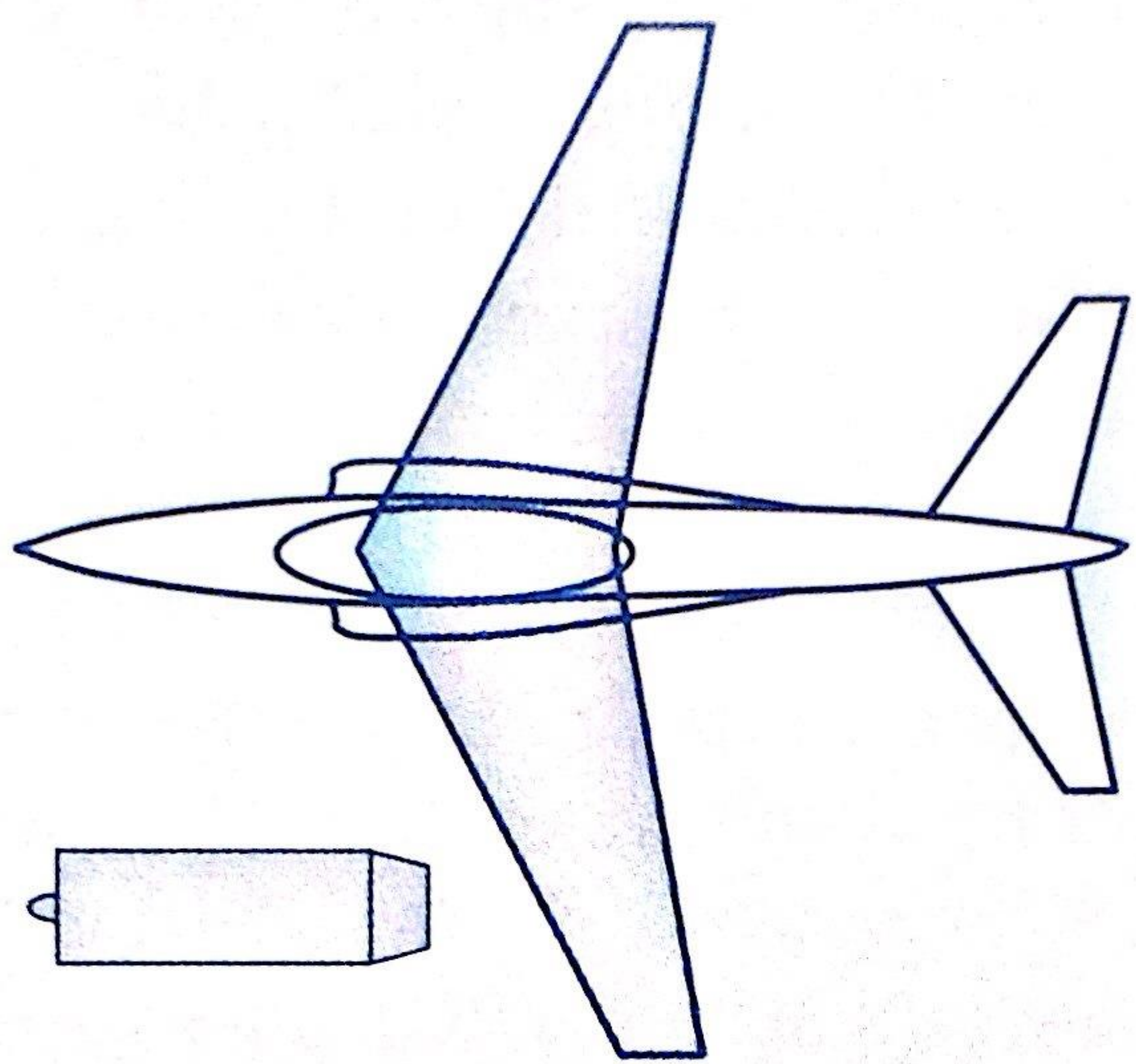
ME4932 Aircraft Performance & Design

T/ W and W/S (Chapter5)



Source: Aircraft Design by Daniel P. Raymer

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T/ W and W/S (Chapter5)

- T/W and W/S have the greatest effect on performance so we need to choose them well
- We look at the performance requirements
- Inappropriate to use purely historical data
- Cannot draw the A/C without wing or engine!

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T/ W and W/S (Chapter5)

- These values are normally listed at Wo, sea level, STP

Aircraft type	Typical installed T/W
Jet trainer	0.4
Jet fighter (dogfighter)	0.9
Jet fighter (other)	0.6
Military cargo/bomber	0.25
Jet transport (higher value for fewer engines)	0.25–0.4

Aircraft type	Typical P/W		Typical power loading (lb/hp)
	hp/lb	{Watt/g}	
Powered sailplane	0.04	{0.07}	25
Homebuilt	0.08	{0.13}	12
General aviation—single engine	0.07	{0.12}	14
General aviation—twin engine	0.17	{0.3}	6
Agricultural	0.09	{0.15}	11
Twin turboprop	0.20	{0.33}	5
Flying boat	0.10	{0.16}	10

Source: Aircraft Design by Daniel P. Raymer

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$T/W_0 = \alpha M_{max}^{C}$	a	C
Jet trainer	0.488	0.728
Jet fighter (dogfighter)	0.648	0.594
Jet fighter (other)	0.514	0.141
Military cargo/bomber	0.244	0.341
Jet transport	0.267	0.363

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- These values are normally listed at Wo, sea level, STP

$P/W_0 = \alpha V_{max}^C$: hp/lb{W/g}	a	C
Sailplane—powered	0.043 {0.071}	0
Homebuilt—metal/wood	0.005 {0.006}	0.57
Homebuilt—composite	0.004 {0.005}	0.57
General aviation—single engine	0.025 {0.036}	0.22
General aviation—twin engine	0.036 {0.048}	0.32
Agricultural aircraft	0.009 {0.010}	0.50
Twin turboprop	0.013 {0.016}	0.50
Flying boat	0.030 {0.043}	0.23

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Thrust Matching:

$$\left(\frac{T}{W}\right)_{\text{cruise}} = \frac{1}{(L/D)_{\text{cruise}}}$$

$$\left(\frac{T}{W}\right)_{\text{climb}} = \frac{1}{(L/D)_{\text{climb}}} + \boxed{\frac{V_{\text{vertical}}}{V}}$$

Climb rate requirement frequently sizes T/W!

To convert to T/Wo must do this:

From mission weight fractions

$$\left(\frac{T}{W}\right)_{\text{takeoff}} = \left(\frac{T}{W}\right)_{\text{cruise}} \left(\frac{W_{\text{cruise}}}{W_{\text{takeoff}}}\right)\left(\frac{T_{\text{takeoff}}}{T_{\text{cruise}}}\right)$$

From engine data

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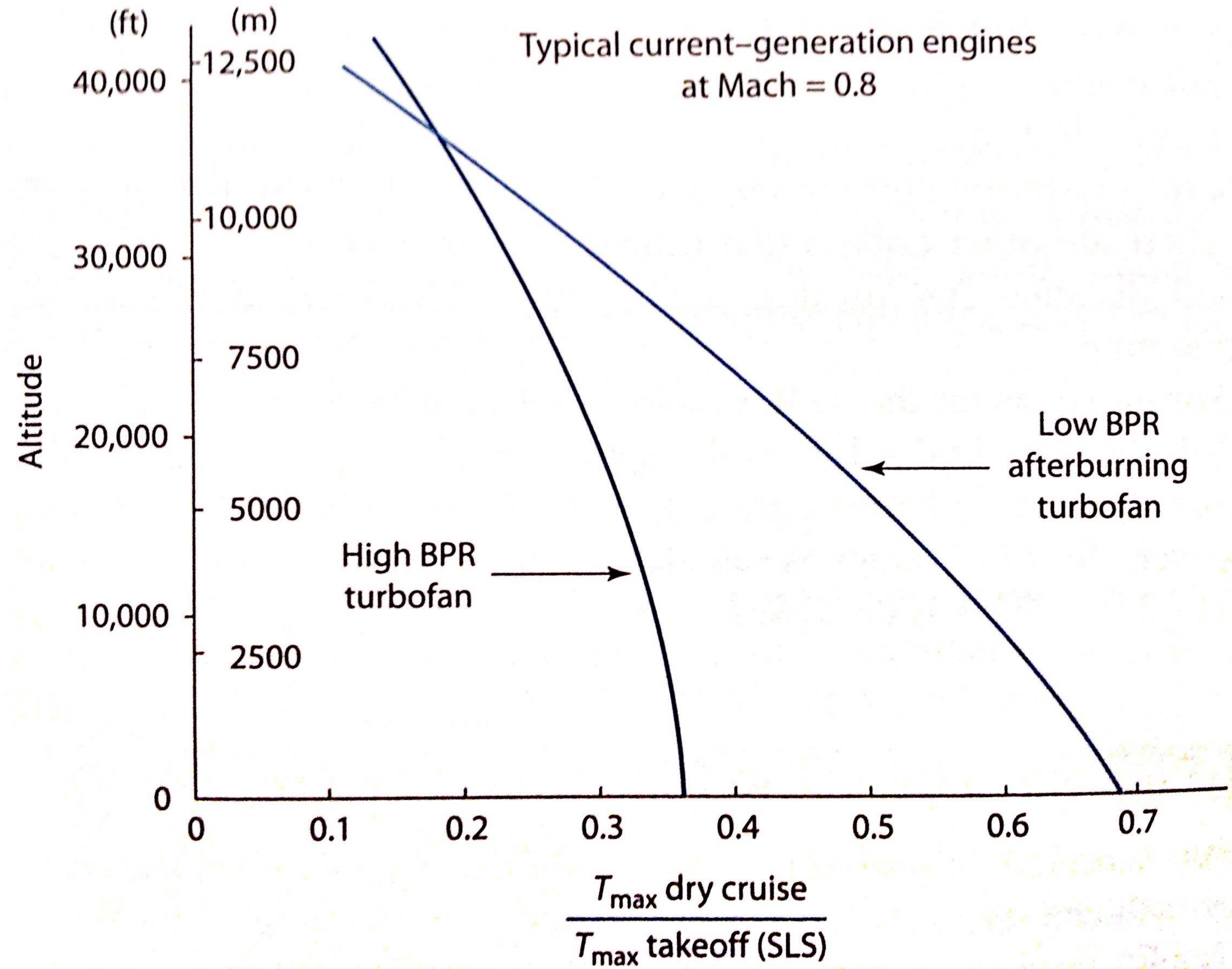

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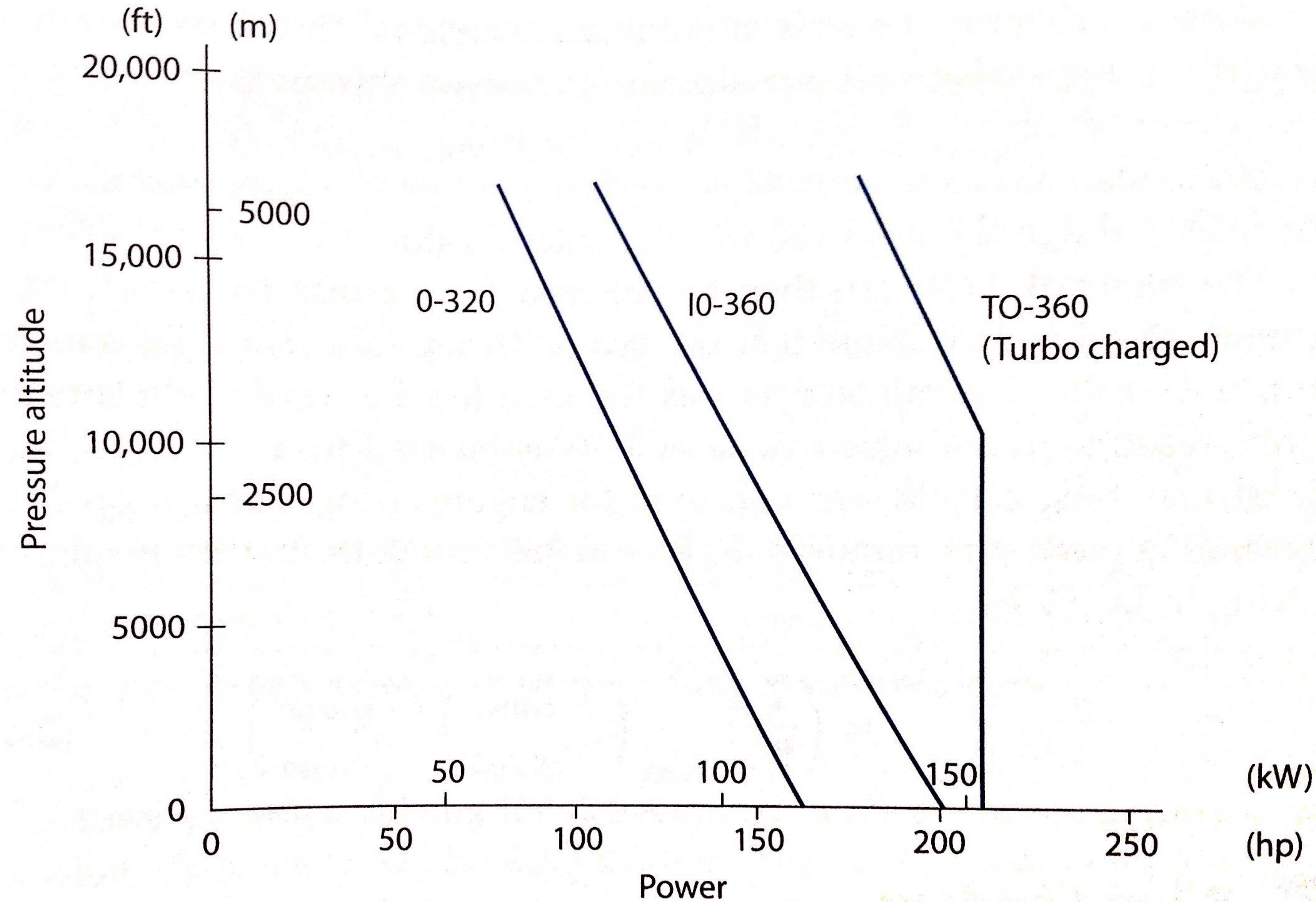

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T/ W and W/S (Chapter5)

- Mostly to get a "flavor" of what a typical W/S would be:

Typical Takeoff *W/S*		
Historical trends	**lb/ft^2**	**$\{kg/m^2\}$**
Sailplane	6	{30}
Homebuilt	11	{54}
General aviation—single engine	17	{83}
General aviation—twin engine	26	{127}
Twin turboprop	40	{195}
Jet trainer	50	{244}
Jet fighter	70	{342}
Jet transport/bomber	120	{586}

Source: Aircraft Design by Daniel P. Raymer

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- Stall speed requirement sets W/S:

$$W = L = q_{\text{stall}} S C_{L_{\max}} = \frac{1}{2}\rho V_{\text{stall}}^2 S C_{L_{\max}}$$

$$W/S = \frac{1}{2}\rho V_{\text{stall}}^2 C_{L_{\max}}$$

$$C_{L_{\max}} = 0.9 C_{\ell_{\max}} \cos \Lambda_{0.25c}$$

- If stall speed is a requirement, you can compute a W/S from it and from a section Clmax. Then, you can compare this W/S with the one required by other requirements (like takeoff/landing) and decide what high-lift devices to use to change Clmax to then change W/S to a more consisting o less penalizing one!

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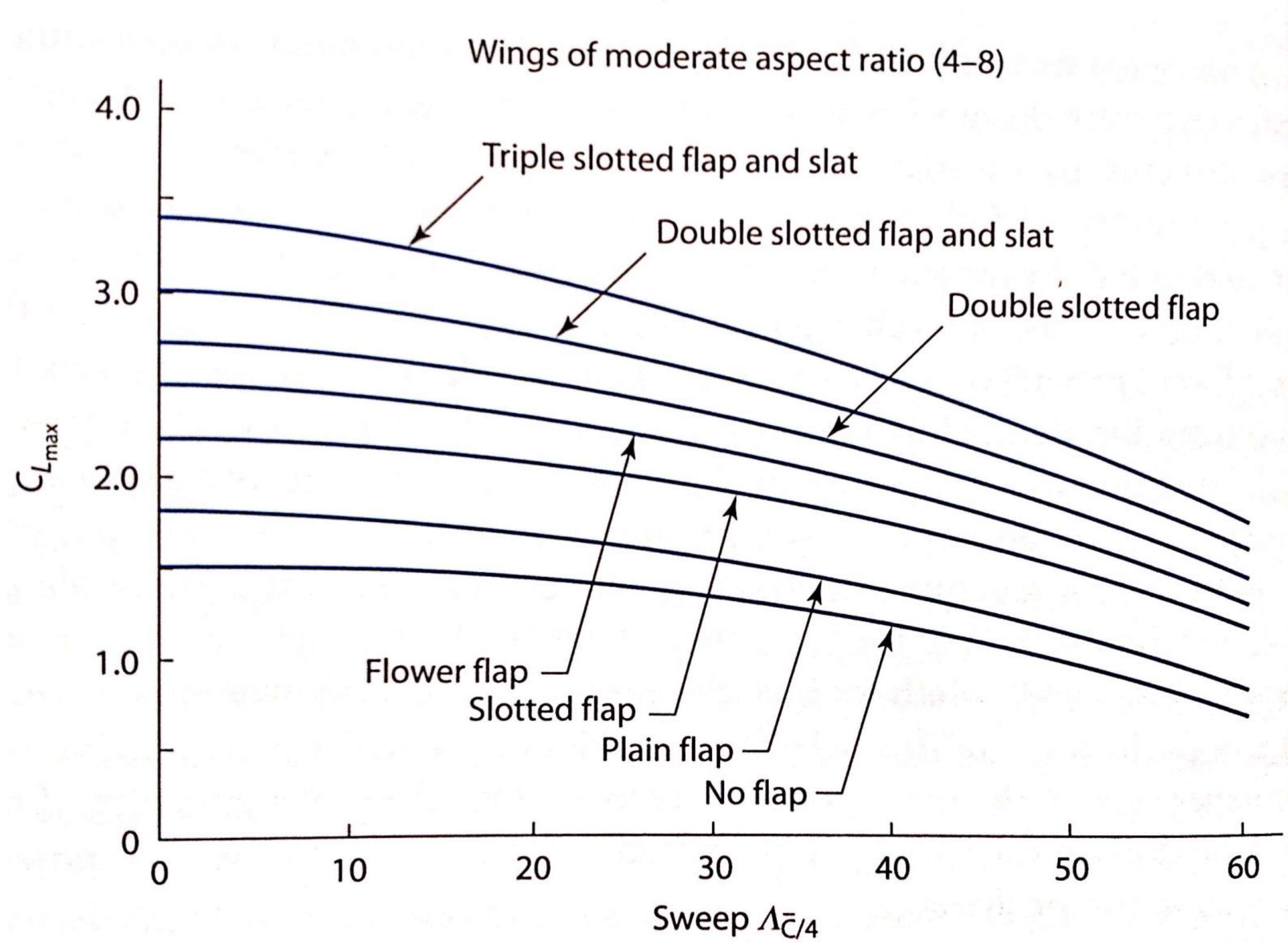

- HLD will allow you to have a larger W/S, that way avoiding penalties of a huge wing (wetted area and weight) that would hurt your design in other areas by not meeting a requirement (like max speed) or requiring a huge T/W and again Wo!

Source: Aircraft Design by Daniel P. Raymer

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- Takeoff distance:
  - Ground roll
  - Total distance to clear an obstacle (35 or 50 ft.)
  - Balanced field length (distance required to clear the obstacle when an engine fails at decision speed)
  - Liftoff speed = 1.1 Vstall
  - Decision speed = speed at which the distance to stop after an engine fails equals the distance to continue and clear the obstacle
  - Takeoff distance requirements can set T/W and/or W/S
  - FAR,MIL regulations

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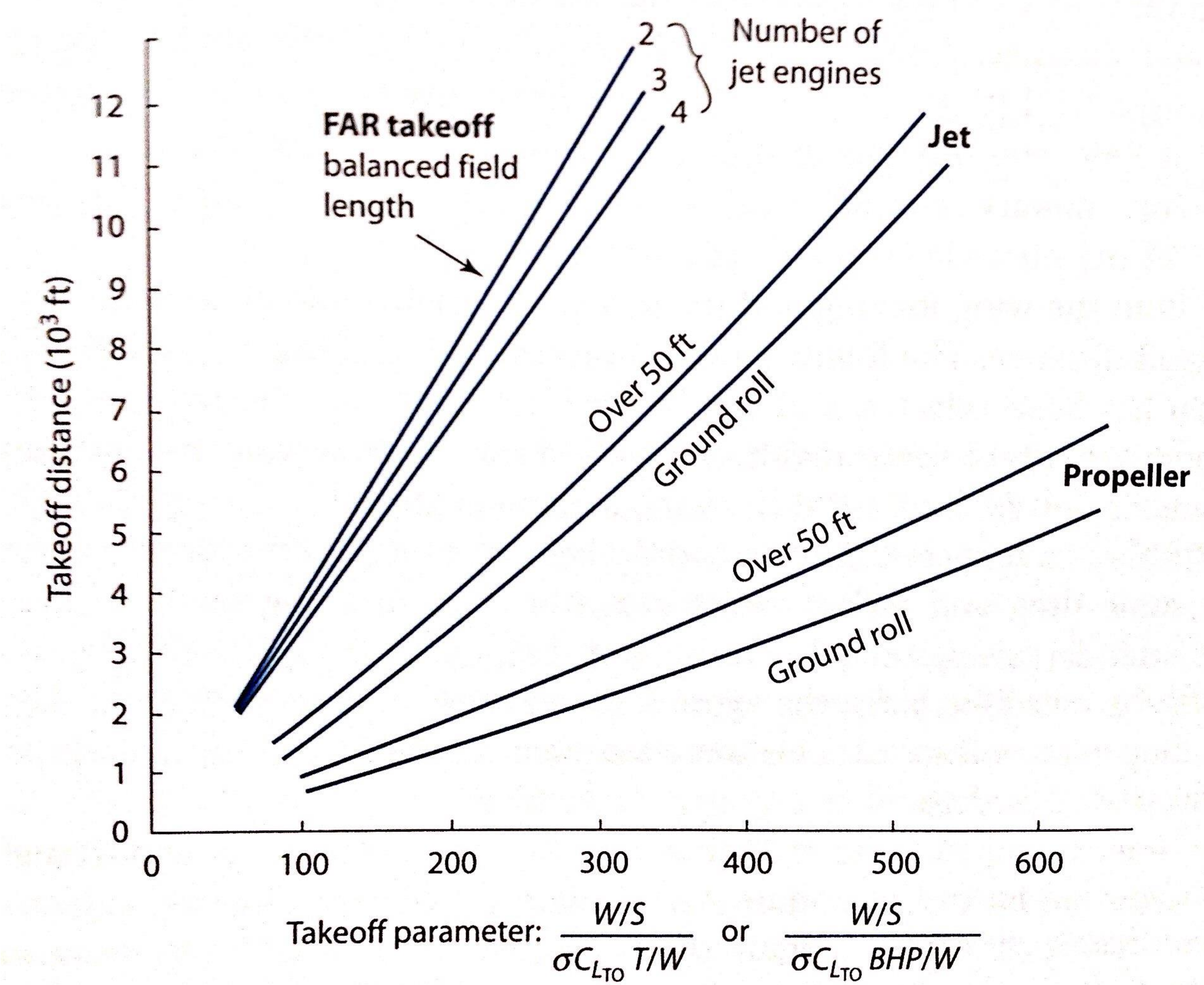
T/ W and W/S (Chapter5)

- Takeoff distance requirements can set T/W and/or W/S:



$$(W/S) = (\text{TOP})\sigma C_{L_{\text{TO}}}(\text{hp}/W)$$

$$(W/S) = (\text{TOP})\sigma C_{L_{\text{TO}}}(T/W)$$

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- Catapult takeoff
  - Current steam catapults accelerate light aircraft more than heavier aircraft!
  - Vend= catapult end speed
  - Vwod =wind speed over deck
  - Vthrust = extra velocity (3-10 kts) provided by engine
  - In the end, the velocity of the aircraft, as it leaves the catapult should be greater or equal to 1.1 stall

$$\left(\frac{W}{S}\right)_{\text{takeoff}} = \frac{1}{2}\rho(V_{\text{end}} + V_{\text{wod}} + \Delta V_{\text{thrust}})^2 \frac{(C_{L_{\max}})_{\text{takeoff}}}{1.21}$$

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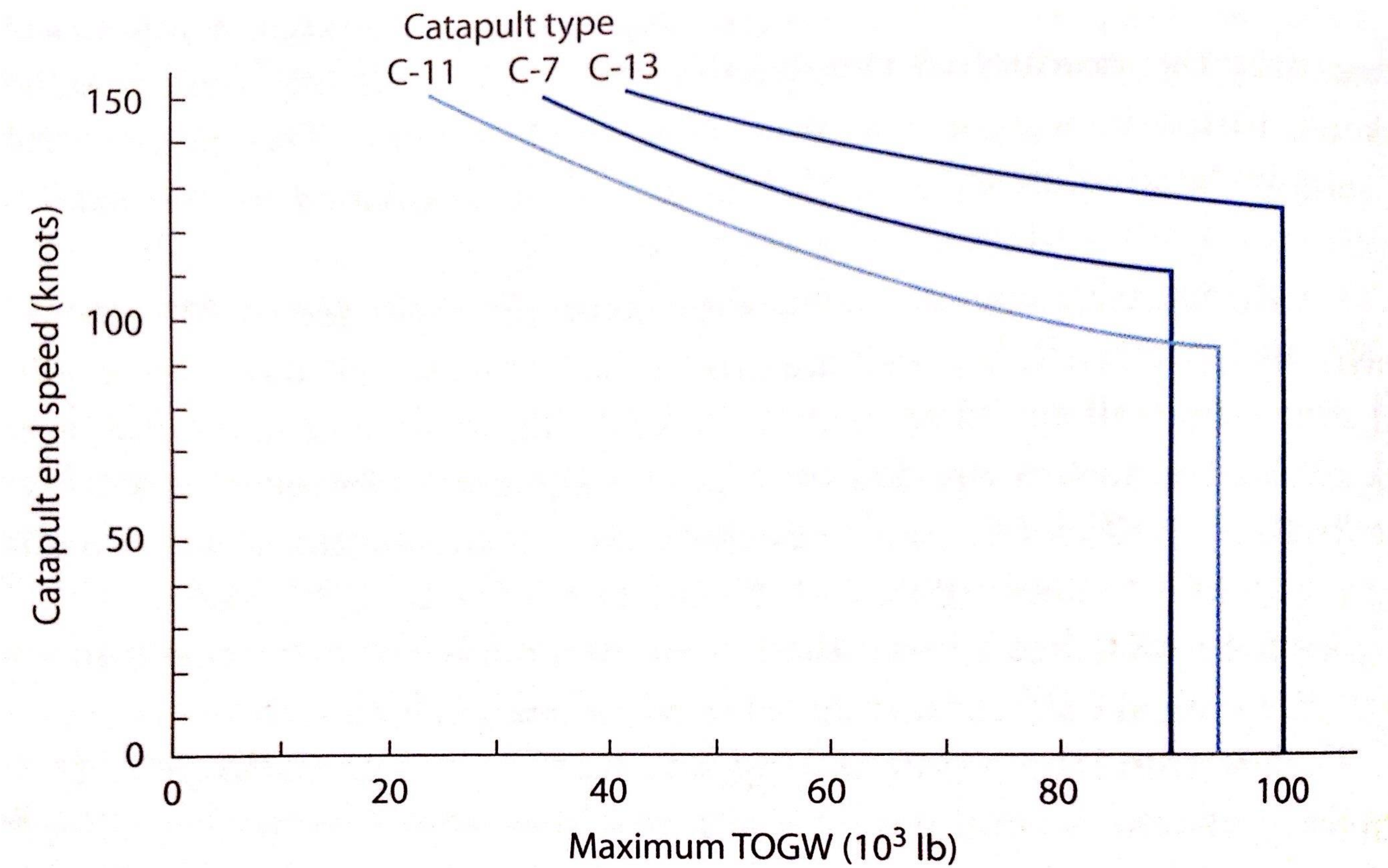
T/ W and W/S (Chapter5)

- Catapult takeoff:



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T/ W and W/S (Chapter5)

- Landing distance can set W/S:
  - Ground roll, or total distance from a 50 ft. obstacle?
  - Approach speed = 1.2 Vstall for military (1.3 civil)

$$S_{\text{landing}} = 80\left(\frac{W}{S}\right)\left(\frac{1}{\sigma C_{L_{\max}}}\right) + S_a \quad \{\text{ft}\}$$

$$= 5\left(\frac{W}{S}\right)\left(\frac{1}{\sigma C_{L_{\max}}}\right) + S_a \quad \{\text{m}\} \qquad (5.11)$$

where

σ = density ratio = $\rho_{\text{landing}}/\rho_{\text{sea-level standard day}}$
($\sigma = 1.0$ for sea-level standard day; $\sigma = 0.794$ for hot day at 5000 ft)
S_a = 1000 ft {305 m} for airliner-type, 3-deg glideslope
= 600 ft {183 m} for general-aviation-type power-off approach
= 450 ft {137 m} for STOL, 7-deg glideslope

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- Remember that if your W/S twas calculated at a reduced weight (landing or other) you need to bring it to Wo level!

- For example if the landing requirement was at 80%Wo, and you came up with a W/S of 16, then at Wo this is a W/S of 16/0.8 = 20! Otherwise,you will end up with a wing that was unnecessarily large!

- In general, be careful to compare "apples to apples"....

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- W/S at cruise/loiter (what segment dominates the mission fuel requirement?):
    - Mostly calculated for reference, because the W/S that cruise and/or loiter conditions dictate is usually too low (large wing) to be able to do many other requirements.
    - For propeller aircraft, best cruise is at maximum L/D, where zero-lift drag and drag due-to-lift are equal in magnitude.
    - For jets, best cruise is at a lower L/D, where zero-lift drag is three times the magnitude of drag due-to-lift.
    - For loiter, jets prefer maximum L/D; propeller aircraft a lower L/D.

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W/S at cruise/loiter (continued):

- Maximum prop range or jet loiter: $$W/S = q\sqrt{\pi A e C_{D_0}}$$
- Maximum jet range: $$W/S = q\sqrt{\pi A e C_{D_0}/3}$$
- Maximum prop loiter: $$W/S = q\sqrt{3\pi A e C_{D_0}}$$

Assume:

- CDo = 0.015 jet, 0.02 (clean prop) to 0.03 (dirty prop , fixed gear)
- e = 0.6 to 0.8
- Altitude = limit h for turbocharged prop (S.L. if no turbo charger), 35,000 for jet
- Loiter speed = 150-200 kts. (jets), 80-120 kts. (props)

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- W/S for **instantaneous** turn rate requirements:
- 2 deg./sec. advantage is significant.
- Maximum instantaneous turn rate is set by CLmax and maximum load factor (remember CLmax is for the req'd flight conditions!):

$$\dot{\psi} = \frac{g\sqrt{n^2 - 1}}{V}$$

$$n = \frac{qC_L}{W/S}$$

$$\rightarrow \quad n = \sqrt{\left(\frac{\dot{\psi}V}{g}\right)^2 + 1} \quad \rightarrow \quad \frac{W}{S} = \frac{qC_{L_{\max}}}{n}$$

- W/S for turn rate requirements must be corrected back to Wo!

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- W/S for **sustained** turn rate requirements:

- Maximum load factor at which velocity and altitude can be sustained. (T = D, L = n x W).

$$n = (T/W)(L/D)$$

- Maximize T/W and L/D!

$$\frac{W}{S} = \frac{(T/W) \pm \sqrt{(T/W)^2 - (4n^2 C_{D_0}/\pi A e)}}{2n^2/q\pi A e}$$

- Warning: the higher the load factor, the less appropriate the parabolic drag polar is (e may be too optimistic).

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- Climb and Glide requirement could set W/S if T/W is set low.
- Define G, climb gradient as the ratio of vertical and horizontal distance traveled:

$$G = (T - D)/W$$

$$\frac{W}{S} = \frac{[(T/W) - G] \pm \sqrt{[(T/W) - G]^2 - (4C_{D_0}/\pi Ae)}}{2/q\pi Ae}$$

- If set T/W = 0, can obtain the W/S for a required power-off glide angle.
- The term inside the square root sign must be positive! No matter how clean your design is, T/W must be higher than the desired climb gradient! That's why a climb rate requirement frequently sets T/W instead of W/S!

$$\boxed{\frac{T}{W} \geq G + 2\sqrt{\frac{C_{D_0}}{\pi Ae}}}$$

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- Ceiling requirement:
- At the absolute ceiling, Ps = R/C = 0
- At the service ceiling , Ps = R/C = 100 ft./min.
- Can use the previous formula, setting G = (Required Ps) / V if T/W known.
- Can use a design lift coefficient and W/S = qCL
- Check with W/S for minimum power: $W/S = q\sqrt{\pi A e C_{D_0}}$

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- Estimate T/W, P/W initially (better to user maximum speed and perhaps climb rate requirements)
- Calculate the lowest W/S (remember correction to Wo level)
- Remember that both **high** T/W and **low** W/S are expensive! Especially with W/S find alternatives (like HLD) to mitigate the effects on Wo. If necessary, relax a requirement!
- Re-check your final T/W and W/S and use for configuration layout!