow-path carbon deposition
- APU altitude relight

- Tests identified but not defined
- No test conditions or acceptance criteria

OEM Proposed Combustion Rig Evaluation



- General Electric
- Honeywell
- Pratt & Whitney
- Rolls-Royce Liberty Works
- Williams

Testing protocol development requires baseline/reference fuels

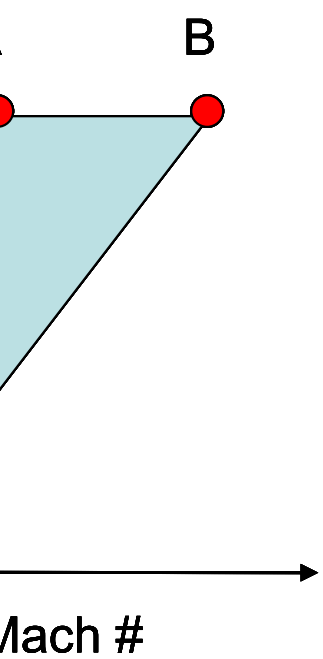
- **Category A – Best/worst/average JP-8/Jet A**
- **Category B – Current alt fuels (good/bad)**
- **Category C – Test fuels pushing spec limits**

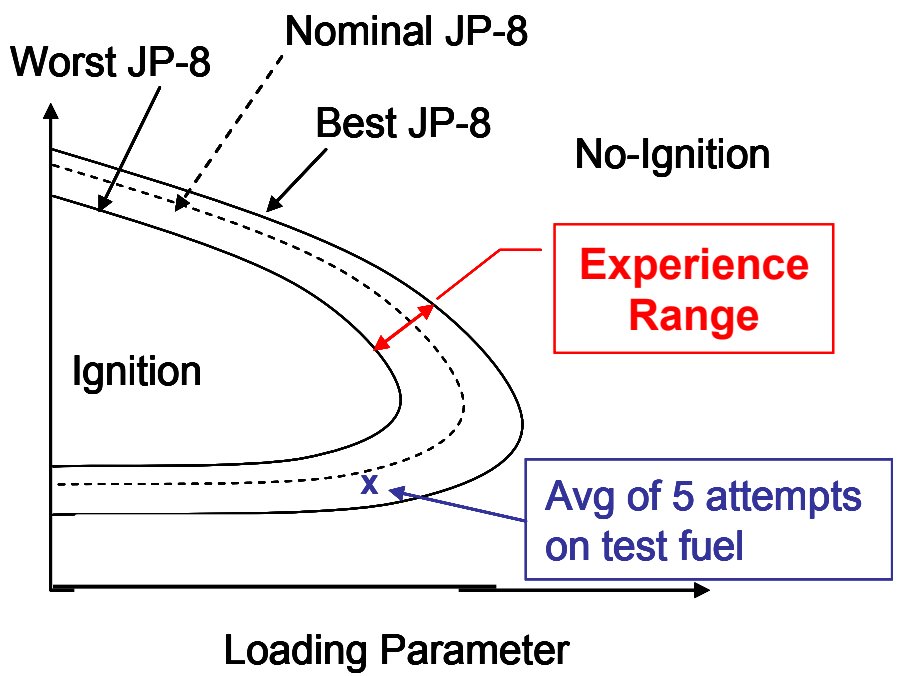
In Progress:

- **Define Category C**
- **Volumes**
- **Coordinate with AFOSR combustion prog.**

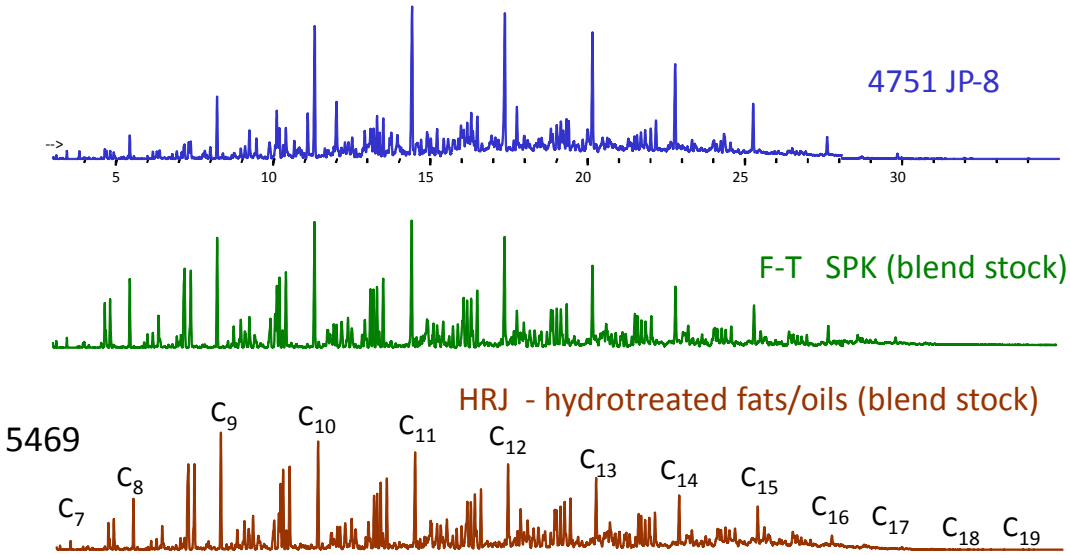
Baseline Jet Fuels

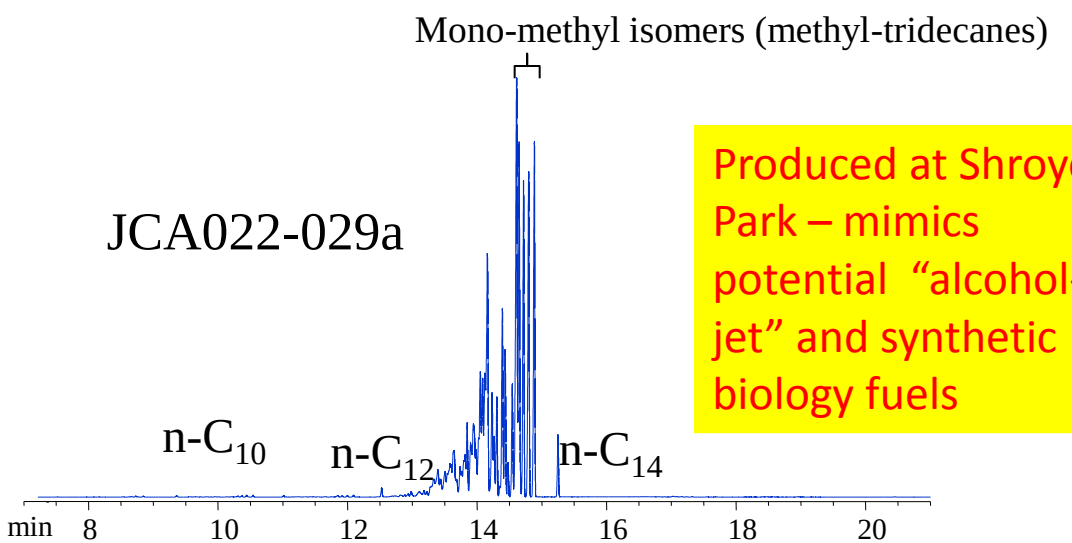
- Best/worst jet fuel may vary with metric (cold start, LBO, relight, …)
- Need to understand experience base with current fuels
  - In many cases, no experience with best/worst jet fuels
  - Thus, limits uncertain (what is a "fail"?)





Example "Worst-Case" Test Fuel





Produced at Shroyer Park – mimics potential "alcohol-to-jet" and synthetic biology fuels

Summary

- **International collaborative effort has been enabling alternative aviation fuel development**
  - Partnering over entire fuel life cycle required (production to deployment/use)
- **U.S. Government interagency collaboration also key enabler**
- **Funding challenges will limit pace of program**