Demonstrating FAA Certifiable Ultra-Efficient Commercial Aircraft Configurations

FAA CLEEN-II Public Session

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Aurora Flight Sciences Corporation
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Program Synopsis

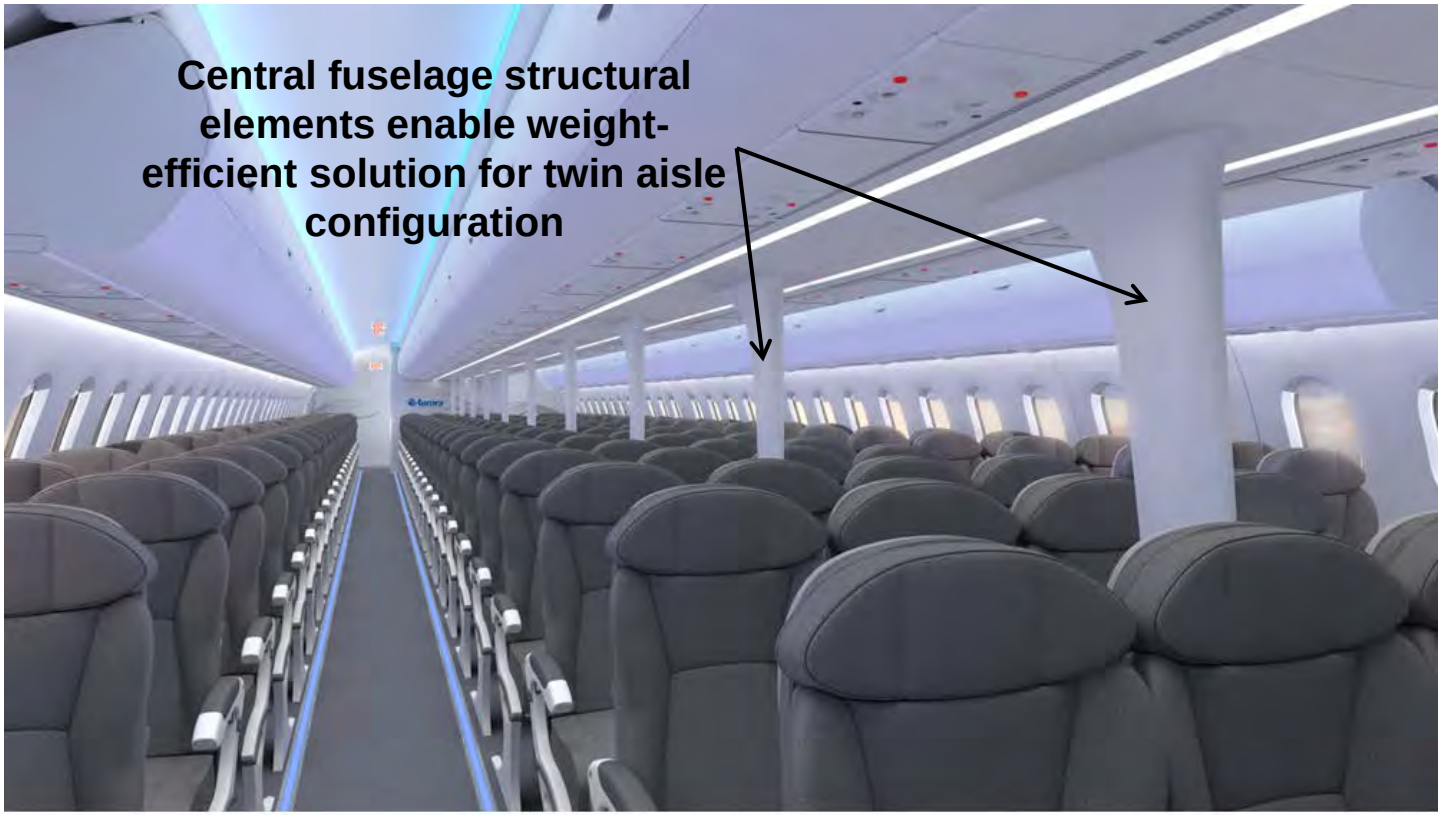
- Under the FAA CLEEN II program, Aurora is developing composite airframe technologies that will enable unconventional aircraft configurations and reduce fuel burn, emissions, and noise.
- A common theme amongst future ultra-efficient aircraft concepts is the non-traditional, complex shape of the aircraft 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 49% fuel burn reduction, 40EPNdB cumulative noise reduction with integrated boundary layer ingesting (BLI) engines. The D8 fuselage further enables 10% 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 FY2017

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

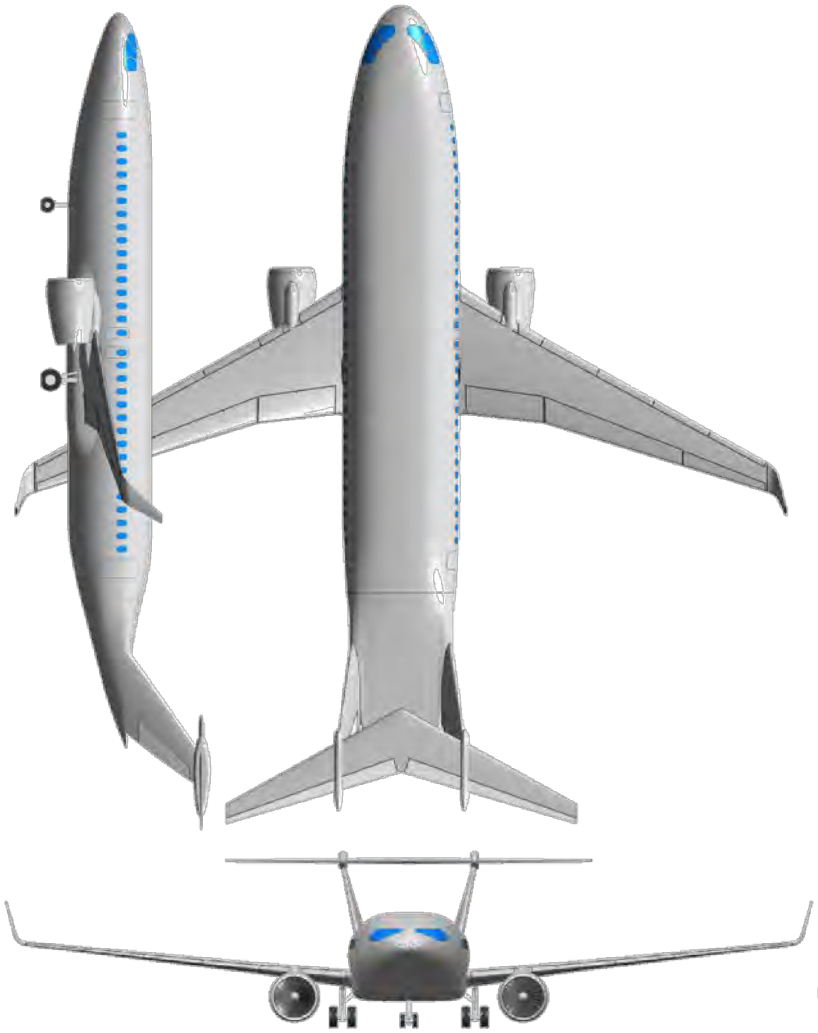
Aurora's D8 Subsonic Transport Aircraft

Tension rods periodic throughout cabin



Double-Bubble Fuselage Video

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

Advanced concepts are exposed to several risks

Technical risk

Financial risk

Market risk

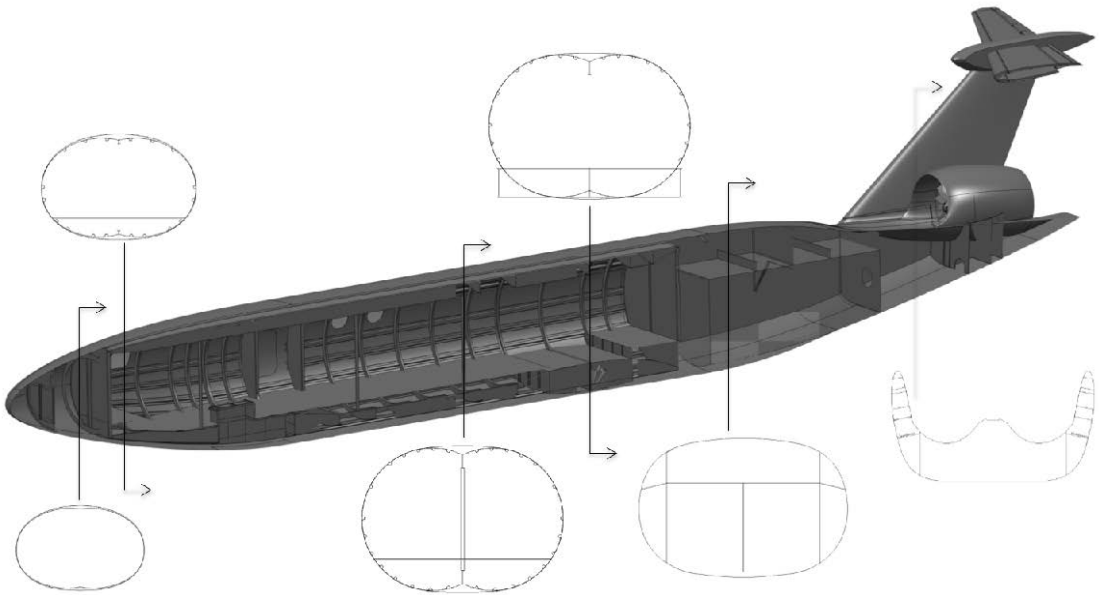
Focus of Aurora CLEEN II

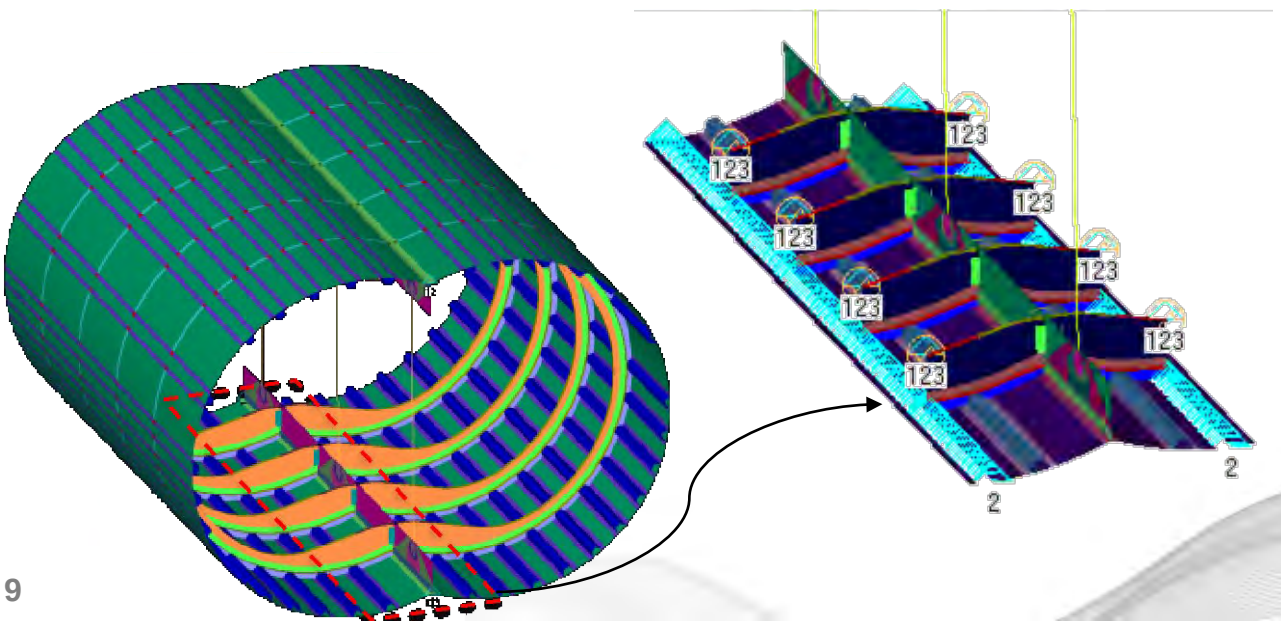
1 **Double Bubble Airframe – related risks**
Double-bubble fuselage performance, manufacturing, certifiability, etc.

2 **BLI – related risks**
Engine operability, fan performance, etc.

3 **Integration risks**
Propulsion-airframe structural integration, airframer-engine manufacturer coordination and analysis, etc.

Challenge 1: Double Bubble Airframe

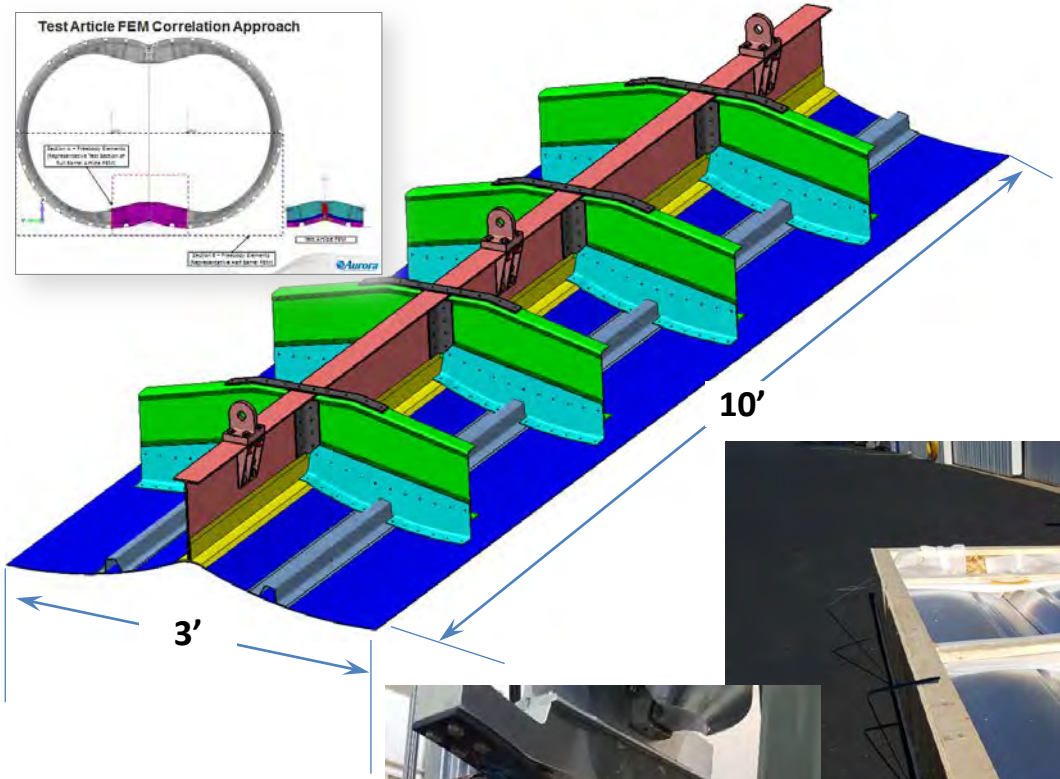


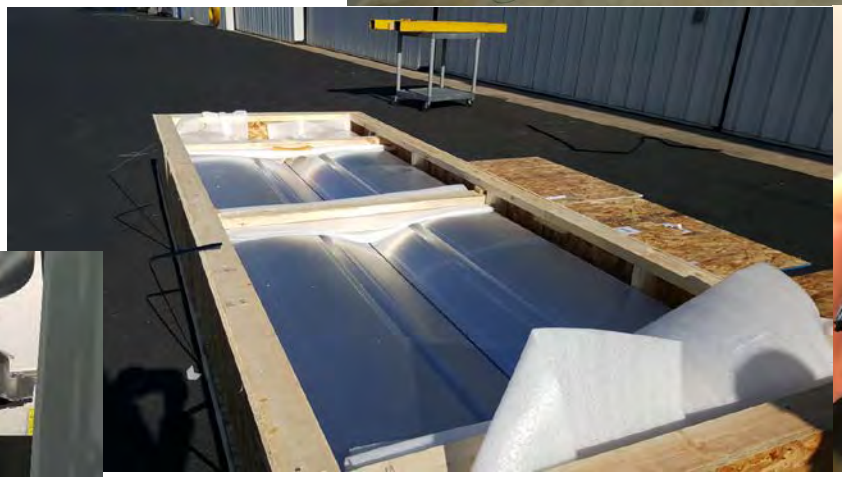


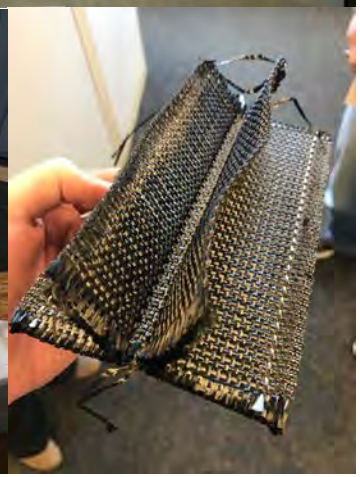
- Wide, lifting-body fuselage driven by aerodynamics
- Departure from traditional ‘round’ pressure “tube”
- Challenge: Create mass efficient solution using proven composite manufacturing methods
  - Dual-lobed design requires new fuselage structural arrangement optimization
  - Advanced composite manufacturing features to efficiently integrate central structural element
  - Y-joint and certification

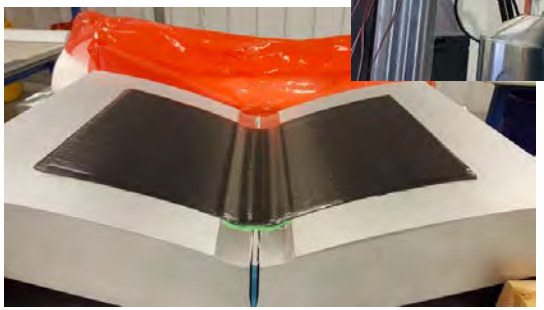
Challenge 1: Double-Bubble Airframe

Demonstrating Fuselage Technology



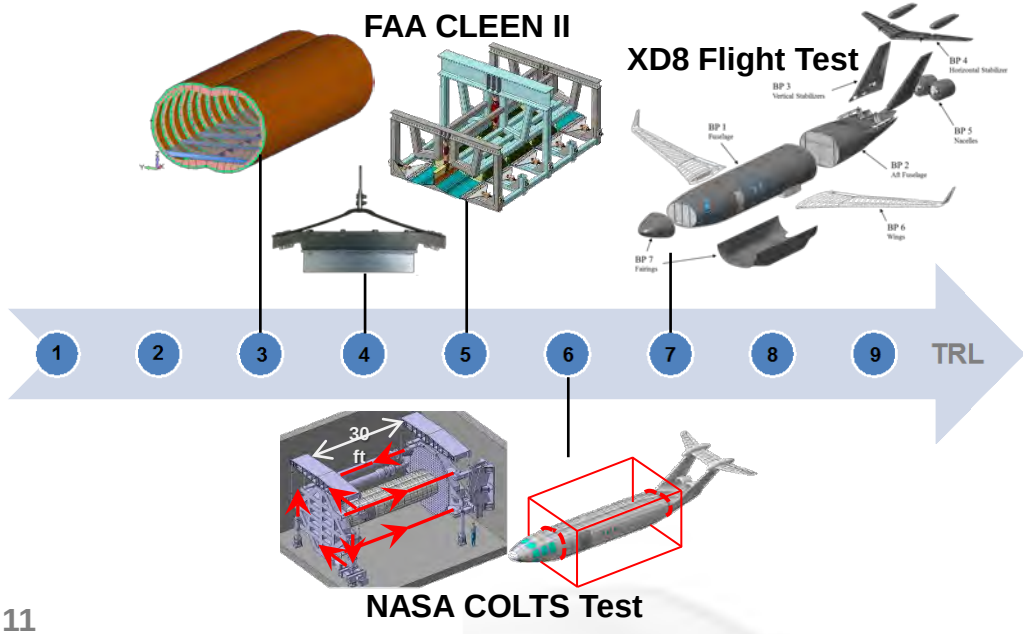






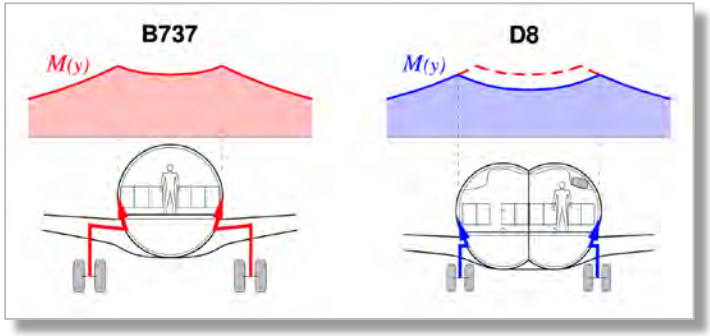
Structural risk mitigation activities are being investigated with initial test articles currently being built. The goal of this building block test is to demonstrate the non-round fuselage structural performance and producibility.

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

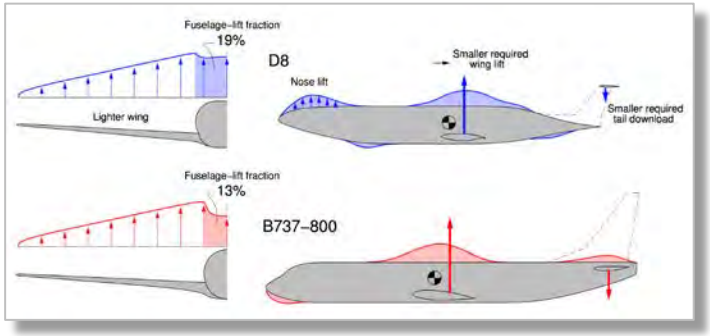


- As part of FAA CLEEN II program, Aurora is demonstrating critical "Y-joint"
- Mechanisms driving fuel efficiency benefits:

Reduced landing gear and wing weight

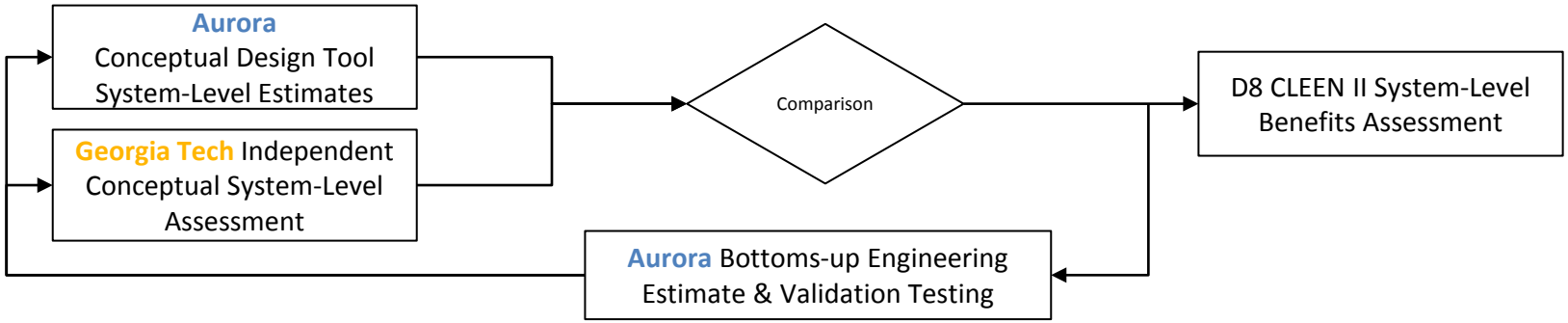


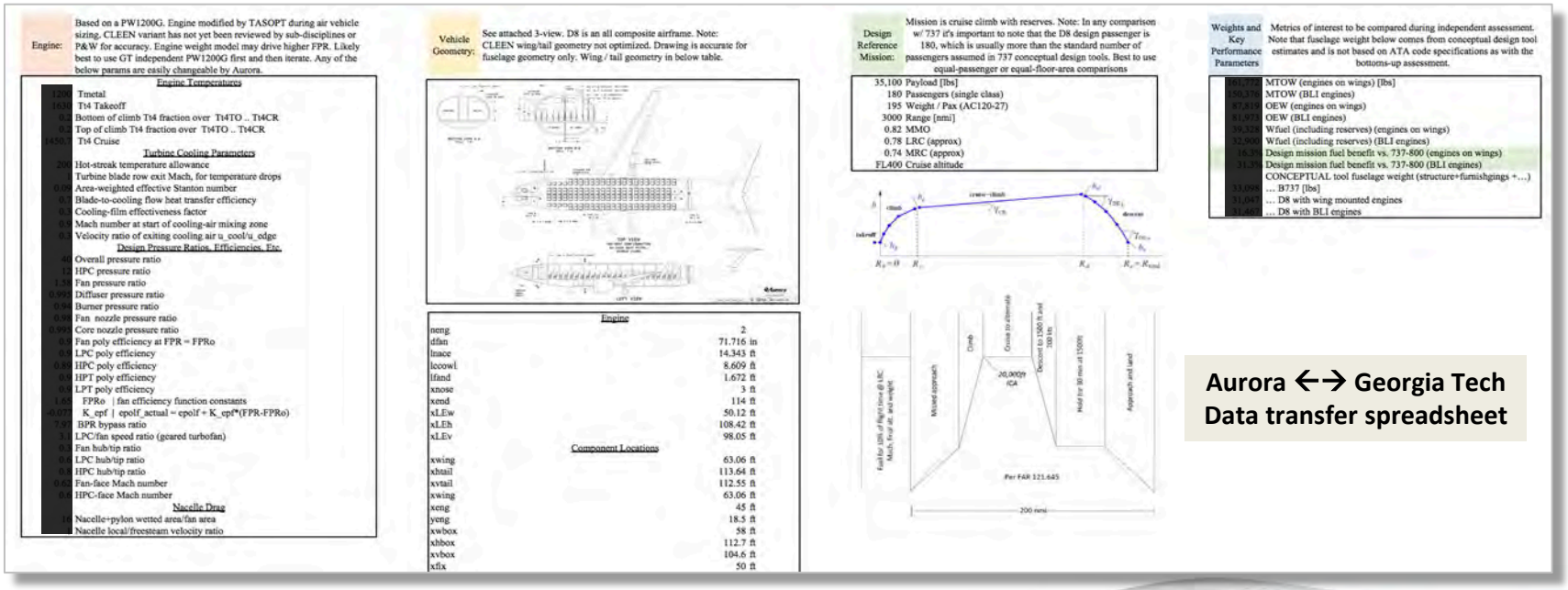
Increased carryover lift → smaller wing & tail



Georgia Tech Performance Assessment

Aurora has started working with Georgia Tech in order to support an independent assessment of the system-level benefits of the dual-lobe fuselage





Engine: Based on a PW1200G. Engine modified by TASOPT during air vehicle sizing. CLEEN variant has not yet been reviewed by sub-disciplines or P&W for accuracy. Engine weight model may drive higher FPR. Likely best to use GT independent PW1200G first and then iterate. Any of the below params are easily changeable by Aurora.

Engine Temperatures	
1200	Tmetal
1630	Tt4 Takeoff
0.2	Bottom of climb Tt4 fraction over Tt4TO .. Tt4CR
0.2	Top of climb Tt4 fraction over Tt4TO .. Tt4CR
1450.37	Tt4 Cruise
Turbine Cooling Parameters	
200	Hot-streak temperature allowance
	Turbine blade row exit Mach, for temperature drops
0.05	Area-weighted effective Stanton number
0.5	Blade-to-cooling flow heat transfer efficiency
0.5	Cooling-film effectiveness factor
0.3	Mach number at start of cooling-air mixing zone
0.3	Velocity ratio of exiting cooling air u_cool/u_edge
Design Pressure Ratios, Efficiencies, Etc.	
40	Overall pressure ratio
1.7	HPC pressure ratio
1.5	Fan pressure ratio
0.995	Diffuser pressure ratio
0.96	Burner pressure ratio
0.99	Fan nozzle pressure ratio
0.995	Core nozzle pressure ratio
0.9	Fan poly efficiency at FPR = FPRo
0.9	LPC poly efficiency
0.88	HPC poly efficiency
0.9	HPT poly efficiency
0.9	LPT poly efficiency
1.65	FPRo | fan efficiency function constants
-0.075	K_cpf | cpolf_actual = cpolf + K_cpf*(FPR-FPRo)
7.95	BPR bypass ratio
3	LPC/fan speed ratio (geared turbofan)
0.9	Fan hub/tip ratio
0.5	LPC hub/tip ratio
0.5	HPC hub/tip ratio
0.6	Fan-face Mach number
0.4	HPC-face Mach number
Nacelle Drag	
1.1	Nacelle+pylon wetted area/fan area
	Nacelle local/freestream velocity ratio

Vehicle Geometry: See attached 3-view. D8 is an all composite airframe. Note: CLEEN wing/tail geometry not optimized. Drawing is accurate for fuselage geometry only. Wing / tail geometry in below table.

Engine	
neng	2
dfan	71.716 in
lnace	14.343 ft
lcowl	8.609 ft
lfand	1.672 ft
xnose	3 ft
xend	114 ft
xLEw	50.12 ft
xLEh	108.42 ft
xLEv	98.05 ft
Component Locations	
xwing	63.06 ft
xhtail	113.64 ft
xvtail	112.55 ft
xwing	63.06 ft
xeng	45 ft
yeng	18.5 ft
xwbox	58 ft
xhbox	112.7 ft
xvbox	104.6 ft
xflx	50 ft

Design Reference Mission: Mission is cruise climb with reserves. Note: In any comparison w/ 737 it's important to note that the D8 design passenger is 180, which is usually more than the standard number of passengers assumed in 737 conceptual design tools. Best to use equal-passenger or equal-floor-area comparisons

35,100	Payload [lbs]
180	Passengers (single class)
195	Weight / Pax (AC120-27)
3000	Range [nmi]
0.82	MMO
0.78	LRC (approx)
0.74	MRC (approx)
FL400	Cruise altitude

Weights and Key Performance Parameters: Metrics of interest to be compared during independent assessment. Note that fuselage weight below comes from conceptual design tool estimates and is not based on ATA code specifications as with the bottoms-up assessment.

181,974	MTOW (engines on wings) [lbs]
150,376	MTOW (BLI engines)
87,819	OEW (engines on wings)
81,973	OEW (BLI engines)
39,328	Wfuel (including reserves) (engines on wings)
32,900	Wfuel (including reserves) (BLI engines)
16,39	Design mission fuel benefit vs. 737-800 (engines on wings)
31,39	Design mission fuel benefit vs. 737-800 (BLI engines)
	CONCEPTUAL tool fuselage weight (structure+furnishgings +…)
33,098	… B737 [lbs]
31,047	… D8 with wing mounted engines
31,447	… D8 with BLI engines

Aurora ←→ Georgia Tech Data transfer spreadsheet

CLEEN Technology Current Status

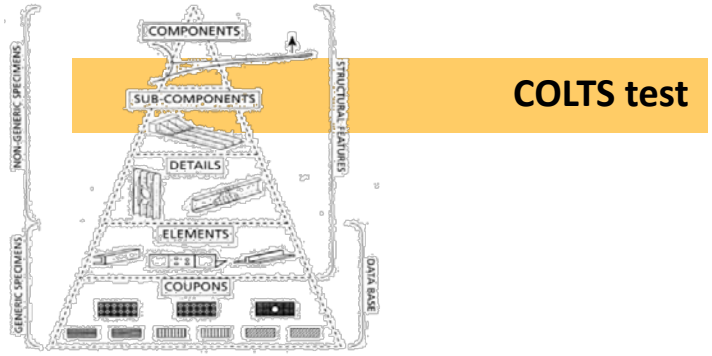
CLEEN Technology	Goal Impact	Benefits and Application
Advanced composite, unconventional airframe design-build	Primary: Fuel burn Secondary: noise reduction	49% fuel, 40EPNdB cumulative noise benefits with current technology and integrated engines 16% fuel, 16 EPNdB cumulative noise benefits for 2025 with wing mounted engines

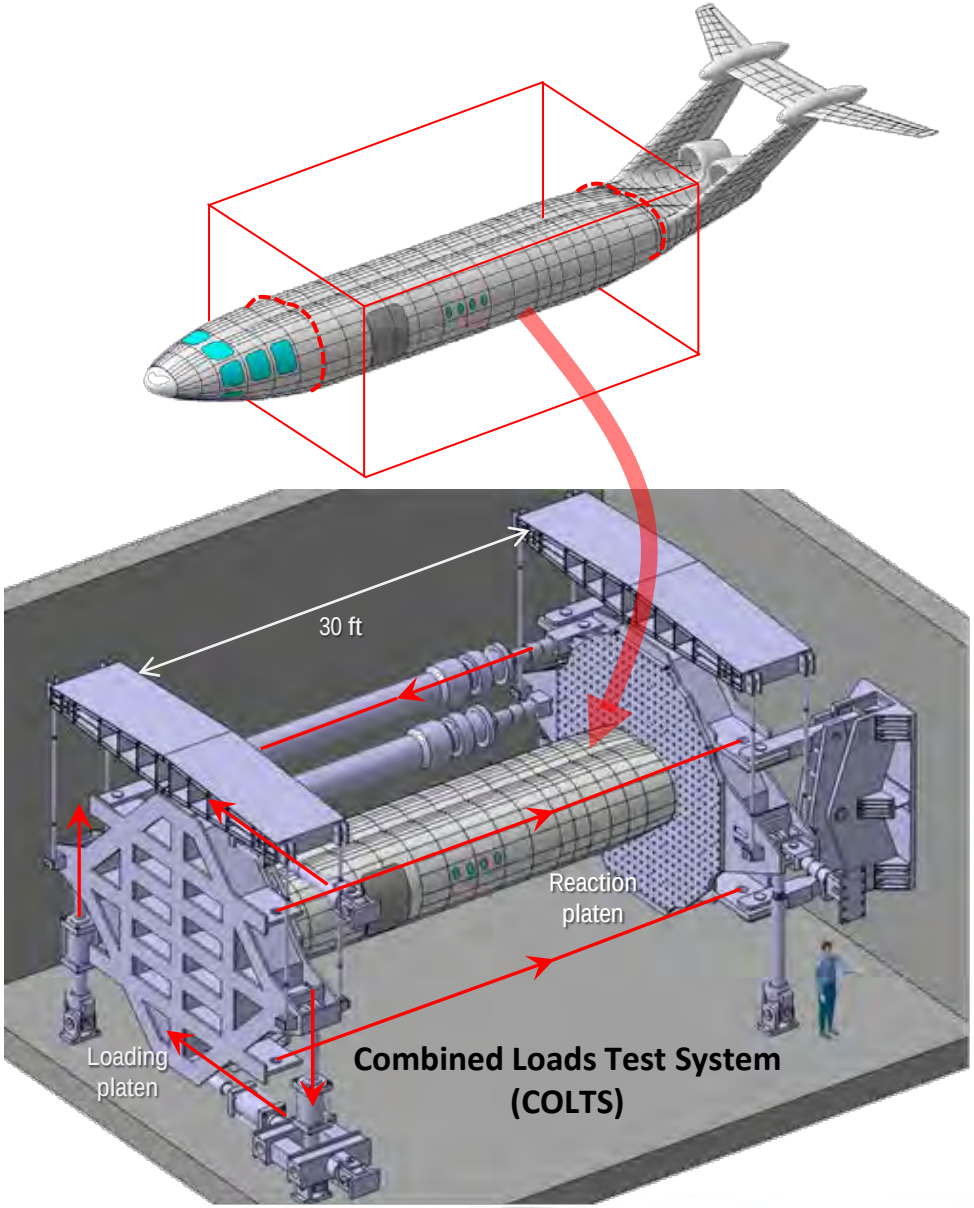
Updating based on learnings from test results, FEM, and air vehicle-level optimization from both Aurora and GTech

Program Description

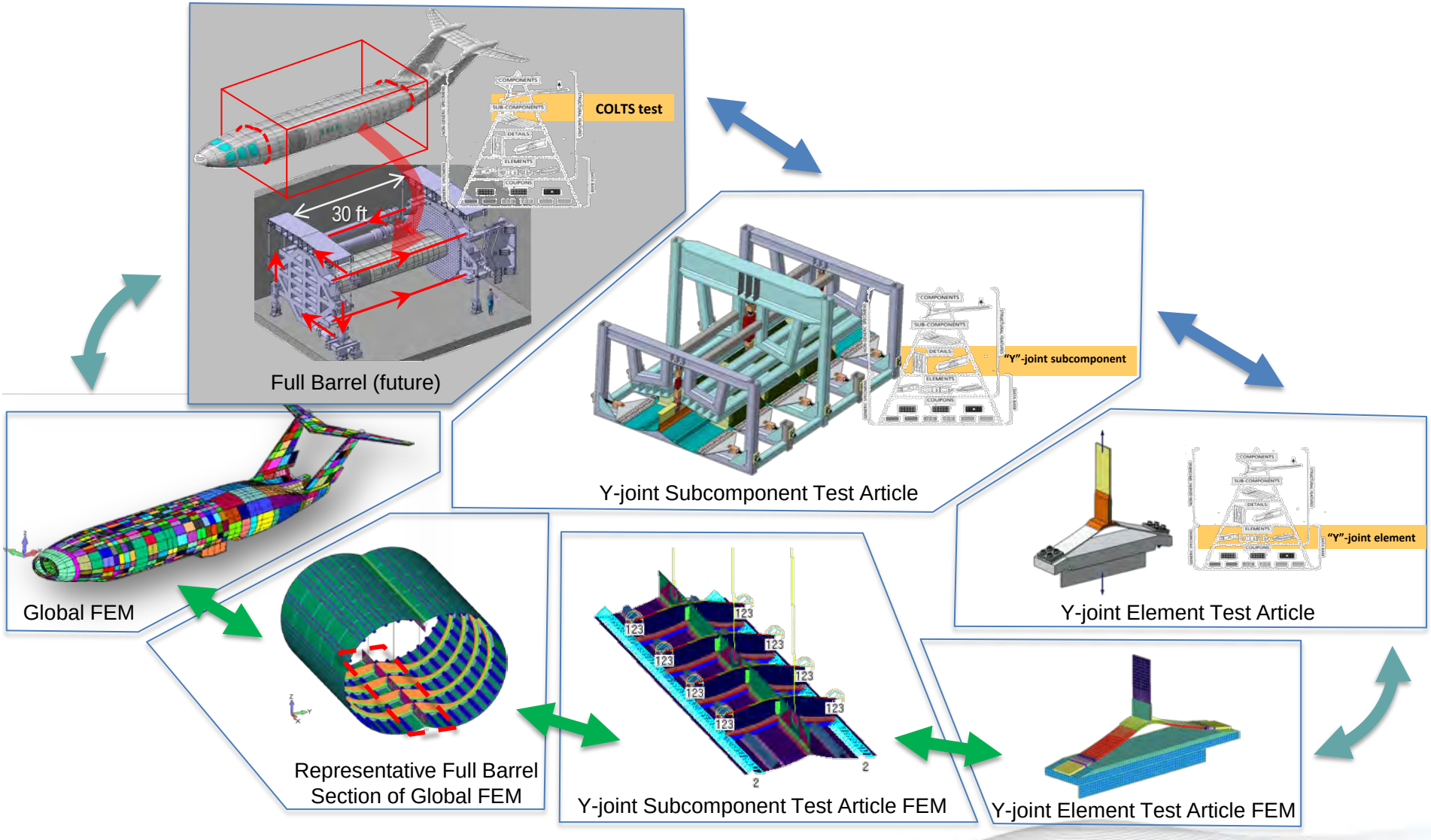
Design and manufacture an all-composite, half-scale fuselage section of the D8 using materials and manufacturing processes that demonstrate configuration feasibility, weight benefits, and the ability to be FAA-certified. The build approach for the fuselage includes Automated Fiber Placement (AFP) manufacturing of the fuselage barrel.

The development culminates in testing a 30ft section of the fuselage under combined shear, bending, and pressure loads in the NASA Langley COLTS facility.

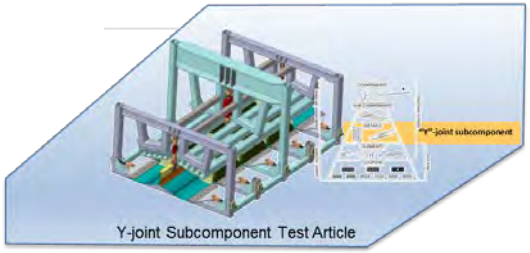




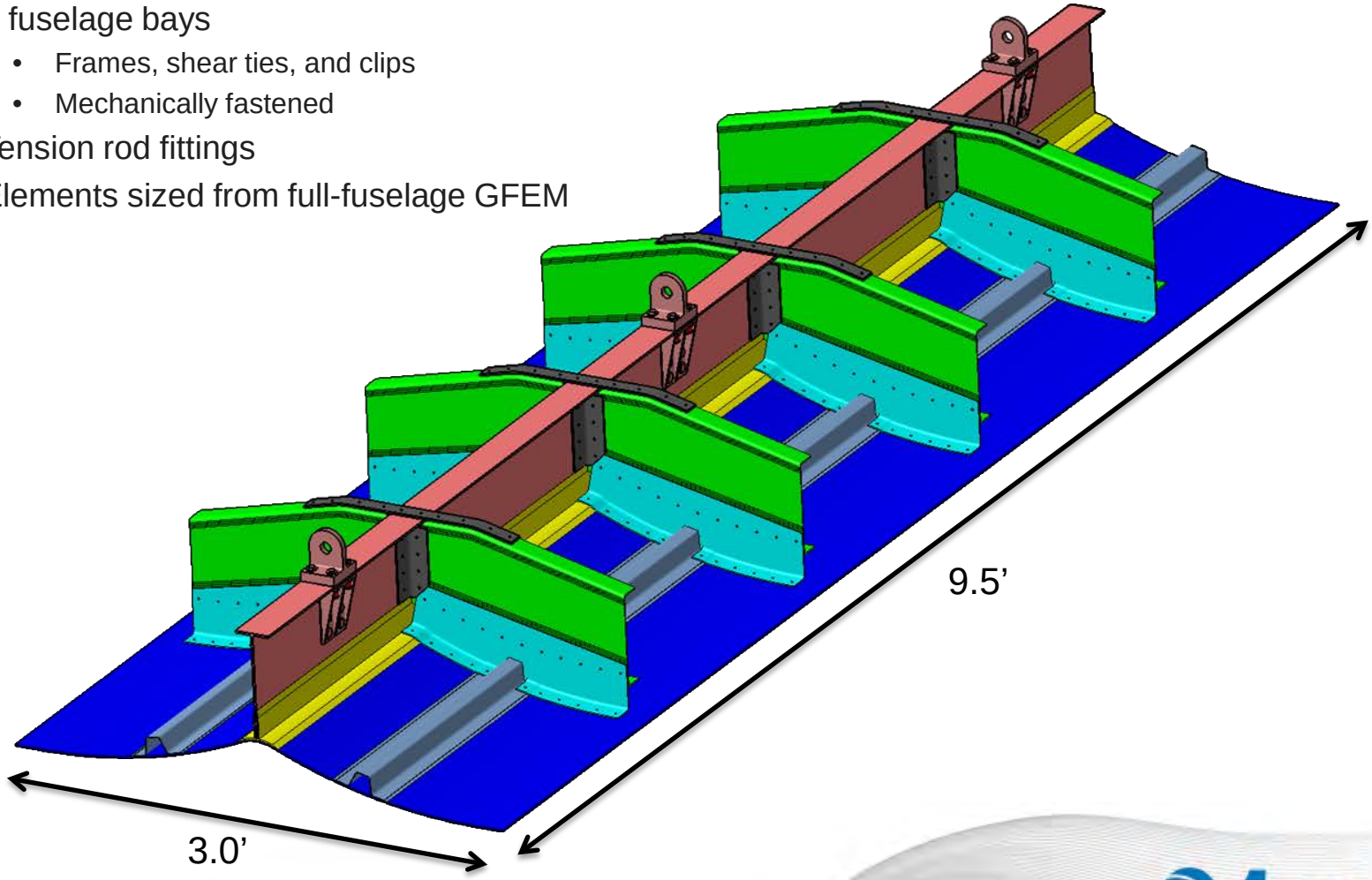
Building Block Approach to Fuselage Development



Y-joint Subcomponent Test Article

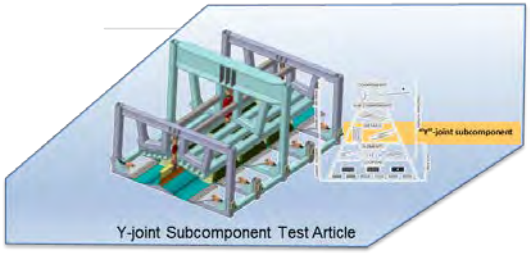


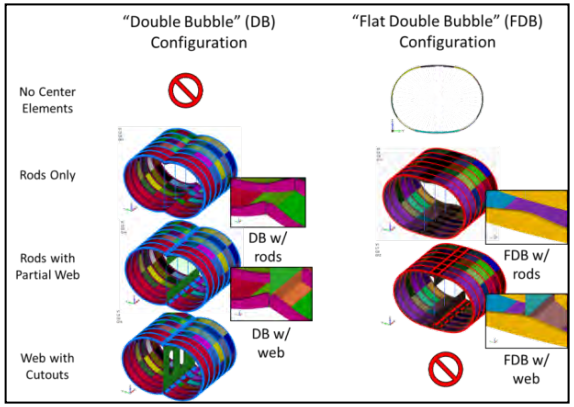
- Article consists of :
  - Co-cured skin, Y-joint, and hat-stiffeners
  - Continuous keel
  - 5 fuselage bays
    - Frames, shear ties, and clips
    - Mechanically fastened
  - Tension rod fittings
  - Elements sized from full-fuselage GFEM

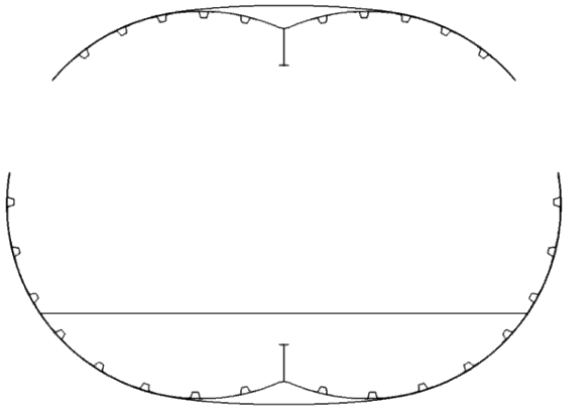


Test Purpose

- Validate the dual lobe fuselage structural benefits through experimental testing
- Y-joint subcomponent article:
  - load distribution between struts, keel, and Y-joint
  - model validation for skin/keel bay with and without tension rods
  - Quantity: 1 article test
- Y-joint elements:
  - Understanding the load flow through the Y-joint
  - Quantify quasi-static tensile load response
  - Quantify magnitude of joint capability
  - Quantity: 63 element tests

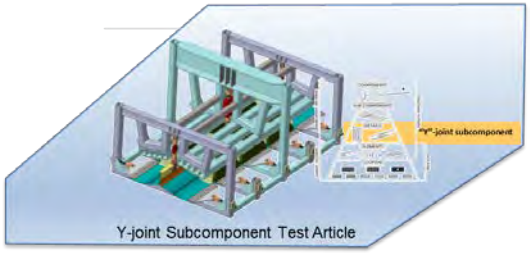




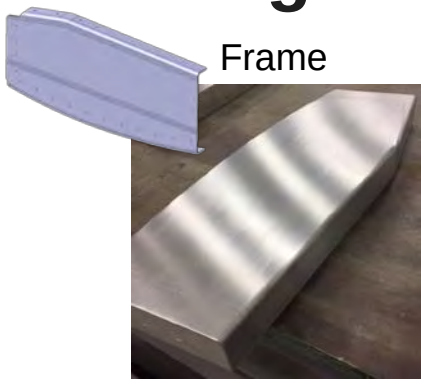


Test Article Element Tooling

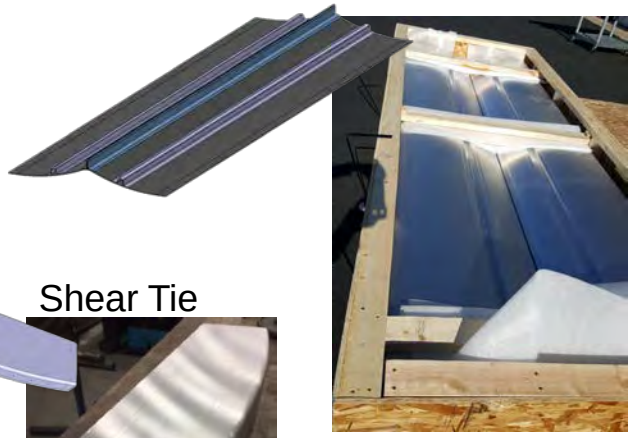
- All tooling manufactured or in-process
- Frame clips and cap straps to be manufactured on single tool each and cut apart
- Mirrored tools for frame and shear tie
- Skin tool
  - Uncured stringers placed in stringer grooves
  - Y clip preform placed in between 2 sides of tool
  - Skin laid up over fully assembled tool
- Keel Tool
  - Web plies laid up on both sides of tool
  - Cap plies laid up over fully assembled tool



Frame



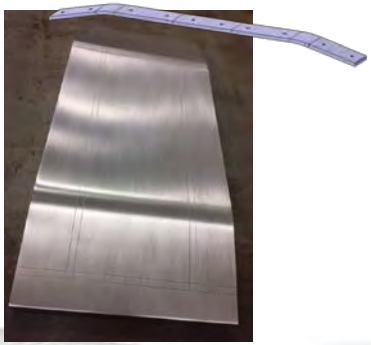
Skin



Frame Clip

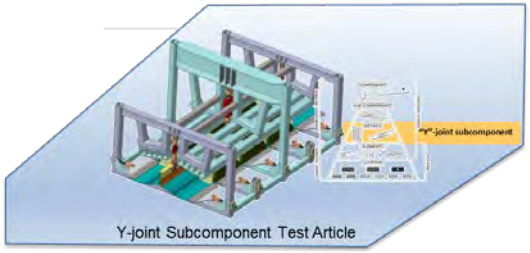
Shear Tie

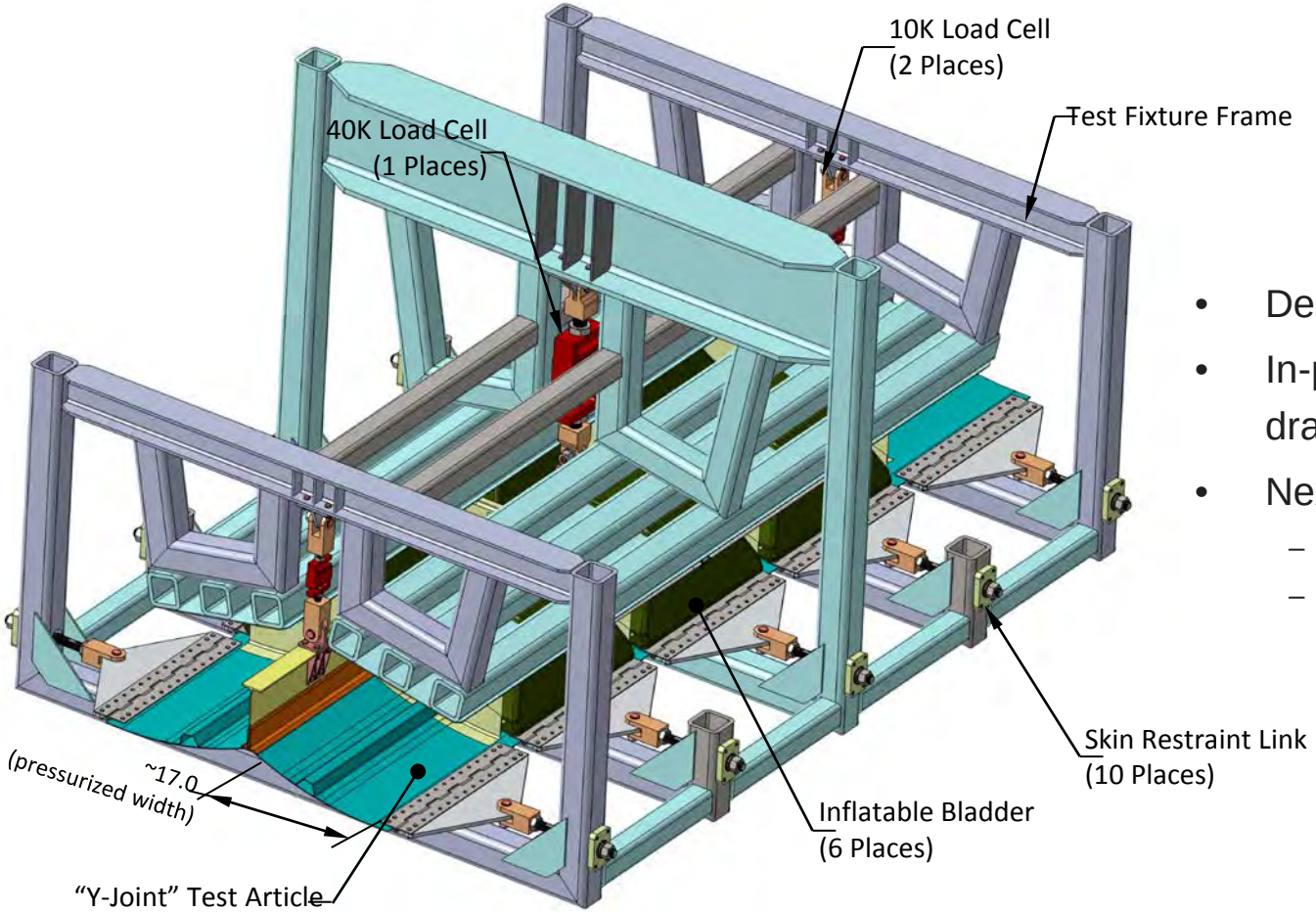
Cap Strap



Keel

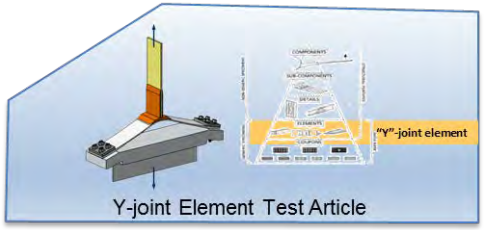
Test Article Fixture – Self-Reacting Load Frame

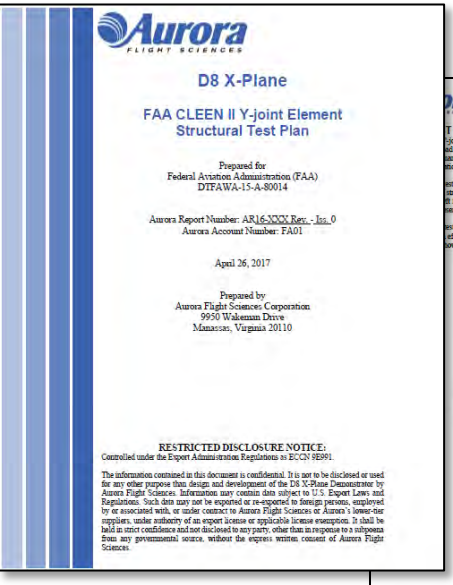




- Design and sizing complete
- In-process of releasing drawings
- Next steps
  - Fixture fabrication
  - Bladder procurement

FAA CLEEN II Y-joint Element Structural Test Plan





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D8 X-Plane

FAA CLEEN II Y-joint Element Structural Test Plan

Prepared for
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DTFAWA-15-A-80014

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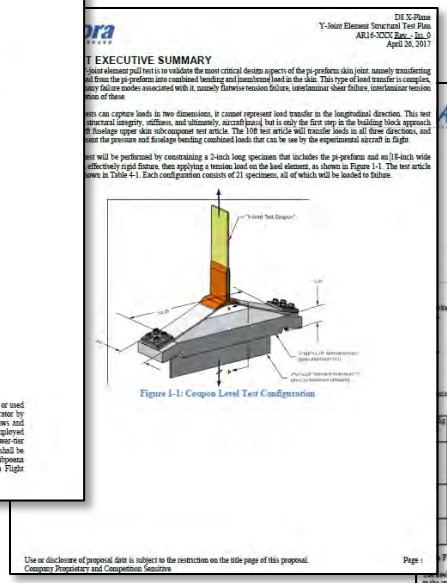

D8 X-Plane
Y-Joint Element Structural Test Plan
AR16-XXX Rev. - Iss. 0
April 26, 2017

T EXECUTIVE SUMMARY

-joint element pull test is to validate the most critical design aspects of the pi-preform skin joint, namely transferring d from the pi-preform into combined bending and membrane load in the skin. This type of load transfer is complex, any failure modes associated with it, namely flatwise tension failure, interlaminar shear failure, interlaminar tension tion of these

sts can capture loads in two dimensions, it cannot represent load transfer in the longitudinal direction. This test structural integrity, stiffness, and ultimately, aircraft based but is only the first step in the building block approach ll fuselage upper skin subcomponent test article. The 108 test article will transfer loads in all three directions, and nst the pressure and fuselage bending combined loads that can be see by the experimental aircraft in flight.

est will be performed by constraining a 2-inch long specimen that includes the pi-preform and an 18-inch wide effectively rigid fixture, then applying a tension load on the keel element, as shown in Figure 1-1. The test article own in Table 4-1. Each configuration consists of 21 specimens, all of which will be loaded to failure.

Figure 1-1: Coupon Level Test Configuration

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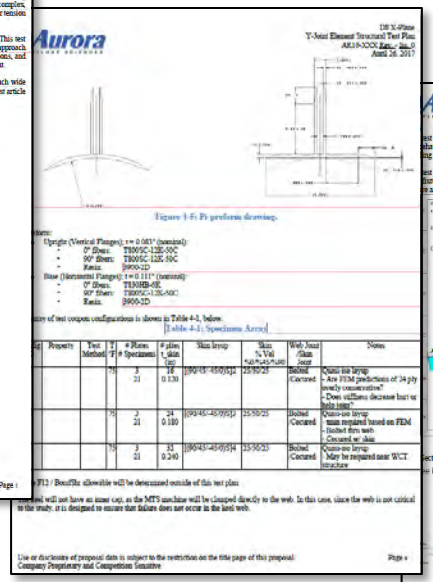
Company Proprietary and Competition Sensitive



Aurora FLIGHT SCIENCES

D8 X-Plane
Y-Joint Element Structural Test Plan
AR16-XXX Rev. - Iss. 0
April 26, 2017

Figure 1-5: Pi preform drawing.

Upright (Vertical Flanges): t= 0.083" (nominal):
- 0° fibers: T1000G-12K-50C
- 90° fibers: T800SC-12K-50C
- Resin: 8900-2D

Base (Horizontal Flanges): t= 0.111" (nominal):
- 0° fibers: T830HB-6K
- 90° fibers: T800SC-12K-50C
- Resin: 8900-2D

ary of test coupon configurations is shown in Table 4-1, below.

Table 4-1: Specimens Array

Property	Test Method	T/F	# Plates	# Specimens	# plies t_skin (in)	Skin layup	Skin % Vol %0/%45/%90	Web layup / Skin layup	Notes
			75	3 21	14 0.130	[90/45/-45/0]s2	25/50/25	Bolted Cocured	Quasi-iso layup - Are FEM predictions of 34 ply overly conservative? - Does stiffness decrease but ss bolts more?
			75	2 21	24 0.180	[90/45/-45/0]s3	25/50/25	Bolted Cocured	Quasi-iso layup - mass required based on FEM - Bolted thru web - Cocured w/ skin
			75	3 21	33 0.240	[90/45/-45/0]s4	25/50/25	Bolted Cocured	Quasi-iso layup - May be required near WCT structure

F12 / Bend3k allowable will be determined outside of this test plan

will not have an inner cap, as the MTS machine will be clamped directly to the web. In this case, since the web is not critical to the study, it is designed to ensure that failure does not occur in the keel web.

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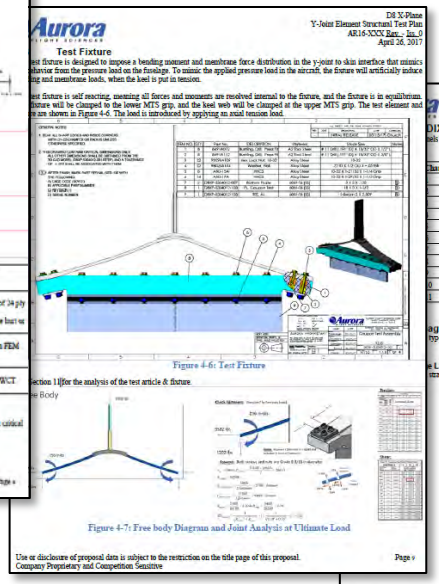

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D8 X-Plane
Y-Joint Element Structural Test Plan
AR16-XXX Rev. - Iss. 0
April 26, 2017

Test Fixture

est fixture is designed to impose a bending moment and membrane force distribution in the y-joint to skin interface that mimics behavior from the pressure load on the fuselage. To mimic the applied pressure load in the aircraft, the fixture will artificially induce ing and membrane loads, when the keel is put in tension.

est fixture is self reacting, meeting all forces and moments are resolved internal to the fixture, and the fixture is in equilibrium. fixture will be clamped to the lower MTS grip, and the keel web will be clamped at the upper MTS grip. The test element and ture shown in Figure 4-6. The load is introduced by applying an axial tension load.

Figure 4-6: Test Fixture

ection 11for the analysis of the test article & fixture.

e Body

Figure 4-7: Free body Diagram and Joint Analysis at Ultimate Load

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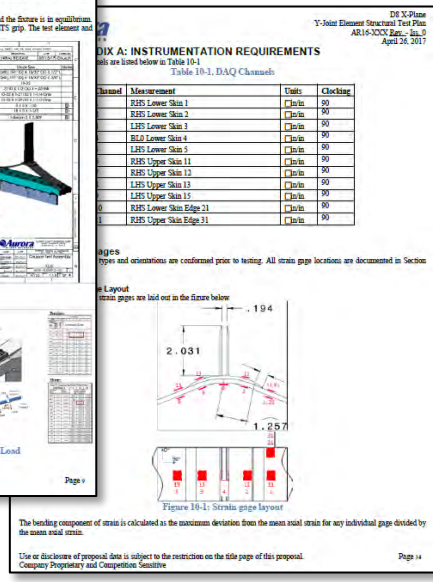
Company Proprietary and Competition Sensitive



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DIX A: INSTRUMENTATION REQUIREMENTS

ols are listed below in Table 10-1

Table 10-1, DAQ Channels

Channel	Measurement	Units	Clocking
	RHS Lower Skin 1	in/in	90
	RHS Lower Skin 2	in/in	90
	LHS Lower Skin 3	in/in	90
	BL0 Lower Skin 4	in/in	90
	LHS Lower Skin 5	in/in	90
	RHS Upper Skin 11	in/in	90
	RHS Upper Skin 12	in/in	90
	LHS Upper Skin 13	in/in	90
	LHS Upper Skin 15	in/in	90
0	RHS Lower Skin Edge 21	in/in	90
1	RHS Upper Skin Edge 31	in/in	90

ages

ypes and orientations are conformed prior to testing. All strain gage locations are documented in Section

e Layout

strain gages are laid out in the fixture below

.194
2.031
1.257

Figure 10-1: Strain gage layout

The bending component of strain is calculated as the maximum deviation from the mean axial strain for any individual gage divided by the mean axial strain.

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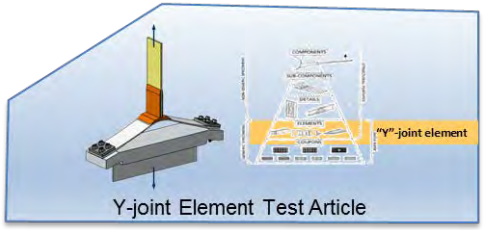
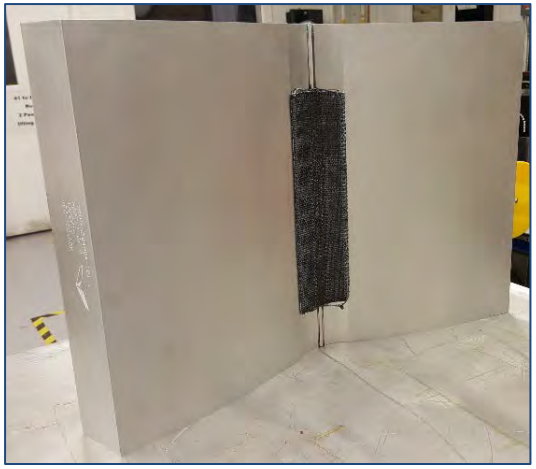
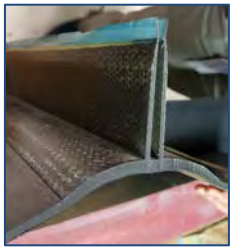
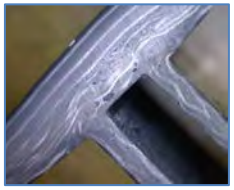
Element Manufacturing

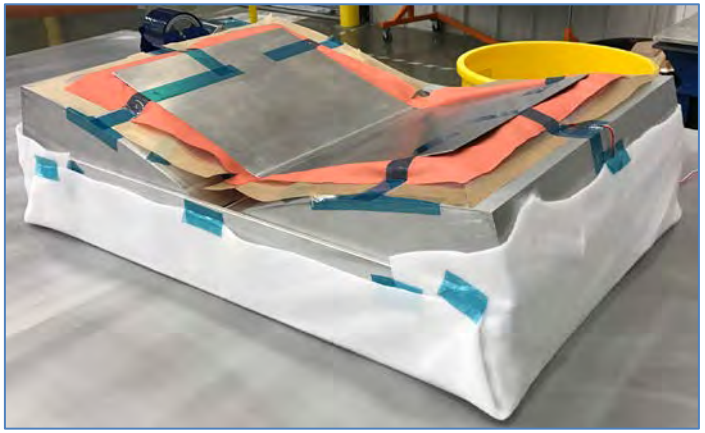
- Initial component fabrication trials conducted
- Tooling and manufacturing process parameters investigated

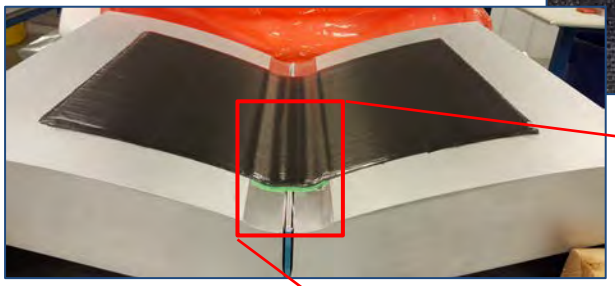


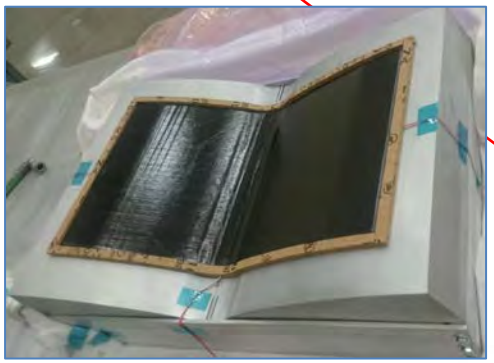




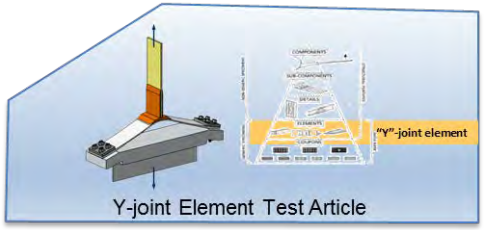




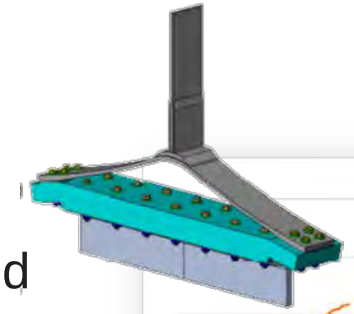


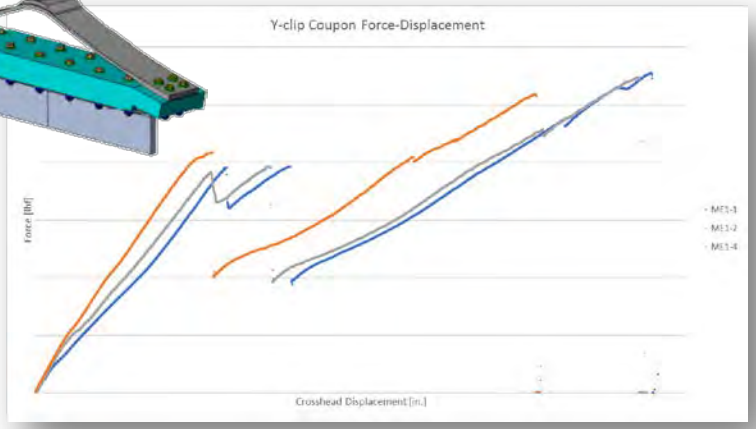


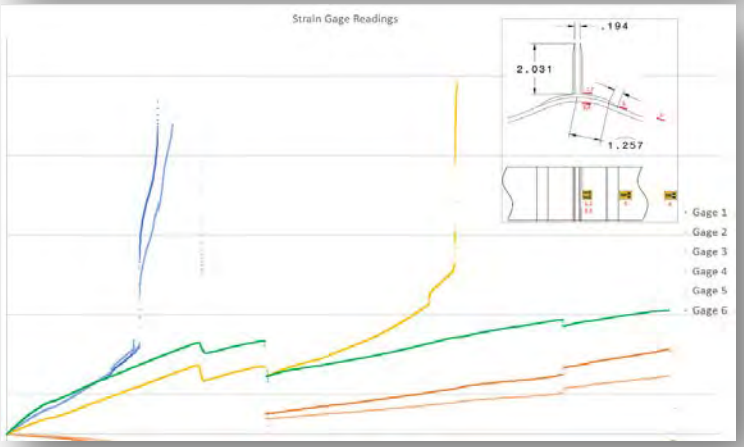
Y-Joint Element Coupon Tests

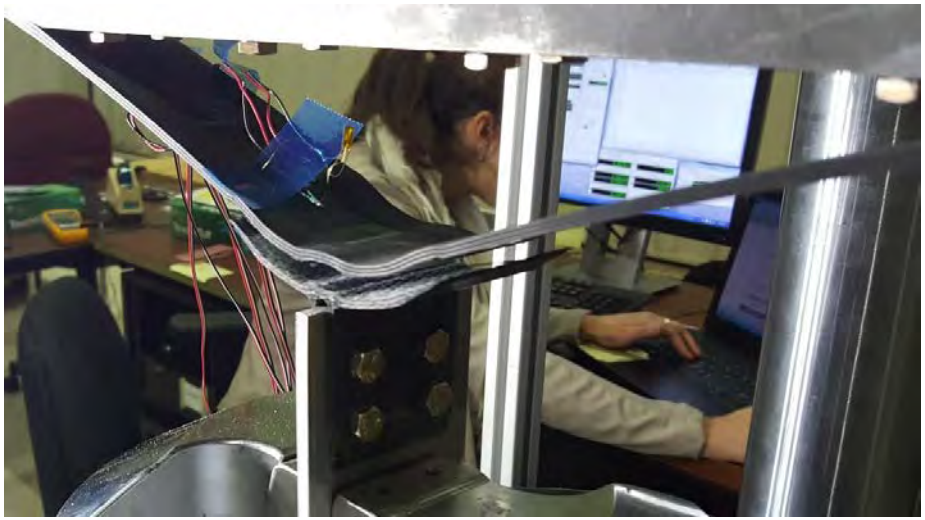


- Initial Manufacturing Exploration (ME) elements loaded to ultimate failure
- Developed test protocol and created load program
- Performing qualitative and quantitative data analysis; correlating data collected from test article with finite element modeling

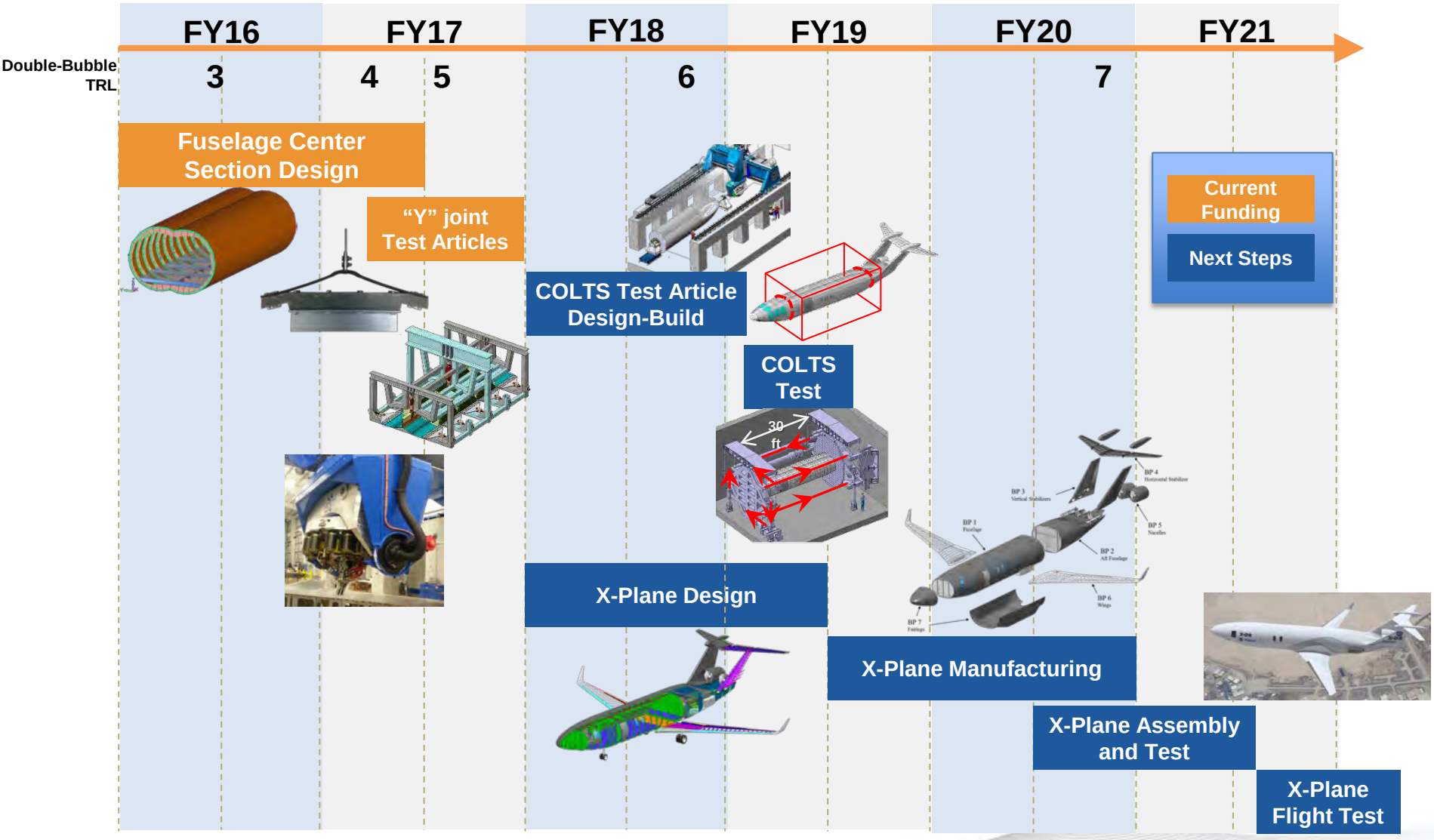




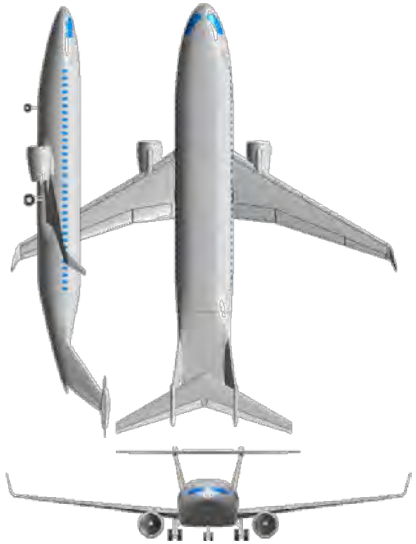


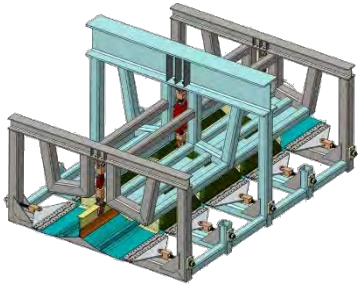


High-Level XD8 Project Schedule



Advanced Composite Unconventional Airframe Design-Build





Anticipated Benefits:

- *49% fuel and 40EPNdB cumulative noise benefits with current technology and integrated engines*
- *16% 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*
- *Combined load test at NASA Langley COLTS facility*

Objectives:

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

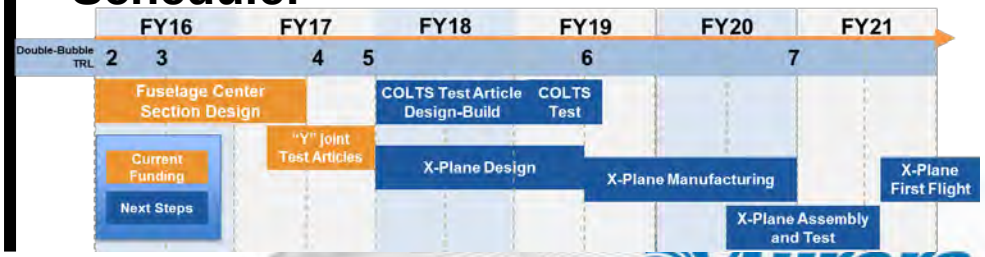
Work Statement:

- *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*
- *Drafted Test Evaluation Master Plan (TEMP)*
- *Optimized test coupon and article design*
- *Designed and procured cure tools*
- *Manufactured and loaded first coupons*
- *Identified manufacturing process improvements*

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 49% fuel burn reduction with integrated boundary layer ingesting (BLI) engines and 16% 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