Demonstrating FAA Certifiable Ultra-Efficient Commercial Aircraft Configurations

FAA CLEEN-II Public Session

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Program Synopsis

- Under the FAA CLEEN II program, Aurora is developing composite airframe technologies that will enable unconventional aircraft configurations and reduce fuel burn, emissions, and noise.
- A common theme amongst future ultra-efficient aircraft concepts is the non-traditional, complex shape of the aircraft structure. One of these aircraft concepts, the D8 (developed by NASA, MIT, Aurora, and P&W), is particularly interesting from an advanced composite aerostructures standpoint because the configuration alone is responsible for most of the projected benefits. The step change in performance due to the shape of the aircraft – rather than for any of the individual technologies integrated into the aircraft – implies that a significant efficiency benefit can be realized on a much shorter time scale than would be required for the maturation of many separate, incremental technologies.
- The D8 configuration, enabled by its uniquely shaped fuselage, results in up to 56% fuel burn reduction, 32EPNdB cumulative noise reduction with integrated boundary layer ingesting (BLI) engines. The D8 fuselage further enables 29% fuel burn reduction and 16EPNdB cumulative noise reduction with wing mounted engines. Advanced composite airframe design and manufacturing methods will enable the D8 and shapes like it to be built with reliable, repeatable, and certifiable processes.
- The program was initiated in November 2015 and is currently funded through CY2017

Program Purpose

- Aircraft fuel efficiency generally improves at 1.5% per year
- NASA and others have been funding low-TRL studies of aircraft with disruptive improvements in all domains of environmental efficiency (noise, fuel, emissions) in order to accelerate the rate of efficiency improvements
  - These concepts are now moving up the TRL scale with wind tunnel tests and flight demonstrators
- A common theme amongst the advanced concepts is the non-traditional, complex shape of the aircraft structure
  - Advanced composites enables reliable production of new shapes that were otherwise difficult or inefficient to build

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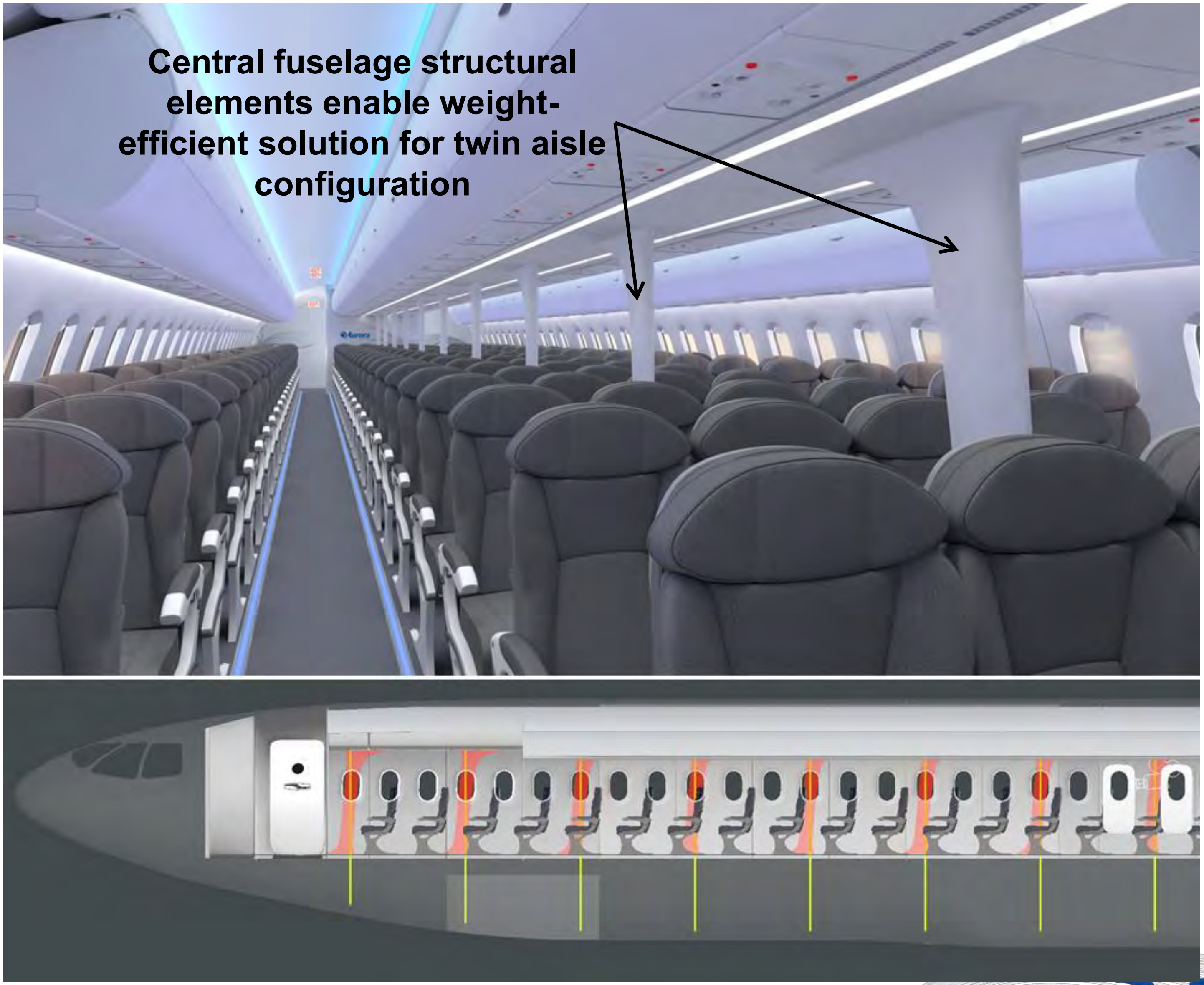
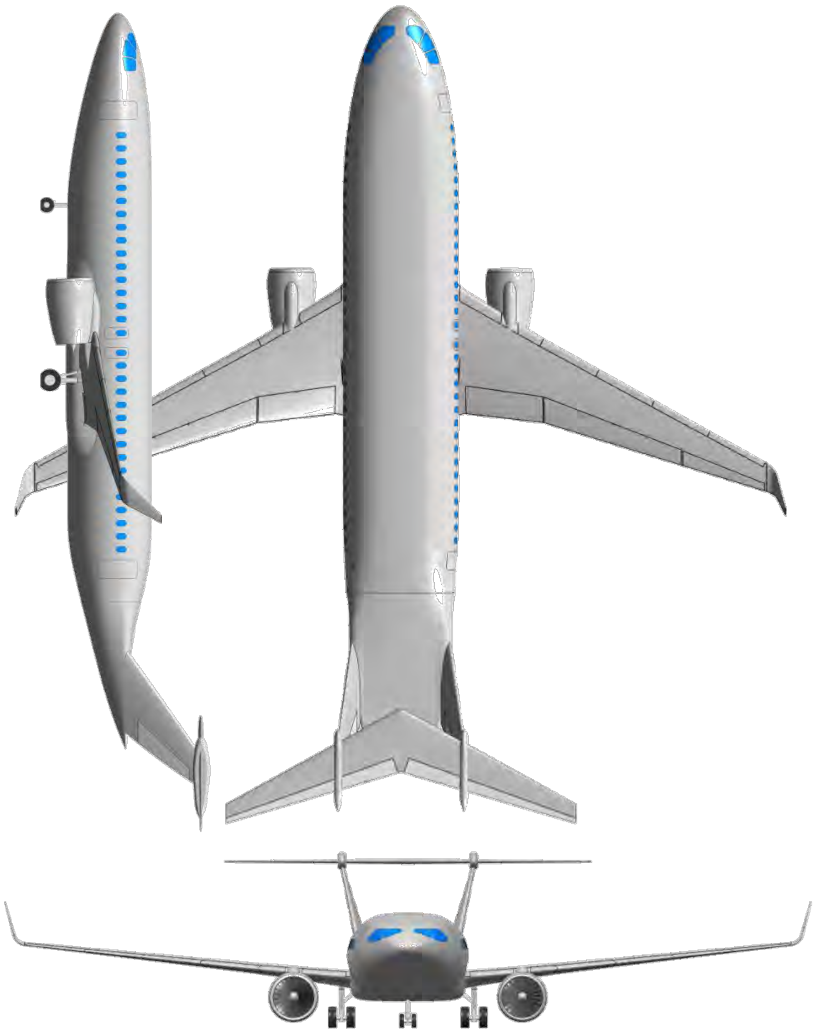
Aurora's D8 Subsonic Transport Aircraft

Tension rods periodic throughout cabin



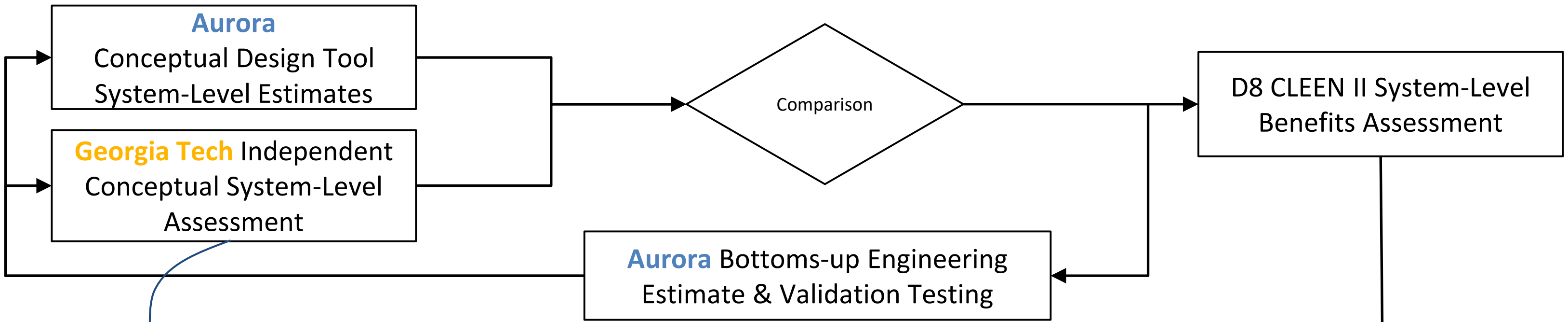
The CLEEN D8 Variant has a twin aisle fuselage and wing mounted engines

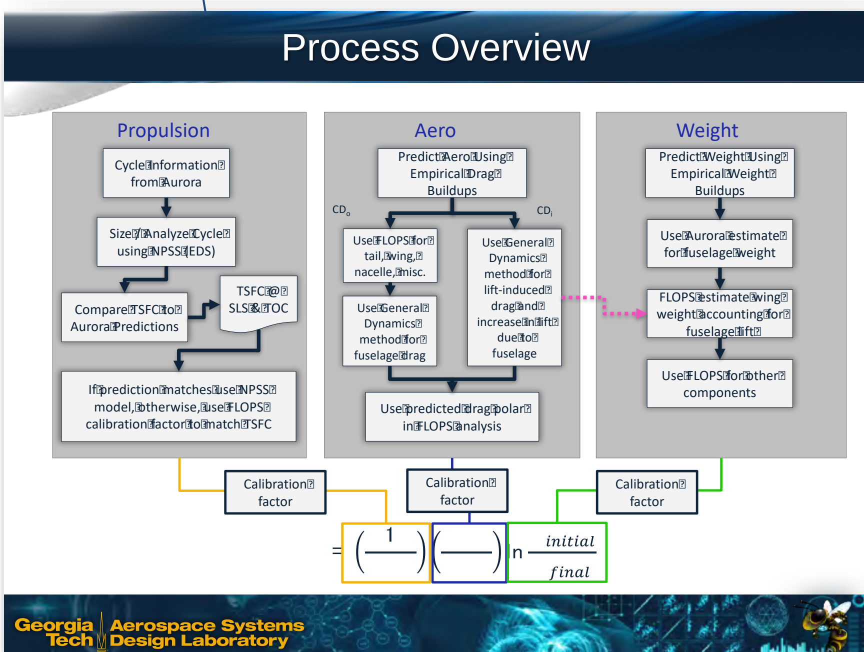


Technology developed in CLEEN-II enables advanced configurations :

- B737-800/A320 class
  - 180pax, 3000 nmi range
- Enabling technology is non-round double-bubble fuselage

Georgia Tech Performance Assessment Complete





Georgia Tech's independent assessment has shown that the CLEEN II D8 configuration, when compared with a 737-800 aircraft, results in a **30% block fuel reduction**

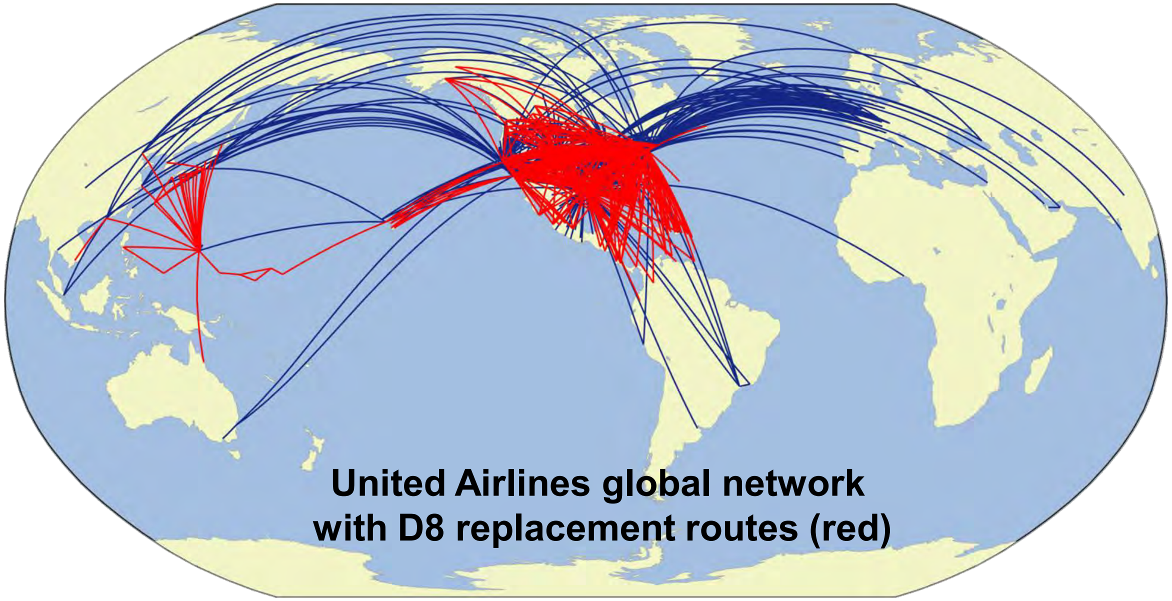
CLEEN II Technology Current Status

CLEEN Technology	Goal Impact	Benefits and Application
Advanced composite, unconventional airframe design-build	Primary: Fuel burn Secondary: noise reduction	56% fuel, 32EPNdB cumulative noise benefits with 2035 technology and integrated engines 29% fuel, 16 EPNdB cumulative noise benefits for 2025 with wing mounted engines

Updated based on learnings from test results, FEM, and air vehicle-level optimization from both Aurora and GTech

D8 significantly reduces air transportation system fuel use

- The D8 aircraft is designed for the market that contributes the most to both **global fuel consumption** as well as a large majority of **airline operations** (frequent noise around airport communities)
- Aurora has simulated the networks of major international and domestic airline carriers with and without the D8 aircraft. Examples:
  - American
  - Delta
  - Jetblue
  - Southwest
  - United



Airline	2014 Flights [#]	2014 Fuel [10^6 gallons]	2014 Fuel [w/ 2035 D8]	Gallons Saved [millions]
JetBlue	204,273	387.50	192.83	194.67
Southwest	578,970	615.26	239.95	375.31
American	1,299,790	2,358.37	1,733.84	624.53
Delta	1,949,160	3,941.87	3,246.35	695.52
United	1,973,050	3,475.65	2,805.61	670.04

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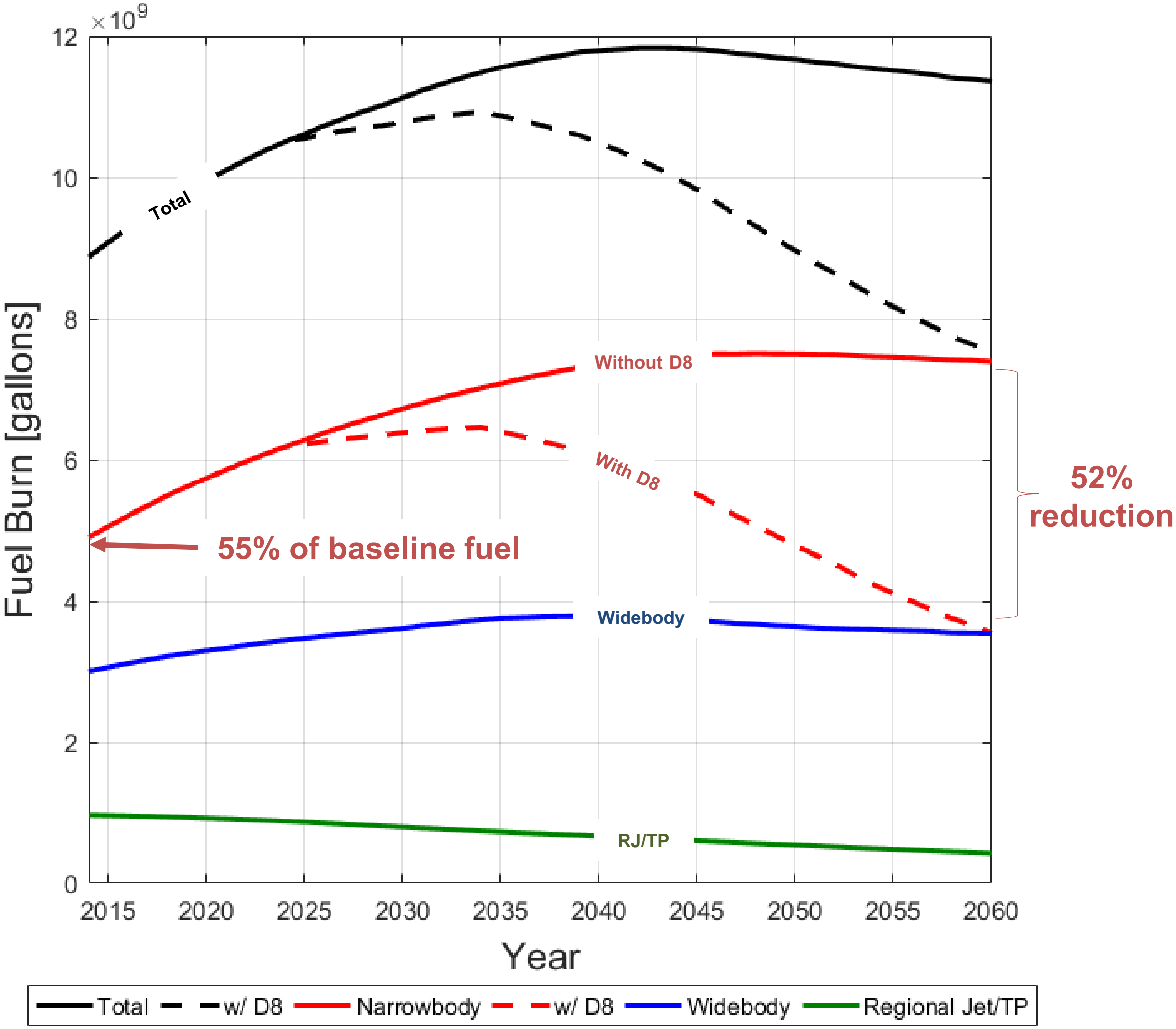
Far-Term Projected North American Fleet Fuel Burn



- Aurora analysis of North America (originating or terminating) fleet fuel consumption assuming D8 introduction with typical commercial aircraft production and survival curves
- Finding 1: today, narrowbody market contributes majority of North America fuel burn → biggest lever for change
- Finding 2: D8 leads to 52% reduction in narrowbody fleet fuel consumption

- Flights originating or terminating in North America (Jetblue, Southwest, AA, Delta, United)
- Growth according to Boeing Current Market Outlook (CMO)
- Baseline aircraft age according to public airline SEC reports and statements
- Aircraft retirement/survival curves according to Boeing (Jiang, 2013)
- Baseline efficiency improvement: compounding 1.5% per year
- D8 applied only to narrowbody market
- Near-term D8 benefit: OD8
- Midterm D8 benefit: vision system

Community Noise Assessment Method

Development of Rapid Fleet-Wide Environmental Assessment Capability

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This paper describes the development of a method for rapid air transportation system-level analysis of noise and emissions. The purpose of this model is to enable broad parametric explorations in environmental studies. The current suite of environmental analysis tools used in government and industry typically model flights on an individual basis, making them difficult to use for broad studies due to their expense in terms of labor and run time. There is a need for fast models to allow analysts, regulators, and industry stakeholders to objectively identify the most valuable focus areas for higher-fidelity analysis. The method introduced in this paper addresses the challenge of rapid environmental assessment using a combination of fast modeling approaches. Outputs from existing high-fidelity models are used to build gridded single-event environmental databases that allow rapid summation and cumulative impact calculations. A case study involving hypothetical fleet changes at a single airport is developed to demonstrate the analytical approach. In addition, rapidly-generated noise results on a nation-wide level are shown based on a simplified approach.

I. Introduction

Assessment of system-level aircraft environmental impact is a crucial component of decision making for analysts, regulators, and industry stakeholders. Changes in fleet mix, frequency, gauge, or operational procedures all drive change in noise, fuel burn, and emissions. These changes have significant operational, social, and political ramifications. Noise is one significant concern; the Federal Aviation Administration (FAA) mandates the submission of a costly and time-intensive environmental analysis for any procedural or infrastructure modification that changes noise impacts by 1.5 dB within the 65 dB contour in terms of Day-Night Level (DNL)[1]. Changes in fuel burn and emissions are another important factor for industry stakeholders. United States major carriers spent $26.5 billion on jet fuel in 2016[2]. In addition, aviation emissions impact climate, air quality, and human health.

The primary FAA environmental analysis tool is the Aviation Environmental Design Tool (AEDT). This code has proven effective, but typically requires modeling operations on a flight-by-flight basis. This is time-intensive, making exploration of multiple potential scenarios difficult. With the ability to rapidly model environmental impacts, stakeholders could quickly compare a much broader set of possibilities. This rapid assessment could then be supplemented by higher fidelity modeling using tools such as AEDT.

There are several challenges that a rapid environmental impact analysis method must overcome. First, the method must be able to model future aircraft types or modifications to existing types. Most existing models use aircraft performance data derived from flight testing which limits utility for analysis of novel aircraft types.[3] A second challenge is the integration of results for noise, fuel, and emissions. The key differences between these outputs are shown in Table 1.

Table 1. Characteristics of Integrated Environmental Analysis

Noise	Fuel & Emissions
• Location-specific problem ➤ Spatial distribution of tracks ➤ Schedule and timing ➤ Runway configuration • Requires segment-by-segment analysis of a procedure, including detailed thrust and configuration	• Location-agnostic • Emissions calculated by species based on engine, altitude, speed, thrust level, and fuel flow using emissions indices • Flight procedure definitions generated for noise calculation can also be used for emissions calculation

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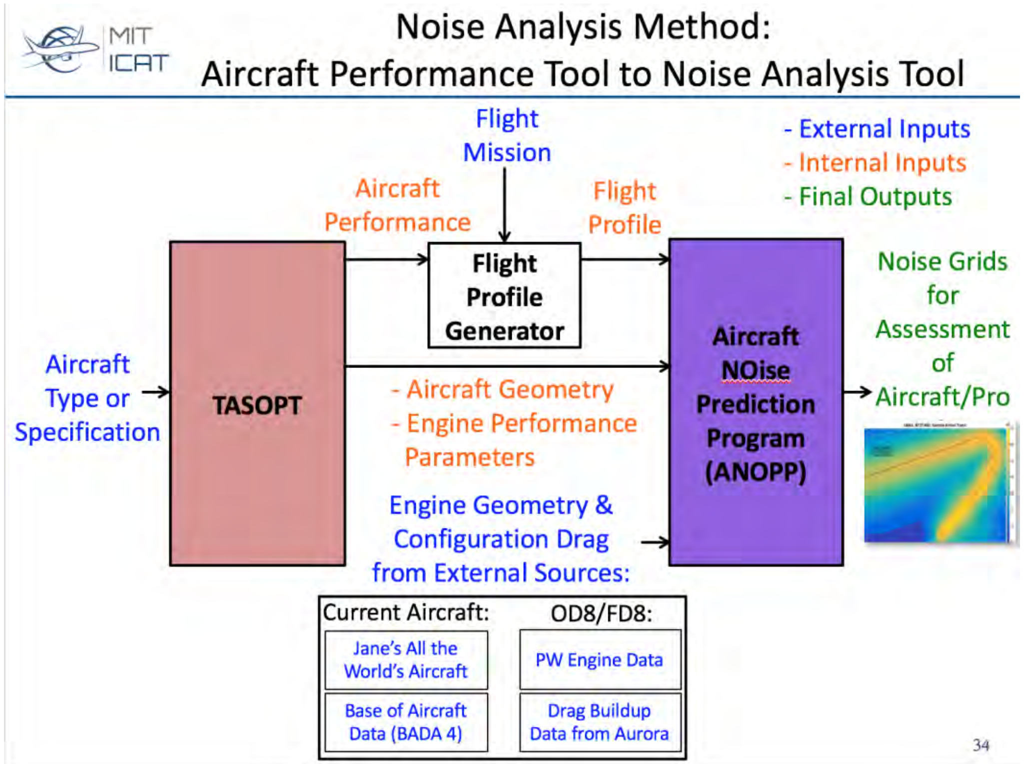

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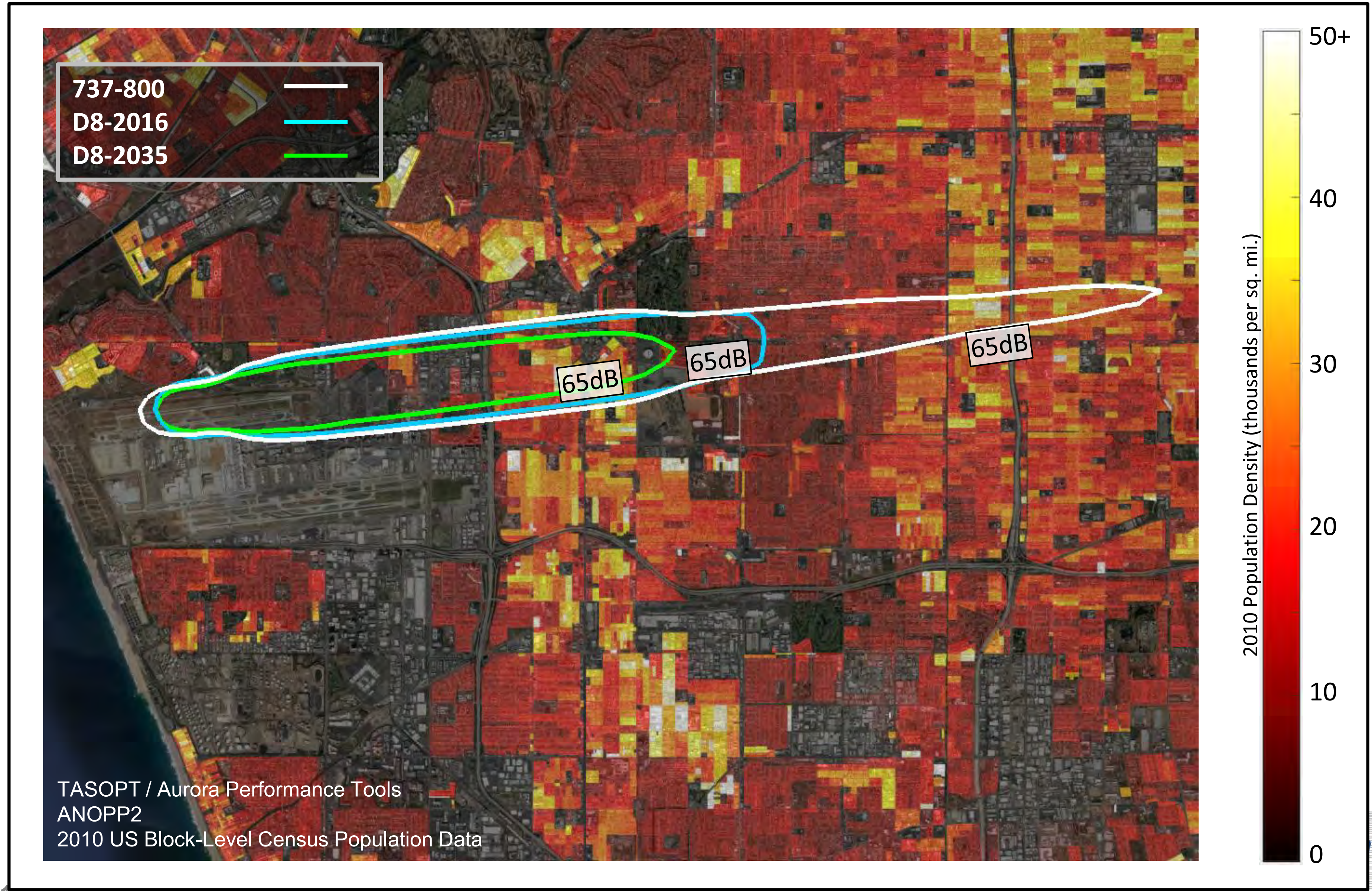
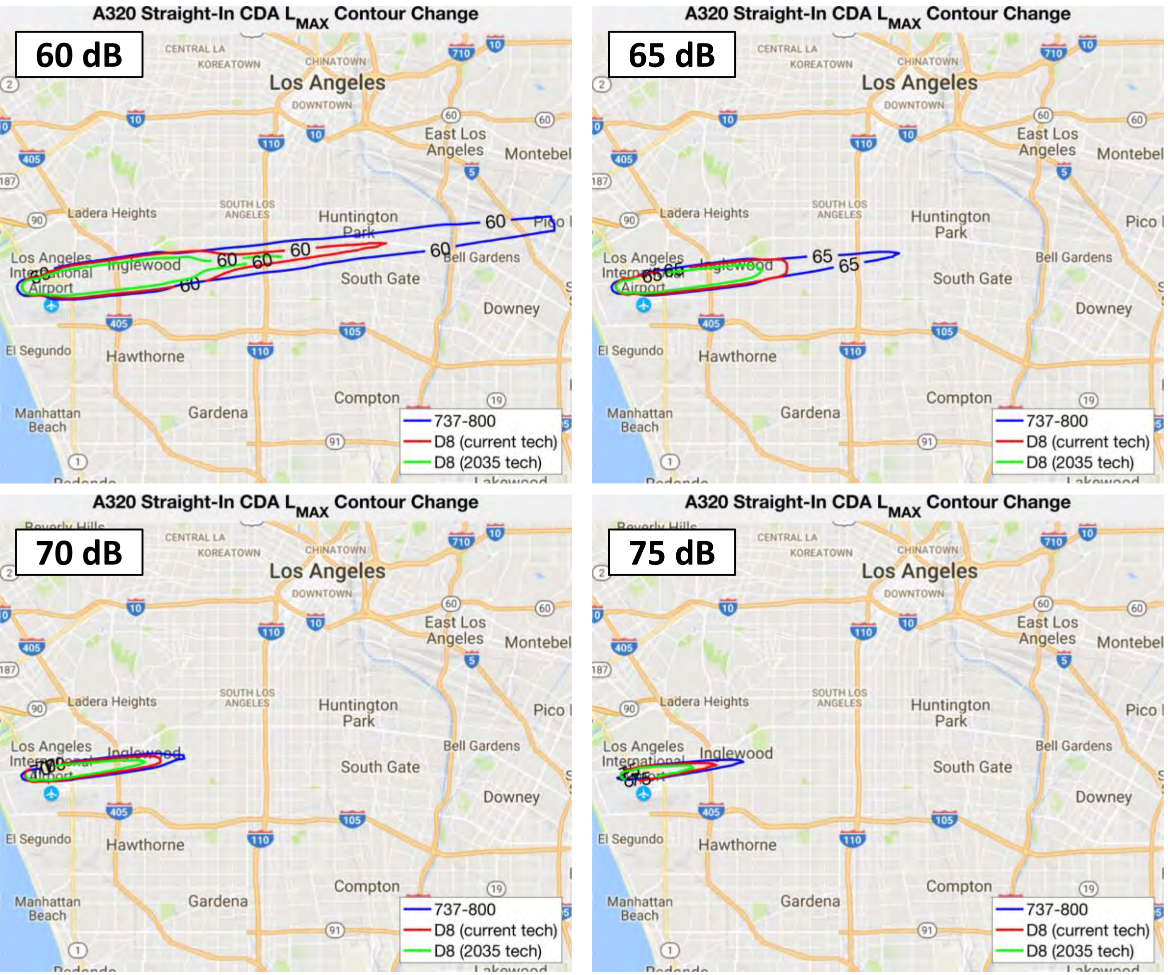
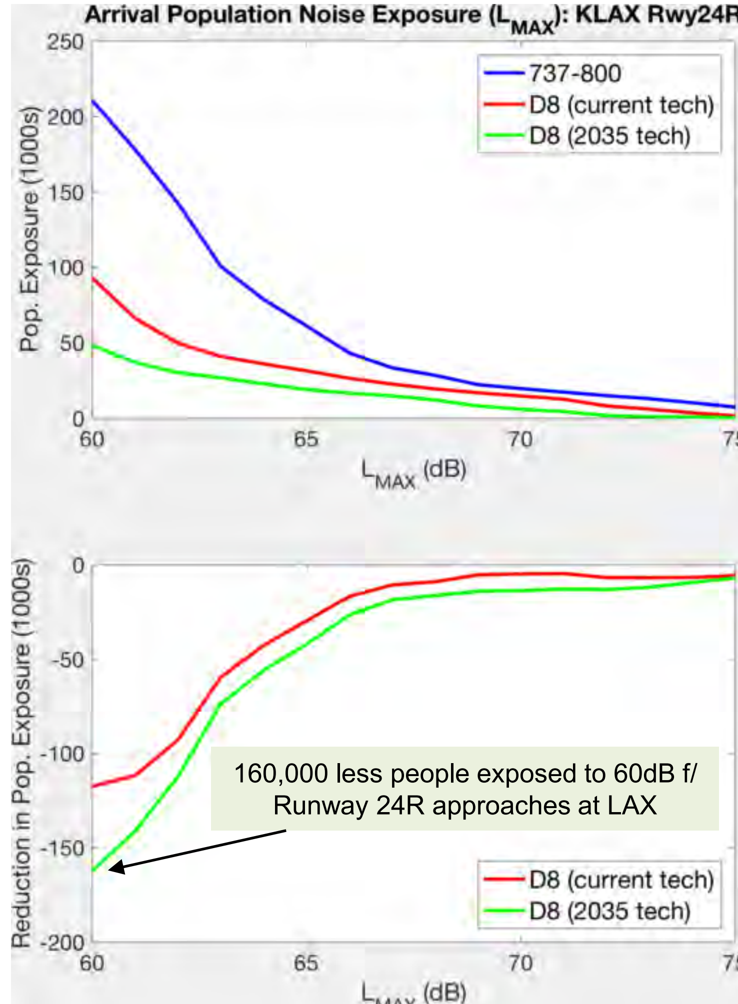
65dB L_{MAX} Approach Noise Contours LAX Runway 24R

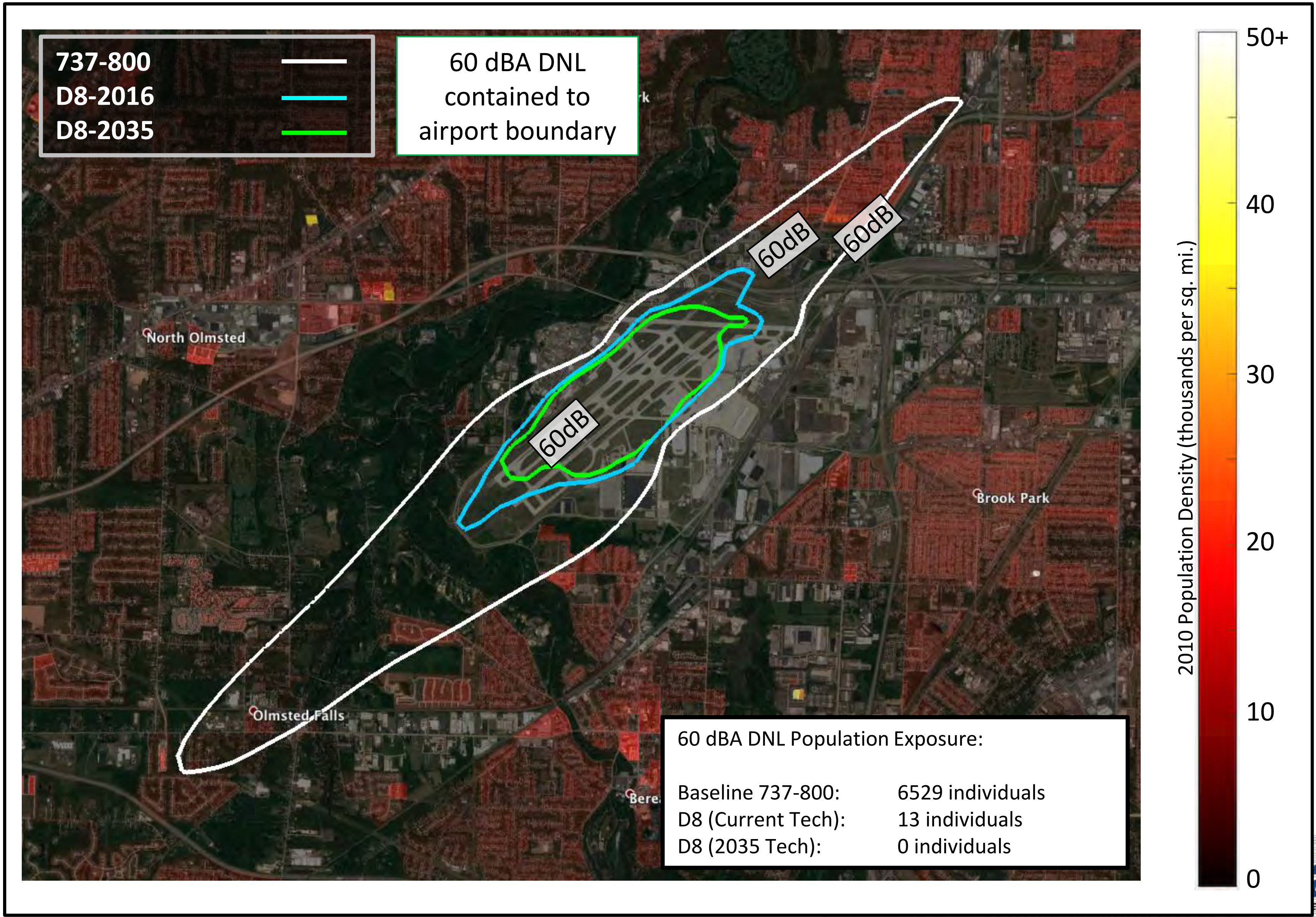


L_{MAX} Approach Noise (LAX Rwy 24R): Population Exposure Reduction





DNL Contour Impacts (60 dBA)
CLE Airport, 2016 Traffic Baseline



DNL Population Exposure Reduction at 20 Busiest US Airports: 60 dBA

Airport Rank	Airport	60 dBA DNL Population Exposure			Pop. Exposure Reduction
		Baseline	D8-2016	D8-2035	
1	ATL	81,005	49,736	39,826	41,179
2	ORD	152,594	72,423	56,275	96,319
3	DFW	41,960	5,881	4,125	37,835
4	LAX	263,190	143,960	126,749	136,441
5	DEN	88	25	9	79
6	CLT	12,513	4,771	2,483	10,030
7	IAH	17,180	7,451	5,714	11,466
8	JFK	409,659	307,259	270,355	139,304
9	SFO	10,288	3,270	2,921	7,367
10	PHX	39,841	21,279	11,213	28,628
11	EWR	88,304	58,712	53,775	34,529
12	PHL	30,395	16,524	13,483	16,912
13	MSP	50,722	22,361	17,427	33,295
14	SEA	92,170	42,425	33,812	58,358
15	DTW	9,661	1,472	751	8,910
16	LAS	138,327	56,527	40,826	97,501
17	LGA	259,663	100,049	67,524	192,139
18	BOS	68,652	22,674	18,544	50,108
19	MIA	160,756	102,769	90,367	70,389
20	MCO	17,614	3,584	1,063	16,551

- *2015 operations; Baseline noise modeling = AEDT; D8 = ANOPP2 + TASOPT; Straight-in, straight-out operations with standard arrival and departure procedure on 3º ILS; ICAO01 departure. Hourly, runway-specific analysis for entire year. Runway assignment = equal weighting.*
- *Population = 2010 US Census Bureau Block-Level Population Data*

- **1.10M less people** exposed to 60 dBA DNL noise
- **56% reduction** in population exposed to 60 dBA DNL noise

- Note: best to compare percentage reduction due to some simplifying operational assumptions (equal weighting of runway assignment vs. implementing time/weather-specific local noise abatement procedures, 3º ILS standard arrival, ICAO 01 departure, etc.)

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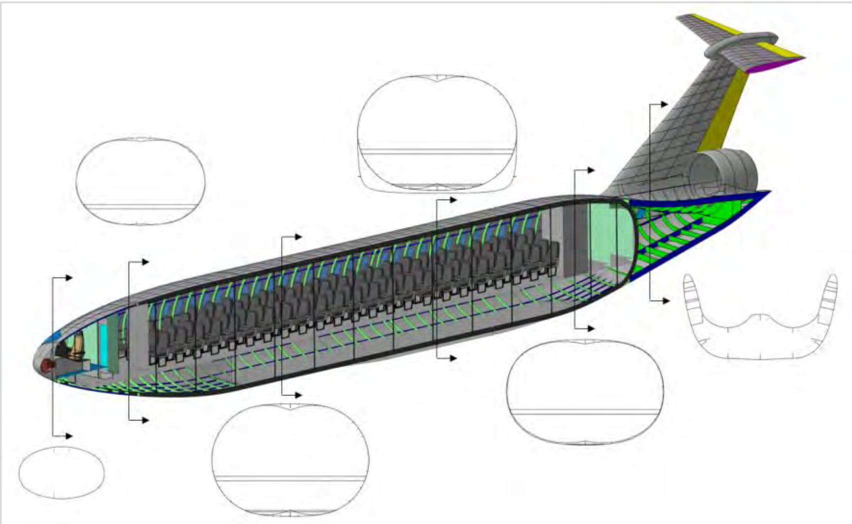
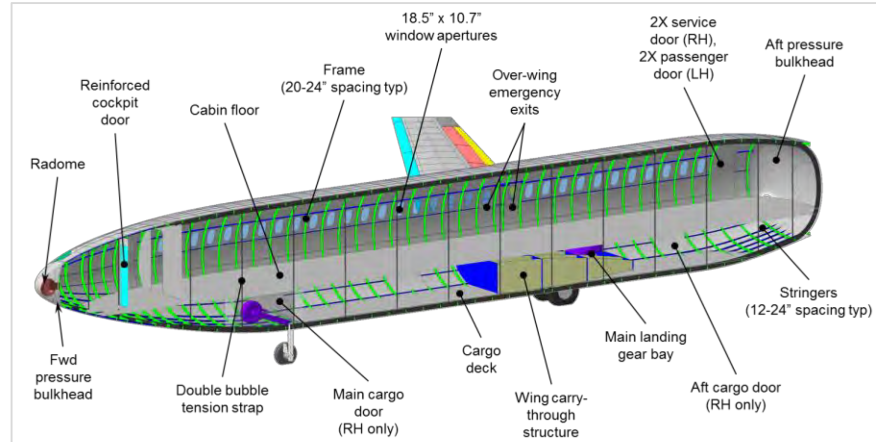
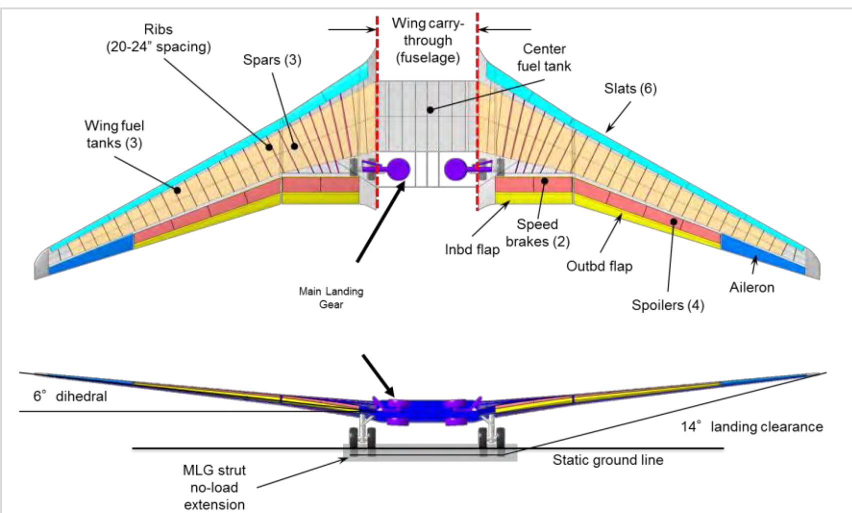
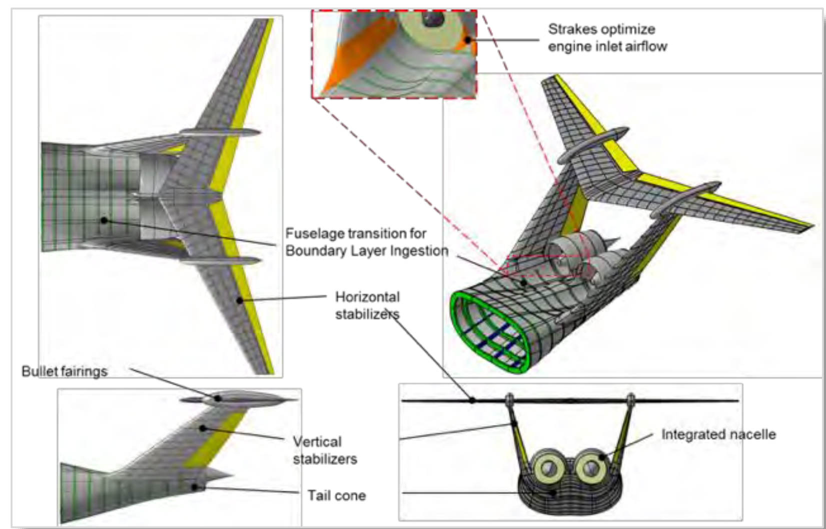
Structural Design of Major Aircraft Elements





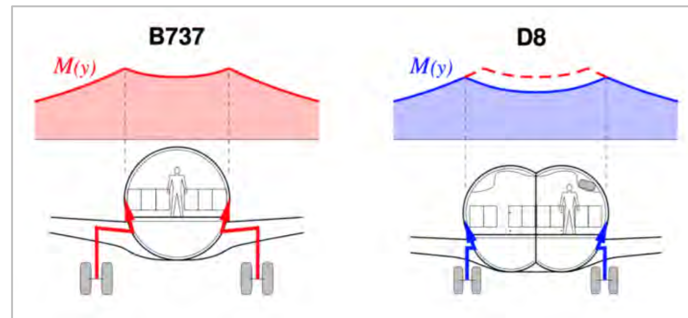




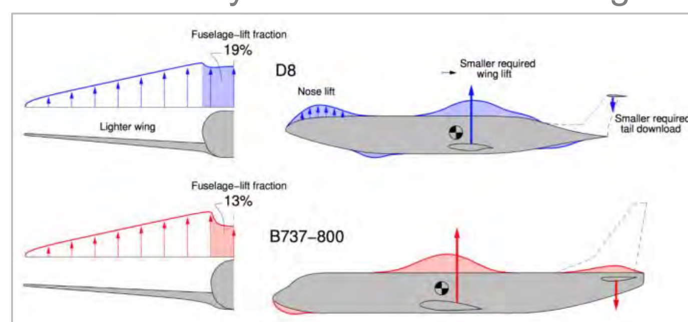
Non-BLI D8 Variant: Twin-Aisle Fuselage with Wing-Mounted Engines

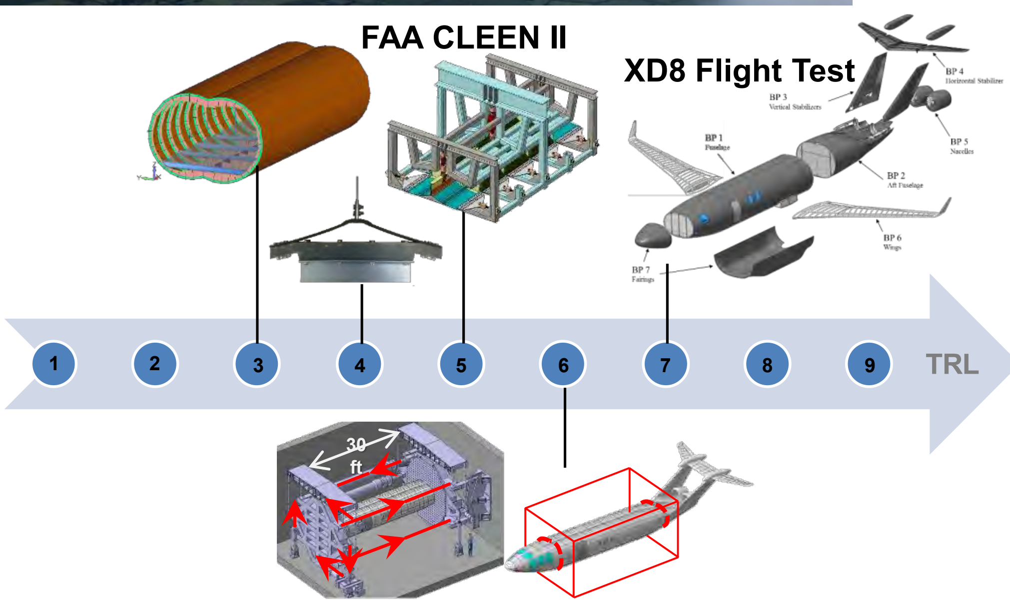
- As part of FAA CLEEN II program, Aurora is demonstrating critical “Y-joint”
- Mechanisms driving fuel efficiency benefits:

Reduced landing gear and wing weight



Increased carryover lift → smaller wing & tail





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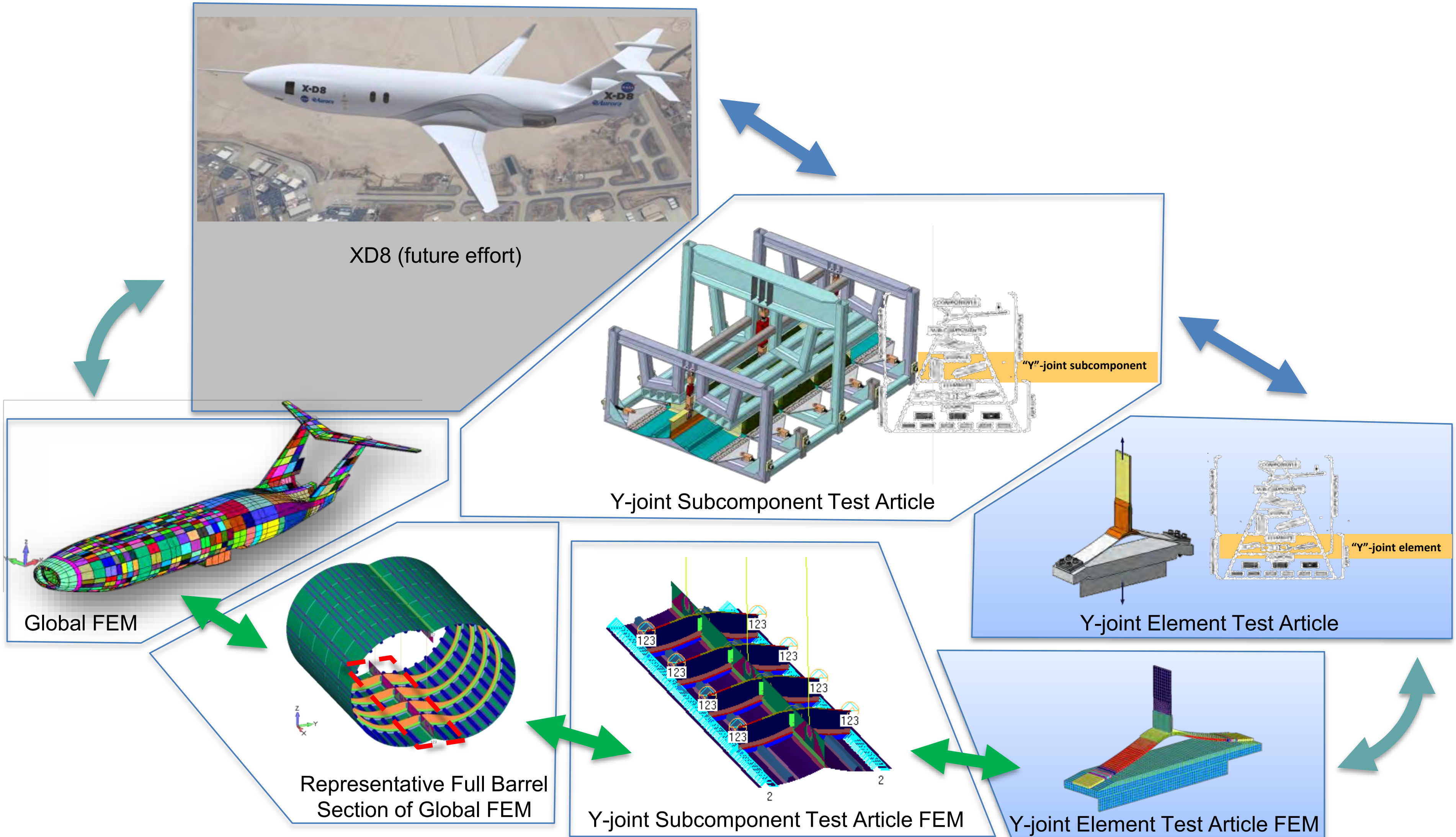
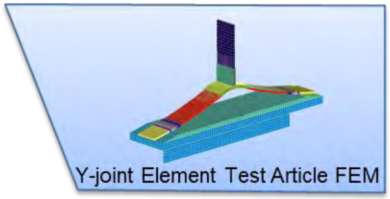
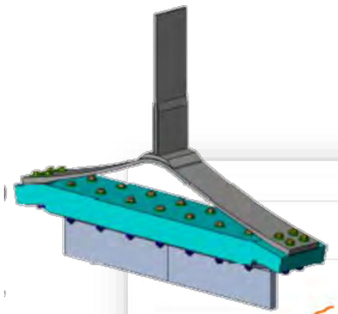
Building Block Approach to Fuselage Development

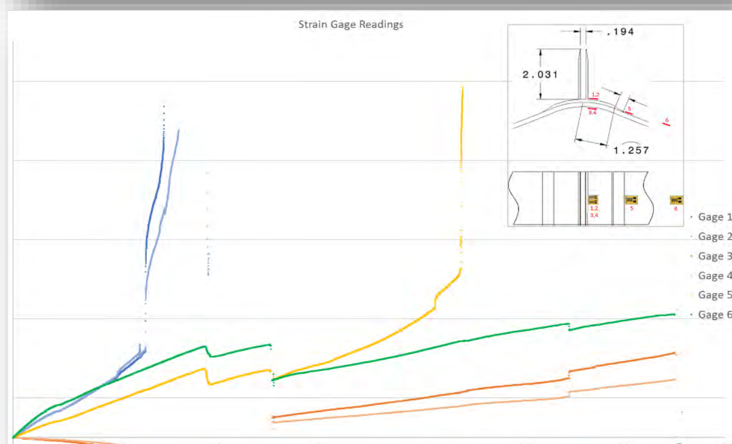


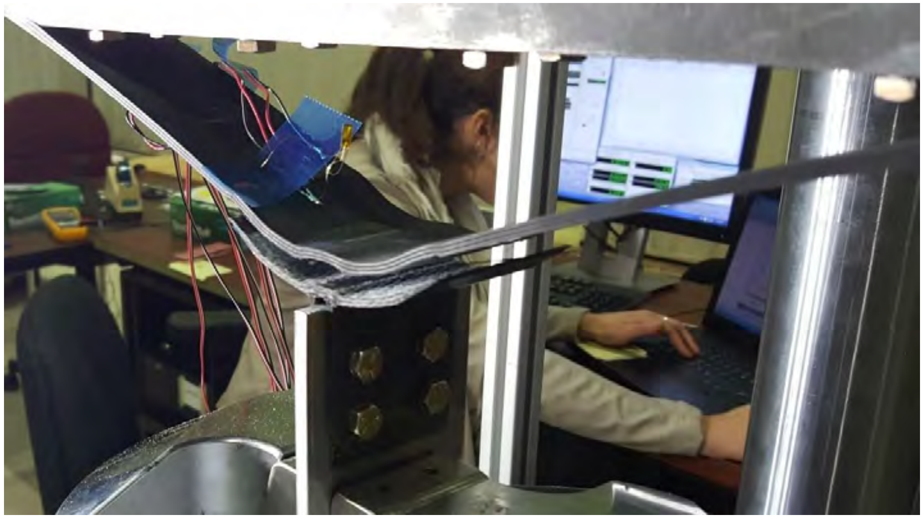
Y-Joint Element Testing



- Element test campaign explored tensile capability of the Y-joint
- FEA predictions identified configurations of interest to experimentally test
- Performed qualitative and quantitative data analysis; correlating data collected from elements with finite element modeling







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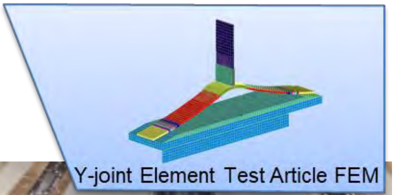
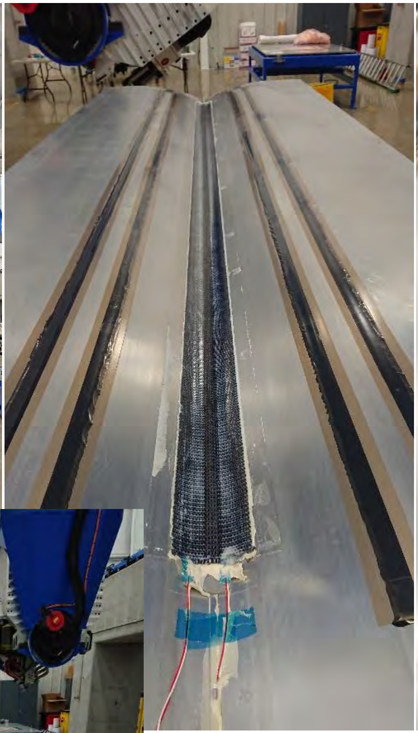
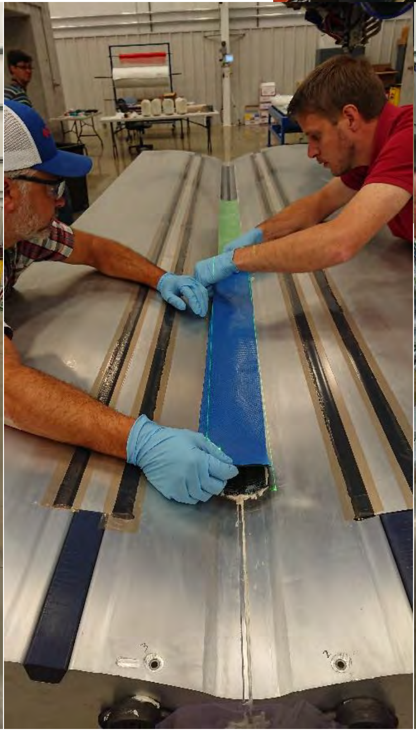
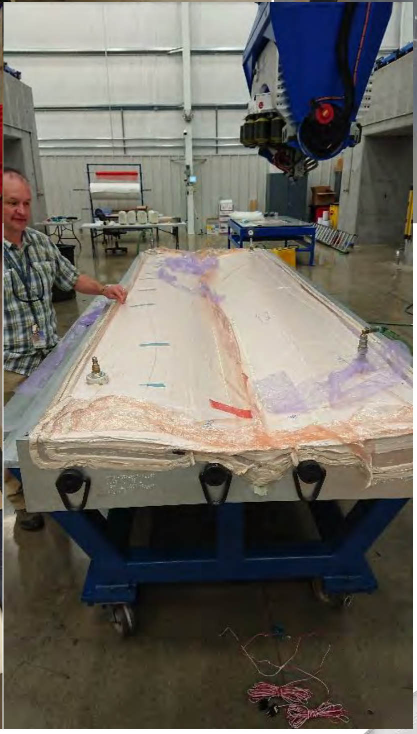
Y-Joint Element Manufacturing

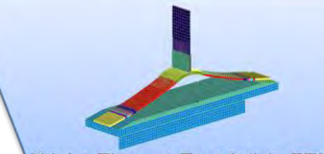


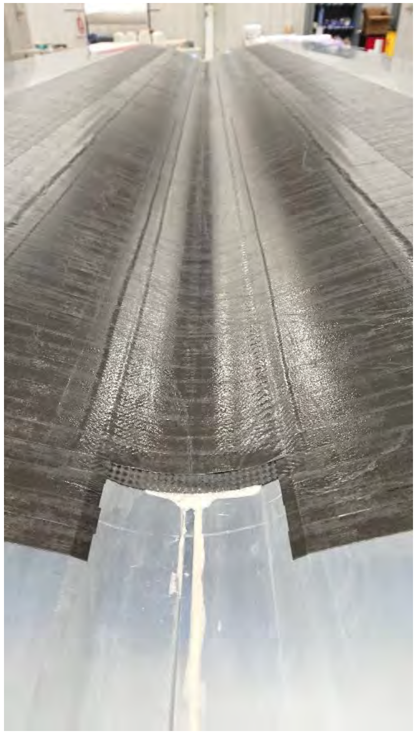


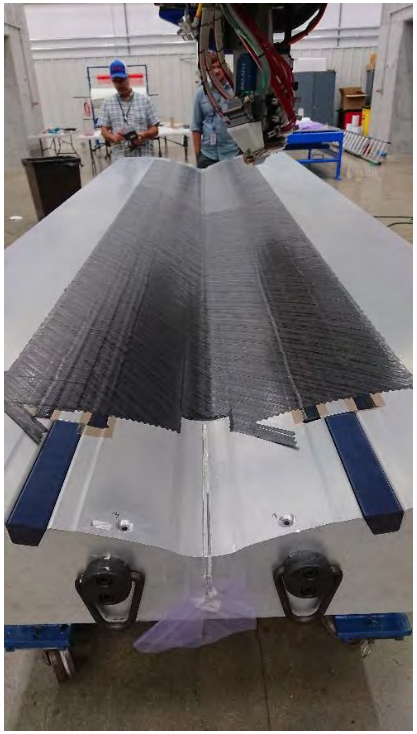




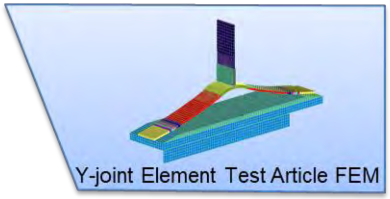
Y-Joint Element Manufacturing

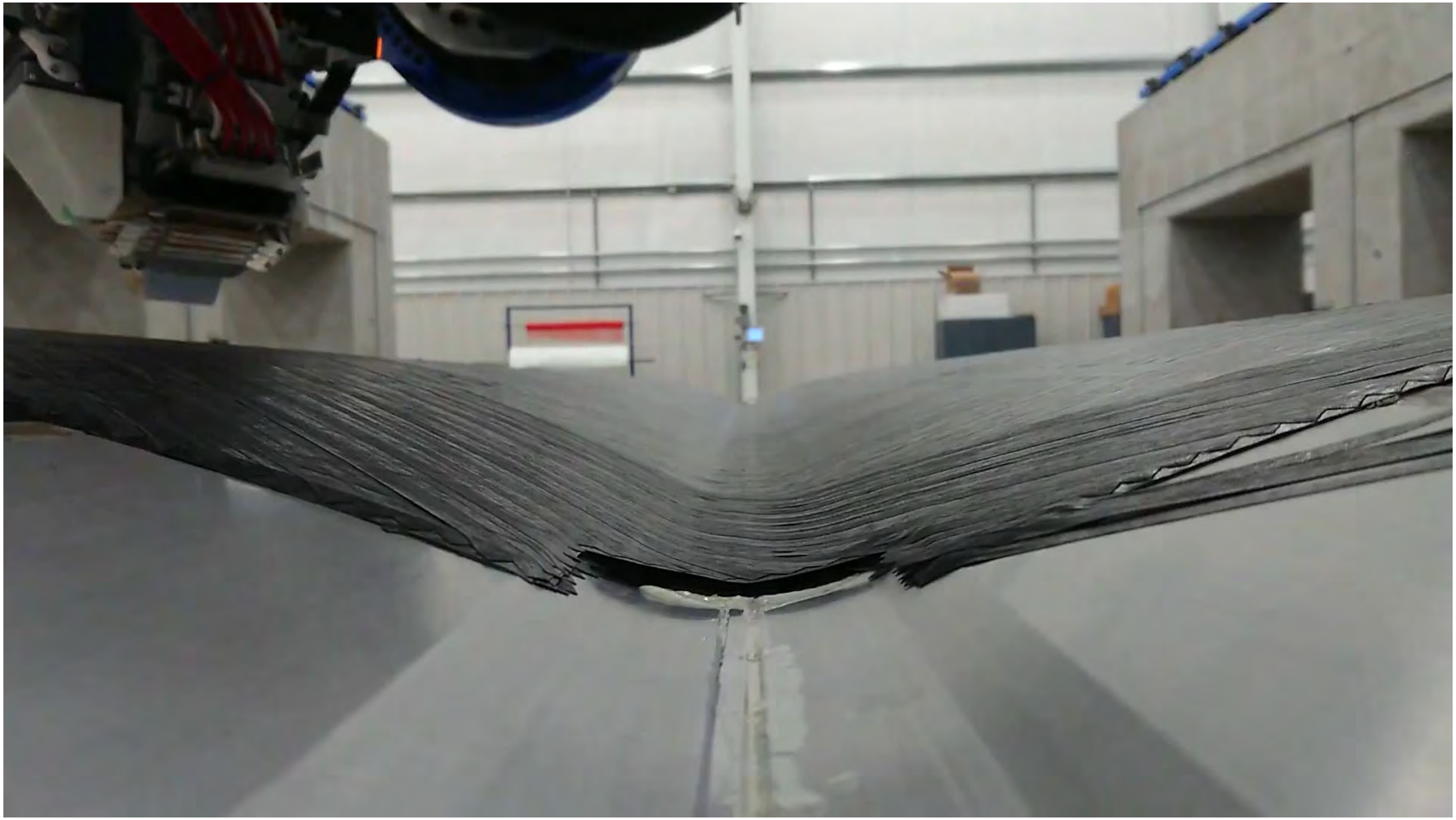

Y-joint Element Test Article FEM



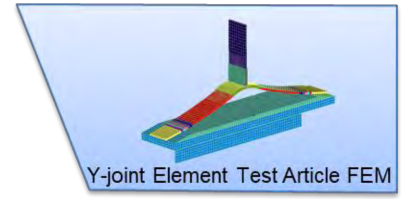


45-ply AFP Video

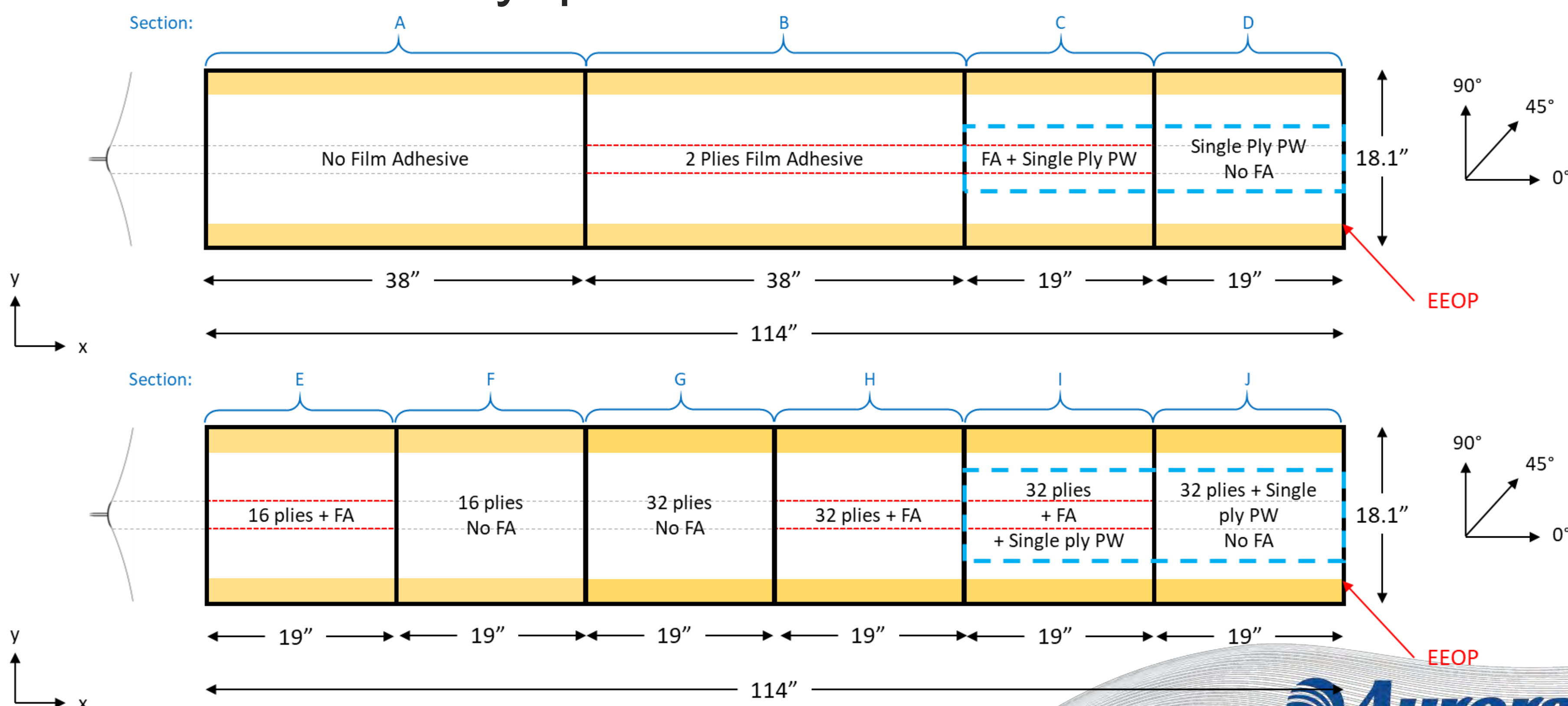




Element Manufacturing Configurations

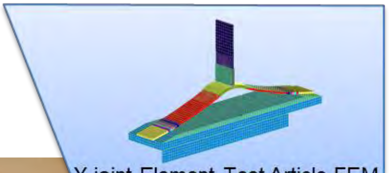


- 10 configurations manufactured and tested
  - No FA, FA, FA+PW, PW no FA
  - Two AFP layups



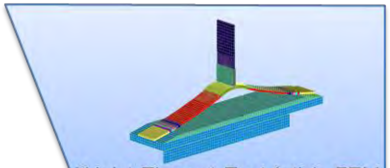
Y-joint Elements

Configuration	Skin Thickness [plies]	Interface	# Elements
A	24	-	17
B	24	FA	17
C	24	FA + PW	8
D	24	PW	8
E	16	FA	8
F	16	-	8
G	32	-	8
H	32	FA	8
I	32	FA + PW	8
J	32	PW	8
TOTAL			**98**

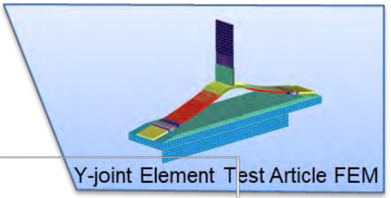

Y-joint Element Test Article FEM

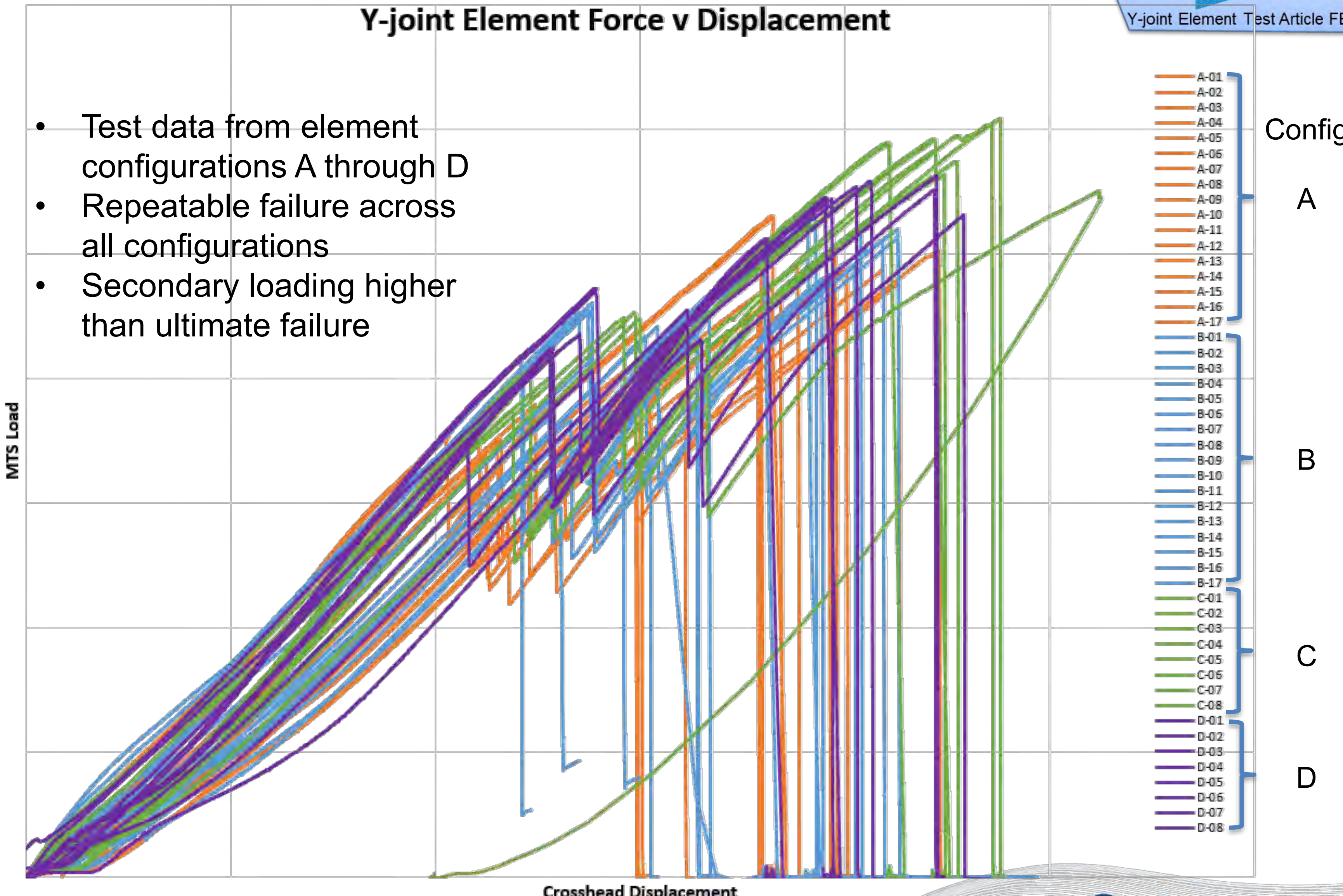
- 10 configurations experimentally tested
- Elements cut via water jet
- Drill jigs for repeatable hole locations

Elements Tensile Tested


Y-joint Element Test Article FEM

Y-Joint Element Results





- Test data from element configurations A through D
- Repeatable failure across all configurations
- Secondary loading higher than ultimate failure

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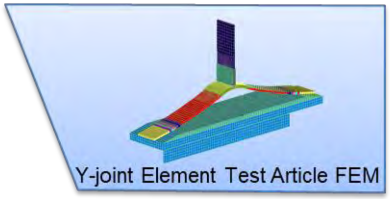
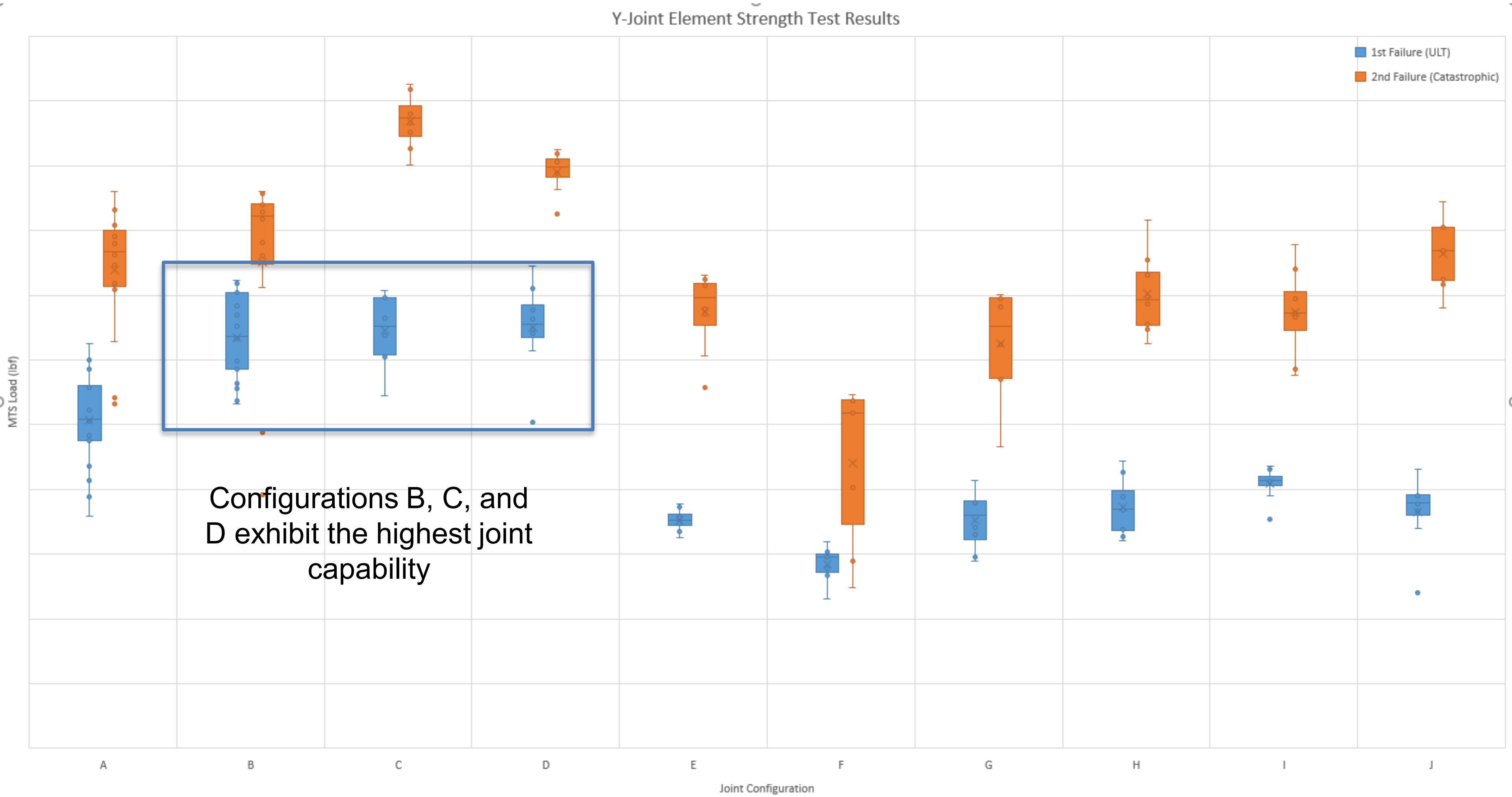
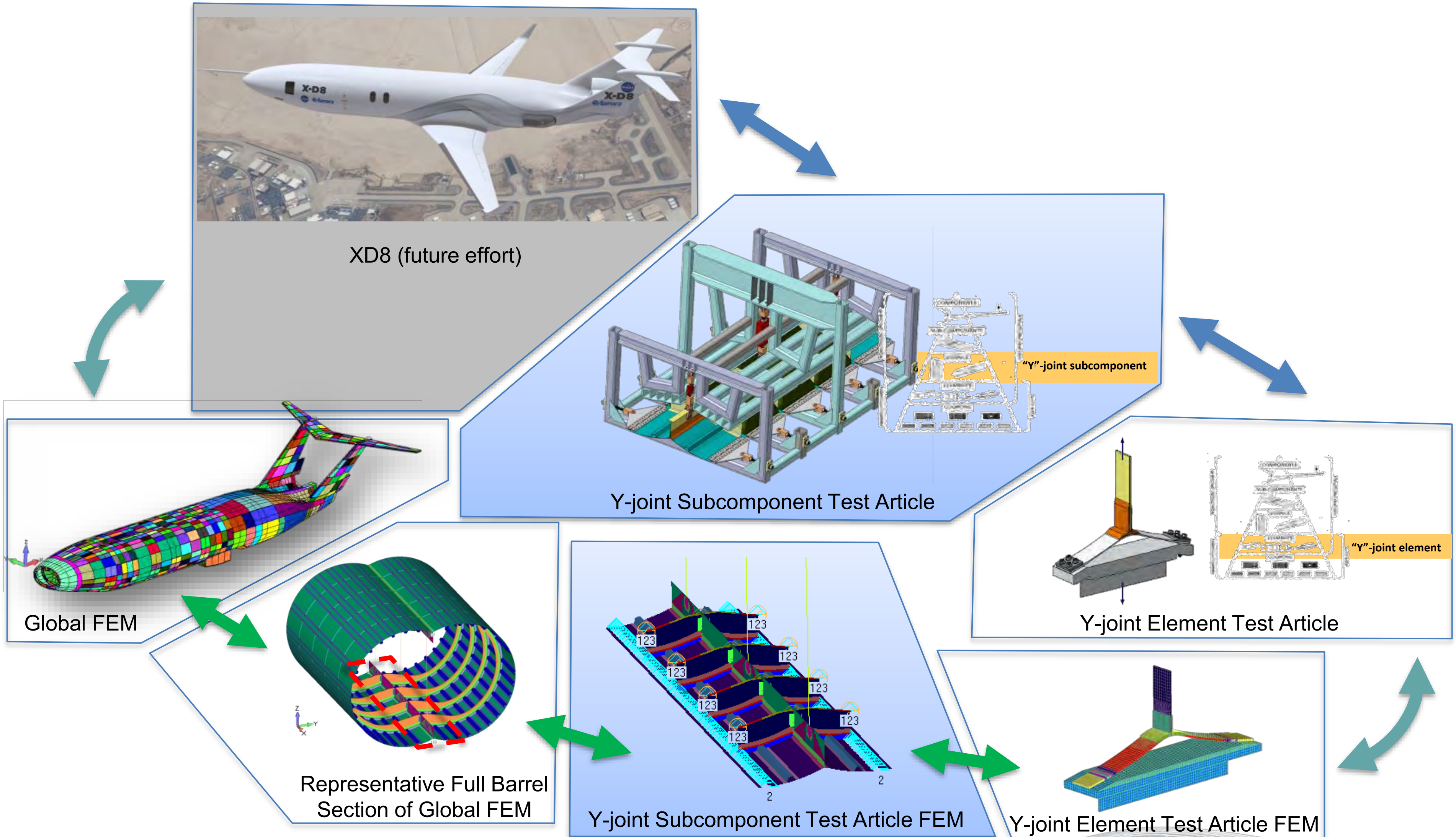
Y-Joint Configuration Capability





Building Block Approach to Fuselage Development



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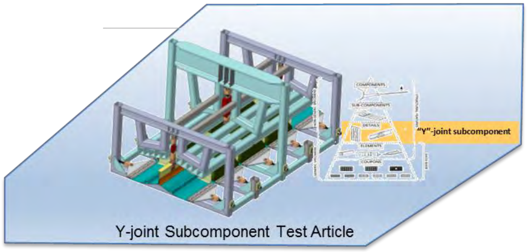
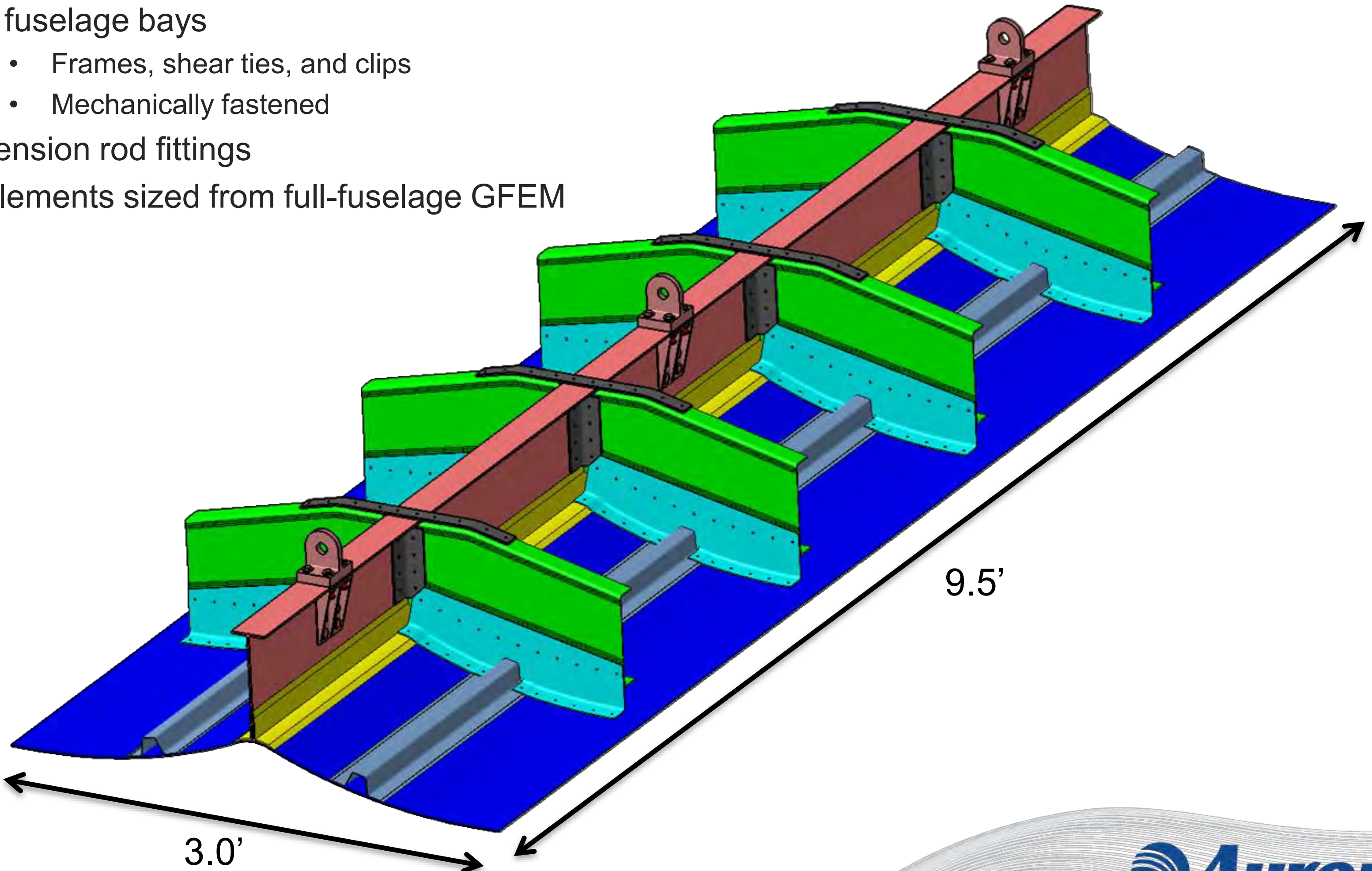
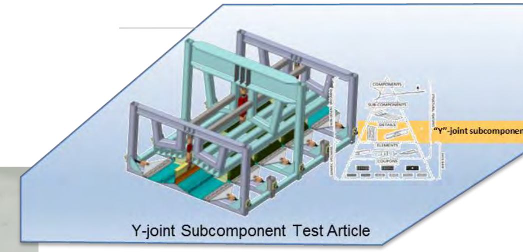
Subcomponent Test Article

- Article consists of :
  - Co-cured skin, Y-joint, and hat-stiffeners
  - Continuous keel
  - 5 fuselage bays
    - Frames, shear ties, and clips
    - Mechanically fastened
  - Tension rod fittings
  - Elements sized from full-fuselage GFEM



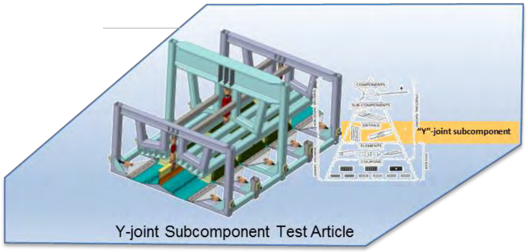


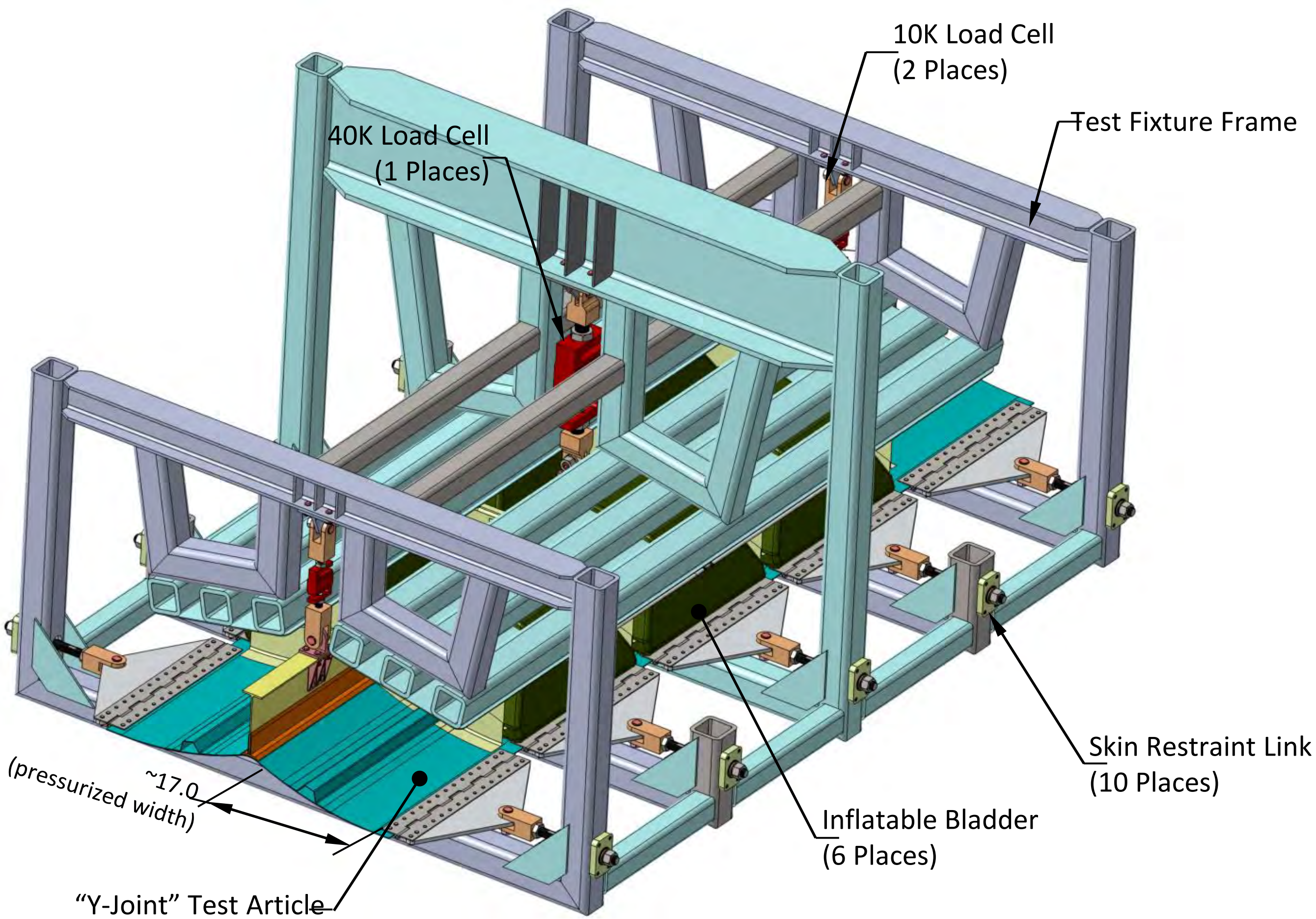
Fully Assembled Subcomponent



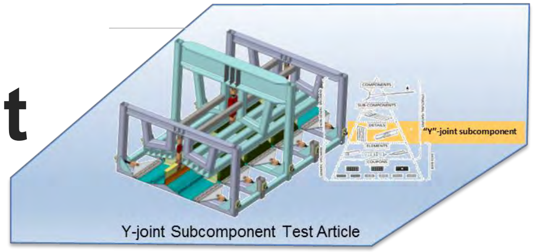
Y-joint Subcomponent Test Article

Test Article Fixture –
Self-Reacting Load Frame



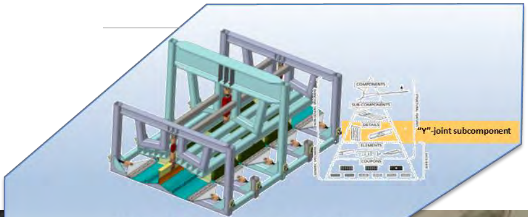


Self-Reacting Load Frame Weldment



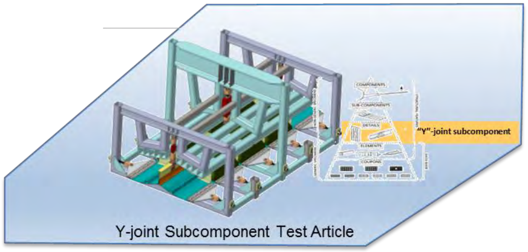
Y-joint Subcomponent Test Article

Subcomponent Testing Assembly

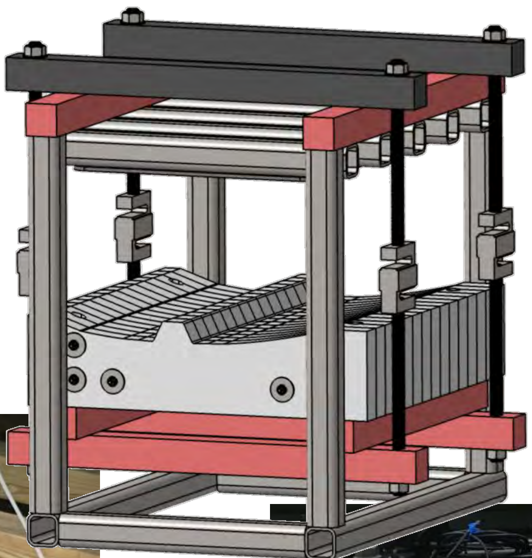


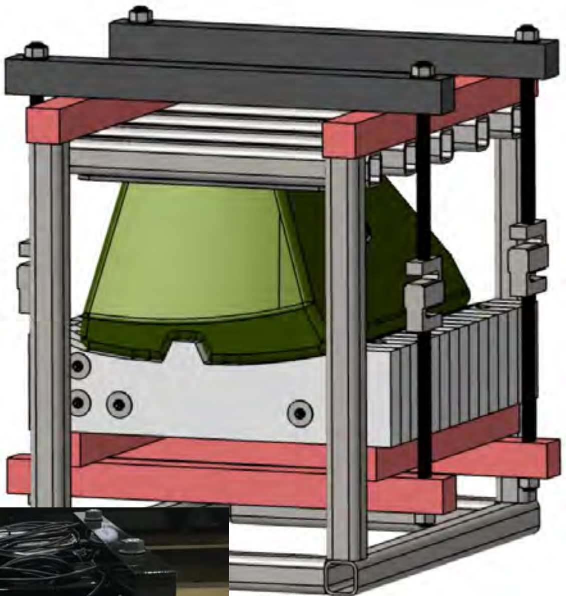
Y-joint Subcomponent Test Article

Air Bladder Characterization



- Test frame created to characterize overall force versus pressure as well as center of pressure for each of the six bladders





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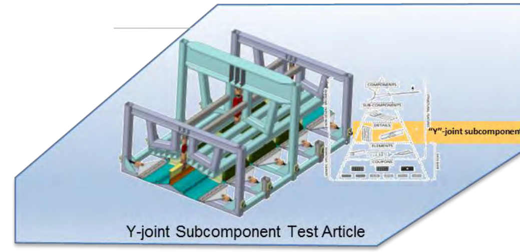
Subcomponent Testing Campaign



- Final strain gage instrumentation underway
- Testing to occur over next weeks

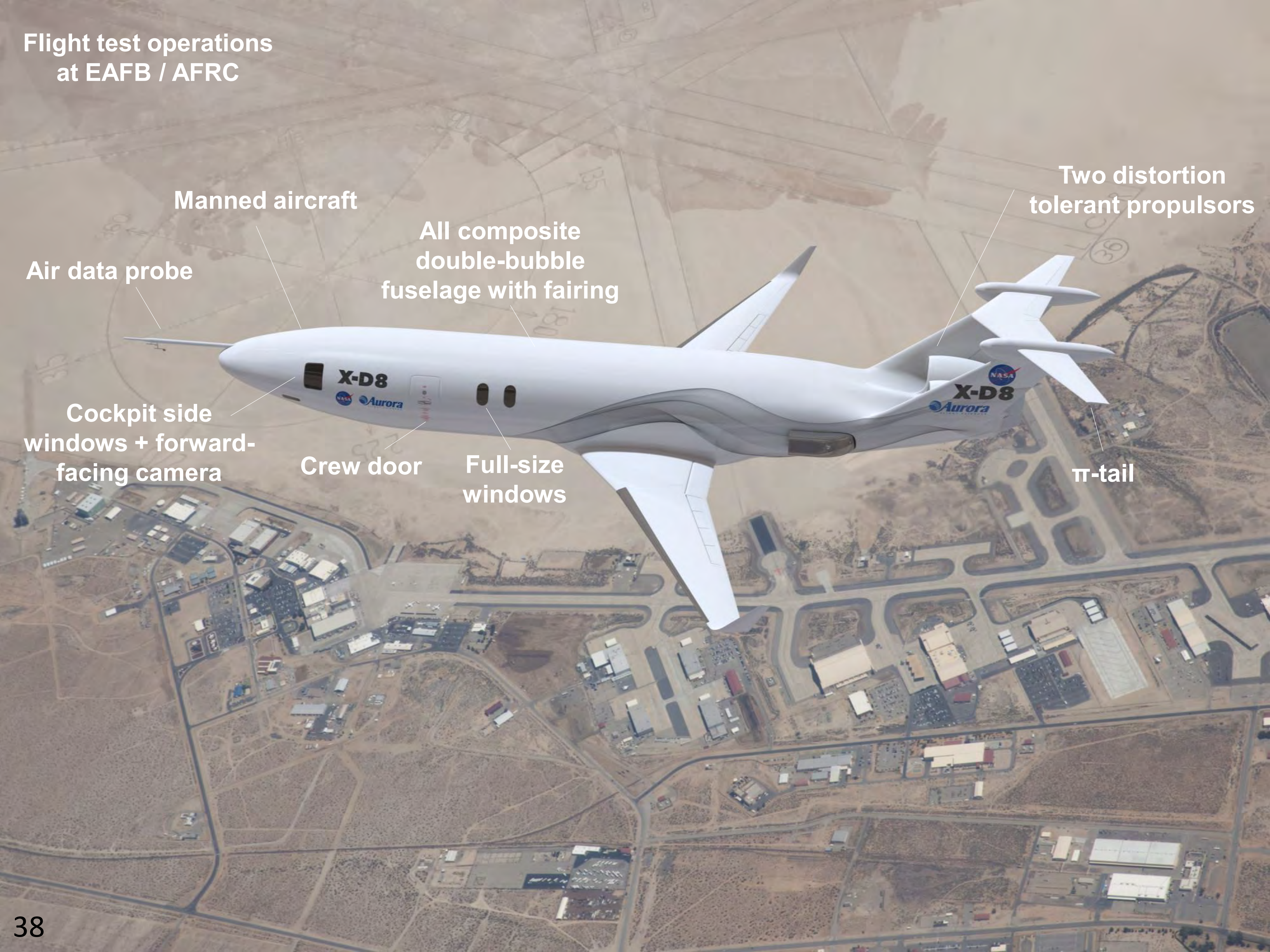
CLEEN II Fuselage Development Results

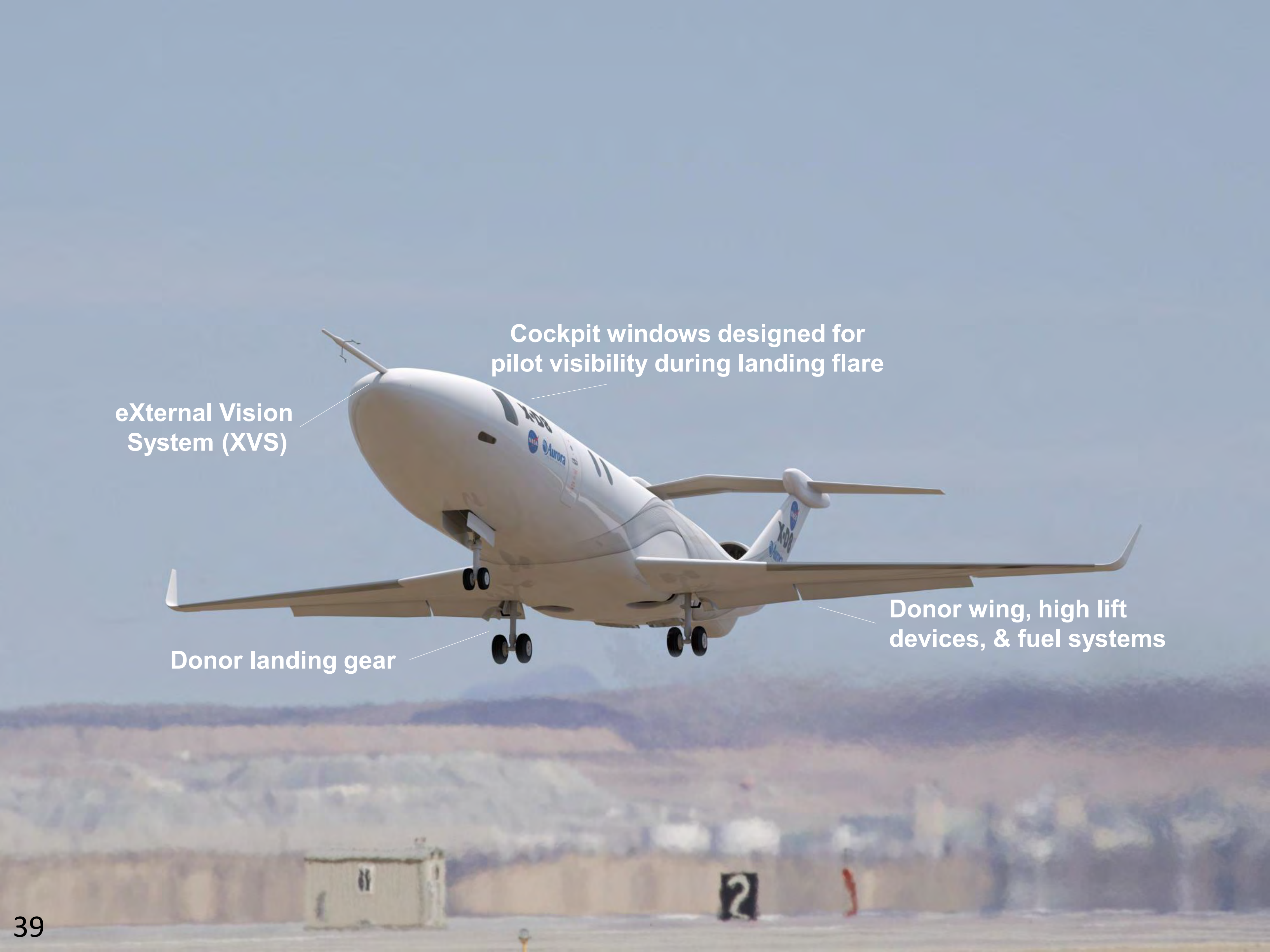
- D8 Y-joint technology enables a mass-efficient dual-lobed fuselage solution
- Structural performance of Y-joint technology tested during the CLEEN II program exceeded pre-test predictions
- After completion of subcomponent testing, D8 fuselage Y-joint technology is ready to proceed to flight demonstration

What Comes Next?

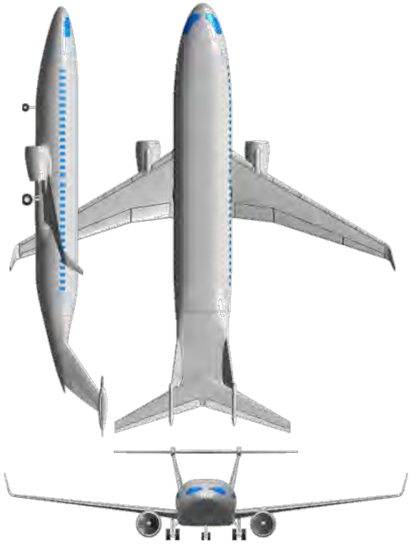
52% Scale X-Plane designed to mature vision system enabling technologies.

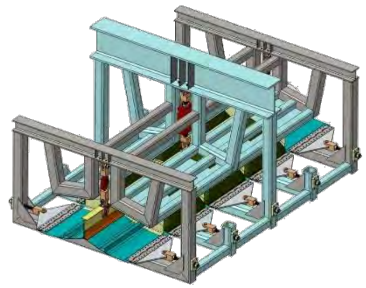
Vision system capable of meeting NASA/FAA efficiency goals and market desires.


Flight test operations
at EAFB / AFRC
Manned aircraft
Air data probe
All composite
double-bubble
fuselage with fairing
Two distortion
tolerant propulsors
X-D8
NASA
Aurora
Cockpit side
windows + forward-
facing camera
Crew door
Full-size
windows
π-tail


Cockpit windows designed for pilot visibility during landing flare
eXternal Vision System (XVS)
Donor wing, high lift devices, & fuel systems
Donor landing gear

Advanced Composite Unconventional Airframe Design-Build





Anticipated Benefits:
- *56% fuel and 32EPNdB cumulative noise benefits with 2035 technology and integrated engines*
- *29% fuel and 16 EPNdB cumulative noise benefits for 2025 with wing mounted engines*

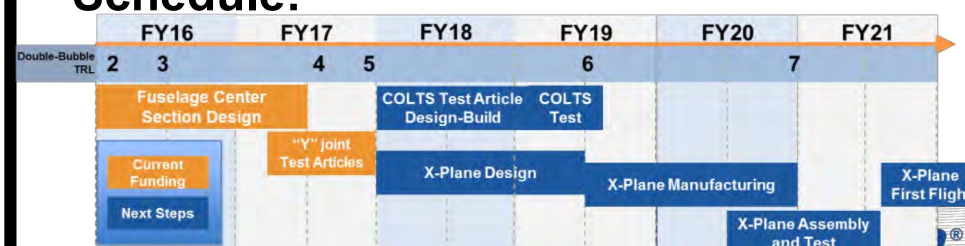
Risks/Mitigation Plans:
- *Building block approach to design validation*
- *"Y"-clip element tests*
- *Flight demonstrator*

Objectives:
- *Satisfy load and geometry constraints with weight efficient design*
- *Demonstrate airframe fabrication using production methods capable of type certification*

Work Statement:
- *Design center fuselage of scale demonstrator*
- *Test article design and fabrication*
- *AFP tool design and fabrication*
- *Test and evaluation*

Accomplishments/ Milestones since you initiated this technology/project:
- *Performed design trade studies*
- *Optimized test coupon and article design*
- *Designed and procured cure tools*
- *Manufactured coupons, test article, and test fixture*
- *Completed coupon test campaign*
- *Proceeded to subcomponent testing*

Schedule:



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Summary

- Under CLEEN II, Aurora is developing composite airframe technologies enabling unconventional configurations that will reduce fuel burn, emissions, and noise
- The D8 configuration developed by NASA / MIT/ Aurora / P&W results in up to 56% fuel burn reduction with integrated boundary layer ingesting (BLI) engines and 29% with wing mounted engines
- Advanced composite airframe design and manufacturing methods can enable efficient aircraft configurations to be built with reliable, repeatable, and certifiable processes

Thanks to NASA and the FAA for their continued D8 partnership since 2008. This work would not have been possible without their support.