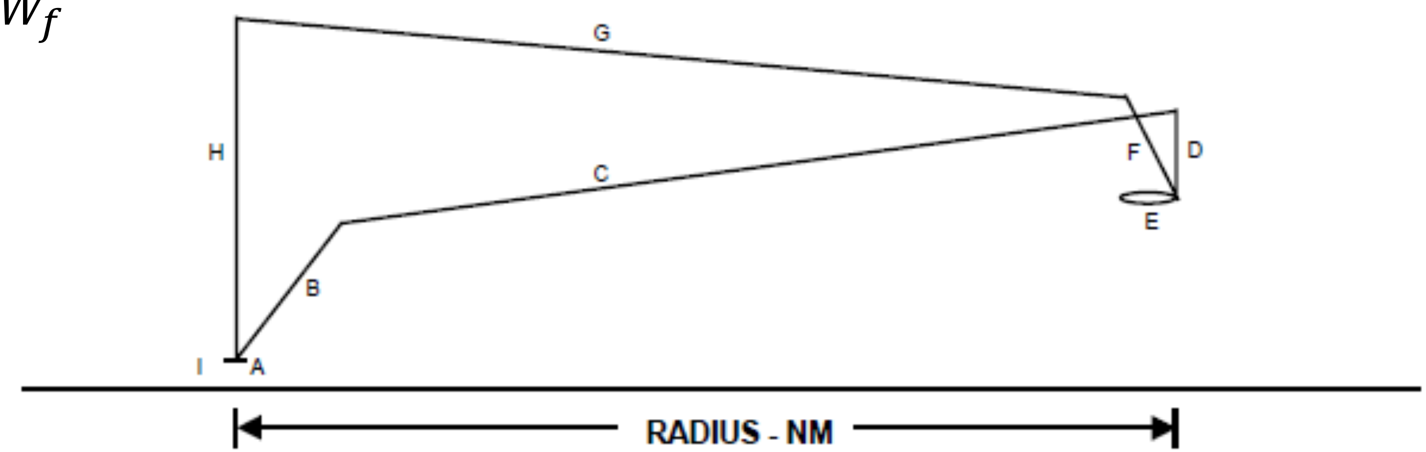
# Sizing to Constraints

Errikos Levis

Based on the mission profile we have:

- Assumed $(L/D)_{max}$ and sfc based on baseline and current state of the art
- Used range and endurance equations, and empiricism to estimate
  - Gross Weight (MTOW) $W_0$
  - Operating Empty Weight (OEW) $W_e$
  - Fuel Weight $W_f$




Mission profile for an Airborne Warning And Control System (AWACS) aircraft (MIL-STD 3013)

## What's next?

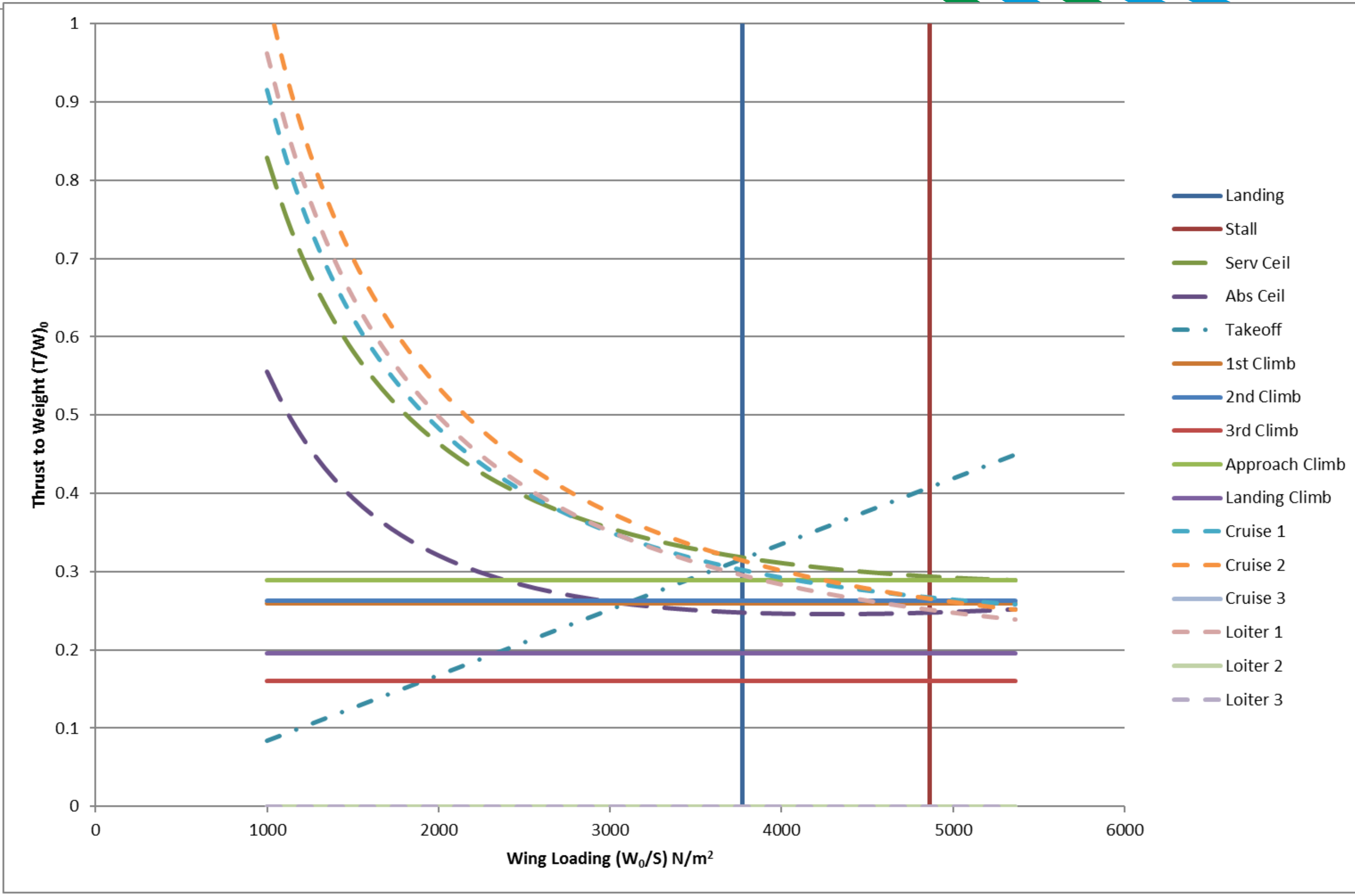
- Make sure aircraft can complete the stipulated design mission profile

- Make sure aircraft capable of achieving performance targets like
  - Ceilings (absolute, service, combat)
  - Maximum speed
  - Time to climb / Rates of climb
  - Sustained turn rates / radii
  - Level (axial) acceleration

  - Takeoff and Landing distances (TODA & LDA)
  - Stall speed

- Make sure aircraft meets airworthiness requirements

# Key Parameters?


Thrust to Weight $(T/W)_0$
Wing Loading $(W_0/S)$ N/m$^2$
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
1000
2000
3000
4000
5000
6000
Landing
Stall
Serv Ceil
Abs Ceil
Takeoff
1st Climb
2nd Climb
3rd Climb
Approach Climb
Landing Climb
Cruise 1
Cruise 2
Cruise 3
Loiter 1
Loiter 2
Loiter 3

# Point Performance

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From definition of Specific Excess Power:

for thrust producing powerplants (jet)

$$\frac{dh}{dt} + \frac{V_\infty}{g}\frac{dV_\infty}{dt} = V_\infty\left(\frac{T-D}{W}\right)$$

for power producing powerplants (jet)

$$\frac{dh}{dt} + \frac{V_\infty}{g}\frac{dV_\infty}{dt} = \frac{P}{W} - \frac{V_\infty D}{W}$$

Assuming a parabolic drag curve at load factor $n$

$$\frac{D}{W} = \frac{\frac{1}{2}\rho V_\infty^2 C_{D_0}}{W/S_{ref}} + \frac{n^2\, W/S_{ref}}{\frac{1}{2}\rho V_\infty^2\, \pi\, AR\, e}$$

where $C_{D_0} = f(S_{wet}/S_{ref})$

$$\left(\frac{L}{D}\right)_{max} = \frac{1}{2}\sqrt{\frac{\pi AR\, e}{C_{D_0}}} = K_{LD}\sqrt{\frac{AR}{S_{wet}/S_{ref}}}$$

and dependent on configuration:

| | | |
|---|---|---|
| undercarriage | $\Delta C_{D_0} \approx 0.02$ | $\Delta e \approx -0.05$ |
| t/o flaps | $\Delta C_{D_0} \approx 0.02$ | $\Delta e \approx -0.05$ |
| landing flaps | $\Delta C_{D_0} \approx 0.07$ | $\Delta e \approx -0.10$ |

SEP equation for jet becomes

$$\frac{dh}{dt} + \frac{V_\infty}{g}\frac{dV_\infty}{dt} = V_\infty\left(\frac{T}{W} - \frac{\frac{1}{2}\rho V_\infty^2 C_{D_0}}{W/S_{ref}} - \frac{n^2\, W/S_{ref}}{\frac{1}{2}\rho V_\infty^2\, \pi\, AR\, e}\right)$$

or

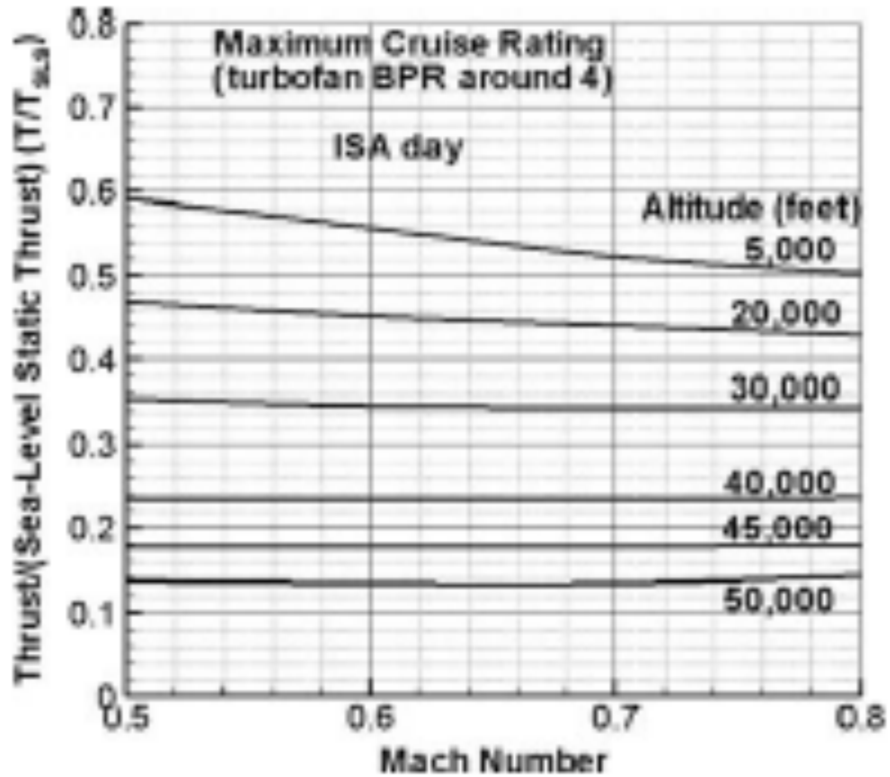
$$\frac{T}{W} = \frac{1}{V_\infty}\frac{dh}{dt} + \frac{1}{g}\frac{dV_\infty}{dt} + \frac{\frac{1}{2}\rho V_\infty^2 C_{D_0}}{W/S_{ref}} + \frac{n^2\, W/S_{ref}}{\frac{1}{2}\rho V_\infty^2\, \pi\, AR\, e}$$

# Scaling to sea-level, static, takeoff conditions

(Kundu, Aircraft Design, 2010)

$$\alpha = \frac{W}{W_0}$$

$$\beta = \frac{T}{T_0}$$




Hence for jet

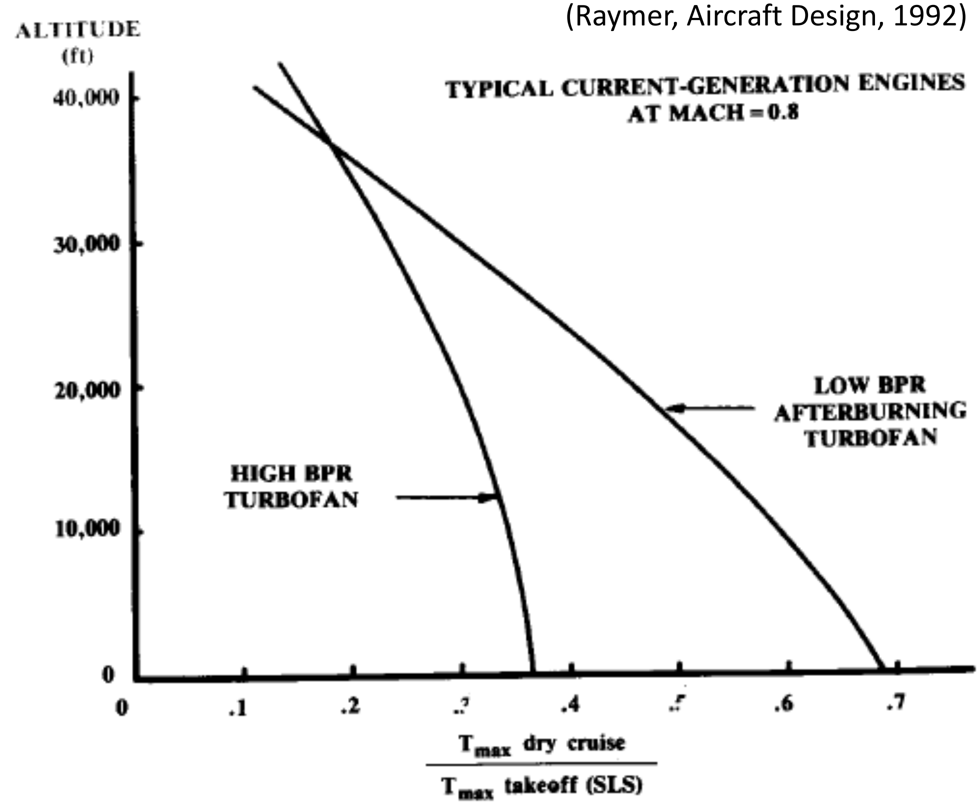
$$\left(\frac{T}{W}\right)_0 = \frac{\alpha}{\beta}\left[\frac{1}{V_\infty}\frac{dh}{dt} + \frac{1}{g}\frac{dV_\infty}{dt} + \frac{\frac{1}{2}\rho V_\infty^2 C_{D_0}}{\alpha\, W_0/S_{ref}} + \frac{\alpha\, n^2 W_0/S_{ref}}{\frac{1}{2}\rho V_\infty^2\, \pi\, AR\, e}\right]$$

# Scaling to sea-level, static, takeoff conditions

(Raymer, Aircraft Design, 1992)

$$\alpha = \frac{W}{W_0}$$

$$\beta = \frac{T}{T_0}$$




Hence for jet

$$\left(\frac{T}{W}\right)_0 = \frac{\alpha}{\beta}\left[\frac{1}{V_\infty}\frac{dh}{dt} + \frac{1}{g}\frac{dV_\infty}{dt} + \frac{\frac{1}{2}\rho V_\infty^2 C_{D_0}}{\alpha\, W_0/S_{ref}} + \frac{\alpha\, n^2 W_0/S_{ref}}{\frac{1}{2}\rho V_\infty^2\, \pi\, AR\, e}\right]$$

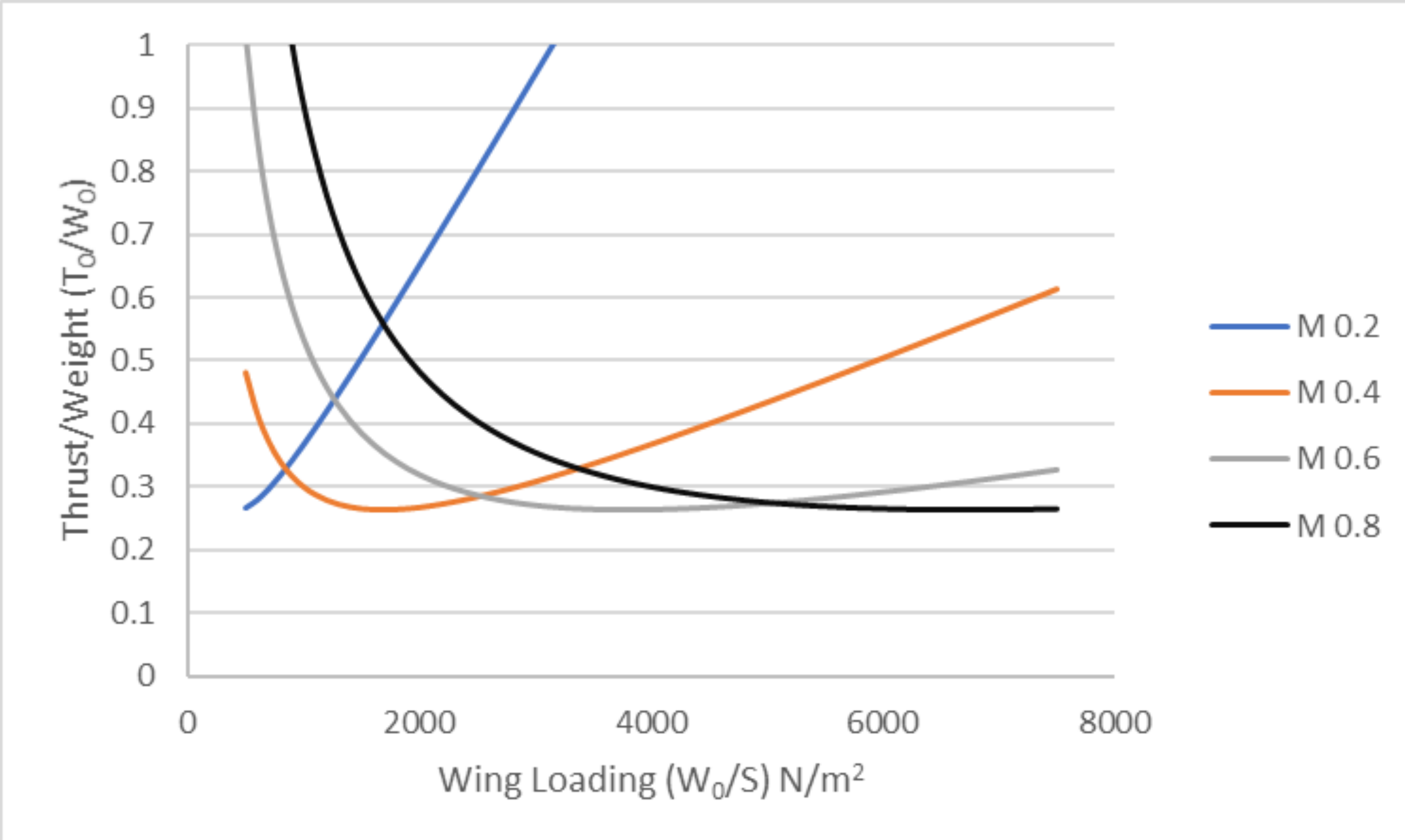
Consider aircraft with following assumed characteristics

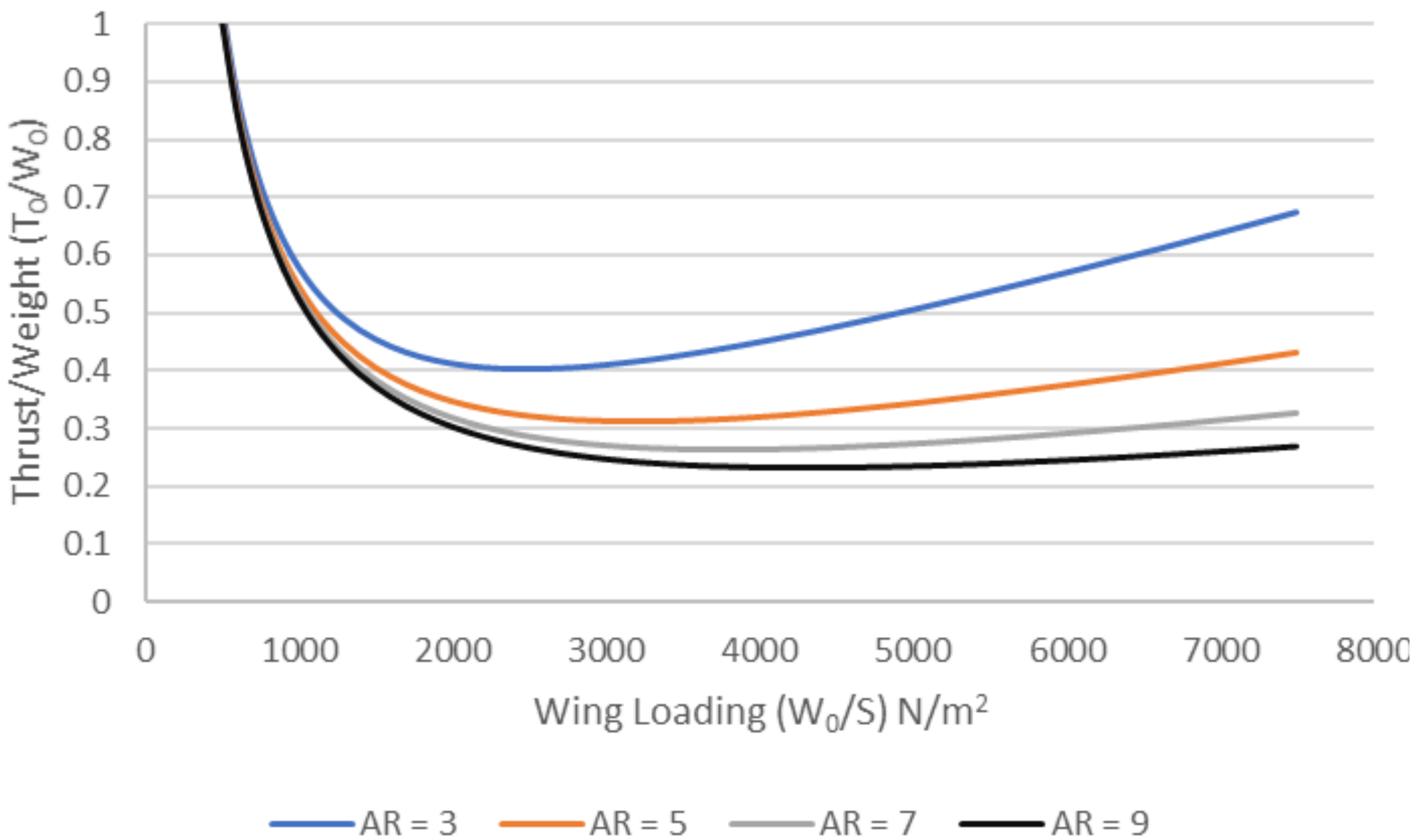
$$C_{D_0} = 0.02$$
$$AR = 7$$
$$e = 0.9$$

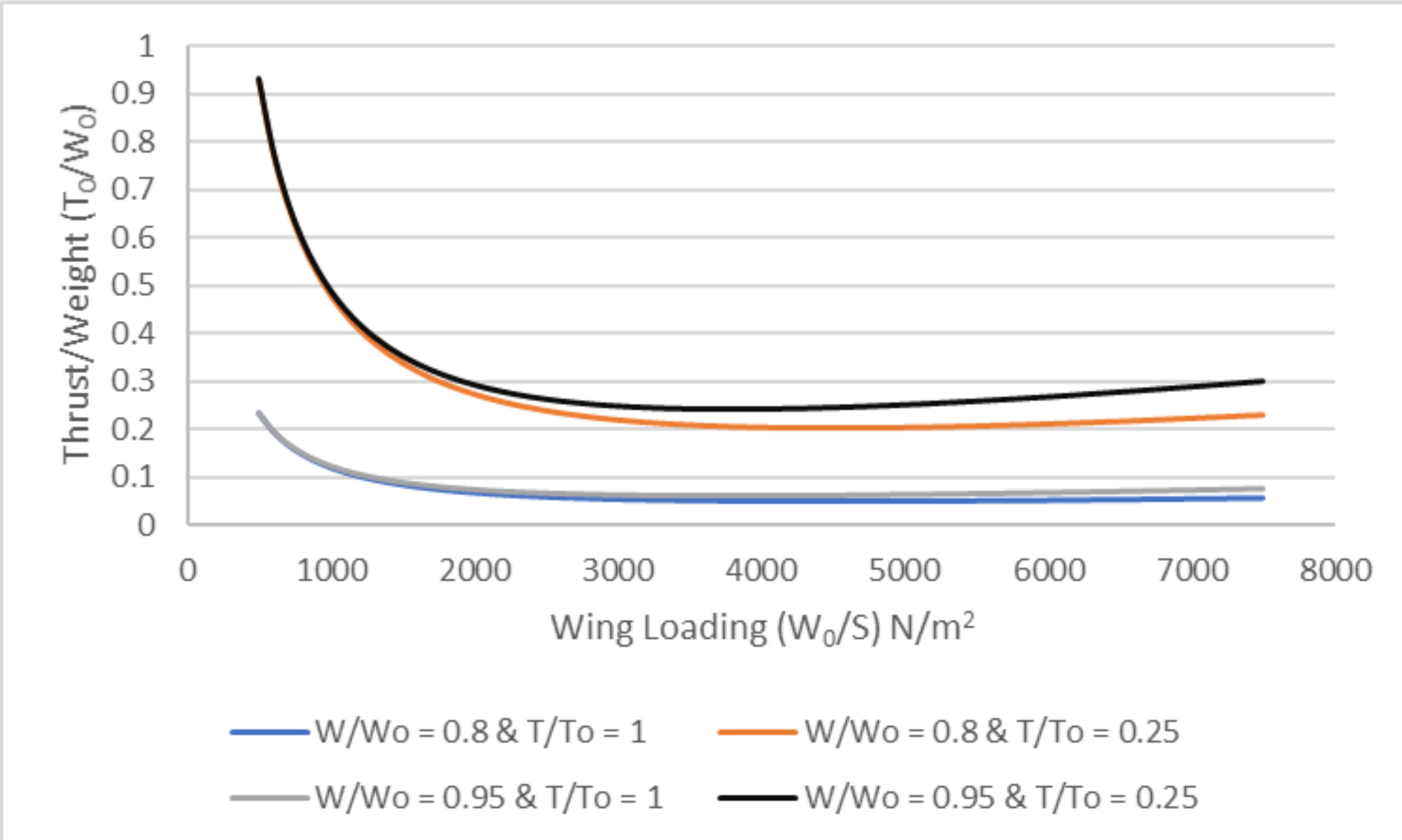
analyzed at the start of its cruise segment, at 11,000 ft and Mach 0.6, in steady level flight where

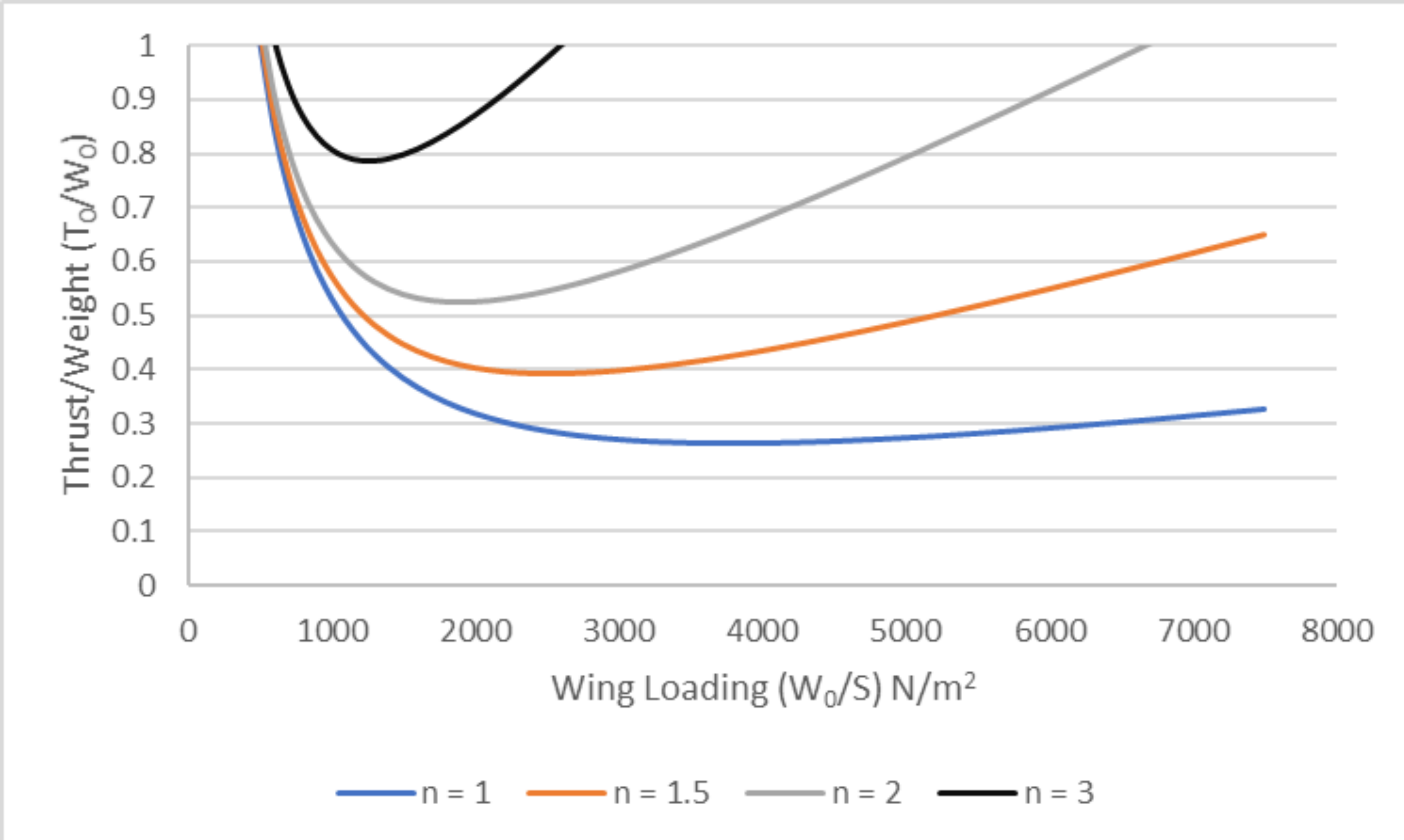
$$\frac{T}{T_0} = 0.23$$
$$\frac{W}{W_0} = 0.96$$

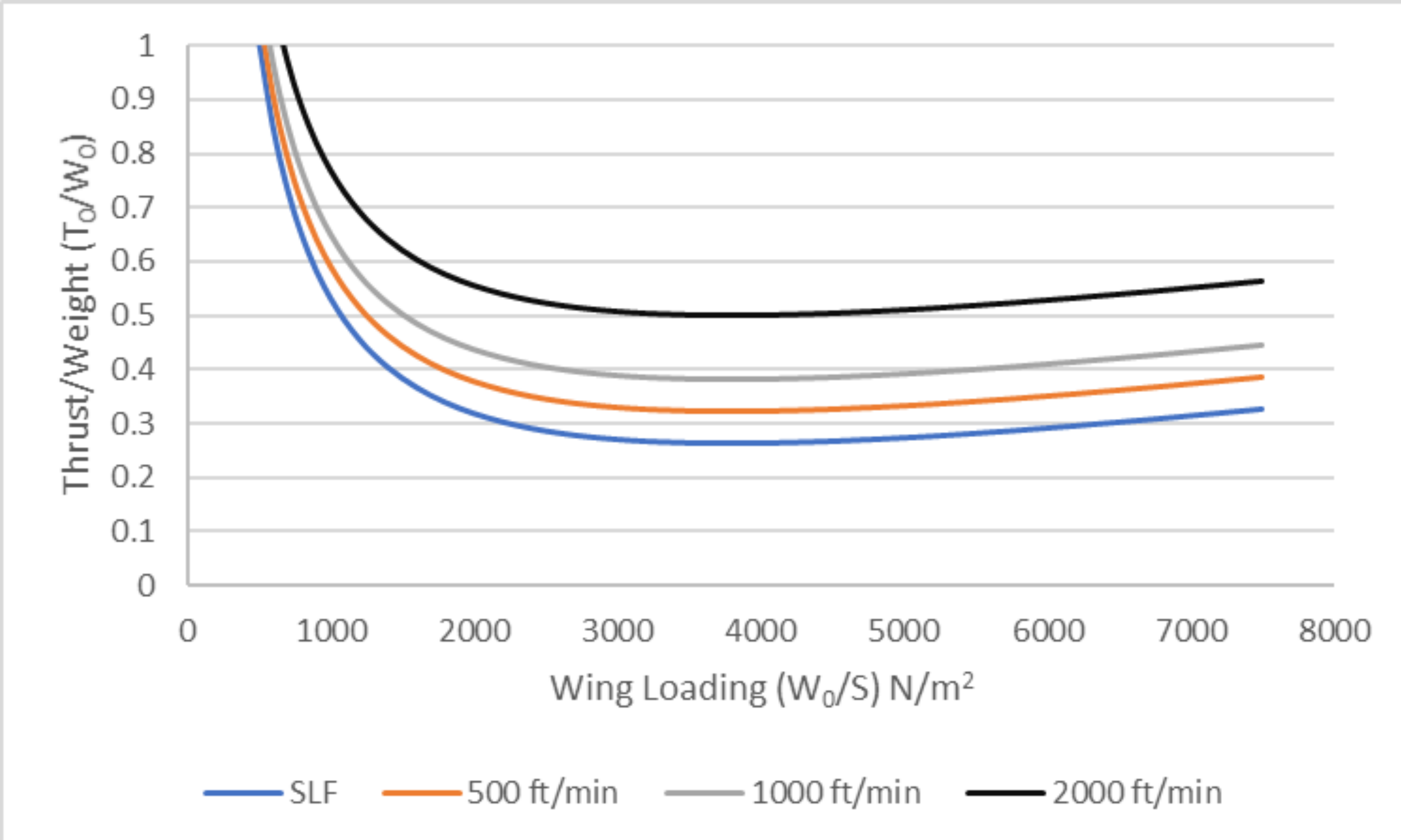
(all values assumed for illustration purposes)


Thrust/Weight ($T_O/W_O$)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2000
4000
6000
8000
Wing Loading ($W_0/S$) N/m$^2$
M 0.2
M 0.4
M 0.6
M 0.8


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Thrust/Weight ($T_0/W_0$)
0
1000
2000
3000
4000
5000
6000
7000
8000
Wing Loading ($W_0/S$) $N/m^2$
AR = 3
AR = 5
AR = 7
AR = 9


Thrust/Weight ($T_O/W_O$)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1000
2000
3000
4000
5000
6000
7000
8000
Wing Loading ($W_0/S$) N/m²
W/Wo = 0.8 & T/To = 1
W/Wo = 0.8 & T/To = 0.25
W/Wo = 0.95 & T/To = 1
W/Wo = 0.95 & T/To = 0.25


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Thrust/Weight ($T_0/W_0$)
0
1000
2000
3000
4000
5000
6000
7000
8000
Wing Loading ($W_0/S$) $N/m^2$
n = 1
n = 1.5
n = 2
n = 3


Thrust/Weight ($T_0/W_0$)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1000
2000
3000
4000
5000
6000
7000
8000
Wing Loading ($W_0/S$) $N/m^2$
SLF
500 ft/min
1000 ft/min
2000 ft/min

# Field Performance

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Key terms:

Take-Off Distance Available (TODA)
Landing Distance Available (LDA)

Take-Off Distance Required
Landing Distance Required

Actual TakeOff Distance
Balanced Field Length
Actual Landing Distance

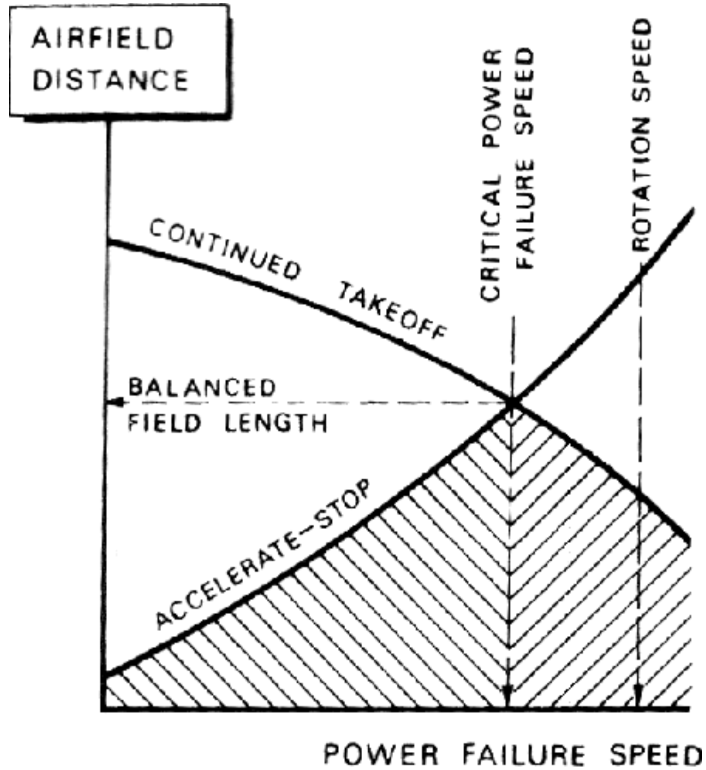
(for design purposes we always assume dry, flat runway with no crosswind)

Key terms:

Take-Off Distance Available (TODA)
Landing Distance Available (LDA)

Take-Off Distance Required
Landing Distance Required

Actual TakeOff Distance
Balanced Field Length
Actual Landing Distance




(Torenbeek, Synthesis of Subsonic Aircraft Design, 1982)

(for design purposes we always assume dry, flat runway with no crosswind)

# Parameters affecting Takeoff Distance

- Stall Speed
- Ground Acceleration
- Excess Power
- Obstacle Height

Empirically (in SI):
BFL - $TODA \geq (0.297 - 0.019\, N_E)\, TOP$
AEO to 50 ft - $TODA \geq 0.144\ TOP$

where $TOP = \dfrac{W/S}{T/W\ \sigma\ C_{L_{LOF}}}$

(Similar methods for propeller available in literature but TOP = $\frac{W/S}{P/W \sigma\ C_{L_{LOF}}}$)

(Raymer, Aircraft Design, 1992)

# Parameters affecting Landing Distance

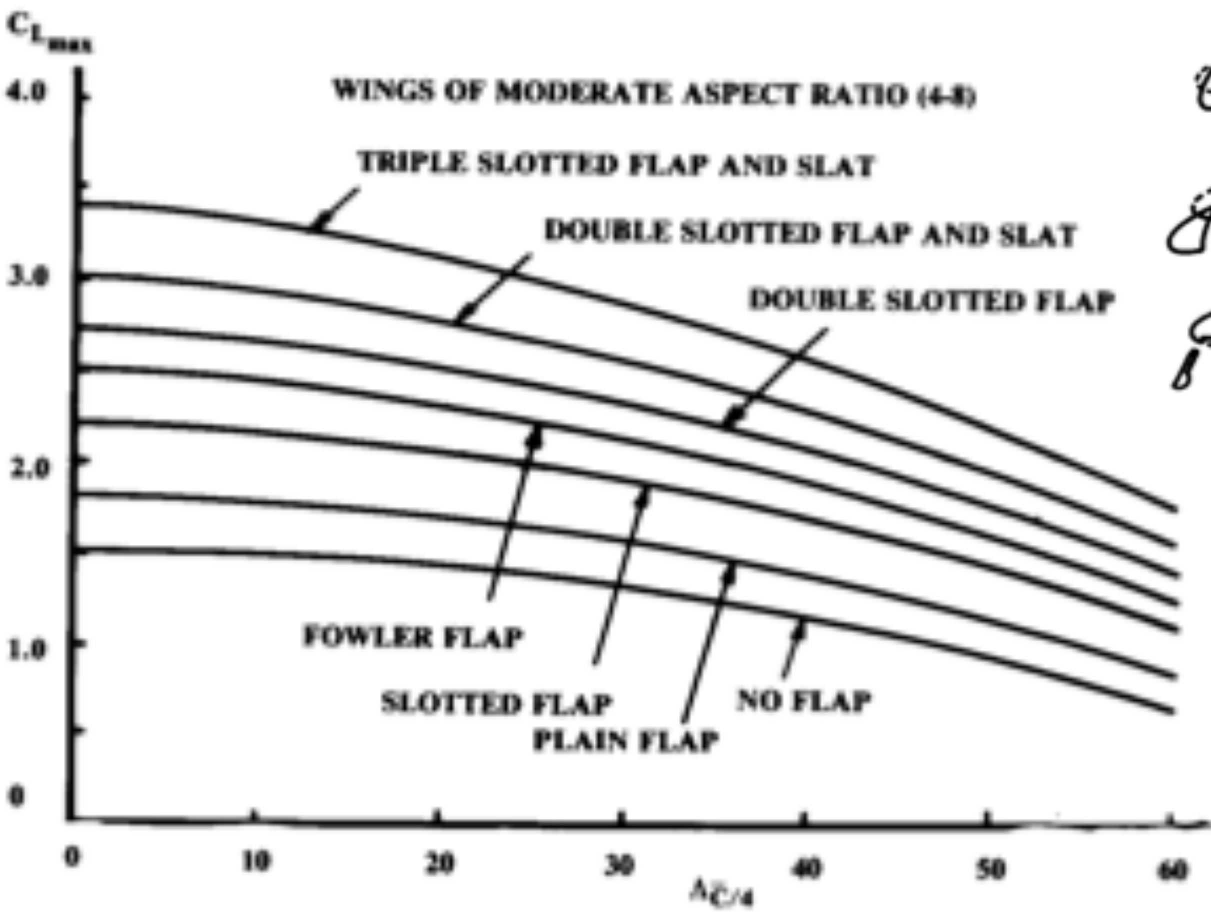
- Approach Speed
- Deceleration
- Glide Slope
- Obstacle Height

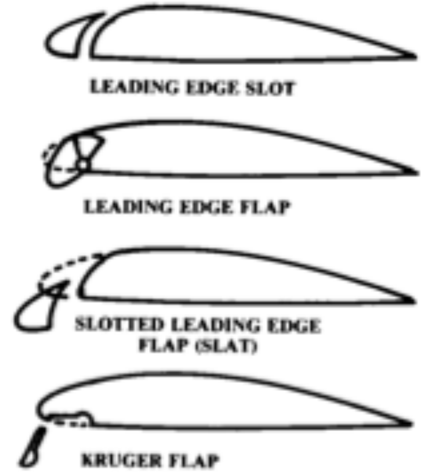
Empirically (in SI):

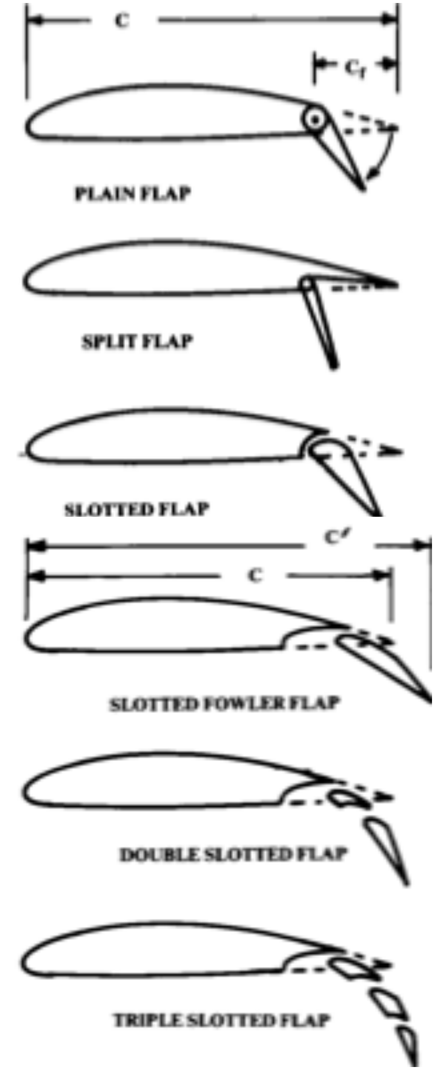
$$ALD = 0.51 \frac{W/S}{\sigma\, C_{L_{maxL}}} K_R + S_a$$

| $S_a$ | |
|---|---|
| 305 m | Airliner type 3 degree glideslope |
| 183 m | For GA type powered off approach |
| 137 m | For STOL, 7 degree glideslope |

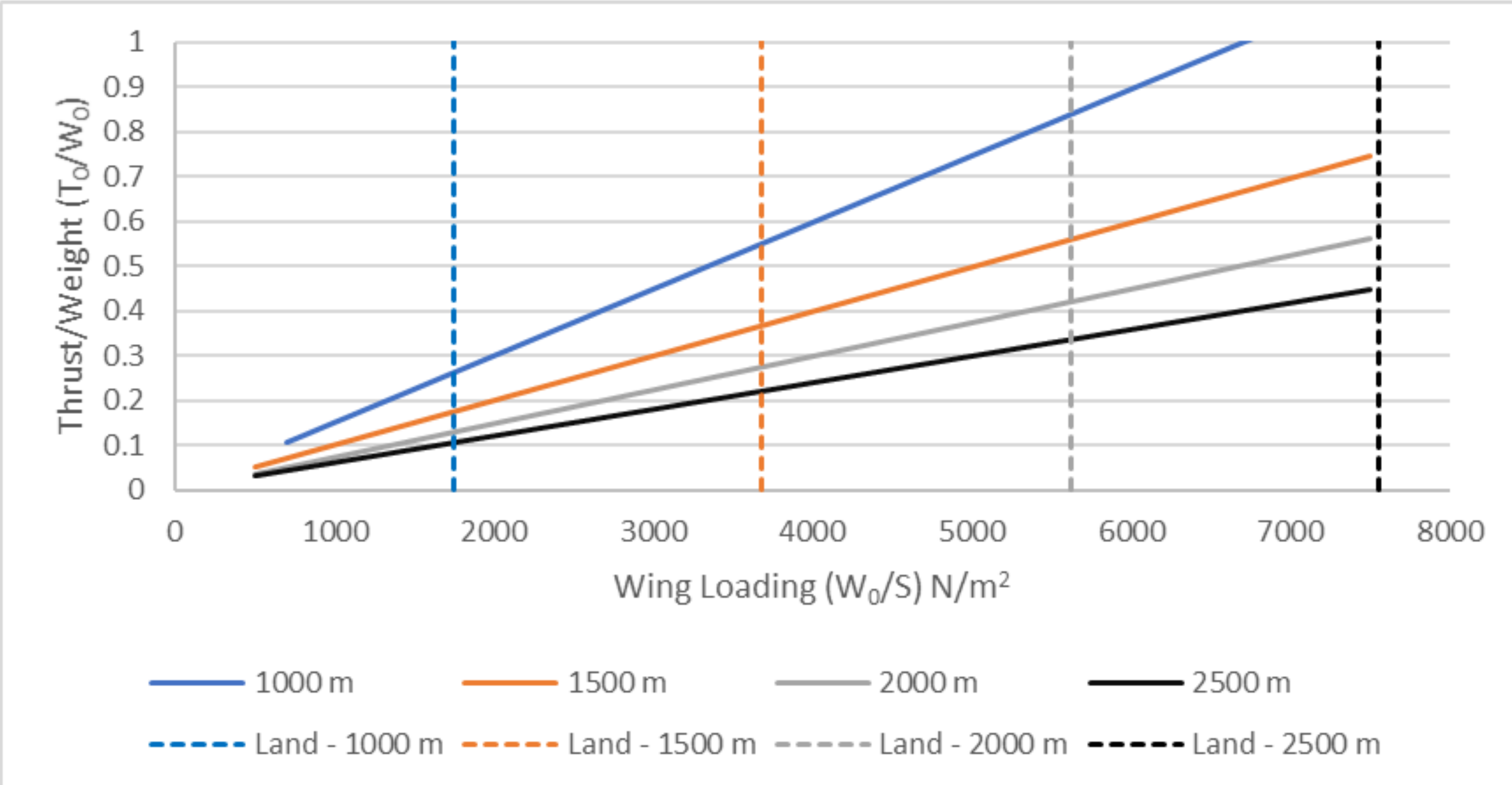
(Raymer, Aircraft Design, 1992)

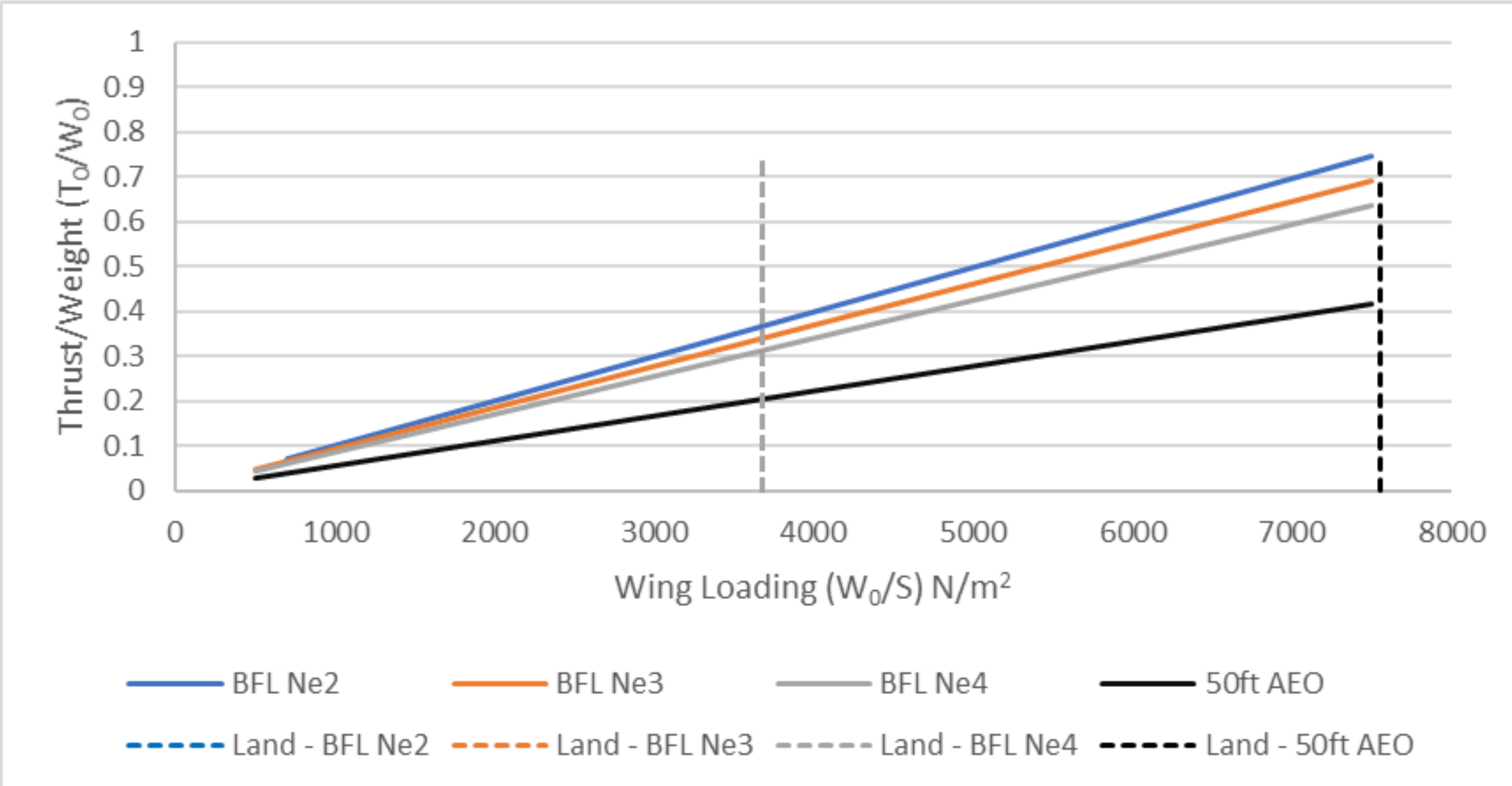


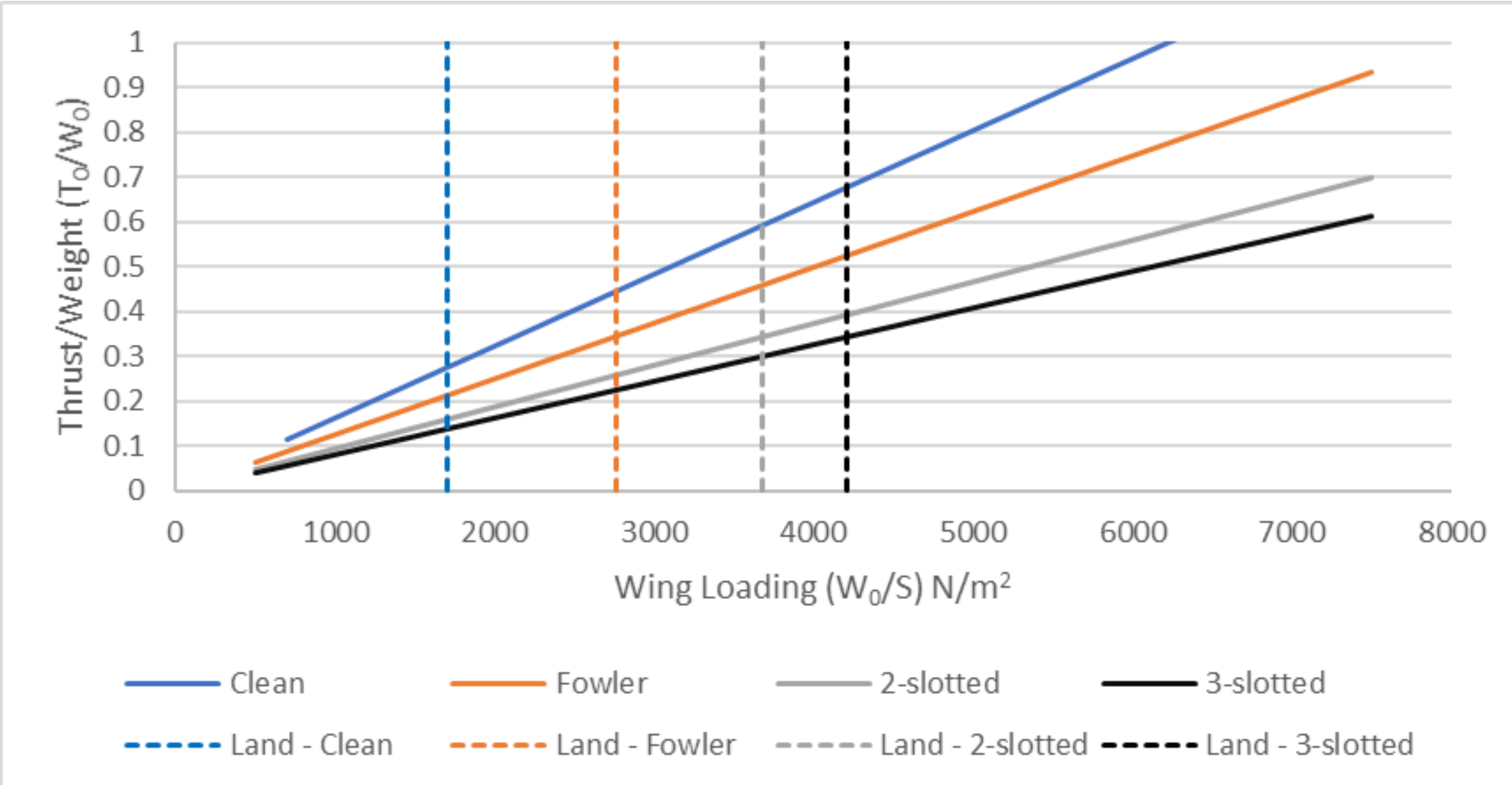



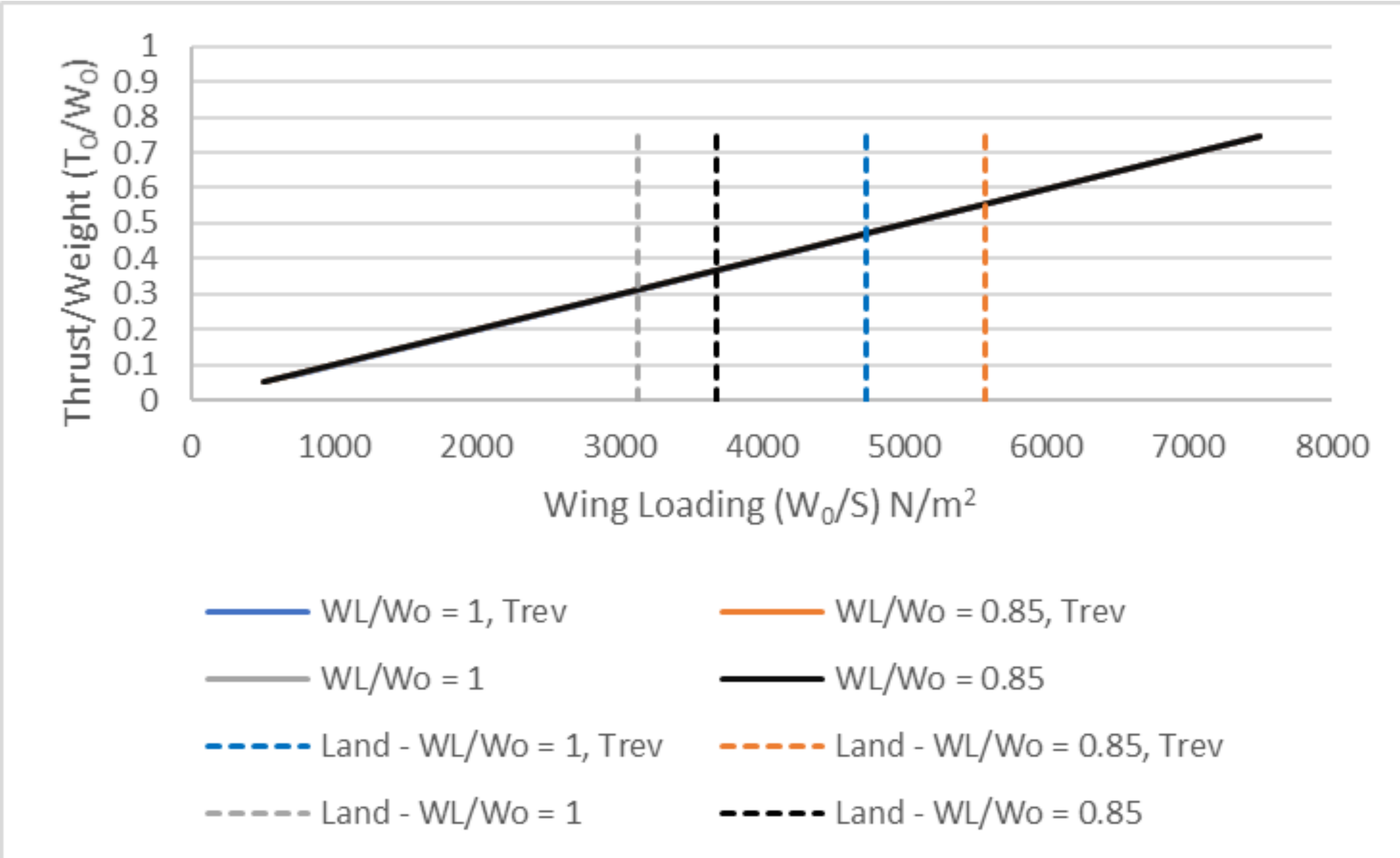




(Raymer, Aircraft Design, 1992)


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Thrust/Weight ($T_0/W_0$)
0
1000
2000
3000
4000
5000
6000
7000
8000
Wing Loading ($W_0/S$) $N/m^2$
1000 m
1500 m
2000 m
2500 m
Land - 1000 m
Land - 1500 m
Land - 2000 m
Land - 2500 m


Thrust/Weight ($T_0/W_0$)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1000
2000
3000
4000
5000
6000
7000
8000
Wing Loading ($W_0/S$) $N/m^2$
BFL Ne2
BFL Ne3
BFL Ne4
50ft AEO
Land - BFL Ne2
Land - BFL Ne3
Land - BFL Ne4
Land - 50ft AEO


Thrust/Weight ($T_0/W_0$)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1000
2000
3000
4000
5000
6000
7000
8000
Wing Loading ($W_0/S$) $N/m^2$
Clean
Fowler
2-slotted
3-slotted
Land - Clean
Land - Fowler
Land - 2-slotted
Land - 3-slotted


Thrust/Weight ($T_0/W_0$)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1000
2000
3000
4000
5000
6000
7000
8000
Wing Loading ($W_0/S$) $N/m^2$
WL/Wo = 1, Trev
WL/Wo = 0.85, Trev
WL/Wo = 1
WL/Wo = 0.85
Land - WL/Wo = 1, Trev
Land - WL/Wo = 0.85, Trev
Land - WL/Wo = 1
Land - WL/Wo = 0.85