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

Boeing Program Update

CLEEN Consortium Public Session
November 2, 2011

Boeing is committed to action on carbon neutral growth in its commercial products

enviro,aero

Aviation Industry Commitment to Action on Climate Change

As leaders of the aviation industry, we recognise our environmental responsibilities and agree on the need to:

- build on the strong track record of technological progress and innovation that has made our industry the safest and most efficient transport mode; and
- accelerate action to mitigate our environmental impact, especially in respect to climate change while preserving our driving role in the sustainable development of our global society.

Therefore, we, the undersigned aviation industry companies and organisations declare that we are committed to a pathway to carbon-neutral growth and aspire to a carbon-free future.

To this end, in line with the four-pillar strategy unanimously endorsed at the 2007 ICAO Assembly, we will:

1. push forward the development and implementation of new technologies, including cleaner fuels;
2. further optimise the fuel efficiency of our fleet and the way we fly aircraft and manage ground operations;
3. improve air routes, air traffic management and airport infrastructure; and
4. implement positive economic instruments to achieve greenhouse gas reductions wherever they are cost-effective.

We urge all governments to participate in these efforts by:

1. supporting and co-financing appropriate research and development in the pursuit of greener technological breakthroughs;
2. taking urgent measures to improve airspace design including civil/military allocation, air traffic management infrastructure and procedures for approving needed airport development; and
3. developing and implementing a global, equitable and stable emissions management framework for aviation through ICAO, in line with the United Nations roadmap agreed in Bali in December 2007.

Our efforts and commitment to work in partnership with governments, other industries and representatives of civil society will provide meaningful benefits on tackling climate change and other environmental challenges.

We strongly encourage others to join us in this endeavour.

Robert J. Aaronson, Director General — James C. Cherry, Chairman — ICAO — Alexander de Juniac, Secretary General — Ashley Smout, Chairman — IATA — Giovanni Bisignani, Director General & CEO — Fernando Pinto, Chairman — Marice C. Blakey, Chair — Takayuki Hosoya, Vice-Chair — AIRBUS — Thomas Enders, President & CEO — BOEING — Scott Carson, President & CEO — BOMBARDIER — Steve Rudd, President Regional Aircraft — CFM — Eric Bachelet, CEO — EMBRAER — Frederico Fleury Curado, President & CEO — GE Aviation — Scott C. Donnelly, President & CEO GE Aviation — Pratt & Whitney — Stephen Finger, President — Rolls-Royce — Mark King, President Civil Aerospace — ATA — Philippe Rochat, Executive Director

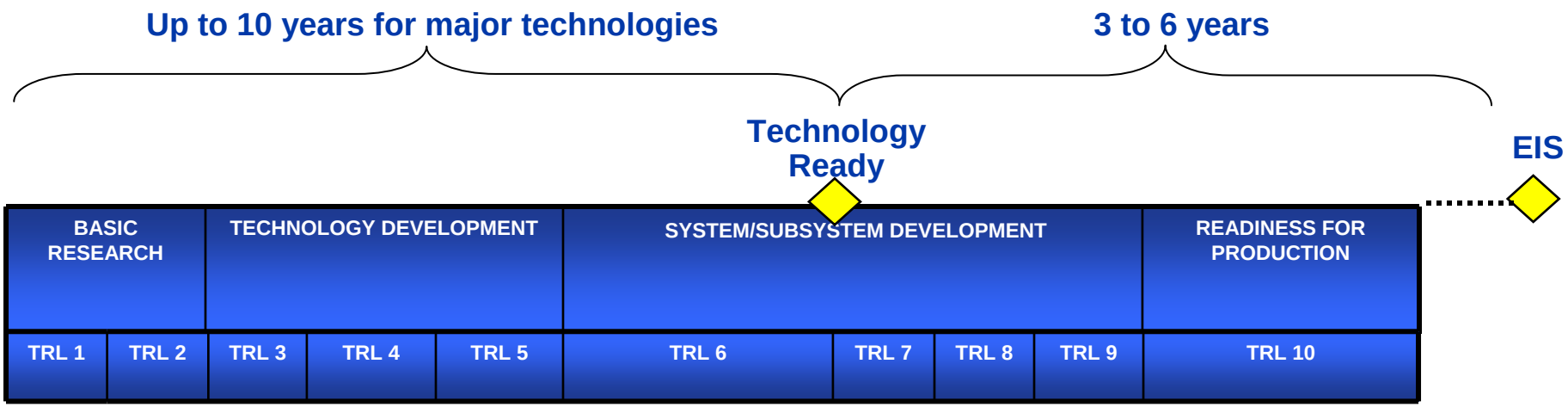
1st Aviation & Environment Summit, 22nd April 2008, Geneva, Switzerland

"…we are committed to a pathway to carbon-neutral growth and aspire to a carbon-free future."

– ATAG 2008 industry declaration for action on climate change

Technology Maturity Levels
Timeline to airplane incorporation

- **Maturity measured on the NASA Technology Readiness Levels (TRL)**
- **TRL 6 “Technology Ready” necessary for product application consideration**
- **Technology selection for new products typically occurs 3 - 6 years prior to airplane Entry Into Service (EIS)**



Demonstrators help accelerate technology maturity

Noise reducing chevrons were developed during the Quiet Technology Demonstrator Program

Boeing CLEEN Program

Major Program Elements

Low Speed, High RN
QinetiQ 5m WT

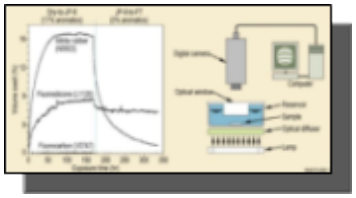
CMC Ground Test
RR Derby, UK

737-800 w/ ATE

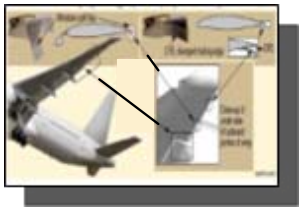
787-8 w/ CMC

ATP — 2010
ATE WT Test — 2011
CMC Ground Test — 2012
Flight Demo 1 — 2012
Flight Demo 2 — 2013
Final Report — 2014

Technologies



Alt Fuels / Aromatics, Seals



Adaptive Trailing Edges

Ceramic Matrix Composite/Ox-Ox Acoustic Nozzle

Legend
Fuel Burn
Noise Reduction
Alt Fuel Transition

Volume Swell of Alternative Fuels

Objective:

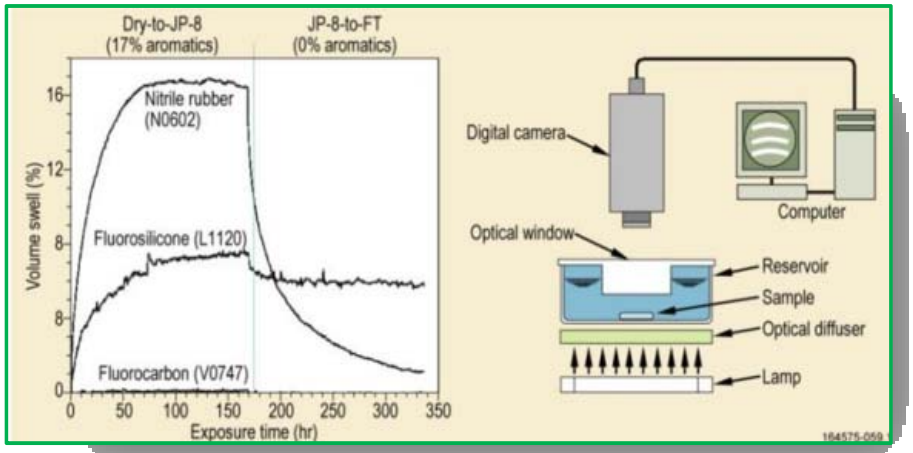
Generate data to help industry:

- **Understand effects of aromatic compounds on fuel system polymeric materials**
- **Evaluate which aromatics we'd prefer to see produced from future processes**

Work Statement:

- **Measure composition of fuel absorbed by materials for a variety of fuels/blends**
- **Establish statistical bounds for behavior of typical fuel system material**
- **Conduct volume swell tests for common components such as O-rings, sealants, and coatings**
- **Provide a basis for risk identification and mitigation**

Potential Transition: Aviation Fleet



Volume swell for given exposure time of different materials shown in the left panel. Optical dilatometry system used to measure the swell is shown in the right panel.

Benefits:

- **Future alternative fuels approved for commercial flight for blends beyond 50%.**
- **Reduced dependence on petroleum**
- **Reduced total CO2 footprint**

Alternative Fuels Summary

- ✓ Sample Selection
- ✓ Volume Swell Analysis of Reference Fuels
- ✓ Analysis of Absorbed Fuel
- ✓ Volume Swell of 50% Blends
- ✓ SPK Blended with Aromatics
- ✓ Presentation of Findings at CRC Meeting
  - May 2-5, Seattle, WA
- ✓ Final Report Released
  - Available via FAA CLEEN Public Sharepoint

Acknowledgements: CRC Paper and Final Report

"Evaluating the Impact of SPK Fuels and Fuel Blends on Non-metallic Materials used in Commercial Aircraft Fuel Systems"

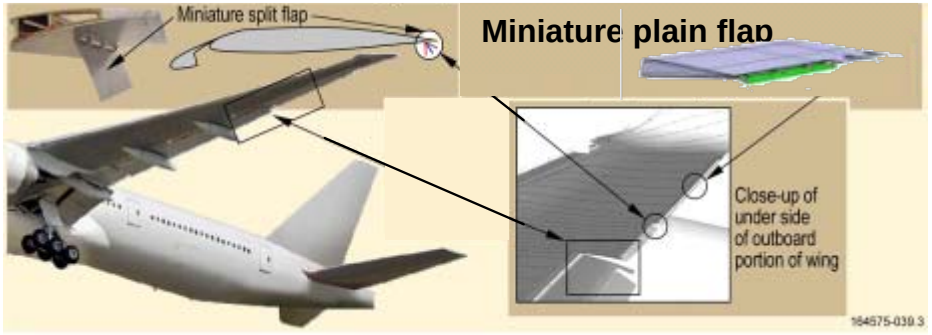
John L. Graham
University of Dayton Research Institute

Timothy F. Rahmes, Mark C. Kay, Jean-Philippe Belieres, James D. Kinder, Steven A. Millett, Jean Ray, William L. Vannice
The Boeing Company

Adaptive Trailing Edges

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.**

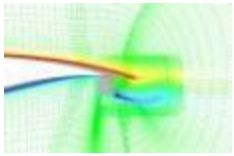
Potential Transition: New and Derivative Airplanes

ATE Accomplishments & Plans

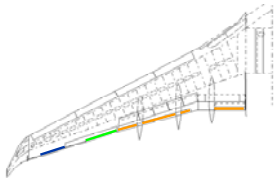
2010: O N D

2011: J F M A M J J A S O N D

Actuation Trade study, Technology Survey, CFD Analysis



Flight Test Configuration Downselect



Actuation Component Test

Low Speed WT Test

PDR

Actuation System prototype

2012: J F M A M J J A S O N D

CDR

Actuation system testing

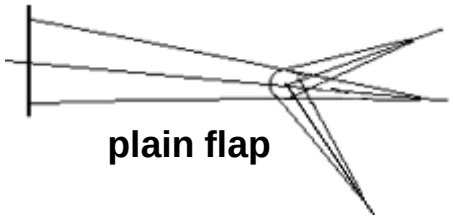
Ground Test

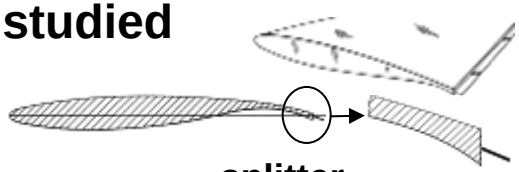
Flight Test

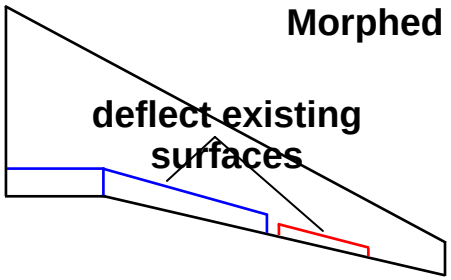
737-800

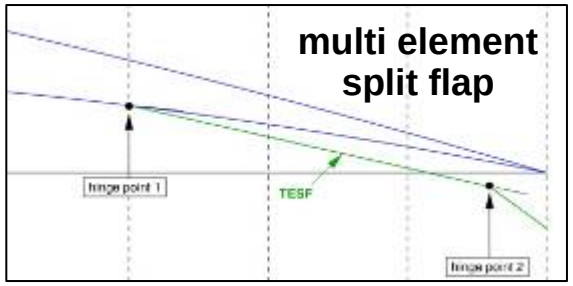
Technology Survey: *Motivation*

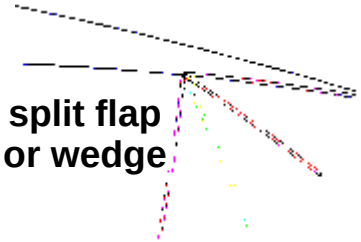
- Geometry changes over the last 5% of chord can be a simple and powerful way to realize significant aerodynamic improvement
  - Many trailing edge concepts have been studied

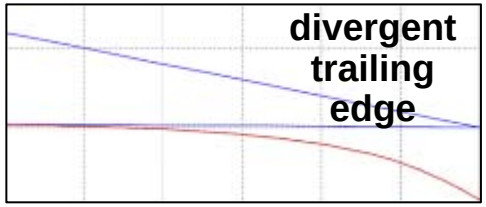


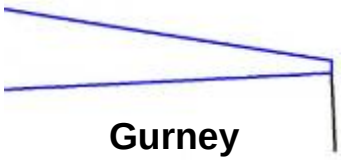


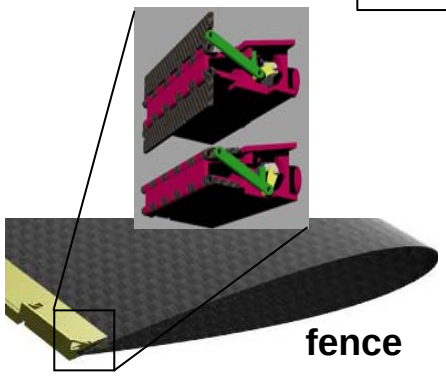


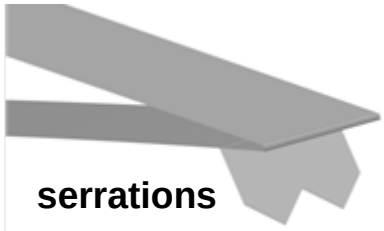






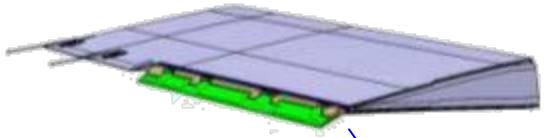


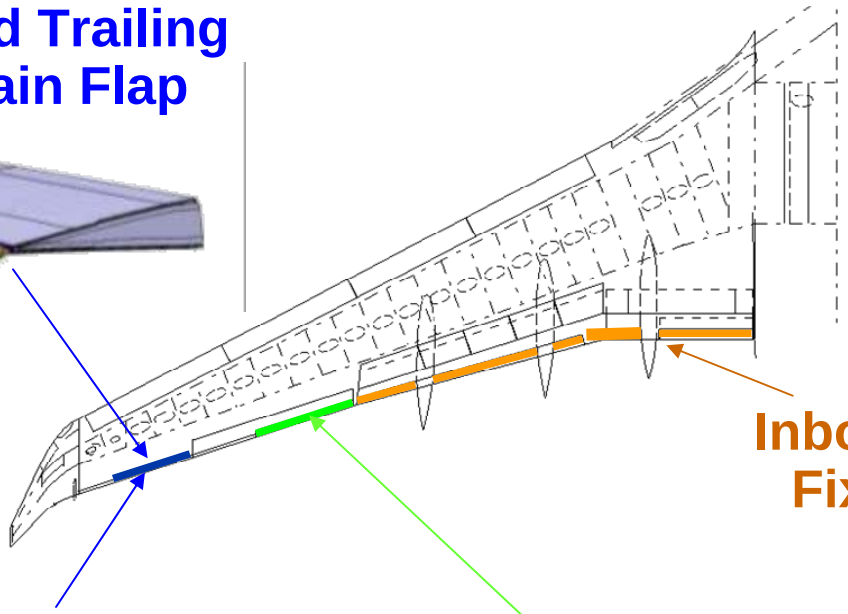




Flight Test Configurations Selected

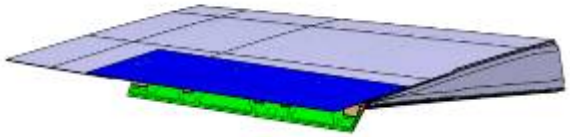
Outboard Fixed Trailing Edge Mini Plain Flap



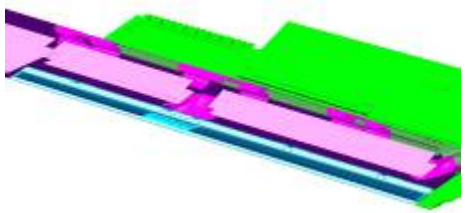


Inboard, Outboard Flap Fixed Mini Split Flap

Outboard Fixed Trailing Edge Mini Split Flap



Drooped Aileron Tab

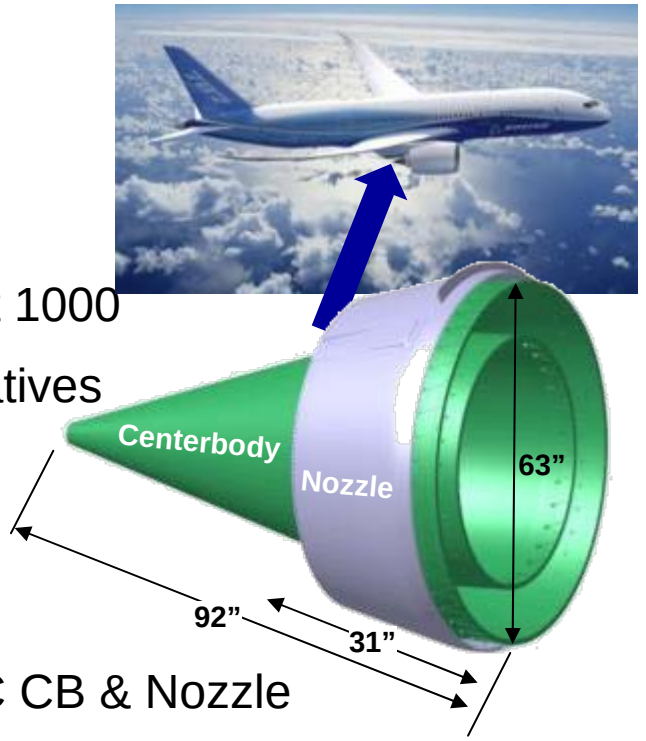


ATE Development Progress

- ✓ 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

Oxide CMC Exhaust Nozzle

Objective: Develop and demonstrate an acoustic ceramic matrix composite exhaust nozzle to TRL 7 through a building block approach

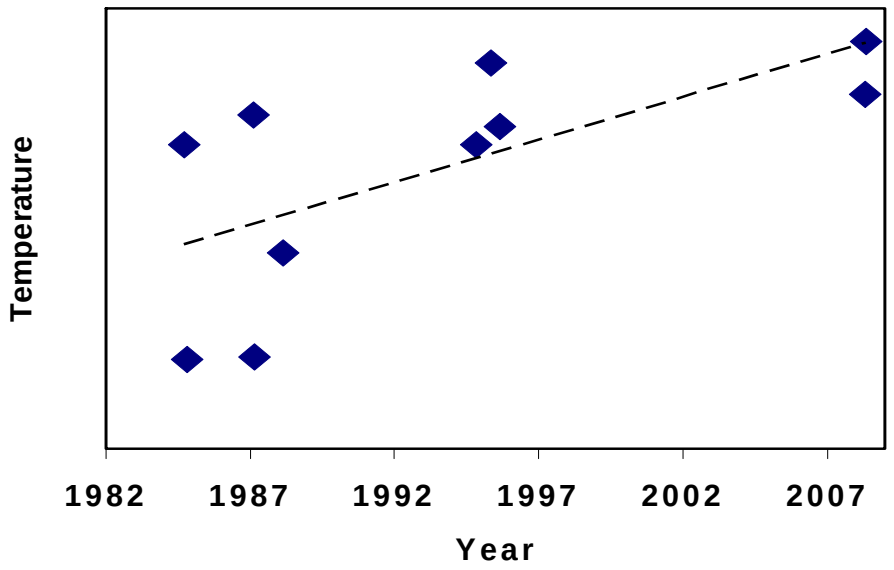


- **Baseline Material:** 2D N610/AS Oxide CMC
- **Supplier Partners ATK/COIC and AEC**
- **Baseline Demonstration Engine:** Rolls Royce Trent 1000
- **Potential Transition:** New Boeing Products & Derivatives

- **Key Milestones/Events**
  - TRL 5: Subcomponent fabrication & test
  - TRL 6: Full-scale engine ground test of oxide CMC CB & Nozzle
  - TRL 7: Flight test of full-scale oxide CMC CB & Nozzle

CMC Technology Need

- **Platforms challenged by hotter engines & tighter noise restrictions**
  - Impact to exhaust & nacelle packaging (propulsion integration)
  - SOA titanium exhausts at performance limits
  - Superalloy alternatives add weight
- **CMC improvements relative to SOA**
  - Material thermal margin
  - Component weight savings
  - Acoustic attenuation
  - Life



CMCs may enable hotter more efficient engines

Oxide CMC Nozzle Accomplishments & Plans

2010: O N D

2011: J F M A M J J A S O N D

GTD Nozzle PDR

Subcomponent Fabrication

Cylinder Thermal Test

Subcomponent Dynamic Test

Ground Test Article CDR

Nozzle Development Unit Fabrication

Ground Test Article Fabrication

2012: J F M A M J J A S O N D

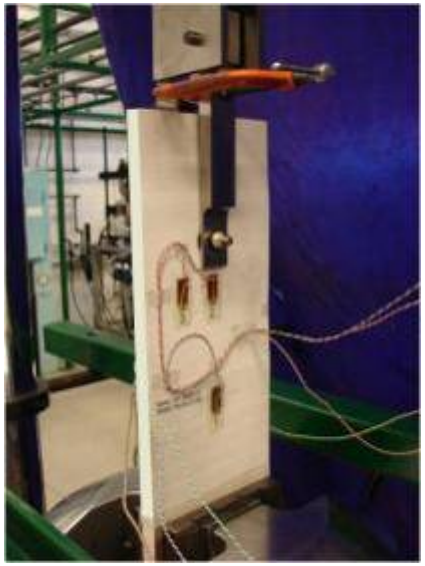
GTD Instrumentation &Test Integration

GTD Test in Stand

Flight Test Prototype CDR

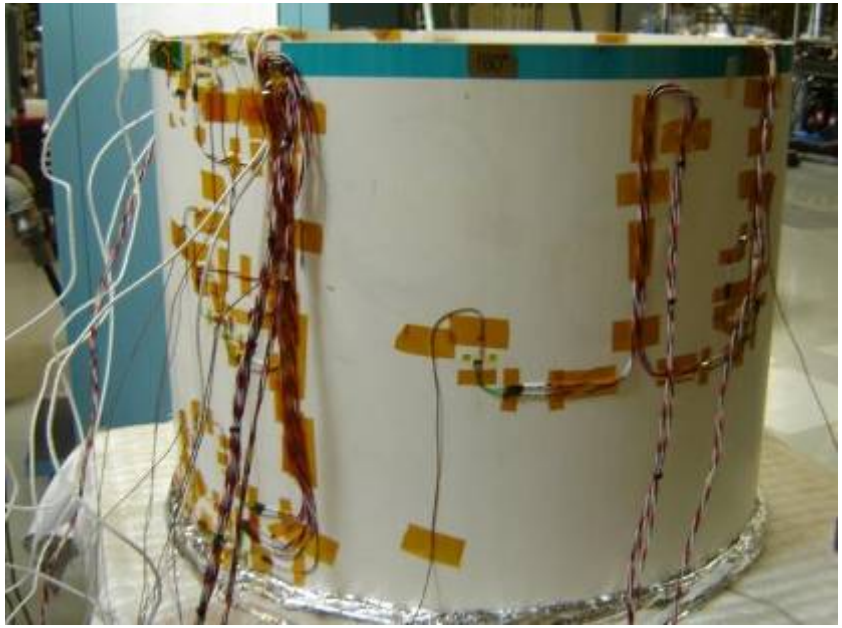
FWD Joint Testing

- Static Testing
  - RT and 1000°F
  - Demonstrates 2xUlt
- Fatigue
  - 220,000 cycles
  - 1000°F
  - residual strength > 2xUlt



Sandwich Cylinder Subelement Thermal Test

- 24” dia. x 24” tall
- Early producibility demo
- Subjected to thermostructural gradients
- Exceeds ultimate conditions, even with induced damage



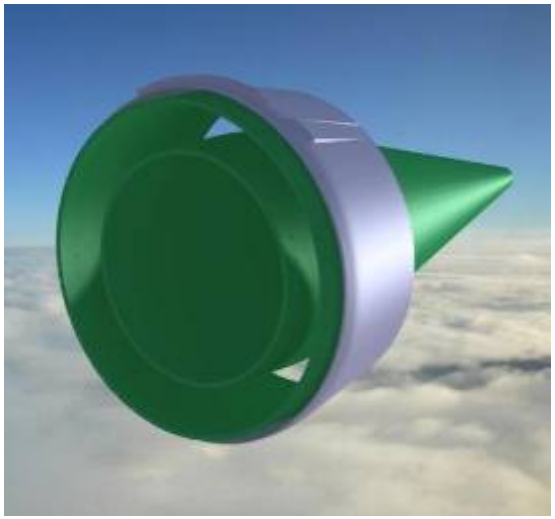
CMC Centerbody Subcomponent Test

- Dynamic testing via shaker table
- Survives > 10,000 hrs equivalent service
- Passes 2 FBO shock load events followed by wind milling

CMC Nozzle Engineering Development Unit

Oxide CMC Nozzle Development Progress

- ✓ **Successful Joint & Acoustic Element Tests**
- ✓ **Preliminary Design Complete 4Q2010**
- ✓ **TRL 5 Subcomponent Test 2Q2011**
- ✓ **Detailed Design Complete 2Q2011**
- **TRL 6 Ground Test 2Q2012**
- **TRL 7 Flight Test 3Q2013**



BOEING ATK ALBANY Engineered Composites

ecoDemonstrator

ecoDemonstrator Strategy

Vision: Accelerate technology maturation / Build & integrate more rapidly

Model:

- Implement "continuum" of demonstrations to reduce risk, accelerate transition
- Leverage synergies with Government programs, industry partners, suppliers and internally funded development

ecoDemonstrator will leverage CLEEN airplanes & instrumentation in 2012 and 2013

- Additional technologies will be demonstrated concurrently with CLEEN
- Each technology brings its own funding, and pays for instrumentation or dedicated flight hours specific to its needs

CLEEN is the foundational element & enabler of Boeing's ecoDemonstrator strategy

ecoDemonstrator – Paris Air Show

Engineering, Operations & Technology

News Release

Boeing Commercial Airplanes
P.O. Box 3707 MC 21-70
Seattle, WA 98124-2207
www.boeing.com

Boeing and American Airlines to Accelerate Quieter, Cleaner Aviation Technologies
-Leading global carrier to be the customer for first ecoDemonstrator
-Advanced noise and fuel

LE BOURGET, France, June 22, 2011 – Reducing fuel consumption, carbon emissions and community noise are the focus as Boeing [NYSE: BA] and American Airlines [NYSE: AMR] announced that the airline will be the launch customer for the evolutionary ecoDemonstrator Program. A Boeing Next-Generation 737-800 aircraft will be used to flight test and accelerate the market readiness of emerging technologies

"We are proud to have American Airlines as our launch partner for this new generation of technology that can bolster aviation's role as the most efficient means of global transportation," said Boeing Vice President of Environment and Aviation Policy Billy Glover. "There's no better way to prepare advanced technologies for market entry than flying them and no better choice than the best selling single-aisle airplane of all time -- the Boeing Next-Generation 737."

"American Airlines recognizes our responsibility to minimize our impact on the environment as much as possible, and we look for every opportunity to do so," said Captain John Hale, American's vice president – Flight. "Our partnership with Boeing allows us to make significant strides in putting more fuel-efficient planes in the air, which is the most effective way to reduce our carbon footprint. We remain committed to identifying and implementing new technologies and programs that further our environmental performance"…

2012 ecoDemonstrator – 737NG Test Platform

Quieter, cleaner, more fuel efficient, environmentally progressive solutions

Foundational FAA CLEEN Contract

Boeing/Supplier Collaboration

Adaptive Trailing Edges

Variable Area Fan Nozzle

Regenerative Fuel Cells

Alternative Fuels – Seals

Flight Trajectory Optimization

Legend

Airplane Fuel Efficiency
Noise Reduction
Operational Efficiency
Airplane Applicability

Other technologies
(tbd)

Program Milestones

Boeing Announces ecoDemonstrator

Begin Detailed FT Planning

Final FT Plan Approved

Test Articles At Test Site

Flight Test 8/12 to 9/12

2010 | **2011** | **2012**

Paris Airshow Boeing/AAL ecoDemonstrator Partnership Announcement

Boeing CLEEN Program Summary

Three Technologies

- ✓ *Alternative Fuels – Report Complete, results available*
- *Adaptive Trailing Edges – WTT Complete, Flight Test in 2012*
- *Oxide CMC Nozzle – Ground Test in 2012, Flight Test in 2013*

Two Flight Test Demonstration Programs

- *2012: 737-800 in partnership with AAL*
- *2013: 787-8 from Boeing's Flight Test Fleet*

Developing and working plans for transitioning technologies to Boeing products

Creating leverage for ecoDemonstrator and other technology collaborations