



# Rolls-Royce CLEEN II Low Emission Combustion Technology

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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 phased development approach to develop and demonstrate low emission performance
  - Combustion design guided by high fidelity CFD analysis
  - Lower TRL rigs used for initial technology development
  - TRL5 full annular rigs used to demonstrate system performance
  - TRL6 engine testing using to demonstrate viability in engine environment. Engine combustor design supported by rig test results.



# Program Schedule

## Rolls-Royce Low NOx Combustion Program

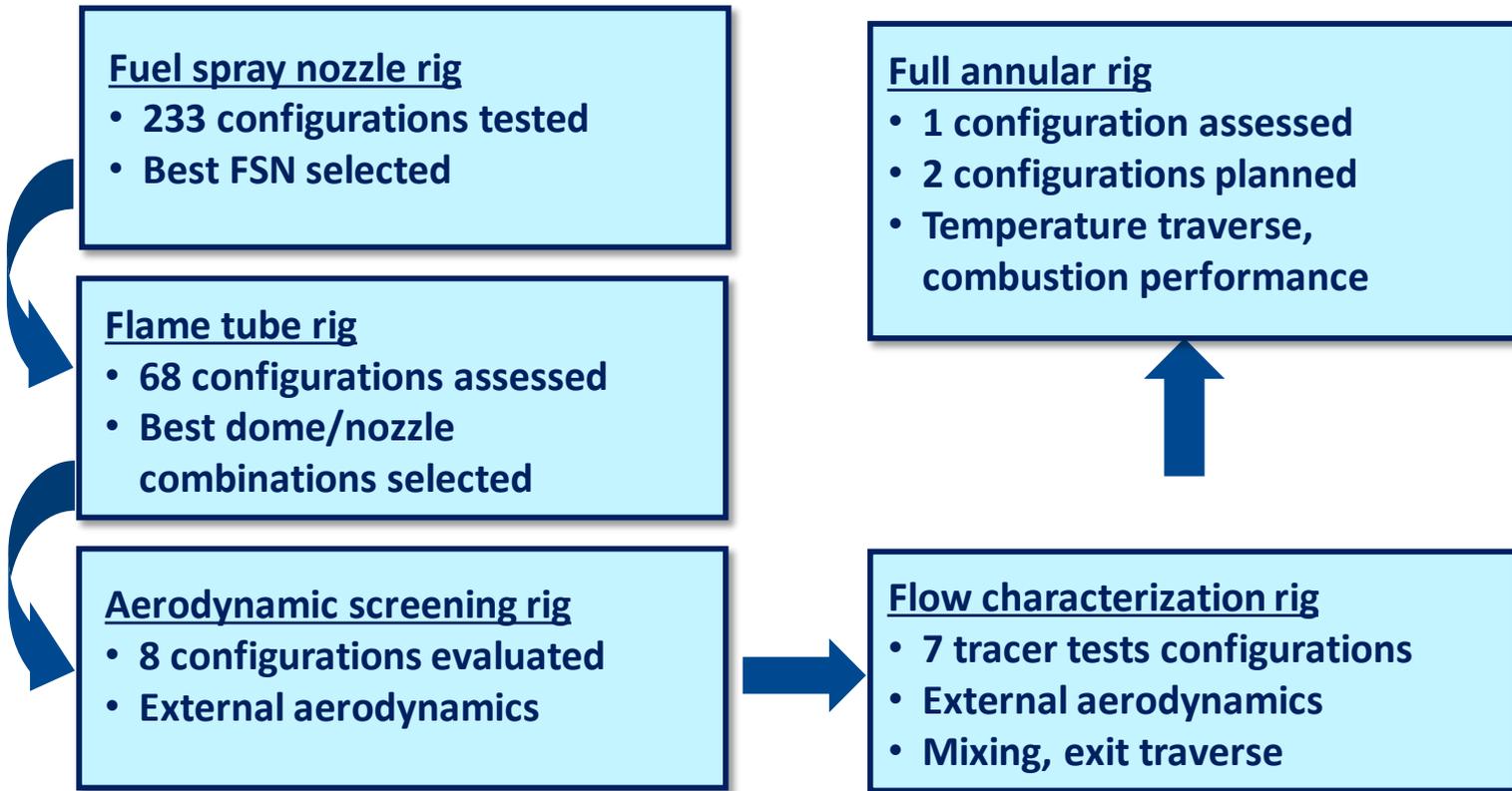
### Advanced RQL Low NOx Combustion System





# Combustion Rig Progression

Rolls-Royce  
Low NOx  
Combustion  
Program





## Rolls-Royce Low NOx Combustion Program

# Past 18 Month Achievements

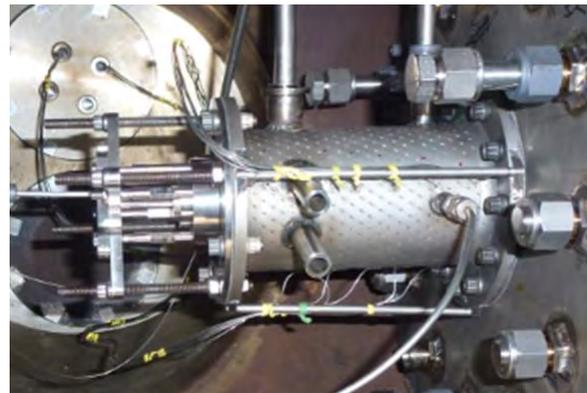
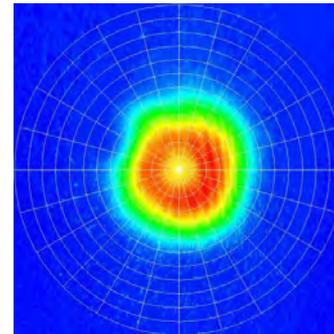
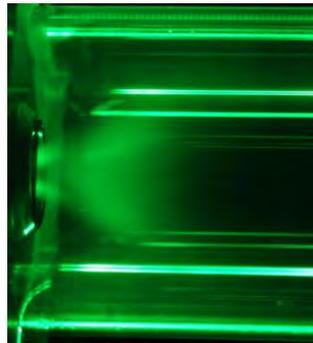
- Completed TRL5 rig testing on Gen2 combustion system
  - Full annular combustor rig delivery, assembly, and checkout
  - Combustor operability assessed, exit temperature distribution quantified, and wall temperatures mapped
  - Gen2 combustor cleared for Engine demo build
- Completed TRL3 activities to support Gen3 combustor definition
  - Fuel spray diagnostics identified fuel nozzle tip candidates for flametube combustion testing
  - Single-sector flametube evaluation at high pressure and high temperature to assess combustion performance of fuel injector candidates
  - Confirmed fuel nozzle tip configuration for Gen3 combustor
- Conducted design studies to define Gen3 combustion system design
  - High fidelity, system level CFD analyses used to capture design details, generating flow field solutions and performance predictions
  - Identified combustor aerodynamic approach and finalizing mechanical design details.



# 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





## Full Annular Combustor Rig

### Rolls-Royce Low NOx Combustion Program

- 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 is on  
track to deliver  
program  
objectives**

## **Project Plan for Year 4 into Year 5**

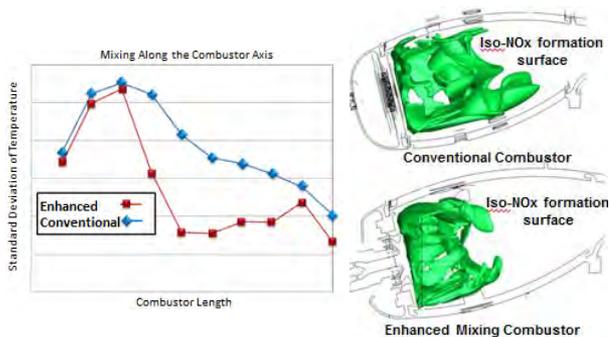
- Fabricate Gen3 combustor
  - Expanded use of DLD construction
- Employ full annular rig testing to characterize Gen3 combustion system design
  - Characterize full system performance
  - TRL5 demonstration of advanced combustion technology
- Assemble and test technical demonstrator engine
  - TRL6 validation of Generation 2 CLEEN combustion technology
- Design Gen4 combustor





## 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:

- Design and fabrication of combustion system
- 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

### Schedule:

