

DEMONSTRATING FAA CERTIFIABLE ULTRA-EFFICIENT COMMERCIAL
AIRCRAFT CONFIGURATIONS
FAA CLEEN-II PUBLIC SESSION
2 MAY 2018

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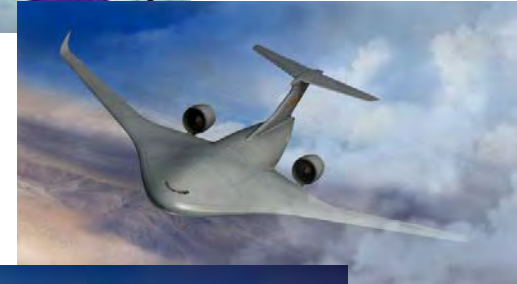
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Program Synopsis

- 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 GFY2018

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



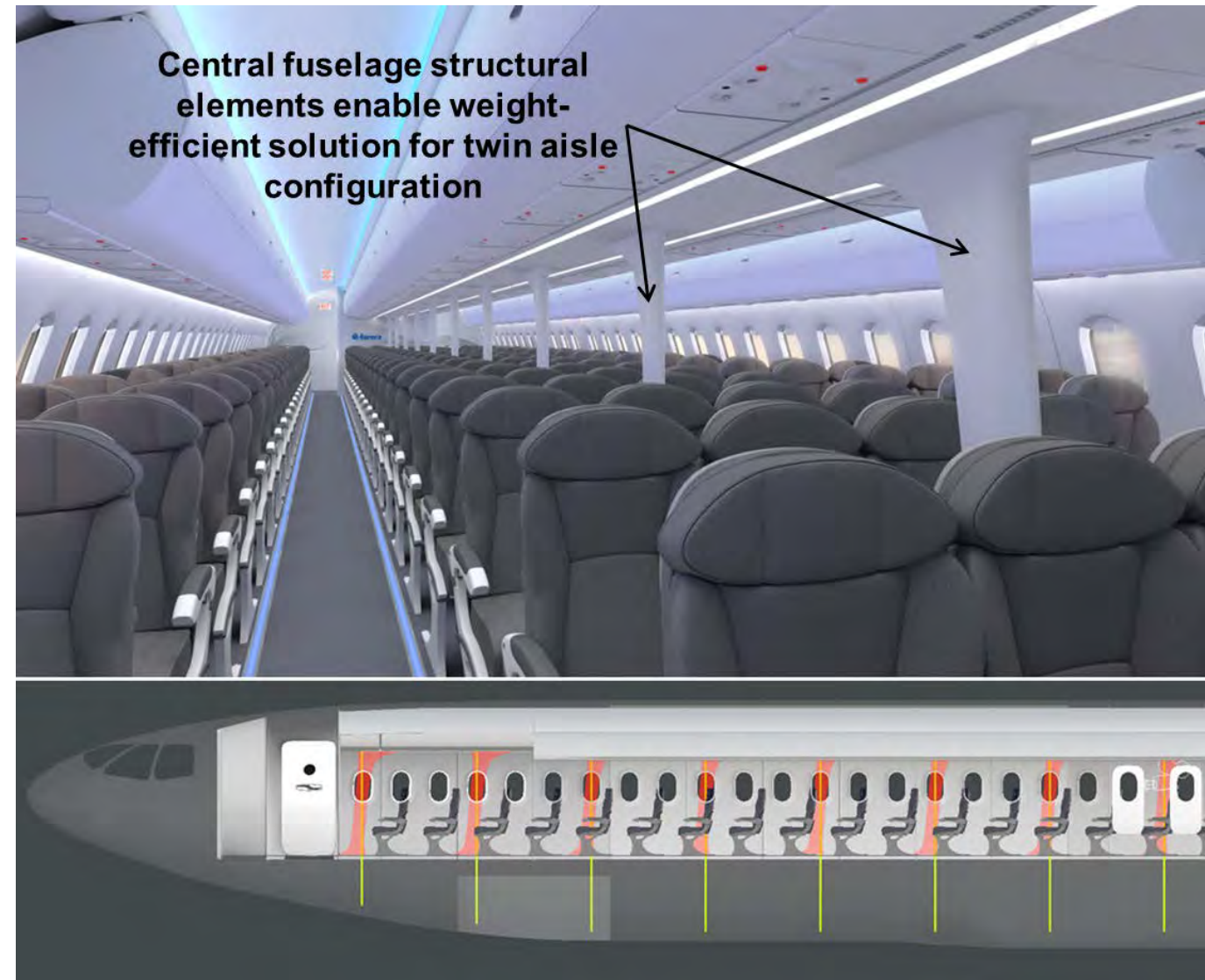
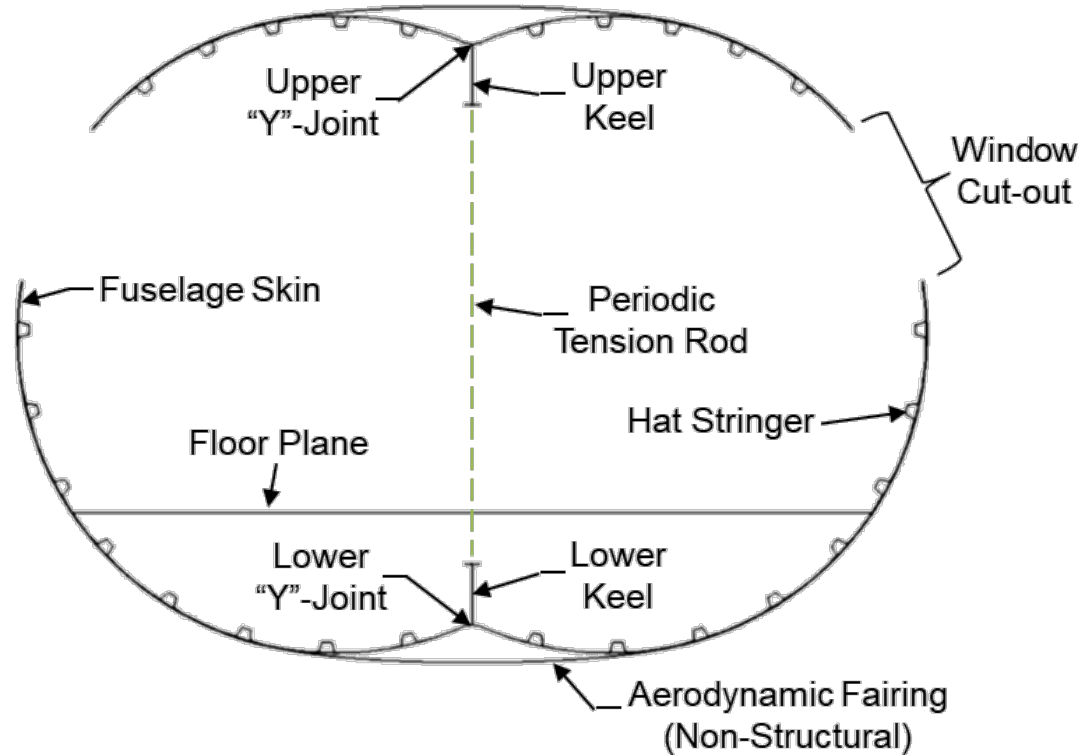
Aurora's D8 Subsonic Transport Aircraft

Integrated airframe and
propulsion for Boundary
Layer Ingestion (BLI)

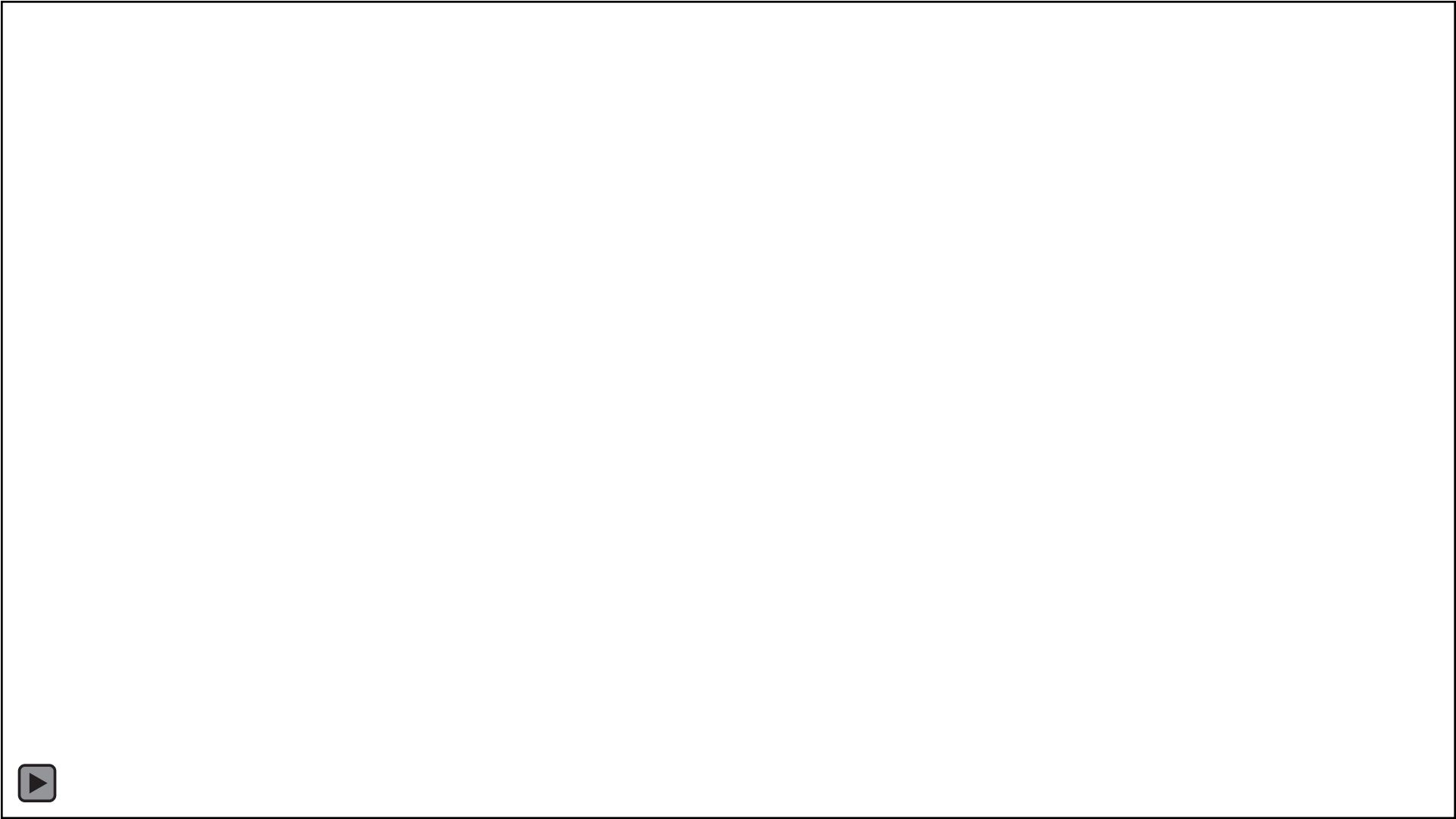
Non-round "double-
bubble" composite
fuselage



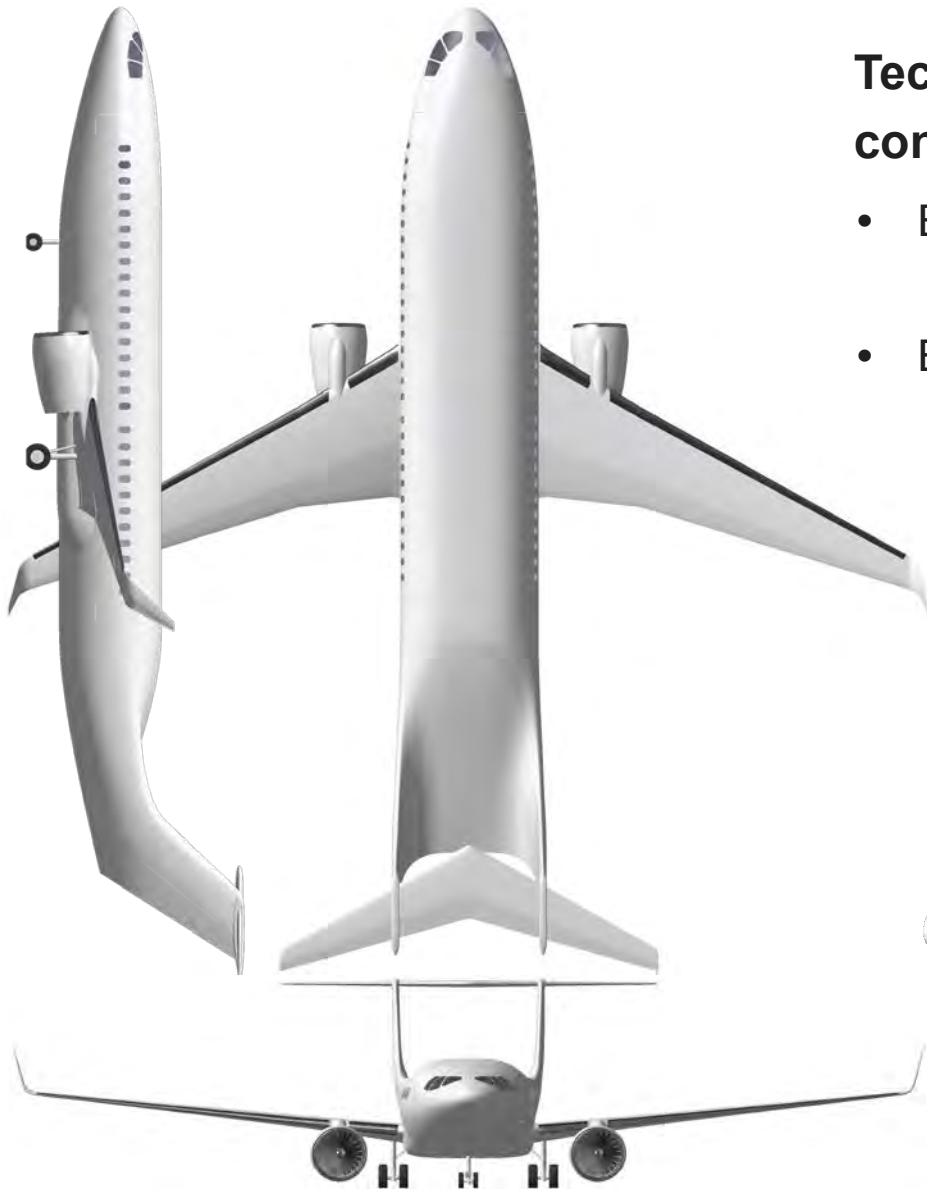
Future D8 Transport: Double-Bubble Fuselage Requires Unique Central Elements



D8 Cabin Fly Through



CLEEN D8 Variant has 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



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

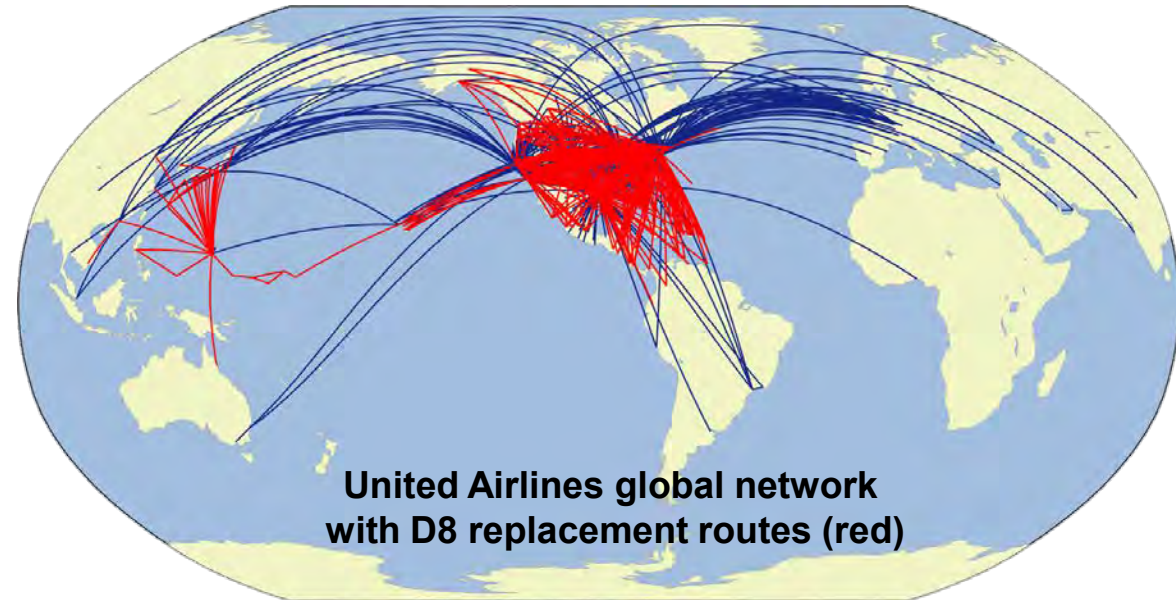
Benefits relative to a B737-800 aircraft. See Yutko et al, 2017 for details.

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.

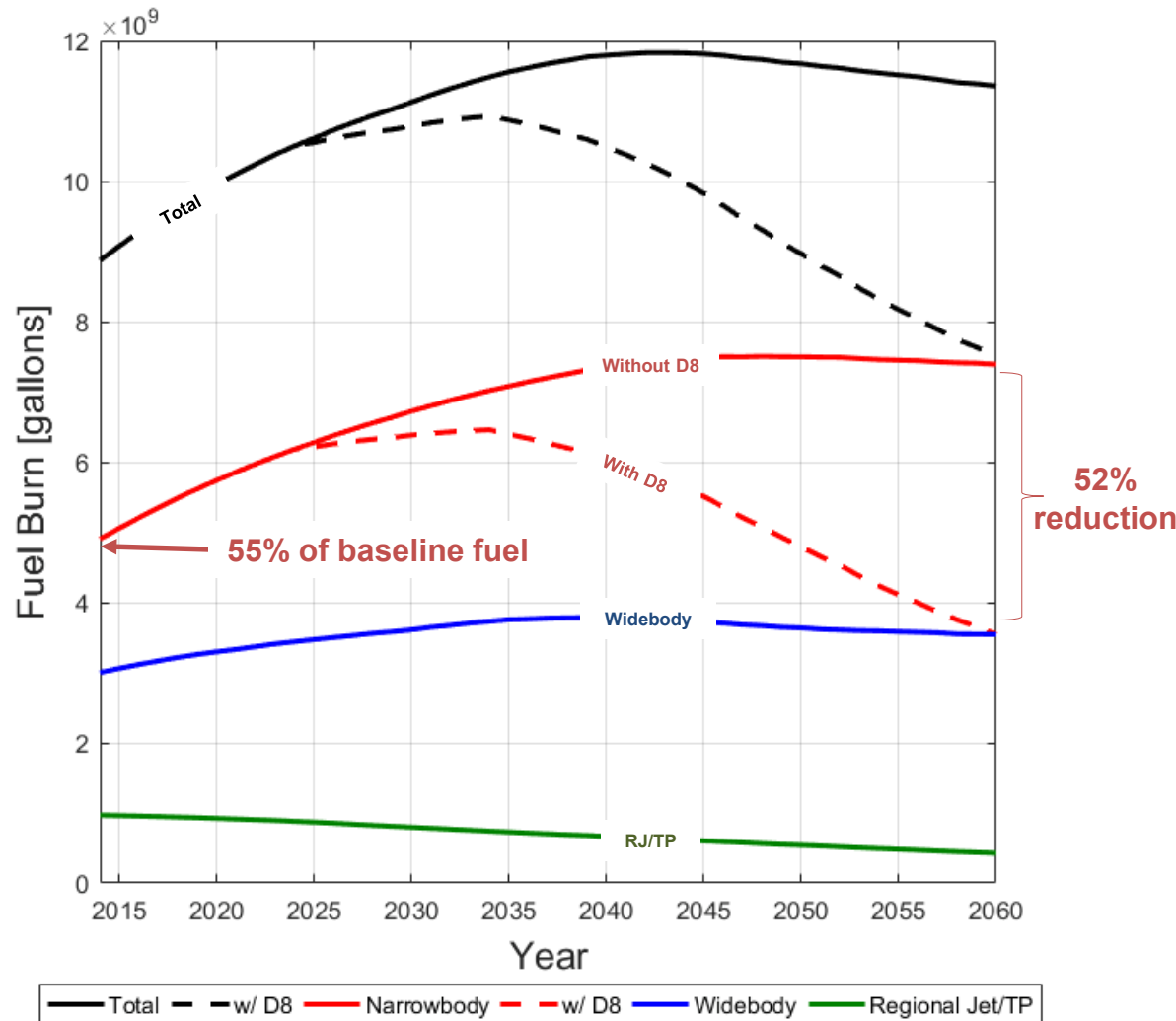
Examples:

- 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

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

Luke L. Jensen^{*}, Jacqueline Thomas^{*}, Callen Brooks^{*}, Morrisa Brenner^{*}, and R. John Hansman[†]
Massachusetts Institute of Technology, Cambridge, MA 02139, USA

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

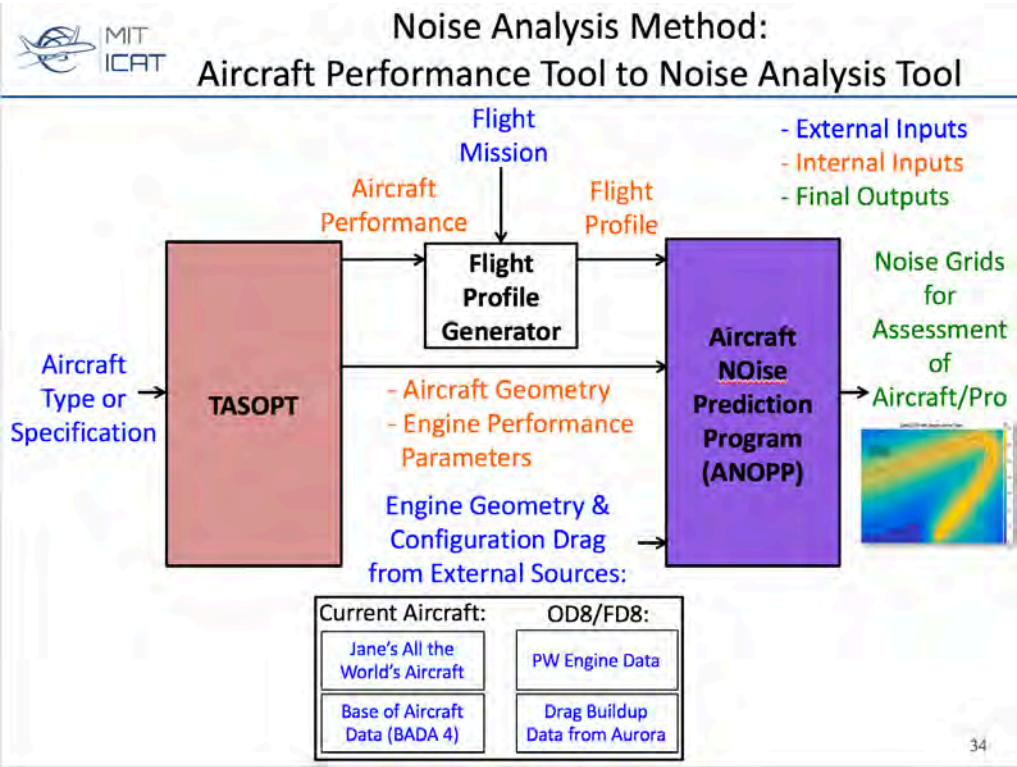
Assessment of system-level aircraft environmental impact is a crucial component of decision making for analysts, regulators, and industry stakeholders. Changes in fleet mix, frequency, gauge, or operational procedures all drive change in noise, fuel burn, and emissions. These changes have significant 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 2016². 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.

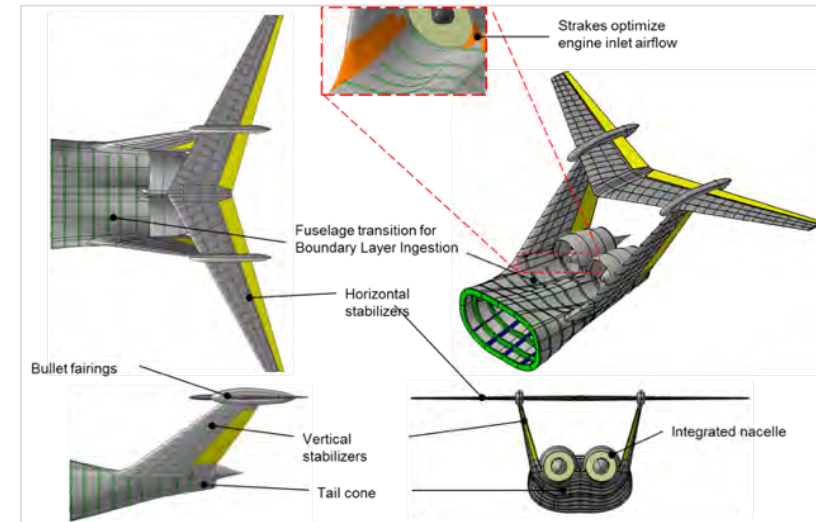
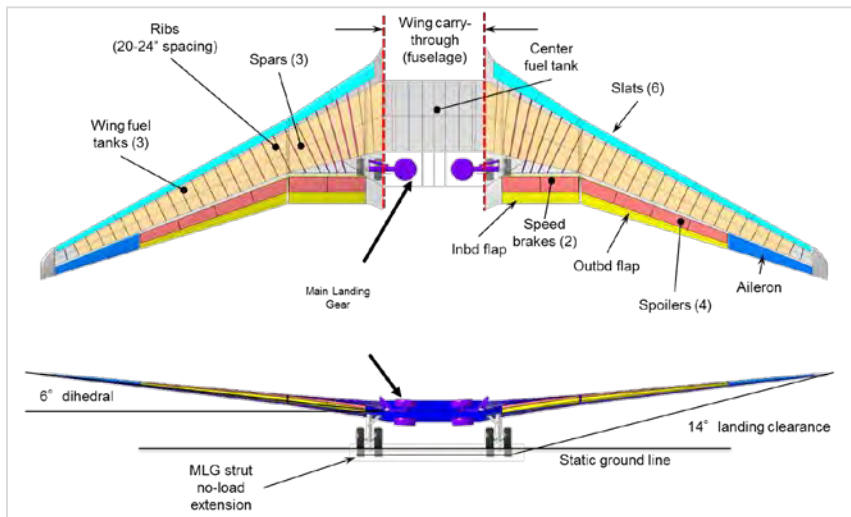
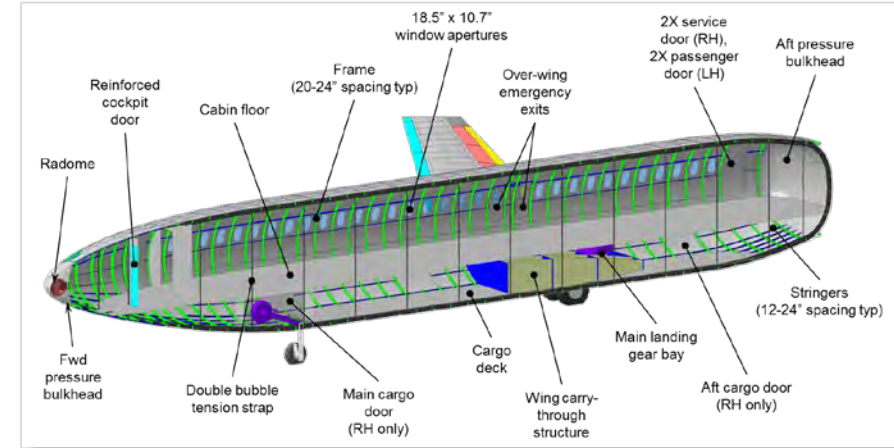
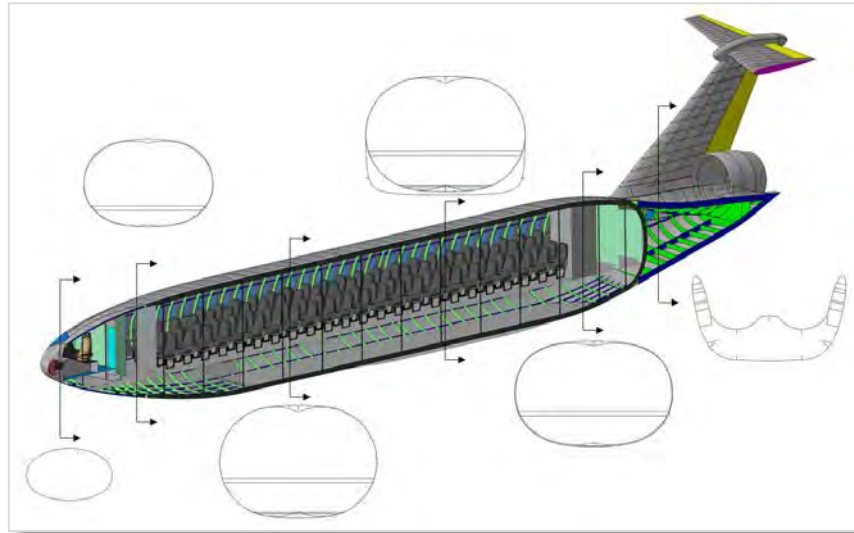
There are several challenges that a rapid environmental impact analysis method must overcome. First, the method must be able to model future aircraft types or modifications to existing types. Most existing models use aircraft performance data derived from flight testing which limits utility for analysis 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.

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

AVIATION 2017



Structural Design of Major Aircraft Elements

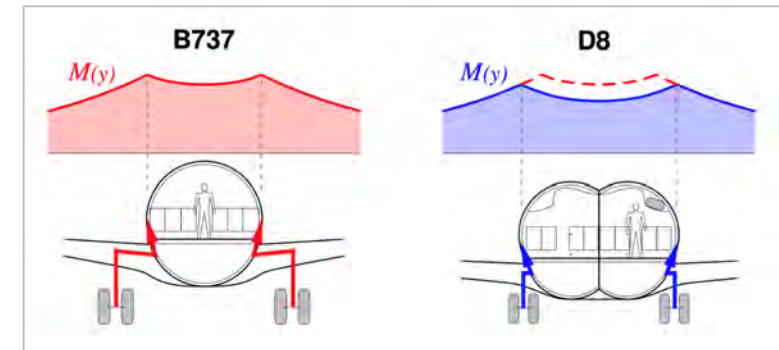


Non-BLI D8 Variant: Twin-Aisle Fuselage with Wing-Mounted Engines

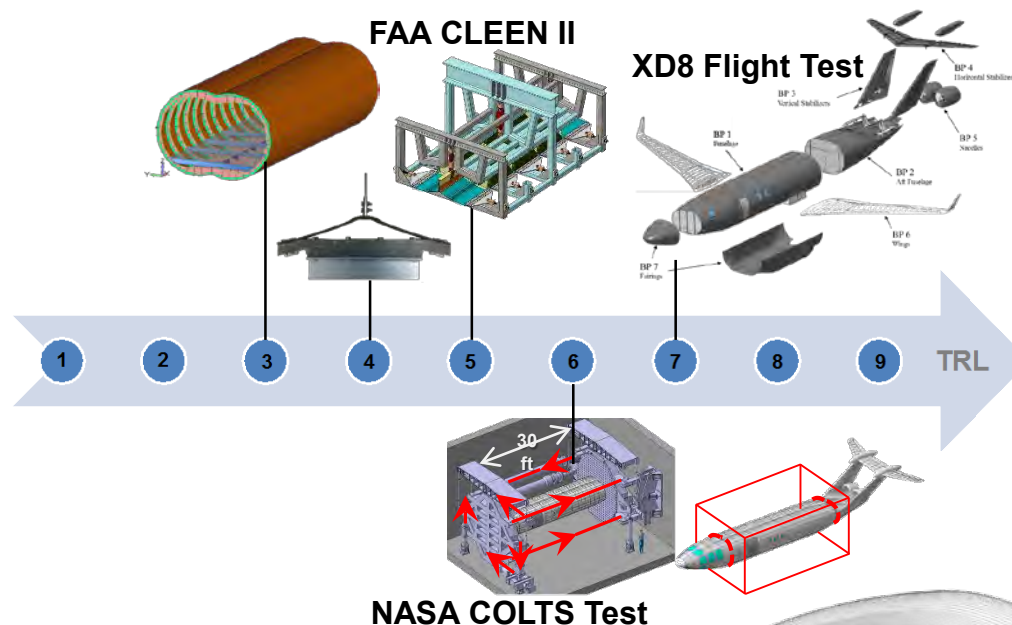
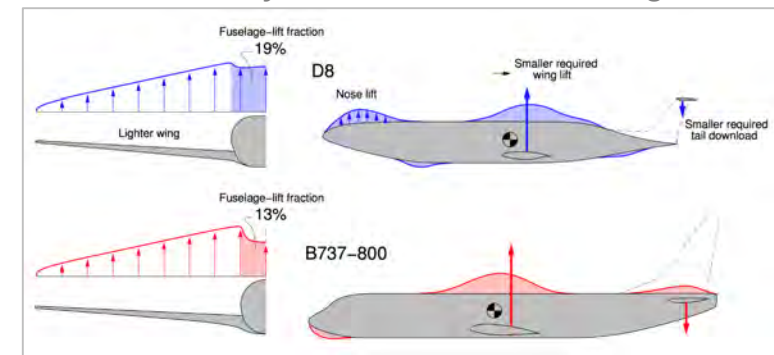


- As part of FAA CLEEN II program, Aurora is demonstrating critical “Y-joint”
- Mechanisms driving fuel efficiency benefits:

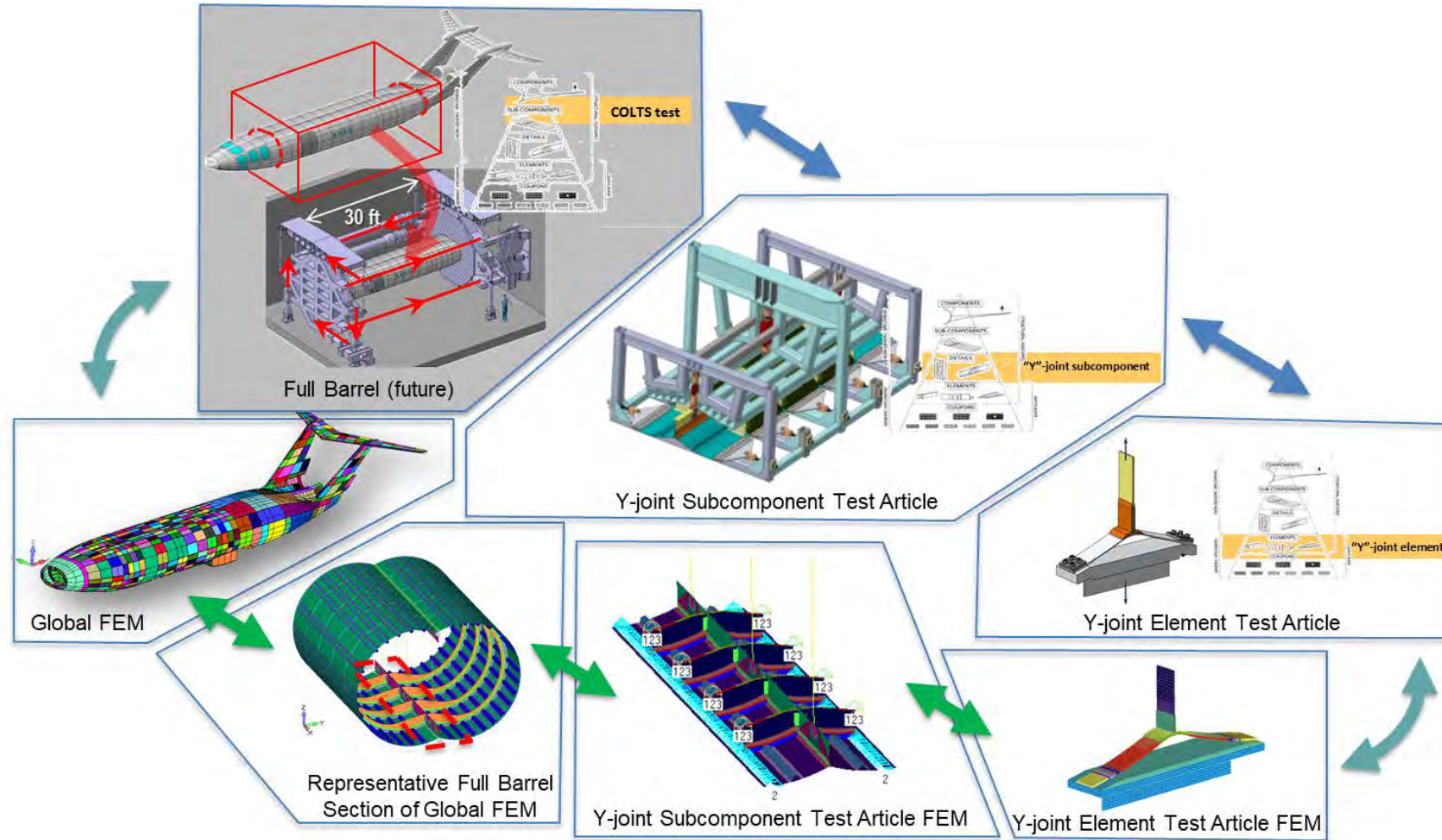
Reduced landing gear and wing weight



Increased carryover lift → smaller wing & tail



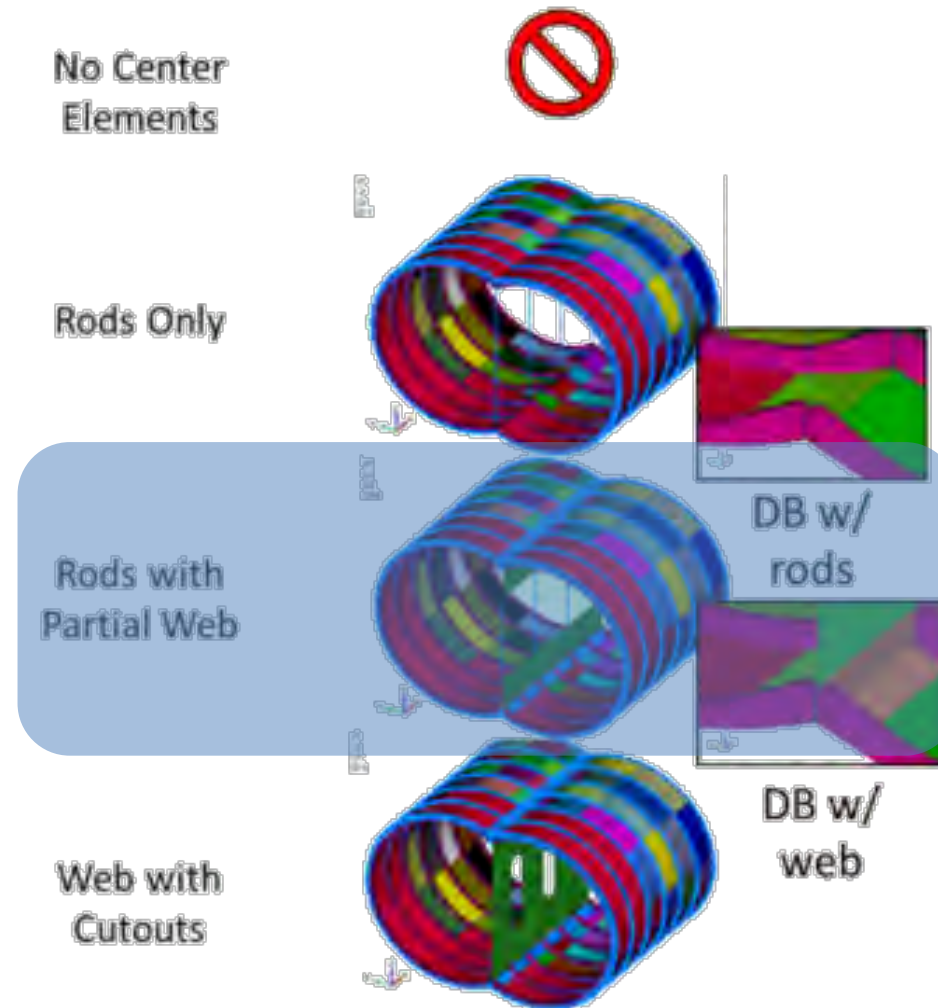
Building Block Approach to Develop D8 Double-Bubble Fuselage



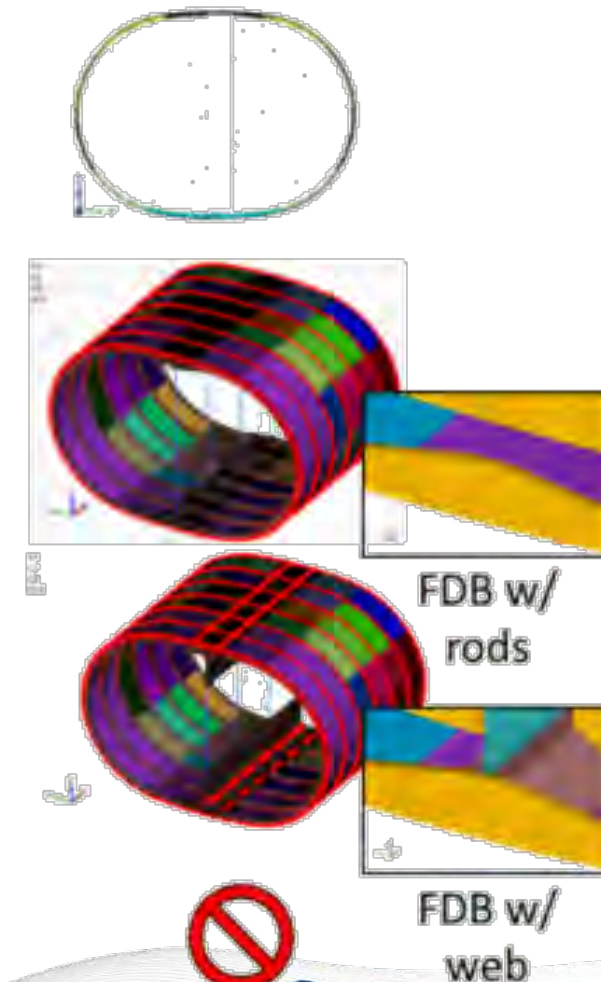
D8 Fuselage Cross-Section Trade Space (Reported at SciTech 2017)

- Trade found “Double Bubble” configuration with rods and partial web to be most mass efficient
- Web height had diminishing weight returns
- Massive frames required to react flat pressure bays of “Flat Double Bubble” configuration
- NASA independent trade reports similar trends

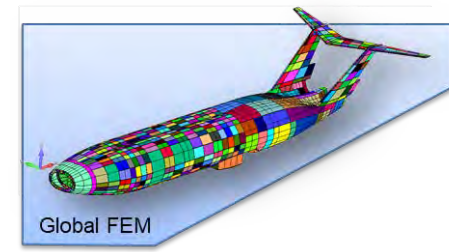
“Double Bubble” (DB)
Configuration



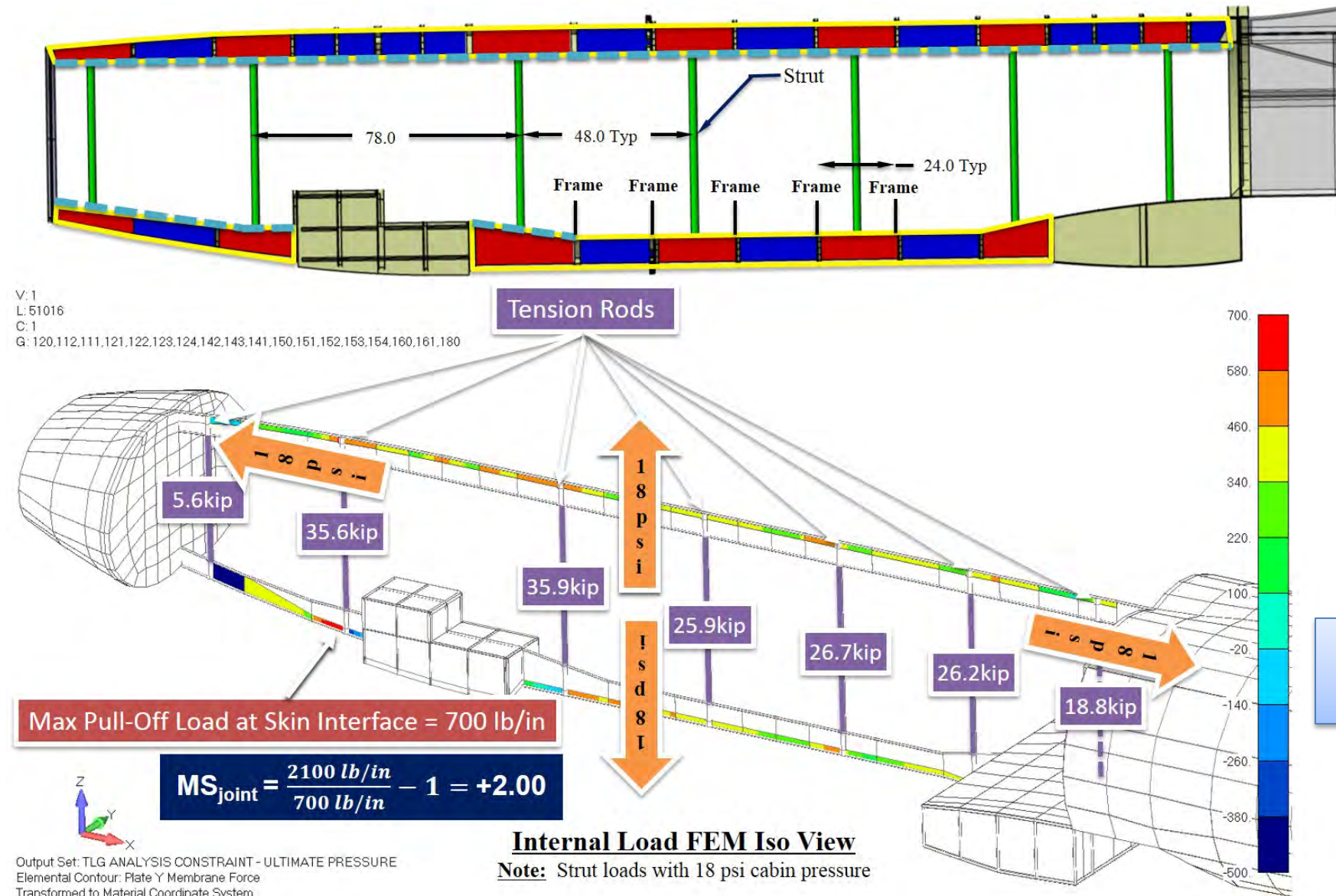
“Flat Double Bubble” (FDB)
Configuration



Global FEM Predicts Required Joint Capability

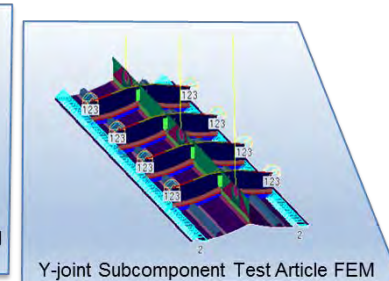
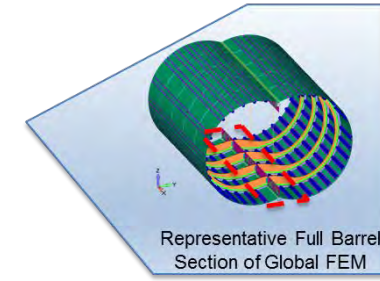
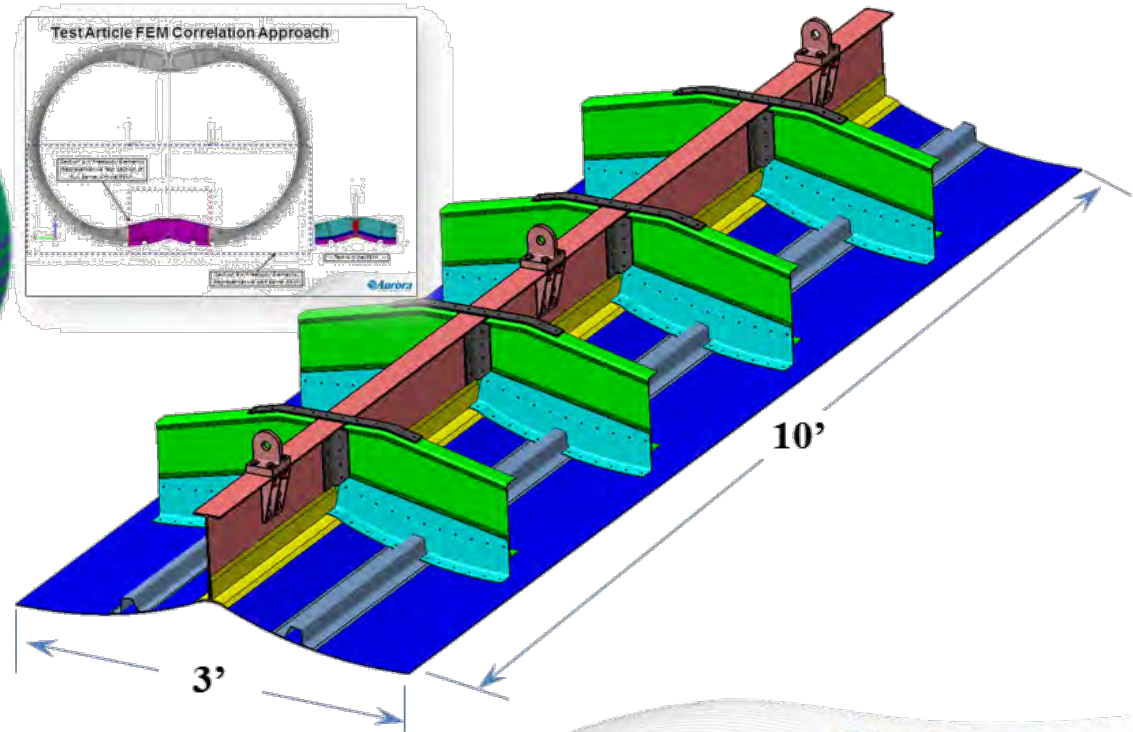
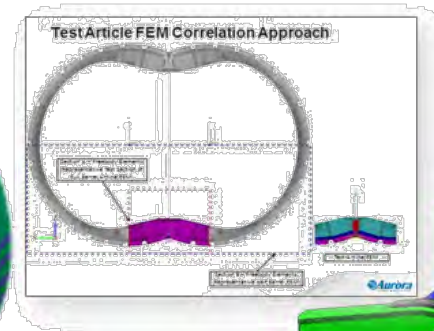
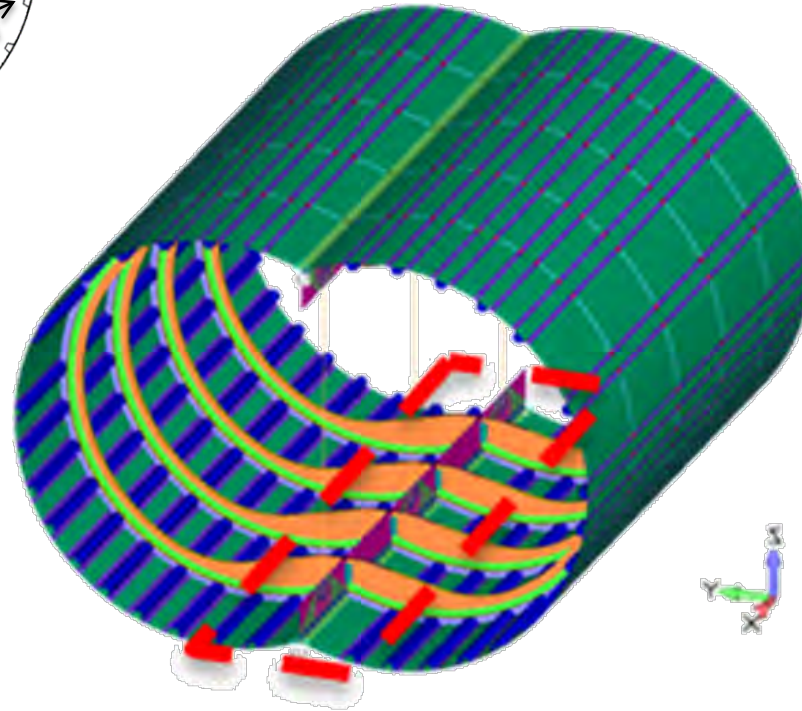
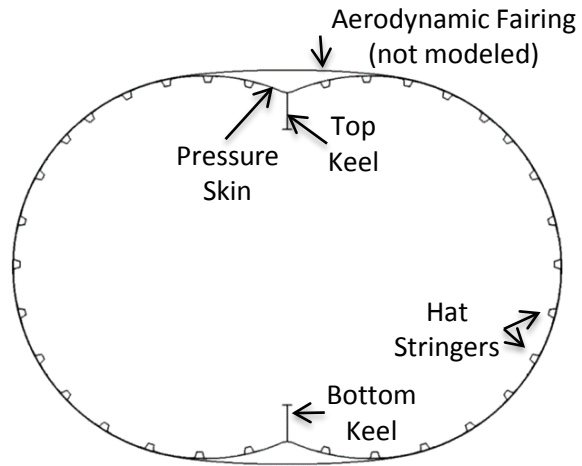


- GFEM assesses “Y”-joint capability for pressurized cabin at altitude load case
- Tension rod loads range predicted up to 36 kip
- Maximum “Y”-joint to skin pull-off load predicted just forward of nose landing gear bay



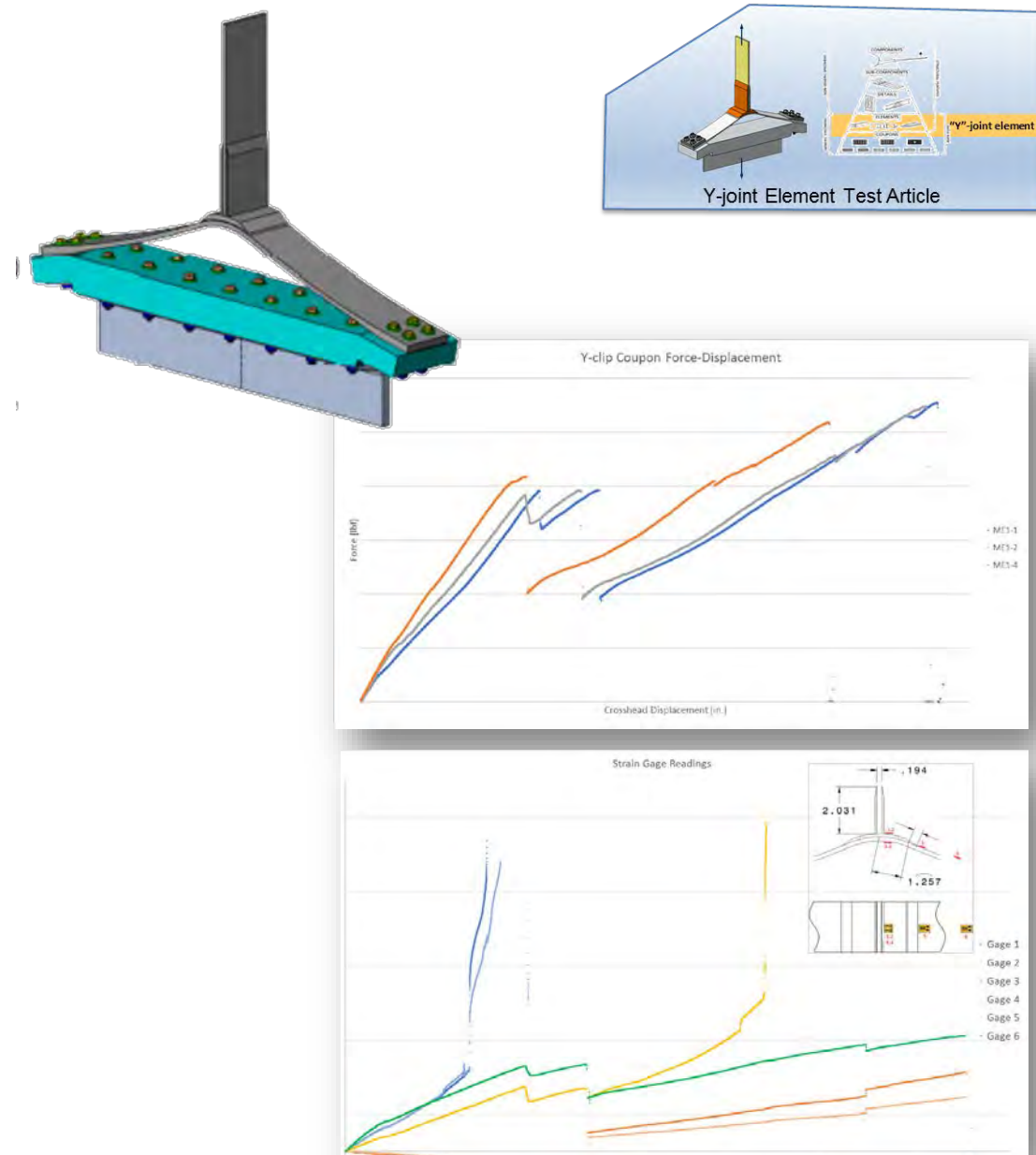
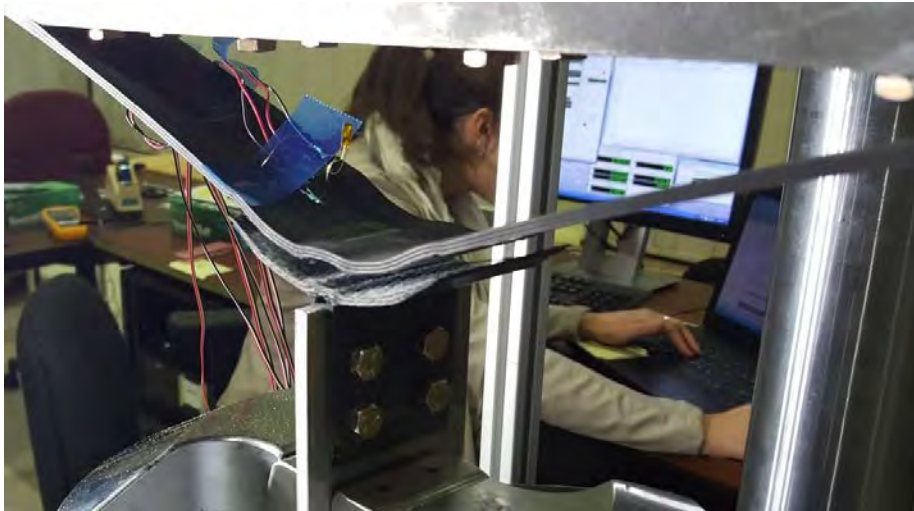
“Y”-joint capability must exceed 700 pounds per inch

Double-Bubble Fuselage Subcomponent

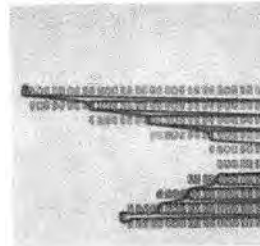
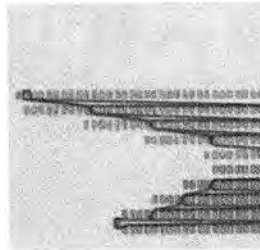
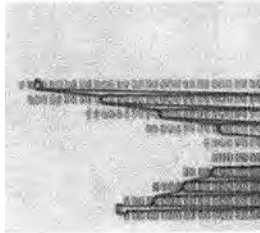
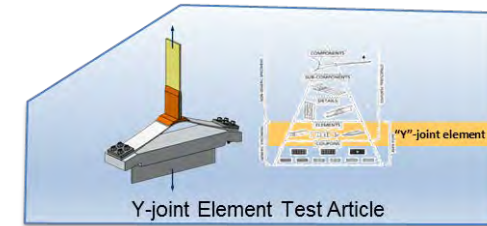


“Y”-joint Element Testing

- Element test campaign explored tensile capability of “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



“Y”-Joint is 3D Woven Preform

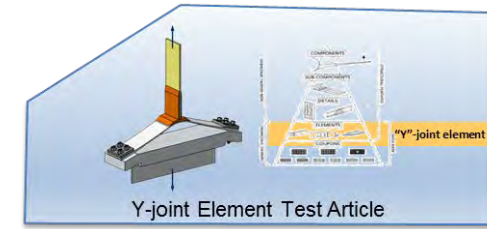


US 8127802 B2

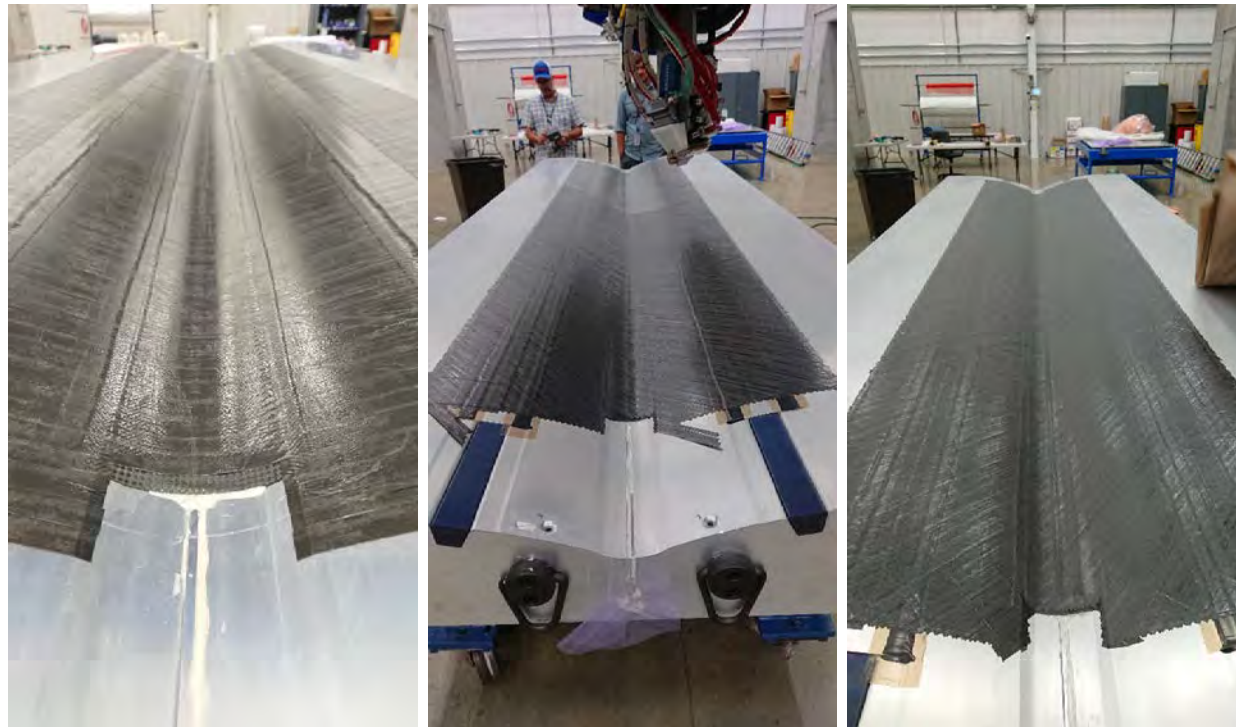
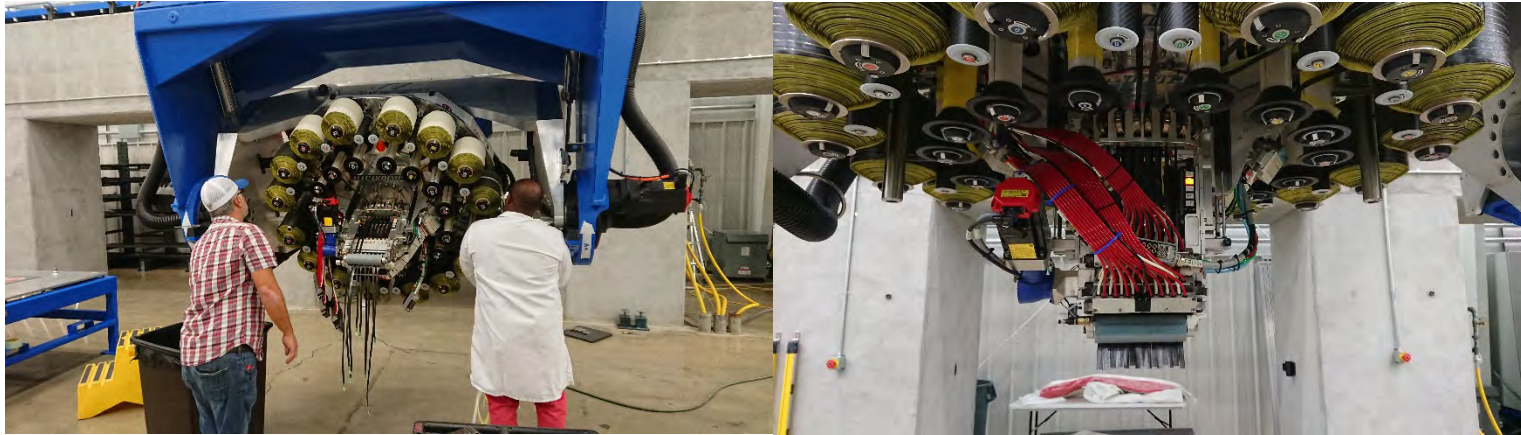
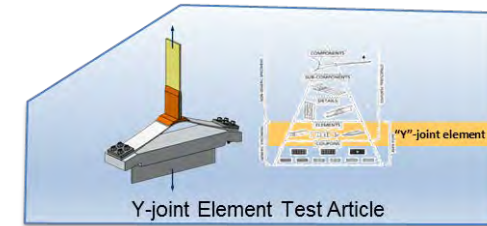


T800/3900-2 preforms
Toray donated material for preforms
Preform arrives as a prepreg

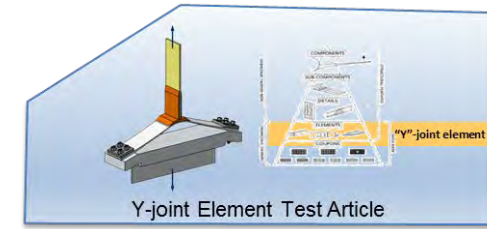
Y-Joint Element Manufacturing



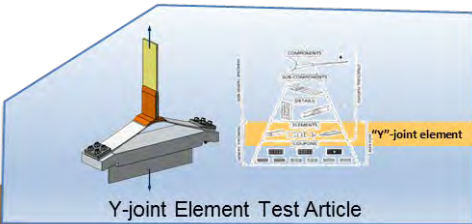
Y-Joint Element Manufacturing



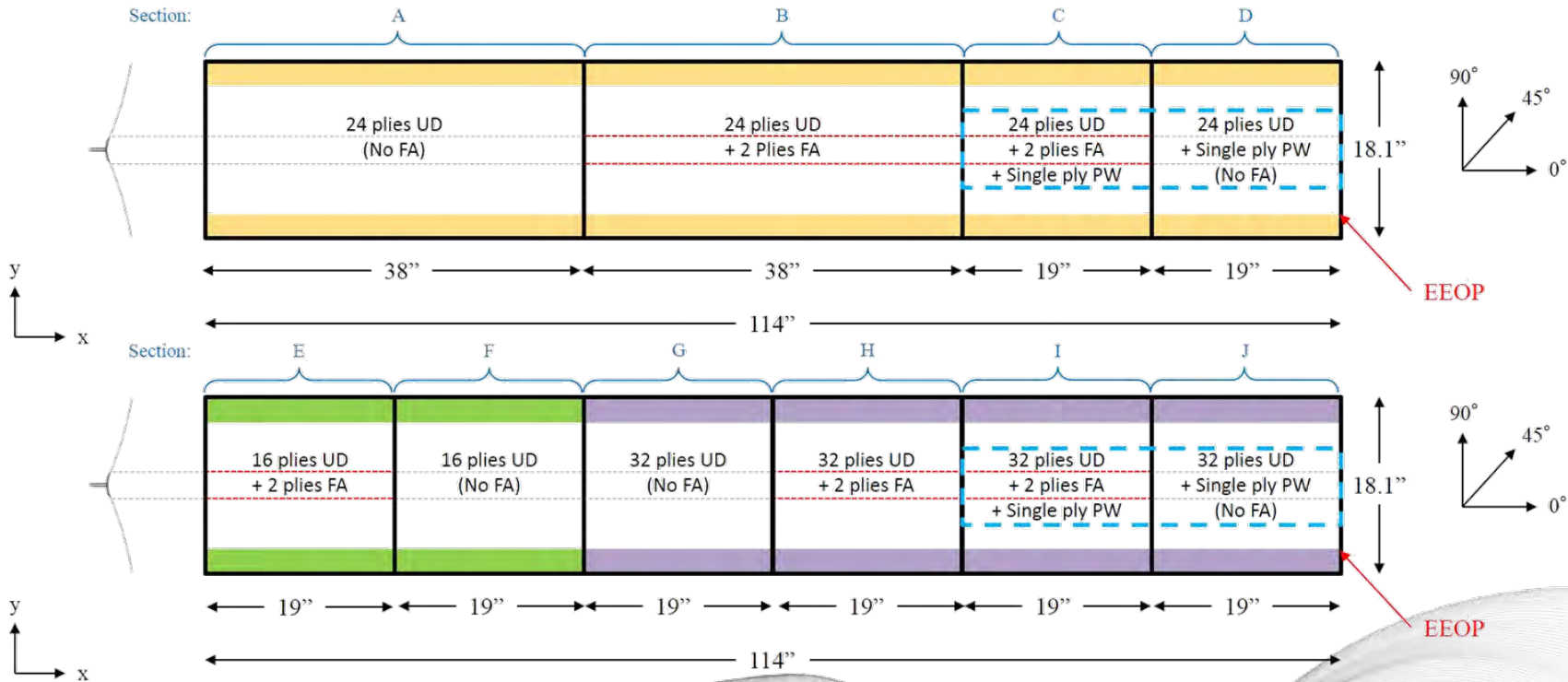
45-ply AFP Video



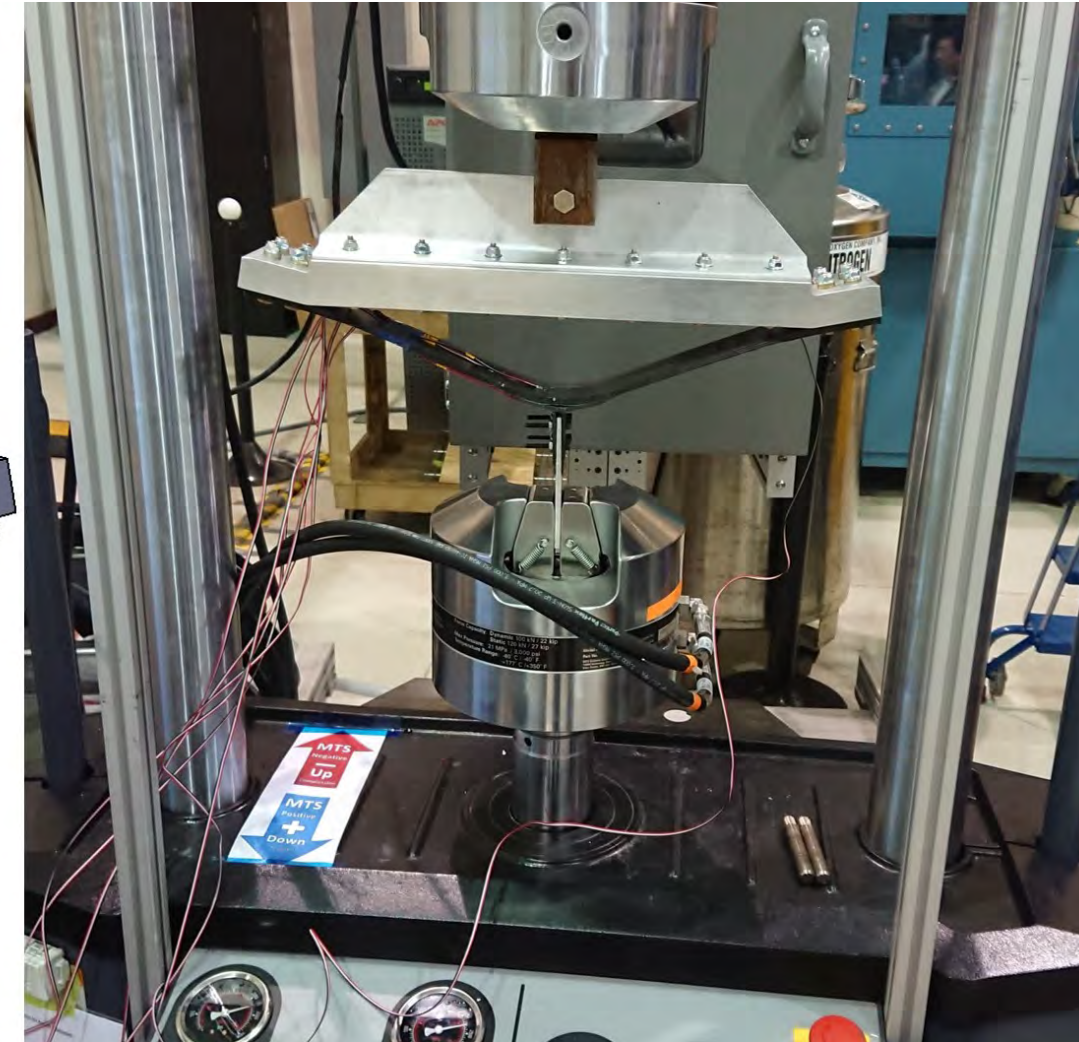
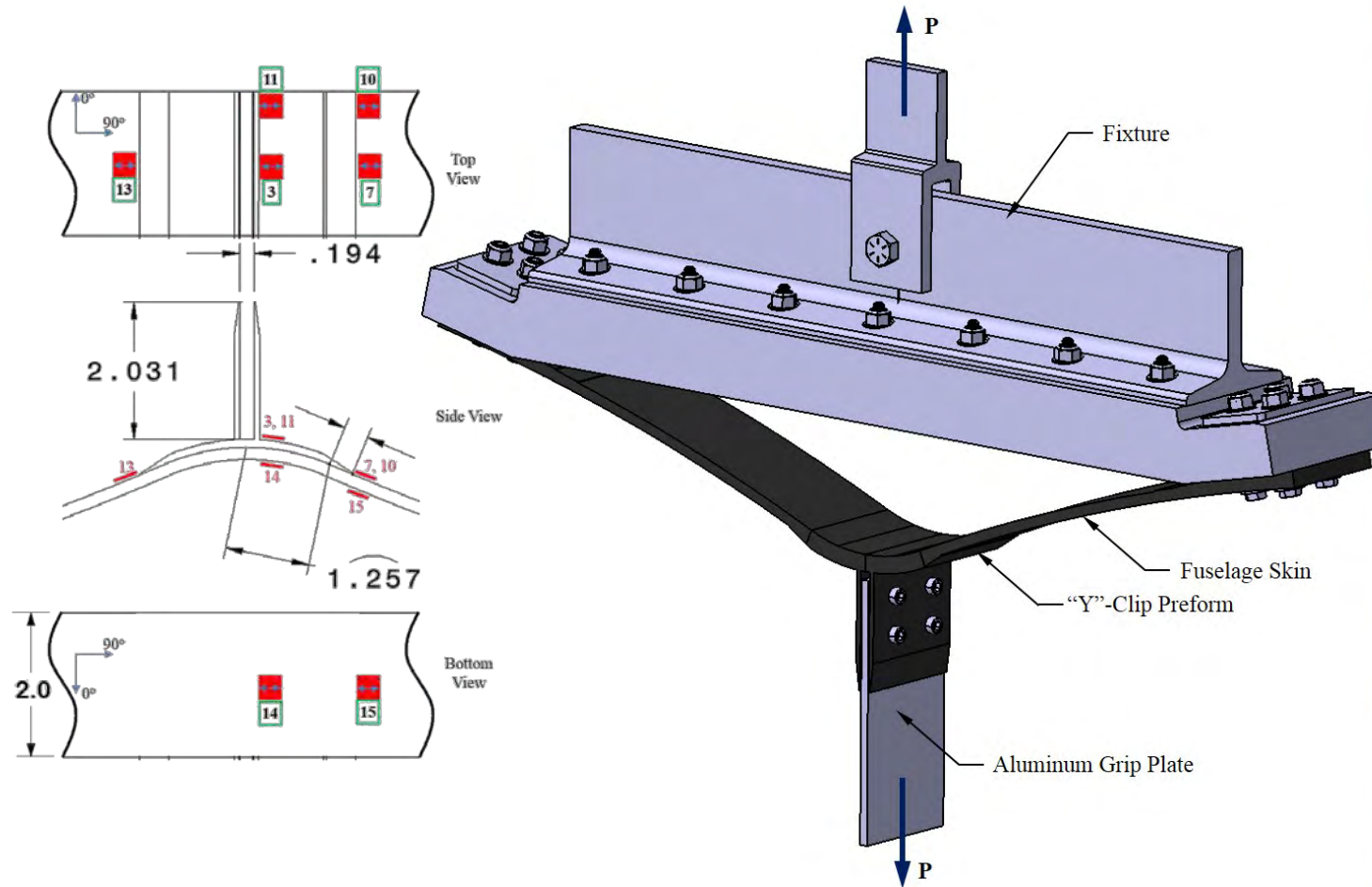
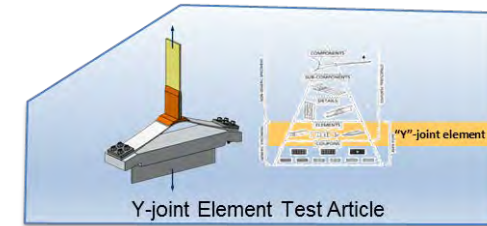
10 Element Configurations Manufactured and Tested



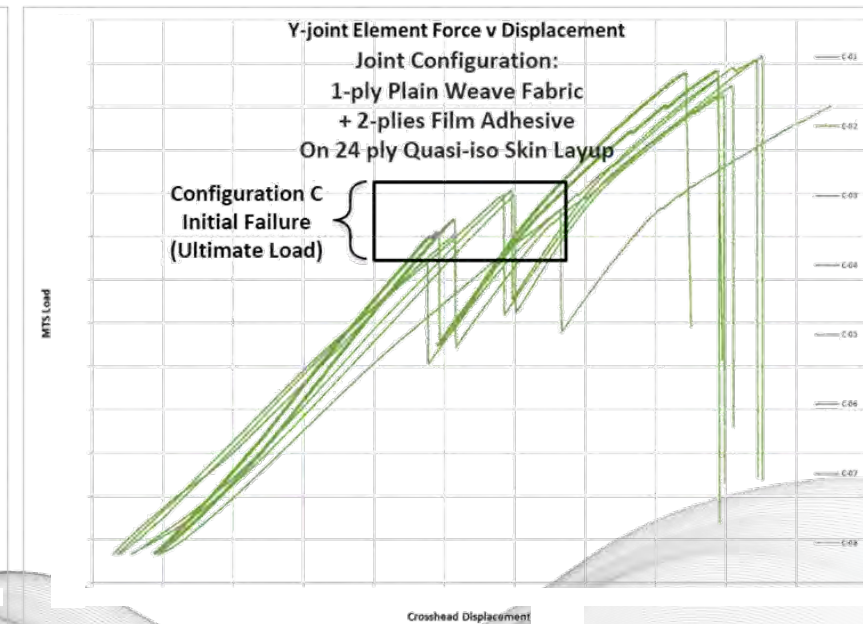
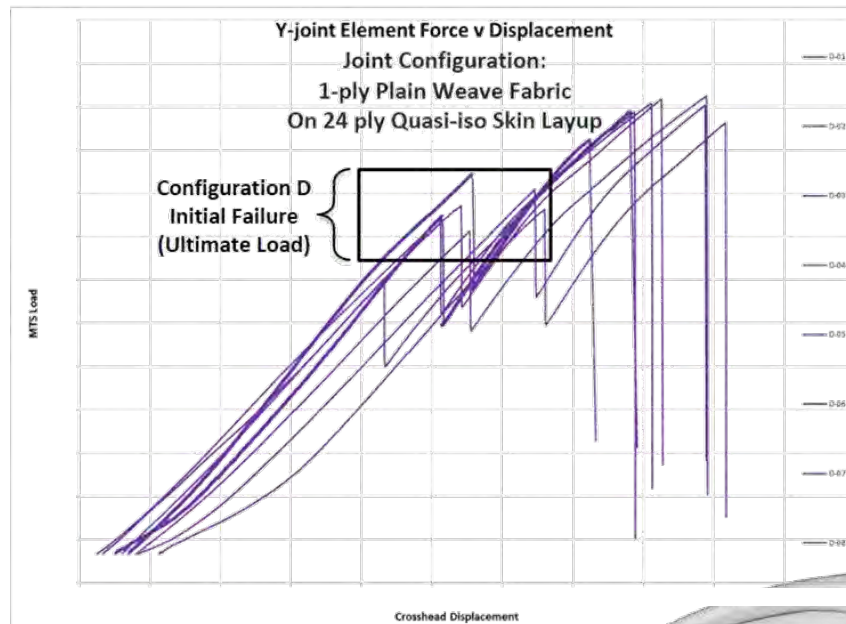
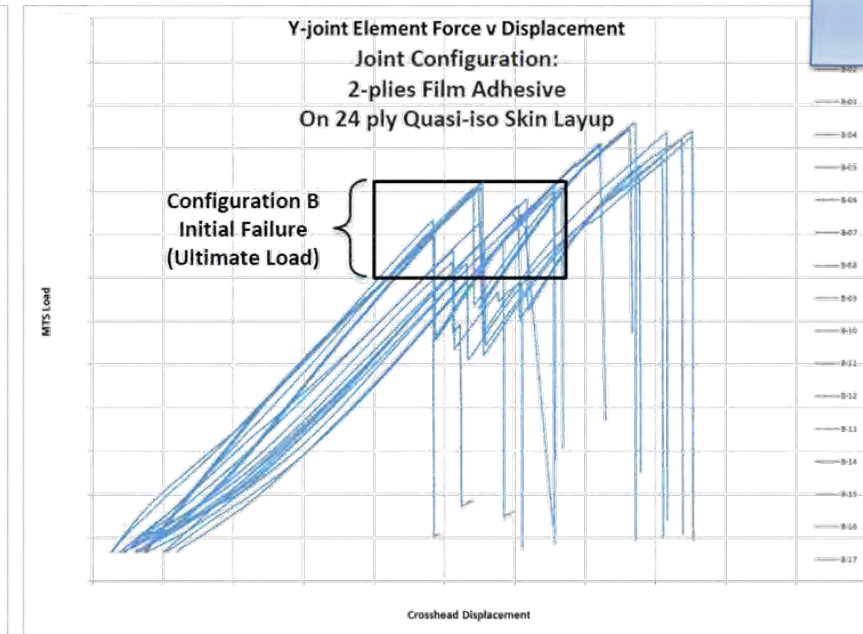
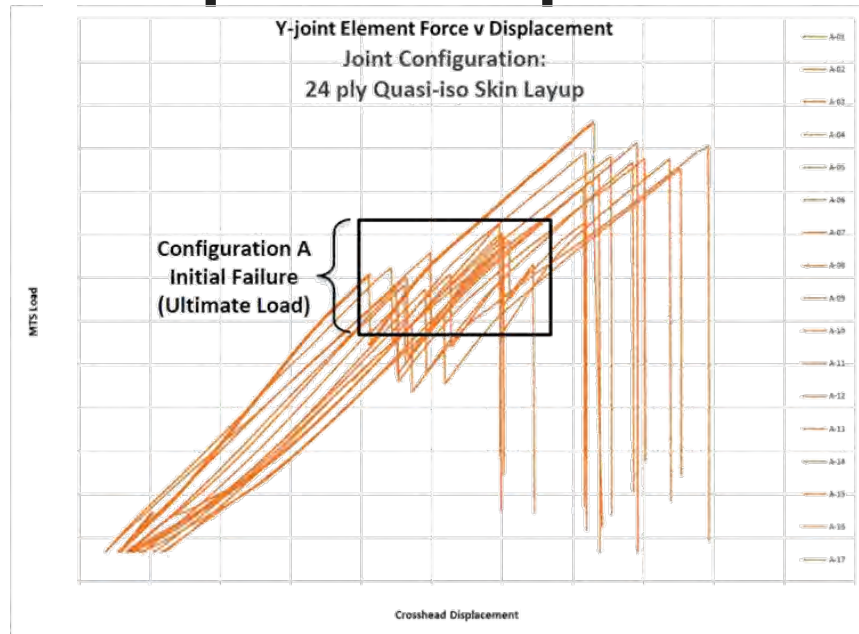
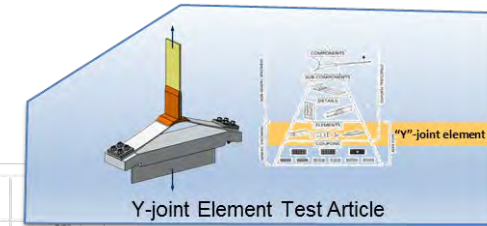
Configuration	Skin Thickness [plies]	Interface	# Elements
A	24	-	17
B	24	FA	17
C	24	FA + PW	8
D	24	PW	8
E	16	FA	8
F	16	-	8
G	32	-	8
H	32	FA	8
I	32	FA + PW	8
J	32	PW	8
TOTAL			98



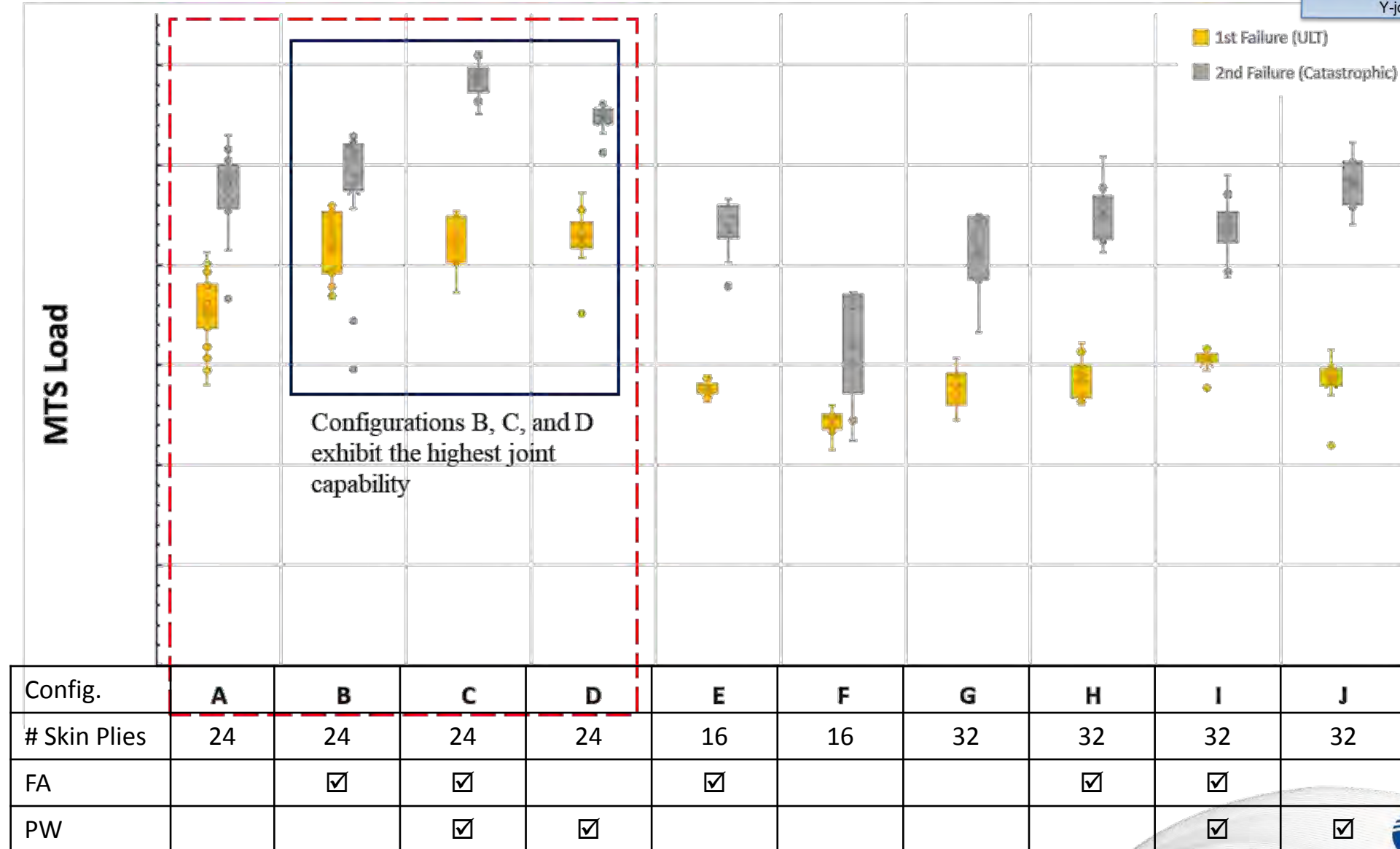
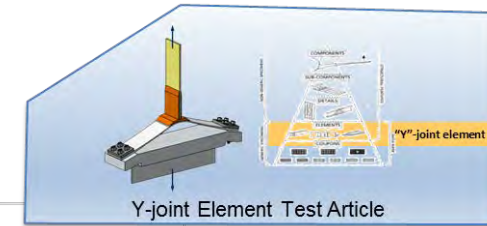
“Y”-joint Element Experimental Setup



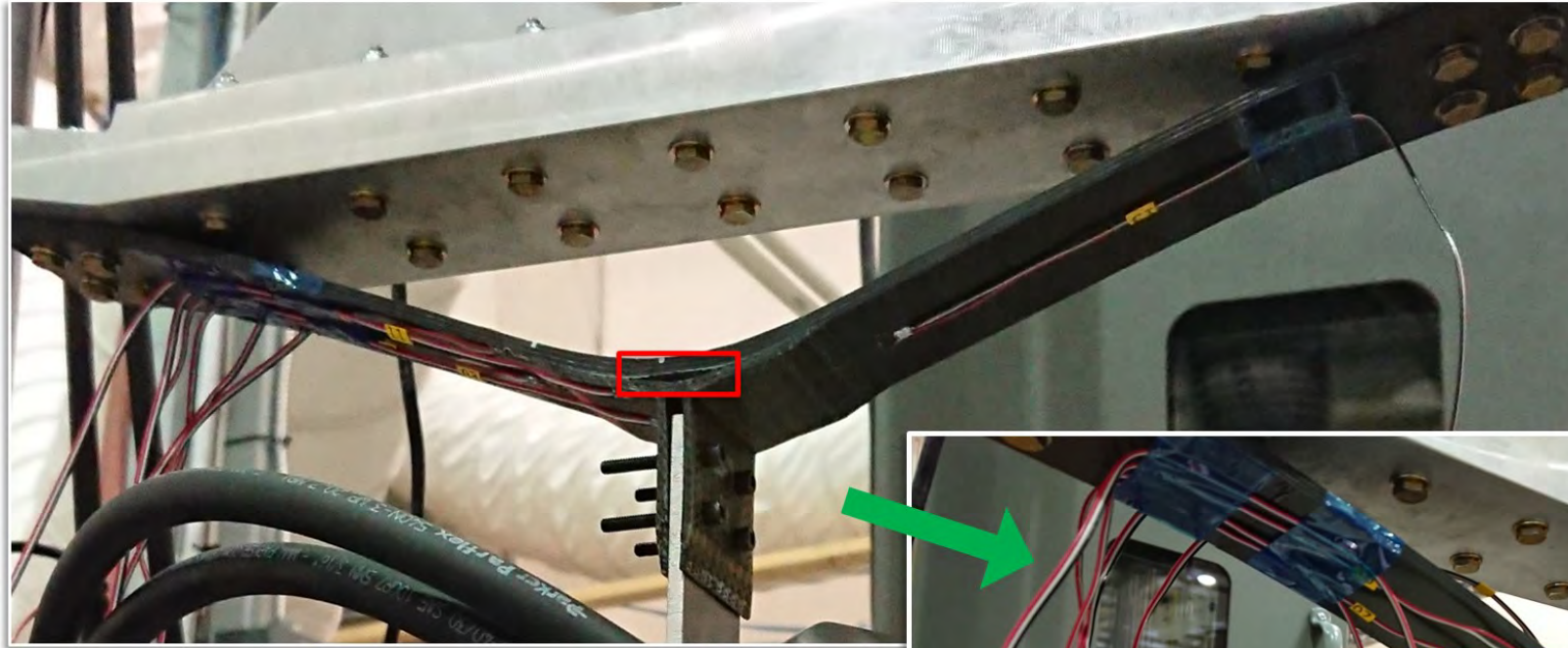
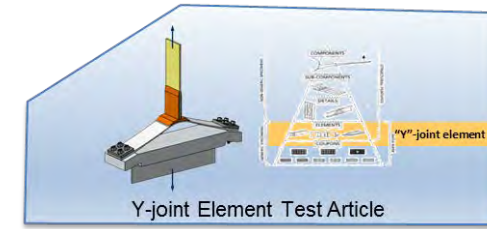
Element Response Repeatable



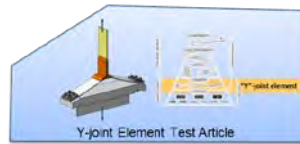
Element Load Capability Summary



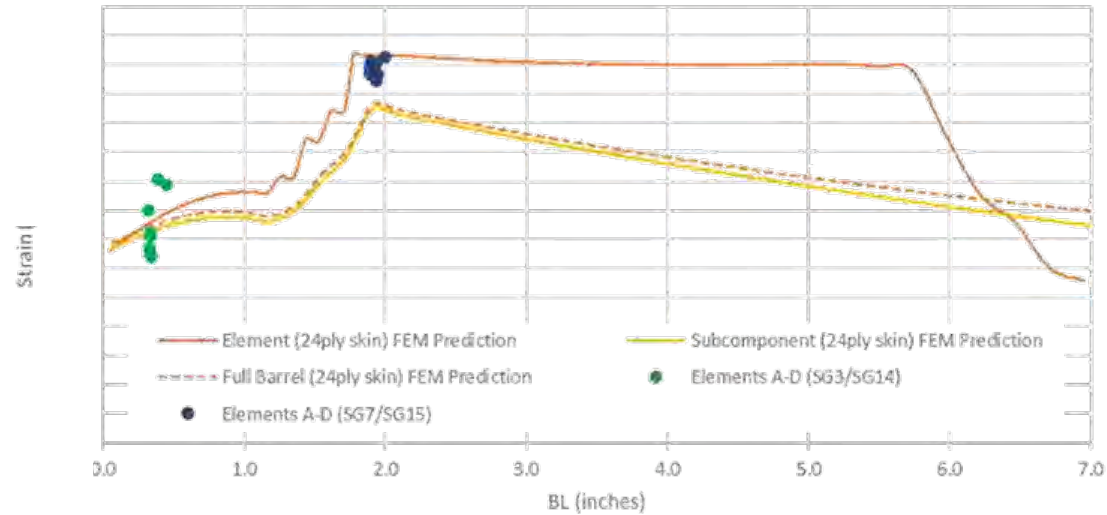
Typical Failure Progression



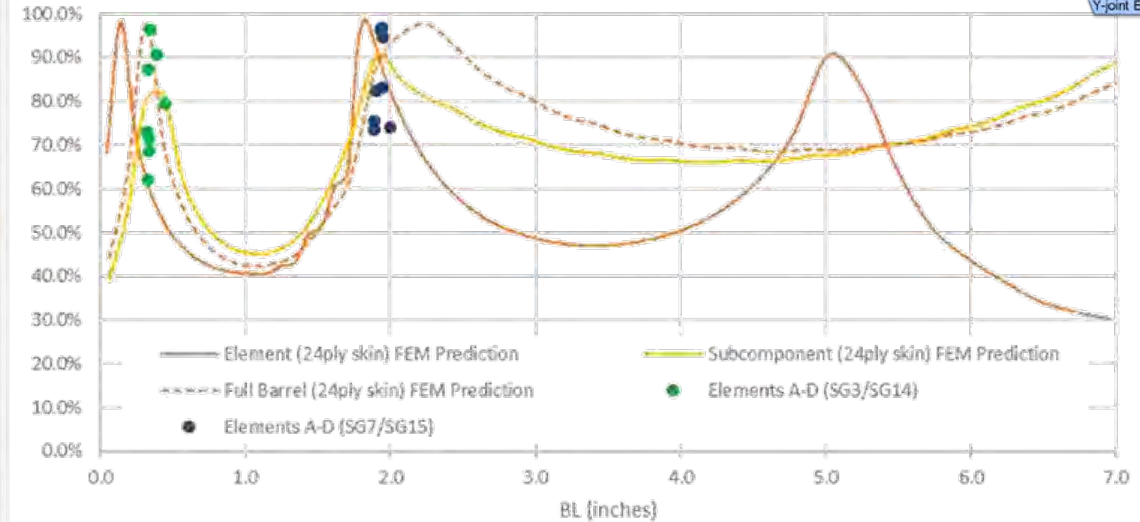
Observed Experimental Data Complies with FEM Predictions



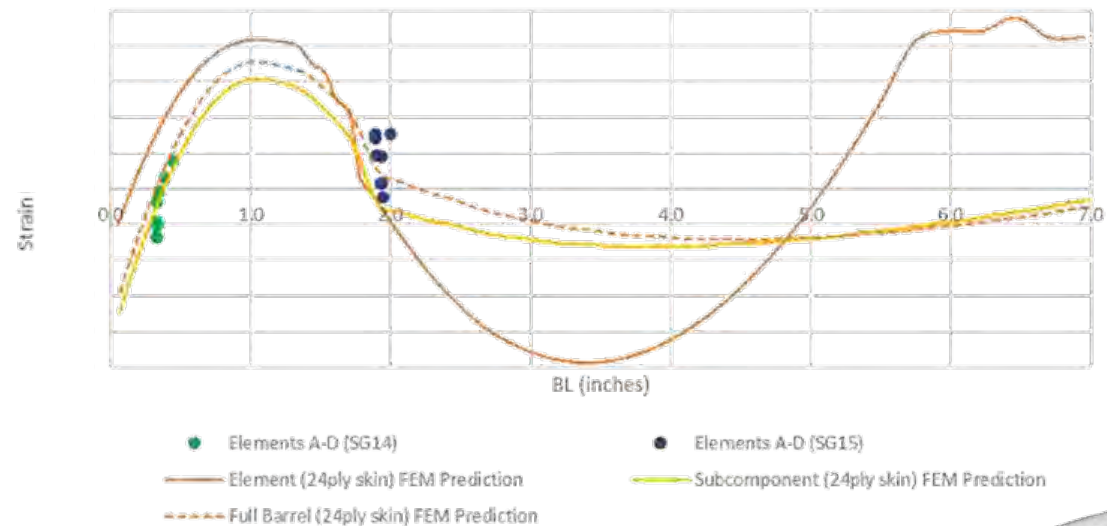
Membrane Strain Component



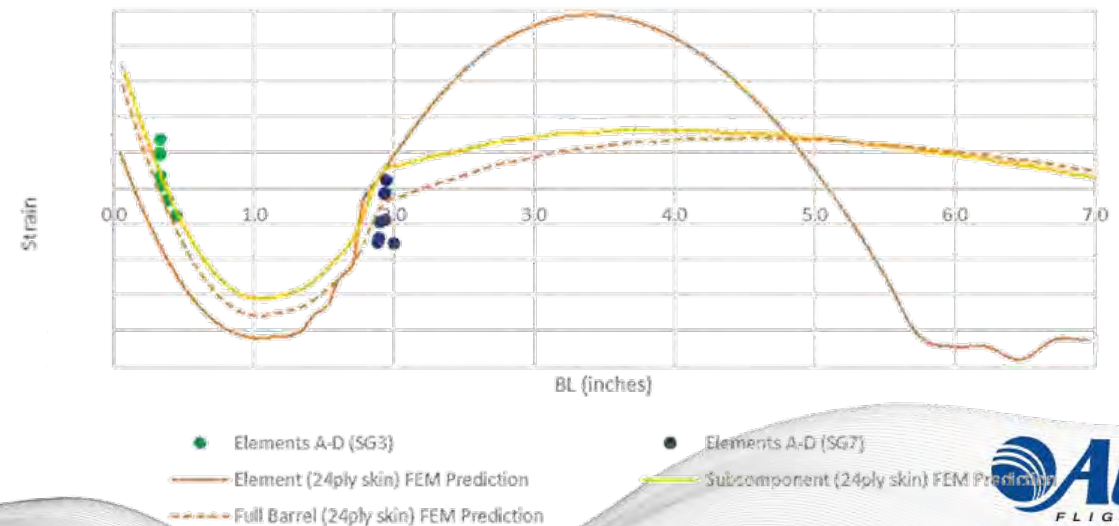
Membrane Strain / Total Strain



Bending Strain Component (OML)



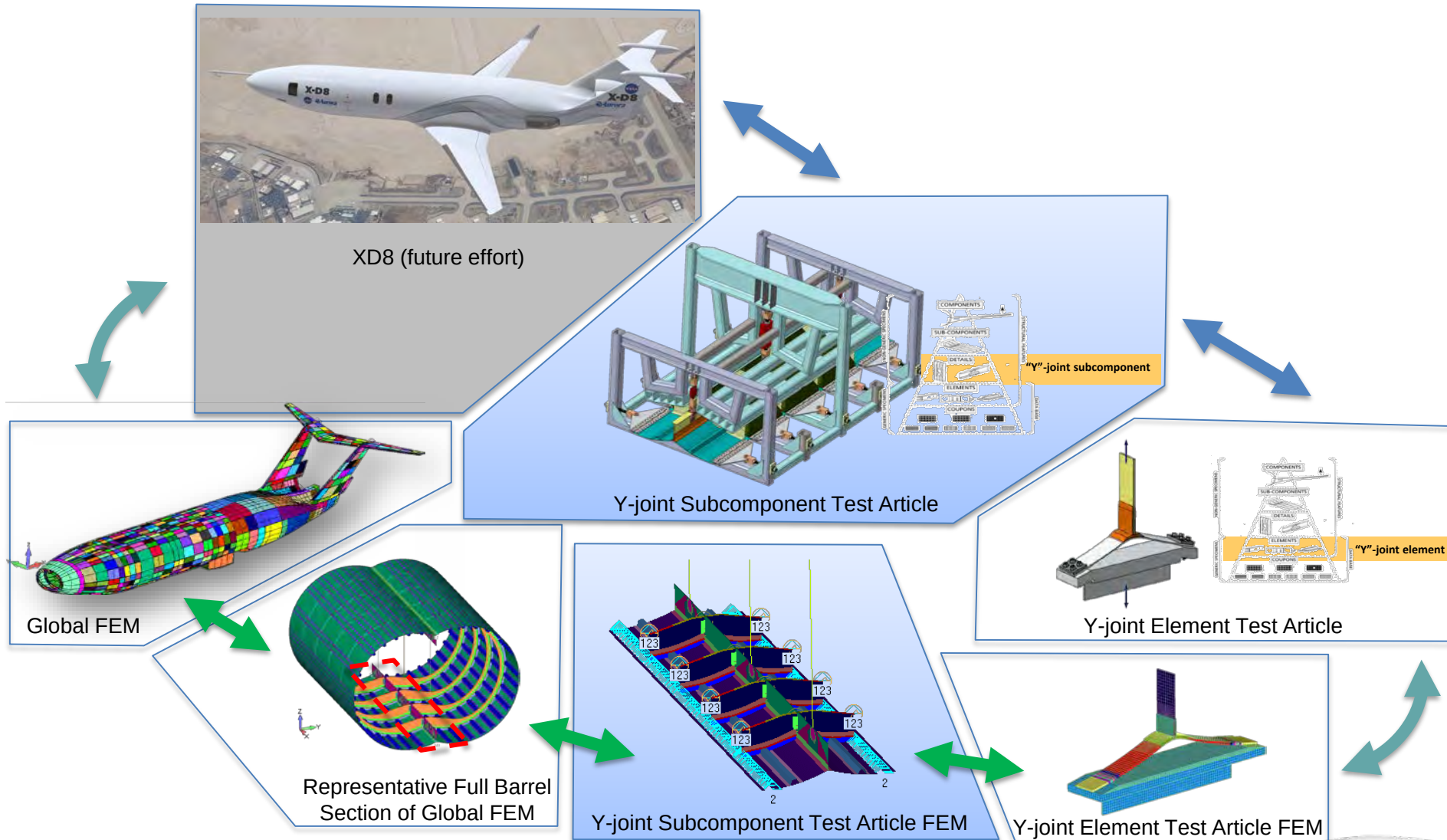
Bending Strain Component (IML)



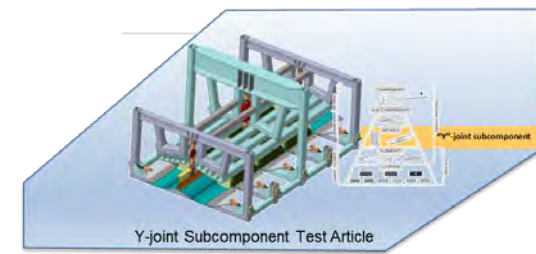
Element Experimental Testing Conclusions

- Preform fiber geometry critical to realize maximum joint capability
- Addition of film adhesive or under-wrap ply reduces peaking at interface of preform and skin plies, resulting in highest joint capability
- “Y”-joint configuration behaves different than pi-joint – flatwise tension under uprights, shear critical following ultimate failure

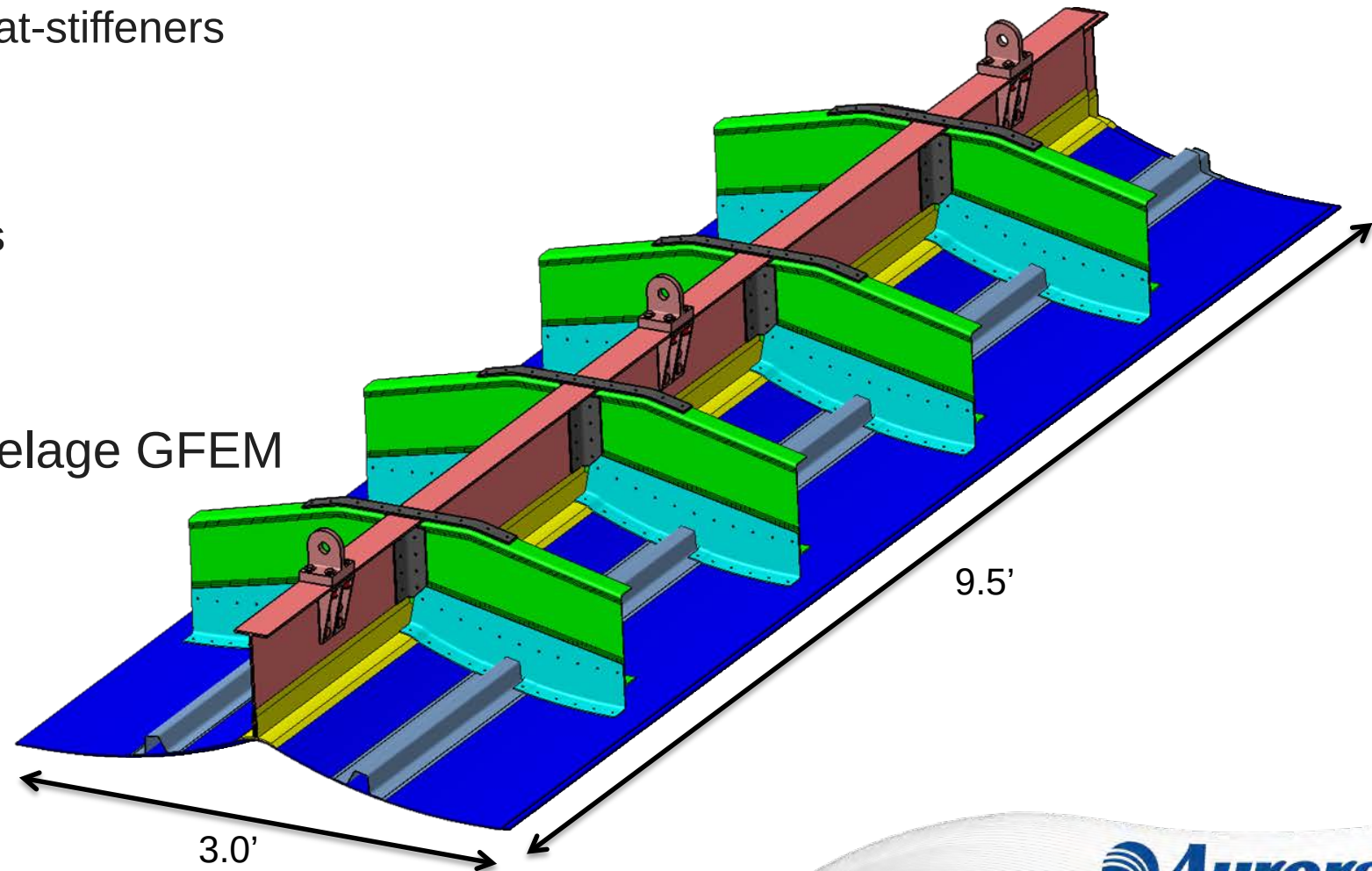
Building Block Approach to Fuselage Development



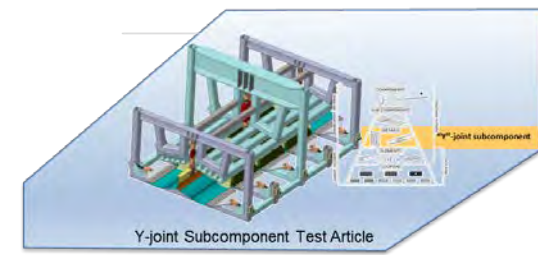
Subcomponent Test Article



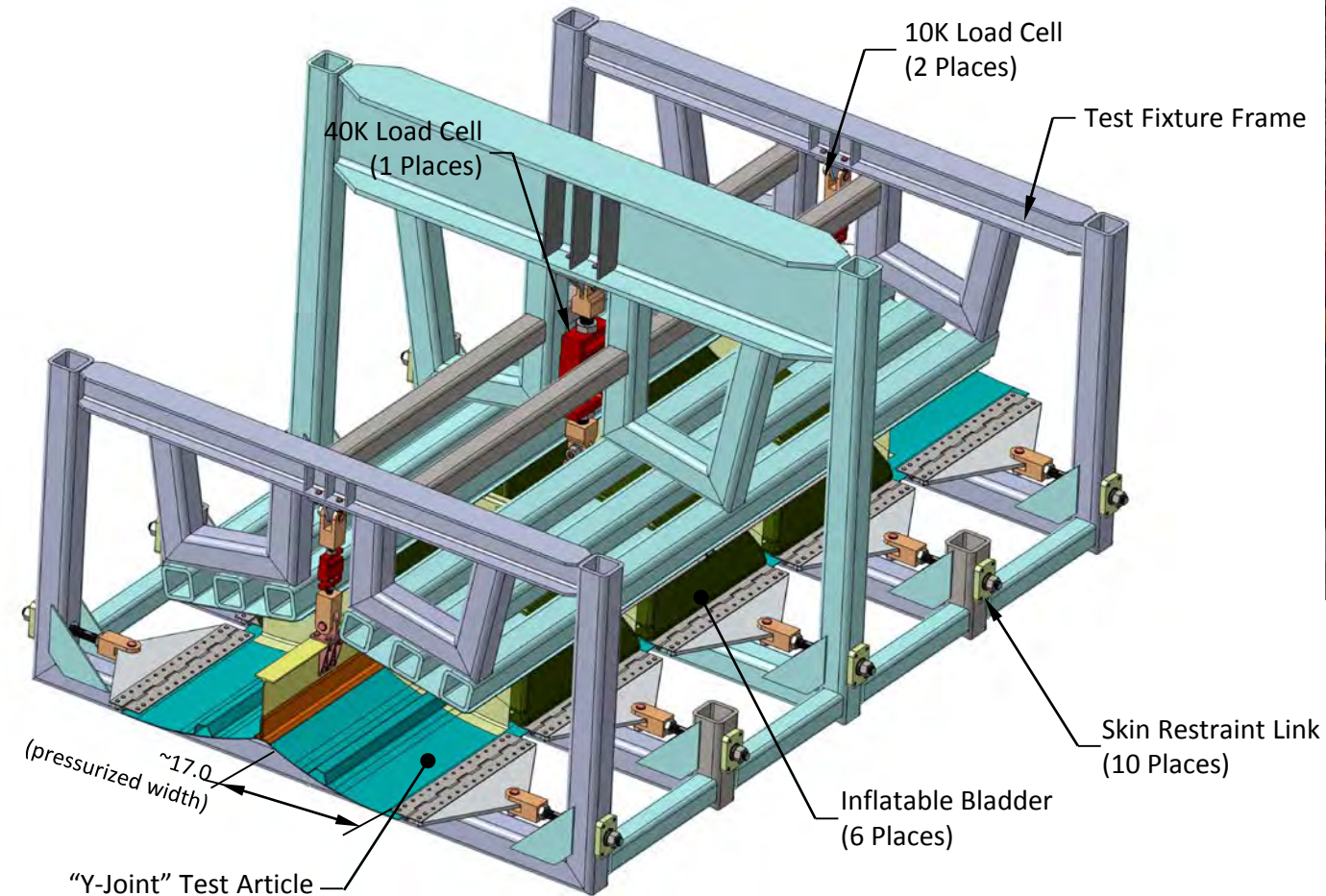
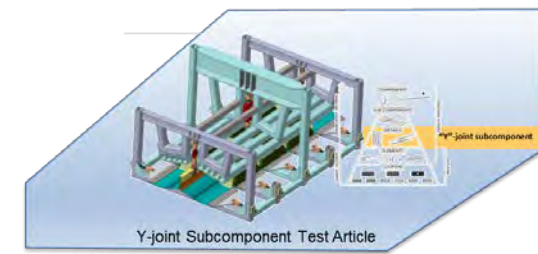
- Article consists of :
 - Co-cured skin, Y-joint, and hat-stiffeners
 - Continuous keel
 - 5 fuselage bays
 - Frames, shear ties, and clips
 - Mechanically fastened
 - Tension rod fittings
- Elements sized from full-fuselage GFEM



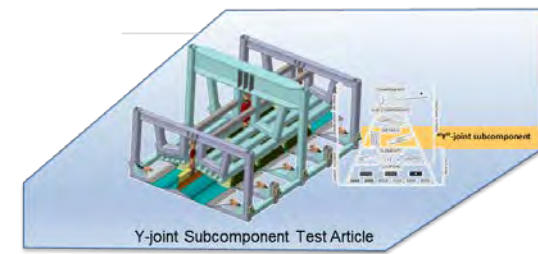
Fully Assembled Subcomponent



Test Article Fixture – Self-Reacting Load Frame



Subcomponent Test Procedure



D8 X-Plane

FAA CLEEN II Y-joint Subcomponent Structural Test Plan

Prepared for
Federal Aviation Administration (FAA)
DTFAWA-15-A-80014

Aurora Report Number: AR17-418 Rev. - Iss. 0
Aurora Account Number: FA01

November 20, 2017

Prepared by
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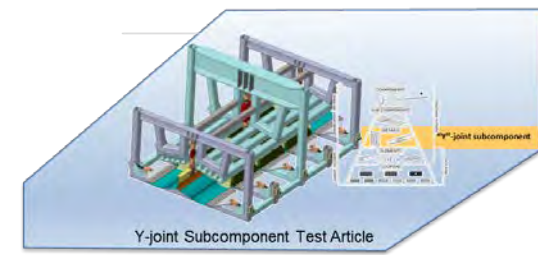
Form ENG-RE-018-

- Quasi-static testing
 - 33% DLL
 - 66% DLL
 - 100% DLL
- Four test runs conducted on article
- Data acquired continuously
 - Strain, load, displacement, pressure

Successful 100% DLL Pressure Load Test



Subcomponent Summary



- Successful experimental testing of “Y”-joint subcomponent complete
 - Subcomponent article exhibited no failure up to 100% DLL
 - Premature pressure bladder failure limited load application to 100% DLL
- Established manufacturing technique of co-cured “Y”-joint for dual-lobed fuselage configuration
- Proved double-bubble fuselage assembly methodology
- Validation of FEM in work

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

Air data probe

Manned aircraft

All composite double-bubble fuselage with fairing

Cockpit side windows + forward-facing camera

Crew door

Full-size windows

Two distortion tolerant propulsors

π -tail



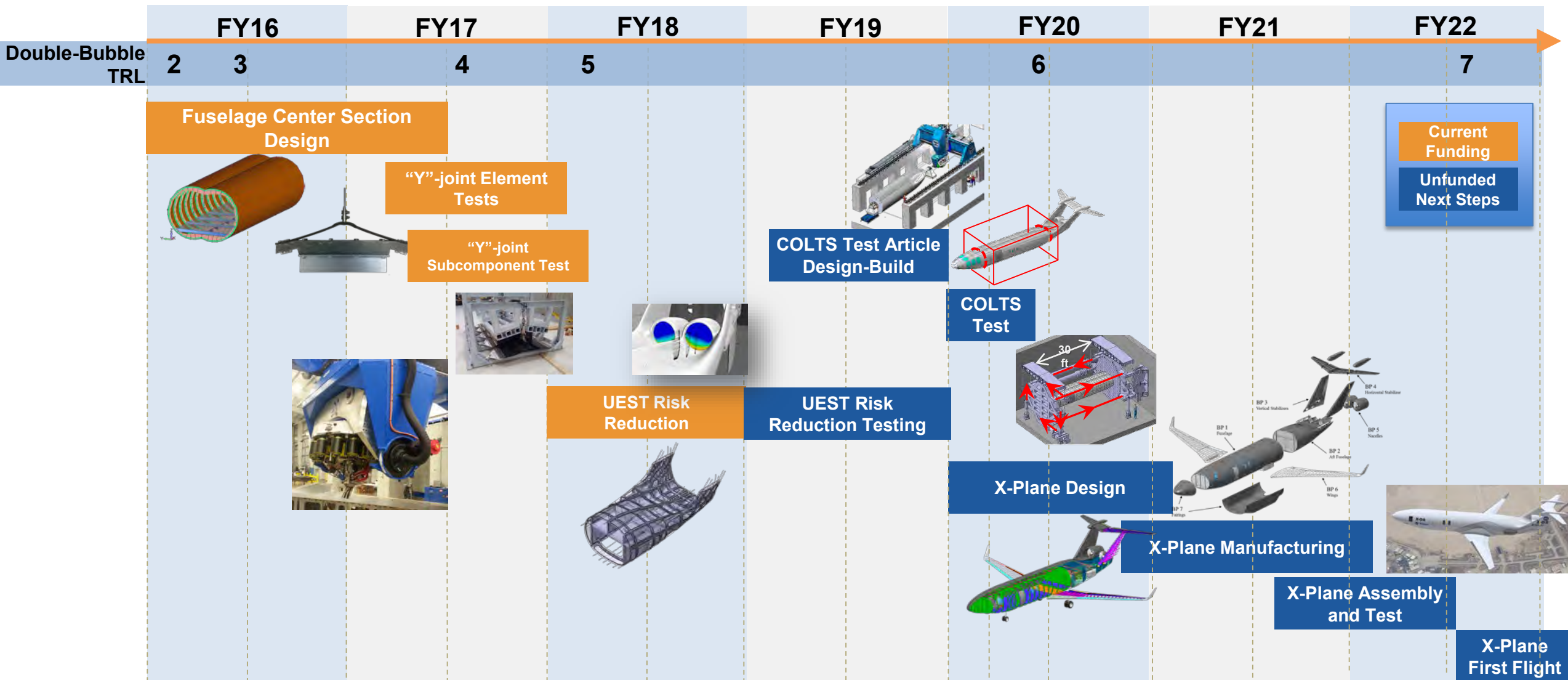
Cockpit windows designed for
pilot visibility during landing flare

eXternal Vision
System (XVS)

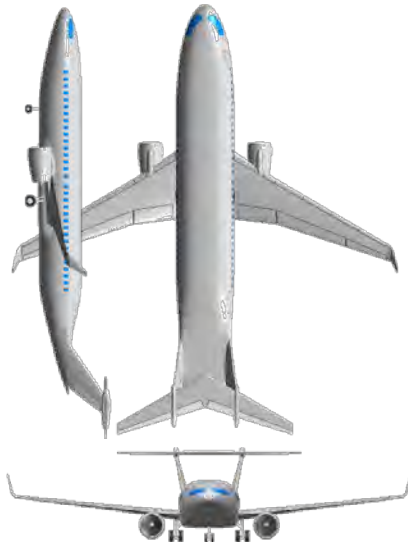
Donor landing gear

Donor wing, high lift
devices, & fuel systems

Project Schedule



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

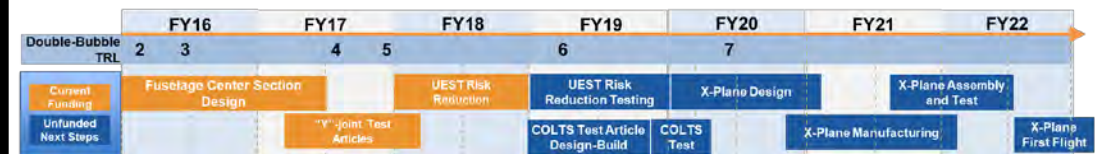
Work Statement:

- 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:

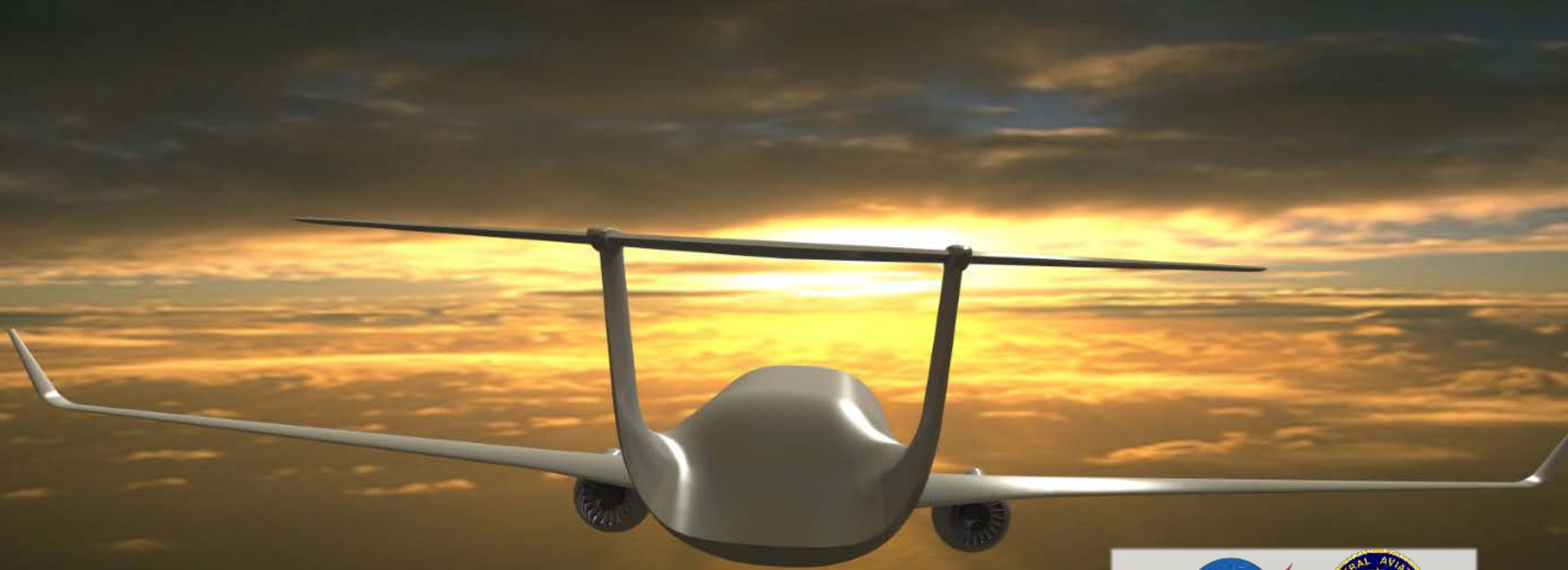
- Performed design trade studies
- Optimized test coupon and article design
- Designed and procured cure tools
- Manufactured coupons, test article, and test fixture
- Completed coupon test campaign
- Proceeded to subcomponent testing

Schedule:



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.