Continuous Lower Energy, Emissions and Noise (CLEEN) Technologies Development

Boeing Program Update

Craig Wilsey, Program Manager
CLEEN Consortium Public Session 2012
Boeing CLEEN Program Overview

Low Speed, High RN
QinetiQ 5m WT

CMC Ground Test
Stennis, MS

2010

ATE
WT Test

737 ATE
Flight Demo

CMC
Gnd Test

787 CMC
Flight Demo

Final
Report

2010 2011 2012 2013 2014

Alt Fuels / Aromatics, Seals

Adaptive Trailing Edges

Ceramic Matrix Composite/Ox-Ox
Acoustic Nozzle

Three Technologies / Two Flight Demonstrations

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Three Technologies

- Alternative Fuels – Report Complete, results available, 2013 SOW Added
- Adaptive Trailing Edges – WTT Complete, Flight Test Complete
- Oxide CMC Nozzle – Ground Test Delayed, Flight Test planned for 2013

Two Flight Test Demonstration Programs

- 2012: 737-800 in partnership with AAL – Complete
- 2013: 787-8 from Boeing’s Flight Test Fleet – Airplane/Engines Identified

Developing and working plans for transitioning technologies to Boeing products

CLEEN is foundational element & enabler for ecoDemonstrator
CMC Nozzle Development

Mitch Petervary, Principal Investigator
CLEEN Consortium Public Session 2012
Objective: Develop and demonstrate an acoustic ceramic matrix composite exhaust nozzle to TRL 7 through a building block approach

- Key Milestones/Events
  - TRL 5: Subcomponent fabrication & test
  - TRL 6: Full-scale engine ground test
  - TRL 7: Full-scale flight test

- Baseline material: 2D N610/AS oxide CMC
- Supplier partners: ATK/COIC and AEC
- Baseline demonstration engine: Rolls Royce Trent 1000
- Potential transition: new Boeing products & derivatives

Enable the packaging of quieter, hotter, more efficient engines
Oxide CMC Nozzle Accomplishments & Plans

2010
- Ground Test
- Nozzle PDR

2011
- Subcomponent Fabrication
- Cylinder Thermal Test
- Centerbody Subcomponent Dynamic Test
- Ground Test Article CDR

2012
- GTD Assembly & Instrumentation
- Ground Test in Stand
- Flight Test Prototype CDR

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Sectioned CMC Exhaust System Components

- Nozzle Interface
- Tail Bearing Housing (TBH)
- Core Flow
- CMC Acoustic Sandwich
- Centerbody Interface
- Ti Aft Cap
- Centerbody
- Ti Nozzle Fairing
- Fan Flow

Courtesy of Rolls Royce

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Ground Test Demonstrator CMC Builds

The largest oxide CMC parts ever made

Courtesy of ATK/COIC

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Completed Instrumented Oxide CMC Exhaust
Completed Installation Simulation
Ground Test Objectives

• Verify structural integrity under enveloping steady-state & transient loads
• Validate/correlate temperature predictions
• Demonstrate installation on Trent 1000 engine
• Accumulate minimum engine run time & cycles to qualify for flight test
Oxide CMC Nozzle Development Progress

✓ Coupon, Joint & Acoustic Element Tests
✓ Preliminary Design Complete 4Q2010
✓ TRL 5 Subcomponent Test 2Q2011
✓ Detailed Design Complete 2Q2011
✓ Successful Ground Test build
  • TRL 6 Ground Test 4Q2012
  • TRL 7 Flight Test 4Q2013
Adaptive Trailing Edges Development

Rene Hyymen, Integrated Product Team Leader
Tad Calkins, Principal Investigator
CLEEN Consortium Public Session 2012
Objective:

- Develop and validate an adaptive trailing edge system capable of tailoring wing performance to reduce noise and fuel burn at different flight regimes

Work Statement:

- Evaluate airplane performance improvements through the use of ATE devices
- Develop actuation systems for ATEs
- Demonstrate actuation and control system through flight test program.

Potential Transition: New and Derivative Airplanes
ATE Development Timeline

2010

- Actuation Trade study, Technology Survey, CFD Analysis
- Flight Test Configuration Downselect

2011

- Actuation Component Test
- Low Speed WT Test
- PDR
- Detail Design

2012

- Actuation System prototype
- CDR
- Actuation system testing
- Ground Test
- Flight Test

Fabrication

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Adaptive Trailing Edge Flight Test Overview

Flight Test Summary

- 10 Flight Test days in Glasgow, MT
- 28 August – 6 September 2012
- 51.5 Hours of flight test time
- 6 airplane configurations
- Measurements included airplane performance, flow visualization, community noise, and mini-flap control system parameters
6 Airplane Configurations

- Mini plain flap outboard wing
  
  \[ +\delta_{MPF} \]
  
  Actuated MPF

- Mini split flap outboard wing
  
  \[ +\delta_{MSF} \]
  
  Actuated MSF

- Inboard/Outboard Flap Single
  Slotted flap with simulated Mini split flap wedge

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IB/OB Single Slotted Flap and Simulated Split Flap Wedge

Flight Test data correlates well with predictions & wind tunnel performance and noise data
Instrumentation

Airplane instrumentation
• Pressure belts
• Accelerometers
• Thermocouples
• Strain Gages
• Kulites
• Flow Cones

Ground instrumentation
• Community noise microphones
• Phased Array Microphones

Installation
Controllable Mini Plain Flap

Mini Plain Flap
Deflects from 30 degrees
up to 60 degrees down
Results

- Gained experience Integrating actuation components into the wing trailing edge
- Successfully tested all planned conditions and configurations
  - Generated aerodynamics and loads data on high and low speed flight conditions
  - Generated community noise take off and approach data using certification microphones and phased array
  - Demonstrated Mini-Flap configurations at low and high speed conditions
  - Tested single slotted flap and simulated mini-split-flap at low speed
  - Demonstrated operational mission profile for short haul aircraft
ATE Development Progress

- Technology Survey Complete
- CFD / Benefits Analysis completed
- Actuation Trade Studies complete
- Low speed wind tunnel test completed
- Flight Test configurations identified
- Preliminary Design complete
- Actuator Prototype Testing Complete 4Q2011
- Detailed design complete/ CDR 1Q2012
- System Integration Testing Complete 2Q2012
- Ground / Flight Test 3Q2012
  - Flight Test Report 4Q2012
  - Benefits assessment and Final Report 2Q2013
ATE Flight Test Team
ecoDemonstrator Program
Motivation: Need to Accelerate Technology Maturation

- TRL 6 needed for “Technology Readiness”
- Technology selection occurs 3 to 6 years prior to Entry Into Service (EIS)

The Challenge: How toaccelerate technology maturation?
Experience: Demonstrators Accelerate Implementation

Quiet Technology Demonstrator 2 (QTD2) conducted in 2005

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Accelerate Technology

**ecoDemonstrator Program**

**Goals**

Accelerate technology for more fuel efficient, cleaner, quieter, advanced materials

Faster innovation to application-ready technologies

Work together, industry, suppliers and government

Learn prior to critical path

Build, integrate, fly (annually)

Federal Aviation Administration
Continuous Lower Energy and Emissions and Noise
FAA CLEEN

Potential collaborations

NASA Environmentally Responsible Aviation

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**2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **20XX**
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737 Platform

787 Platform

Advanced wing

Optimized integration

Hybrid power

**CLEEN is foundational element & enabler of Boeing ecoDemonstrator strategy**

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2012 ecoDemonstrator

Adaptive trailing edges (FAA CLEEN)

Advanced ATM
- Flight trajectory optimization and information management
- Onboard network systems
- Optimum Flight

Regenerative fuel cell with IHI

Active engine vibration reduction (EVRN-AVC)

Variable area fan nozzle

Legend
- Fuel burn
- Noise reduction
- Operational efficiency
2012 ecoDemonstrator
Additional Technologies

- RFID Emergency Equipment Demo
- Insulated Galley Cart
- Recyclable Carpet
2012 Flight Demonstration Milestones

- **Flight Simulator sessions begin**
- **Install technologies 7/9**
- **Airplane enters factory 6/7**
- **Flight testing in Glasgow 8/18**
- **AIA National Aerospace week 9/18**
- **Flight Test Boeing Field 10/2**
- **Airplane delivered to American**

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Program Keys to Success

One Boeing Team = Best of Boeing

- Top engineers from across Boeing (Boeing Research & Technology, Boeing Commercial Airplanes, Boeing Test and Evaluation, Boeing Defense and Security)
- Creative and energized team
- Flexible program leadership

Rapid technology implementation for flight test = new paradigm for technology maturation

- Dynamic and flexible flight test planning and execution enabled efficient flight test
- Aggressive Design-Build schedule to meet fixed flight test date
- New technology demonstration process validated by ATE flight test success

Great Partnerships & Collaborations
Thank you