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

Boeing Program Overview

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CLEEN Consortium Public Session

October 27, 2010

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

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.

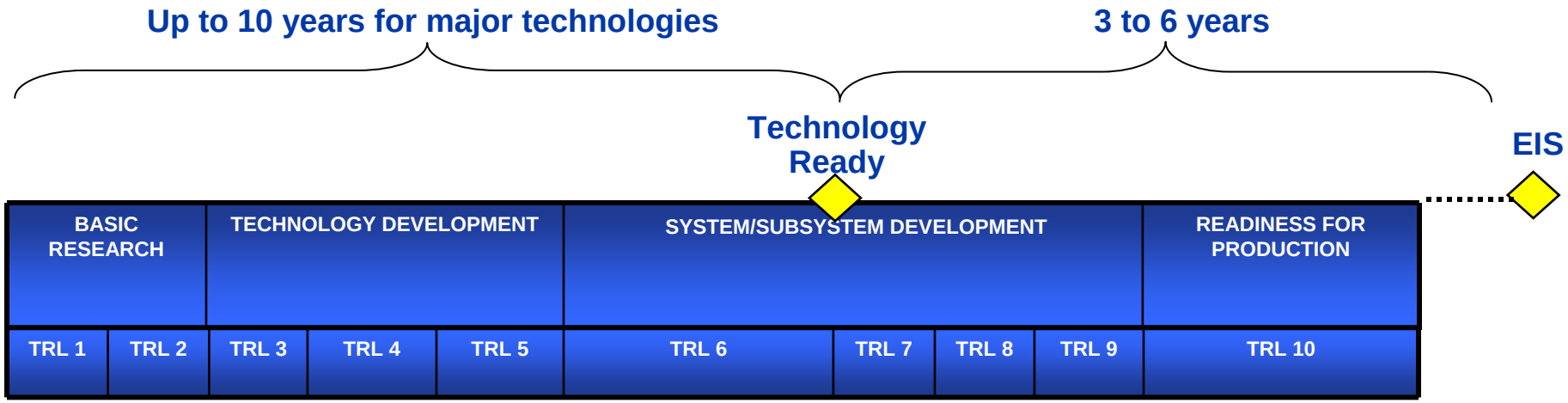
IATA · AIRBUS · BOEING · BOMBARDIER · EMBRAER · Rolls-Royce · Pratt & Whitney

"…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's CLEEN Program

Three Technologies:

- ***Alternative Fuels: Aromatics, Seals***
- ***Adaptive Trailing Edges***
- ***Ceramic Matrix Composite Nozzle***

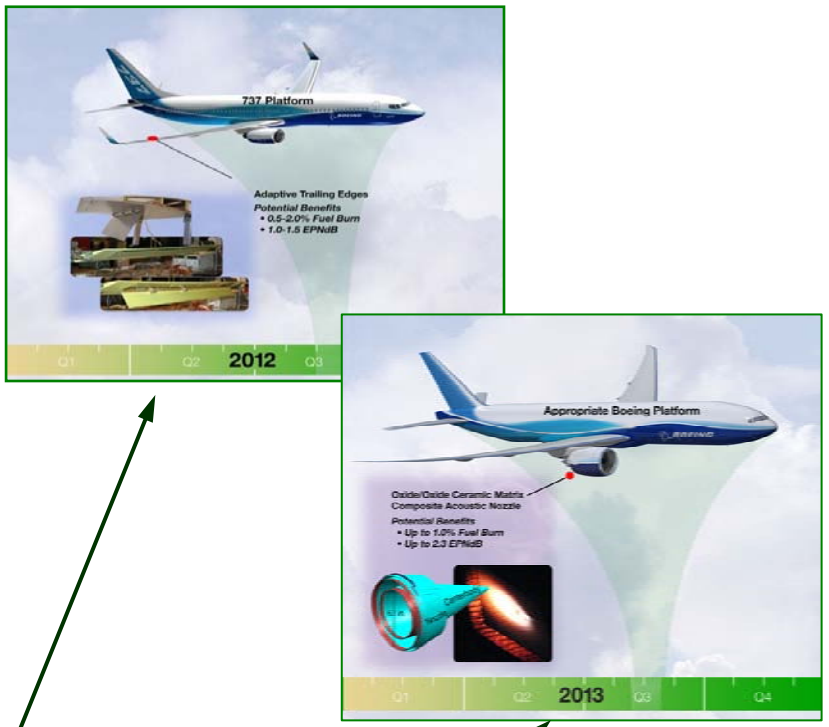
One Ground test

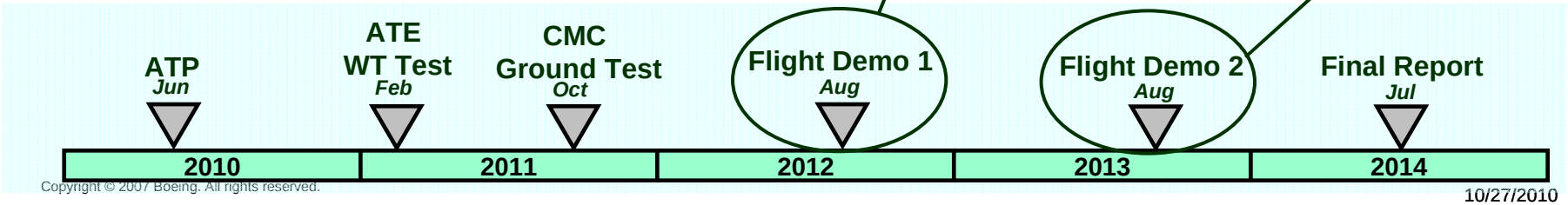
2011: Trent1000 (CMC)

Two Flight Demonstrations:

2012: 737-800 (ATE)

2013: 787-8 (CMC)





ecoDemonstrator

- **CLEEN is also the foundational element/enabler of the Boeing ecoDemonstrator strategy for [airframe] technology demonstration strategy.**
- **Vision:**
  - **Accelerate technology maturation**
  - **Build & integrate more rapidly**
- **Model:**
  - **A continuum of technology demonstrations**
  - **Working together: industry, suppliers and government**

Airplane Sourcing for 2012

- **Opportunity for the partner airline**
  - **Airline opportunity to demonstrate environmental commitment through highly visible flight test program**
  - **Airline contribution is generally by allowing use of airplane prior to delivery**
- **Requirements**
  - **737-800 in 3Q2012**
  - **Expected duration of use ~2.5 months**

- **Approach**
  - **Airplane will be modified, flight tested and returned to delivery condition by Boeing**
  - **Test parts and flight test instrumentation will be installed and removed**
  - **Modifications to the airplane will be returned to certified condition using Boeing approved repair procedures**

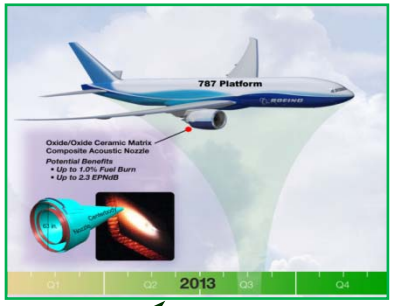
Technology Tests / Demonstrations

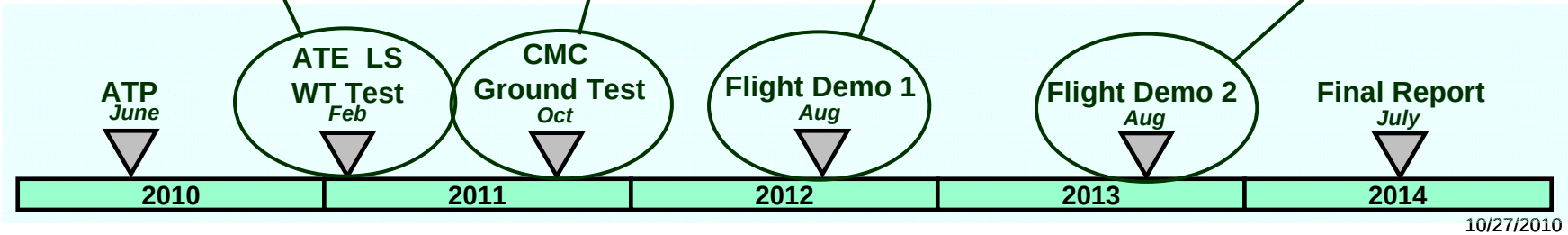
Low Speed, High RN
QinetiQ 5m tunnel
1Q11

CMC Ground Test
Under wing -or- Stand
Oct/Nov 2011

737-800 w/ ATE
Aug/Sept 2012

787-8 w/ CMC
Aug/Sept 2013





10/27/2010

Alternative Fuels - Objective

Objective:

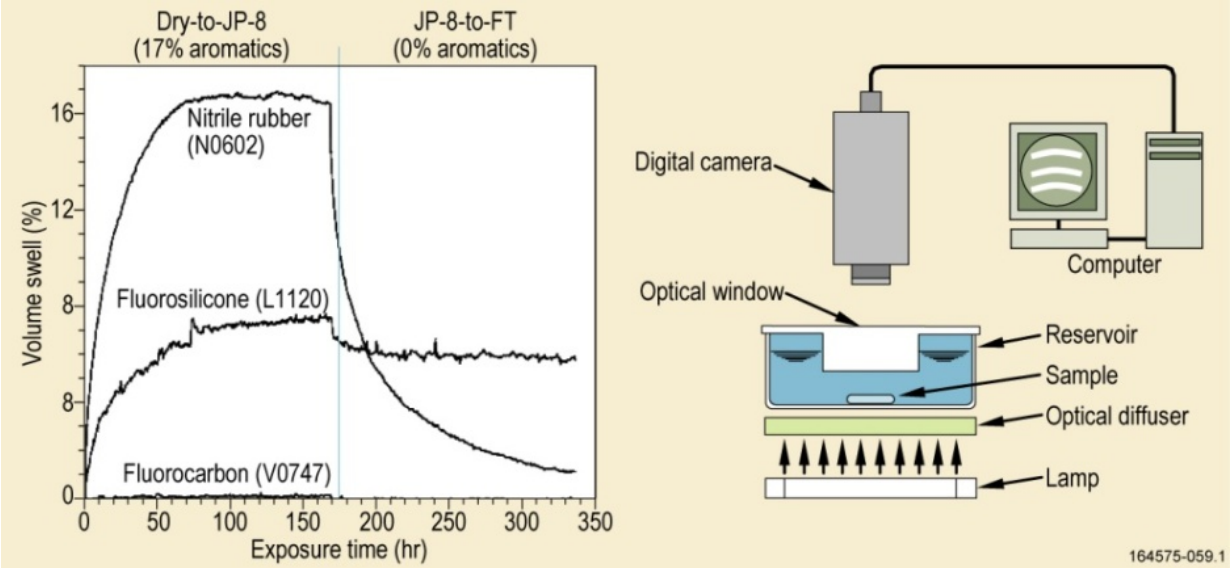
Reduce overall CO2 footprint, and reduce dependence on petroleum, by maturing technology to allow alternative fuel use for commercial flights with fuels with a greater than 50% blend.

Work Statement:

- **Assess the compatibility of synthetic paraffinic kerosene (SPK) fuels with non-metallic materials used in commercial aircraft fuel systems**
- **Assess effect of the type and concentration of the aromatic compounds on material properties (e.g. seal swell)**
- **Generate data to help industry determine:**
  - **Effects of aromatic compounds on fuel system polymeric materials**
  - **Evaluate which aromatics we'd prefer to see produced from future processes**

Potential Transition: Aviation Fleet

Volume Swell of Alternative Fuels



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.

Project Overview:

- **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**

Benefits:

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

Alternative Fuels

Fuel	Aromatics
SRI-1	8.7%
4597	15.0%
5245	15.5%
3166	17.6%
4598	17.6%
4600	17.7%
4658	17.7%
4626	17.9%
5661	18.1%
4877	19.6%
4599	19.9%
3602	23.1%
SPK-1	0.0%
SPK-2	0.0%
SPK-3	0.0%
SPK-4	0.0%

Phase 1 (Compete)

Task 2: Volume Swell of Reference Fuels

Task 3: Analysis of Absorbed Fuel

Task 4: Volume Swell of 50% blends

Phase 2

Task 5: SPK blended w/ Aromatics

Task 6: Analysis and Reporting

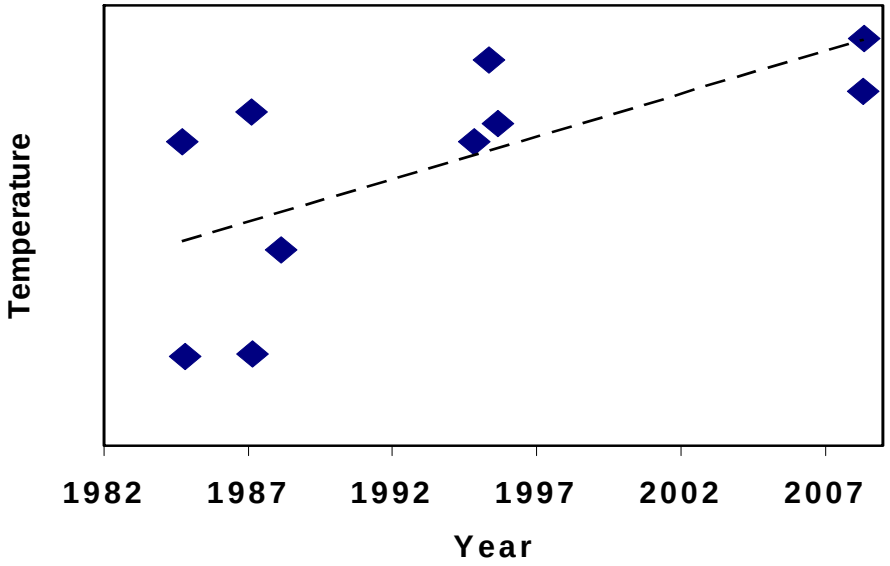
Material	Purpose
Nitrile	Gasket, o-ring
Nitrile	Gasket, o-ring, extracted plasticizer
Polysulfide Lightweight	Sealant
Epoxy BMS 10-20	Coating
Fluorosilicone	Gasket, o-ring
Nylon	Film
Kapton	Film
LowTemp Fluorocarbon	Gasket
Polythioether	Sealant
BMS 10-123 Paint	fuel tank coating
Fluorocarbon (regular)	Gasket

Alternative Fuels - Next Steps

- **Complete Testing**
- **Publish Results**
  - **Spring 2011**
- **Support Development of ASTM D7566 approval for 50% bio-SPK**

Oxide CMC Nozzle - 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

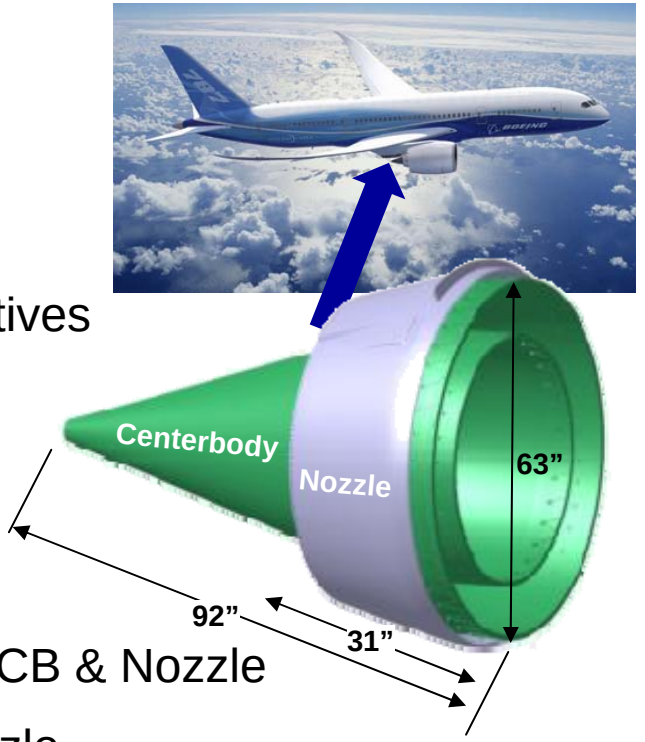


CMCs may enable hotter more efficient engines

Oxide CMC Exhaust Nozzle

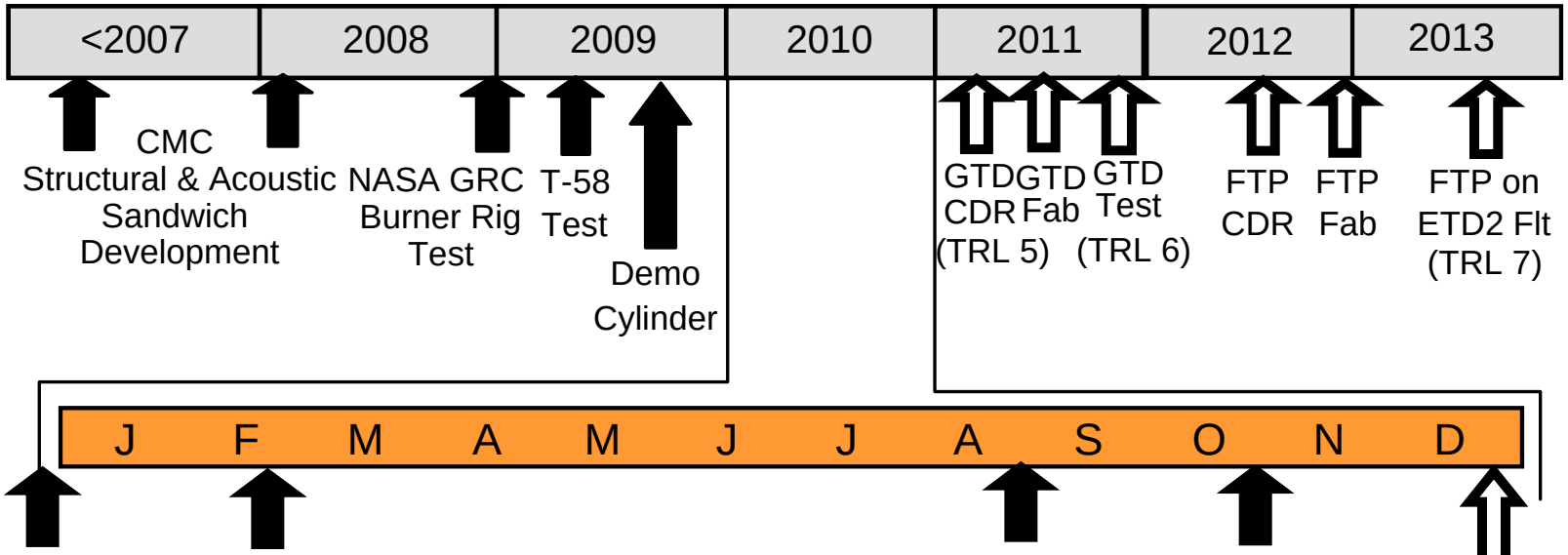
Objective: Develop and demonstrate an acoustic ceramic matrix composite exhaust nozzle to TRL 7 through a building block approach

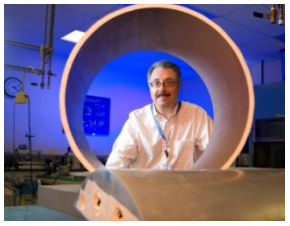
- **Baseline Engine:** Trent 1000 engine
- **Baseline Material:** 2D N610/AS Oxide-Oxide CMC
- **Potential Transition:** New Boeing Products & Derivatives

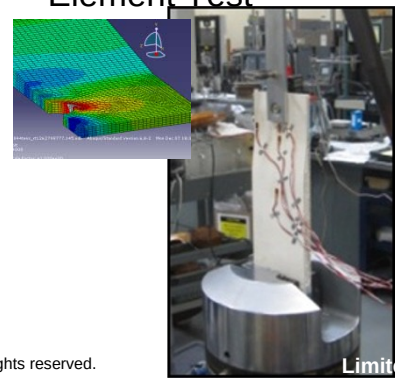


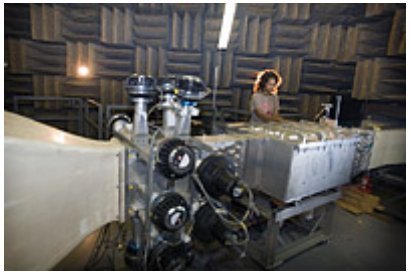
- **Key Milestones/Events**
  - TRL 5: Subcomponent fabrication & test
  - TRL 6: Full-scale engine ground test of oxide CMC CB & Nozzle
  - TRL 7: Flight test of full-scale oxide CMC CB & Nozzle

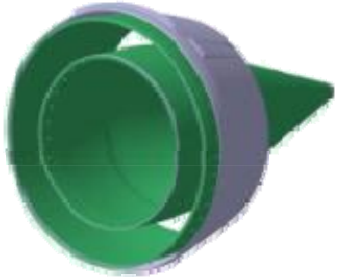
2010 Accomplishments & Next Steps

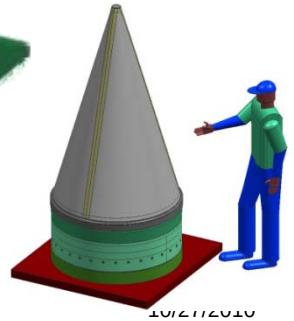






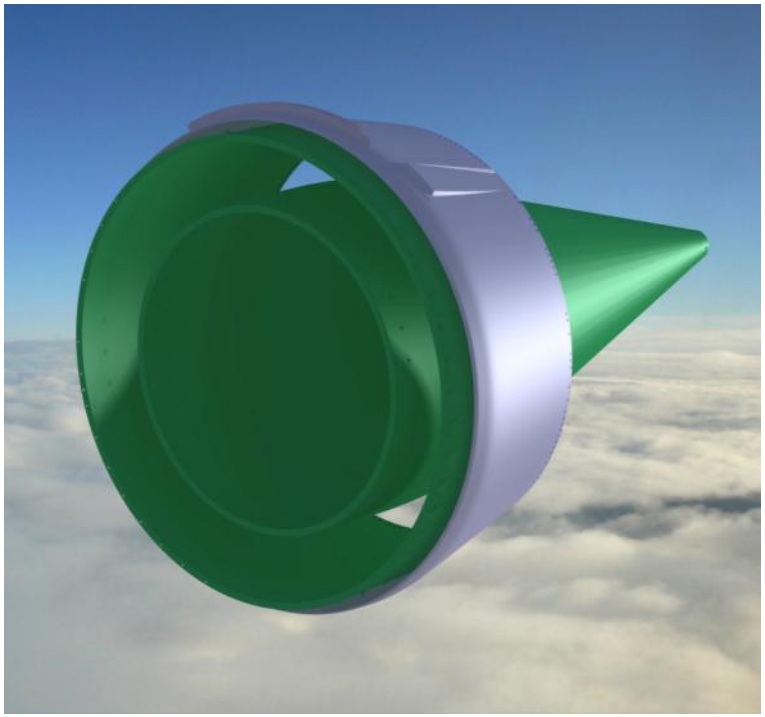






CLEEN Oxide CMC Nozzle Summary

- **Successful Joint & Acoustic Element Tests**
- **Preliminary Design Complete**
- **Detail Design in-work**
- **TRL 5 Subcomponent Test 1Q2011**
- **TRL 6 Ground Test 4Q2011**
- **TRL 7 Flight on Eco2 3Q2013**



BOEING ATK ALBANY Engineered Composites

Adaptive Trailing Edges - Objective

Objective:

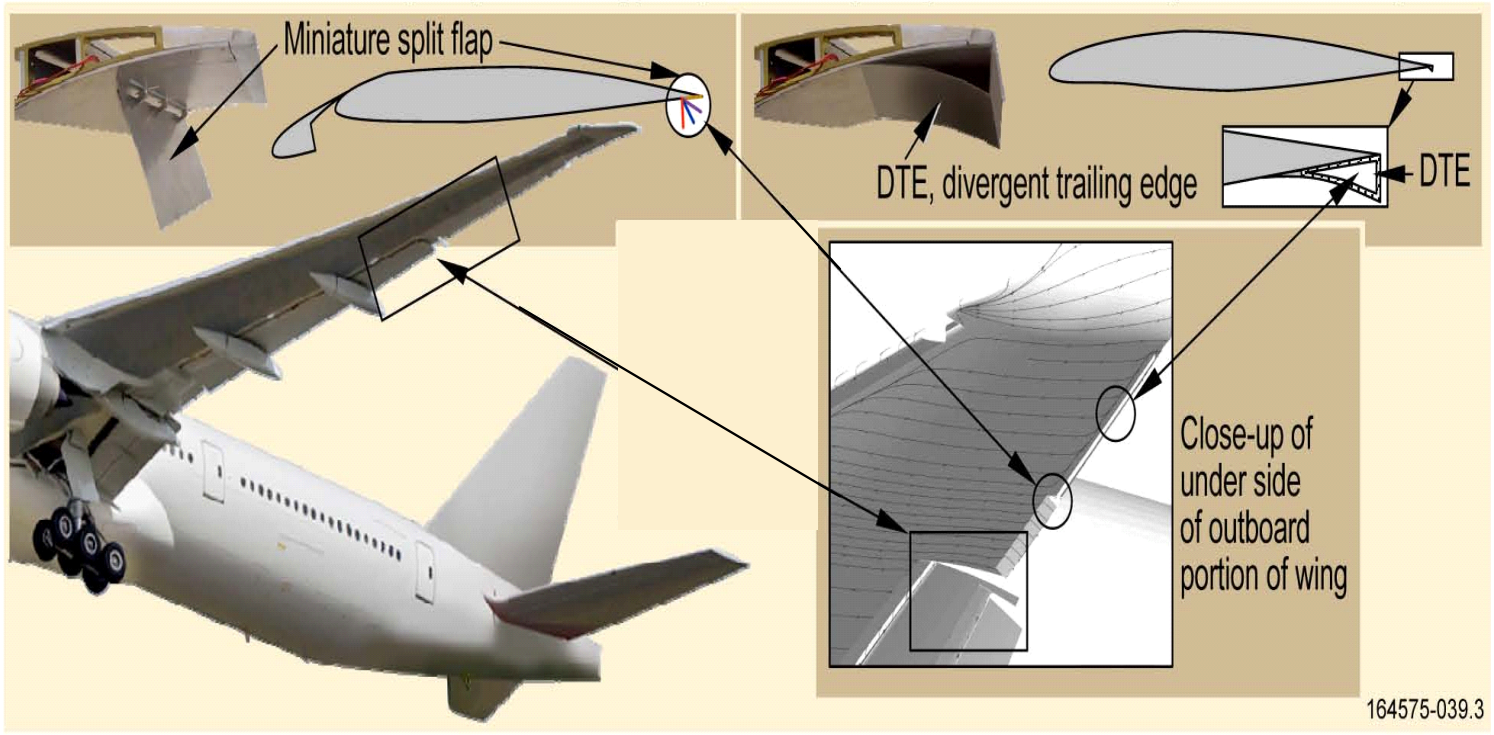
Improve airplane fuel burn and noise through the use of adaptive trailing edge edges.

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**

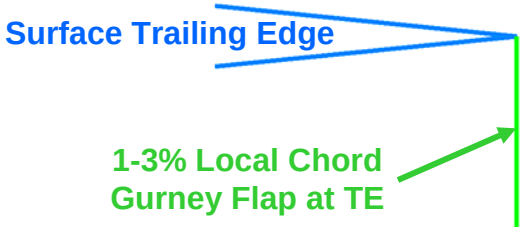
Adaptive Trailing Edge Goal



Develop and validate by full-scale flight test on 737-800 an adaptive trailing edge system relevant to new and derivative commercial airplanes capable of tailoring wing performance to reduce noise and fuel burn at different flight regimes

Adaptive Trailing Edge Elements

ATE's utilize small devices on airfoil trailing edges to alter sectional aerodynamic performance



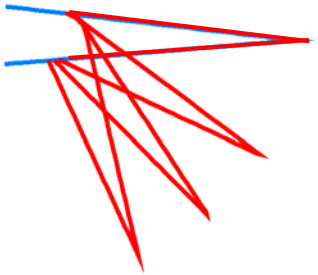
"Gurney Flap" used in race car applications in early 1970's (although similar devices applied to aircraft since 1930's)

Other device types can be employed, with variations in:

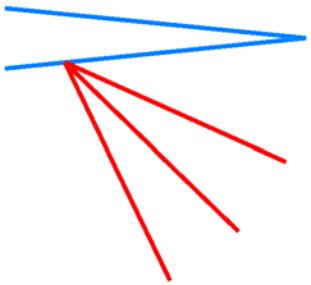
- **Ease of integration**
- **Magnitude of high and/or low speed benefits**
- **The physics of how they work…and resulting ramifications (e.g. noise impact)**

Divergent TE

Mini Plain Flap (MPF)

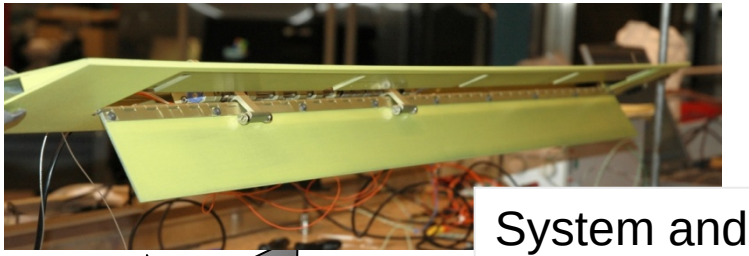


Mini Split Flap (MSF)



Technology Development

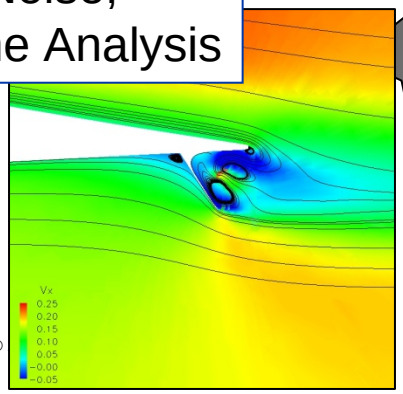
Actuation technology development



System and integration solutions

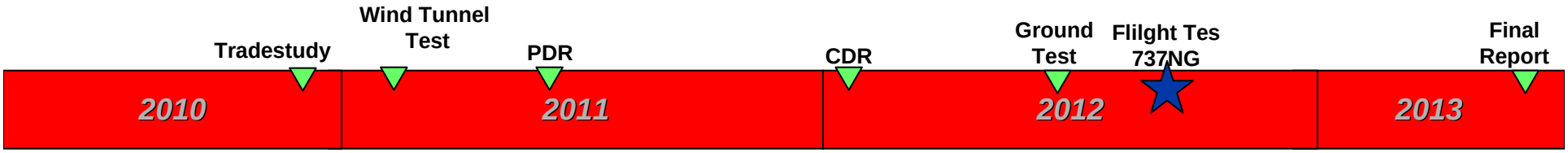
Implementation of deployable, controllable trailing edge elements

Aero, Noise, Airplane Analysis



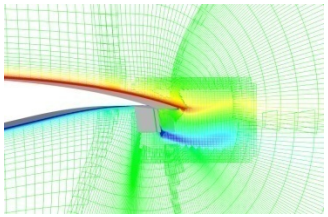
Testing and Validation

ATE – Development Plan

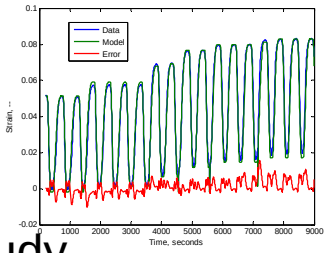


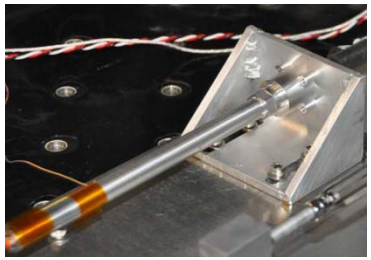
Technology Maturation

Unsteady CFD Analysis

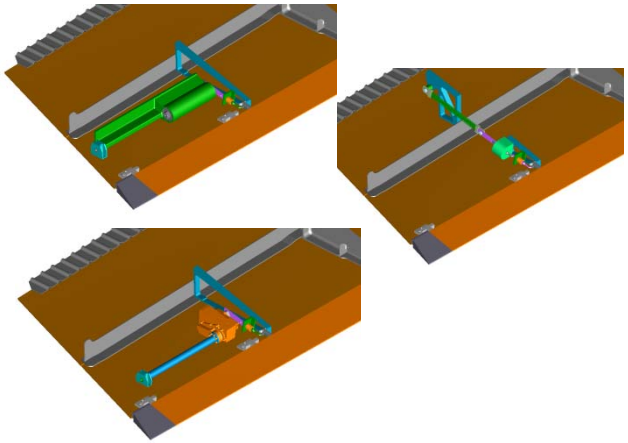


Actuation Technology Modeling/Controls/Testing





Actuation Tradestudy



Boeing – FAA CLEEN Summary

- **Working 3 Technology Areas**
  - **Alternative Fuels**
  - **Oxide CMC Nozzles**
  - **Adaptive Trailing Edges**
- **Two Flight Test Demonstration Programs**
  - **2012 – 737 - 800**
  - **2013 – 787**
- **Developing and Working plans for transitioning technology to Boeing products**

Suggested Future Workshop Topics

- **Systems Level Modeling**
  - **Accounting for combinations of technologies in SLM**
  - **Model validation / long term usage**
  - **Mixed origin/ownership technology effects**
  - **Accounting for Airframe-specific integration challenges and issues**
- **Certification of new technologies**

THANK YOU