Engineering, Operations & Technology
Boeing Research & Technology

CLEEN II –
Structurally Efficient Wing (SEW)
Compact Nacelle (CN) Short Inlet Ground Test

CLEEN II Consortium Public Plenary Session

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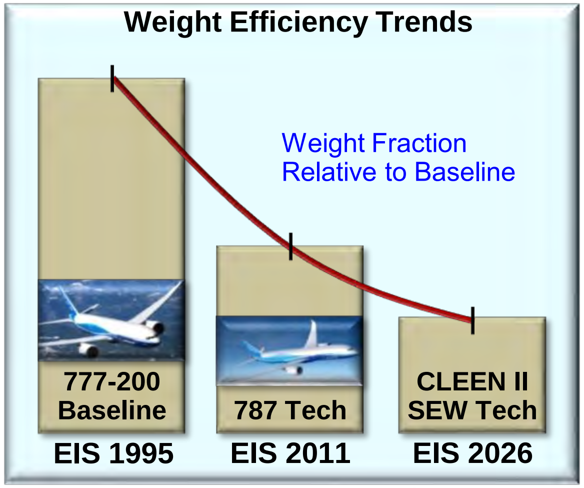
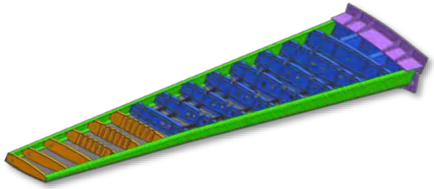
Boeing CLEEN II Projects

Structurally Efficient Wing:

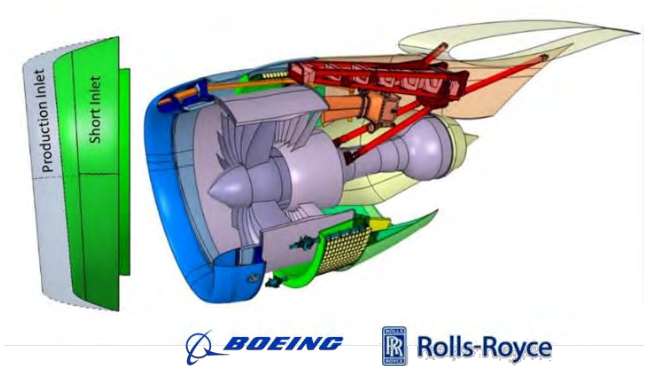
- Develop, build, and test a next-generation wing structure that demonstrates significant improvements in structural efficiency
- Show a continued weight reduction as compared to the 777-200 baseline
- Contribute to the FAA CLEEN II goal of reducing fuel burn, potentially reducing fuel consumption up to 3.5% through weight reduction of the wing.





Compact Nacelle:

- Demonstrate aerodynamic performance of a short inlet by testing on the ground in crosswind, using existing hardware and a Rolls-Royce Trent 1000 engine.
- Validate propulsion-aero design tools and transition to development program.
- Contribute to the FAA CLEEN II goal of reducing fuel burn 1.0% through weight and drag reduction of the nacelle



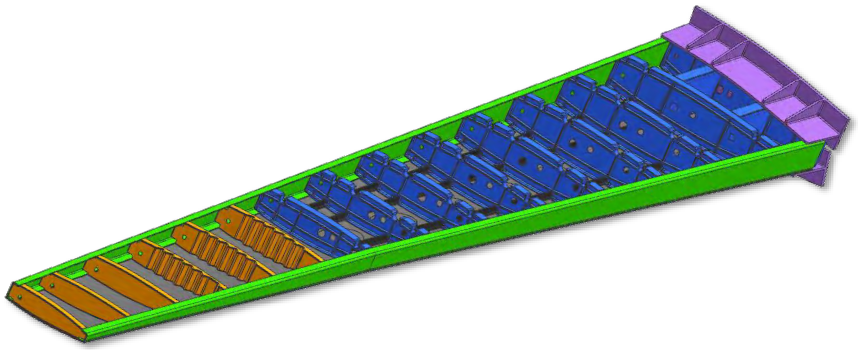
CLEEN II SEW & CN Technologies

SEW CLEEN II Technology	Goal Impact	Benefits and Application
• Advancing manufacturing technologies • Advanced prepreg composites • Resin-infused stitched blade stringers • Resin-infused hat stringers • Advanced alloy metallic ribs • Resin-infused sine wave rib • Stamped thermoplastic ribs	Fuel burn reduction CO_2 Production Avoidance	Lower weight, higher performance wing

CN CLEEN II Technology	Goal Impact	Benefits and Application
• Reduced length and diameter nacelle as compared to in-service engine installations	Fuel burn reduction CO_2 Production Avoidance	CN technologies provide 14%-16% reduction in fuel consumption on 125-seat and larger aircraft yielding over 400 million tons of fuel saved

All technologies contribute to the fuel consumption reduction goal by reducing structural weight and/or Drag

Boeing Structurally Efficient Wing (SEW)



Anticipated Benefits: *Cumulative predicted impact over twenty years:*

- *Jet A fuel consumption savings of approximately 200 million tons*
- *CO2 production avoidance of approximately 660 million tons*

Risks/Mitigation Plans:

- *Risks Identified, mitigation plans in place*

Objectives: *Demonstrate a suite of material and structural technologies that will contribute to the FAA's CLEEN II goal of achieving fuel burn reductions by 2026.*

Work Statement: *Boeing's disciplined development and building-block test approach will mature structural wing technologies and will demonstrate via the Wing Component Test Article (WCTA).*

Accomplishments/ Milestones since Boeing initiated this technology/project:

- *OTA Signed Oct 2015*
- *CoDR completed Mar 2016*
- PDR completed Jan 2017
- DDR completed Jul 2017

Schedule:

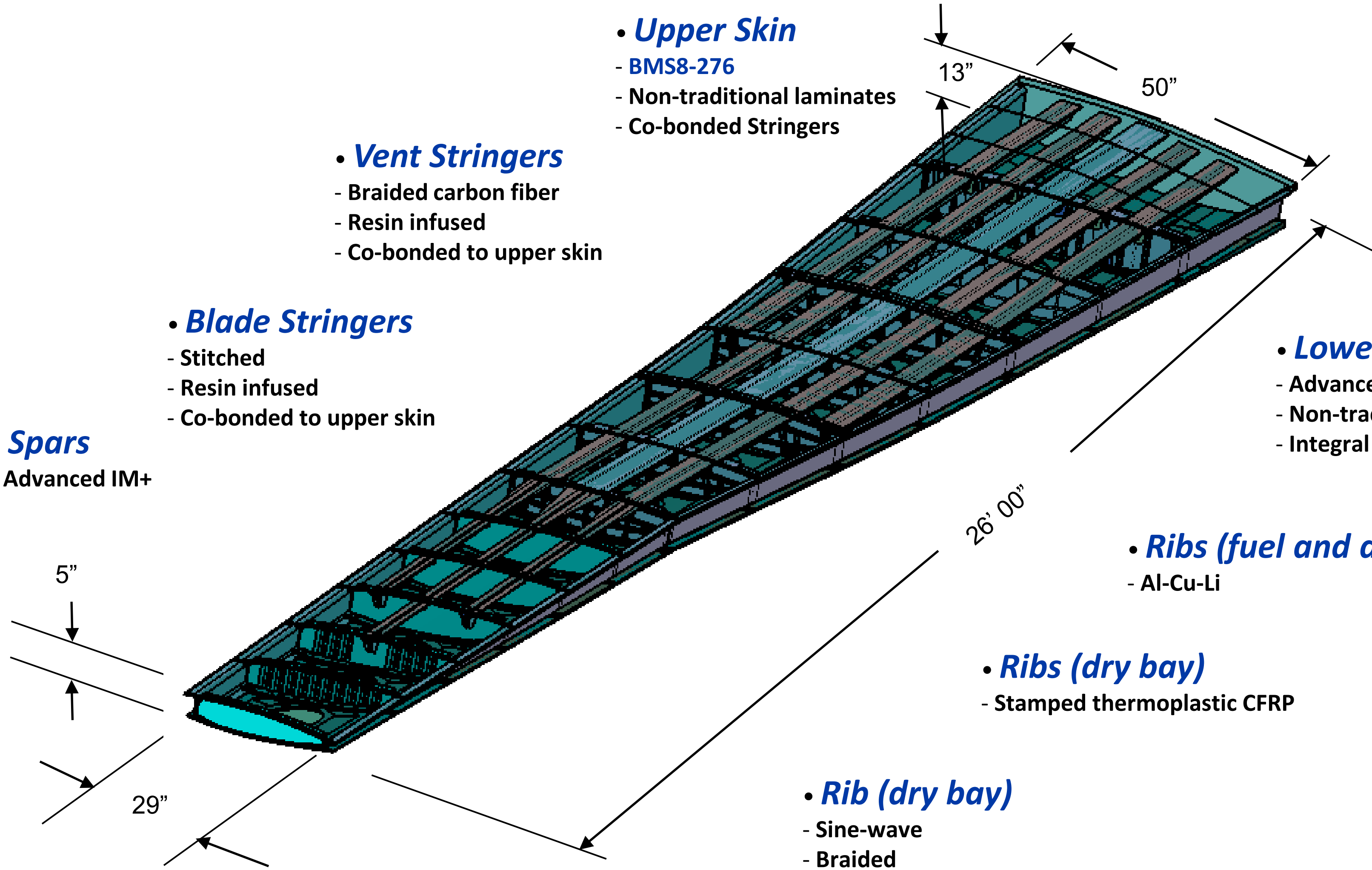
- *Oct 2015 ATP (completed)*
- *Mar 2016 CoDR (completed)*
- *Jan 2017 PDR (completed)*
- *Jul 2017 DDR (completed)*
- *Jun 2018 TRR*
- *Jun 2019 Program End*

SEW Year 1-3 Major Achievements

Technology Risk

- *Concept of Design Review (CoDR) completed early*
- *Preliminary Design Review (PDR) & Coupon Tests completed (TRL4)*
- *Building Block Tests Completed (TRL5)*
- *Detail Design Review (DDR) completed early*
- *Tooling, Part & Test Fixture Fab Completed*

CLEEN II Structurally Efficient Wing (SEW) Technology Demonstrations

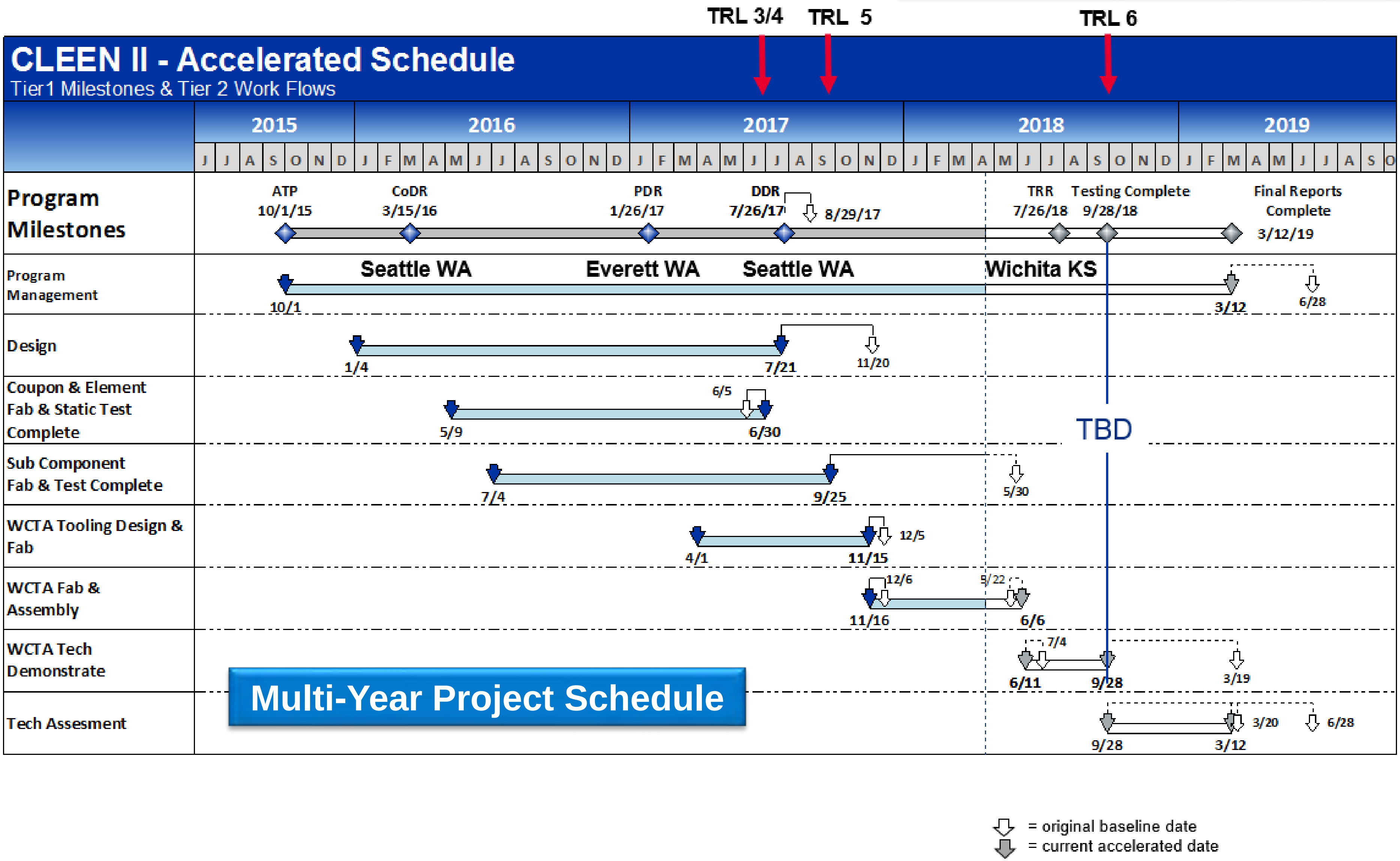


- ***Upper Skin***
  - **BMS8-276**
  - **Non-traditional laminates**
  - **Co-bonded Stringers**
- ***Vent Stringers***
  - **Braided carbon fiber**
  - **Resin infused**
  - **Co-bonded to upper skin**
- ***Blade Stringers***
  - **Stitched**
  - **Resin infused**
  - **Co-bonded to upper skin**
- ***Spars***
  - **Advanced IM+**
- ***Lower Skin***
  - **Advanced IM+**
  - **Non-traditional laminates**
  - **Integral Stringers**
- ***Ribs (fuel and dry bay)***
  - **Al-Cu-Li**
- ***Ribs (dry bay)***
  - **Stamped thermoplastic CFRP**
- ***Rib (dry bay)***
  - **Sine-wave**
  - **Braided**
  - **Resin infused**

Reduce Weight up to 28% as Compared to the 777-200

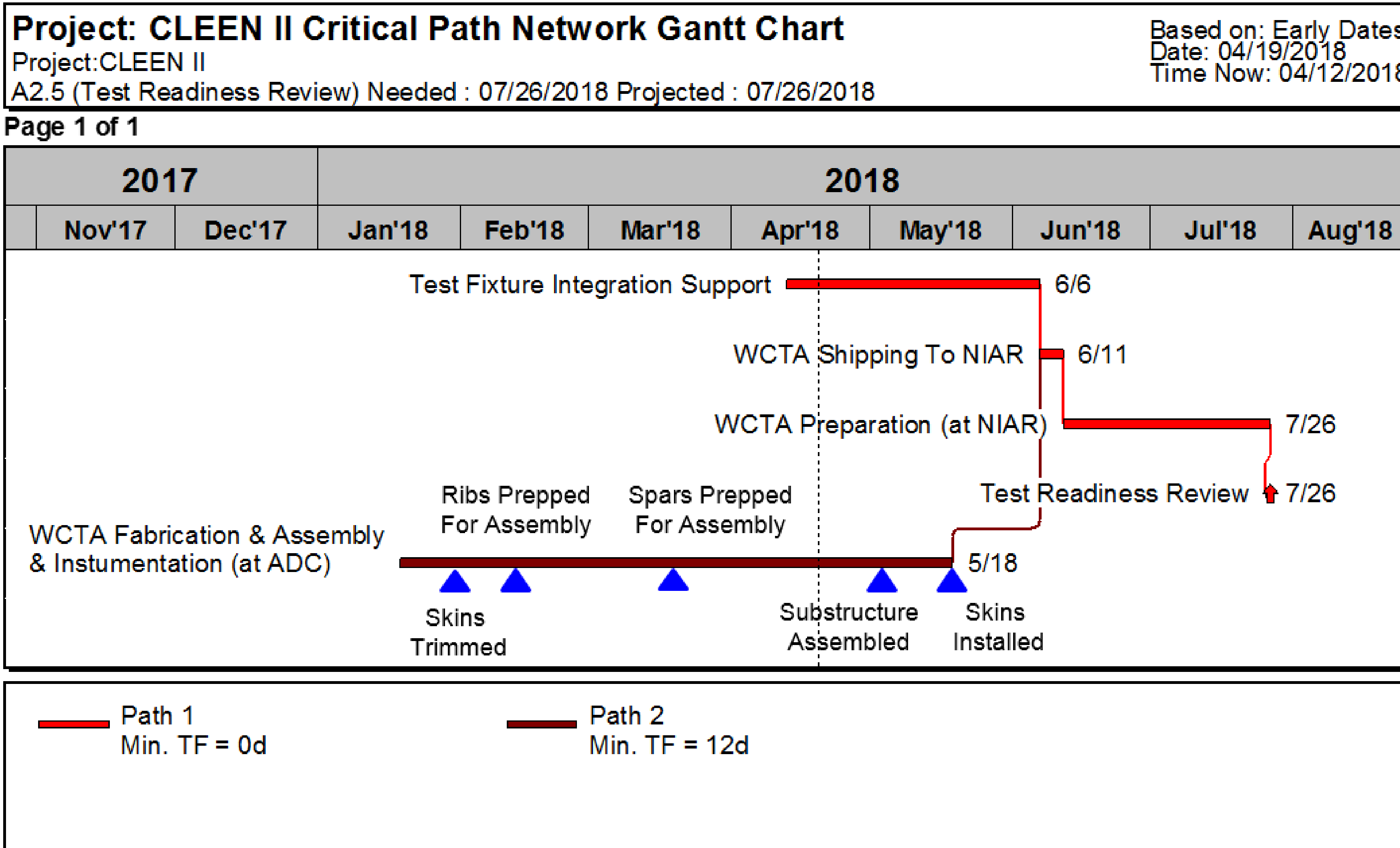
CLEEN II Boeing SEW – Accelerated Schedule

Technology Risk Reduction



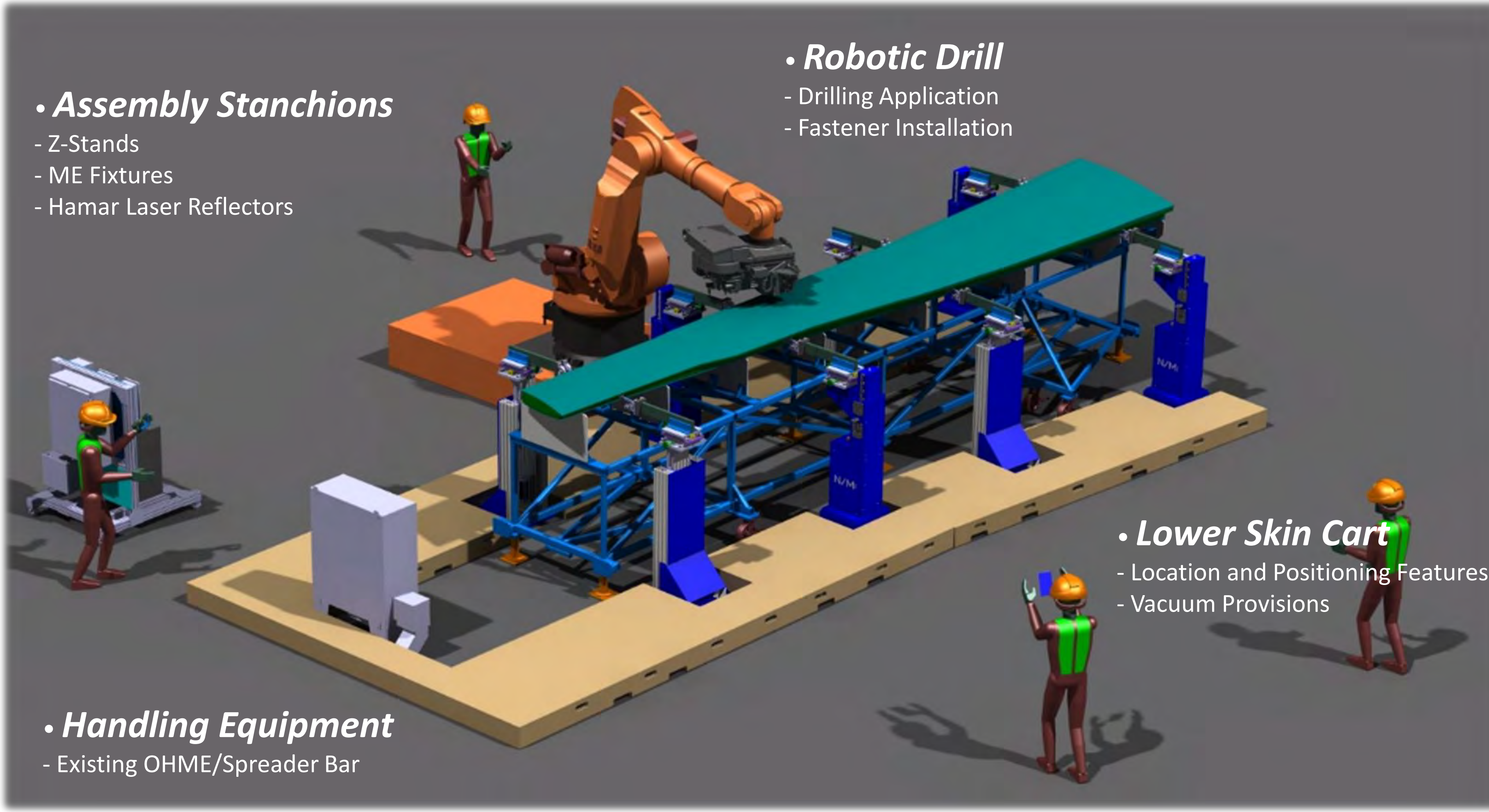
Multi-Year Project Schedule

SEW Critical Path to Test Readiness Review (TRR)

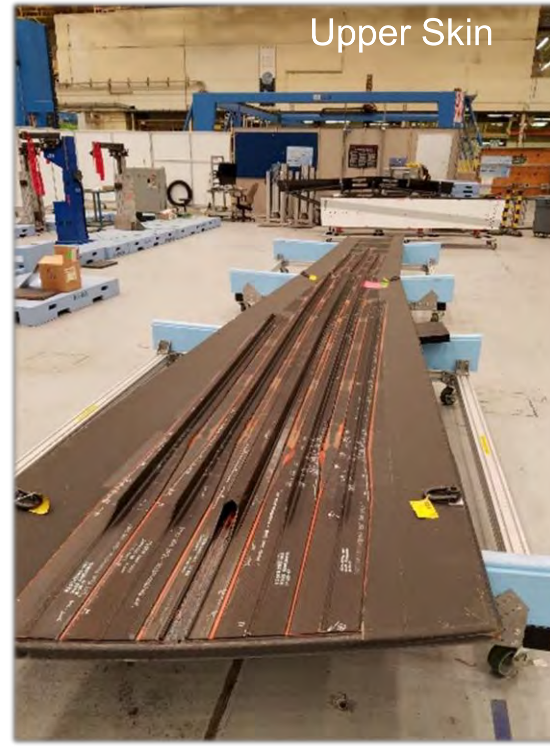


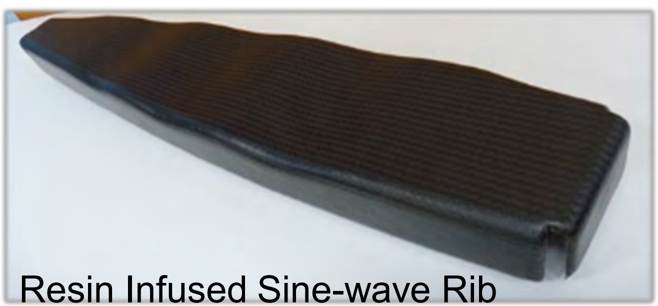
WCTA Assembly and Test Fixture Integration Receive "Critical Path" Attention

SEW WCTA Assembly Plan Overview



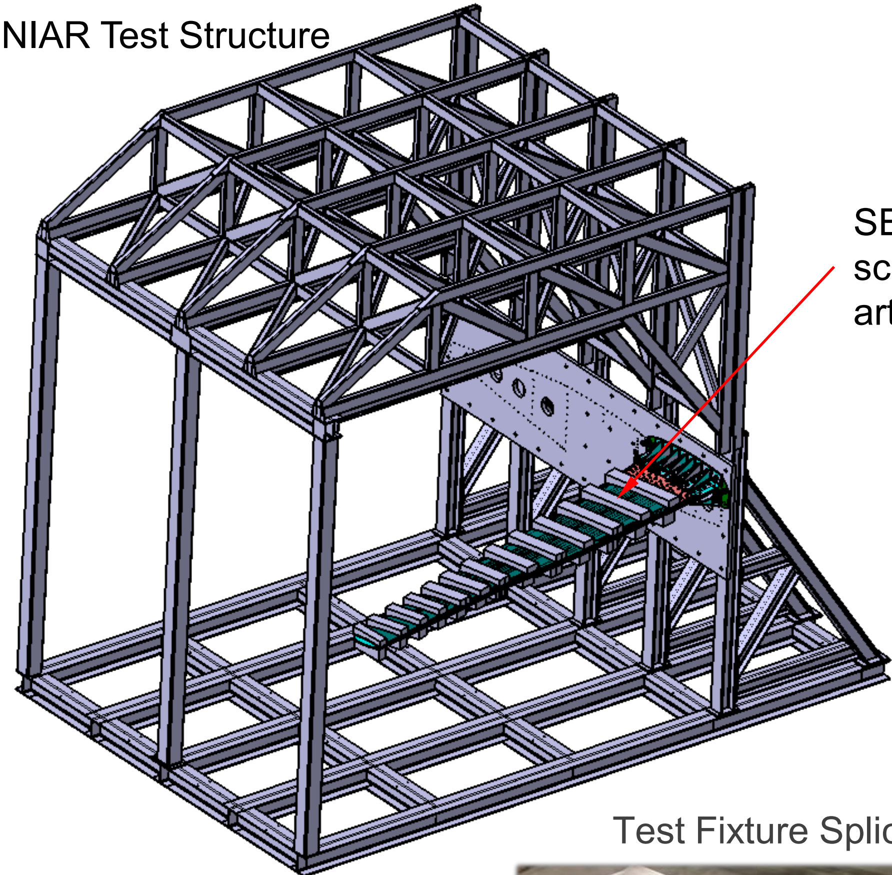
SEW WCTA Assembly Preparation





SEW Wing Component Test Article Test

NIAR Test Structure

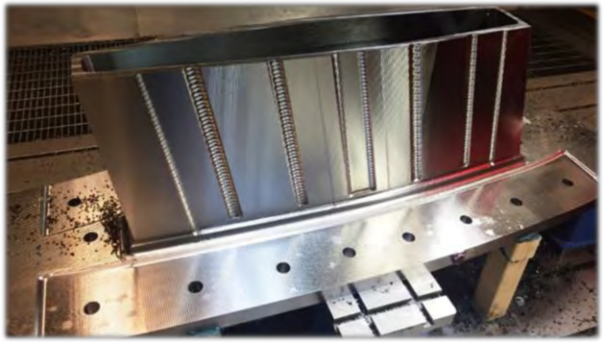


SEW full scale test article

Test Instrumentation

- Fully Instrumented with 90 Gages
  - 30 Axial Strain Gages
  - 60 Rosetted Strain Gages

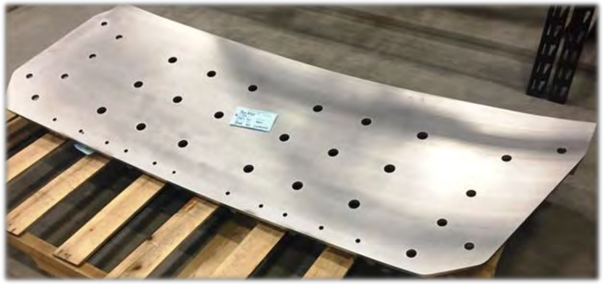
Test Fixture Internal Fitting



Test Sequence

- DLL Checkout
- 1 DSO .52 DLL, R=-.4
- 1.0 DLL Up & Down Bending
- 1.5 DLL (DUL) Up & Down Bending
- Up Bending to Failure or 2.25DLL

Test Fixture Splice Plate



Test Fixture Upper/Lower External Fittings

SEW - TRR Exit Criteria

Criteria	ECD
WCTA Assembly Complete (test fixture, instrumentation assembled and delivered)	6/11/2018
WCTA Test Plan Complete (objectives, configuration, loads, test sequencing, inspections, instrumentation, and schedule all defined)	7/10/2018
WCTA Test Integration • Test Setup Complete • **Test Safety Reviewed, Agreed Upon and Complete** • FAA/Boeing/NIAR Agree Test is Ready to Go	7/26/2018
Test Readiness Review (TRR) Complete	7/26/2018

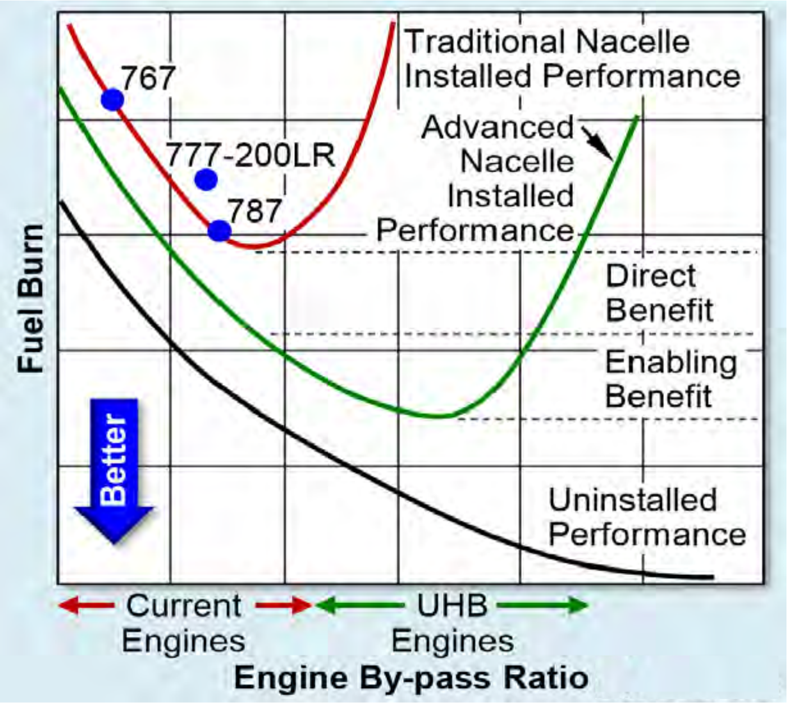
Compact Nacelle – Overview

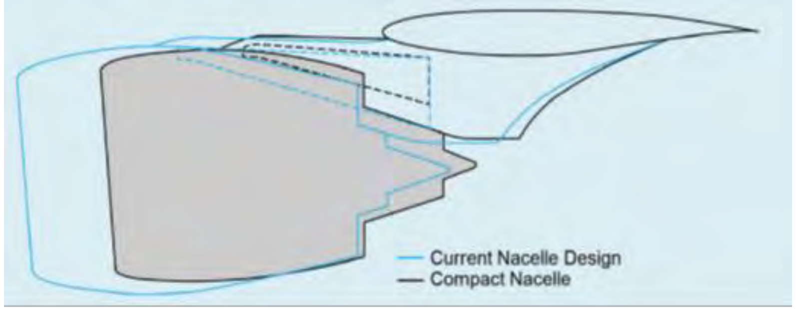
General Engine Characteristics

- **2025 EIS**
- **Geared Low Pressure Ratio Fan**
- **Bypass Ratio of 12 to 14**
- **Large Fan, Small Core**
- **Core Mounted Accessories**

Nacelle Technologies Required

- **PAI Optimization**
- **Short Inlet (0.4 L/D or less)**
- **Advanced T/R Configuration**
- **Improved Acoustic Solutions**
- **Advanced Manufacturing**
- **New High-temp materials**
- **Advanced Bleed Systems**





Compact Nacelle (CN) - Short Inlet

Anticipated Benefits: *Cumulative predicted impact over twenty years:*

- *Compact Nacelle architecture is enabler of advanced UHB engines with 2025 EIS*
- *14%-16% reduction in fuel consumption on 125-seat and larger aircraft yielding over 400 million tons of fuel saved.*
- *CO2 production avoidance of ~1200 M tons*
- *Achieve 1% Block Fuel savings through weight and drag reductions*

Objectives:

- *Measure effects of inlet flow distortion at the fan face in cross wind.*
- *Validate Short Inlet design tools for transition to Boeing's next development program.*

Work Statement:

Conduct ground crosswind test of a Boeing Short inlet installed on a Trent 1000 engine at the Rolls-Royce Stennis, Mississippi test facility.

Accomplishments since project launch:

- ✓ *Project Launched – Apr '17*
- ✓ *Short Inlet delivered to Stennis – Apr '17*
- ✓ *Kickoff Meeting / Test Plan review – Jul '17*
- ✓ *Block 1 testing completed – Aug '17*
- ✓ *Baseline Inlet delivered to Stennis – Dec '17*
- ✓ *Block 2 TRR completed – Dec '17*
- ✓ *Block 2 testing completed – ~~May '18~~ Mar '18*

Schedule:

- *Limited Rights Report – ~~Aug '18~~ Jul '18*
- *Public Report – ~~Nov '18~~ Sep '18*
- *Final Briefing – ~~Nov '18~~ Sep '18*
- *Program End – ~~Dec '18~~ Oct '18*

Short Inlet Technology Risk Reduction

Technology Risk Reduction

Technology Risk

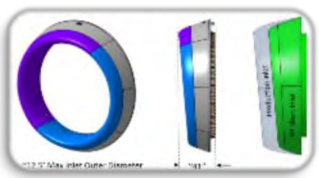
Technical Risk	Mitigation
Inlet lip separation at off-design conditions	• Completed Phase 1 study on aerodynamic design and prediction tool verification prior to design of hardware • Developed plan using aggressive short inlet to exercise tools • Using experimental results to validate tools • Calibrating tools using 787 Certification Data
Inlet - fan face distortion, impacting fan efficiency, weight and flutter/resonance (Rolls-Royce focus)	• RR performed separate fan flutter and resonance test (outside CLEEN) • Served as risk reduction to proceed with crosswind testing
Nacelle integration and build impacts	• Close coordination with program nacelle design team • Integration addressed during requirements and design phases • Consistent bulkheads, engine interfaces, loads cases, equipment integration requirements

Aerodynamic integration with production BPR/FPR (2025 EIS)	• Leverage existing capabilities and extensive certification database
	• Models calibrated and verified by ground test with baseline inlet previously tested on 787 ecoDemonstrator (2014)
	    • Short Inlet Aerodynamics & prediction tools (separation & prediction)
	    • Fan Aerodynamics (stall, efficiency in distorted flow)
	    • Fan Aeromechanics (flutter and resonant responses) (RR only test)

Modeling is key to Successful short inlet integration with low FPR Fan

Short Inlet Development

Multi-Year Project Schedule






NextGEN CLEEN

Project Launch – SRR – DDR – RR Short Inlet H/W Complete – CLEEN ATP – H/W On Dock at Stennis – K/O Mtg – Ground Test Block 1 – Ground Test Blocks 2/3/4 – Final Report

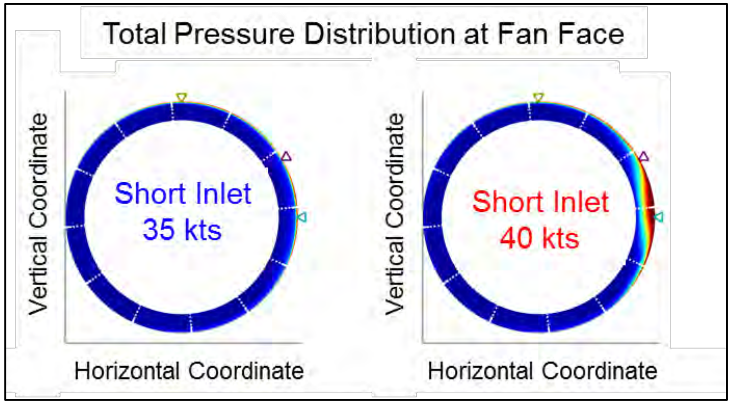
2015	2016	2017	2018
Tool Calibrations	Reqts & HW Dev	Ground Testing	Reporting
Puget Sound	Charleston, SC	Stennis, MS Rolls-Royce	

TRL 4 *TRL 5* *TRL 6*

Short Inlet Ground Test (TRL6) – March 2018

Short Inlet - Initial Ground Test Results

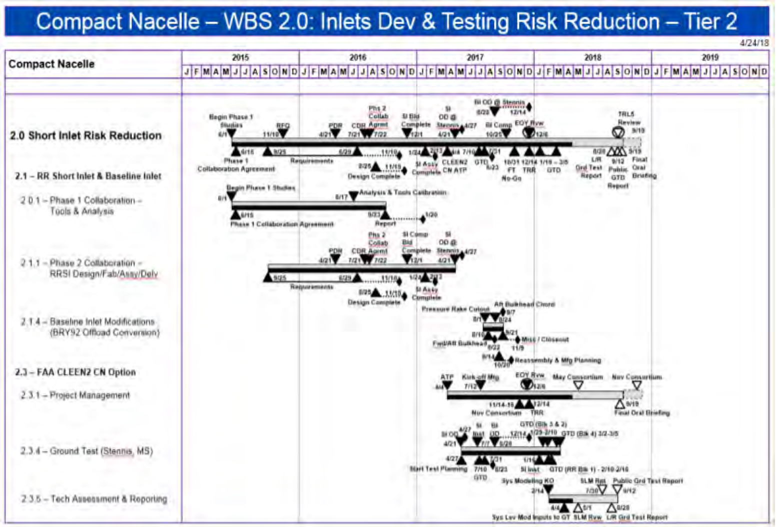
- **Fan Flutter testing cleared engine/inlet for test [RR test only]**
- **Short inlet performed as predicted by developmental tools, in-line with baseline inlet performance**
  - Attached up to 35 kts
  - Separation at 40 kts



- **Inlet rakes did not affect inlet lip isentropic Mach number distribution**
- **Gained confidence in tools during worst case crosswind test that supported rationale for not pursuing flight test option**

Short Inlet Accomplishments & Next Steps

- ✓ ***Project Launched – Apr '17***
- ✓ ***Short Inlet delivered to Stennis – Apr '17***
- ✓ ***Kickoff Meeting / Test Plan review – Jul '17***
- ✓ ***Block 1 testing completed – Aug '17***
- ✓ ***Baseline Inlet delivered to Stennis – Dec '17***
- ✓ ***Block 2 TRR completed – Dec '17***
- ✓ ***Block 2 testing starting – Jan '18***
- ✓ ***Block 2 testing completed – ~~May '18~~ Mar '18***
- ***Data analysis complete – ~~Jul '18~~ Jun '18***
- ***SLM complete – ~~Aug '18~~ Jul '18***
- ***Limited Rights Report delivered – ~~Aug '18~~ Jul '18***
- ***Public Report delivered – ~~Nov '18~~ Sep '18***
- ***Final Briefing – ~~Nov '18~~ Sep '18***
- ***Project Completes – ~~Dec '18~~ Oct '18***



Program Completion is accelerated by two months

CLEEN II Program Participation Advantages

Impacts of No FAA Funding

Benefits to Boeing for participation in CLEEN II

- Collaboration with FAA and visibility of Industry's collective progress toward shared goals
- Accelerates technology risk reduction and transition into the fleet.

Potential impact if projects were not funded by the FAA

- Reduced FAA visibility of industry tech development
- Reduced fidelity of System Level Models and Fleet benefits projections
- Overall influence on fleet would be under/overstated
- Reduced Visibility into Potential constraints on sustained aviation growth

Collateral Benefits

Opportunity Cost / Collateral benefits

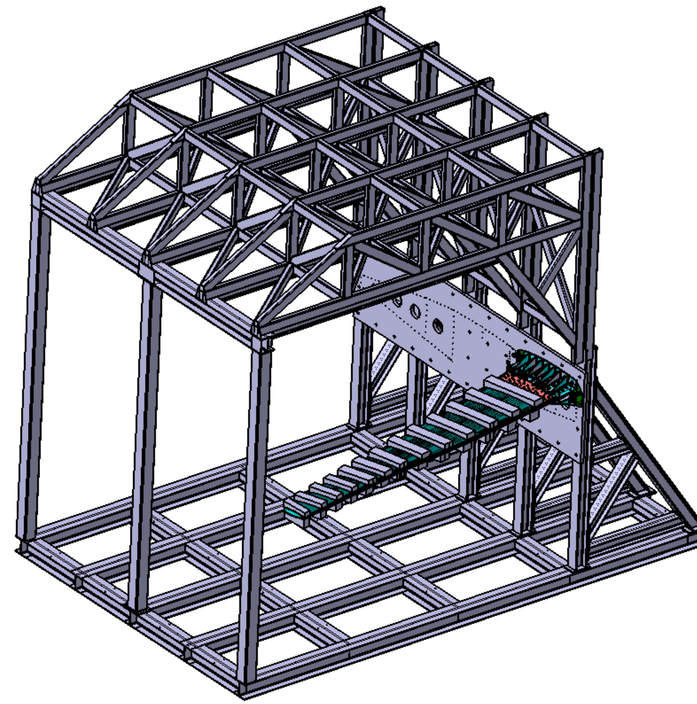
- ***Structurally Efficient Wing (SEW)***
  - *Broad applications across current/future Commercial & Defense programs*
  - *Accelerates Development & Validates Simulations*
    - *Thermoplastics*
    - *Resin Infusion*
    - *IM+ Material System*
    - *Advanced Fabrication and Assembly Techniques*
- ***Short Inlet for Compact Nacelle (CN)***
  - *Baseline for new development program*
  - *Baseline for follow on development programs*

Summary

Boeings CLEEN II technologies represent some of our highest impact concepts with a clear path to certification and implementation.

- The building-block test approach on SEW will develop the selected technologies along the TRL scale, resulting in a TRL 6 demonstration when the Wing Component Test Article (WCTA) test is complete
- Short Inlet testing, successfully completed in March (TRL 6), will validate the Short Inlet design tools & methods
- Compact Nacelle will complete in October – two months early
- SEW & CN contribute to the FAA's CLEEN II goal of reducing fuel burn
- FAA & Industry benefit from continued CLEEN program investment and collaboration.

Thank you



Georgia Tech Aerospace Systems Design Laboratory

Acronyms

ATP	Authority to Proceed
CoDR	Concept Design Review
DDR	Detailed Design Review
DLL	Design Limit Load
DUL	Design Ultimate Load
DSO	Design Service Objective
ECD	Estimated Completion Date
EIS	Entry Into Service
H/W	Hardware
K/O	Kick Off
Kts	Knots
OGV	Outlet Guide Vane
PDR	Preliminary Design Review
RR	Rolls Royce
SEW	Structurally Efficient Wing
T/R	Thrust Reverser
TRL	Technology Readiness Level
TRR	Test Readiness Review
WCTA	Wing Component Test Article

BOEING