

Inside NASA's X-57 Configuration - More than Just Electrifying an Airplane

(EAA AirVenture 2018 title: NASA X-57, More Than Electrons)

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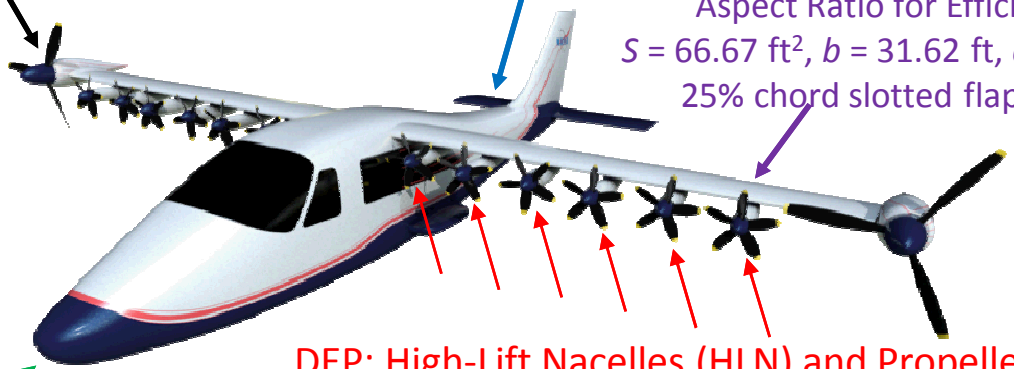
Outline

- Background
  - Test Configurations (Mods I-IV)
  - Mod I Findings
  - NASA X-57 Aircraft Goals and Focus of this Research
  - NASA X-57 Configuration
  - Build-up Approach to Evaluate X-57 Performance
- Results
  - Flow Conditions
  - Explanation of Codes
  - Modeling Powered Cases
  - Code Comparisons
  - Wing Aerodynamics
    - Effect of High-Lift Nacelles (HLN)
    - Lift Augmentation from High-Lift (HL) System (DEP + 30° flap deflection)
    - Effects of Fuselage: span loading and stall differences
  - Stabilator Aerodynamics
  - Stabilator Alone CFD, Stabilator Alone WT
    - Downwash
  - Aileron Control
- Summary and Conclusions
- Wing Structure

X-57 Maxwell

- Originally named **SCEPTOR: S**calable **C**onvergent **E**lectric **P**ropulsion **T**echnology and **O**perations **R**esearch
- X-57: Utilizes electric motor/battery technology to enable the optimization of aerodynamics, propulsion, structures, and aeroelasticity for an optimized cruise efficiency, while still achieving low-speed stall requirements
- The X-57 is a technology demonstrator

NASA X-57 Maxwell Configuration



Stabilator
All-moving Horizontal Tail
With Geared Trim Tab

Wingtip Propulsion
Electric Motors
Propellers Opposing Wingtip Vortex

WING
Reduced Area (S) and Increased Aspect Ratio for Efficiency
S = 66.67 ft^2, b = 31.62 ft, c = 2.13 ft
25% chord slotted flap (30°)

DEP: High-Lift Nacelles (HLN) and Propellers
12 Electric Motors
Staggered Propeller Planes
Corotating, Opposing Wingtip Vortex
Folded Back, Conformal onto HLN at Cruise

Tecnam P2006T Fuselage, Stabilator and Vertical Tail
Single Pilot

X-57 DEP Project Approach



Ground validate DEP high-lift system



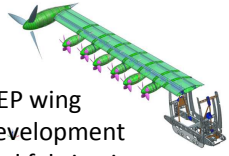
Flight test: baseline Tecnam P2006T

Goals:
- Establish Baseline Performance
- Pilot Familiarity



Ground and flight test validation: electric motors, battery, and instrumentation

Goals:
- Establish Electric Power System Flight Safety
- Establish Electric Tecnam Baseline



DEP wing development and fabrication



Flight test: electric motors in wingtips on DEP wing and high-lift nacelles

Achieves Primary Objective
- High Speed Cruise Efficiency

Spiral Development Process
Build – Fly – Learn



Flight test: DEP motors, controllers, folding props, and cruise motors in wingtips

Achieves Secondary Objectives
- DEP Acoustics Testing
- Low Speed Control Robustness
- Certification Basis of DEP Technologies

Mod I

Mod II

Mod III

Mod IV

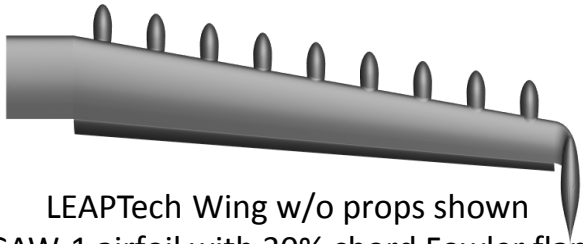
Leading Edge Asynchronous Propeller Technology LEAPTech Wing

- High-lift wing with 40° flap deflection tested on the HEIST truck at NASA Armstrong Flight Research Center
  - 18 staggered high-lift nacelle/props, follow the wing leading-edge sweep
  - 4° wing twist
  - S_{ref}=55.17 ft^2
  - b_{ref}=31 ft
  - Aspect Ratio = 17.4

Hybrid-Electric Integrated Systems Technology (HEIST) truck test



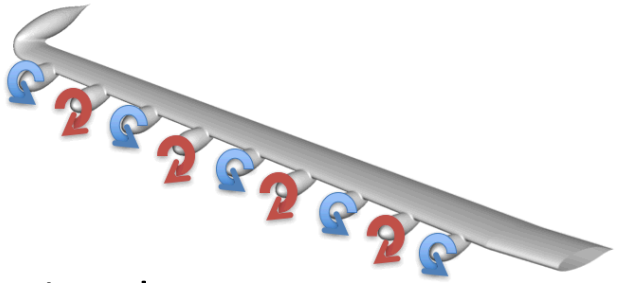




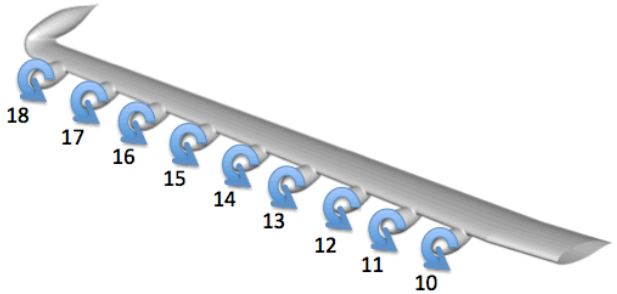
LEAPTech Wing w/o props shown
(GAW-1 airfoil with 30% chord Fowler flap)

Propeller Rotation Study

- Conditions: 73 mph at 2300 ft, Re_c=1M, 60°F, 16.7 hp/prop at 6,147 RPM
- Counter-rotating propellers



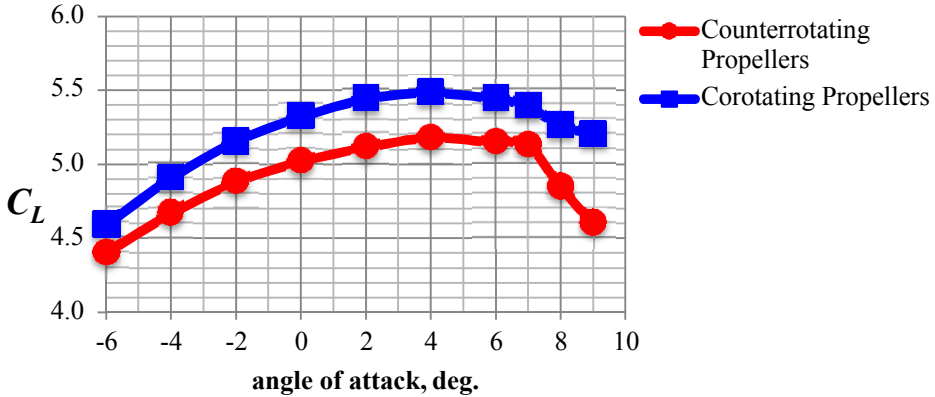
- Corotating propellers, all opposing the wingtip vortex



Propeller Rotation Study

Effect on Lift Coefficient

- Experiment designed for counter-rotating props for acoustics
- Corotating propellers have increase in lift
- Corotating and counter-rotating props have $C_{L,max}$ at α=4°, but corotating props higher lift (ΔC_L = 0.31 - 6% increase)
- Project changed to all corotating props from CFD results

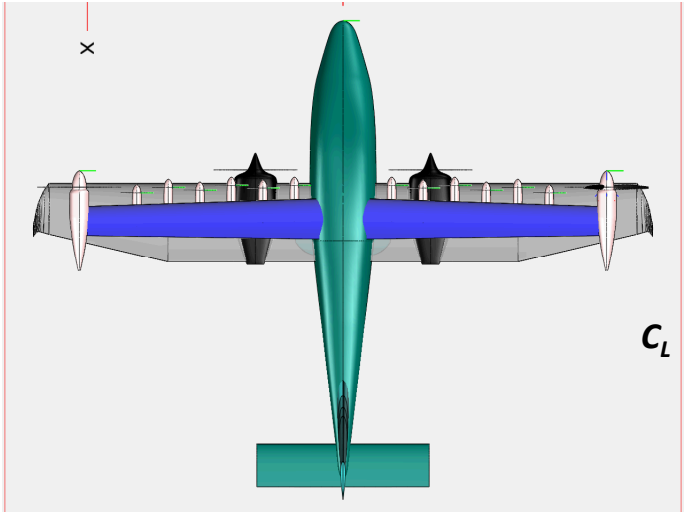


X-57 Wing Area Reduced for Cruise Efficiency with Powered Lift Augmentation for Low-Speed Performance

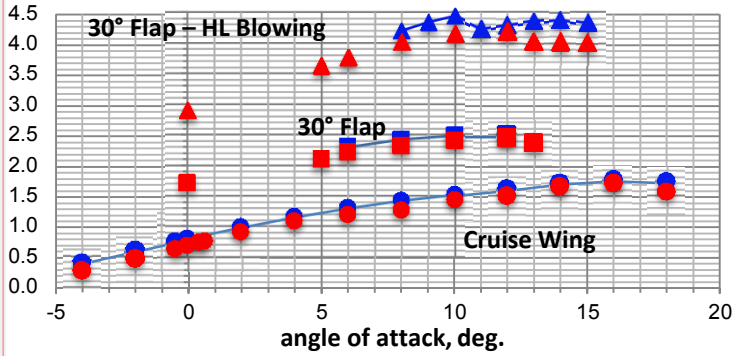
Wing area reduced to 42% of original Tecnam P2006T Wing

Objectives:

- **Increase cruise efficiency (1.2X)**
- **Retain low-speed performance, stall at 58 knots**



Powered Lift Augmentation:
Distributed propellers increase the velocity of the air over the wing to increase the lift at low speeds



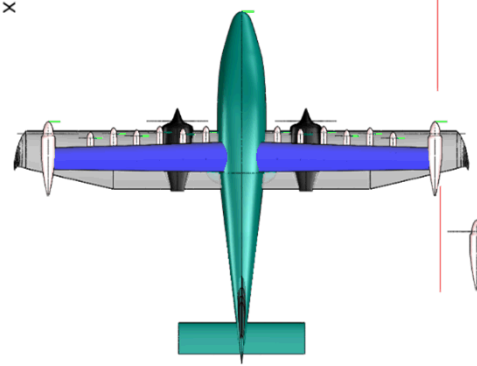
X-57 Induced Drag vs Span Sensitivities

X-57: Design cruise thrust: 216.5 lbs

Tecnam
W_g = 2,558 lbs
Wing Area(S) = 158.9 ft²
Span(b) = 37.4 ft
Aspect Ratio(AR) = 8.8
Di = 28.72 lbs
Di = 13.3% cruise thrust

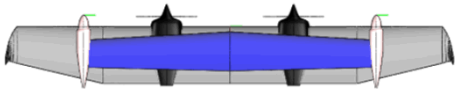
Increased Gross Weight
W_g = 3,000 lbs
Span(b) = 37.4 ft
D_i = 39.49 lbs (+37.6%)
Di = 18.3% cruise thrust

X-57
W_g = 3,000 lbs
Wing Area(S) = 66.67 ft²
Span(b) = 31.62 ft
Aspect Ratio(AR) = 15
D_i = 53.23 lbs (+85.4%)
Di = 24.6% cruise thrust

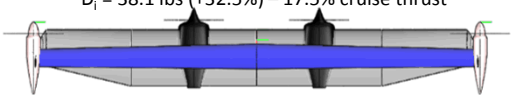


All examples: Wing Planform - S = 66.67 ft²

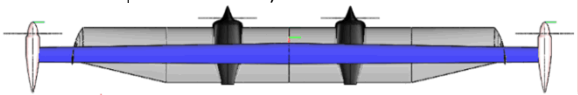
Geometrically Scaled Span and Chord
b = 15.7 ft, AR = 3.7
D_i = 216.2 lbs (+653%) – 99.9% cruise thrust



Span Equals Tecnam P2006T Span
b = 37.4 ft, AR = 21.0
D_i = 38.1 lbs (+32.5%) – 17.5% cruise thrust



Span Loading Equals Tecnam P2006T
b = 43.9 ft, AR = 28.9
D_i = 27.7 lbs -3.7%) – 12.8% cruise thrust



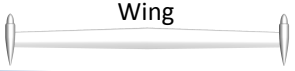
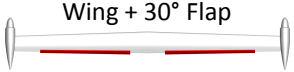
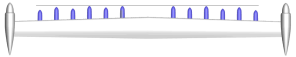
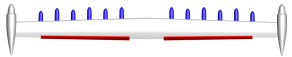
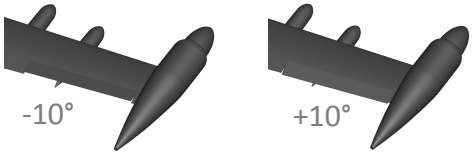
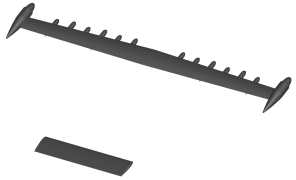
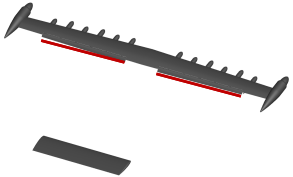
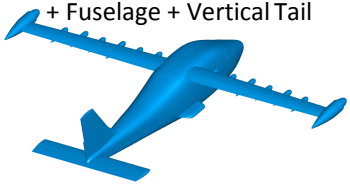
NASA X-57 Aircraft Goals
and Focus of this Work



- Goals: At 3000 lb gross weight
  - Cruise speed of 150 knots at 8,000 ft
  - C_D = 0.0542 (ref. 1)
  - Stall speed of 58 knots
  - Distributed Electric Propulsion (DEP) blown wing has to meet C_L = 3.95
- No wind tunnel tests would be conducted to characterize or validate cruise/high-lift performance
- Characterize aircraft performance using CFD to determine:
  - If wing C_L and C_D goals can be met
  - If airplane is controllable, and also quantify stabilator hinge moments
- Use multiple codes (RANS and hybrid RANS/LES - DDES) and turbulence models to help quantify uncertainty of CFD-only results

[1]*Borer et al.: AIAA 2016-3920*

Build-up Approach to Evaluate X-57 Performance

Research Topic	Cruise Geometry	High-Lift Geometry
Basic Performance Wing Alone	Wing 	Wing + 30° Flap 
Effect of Adding HLN and Pylons	Wing + HLN 	Wing + 30° Flap + HLN 
Characterize S&C Performance of Stabilator Alone  Trim tab settings 0°, -5°, -10°	Stabilator 	Stabilator 
Effect of Adding Stabilator to Wing  -10° +10° Also Evaluated Effectiveness of Ailerons	Wing + HLN + Stabilator 	Wing + 30° Flap + HLN + Stabilator 
Effect of Adding Fuselage and Vertical Tail	Wing + HLN + Stabilator + Fuselage + Vertical Tail 	Not Computed Yet

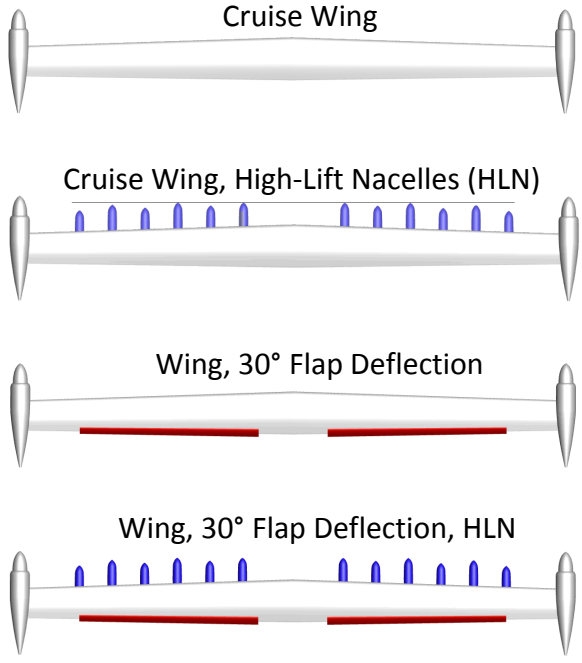
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    - Lift Augmentation from High-Lift (HL) System (DEP + 30° flap deflection)
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Configuration – X-57 Wing
CFD Grids

- 4 wing grids to investigate:
  - Cruise wing performance
  - Effects of high-lift nacelles (HLN) on cruise wing and 30° flapped wing
  - Cruise power affects on induced drag reduction
  - Performance of 30° high-lift flap (unblown)
  - Lift increment of DEP blowing
- Geometry and Assumptions:
  - 2° twist, α= 0° is defined when root section incidence is 2°
  - S_{ref}=66.67 ft^2, b_{ref}=31.62 ft, c_{ref}=2.13 ft
  - β = 0° so use semispan grids with symmetry boundary condition
- Propellers:
  - Corotating - ALL opposing wingtip vortex
  - 12 fore- and aft-staggered HLN/props
  - Wingtip propulsion on cruise wing only
  - Simulated by actuator disk model



Conditions – X-57 Wing CFD

- Cruise Wing
  - 150 KTAS (M = .233) at 8,000 ft, T = 30.5°F and Re_c = 2.83 million
  - Angle-of-attack range from α = -4° to α = 18°
  - Cruise power:
    - Power: Thrust = 230 lb (total), 58.69 hp/prop at 2250 RPM, Torque/prop = 137 ft-lb
    - No power
- Wing with 30° flap deflection (High-Lift Wing)
  - 58 KTAS (M = 0.088) at sea level conditions, T = 59°F and Re_c = 1.33 million
  - Angle-of-attack range from α = 0° to α = 19°
  - High-Lift Landing Power:
    - Blowing: Thrust = 596.4 lb (total), 13.7 hp/prop at 4548 RPM, Torque/prop = 15.9 ft-lb
    - No Power

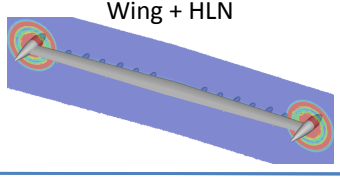
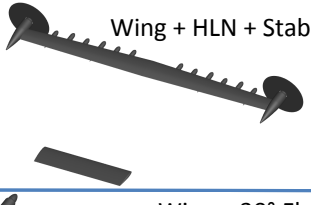
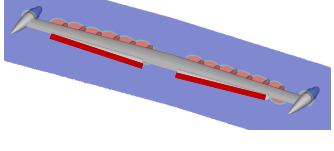
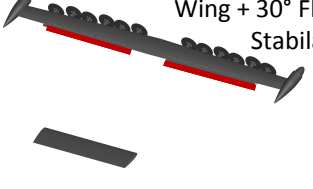
Explanation of Codes

- FUN3D node-based flow solver
  - First code used due to ease of modeling multiple propellers
  - SA-RC-QCR2000 turbulence model
- USM3D cell-centered flow solver
  - Grids size grew adding features and improving resolution, changed from FUN3D to USM3D, advantage of smaller grids for cell-centered code to get the same or better resolutions
  - SA and SA Detached-Eddy Simulations (DES) turbulence models, and Langtry-Mentor (LM) transition model
    - LM to compare to WT low speed results (not expecting cross flow)
- Kestrel cell-centered flow solver
  - To corroborate the lower lift predicted with USM3D SA DES, than with SA model
  - SA and SA Delayed Detached-Eddy Simulations (DDES) turbulence models
- Expect hybrid RANS/LES models of DES and DDES to predict $C_{L,max}$ better

Modeling Powered Cases

Actuator Disk

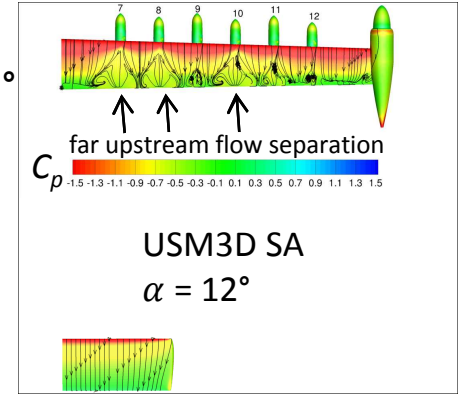
- Actuator disk models pressure jump across the propeller plane
  - Will not capture tip vortices from individual blades
- FUN3D blown HL wing using actuator disk had slightly lower C_L compared to OVERFLOW modelled propellers, with similar flow contours
- **Cruise power:** Wingtip propellers with cruise geometry at 150 KTAS
  - Totals: Thrust = 230 lbf and 117.38 hp at 2250 RPM (Torque/cruise-prop = 137 ft-lb)
- **Landing power:** HL blowing with HL geometry at 58 KTAS
  - Total Thrust = 596.4 lbf at 4548 RPM (13.7hp/HL-prop and Torque/HL-prop = 15.9 ft-lb)
- Thrust and power coefficients constant through angle-of-attack range

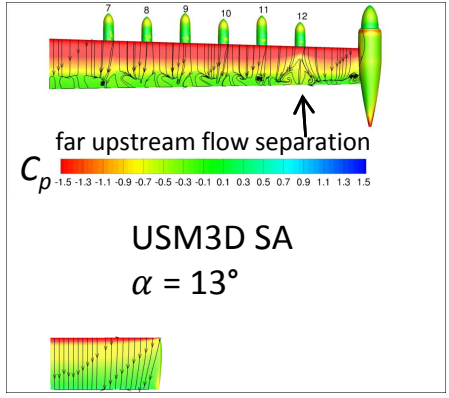
Cruise Power with Cruise Geometry	Wing + HLN 	Wing + HLN + Stabilator 
DEP High-Lift Blowing with High-Lift Geometry	Wing + 30° Flap + HLN 	Wing + 30° Flap + HLN + Stabilator 

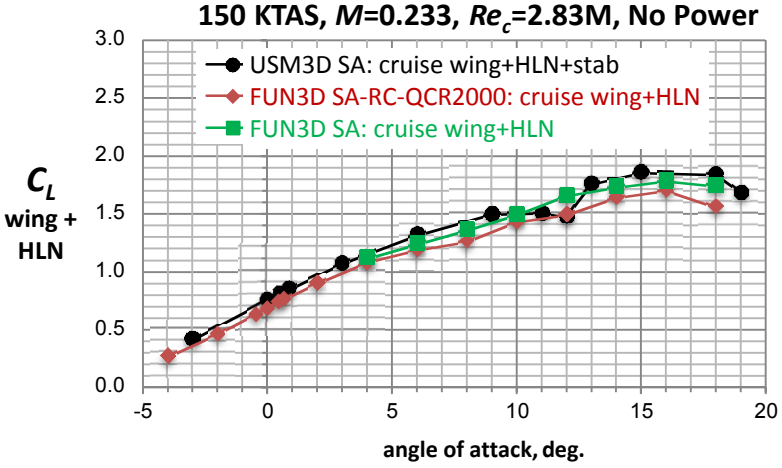
[8]*Deere et al.: AIAA 2016-3925*

Unpowered Cruise Wing
Code Comparison: FUN3D vs USM3D

- Fair agreement in lift curve slope
- USM3D higher lift across α, except α = 11°, 12°
- Codes predict $C_{L,max}$ within α of 1°
  - $C_{L,max}$ = 1.85 **USM3D SA**
  - $C_{L,max}$ = 1.78 **FUN3D SA**
  - $C_{L,max}$ = 1.70 **FUN3D SA-RC-QCR2000**



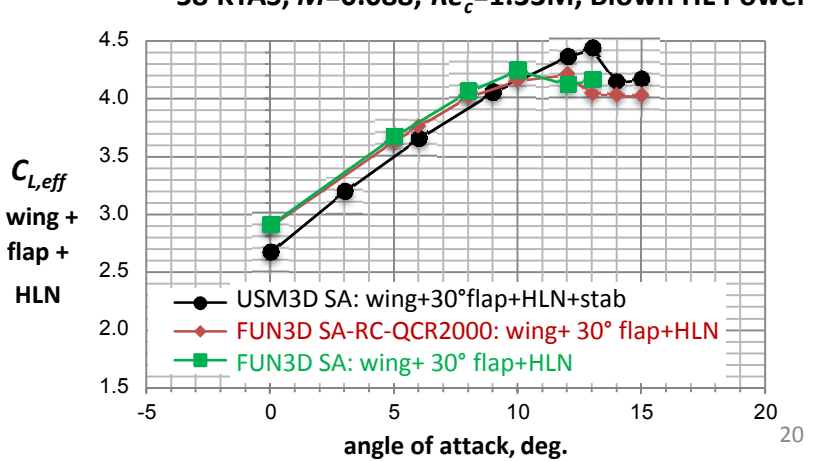




Blown Wing with 30° Flap Deflection

Code Comparison: FUN3D vs USM3D

- Both FUN3D turbulence models predict more lift than USM3D SA for $\alpha < 10°$, but less lift for $\alpha > 10°$
- USM3D SA code predicts a higher $C_{L,max}$ than FUN3D but both codes predict similar flow separation at wing stall
- $C_{L,max}$ for all codes exceeds goal of 3.95
  - $C_{L,max}$ = 4.42**USM3D SA**
  - $C_{L,max}$ = 4.25 **FUN3D SA**
  - $C_{L,max}$ = 4.20 **FUN3D SA-RC-QC**R2000



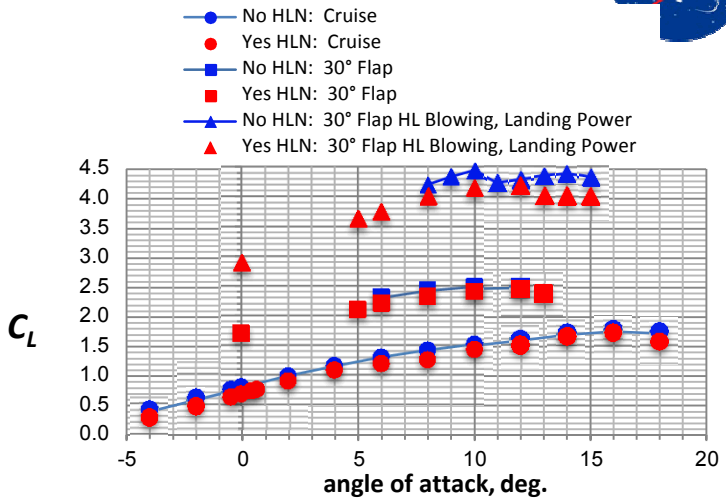
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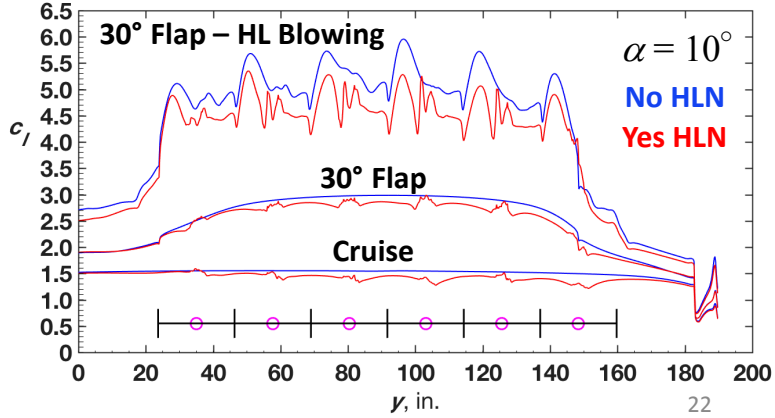


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Effect of High-Lift Nacelles (HLN)

- **Cruise**
  - **150 KTAS, *M*=0.233, Re_c=2.83M**
  - C_L decreases (~-0.15) across α range with addition of HLN
  - Same stall α
  - Section c_l is reduced in total region of HLN
- **30° Flap**
  - **58 KTAS, *M*=0.088, Re_c=1.33M**
  - C_L decreases (~-0.10) across α range with addition of HLN below α stall
  - Section c_l is reduced in between HLN
- **30° Flap – HL Blowing, Landing Power**
  - **58 KTAS, *M*=0.088, Re_c=1.33M**
  - C_L decreases across α by adding HLN
  - Stall α is increased with HLN, but $C_{L,max}$ is decreased by ~-0.24.
  - Section c_l is reduced in region of HLN





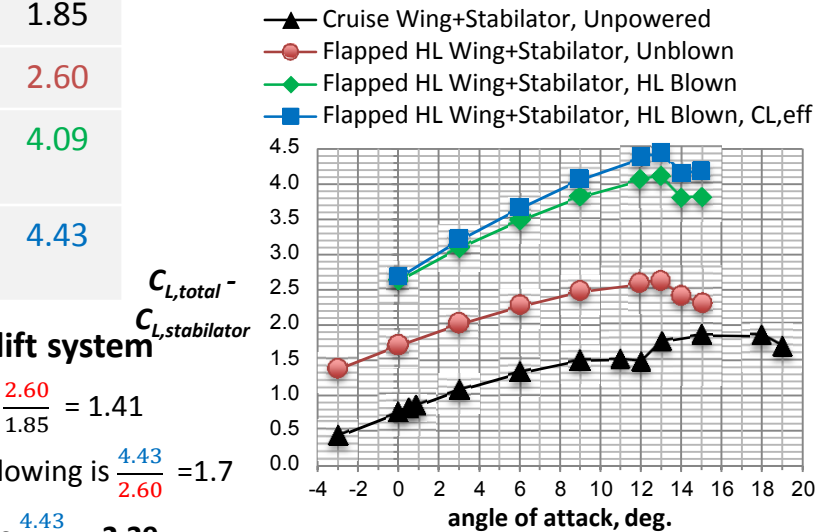
Code: FUN3D SA-RC-QCR2000

Lift Augmentation with HL Wing System

Wing + Stabilator Configuration at Design Stall Speed

Wing Alone	$C_{L,max}$
Cruise wing, unpowered	1.85
Flapped HL wing, unblown	2.60
Flapped HL wing, DEP blown, without propulsion contribution	4.09
Flapped HL wing, DEP blown, with propulsion contribution ($C_{L,eff}$)	4.43

58 KTAS, M=0.088, Re_c=1.33M, 13.7 hp/HL prop



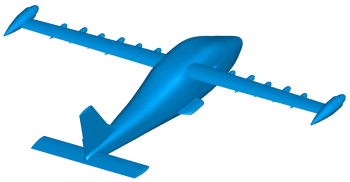
Code: USM3D SA

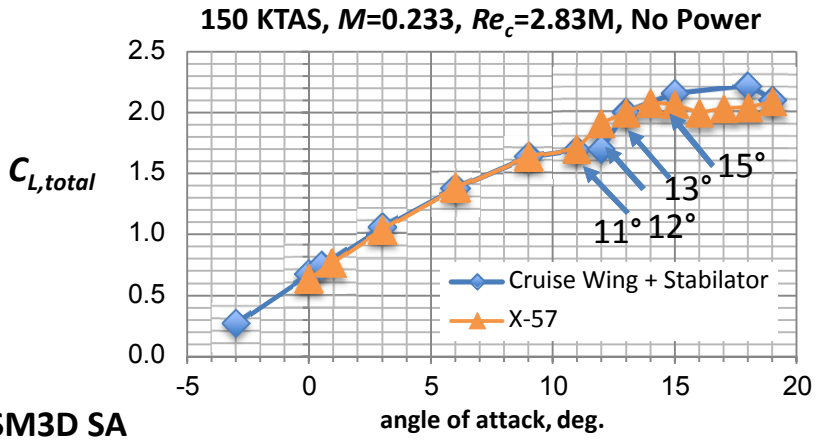
- **Lift augmentation from high-lift system**
  - Lift augmentation from flap is $\frac{2.60}{1.85}$ = 1.41
  - Lift augmentation from DEP blowing is $\frac{4.43}{2.60}$ =1.7
  - **Total high-lift augmentation is $\frac{4.43}{1.85}$ = 2.39**
- Thrust vector in direction of lift ($\Delta C_{L,max,eff}$) increases wing lift by 8%
- Computational $C_{L,max,eff}$ = 4.43 for the wing alone, gives a 12% margin above the stall speed goal of 3.95
- Minimum value $C_{L,max,eff}$ = 4.20, FUN3D SA-RC-QCR2000, gives a 6% margin above the stall speed goal of 3.95

Cruise Configuration Maximum Lift Coefficient

Fuselage Effects on Cruise Wing

- Cruise Wing + Stabilator Configuration
  - $C_{L,total,max}$ = 2.21 at α = 18°
- X-57 full configuration
  - $C_{L,total,max}$ = 2.07 at α = 14° and α = 19°
  - $C_{L,wing,max}$ occurs at α = 14°, but the fuselage and stabilator continue to generate lift up through α = 19°
- Adding fuselage reduces $C_{L,max}$ by -0.14



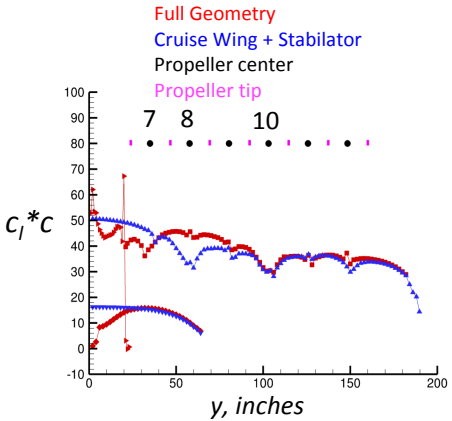


Code: USM3D SA

Sectional Lift and C_f at α = 11°

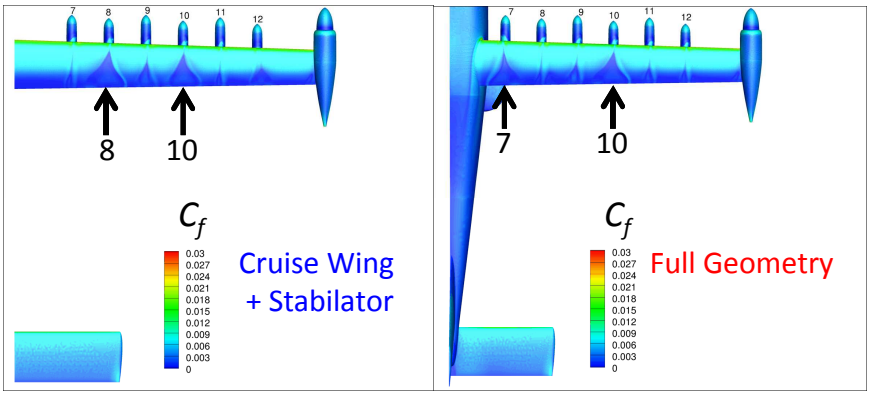
Fuselage Effects on Cruise Wing

- Both have loss of lift from flow separation at HLN10 (y = 100 in.)
- Adding fuselage
  - Moves large flow separation inboard, from HLN8 to HLN7, seen in span loading between y = 20 in. and y = 80 in. and in C_f contours
  - Decreases c_l on stabilator for y < 25 in.



Code: USM3D SA

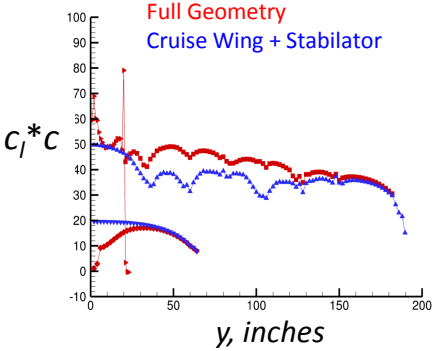
α = 11°, 150 KTAS, M=0.233, Re_c=2.83M, No Power



Sectional Lift and C_p at α = 12°

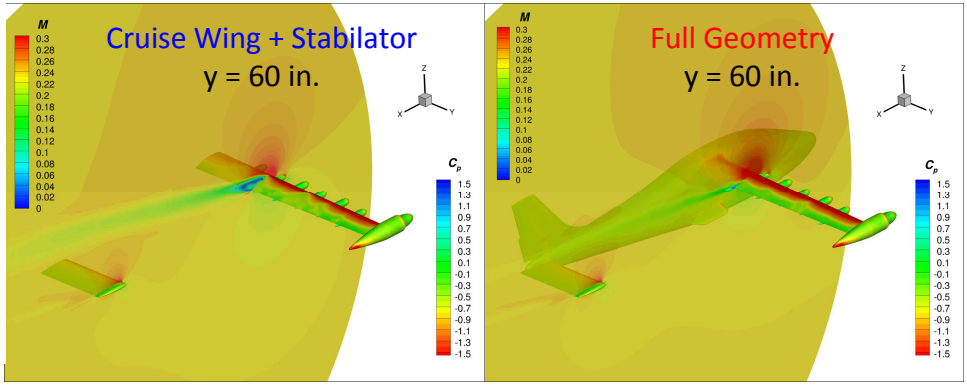
Fuselage Effects on Cruise Wing

- Full geometry $C_{L,total}$ > cruise wing + stabilator $C_{L,total}$
- Adding fuselage
  - Increases sectional lift between 30 in. < y < 120 in.
  - Decreases c_l on stabilator for y < 25 in.
  - Increases inboard lift y < 25 in.



Code: USM3D SA

α = 12°, 150 KTAS, M=0.233, Re_c=2.83M, No Power

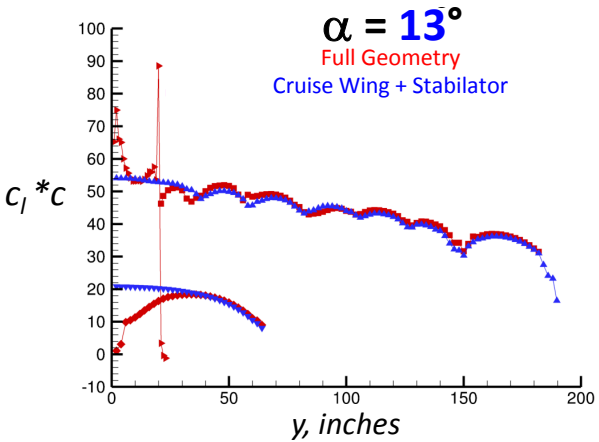


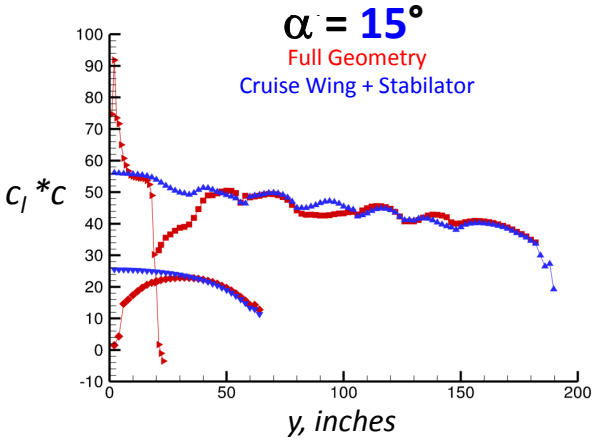
Sectional Lift at α = 13° and α = 15°

Fuselage Effects on Cruise Wing

- For y < 10 in.: fuselage c_l > wing c_l and lift decreased on stab for y < 25 in.
- At α = 13°: $C_{L,total}$ full geometry = $C_{L,total}$ for wing + stab
  - Effect of fuselage limited to y < 30 in.
- At α = 15°: $C_{L,total}$ full geometry < $C_{L,total}$ for wing + stab
  - Loss of lift on fuselage wing section for 20 in. < y < 40 in.

150 KTAS, M=0.233, Re_c=2.83M, No Power





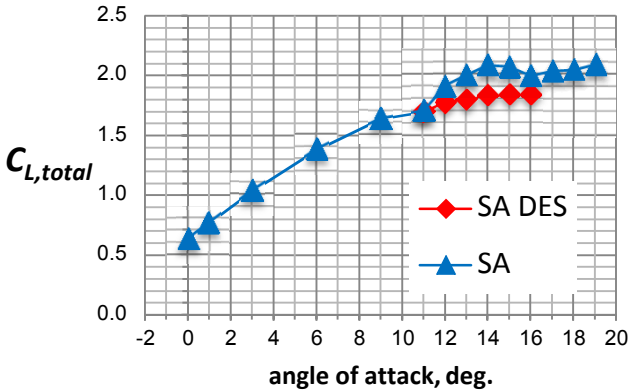
Code: USM3D SA

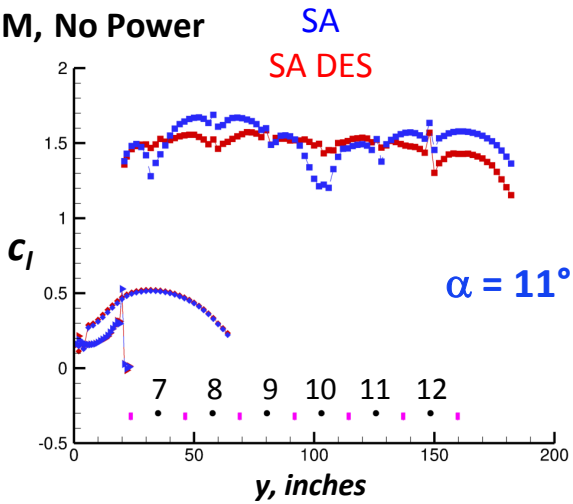
Effect Of Turbulence Model

X-57 Full Cruise Configuration

- SA DES model run to understand if SA model underestimates flow separation at high α
- $C_{L,total}$ compares well between the models at α = 11°, but c_l is different on the wing and same on fuselage and stabilator
- SA has higher c_l across most of the wing, except downstream of HLN10 where SA predicts flow separation near the wing leading edge

150 KTAS, M=0.233, Re_c=2.83M, No Power





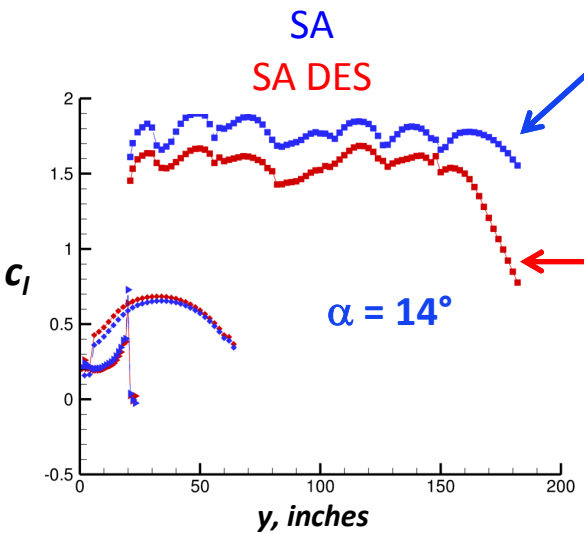
Code: USM3D SA

Effect Of Turbulence Model

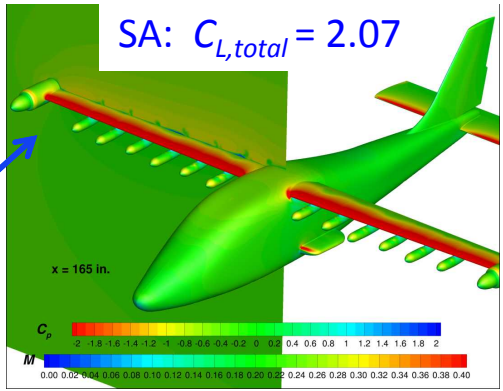
X-57 Full Cruise Configuration at α = 14°

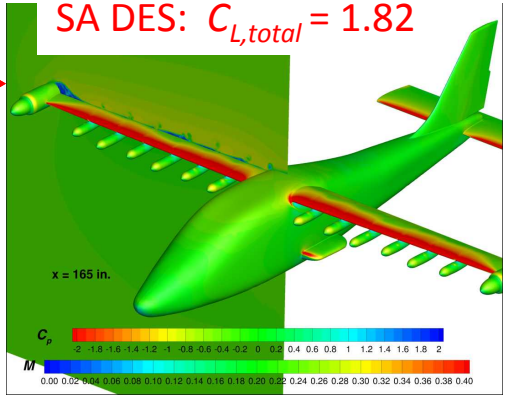
150 KTAS, M=0.233, Re_c=2.83M, No Power

- SA DES c_l much lower across full wingspan than SA c_l especially near wingtip



Code: USM3D SA



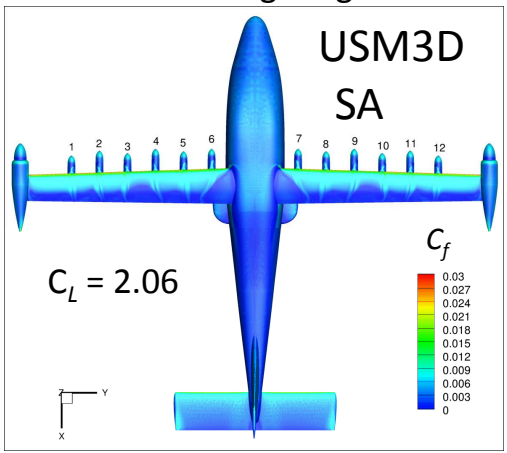


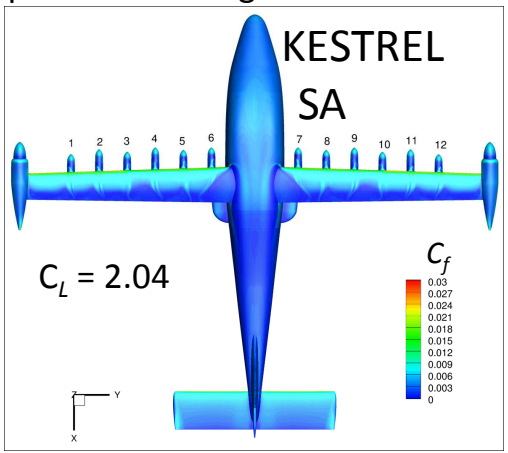
Compare Codes USM3D and Kestrel

X-57 Full Cruise Configuration

α = 15°, 150 KTAS, M=0.233, Re_c=2.83M, No Power

- To corroborate USM3D SA DES model predicting lower C_L than the SA model at α, Kestrel CFD code was used
  - USM3D DES model, Kestrel DDES model
- Comparisons between the codes are very good with basic SA
  - Small differences in implementation of SA model
  - C_L was within 1% for both α = 0° and α = 15° using the SA
  - Both have large region of flow separation at wingroot



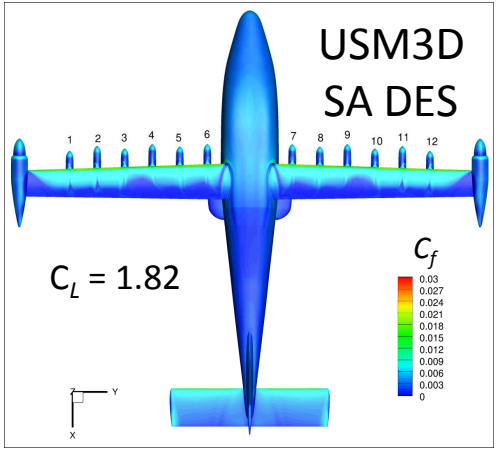


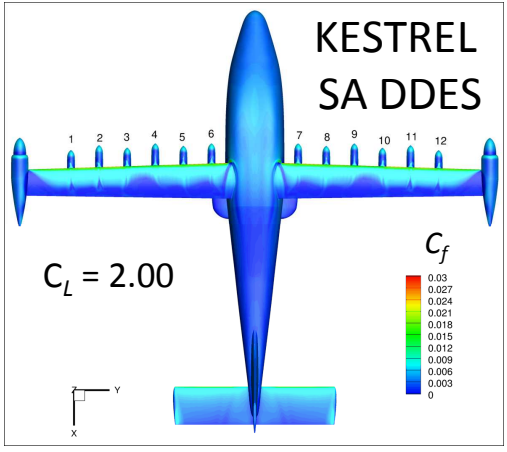
Compare Codes using Hybrid RANS/LES

X-57 Full Cruise Configuration

α = 15°, 150 KTAS, M=0.233, Re_c=2.83M, No Power

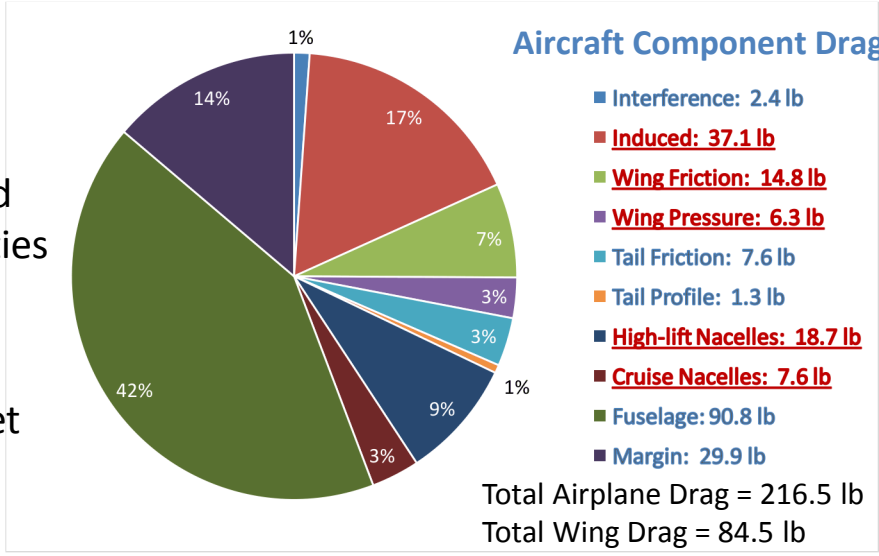
- Neither code predicts large inboard flow separation like SA
- Both codes predict
  - Two streaks at wingroot indicating vortices shedding off leading edge
  - More flow separation near wingtip nacelle than SA
  - A lower C_L than SA was confirmed with Kestrel SA DDES, although not as big a decrement as in USM3D





Aircraft Sizing Study[1] Drag Component Breakdown

- Airplane drag to meet cruise speed goal is C_D=0.05423
- Margin of 13.8% included to account for uncertainties in the estimate
  - $C_{D,margin}$=0.00749
- The total estimated target wing drag is C_D=0.02115

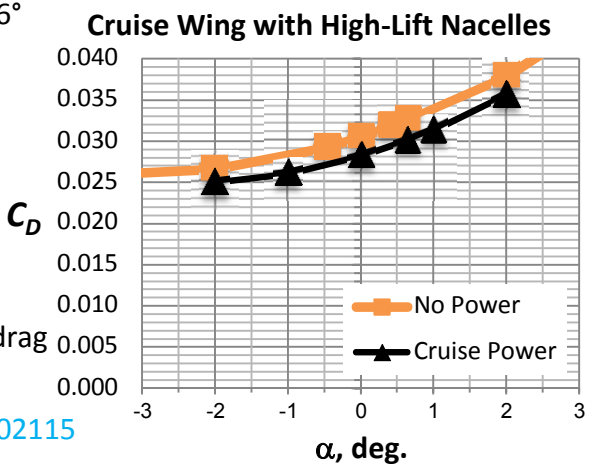


Cruise Conditions: 150 knots, 8000 ft, ρ=0.00187 slugs/ft^3, T=30.5°F, Re_c=2.83x10^6, q=59.87 lb/ft^2, S_{ref}=66.67 ft^2, c_{ref}=2.13 ft

[1]*Borer et al.: AIAA 2016-3920*

Effect of *Cruise* Power on Drag

- Cruise conditions 150 KTAS at 8,000 feet and α = 0.6°
  - Unpowered: C_D = 0.03290
  - Cruise power: C_D = 0.03006
    - 28 count induced drag reduction
    - 117.38 hp (total) at 2250 RPM
    - Total thrust is 230 lbf
  - This is a 8.6% reduction in wing drag
  - 4.9% of total target configuration unpowered drag

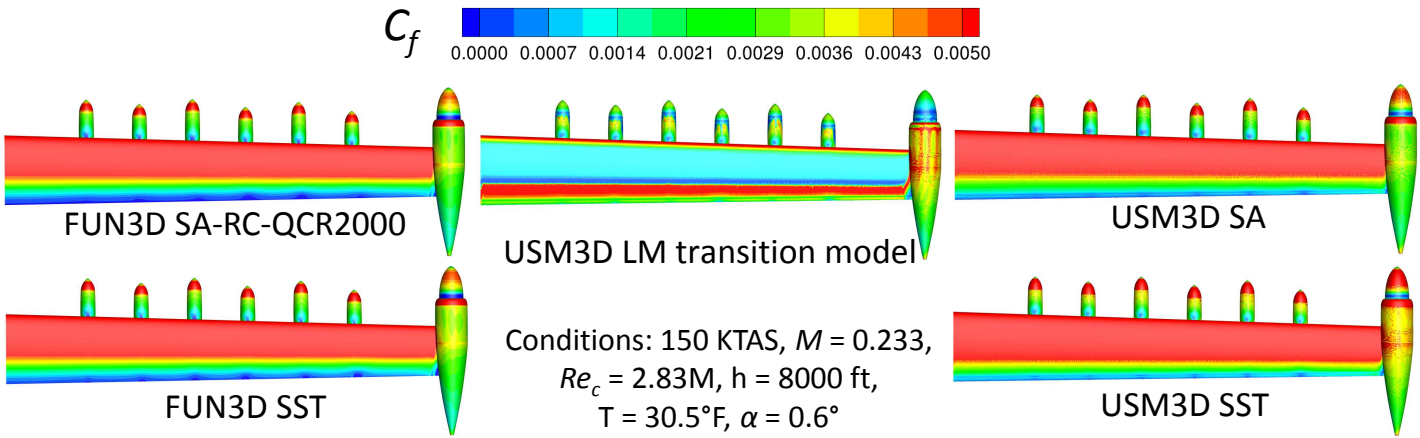


Note: This is above projected target wing drag of C_D=0.02115

- Noteworthy Assumptions
  - CFD wing geometry extends to centerline
    - ΔC_D = -0.0048
  - CFD is fully turbulent, however, some laminar flow is expected
    - ΔC_D = -0.0034
  - Projected Drag Margin
    - $\Delta C_{D,margin}$=0.00749

Effect of Laminar Flow on Wing Drag

- USM3D LM transition model predicts substantial laminar flow, low C_f to approximately 65% chord
- Fully turbulent predictions with FUN3D and USM3D are mostly similar and have high C_f to 65% chord



Drag Coefficient
X-57 Full Cruise Configuration

- Cruise speed goal: aircraft drag is $C_{D,total} = 0.0542$
- CFD cruise drag: $C_{D,total} = 0.0517$ at $C_{L,total} = 0.75$ ($\alpha = 0.91°$)
- CFD drag of full aircraft is **25 count margin** below goal
- Real aircraft rivets and surface intersections not modeled in smooth computational geometry
- Some drag reduction expected from sources not modeled in the fully turbulent/unpowered CFD solution (ref. 2)
  - Induced drag reduction with cruise power: 28 counts
  - Laminar flow on wing at cruise: 34 counts

[2]*Deere et al.: AIAA 2017-3923*

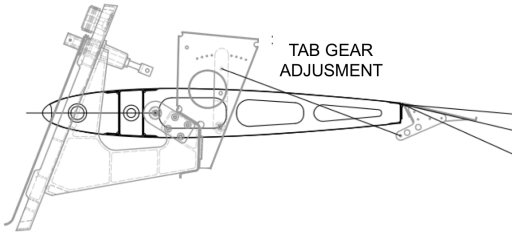
Outline



- Background
  - Test Configurations (Mods I-IV)
  - Mod I Findings
  - NASA X-57 Aircraft Goals and Focus of this Research
  - NASA X-57 Configuration
  - Build-up Approach to Evaluate X-57 Performance
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    - Effect of High-Lift Nacelles (HLN)
    - Lift Augmentation from High-Lift (HL) System (DEP + 30° flap deflection)
    - Effects of Fuselage: span loading and stall differences
  - Stabilator Aerodynamics
  - Stabilator Alone CFD, Stabilator Alone WT
    - Downwash
  - Aileron Control
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- Wing Structure

Stabilator Aerodynamics
Wind Tunnel Test

- NASA LaRC 12-Foot Low Speed Tunnel
- 42% scale model of stabilator
- Various trim tab settings
  - CFD at 0°, -5°, -10°
  - Tab effects



Front, looking aft



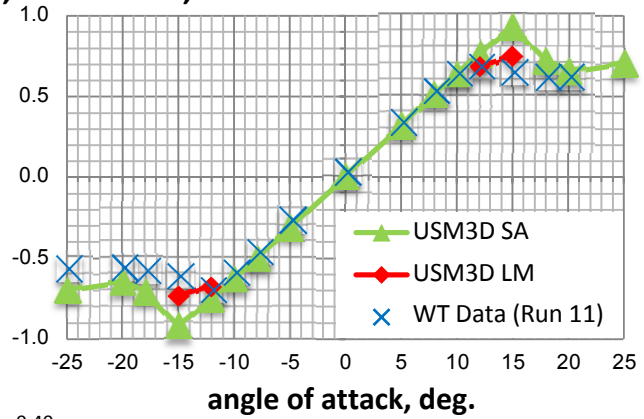
Aft, looking forward

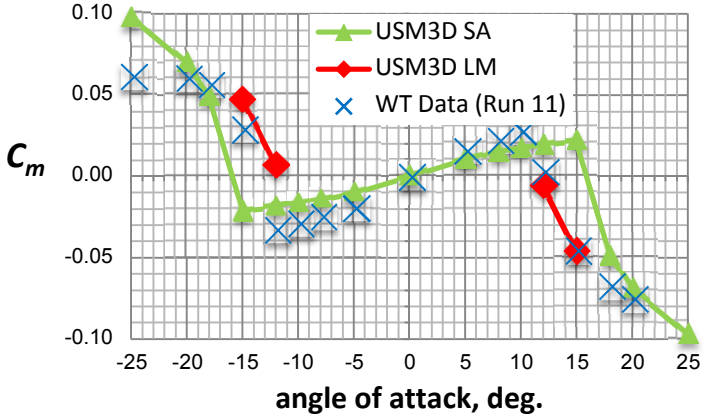


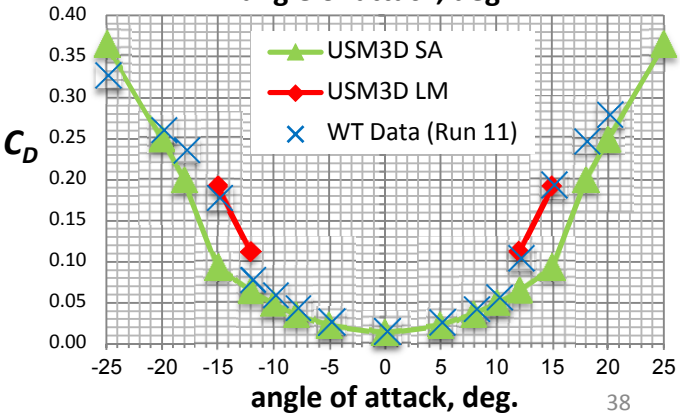
Stabilator Aerodynamics
Comparison of CFD to WT Data

34 KTAS, M=0.05, Re_c=0.38M, No Power ,Trim Tab = 0°

- Wing tunnel speed conditions
- SA has different stall characteristics than WT data
- LM has similar stall characteristics as WT data



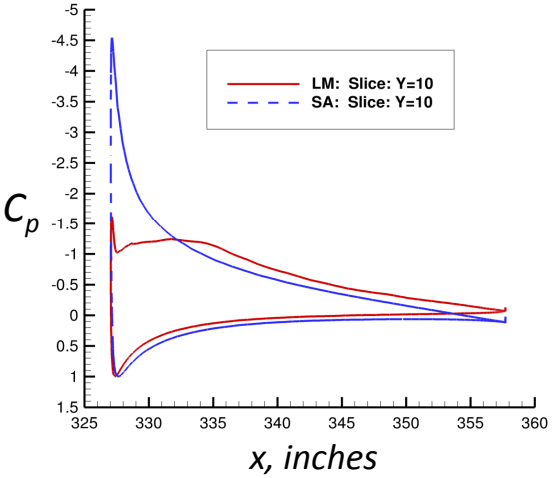


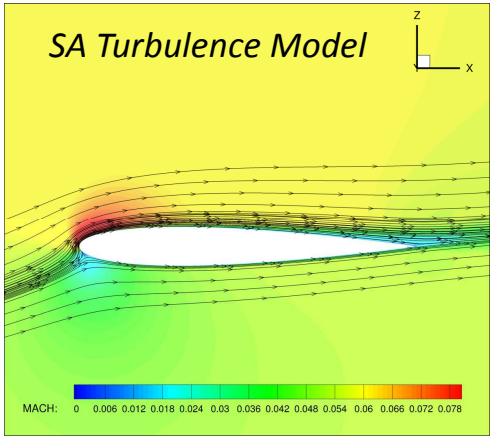


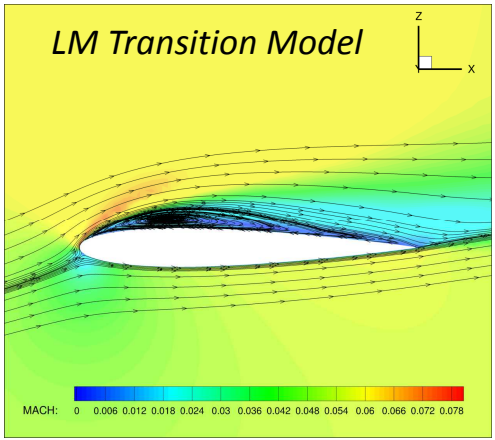
Stabilator Alone
Comparison to WT Data

34 KTAS, M=0.05, Re_c=0.38M, No Power

- α = 12° and y = 10”
- Wind tunnel conditions
- Langtry_Mentor (LM) matches WT C_L data
- LM solution has a separation bubble, stall







Downwash Computation

USM3D SA

$$C_{L,stab} = \frac{\partial C_{L,stab}}{\partial \alpha}(\alpha_{stab}) = \frac{\partial C_{L,stab}}{\partial \alpha}(\alpha_w + i_w + i_{stab} - \epsilon)$$

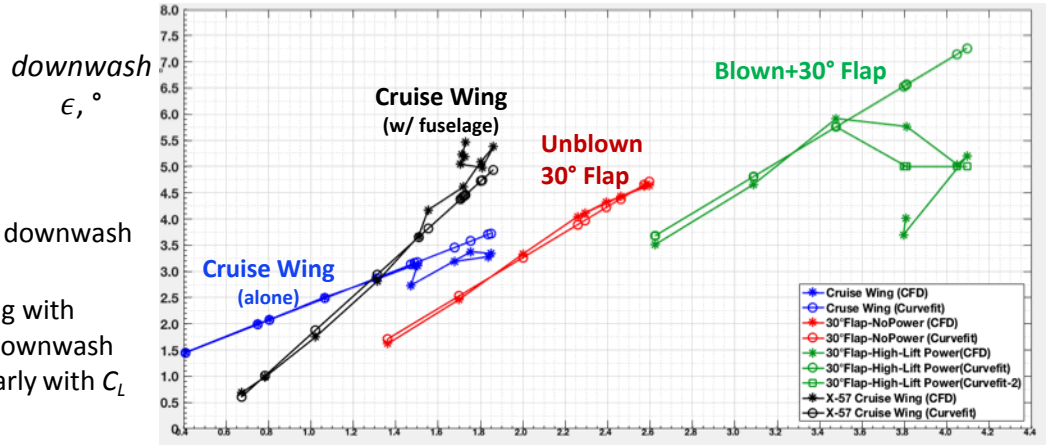
$$\epsilon^\circ = \left(\frac{180}{\pi}\right) * \epsilon_{rad} = \left(\frac{180}{\pi}\right) * \frac{2 * C_L}{\pi * AR}$$ (Perkins and Hage)

Curve Fit for Downwash

$$\epsilon^\circ = \left(\frac{180}{\pi}\right) * \left[\frac{2 * (\boldsymbol{m} * C_L + \boldsymbol{b})}{\pi * AR}\right] + \boldsymbol{offset}$$

Coefficients for Downwash Curve Fit

Configuration	m	b	offset
HLNCWSTABA00	0.65	0.33	0.0
HLN30FSTABA00 (No HL Blowing)	1.0	0.00	-1.6
HLN30FSTABA00 (w/ HLBlowing)	1.0	0.00	-2.7
X57CWA00	1.5	-0.76	0.0



- With fuselage slope of downwash is increased
- For the flapped HL wing with high-lift blowing, the downwash does not increase linearly with C_L > 3.5

Outline



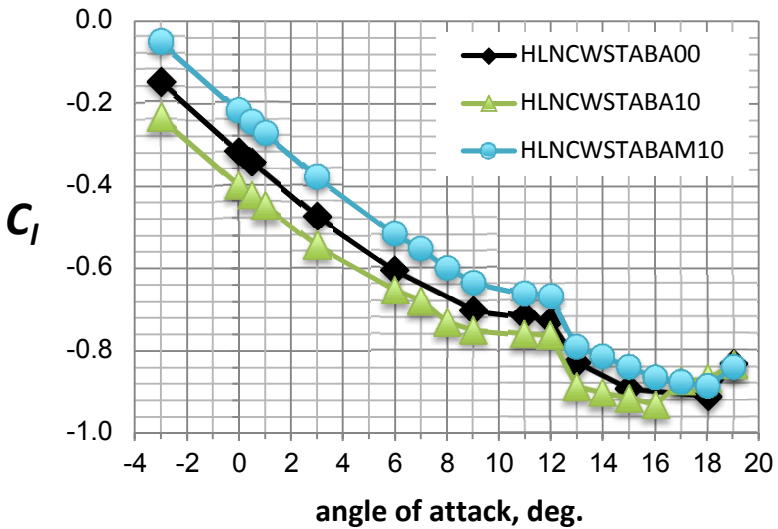
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Aileron Control, Rolling Moment

Design Cruise Speed

α = 15°, 150 KTAS, M=0.233, Re_c=2.83M, No Power

- Semispan model so aileron control power computed as a differential between AD+10° and AD-10°
- Fairly constant control power up through α=12°, smaller differential up through α=16°

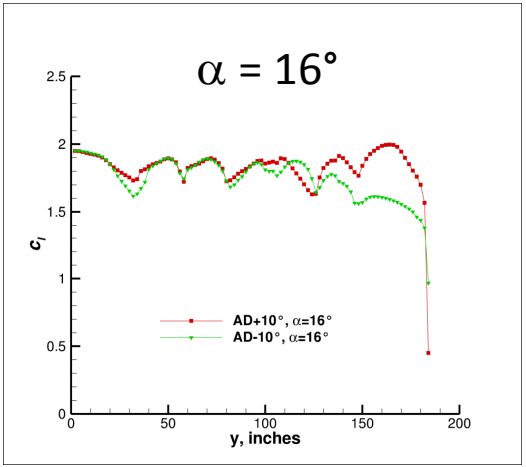


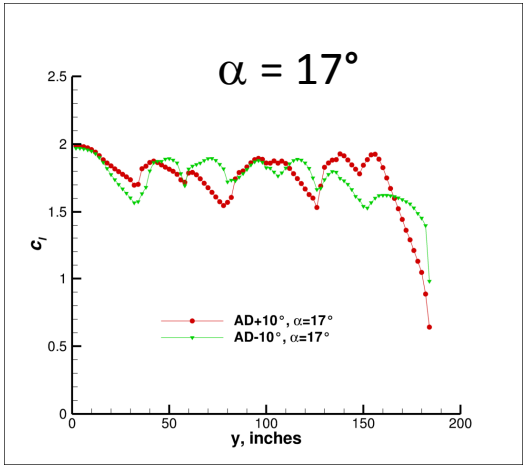
Aileron Control, Sectional Lift Coefficient

Design Cruise Speed

α = 15°, 150 KTAS, M=0.233, Re_c=2.83M, No Power

- At α=16° good differential in c_l for y > 130 in. between +10° and -10° of aileron deflection (AD)
- At α=17° rolling moment differential is zero
  - c_l distribution for AD-10° doesn't change much from α = 16°
  - AD+10° loses control power from drop in lift for y > 160 in. Also, drop in c_l at 60 in. < y < 85in.





Summary
(CFD and Performance Estimates)

- Used several codes and turbulence models to predict component and full aircraft aerodynamic data due to lack of wind tunnel tests
- Examined wing aerodynamics with three codes and several turbulence models
  - FUN3D: slight lift decrement from HLN vs clean wing
  - FUN3D and USM3D: both used for maximum lift investigation on cruise wing, wing with high-lift flap, and DEP powered wing with high-lift flap
  - USM3D: SA and Langtry-Menter for cruise drag estimate, and powered lift drag estimate
  - USM3D: added stabilator to wing geometry to quantify downwash of each configuration
  - Quantified effect of fuselage on the cruise wing and stabilator aerodynamics
    - Inboard flow separation at wing root
    - Reduction in sectional lift on the stabilator to about 50 percent of the span
  - USM3D and Kestrel: investigate high lift coefficients with higher order DES/DDES models to compare with SA results
    - Large inboard flow separation at wing root is mostly eliminated with the DES/DDES models
    - Spanwise separation front moves forward compared to SA

Conclusions

- Cruise Speed Goal
  - Airplane drag required to meet cruise speed goal is $C_D = 0.0542$
  - Computed, full aircraft, fully-turbulent drag was $C_{D,total} = 0.0517$ at $C_{L,total} = 0.75$ ($\alpha = 0.91°$)
  - Drag is difficult to precisely predict, but computed drag indicates a 25 count margin
- Stall Speed Goal
  - Investigated wing $C_{L,max}$ performance with multiple CFD codes and SA and DES turbulence models
  - Lift augmentation for the high-lift system (flap + DEP power) compared to cruise wing is a factor of 2.38
  - Adding the fuselage reduces the maximum cruise configuration lift by $\Delta C_L = -0.14$
  - Computed powered lift for the wing alone (with 30° flap) exceeds the goal $C_{L,eff} > 3.95$ (For SA turbulence model cases – multiple codes)
  - Still need to run full geometry blown high-lift configuration with DES/DDES solutions understand possible decrement to $C_{L,max}$ estimate



X-57 SCEPTOR
Wing Design - Structural

Xperimental LLC
Ryan Malherbe, Nick Jenkins, Paulo Iscold

Materials

Wing Construction Materials



Prepreg Resin system

Patz F4

- Cure at 121°C Tg 160°C
- Inside and outside autoclave
- Interlaminar Shear Strength > 50MPa (up to 70MPa)
- 24 months shelf life (-18°C)

Wet Lay-up Resin System

MGS L285

- Approved by the German Federal Aviation Authority for sailplanes
- Multi hardener system – 10min to 7h of pot life
- Cure at 80°C Tg 100°C
- Interlaminar Shear Strength 47 to 55MPa

Fibers

IM2C/UDP – Uni directional tape for spar caps

IM2A/2T – Bias fabric for shear web

CMH12K – HM63 – Non crimped biaxial fabric for skin

Hexcel 282 – fairings and small components

Glue

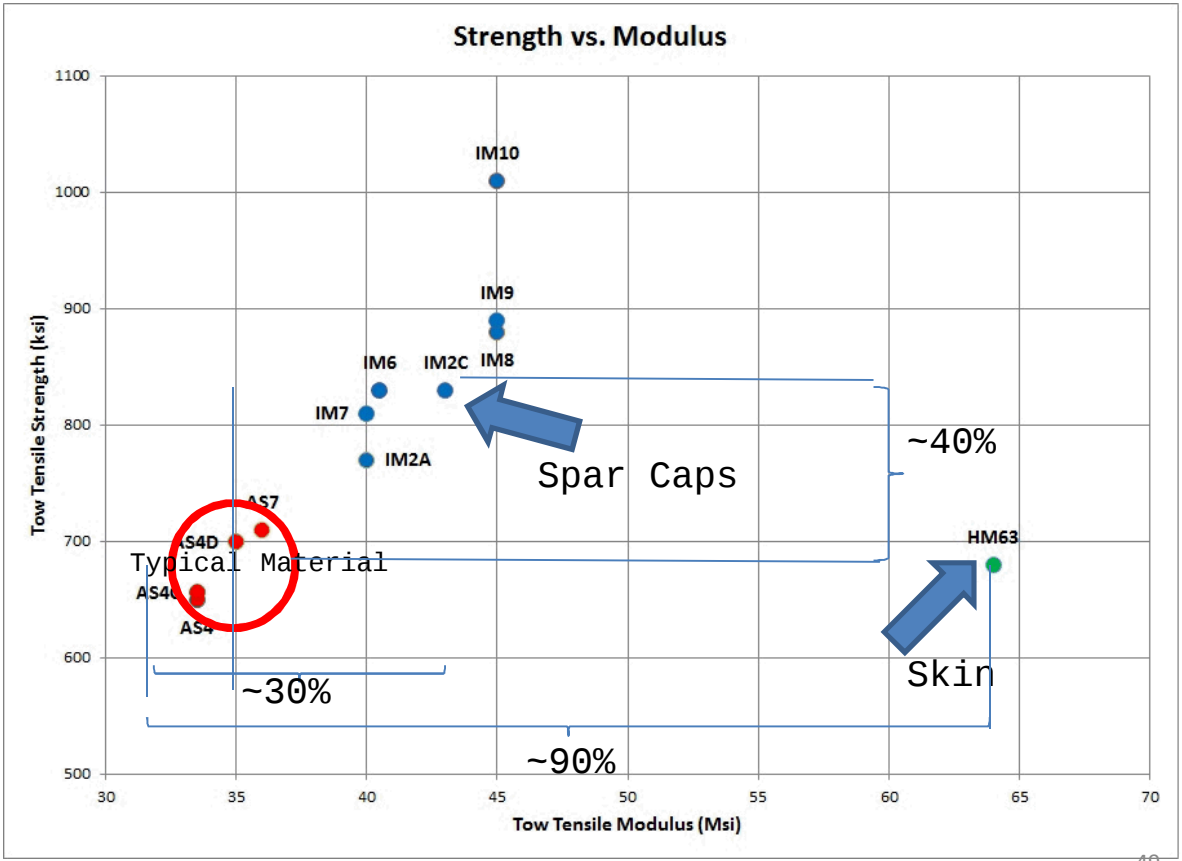
Hysol 9359.3

- Shear strength of 4500psi at 77F
- Shear strength of 2000psi at 180F
- Peel strength 60lb/in
- 5mil glass beads for thickness control

Core

- Divinycell PVC foam H60

Comparison of Fiber Strength and Modulus



Design Concept



Wing Design/Construction
Basic Assumptions

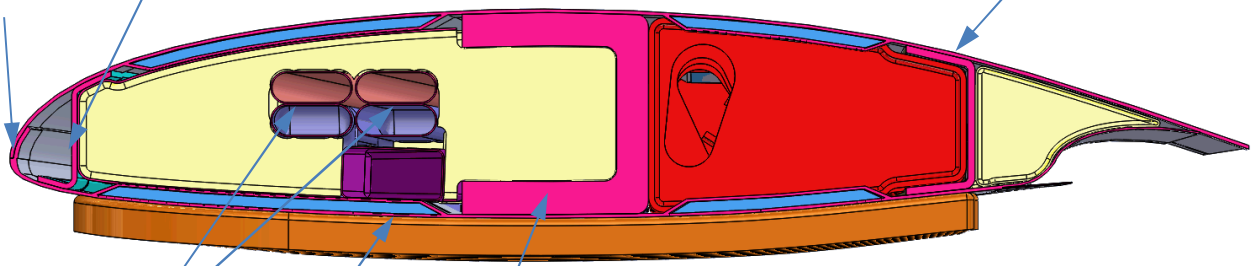
- Composite – semi-monocoque wing
- Single and continuous main spar – responsible to carry normal and axial loads (shear and bending)
- Working skin – buckling free – responsible to carry torsional loads
- Front and rear spars used to receive external loads (nacelles and controls)
- Isostatic attachment to the fuselage (No moment transferred to flexible fuselage with wing bending)

Wing Construction Features

Front Spar
- Z shape
- Better Torsional box
- Hard point for HL nacelles
- "Bird" strike

Rear Spar
- C shape
- Closes the back torsion box
- Hard point for bell cranks and aileron hinges

Leading edge Lap joint



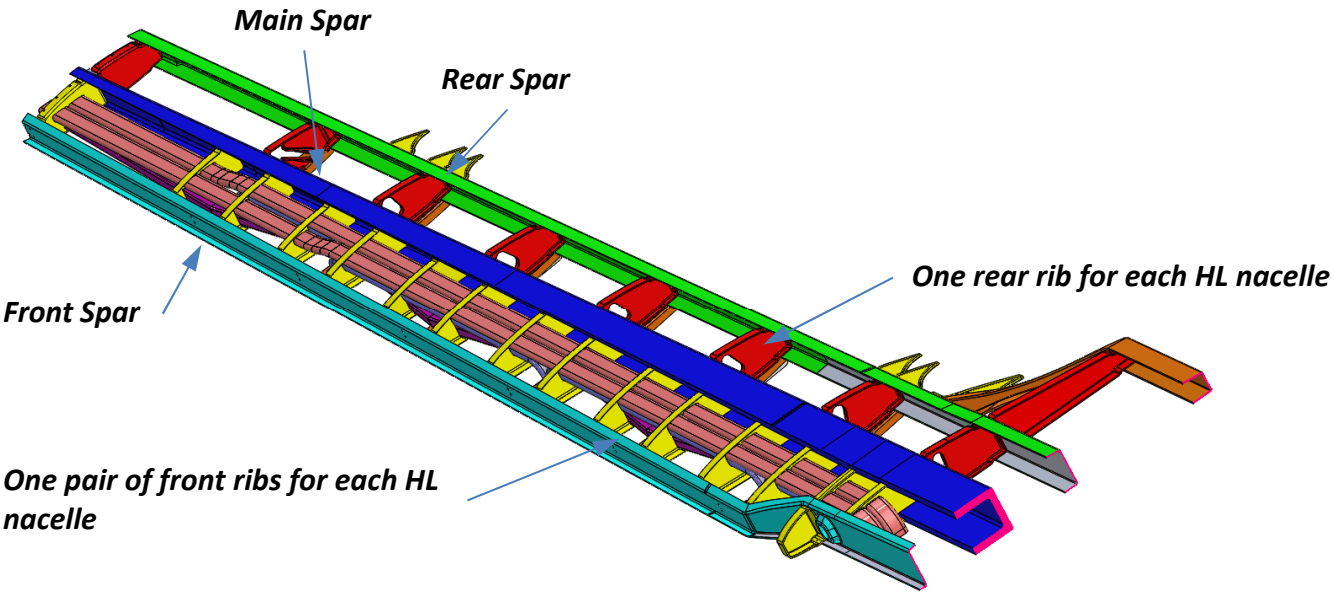
Carbon fiber skin with 1/4in PVC foam

Main Bus duct

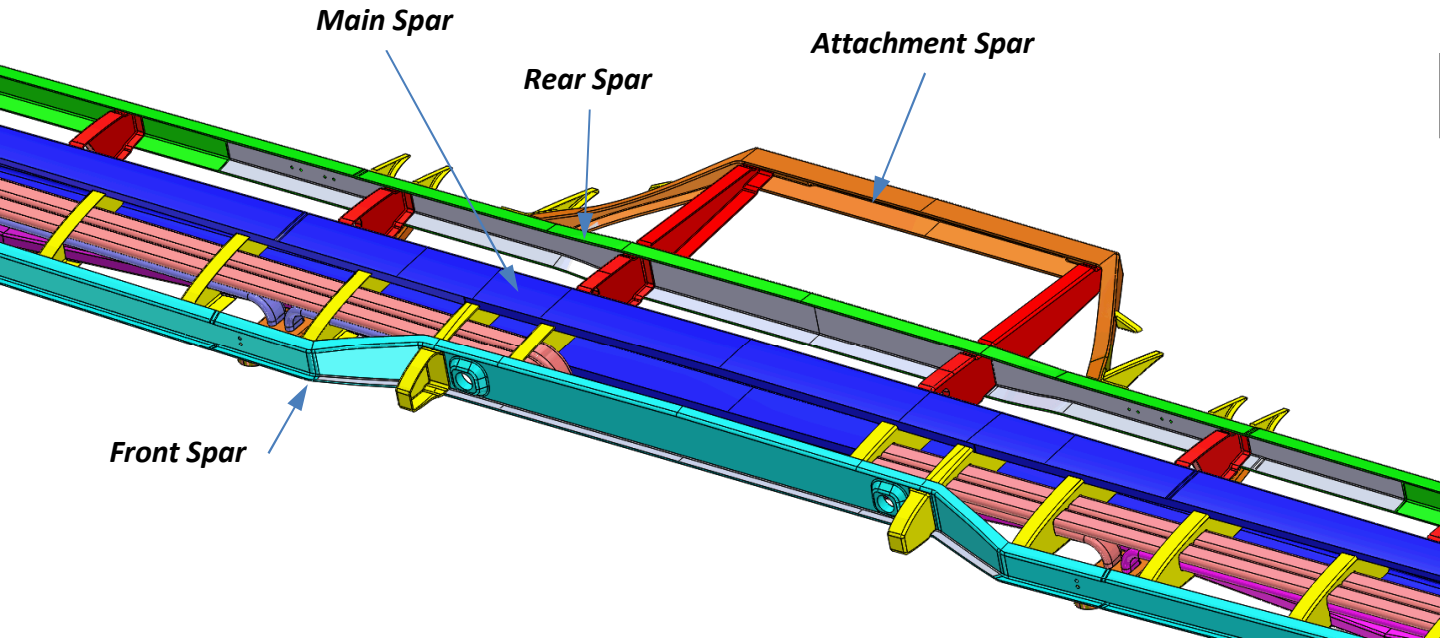
Instrumentation duct

Main Spar
- C shape
- Easy fabrication of a monolithic structure
- Pre-Preg fabrication
- Front ribs will act as stiffener for warp deformation

Wing Internal Ribs

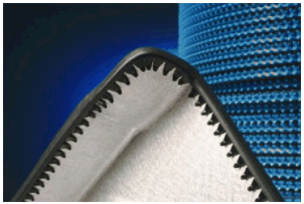


Wing Center Section



Internal Ducts for Power and Instrumentation Wiring (Lower Surface View)

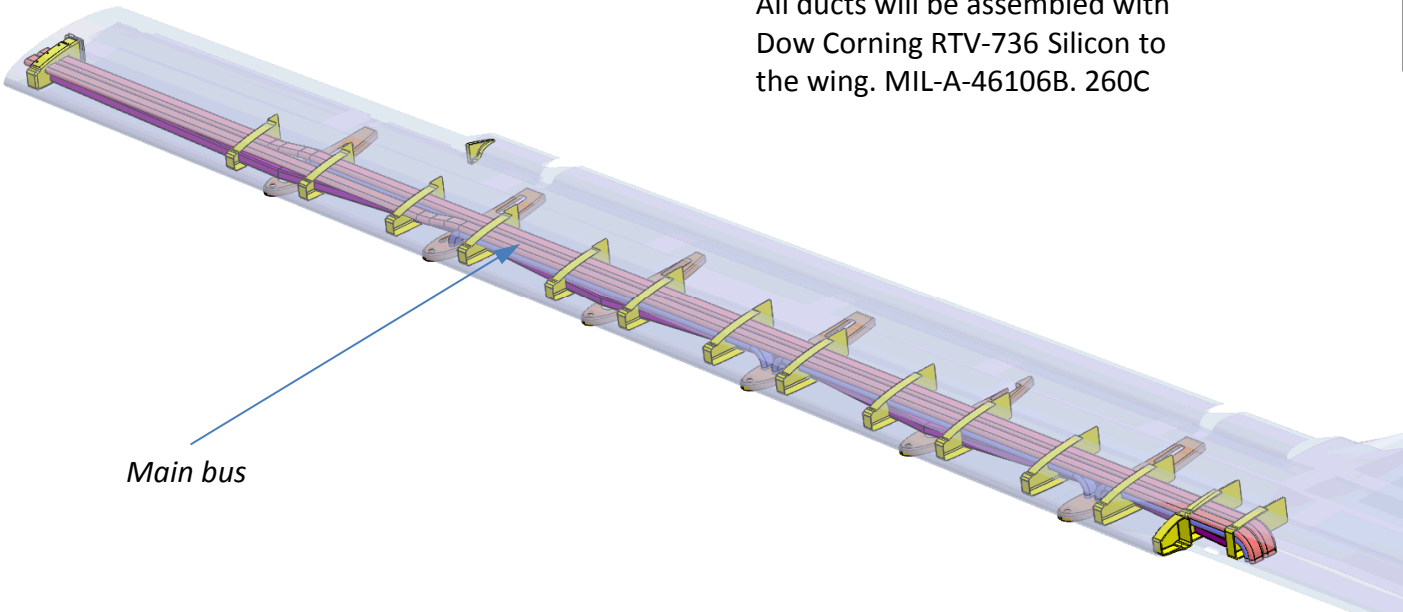
All ducts will be assembled with Dow Corning RTV-736 Silicon to the wing. MIL-A-46106B. 260C. Thermally isolate duct from rib



Edge protection for duct openings

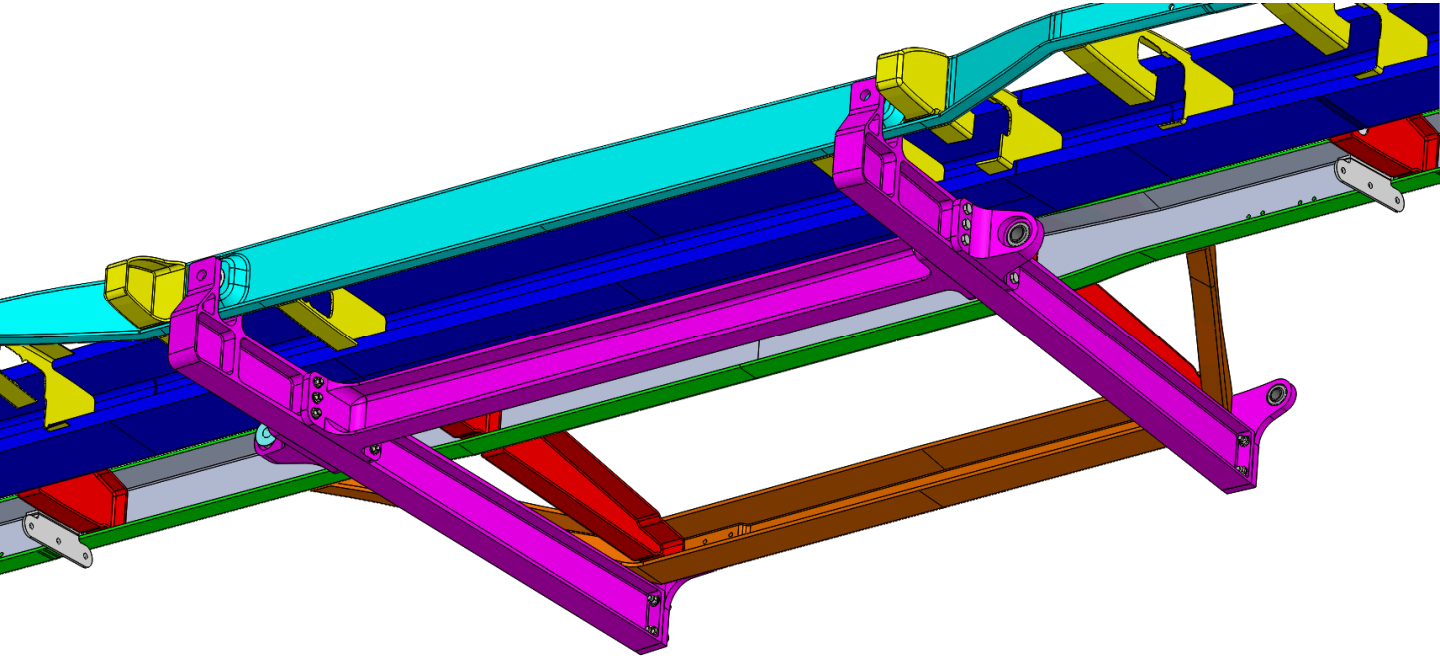
Internal Ducts for Power and Instrumentation Wiring (Upper Surface View)

All ducts will be assembled with Dow Corning RTV-736 Silicon to the wing. MIL-A-46106B. 260C

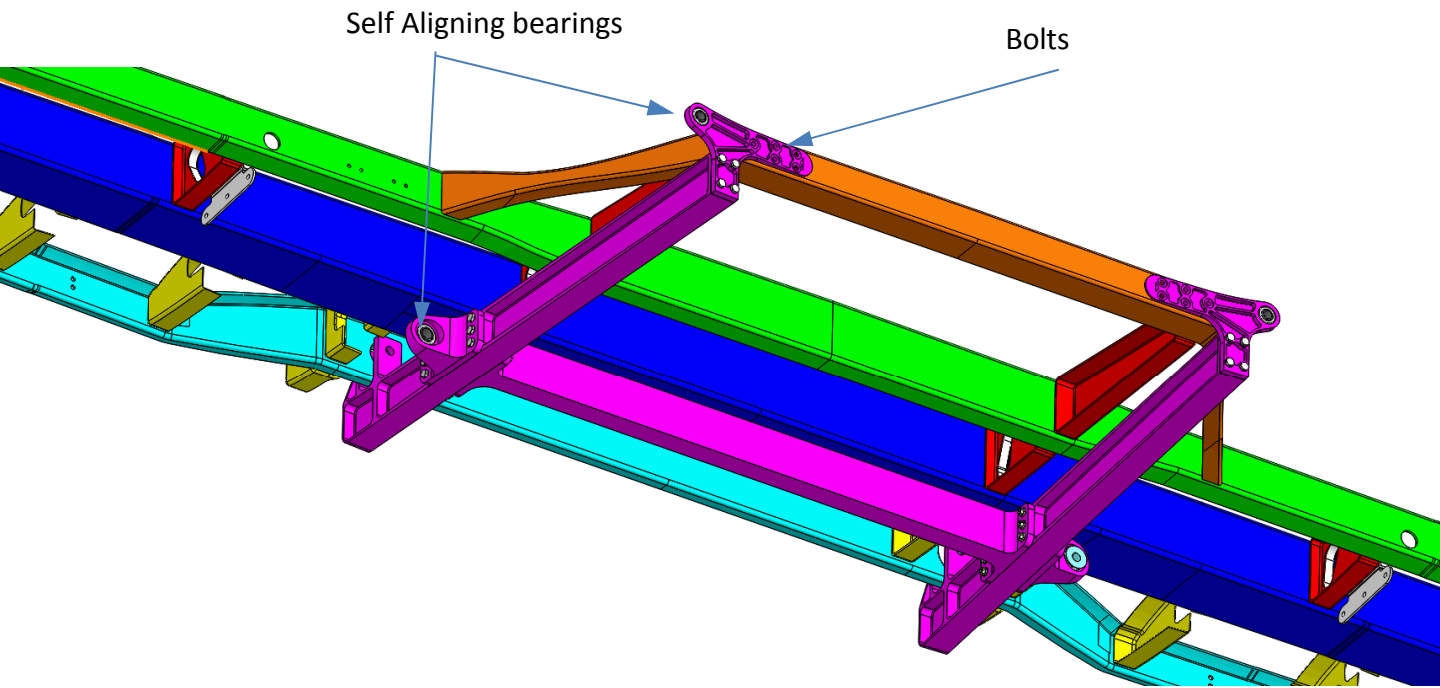


Wing Attachment

Wing Attachment Frame
(purple)



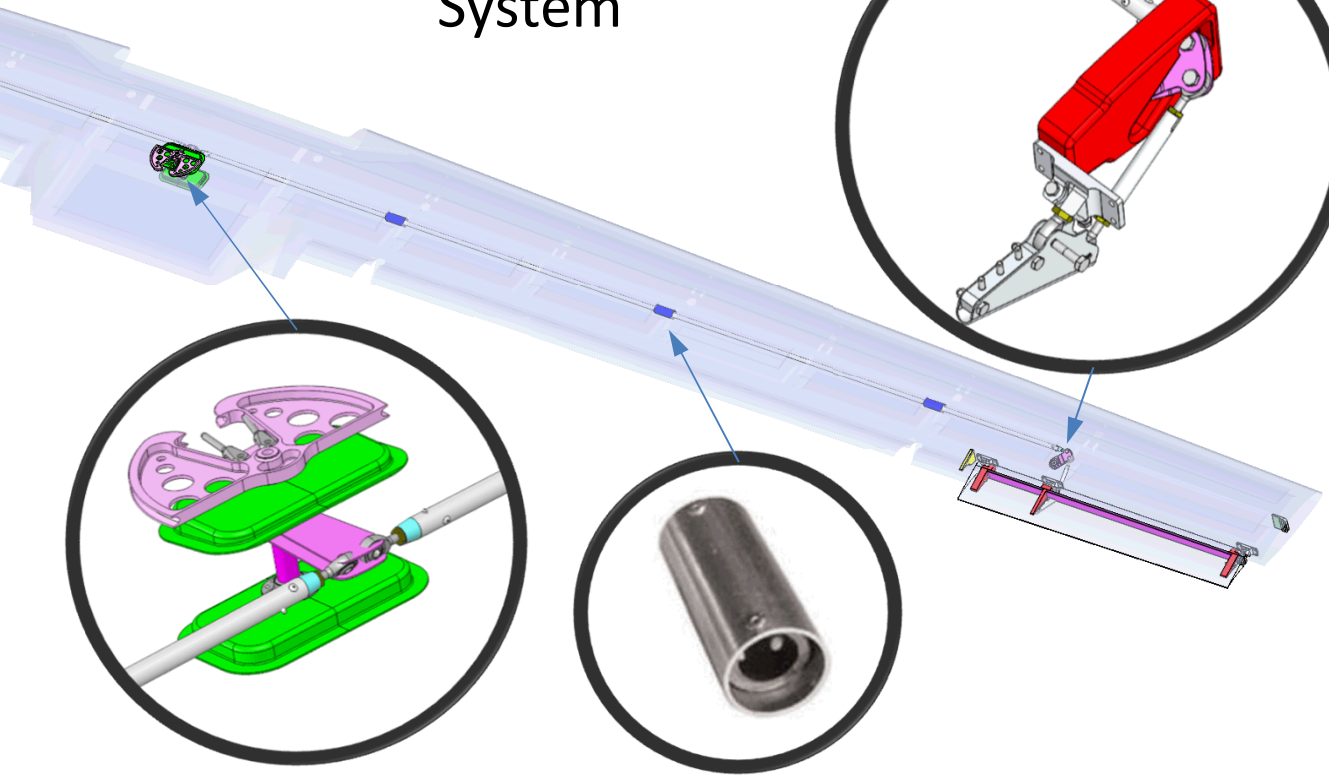
Wing Attachment Frame
(purple)



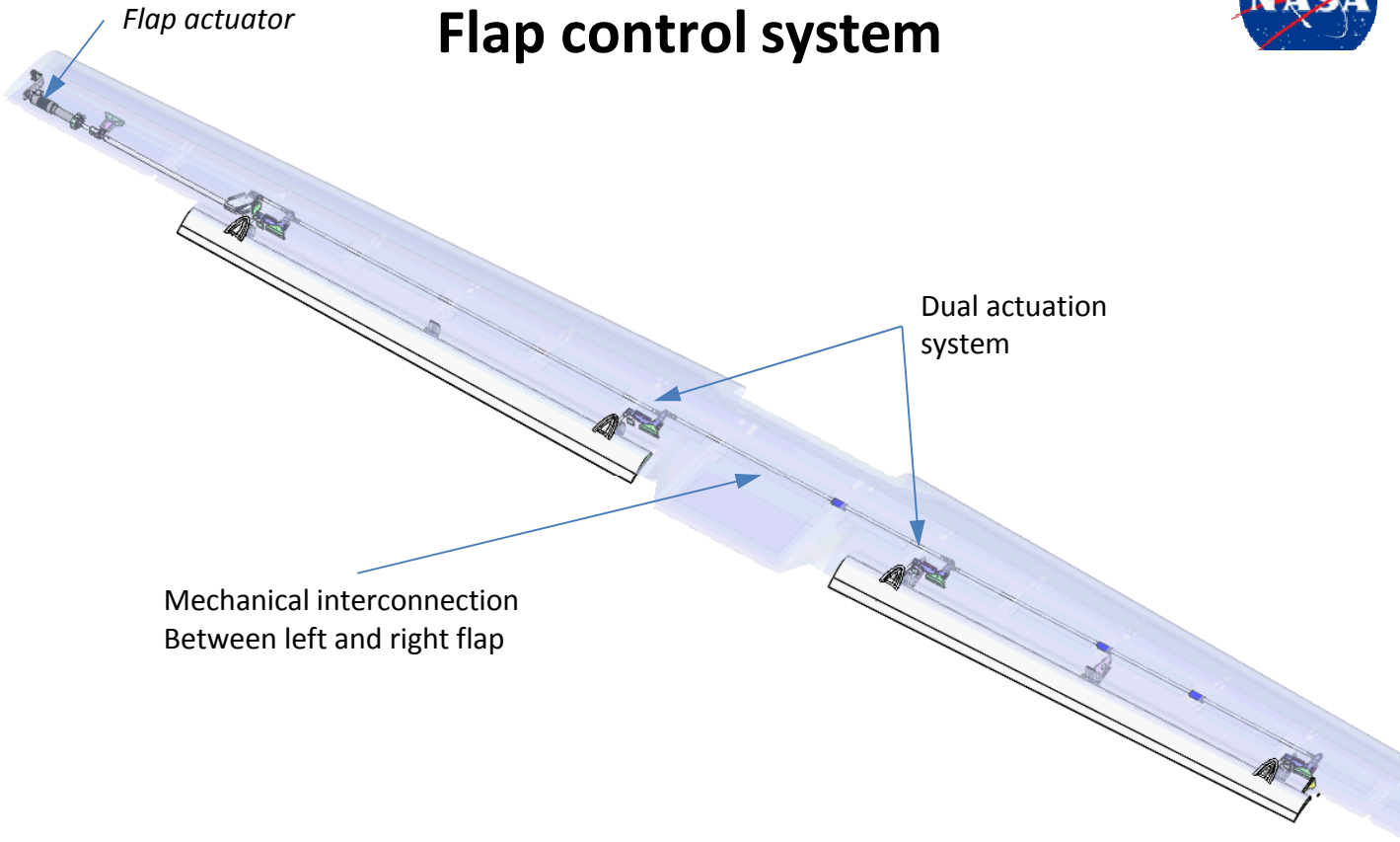


Control System

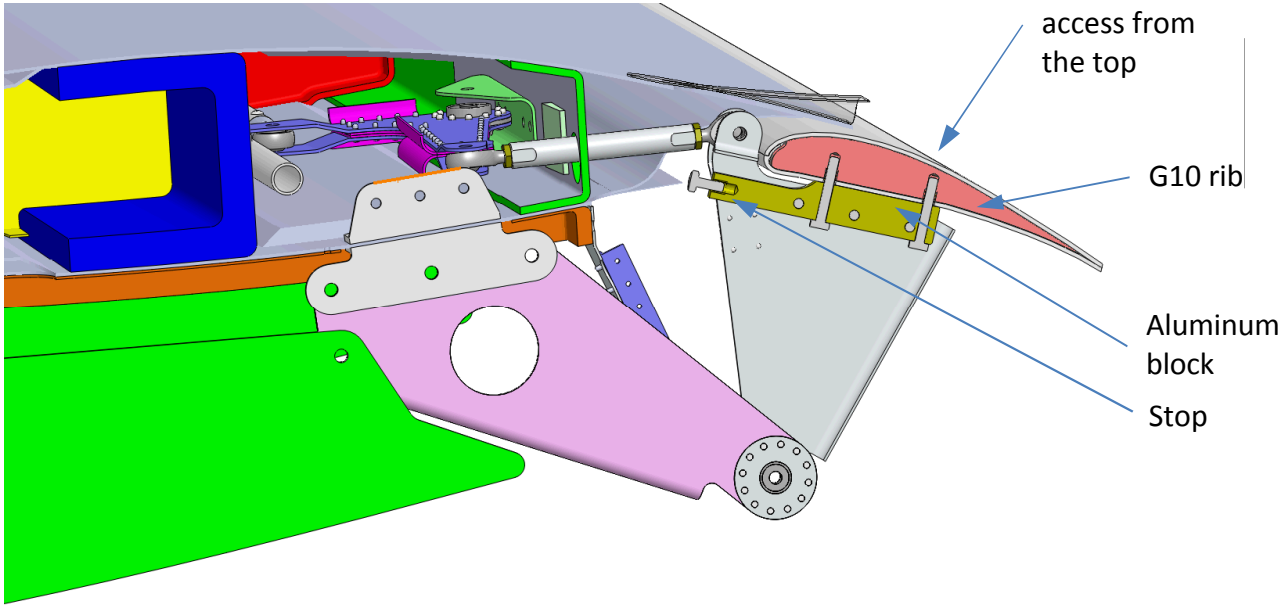
Aileron Control System



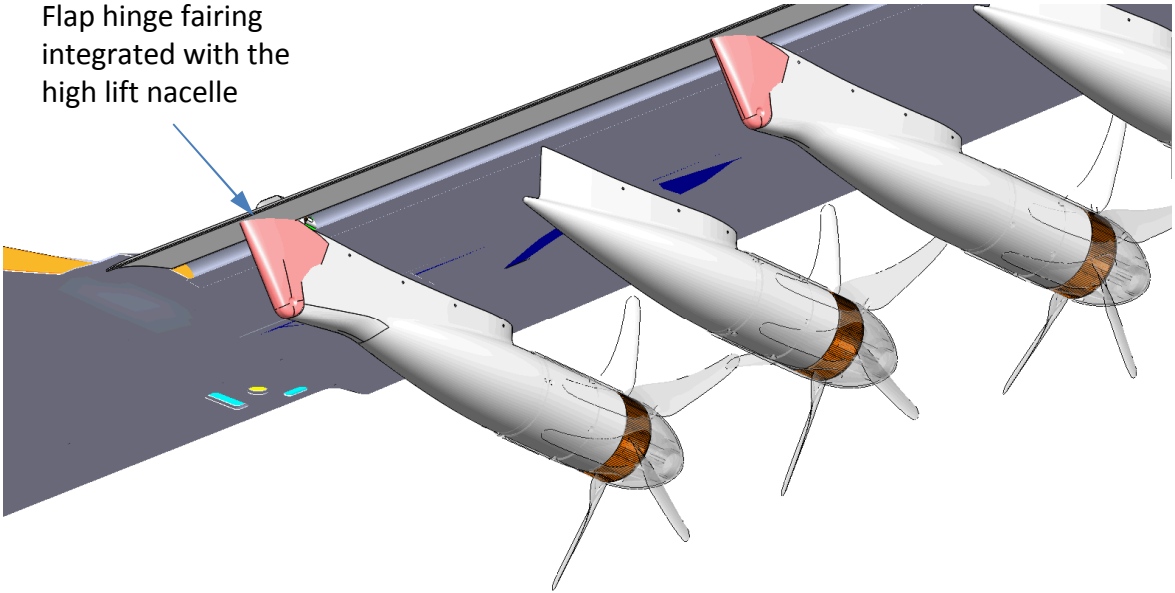
Flap control system



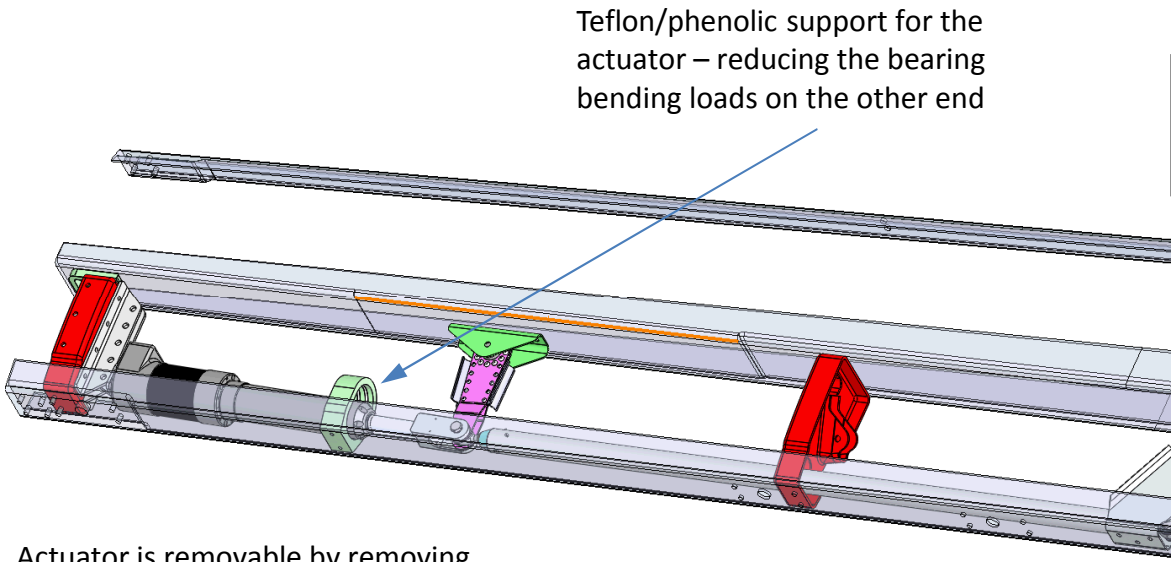
Outer Flap Actuation Bell Crank and Hinge



Flap Hinge Fairing and High-Lift Nacelle



Flap Actuator



- Actuator is removable by removing the last rib.
- The last rib is connected to the wing skin and rear spar using the bolt's/screws that holds the tip nacelle.

Fabrication

Facilities



24in x 40ft autoclave



Lamination room



MAIN SPAR

MAIN SPAR (PARTIALLY TRIMMED STATE) SITTING IN THE WING SKIN WITH THE REAR SPAR AND PARTIAL CONTROL SYSTEM INSTALLED



Future Timeline

- Wing under fabrication at Xperimental, LLC facilities in San Luis Obispo
- Front spar fabricated August 2018
- Delivered to Armstrong Flight Research Center Sept.-Oct 2018
- Proof test wing structure Oct. – Dec. 2018
- Mod II Flights end of 2019
- Mod III flights 2021