DLR/NASA MDAO Information Exchange Meeting

GEN2 Hybrid Wing Body Design Team

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Outline

- Background
- Objective & approach
- HWB analysis toolbox
- HWB design problem
- Schedule and status
  - NASA team
  - Contracts

Goals & Milestones

- APG 10AT07 -- Complete new suite of integrated multidisciplinary analysis tools to predict noise, NOx, takeoff/landing performance, cruise performance, and Take-Off Gross Weight (TOGW) for conventional ("tube and wing") aircraft and unconventional aircraft (e.g. hybrid wing-body).
- SFW.01.01.010 – Complete GEN2 Integrated Multi-disciplinary Toolset. Verify successful integration of multiple low/intermediate/high fidelity modules within an MDAO framework through replication of previous (“GEN1”) analysis on a reference conventional system (B787/GEnx-2B67) & compare performance prediction against experimental data.

HWB Studies Overview

Currently Exploring "Corners of the Trade Space"

Noise: NASA/Boeing/MIT/UCI NRA

Boeing LSAF Tests:
BWB 450 Mod

N2A (podded engines)

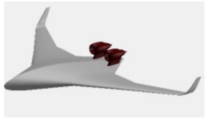
N2B (embedded engines)

Fuel Burn: NASA/AFRL/Boeing Energy Efficiency Contract Options 1&2 plus NASA in-house

BWB EET-700 — HWB sized for 777F mission

BWB N2-RFB — Reduced Fuel Burn Version of N2A

HWB300



Take-off: NASA in-house

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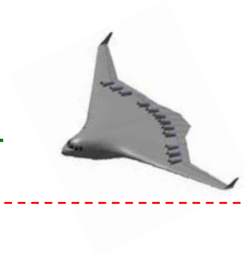
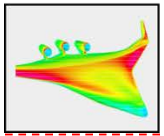


Testing: BWB-450 legacy



X-48B

External: Boeing/AFRL Energy Efficiency Contract

BWB-MM — Medium Mobility HWB C-130 Replacement

HWB Demonstrator "BWB-101" ???

Objective

- Improve NASA's conceptual design and analysis capabilities for unconventional subsonic configurations, with a focus on HWB configurations
- Refine HWB MDAO capabilities building off of GEN 1 toolset resulting in a validated GEN 2 toolset (6/30/2010)
- BWB EET-700 configuration, reconcile with Boeing, update model
- Apply updated modeling capability to HWB300, update N+2 metrics

Approach

- Build off of a successfully completed "GEN 1" capability, and expand the capability to include integrated, variable fidelity analysis capabilities for aerodynamics, structures and stability & control.
- Special attention is given to improving analysis capabilities in discipline areas for which shortcomings exist when applied to HWB configurations (S&C, weights, noise)
- Provide the ability to optimize an HWB wing planform with S&C, weights, and performance constraints
- In parallel, incorporate NRA products (AVID, Cal Poly/Phoenix) and discipline expert inputs to meet as many MDAO requirements as possible prior to June 2010 milestone
- In the near term, integrate process models within ModelCenter. In the long term, NASA is developing OpenMDAO

GEN2 HWB Team Members

Team Members:

Lead - Erik Olson (~0.9 FTE)

Aerodynamics - Beth Lee-Rausch (0.25 FTE)

Structures - Andrew Lovejoy (0.25 FTE ?)

Propulsion - Ken Fisher (0.25 FTE ?)

Stability & Control - Ken Moore (0.25 FTE)

Noise - Casey Burley (0.1 FTE)

Software Integration Support - Scott Townsend (0.25 FTE)

Geometry and Cost Analysis - NRA products

HWB Systems Analysis Toolbox (1 of 2)

- Geometry: Vehicle Sketch Pad (VSP) ModelCenter Plugin
  - Enhanced to improve the geometric definition of HWB aircraft (AVID)
  - Improved gridding and internal structural layout (J.R.)
- Propulsion: NPSS/WATE++
- Aerodynamics: Vorview, PMARC (CalPoly), CPPAERO (AVID), supplementary CFD
  - Induced drag (Vorview, PMARC) to override FLOPS internal analysis
  - Stability derivatives
  - Total drag (CFD)
  - High-lift aero
- Structures & Weights: PDARB/ELAPS, AVID PDARB mods, Boeing Centerbody Weight Tool, supplementary FEM
- Stability & Control: MaSCoT
  - latest version supports static and dynamic stability & control analysis

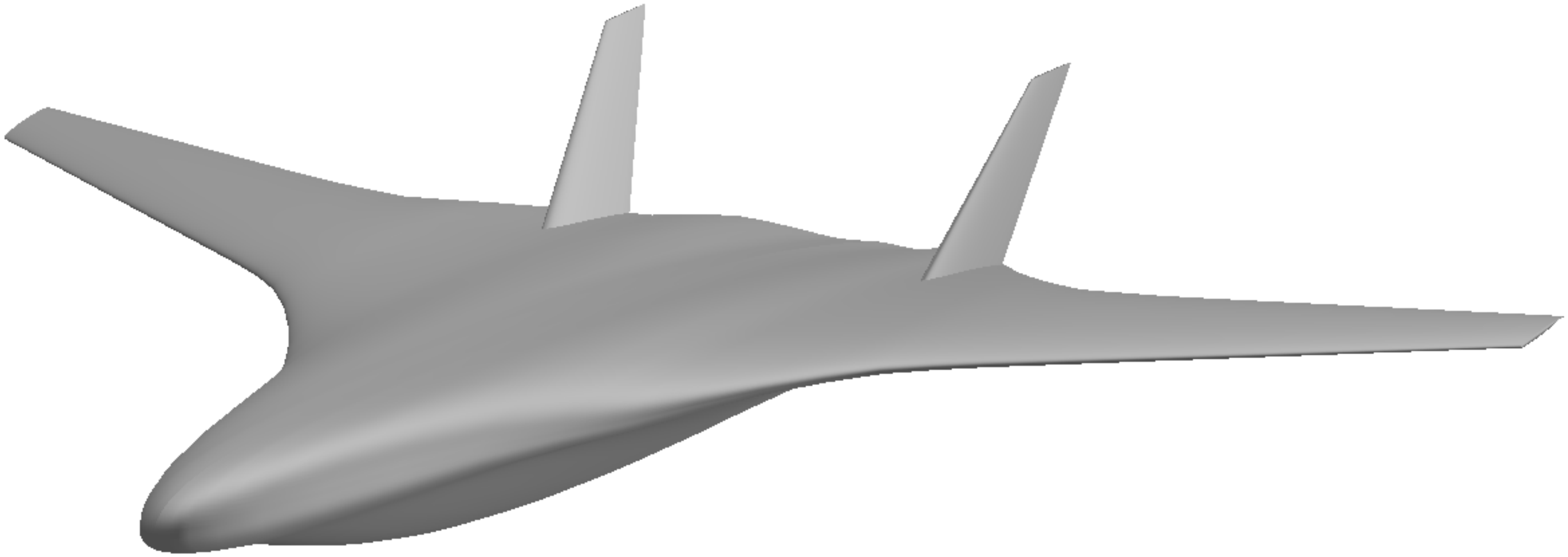
HWB Systems Analysis Toolbox (2 of 2)

- Mission Performance: FLOPS
  - Updates for HWB
- Noise: ANOPP
  - enhanced with new acoustic shielding analysis
- Cost: ALCCA
  - enhanced for HWB (AVID)
- Integration: ModelCenter
  - Higher-order codes included using approximation methods or direction integration where feasible
  - M4 correction toolkit
  - Leverage supersonics GEN2 work

HWB System Optimization

1. Payload requirement drives cabin volume (FLOPS or VSP or analogy to existing designs)
2. Initial VSP model
3. Gross planform design to optimize wing shape and engine thrust
   - Objective function: minimize TOGW (or life-cycle cost?)
   - Constraints
     - Cabin constrained by payload
     - Stability & control constraints: Mach buffet, trim at critical conditions
     - Span constrained to airport compatibility limits
     - Noise equal to or less than the N+1 metric
     - Critical field length less than 11,100 ft (from Boeing requirements)
   - Design variables
     - Planform variables (next slide)
     - Engine Thrust
4. Optimize spanwise twist distribution for minimum cruise $C_{D,i}$ (or TOGW?)

N2A Baseline



HWB Planform Parameterization

ACABIN = cabin area represented by shaded region on figure

XLp = length of passenger cabin at centerline

Wf = width of passenger cabin

XLw = length of passenger cabin sidewall at outboard station or wing root

XL = total fuselage length

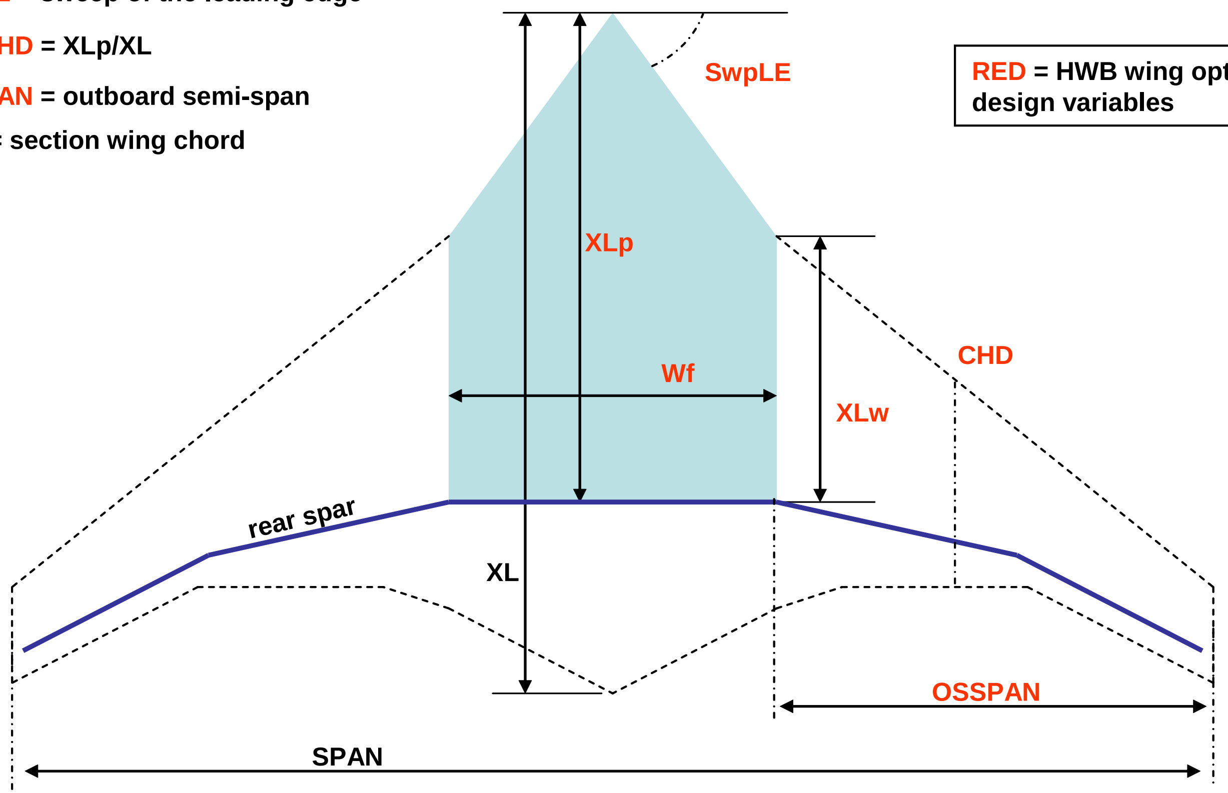
SwpLE = sweep of the leading edge

RSPCHD = XLp/XL

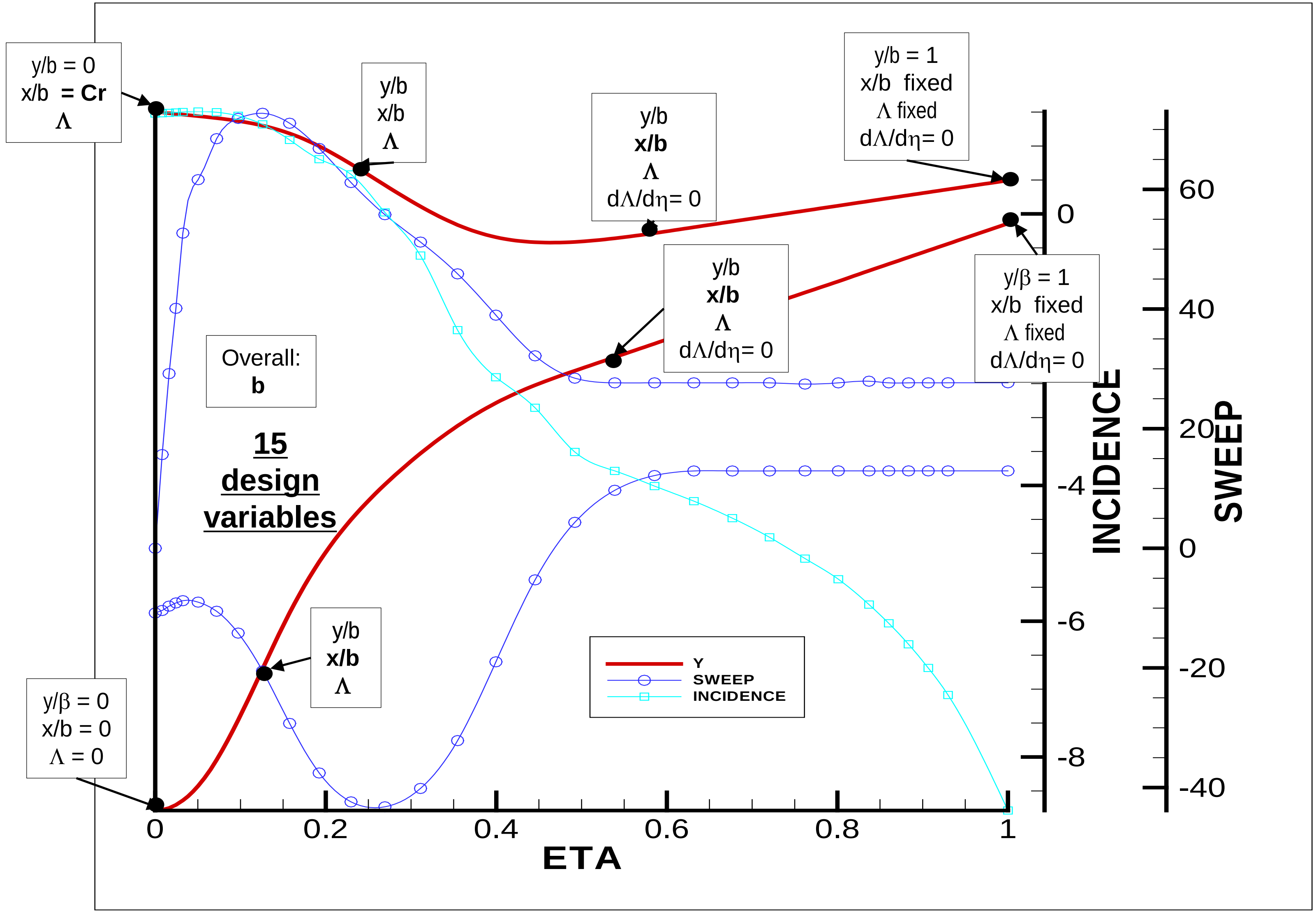
OSSPAN = outboard semi-span

CHD = section wing chord

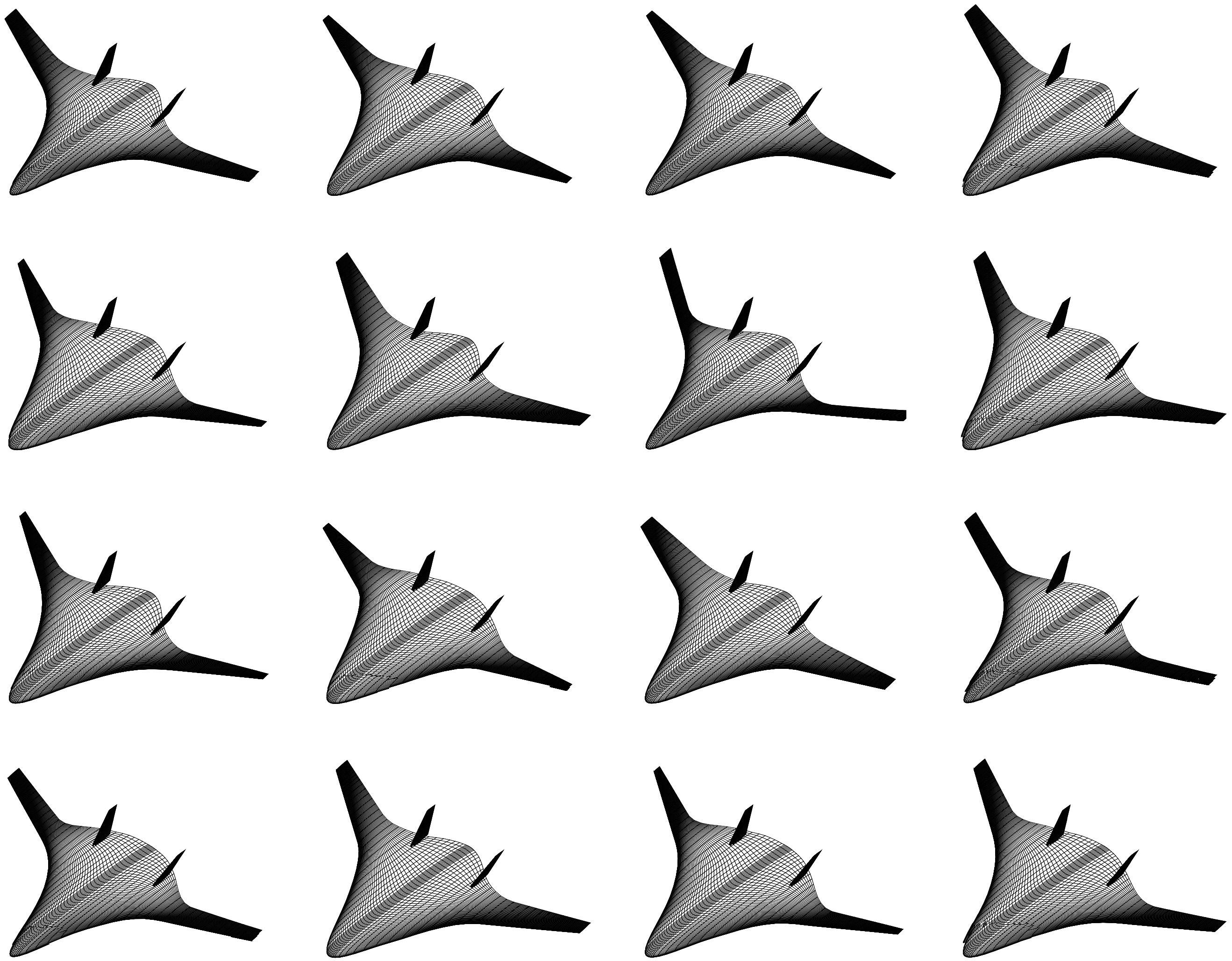
RED = HWB wing optimization design variables



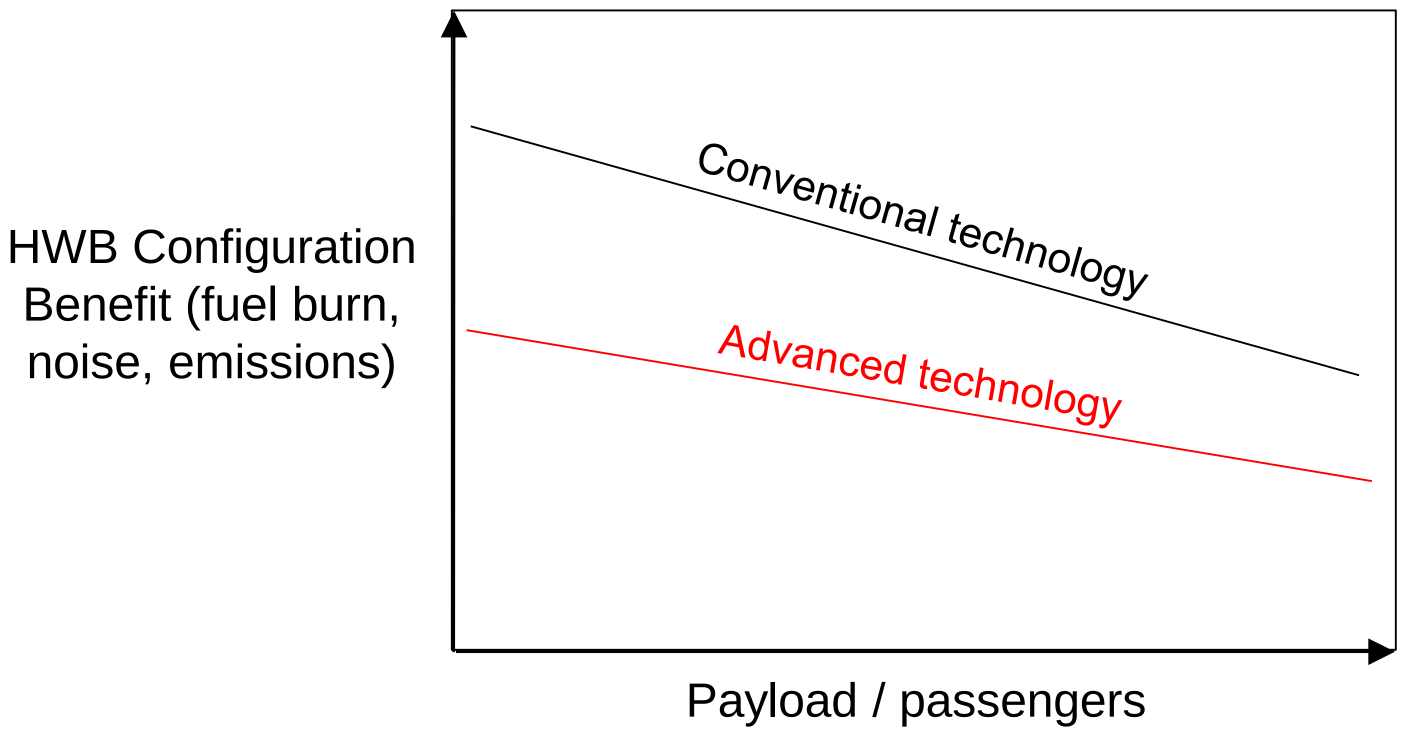
HWB Planform Discretization



Sample Perturbed Planforms

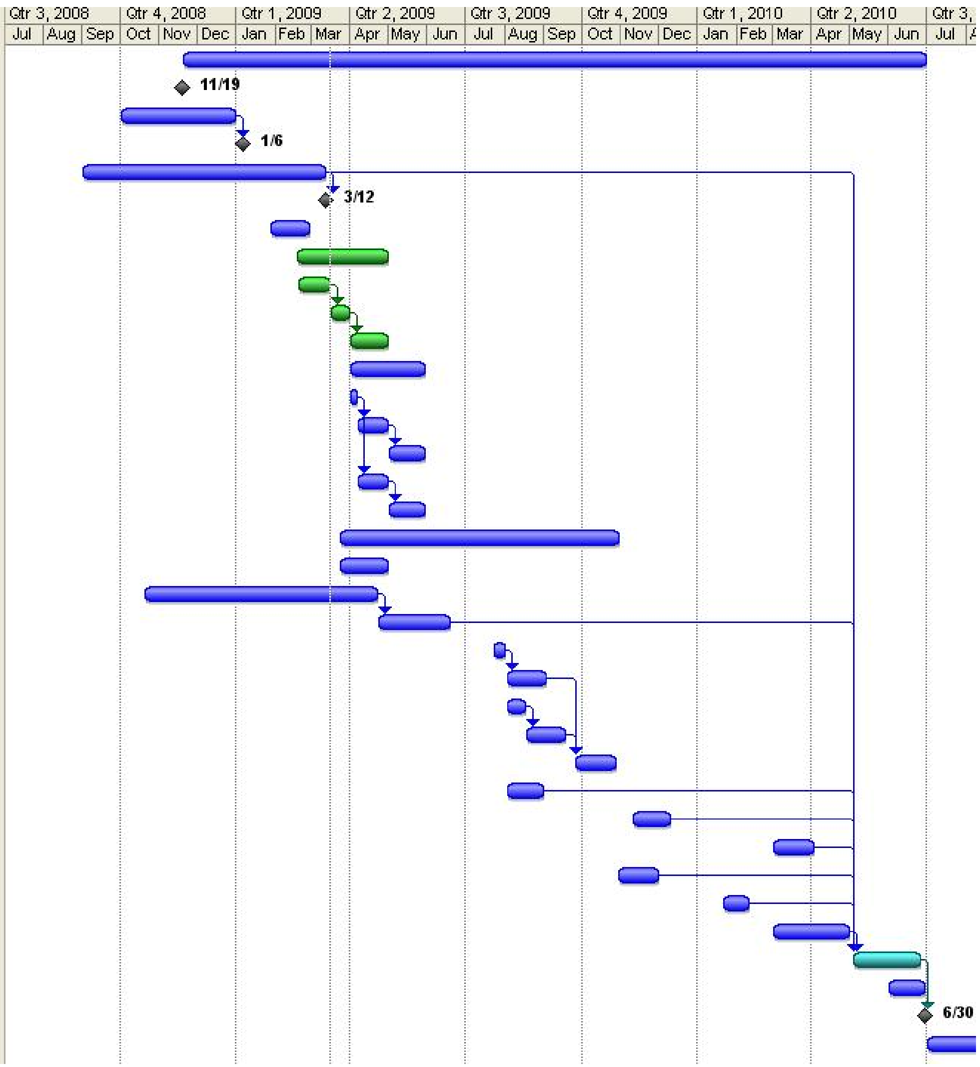


- What is the effect of payload on HWB benefits?
- What is the effect of technology?



Schedule

	Task Name	Duration	Start	Finish	Prede
1	GEN 2 HWB Design Team	421 days	Wed 11/19/08	Wed 6/30/10	
2	Kick-off Meeting	0 days	Wed 11/19/08	Wed 11/19/08	
3	HWB300 Benchmark Design	66 days?	Wed 10/1/08	Wed 12/31/08	
4	ASM Paper Orlando	0 days	Tue 1/6/09	Tue 1/6/09	3
5	HWB VSP Mods from AVID	139 days?	Mon 9/1/08	Thu 3/12/09	
6	VSP V1.4 Released with HWB Mods	0 days	Thu 3/12/09	Thu 3/12/09	5
7	ERA Analysis	24 days?	Tue 1/27/09	Fri 2/27/09	
8	777F Baseline Design	52 days?	Wed 2/18/09	Thu 4/30/09	
9	Propulsion Modeling, GE90-110B	18 days?	Thu 2/19/09	Mon 3/16/09	
10	FLOPS Model	11 days?	Tue 3/17/09	Tue 3/31/09	9
11	ANOPP Model	22 days?	Wed 4/1/09	Thu 4/30/09	10
12	N2A Modeling	43 days?	Wed 4/1/09	Fri 5/29/09	
13	VSP	4 days?	Wed 4/1/09	Mon 4/6/09	
14	FLOPS	18 days?	Tue 4/7/09	Thu 4/30/09	13
15	ANOPP	21 days?	Fri 5/1/09	Fri 5/29/09	14
16	Aero Gridding	18 days?	Tue 4/7/09	Thu 4/30/09	13
17	CFD	21 days?	Fri 5/1/09	Fri 5/29/09	16
18	BWB-700 Modeling	160 days?	Mon 3/23/09	Fri 10/30/09	
19	Obtain and run aero grid in FUN3D	29 days?	Mon 3/23/09	Thu 4/30/09	
20	BWB Centerbody Weight Estimation Tool [	133 days?	Mon 10/20/08	Wed 4/22/09	
21	Obtain Tool, Test with HWB300, N2A etc.	41 days?	Thu 4/23/09	Thu 6/18/09	20
22	VSP Model Final BWB-700 Config	7 days?	Thu 7/23/09	Fri 7/31/09	
23	FLOPS Model, Final BWB-700 Config.	23 days?	Mon 8/3/09	Wed 9/2/09	22
24	Aero grid Final BWB-700 Config	11 days?	Mon 8/3/09	Mon 8/17/09	
25	CFD Analysis Final BWB-700 Config	24 days?	Tue 8/18/09	Fri 9/18/09	24
26	Boeing reconciliation on BWB-700	23 days?	Fri 9/25/09	Tue 10/27/09	23,25
27	VSP Structures Update	21 days	Mon 8/3/09	Mon 8/31/09	
28	M4 Correction Toolkit Integration	23 days?	Tue 11/10/09	Thu 12/10/09	
29	Cal Poly Initial Aero Tool Integration	25 days?	Mon 3/1/10	Fri 4/2/10	
30	AVID Structures Tool Integration	22 days	Fri 10/30/09	Mon 11/30/09	
31	AVID Cost Tool Integration	16 days?	Wed 1/20/10	Wed 2/10/10	
32	AVID/NASA MaSCoT Integration	45 days?	Mon 3/1/10	Fri 4/30/10	
33	GEN 2 Integrated Process Model Completi	40 days?	Mon 5/3/10	Fri 6/25/10	32,31
34	GEN 2 Documentation	21 days	Tue 6/1/10	Tue 6/29/10	
35	GEN 2 Milestone	0 days	Wed 6/30/10	Wed 6/30/10	33
36	HWB300F Update	60 days?	Thu 7/1/10	Wed 9/22/10	

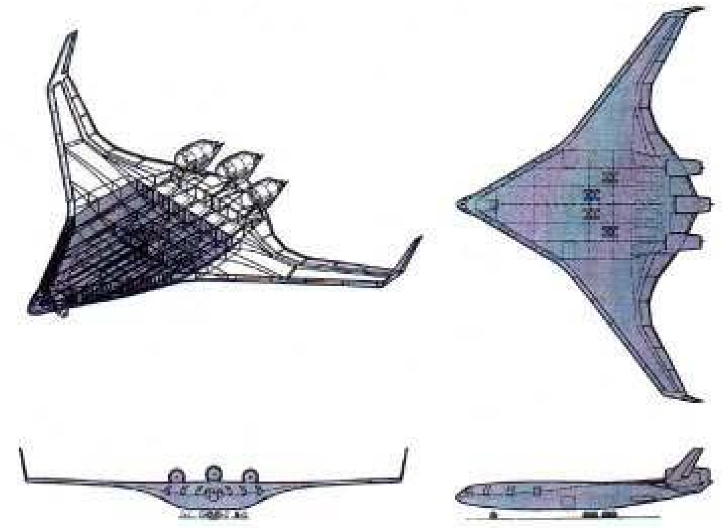


NASA Team Activities

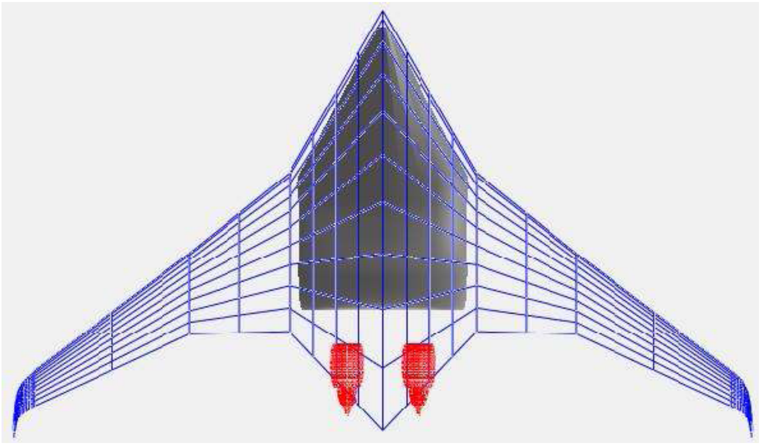
- HWB300 Benchmark Design
  - Craig's ASM Orlando paper
- 777-200ER aeroacoustics model
- 777-200F Baseline
  - Undergoing model development (VSP, Vorview, FLOPS, MaSCoT, ANOPP)
- N2A Modeling
  - Initial model complete (NPSS, VSP, FLOPS, ANOPP)
  - Undergoing gridding and CFD analysis
- BWB-700 Modeling
  - Waiting for Boeing to finish configuration development

HWB300 Configuration

- Nickol, McCullers, "Hybrid Wing Body Configuration System Studies", AIAA 2009-931
- 39% block fuel reduction relative to conventional tube-and-wing
- 12% block fuel reduction relative to advanced tube-and-wing
- FLOPS modifications
- Biggest discrepancy relative to Boeing analysis: compressibility drag, centerbody weights



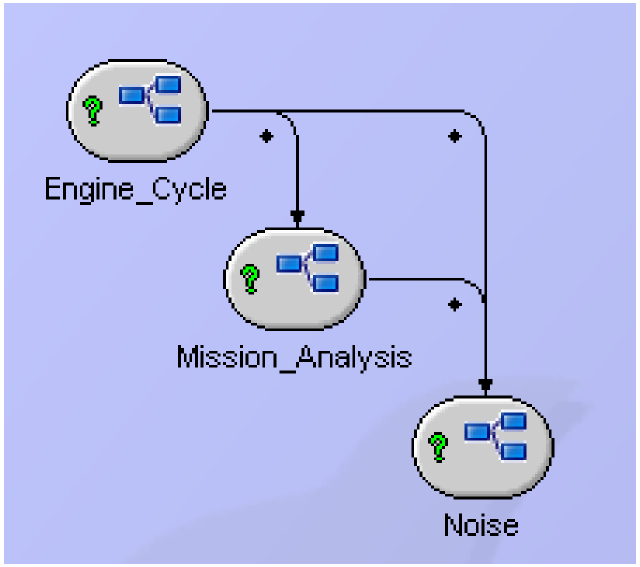
BWB-450



HWB300

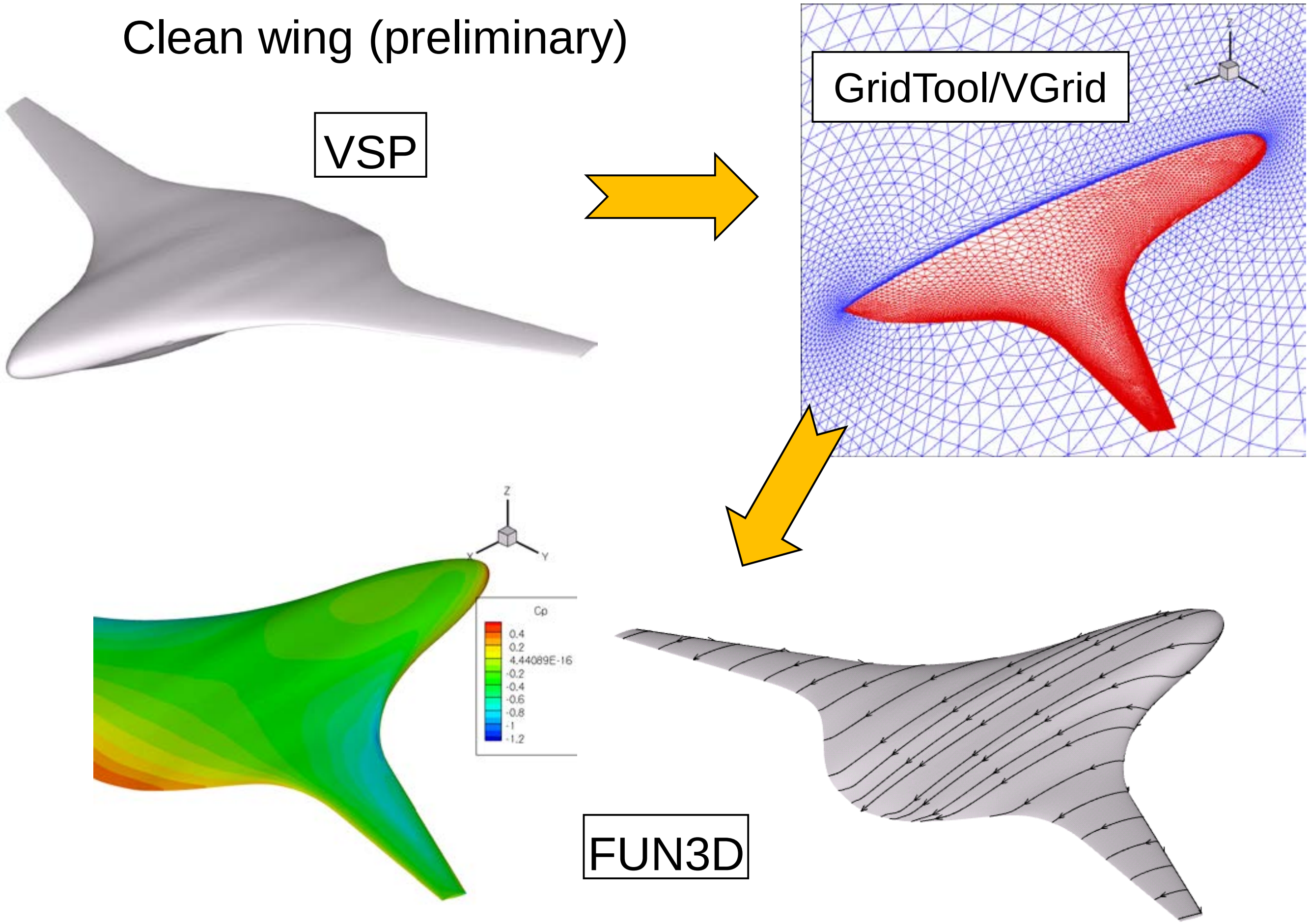
777-200ER Reference Model

- Developed in conjunction with ANOPP group at NASA-Langley
- Baseline for HWB noise benefits assessment
- Next step: quantify HWB300 noise benefits



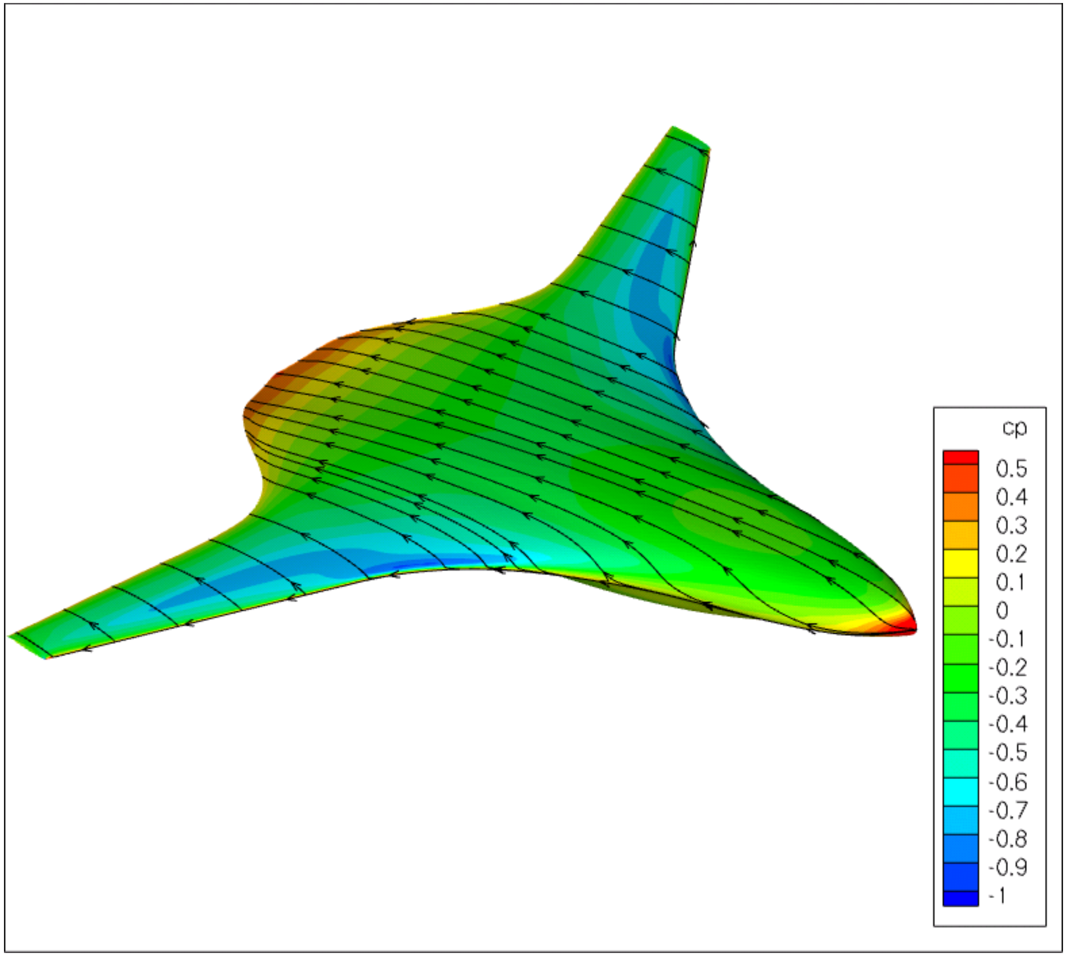
N2A CFD Analysis

Clean wing (preliminary)

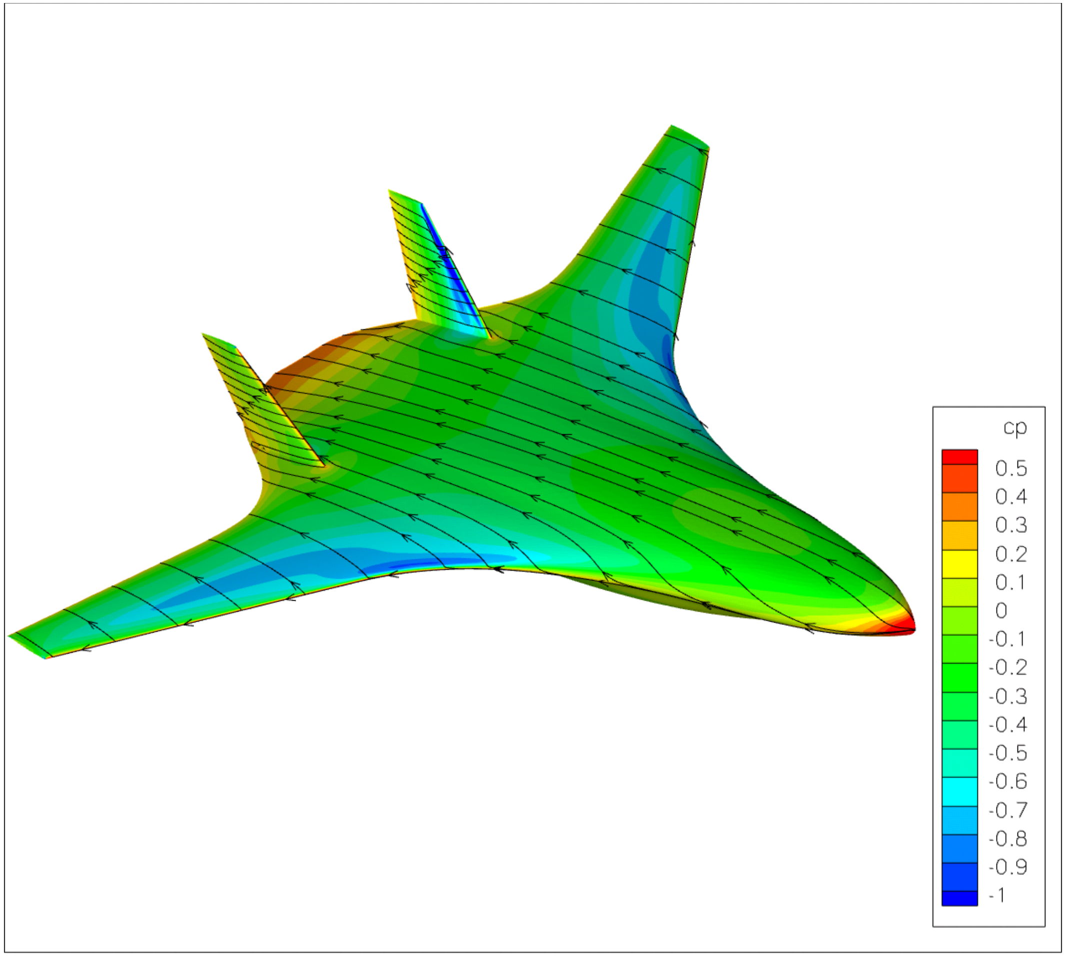


- Estimated total drag compares well with similar Boeing structured-grid Navier-Stokes analysis
- Currently a manual process

Cp Surface Contours, No Tails



Cp Surface Contours



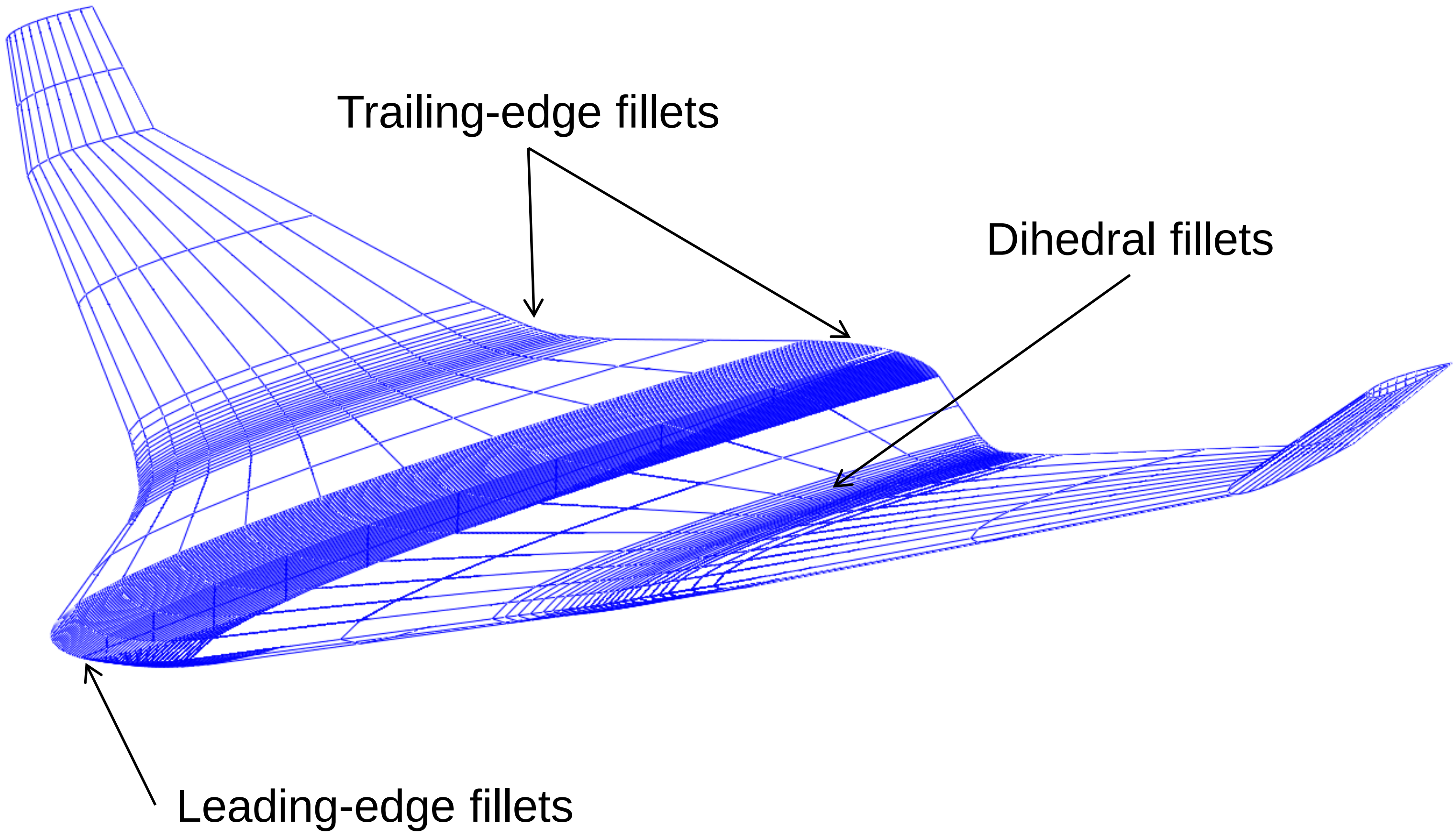
HWB-Related Contracts

- AVID NRA
- Boeing Energy Efficiency Study
- CalPoly/Phoenix/J.R. Gloudemans NRA

AVID NRA Contract

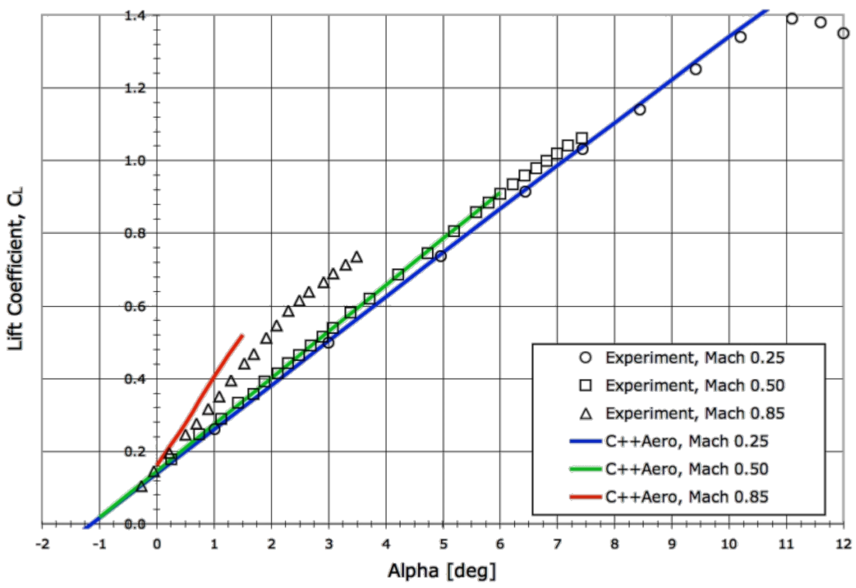
- VSP enhancement and bug fixes
  - HWB component
- Aerodynamics modeling
  - CPPAERO semi-empirical, medium-fidelity
  - High-lift
  - S&C derivatives
  - HWB thrust-drag accounting
  - Aero-propulsion analysis for highly-integrated concepts
- Structural modeling
  - Material selection library
  - Add PRSEUS to PDARB
  - PDCYL cabin floor weight estimation

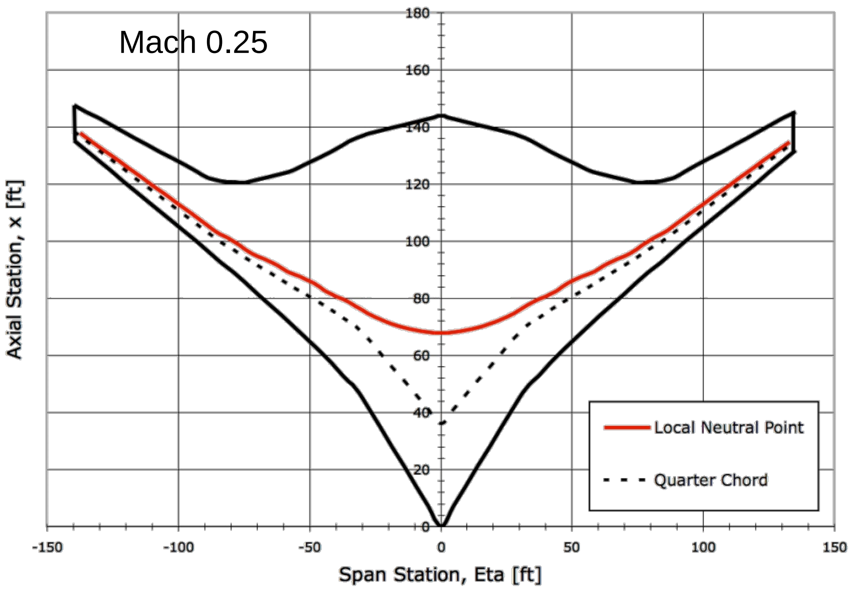
AVID VSP HWB Component



AVID CPPAERO

- Validating against NASA BWB NTF model
- Excellent qualitative agreement, but still resolving issues with shock location, critical Mach estimation, and drag calculations

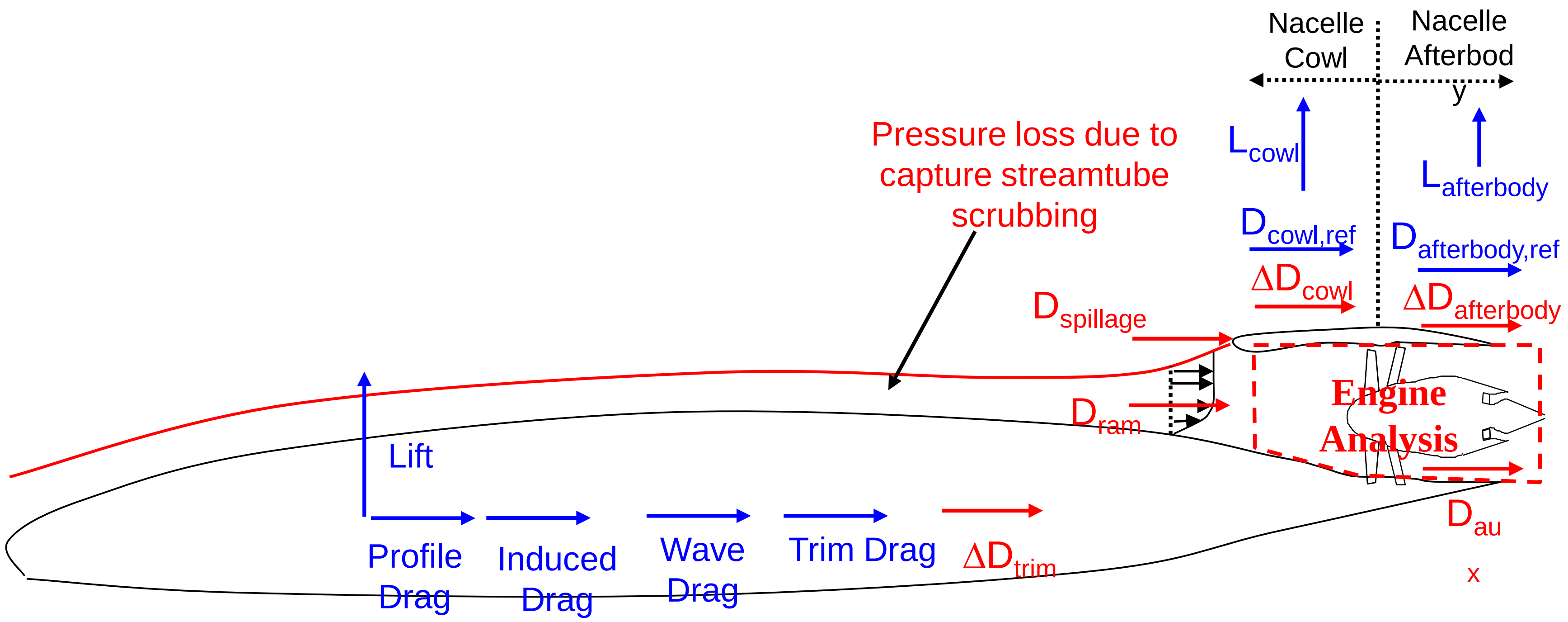




AVID HWB High-Lift Modeling

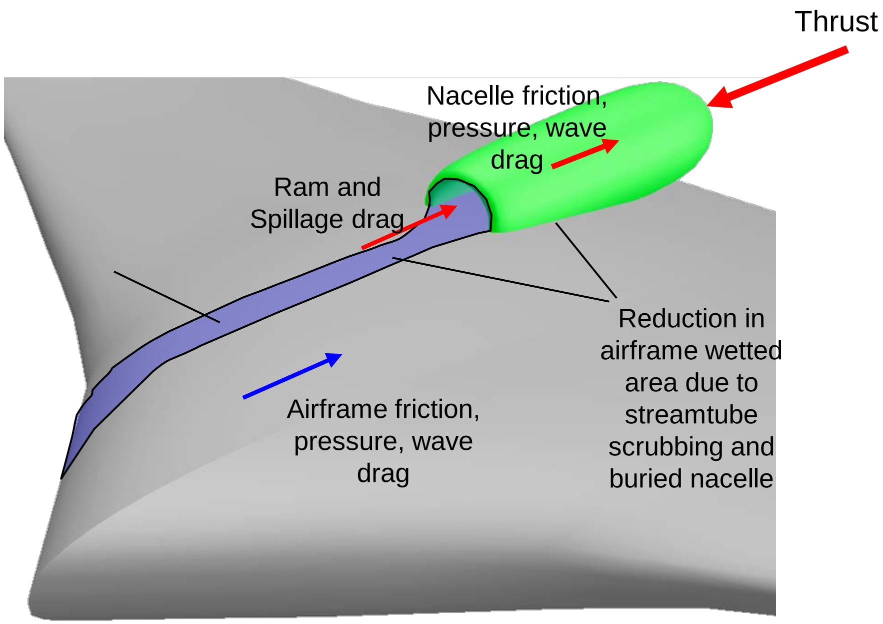
- Embedded version of AVID RAPT for C_L, C_D, C_M increments due to flap deflection
- Improvement over DATCOM-based calculations
- Capable of modeling:
  - Plain Flaps
  - Single-Slotted Flaps
  - Double-Slotted Flaps
  - Slats
  - Krueger Flaps
- Validation underway
  - Plain Flaps - NACA TN's
  - Single-Slotted w/Slats - NASA 14x22' data??
  - Additional cases?

HWB Aero-Propulsion Forces



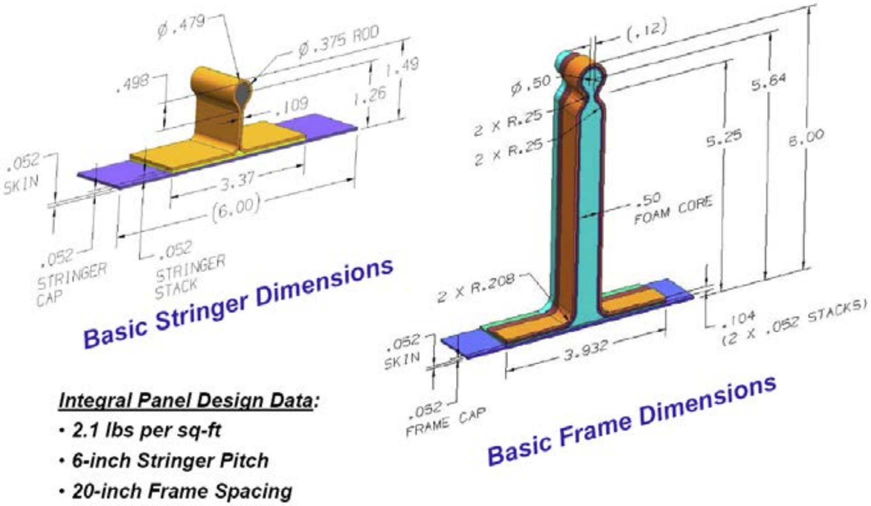
AVID Integrated Aero-Propulsion

- Goal is to establish framework, identify problems, construct an integrated solution
- Key areas:
  - Boundary layer code for BLI inlet model
  - Engine cycle analysis
  - S-duct losses/distortion
  - T-D accounting



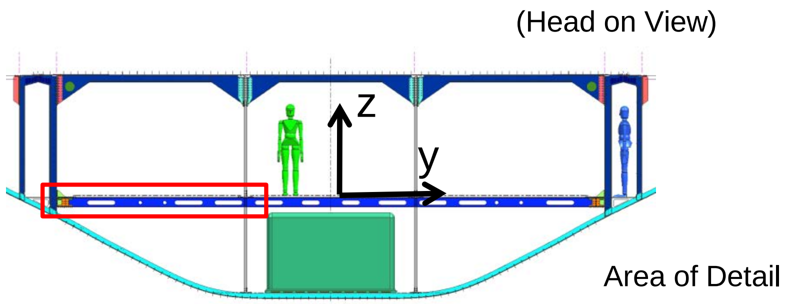
AVID Addition of PRSEUS to PDARB

- Addition of structural concepts into PDARB is fairly straightforward
- Requires five additional structural factors
  - K_p, a knock-down factor for accounting for material that doesn't contribute to resisting hoop stress
  - K_{mg}, a shell geometry parameter
  - K_{th}, a sandwich thickness parameter
    - Obviously irrelevant for PRSEUS
  - ε, buckling efficiency
  - m, still researching

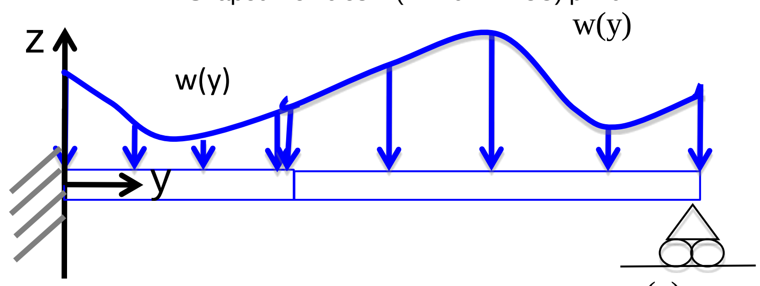


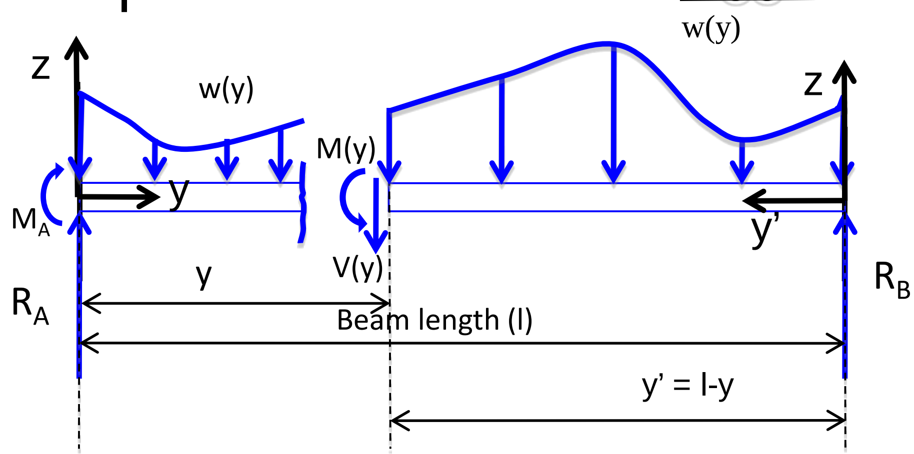
AVID PDCYL-Floor Plans

- Modifications to PDCYL's Wing weight algorithm
  - PDCYL models the wing as a cantilevered beam
  - Modify the analysis to compute the loads in the statically indeterminate case.
  - PDCYL's numerical integration subroutine used to determine the Moment M(x) and Shear forces V(x) imposed by an arbitrary load.
- PDCYL can estimate the weight of composite structures
- Uses existing PDCYL optimization algorithm



Velici, Alex, Yovanof, Nikki. "Damage Arresting Composites for Shaped Vehicles." (NNL07AA48C) p. 20





AVID HWB Cost Estimation

- New Airframe Cost estimation method
  - Calculates the labor input for
    - General Recurring Manufacturing
    - Recurring Tooling
  - Based on the amount and type of structural materials
  - Applies appropriate Labor Rates, material costs and Learning Curves to estimate the manufacturing cost of major airframe components
- Boeing Based CER's
  - CER's based on production data from Boeing aircraft
- Retains ALCCA functionality
  - 2 tiered learning Curves
  - ROI calculator
  - Advanced RDT&T
  - Cash flow Analysis
  - Old Weight based methods

AFRL Boeing Fuel Efficiency Study

- Develop efficient HWB for medium mobility
- Identify high efficiency propulsions systems
- Investigate methods to reduce viscous drag
- Investigate methods to improve low speed performance
- Design for formation flight
- Create technology and flight demonstration plans
- NASA Funding for Options 1 & 2

Boeing Configuration Scorecard

- B777-200F payload and mission
- BWB-700: baseline HWB
- BWB-710: advanced HWB
  - Advanced Rolls-Royce turbofan
  - Hybrid laminar flow on the outer wings
    - Based on Basic Task 3 effort
    - Combined with Krueger flaps
  - Riblets for reduced viscous drag
- BWB-720: advanced tube-and-wing
  - BWB-710 technologies where appropriate
- BWB-600: B767F payload and mission
  - Based on latest version of -700
  - Single-deck
  - Exploits reduced Mach number (0.80 versus 0.84 for -710)

Option 1: HWB Sized to 777-200F Capability

Goal: Develop HWB configurations and compare to a conventional configuration for 777-200F mission capability

- Primary metric is fuel burn
- Configuration will reflect results of NASA Contract NNL07AA54C (N+2)
- Advanced aerodynamic & propulsion technologies will be incorporated
- EIS of 2025 assumed to accommodate necessary technology developments
- Boeing will provide geometry, aero, propulsion, weights and performance

Option 2: HWB Sized to 767-200F Capability

Goal: Develop HWB options and compare to a conventional configuration option for 767-200F mission capability

- Primary metric is fuel burn
- Noise goal will be defined in Task 2.6 based on extrapolation of historical trends
- Advanced aerodynamic & propulsion technologies will be incorporated
- EIS of 2025 assumed to accommodate necessary technology developments
- Provide OML and plan high-speed wind tunnel test

Boeing Centerbody Weight Estimation Tool

- Weight prediction method for HWB nose, centerbody and afterbody structural regions
- Developed from Boeing proprietary methods
- Remains Boeing proprietary
- Intended for use in conceptual studies
- Enables incorporation of benefits from technology advancements
  - PRSEUS
  - Others

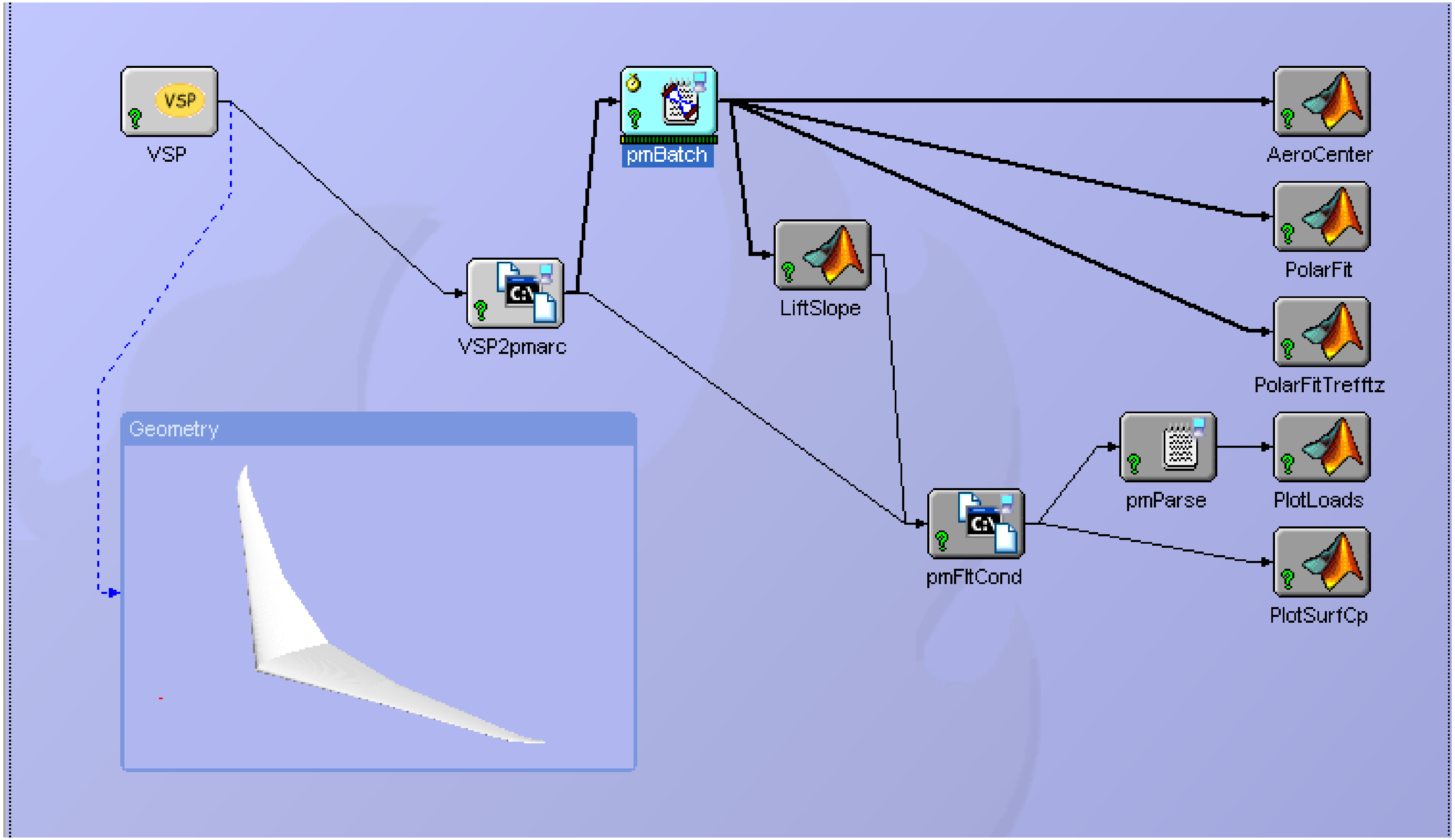
Boeing Large-Scale HWB Demonstrator

- Features
  - Demonstrates fuel efficiency and reduced noise
  - Full envelope performance
  - Flight mechanics (incl. stall chars.)
  - Residual operational capability with payload
  - Addresses military and commercial freighter missions
- Technologies Matured
  - PRSEUS structure (affordable production incl. pressure shell)
  - Cargo ramp and handling systems
  - Flight controls & S/W (all flight regimes)
- Follow-on Flight Tests
  - BLI inlet
  - Open rotors
  - Integrated Power System
  - Fuel cell
  - Superconducting electric power
  - Hybrid Laminar Flow Control

CalPoly/Phoenix/J.R. NRA Contract

- PMARC integration delivered, undergoing NASA evaluation
- Unstructured Panel Code
- VSP Structural Modeling

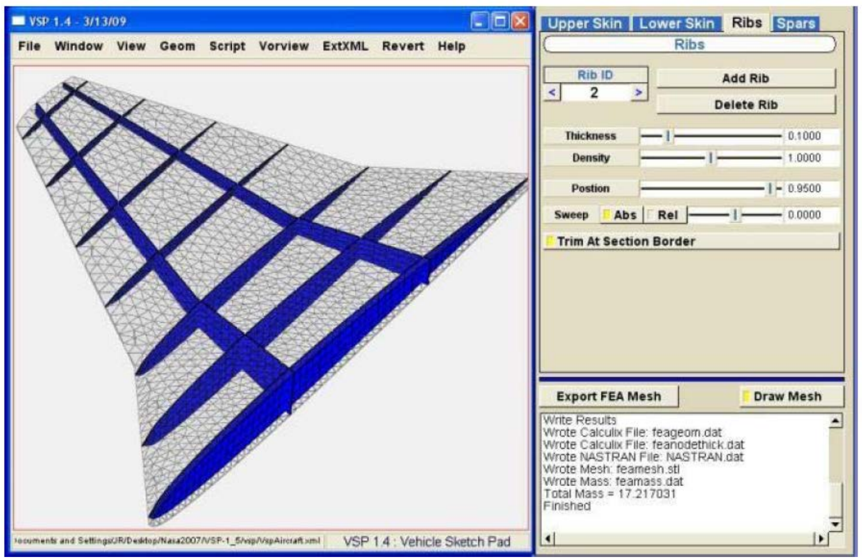
PMARC ModelCenter Integration



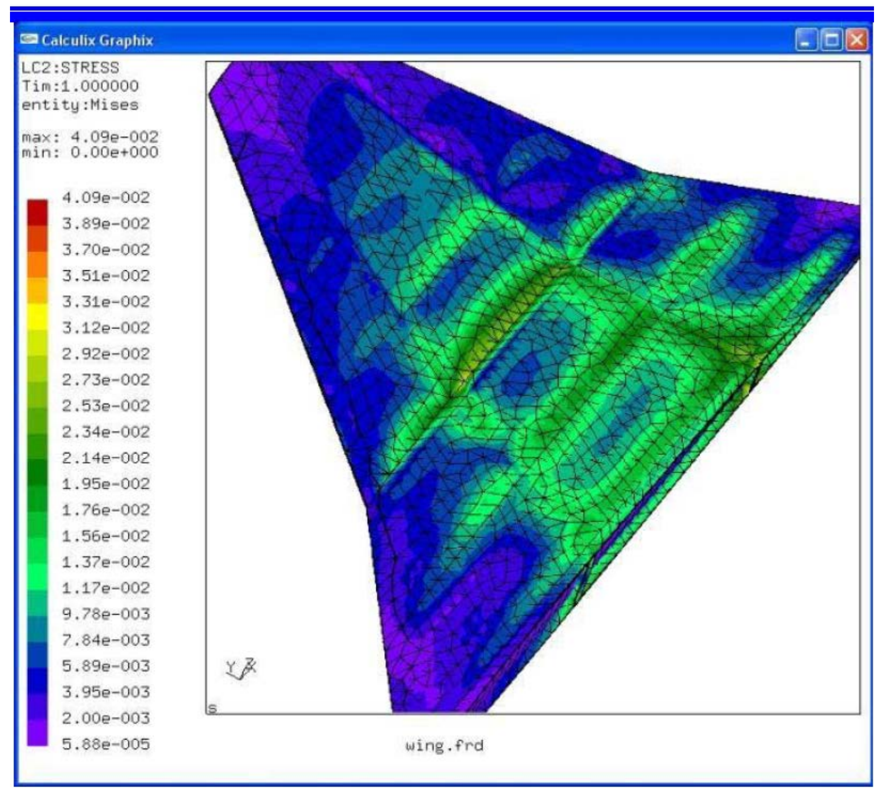
CalPoly Unstructured Panel Code

- Geometry library + panel code library = tools and components to construct an analysis
- Considerable computational overhead
- Vortex-particle method
  - Preliminary validation against analytical actuator disk solutions shows promise
- Dual-reciprocity method
  - No mesh needed
  - Validated against compressible flow over a cylinder shows excellent agreement

VSP Structural Modeling

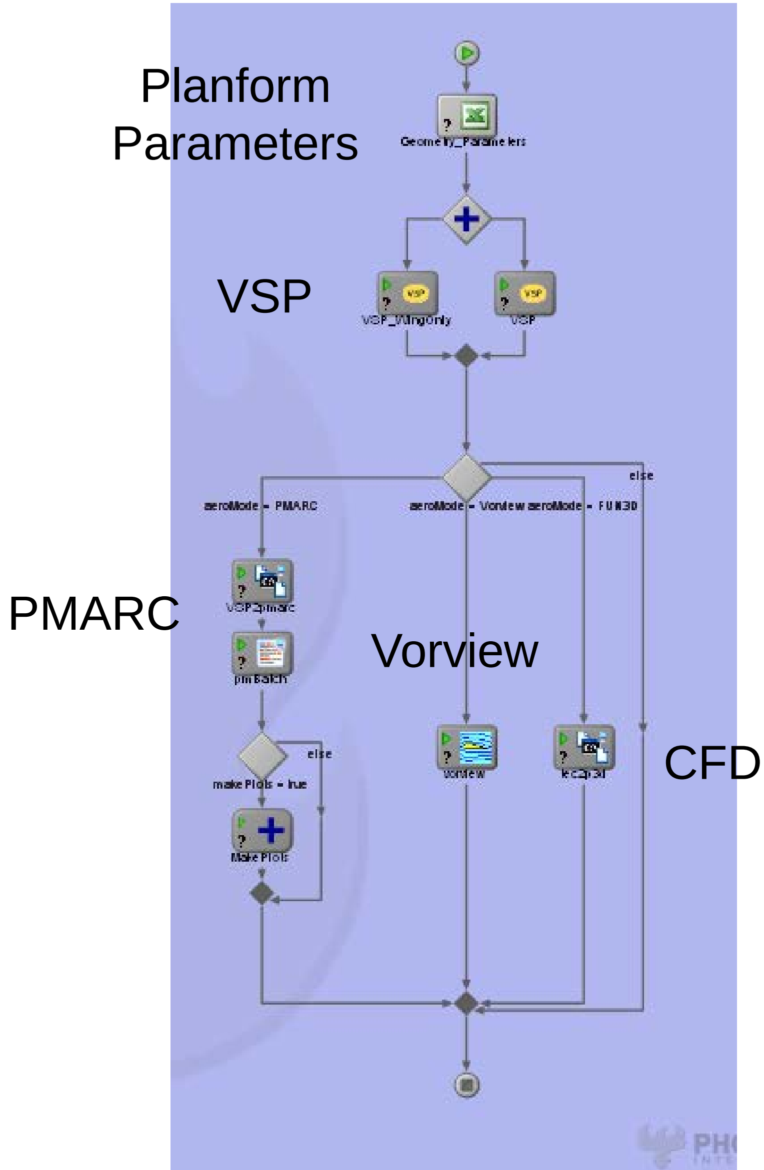


VSP



Sample Analysis (Calculix)

Initial MC9 Process Flow Model



Outline

- Milestones
- GEN2 Validation objective & approach
- HWB analysis toolbox
- HWB design problem
- NASA team activities
- AVID NRA contract
- Boeing Energy Efficiency contract
- CalPoly NRA contract