AEEM 3042 – Aircraft Performance & Design

Block 1
Material
Review

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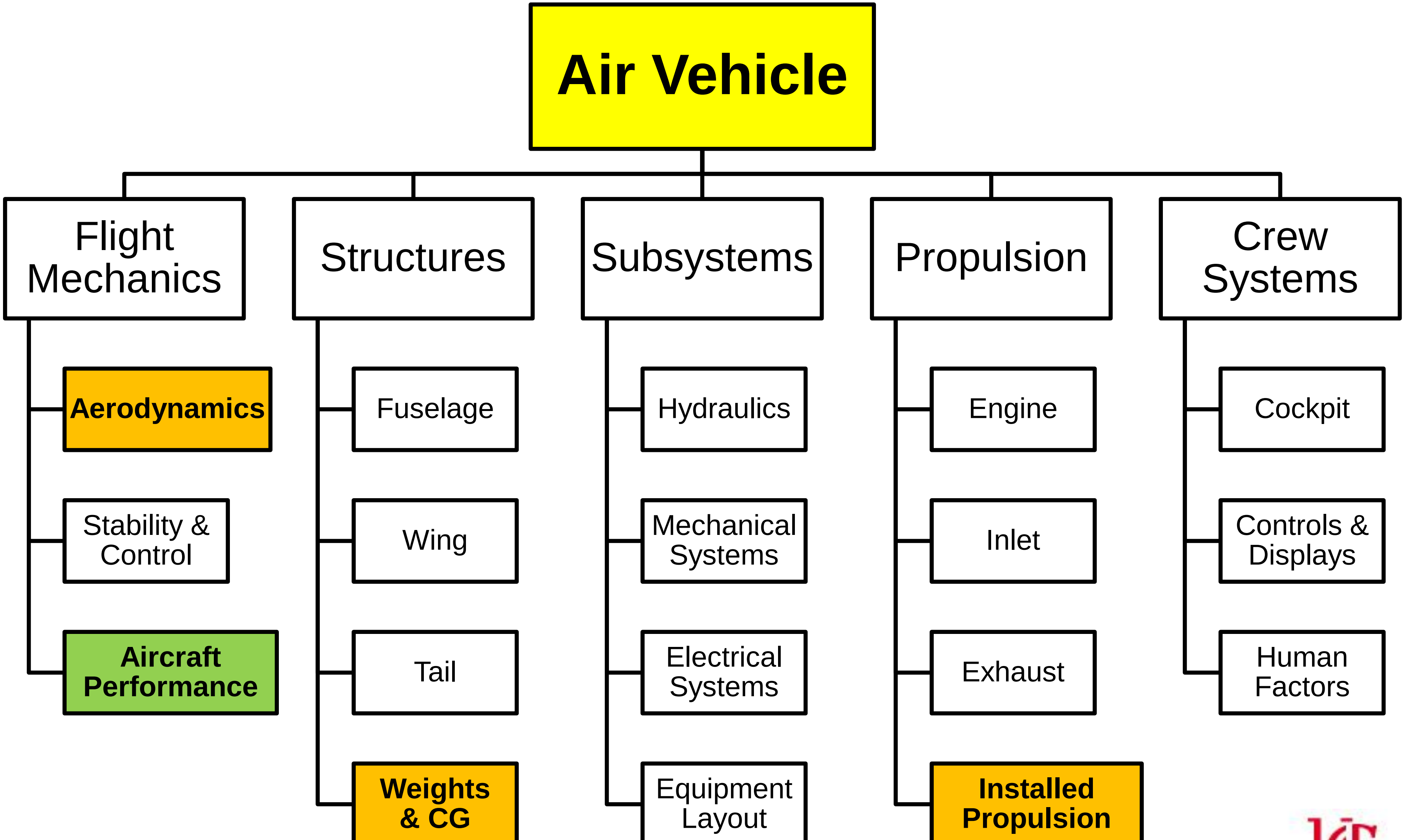
AEEM 3042 – Aircraft Performance & Design



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Airspeed Definitions

IAS → **CAS** → **EAS** → **TAS**

position error · compressibility · density

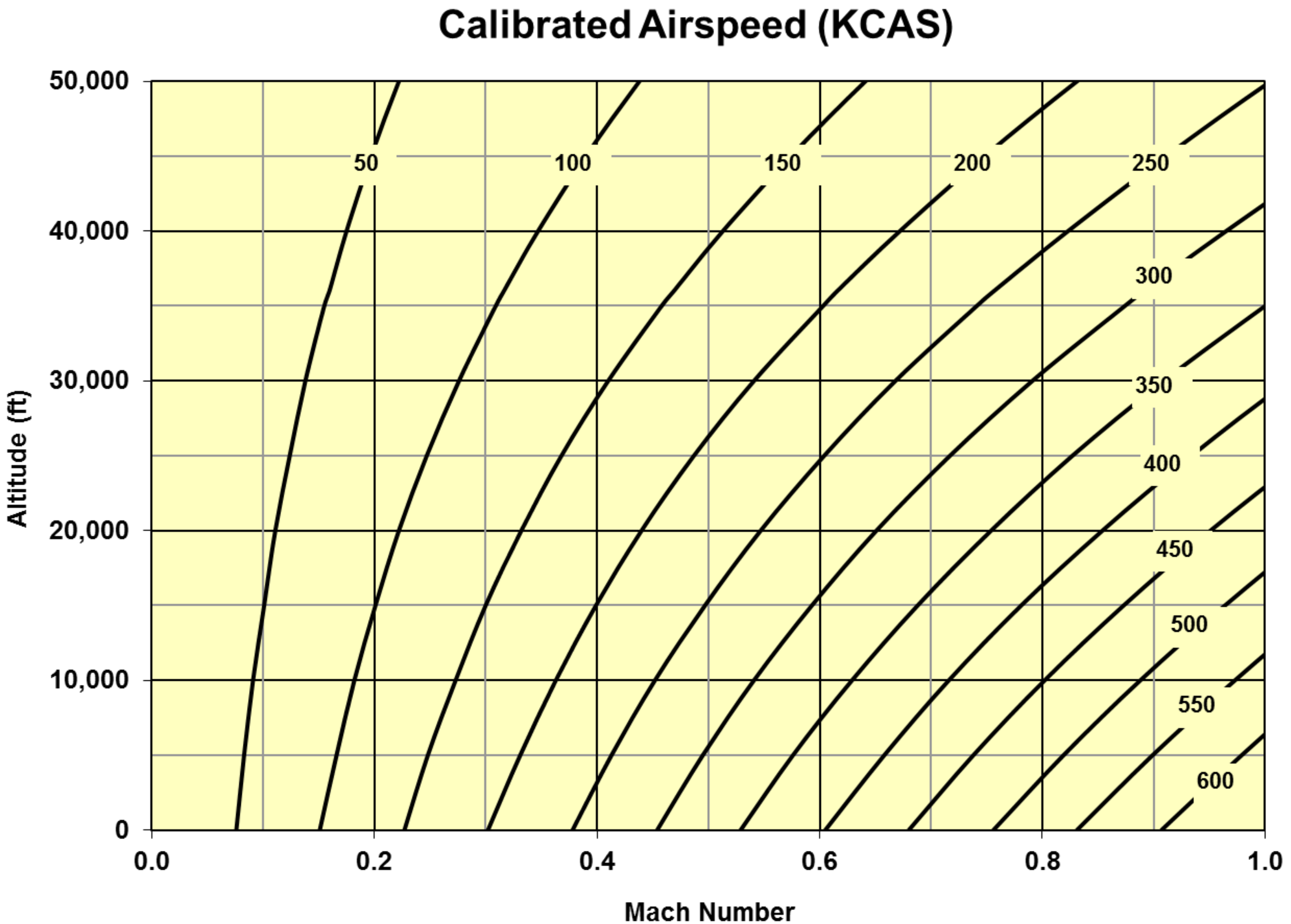
"ICET"

Indicated Airspeed (IAS):	**Pilots read IAS or CAS on the instrument panel**
Calibrated Airspeed (CAS):	**Pilots use CAS to fly the aircraft**
Equivalent Airspeed (EAS):	**Constant EAS = Constant dynamic pressure (q)** **Used in aerodynamics & structures calculations**
True Airspeed (TAS):	**Actual speed of the aircraft relative to the air**

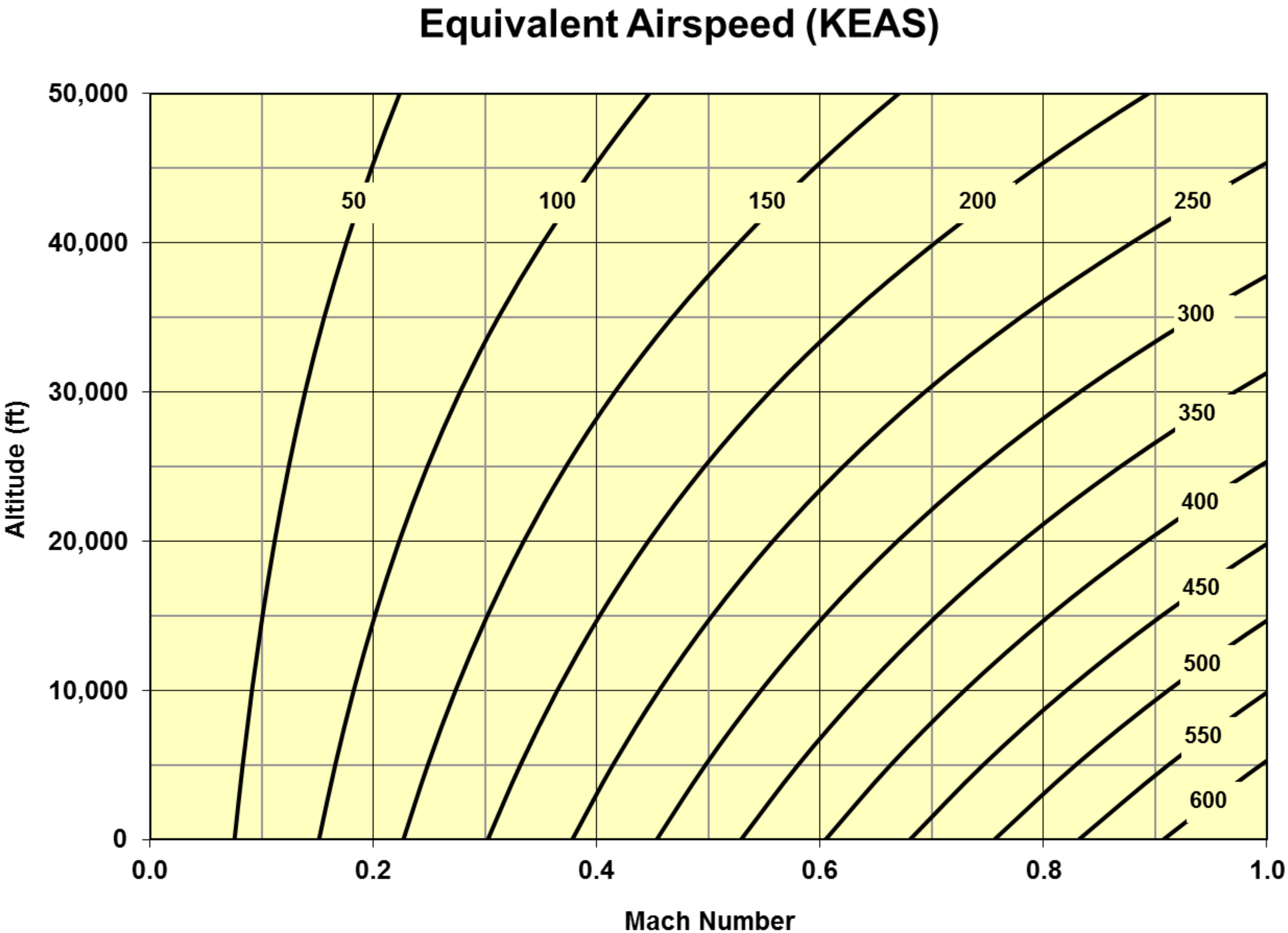
Airspeed is usually expressed in knots (NM/hr)

KIAS → **KCAS** → **KEAS** → **KTAS**

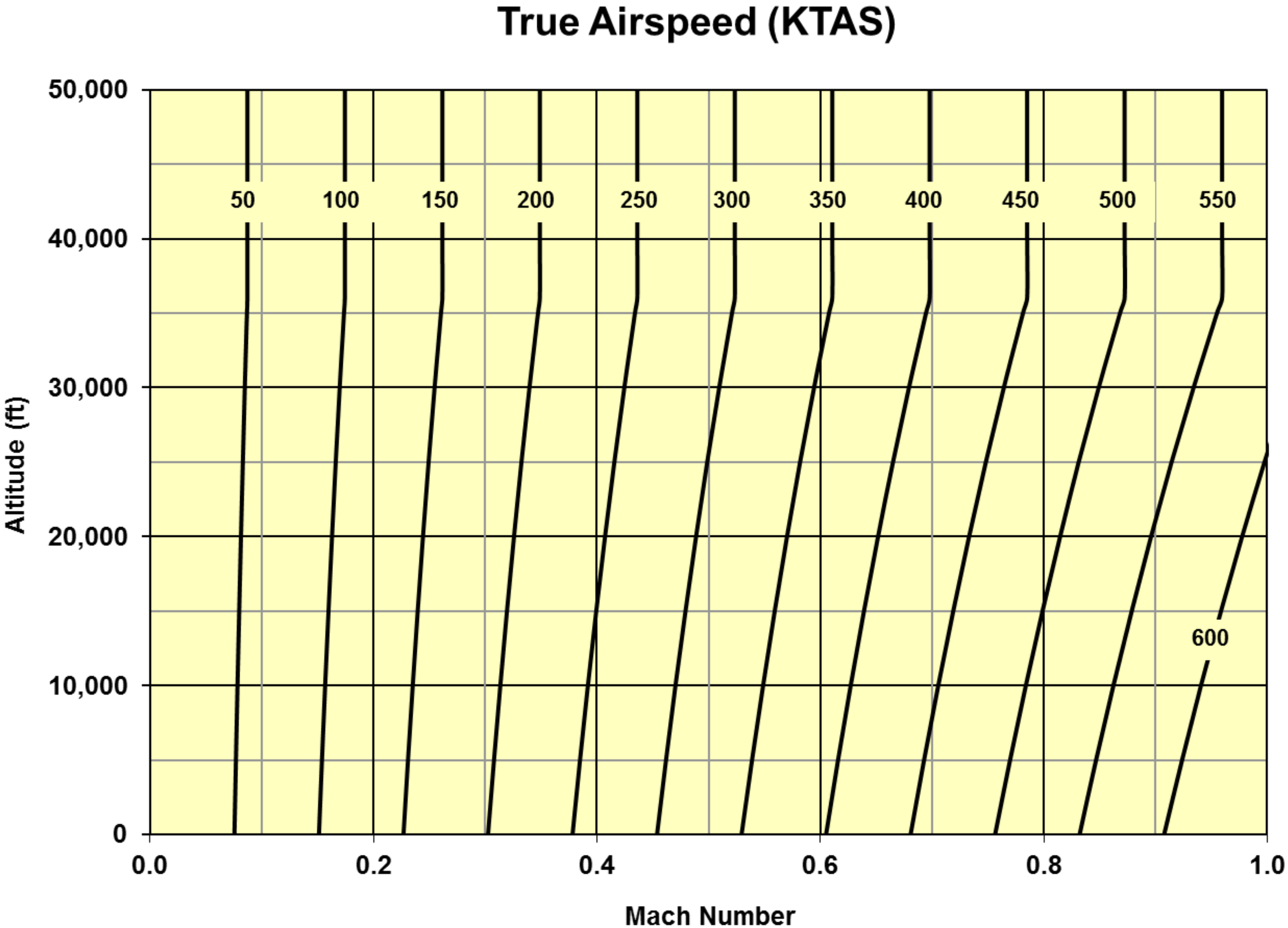
The Standard Atmosphere



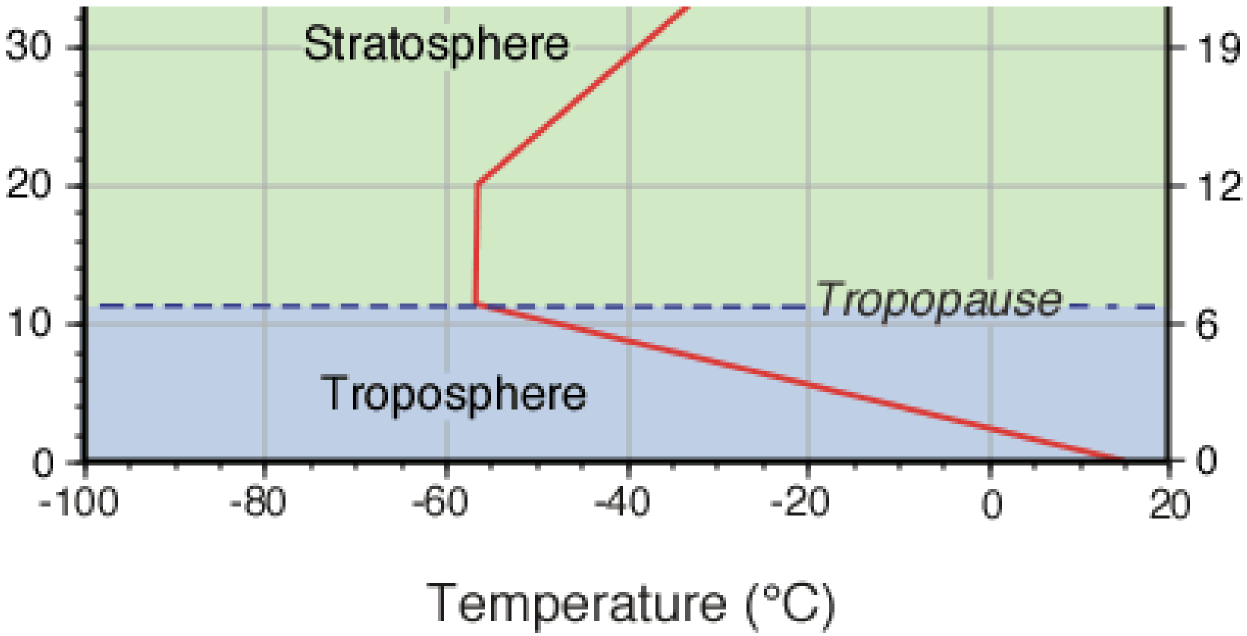
The Standard Atmosphere



The Standard Atmosphere



The Standard Atmosphere



– 65,617 ft

– 36,089 ft

Troposphere: **Sea Level to 36,089 ft**
Temperature Lapse rate (dT/dh) = 3.56° R / 1,000 ft

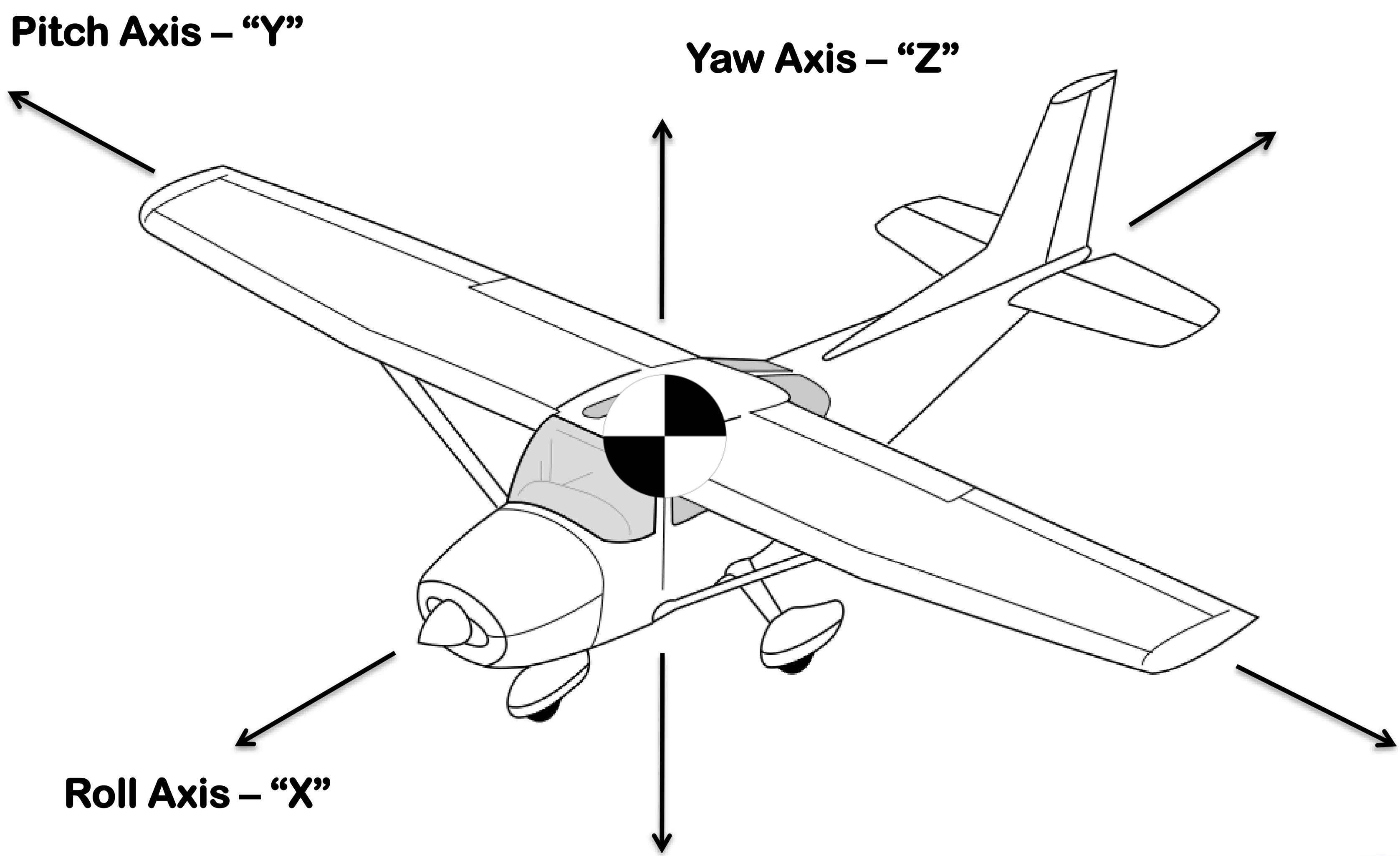
Tropopause: **36,089 ft**
Boundary between troposphere and stratosphere

Lower Stratosphere: **36,089 to 65,617 ft**
Isothermic layer, temperature = 389.99° R

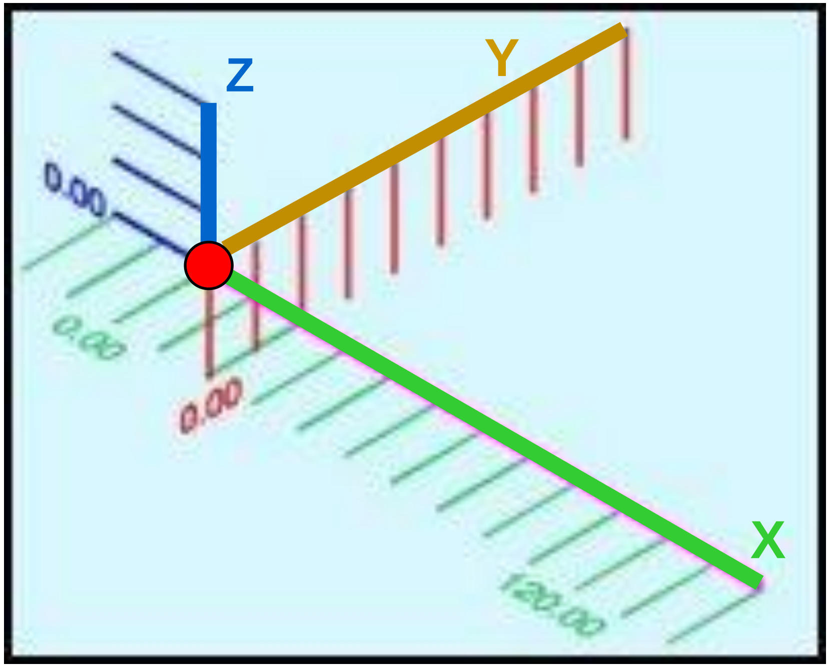
The Standard Atmosphere

h	TEMPF	TEMPR	TEMPC	TR	PR	PRESHG	PRES	RHO	DR	SQRTDR	QMS	SPW	ASPEED	VELA
0	59.0	518.7	15.0	1.0000	1.0000	29.92	2116.22	0.00237688	1.0000	1.0000	1481.4	0.0765	1116.45	661.1
2000	51.8	511.5	11.0	0.9862	0.9298	27.82	1967.68	0.00224086	0.9428	0.9710	1377.4	0.0721	1108.75	656.5
4000	44.7	504.4	7.1	0.9725	0.8637	25.84	1827.70	0.00211087	0.8881	0.9424	1279.4	0.0679	1100.99	651.9
6000	37.6	497.3	3.1	0.9587	0.8014	23.98	1695.89	0.00198673	0.8359	0.9143	1187.1	0.0639	1093.18	647.3
8000	30.4	490.1	-0.9	0.9450	0.7428	22.22	1571.89	0.00186826	0.7860	0.8866	1100.3	0.0601	1085.31	642.6
10000	23.3	483.0	-4.8	0.9312	0.6877	20.58	1455.33	0.00175527	0.7385	0.8593	1018.7	0.0565	1077.39	637.9
12000	16.2	475.9	-8.8	0.9175	0.6360	19.03	1345.87	0.00164758	0.6932	0.8326	942.1	0.0530	1069.40	633.2
14000	9.0	468.7	-12.8	0.9037	0.5875	17.58	1243.18	0.00154502	0.6500	0.8062	870.2	0.0497	1061.36	628.4
16000	1.9	461.6	-16.7	0.8900	0.5420	16.22	1146.93	0.00144742	0.6090	0.7804	802.8	0.0466	1053.25	623.6
18000	-5.2	454.5	-20.7	0.8762	0.4994	14.94	1056.80	0.00135461	0.5699	0.7549	739.8	0.0436	1045.09	618.8
20000	-12.4	447.3	-24.6	0.8625	0.4595	13.75	972.49	0.00126642	0.5328	0.7299	680.7	0.0407	1036.85	613.9
22000	-19.5	440.2	-28.6	0.8487	0.4223	12.64	893.72	0.00118269	0.4976	0.7054	625.6	0.0381	1028.56	609.0
24000	-26.6	433.1	-32.6	0.8350	0.3876	11.60	820.19	0.00110326	0.4642	0.6813	574.1	0.0355	1020.19	604.1
26000	-33.7	426.0	-36.5	0.8212	0.3552	10.63	751.64	0.00102798	0.4325	0.6576	526.1	0.0331	1011.75	599.1
28000	-40.9	418.8	-40.5	0.8075	0.3250	9.72	687.81	0.00095670	0.4025	0.6344	481.5	0.0308	1003.25	594.0
30000	-48.0	411.7	-44.5	0.7937	0.2970	8.89	628.43	0.00088926	0.3741	0.6117	439.9	0.0286	994.67	588.9
32000	-55.1	404.6	-48.4	0.7800	0.2709	8.11	573.28	0.00082551	0.3473	0.5893	401.3	0.0266	986.02	583.8
34000	-62.3	397.4	-52.4	0.7662	0.2467	7.38	522.11	0.00076533	0.3220	0.5674	365.5	0.0246	977.29	578.7
36000	-69.4	390.3	-56.3	0.7525	0.2243	6.71	474.71	0.00070856	0.2981	0.5460	332.3	0.0228	968.48	573.4
38000	-69.7	390.0	-56.5	0.7519	0.2038	6.10	431.20	0.00064415	0.2710	0.5206	301.8	0.0207	968.08	573.2
40000	-69.7	390.0	-56.5	0.7519	0.1851	5.54	391.68	0.00058512	0.2462	0.4962	274.2	0.0188	968.08	573.2
42000	-69.7	390.0	-56.5	0.7519	0.1681	5.03	355.78	0.00053149	0.2236	0.4729	249.0	0.0171	968.08	573.2
44000	-69.7	390.0	-56.5	0.7519	0.1527	4.57	323.18	0.00048278	0.2031	0.4507	226.2	0.0155	968.08	573.2
46000	-69.7	390.0	-56.5	0.7519	0.1387	4.15	293.56	0.00043853	0.1845	0.4295	205.5	0.0141	968.08	573.2
48000	-69.7	390.0	-56.5	0.7519	0.1260	3.77	266.65	0.00039834	0.1676	0.4094	186.7	0.0128	968.08	573.2
50000	-69.7	390.0	-56.5	0.7519	0.1145	3.42	242.21	0.00036183	0.1522	0.3902	169.5	0.0116	968.08	573.2

Aircraft Control (3 Axes)



Aircraft Dimensions Nomenclature



Start with an XYZ coordinate system

X axis: front to back

Y axis: from centerline to wing tip

Z axis: from ground to top

Place the Origin at (0,0,0)

Dimensions are usually measured in inches or feet

X axis: Fuselage Station (FS)

Y axis: Buttock Line (BL)

Z axis: Water Line (WL)

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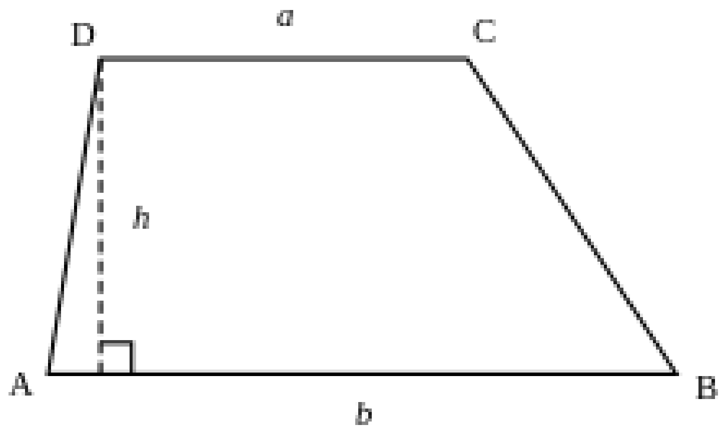
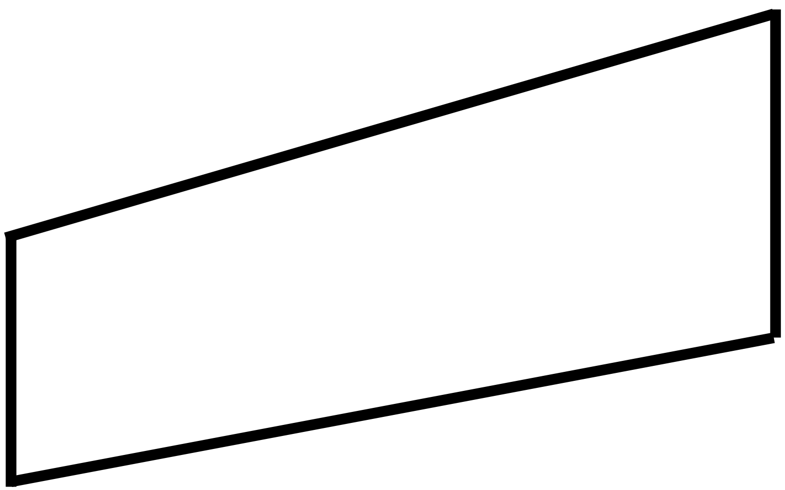
Aircraft Wing Dimensions

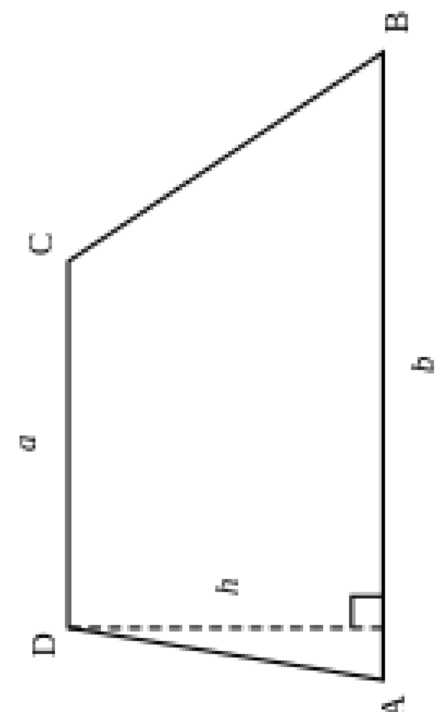


<u>Wing Planform Assumption</u>

- Convex quadrilateral = trapezoid

- Acute, Right, or Obtuse Trapezoid





$$\textbf{Area of Trapezoid} = \mathbf{h} * \frac{\mathbf{a+b}}{\mathbf{2}}$$

Aircraft Wing Dimensions

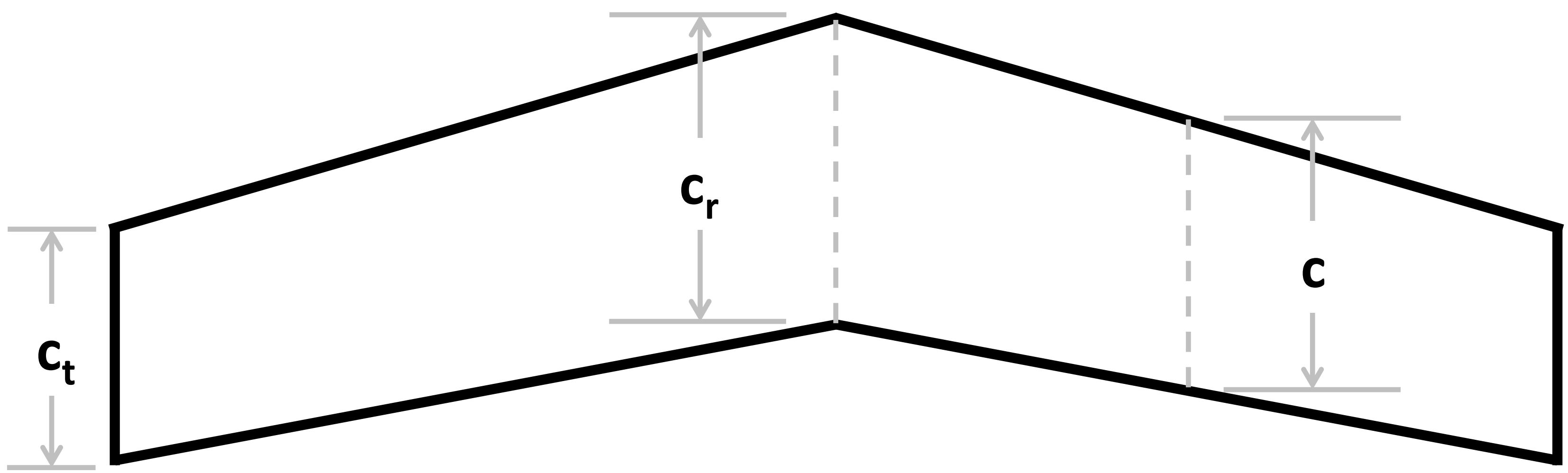
Wing Planform Characteristics

Tip Chord (c_t) **Taper Ratio (λ)**

Root Chord (c_r) **Average Chord (c)**

$$\lambda = \frac{c_t}{c_r}$$

$$c = \frac{c_t + c_r}{2}$$



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Aircraft Wing Dimensions

<u>Wing Planform Characteristics</u>

Tip Chord (c_t)
Root Chord (c_r)
Wing Span (b)

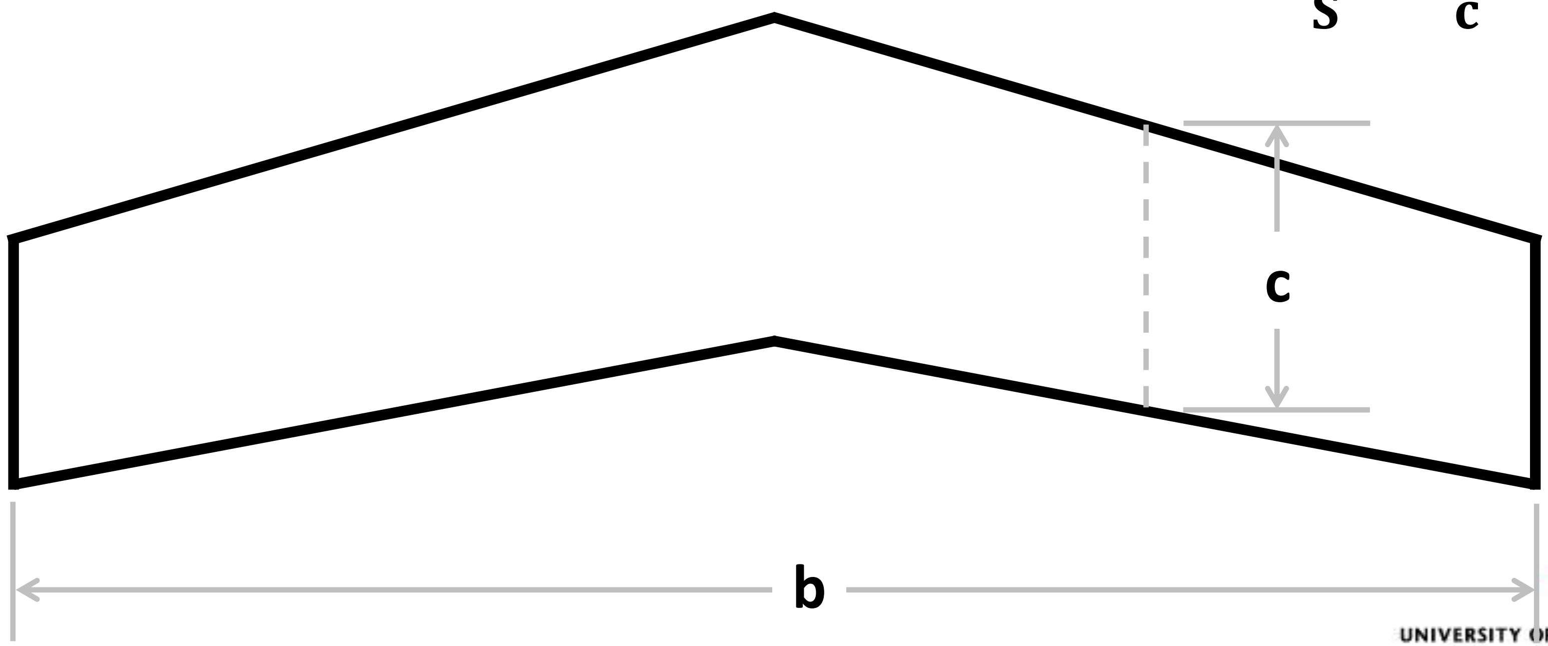
Taper Ratio (λ)
Average Chord (c)
Wing Area (S)
Aspect Ratio (AR)

$$\text{Area of Trapezoid} = \mathbf{h} * \frac{\mathbf{a+b}}{\mathbf{2}}$$

$$\mathbf{c} = \frac{\mathbf{c_t + c_r}}{\mathbf{2}}$$

$$\mathbf{S = b\ c}$$

$$\mathbf{AR} = \frac{\mathbf{b^2}}{\mathbf{S}} = \frac{\mathbf{b}}{\mathbf{c}}$$



Aircraft Wing Dimensions

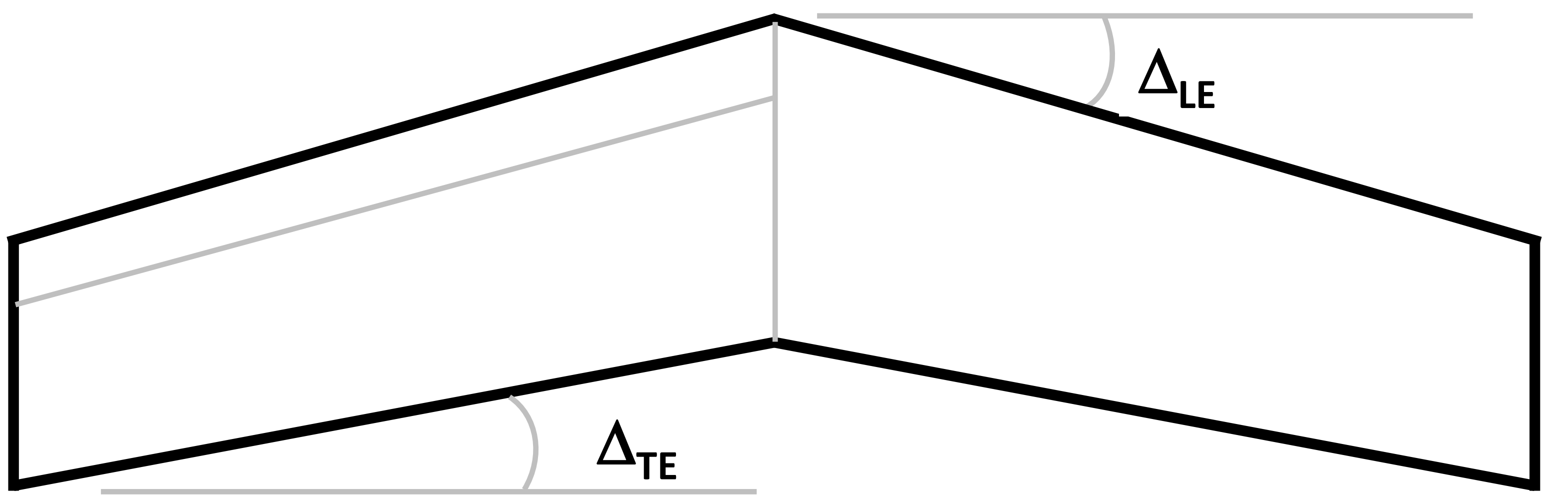
<u>Wing Planform Characteristics</u>

Tip Chord (c_t)
Root Chord (c_r)
Wing Span (b)

Taper Ratio (λ)
Average Chord (c)
Wing Area (S)
Aspect Ratio (AR)

Leading Edge Sweep (Δ_{LE})
Trailing Edge Sweep (Δ_{TE})

Quarter-Chord Sweep ($\Delta_{c/4}$)



$$\Delta_{c/4} = \tan^{-1}[\tan \Delta_{LE} - 0.25 * c_r * (1-\lambda)/(b/2)]$$

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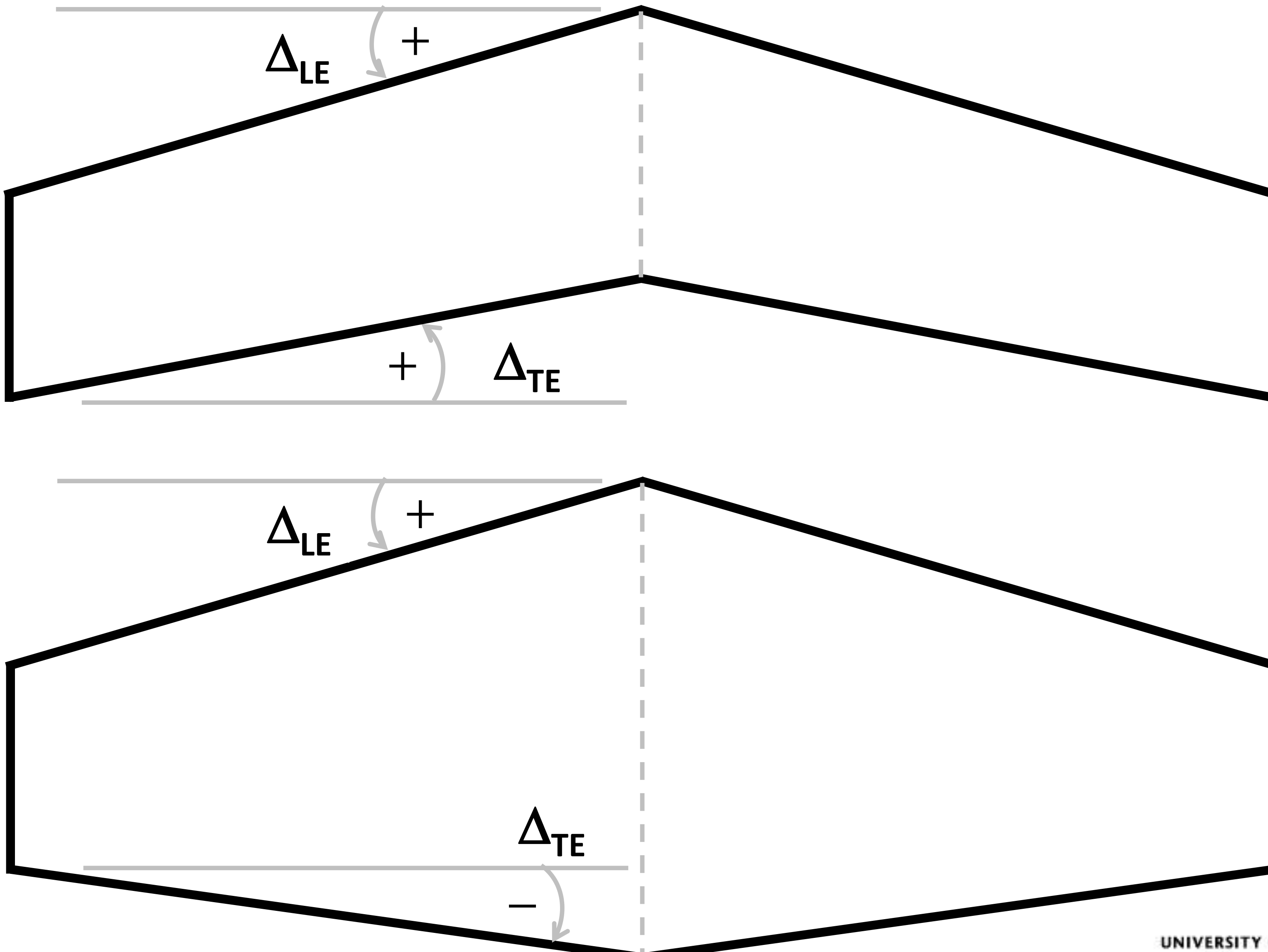
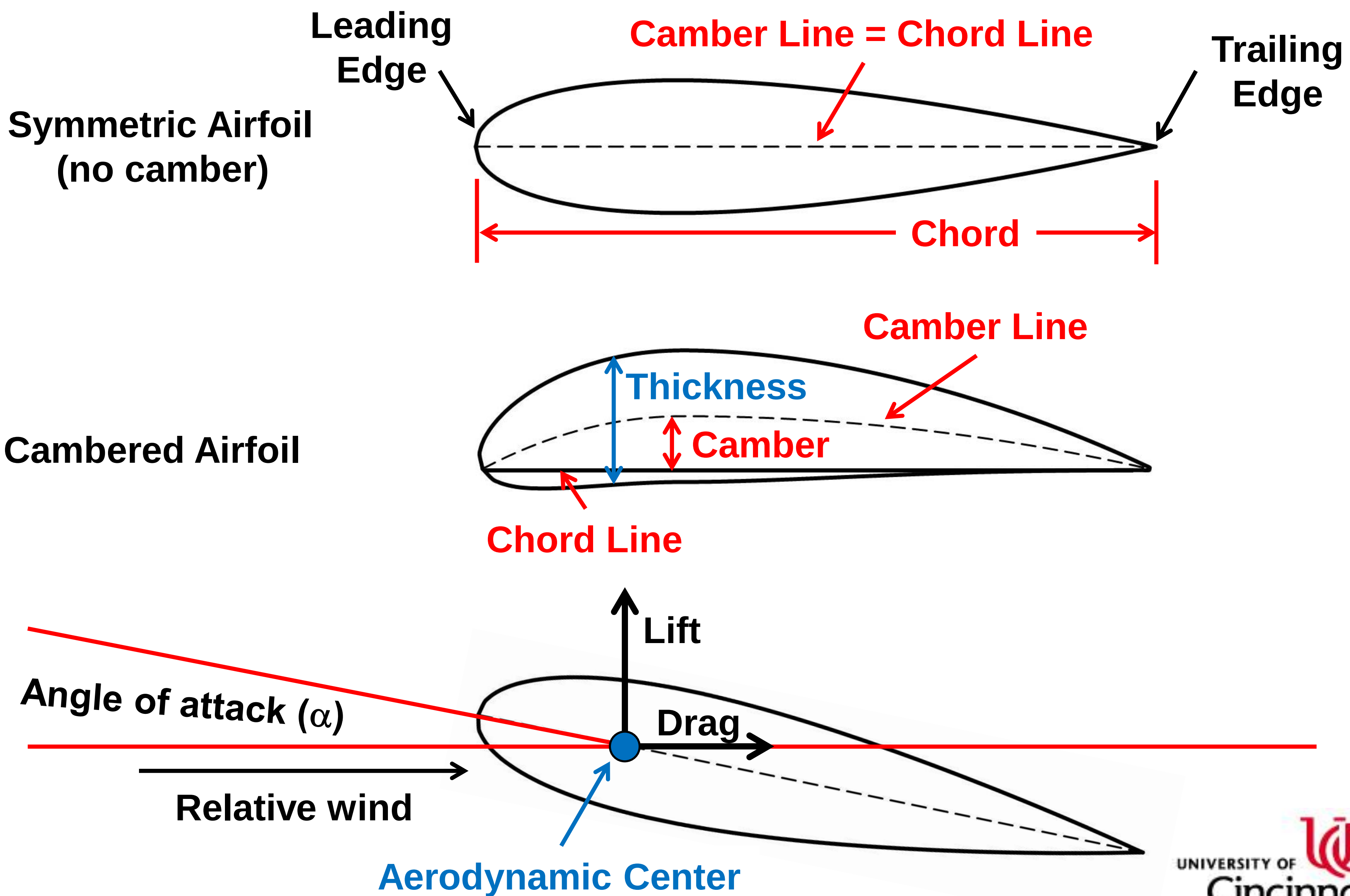
Aircraft Wing Dimensions



Airfoil Nomenclature

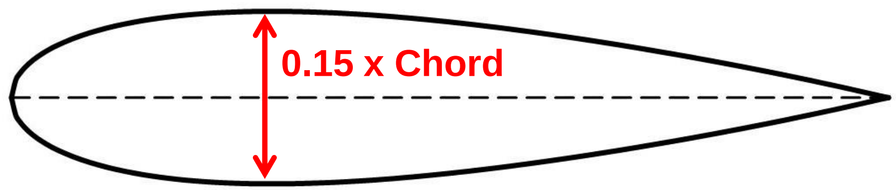


Airfoil Nomenclature

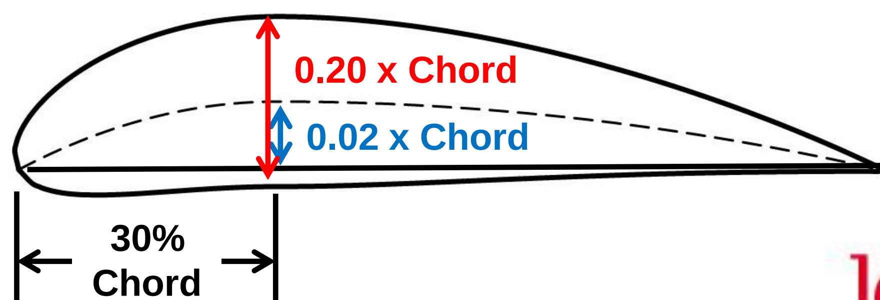
The NACA four-digit wing sections define the profile by:

- 1st digit is maximum camber as % of chord
- 2nd digit is the distance of maximum camber from the airfoil leading edge in 10x% of chord
- Last two digits are the maximum airfoil thickness as % of chord

<u>NACA 0015</u>
Symmetric Airfoil
(no camber)
15% thickness



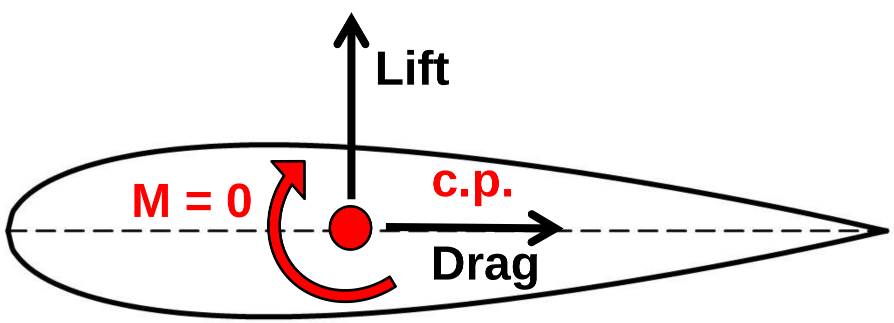
<u>NACA 2320</u>
Max camber is 2% chord
Max camber occurs at 30% chord
20% thickness

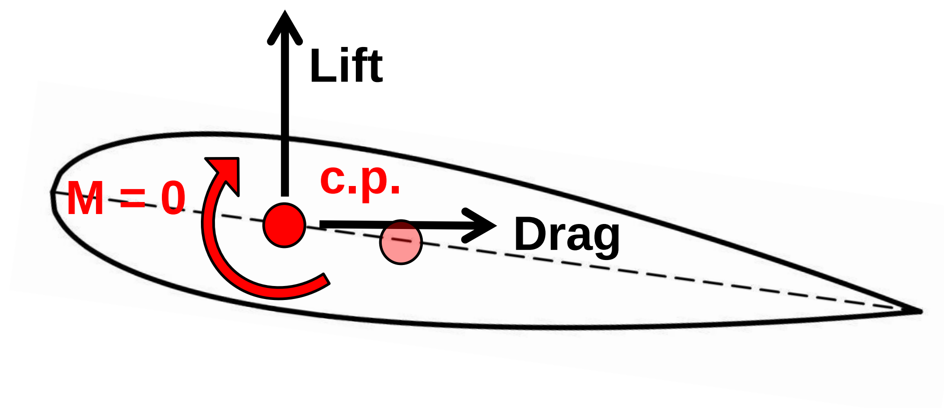


Center of Pressure

The Center of Pressure is the point on a body where the total moment due to aerodynamic forces is zero and where the lift and drag forces act

The Center of Pressure will move forward as angle of attack increases

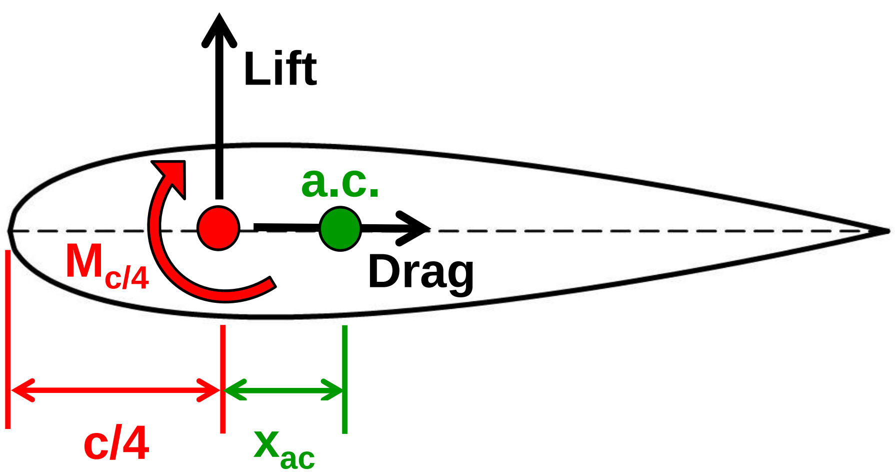




Aerodynamic Center

The Aerodynamic Center is the point on a body about which the moments are independent of angle of attack

$C_{M_{ac}}$ is constant over a practical range of α



$$\boxed{\frac{x_{ac}}{c} = -\frac{m_0}{a_0}}$$

$$m_0 = \frac{dc_{m_{c/4}}}{d\alpha}$$

$$a_0 = \frac{dc_l}{d\alpha}$$

Aircraft Aerodynamics

Lift Coefficient and Drag Coefficient are defined by:

$$\mathbf{C_L = \frac{nW}{qS} = C_{L_\alpha}(\alpha - \alpha_{L=0}) = a\,(\alpha - \alpha_{L=0})}$$

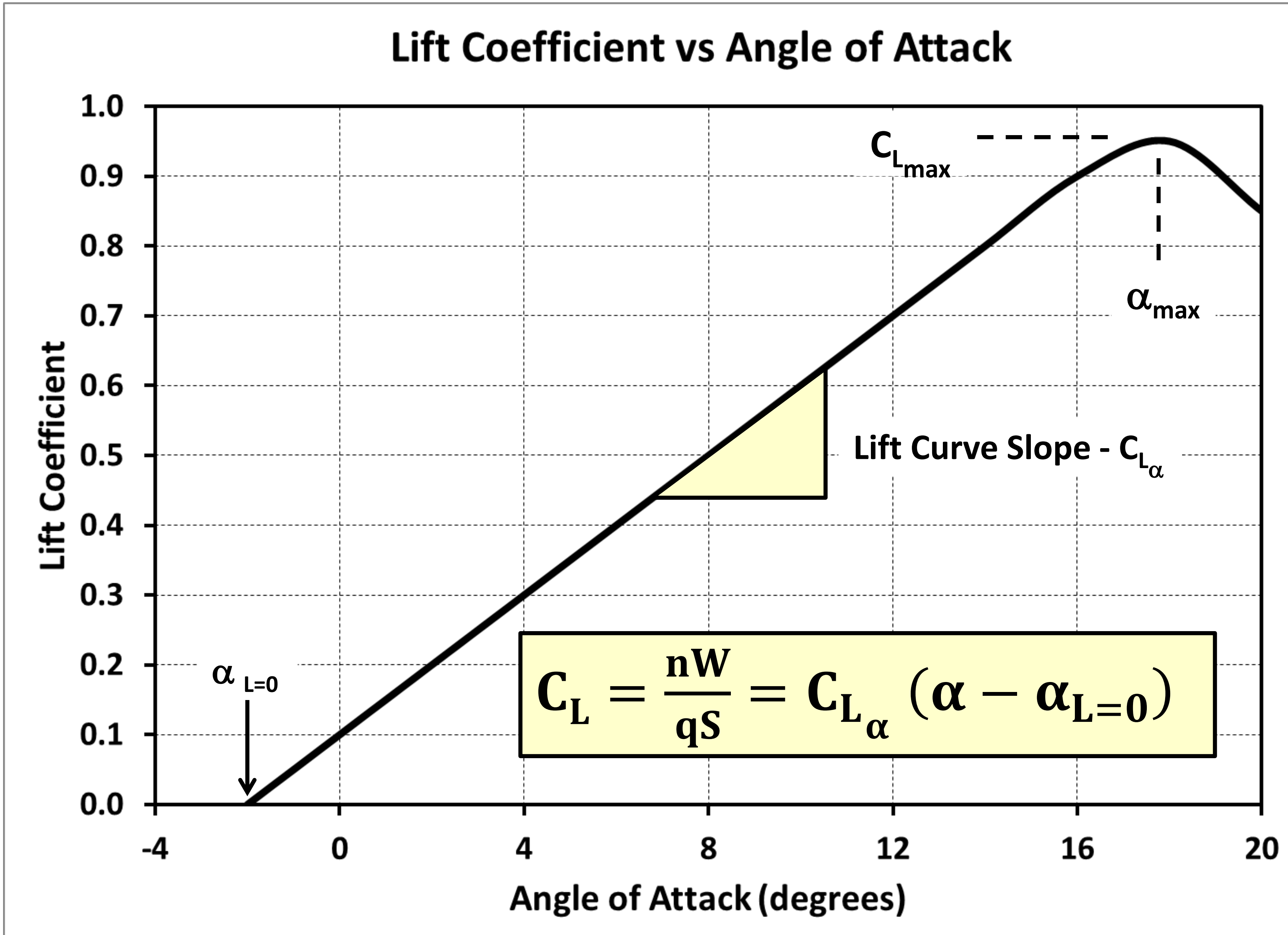
$$\mathbf{q = \frac{1}{2}\rho V^2 = (q/M^2)\, M^2}$$

$$\mathbf{V = a_\infty M}$$

$$\mathbf{C_D = \frac{D}{qS}}$$

n = load factor (g's)
W = aircraft weight (lb or kg)
q = dynamic pressure (lb/ft^2 or kg/m^2)
S = wing reference area (ft^2 or m^2)
ρ = density (slugs/ft^3 or kg/m^3)
V = velocity (ft/sec or m/sec)
M = Mach Number
a_∞ = speed of sound (ft/sec or m/sec)
a = lift curve slope (1/degree or 1/radian)

Aircraft Aerodynamics



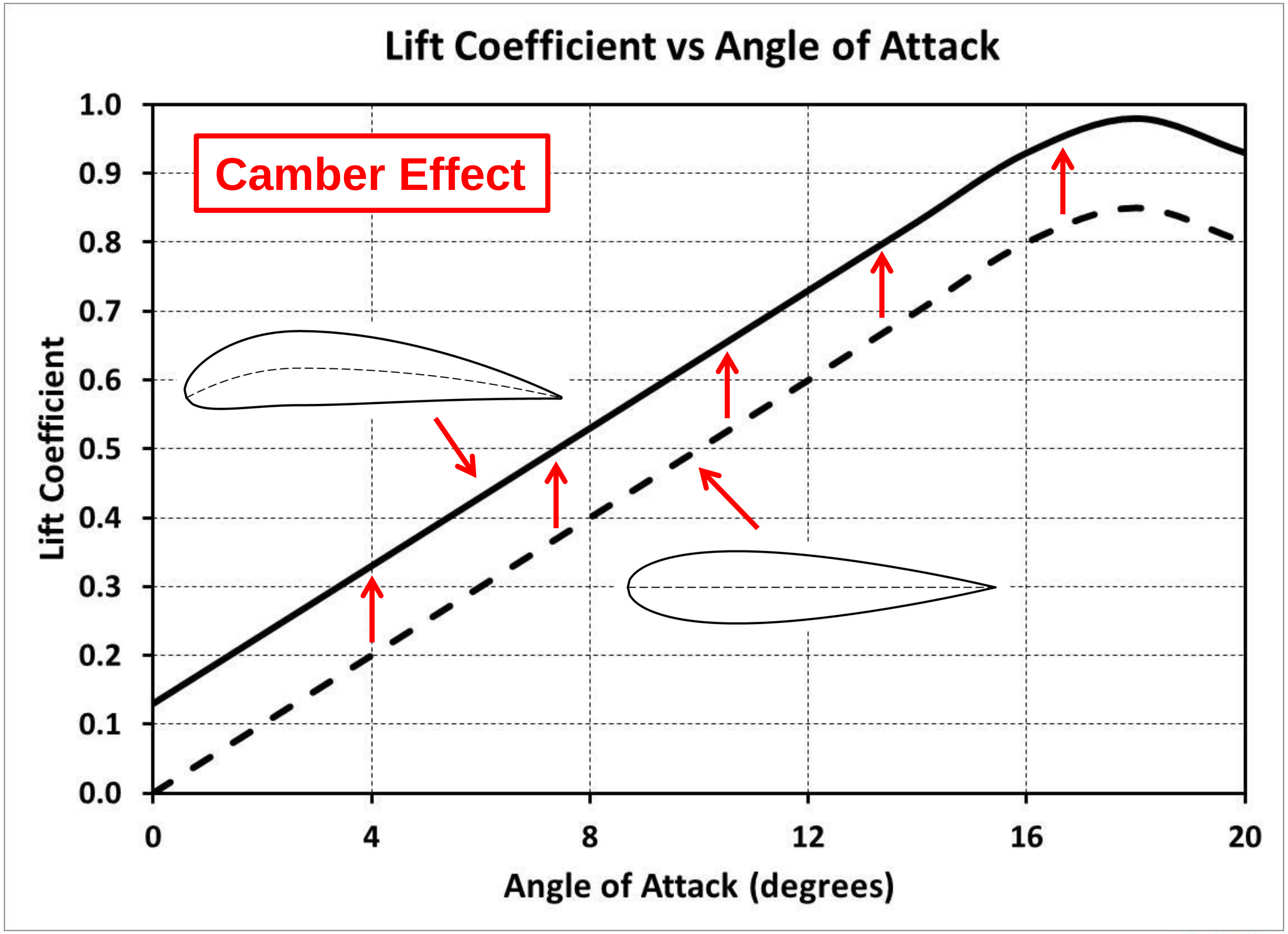
Aircraft Aerodynamics

Other Wing Planform Characteristics

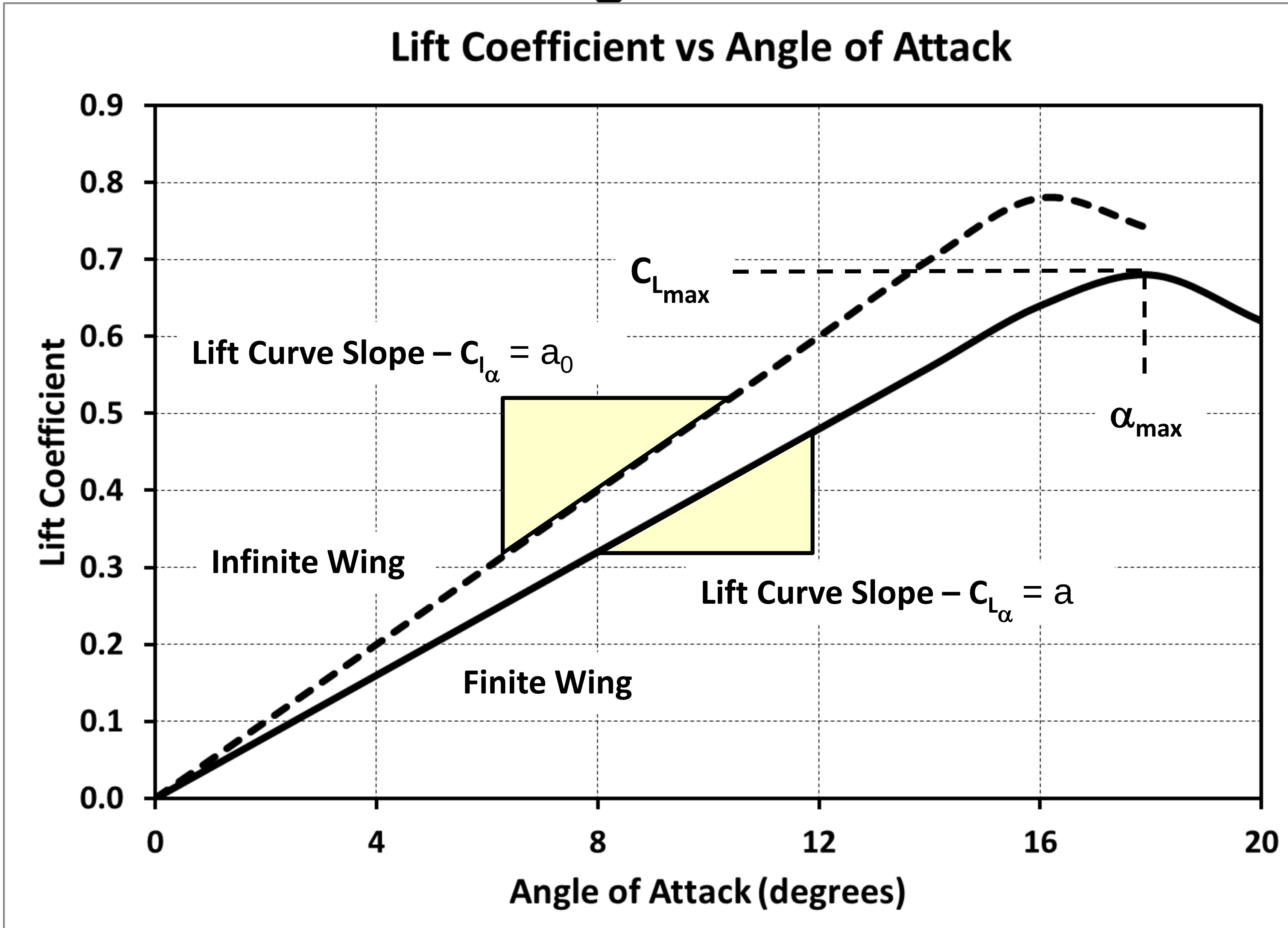
Airfoil Camber

Spanwise Twist

Wing Dihedral



Finite Wing Lift Curve



Finite Wing Lift Curve

High aspect ratio straight wing

$$\mathbf{a} = \frac{\mathbf{a_0}}{\mathbf{1} + \frac{\mathbf{a_0}}{\boldsymbol{\pi}\,\mathbf{e_1}\,\mathbf{AR}}}$$

Low speed

$$\mathbf{a} = \frac{\mathbf{a_0}}{\sqrt{\mathbf{1} - \mathbf{M^2}} + \frac{\mathbf{a_0}}{\boldsymbol{\pi}\,\mathbf{e_1}\,\mathbf{AR}}}$$

Subsonic

$$\mathbf{a} = \frac{\mathbf{4}}{\sqrt{\mathbf{M^2} - \mathbf{1}}}$$

Supersonic

Derived from Prandtl's lifting line theory and Prandtl-Glauert rule

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Finite Wing Lift Curve

Low aspect ratio straight wing

$$\mathbf{a} = \frac{\mathbf{a_0}}{\sqrt{1 + \left(\frac{\mathbf{a_0}}{\pi \mathbf{AR}}\right)^2} + \frac{\mathbf{a_0}}{\pi\ \mathbf{AR}}}$$

Low speed

$$\mathbf{a} = \frac{\mathbf{a_0}}{\sqrt{1 - \mathbf{M}^2 + \left(\frac{\mathbf{a_0}}{\pi \mathbf{AR}}\right)^2} + \frac{\mathbf{a_0}}{\pi\ \mathbf{AR}}}$$

Subsonic

$$\mathbf{a} = \frac{\mathbf{4}}{\sqrt{\mathbf{M}^2 - \mathbf{1}}}\left(\mathbf{1} - \frac{\mathbf{1}}{\mathbf{2}AR\sqrt{M^2 - \mathbf{1}}}\right)$$

Supersonic

Derived from Helmbold’s equation and Hoerner & Borst

Finite Wing Lift Curve

Swept wing

$$\mathbf{a} = \frac{\mathbf{a_0 \cos\Lambda}}{\sqrt{1 + \left(\frac{\mathbf{a_0 \cos\Lambda}}{\pi \mathbf{AR}}\right)^2} + \frac{\mathbf{a_0 \cos\Lambda}}{\pi\, \mathbf{AR}}}$$

Low speed

$$\mathbf{a} = \frac{\mathbf{a_0 \cos\Lambda}}{\sqrt{1 - \mathbf{M}^2 \cos^2\Lambda + \left(\frac{\mathbf{a_0 \cos\Lambda}}{\pi \mathbf{AR}}\right)^2} + \frac{\mathbf{a_0 \cos\Lambda}}{\pi\, \mathbf{AR}}}$$

Subsonic

a = very complicated methodology

Supersonic

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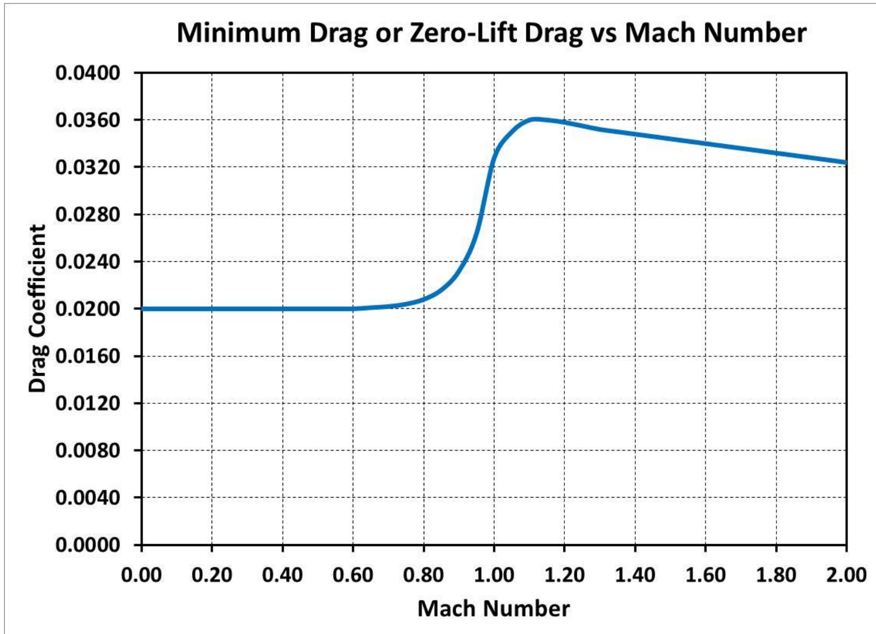
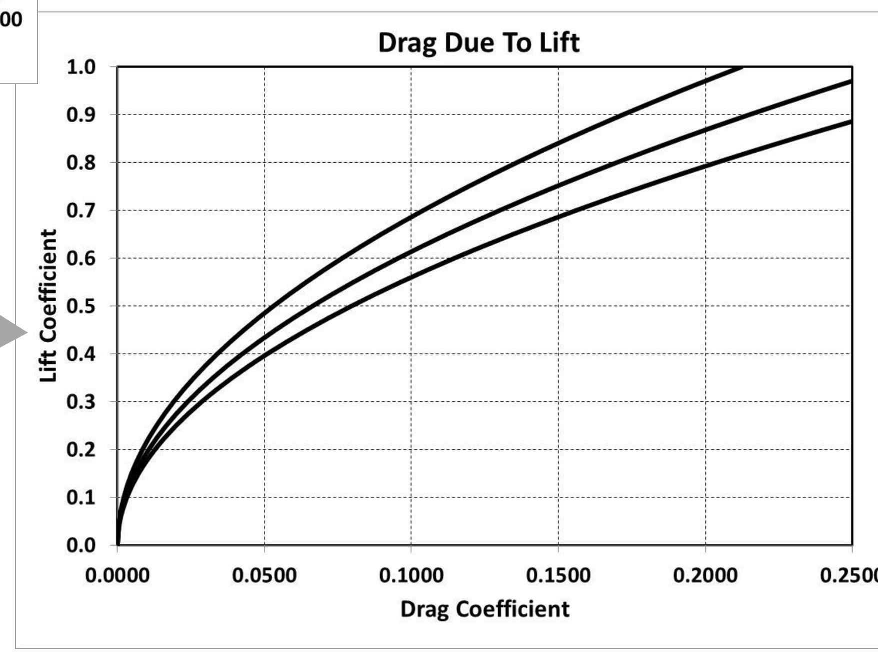
Finite Wing Drag



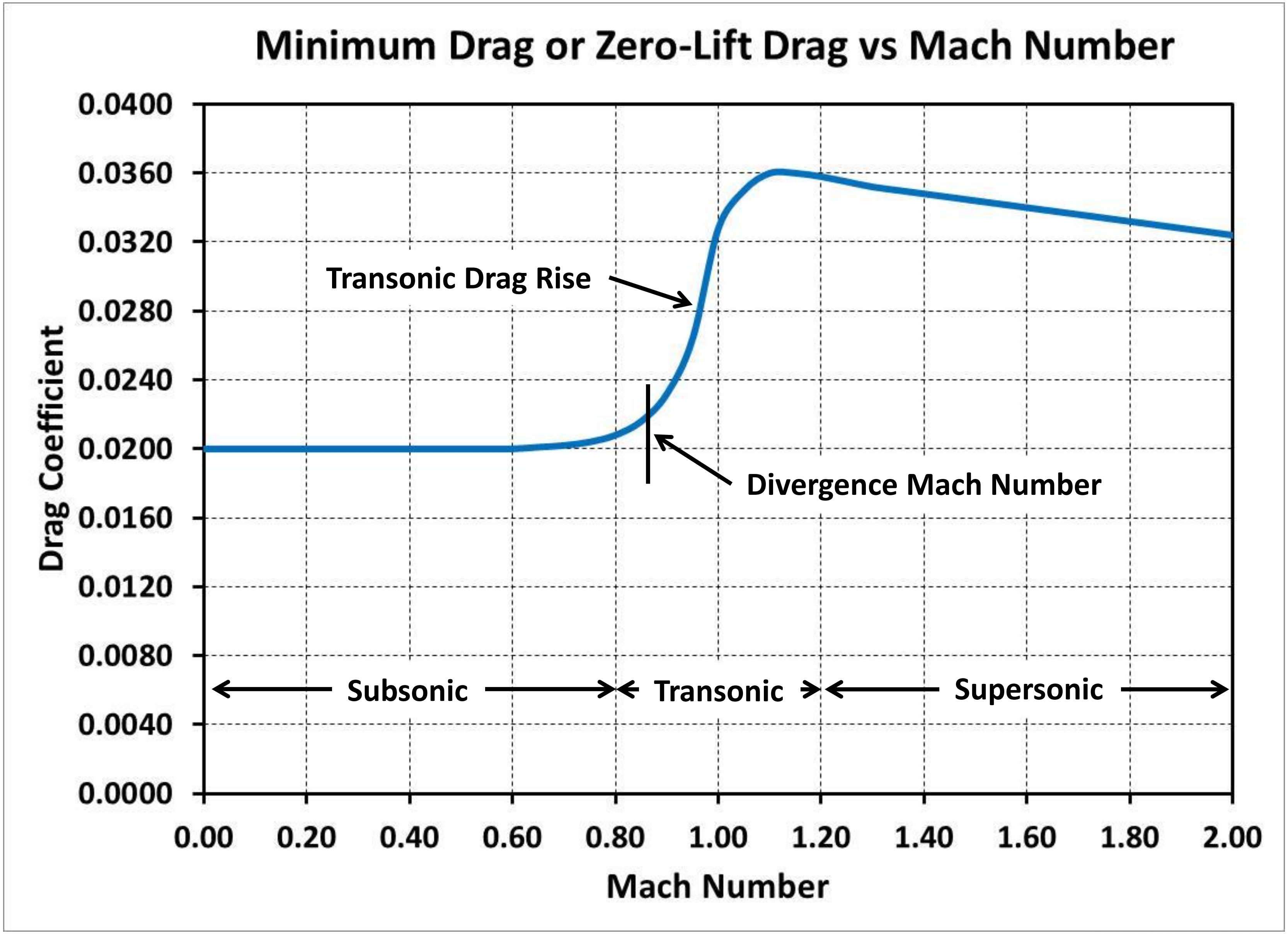
$$C_{D_0} \sim f\,(M, h)$$

$$C_{D_L} \sim f\,(C_L, M, c.g.)$$

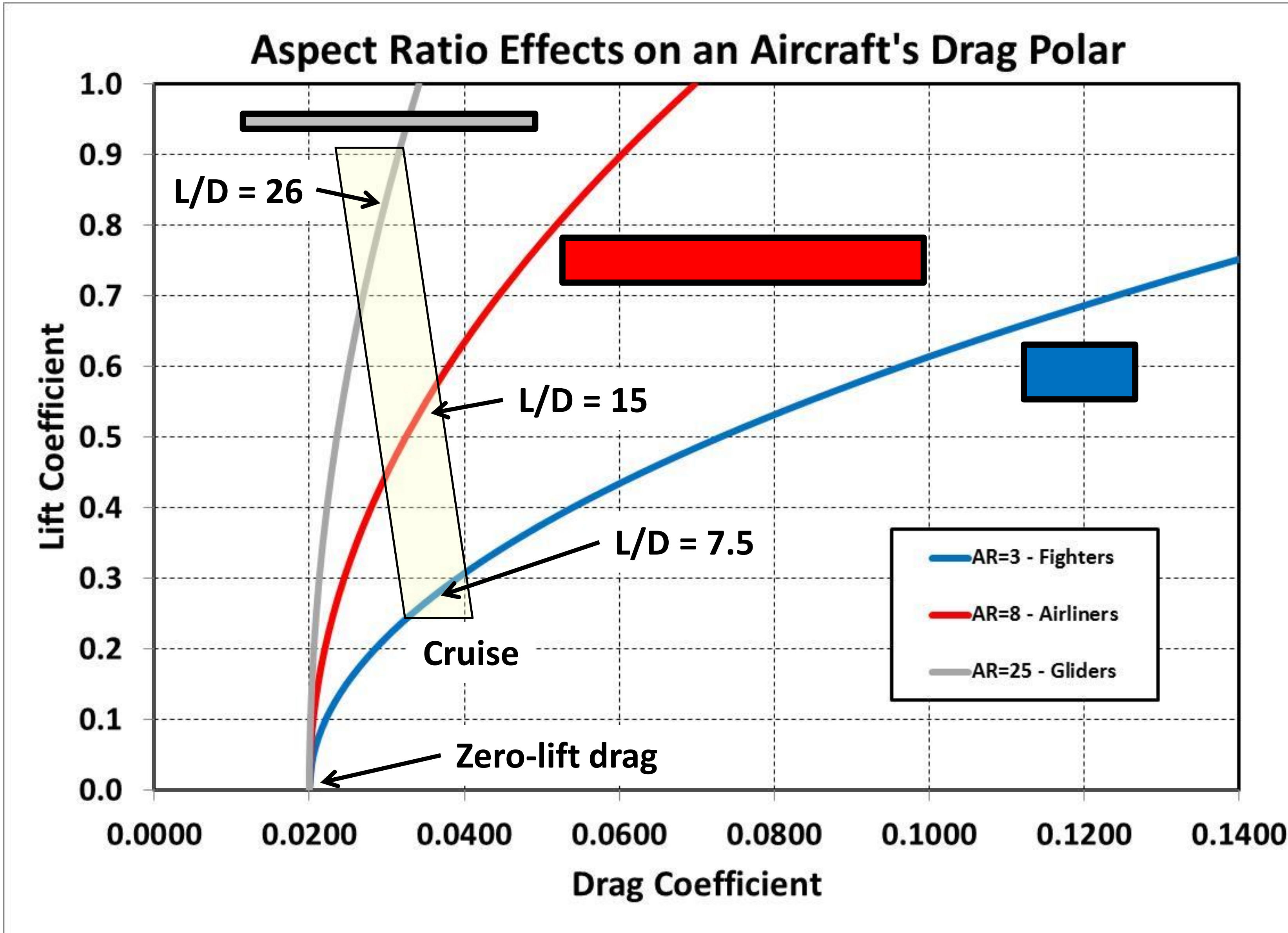
$$C_D = C_{D_0} + K\,C_L^{\;2}$$



Aircraft Aerodynamics



Aircraft Aerodynamics



Aircraft Thrust

Piston engine / propeller $$T_A = SHP_{SL}\left(\frac{\eta_P}{V}\right)\left(\frac{\rho}{\rho_{SL}}\right)$$

Turboprop $$T_A = ESHP_{SL}\left(\frac{\eta_P}{V}\right)\left(\frac{\rho}{\rho_{SL}}\right)$$

High-bypass turbofan $$T_A = T_{SL}\left(\frac{0.1}{M}\right)\left(\frac{\rho}{\rho_{SL}}\right)$$

Low-bypass turbofan & Turbojet $$T_A = T_{SL}\left(\frac{\rho}{\rho_{SL}}\right)$$

Afterburner $$T_A = T_{SL}\left(\frac{\rho}{\rho_{SL}}\right)(1 + 0.7\,M)$$

Aircraft Fuel Flow

Piston engine / propeller	$\mathbf{FFR = SHP\ c}$
Turboprop	$\mathbf{FFR = ESHP\ c}$
High-bypass turbofan	$\mathbf{FFR = T\ c_{SL}\left(\frac{a}{a_{SL}}\right)}$
Low-bypass turbofan & Turbojet	$\mathbf{FFR = T\ c_{SL}\left(\frac{a}{a_{SL}}\right)}$
Afterburner	$\mathbf{FFR = T\ c_{SL}\left(\frac{a}{a_{SL}}\right)}$

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Aircraft Weights

Basic Mission Takeoff Gross Weight =
OW + Mission Payload + Mission Fuel

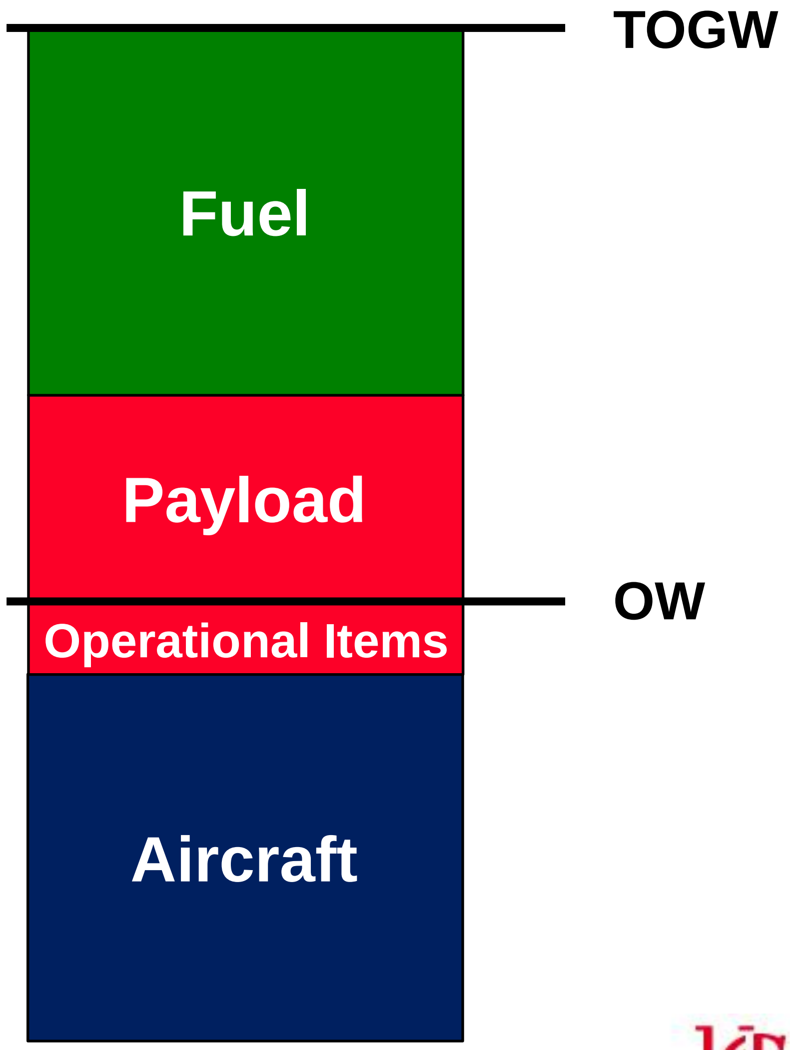
Maximum Fuel – full capacity
Mission Fuel – specific mission capability

Maximum Payload – full capacity loadout
Mission Payload – specific mission loadout

Maximum Takeoff Gross Weight =
OW + Maximum Payload + Maximum Fuel

- or -

Maximum Takeoff Gross Weight
could be set by other factors
(landing gear limit, c.g. limits, etc)



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Aircraft Weights

Common Weight Ratios

$$\textbf{Fuel Fraction} = \frac{W_{fuel}}{W_{TO}}$$

$$\textbf{Payload Fraction} = \frac{W_{payload}}{W_{TO}}$$

$$\textbf{Weight Empty Fraction} = \frac{W_{empty}}{W_{TO}}$$

$$\textbf{Crew Weight Fraction} = \frac{W_{crew}}{W_{TO}}$$

Aircraft Weights

$$\mathbf{W_{TO} = W_{crew} + W_{payload} + W_{fuel} + W_{empty}}$$

$$\mathbf{W_{TO} = \frac{W_{crew} + W_{payload}}{1 - \frac{W_{fuel}}{W_{TO}} - \frac{W_{empty}}{W_{TO}}}}$$

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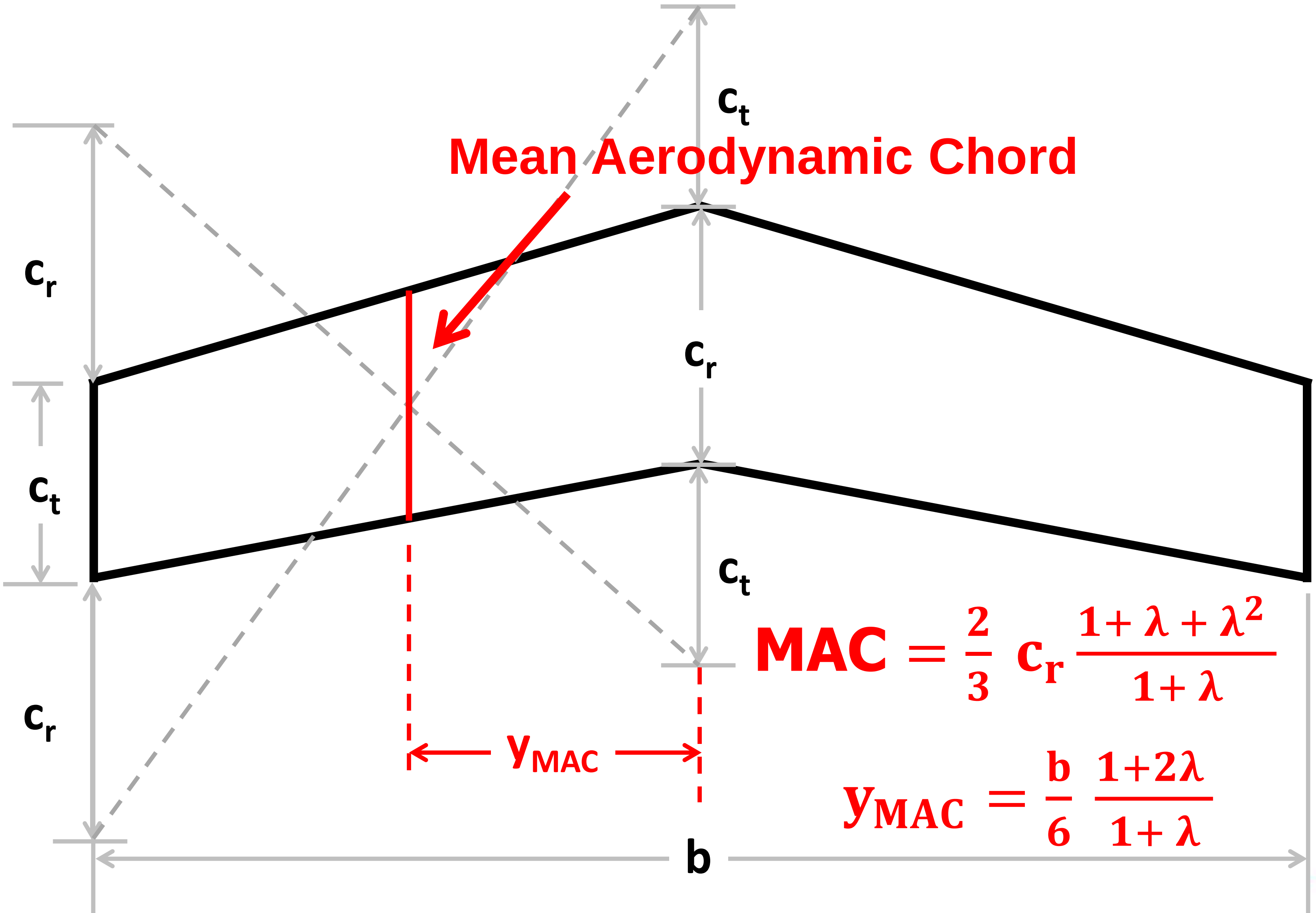
MAC Graphical Determination



$$\mathbf{MAC} = \frac{2}{3}\, c_r \frac{1+\lambda+\lambda^2}{1+\lambda}$$

$$y_{MAC} = \frac{b}{6}\, \frac{1+2\lambda}{1+\lambda}$$

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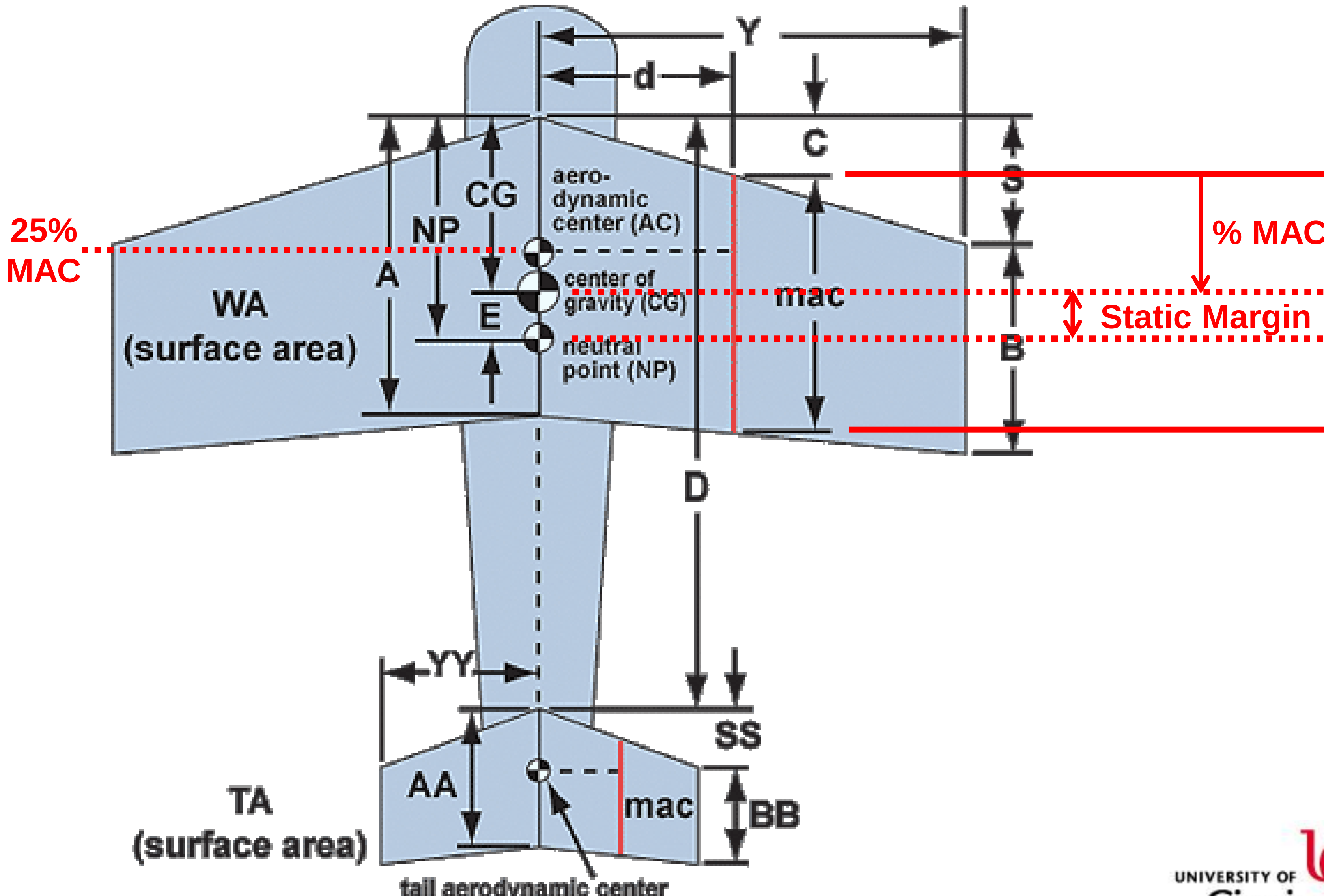
CG Location as % MAC



Building Blocks

PRODUCTS	Values	Graphs	Diagrams	Aircraft Design
METHODS	Equations	Calculations	Methodologies	
TOOLS	Excel Developer	Excel Name Manager	1-Dimensional Table Lookup	
DATA	Atmosphere Table	Aerodynamics Propulsion Aircraft Weights	Aircraft Dimensions	

Course Flow Diagram

Blocks 1 & 2 – Aircraft Performance

Block 1 Homework

5%

Ingredient Data

Computational Tools

Block 2 Homework

10%

Performance

Concepts & Equations

Project #1

15%

16%

Quiz #1
Quiz #2
Exam #1

29%

Quiz #3
Quiz #4
Exam #2
Quiz #5
Exam #3

Block 3 – Aircraft Design

Block 3 Homework

10%

Design Choices

Computational Tools

Project #2

15%

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AEEM 3042 – Aircraft Performance & Design

Course Exams

Will be done online via Canvas:

Exam #1 – Thursday, January 26 at 3:30 pm ET

Exam #2a – Thursday, February 16 at 3:30 pm ET

Exam #2b – Thursday, March 9 at 3:30 pm ET

Start the exam between 3:30 and 3:40 pm ET

You will have **80 minutes** to complete the exam

Allowable resources include your notes, calculator, lecture slides, reference materials, spreadsheets

Academic Integrity = no help from other students!!

Questions are randomly selected

Exam will be graded automatically

Students will know their exam grade immediately

Correct answers available on Canvas 6:00 pm – 10:00 pm

AEEM 3042 – Aircraft Performance & Design

Course Exam Tips

Be ready to take this exam!

There are 10 questions to answer (~100 points each):

- True / False
- Multiple Choice
- Matching
- Numerical values

Answers do not depend on any previous calculations, which means that there is no partial credit

You can answer the questions in any order

You can review any of the questions at any time

Do not hit the “Submit” button until you have finished

Next Lecture (Tuesday) – bring your laptop

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Questions?