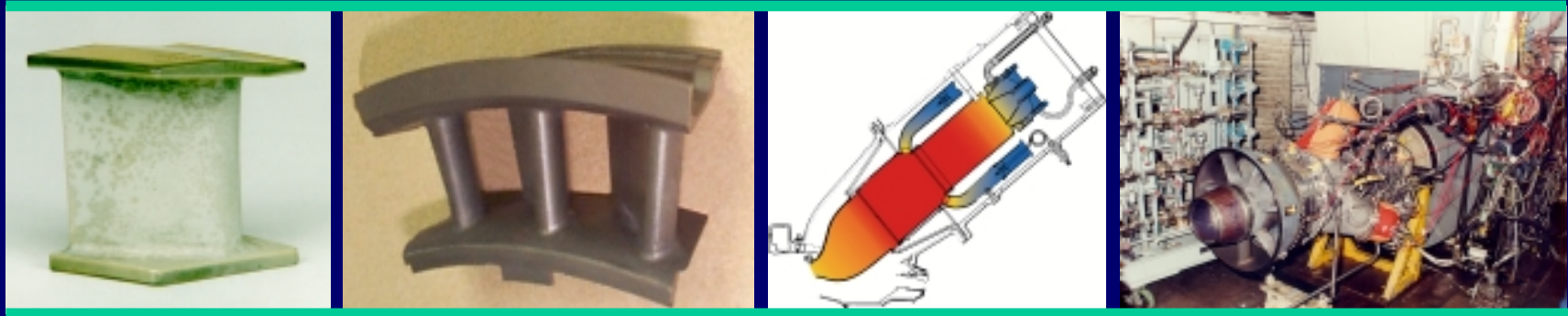


Advanced Turbine Systems

Annual Program Review



Frank Macri

ATS Program Manager
Rolls-Royce Allison

November 1999 Program Update

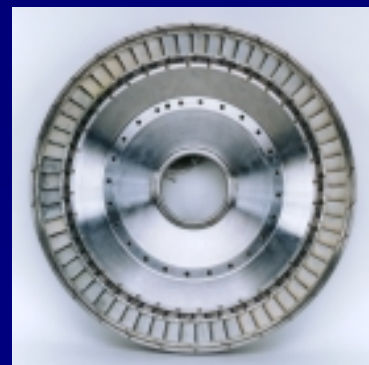
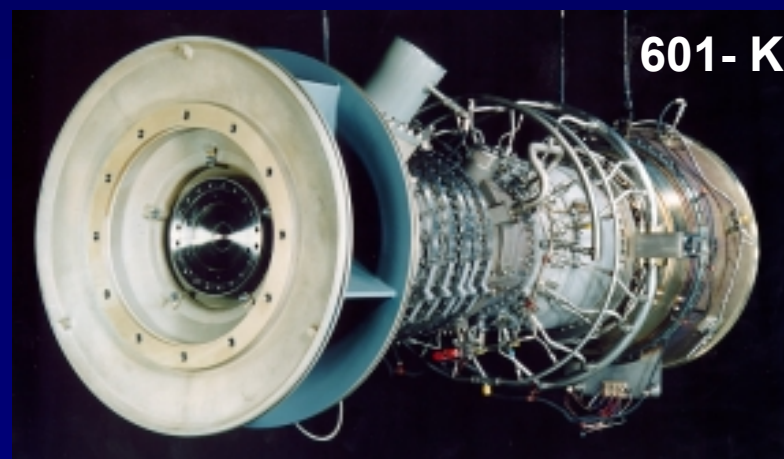
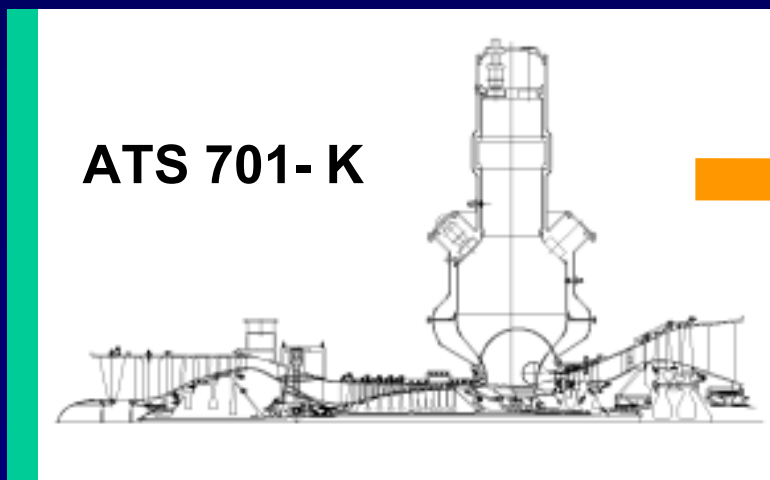
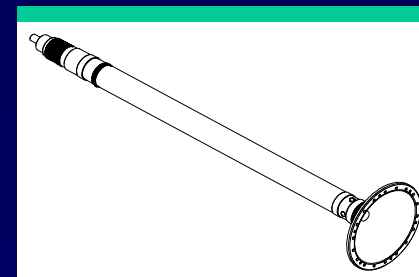
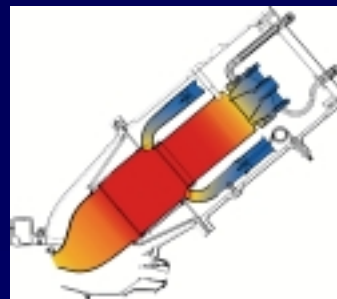
In cooperation with
the US Department of Energy



Rolls-Royce

Allison
VSK-1899

ATS focus at Rolls-Royce Allison has changed



Rolls-Royce

Allison
VSK-1901

ATS focus at Rolls-Royce Allison has changed

- Low / minimal risk alternative is being pursued
- No longer pursuing unique 701-K engine core
 - *Market strength*
 - *Required investment to commercialize*
- Will address market (>10 MW) with 601-K engine core
 - *Core is mature and fielded*
 - *Achieve DOE performance goals through infusion of ATS technologies*



Rolls-Royce

Allison
VSK-1902

Advanced Turbine Systems program goals

- Enhance the global competitiveness of U.S. industry
- Environmental benefits
 - *Reduced emissions*
 - *Economic benefits*
 - *15% performance improvement over state-of-the-art systems*
 - *Busbar cost of electricity at least 10% below current systems*
- Competitive benefits
 - *Successful in global markets for power generation / cogeneration and mechanical drive applications*
- Commercialization of innovative technology



Rolls-Royce

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Rolls-Royce Allison ATS approach

Technology building blocks to improve engine efficiency and reduce combustion emissions

- Combustion technology advances to achieve single digit NOx control
- Hot section material enhancements
 - *Ceramic structural components*
 - *Advanced coating technology*
- Lower bearing/sump temperatures with diffuser, center sump and super-critical shaft enhancements



Rolls-Royce

Allison
VSK-1904

Rolls-Royce Allison ATS approach

- Demonstrate/develop technologies internally and at field test sites
- Apply the demonstrated technologies to the Rolls-Royce Allison family of industrial engine products
 - 501-K
 - 601-K
- Commercialize these building block technologies at lower risk, lower cost
- Applicable to power generation and to mechanical drive and marine applications



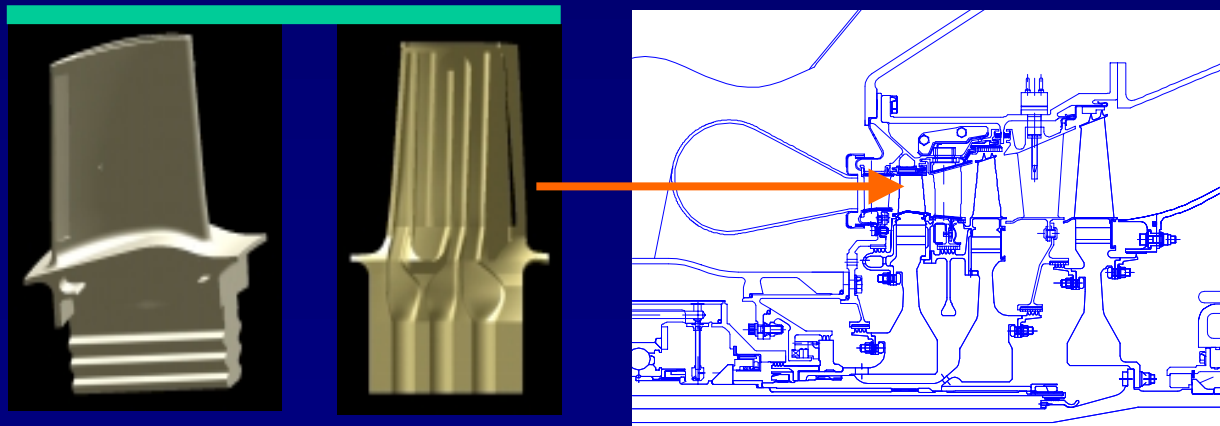
Rolls-Royce

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ATS advanced design concepts

Advanced design technologies completed for insertion in future growth Model 601-K configurations

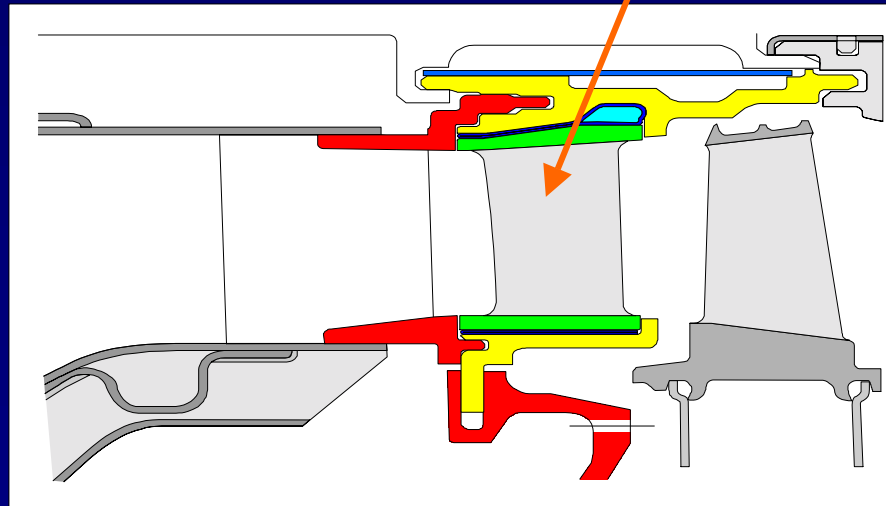
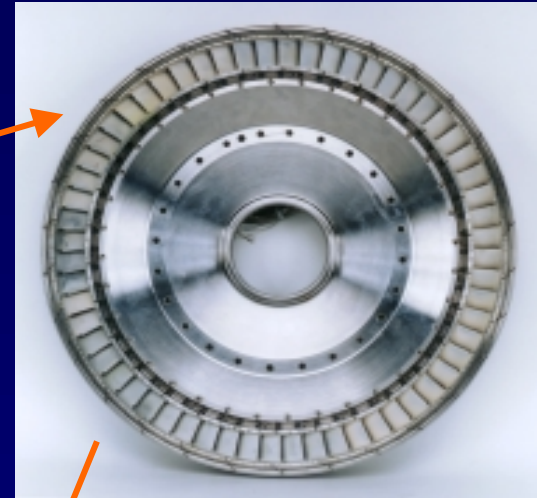
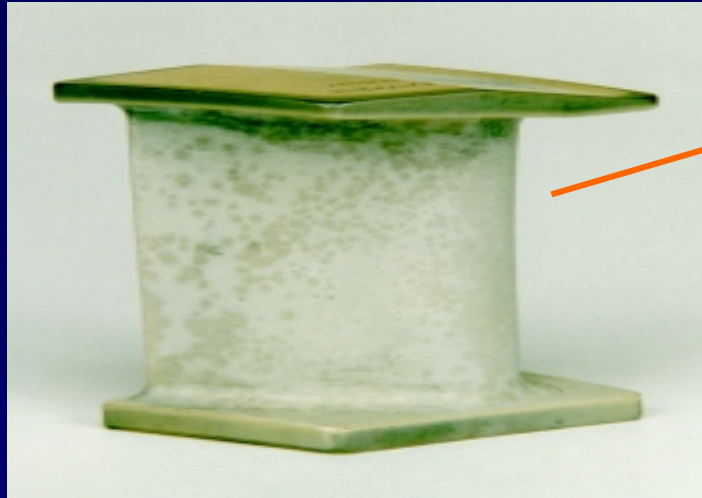
- ATS/701-K low pressure compressor to achieve significant efficiency improvement and power increase
- ATS/701-K advanced HP turbine for additional power increase
 - *2400°F turbine design*
 - *Blade cooling technology validated through rig test*



Rolls-Royce

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VSK-1906

Ceramic turbine vane development



Rolls-Royce

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VSK-1907

Ceramic turbine vane development

Approach

- Design and fabricate ceramic first stage turbine vane and associated mounting hardware using Model 501-K turbine architecture
- Evaluate ceramic first stage vane integrity through design analysis and thermal shock testing
- Conduct initial engine proof test
- Evaluate through 4000 hours field test - EXXON facility



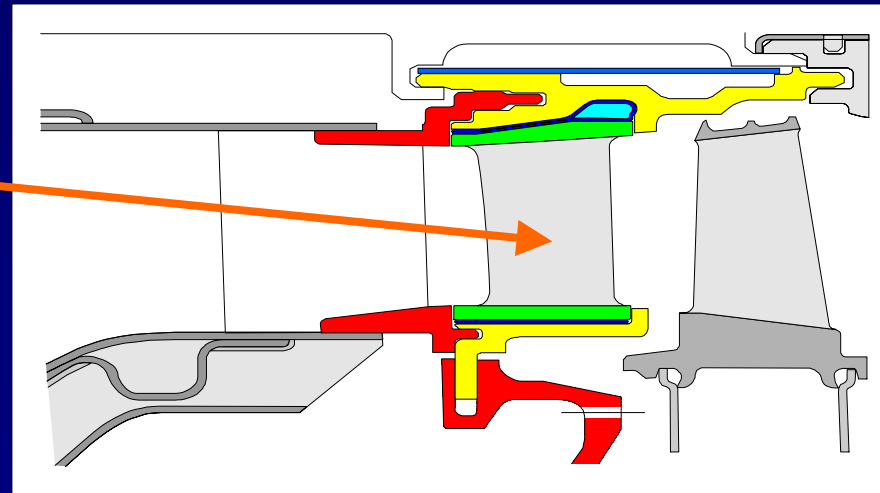
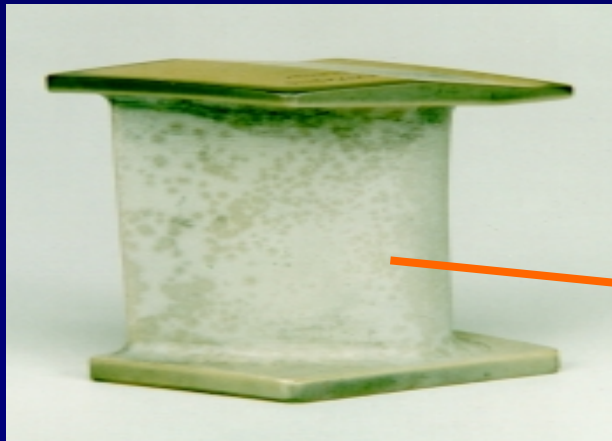
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Ceramic turbine vane development

Benefits of ceramic turbine airfoils

- Reduce turbine module cooling flows
- Higher power, increased efficiency



Rolls-Royce

Allison
VSK-1909

Ceramic turbine vane development



EXXON Natural Gas
Processing Plant - Engine Skid



Model 501- KB5 Engine



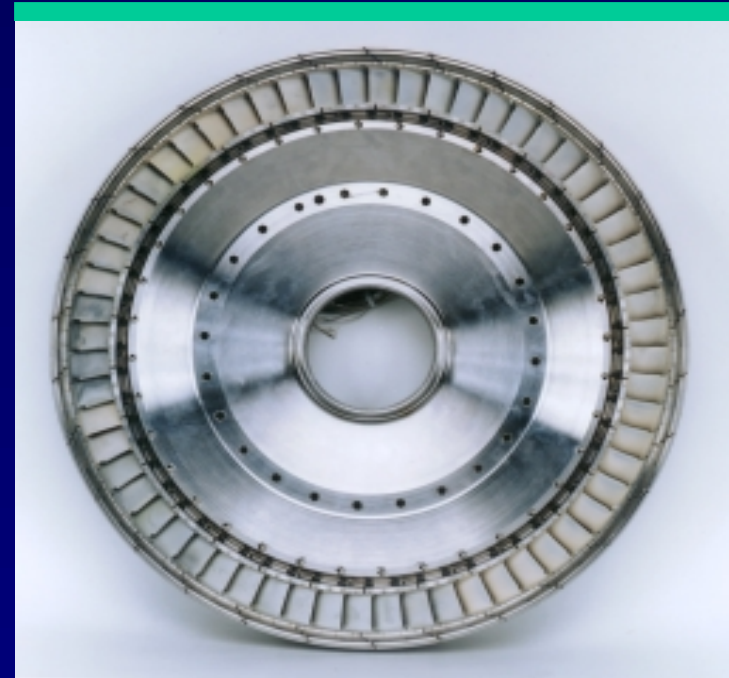
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Ceramic turbine vane development

Accomplishments

- Ceramic vane and mount assembly successfully designed and fabricated
- 22 hours proof testing completed at Standard AERO
- 793 hours of field test operation completed without incident over full range of power



501- K Ceramic First Stage Vane Assembly

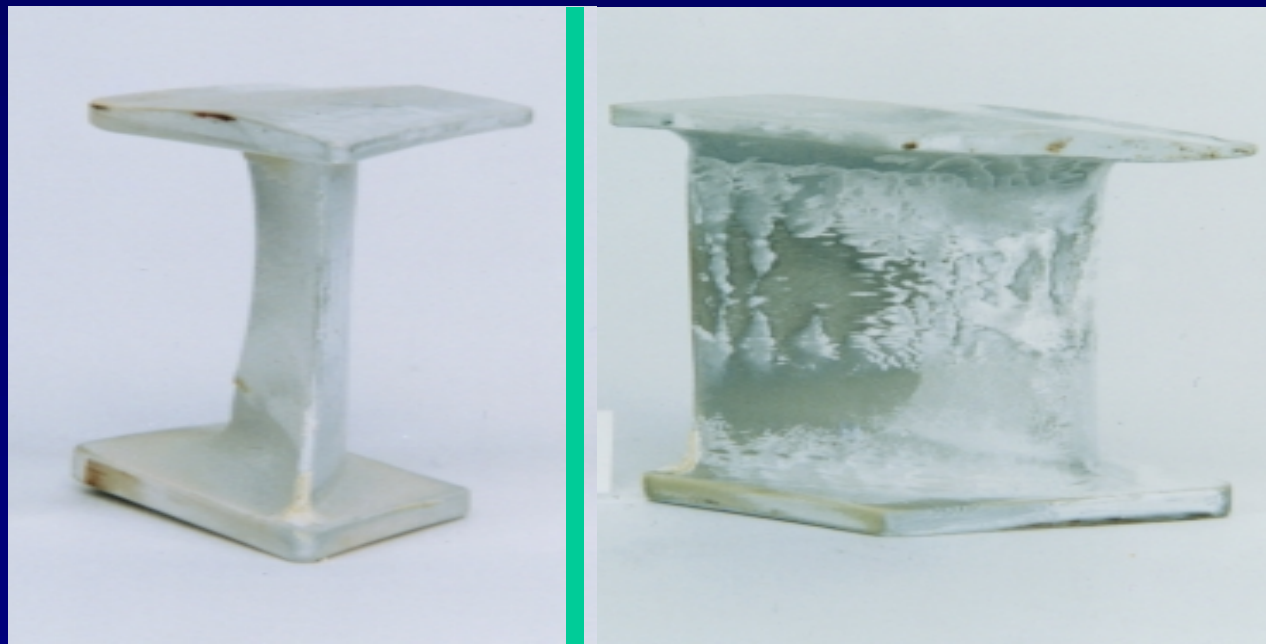


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Ceramic turbine vane development

Phase I test results support need for improved environmental barrier coating (EBC) technology to increase oxidation resistance



Ceramic Vane After Field Test Operation



Rolls-Royce

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VSK-1912

Ceramic turbine vane development

Phase II plan developed (future activity)

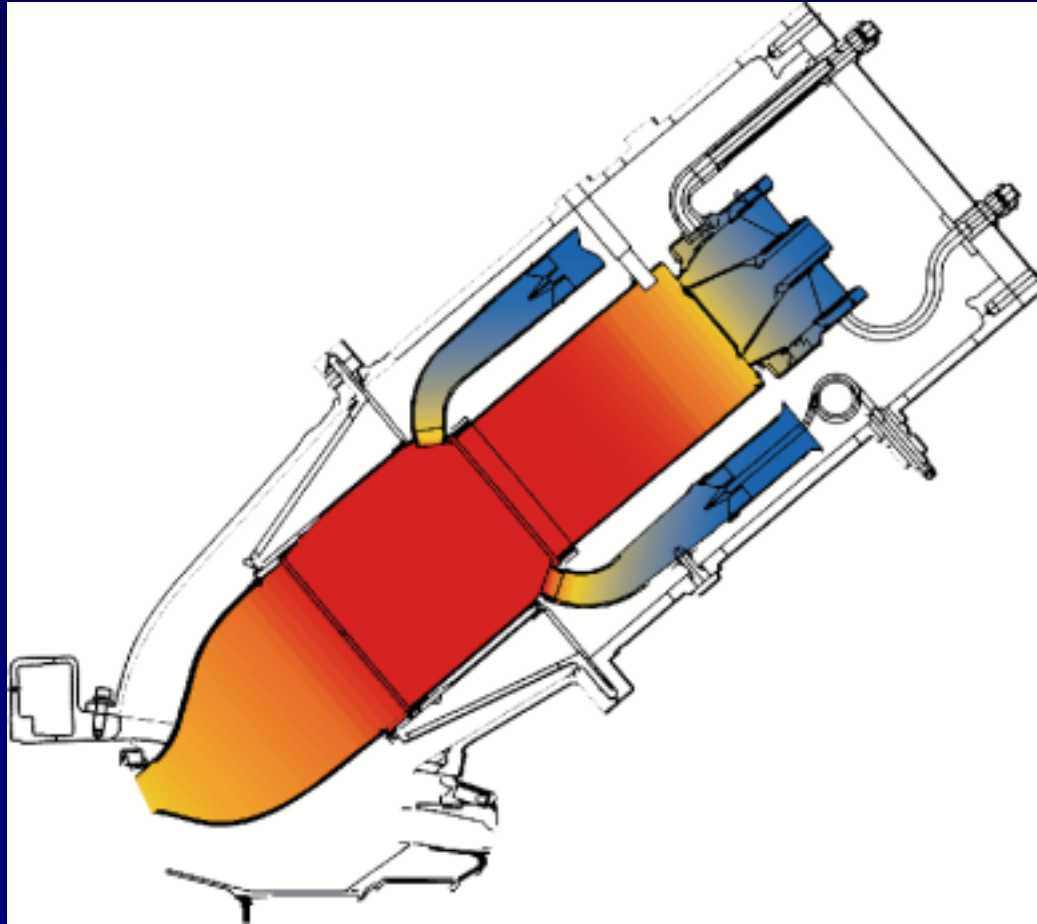
- Collaborative effort to develop EBC system
 - *Solar Turbines*
 - *Pratt & Whitney*
 - *Oak Ridge National Labs*
 - *NASA Glenn Research Center*
- Develop test matrix using AS-800 and SN-282 ceramic materials for 501-K design first stage vanes with several EBC candidates
- Field test evaluation at EXXON - 4000 hours



Rolls-Royce

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VSK-1913

ATS combustion technology



Rolls-Royce

Allison
VSK-1914

ATS combustion technology

Approach

- Dry low emissions (DLE) effort is focused in two areas
 - *Lean premix (LPM) technology*
 - *Catalytic combustion technology*
- Program goal is single digit NOx emissions with stable operation
- LPM approach involves primary and secondary staging (premix) development
 - *Primary staging design based on LE4 system currently used on model 501- K industrial fleet*

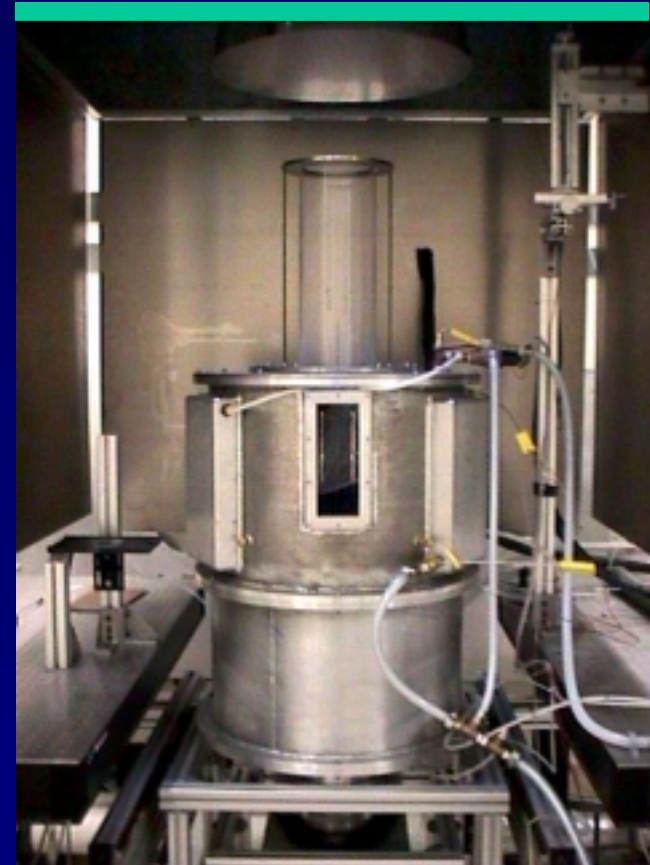


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ATS combustion technology

- Design and development approach
 - *Advanced CFD simulation*
 - *Component bench testing*
 - *Atmospheric diagnostics*
 - *System tests at simulated engine conditions*
 - *Engine development test*
- LPM module development rig testing
 - *Optimization of swirler design configurations*
 - *Atmospheric bench test evaluation*



Atmospheric Test Rig



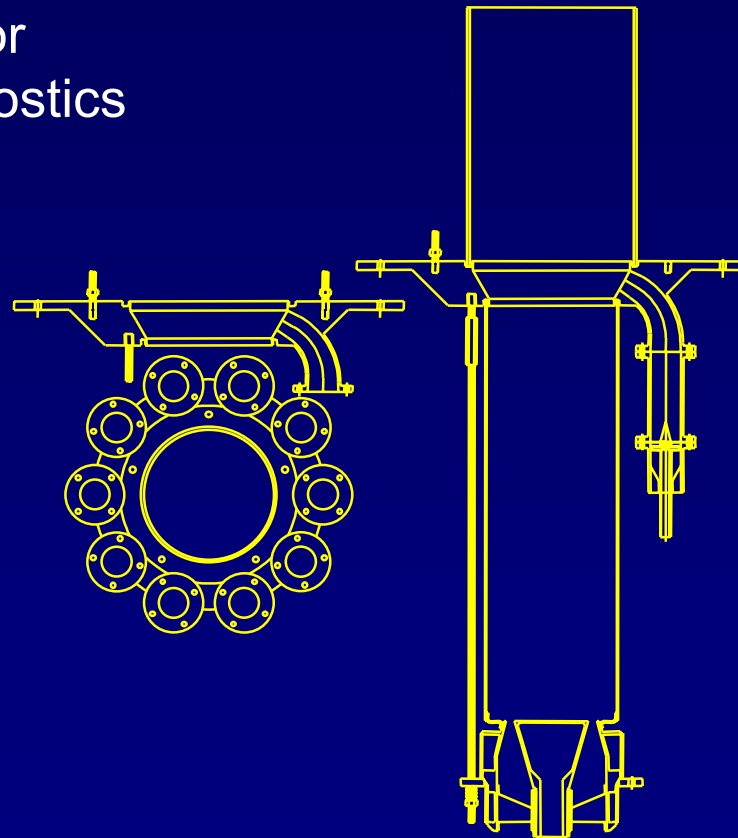
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ATS combustion technology

Atmospheric Bench Testing

2-stage combustor with
optical access for
advanced diagnostics

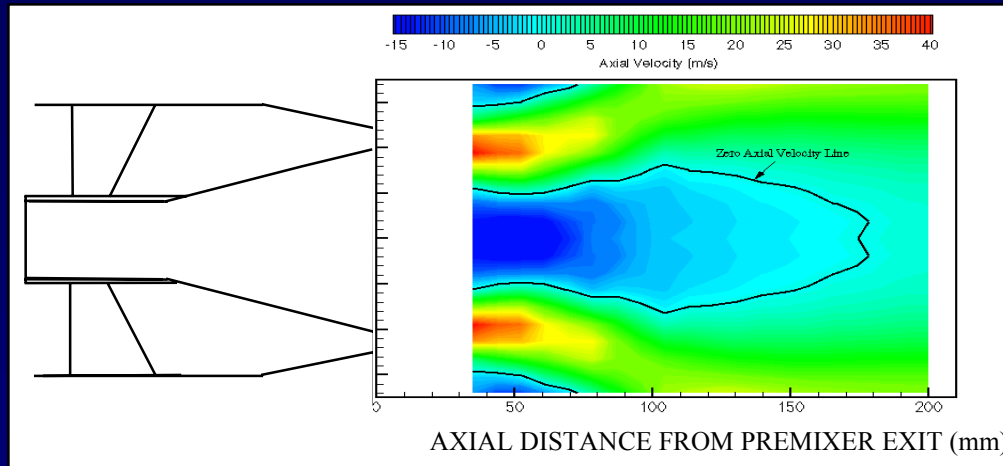


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VSK-1917

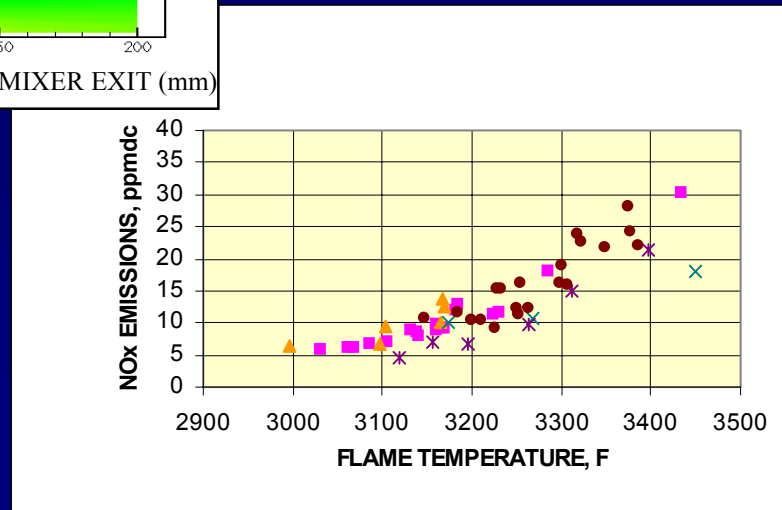
ATS combustion technology

Primary premixer performance characteristics



Axial velocity field

NOx emission characteristics



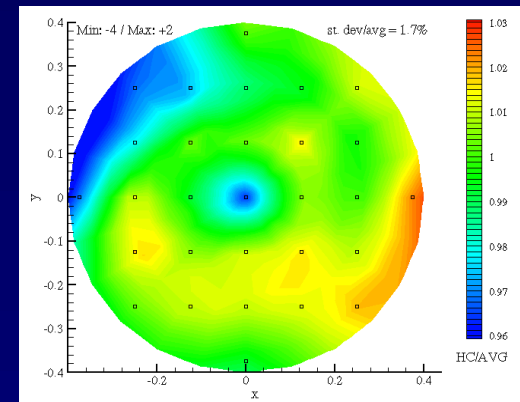
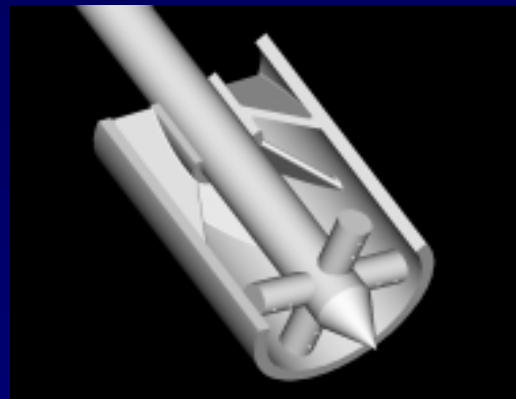
Rolls-Royce

Allison
VSK-1918

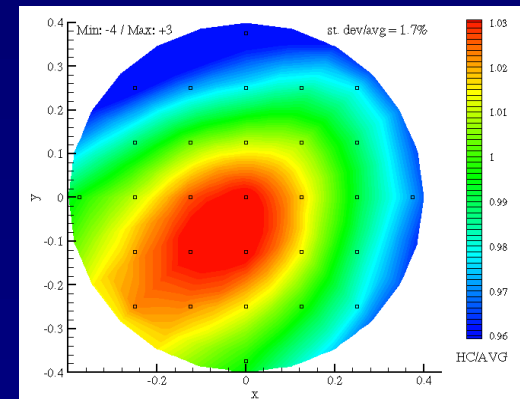
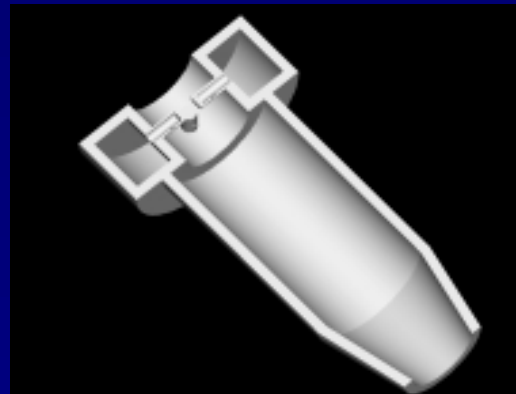
ATS combustion technology

Development of secondary pre-mixer designs have produced configurations that pre-mix reactants to within +3 / -4 % uniformity

**Swirler W/4
Fuel Bar Inlet**



**Downstream
Vortex Premixer**

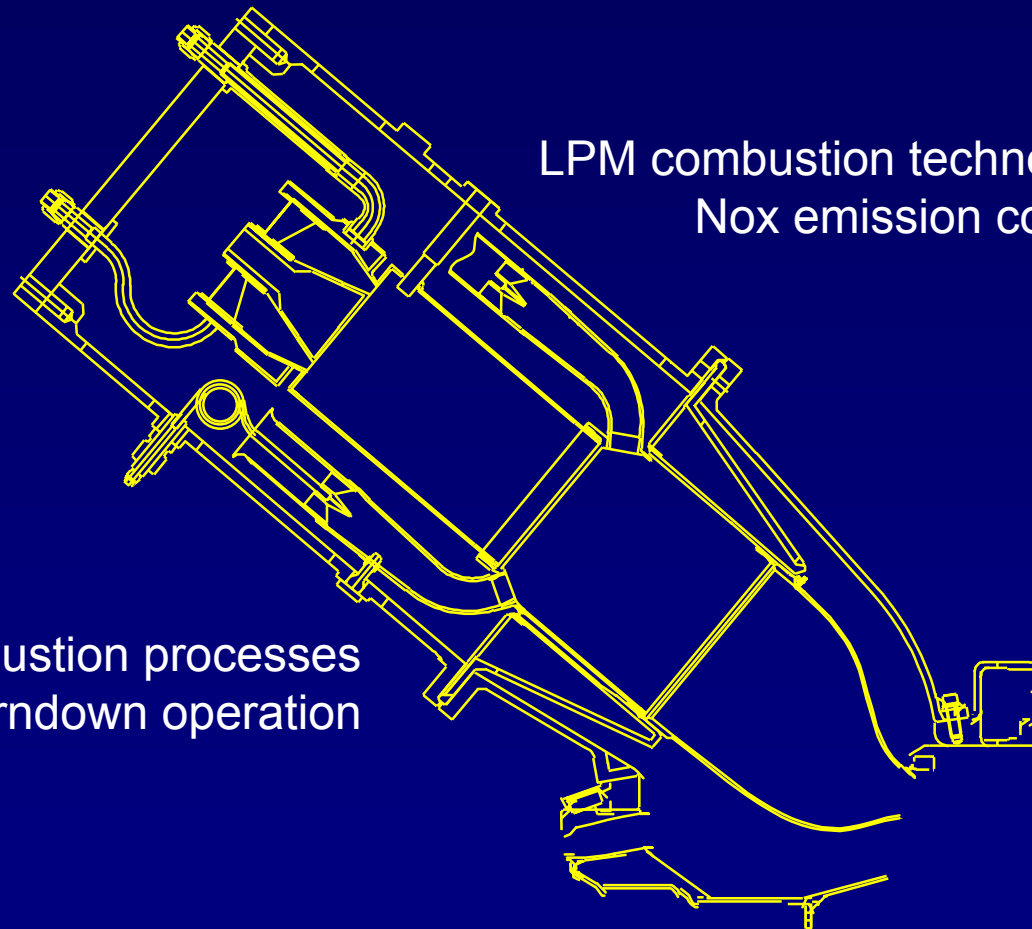


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ATS combustion technology

Full scale LPM combustion system preliminary design configuration completed



LPM combustion technology for low
Nox emission control

Staged combustion processes
for wide turndown operation

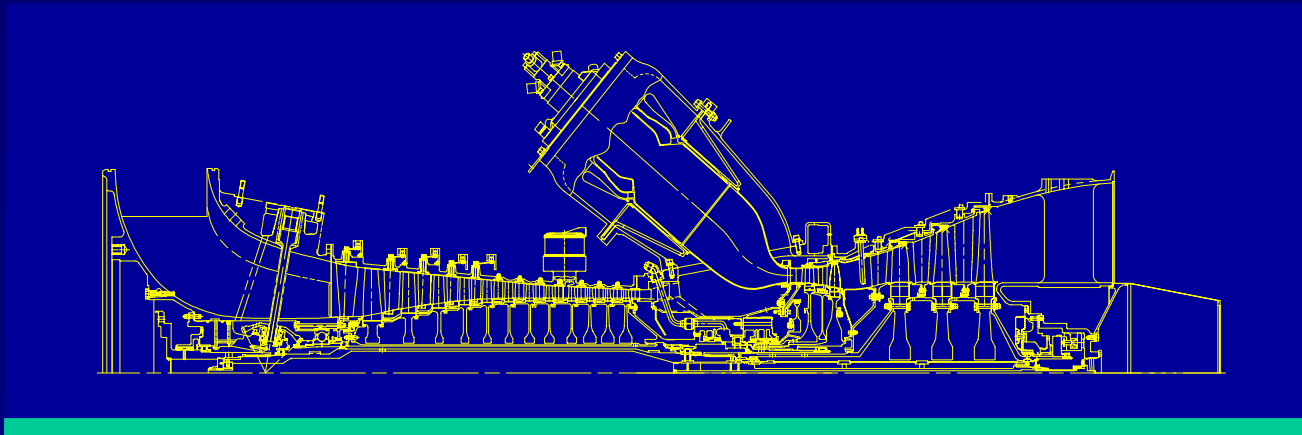


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Allison
VSK-1920

ATS combustion technology

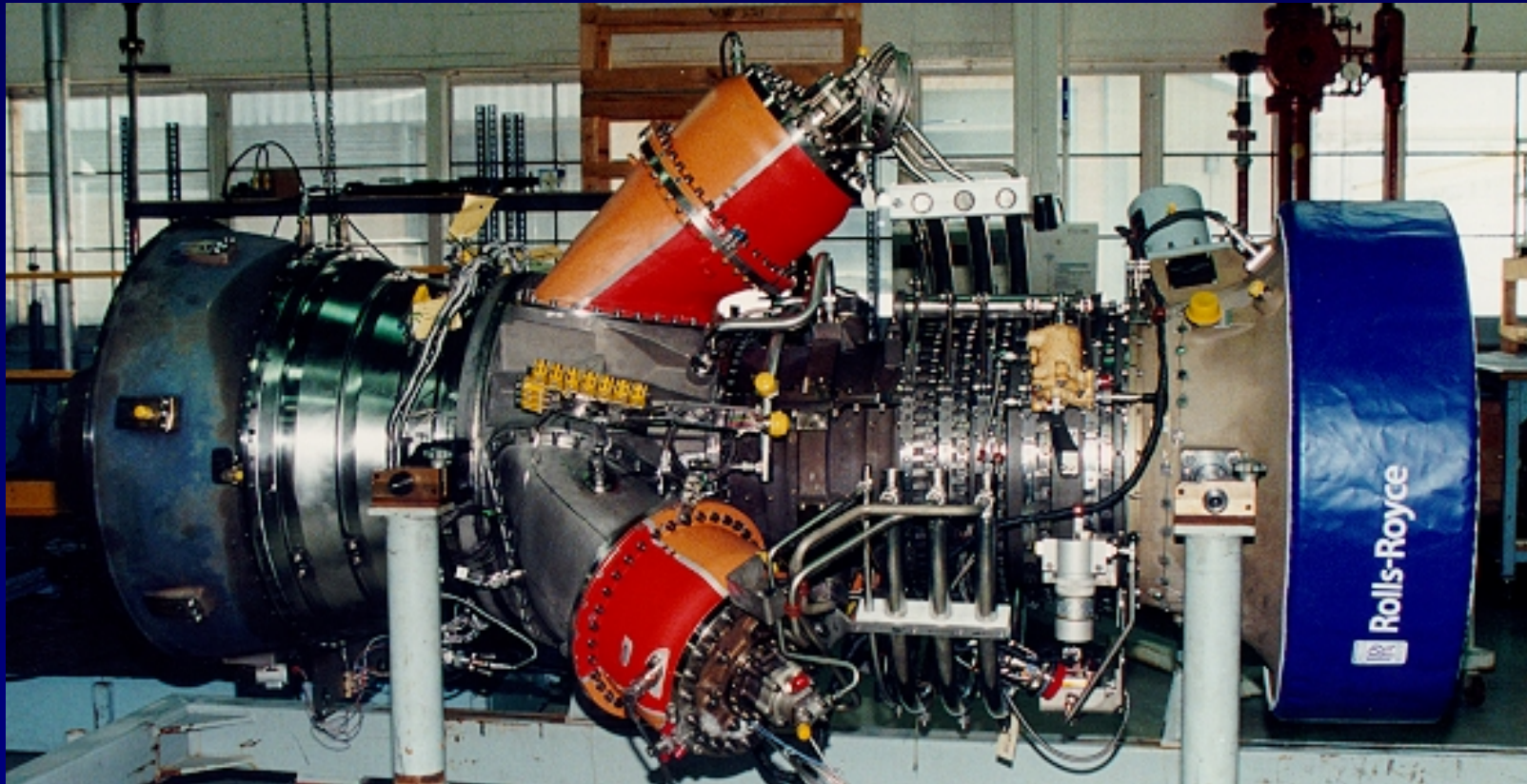
- Established plan to demonstrate and commercialize single digit NOx DLE technology on the Rolls-Royce Allison Model 601-K9 DLE platforms
 - *3 Can Silo-Combustion system architecture selected*
 - *Full scale sector rig test (1st Qtr 2000)*
 - *ATS engine demonstration (4th Qtr 2000)*



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ATS combustion technology



Model 601- K9 DLE

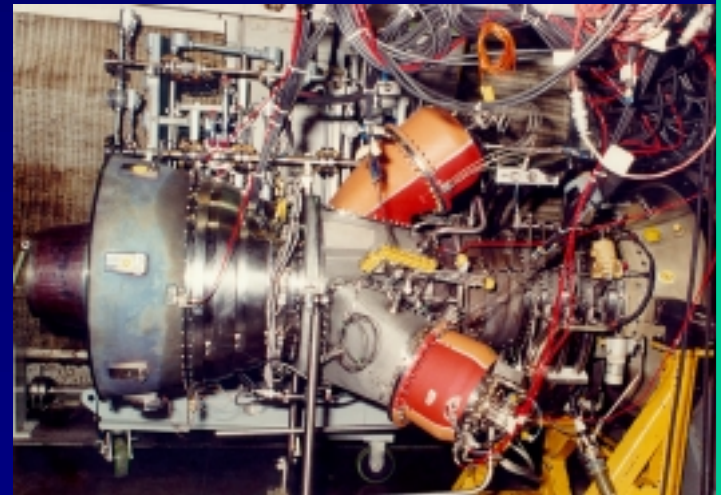
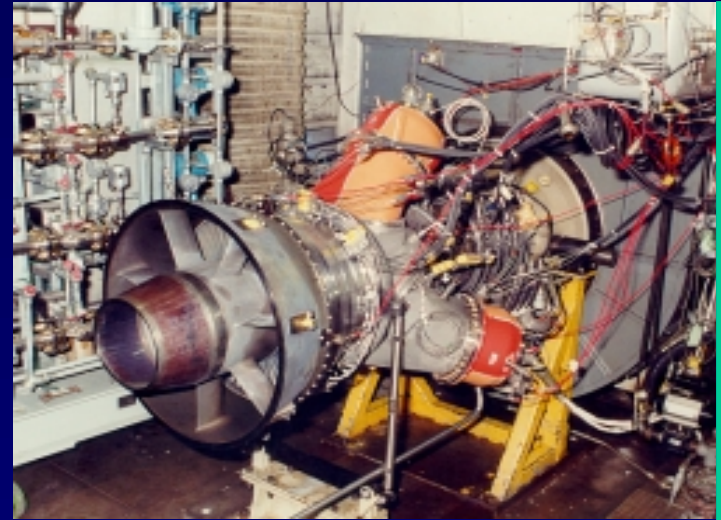


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ATS combustion technology

- K9 DLE engine test development currently in progress
- Features RB211 combustion platform
- 25 ppm NOx emissions guarantee



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ATS combustion technology

- Initiated a cooperative program among Solar, Catalytica, and Rolls-Royce Allison to test catalyst durability
 - *Mechanical system evaluation*
 - *Durability at high pressure, high temperature conditions*
 - *Susceptibility to contaminants*
 - Fuel
 - Lubricants
 - Salt (marine environments)
 - Dust and other inlet contaminants



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Allison
VSK-1924

HPT vane improved materials and coatings evaluation



Rolls-Royce

Allison
VSK-1925

HPT vane improved materials and coatings evaluation

Objective

- Demonstrate enhanced durability thermal barrier coatings in industrial engine applications

Approach

- Procure 501-K first stage turbine vanes in an improved material (Mar-M247)
- Conduct cyclic thermal exposure tests of coated coupons to select coating system
- Coat vanes with selected coating system
- Subject coated vane to cyclic testing
- Install and run coated vanes in field engines



Rolls-Royce

Allison
VSK-1926

HPT vane improved materials and coatings evaluation

Benefits

- Enhanced durability of first stage vanes when compared with existing vane alloy/coating system
- Reduced operating expense to end user based upon increased time between overhaul
- Improved performance resulting from higher temperature operation



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HPT vane improved materials and coatings evaluation

Accomplishments

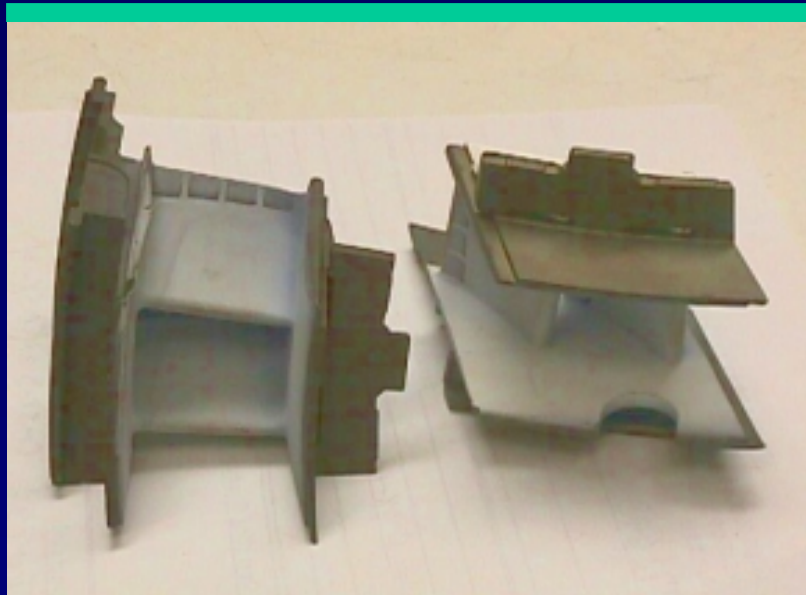
- Coupons have been coated using three candidate thermal barrier coating systems
- Coated coupons are undergoing cyclic thermal exposure testing
- MAR-M247 vanes have been cast and are awaiting machining
- Tooling for coating vanes designed and fabricated



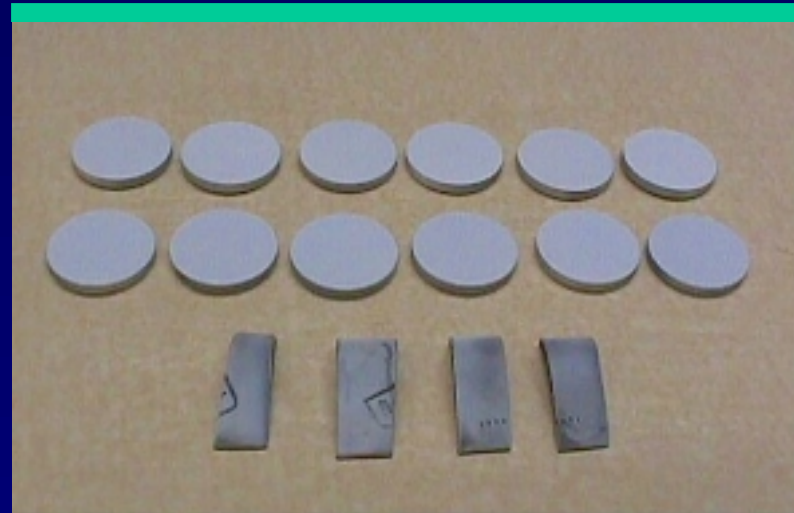
Rolls-Royce

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VSK-1928

HPT vane improved materials and coatings evaluation



Model 501- K Vane Configuration



Coated Specimens



Rolls-Royce

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VSK-1929

HPT vane improved materials and coatings evaluation

Future Activity

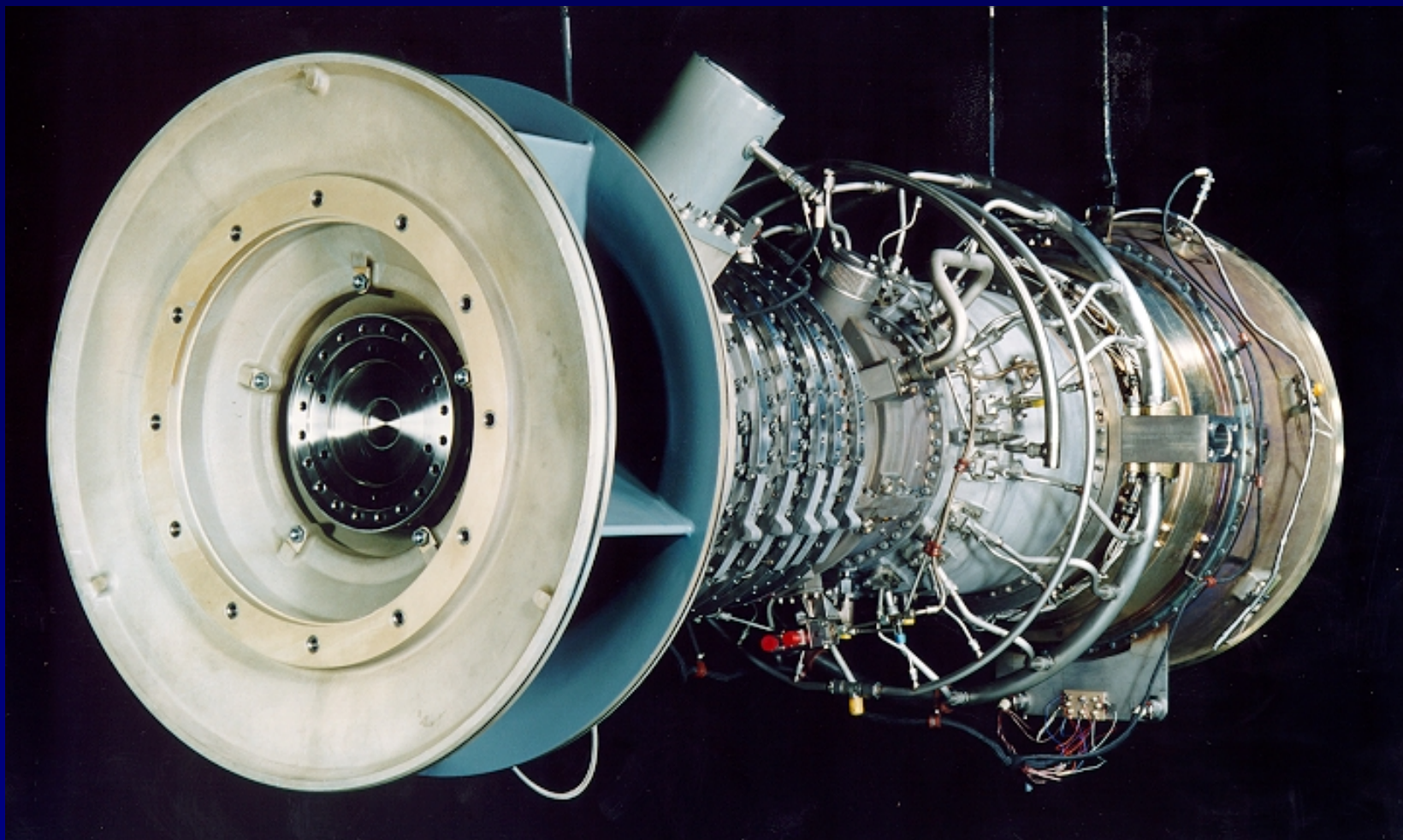
- Finish machine vanes and apply optimized coating system to 501-K first stage vanes for engine installation
- Field test evaluation of coated vanes at specific 501-K user sites
- Apply coating technology to 601-K first stage vanes and demonstrate during 4th Qtr 2000 ATS engine test



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VSK-1930

Mechanical technology improvements



Rolls-Royce

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VSK-1931

Mechanical technology improvements

Approach

- Mechanical technology improvements for 601-K focused on the following areas:
 - *Improved diffuser design*
 - *Super-critical shaft integration*
 - *Center sump bearing simplification*

Benefits

- Eliminates need for inter-shaft bearing and sump arrangement - *reduces engine cost*

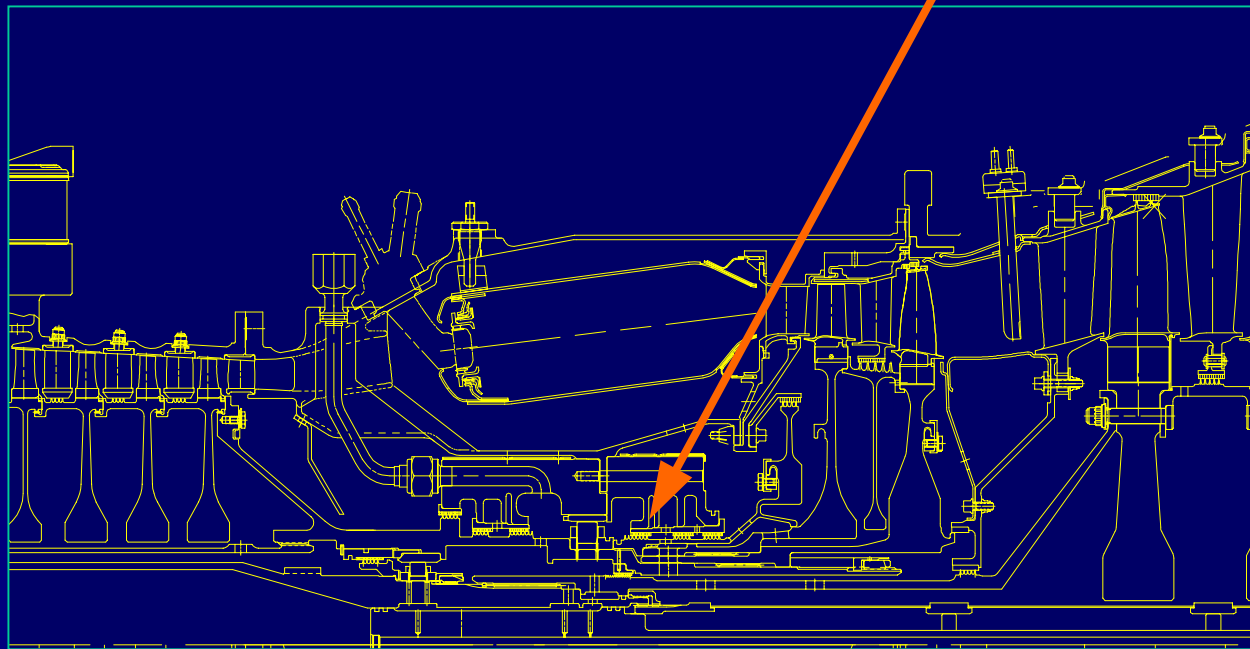
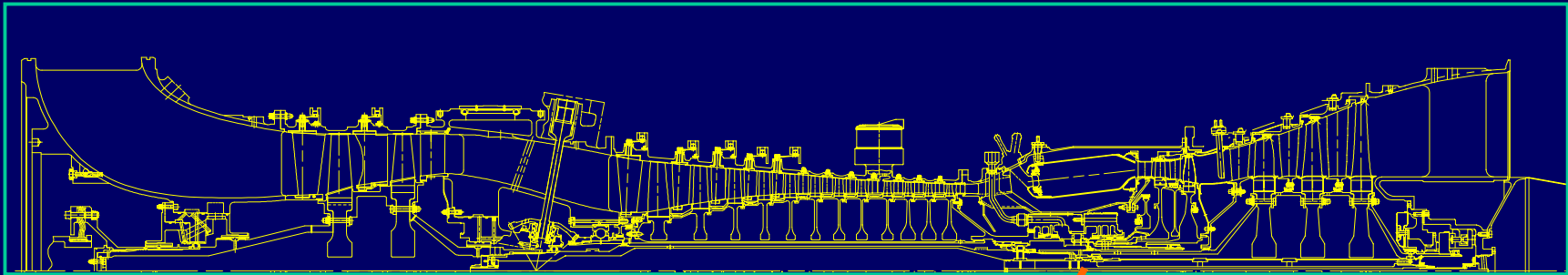


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Mechanical technology improvements

Original shafting and center sump configuration

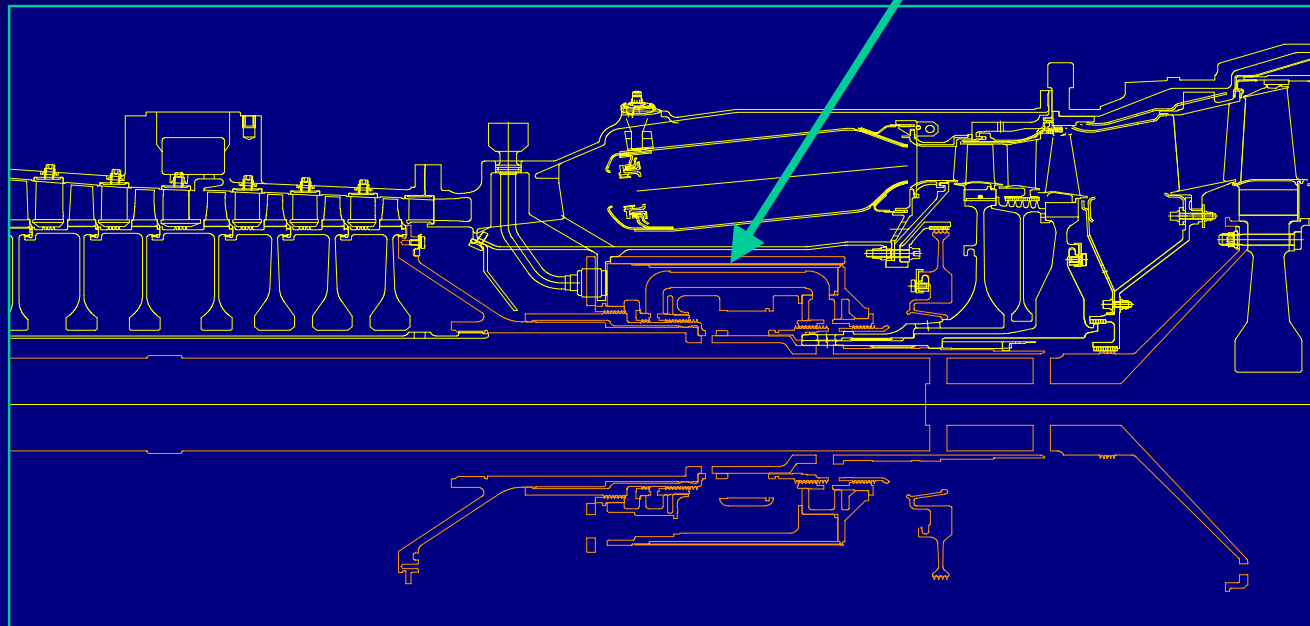
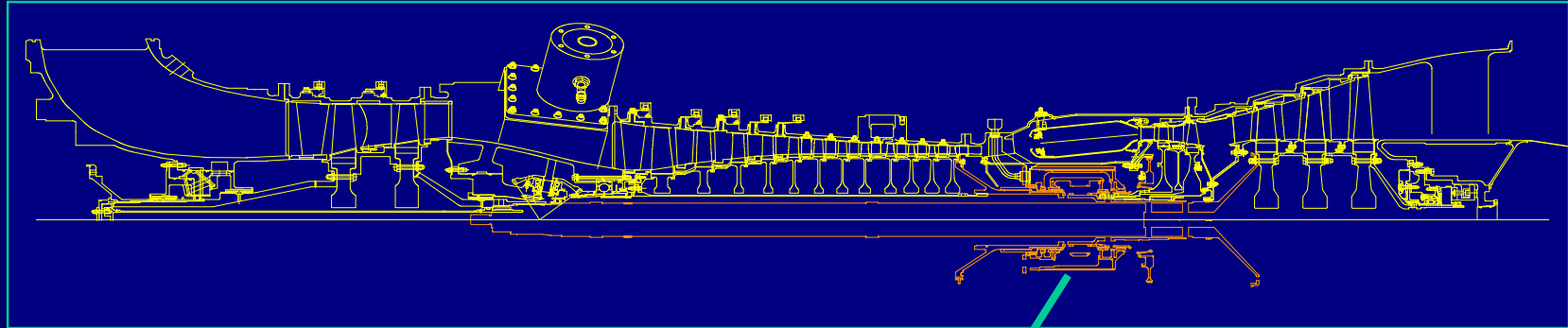


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Mechanical technology improvements

Super-critical shaft with simplified sump arrangement



Rolls-Royce

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VSK-1933

Mechanical technology improvements

Future Activity

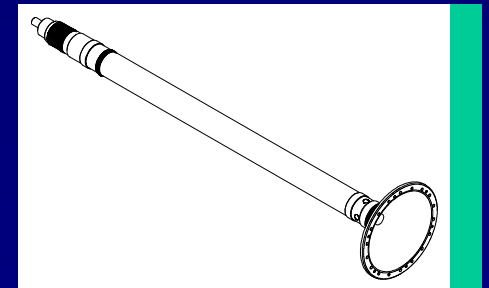
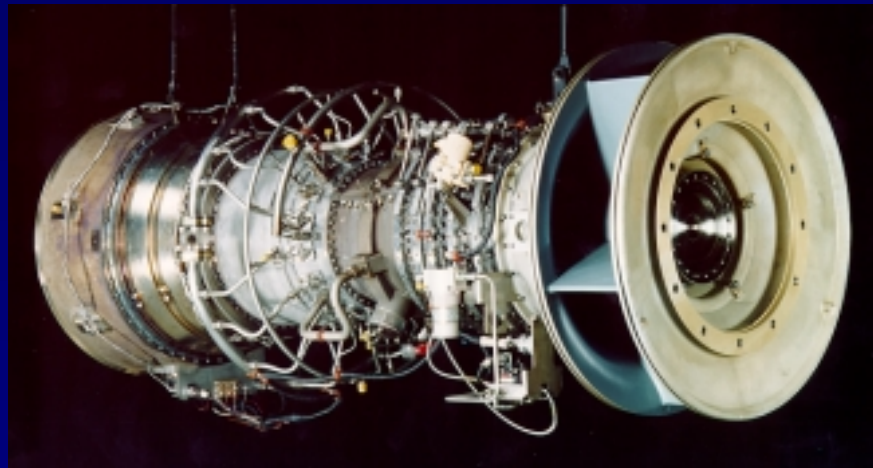
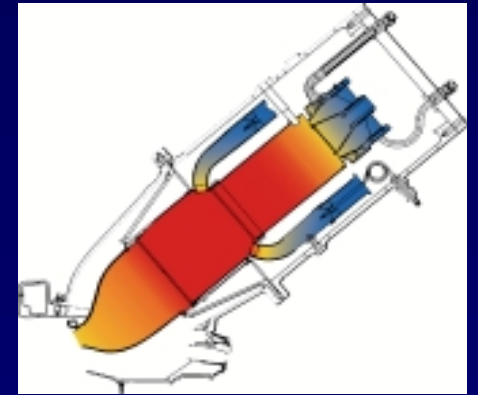
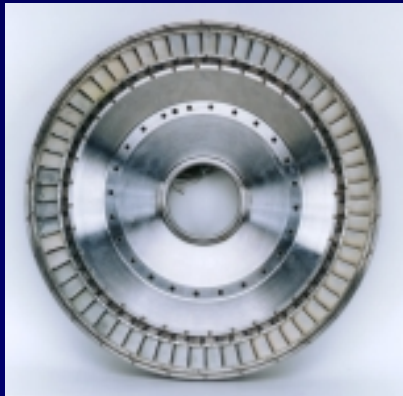
- Complete diffuser, shafting and sump design
- Develop technology under 601-K11 program
- Demonstrate technology enhancement in ATS 601-K9 engine configuration (4th Qtr 2000)



Rolls-Royce

Allison
VSK-1934

ATS technologies



Rolls-Royce

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