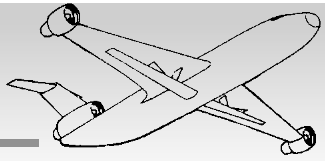
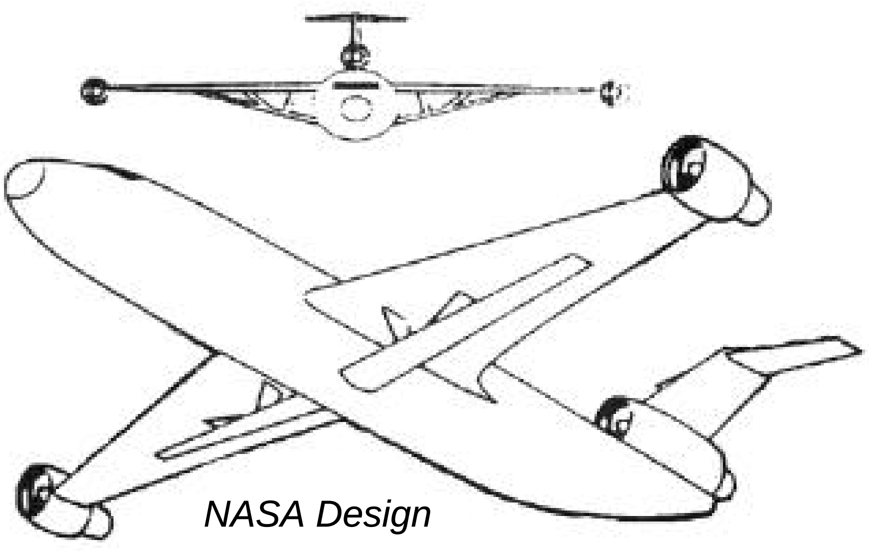


Multidisciplinary Design Optimization of a Truss-Braced Wing Aircraft with Tip-Mounted Engines



NASA Design

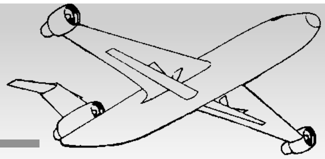
MAD Center Advisory Board Meeting, November 14, 1997

Students: J.M. Grasmeyer, A. Naghshineh-Pour, P.A. Tetrault, M. Colangelo
Faculty: B. Grossman, R.T. Haftka, R.K. Kapania, W.H. Mason, J.A. Schetz

Problem Statement

Responding to Dennis Bushnell's challenge:

- Apply MDO methodology to a transonic, truss-braced wing design to seek a major increase in performance
- Minimize Takeoff Gross Weight
- Use the mission profile of the Boeing 777-200IGW



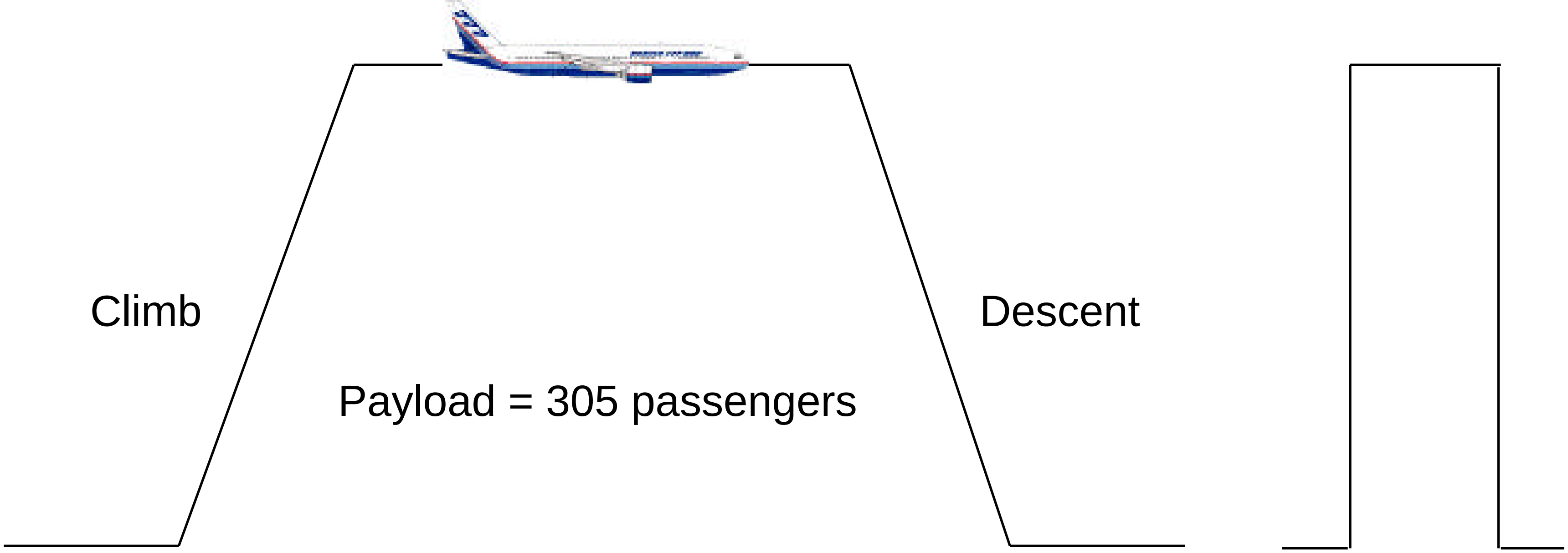
Technology Integration

- High aspect ratio via strut bracing
- Laminar flow via low sweep
- Tip-mounted engines

Special Challenges

- Wing-strut interference drag
  - CFD Design
- Engine-out condition
  - Circulation control on vertical tail
- Aeroelasticity
  - Load alleviation and active control

Design Mission Profile (777)



Cruise

Range = 7,380 nmi
M = 0.85

Reserve = 500 nmi

Climb

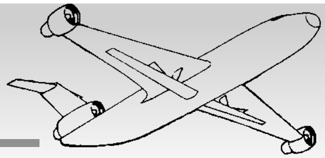
Descent

Payload = 305 passengers

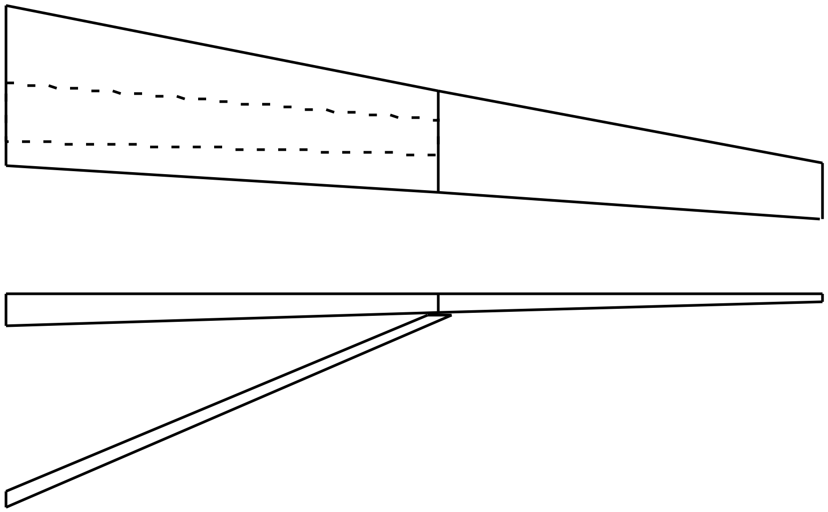
Warmup
Taxi
Takeoff

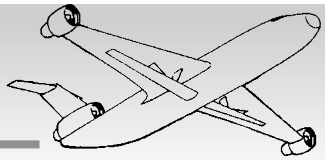
Landing

Single-Strut Optimization

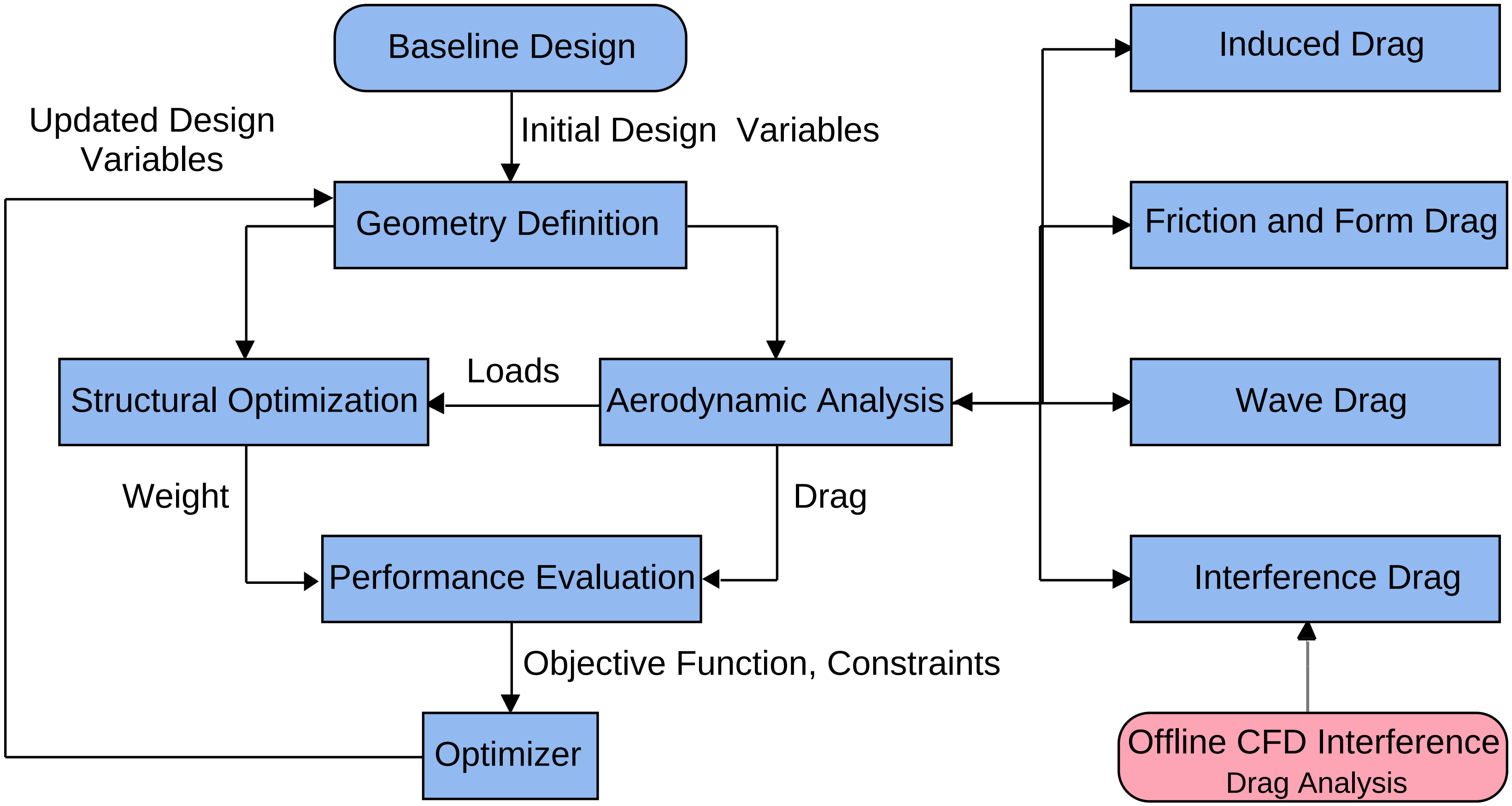


- Objective function: minimize takeoff gross weight
- 17 design variables
  - 12 wing shape variables
  - 2 weight variables
  - Optimum strut force
  - Altitude
  - Circulation control
- 7 constraints
  - Weight convergence
  - Range
  - C_{Lmax} at a given approach speed
  - Maximum allowable section C_l
  - Fuel volume
  - Engine-out at minimum control speed
  - 80 meter gate box limit





Multidisciplinary Approach



Baseline Design

Initial Design Variables

Updated Design Variables

Geometry Definition

Structural Optimization

Loads

Aerodynamic Analysis

Weight

Drag

Performance Evaluation

Objective Function, Constraints

Optimizer

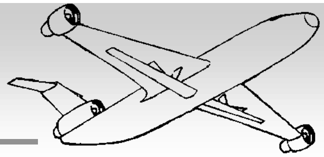
Induced Drag

Friction and Form Drag

Wave Drag

Interference Drag

Offline CFD Interference Drag Analysis

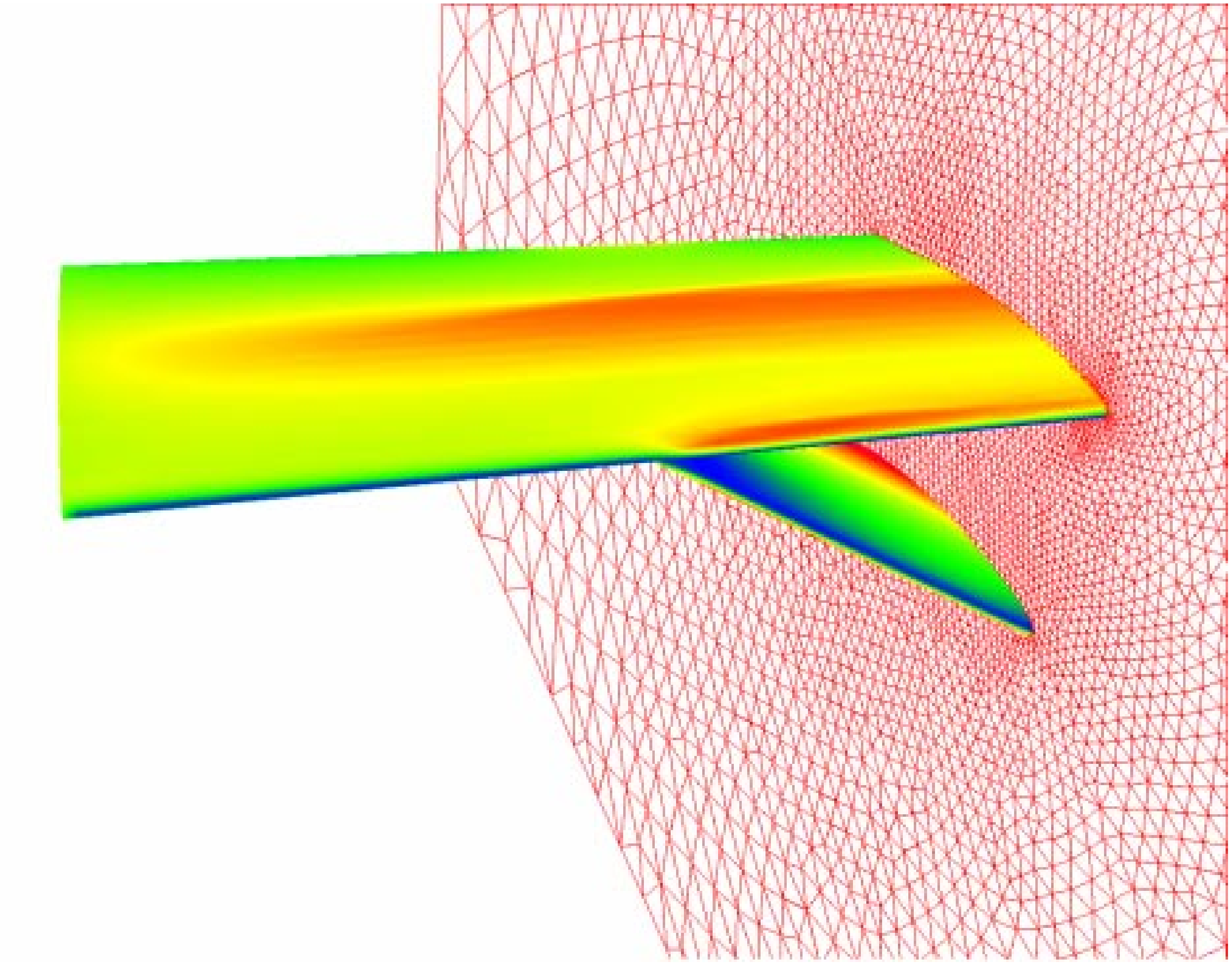


Interference Drag Approach

- Estimate the Drag Penalty of the Wing-Strut Junction
- Use CFD Tools to Generate “Empirical” ΔC_D Data
  - CFD code: USM3D
  - Inviscid/Euler formulation at this stage
  - Unstructured grid generation with GRIDTOOL
- Study Various Configurations
  - Single/Multiple strut designs
  - Arch-shaped strut
- Parametrically Vary the Shape of the Strut to Minimize the Drag

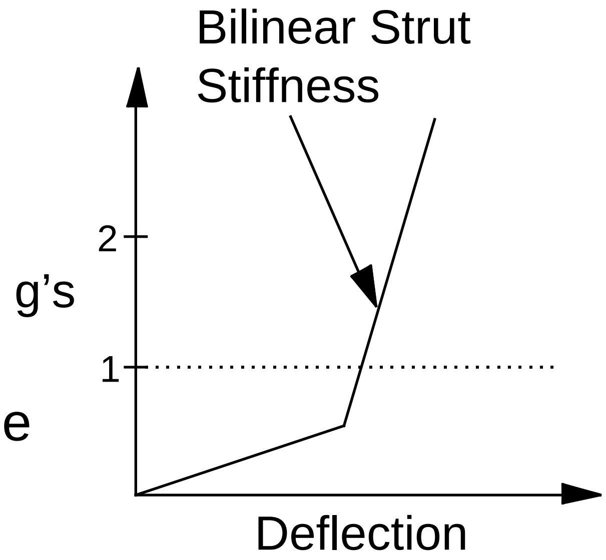
Wing-Strut Configuration

M=0.75, $\alpha=0^o$

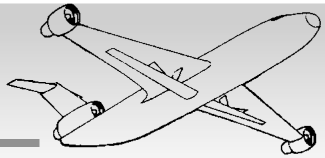


Structural Optimization

- Determine the minimum bending material weight for a given configuration
- Piecewise linear beam theory
- Critical load cases
  - 2.5 g’s: strut in tension
  - -1.0 g: strut inactive in compression
  - Strut buckling is the critical design issue

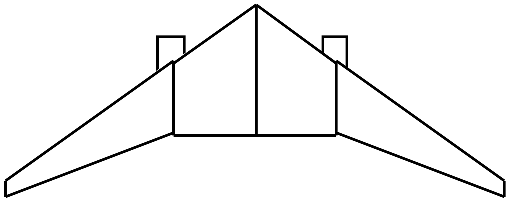


- Future Work
  - Include aeroelastic effects using NASTRAN
  - Create response surface from FEM optimizations
  - Evaluate other load cases such as landing and taxi bump



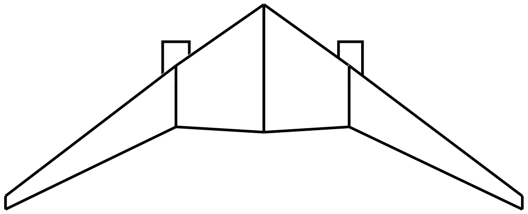
Baseline and Optimum Configurations

Baseline
Cantilever



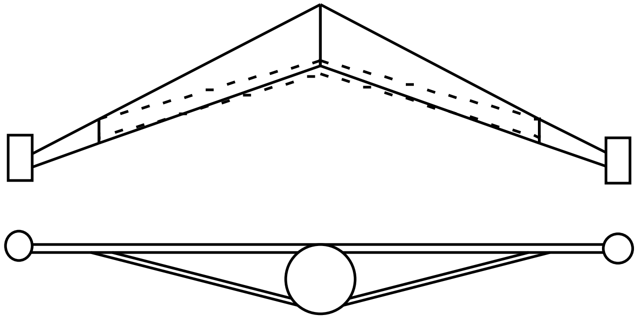
- Statically Stable
- Completely Turbulent

"Optimum"
Cantilever
(Obtained with
VT MDO tools)



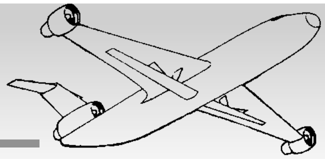
- Relaxed Static Stability
- Partially Laminar
- Rubber Engine Sizing

Optimum
Single-Strut

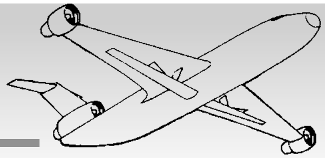


- Relaxed Static Stability
- Partially Laminar
- Rubber Engine Sizing
- Circulation Control for Engine-Out

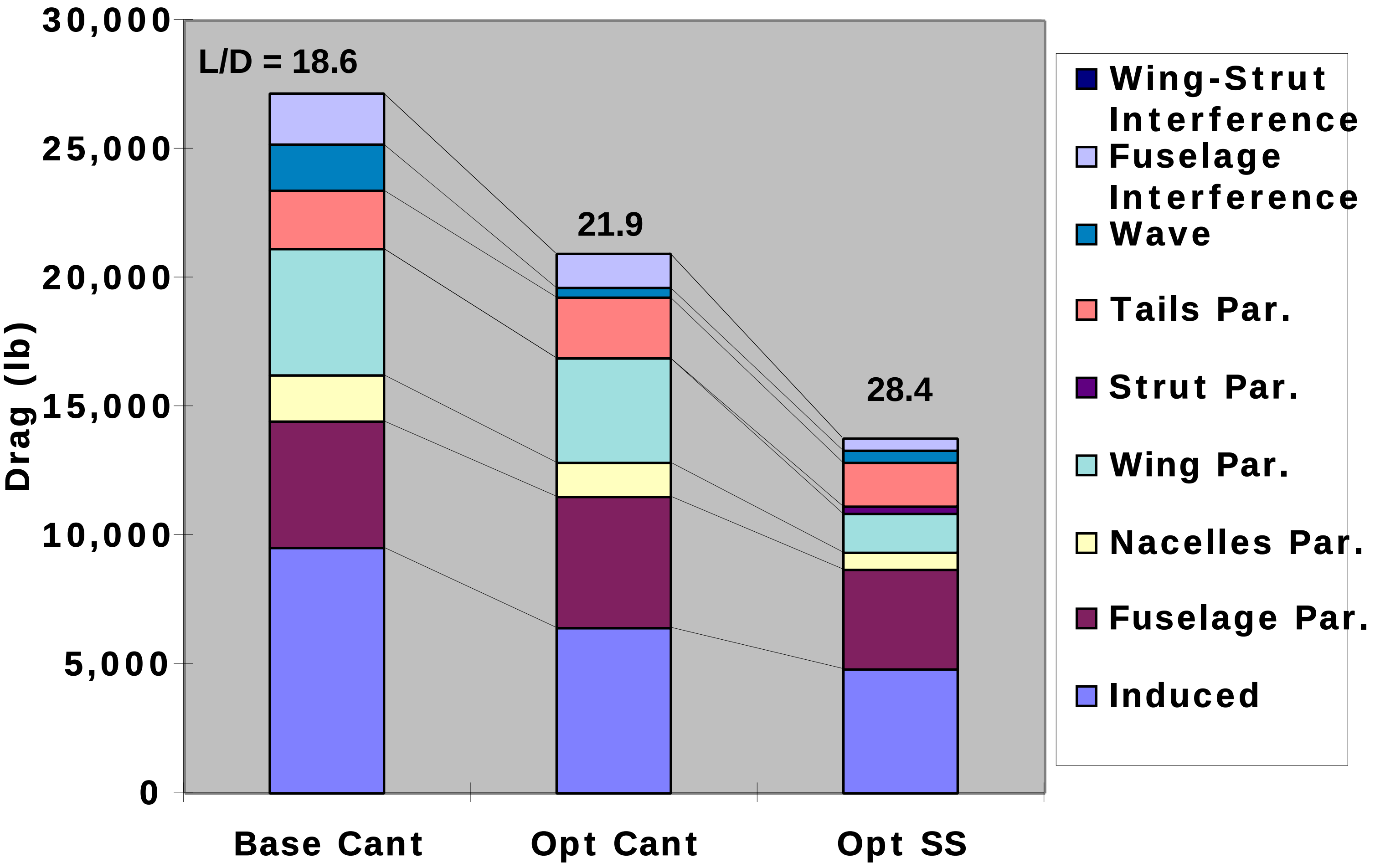
Configuration Comparison



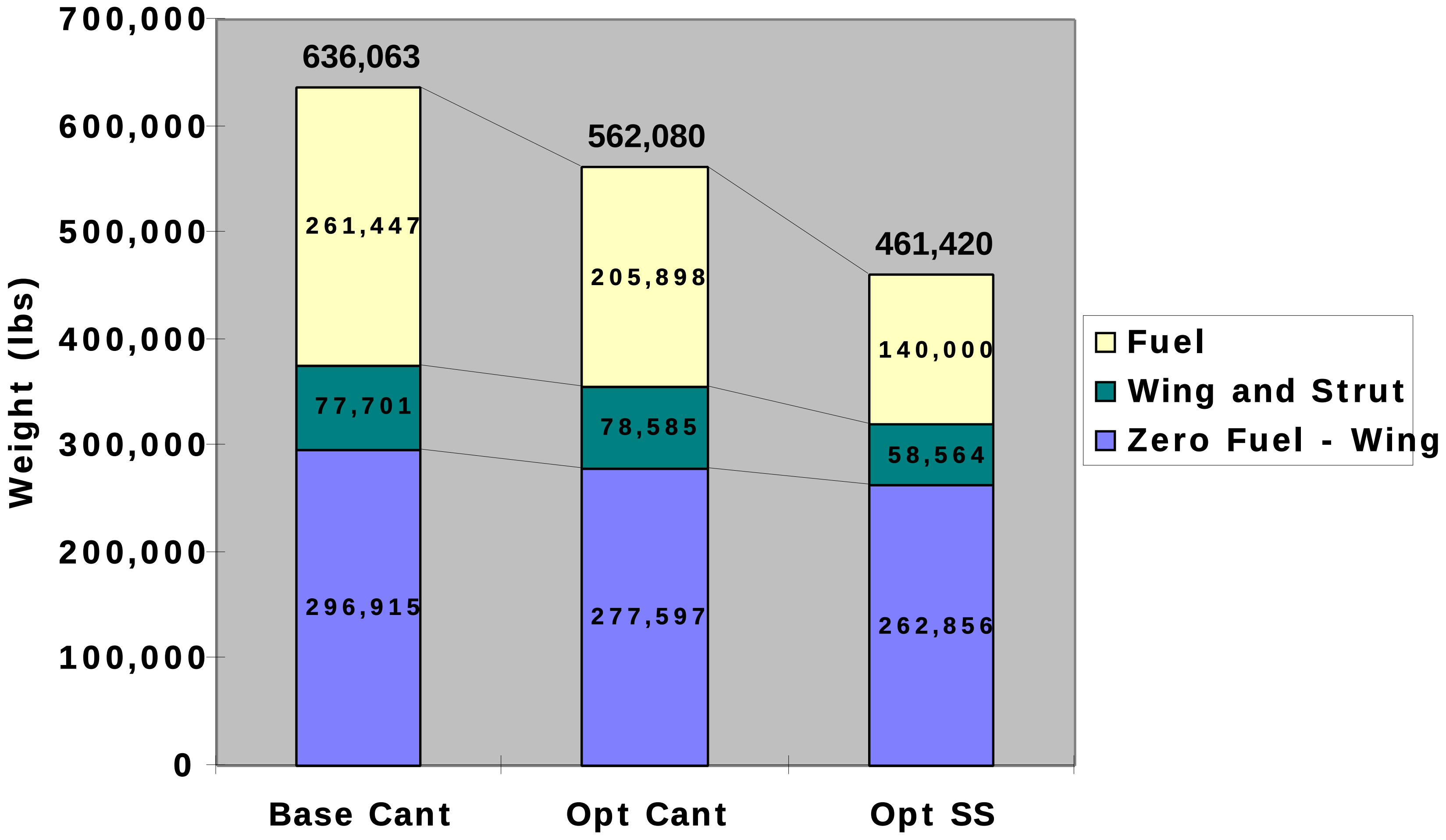
	Base Cant	Opt Cant	Opt SS
Wing Span (ft)	199.9	208.2	232.3
Wing Area (ft^2)	4,607	4,244	3,606
Aspect Ratio	8.7	10.2	15.0
Inboard Wing Sweep (deg)	31.6	33.6	25.6
Outboard Wing Sweep (deg)	31.6	33.6	25.6
Strut Sweep (deg)	N/A	N/A	14.5
Inboard Wing t/c	13.0%	12.5%	8.9%
Outboard Wing t/c	10.9%	10.2%	4.6%
Strut t/c	N/A	N/A	4.60%
Cruise L/D / Max L/D	18.6/20.2	21.9/24.3	28.4/30.0
Specific Range (nmi/1000 lb)	26	34	54
Seat Miles per Gallon (seats*nmi/gal)	60	76	112
Wing Weight (lb)	77,701	78,585	58,564
Takeoff Gross Weight (lb)	636,063	562,080	461,420

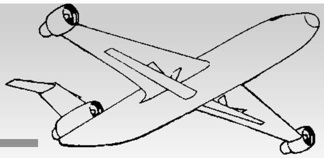


Drag Comparison



Weight Comparison

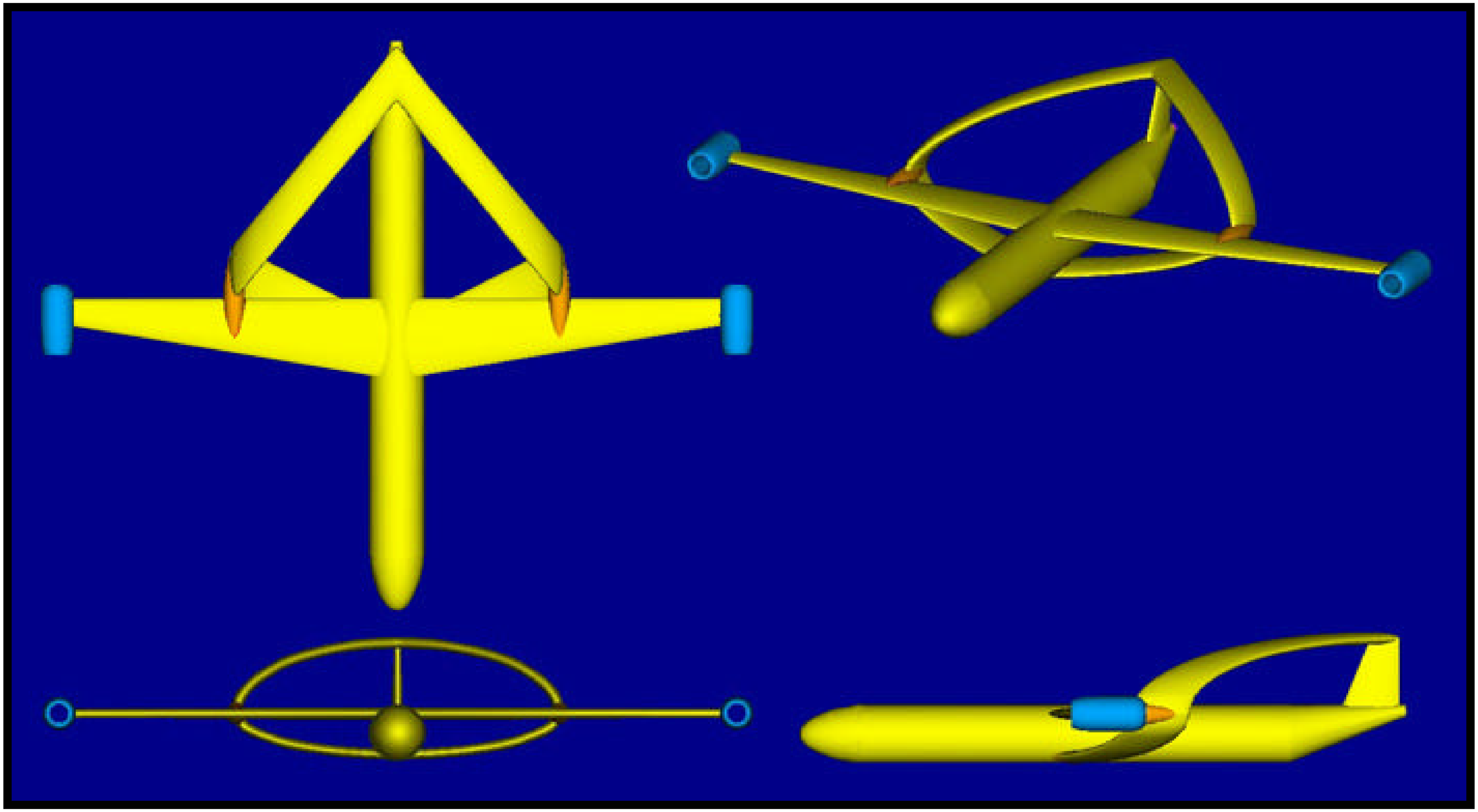


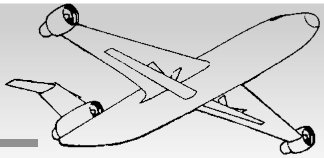


Discussion of Results

- Strut alleviates large span weight penalty and allows a reduction of *t/c*
- Increased span reduces induced drag
- Decreased *t/c* allows some unsweeping of the wing and some reduction in wave drag
- Parasite drag is reduced via increased laminar flow
  - Higher AR means smaller chords and smaller Re
  - Unsweeping wing reduces cross-flow instability
  - Decreasing *t/c* allows more favorable pressure gradients and delays shock formation
- **Result:** Synergistic increase in overall aircraft efficiency

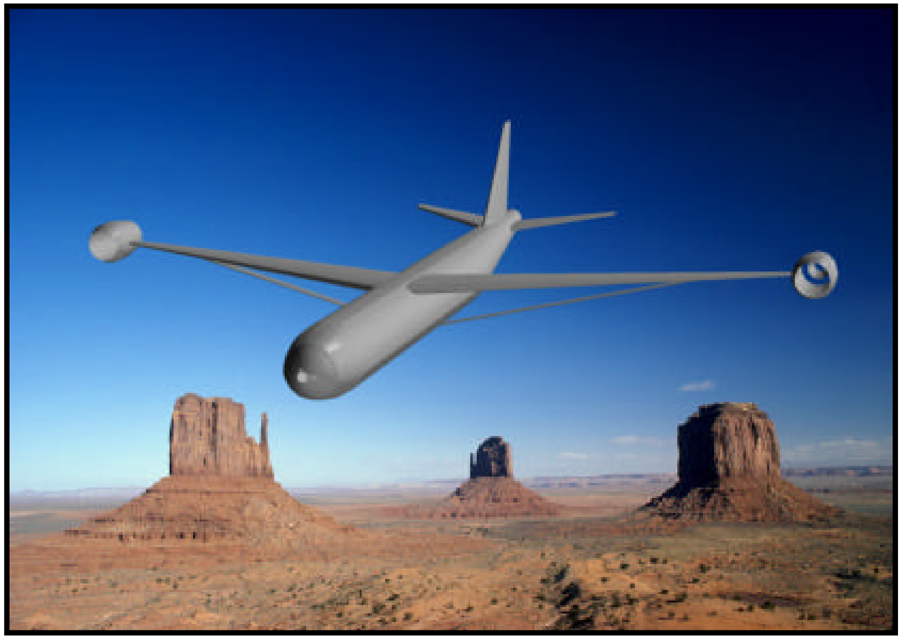
Innovative Concepts





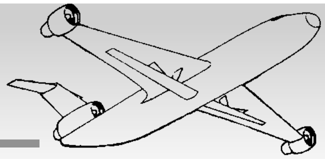
On-screen Visualization

- Fortran subroutine creates DXF file
- AutoCAD and Infini-D are used to create rendered images and animations



Rapid Prototyping

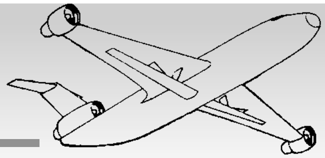
- A solid model is created in I-DEAS
- Fused Deposition Modeling is used to create a plastic model



Current Conclusions

% Improvement Over →	Baseline Cantilever	Optimum Cantilever
Takeoff Gross Weight	- 27%	- 18%
Fuel Weight	- 46%	- 32%
L/D	+53%	+30%
Seat-Miles/Gallon	+87%	+47%

- The strut-braced wing configuration achieves a significant increase in performance
- This merits further study



Future Work

- Broaden the parameter set to allow optimization of more complex and innovative truss geometries
- Refine analyses
  - Create a structural response surface with finite element model optimizations
  - Create a response surface from CFD interference drag analyses
  - Include aeroelastic effects
  - Utilize load alleviation at the critical load cases
- Design a wind tunnel model