FAA Continuous Lower Energy, Emissions & Noise (CLEEN) Technologies

Rolls-Royce Program Overview

8 November 2012

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Rolls-Royce CLEEN Technologies Program

Dual-Wall Turbine Blades
Design, Fabricate, Engine Test

Ceramic Matrix Composite (CMC) Turbine Blade Tracks
Design, Fabricate, Engine Test

Fuel Burn Reduction

US Alt Fuels Program
Lab & Rig Test; AE 3007 Engine & Flight Demo

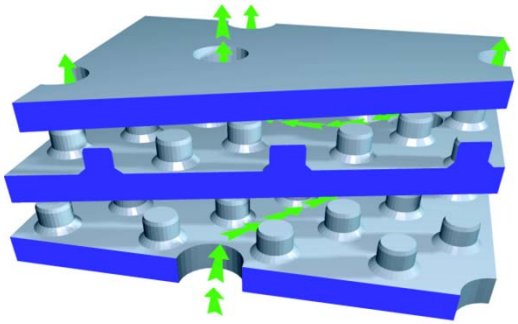
UK Alt Fuels Program
Lab & Rig Test; RB211-524 Engine Demo

Alternative Fuels Feasibility

Dual-Wall Turbine Cooling Technology

- **Highly-efficiency turbine cooling is a key technology for Reduced Fuel Burn in NextGen product applications**
  - Reduction in cooling flow in current engine cycles
  - Enables progression toward more advanced engine cycles

- **Rolls-Royce has developed and patented high effectiveness, dual-wall turbine airfoil cooling systems**
  - Manufacturing cost has limited technology to advanced military applications



Cooling Airflow

Dual-Wall Turbine Blade Program – Status

- **Rolls-Royce LeanCool™ blade technology combined advanced cooling and casting technologies**
  - Objective of fuel burn reduction with low weight, long life, and affordability
- **Rolls-Royce completed blade design, manufacture, and bench-testing**
  - Casting process progressively developed
  - Frequency screening and HCF bench testing completed
- **LeanCool blades were not cleared for engine demonstration testing due to casting quality issues**
  - Alternative schemes for subsequent engine testing are under review

Dual-Wall Turbine Blade Program – Status

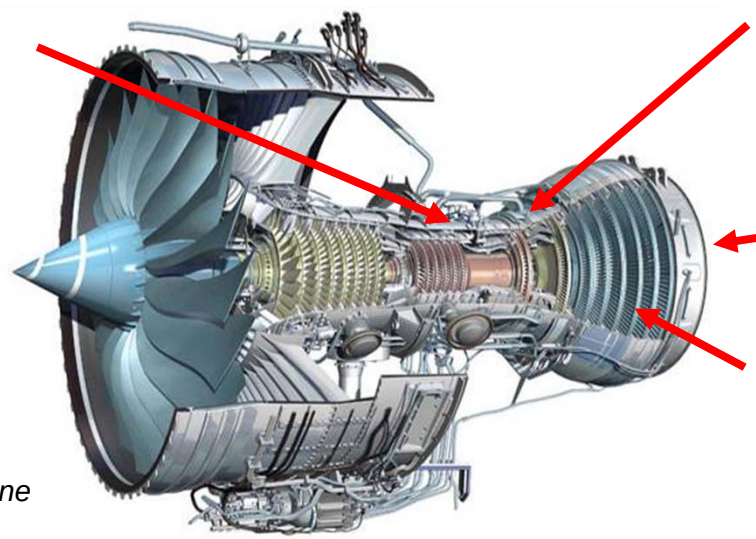
- **Blades development under CLEEN has generated several lessons-learned and improvements in the areas of:**
  - Design practices
  - Casting and manufacturing processes
  - Enhanced inspection methods

- **Rolls-Royce remains committed to dual-wall cooling technologies**
  - Focus on maturing casting / manufacturing technologies for near-term civil engine applications

Ceramic Matrix Composite (CMC) Technology

- **Application of advanced CMC turbine materials enables Reduced Fuel Burn in NextGen product applications**
  - Reduction in cooling flow and weight savings in current engine cycles
  - Enables progression toward more advanced engine cycles

<u>Combustion liners</u>
Increased wall temperature
Reduced emissions



<u>Blade tracks/shrouds</u>
Increased temperature
Reduced weight
Improved SFC

<u>Exhaust components</u>
Increased temperature
Reduced weight

<u>Airfoils (blades/vanes)</u>
Increased temperature
Reduced weight
Improved SFC

Large Civil
3-Shaft Engine

CMC Turbine Blade Track Program – Benefits

- **Reduction in weight possible due to lower density material – 1/3 density of Ni-based superalloys**
- **Potential to increase size of blade track**
  - Reduced blade track count
- **Lower coefficient of thermal expansion (CTE) than metal**
  - Hardware will not curl/flatten as much as metallic parts
- **Improved turbine blade tip clearance**
- **System uses no strategic materials**
- **Higher temperature capability up to 2450°F**
- **Reduced cooling air – specific fuel consumption (SFC) benefit**

CMC Turbine Blade Track Program – Status

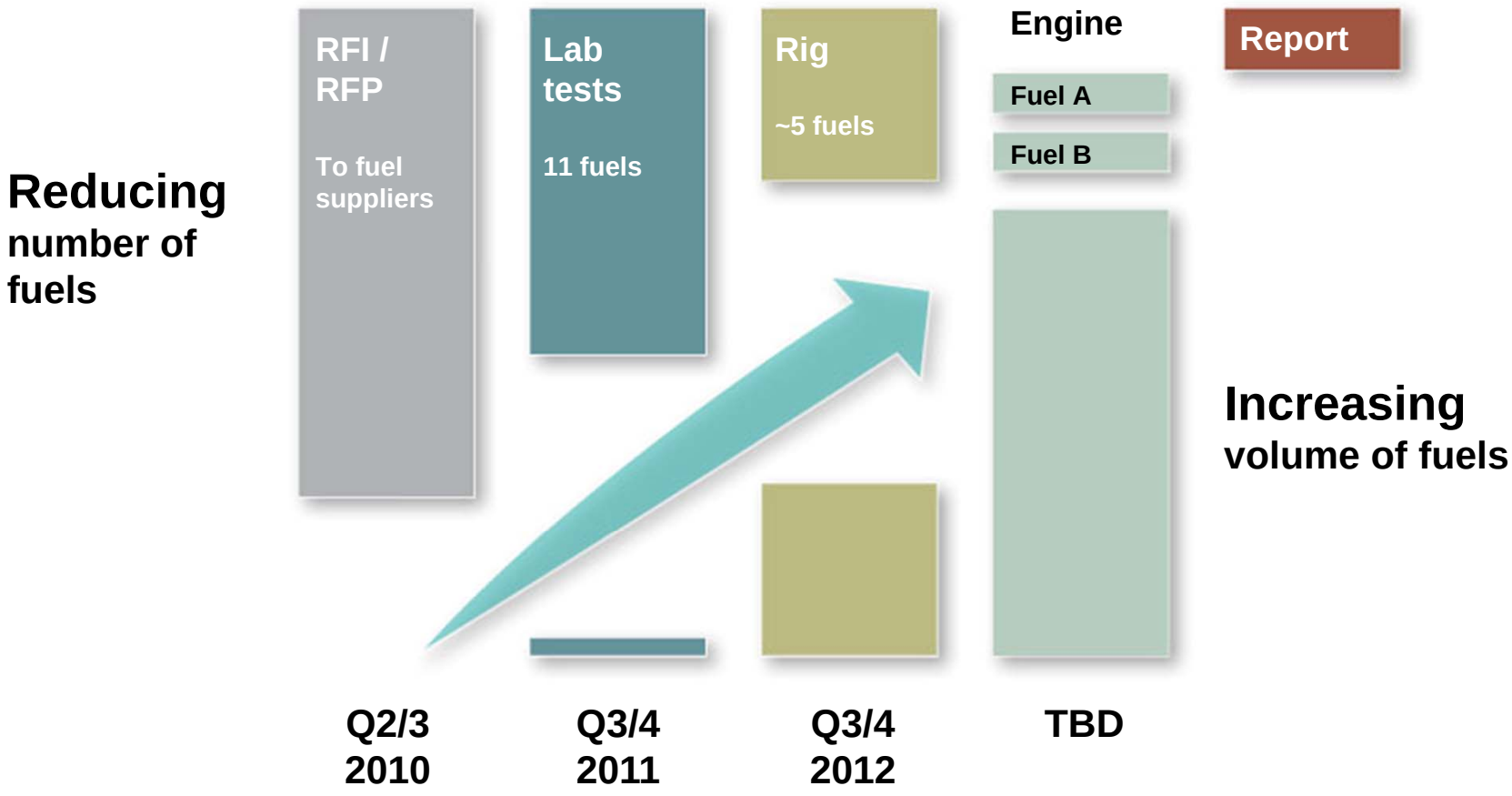
- **Rolls-Royce has completed design, manufacture, and rig testing of SiC/SiC CMC High Pressure Turbine Blade tracks**
  - All thermo-mechanical validation testing conducted without issue
  - Blade tracks are assembled into engine and awaiting test

- **Technology demonstration will be conducted as part of the UK Environmentally Friendly Engine (EFE) program**
  - Cyclic Endurance Test – Early 2013
    - *Demonstrate durability and useful life*
  - Telemetry Test – Late 2013
    - *Opportunity to gather additional data for alternate engine cycles*

UK Alternative Fuels Program

- **Programme overview and status.**
- **Candidate fuel overview.**
- **Overview of lab. analysis of candidate blends.**
- **Status/Technical review – rig scale work.**
  - Combustion operability.
  - Elastomer seal performance.
  - APU Combustion/Emissions testing.

UK Alternative Fuels Program



Testing matrix

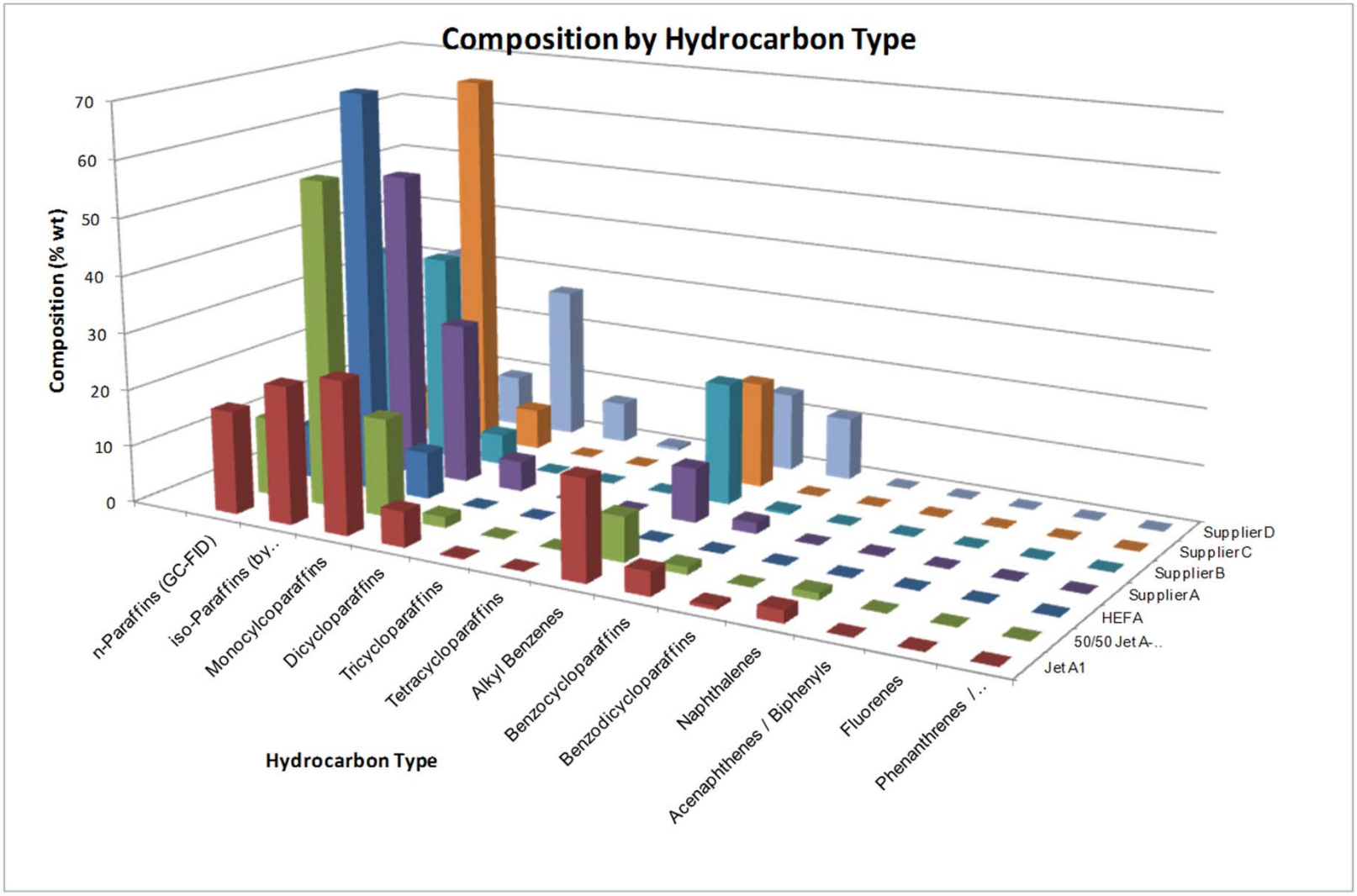
		Fuel Description			Spec and speciation	Combustion		Elastomer Compatibility	Thermal Stability	
	Supplier	Fuel Type and Description		Aromatic content	Lab Analysis	APU (Emissions)	Operability	Elastomer Testing (Elasticon)	JFTOT (Spec Test)	HiRets
Baseline blends	Jet A-1/ Dynamics HEFA Blends	Jet A-1 (baseline)	Conventional	~16%	Done	WIP	Done	WIP	Done	Done
		Jet A-1 and SPK1	ASTM 7566 type Blend	8%	Done	WIP	Done	WIP	Done	Done
		Jet A-1 and SPK1	ASTM 7566 type Blend	4%	NA	WIP	Done	WIP	NA	Done
		SPK1	ASTM 7566 type SPK	0%	Done	WIP	Done	WIP	Done	Done
Novel Fully Synthetic fuels	Byogy (A)	Alcohol to Jet	Novel Single Process No1	8-25% (TBD)	Done	X	Done	X	Done	Done
	Shell/ Virent (B)	GtL + Sugar Bioforming	Novel Blend No 1	8-25% (TBD)	Done	X	Done	X	Done	Done
	Algeon/ Swift (C)	Cellulose - Aromatic +SPK	Novel Blend No2	8-25% (TBD)	Done	X	Done	X	Done	Done
	ARA (D)	Catalytic Hydrotherm-olysis	Novel Single Process No 2	8-25% (TBD)	Done	X	Done	X	Done	Done

Note: Vendors requested to provide typical production blend

Laboratory analysis of candidate fuels

- **Full specification analysis – complete.**
  - Samples met expectations.
- **Speciation of hydrocarbon types – completed.**
  - Composition supports interpretation
- **Breakpoint analysis – complete.**
  - Comparison with HiReTS.
- **Trace metals full sweep to ppm and specific metals to ppb – ongoing.**

Hydrocarbon speciation – Mass Spec and GC



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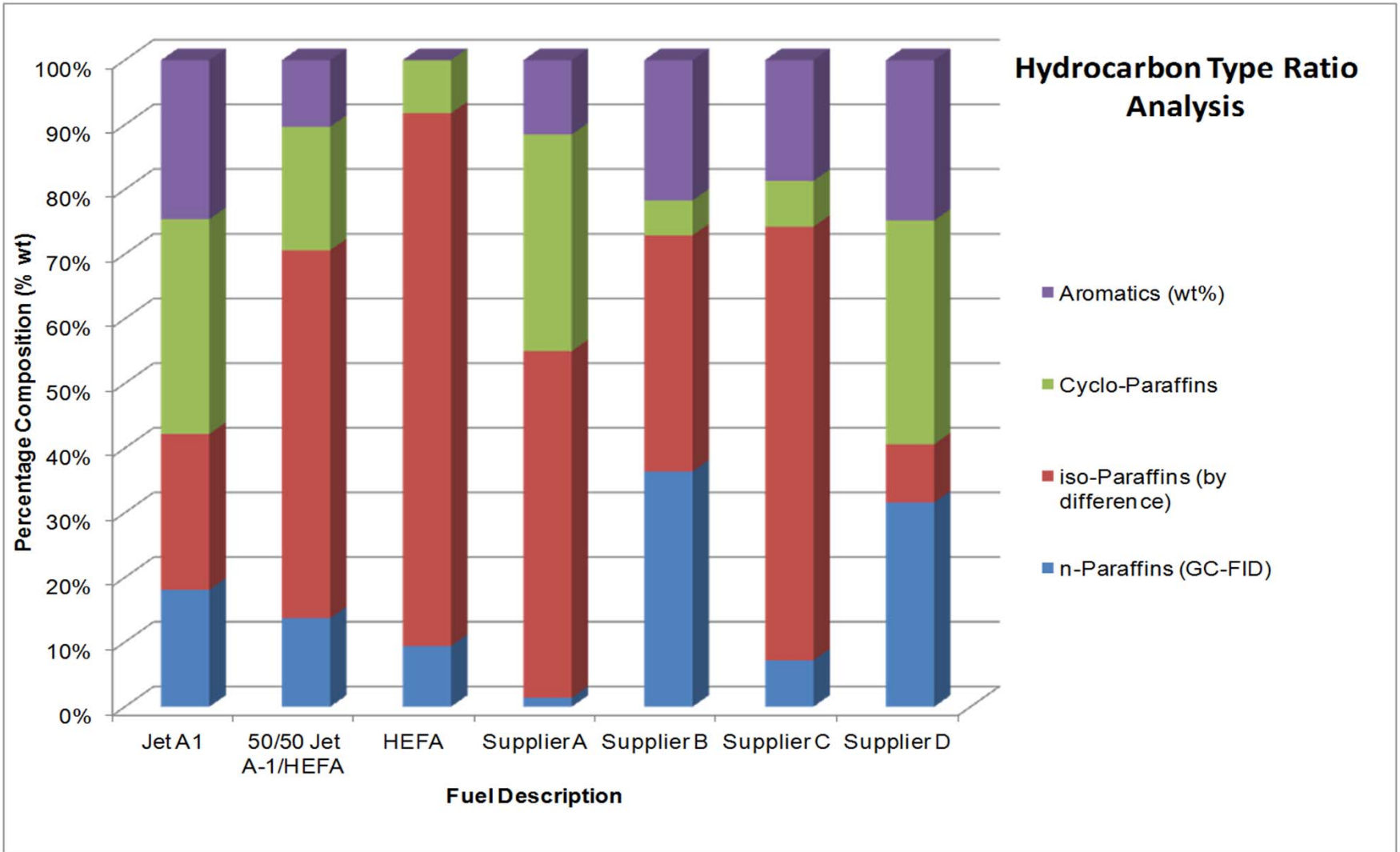
Hydrocarbons grouped by type



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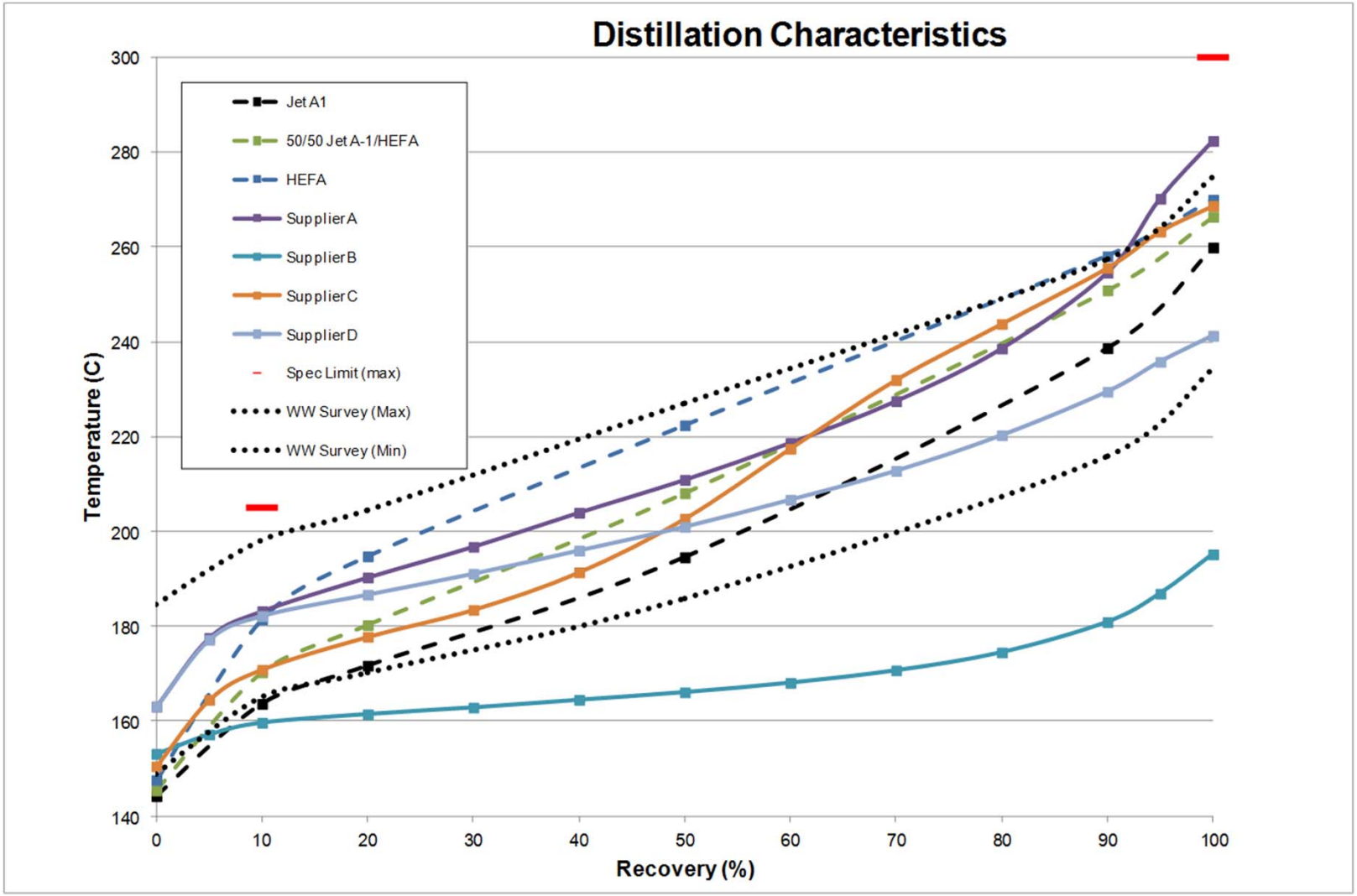
Distillation characteristics



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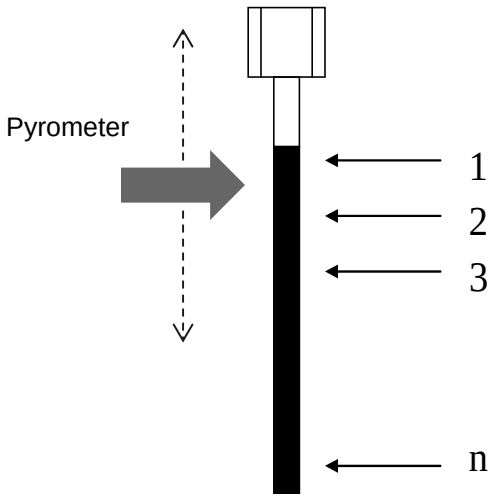
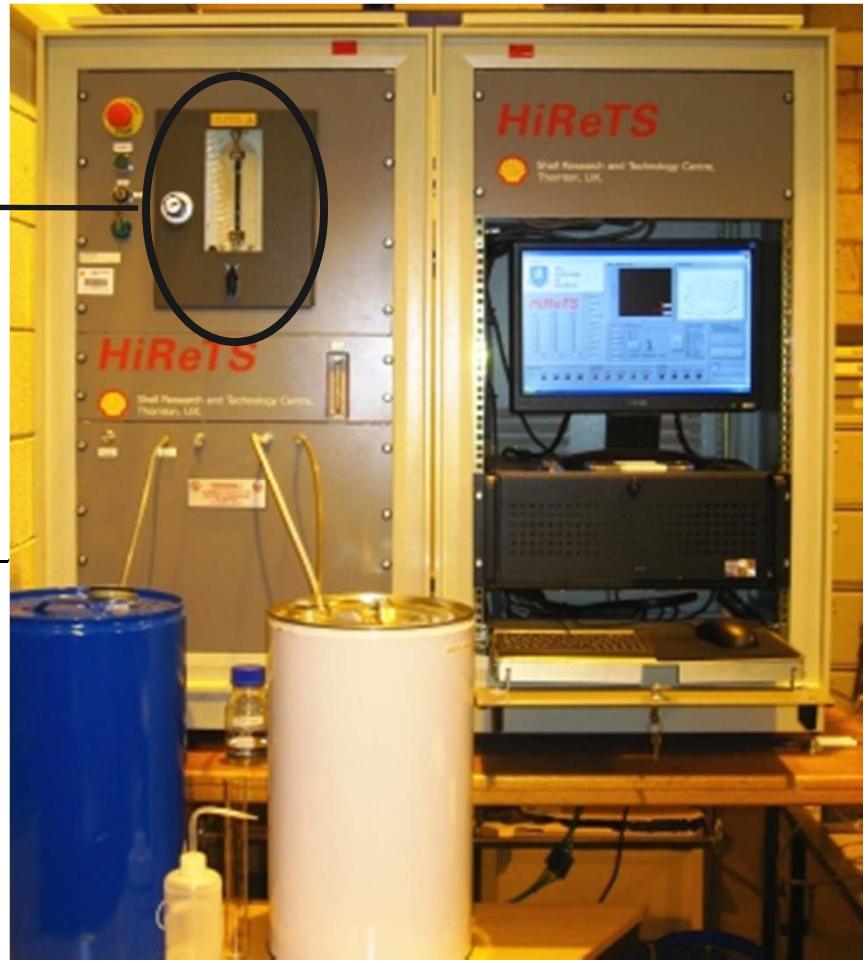
HiReTS Testing





Test Temperature (°C)	290
Fuel Flow Rate (ml/min)	35
Test Pressure (MPa)	2.0
Test Time (mins)	125
Number of Positions Measured / Scan	12
Scans / Test	25
Distance Between Measured Positions (mm)	2.5
Fuel Aeration Time (mins)	12

HiReTS/Break Point comparison

	65min HiReTS total number	125min HiReTS total number	125 HiReTS peak number	JFTOT Break Point (°C)
Jet A-1/HEFA Blends				
Baseline Jet A-1 - Run 1	**1**	**8**	**2**	**290**
Baseline Jet A-1 - Run 2	**4**	**9**	**2**	
HEFA - Run 1	**55**	**130**	**14**	**>380**
HEFA - Run 2	**40**	**89**	**11**	
HEFA - Run 3	**38**	**95**	**13**	
Jet A-1/HEFA 50/50 (8% aromatics)	**9**	**35**	**6**	**305**
Jet A-1/HEFA 75/25 (4% aromatics)	**7**	**13**	**3**	**NA**
Novel Blends				
Supplier A	**6**	**10**	**2**	**>380**
Supplier B	**5**	**8**	**2**	**305**
Supplier C	**2**	**10**	**2**	**285**
Supplier D	**5**	**19**	**3**	**295**

Observations

- **HiReTS (R&D test):**
  - All results (total number) are <150 indicating excellent thermal stability
- **Breakpoint (spec related test):**
  - Values are typical for base Jet A-1 and HEFA
  - Values for novel blends indicate from excellent to typical Jet A-1 values.
- **Break point and HiReTS show different aspects of thermal stability.**

Rig testing of candidate fuels

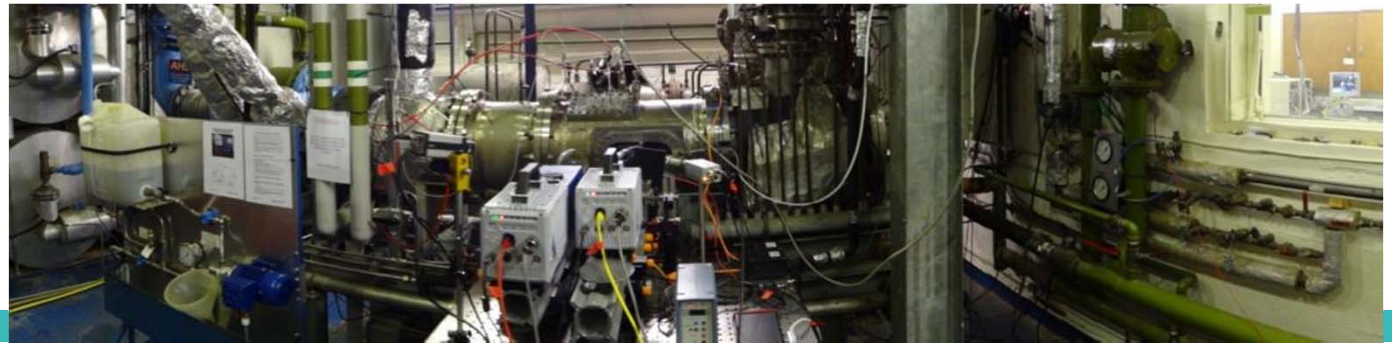
1. **Combustion operability.**

2. **Elastomeric seal performance.**

3. **APU combustion/emissions testing.**

Combustion Operability Test Rig

- 2 sector Current Civil Combustor with access windows for measurements.
- Sub-atmospheric conditions obtained via Vacuum pump and Refrigeration unit.
- Portable fuel system for testing various fuels.
- Heat exchanger used to maintain specified fuel temperature.

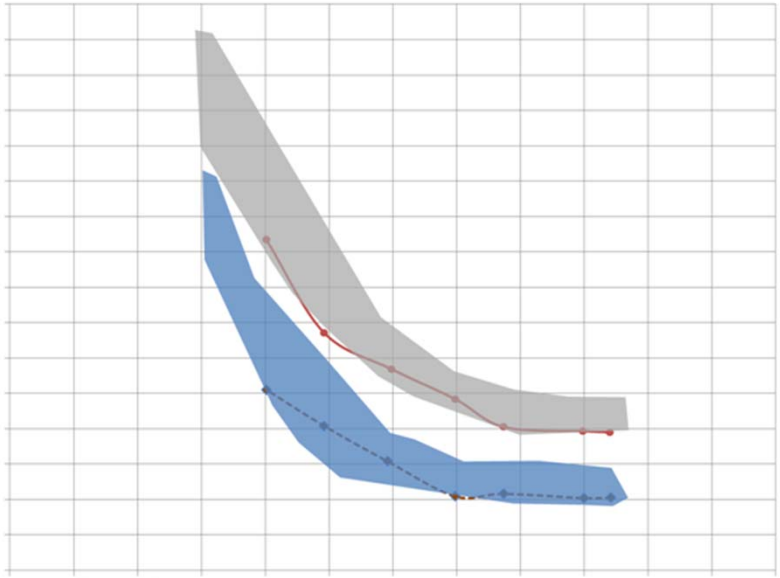


Altitude Relight Test – Prelim observations

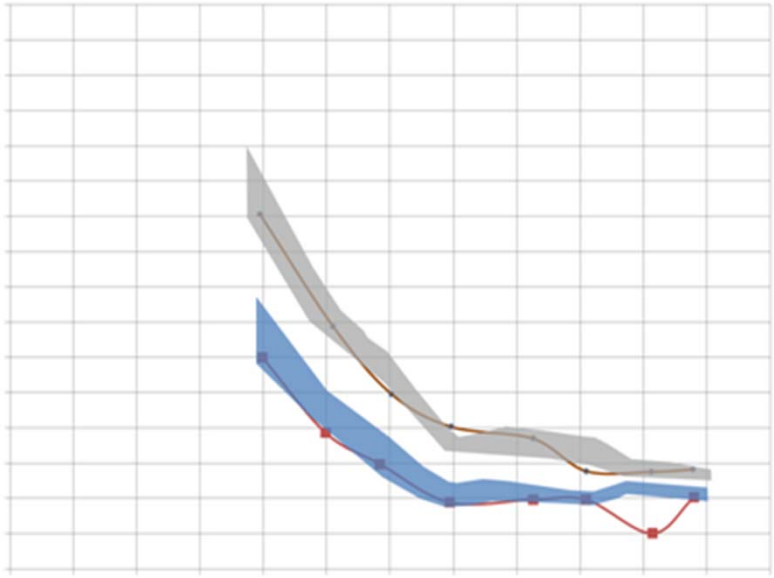
- All Jet A-1/HEFA blends performed within typical Jet A-1 bounds
- Broadly, the 4 novel fuel show no significant deterioration rel JetA1ignition performance.
- 8 psi shows variation in ignition loop whereas 6 psi didn't show much variation.
- Results being reconciled against fuel composition and report in preparation

Example plot of data against Jet A-1 results

Inlet Pressure (P30) = 6 psi
Air Temp = 265 K and Fuel Temp = 288 K



Inlet Pressure (P30) = 8 psi
Air Temp = 278 K and Fuel Temp = 288 K

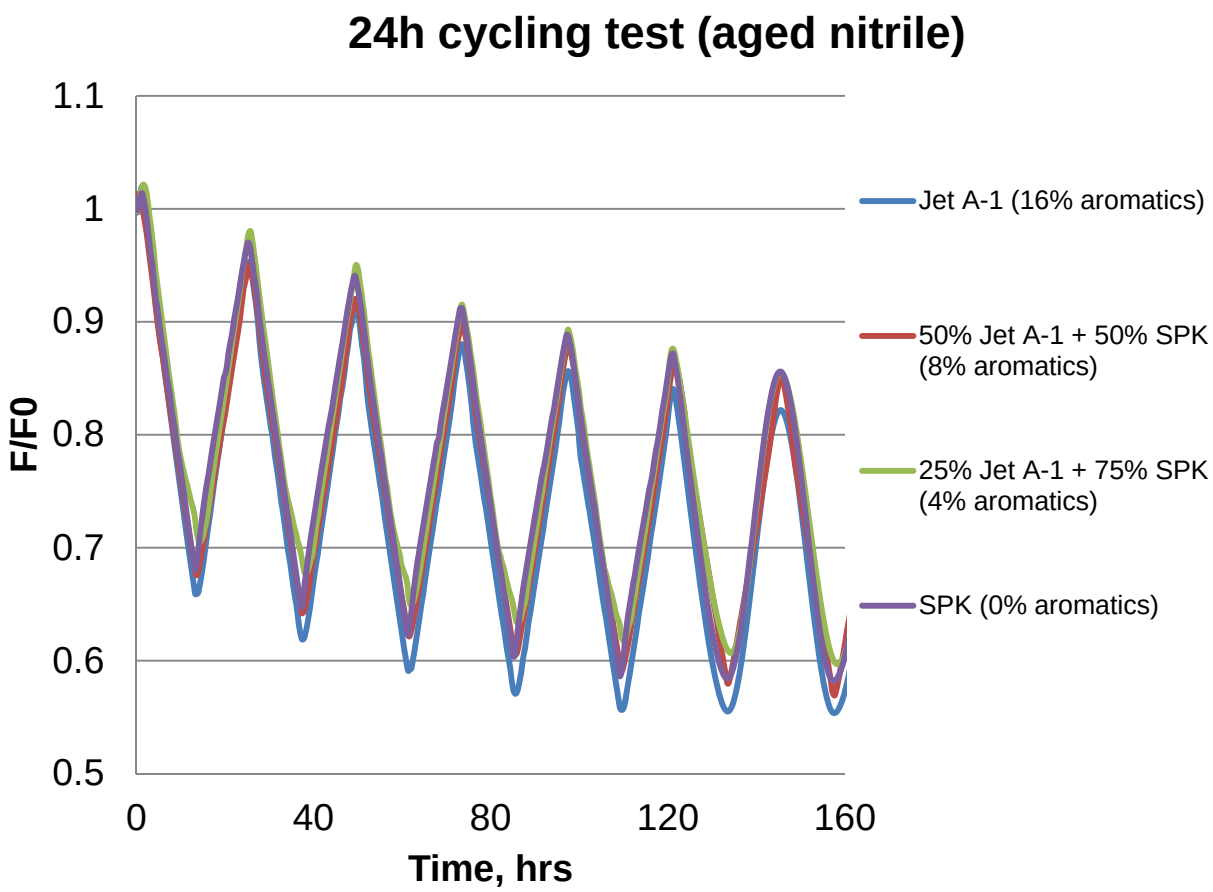


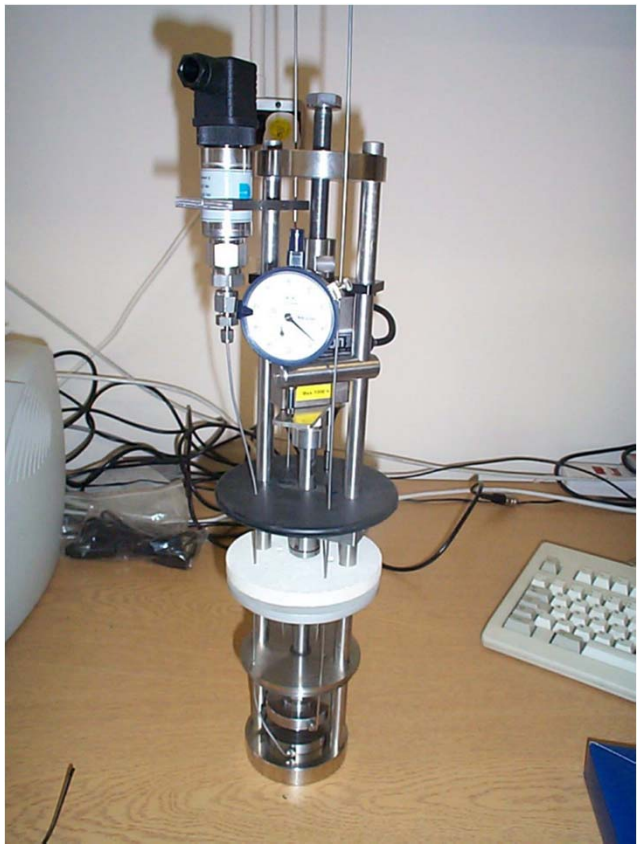
Jet A1- Light

Jet A1- No Light

***JetA1 data from 5 repeat points, including data** not carried out under FAA/CLEEN funding

Example of thermal cycling impact on sealing force





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Test Plan – Combustion and Emissions

- **Comprehensive Emissions Measurement on APU:**
  - Honeywell Model No. GTCP85-129E (from a B737) ex British Airways

- **Emissions measurements:**
  - UHC (including speciation),
  - NOx
  - CO
  - CO2
  - SAE smoke number
  - Smoke particulate distribution.

- **Measurements will be at idle (engine cold), full power and idle (engine hot) on all fuels defined.**
- **Installation complete - testing planned for early Nov.**

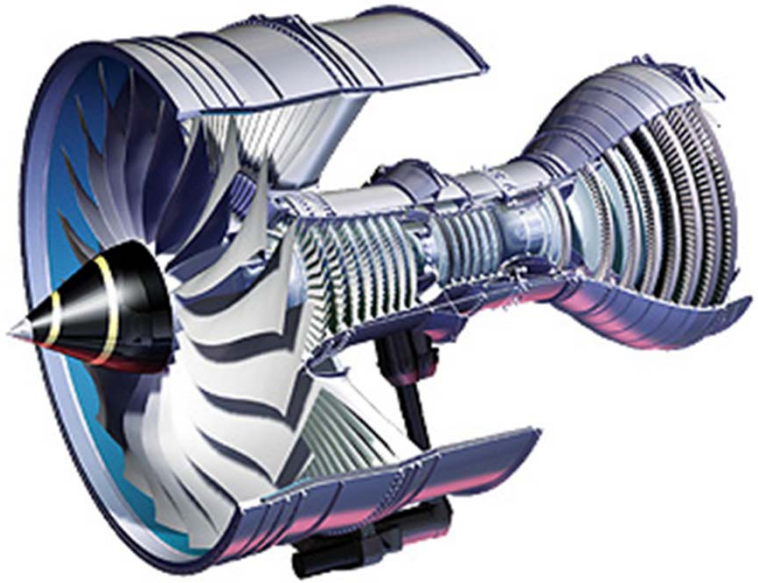
Overall test summary

- **Laboratory spec and "forensic" analysis**
  - Fuel suitability for rig testing confirmed.
  - Compositional data will support rig test interpretation.
- **HiReTS thermal stability testing**
  - Fuels show spec compliant thermal stability.
  - A number of "Interesting" results – R&D database.
- **Combustion altitude relight/operability testing**
  - All fuels show performance within Jet A-1 bounds.
  - Further analysis and reporting underway
- **Seal performance testing**
  - 2nd iteration O-ring groove testing completed, groove defined
  - Baseline JetA1/HEFA tests almost completed
- **APU combustion emissions testing (currently not critical path)**
  - Engine installation/integration almost completed.
  - Testing commencing November

Thank you for your time and attention

Environmentally Friendly Engine (EFE) Program

- **Demonstration program to validate new technologies aimed at reducing noise, fuel burn and emissions**
- **6 builds, first run start 2010**
  - Builds 1&2 completed
  - Build 3 next – Q1 2013
- **Key Technology Areas**
  - High temperature materials
  - High efficiency turbines
  - Low emissions combustion
  - Advanced manufacturing
  - Engine control and actuation



- **Provides a demonstration vehicle for CLEEN fuel burn reduction technologies**

Summary

- **Rolls-Royce has made substantial progress during 2012**
  - Design and fabrication of turbine components
  - Lab and rig tests of alternative fuels
- **Effort planned for 2013 will provide valuable data and validation of selected technologies**
  - Engine demonstration of turbine blade track components (TRL6)
  - Rig testing of selected alternative fuels
- **Technologies and approaches selected will provide a significant contribution to the FAA CLEEN program goals**
  - Reduced Fuel Burn
  - Alternative Fuels Feasibility