



Rolls-Royce CLEEN II

Low Emission Combustion Technology

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CLEENII Consortium Public Day

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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 NOx 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 NOx 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-NOx configuration.



Overall program time line

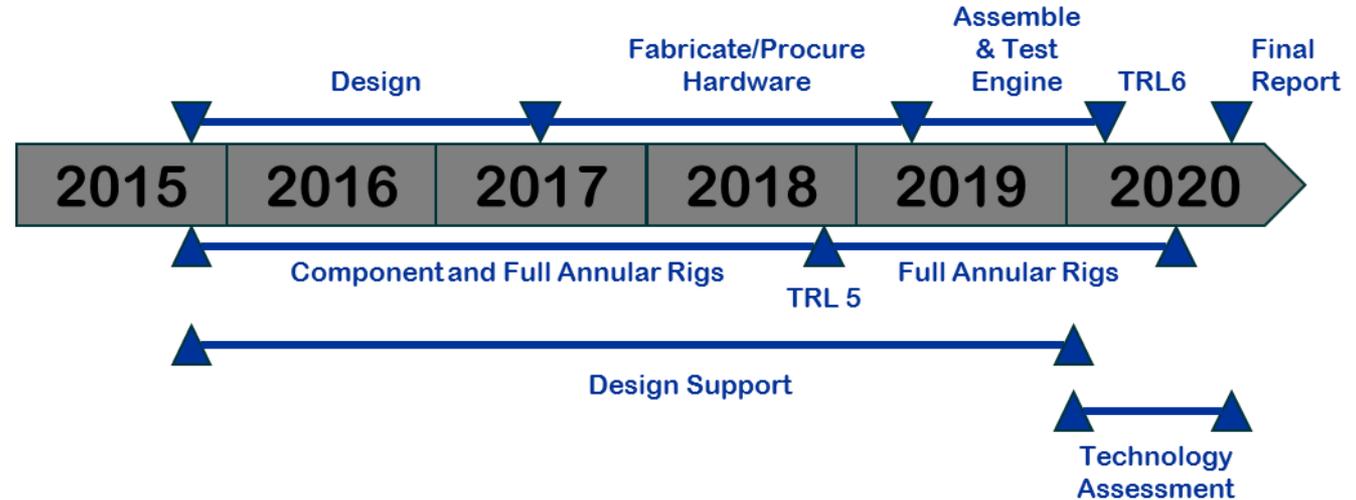
Low NOx Combustion Program key points

Program launched in October 2015

Component rig testing (TRL3) in 2016-17 used to inform combustor design

Full annular rig testing (TRL5) of designs began in 2018

Engine testing (TRL6) initiated in late 2019



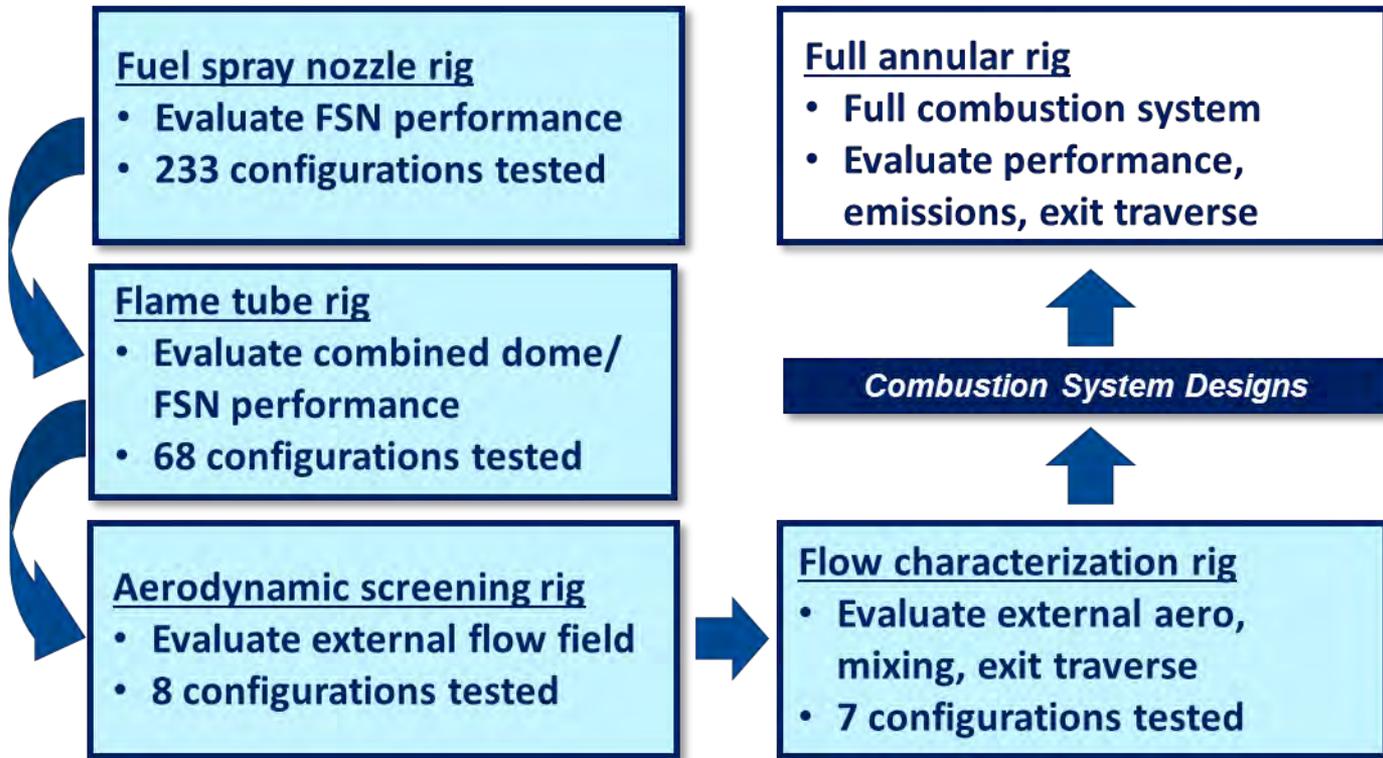
Final phase of program is now underway



Combustion design validation & verification

Low NO_x Combustion Program key points

Progressive validation via component and system rigs to inform designs and down-select configurations



Full annular rig testing informs engine test readiness

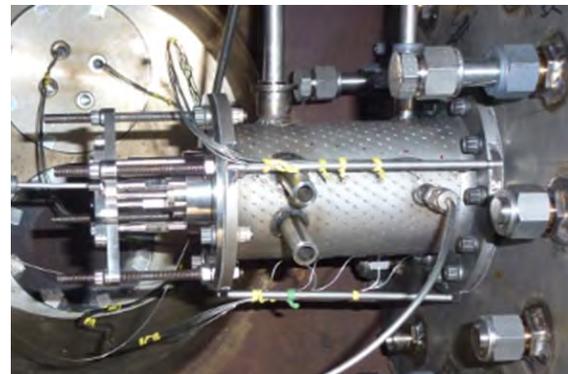
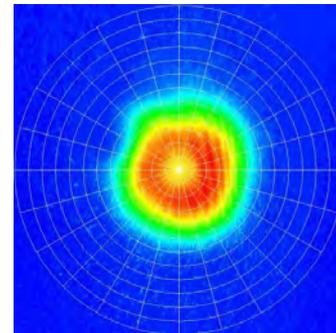
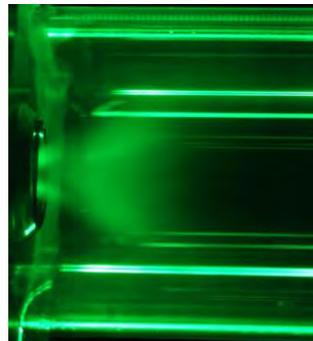


TRL3 Activities to Characterize Fuel Injector and Assess Combustion Performance

Rolls-Royce Low NOx Combustion Program

- 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





Rolls-Royce Low NOx Combustion Program

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 & fabricated hardware
 - Completed design for Gen3 combustor
 - Incorporated incremental design improvements for reduced NOx
 - Expanded application of additive layer manufacturing
- Full annular rig testing (TRL5) activities
 - Conducted testing of first two Gen2 combustors, including performance & operability, emissions, exit temperature distribution, and wall temperatures mapping
 - Initial Gen2 combustor cleared for engine demonstration
 - Third Gen 2 combustor slated for test prior to engine demonstration
- Engine testing (TRL6) activities
 - Combustor operation supporting all engine test objectives.



Rolls-Royce Low NOx Combustion Program

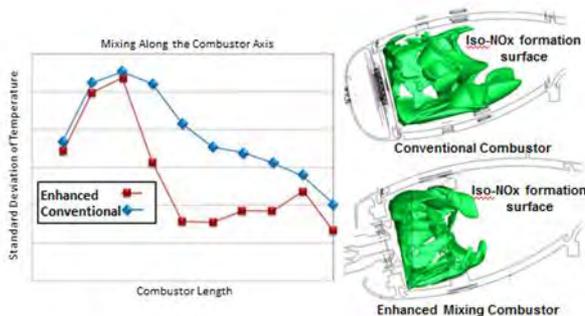
Future Project Plans

- Complete full annular rig (TRL5) testing of recent Gen2 design iteration
 - Performance qualification for future engine tests
 - Back-to-back testing on Jet-A and ATJ synthetic fuel
- Continue 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 TRL6 demonstration
- Design refinements to enhance performance

Schedule:

