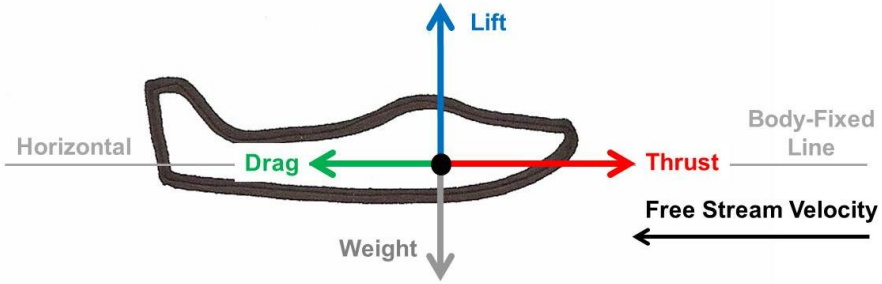
Aircraft Performance
Flight Envelope

Flight Envelope



V_{max} = How <u>FAST</u> can an airplane fly?

V_{min} = How <u>SLOW</u> can an airplane fly?

Ceiling = How <u>HIGH</u> can an airplane fly?

Maneuver = How <u>MANY G's</u> can the airplane pull?

Two answers to each of these questions …

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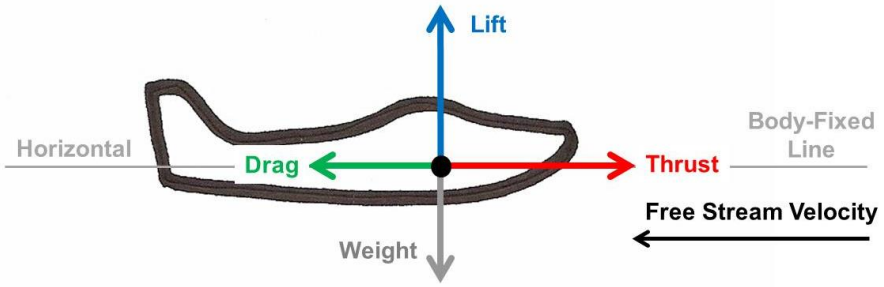
Flight Envelope

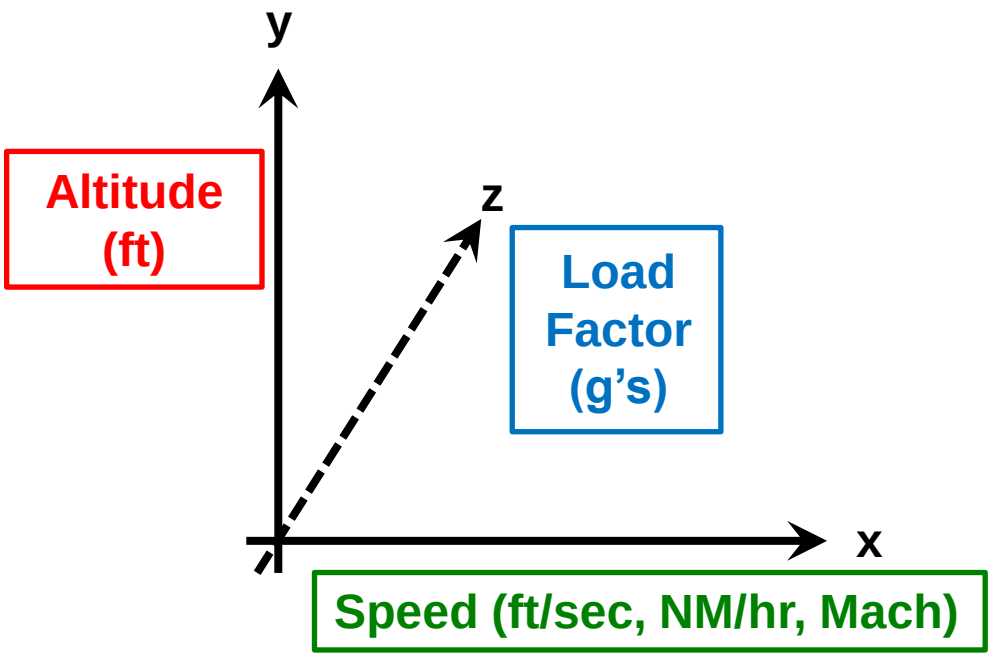


Two answers:

1. **Limitations of the aircraft (covered today)**
   - **structure (dynamic pressure, flutter, g's)**
   - **aerodynamics ($C_{L_{max}}$, controllability)**
   - **subsystems (hydraulic power, cockpit)**
2. **Available thrust (covered later)**

Aircraft Flight Envelope

Flight envelope is defined as the boundary of altitude and speed combinations within which flight is possible for a given weight, load factor, and configuration.



Flight Envelope Chart
Altitude vs Speed given Weight, Load Factor & Configuration

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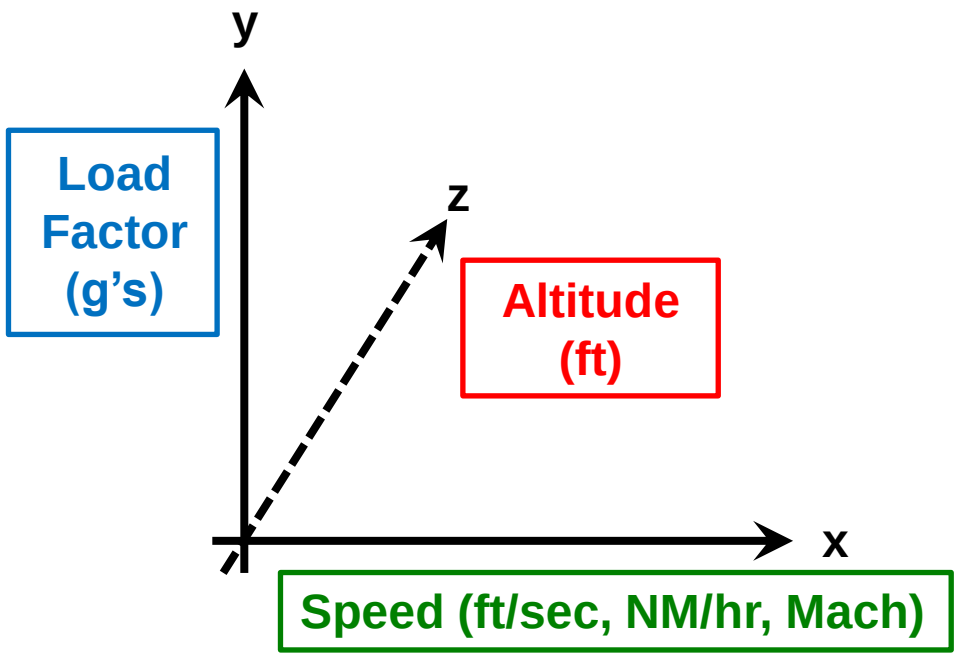
Aircraft Flight Envelope

Flight envelope is defined as the boundary of altitude and speed combinations within which flight is possible for a given weight, load factor, and configuration.



V-n Diagram
Load Factor vs Speed given Weight, Altitude & Configuration

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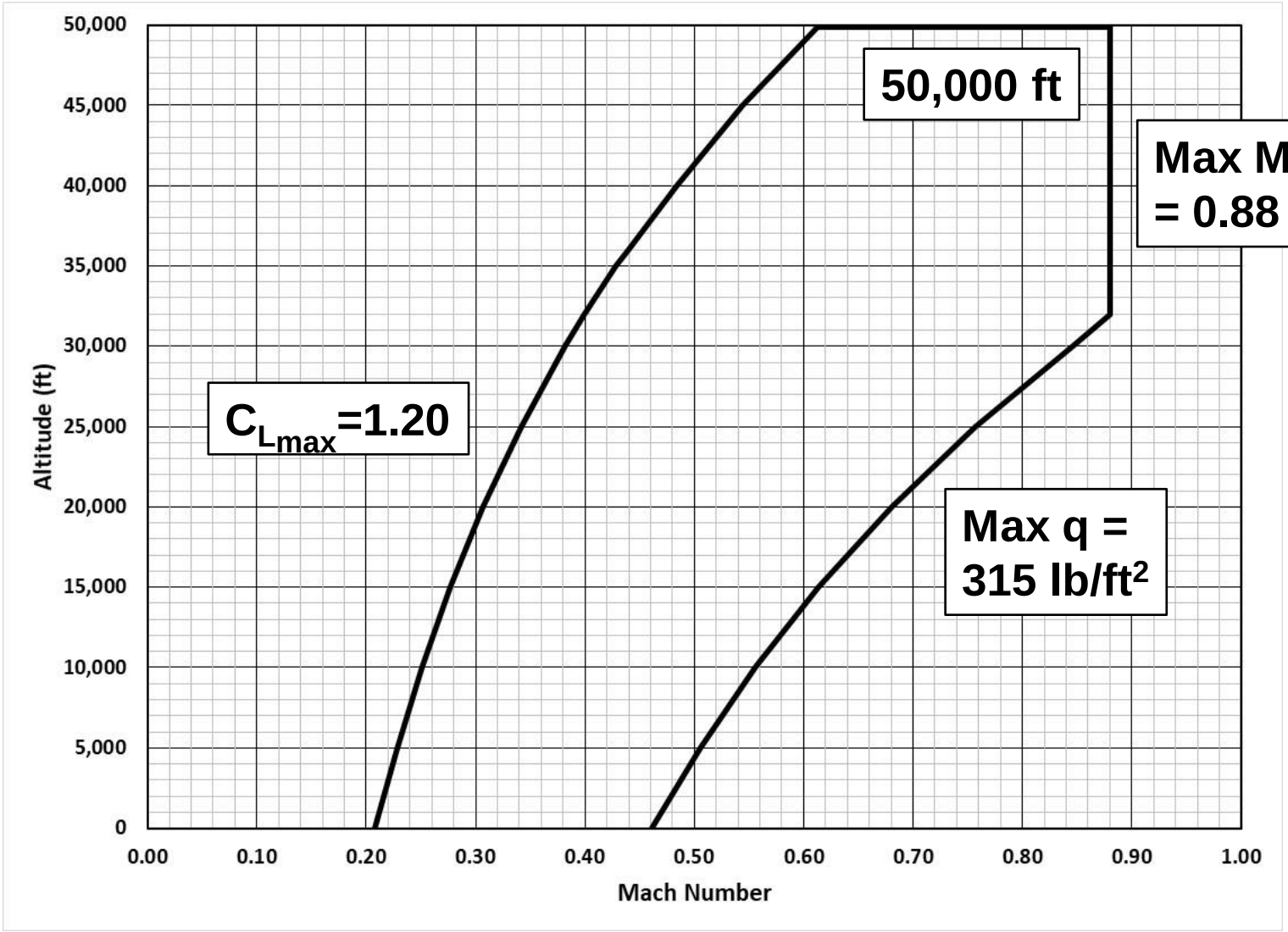
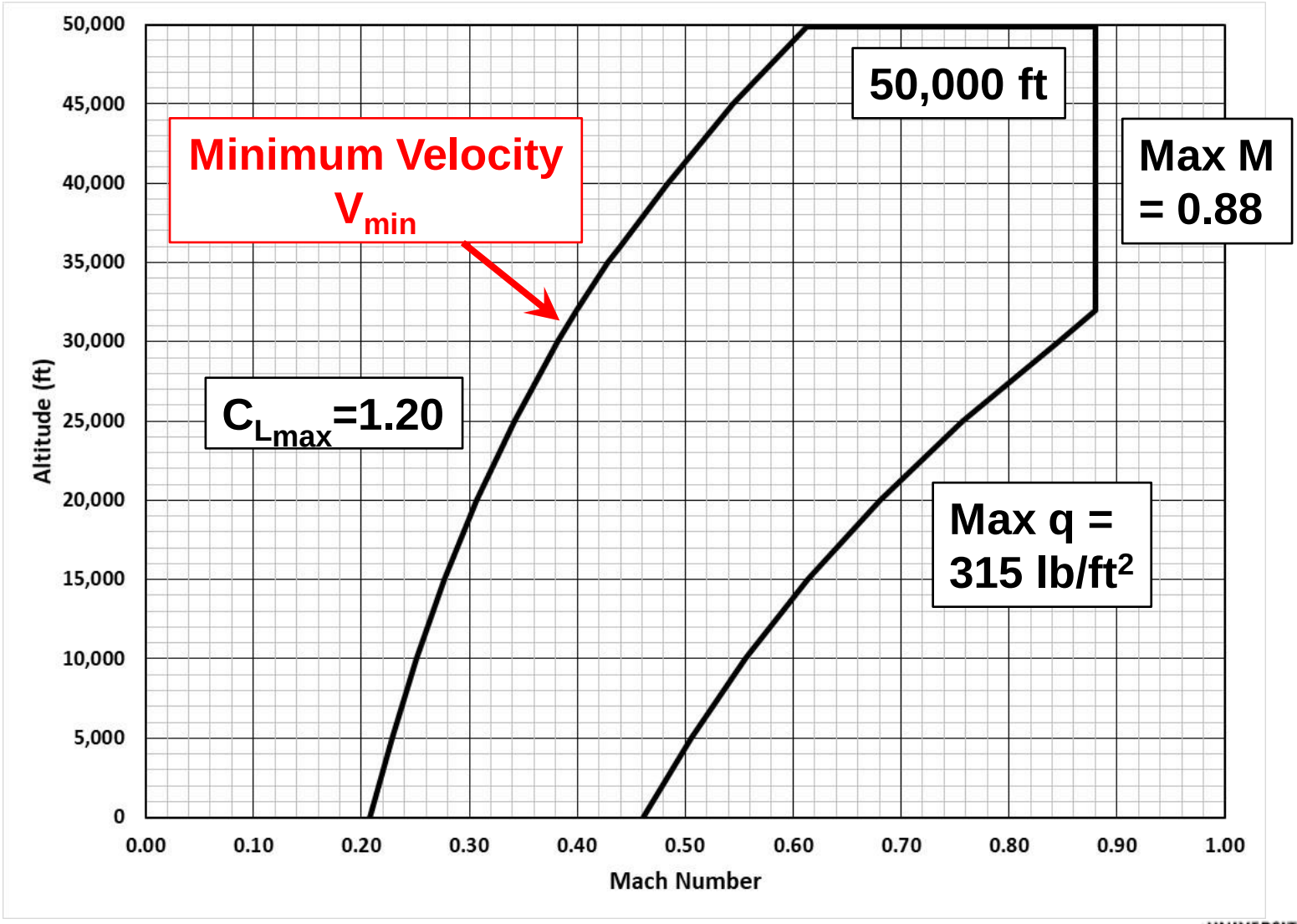
Flight Envelope



Flight Envelope

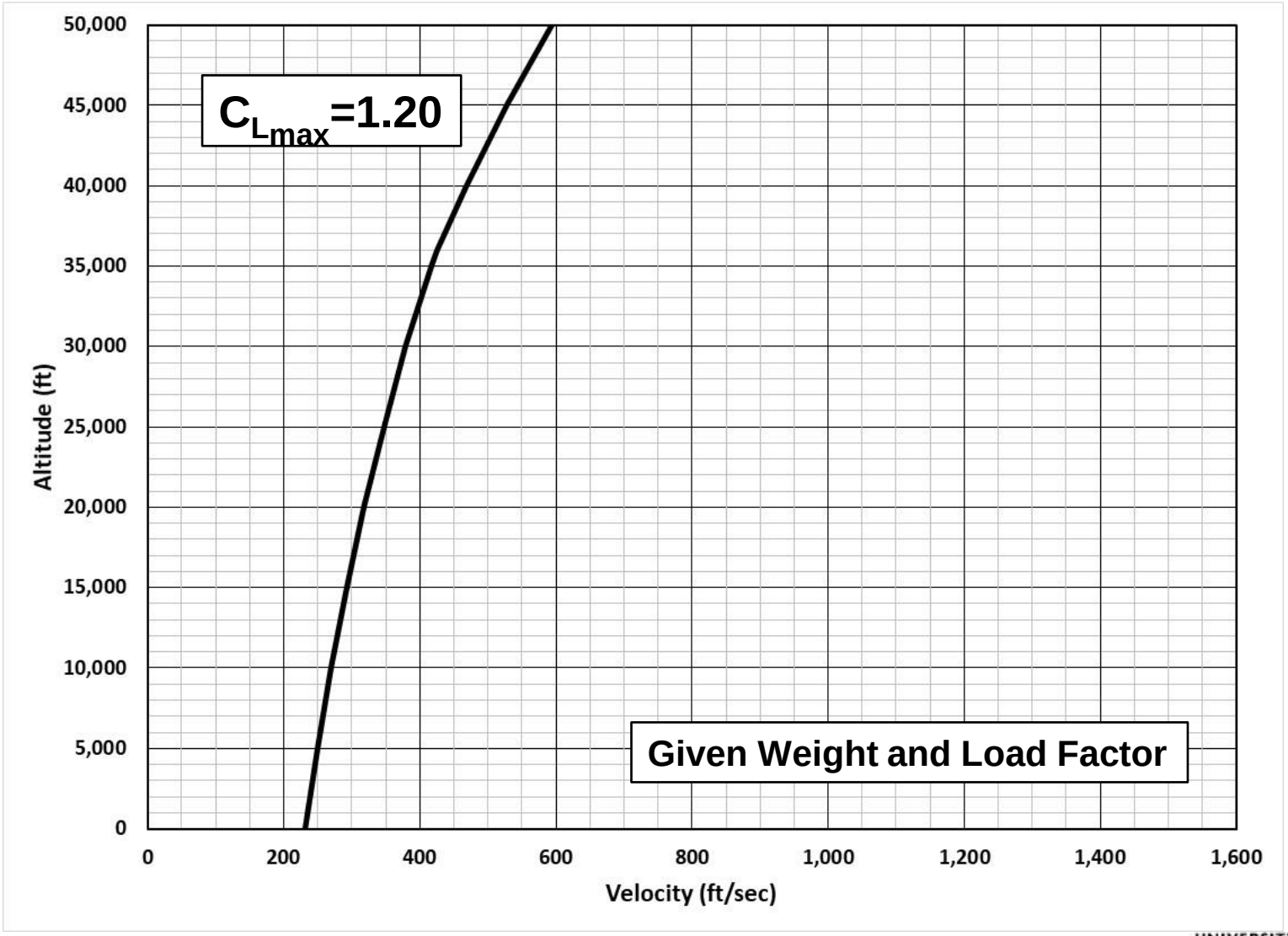


Stall Speed

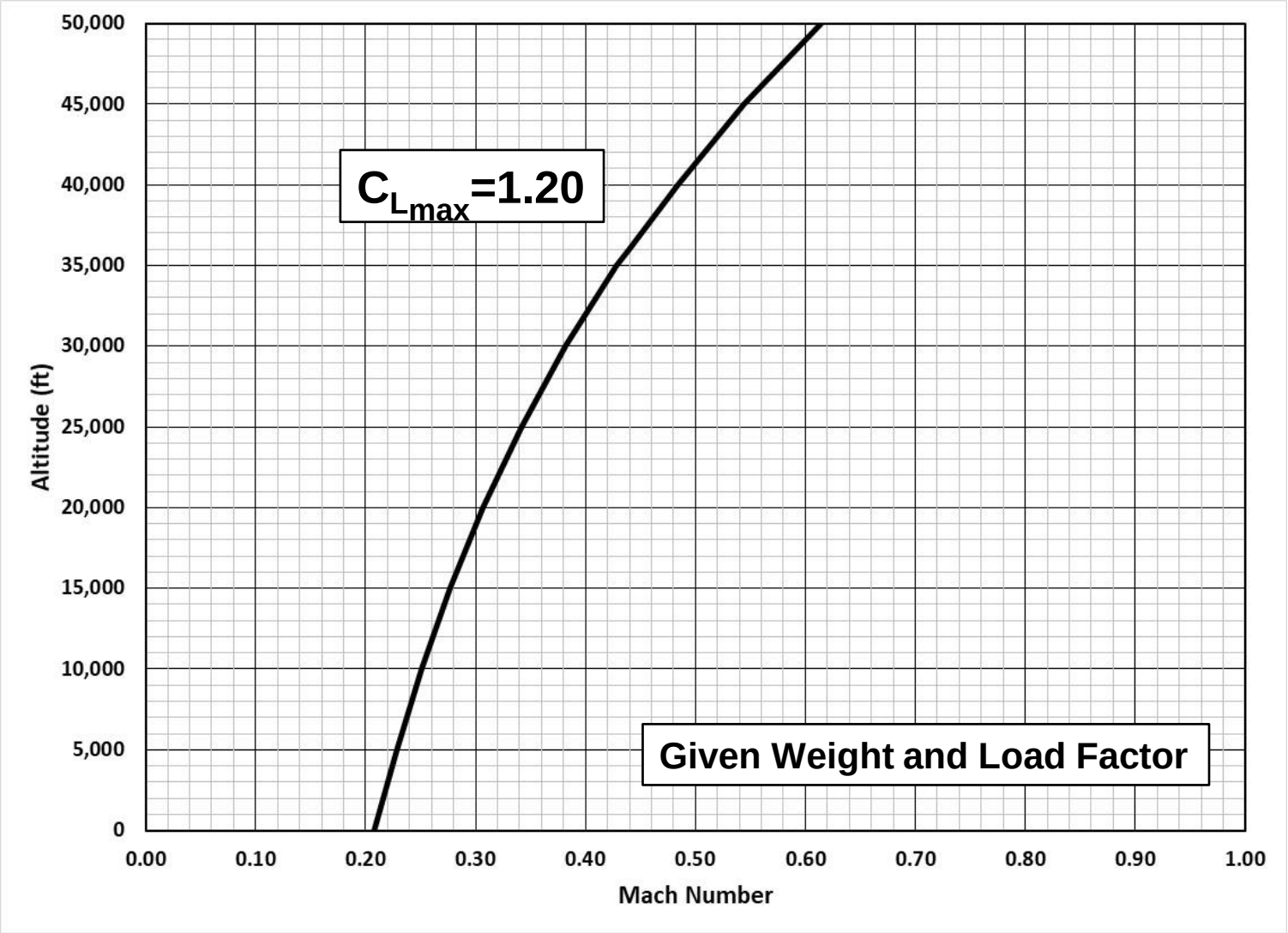
$$C_L = \frac{n\,W}{q\,S} = \frac{n\,W}{\frac{1}{2}\,\rho\,V^2\,S}$$

$$C_{L_{max}} = \frac{n\,W}{\frac{1}{2}\,\rho\,V_{stall}{}^2\,S} \longrightarrow V_{stall} = \sqrt{\frac{2}{\rho}\,\frac{W}{S}\,\frac{n}{C_{L_{max}}}}$$

Stall Speed – Flight Envelope



Stall Speed – Flight Envelope



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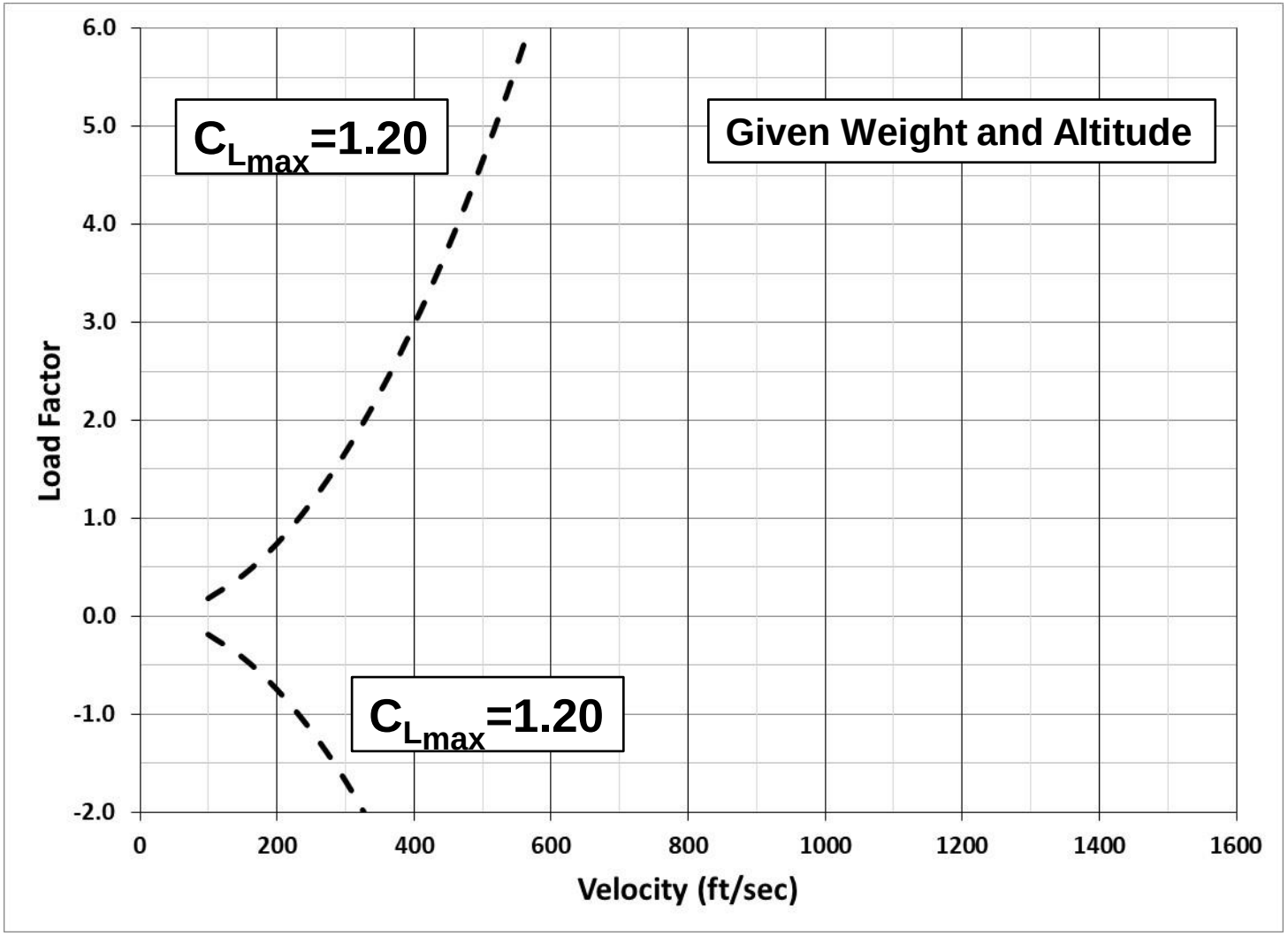
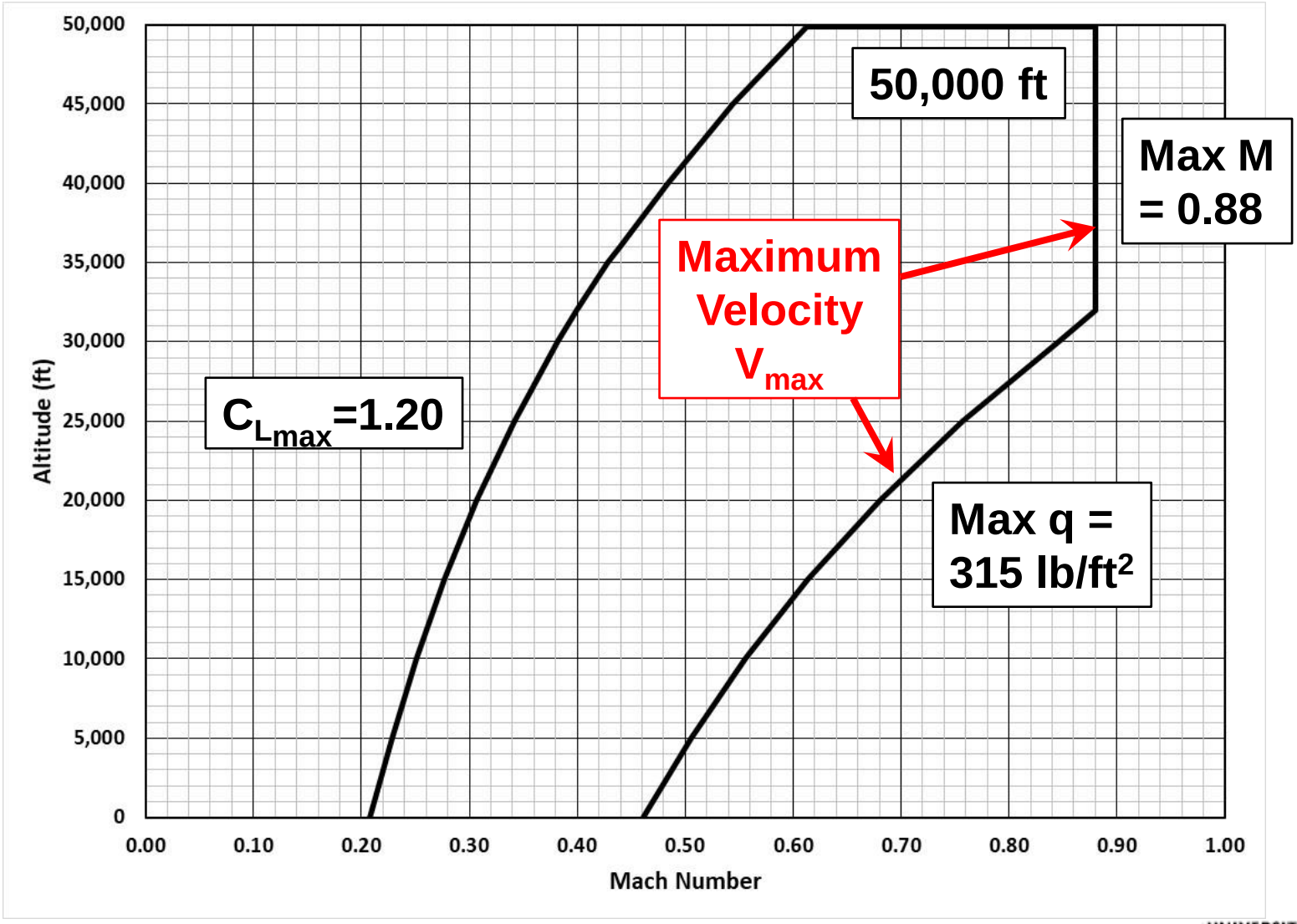
Stall Speed – V-n Diagram



Flight Envelope



Limit Speed

Maximum Mach Number

Maximum dynamic pressure (max q = q_{max})
Maximum KEAS

Stability and control constraints

Engine performance constraints

Landing gear, flaps, speedbrake

At any altitude, an aircraft's maximum velocity is constrained to the least of these speeds

$$V_{max} = \sqrt{\frac{2}{\rho} q_{max}} \quad \text{- or -} \quad V_{max} = M_{max}\ a$$

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Limit Speed

Maximum Mach Number (Max M = X.YY)

Maximum dynamic pressure (q_{max} = X.Y lb/ft^2)

Maximum KEAS (Max KEAS = X.Y NM/hr or kts)

At any altitude, an aircraft's maximum velocity is constrained to the least of these speeds

$$V_{max} = \sqrt{\frac{2}{\rho} q_{max}} \quad \text{- or -} \quad V_{max} = M_{max}\ a$$

$$\text{Max } q = \left(\frac{q}{M^2}\right)_{SL} \left(\frac{\text{Max KEAS}}{a_{SL}}\right)^2$$

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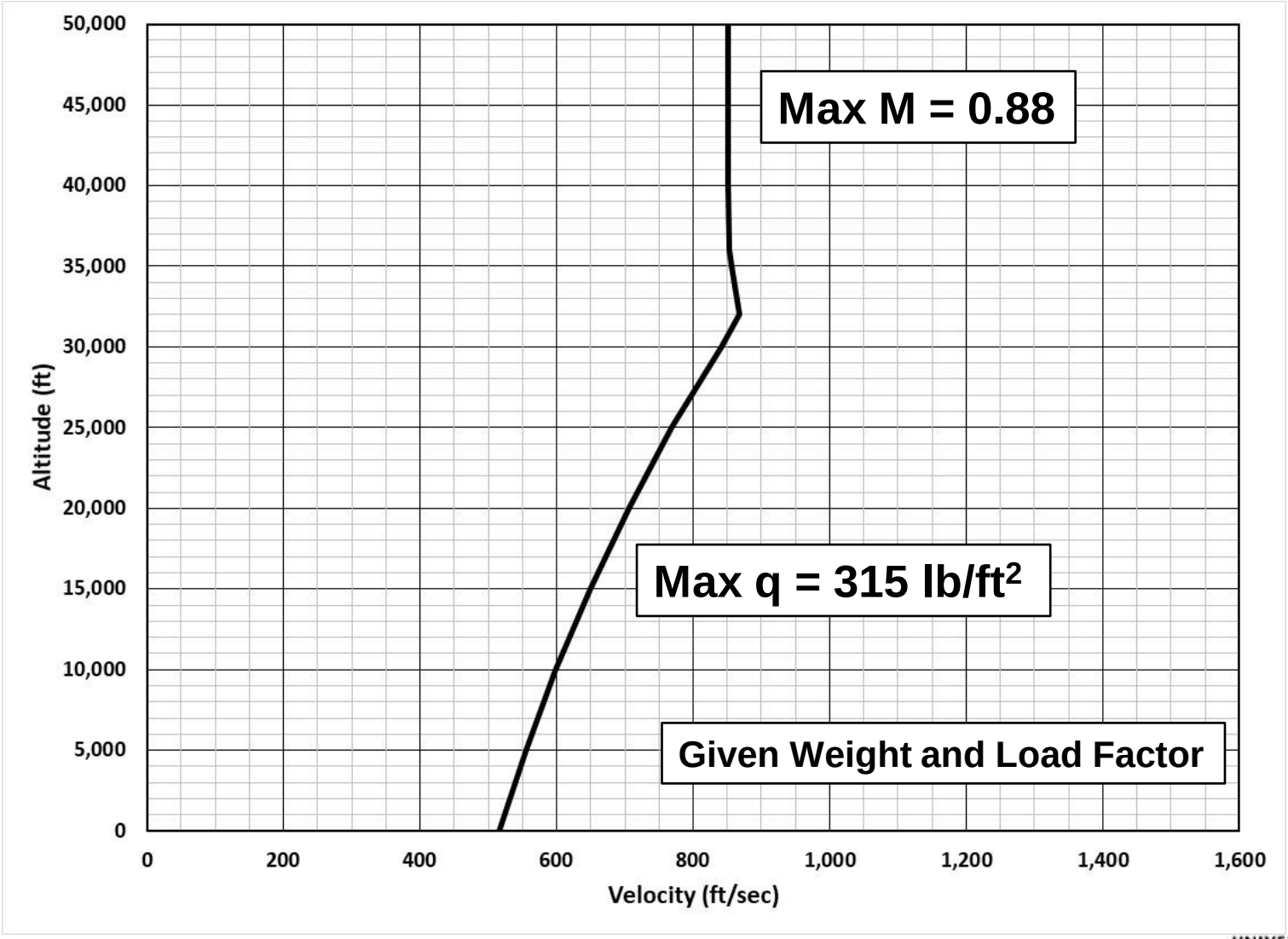
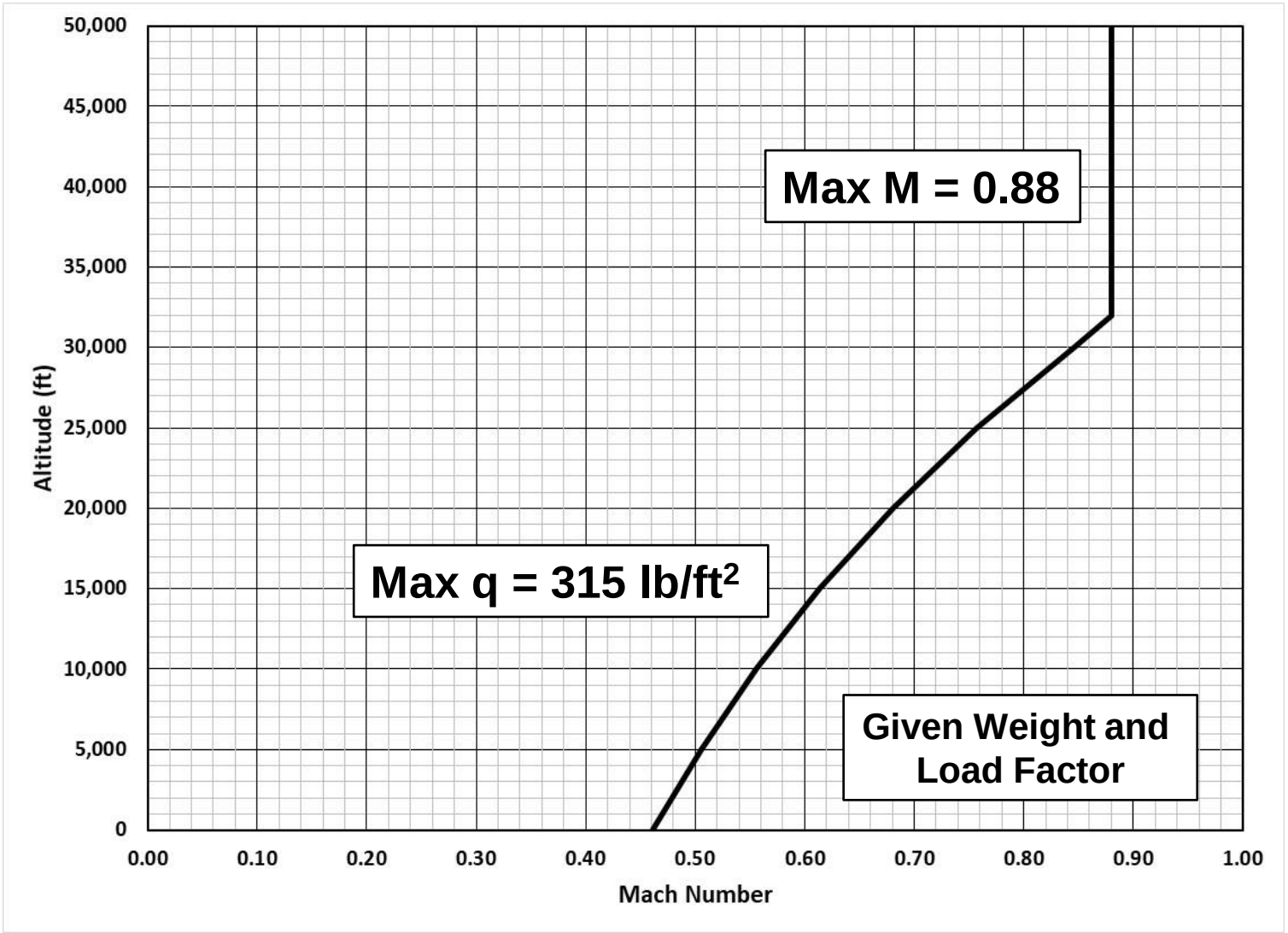
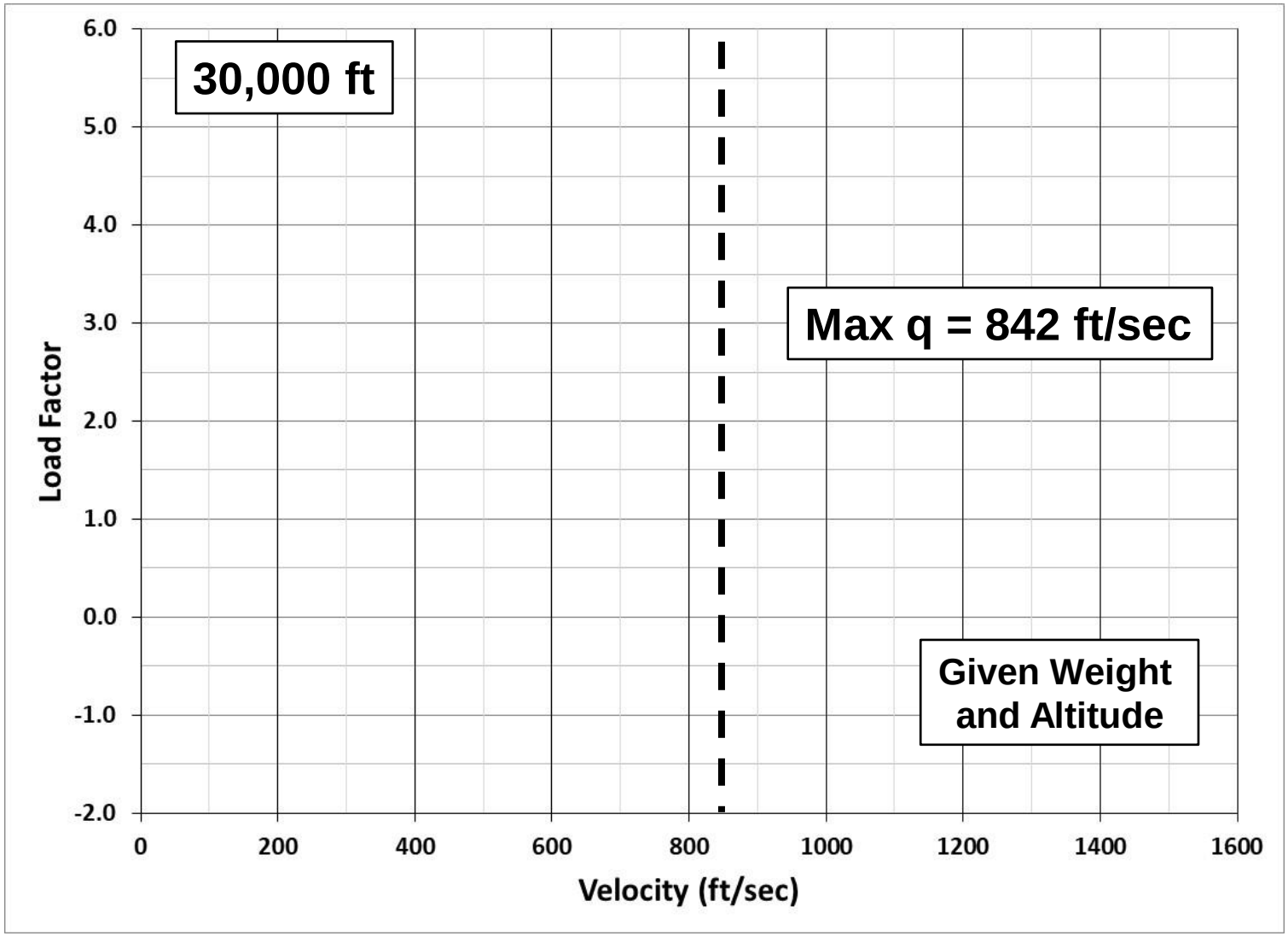
Limit Speed – Flight Envelope



Limit Speed – Flight Envelope



Limit Speed – V-n Diagram



Limit Speed – Flight Envelope

Max KEAS = 305 NM / hr

Max q = 315 lb/ft²

Max M = 0.88

$$\text{Max q} = \left(\frac{q}{M^2}\right)_{SL}\left(\frac{\text{Max KEAS}}{a_{SL}}\right)^2$$

Limit Mach = MIN(Max q, Max Mach)

Altitude	rho	a	QMS	g's	CLmax	Vel	Mach	Max q	Max Mach	Max Mach	Limit Mach
(ft)		(ft/sec)				(ft/sec)		(lb/ft^2)	(max q)		
0	0.00237688	1116.45	1481.4	1.00	1.20	232.1	0.2079	315.0	0.4611	0.88	0.4611
5,000	0.00204808	1097.09	1232.6	1.00	1.20	250.1	0.2279	315.0	0.5055	0.88	0.5055
10,000	0.00175527	1077.39	1018.7	1.00	1.20	270.1	0.2507	315.0	0.5560	0.88	0.5560
15,000	0.00149561	1057.31	836.0	1.00	1.20	292.6	0.2768	315.0	0.6138	0.88	0.6138
20,000	0.00126642	1036.85	680.7	1.00	1.20	318.0	0.3067	315.0	0.6802	0.88	0.6802
25,000	0.00106511	1015.98	549.7	1.00	1.20	346.8	0.3413	315.0	0.7570	0.88	0.7570
30,000	0.00088926	994.67	439.9	1.00	1.20	379.5	0.3815	315.0	0.8462	0.88	0.8462
32,000	0.00082551	986.02	401.3	1.00	1.20	393.9	0.3995	315.0	0.8859	0.88	0.8800
35,000	0.00073652	972.89	348.6	1.00	1.20	417.0	0.4286	315.0	0.9506	0.88	0.8800
36,000	0.00070856	968.48	332.3	1.00	1.20	425.1	0.4390	315.0	0.9736	0.88	0.8800
40,000	0.00058512	968.08	274.2	1.00	1.20	467.8	0.4833	315.0	1.0718	0.88	0.8800
45,000	0.00046012	968.08	215.6	1.00	1.20	527.6	0.5450	315.0	1.2087	0.88	0.8800
50,000	0.00036183	968.08	169.5	1.00	1.20	594.9	0.6146	315.0	1.3630	0.88	0.8800

Limit Speed – Flight Envelope

Max KEAS = 305 NM / hr

Max q = 315 lb/ft²

Max M = 0.88

At what altitude do the Max q and Max M lines intersect?

$$\frac{q}{M^2} = \frac{\text{Max q}}{(\text{Max Mach})^2} = \frac{315}{(0.88)^2} = 406.8$$

Altitude (ft)	rho	a (ft/sec)	QMS	g's	CLmax	Vel (ft/sec)	Mach	Max q (lb/ft^2)	Max Mach (max q)	Max Mach	Limit Mach
0	0.00237688	1116.45	1481.4	1.00	1.20	232.1	0.2079	315.0	0.4611	0.88	0.4611
5,000	0.00204808	1097.09	1232.6	1.00	1.20	250.1	0.2279	315.0	0.5055	0.88	0.5055
10,000	0.00175527	1077.39	1018.7	1.00	1.20	270.1	0.2507	315.0	0.5560	0.88	0.5560
15,000	0.00149561	1057.31	836.0	1.00	1.20	292.6	0.2768	315.0	0.6138	0.88	0.6138
20,000	0.00126642	1036.85	680.7	1.00	1.20	318.0	0.3067	315.0	0.6802	0.88	0.6802
25,000	0.00106511	1015.98	549.7	1.00	1.20	346.8	0.3413	315.0	0.7570	0.88	0.7570
30,000	0.00088926	994.67	439.9	1.00	1.20	379.5	0.3815	315.0	0.8462	0.88	0.8462
32,000	0.00082551	986.02	401.3	1.00	1.20	393.9	0.3995	315.0	0.8859	0.88	0.8800
35,000	0.00073652	972.89	348.6	1.00	1.20	417.0	0.4286	315.0	0.9506	0.88	0.8800
36,000	0.00070856	968.48	332.3	1.00	1.20	425.1	0.4390	315.0	0.9736	0.88	0.8800
40,000	0.00058512	968.08	274.2	1.00	1.20	467.8	0.4833	315.0	1.0718	0.88	0.8800
45,000	0.00046012	968.08	215.6	1.00	1.20	527.6	0.5450	315.0	1.2087	0.88	0.8800
50,000	0.00036183	968.08	169.5	1.00	1.20	594.9	0.6146	315.0	1.3630	0.88	0.8800

Interpolate to find altitude ⟶ 31,707 ft

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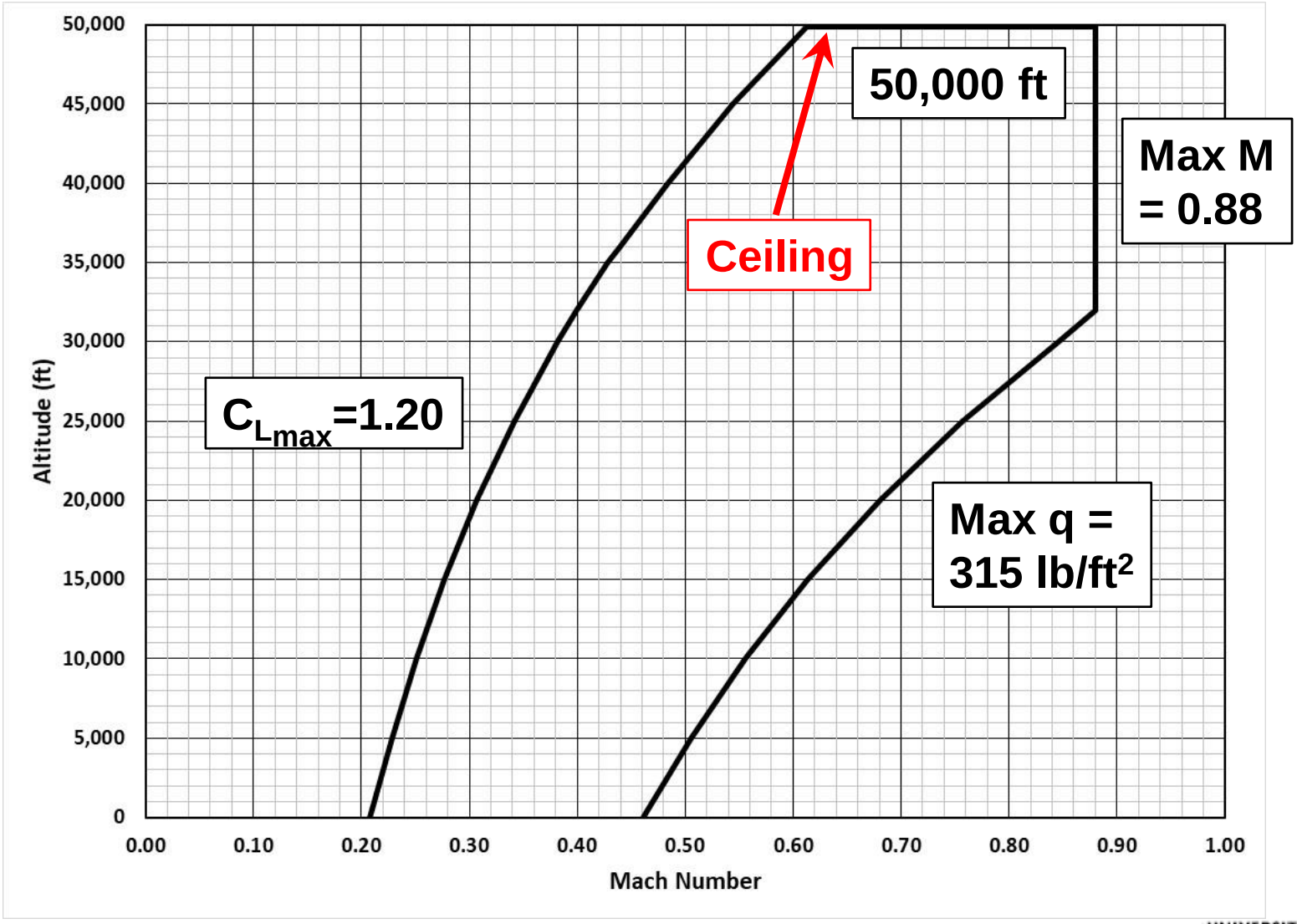
Flight Envelope



Ceiling – Flight Envelope

Unpressurized aircraft - ceiling altitude without oxygen masks will not exceed 10,000 ft

Unpressurized aircraft – ceiling altitude with oxygen masks will not exceed 25,000 ft

Pressurized aircraft – ceiling altitude will not exceed 50,000 ft

A pressure suit is required for extended periods above 50,000 ft in a pressurized air vehicle.

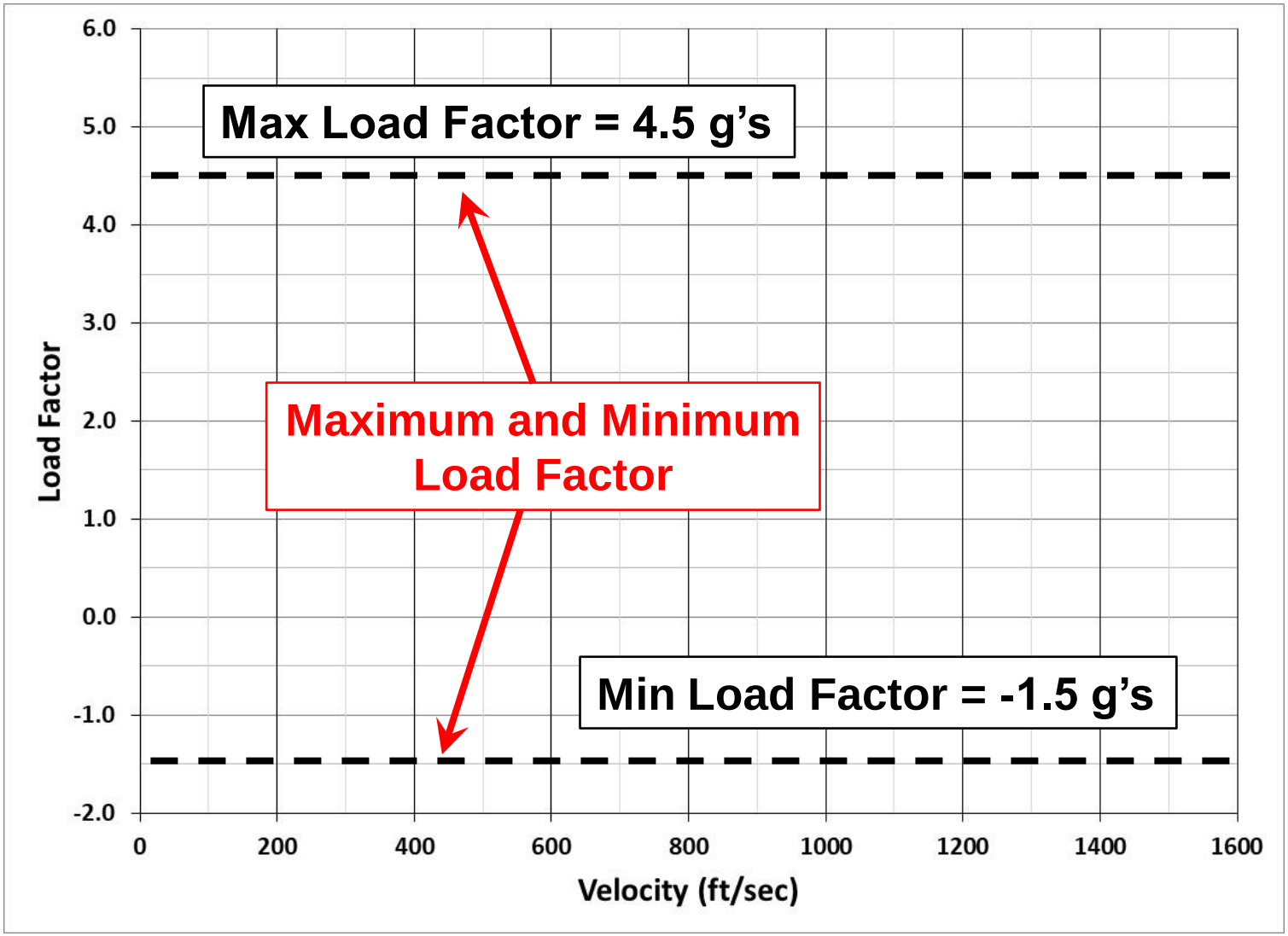
Load Factor

Load factor is defined as the resultant force divided by the air vehicle weight.

$$n = \frac{L}{W}$$

$$C_L = \frac{n\,W}{q\,S} = \frac{n\,W}{\frac{1}{2}\,\rho\,V^2\,S}$$

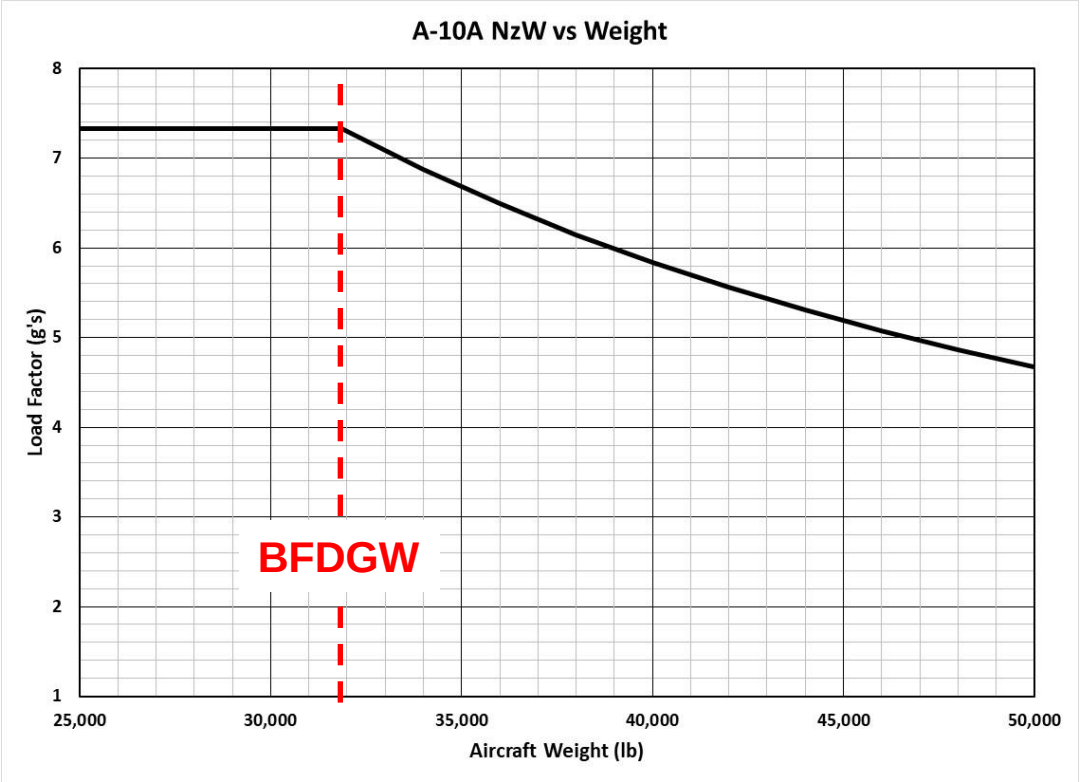
Load Factor – V-n Diagram



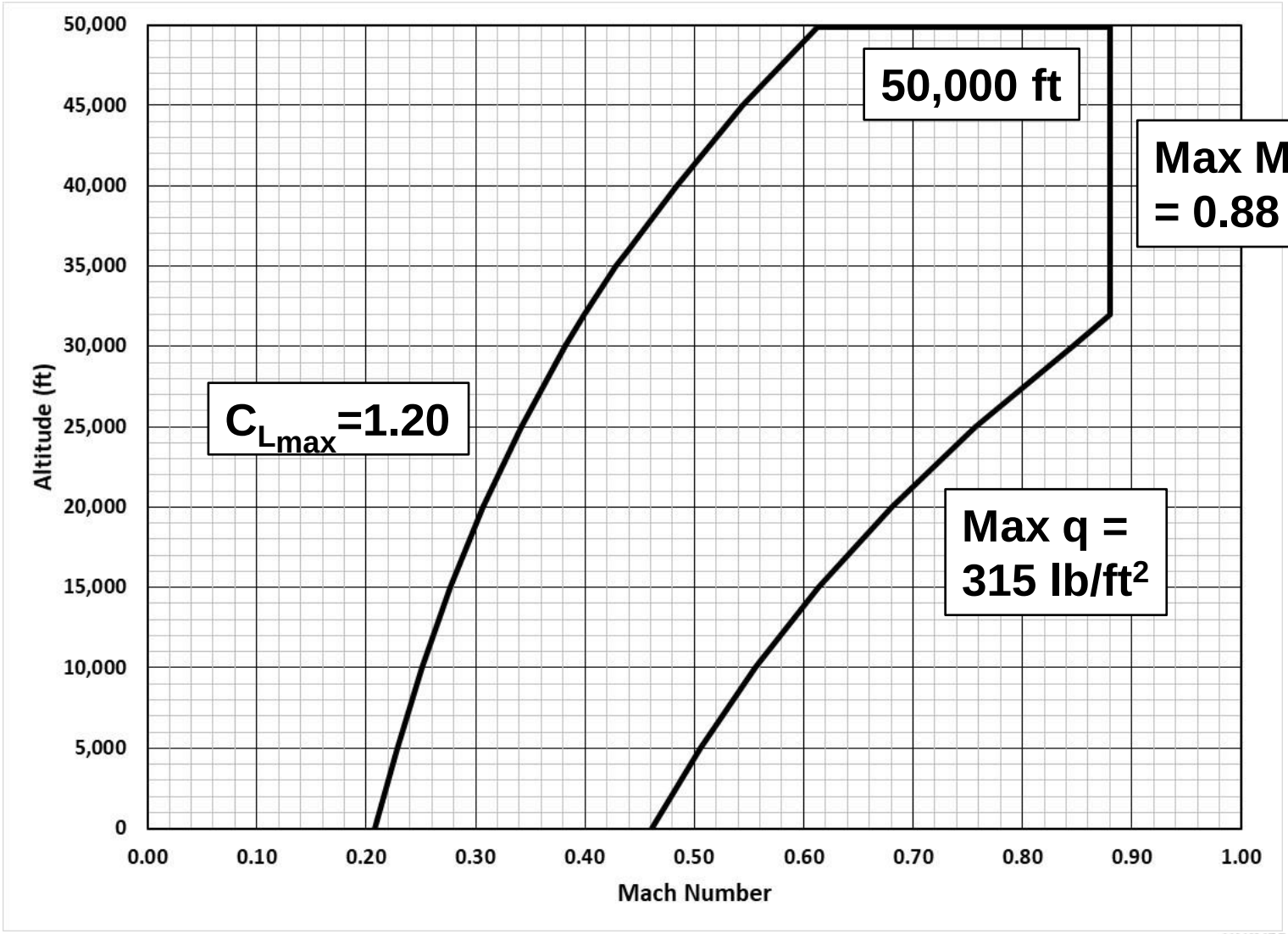
Load Factor Limitations

Basic Flight Design Gross Weight (BFDGW) is defined as the highest flight weight authorized for the maximum positive and negative load factors for maneuvering flight.

A-10A
BFDGW=31,867 lb
Max g's = 7.33
n_zW = 233,585 lb



G-IV Flight Envelope



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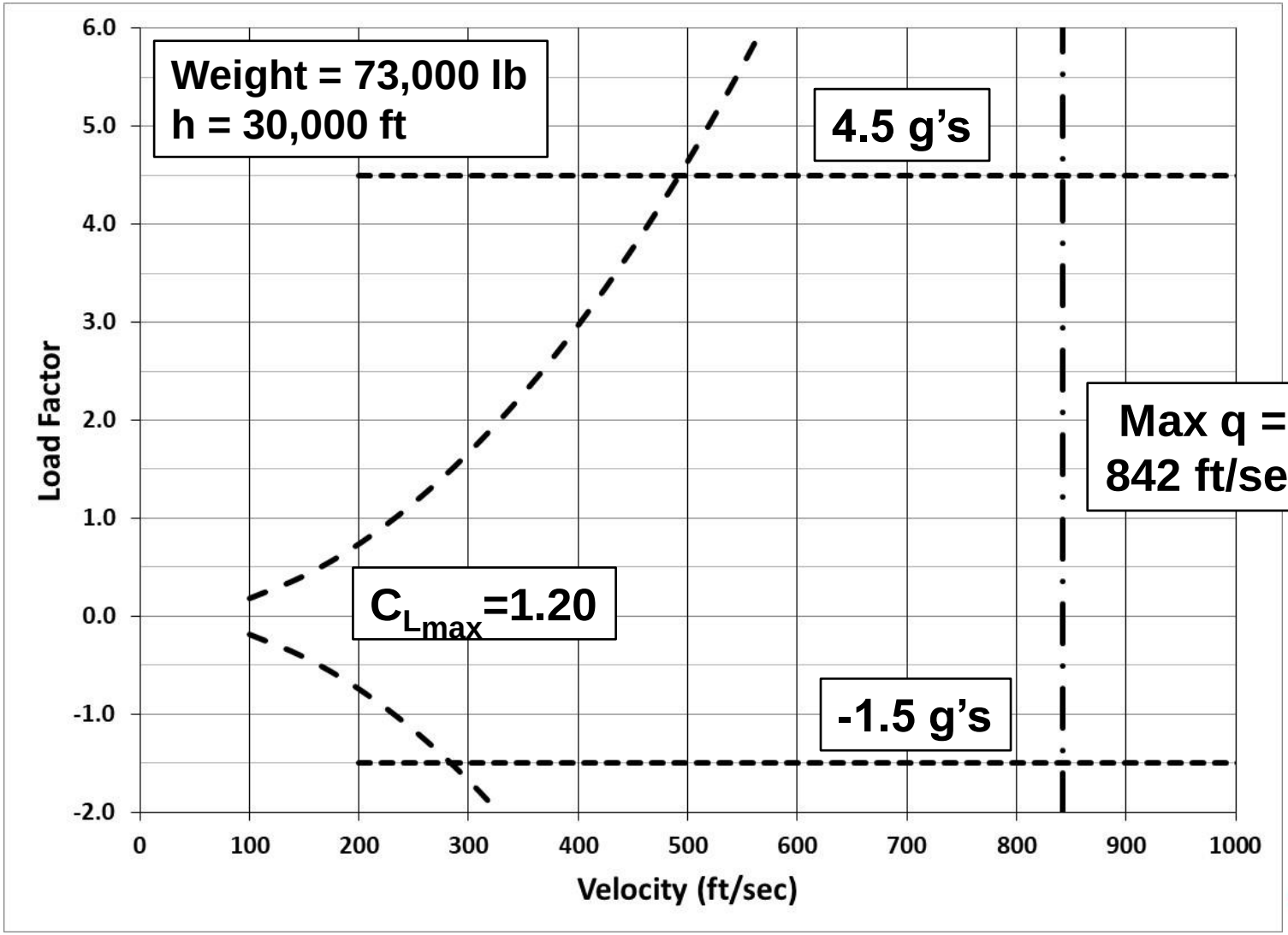
G-IV V-n Diagram



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Homework Assignment

HW #7 – Flight Envelope
(due by 11:59 pm ET on Monday)
Reading – Chapters 4, 5.9, & 6.5 in textbook

<u>HW Help Session</u>
Monday 1:00 – 2:00 pm ET

<u>Posted on Canvas</u>
HW #7 Assignment with instructions, tips, and checklist
HW #7 Aircraft Fact Sheet

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Homework #7

BD-5J Home-built Jet Aircraft

Explicit Calculations
Plot Performance Charts

Video #1

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Questions?