



Rolls-Royce CLEEN II

Low Emission Combustion Technology

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Jurisdiction	Export Control Classification (Rating)	Date
US	No Technical Data	11-18-2019 BDB



CLEEN Technologies

CLEEN Technology Name	Goal Impact	Benefits and Application
Advanced RQL Low NOx Combustion System	NOx Reduction	Develop and demonstrate significant NOx reduction with advancing combustion technology that is suitable for emerging high pressure ratio, small core engines



Rolls-Royce Low NOx Combustion Program

Elevator Speech

The Rolls-Royce CLEENII Low NOx Combustor Program will advance the state-of-the-art in Rich-Quench-Lean (RQL) combustor performance, enabling significant reduction in NOx pollution for advanced engine platforms with aggressive turbine entry temperatures.

The comprehensive approach incorporates advanced fuel injection and wall cooling technologies coupled with implementation of enhanced mixing methodology.

A rigorous development plan with progressive validations through component rig and system level testing will mitigate risk and develop a combustion platform for engine evaluation.

We will build upon prior Rolls-Royce development to demonstrate emission reductions in two phases with a near-term configuration targeting NOx emission levels 40% below CAEP/8 limits and a final configuration with NOx level 65% below CAEP/8.



Rolls-Royce Low NOx Combustion Program

Program Objectives

- Define cycle efficiency improvement and emissions reduction technologies that work together in future engine architectures to provide significant contributions toward the CLEEN II goals
- Develop RQL combustion technology capabilities through the application of advanced technologies, new design methods, research of fundamental principles
- Demonstrate through component and full-scale system testing LTO NOx emissions 65% below CAEP/8 requirements, while limiting or reducing other gaseous and particle emissions
- Conduct TRL6 engine testing to demonstrate viability for next generation production application and fleet engine retrofit opportunities



Rolls-Royce Low NO_x Combustion Program

Program Approach

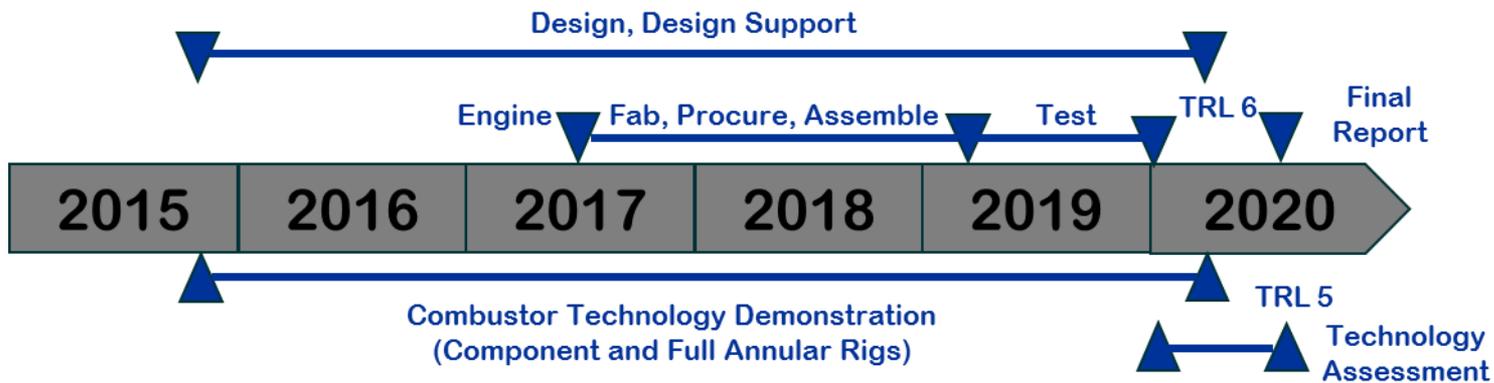
- Integrate low emission enabling technologies in Rich-Quench-Lean (RQL) combustion system
 - Innovative fuel injection to improve uniformity and dispersion
 - Novel mixing aerodynamics to minimize NO_x formation
 - Advanced wall cooling to improve cooling effectiveness
 - Optimized combustor shape to reduce residence time
- Conduct progressive development and demonstration of combustor performance
 - Combustion design guided by high fidelity CFD analysis
 - TRL3 rigs used for component technology development
 - TRL5 rigs used to demonstrate system performance
 - Engine testing to demonstrate integration and viability in the engine environment (TRL6).
 - Phased approach to incorporate prior results and lessons-learned into ultimate low-NO_x configuration.



Program Schedule

**Rolls-Royce
Low NOx
Combustion
Program**

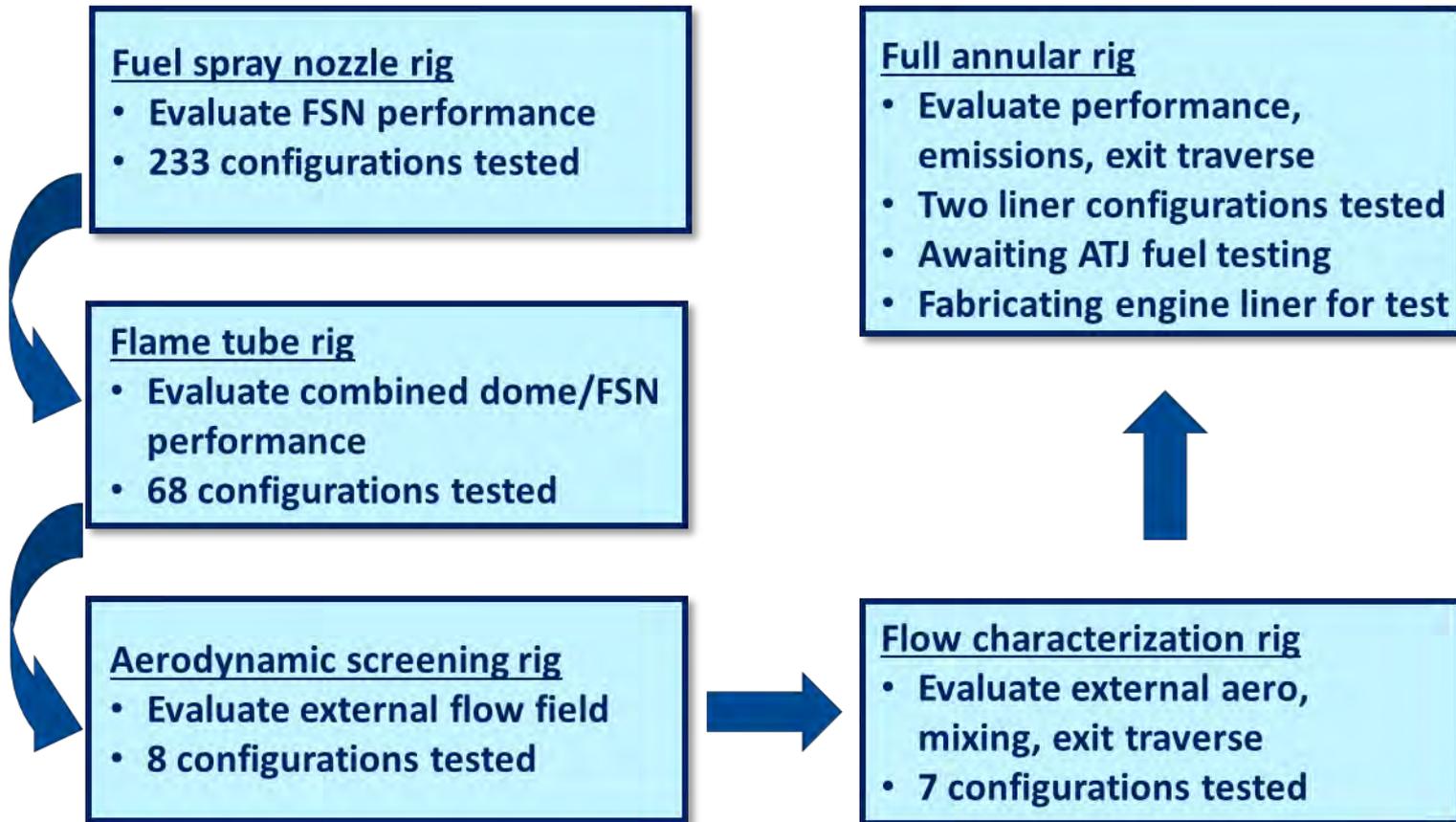
**Advanced RQL
Low NOx
Combustion
System
Development**





Combustion Rig Progression

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Program



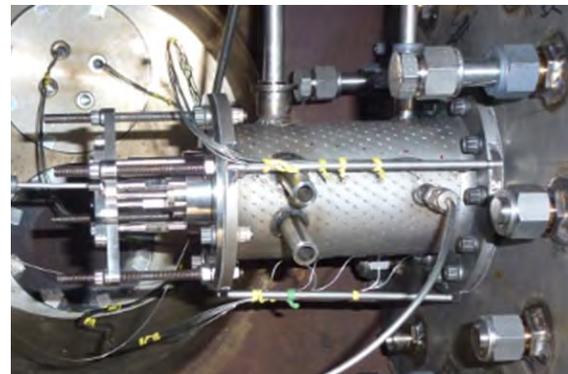
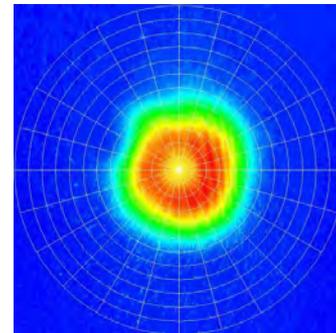
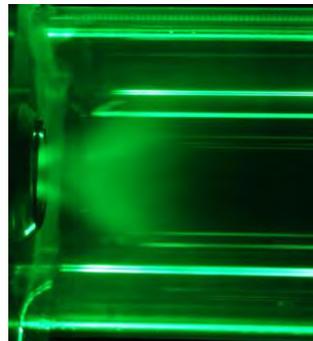


TRL3 Activities to Characterize Fuel Injector and Assess Combustion Performance

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- Fuel Spray Diagnostics
 - Fuel spray quality
 - Liquid droplet dispersion
 - Transient spray effects
 - Spray visualization

- Single Sector Flametube
 - High inlet temperature and moderate pressures
 - Emissions
 - Operability
 - Flexibility to assess multiple concepts





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Full Annular Combustor Rig

- Key objectives to characterize combustor exit temperatures, wall temperatures, emissions and operability
- Will incorporate lessons-learned into engine liner design
- Features rotating emission and temperature probes to map the combustor exit
- Maintains comprehensive aerodynamic similarity to the engine design
- Provides combustion system level performance validation prior to installation into demo engine





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Past 18 Month Achievements

- Combustion system design activities
 - Completed design iteration for Gen2 combustor
 - Utilized results of initial full annular rig testing to define design refinements
 - Completed aero and mechanical design & released components for fabrication
 - Completed design for Gen3 combustor
 - High fidelity, system level CFD analyses used to capture design details, generating flow field solutions and performance predictions
 - Incorporated incremental design improvements for reduced NOx
 - Expanded application of additive layer manufacturing
- Full annular rig testing (TRL5) activities
 - Completed rig hardware fabrication, assembly, and checkout
 - Conducted testing of first two Gen2 combustors, including performance & operability, emissions, exit temperature distribution, and wall temperatures mapping
 - Initial Gen2 combustor cleared for engine #1 demonstration
 - Second Gen 2 combustor on test for ATJ fuel assessment
 - Third Gen 2 combustor slated for test prior to engine #2 demonstration



**Rolls-Royce
Low NOx
Combustion
Program is on
track for TRL6
validation**

Future Project Plans

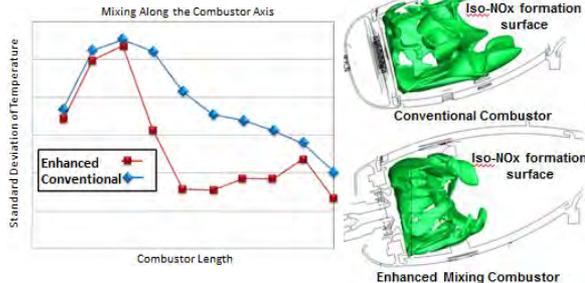
- Complete full annular rig (TRL5) testing of ATJ synthetic fuel with Gen2 combustor
- Complete full annular rig testing of third Gen2 combustor
 - Intent to clear combustor for engine #2 demonstration
- Conduct engine demonstrations of Gen2 combustors
 - TRL6 validation of CLEEN II combustion technology
- Conduct full annular rig testing of Gen3 combustor
 - Complete fabrication & assembly of hardware
 - TRL5 validation of incremental low NOx technologies





Advanced RQL Low NOx Combustion System

Quad Chart



Anticipated Benefits:

- Significant NOx reduction
- Negligible operability impact
- Highly cost effective
- Technology capable of broad product insertion
- Advanced wall cooling and manufacturing technology

Risks/Mitigation Plans:

- Rigs are planned to manage risk and provide
 - Analysis benchmarking
 - Component and system development

Objectives:

- Demonstrate LTO NOx emissions 65% below CAEP/8 requirements, while limiting or reducing other gaseous and particle emissions
- Conduct TRL6 engine testing to demonstrate viability for next generation production application and fleet engine retrofit opportunities

Work Statement:

- Integrate low emission enabling technologies in a Rich-Quench-Lean (RQL) combustion system and develop and demonstrate low emission performance

Accomplishments / Milestones:

- Conducted detailed fuel spray diagnostics (TRL2)
- Completed array of single sector flame tube tests (TRL3)
- Aero rig testing to screen system configurations
- Design, fabrication, and validation test of combustion system to support engine demonstrator
- Design defined for lower NOx combustion system.

Schedule:

