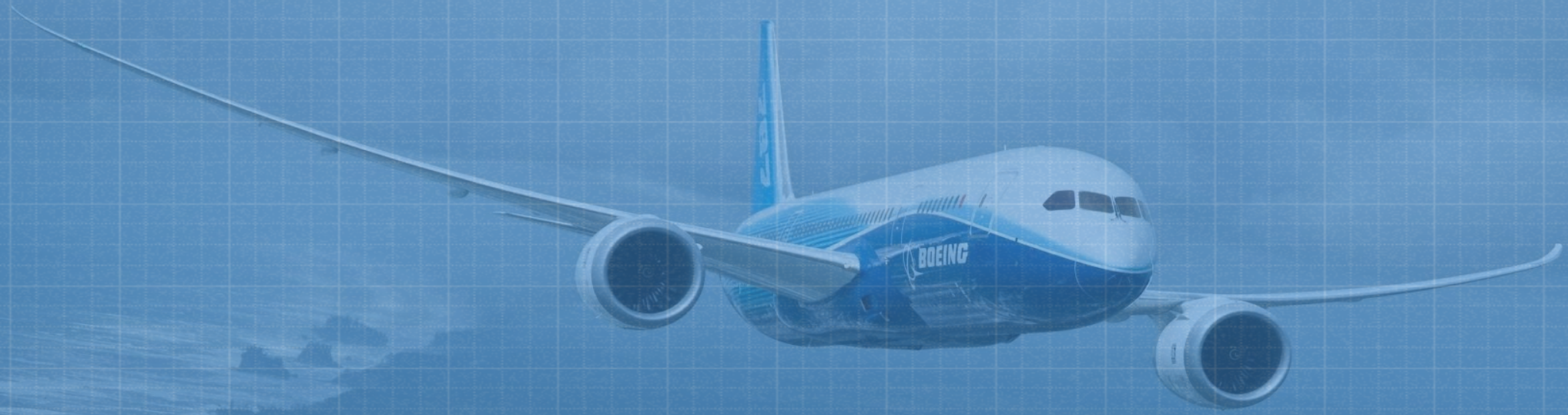


Design Lab

Boeing 787-8 Modifications

Group 9:

Forrest Barnes, Chris Leighton, Michael Patterson, Nicholas Renninger

Presentation Outline

- Forrest Barnes: Characterizing the 787-8
- Chris Leighton: Weight Sensitivity Analysis
- Nicholas Renninger: Summary and Conclusions
- Michael Patterson: Changing Mission Specifications

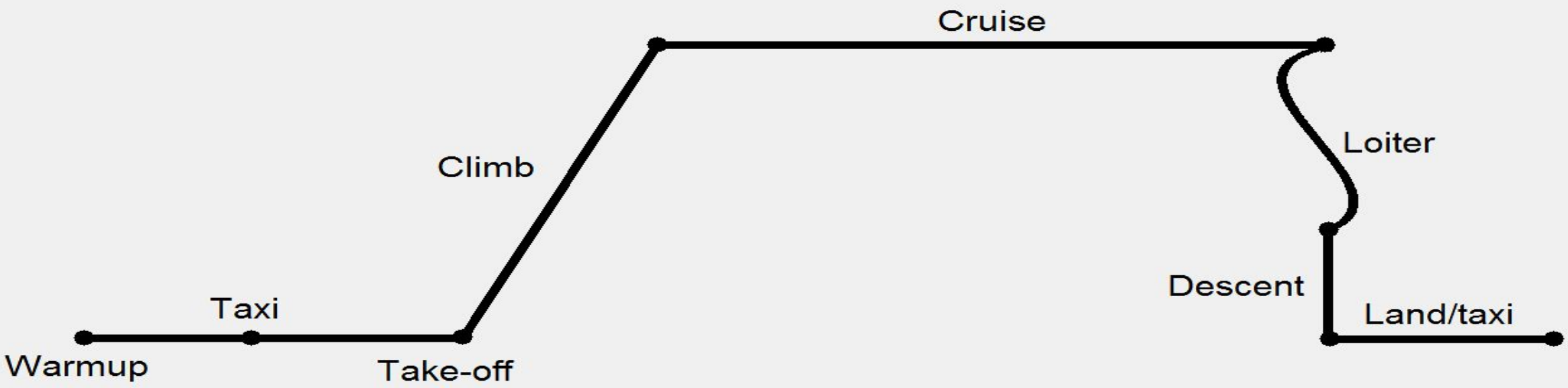
1

Characterizing the 787-8

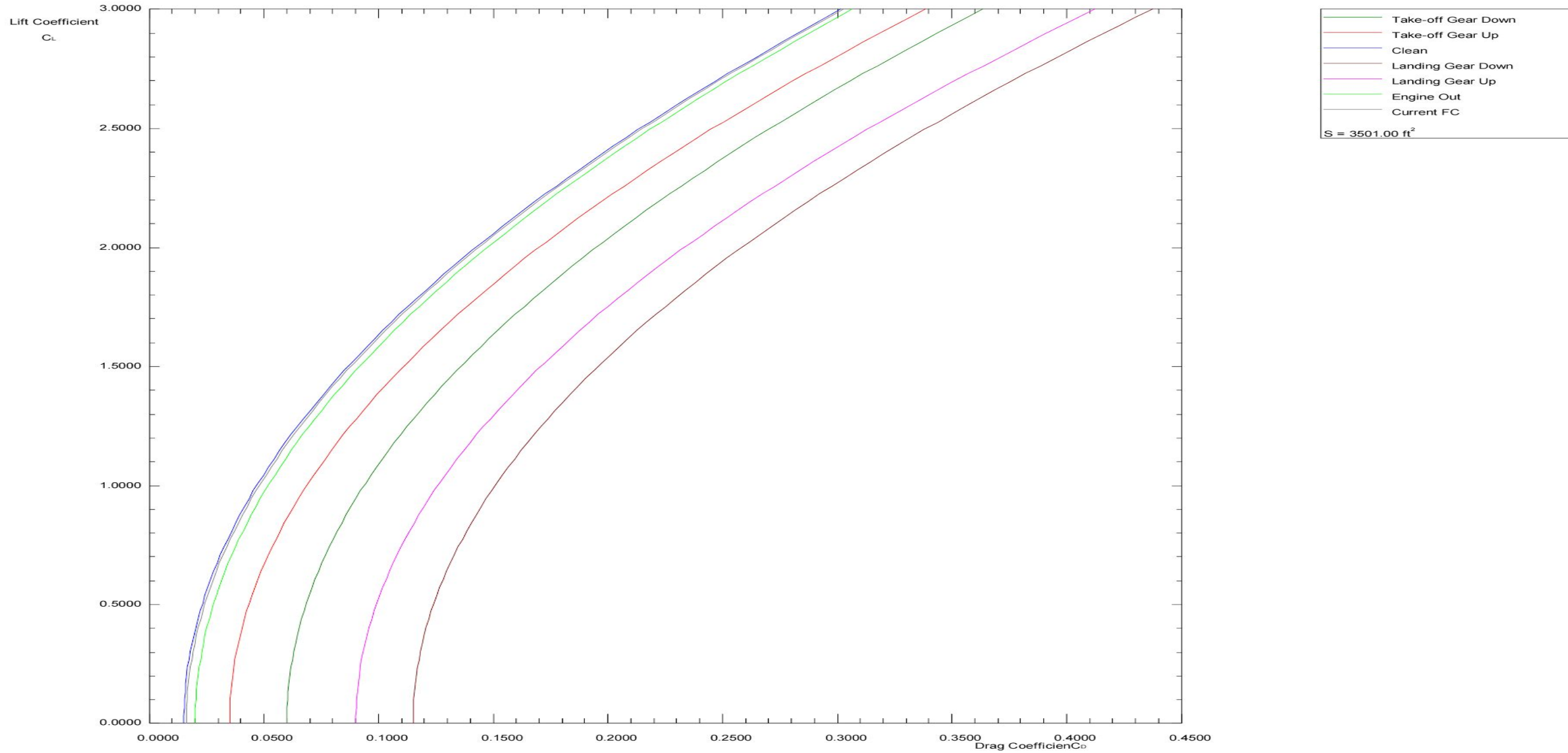
Mission Specifications

- Airport: DIA
- Cruising Altitude: 43,000 ft
- Range: 7,355 nm
- 242 passengers, 2 pilots, 5 flight attendants[1]:
  - Each person weighs 175 lbs
  - 40 lbs baggage per passenger
- Additional cargo: 3,000 lbs

Mission Profile



Drag Polar - Original 787-8



Performance Constraints

- Takeoff/Landing Altitude: 5,430
- Range: 7,355 nm
- Cruising Speed: Mach 0.85
- Takeoff/Landing Airstrip Length: 12,000 ft
- Loiter Time: 45 minutes
- Carrying 242 passengers and 7 crew members:
  - Each person weighs 175 pounds and have 40 lbs baggage. *3000 lbs additional cargo*
- Engines (*GEnx*):
  - C_j: 0.37 lb/lbf-hr
  - Thrust: 64,000 lbs thrust
- Wing Area: 3,501 ft^2

Equations Used

$$W_{TO} = W_{empty} + W_{payload} + W_{fuel,reqd} + W_{fuel,res} + W_{crew} + W_{tfo}$$

$$W_{fuel,reqd} = (W_{TO} - W_L) = \left(1 - \left(\frac{W_L}{W_{TO}}\right)\right) = (1 - M_{ff})W_{TO}$$

$$M_{ff} = \frac{W_L}{W_{TO}} = \frac{W_1}{W_{TO}}\frac{W_2}{W_1}\cdots\frac{W_N}{W_{N-1}}$$

$$R = \frac{V}{c_j}\frac{L}{D}ln\left(\frac{W_{i-1}}{W_i}\right)$$

$$E = \frac{1}{c_j}\frac{L}{D}ln\left(\frac{W_{i-1}}{W_i}\right)$$

Equations Used (cont.)

$\left(\frac{L}{D}\right)_{max}$ Occurs at $C_D = 2C_{D,i}$

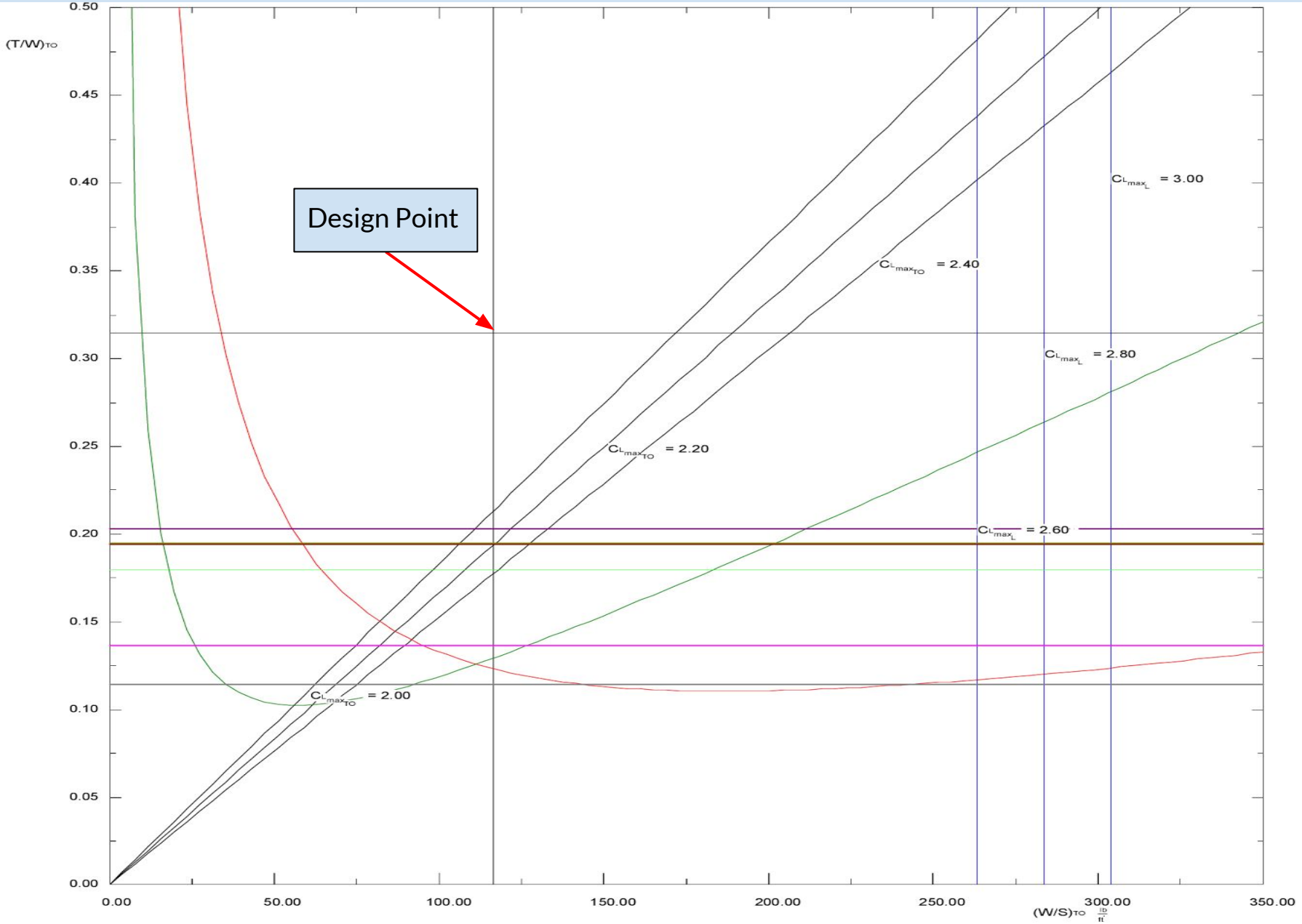
$$\therefore C_D = 2\frac{C_L^2}{4\pi eAR}$$

$$\therefore \left(\frac{L}{D}\right)_{max} = \frac{2\pi eAR}{C_L}$$ Now we assume that $C_L \perp\!\!\!\perp AR$

$$\therefore \left(\frac{L}{D}\right)_{max} \propto AR$$

We used this equation to adjust L/D when we changed AR

Performance Sizing Plot - Original 787-8



Take-off Distance

ΔTTO = 0 deg F

Maximum Cruise Speed

Sustained g / Turn Rate

Landing Distance

ΔTL = 0 deg F

Climb O.E.I.

Climb O.E.I., Transition

Climb O.E.I., Second Seg

Climb O.E.I., En-Route

Climb O.E.I., Approach

Climb A.E.O., Landing

WTO = 407069.7 lb

(W/S)TO = 116.34 lb/ft²

(T/W)TO = 0.31

Sw = 3499.00 ft²

Tavail = 127951 lb

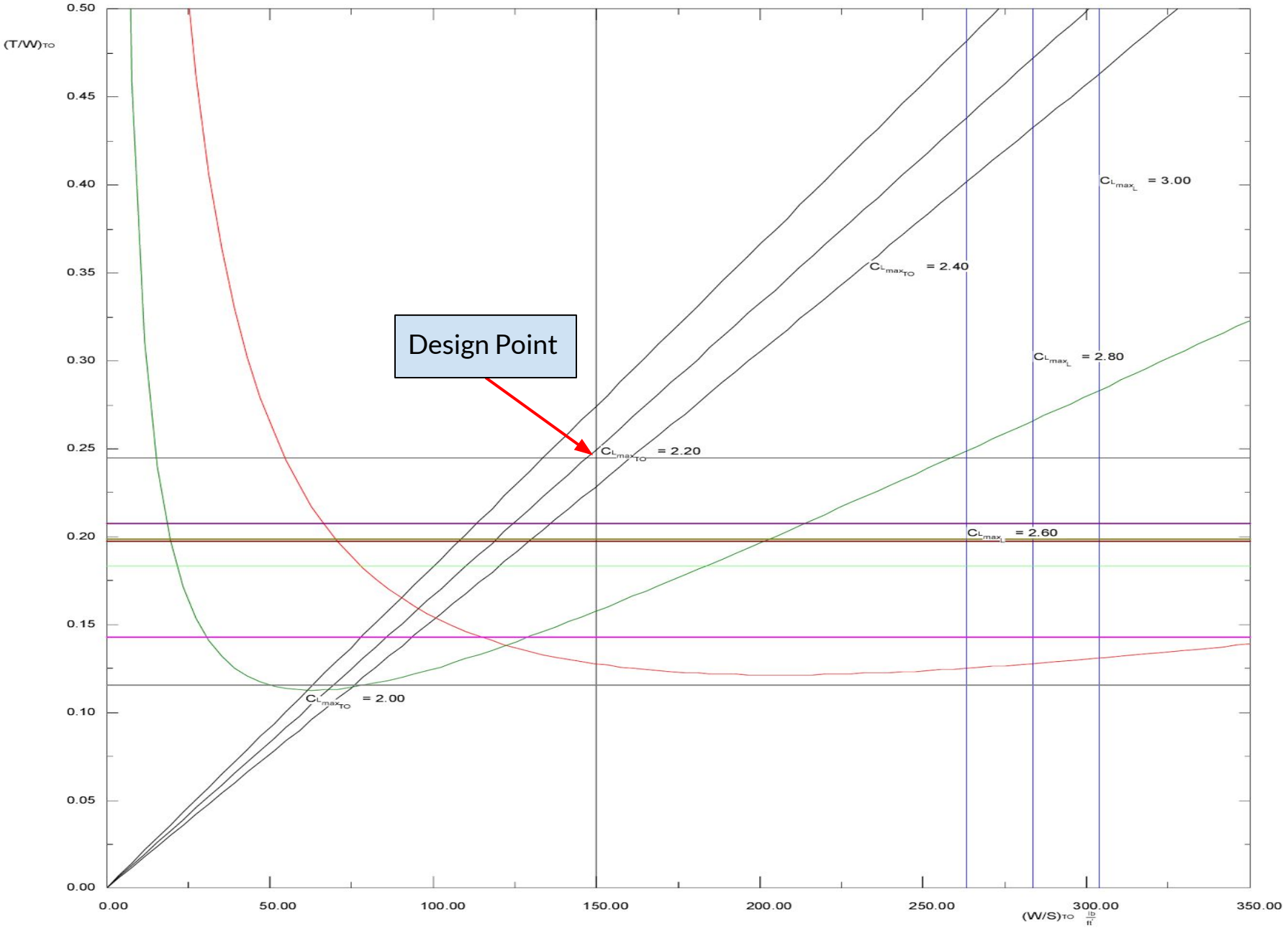
Initial Design Parameters

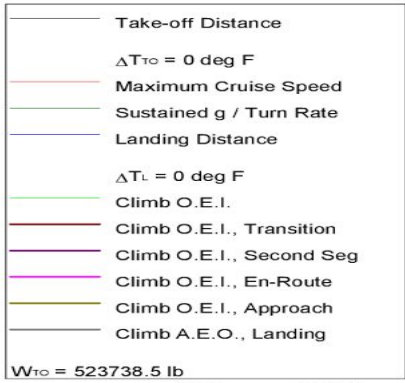
	Takeoff Weight [lb]	**Design Thrust** [lb]	**Wing Area** [ft^2]	**AR**
Original Design	407,070	128,000	3501	11.1

2

Changing Mission Specifications

Performance Sizing Plot - Add 85 Passengers





W_{TO} = 523738.5 lb

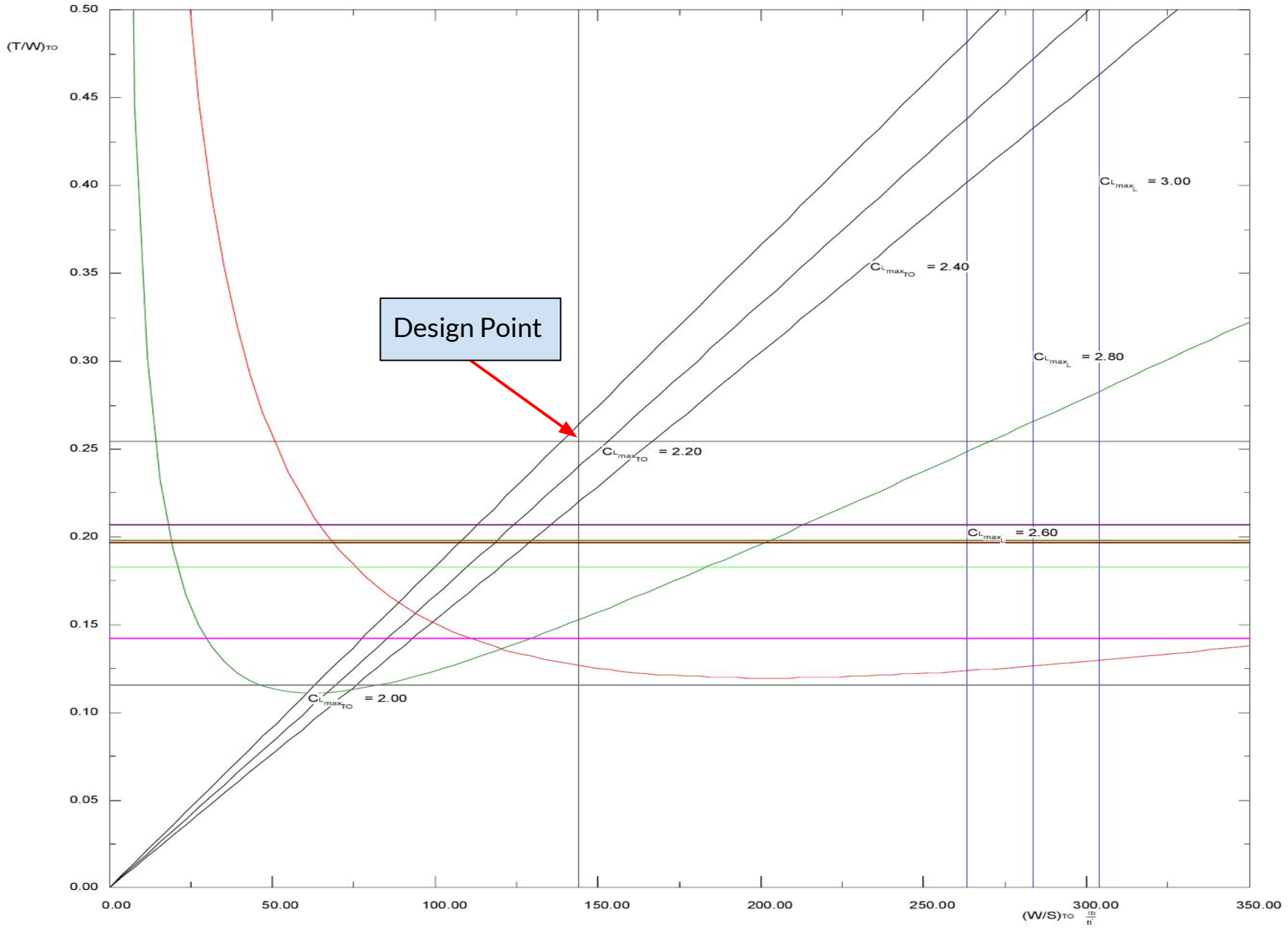
$(W/S)_{TO}$ = 149.77 $\frac{lb}{ft^2}$

$(T/W)_{TO}$ = 0.24

S_w = 3497.05 ft^2

T_{avail} = 128113 lb

Performance Sizing Plot - Increased Range (1000 nmi.)



Take-off Distance

ΔTTO = 0 deg F

Maximum Cruise Speed

Sustained g / Turn Rate

Landing Distance

ΔTL = 0 deg F

Climb O.E.I.

Climb O.E.I., Transition

Climb O.E.I., Second Seg

Climb O.E.I., En-Route

Climb O.E.I., Approach

Climb A.E.O., Landing

W_{TO} = 503428.8 lb

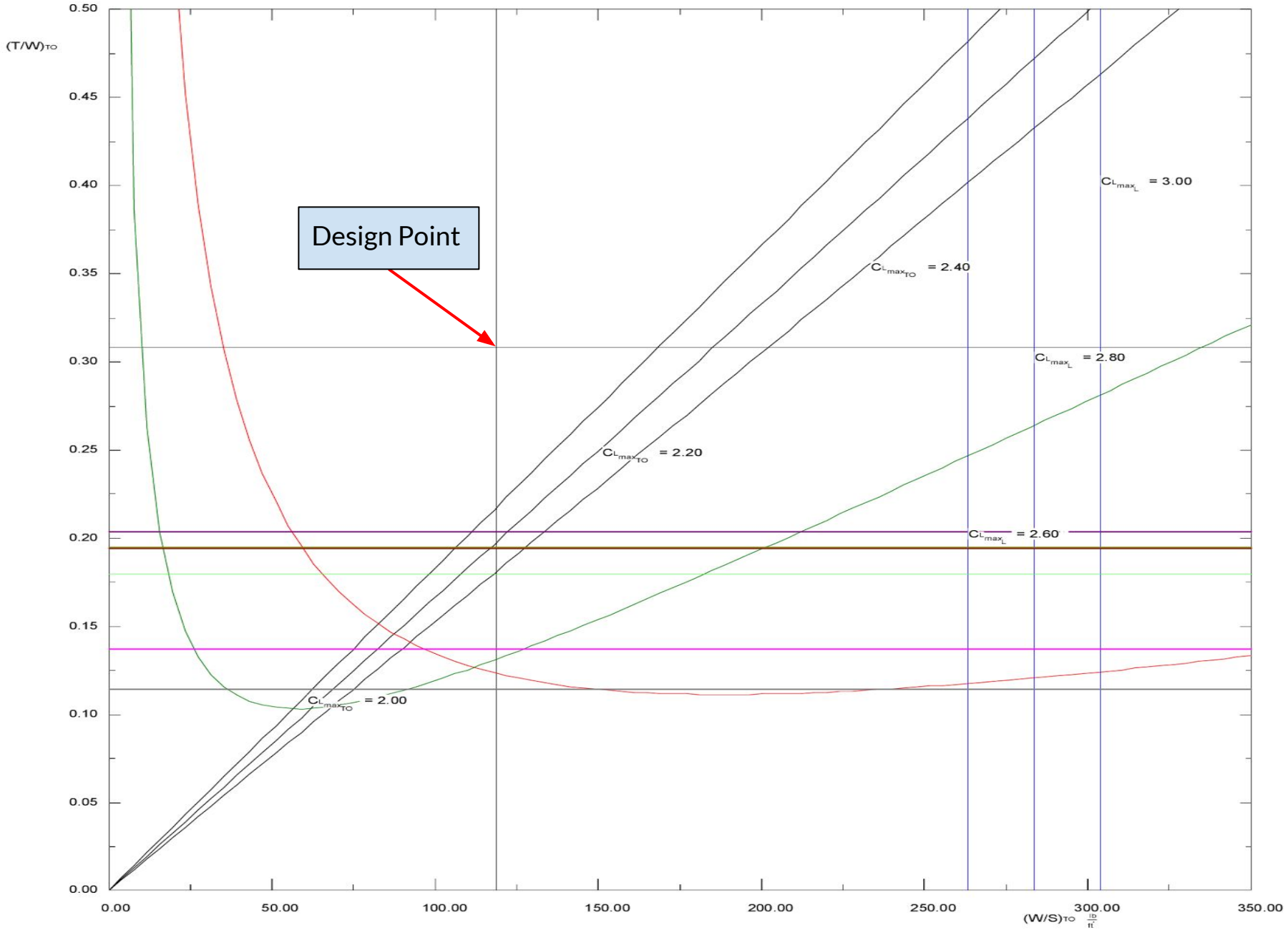
$(W/S)_{TO}$ = 143.87 $\frac{lb}{ft^2}$

$(T/W)_{TO}$ = 0.25

S_w = 3499.26 ft^2

T_{avail} = 127931 lb

Performance Sizing Plot - Loiter Increased by 15 min.



Take-off Distance

ΔT_{TO} = 0 deg F

Maximum Cruise Speed

Sustained g / Turn Rate

Landing Distance

ΔT_{L} = 0 deg F

Climb O.E.I.

Climb O.E.I., Transition

Climb O.E.I., Second Seg

Climb O.E.I., En-Route

Climb O.E.I., Approach

Climb A.E.O., Landing

W_{TO} = 415494.3 lb

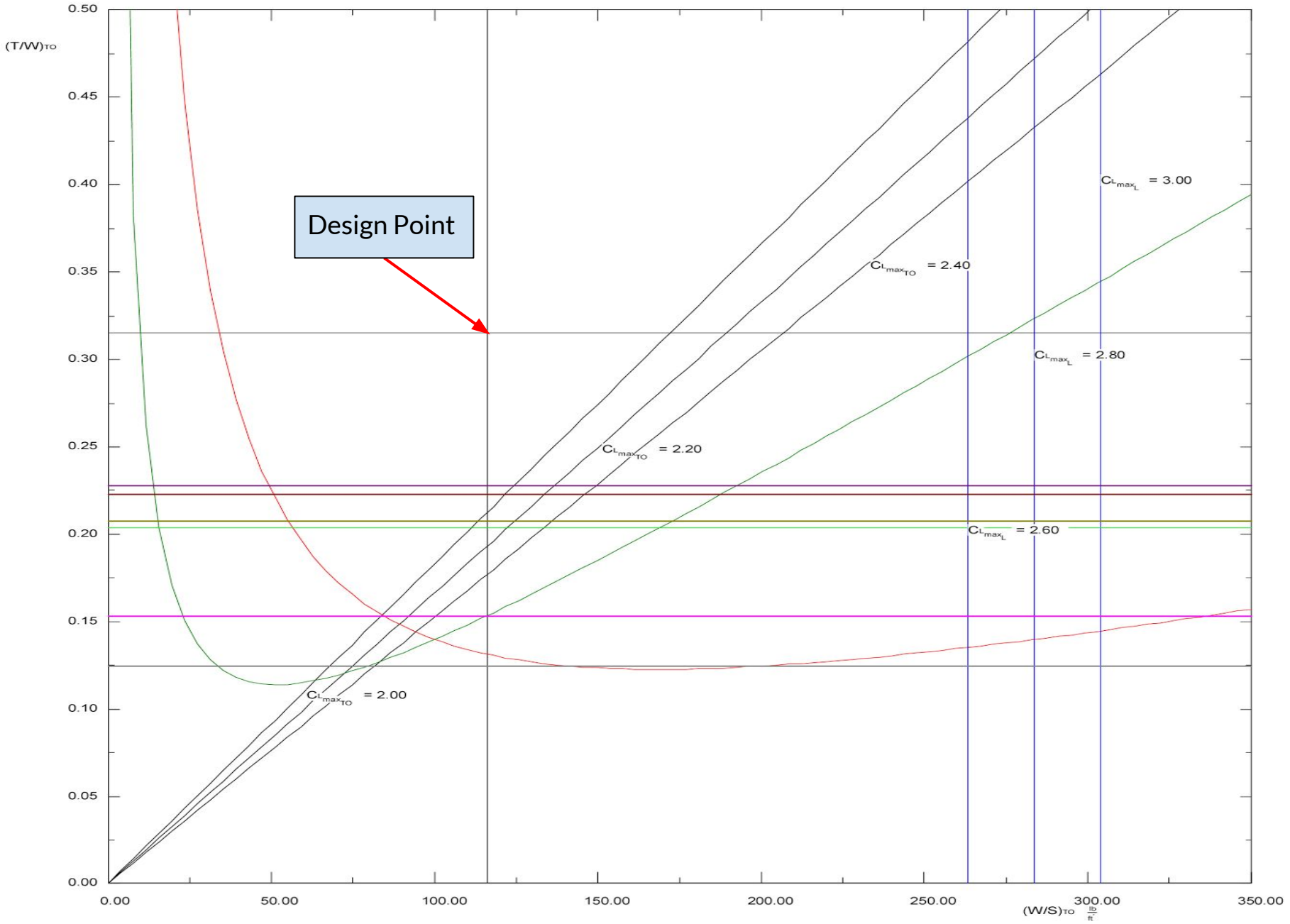
$(W/S)_{TO}$ = 118.63 $\frac{lb}{ft}$

$(T/W)_{TO}$ = 0.31

S_w = 3502.35 ft^2

T_{avail} = 127966 lb

Performance Sizing Plot - Aspect Ratio Decreased to 9



Take-off Distance

ΔTTO = 0 deg F

Maximum Cruise Speed

Sustained g / Turn Rate

Landing Distance

ΔTL = 0 deg F

Climb O.E.I.

Climb O.E.I., Transition

Climb O.E.I., Second Seg

Climb O.E.I., En-Route

Climb O.E.I., Approach

Climb A.E.O., Landing

WTO = 407069.7 lb

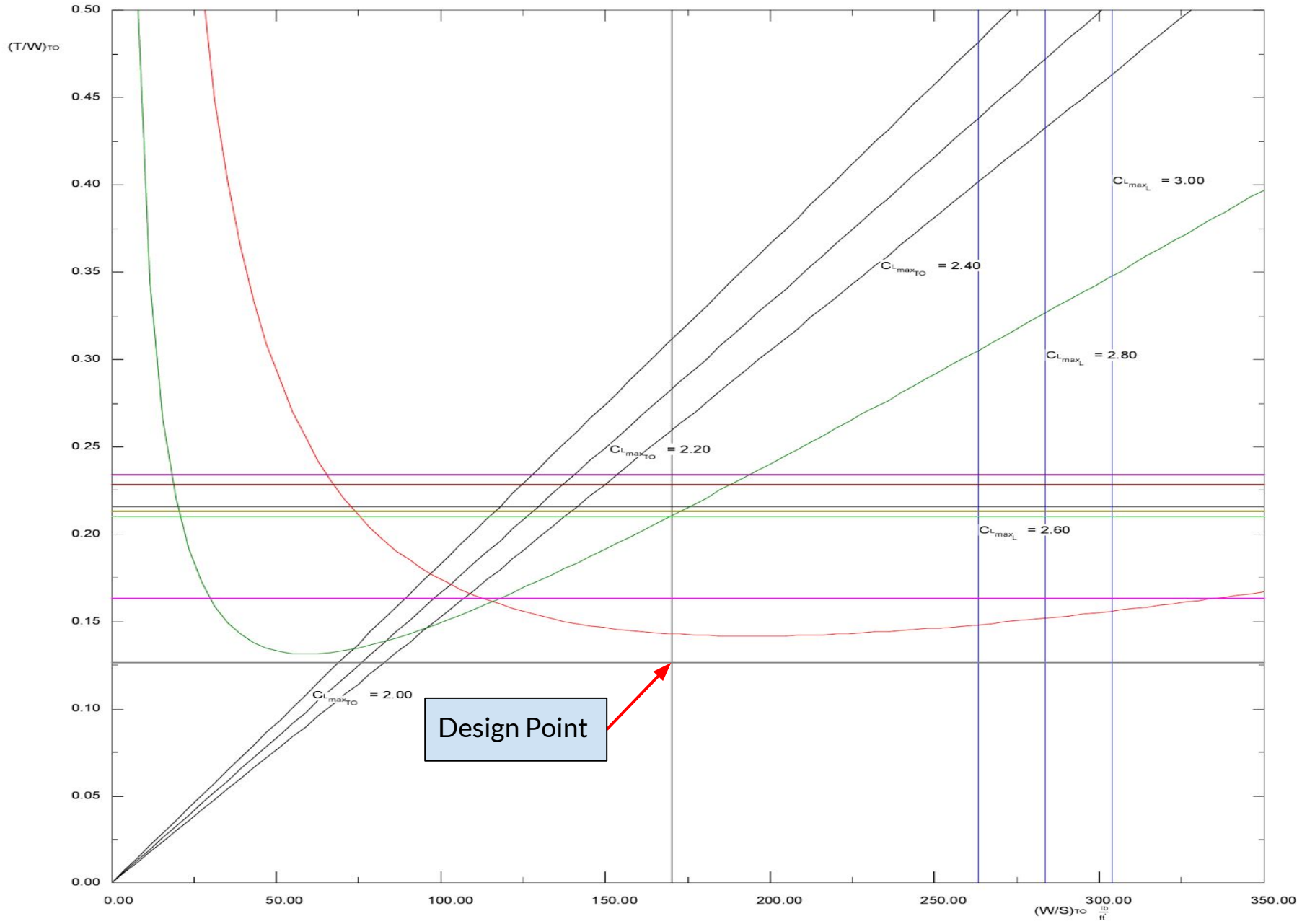
(W/S)TO = 116.01 lb/ft²

(T/W)TO = 0.31

Sw = 3508.88 ft²

Tavail = 128209 lb

Performance Sizing Plot - Aspect Ratio Decreased to 9 (L/D adjusted)



Take-off Distance

ΔTTO = 0 deg F

Maximum Cruise Speed

Sustained g / Turn Rate

Landing Distance

ΔTL = 0 deg F

Climb O.E.I.

Climb O.E.I., Transition

Climb O.E.I., Second Seg

Climb O.E.I., En-Route

Climb O.E.I., Approach

Climb A.E.O., Landing

WTO = 595374.5 lb

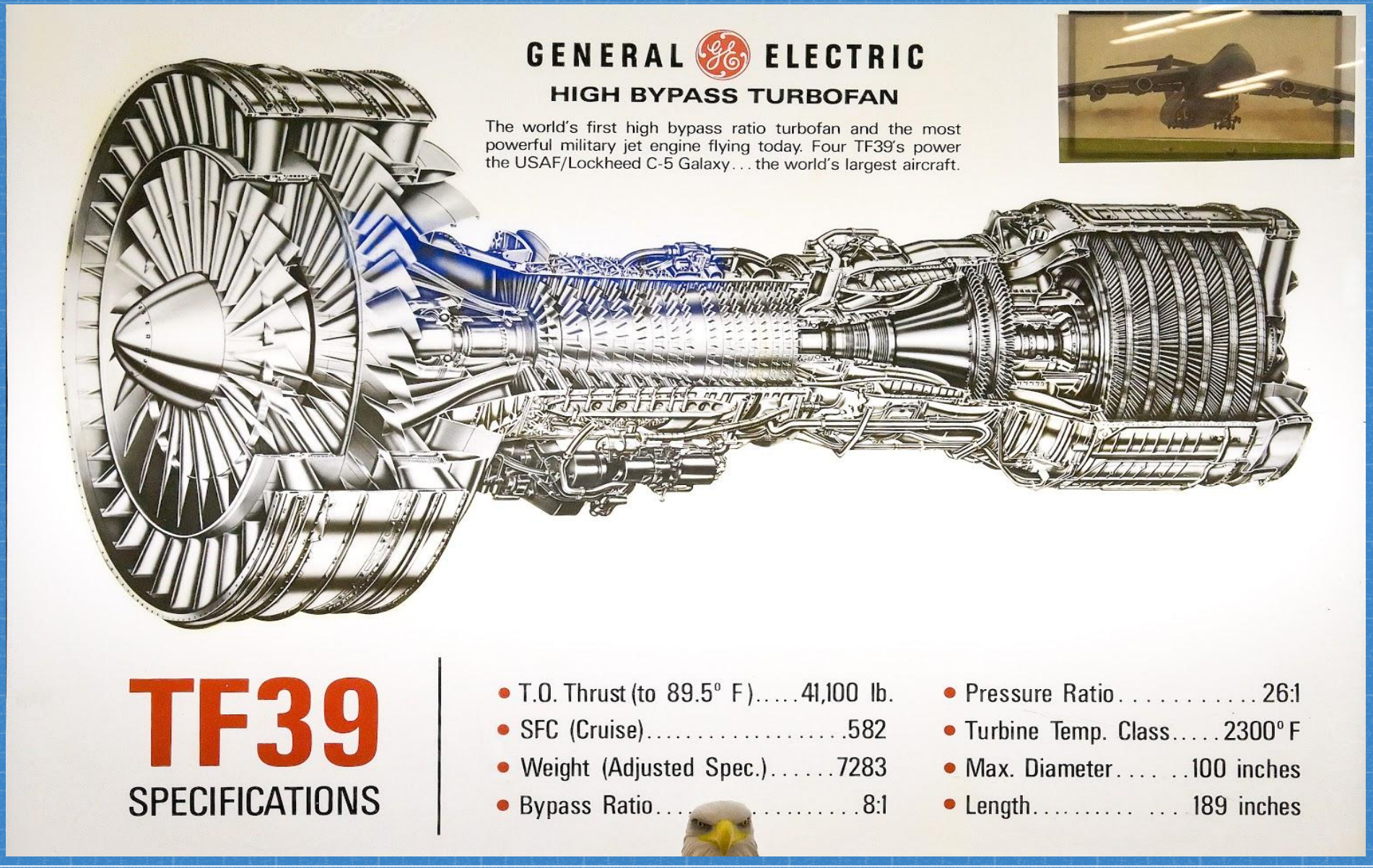
(W/S)TO = 170.08 lb/ft²

(T/W)TO = 0.22

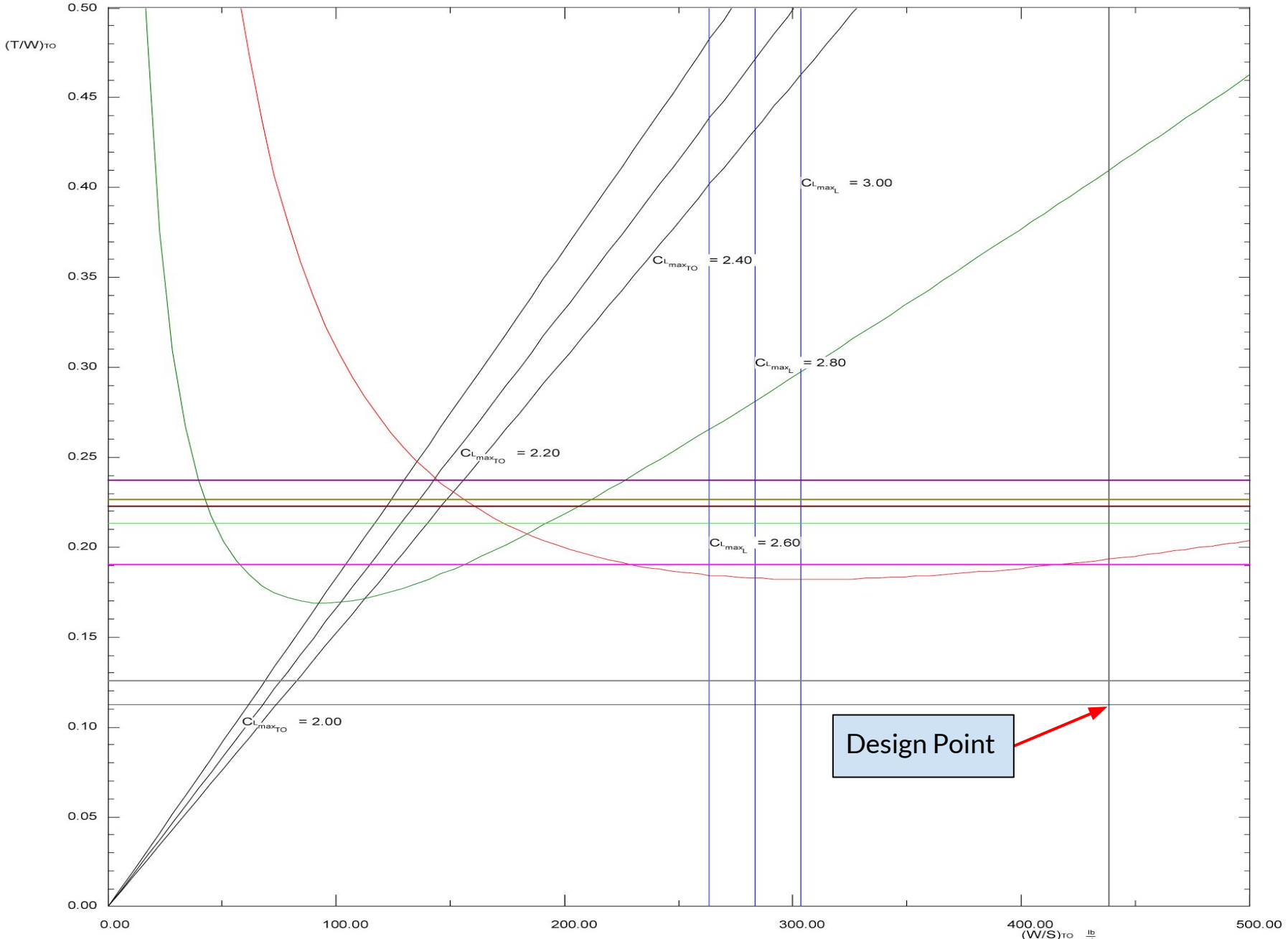
Sw = 3500.47 ft²

Tavail = 128281 lb

Engine Change: GE TF39-1C



Performance Sizing Plot - Engine Change (GE-TF39)



Take-off Distance

ΔTTO = 0 deg F

Maximum Cruise Speed

Sustained g / Turn Rate

Landing Distance

ΔTL = 0 deg F

Climb O.E.I.

Climb O.E.I., Transition

Climb O.E.I., Second Seg

Climb O.E.I., En-Route

Climb O.E.I., Approach

Climb A.E.O., Landing

W_{TO} = 1536173.0 lb

$(W/S)_{TO}$ = 438.20 $\frac{lb}{ft^2}$

$(T/W)_{TO}$ = 0.11

S_w = 3505.63 ft^2

T_{avail} = 172308 lb

3

Analyzing Weight Sensitivities

Weight Sensitivity:

Extra 85 Passengers

- ΔW_{TO} after modification: **116,670 lbs.**

	Hand Calculation $(\Delta W_{TO}/\Delta W_{PL})$	**AAA Calculation** $(\partial W_{TO}/\partial W_{PL})$	**Difference between AAA and Hand Calculation**
Change in W_{TO} per unit change in R [lbs/lbs.]	6.21	6.33	1.9%

Weight Sensitivity:
Extra 1000 nmi. Range

- ΔW_{TO} after modification: **96,360 lbs.**

	Hand Calculation $(\Delta W_{TO}/\Delta R)$	**AAA Calculation** $(\partial W_{TO}/\partial R)$	**Difference between AAA and Hand Calculation**
Change in W_{TO} per unit change in R [lbs/nmi.]	96.4	80.8	16.2%

Weight Sensitivity:

Extra 15 min. Loiter

- ΔW_{TO} after modification: **8,430 lbs.**

	Hand Calculation $(\Delta W_{TO}/\Delta E)$	**AAA Calculation** $(\partial W_{TO}/\partial E)$	**Difference between AAA and Hand Calculation**
Change in W_{TO} per unit change in E [lbs/hr]	33,698	72,482	73.1%

Weight Sensitivity:
AR Decreased to 9

- ΔW_{TO} after modification: **0 lbs. (188,300 lbs.)***

	Hand Calculation $(\Delta W_{TO}/\Delta AR)$	**AAA Calculation** $(\partial W_{TO}/\partial AR)$	**% Difference between AAA and Hand Calculation**
Change in W_{TO} per unit change in R [lbs]	0 (-89,244)	N/A (N/A*)	N/A (N/A*)

** with (L/D) adjustment made for changed AR*

Weight Sensitivity:

Engine Change - GE TF-39

- Δ W_{TO} after modification: **1,129,103.3 lbs.**
- C_j of GE TF-39:
  - **0.313 lb/lbf-hr @ S.L.[2]**
  - **0.582 lb/lbf-hr @ Cruise[3]**

	Hand Calculation $(\Delta W_{TO}/\Delta C_j)$	**AAA Calculation** $(\partial W_{TO}/\partial C_j)$	**Difference between AAA and Hand Calculation**
Change in W_{TO} per unit change in R [lbf-hr]	4.31E6	15.0E6	110.7%

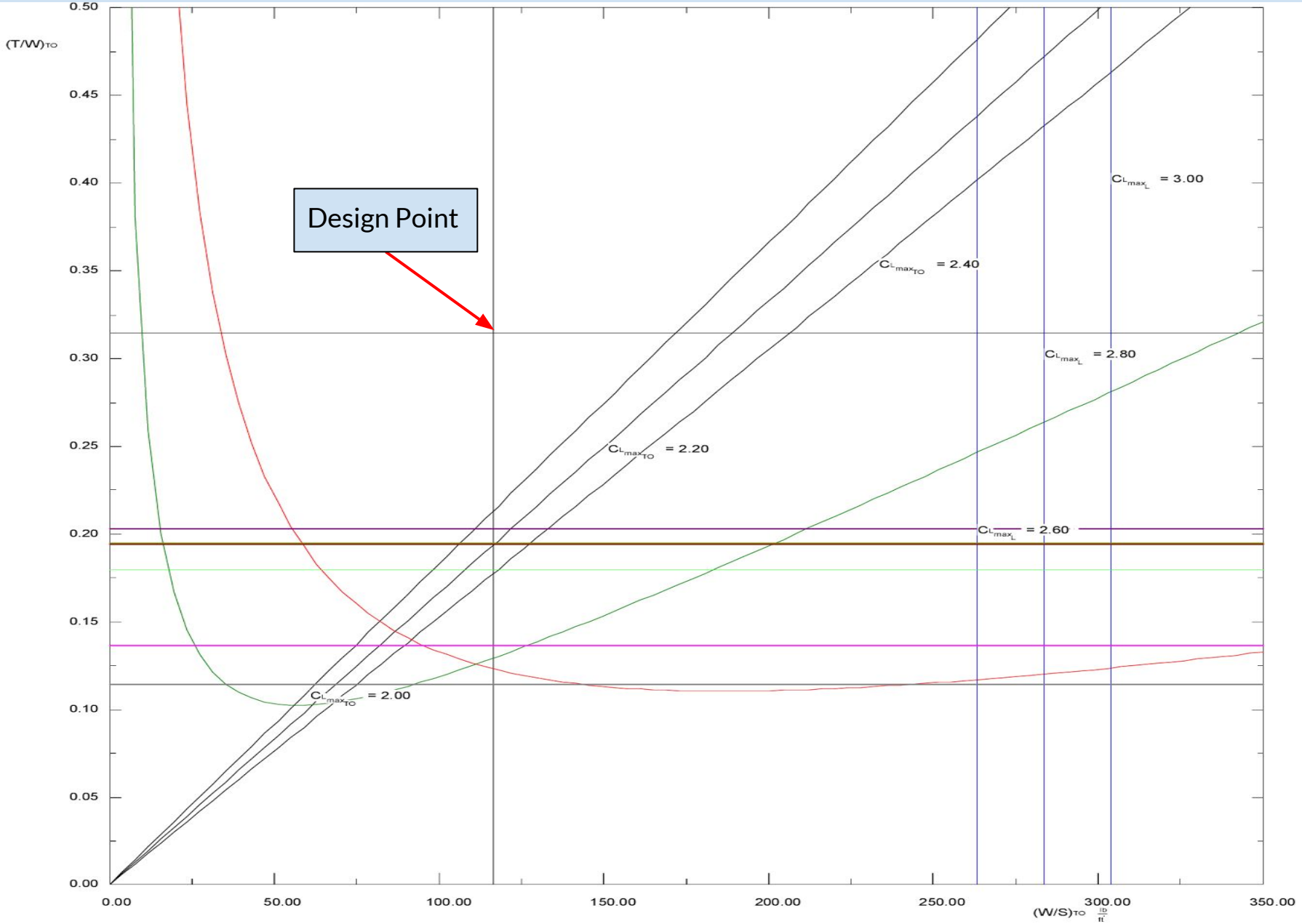
4

Summary and Conclusions

Summary of Results

- Engine Efficiency (C_j) is by far the most sensitive parameter
- **Overall Performance:**
  - Least sensitive parameter: Loiter Time inc. 33%
  - Most Sensitive parameter: C_j inc. 82%
- **W_{TO}:**
  - Least sensitive parameter: Number of Passengers inc. 35%, W_{TO} inc. 2%
  - Most Sensitive parameter: C_j inc. 82%, W_{TO} inc. 277%

Performance Sizing Plot - Original 787-8



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Landing Distance

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Climb O.E.I.

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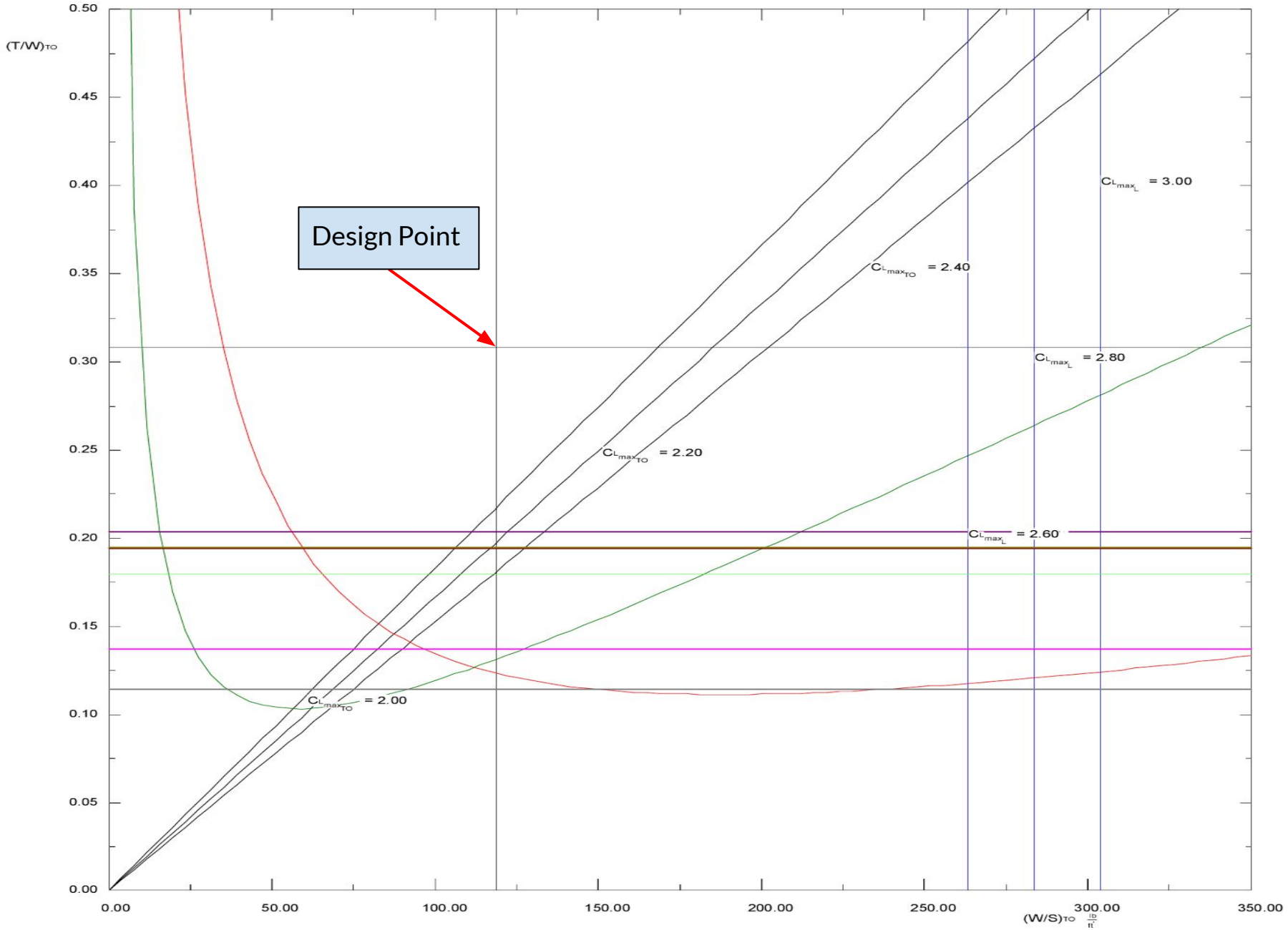

Take-off Distance

ΔT_{TO} = 0 deg F

Maximum Cruise Speed

Sustained g / Turn Rate

Landing Distance

ΔT_{L} = 0 deg F

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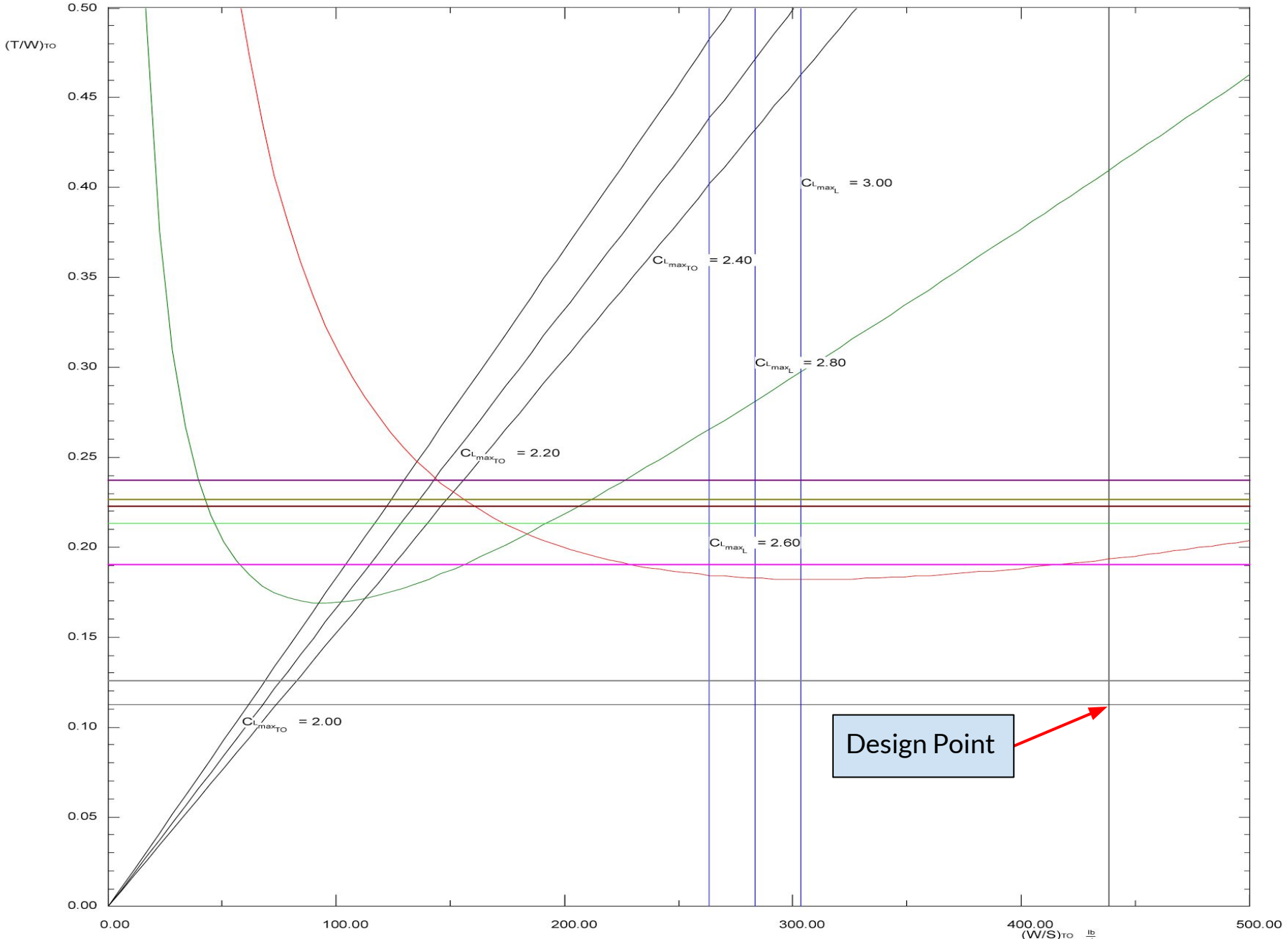

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T_{avail} = 172308 lb

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Weight Sensitivity:

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Weight Sensitivity:

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Change in W_{TO} per unit change in R [lbf-hr]	4.31E6	15.0E6	110.7%

Discussion of Results

- Engine fuel efficiency (C_j) is the most sensitive parameter:
  - Initial fuel weight varies exponentially with efficiency
  - Increases in efficiency have greatly increased performance
- AR is difficult to analyze in AAA
  - Doesn't take into account changes in (L/D)
- The 787-8 is a highly optimized design
  - Most changes negatively affect performance

Other Parameters to Examine

- Oswald Efficiency Factor
- Cruise Velocity
- Cargo weight
- $W_{passenger}$
- (L/D)
- Runway Length

References

1. Ann and H.J. Smead . "Design Lab Aircraft Assignment: Boeing 787 Performance Modifications". Lab Description. University of Colorado - Boulder. Boulder. 2016.
2. Gas Turbine Engines. *Aviation Week & Space Technology Source Book 2009*. p. 119
3. Balik, Roland. "An Era of Dover-built TF39 Engines Throttles down." *Air Mobility Command*. 436th Airlift Wing Public Affairs, 12 Apr. 2016. Web. 20 Feb. 2017. <http://www.amc.af.mil/News/Article-Display/Article/785826/an-era-of-dover-built-tf39-engines-throttles-down/>.