D8 Independent Assessment Briefing

Jason Welstead, ASAB, NASA LaRC

May 7, 2015

Definitions

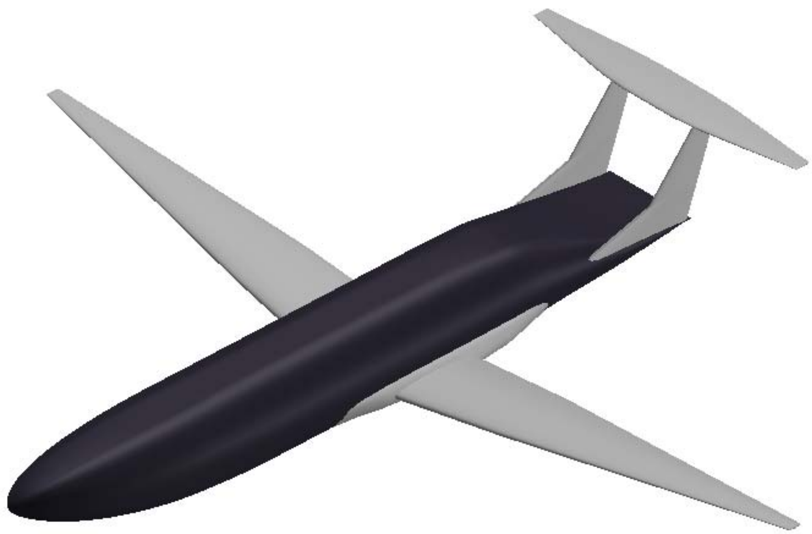
- D8.1: Double bubble concept with 2010 technology assumptions
- D8.2: D8.1 concept with only two engines
- D8.2b: Span constrained version of D8.2 (similar to 737-800 span)
- D8.5: Advanced N+3 technology double bubble concept
- D8.6: D8.5 concept with only two engines

Independent Assessments of D8 (Phase I)

- Several independent assessments have been conducted on the D8 configurations
  - NASA initial Phase I quick look assessment – Andy Hahn
  - Georgia Tech D8 quick look assessment
  - NASA Phase I D8 detailed independent assessment – Andy Turnbull
  - NASA D8.2 follow-on morphing sequence assessment – Jason Welstead
- Each assessment identified a common set of risk areas
  - Airframe weight, specifically the fuselage and empennage
  - Lack of adequate reserve mission, produces measurable system penalty
  - Wing aeroelastics, including transonic dip
  - Safety due to turbine blade burst
- Detailed assessment identified additional areas of risk
  - Terminal area operations, specifically takeoff performance
  - Low-speed, high alpha pitch recovery with power effects

ASAB Detailed Analysis of D8 (Phase I NRA)

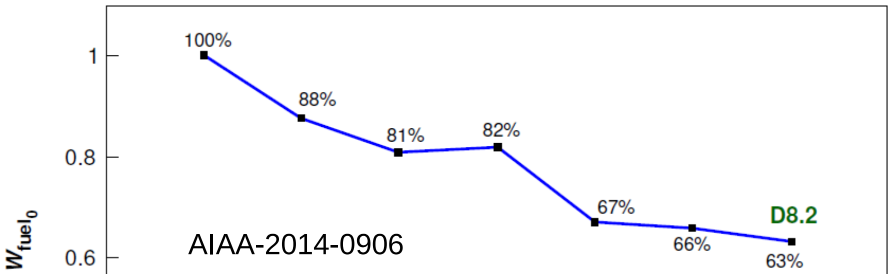
- Performed an independent assessment of the current technology (D8.1) and the advanced technology (D8.5) concepts
- Process for D8 concept evaluation
  – Geometry definition and modeling (compiled from multiple resources)
  – Develop a model including all relevant technology assumptions
  – Obtain an understanding of BLI and the modelling approach (challenging)
  – Use in-house, mission analysis software (FLOPS) to independently verify performance estimates of the D8 concepts



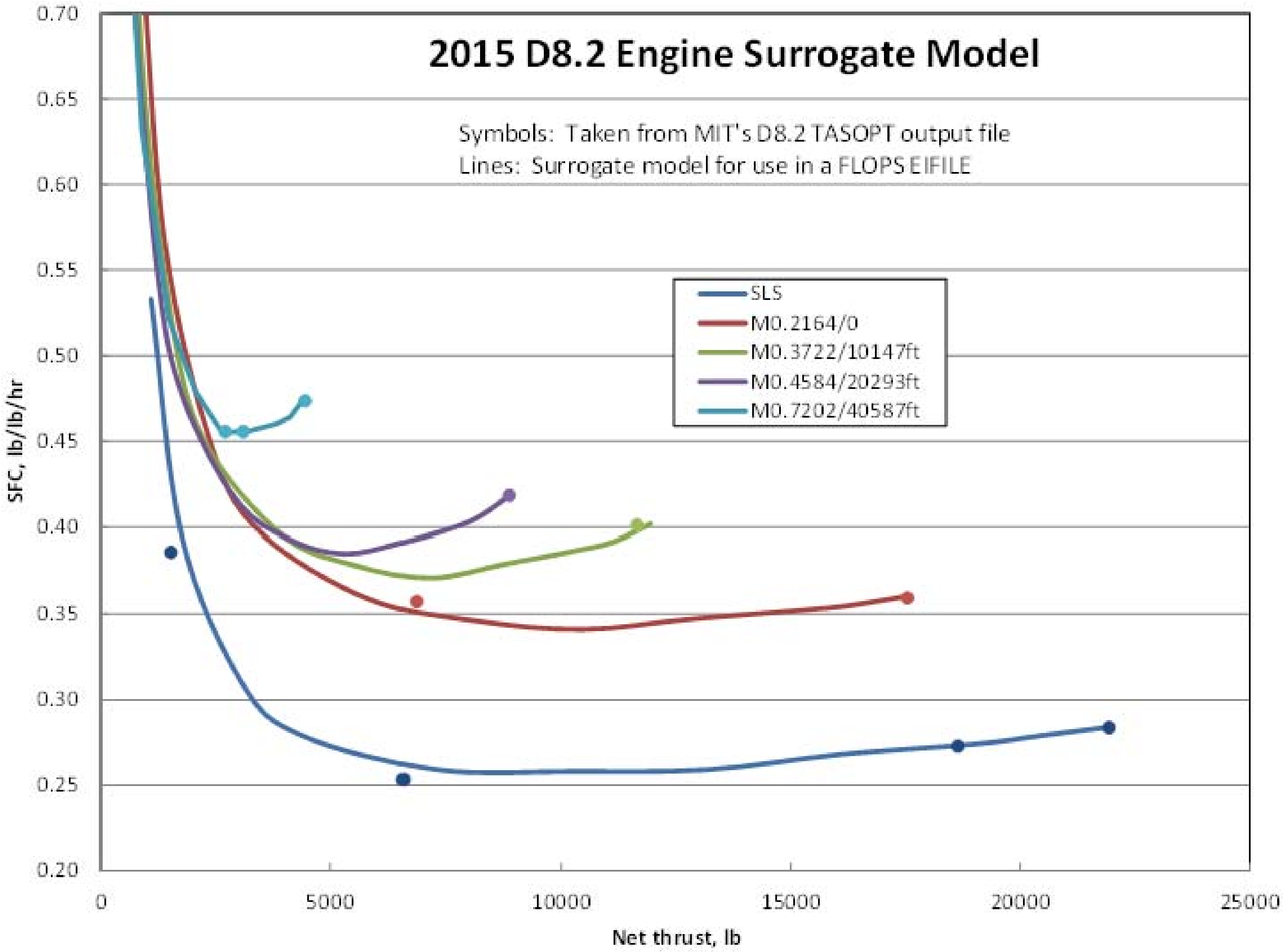
ASAB Detailed Analysis of D8.2

- Using lessons learned from previous D8 analysis, D8.2 morphing sequence recreated
  - Followed step changes from AIAA-2014-0906, skipped steps 3-5
  - Fixed AR to match stated value in conference paper
  - Used D8.2 surrogate engine model generated from TASOpt data
  - Configuration credits given: reduced gear height, nacelle weight and wetted area, constant engine T/W for surrogate engine, adjusted VT and fuselage weight factors

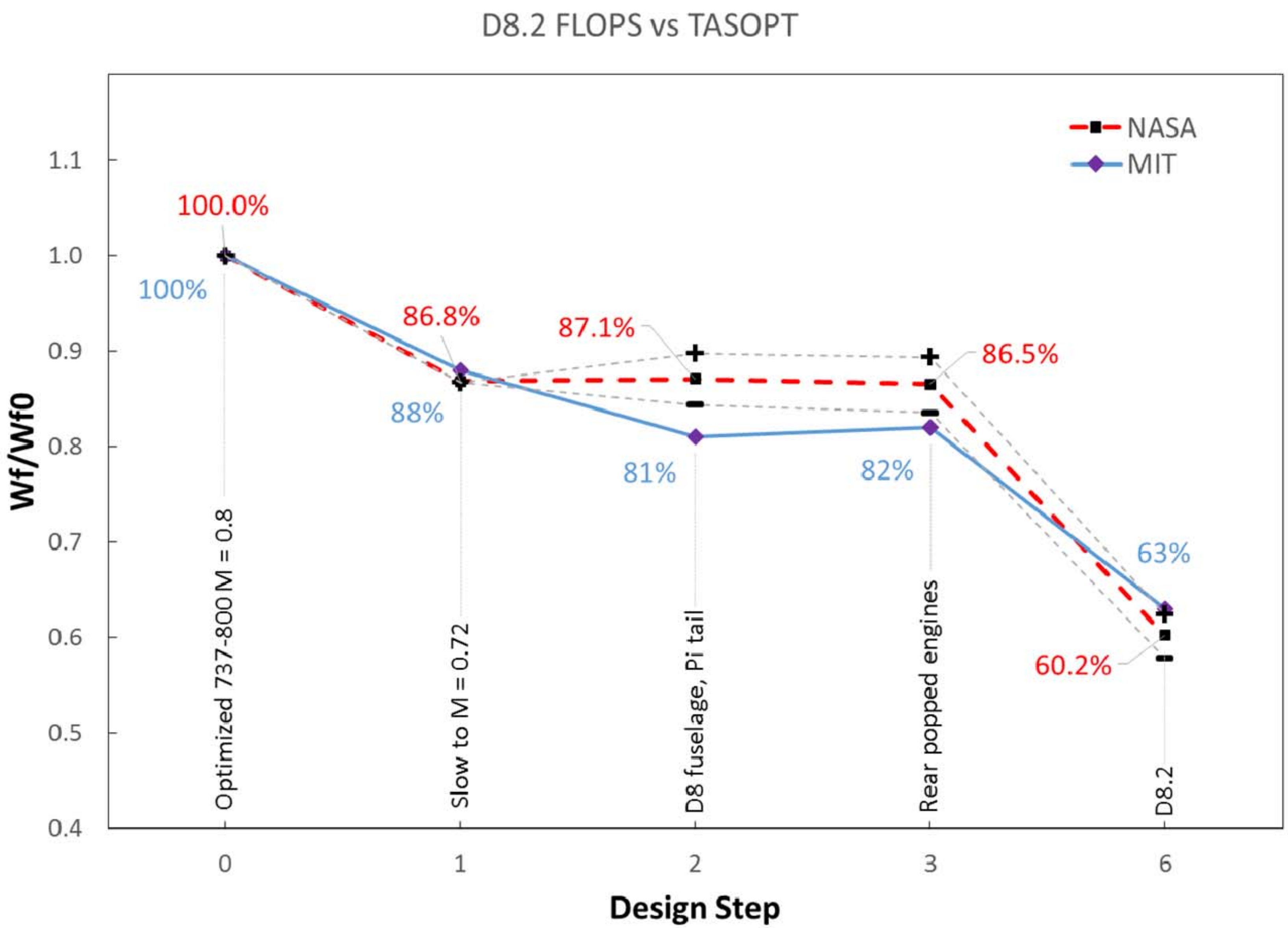
Step	M cruise	BLI?	W_{max} (lb)	W_{fuel} (lb)	Span (ft)	S (ft^2)	AR	Sweep (deg)	C_L	h_{cruise} (ft)	$T_{t\,4}$ (K)	BPR	FPR	OPR
0	0.80	N	160858	35131	115.8	1240	10.8	26.7	0.564	34784	1294	5.100	1.650	30
1	0.72	N	159294	30682	148.9	1338	16.6	11.1	0.677	36110	1233	5.100	1.650	30
2	0.72	N	141850	28518	133.6	1123	15.9	12.0	0.717	36037	1239	5.100	1.650	30
3	0.72	N	144290	28898	143.2	1187	17.3	13.3	0.691	36083	1263	5.100	1.650	30
4	0.72	Y	128852	23517	131.6	1029	16.8	13.1	0.705	35795	1237	5.100	1.650	30
5	0.72	Y	130480	23296	131.0	1033	16.6	12.0	0.711	35769	1419	7.136	1.638	30
6	0.72	Y	129239	22422	132.1	1060	16.5	11.8	0.711	36584	1451	7.704	1.601	40



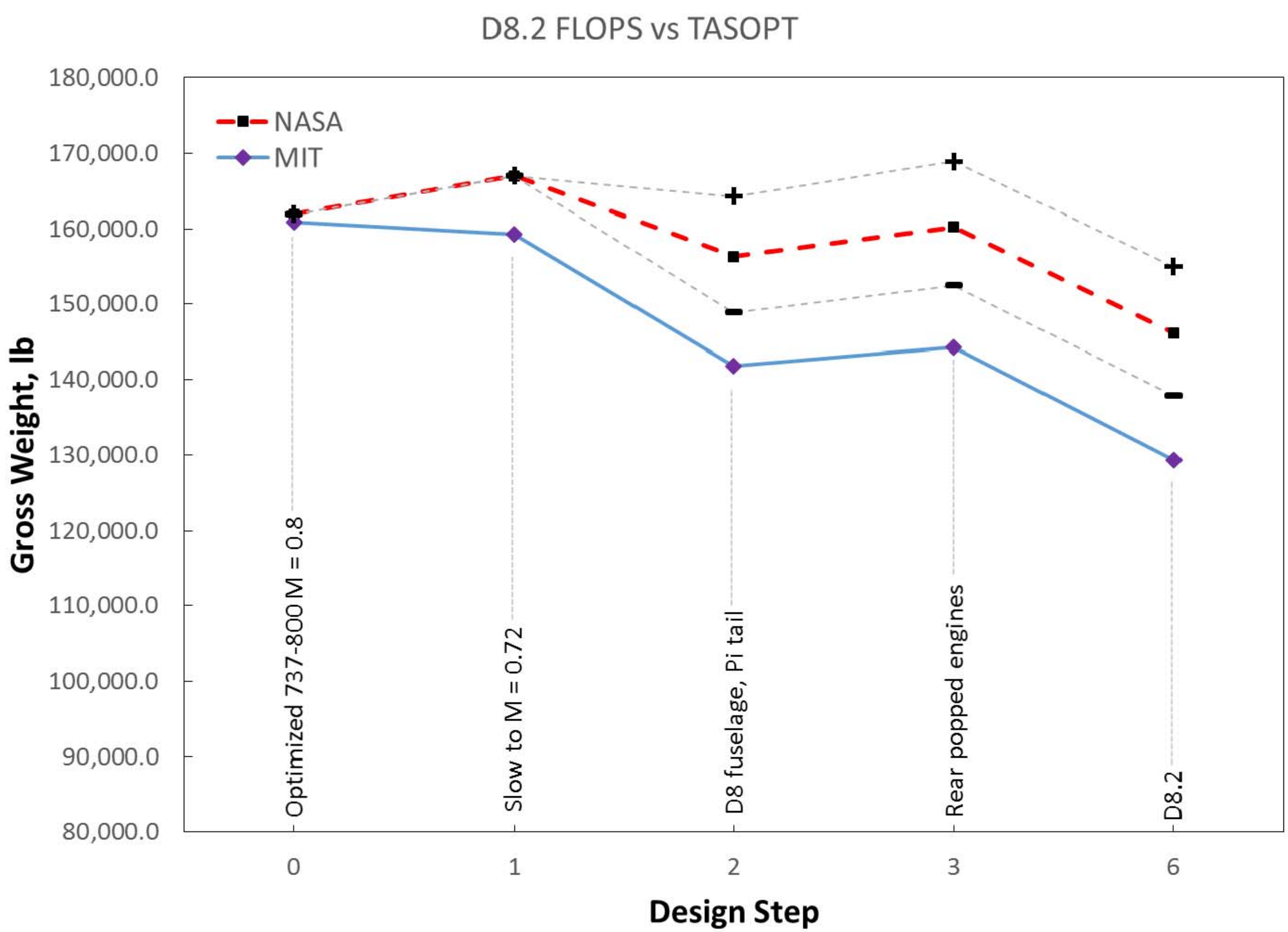
D8.2 Surrogate Engine Model



Normalized Fuel Burn



Max Takeoff Gross Weight



Conceptual Design Areas of Risk/Uncertainty

- Structural design and weight estimates (high)
  - Fuselage, horizontal and vertical stabilizers, high AR wing
  - Aggressive advanced material properties
  - Health monitoring systems that remove flight loads factor of safety
- Non-representative reserve mission (medium)
  - Current D8 analysis uses simple 5% reserve fuel
  - Including an appropriate reserve is a non-trivial performance penalty
- Terminal Area Operations
  - Takeoff and landing analysis with hot day (high)
  - Descent flight path angle (medium)
- Low-speed, high angle of attack analysis (high)
  - Geometrically, potentially high percentage of horizontal blocked at high AoA
  - Unknown how rear BLI will modify horizontal blanketing and pitch recovery
- Propulsion 1 in 20 certification rule (high)

Unconventional Propulsion Architecture

- P&W has designed a new engine architecture to deal with this problem (presented at Aviation 2015)
- No current engine manufacturer customizes an architecture for a single aircraft design
- However, highly integrated PAI could be an enabling technology of future commercial transports

FAA AC 20-128A "1-in-20 Rule"

In the unlikely event of turbine disk burst,
less than 1-in-20 chance of
both engines failure or
loss of aircraft control surfaces

ASAB Analysis of D8 (Current)

- Analysis Capabilities
  - High fidelity takeoff and landing analysis including all relevant regulations
  - High fidelity mission analysis capable of capturing system level benefits of the D8 advanced concept
  - System sensitivities to help bound uncertainty and identify enabling technologies
  - Powered, viscous, BLI analysis (Coming soon)
- Analysis Challenges
  - High aspect ratio wing weight estimation, including flutter constraints
  - Conceptual level D8 fuselage weight estimation
  - BLI propulsion system analysis (due to personnel loss)
  - Propulsion-airframe integration (PAI)

Areas of Potential Collaboration

- Detailed mission analysis and performance estimates
- System analysis of relevant technologies
- Low-speed, high angle of attack, powered CFD
- Static and dynamic stability and control analysis
- Detailed noise analysis
- Emissions (specifically NOx) analysis (through support at GRC)
- Transonic aerodynamic design and analysis
- Composite structure design support

BACKUP

Partial Morphing Sequence

Step	M cruise	BLI?	W_{max} (lb)	W_{fuel} (lb)	Span (ft)	S (ft^2)	AR	Sweep (deg)	C_L	h_{cruise} (ft)	T_{t4} (K)	BPR	FPR	OPR
0	0.80	N	160858	35131	115.8	1240	10.8	26.7	0.564	34784	1294	5.100	1.650	30
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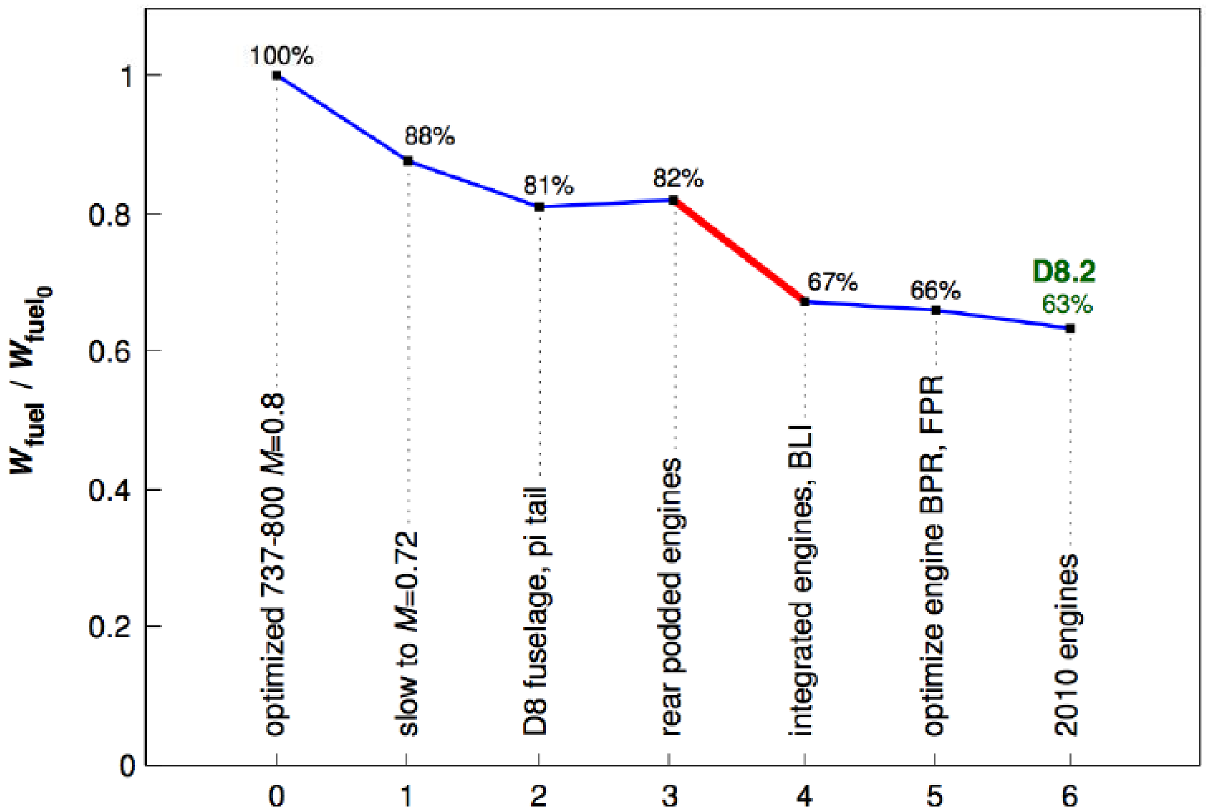
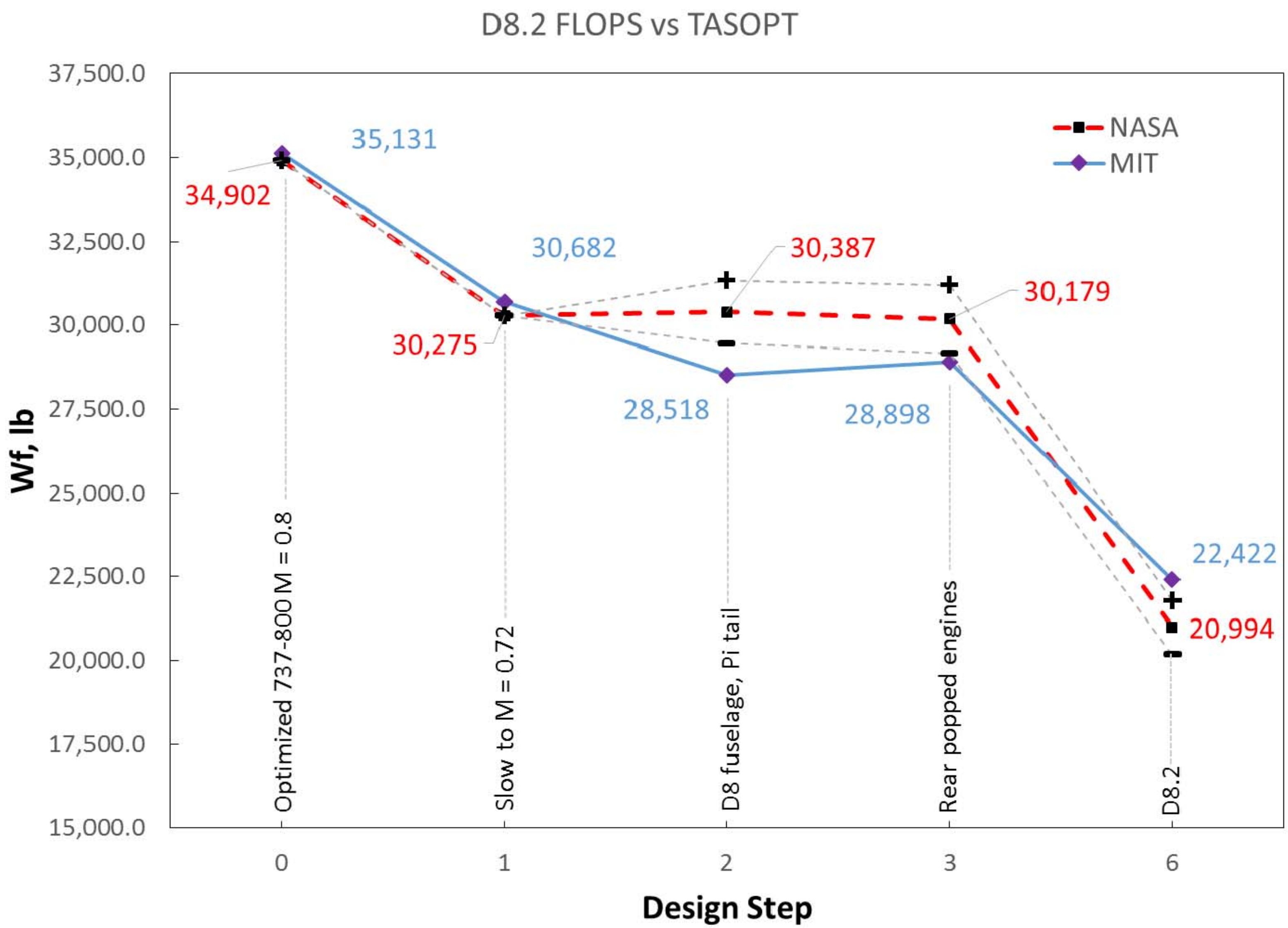
AIAA-2014-0906

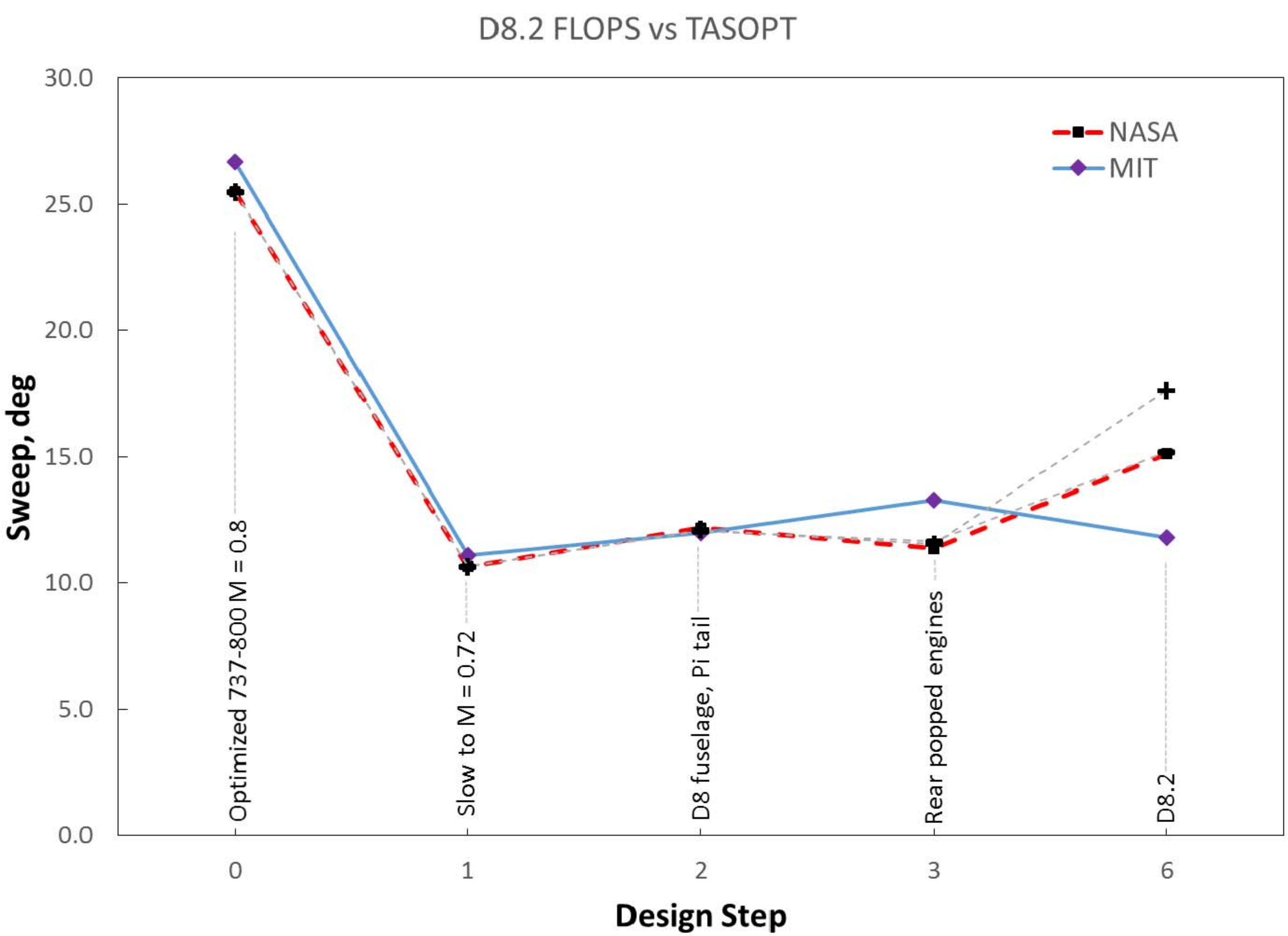


Block Fuel



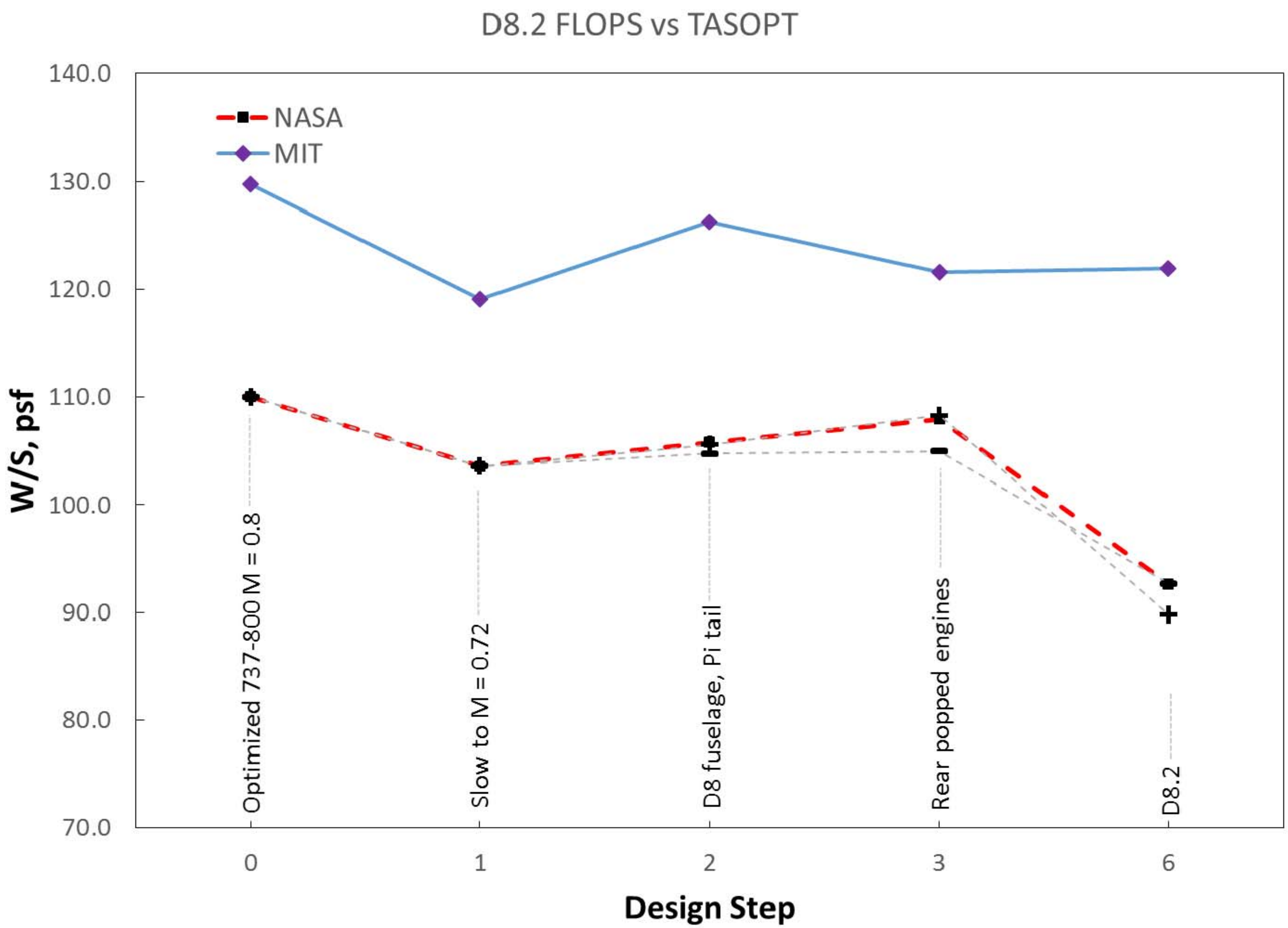
D8.2 FLOPS vs TASOPT
37,500.0
35,000.0
32,500.0
30,000.0
27,500.0
25,000.0
22,500.0
20,000.0
17,500.0
15,000.0
Wf, lb
NASA
MIT
35,131
34,902
30,682
30,275
30,387
30,179
28,518
28,898
22,422
20,994
Optimized 737-800 M = 0.8
Slow to M = 0.72
D8 fuselage, Pi tail
Rear popped engines
D8.2
0
1
2
3
6
Design Step

Sweep

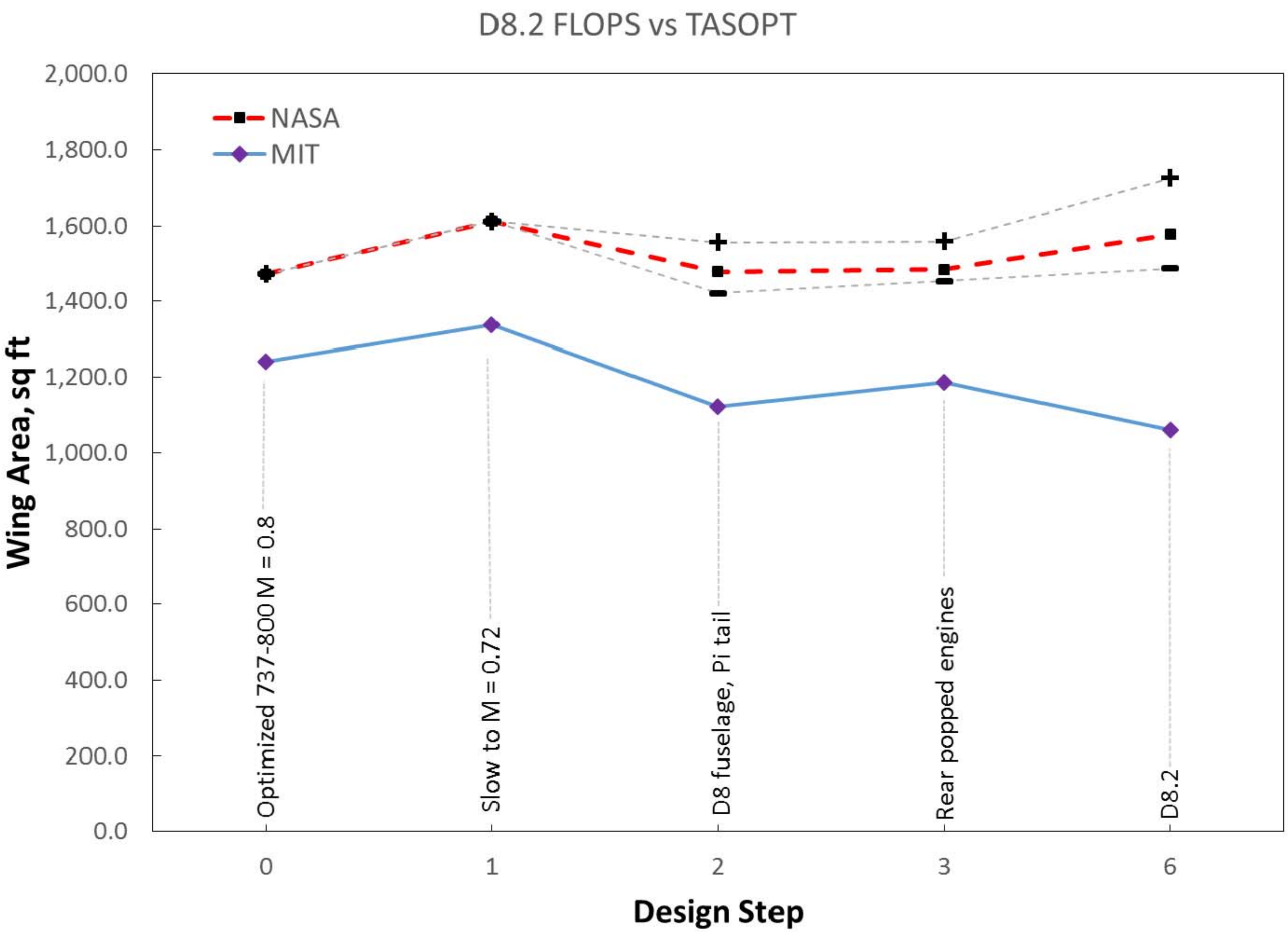


D8.2 FLOPS vs TASOPT
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Sweep, deg
NASA
MIT
Optimized 737-800 M = 0.8
Slow to M = 0.72
D8 fuselage, Pi tail
Rear popped engines
D8.2
0
1
2
3
6
Design Step

Wing Loading

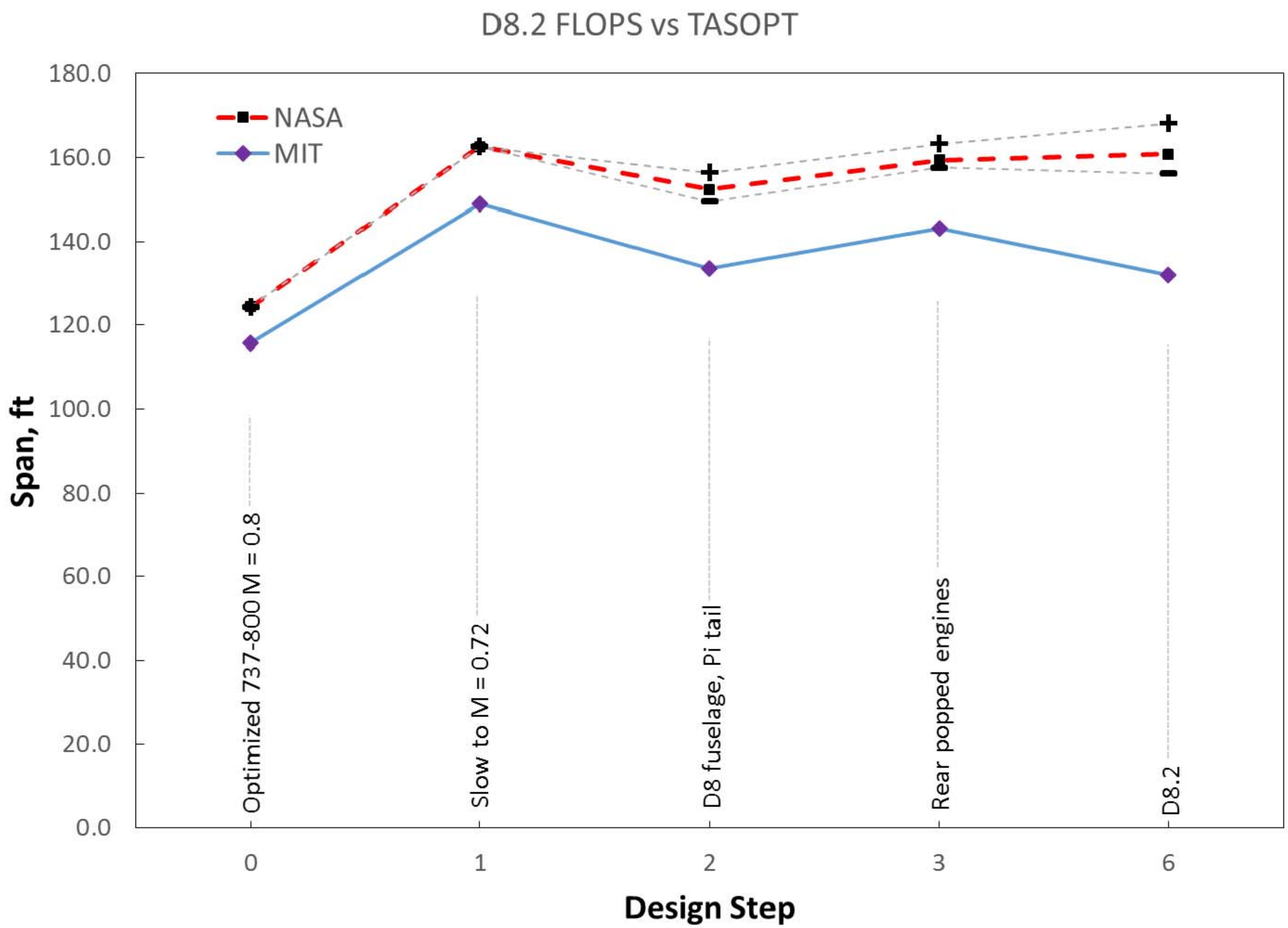


Wing Area



D8.2 FLOPS vs TASOPT
NASA
MIT
Wing Area, sq ft
2,000.0
1,800.0
1,600.0
1,400.0
1,200.0
1,000.0
800.0
600.0
400.0
200.0
0.0
Optimized 737-800 M = 0.8
Slow to M = 0.72
D8 fuselage, Pi tail
Rear popped engines
D8.2
0
1
2
3
6
Design Step

Wing Span



D8.2 FLOPS vs TASOPT
NASA
MIT
Span, ft
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Optimized 737-800 M = 0.8
Slow to M = 0.72
D8 fuselage, Pi tail
Rear popped engines
D8.2
0
1
2
3
6
Design Step

Airframe Weight (A. Hahn)

- Evaluation Basis: MIT weight breakdowns; FLOPS analysis of D8.5 geometry/design conditions; Comparison metrics with similar sized aircraft
- Basic Characteristics:
  - Operating Empty Weight = 51,400 lb (0.51 GW)
  - Payload Weight = 38,700 lb (0.38 GW)
  - Fuel Weight = 11,486lb (0.11 GW)
  - Maximum Gross Weight = 101,586 lb (1.00 GW)
- Overall Rating of **RED**
  - FLOPS analysis conducted assuming conventional materials and construction
  - Unusual weight bookkeeping makes direct comparison difficult, tried to apportion weights as best I could
  - Airframe structural weight indicates very large reductions relative to conventional construction –much more than typically realized

Weight Comparison to FLOPS, ERJ (Hahn)

OUTPUT FROM THE WEIGHTS MODULE	ERJ190ARish Baseline		MIT D8.5		FLOPS D8.5 Aluminum Uniterated		% Change From FLOPS
DESCRIPTION	DIMENSION	VALUE	DIMENSION	VALUE	DIMENSION	VALUE	
Exposed WING WEIGHT/AREA	LB/SQ FT	10.0	LB/SQ FT	11.6	LB/SQ FT	17.6	-34%
Exposed WING WEIGHT/Span	LB/FT	110.6	LB	79.1	LB	126.7	-38%
WING WEIGHT BREAKDOWN							
TERM 1	LB	7190.0	LB	8727.0	LB	17198.0	-49%
TERM 2	LB	2973.5	LB	3142.0	LB	2940.5	7%
TERM 3	LB	1204.5	LB	1571.0	LB	1386.4	13%
HORIZONTAL TAIL AREA	SQ FT	280.0	SQ FT	192.3	SQ FT	192.3	0%
HORIZONTAL TAIL WEIGHT/AREA	LB/SQ FT	4.9	LB/SQ FT	1.3	LB/SQ FT	5.2	-74%
VERTICAL TAIL AREA	SQ FT	174.4	SQ FT	201.4	SQ FT	201.4	0%
VERTICAL TAIL WEIGHT/AREA	LB/SQ FT	3.8	LB/SQ FT	0.9	LB/SQ FT	3.3	-74%
FUSELAGEWEIGHT/WETTED AREA	LB/SQ FT	3.8		0.8		4.1	-80%
LG Weight per Inch	LB/IN	20.9	LB/IN	28.4	LB/IN	22.5	26%
MASS AND BALANCE SUMMARY	**PERCENT WR**	**POUNDS**	**PERCENT WR**	**POUNDS**	**PERCENT WR**	**POUNDS**	
WING	10.2%	11368	13.2%	13,439	21.2%	21525	-38%
HORIZONTAL TAIL	1.2%	1372	0.3%	259	1.0%	1002	-74%
VERTICAL TAIL	0.6%	660	0.2%	173	0.7%	666	-74%
FUSELAGE	11.1%	12347	3.9%	3,915	19.5%	19765	-80%
LANDING GEAR	4.4%	4943	5.0%	5,080	4.0%	4027	26%
STRUCTURE TOTAL	**27.5%**	**30690**	**22.5%**	**22866**	**46.2%**	**46985**	**-51%**
PROPULSION TOTAL	**9.6%**	**10748**	**6.6%**	**6659**	**6.6%**	**6659**	**0%**
SYSTEMS AND EQUIPMENT TOTAL	**15.4%**	**17222**	**21.5%**	**21875**	**24.9%**	**25261**	**-13%**
WEIGHT EMPTY	**52.6%**	**58660**	**50.6%**	**51400**	**77.7%**	**78905**	**-35%**
OPERATING ITEMS	**2.4%**	**2673**	**0.0%**	**0**	**1.6%**	**1608**	**-100%**
OPERATING WEIGHT	**55.0%**	**61333**	**50.6%**	**51400**	**79.3%**	**80513**	**-36%**
PAYLOAD	**19.4%**	**21599**	**38.1%**	**38700**	**38.1%**	**38700**	**0%**
ZERO FUEL WEIGHT	**74.4%**	**82932**	**88.7%**	**90100**	**117.3%**	**119213**	**-24%**
MISSION FUEL	25.6%	28596	11.3%	11486	-17.3%	-17623	-165%
RAMP (GROSS) WEIGHT	**100.0%**	**111528**	**100.0%**	**101586**	**100.0%**	**101590**	**0%**

Weight Comparison to FLOPS, ERJ (Hahn)

- Wing
  - Tech: composites, gust load alleviation, simple High lift
  - **38**% lighter than aluminum
    - SLD accounted: triangular => 21525 lb, elliptical => 29139 lb
    - Gust load alleviation AND triangular SLD?
  - Exposed Wing Weight per Area / Span
    - MIT = 11.6 / 79.1, FLOPS = 17.6 / 126.7, ERJ = 10.0 / 110.6
- Horizontal & Vertical Tails
  - Tech: composites, PI tail
  - **74**% lighter than aluminum cantilever
    - Htail = 1.3 lb/ft^2, FLOPS => 5.2, ERJ => 4.9
    - Vtail = 0.9 lb/ft^2, FLOPS => 3.3, ERJ => 3.8

Weight Comparison to FLOPS, ERJ

- Fuselage
  - Tech: composites, double bubble (lift, fewer windows, center floor support)
  - **80**% lighter than aluminum
    - MIT = 0.8 lb/ft^2, FLOPS => 4.1, ERJ => 3.8
- Landing Gear
  - Tech: short
  - **26**% heavier than FLOPS estimate
    - MIT = 28.4 lb/in, FLOPS => 22.5, ERJ => 20.9

D8 Fuselage Weight: GT Use of MIT Fuse. Algorithm

- Reproduce the weight estimates for the Double Bubble's fuselage using the MIT approach detailed in their report
- The weights of several components are calculated using "weight fractions" (multiplication factors) that were not given in the MIT report

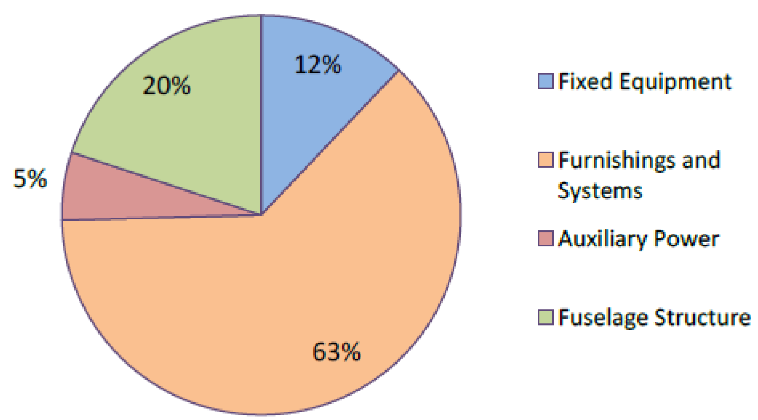
$$W_{\text{shell}} = W_{\text{skin}}(1+\boxed{f_{\text{string}}}+\boxed{f_{\text{frame}}}+\boxed{f_{\text{fadd}}}) + W_{\text{db}} \qquad W_{\text{window}} = \boxed{W'_{\text{window}}}\, l_{\text{shell}}$$

$$W_{\text{apu}} = W_{\text{pay}}\boxed{f_{\text{apu}}} \qquad W_{\text{seat}} = W_{\text{pay}}\boxed{f_{\text{seat}}} \qquad W_{\text{padd}} = W_{\text{pay}}\boxed{f_{\text{padd}}}$$

- The appropriate values for the weight fractions that correspond to the weight estimates of MIT were found using a reverse engineering/goal seeking approach
- The 3-view drawing in the report was used to determine the geometric dimensions needed for the calculations
- Use the MIT approach to estimate the fuselage weights of known aircraft and compare the results (B 737-800 [FLOPS] and DC-9 [NASA report*])

D8 Fuselage Weight: Weights Reproduction

- GT successfully matched MIT's prediction values for DB 8.5 configuration
- Next step is to validate prediction method against standard T&W fuselage



Published values in MIT report

Component	Weight, lbs
Fixed Equipment	3,000
APU	1,355
Fuselage Fixed	11,610
Shell	1,366
Tail Cone	76
Additional Side Material	118
Additional Vertical Material	-
Windows	626
Insulation	1,024
Floor	1,729
Seats	3,870
Total	**24,774**

Comparison between reproduced and published values

Fuselage Components	Calculated	Published	% Error
Fixed Equipment	3,000	3,000	0.0
Fuselage Fixed	11,610	11,610	0.0
Seats	3,870	3,870	0.0
Auxiliary Power	1,355	1,355	0.0
Shell	1,389	1,366	1.7
Cone	68	76	10.5
Floor	1,729	1,729	0.0
Insulation	1,024	1,024	0.0
Windows	626	626	0.0
Added Bending Material	100	118	15.3
Σ	24,770	24,774	0.0

MIT Approach Applied to 737-8 and DC-9

- Compared weights between the MIT weight groups and FLOPS weights (B737 case) & NASA report weights (DC-9 case)
- Mil standard (MIL-STD-1374A) was used as standard bookkeeping practice
- For the DC-9 NASA report, "*Remaining Systems*" term was used to account for systems not defined explicitly

MIT Weight Grouping

Fuselage Fixed:

- Flight Attendants
- Food
- Galleys
- Toilets
- Luggage Compartments
- Furnishings
- Doors and Emergency Exits
- Lighting
- Air-Conditioning Systems
- In-Flight Entertainment Systems
- Etc…

Fixed Equipment:

- Pilots
- Cockpit Windows
- Cockpit Seats
- Control Mechanisms
- Flight Instrumentation
- Navigation Equipment
- Communication Equipment
- Antennas
- Etc…

FLOPS Weight Classification

MASS AND BALANCE SUMMARY	PERCENT WREF	POUNDS
WING	9.13	15748.
HORIZONTAL TAIL	0.85	1470.
VERTICAL TAIL	0.67	1149.
VERTICAL FIN	0.00	0.
CANARD	0.00	0.
FUSELAGE	9.81	16917.
LANDING GEAR	4.25	7321.
NACELLE (AIR INDUCTION)	0.00	0.
STRUCTURE TOTAL	(24.71)	(42605.)
ENGINES	8.18	14109.
THRUST REVERSERS	1.08	1856.
MISCELLANEOUS SYSTEMS	0.00	0.
FUEL SYSTEM-TANKS AND PLUMBING	0.40	697.
PROPULSION TOTAL	(9.66)	(16662.)
SURFACE CONTROLS	1.03	1769.
AUXILIARY POWER	0.61	1049.
INSTRUMENTS	0.28	484.
HYDRAULICS ← *Part of wing weight*	0.63	1082.
ELECTRICAL	1.14	1962.
AVIONICS	0.78	1339.
FURNISHINGS AND EQUIPMENT	9.02	15548.
AIR CONDITIONING	0.95	1641.
ANTI-ICING	0.11	188.
SYSTEMS AND EQUIPMENT TOTAL	(14.54)	(25062.)
WEIGHT EMPTY	48.91	84329.
CREW AND BAGGAGE-FLIGHT, 2	0.26	450.
-CABIN, 6	0.57	975.
UNUSABLE FUEL	0.29	503.

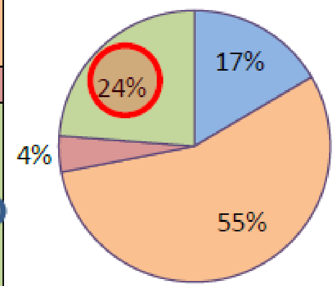
NASA Report Weights

Fuselage	(16,483)
Tail Supt & Bending Mat'l Penalty	767
Frames, Splices & Att. Wing/Gear Supt	2,746
Remaining Fuselage Structure	12,590
Sonic Fatigue Penalty	380
Flight Controls & Hydraulics	(2,502)
Propulsion & Nacelle	(13,407)
Dry Engine	3,860
Propeller, Gearbox & Shaft	6,150
Engine System & Exhaust System	1,130
Nacelle & Mounting Structure	2,267
Furnishings	(11,928)
Acoustic Trim Panel Penalty	815
Remaining Furnishings	11,113
Remaining Systems	(14,741)

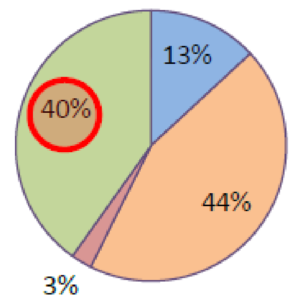
MIT Approach Applied to 737-8 and DC-9

- MIT approach under-predicted the total fuselage structural weight for conventional-tube and wing aircraft
- This is largely due to the under-prediction of the fuselage structure
- Used MIT empirical constants in this comparison, did change physical characteristics of the system

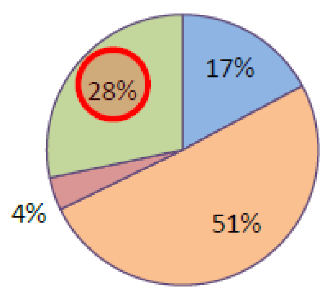
MIT Approach			
Fuselage B 737-800	Fixed Equipment	6,000	6,000
	Fuselage Fixed	15,645	20,115
	Seats	4,470	
	Auxiliary Power	1,565	1,565
	Shell	3,634	8,636
	Cone	359	
	Floor	2,081	
	Insulation	1,143	
	Windows	1,127	
	Added Bending Material	292	
	Σ	36,316	



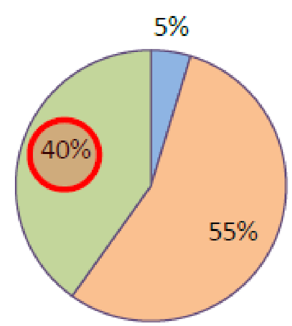
FLOPS			
Fuselage B 737-800	Surface Controls	1,769	5,520
	Electrical	1,962	
	Avionics	1,339	
	Pilots + Baggage	450	
	Instruments	484	18,648
	Furnishings and Equipment	15,548	
	Air-Conditioning	1,641	
	Flight Attendants + Baggage	975	
	Auxiliary Power	1,049	1,049
	Fuselage Structure	16,917	16,917
	Σ	42,134	



MIT Approach			
Fuselage DC 9 Config. 1 8-Blade	Fixed Equipment	6,000	6,000
	Fuselage Fixed	13,767	17,700
	Seats	3,933	
	Auxiliary Power	1,377	1,377
	Shell	4,105	9,899
	Cone	199	
	Floor	2,510	
	Insulation	1,371	
	Windows	1,540	
	Added Bending Material	174	
	Σ	34,976	

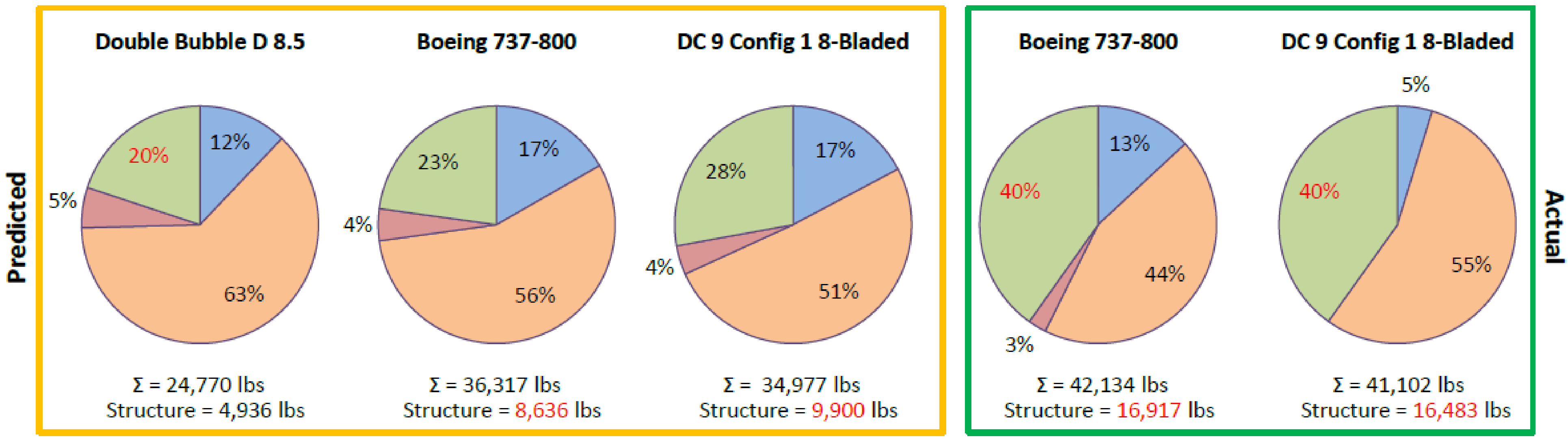


NASA Report			
Fuselage DC 9 Config. 1 8-Blade	Flight Controls	1,500	1,950
	Pilots + Baggage	450	
	Remaining Systems	10,741	22,669
	Acoustic Trim Panel	815	
	Furnishings	11,113	
	Auxiliary Power	-	-
	Tail Support & Bending Matl	767	16,483
	Frames, Splices & Att, ...	2,746	
	Remaining Fuselage Structure	12,590	
	Sonic Fatigue Penalty	380	
	Σ	41,102	



Fuselage Weight Comparisons

- The approach when used to estimate the weights for 737-800 and DC-9, produced a structure almost half the size of the actual structure (50% in case of B737 and 60% in case of DC9 ; dimensions and material properties have been changed in the process to match those of B737 and DC9)



- By changing the MIT values of the weight fractions, the predicted weights (FLOPS-NASA Report) can be achieved

Change Fuselage Structure

$$\boldsymbol{F} = \begin{bmatrix} f_{string} \\ f_{frame} \\ f_{fadd} \\ f_{apu} \\ f_{seat} \\ f_{padd} \\ W_{fix} \end{bmatrix} \qquad \boldsymbol{F_{DB}} = \begin{bmatrix} 0.44 \\ 0.44 \\ 0.44 \\ 0.035 \\ 0.1 \\ 0.3 \\ 3{,}000 \end{bmatrix} \qquad \boldsymbol{F_{B737-DC9}} \approx \begin{bmatrix} 1.75 \\ 1.75 \\ 1.75 \\ 0.03 \\ 0.1 \\ 0.33 \\ 6{,}000 \end{bmatrix}$$

Fuselage Weight Comparisons

- MIT approach used with adjusted weight fractions for B737 and DC9

$$F = \begin{bmatrix} f_{string} \\ f_{frame} \\ f_{fadd} \\ f_{apu} \\ f_{seat} \\ f_{padd} \\ W_{fix} \end{bmatrix} \qquad F_{DB} = \begin{bmatrix} 0.44 \\ 0.44 \\ 0.44 \\ 0.035 \\ 0.1 \\ 0.3 \\ 3{,}000 \end{bmatrix}$$

$$F_{B737} = \begin{bmatrix} 2.0 \\ 2.0 \\ 2.0 \\ 0.023 \\ 0.1 \\ 0.32 \\ 5{,}520 \end{bmatrix}$$

$$F_{DC9} = \begin{bmatrix} 1.65 \\ 1.65 \\ 1.65 \\ 0.035 \\ 0.1 \\ 0.35 \\ 6{,}000 \end{bmatrix}$$

	Fuselage Components	Calculated	Published	% Error
Fuselage B 737	Fixed Equipment	5,520	5,520	0.0
	Fuselage Fixed	18,774	18,648	0.7
	Seats			
	Auxiliary Power	1,028	1,049	2.0
	Shell	16,889	16,917	0.2
	Cone			
	Floor			
	Insulation			
	Windows			
	Added Bending Material			
	Σ	42,211	42,134	0.2

	Fuselage Components	Calculated	Published	% Error
Fuselage DC 9	Fixed Equipment	6,000	24,619	1.9
	Fuselage Fixed	17,700		
	Seats			
	Auxiliary Power	1,377		
	Shell	16,746	16,483	1.6
	Cone			
	Floor			
	Insulation			
	Windows			
	Added Bending Material			
	Σ	41,823	41,102	1.8

Reserve Mission Performance (Hahn)

- Evaluation Basis: MIT Mission Performance Table
- Basic Characteristics:
  - Reserve Fuel = 546.9 lb
- Overall Rating of **RED**
  - No reserve mission cited, must have one
  - Reserve fuel is simply 5% of total fuel, inclusion of reserve mission typically yields four times greater reserve fuel
  - Easily fixed, should not be a discriminator

Conclusions

- MIT Phase I NRA showed a D8 concept that performed well against N+3 fuel burn, noise, and emission metrics
- MIT Phase II NRA and ASAB independent analysis showed that D8 BLI benefits are real
- Concept lacks maturity of other N+3 advanced concepts
- Double bubble configuration benefits have yet to be definitively identified
- Areas of high risk could eliminate the predicted benefits

Conclusions

- If areas of high risk are successfully address/resolved and the benefits remain, this concept can make great progress towards NASA's fuel burn, emissions, and noise goals, *even with current technology*
- *Not* all areas of risk require high-fidelity (high $$$) analysis, but some N+3 assumptions need to be critically reviewed further
  - Health monitoring system removing loads factor of safety
  - Material properties
- Many technology features of this concept require flight testing for analysis validation
  - PAI
  - Natural Laminar Flow (NLF)
  - BLI system robustness and performance
    - Scaling effects prediction validation
    - Off-nominal flight conditions
    - Atmospheric disturbances
  - Low-speed controllability with power influences