D8.x Aircraft Development — Update

Mark Drela

Aero & Astro Presentation

20 Oct 10

NASA's N+3 Program

Chosen Current-Technology Baseline:

B737-800 mission: 3000 nmi, 180 PAX

N+3 Objective:

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

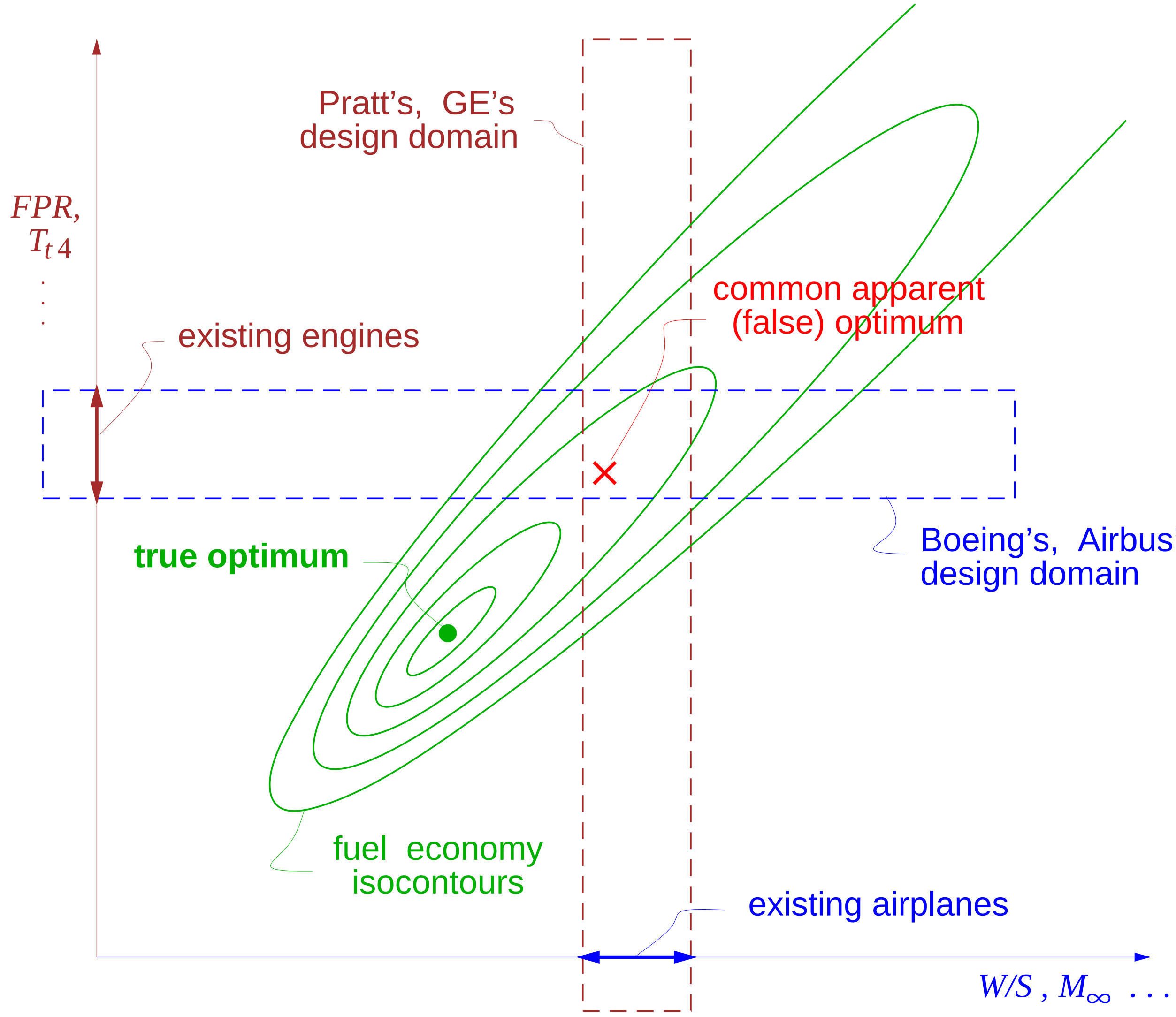
Good bet: Tweaking current designs won't do it

Presentation Outline

- Transport Aircraft System OPTimization (TASOPT)
- D8.x “Double Bubble” transport aircraft concept

TASOPT Objective

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



TASOPT Summary

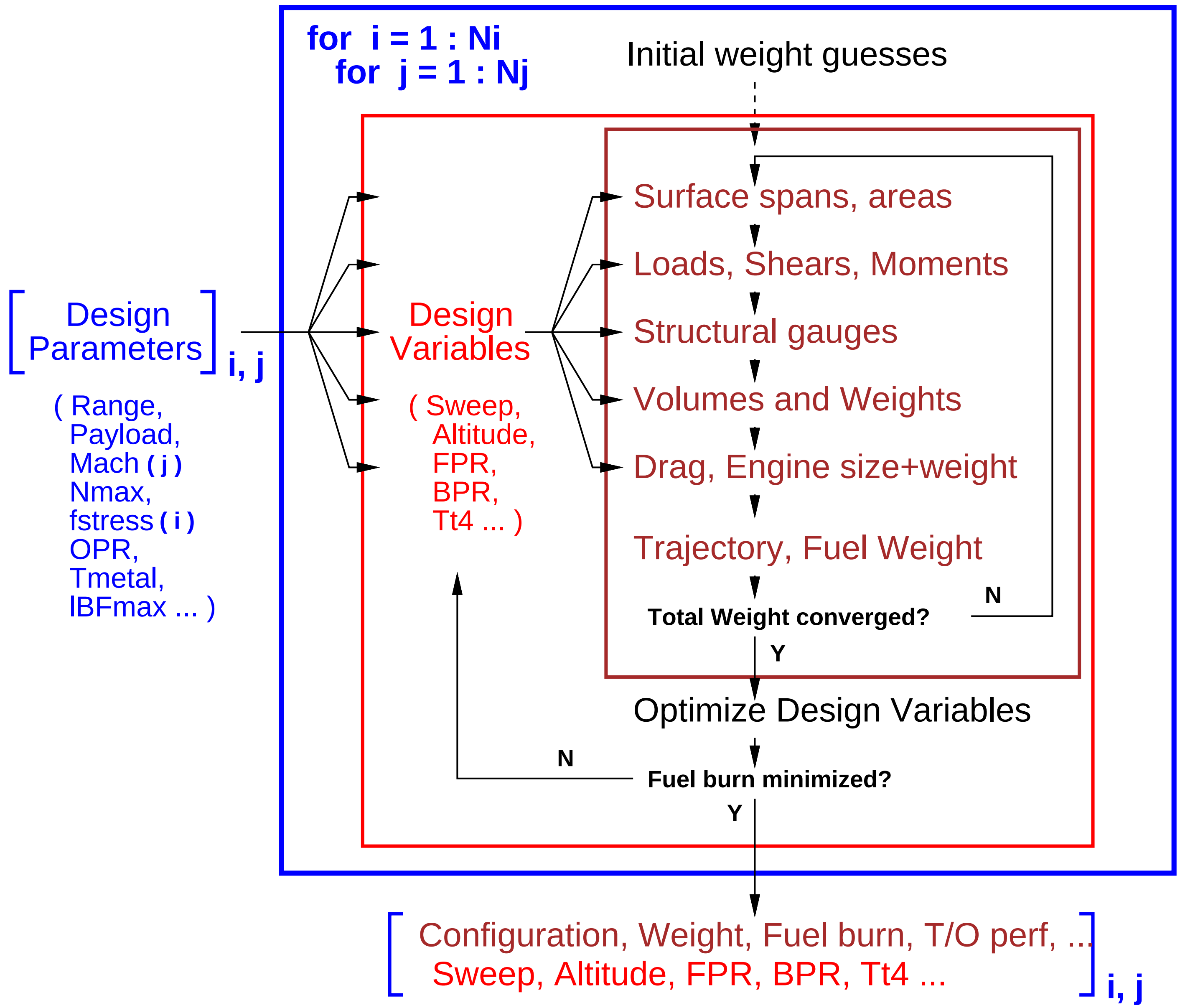
Collection of coupled low-order physical models

- Primary structure
- Aero
- Engine
- Balance, trim, stability
- Flight trajectory

TASOPT Operation

- Inner sizing loop (design closure)
  - Specify design inputs
  - Size airframe via L=W, stresses, stability&trim
  - Size engines via T=D
  - Size fuel burn for design range
  - Iterate on initial weight guesses
- Middle optimization loop
  - Evaluate fuel volume, takeoff performance
  - Tweak chosen subset of inputs (design variables) to minimize fuel burn, with chosen constraints on fuel volume, takeoff, span
  - Back to inner loop
- Outer parameter-sampling loop
  - Explicitly change chosen subset of inputs (design parameters)
  - Back to inner loop

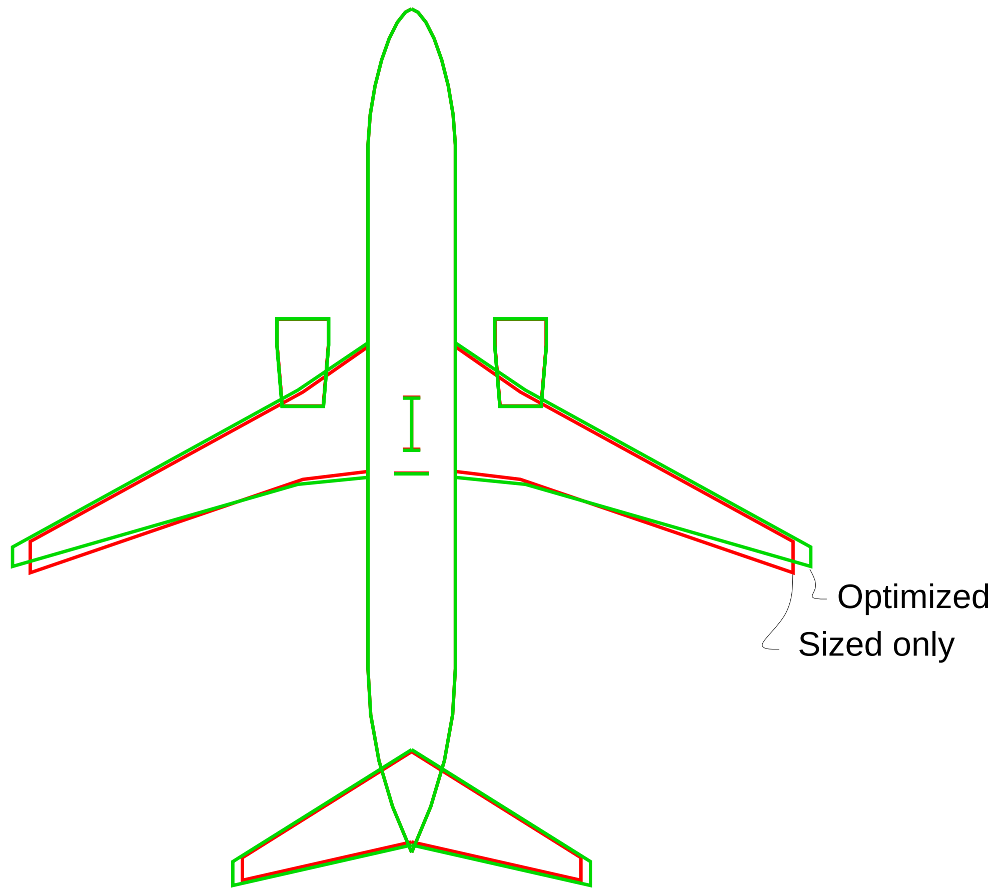
TASOPT Operation



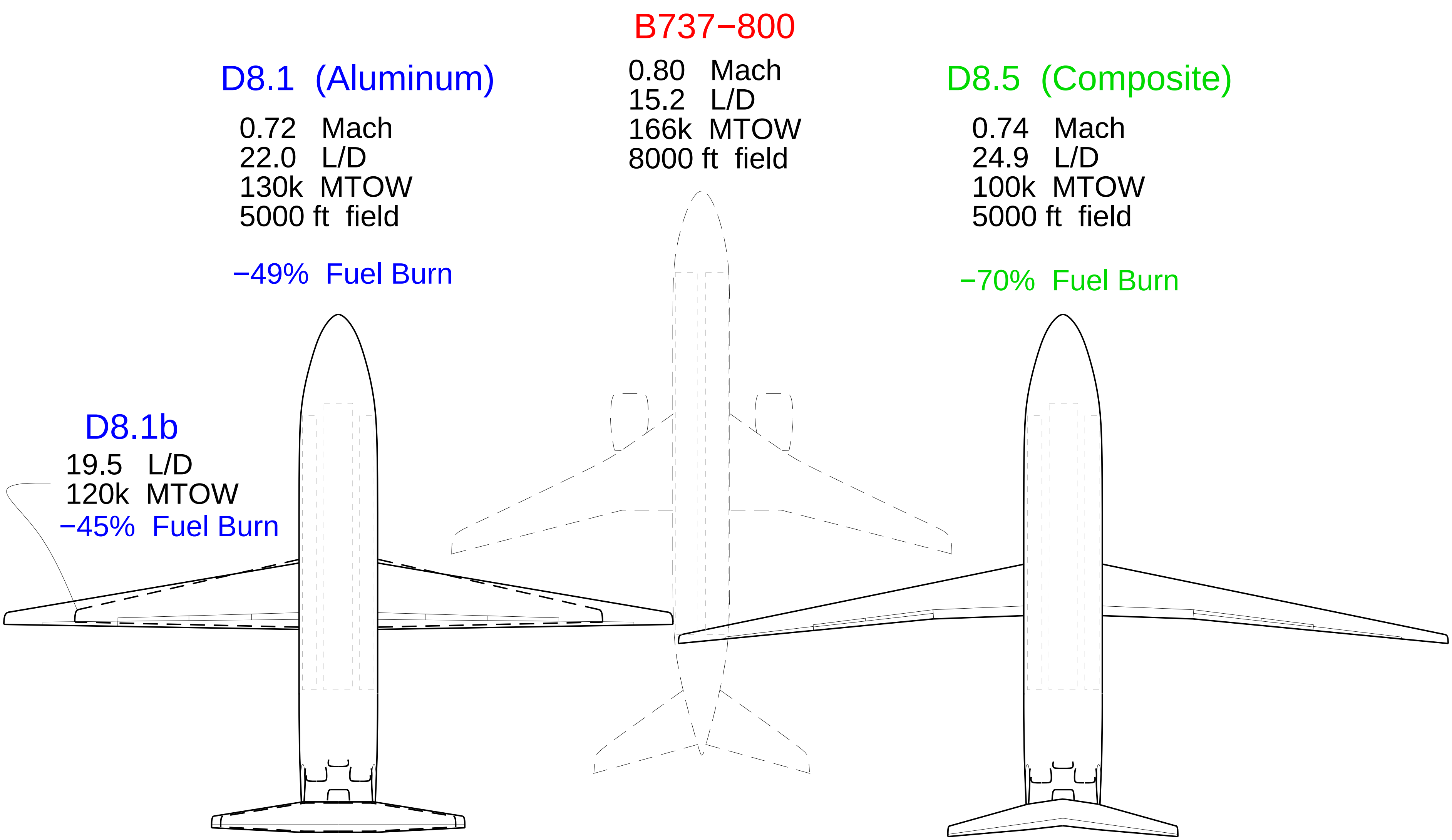
Calibration/Verification

B737-800 Sizing, Airframe+Ops Optimization (fixed engine)

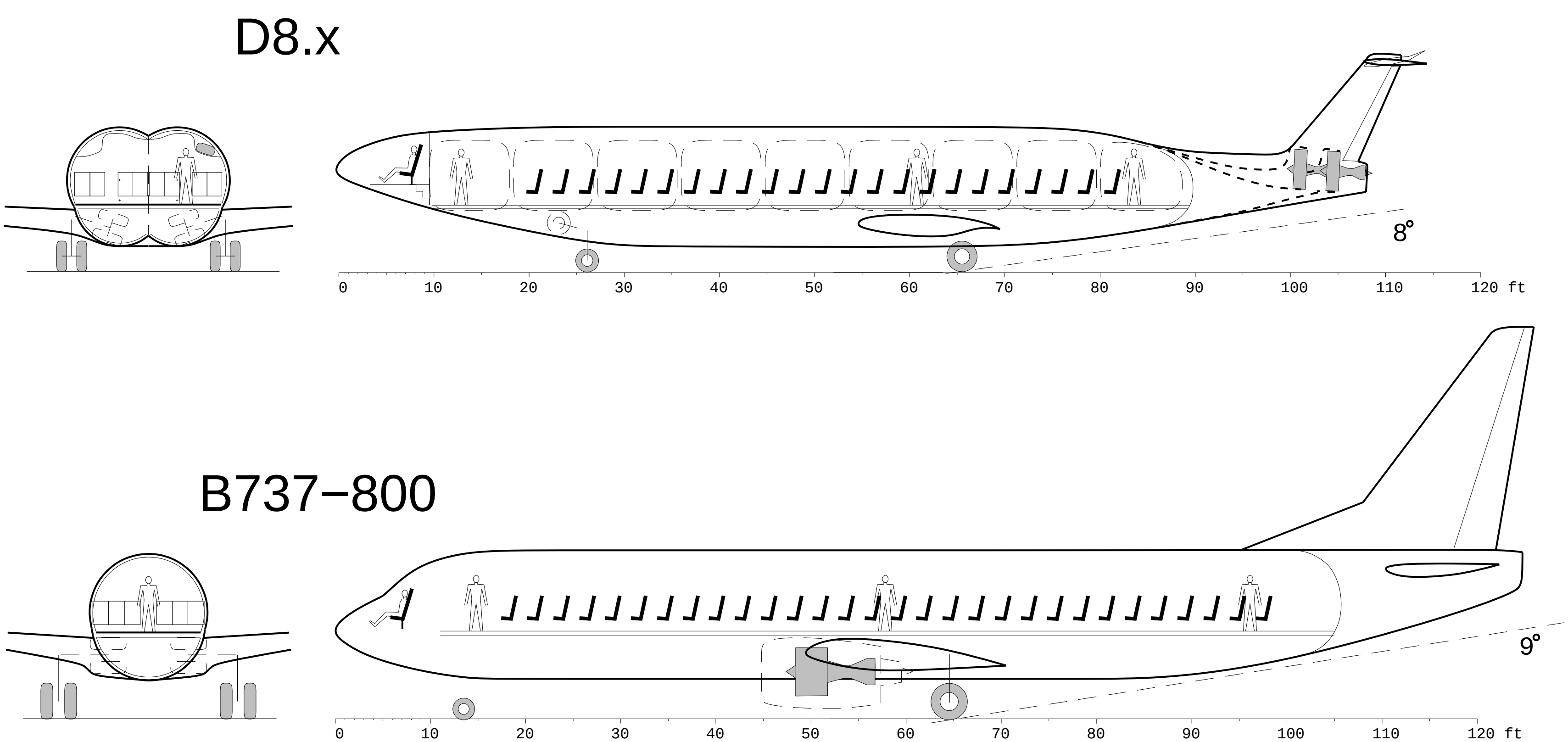
	W_{MTO}	W_{fuel}	S	Λ°	λ_t	AR	$C_{L_{CR}}$	h_{CR}
Actual	171000	39000	1250	25.00	0.250	10.20	0.550	33500
Sized only	166001	38474	1229	25.00	0.250	10.20	0.550	33500
Optimized	163862	36923	1289	24.33	0.144	10.61	0.530	34070



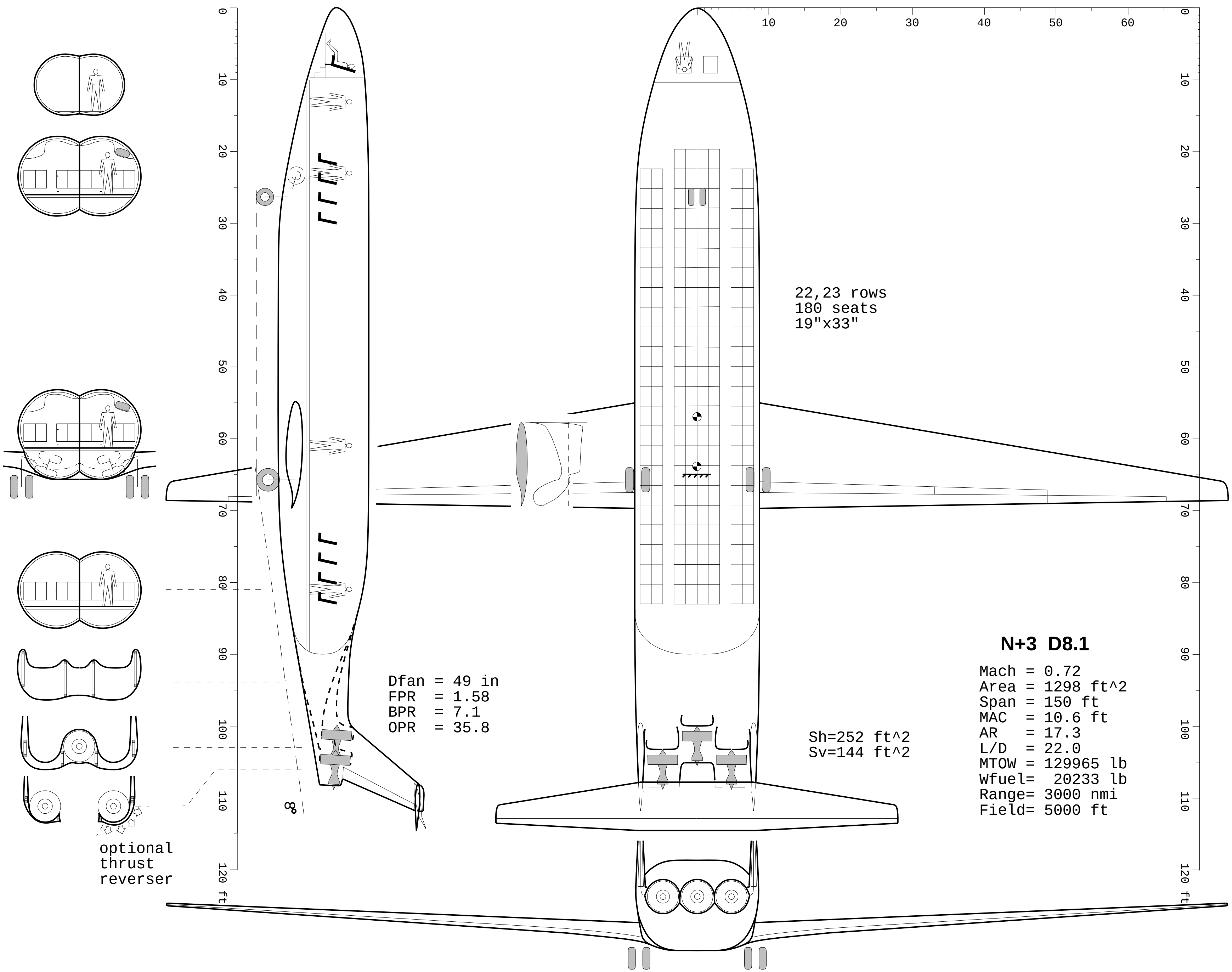
Final N+3 Designs



Fuselage Comparison



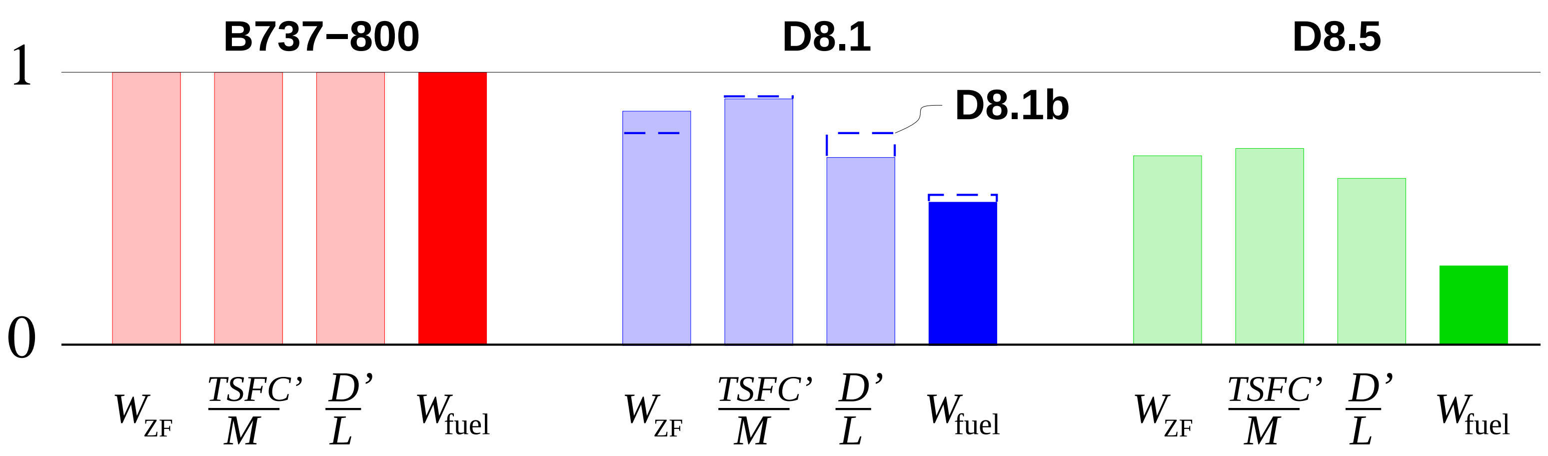
D8.1 Details


22,23 rows
180 seats
19"x33"
Dfan = 49 in
FPR = 1.58
BPR = 7.1
OPR = 35.8
Sh=252 ft^2
Sv=144 ft^2
N+3 D8.1
Mach = 0.72
Area = 1298 ft^2
Span = 150 ft
MAC = 10.6 ft
AR = 17.3
L/D = 22.0
MTOW = 129965 lb
Wfuel= 20233 lb
Range= 3000 nmi
Field= 5000 ft
optional
thrust
reverser
120 ft

Breguet Parameter Comparison

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

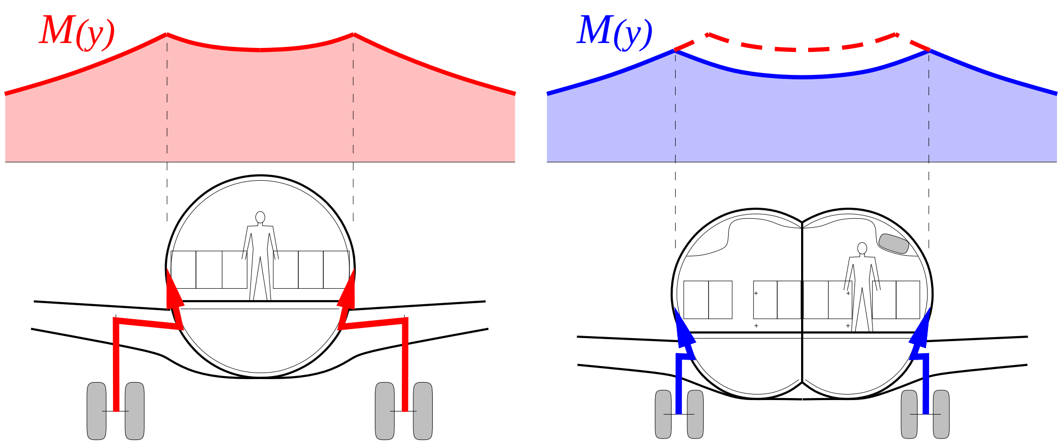
	737-800	D8.1	D8.1b	D8.5
W_{MTO}	166001	129965	120366	99756
W_{fuel}	38474	20233	21174	11296
W_{ZF}	127528	109732	99192	88460
$TSFC'/M$	0.694	0.628	0.633	0.500
L/D'	15.18	22.00	19.53	24.85



D8.x Configuration (vs B737)

Wide double-bubble fuselage

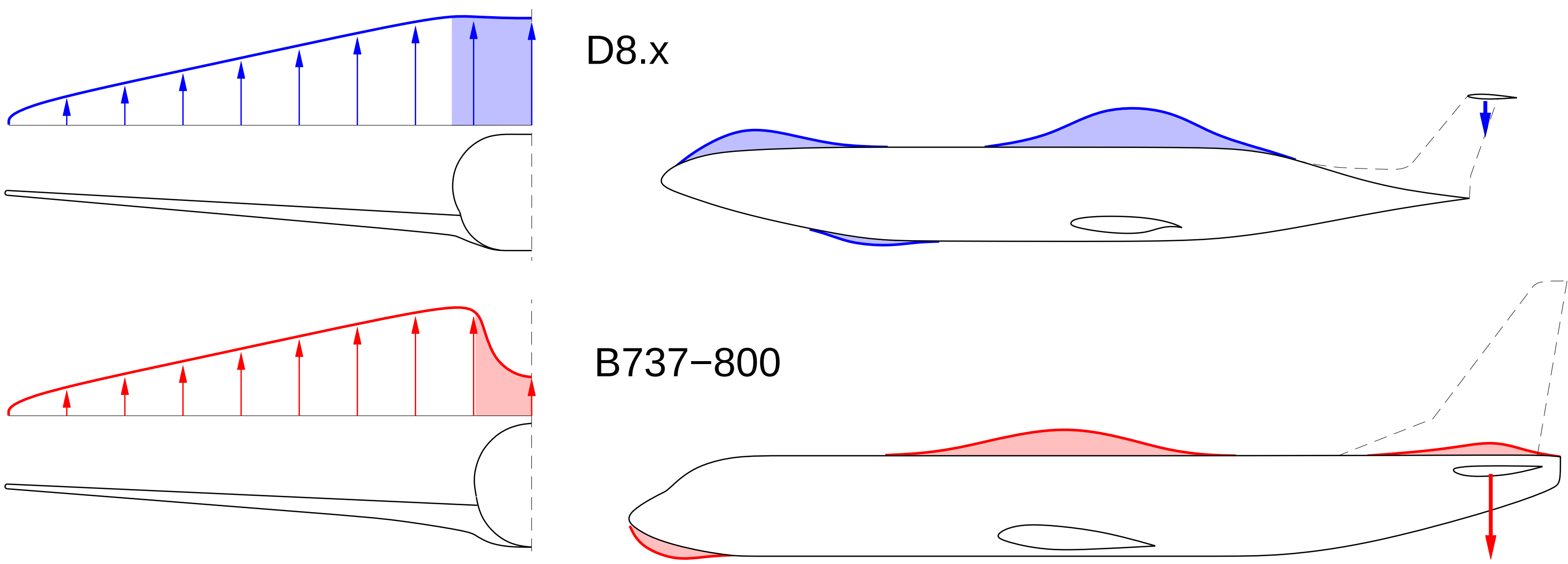
- partial span loading via 216" wide fuselage (vs 154")
- reduced floor-beam weight via center floor support
- shorter landing gear and load path



D8.x Configuration (vs B737)

Lifting nose, rear flat fuselage

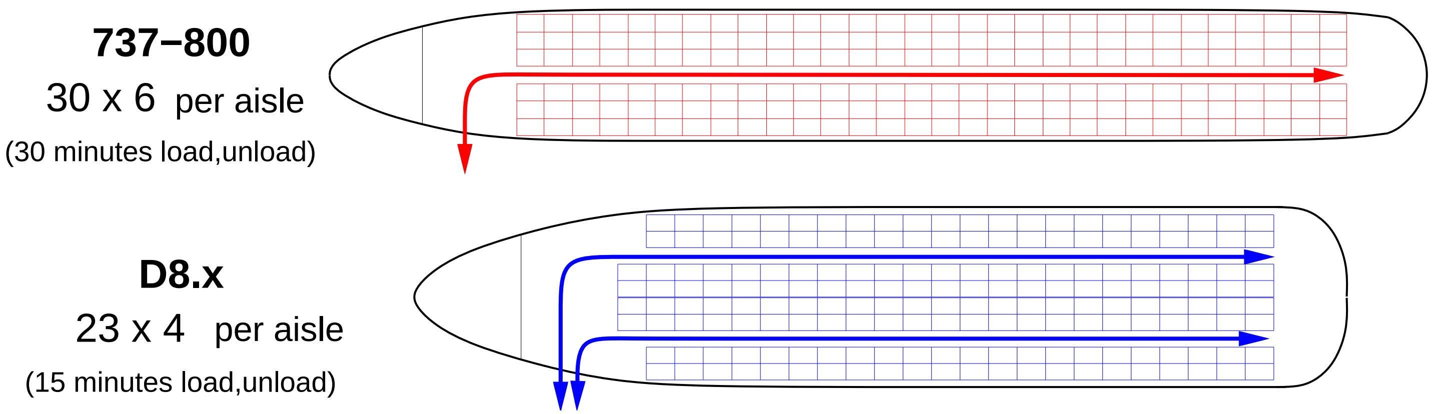
- increased fuselage carryover lift $\rightarrow$ smaller wing
- built-in nose-up moment from nose lift $\rightarrow$ smaller tail



D8.x Configuration (vs B737)

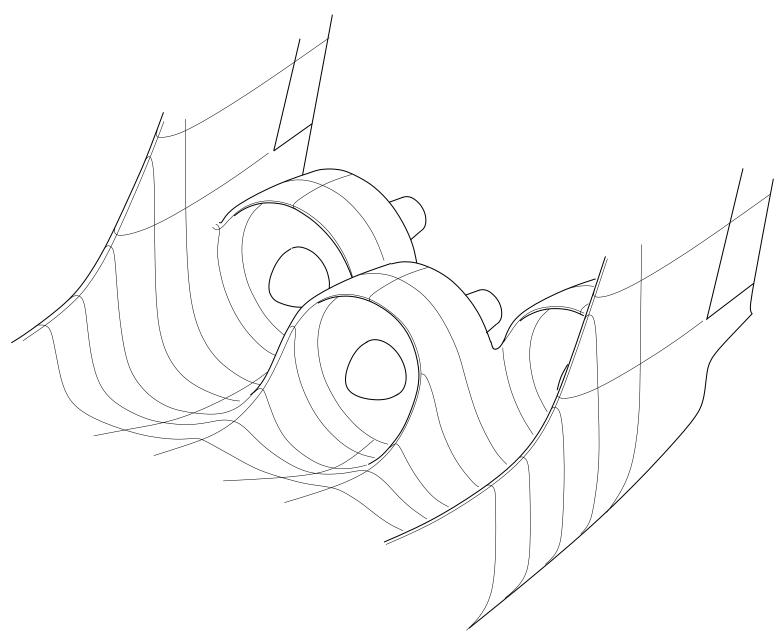
Reduced $M = 0.72$ with unswept wing (vs $M = 0.80$)

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



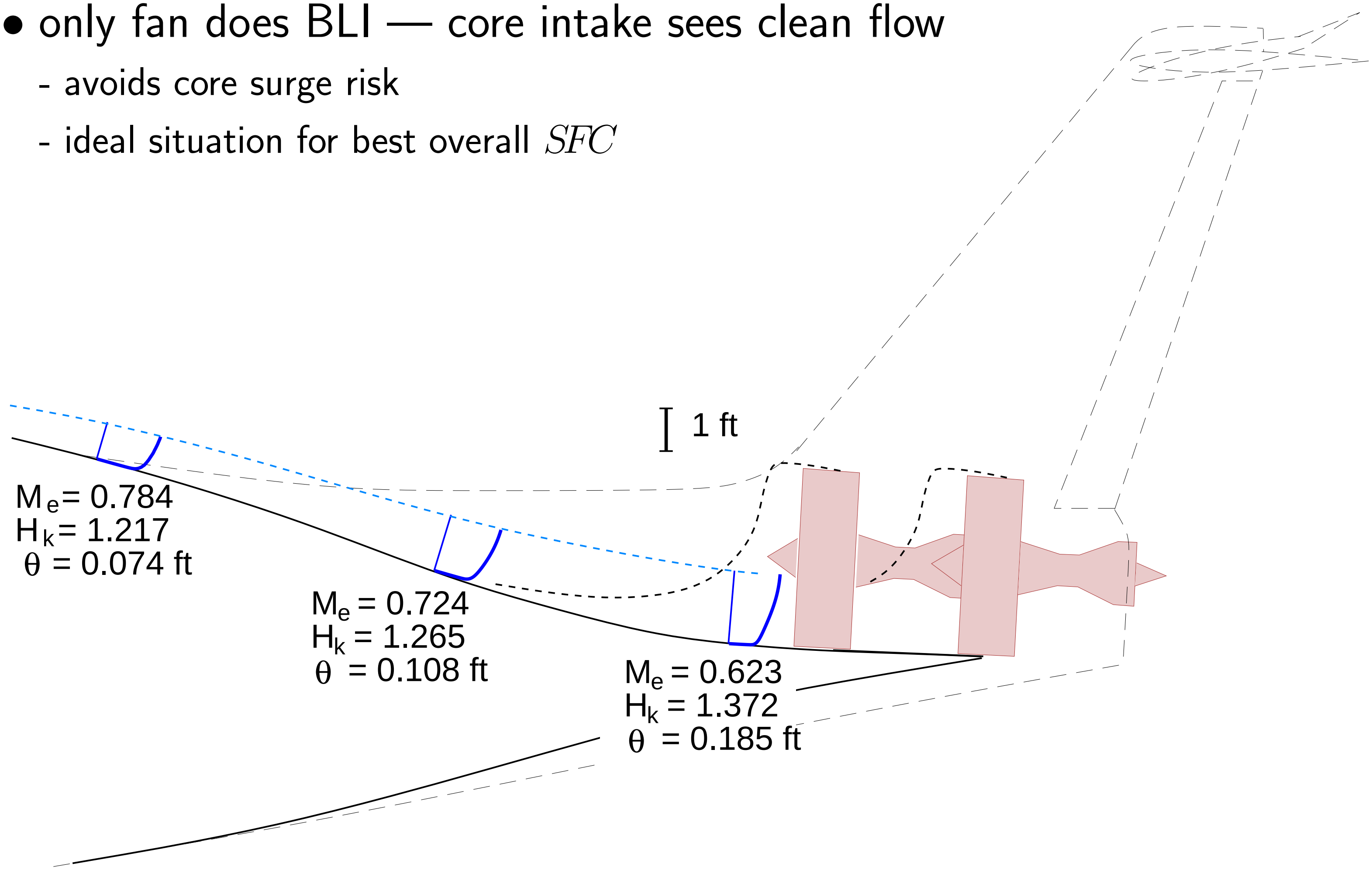
D8.x Engine/Tail Configuration

- Rear fuselage and tails double as flow-aligning nacelles
  - only minimal nacelles needed
  - shield fan faces from ground observers
- Provides Boundary Layer Ingestion (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



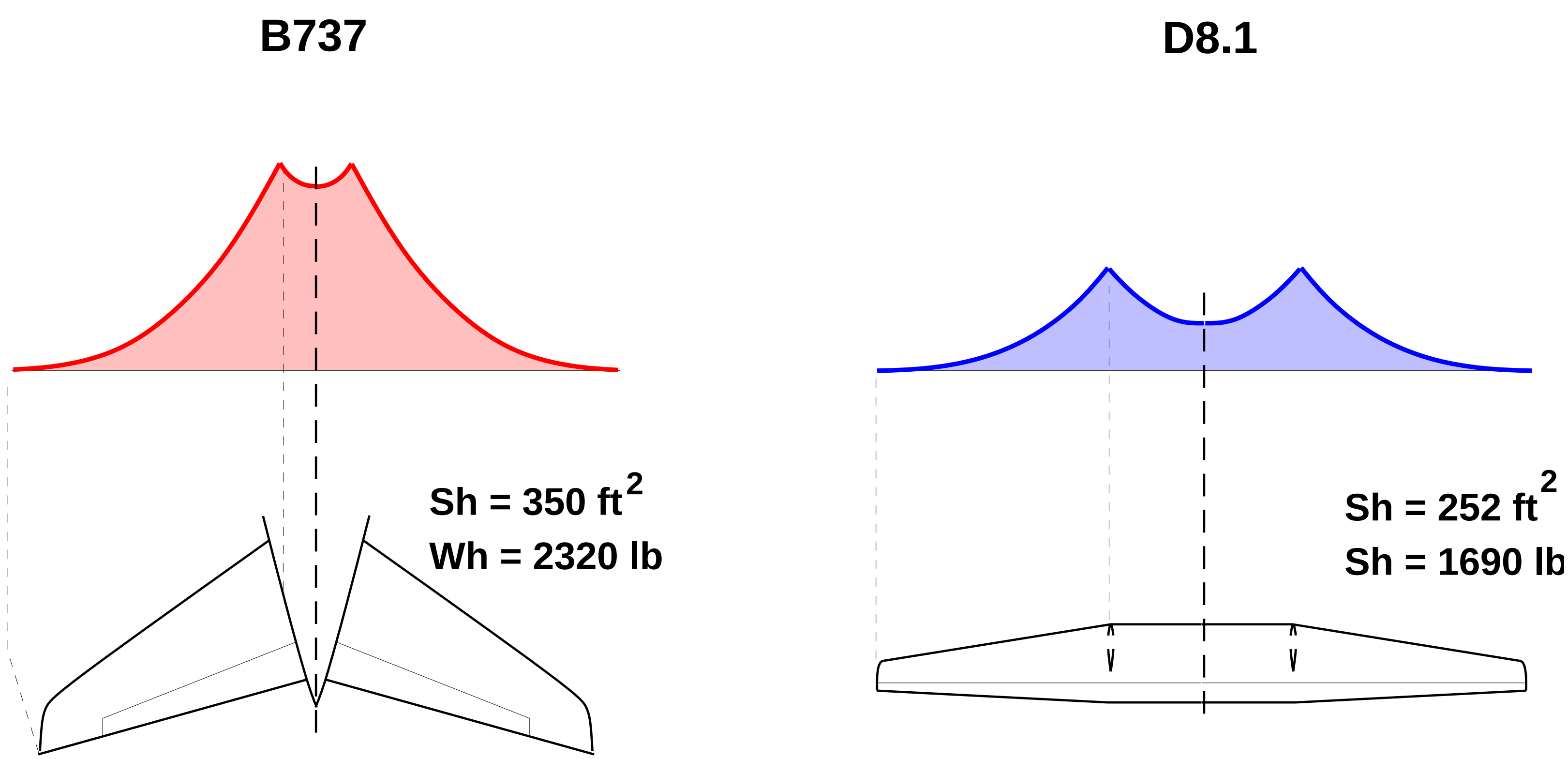
D8.1 BL Profiles at Cruise

- local potential flow $M \simeq 0.6$ matches fan requirement
- little nacelle diffusion – no streamwise vorticity into fan
- only fan does BLI — core intake sees clean flow
  - avoids core surge risk
  - ideal situation for best overall SFC



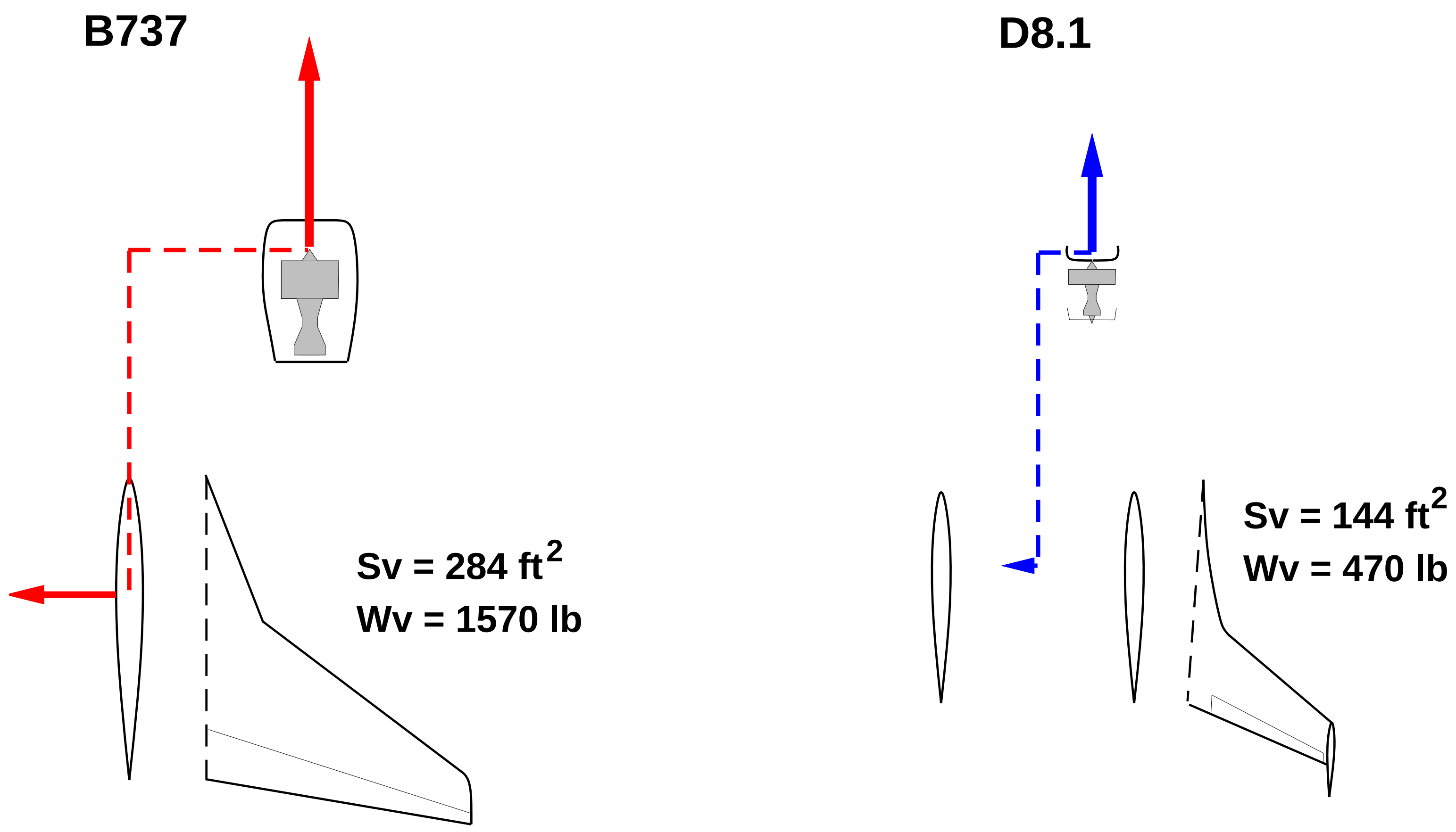
Tail Size and Loads Comparison

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



Tail Size and Loads Comparison

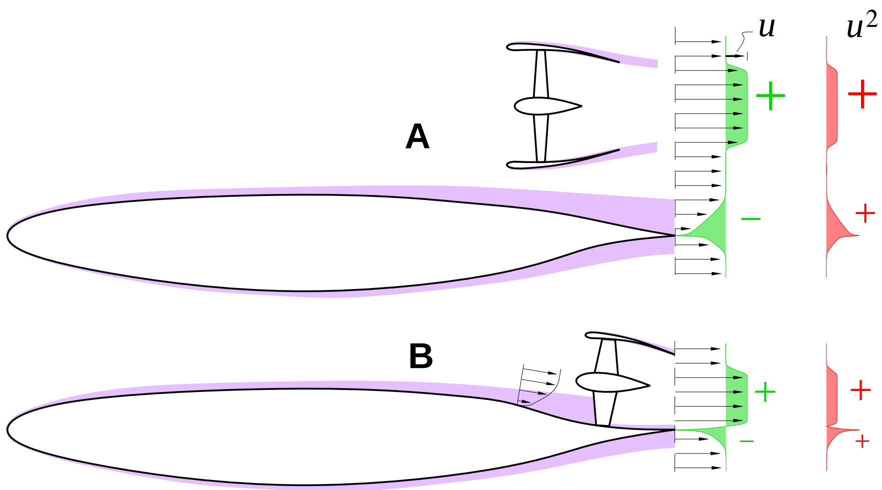
D8.1 vertical tail total is 50% smaller and 70% lighter.
5x smaller engine-out yaw moment no longer sizes the VT.



Optimum-Engine "Surprises"

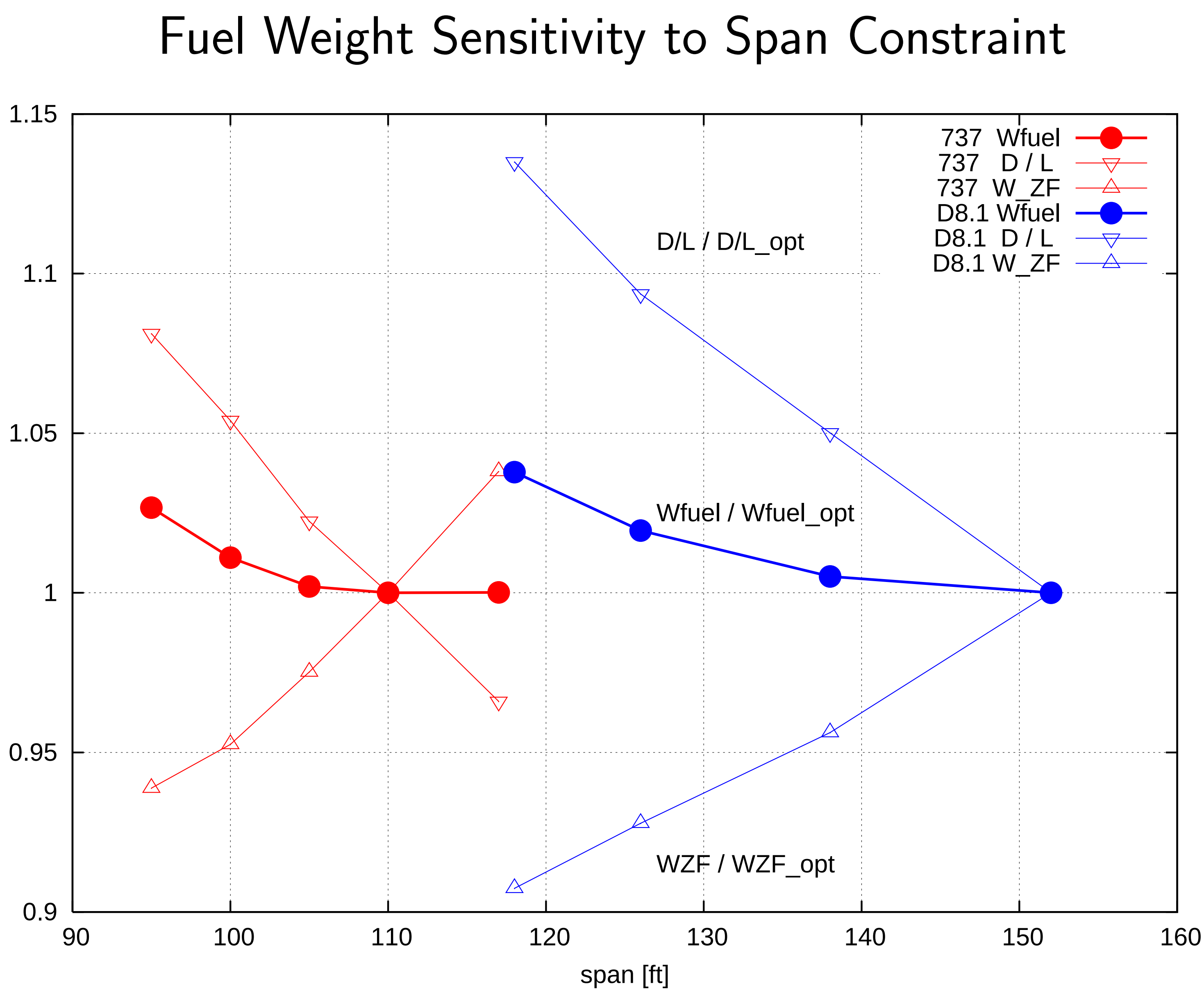
- Optimized takeoff turbine inlet temperature is modest
  $\rightarrow$ Excessive takeoff $T_{t\,4}$ carries cooling-flow penalty in cruise
- Optimized Bypass Ratio and Fan Pressure Ratio are modest
  $\rightarrow$ BLI favors smaller engine and higher fan loading

	D8.1	GE90
$T_{t\,4_{TO}}$	$1543°$ K	$1770°$ K
BPR	7.1	9.0
FPR	1.58	1.50



$$\sum \dot{m}\ u \;=\; (F_{net})_B = (F_{net})_A$$

$$\sum \dot{m}\ \tfrac{1}{2}u^2 \;=\; (\dot{E}_{jet})_B < (\dot{E}_{jet})_A$$

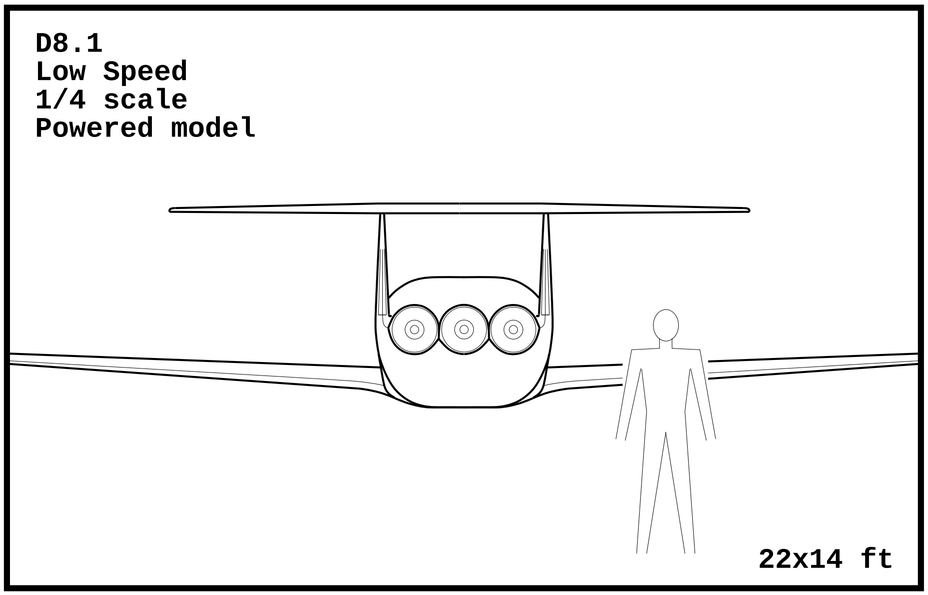

Fuel Weight Sensitivity to Span Constraint
1.15
1.1
1.05
1
0.95
0.9
90
100
110
120
130
140
150
160
span [ft]
737 Wfuel
737 D / L
737 W_ZF
D8.1 Wfuel
D8.1 D / L
D8.1 W_ZF
D/L / D/L_opt
Wfuel / Wfuel_opt
WZF / WZF_opt

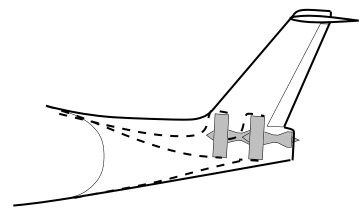
Summary

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

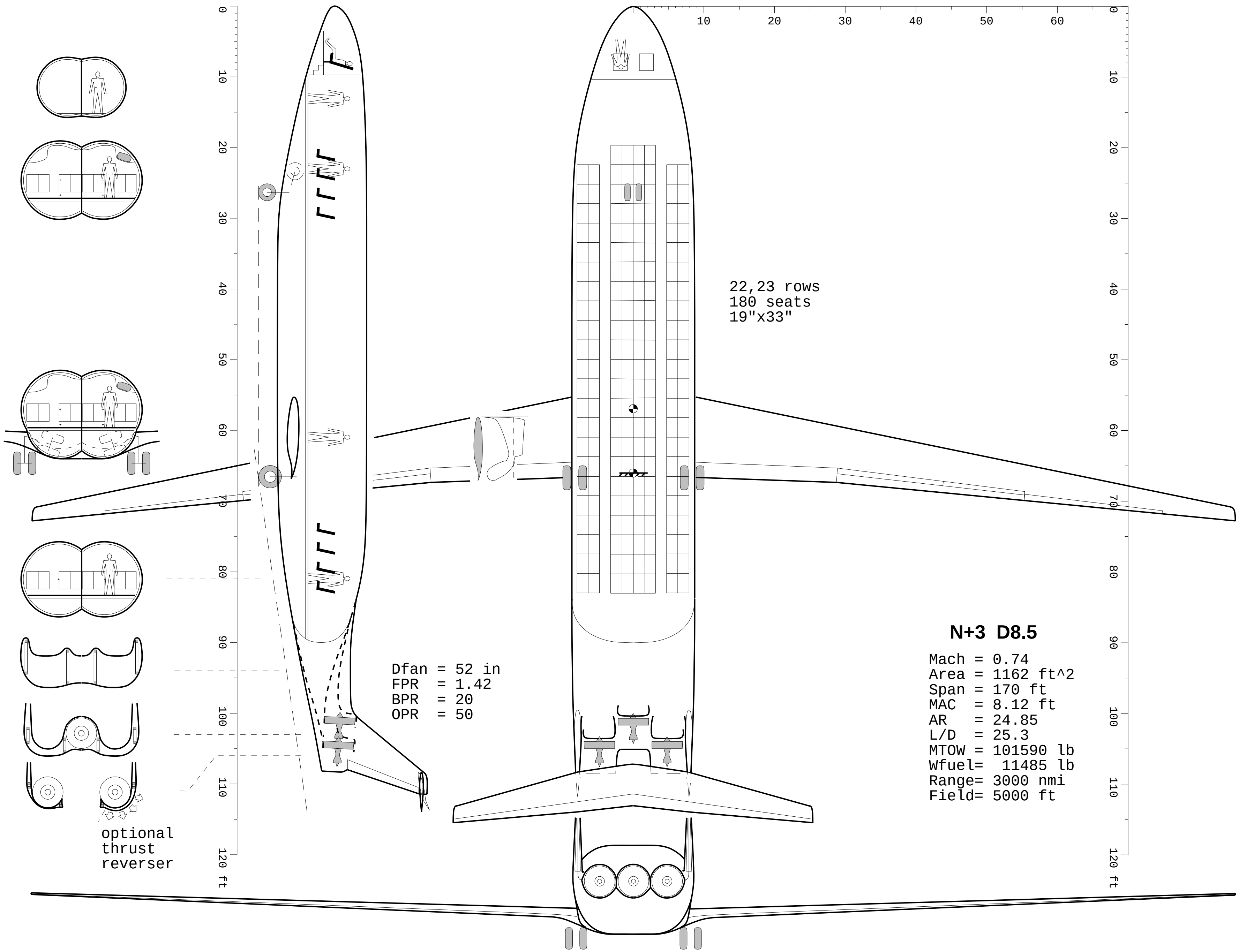
N+3 Phase II

- Detailed design of rear fuselage/engine installation
- Test 1:4 powered model of fuselage + stub wings
- Investigate performance of small-core engines (Pratt)



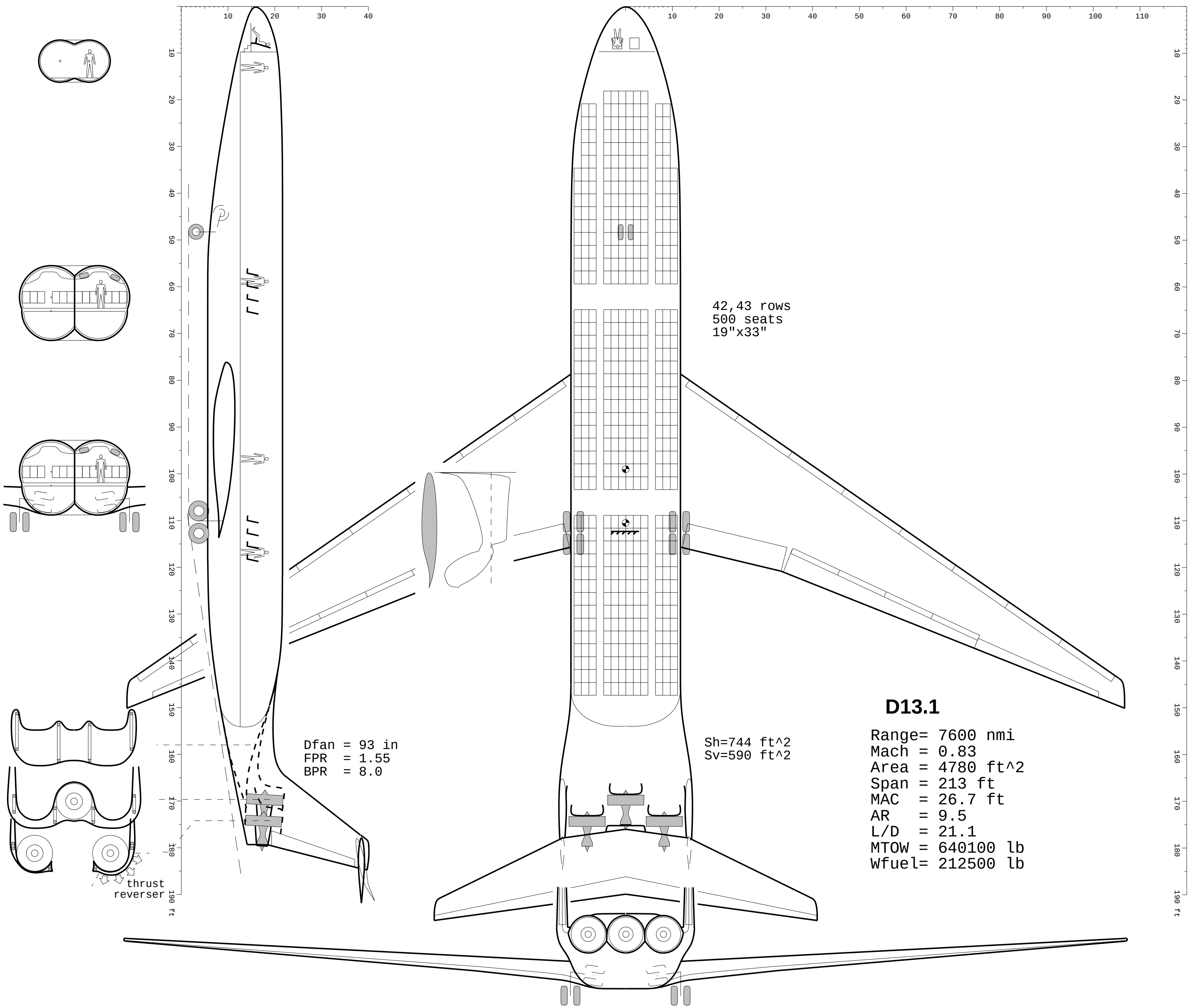


D8.5 Details

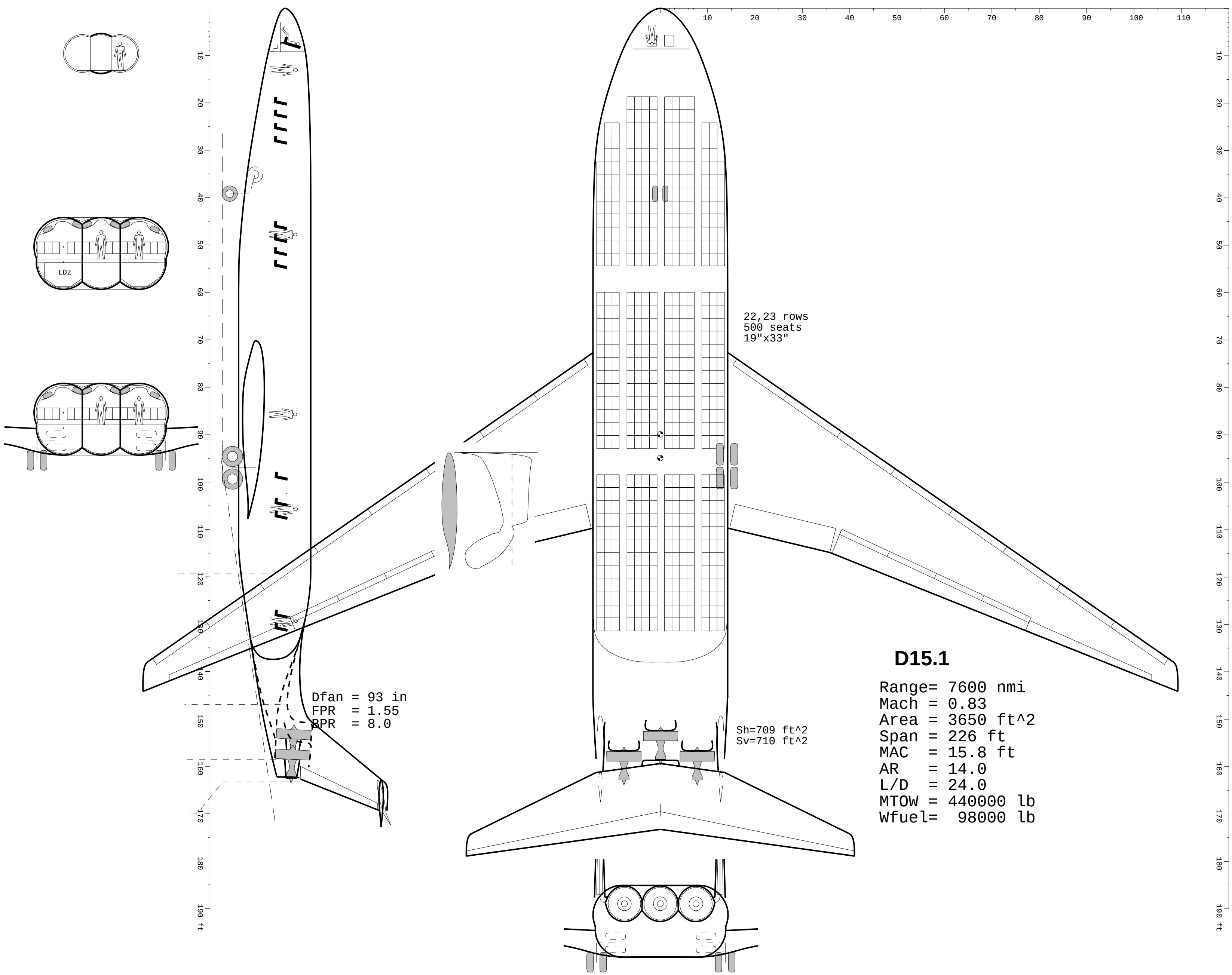


0
10
20
30
40
50
60
70
80
90
100
110
120 ft
22,23 rows
180 seats
19"x33"
Dfan = 52 in
FPR = 1.42
BPR = 20
OPR = 50
N+3 D8.5
Mach = 0.74
Area = 1162 ft^2
Span = 170 ft
MAC = 8.12 ft
AR   = 24.85
L/D = 25.3
MTOW = 101590 lb
Wfuel= 11485 lb
Range= 3000 nmi
Field= 5000 ft
optional
thrust
reverser

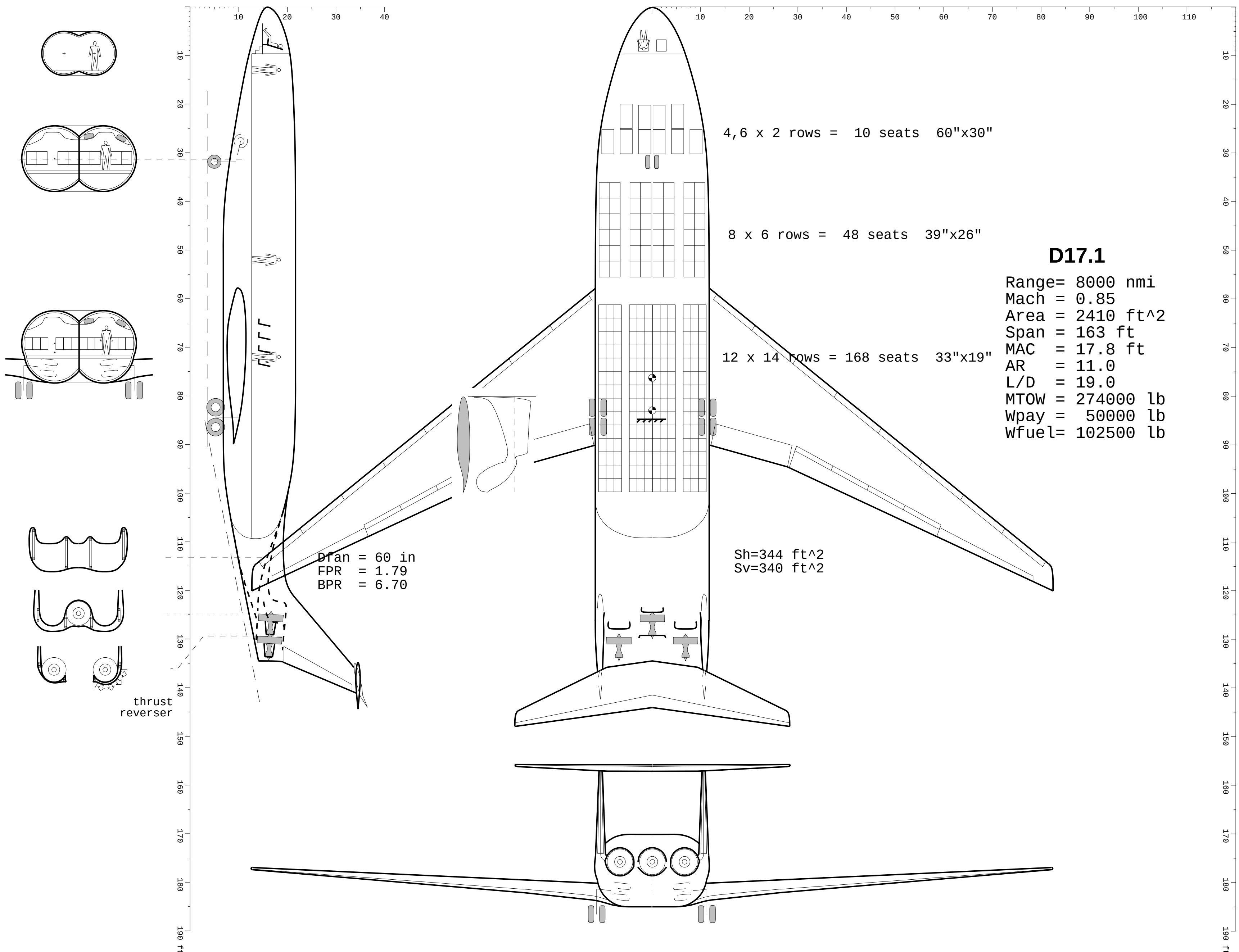
D13.1 (777 size, M=0.72, 1-class, Aluminum)



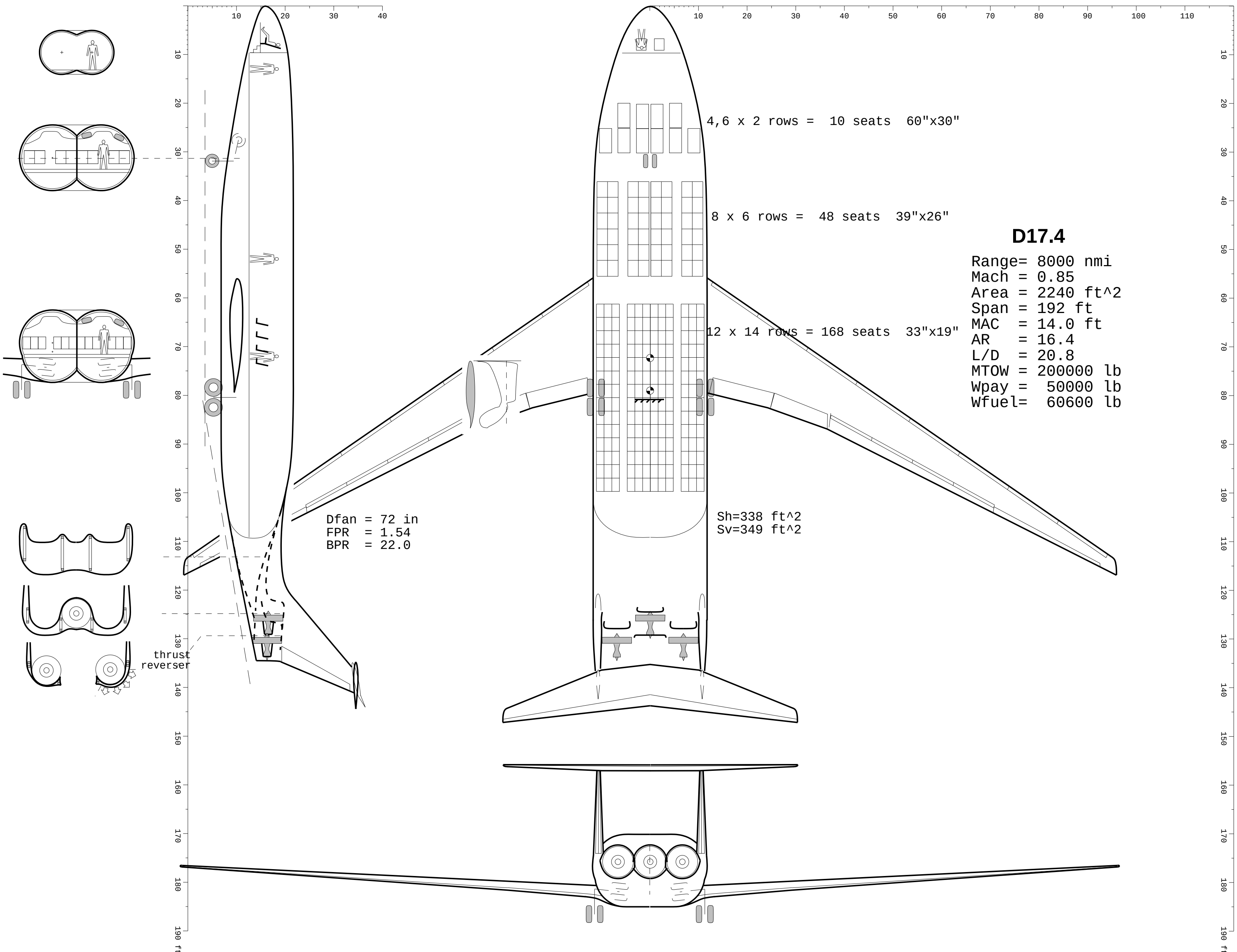
D15.1 (777 size, M=0.83, 1-class, 3-aisle, Aluminum)



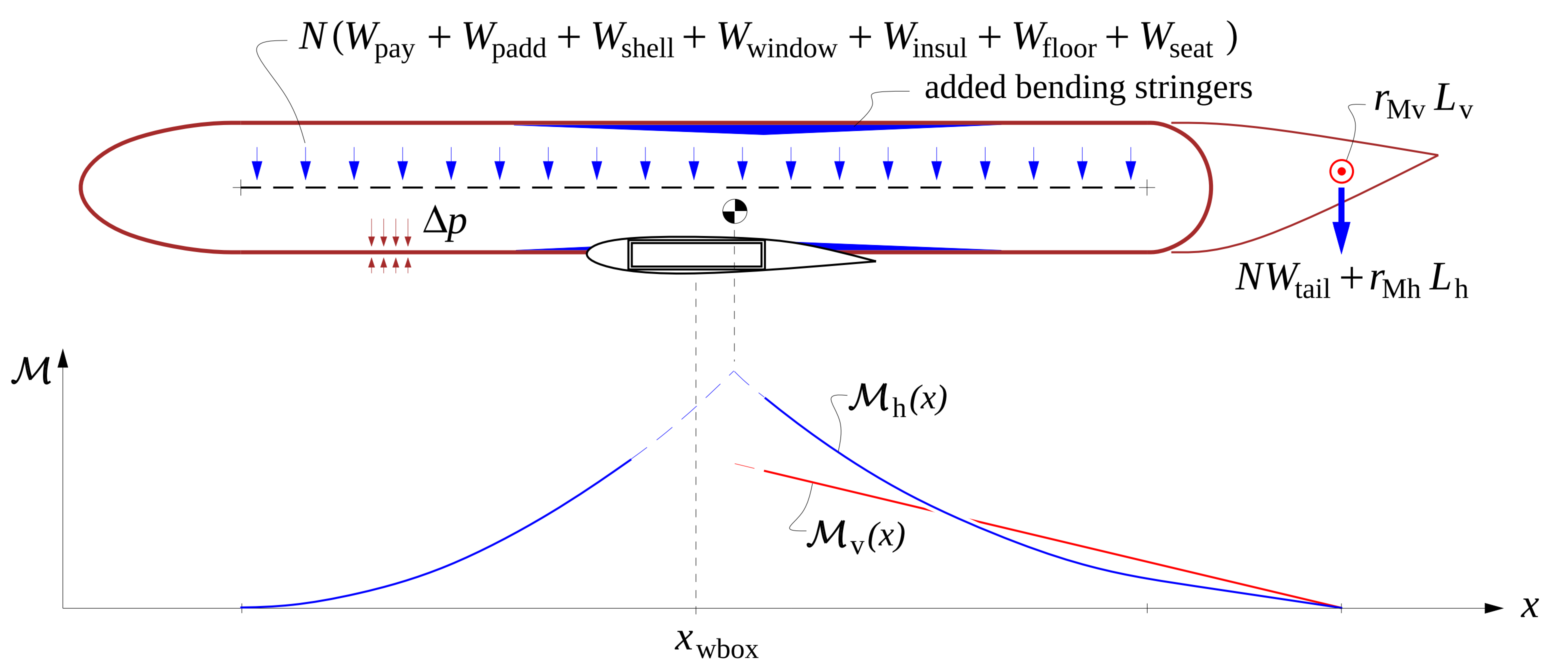
D17.1 (787 size, M=0.85, 3-class, Aluminum)



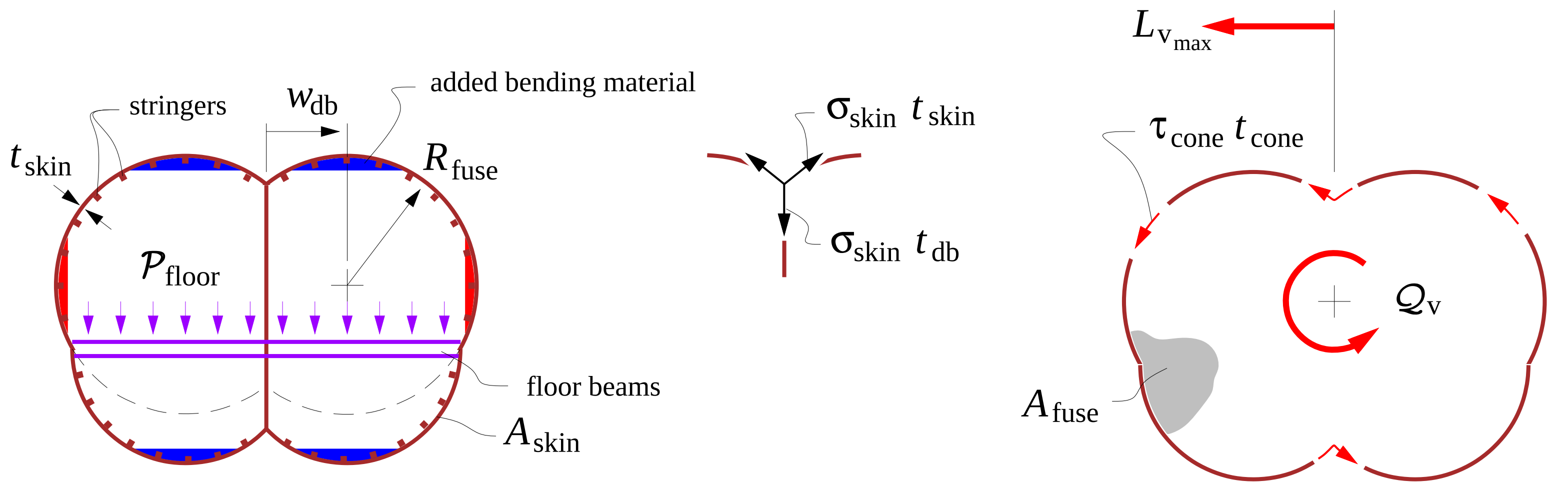
D17.4 (787 size, M=0.85, 3-class, Composite)



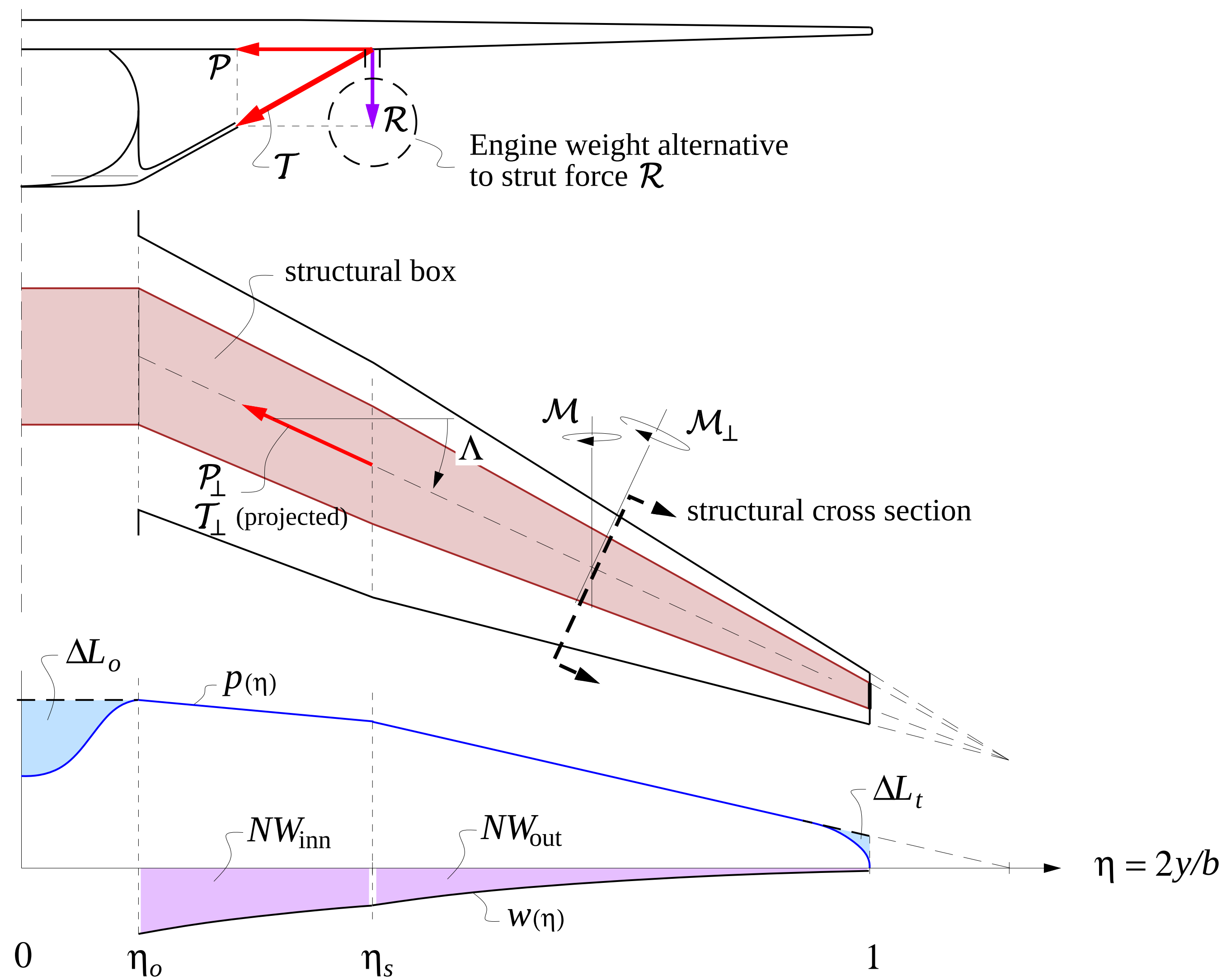
TASOPT Fuselage Loading Model



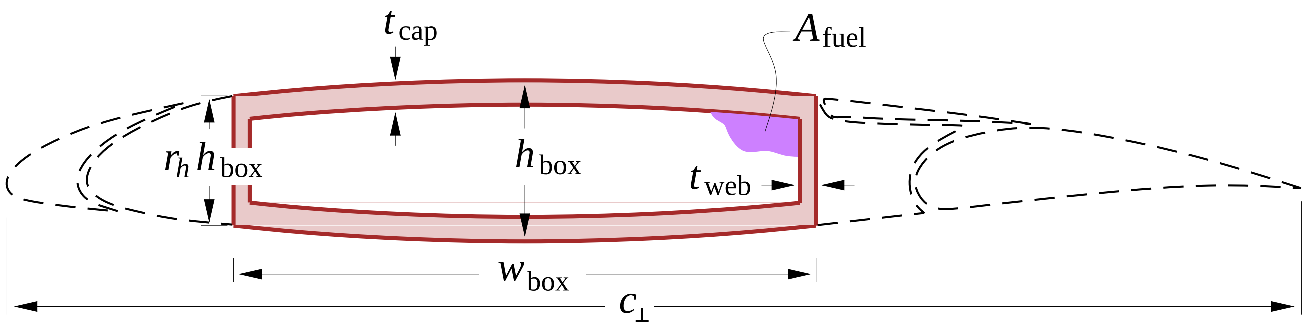
TASOPT Fuselage Section Model



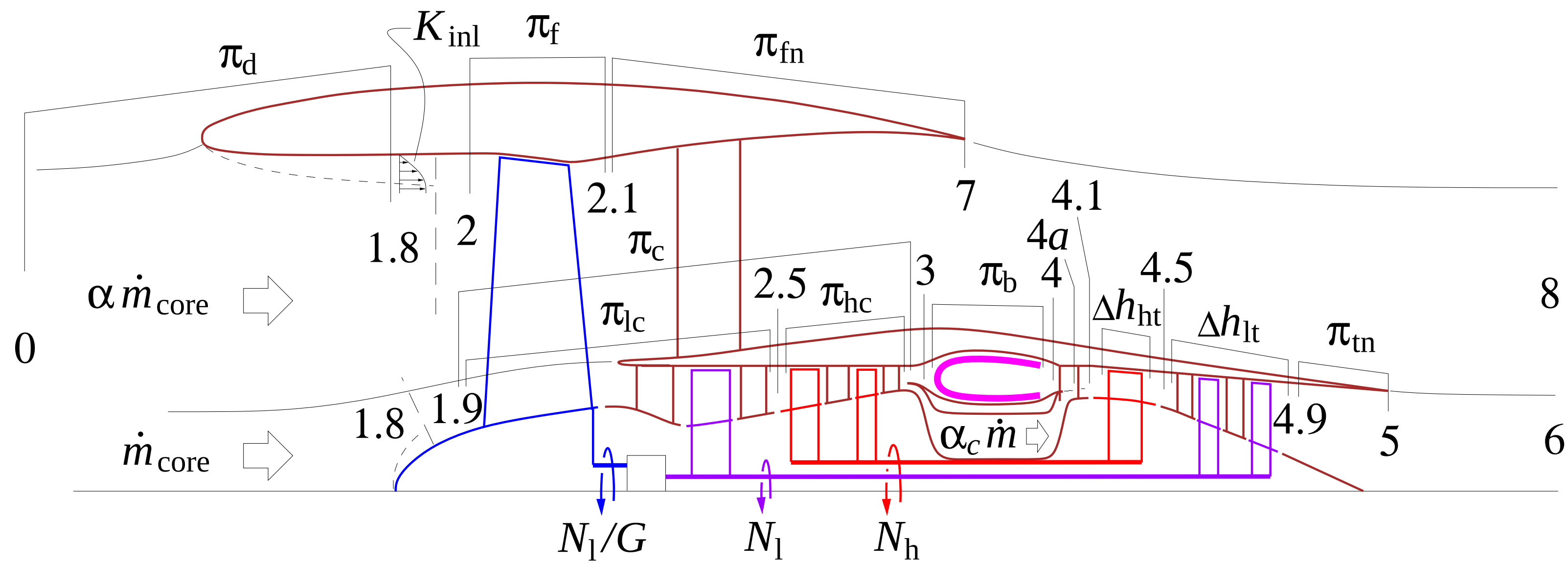
TASOPT Wing Geometry and Loading Model



TASOPT Wingbox Section Model



TASOPT Engine Model



TASOPT Fuselage Drag Model