Supersonic Business Jet Conceptual Design Team

04/30/2012

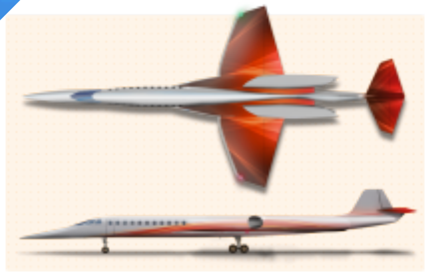
Team Members & Roles

- Brian Groves
  - Team Lead
  - Drag Estimation
  - Weights
- Kevin Antcliff
  - Aerodynamics
- Nathan Bingham
  - Propulsion
- George Buhl
  - Performance
- Chris Cramer
  - Stability and Control
  - Interior Configuration
- David Gayman
  - Structures
- Alex Harrell
  - Propulsion
- Maggie Nate
  - Systems
- Karishma Pillai
  - Landing Gear
  - Sonic Boom Measurement
- Shyla Thomas
  - Emergency Systems
  - FAR Regulations

Vision for Supersonic Travel

- Potential Customers
  - Heads of State, Military Leaders, Corporate Executives.
  - Other VVIP's.
- Why There is a Market
  - High speed culture demands short transit times.
  - Potential for single-day, round-trip, trans-Atlantic travel.

Competitor Research



Aerion SBJ

HyperMach Sonicstar

Tupolev Tu-444

Model	# Pass	Cruise Mach	Range (km)	Length (m)	Wingspan (m)	Thrust (kN)
Aerion SBJ	8	1.7	8,900 (5530 mi)	41.33 (135.6 ft)	19.57 (64.2 ft)	174.4 (39,207 lbf)
HyperMach Sonicstar	20	3.4	11,100 (6900 mi)	?	?	486.6 (109,392 lbf)
Tupolev Tu-444	6	2.0	7,400 (4600 mi)	36.00 (118.11 ft)	16.20 (53 ft)	190.4 (42,803 lbf)
Design Goals & Initial Sizing	12	2.2	9,000 (5590 mi)	38.4 (126 ft)	18.93 (62.1 ft)	180.0 (41,000 lbf)

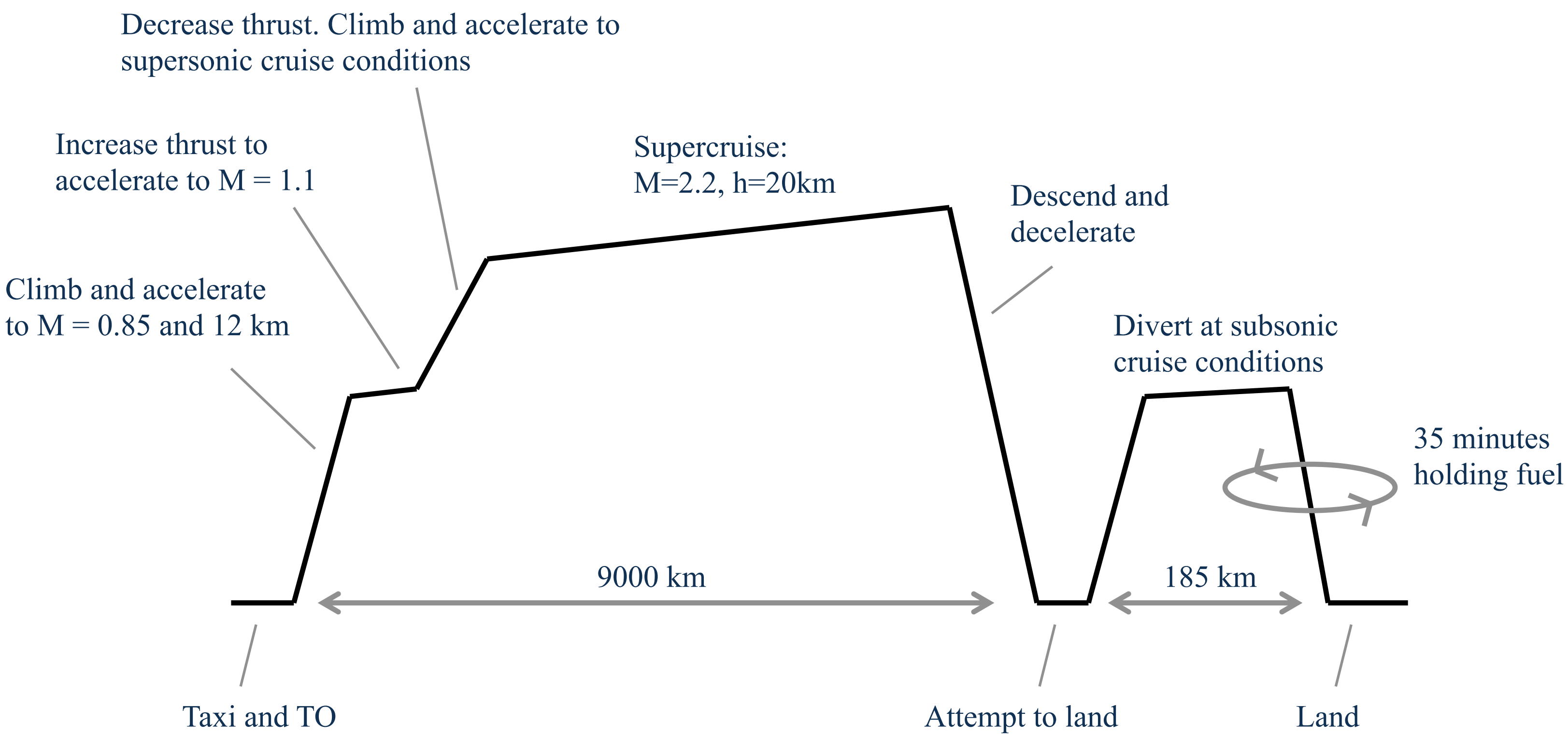
NASA Designs

- NASA Technical Memorandum 74055
  - "A Preliminary Study of the Performance and Characteristics of a Supersonic Executive Aircraft". September 1977.
- NASA/TM-2003-212435
  - "A Supersonic Business-Jet Concept Designed for Low Sonic Boom". October 2003.
- NASA/CR-2010-216842
  - "N+2 Supersonic Concept Development and Systems Integration". August 2010.
- NASA/CR-2011-217084
  - "N+3 Advanced Concept Studies for Supersonic Commercial Transport Aircraft Entering Service in the 2030-2035 Period". April 2011.

Mission Requirements / RFP

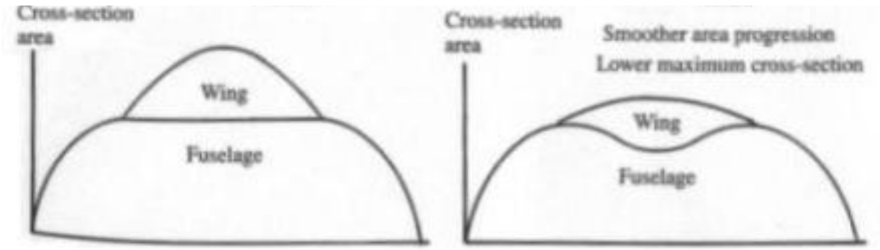
- Supersonic Cruise Speed: M = 2.2
- Range = 9000 km (5592 mi)
- 2 crew + 12 passengers and luggage
- Type 4 (Part 36) noise certification
- No noise impact reaching ground at supersonic cruise
- Reasonable takeoff distance no greater than 2.4km (7,900 ft)
- Meet EPA proposed Tier 8 emission standards

Mission Profile

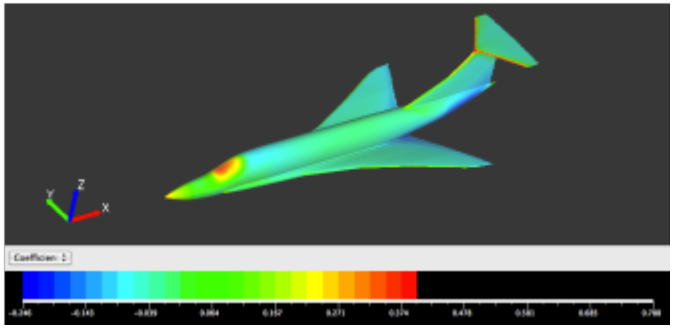


Aerodynamic Studies

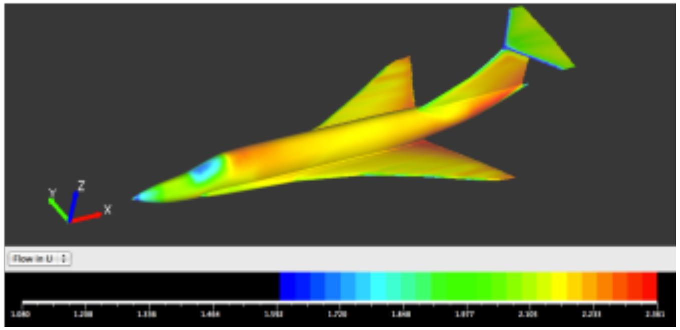
- Accounted for the Whitcomb area rule



- Cart3D CFD analysis



Local Pressure Coefficients, M=2.2



Local Flow Velocities, M=2.2

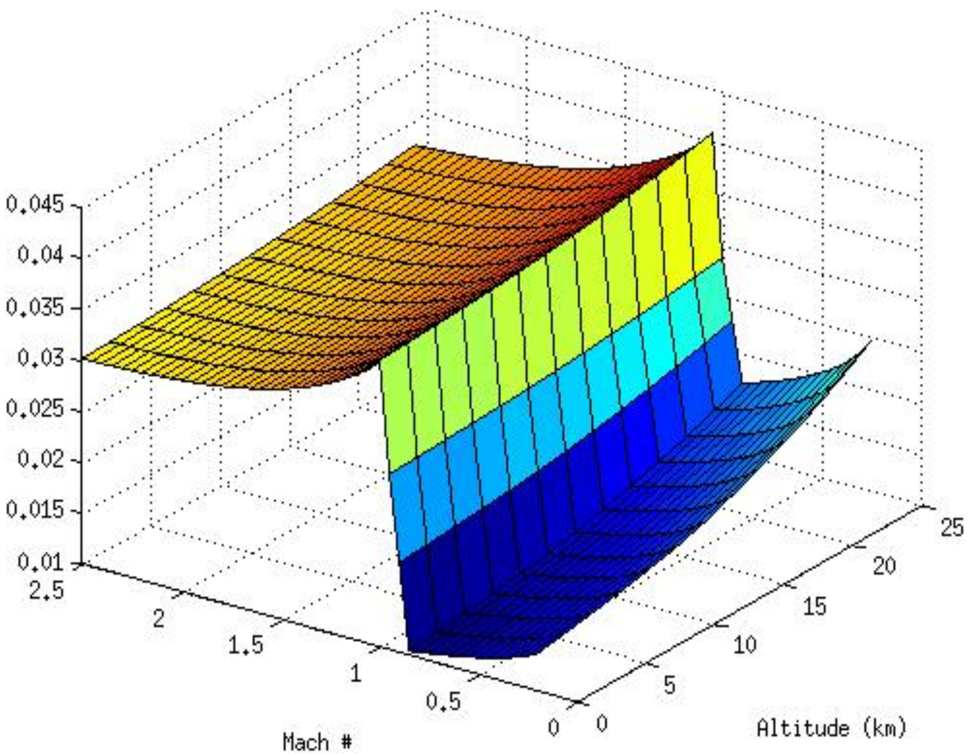
Wing Evolution

- Highly swept delta wing (Preliminary thought)
- Highly swept tapered/traditional wing (First design)
- Addition of LE strakes (Second design)
  - Increase vorticity and flow attachment
  - Decrease in span and area
- Wing shape altered to match closely with NASA study (shown below)

NASA/TM-2003-212435. "A Supersonic Business-Jet Concept Designed for Low Sonic Boom". October 2003.

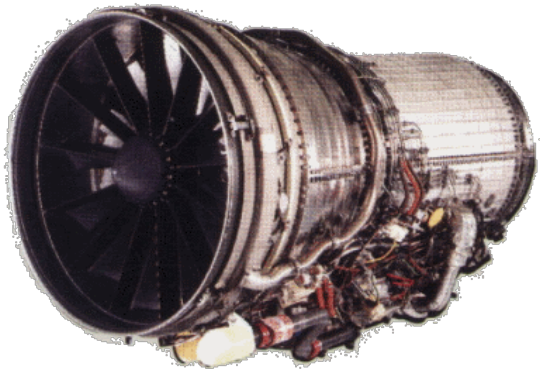
Drag

- Dr. Mason's FRICTION Code
  - Modified for use in our MDA code
- Subsonic zero-lift drag coefficient (CD,o) has high degree of confidence.
- Supersonic CD,o is more of an estimate
  - Disagreement between CFD analysis and component build up method.



- Began by investigating advanced concepts such as pulse detonation engines and magjets
- Narrowed search to military turbofans and turbojets, but turbojets were too inefficient and loud for design goals
- Considered a variable cycle engine that transitioned to ramjet at supersonic speeds, but modeling this was deemed too difficult
- Initially decided on the GE F110 afterburning turbofan, but after resizing the aircraft no longer needed afterburner

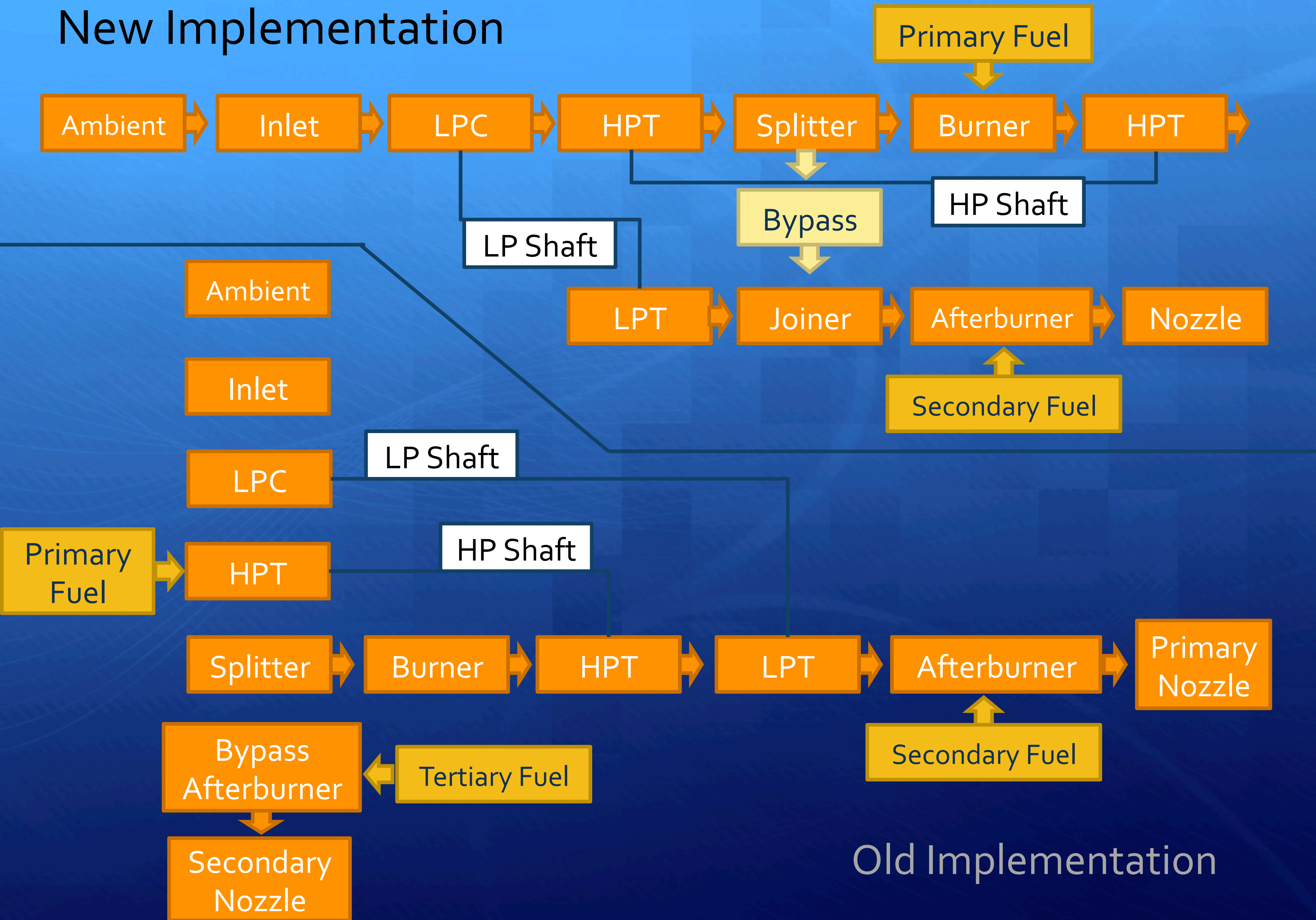
- Final decision : GE F118-CDE



Computer Analysis

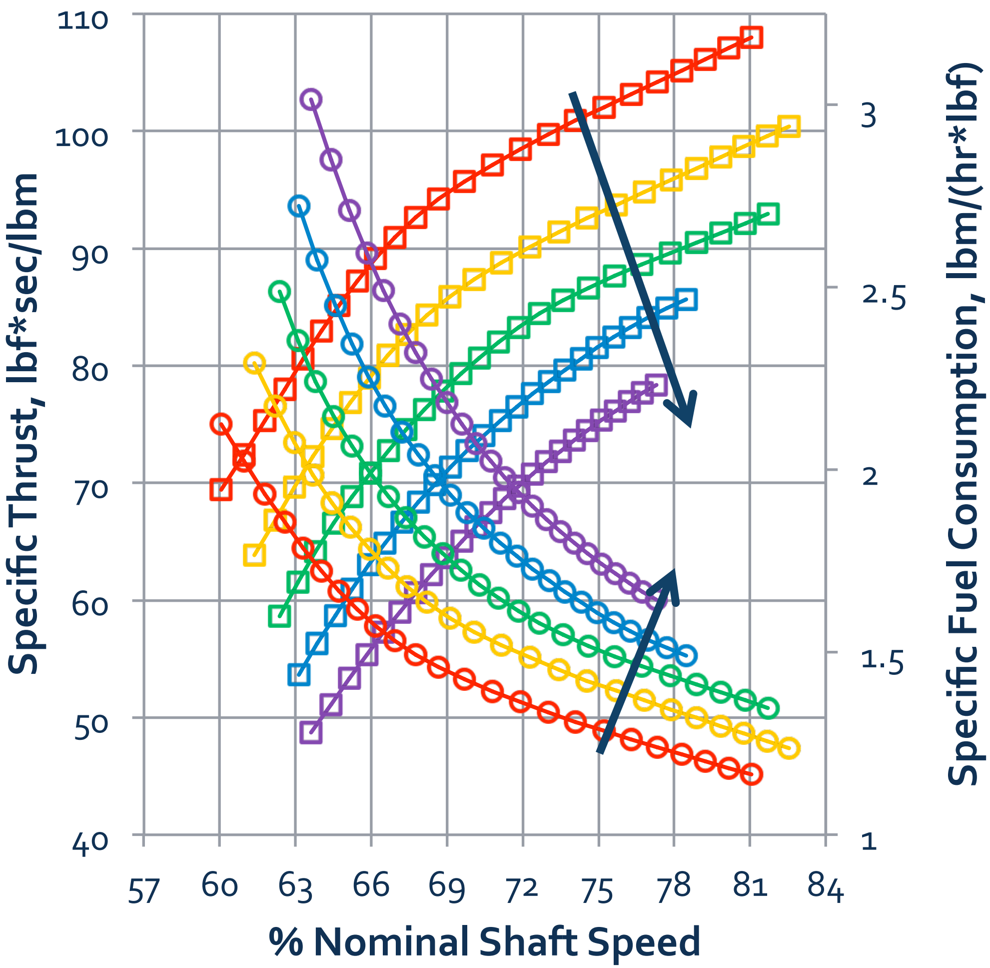
- Utilized Matlab and NPSS to model engines, as well as analyze empirical data from Jane's Aero Engines books
- Initially used simple turbofan and turbojet relations to determine how technological improvements would impact performance
- Started analysis with NPSS by modeling GE F118 and comparing results to known data
- Found engine performance across the mission profile as well as for off-design conditions
- Also modeled a variable bypass version of the F118, but couldn't effectively analyze transition

New Implementation



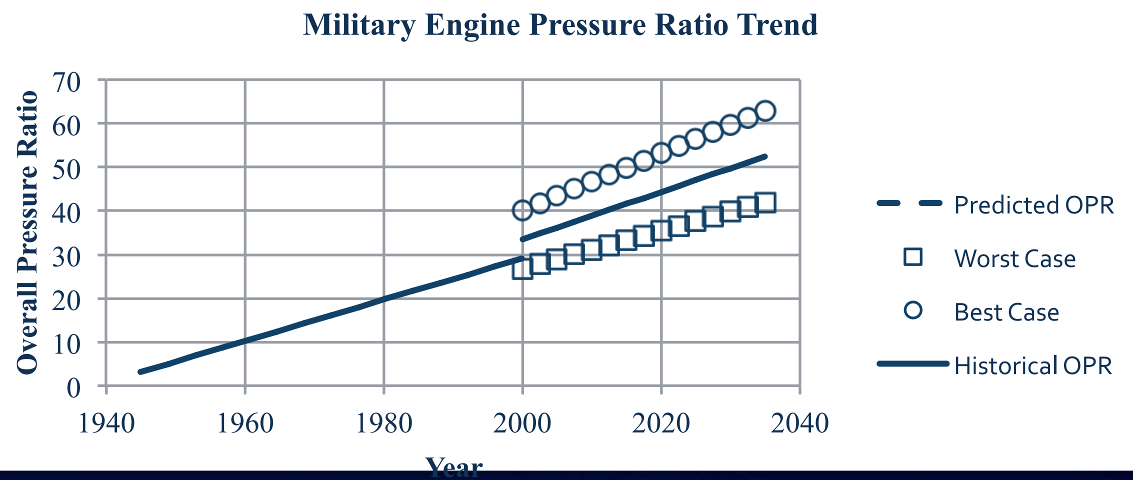
NPSS Off-Design Analysis

- Arrows denote increasing Mach number (0.0, 0.3, 0.6, 0.9, 1.2)
- □ = ST; o = SFC
- According to plot, design-performance can be achieved at less-than-design shaft speeds, but hurts specific fuel consumption
  - Design Sea Level static thrust = 80 lbf*sec/lbm
  - Design Sea Level SFC 0.56 lbm/(hr*lbf)

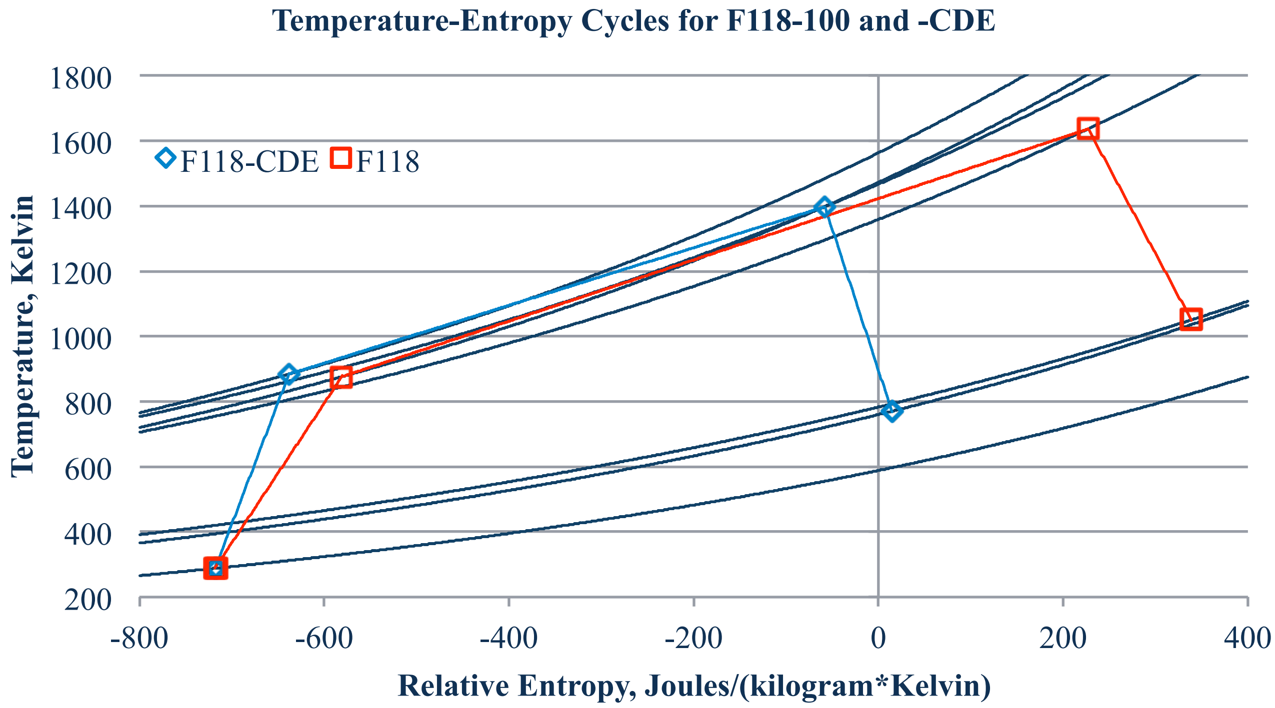


GE F118-CDE

- Modified the GE F118 turbofan with a "future factor" to account for increases in technology
- Based on historical data, can expect improvements in pressure ratio, turbine inlet temperature, thrust and fuel consumption
- Performance Characteristics for GE F118-CDE
  - Thrust: 11,500 lbf - SFC : 0.50 lbm/lbf-hr - T04: 3690 Rankine
  - Weight: 3000 lb - Length: 130 in - Diameter: 35 in
  - Overall Pressure Ratio: 44.4 - BPR: 0.87



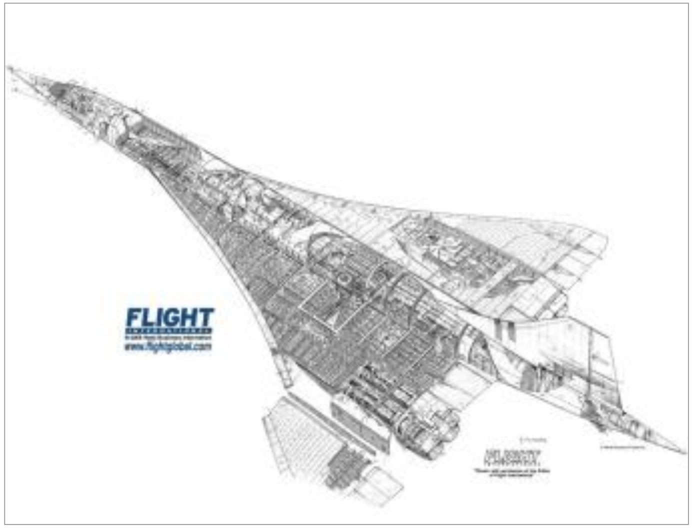
Improvement from GE F118-10

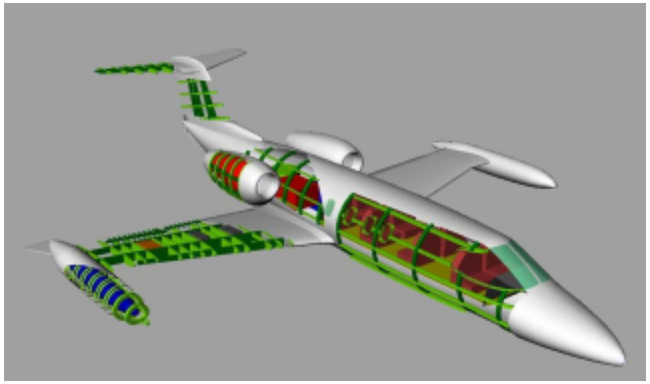


- T-s diagram showing the improvement of the new civil derivative engine over the base model
- Lower entropy cycles from the original F-118

Structures Design Goals

- Configuration needs to support loads for thin supersonic wing
- Cross section varies in essentially piecewise fashion
- Structurally both bending and twisting are important
- Goal: Stress-based initial design



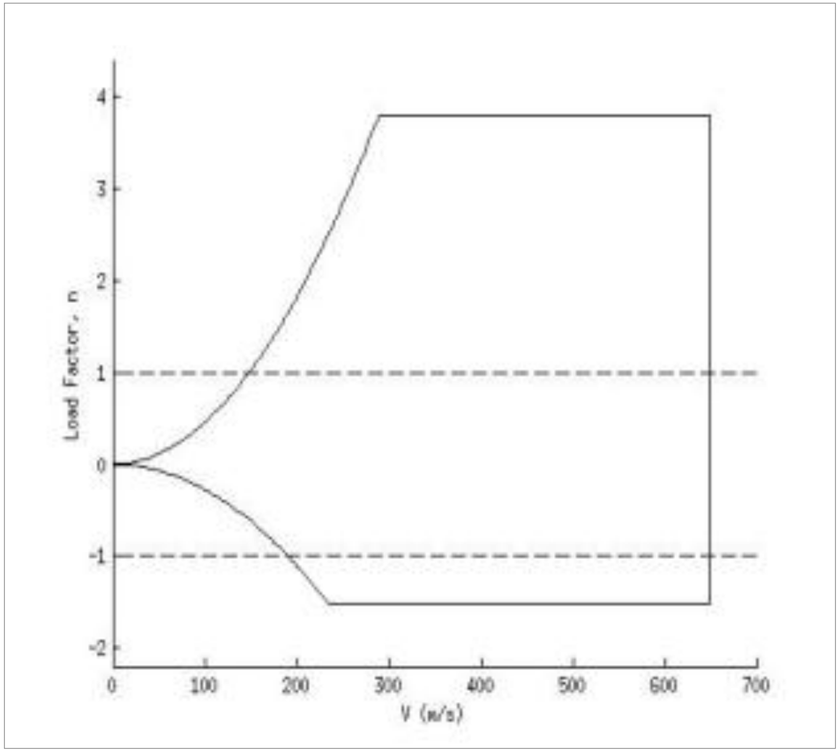


http://grabcad.com/library/bombardier-learjet-35

Load Factors

- Limiting load factors found by assessing several flight scenarios and realistic limiting cases

Method	Load Factor
Maximum bank angle	1.1547
Pull-up maneuver	0.0004
Push-down maneuver	-0.0002
Typical maneuver limit	2.5
Safe landing limit	3.1
Category System limits	3.8
	-1.52



V-n Diagram

Load Modeling

- Flight loads calculated for three limiting cases
  - Takeoff conditions
  - Subsonic cruise with engine-out
  - Max-g pull-up maneuver
- Modeled as elliptic distributed loads

$$f(y)=c\sqrt{1-\left(\frac{y}{a}\right)^2}$$

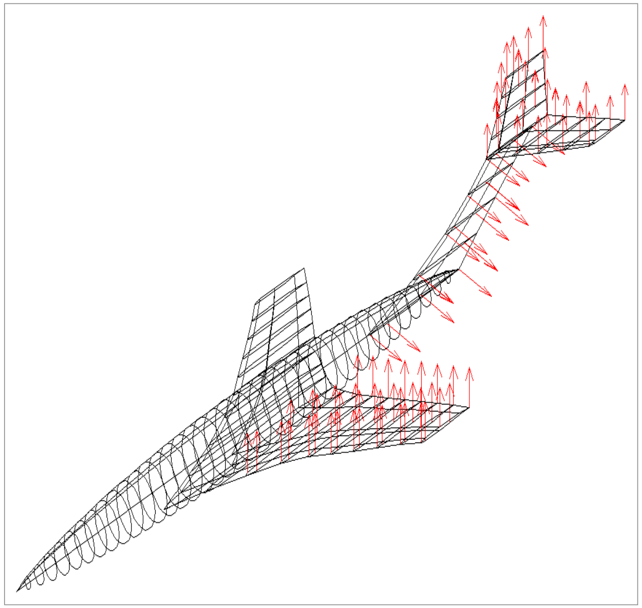
$$a=b/2$$

$$c=\frac{4W}{\pi b}$$

Loading equation

Loading conditions for wing

Loading Case		Normal Force (kN)	Constants
1	Takeoff conditions	21.77	a = 5.019 m c = 2.761 kN
2	Subsonic cruise with engine-out	21.77	a = 5.019 m c = 2.761 kN
3	Max-g pullup	82.69	a = 5.019 m c = 1.049 kN



Model experiencing max load

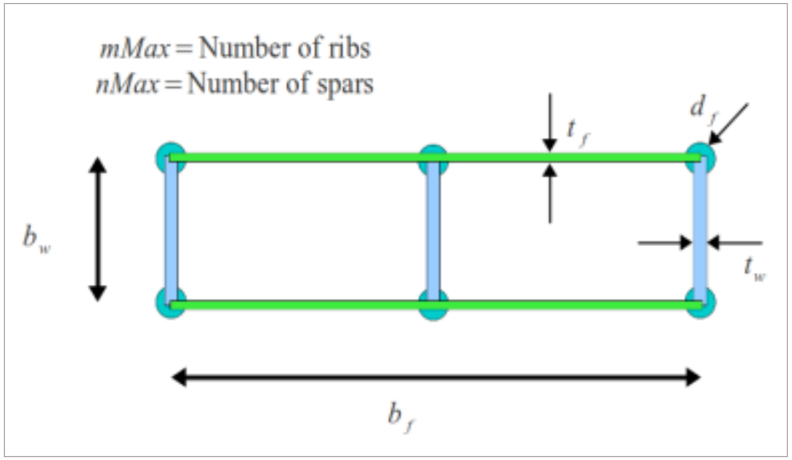
Deformation Limits

- Internal stress limited by material used
- Factor of safety used is 1.5
- Deflection limits are arbitrary, but help verify structure is realistic

Deflection limits for major structural components	
Component	Deformation Limit
Wing	0.9 m at the wingtip
Horizontal Tail	0.2 m at the tip
Vertical Tail	0.1 m at the tip

Computational Problem Setup

- Configuration parameters
  - Number of ribs
  - Number of spars in each section
  - Planform geometry
  - Outer wing box dimensions
- Structural parameters
  - Spar cap area
  - Spar web thickness
  - Skin thickness



Wing Box Cross Section

Beam Bending Analysis

- Beam bending analysis performed for arbitrary configuration
- Uses a matrix-based method
- Cross section allowed to vary piecewise

$$Q(z)=\int\int\int\int q(z)\,dz\,dz\,dz\,dz$$

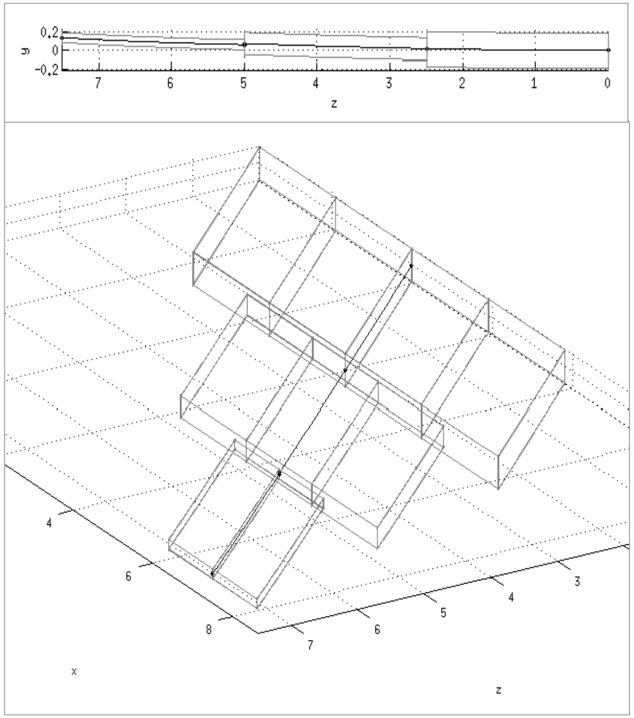
$$EI\begin{pmatrix} w_1(z) \\ w_2(z) \\ \vdots \\ w_m(z) \end{pmatrix} = Q(z) + \frac{1}{6}\begin{pmatrix} C_{0,1} \\ C_{0,2} \\ \vdots \\ C_{0,m} \end{pmatrix} z^3 + \frac{1}{2}\begin{pmatrix} C_{1,1} \\ C_{1,2} \\ \vdots \\ C_{1,m} \end{pmatrix} z^2 + \begin{pmatrix} C_{2,1} \\ C_{2,2} \\ \vdots \\ C_{2,m} \end{pmatrix} z + \begin{pmatrix} C_{3,1} \\ C_{3,2} \\ \vdots \\ C_{3,m} \end{pmatrix}$$

Beam Bending Characteristic Equations

Beam Bending Results

- Results from last semester

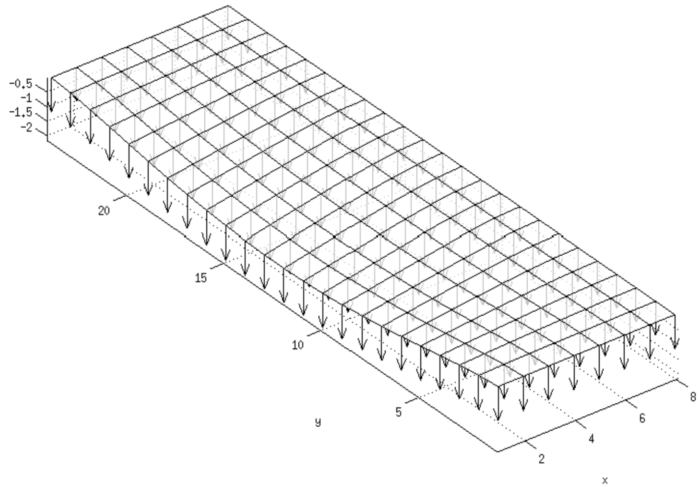
Preliminary wing beam results			
Loading Case	Maximum Internal Stress (MPa)	% Error	Deflection (m)
1	22.01	283.9	0.0372
2	22.01	283.9	0.0372
3	83.6	74.7	0.1412



Wing Model Experiencing Load

Flat Plate Analysis

- Thin plate analysis used for more accuracy
- Lifting surfaces approximated as thin isotropic plates
- Flexural rigidity for composite plates is adapted and averaged over cross sections



Flat Plate Segment Example

$$M(z) = -EI\frac{d^2w}{dz^2}$$

$$V(z) = -\frac{d}{dz}\left(EI\frac{d^2w}{dz^2}\right)$$

$$\sigma_{zz}(z) = \frac{M_x y}{I_{xx}}$$

$$\sigma_{zz}(z) = \left(\frac{y}{I_{xx}}\right) E I_{xx}\left[w''(z)\right]$$

Stress and Moment Equations

Optimization

- Both beam bending and thin plate analysis are integrated in the MDO framework
- Both algorithms are used in function calls from the structural sub-optimizer
- Scripts which take the place of MDO allow for configuration and materials case studies

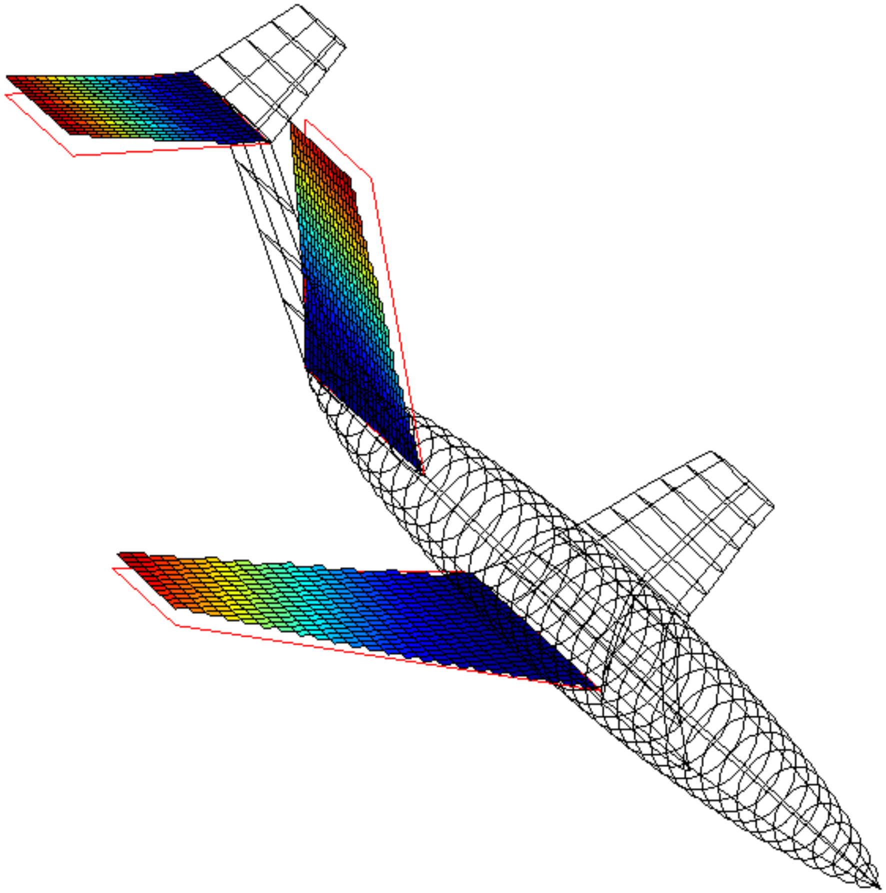
Materials

- Materials case study shows titanium allow has 10^2 increase in cost for 10^1 reduction in weight, compared with aluminum alloy
- Aluminum 6061-T6 confirmed as the material of choice
- Configuration selection made from case study results
- Trends show minimum number of spars needed in each section to satisfy stress constraints

Final Results

Classification	Parameter	Value	
Primary Material	Designation	Aluminum 6061-T6	
	Yield Stress (MPa)	276	
	Density (kg / m^3)	2700	
	Cost (USD / kg)	14064.0399	
Configuration	Number of ribs	3	
	Number of spars	8	(Section 1)
		7	(Section 2)
		6	(Section 3)
	Wing box height (m)	0.138192193	(Section 1)
		0.1105537544	(Section 2)
		0.0829153158	(Section 3)
	Wing box width (m)	3.454804824	(Section 1)
		2.7638438592	(Section 2)
		2.0728828944	(Section 3)
Structural parameters	Spar cap area	5e-05	
	Spar web thickness	0.0010	
	Skin thickness	0.0010	

Structures



Vehicle Deformations under Loading, Flat Plate Method

Stability and Control

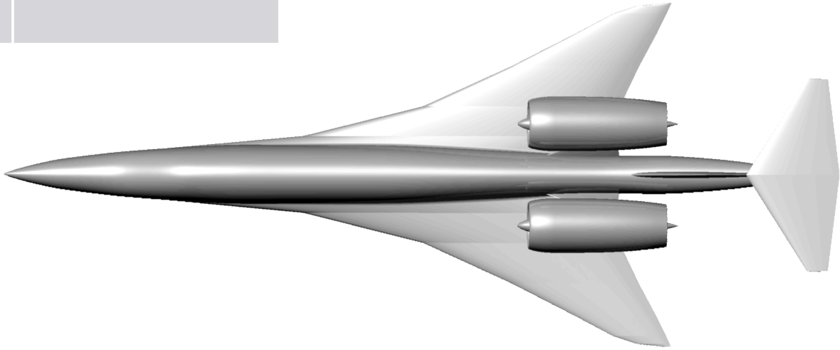
- Static Margin @ Subsonic Opt Cruise: 5.51%
  - Target: ~5%
- Static Yaw Stability: 0.256%

Table 1: Horizontal Tail Sizing		
Mean Chord	2.76 m	9.33 ft
Span	3.0 m	9.84 ft
Area	11.0 m^2	37.19 ft^2

Table 2: Vertical Tail Sizing		
Mean Chord	3.36 m	11.36 ft
Span	4.0 m	13.52 ft
Area	8.0 m^2	27.05 ft^2

Control Surfaces

Table 3: Control Surface Sizing			
Aileron	$0.1S_w$	4.5 m^2	51.44 ft^2
Elevator	$0.4S_h$	4.4 m^2	50.30 ft^2
Rudder	$0.3S_v$	2.4 m^2	27.43 ft^2



Landing Gear

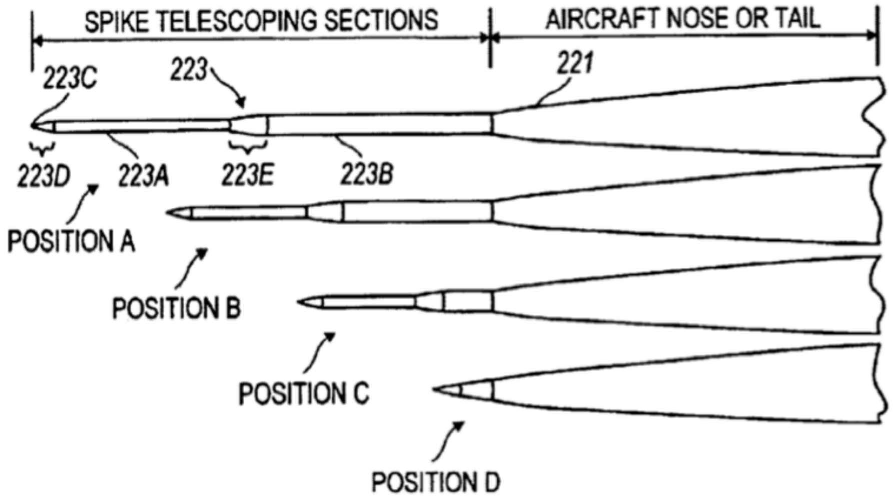
Landing Gear Sizing		
	Main gear	**Nose gear**
Load on gear	19594 kg	2177 kg
Gear Height	1.2 m	1.2 m
Distance from C.G	1.7 m	14.3 m
Wheel Track	4.46 m	
Wheel Diameter	0.83m	0.31 m
Wheel Width	0.3m	0.11 m
Strut Radius	0.039 m	0.0102 m

Passenger Cabin Emergency & PPE

- One lift jacket placed under each passenger seat
- 2 CO2 extinguishers, 1 H20 extinguisher
- Emergency exit door over wing
  - 0.56 m wide, 0.91 m high
- Cabin and Cockpit oxygen system
- First Aid kits
- Audio and visual alert system

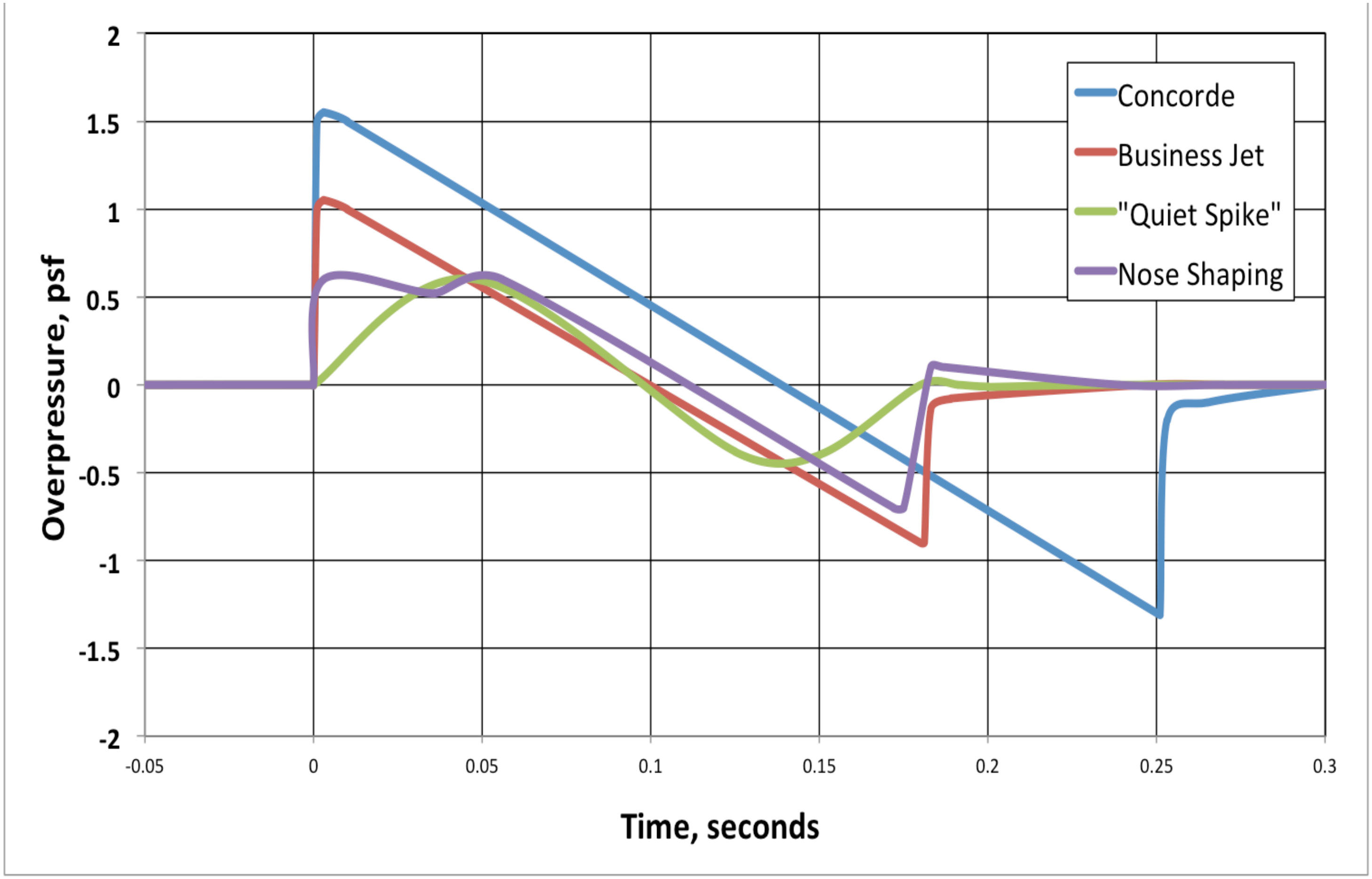
Sonic Boom Mitigation

- "Quiet Spike"
- Nose Shaping
- Area Rule Considerations



"Quiet Spike" detail.
US Patent 6,698,684B1, Fig. 14.

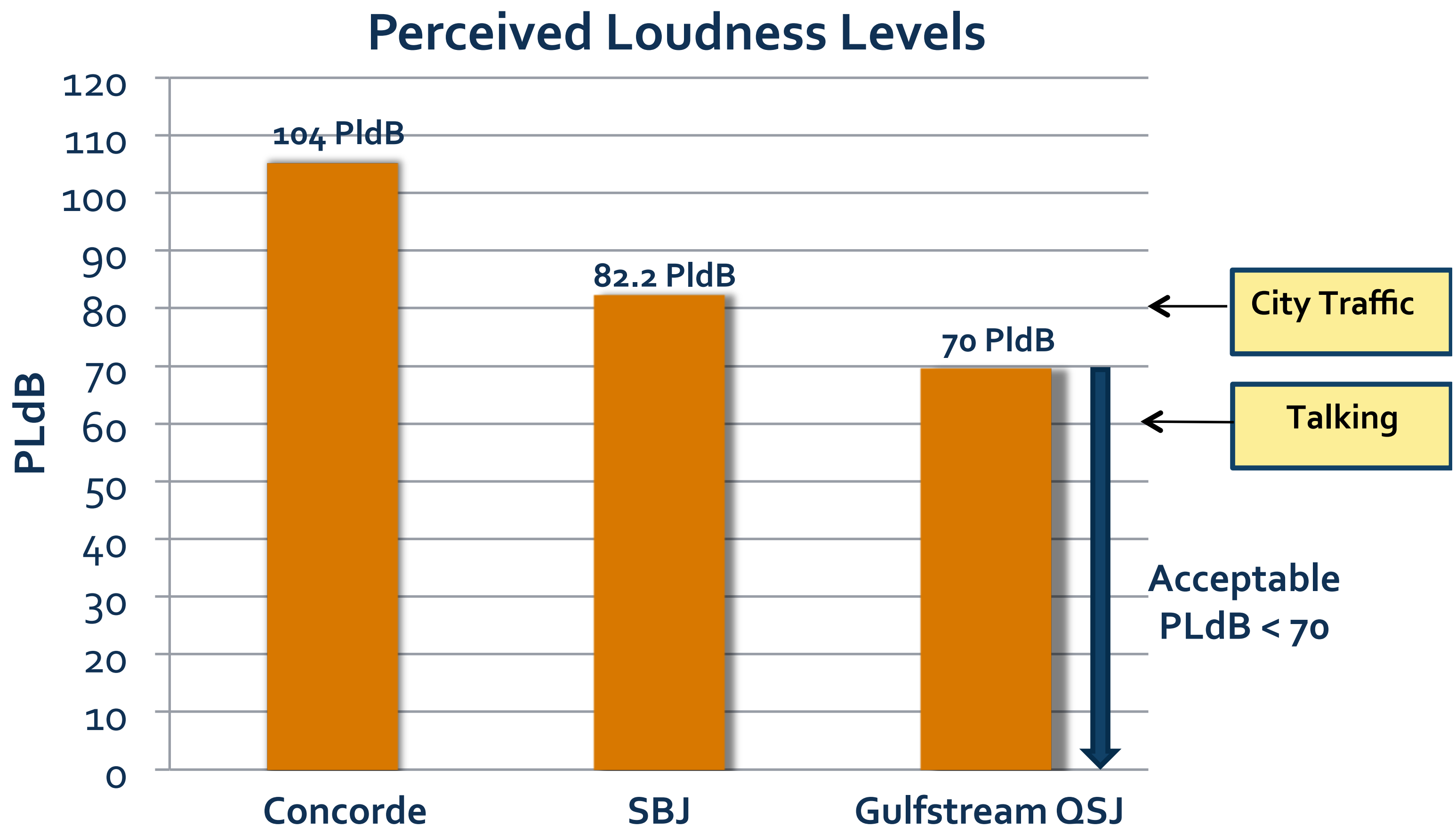
Sonic Boom Ground Signatures



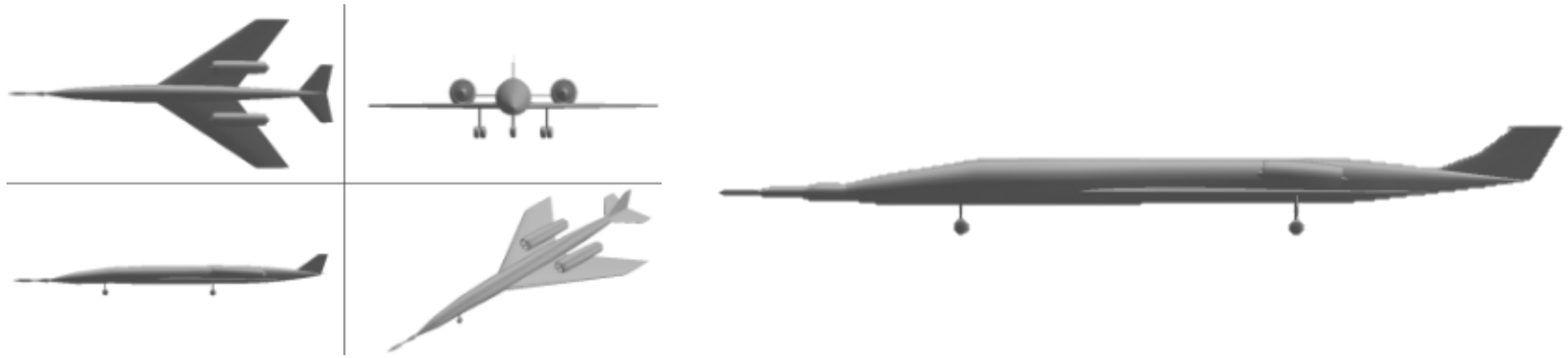
"Supersonic Technology Development", Gulfstream Aerospace Corporation. & "Fixing the Sound Barrier: Three Generations of U.S. Research into Sonic Boom Reduction". NASA. FAA Public Meeting – Supersonics. 14 July 2011.

Sonic Boom Measurement

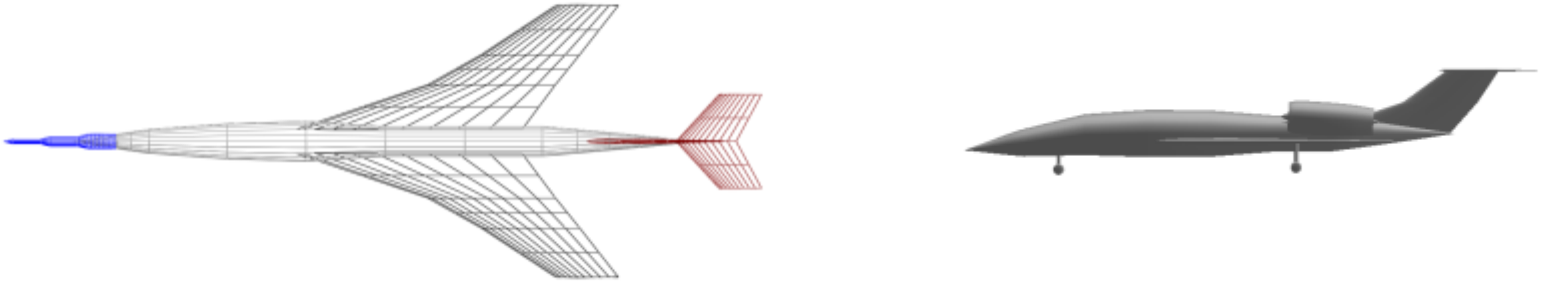
- Loudness Figure of Merit: **1.028**



Evolution of Design



Initial Design

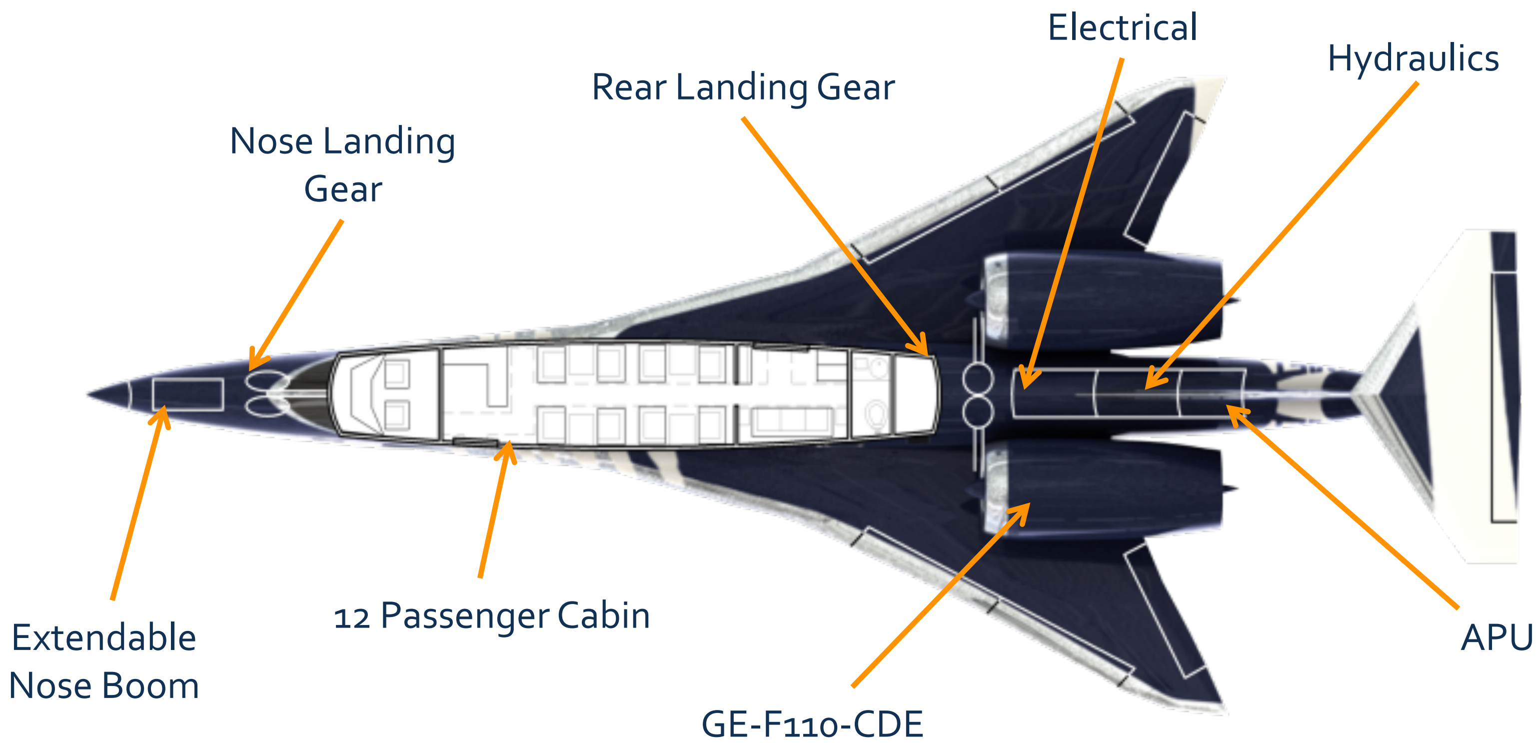


2nd Design Iteration
(aerodynamics design only)

Final Design Vehicle

Final Design Vehicle

Internal Configuration



Cabin Sizing

Part	SonicSwift	Average First Class
Total Length	11.1 m (36.41 ft.)	n/a
Total Width	2 m (6.56 ft.)	n/a
Cabin Lining	0.09 m (0.30 ft.)	0.1 m (0.33 ft.)
Aisles	0.3 m (0.98 ft.)	0.51 m (1.67 ft.)
Arm Rest Width	0.114 m (0.37 ft.)	0.1 m (0.333 ft.)
Seat Cushion Width	0.532 m (1.75 ft.)	0.51 m (1.67 ft.)
Seat Height	1.33 m (4.36 ft.)	1.3 m (4.27 ft.)
Seat Depth	0.6034 m (1.98 ft.)	0.41 m (1.33 ft.)
Lavatory Length	2.0 m (6.56 ft.)	1.52 m (5 ft.)

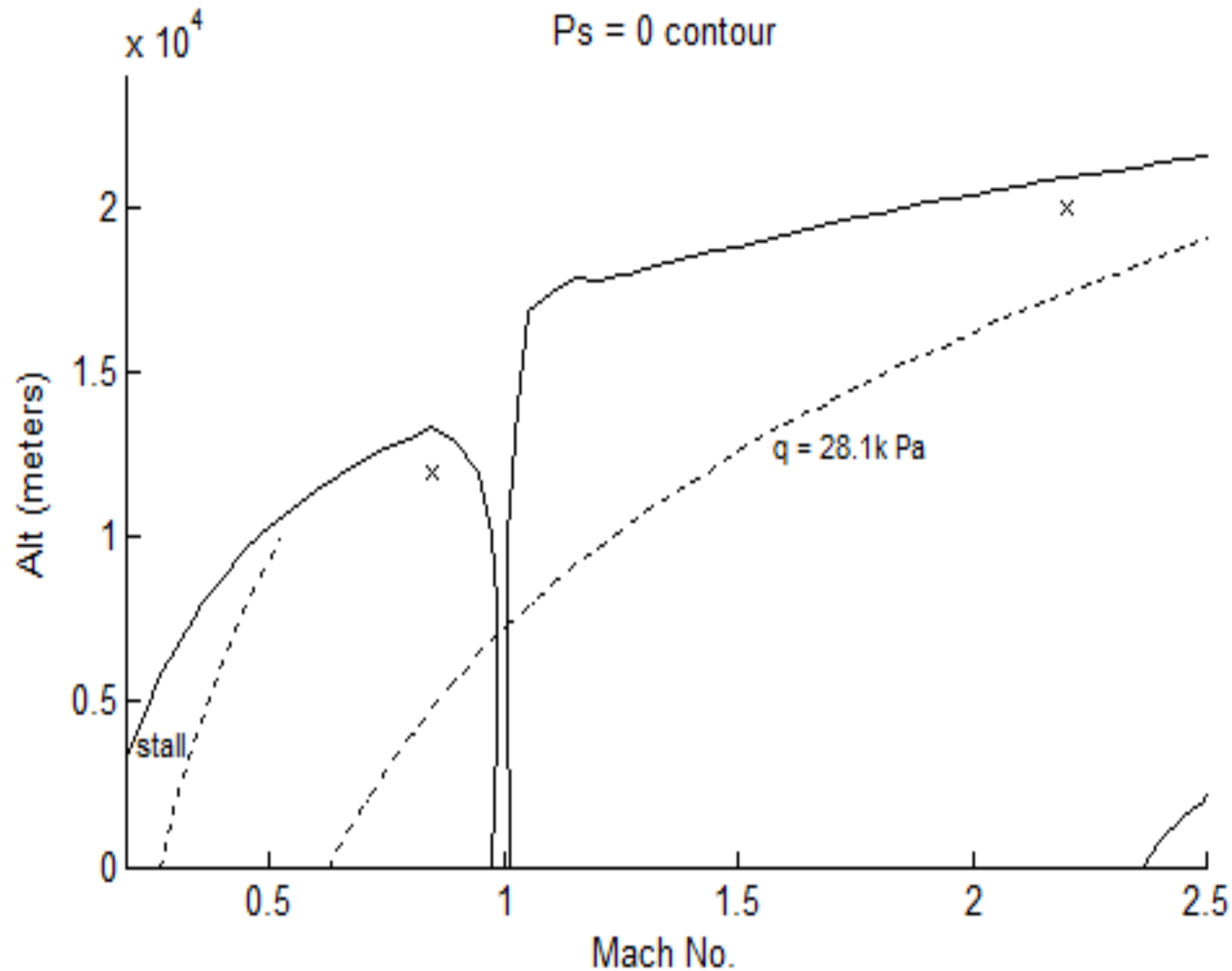
Performance Comparisons

	Current Design	Initial Design Goals	Aerion SBJ	Concorde
Range	9200 km	9000 km	> 7400 km	7250 km
Cruise Mach #	2.2	2.2	1.5	2.04
Ceiling	20,000 m	20,000 m	15,550 m	18,300 m
Thrust	102 kN	--	175 kN	560 kN
Supersonic Cruise L/D	8.83	8.19	--	7.14

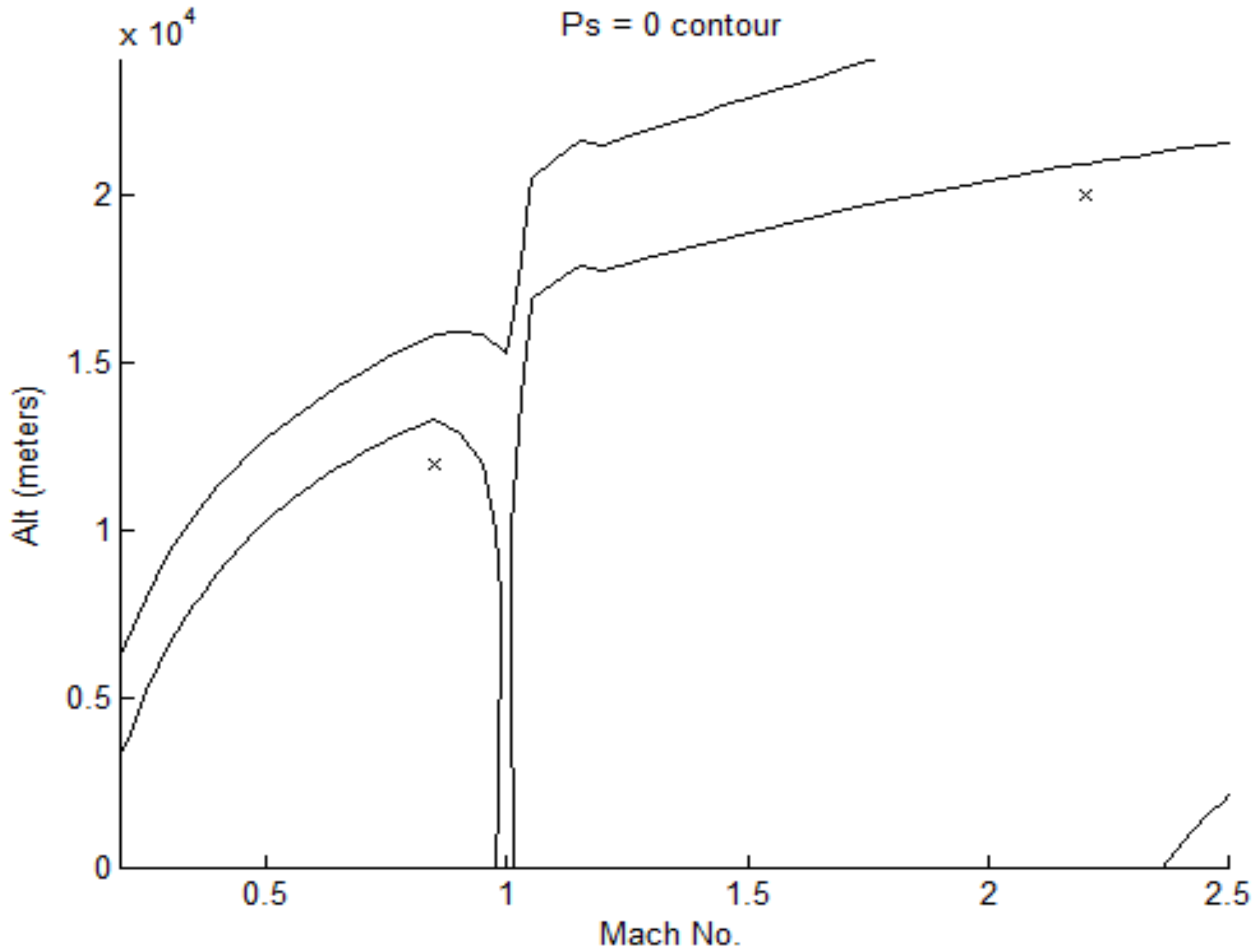
Takeoff and BFL

	Sea Level - Dry	Sea Level - Wet	Hot and High (Denver, 32C)
Takeoff Distance	1521 m [4990 ft]	1572 m [5158 ft]	2204 m [7231 ft]
BFL	2240 m [7350 ft]	2240 m [7350 ft]	3222 m [10570 ft]

Operating Envelope



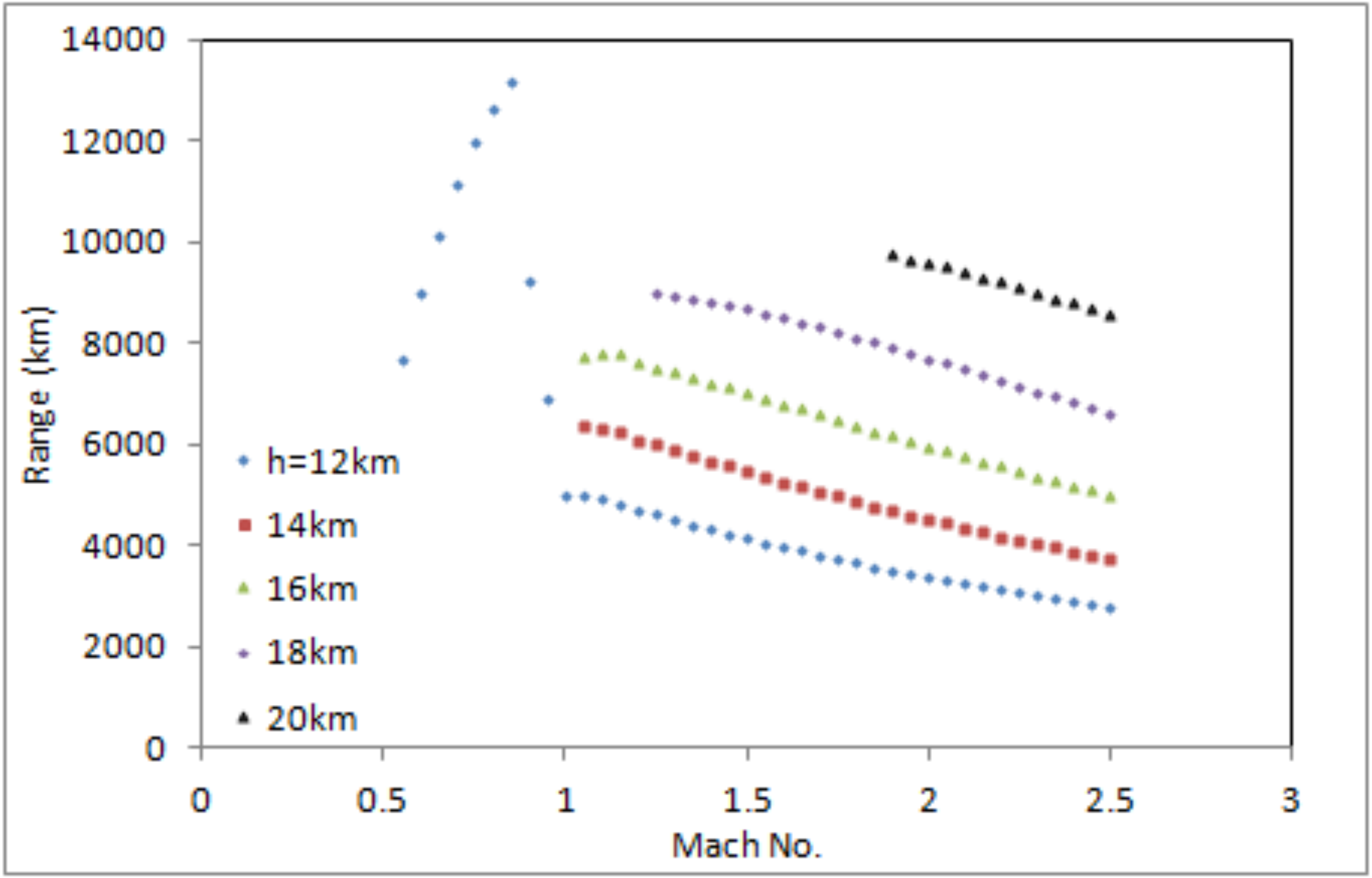
Operating Envelope



Performance – NBAA IFR Range

	Max Subsonic Range	Max Supersonic Range	Supersonic Cruise
Range	13200 km	9750 km	9200 km
Mach Number	0.85	1.9	2.2
Altitude	12 km	20 km	20 km
Ground Speed	903 km/h	2018 km/h	2335 km/h
Fuel per distance	0.94 kg/km	1.27 kg/km	1.35 kg/km
Fuel per time	849 kg/h	2662 kg/h	3152 kg/h

Performance - Range



Performance - Range

Performance – Travel Times

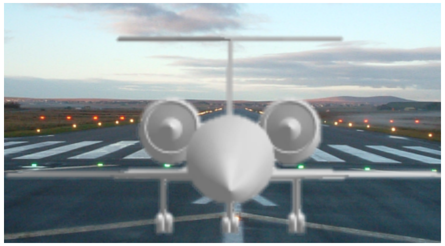
Approximate Air Travel Distances and Times

NYC - Paris:	*3,160 nm (5,850 km) – 3.4 h*
Los Angeles - Tokyo:	*4,770 nm (8,830 km) – 4.6 h*
Washington - Moscow:	*4,260 nm (7,890 km) – 4.2 h*
Virginia Tech - Honolulu:	*4,070 nm (7,535 km) – 4.1 h*

Design Converged to…

- Cessna Citation X

Comparison



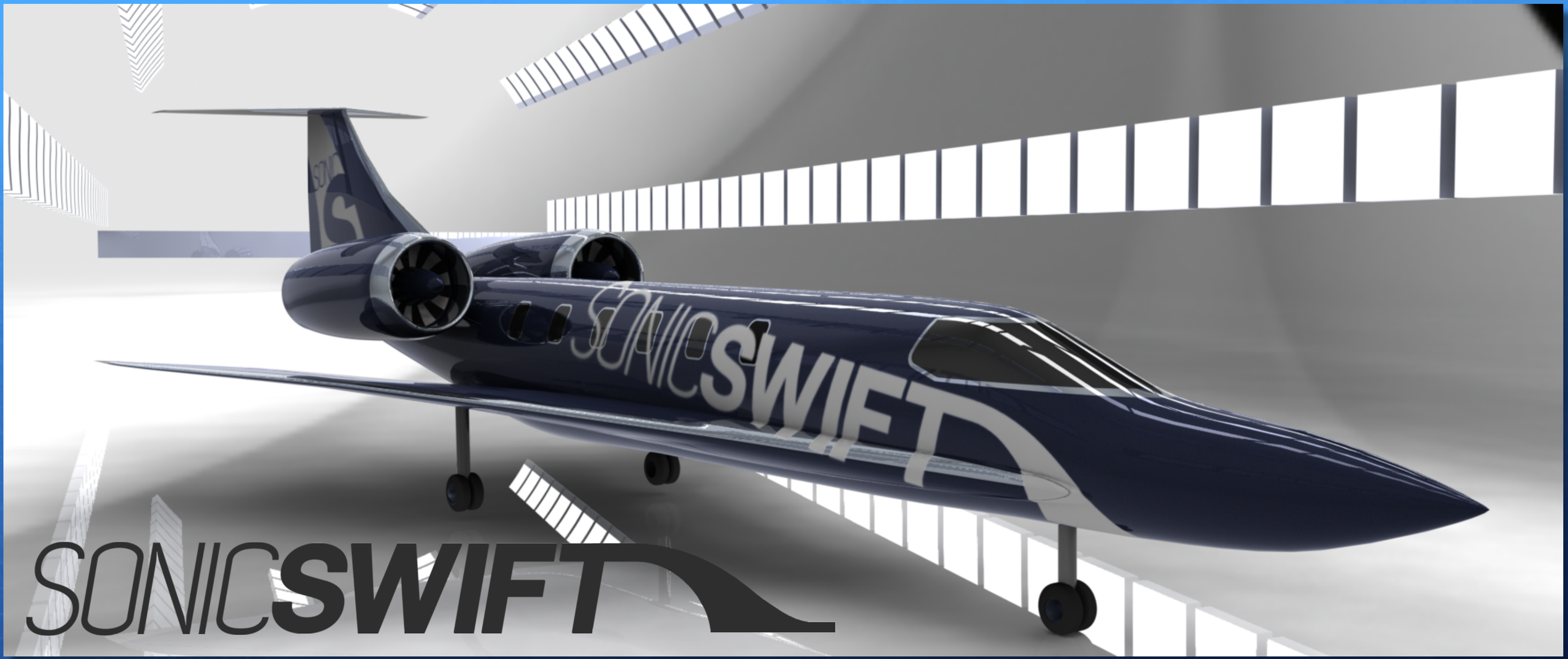
	SonicSwift	Citation X
# Passengers	12	12
Length	25 m	22.05 m
Width x Height	2.00 x 2.20 m	1.70 x 1.73 m
Wing Area	41.86 m2	48.96 m2
V-Tail Area	7.55 m2	10.31 m2
H-Tail Area	13.06 m2	11.15 m2
TOGW	43,335 lb	36,400 lb
Wing Loading	97 lb/sq-ft	68.5 lb/sq-ft
Cruise Mach	2.2	0.92
Cost	$42.4 m	$19.4 - $25 m

Advice for Future Teams

- Communication!
  - Dropbox incredibly useful.
- Stay on top of your project.
  - Have weekly (at least) team meetings and updates for your team.
- Code Structure
  - Integrate component analysis code.

What We've Learned

- Flexibility
- Iterative Designs
- Excellent Data Flow & Communication Structures
- Time Management
- "Bringing it all together"



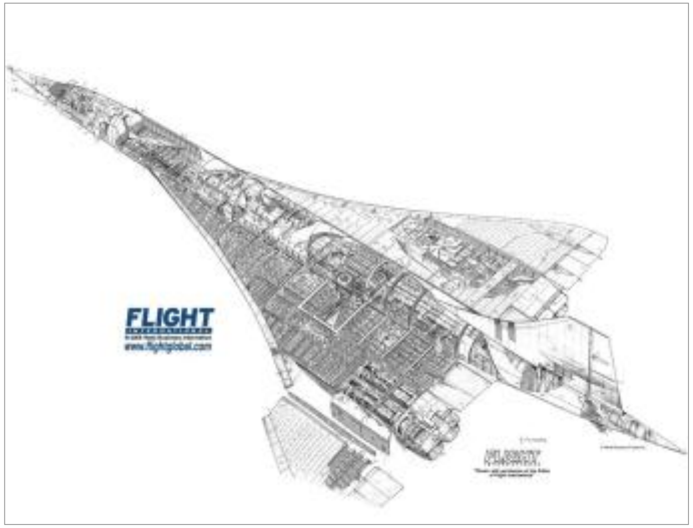
Questions?

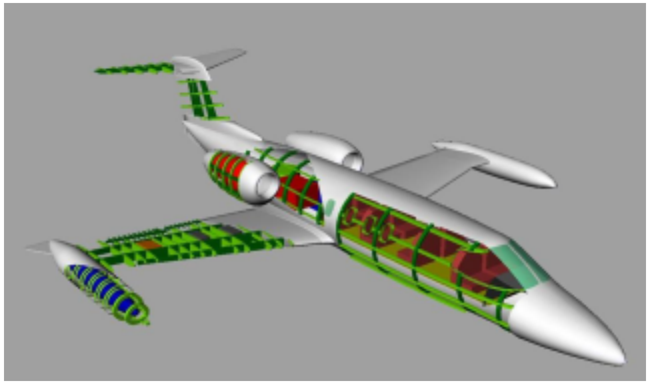
Acknowledgements: NASA Langley
Matt Tucker, Industrial Designer; Michelle Gordon, Interior Designer

Appendix 1: Structural Analysis

Structures

- Configuration needs to support loads for thin supersonic wing
- Cross section varies in essentially piecewise fashion
- Structurally both bending and twisting are important
- Goal: Stress-based initial design

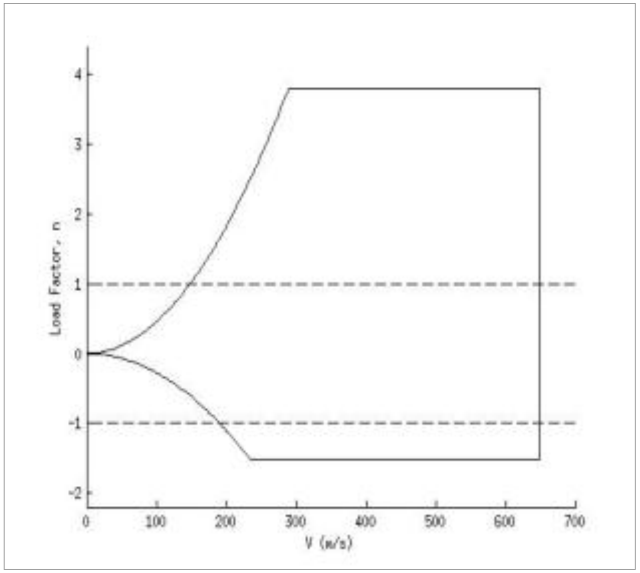




Structures

+ Limiting load factors found by assessing several flight scenarios and realistic limiting cases

Method	Load Factor
Maximum bank angle	1.1547
Pull-up maneuver	0.0004
Push-down maneuver	-0.0002
Typical maneuver limit	2.5
Safe landing limit	3.1
Category System limits	3.8
	-1.52



Load Factor	Final Value
Maximum positive	3.80
Minimum negative	-1.52

Structures

- Flight loads calculated for three limiting cases
  - Takeoff conditions
  - Subsonic cruise with engine-out
  - Max-g pull-up maneuver

$$f(y) = c\sqrt{1-\left(\frac{y}{a}\right)^2}$$

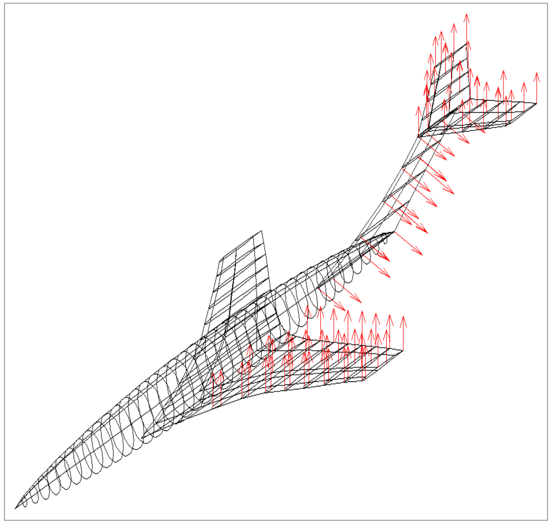
$$a = b/2$$

$$c = \frac{4W}{\pi b}$$

- Modeled as elliptic distributed loads

Table 8.3.4: Loading conditions for wing

Loading Case		Integrated Normal Force (kN)	Constants
1	Takeoff conditions	21.77	a = 5.019 m c = 2.761 kN
2	Subsonic cruise with engine-out	21.77	a = 5.019 m c = 2.761 kN
3	Max-g pullup	82.69	a = 5.019 m c = 1.049 kN



Structures

Table 8.3.5: Loading conditions for the horizontal tail			
Loading Case		Integrated Normal Force (kN)	Constants
1	Takeoff conditions	5.490	a = 3.00 m c = 1.166 kN
2	Subsonic cruise with engine-out	5.490	a = 3.00 m c = 1.166 kN
3	Max-g pullup	20.88	a = 3.00 m c = 4.432 kN

Table 8.3.6: Loading conditions for the vertical tail			
Loading Case		Integrated Normal Force (kN)	Constants
1	Takeoff conditions	0	a = 0 m b = 0 kN
2	Subsonic cruise with engine-out	11.160	a = 4.00 m b = 1.776 kN
3	Max-g pullup	0	a = 0 m b = 0 kN

Structures

- Internal stress limited by material used
- Factor of safety used is 1.5
- Deflection limits are arbitrary, but help verify structure is realistic

Table 8.-: Comparisons of Carbon Fiber with Common Metals

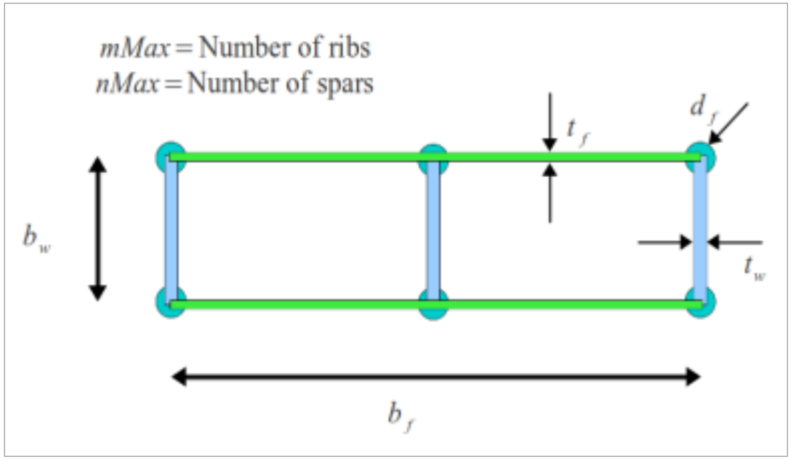
Material	Ultimate Tensile Strength (psi)	Yield Strength (psi)	Modulus of Elasticity (psi)	Density (lb/in^3)	Price ($/lb)
6061 Aluminum Alloy	18000	8000	10 x 10^6	0.0975	1.50
Titanium	50000	30000	17 x 10^6	0.16	8
A36 Steel	58000	35000	29 x 10^6	0.28	<1
Carbon Fiber	435000	200000	29 x 10^6	0.065	16

Table 8.4.1: Deflection limits for major structural components

Component	Deformation Limit
Wing	0.9 m at the wingtip
Horizontal Tail	0.2 m at the tip
Vertical Tail	0.1 m at the tip
Fuselage	0.2 m away from centerline, at all points

Structures

- Computational problem setup:
  - Configuration parameters
    - Number of ribs
    - Number of spars in each section
    - Planform geometry
    - Outer wing box dimensions
  - Structural parameters
    - Spar cap area
    - Spar web thickness
    - Skin thickness



Structures

- Beam bending analysis performed for arbitrary configuration
- Uses a matrix-based method
- Cross section allowed to vary piecewise

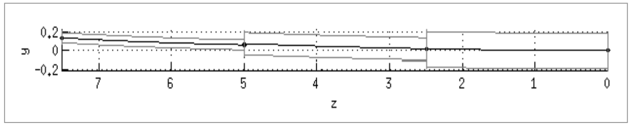
$$Q(z)=\int\int\int\int q(z)\,dz\,dz\,dz\,dz$$

$$EI\begin{pmatrix} w_1(z) \\ w_2(z) \\ \vdots \\ w_m(z) \end{pmatrix}=Q(z)+\frac{1}{6}\begin{pmatrix} C_{0,1} \\ C_{0,2} \\ \vdots \\ C_{0,m} \end{pmatrix}z^3+\frac{1}{2}\begin{pmatrix} C_{1,1} \\ C_{1,2} \\ \vdots \\ C_{1,m} \end{pmatrix}z^2+\begin{pmatrix} C_{2,1} \\ C_{2,2} \\ \vdots \\ C_{2,m} \end{pmatrix}z+\begin{pmatrix} C_{3,1} \\ C_{3,2} \\ \vdots \\ C_{3,m} \end{pmatrix}$$

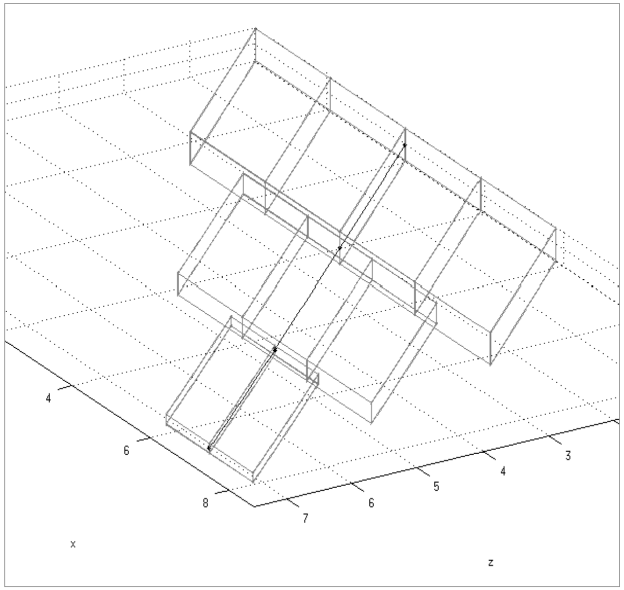
Structures

+ Results from last semester

Preliminary wing beam results			
Loading Case	Maximum Internal Stress (MPa)	% Error	Deflection (m)
1	22.01	283.9	0.0372
2	22.01	283.9	0.0372
3	83.6	74.7	0.1412



Preliminary horizontal tail results			
Loading Case	Maximum Internal Stress	% Error	Deflection (m)
1	18.89	83.1	0.0002
2	18.89	83.1	0.0002
3	72.0	21.8	6.06e-04

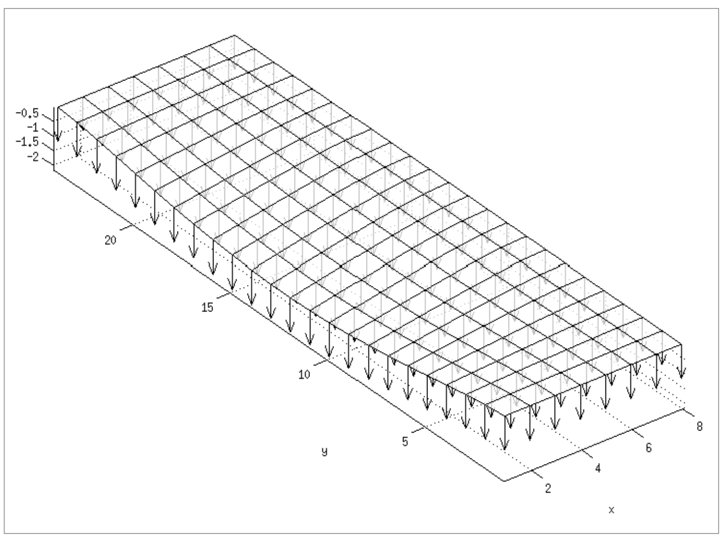


Preliminary vertical tail results			
Loading Case	Maximum Internal Stress (GPa)	% Error	Deflection (m)
1	1.961	8.382	1.102e-4
2	1.961	8.382	1.102e-4
3	7.47	2.2	4.2e-04

Structures

- Thin plate analysis used for more accuracy
- Lifting surfaces approximated as thin isotropic plates
- Flexural rigidity for composite plates is adapted and averaged over cross sections

$$\partial^4 w/\partial x^4 + 2\partial^4 w/\partial x^2 \partial$$



$$M(z) = -EI\frac{d^2 w}{dz^2}$$

$$V(z) = -\frac{d}{dz}\left(EI\frac{d^2 w}{dz^2}\right)$$

$$\sigma_{zz}(z) = \frac{M_x y}{I_{xx}}$$

$$\sigma_{zz}(z) = \left(\frac{y}{I_{xx}}\right) E I_{xx}[w''(z)]$$

Structures

- Thin plate analysis algorithms verification:
  - Rectangular plate results agree with textbook within 26% error
- Both algorithms verified by producing similar results

Computed rectangular plate deflection				
0	1E-15	8E-15	8E-15	0
-6E-15	2.466800805	3.730382294	2.466800805	0
0	3.315895372	5.050301811	3.315895372	-7E-15
-2E-15	2.466800805	3.730382294	2.466800805	0
0	0	0	0	0

Deflection results from textbook				
0	0	0	0	0
0	2.47808	3.31776	2.47808	0
0	3.72736	5.05856	3.72736	0
0	2.47808	3.31776	2.47808	0
0	0	0	0	0

Structures

- Both beam bending and thin plate analysis are integrated in the MDO framework
- Both algorithms are used in function calls from the structural sub-optimizer
- Scripts which take the place of MDO allow for configuration and materials case studies

Materials case study for 8-7-4 spars in the root-to-tip wing sections					
Material	Maximum Stress (Gpa)	% Error in Stress	Maximum Deflection (m)	Weight	Cost (USD)
1. Aluminum 6061-T6	0.1683	3.7391	0.4395	81.2620	78.9950
2. Titanium Ti-6Al-4V	0.1736	68.8520	0.2652	133.3300	1620.1000
3. Titanium-Ti13V -11Cr-3Al	0.1551	78.5150	0.2773	145.0700	1939.0000
4. AISI 4130 Steel	0.1508	45.2630	0.1491	0.2363	0.1723

Structures

- Configuration case study

Number of Ribs	Number of Spars			Maximum Stress (Gpa)	% Error in Stress	Maximum Deflection (m)	Weight	Flange Area (m^2)	Web Thickness (m)	Skin Thickness (m)
	Section 1 (Root)	Section 2	Section 3 (Tip)							
3.0000	8.0000	6.0000	6.0000	0.5037	9.6281	0.7695	210.5600	5.4815e-05	0.0075	0.0011
3.0000	8.0000	6.0000	7.0000	0.5514	1.0598	0.8424	196.8600	5.4928e-05	0.0071	0.0010
3.0000	8.0000	7.0000	4.0000	0.5084	8.7827	0.7767	204.2100	5.4813e-05	0.0073	0.0011
3.0000	8.0000	7.0000	5.0000	0.5271	5.4245	0.8053	210.3500	5.5123e-05	0.0090	0.0010

Structures

- Materials case study shows titanium allow has 10^2 increase in cost for 10^1 reduction in weight, compared with aluminum alloy
- Aluminum 6061-T6 confirmed as the material of choice
- Configuration selection made from case study results
- Trends show minimum number of spars needed in each section to satisfy stress constraints

Structures

- Final wing design

Method	Loading Case	Maximum Internal Stress (MPa)	% Error	Deflection (m)
Beam bending	1	43.998	16.6	0.1146
	2	43.998	16.6	0.1146
	3	167.191	1003.8	0.4355
Thin plate	1	167.19	4.35	0.4367
	2	167.2	4.35	0.43668
	3	635.3	263.5	1.660

Classification	Parameter	Value	
Primary Material	Designation	Aluminum 6061-T6	
	Yield Stress (MPa)	276	
	Density (kg / m^3)	2700	
	Cost (USD / kg)	14064.0399	
Configuration	Number of ribs	3	
	Number of spars	8	(Section 1)
		7	(Section 2)
		6	(Section 3)
	Wing box height (m)	0.138192193	(Section 1)
		0.1105537544	(Section 2)
		0.0829153158	(Section 3)
	Wing box width (m)	3.454804824	(Section 1)
		2.7638438592	(Section 2)
		2.0728828944	(Section 3)
Structural parameters	Spar cap area	5e-05	
	Spar web thickness	0.0010	
	Skin thickness	0.0010	

Structures

- Final horizontal tail design

Method	Loading Case	Maximum Internal Stress (Mpa)	% Error	Deflection (m)
Beam bending	1	2250006.5	36.2	0.00270
	2	2250006.5	36.2	0.00270
	3	8550024.6	31.0	0.0103
Thin plate	1	8.57e+06	9.51	0.0104
	2	8.57e+06	9.51	0.0104
	3	3.26e+07	8.14	0.0391

Classification	Parameter	Value	
Primary Material	Designation	Aluminum 6061-T6	
	Yield Stress (MPa)	276	
	Density (kg / m^3)	2700	
	Cost (USD / kg)	14064.0399	
Configuration	Number of ribs	3	
	Number of spars	6	(Section 1)
		8	(Section 2)
		7	(Section 3)
Structural parameters	Spar cap area	5e-05	
	Spar web thickness	0.0010	
	Skin thickness	0.0010	

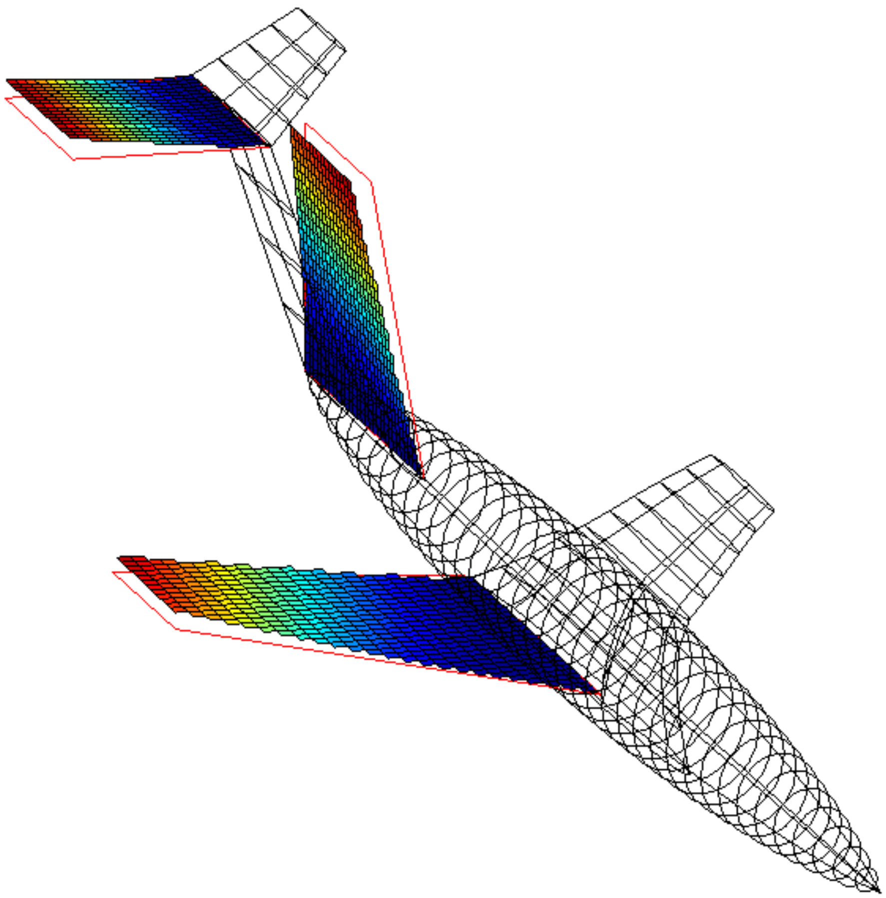
Structures

+ Final vertical tail design

Method	Loading Case	Maximum Internal Stress (Mpa)	% Error	Deflection (m)
Beam bending	1	0	0	0
	2	5.32e+08	2.005e+02	0.195
	3	0	0	0
Thin plate	1	0	0	0
	2	5.41e+08	2.10e+02	0.206
	3	0	0	0

Classification	Parameter	Value	
Primary Material	Designation	Aluminum 6061-T6	
	Yield Stress (MPa)	276	
	Density (kg / m^3)	2700	
	Cost (USD / kg)	71.39	
Configuration	Number of ribs	3	
	Number of spars	6	(Section 1)
		6	(Section 2)
		5	(Section 3)
Structural parameters	Spar cap area	5e-05	
	Spar web thickness	0.0010	
	Skin thickness	0.0010	

Structures



- Primary focus of second semester was thin plate analysis
- Additional analysis techniques recommended for more detailed design stages