FAA CLEEN Technologies
Rolls-Royce Program Overview

19 November 2014

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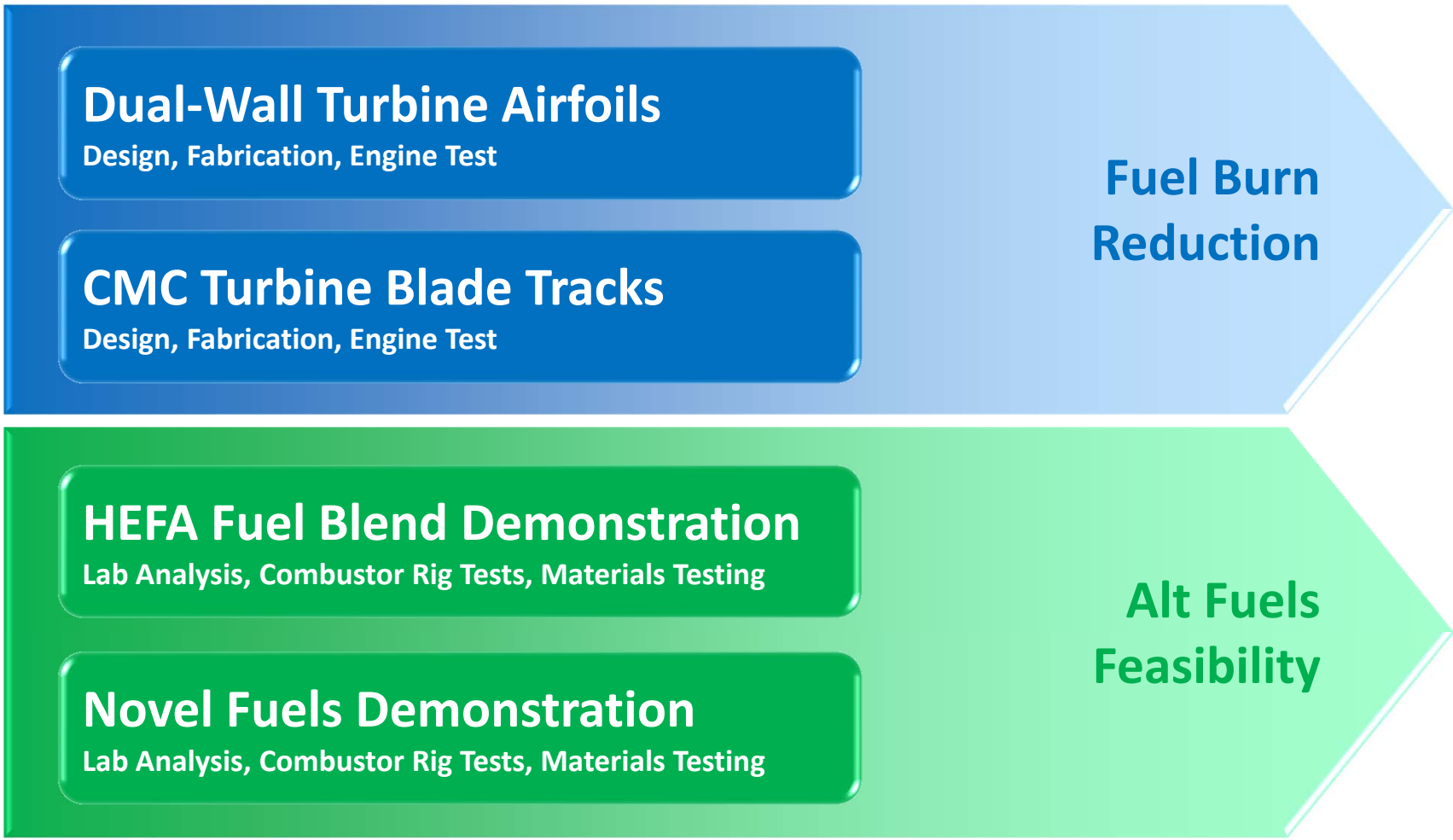
Rolls-Royce CLEEN Technologies Program



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Dual-Wall Turbine Airfoils

Highly-efficient turbine cooling is a key technology for Reduced Fuel Burn in NextGen product applications

- Provides significant reduction in cooling flow for today's engines
- Enables progression toward tomorrow's advanced engine cycles

Rolls-Royce has developed and patented high effectiveness, dual-wall turbine airfoil cooling systems

- To-date, manufacturing cost has limited this technology to advanced military applications
- We are focused on maturing these technologies for near-term civil engine applications
- Rolls-Royce turbine cooling technologies combine advanced cooling and manufacturing technologies

Goal: Demonstrate advanced dual-wall turbine airfoils for near-term civil engine applications

Dual-Wall Turbine Airfoils

In 2012, we completed blade design, manufacture, and bench testing of LeanCool™ turbine blades

- Casting process developed; frequency screening and HCF testing completed
- Final blades not cleared for engine testing due to casting quality issues

In 2013, we applied rapid prototyping lessons-learned to the design and fabrication of CastBond™ turbine vanes

- Successful casting trials using rapid prototyping approach
- Completed vane preliminary design and released castings for manufacture

In 2014, we have completed the vane detailed design, manufacturing trials, and received engine hardware castings

- Manufacture of engine hardware is underway for delivery / test in 2015

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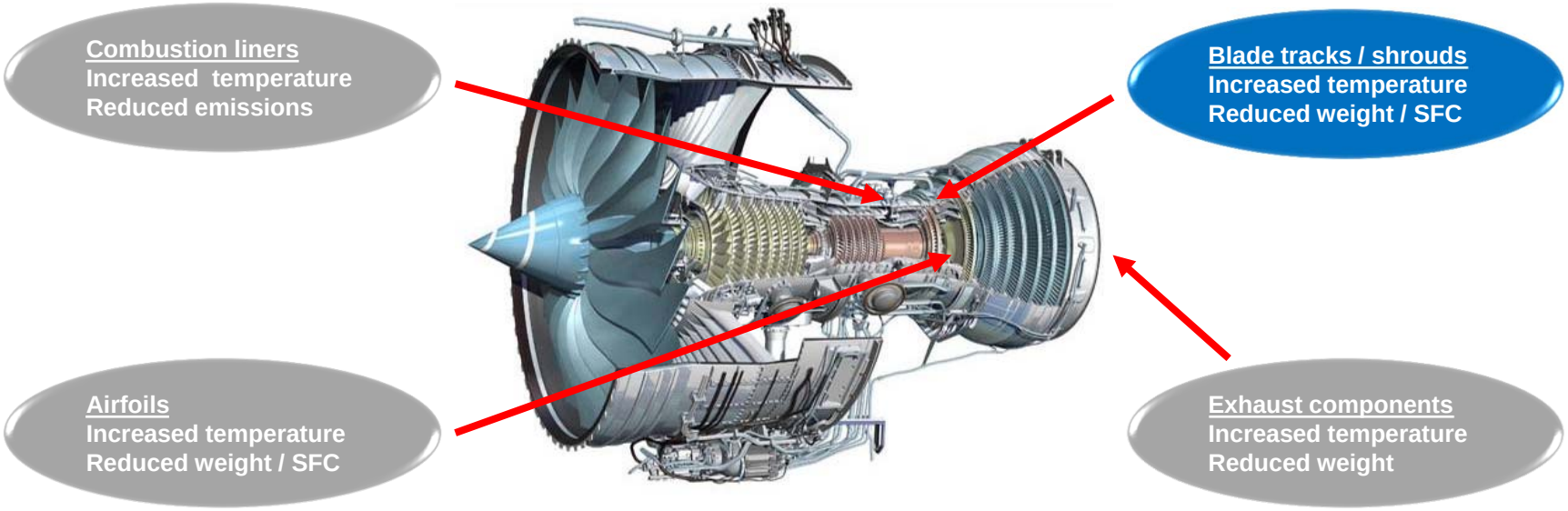
CMC Turbine Blade Tracks

Application of advanced CMC turbine materials enables Reduced Fuel Burn in NextGen product applications

- Provides significant reduction in cooling flow & weight for today's engines
- Enables progression toward tomorrow's advanced engine cycles

Goal: Demonstrate CMC turbine blade tracks for near-term civil engines



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CMC Turbine Blade Tracks

In 2012, we completed design, manufacture, and rig testing

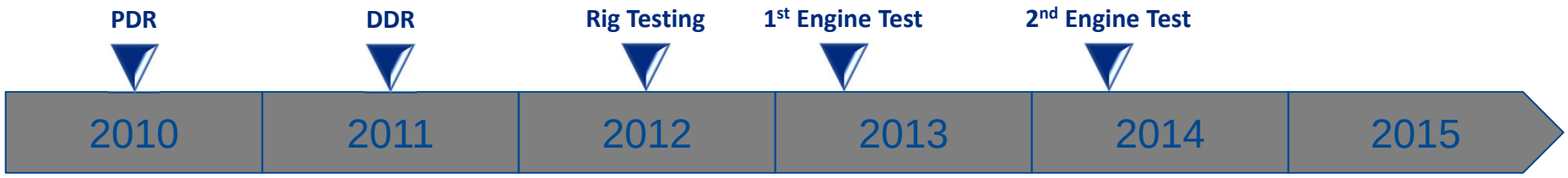
- All thermo-mechanical validation testing was conducted without issue
- Blade track hardware was instrumented and delivered for engine test

In 2013, CMC blade tracks were successfully tested as part of the UK Environmentally Friendly Engine (EFE) program

- Testing validated the performance of CMC components
- Some coating loss was observed; design and processing improvements identified
  - *Subsequent improvements in coating system have been achieved in 2014*

In 2014, blade tracks successfully completed their second test in the EFE demonstrator engine

- Full post-test inspection and analysis is underway



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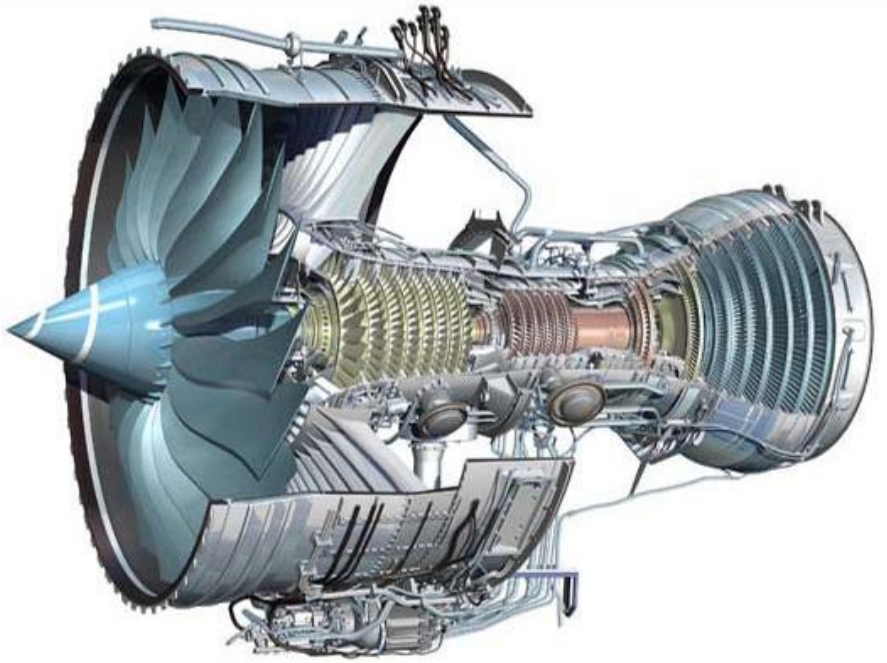
Fuel Burn Reduction – benefit assessment

Rolls-Royce turbine technologies significantly contribute to the CLEEN fuel burn reduction goals

- Ceramic Matrix Composite (CMC) blade tracks offer >50% reduction in cooling and component weight
- Dual-wall turbine airfoils provide >20% reduction in cooling and increased operating temperature capability

Our next-generation Civil products will realize up to 1% in fuel burn reduction by incorporating CLEEN technologies

- Further benefits are attainable through incorporation in advanced engine cycles



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HEFA Fuel Blend Demonstration

Goal: Evaluate suitability of single HEFA fuel blend

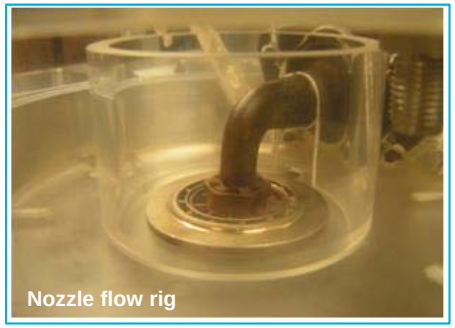
- Dynamic Fuels R-8 HEFA – 50:50 blend with Jet A

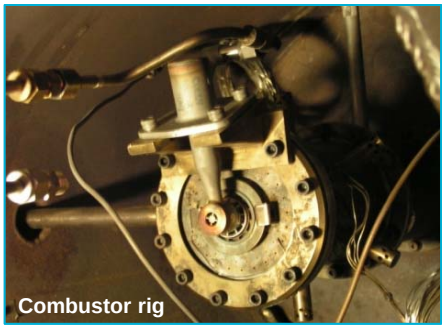
Test plan successfully completed

- Full laboratory analysis
- Drop size measurements
- Ignition and LBO testing
- Emissions testing
- Hot section material endurance testing

Testing confirmed HEFA blend performed as drop-in fuel

- Final test report under review





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Novel Fuels Demonstration

Goal: Evaluate suitability of broad range of novel fuels

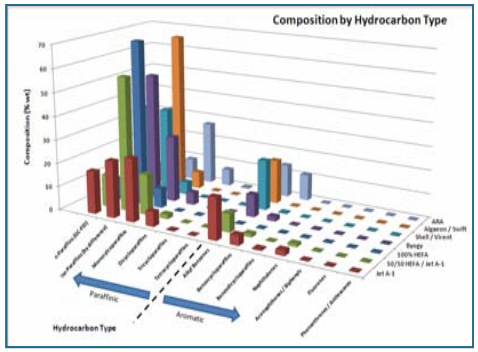
- 8 candidate fuels selected

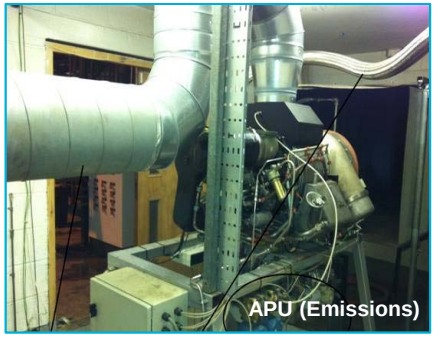
Test plan successfully completed

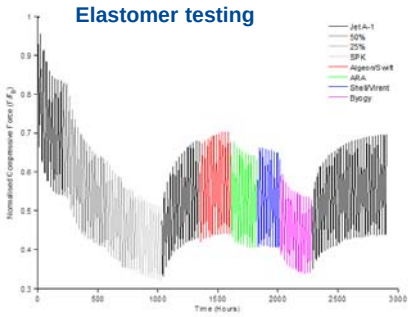
- Full laboratory analysis
- Thermal stability testing
- Ignition and LBO testing
- Emissions testing
- Elastomer sealing force testing
  - *Novel method of measuring seal performance developed*

4 fuels identified as potential drop-in alternatives

- Significant improvement in smoke and particulate observed
- Final test reports under review







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Alternative Fuels – benefit assessment

CLEEN efforts have contributed to the development and deployment of sustainable alternative fuels

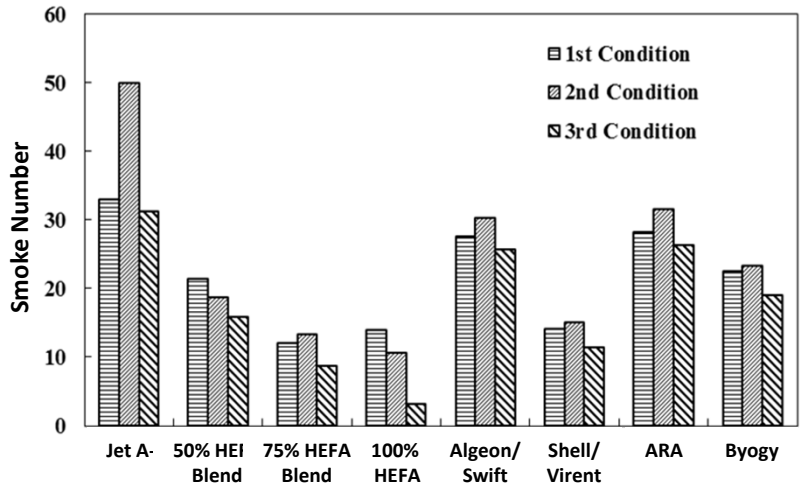
- Testing confirmed HEFA blend performed as drop-in
- 4 novel fuels showed potential as drop-in alternatives to Jet A

Novel method of measuring sealing performance under simulated engine conditions was developed

- Test method is available for future assessment efforts

Significant improvement in smoke and particulate emissions observed

- Emissions decrease with reduced aromatic content



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Summary

Rolls-Royce continues to make significant progress

- Design of dual-wall HP turbine vane is complete
  - *Manufacture of engine hardware is on track for 2015 delivery*
- Engine testing of CMC blade track hardware is complete
  - *Post-test inspection and analysis is underway*
- Lab and rig testing of HEFA fuel blend is complete
  - *Final report is in review*
- Lab and rig testing of novel alternative fuels is complete
  - *Final reports are in review*

Technologies and alternative fuel data are providing significant contribution to FAA CLEEN program goals

- Significant fuel burn reduction in next-generation Civil products, and further benefits through incorporation in advanced engine cycles
- Potential drop-in alternatives to Jet A identified, and novel method of measuring sealing performance developed