Simultaneous Optimization of the Airframe, Powerplant, and Operation of Transport Aircraft

Mark Drela

NIT Aeronautics and Astronautics

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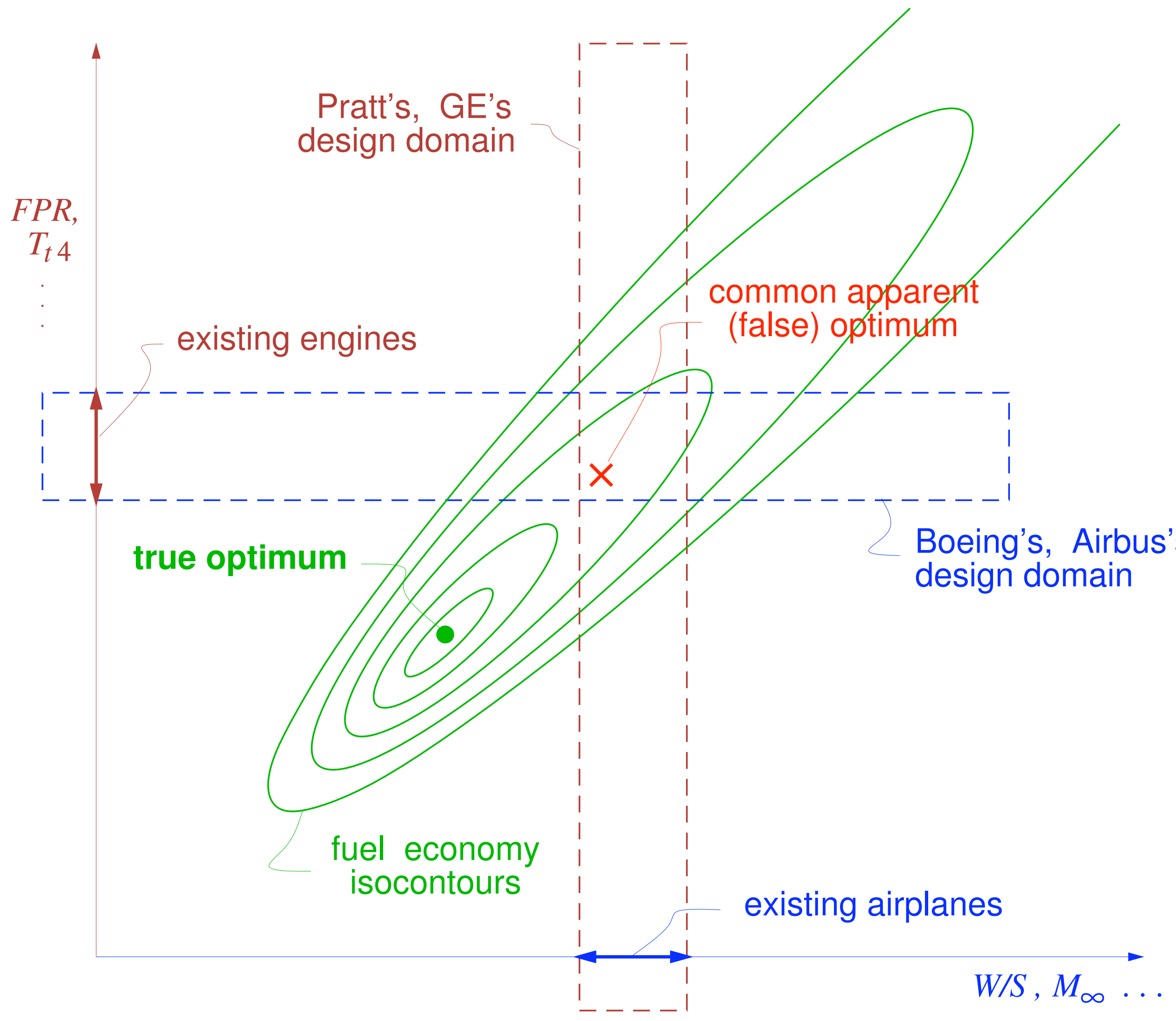
Objective

Find <u>global</u> optimum in Airframe + Engine + Ops design space



Presentation Outline

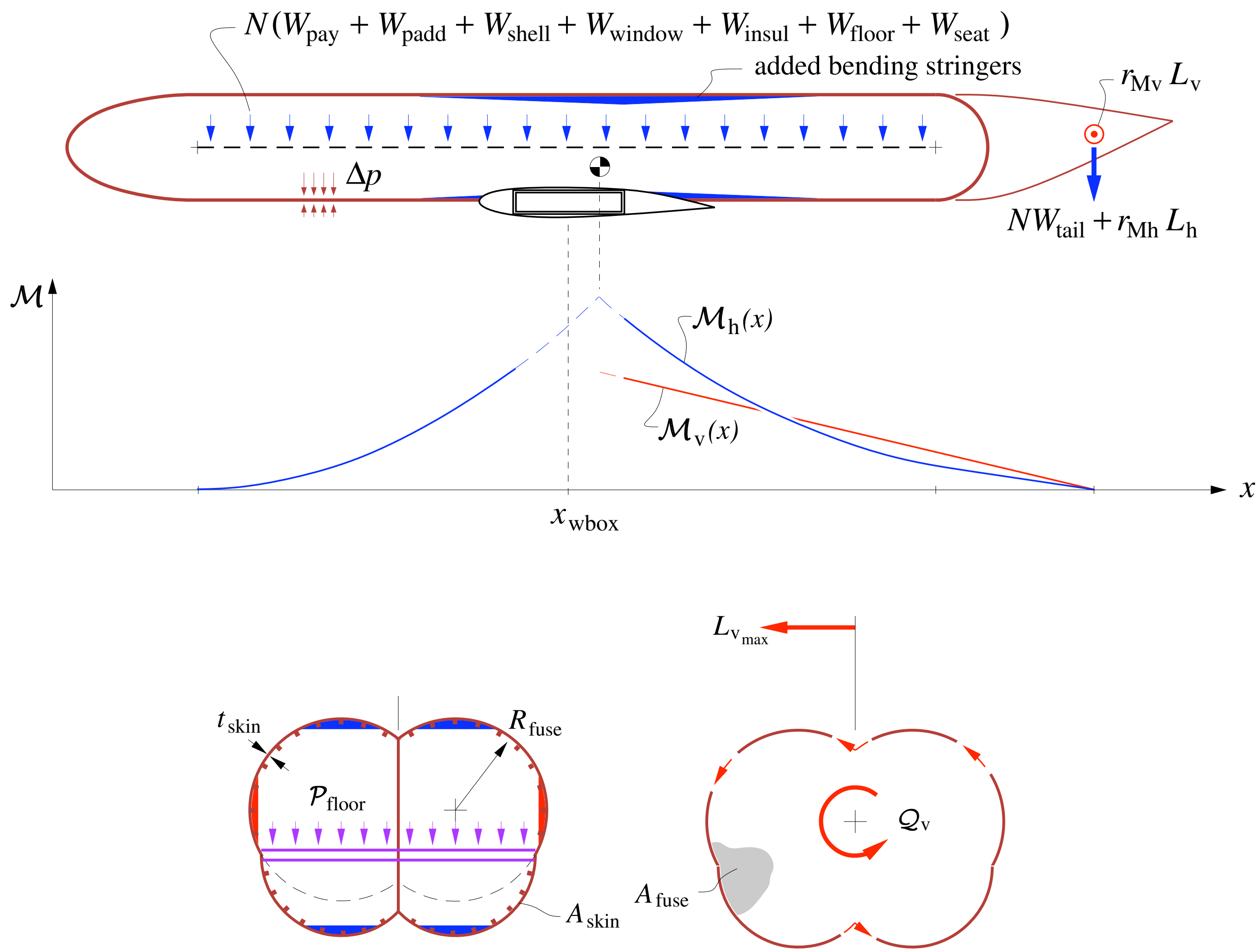
- Transport Aircraft System OPTimization (TASOPT)
- Global optimization effectiveness study
- D8.x "Double Bubble" transport aircraft concept

TASOPT Summary

- Collection of coupled low-order physical models
  - Primary structure: Stress-sized geometric shapes
  - Aero: Viscous/Inviscid CFD, Trefftz-Plane analysis
  - Engine: Turbofan 1D flowpath simulation
  - Trim, stability
  - Flight trajectory (Ops)
- Nested iteration loops
  - Inner design-closure loop
  - Middle optimization loop
  - Outer parameter-sequencing loop

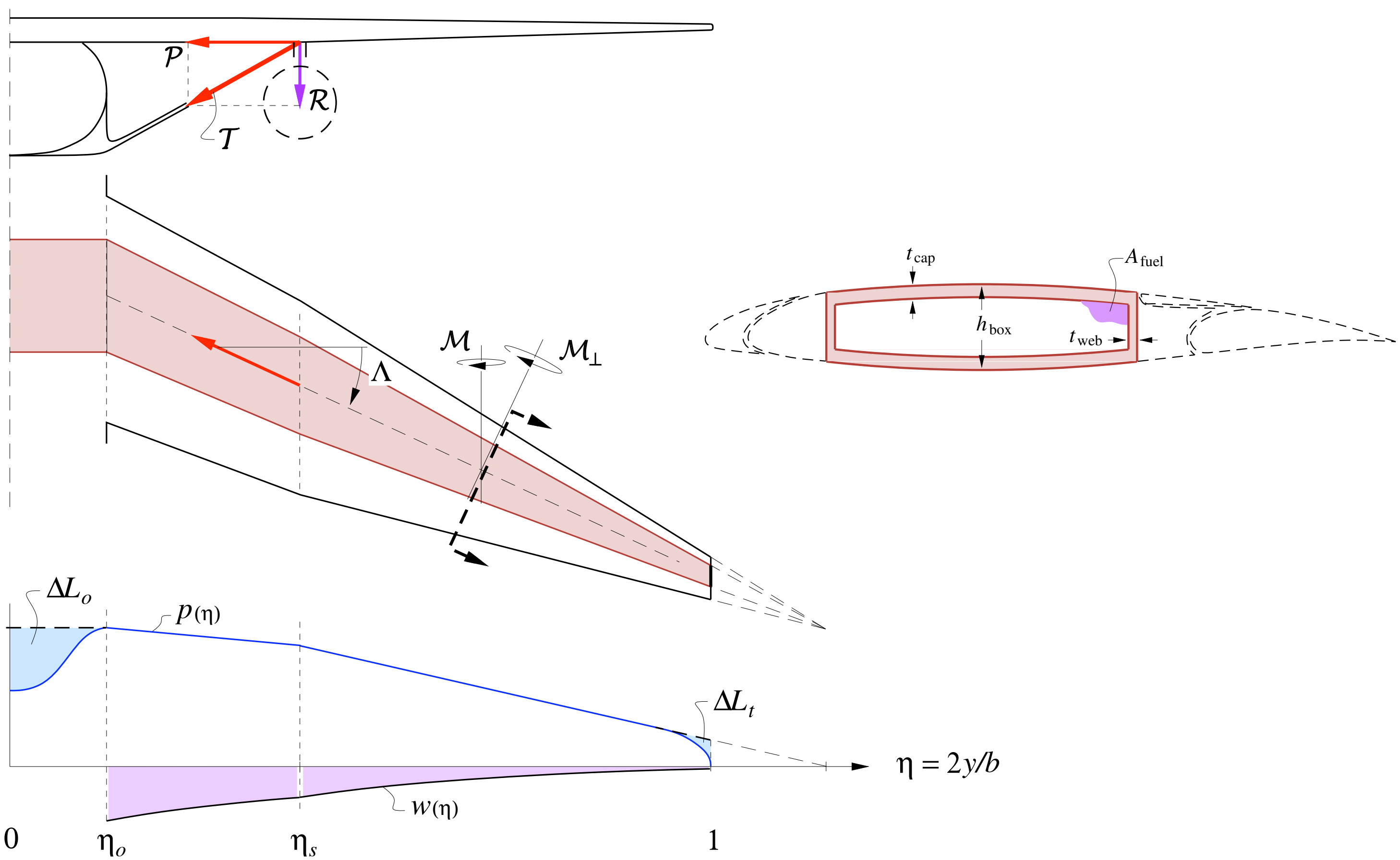
Fuselage Structural Model

Pressurization, tail and landing loads size primary structure



Wing, Tail Structural Model

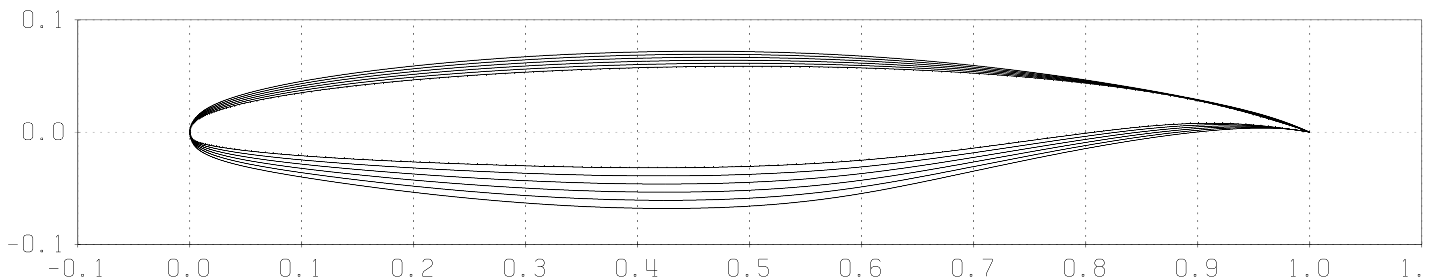
Max load factor and loads at V_{NE} size primary structure



Transonic Airfoil Family

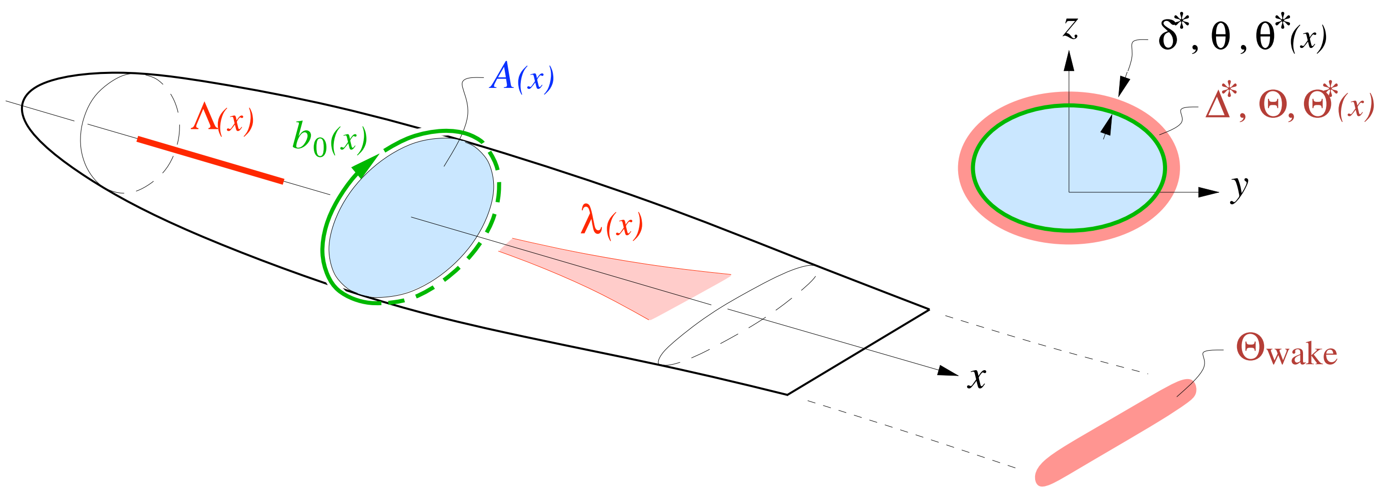
- Airfoil family designed offline for good transonic drag rise
- Viscous/Inviscid CFD database for any $\frac{t}{c}$, c_ℓ, $M_\perp$, Re_c
- Dispenses with wetted-area drag prediction methods
- Provides “rubber airfoil” for optimizer

	NC090	NC100	NC110	NC120	NC130	NC140
area =	0.06210	0.06836	0.07464	0.08093	0.08723	0.09355
thick. =	0.09001	0.10000	0.11000	0.12000	0.13000	0.13999
camber =	0.02142	0.02036	0.01930	0.01826	0.01722	0.01620
r_{LE} =	0.01457	0.01489	0.01522	0.01556	0.01590	0.01632
$\Delta\theta_{TE}$ =	11.78°	11.74°	11.71°	11.68°	11.64°	11.62°



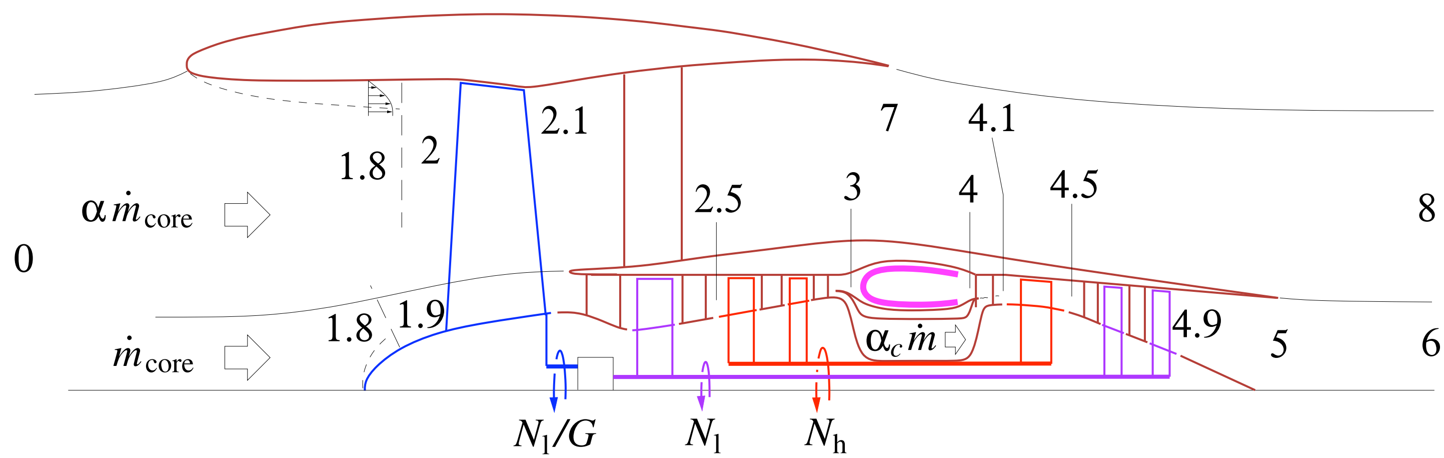
Fuselage Drag Model

- Viscous/Inviscid calculation for any area, perimeter $A(x), b_0(x)$
- Dispenses with wetted-area drag prediction methods
- Also provides accurate input for BLI accounting



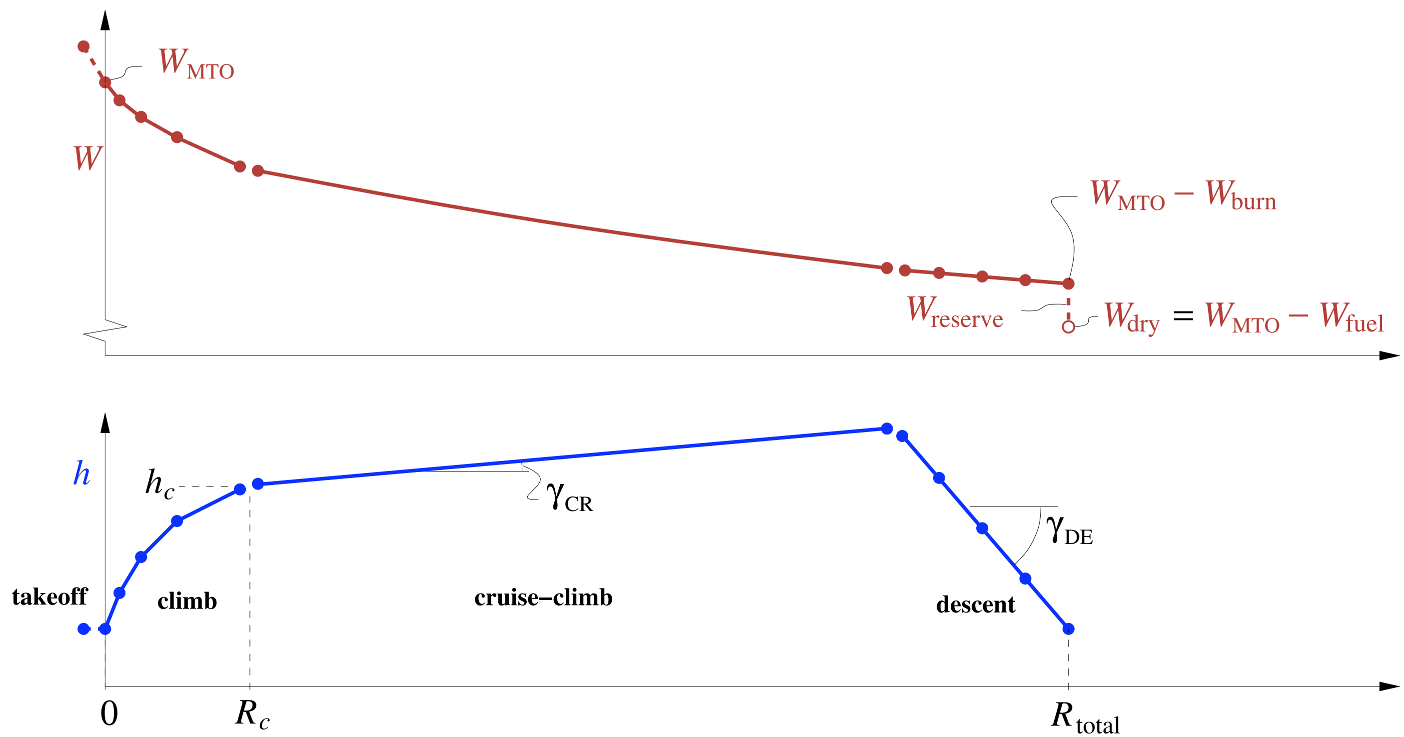
Engine Performance Model

- Complete flowpath simulation for ...
  - ... sizing at cruise design point,
  - ... operation at off-design takeoff, climb, descent, static.
  - Includes effects of turbine cooling bypass flow
  - Includes effects of Boundary Layer Ingestion (BLI), if any
- Dispenses with engine-performance tables or correlations
- Provides "rubber engine" for optimizer

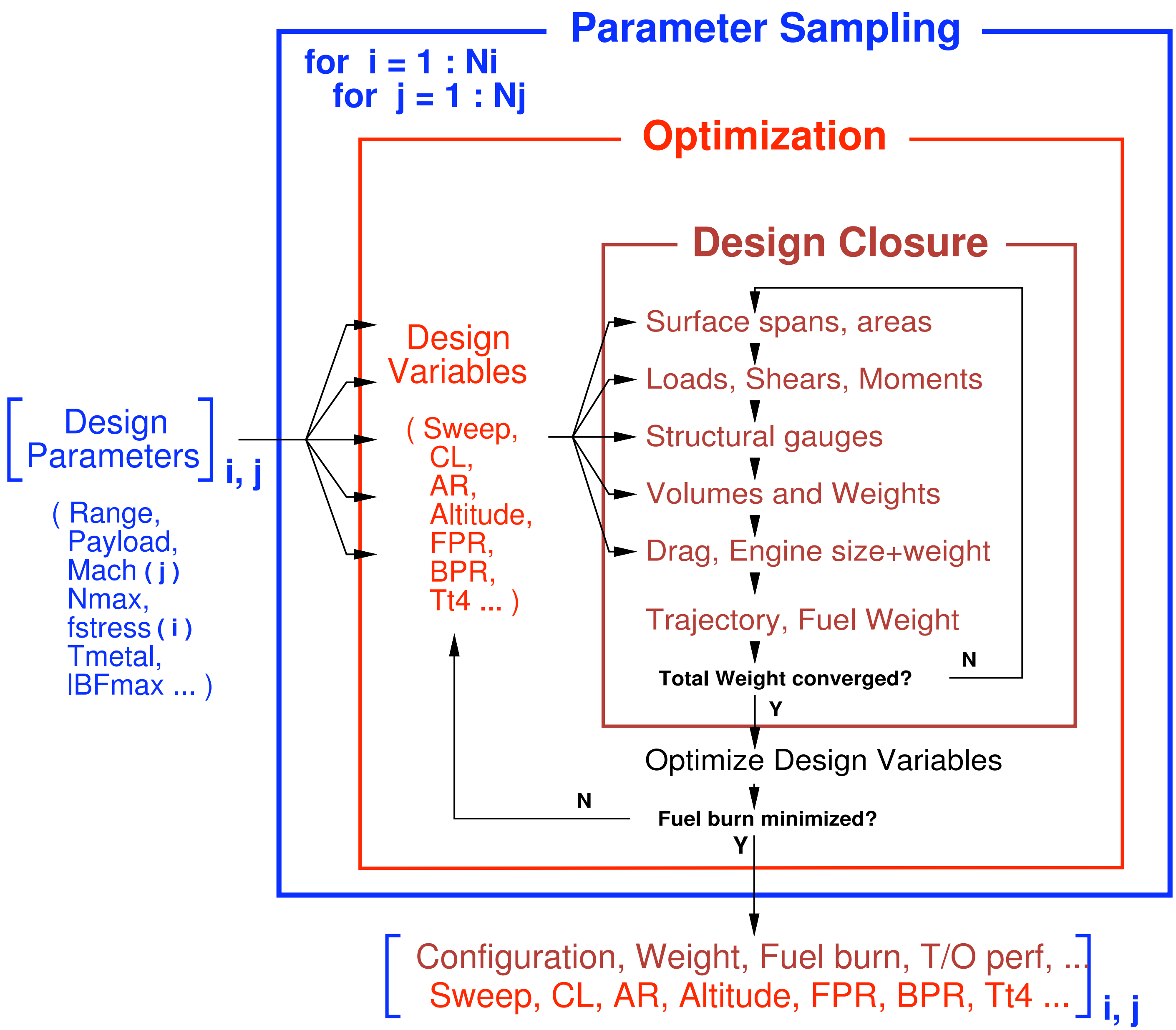


Mission Profiles

- Each design "flown" over specified total range mission to
  - ...size fuel weight,
  - ...evaluate takeoff performance
- Provides "rubber trajectory" for optimizer



TASOPT Calculation Loops



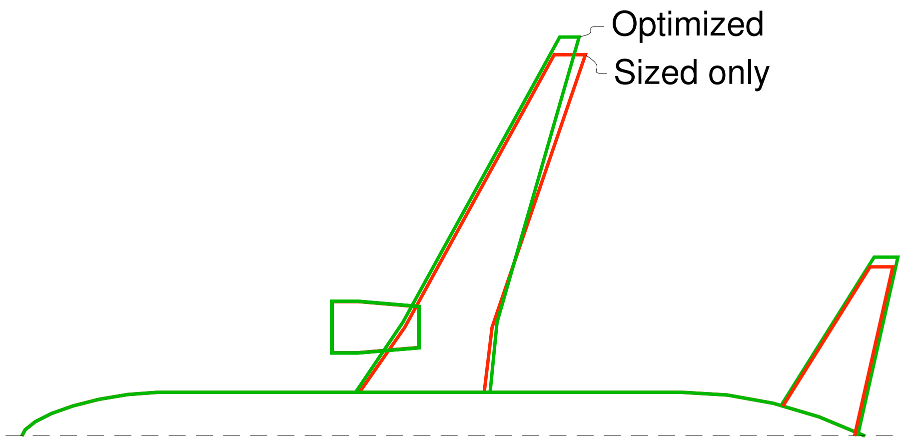
TASOPT Selectable Design Variables

$C_{L_{CR}}$	cruise lift coefficient
Λ	wing sweep
t/c_o	airfoil thickness at wing root
t/c_s	airfoil thickness at planform break
λ_s	inner panel taper ratio
λ_t	outer panel taper ratio
$r_{c_{l_s}}$	cruise c_{l_s}/c_{l_o} at break
$r_{c_{l_t}}$	cruise c_{l_t}/c_{l_o} at tip
OPR_{D}	cruise design overall pressure ratio
FPR_{D}	cruise design fan pressure ratio
BPR_{D}	cruise design bypass ratio
$T_{t\,4_{TO}}$	takeoff turbine inlet temperature
$T_{t\,4_{CR}}$	cruise turbine inlet temperature
h_{CR}	start-of-cruise altitude

TASOPT Calibration/Verification

B737-800 Sizing, Airframe+Ops Optimization

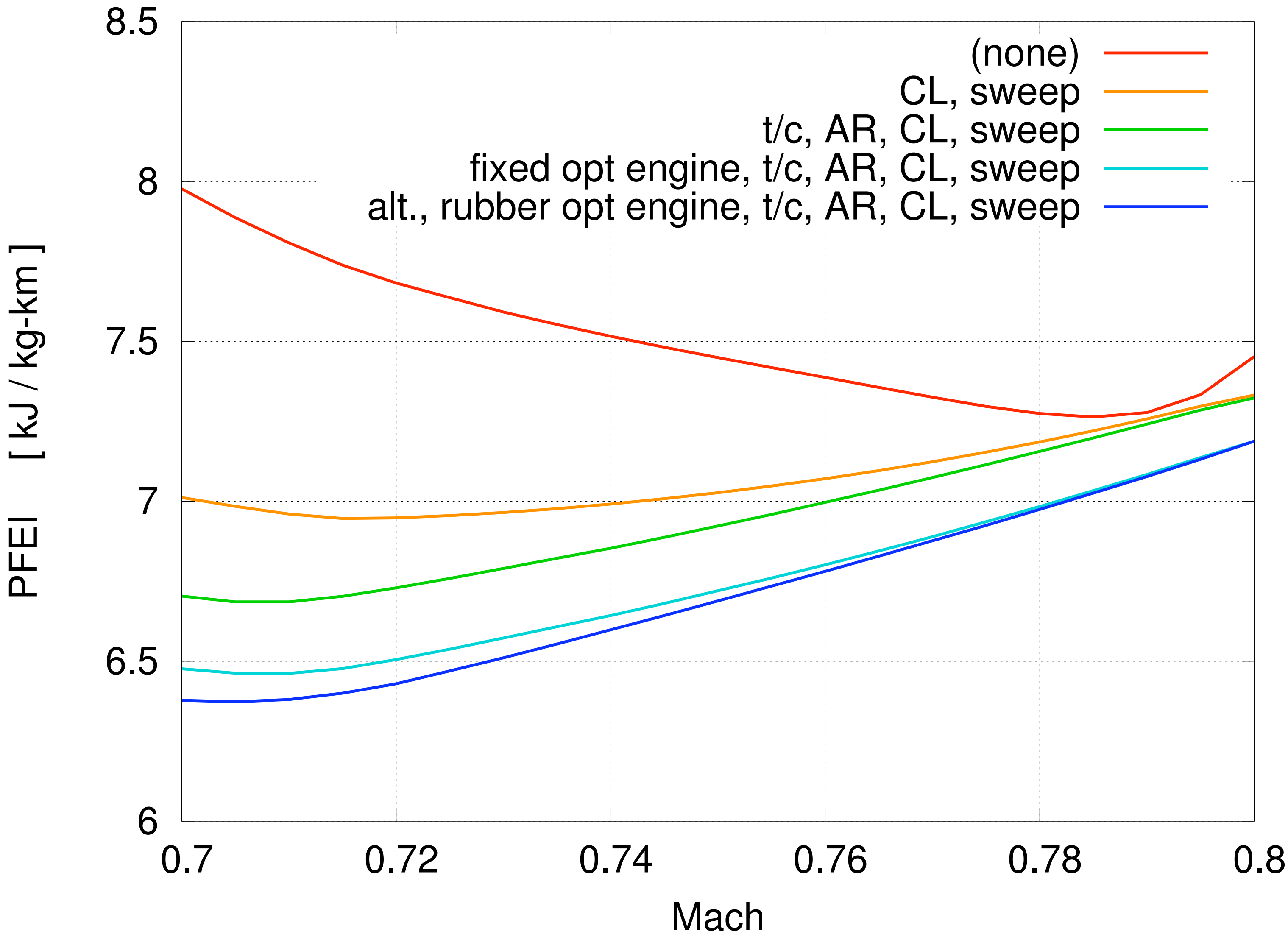
	W_{MTO}	W_{fuel}	S	Λ°	λ_t	AR	$C_{L_{CR}}$	h_{CR}
Actual	171000	39000	1250	25.00	0.250	10.20	0.550	33500
Sized only	166001	38474	1229	25.00	0.250	10.20	0.550	33500
Optimized	163862	36923	1289	24.33	0.144	10.61	0.530	34070



- Sized-only aircraft within 3% weight, 2% area of actual 737
- Optimization then gives only 4% fuel reduction

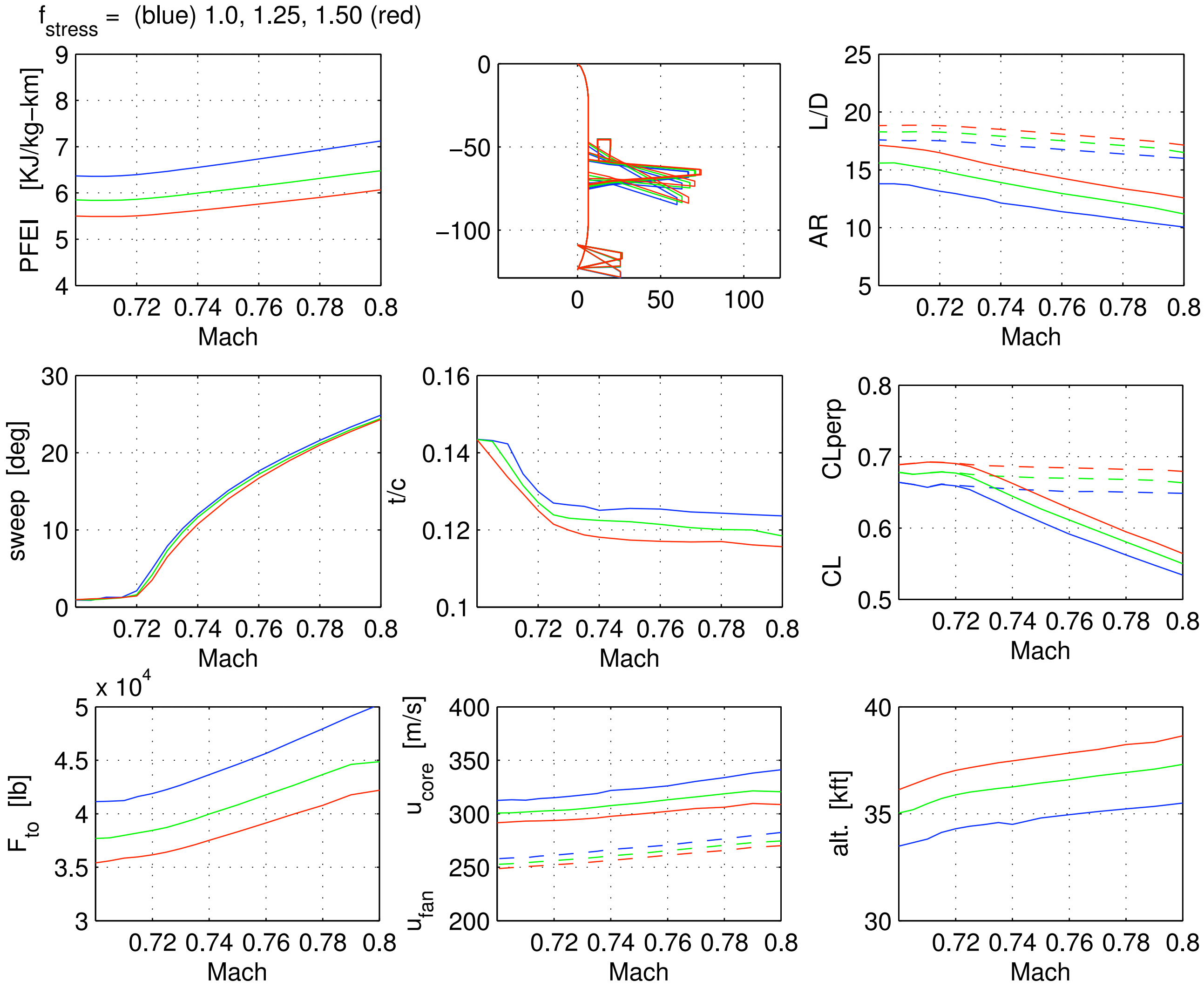
Effect of Design Space Expansion

Addition of airfoil, engine, trajectory to design space gives significantly reduced fuel burn



Optimum Aircraft Variation vs Mach, Material Stress

Airframe, engine, trajectory all vary on min-fuel airplane



TASOPT Application — NASA's N+3 Program

N+3 Program Objective:

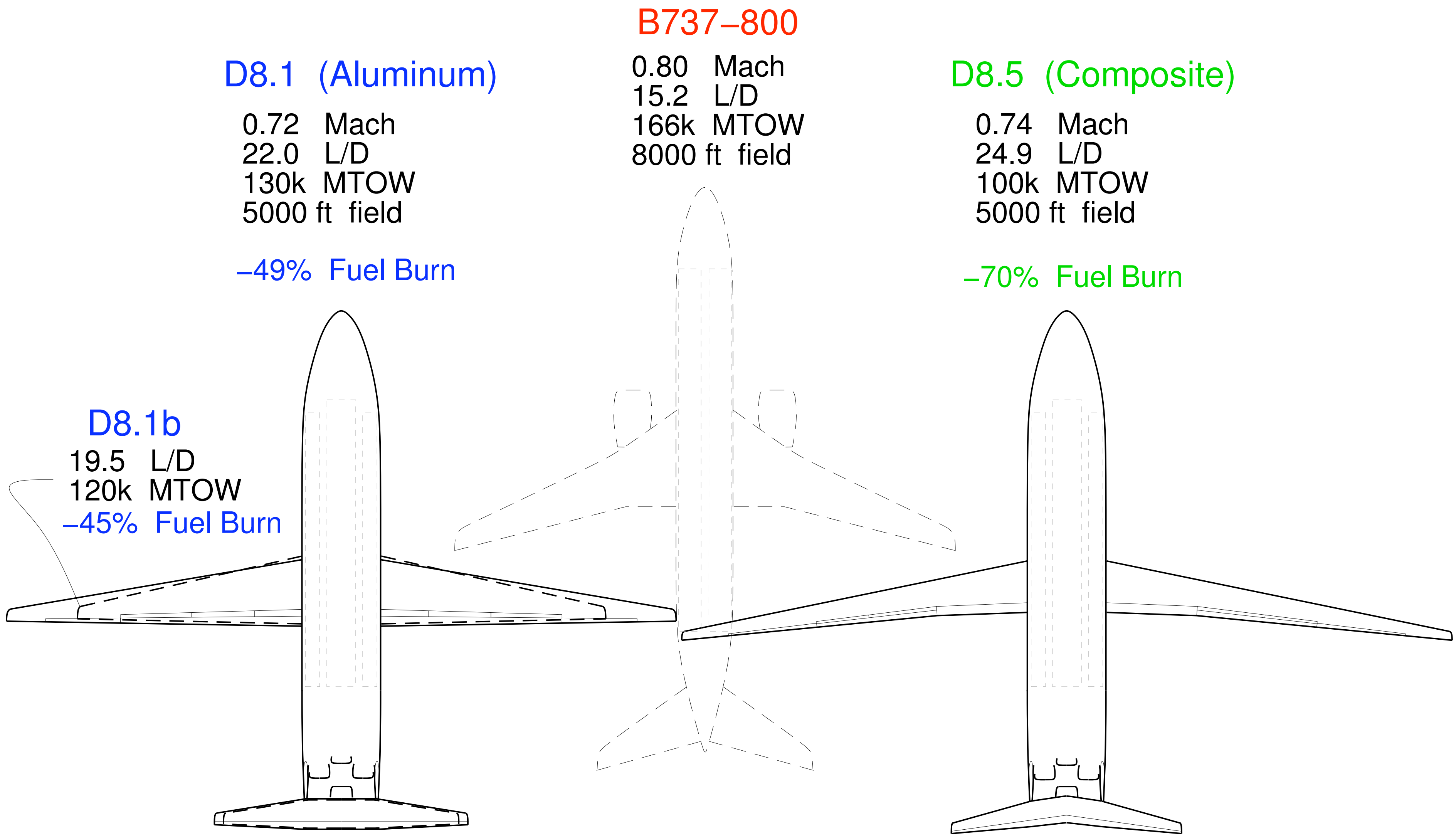
Identify concepts and technologies needed for 70% (!) reduction in Fuel / PAX-mile by 2025

Early Realization:
Optimizing conventional configs (B737-800) won't do it

Solution:
Optimize unconventional configs (D8.x) in global design space

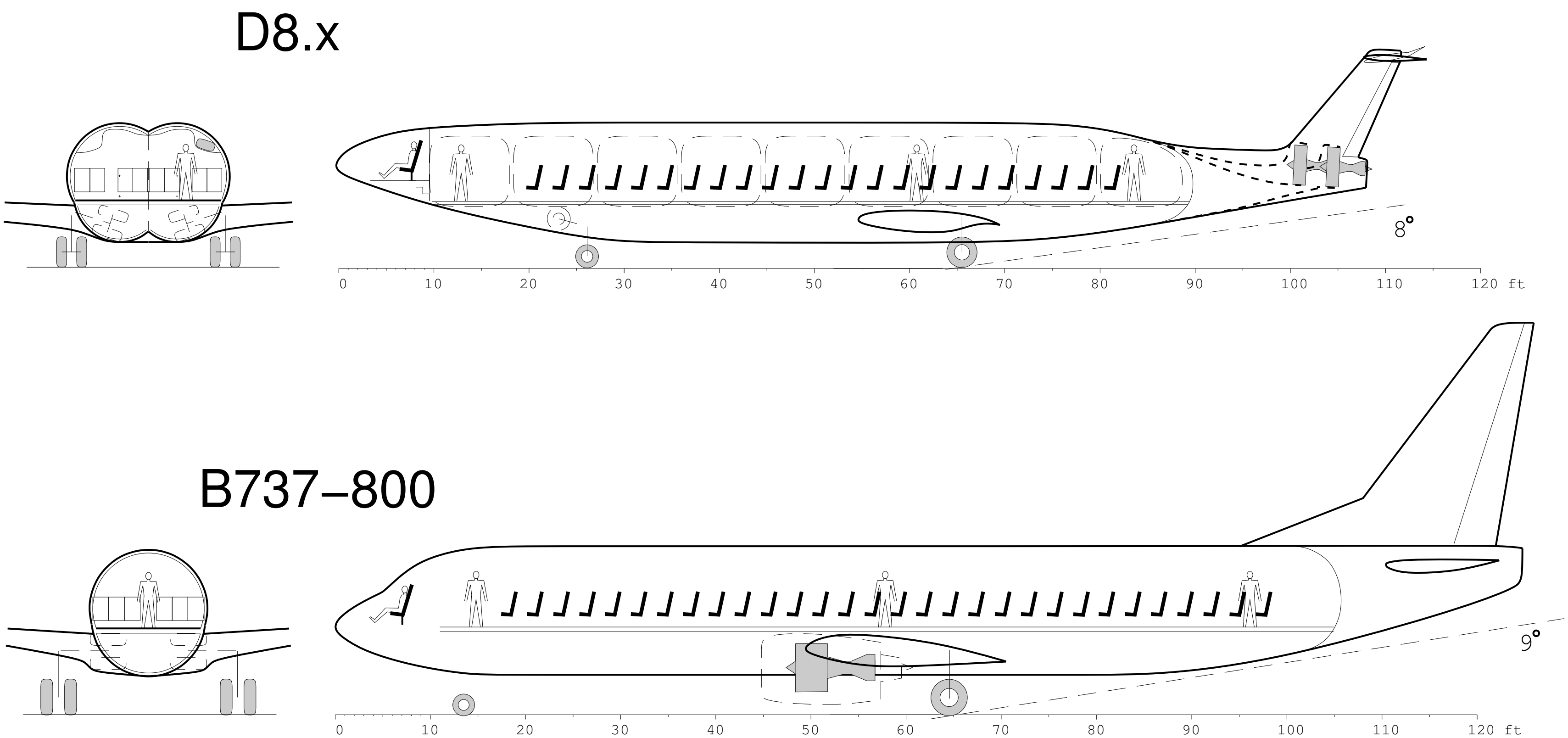
- Today's aluminum technology, today's engines (D8.1)
- Advanced materials, engines, GLA, SHM, NLF (D8.5)

D8.x Designs for B737-800 Replacement



D8.5 Aircraft

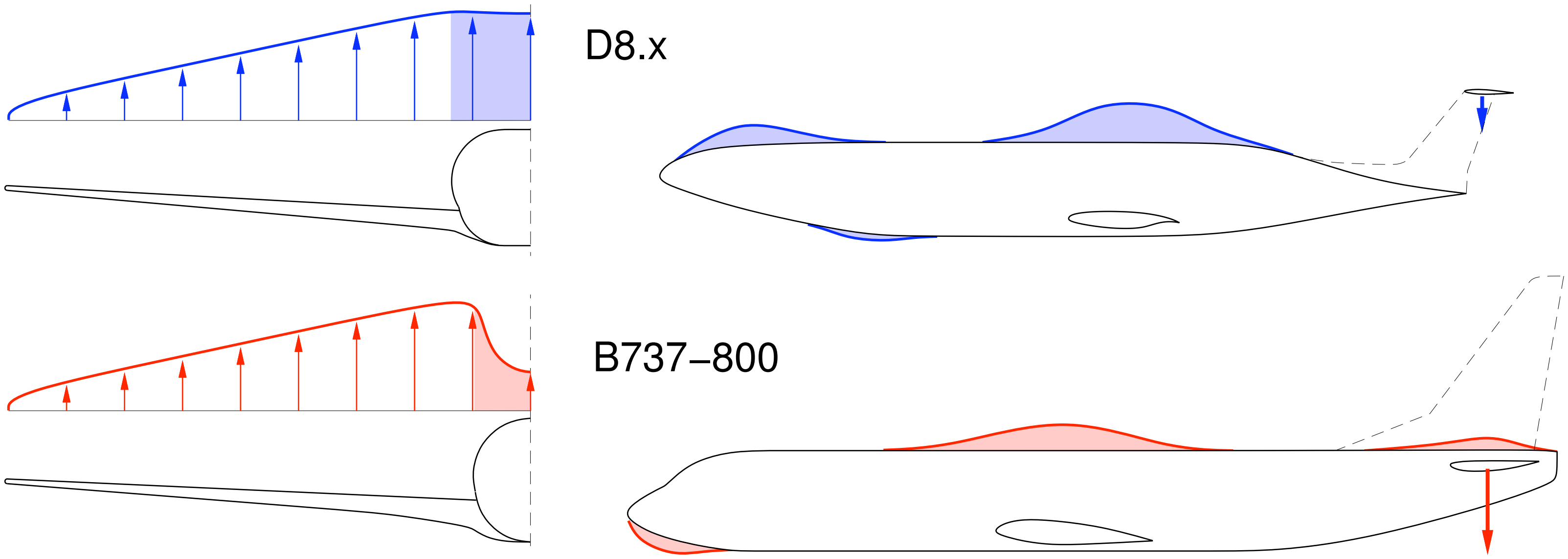
Fuselage Comparison



D8.x Configuration (vs B737)

Lifting nose, rear flat fuselage

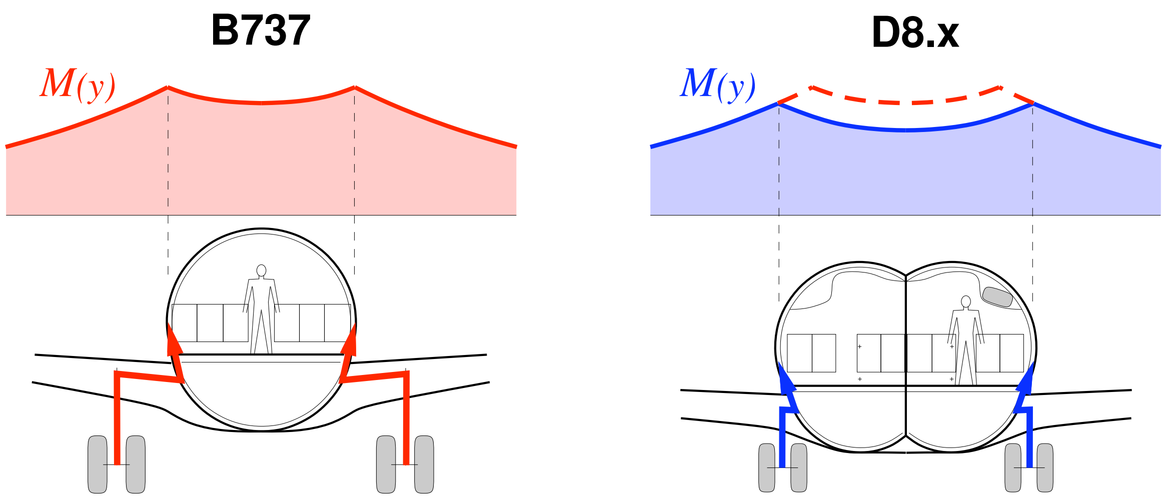
- increased fuselage carryover lift $\longrightarrow$ smaller wing
- built-in nose-up moment from nose lift $\longrightarrow$ smaller tail



D8.x Configuration (vs B737)

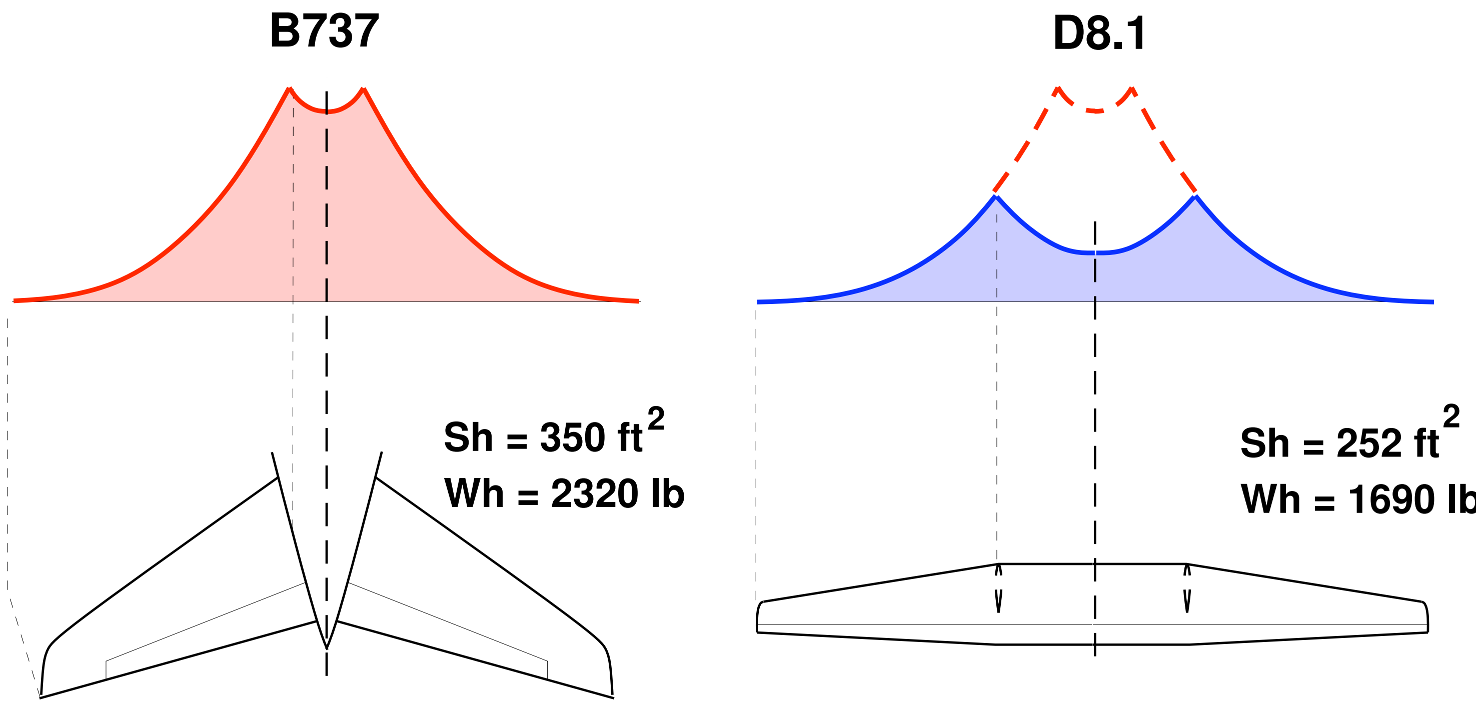
Wide double-bubble fuselage

- partial span loading via 216" wide fuselage (vs 154")
- reduced floor-beam weight via center floor support
- shorter landing gear and load path



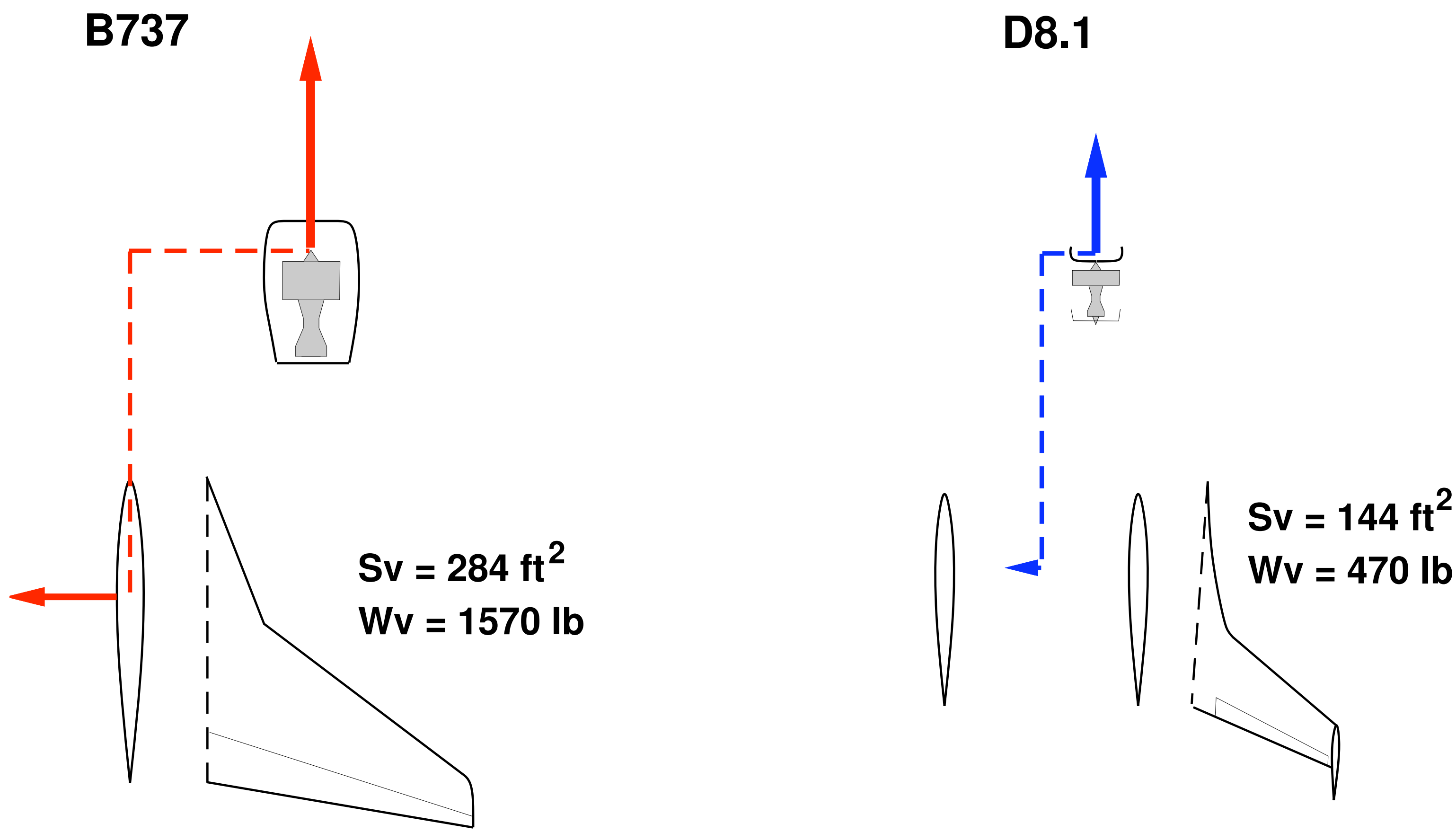
Horizontal Tail Size and Loads Comparison

D8.1 horizontal tail is 28% smaller and 27% lighter.
Two-point support reduces bending moment and weight.



Vertical Tail Size and Loads Comparison

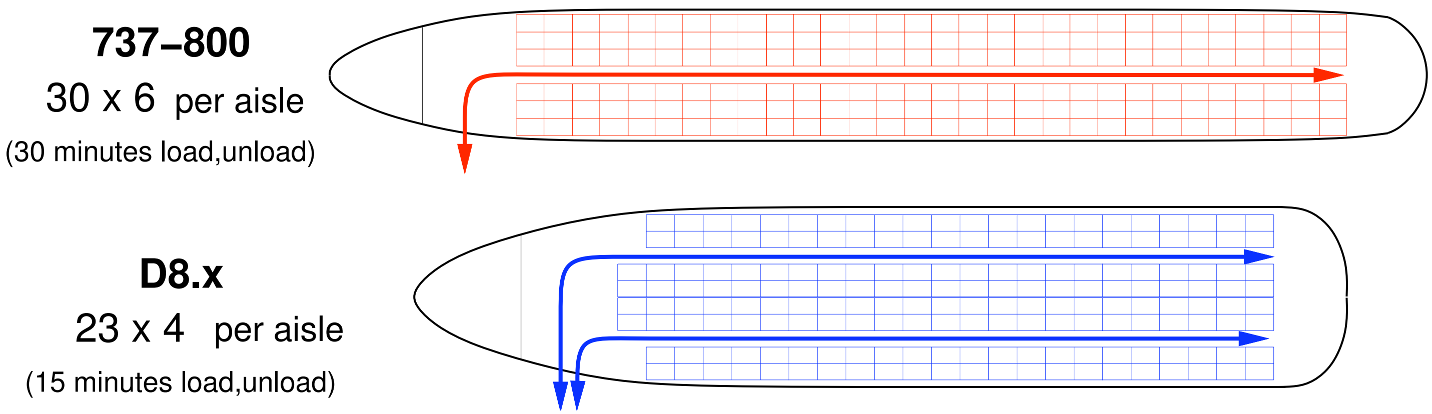
D8.1 vertical tail total is 50% smaller and 70% lighter.
5x smaller engine-out yaw moment no longer sizes the VT.



D8.x Configuration (vs B737)

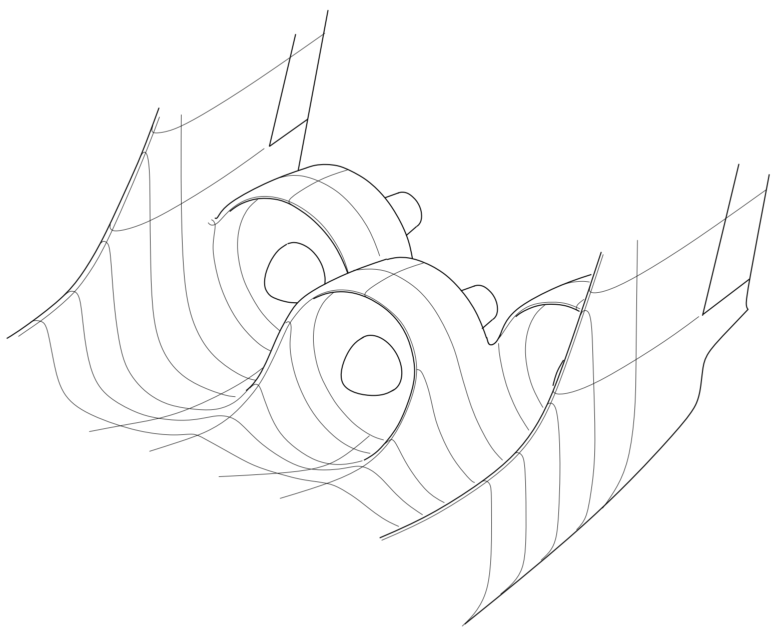
Reduced $M = 0.72$ with unswept wing (vs $M = 0.80$)

- reduced C_{D_i}, via larger AR allowed by unsweep
- LE slat can be eliminated, via increased $C_{L_{\max}}$ from unsweep
- NLF on wing bottom possible, via unsweep and no slat
- faster load/unload of two aisles compensates for slower cruise



D8.x Engine/Tail Configuration

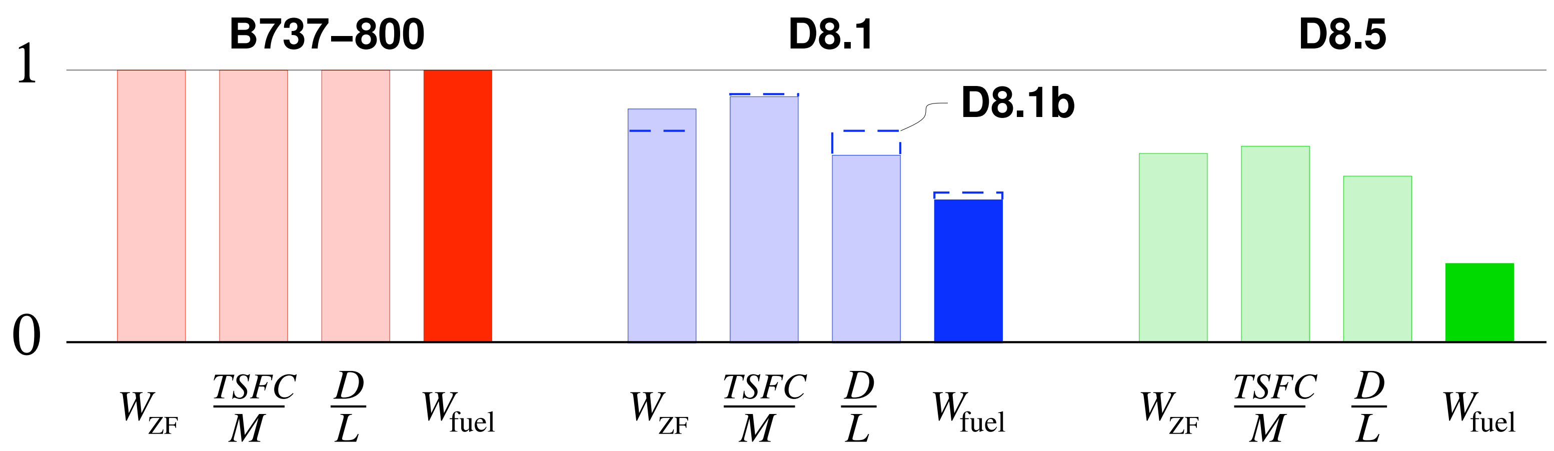
- Rear fuselage and tails function as flow-aligning nacelles
  - greatly reduced nacelle size, weight, drag
  - shield fan faces from ground observers
- Enables low-distortion BLI
  - local potential flow $M \simeq 0.6$ matches fan requirement
  - no additional BL diffusion – no streamwise vorticity into fan
- Fin strakes synergystically exploited:
  - function as pylons carrying engine loads and tail surface loads
  - shield fan faces from ground observers



Breguet Parameter Comparison

$$W_{\text{fuel}} = W_{\text{ZF}} \left[\exp\left(\frac{\mathit{TSFC}}{M} \frac{D}{L} \frac{R}{a} \right) - 1 \right] \simeq W_{\text{ZF}} \frac{\mathit{TSFC}}{M} \frac{D}{L} \frac{R}{a}$$

	737-800	D8.1	D8.1b	D8.5
W_{MTO}	166001	129965	120366	99756
W_{fuel}	38474	20233	21174	11296
W_{ZF}	127528	109732	99192	88460
TSFC/M	0.694	0.628	0.633	0.500
L/D	15.18	22.00	19.53	24.85



Summary

- Examination of entire Airframe+Engine+Ops design space (TASOPT)
- Global optimization for minimum fuel burn
- N+3 D8.x configuration, reduced Mach, give up to 49% fuel burn decrease with conventional technology (45% decrease with 118 ft span constraint)

D8.1 Wind Tunnel Model (20:1, 2.3m span)