Aircraft Design
Wing Design

Video

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Aircraft Design Process

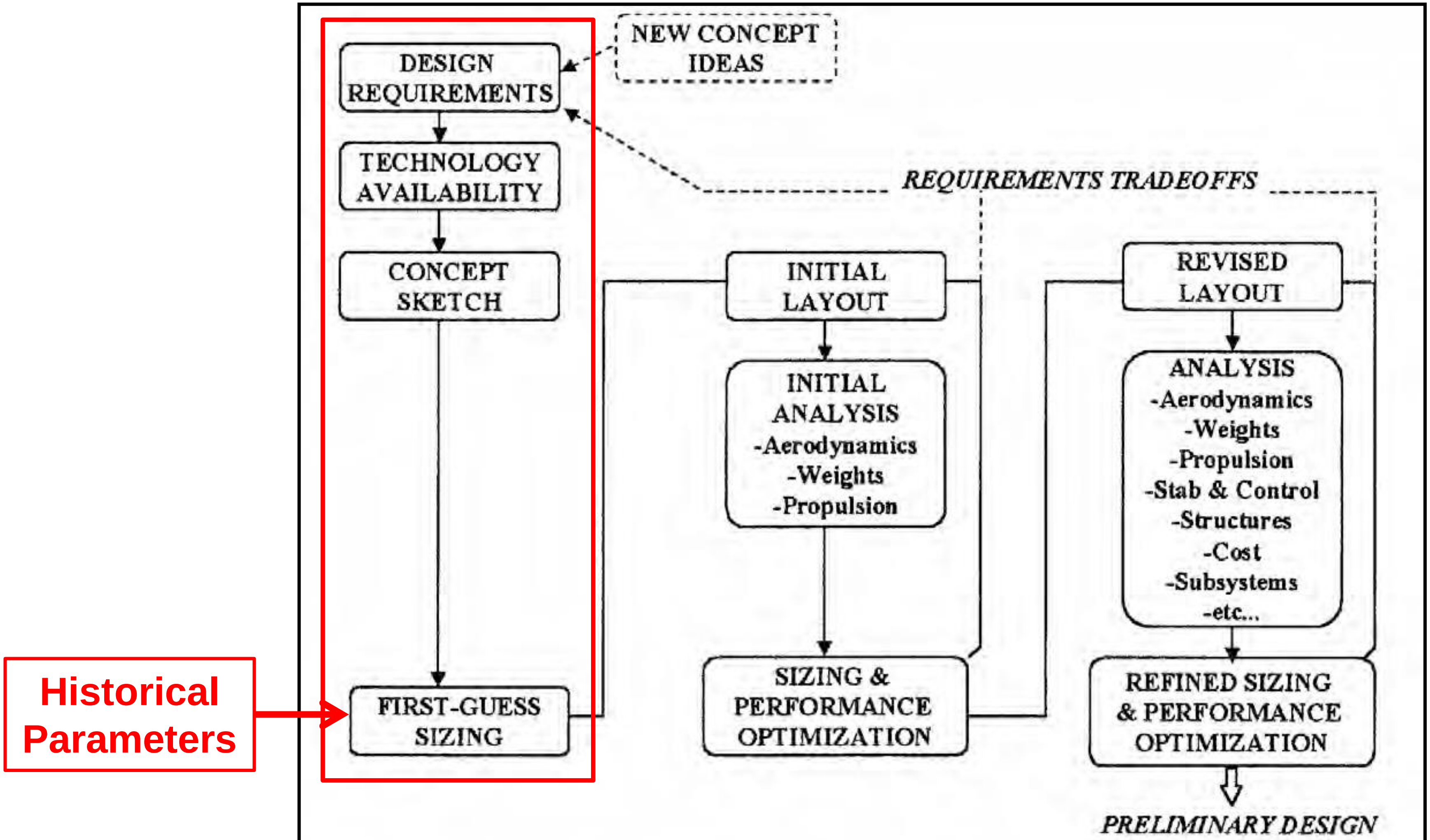

Fig. 2.4 Aircraft conceptual design process.

"Aircraft Design: A Conceptual Approach" by Daniel P. Raymer, page 9

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Finite Wing

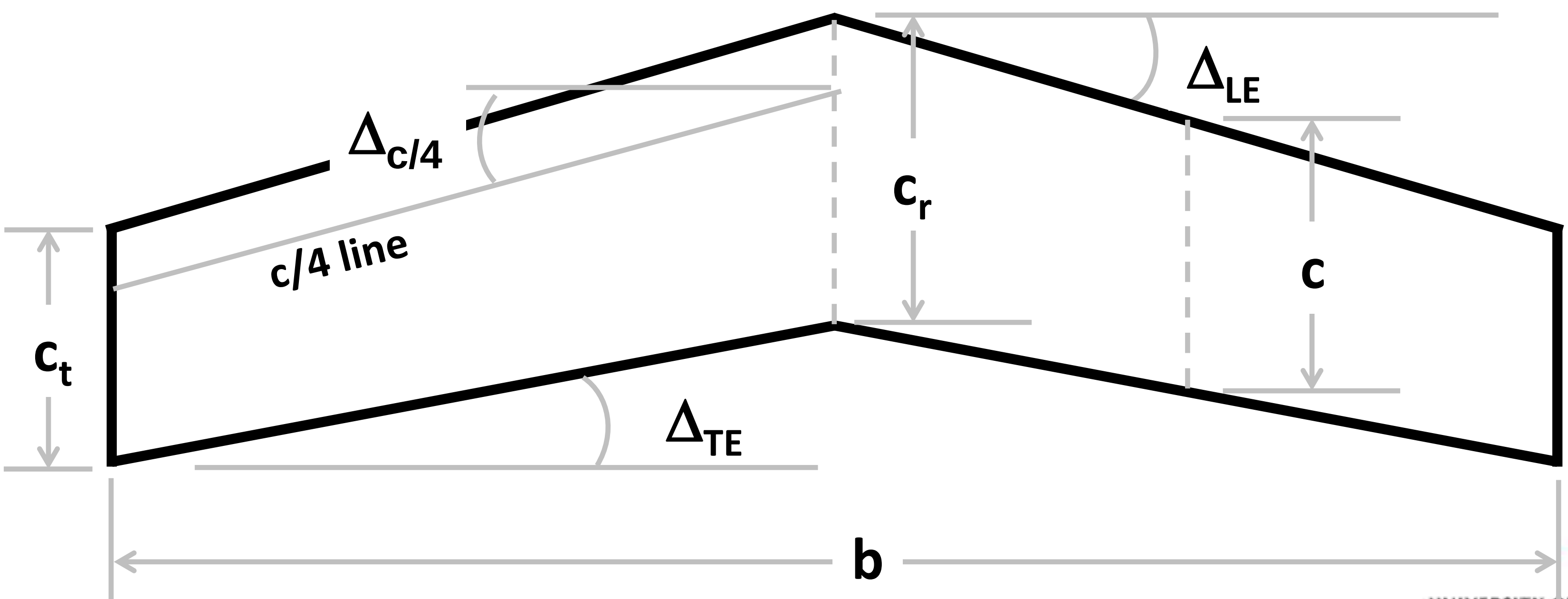
Wing Planform Characteristics

Wing Area (S)	Leading Edge Sweep (Δ_{LE})
Wing Span (b)	Trailing Edge Sweep (Δ_{TE})
Average Chord (c)	Aspect Ratio (AR)
Root Chord (c_r)	Taper Ratio (λ)
Tip Chord (c_t)	Quarter-Chord Angle ($\Delta_{c/4}$)

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

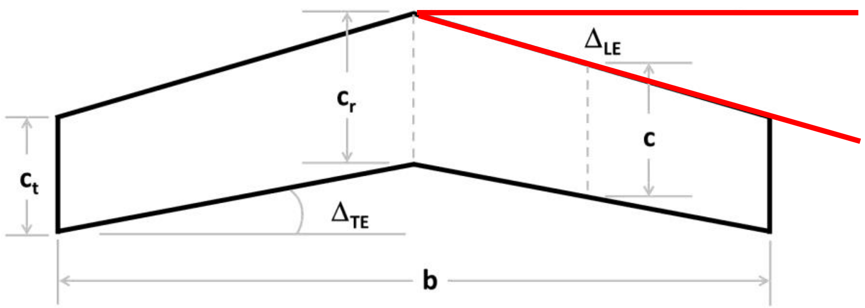
$$\mathbf{AR = \frac{b^2}{S} = \frac{b}{c}}$$

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



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

Aircraft Aerodynamics



Wing Sweep (Δ)

Indicator of an aircraft's subsonic cruise speed

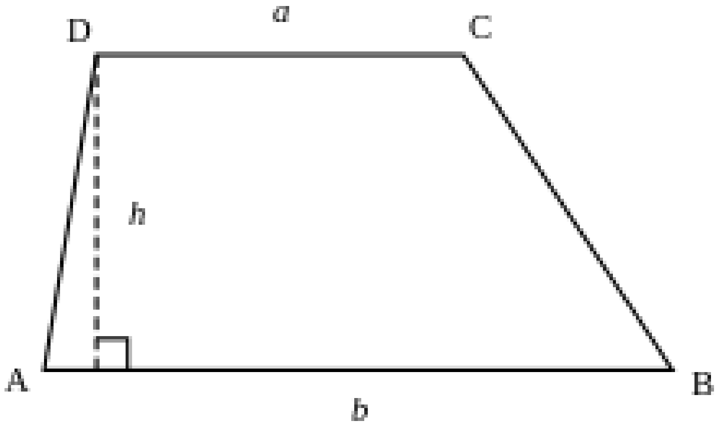
Affects Divergence Mach Number

Low wing sweep (0 to 20 degrees) – sailplanes, gliders
High aspect ratio (AR = 20 - 25)
Slower cruise speed (0.2 - 0.6 Mach)

Medium wing sweep (20 to 40 degrees) – airliners, cargo, bombers
Medium aspect Ratio (AR = 8 - 10)
Moderate cruise speed (0.6 - 0.85 Mach)

High wing sweep (40 to 70 degrees) – fighters, supersonic aircraft
Low aspect ratio (AR = 2 - 4)
Faster cruise speeds (0.8 - 0.9 Mach)

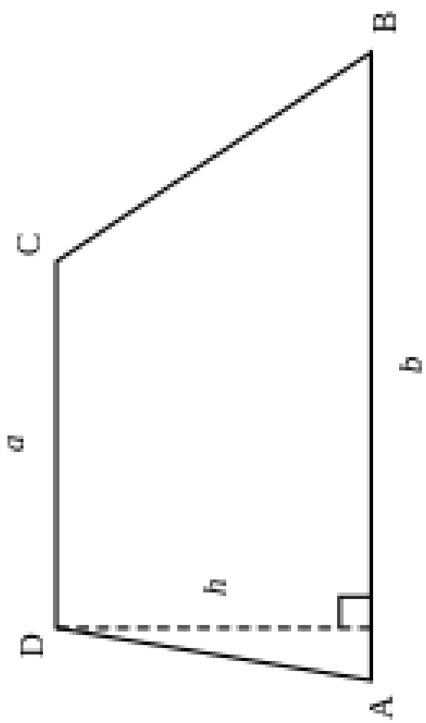
Aircraft Wing Dimensions

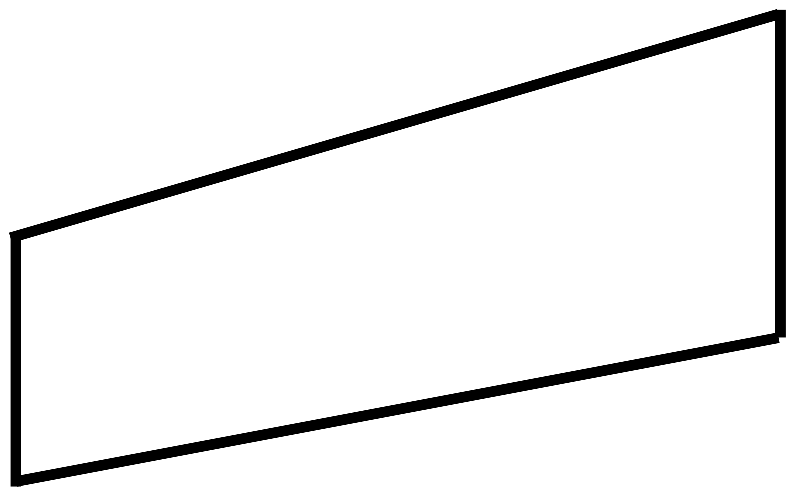


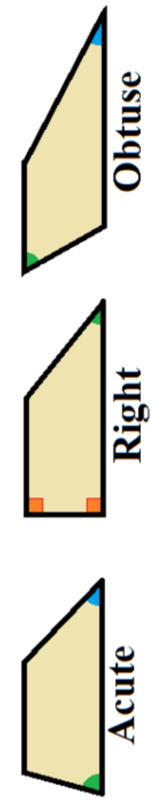
Wing Planform Assumption

- Convex quadrilateral = trapezoid

- Acute, Right, or Obtuse Trapezoid







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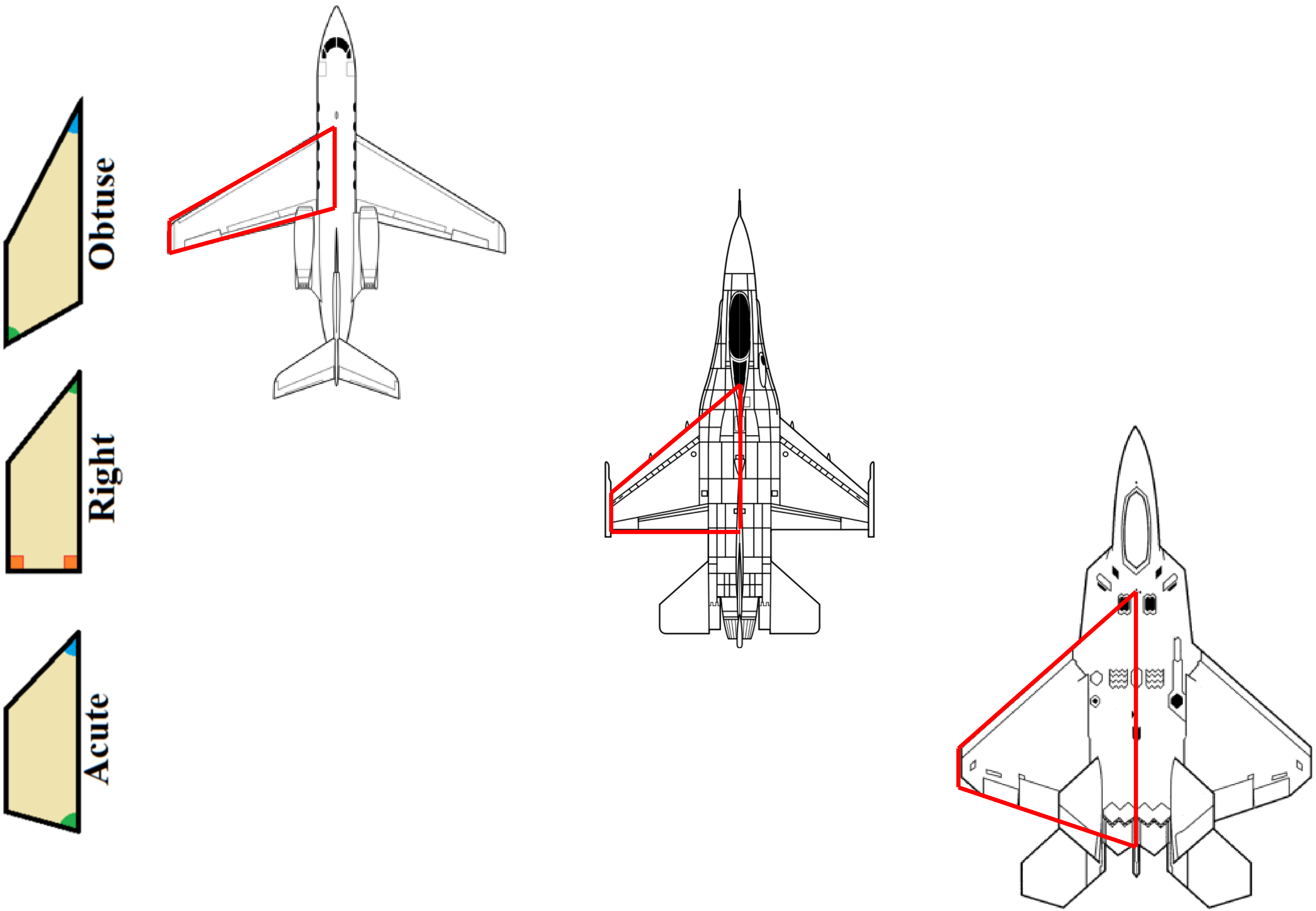
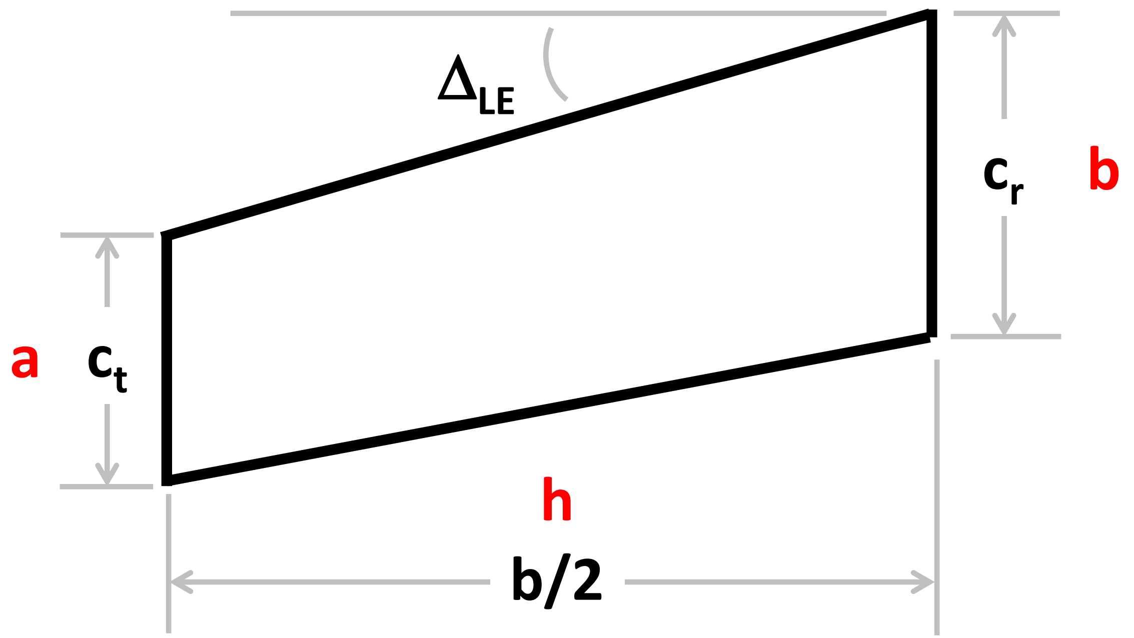
Aircraft Wing Dimensions



Aircraft Wing Dimensions



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

$$\text{Wing Area } (S_{trap}) = \frac{b}{2} * \frac{c_t + c_r}{2} \text{ x } 2 = b * \frac{c_t + c_r}{2}$$

$$AR_{trap} = \frac{b^2}{S_{trap}} = \frac{b}{c}$$

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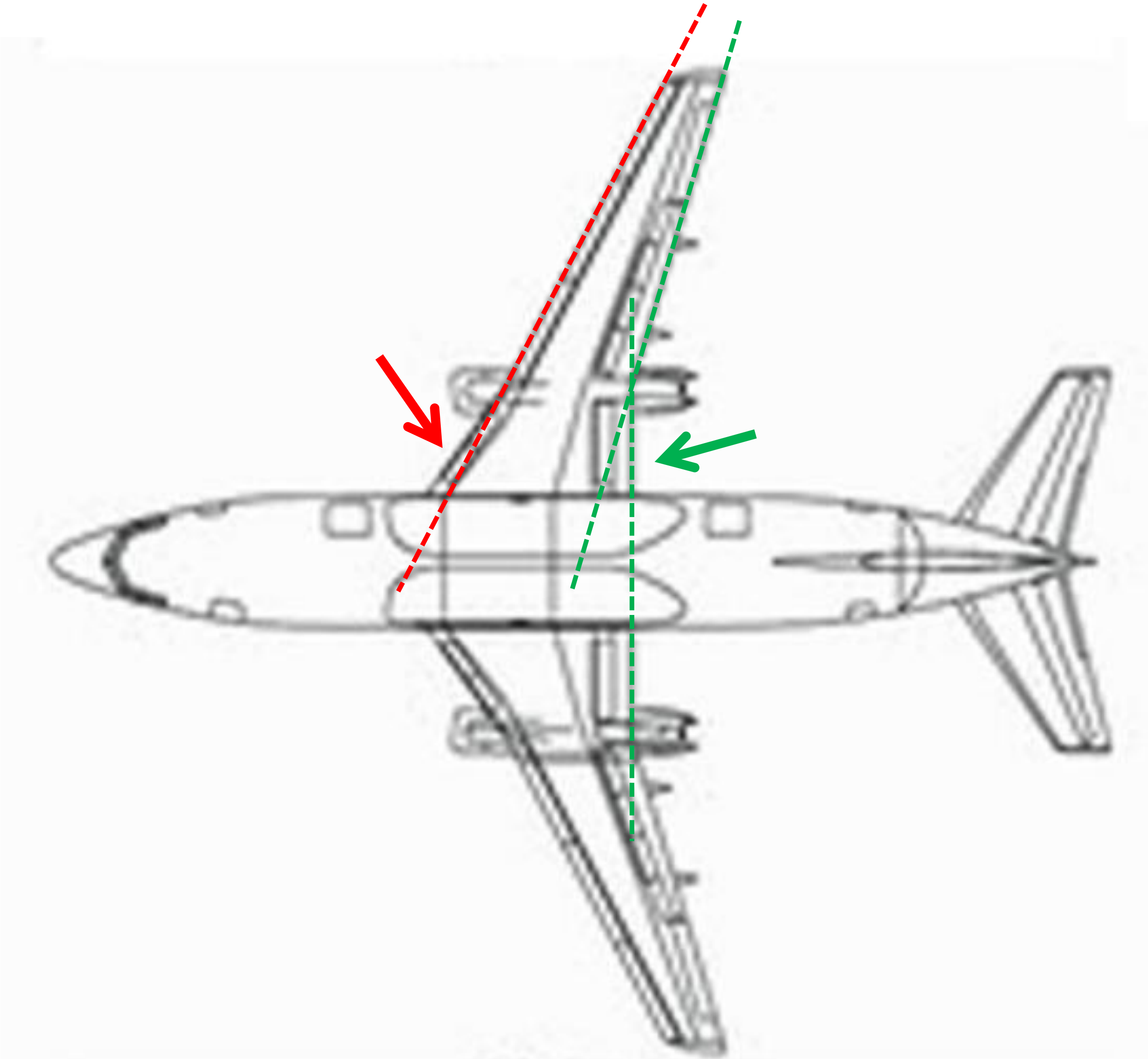
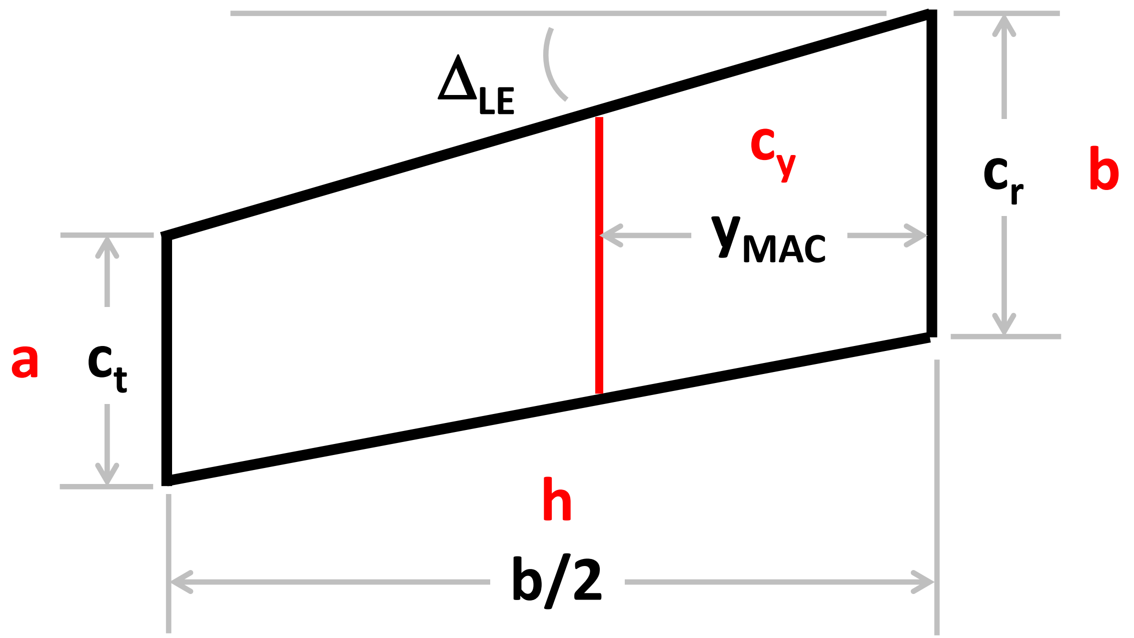
Aircraft Wing Dimensions



Aircraft Wing Dimensions



$$\text{Centroid of Trapezoid: } c_y = h * \frac{2a+b}{3(a+b)}$$

$$\text{Centroid of Wing: } y_{MAC} = \frac{b}{2} * \frac{2c_t + c_r}{3(c_t + c_r)}$$

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Aircraft Wing Dimensions

$$y_{MAC} = \frac{b}{2} * \frac{2\,c_t + c_r}{3\,(c_t + c_r)}$$

$$y_{MAC} = \frac{b}{6} * \frac{2\,c_t + c_r}{c_t + c_r}$$

$$y_{MAC} = \frac{b}{6} * \frac{c_r\,(\,2\,\frac{c_t}{c_r} + 1\,)}{c_r\,(\,\frac{c_t}{c_r}\ +1\,)}$$

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

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

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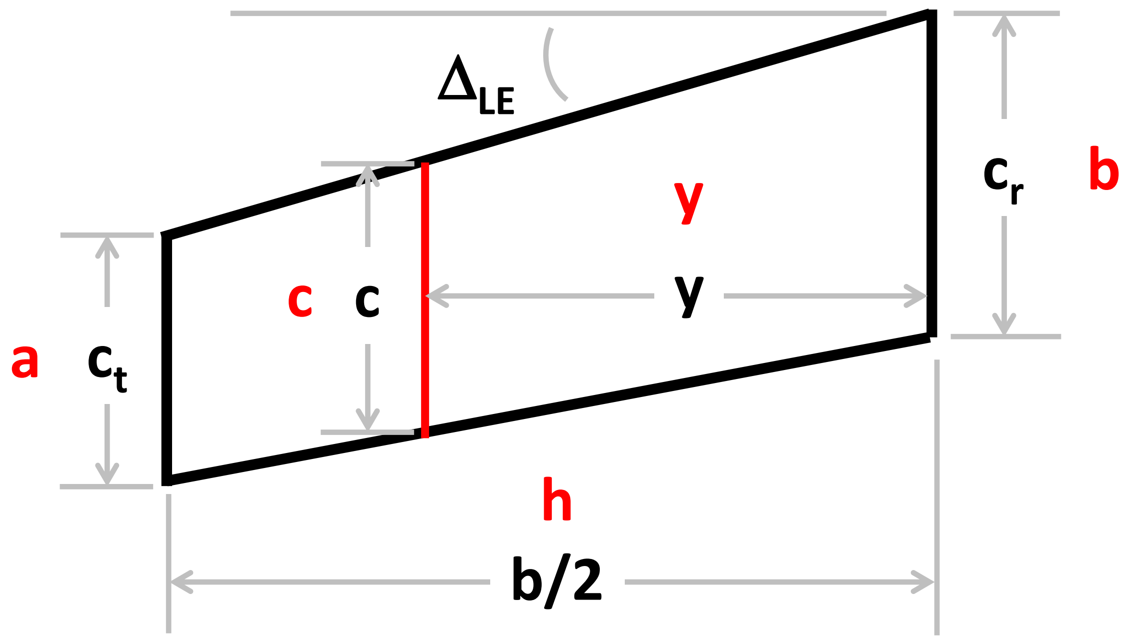
Aircraft Wing Dimensions



The local chord length at any point y away from the longer side

$$c = b\left[1 - \left(1 - \frac{a}{b}\right)\frac{y}{h}\right]$$

$$c = c_r\left[1 - (1 - \lambda)\frac{y}{(b/2)}\right]$$

Aircraft Wing Dimensions

The local chord at any point y away the Root Chord

$$\mathbf{c = c_r \left[1 - (1-\lambda)\,\frac{y}{(b/2)}\right]}$$

We can substitute y with the equation for y_{MAC}

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

… lots of algebra will eventually yield …

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

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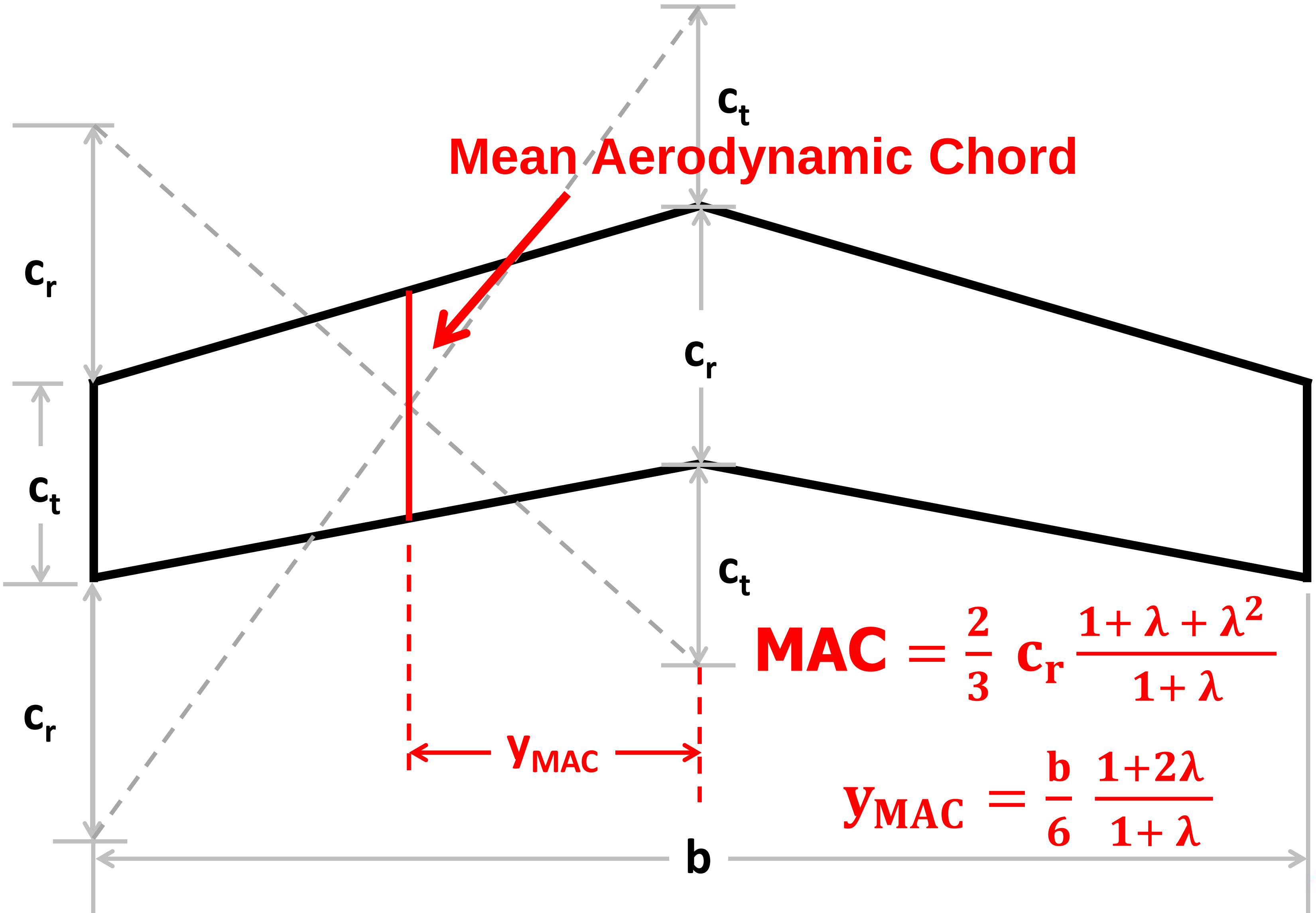
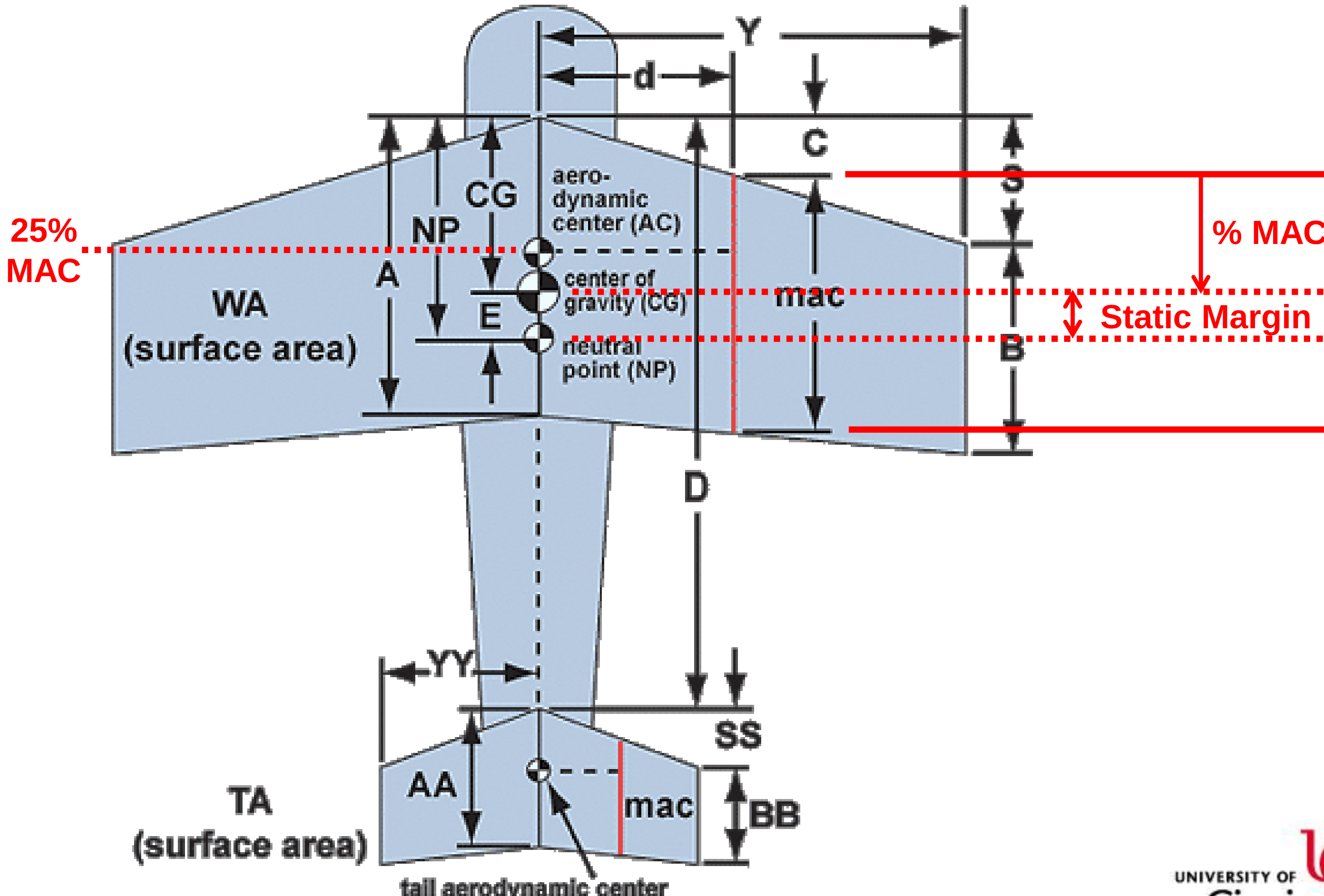
MAC Graphical Determination



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

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

MAC Significance



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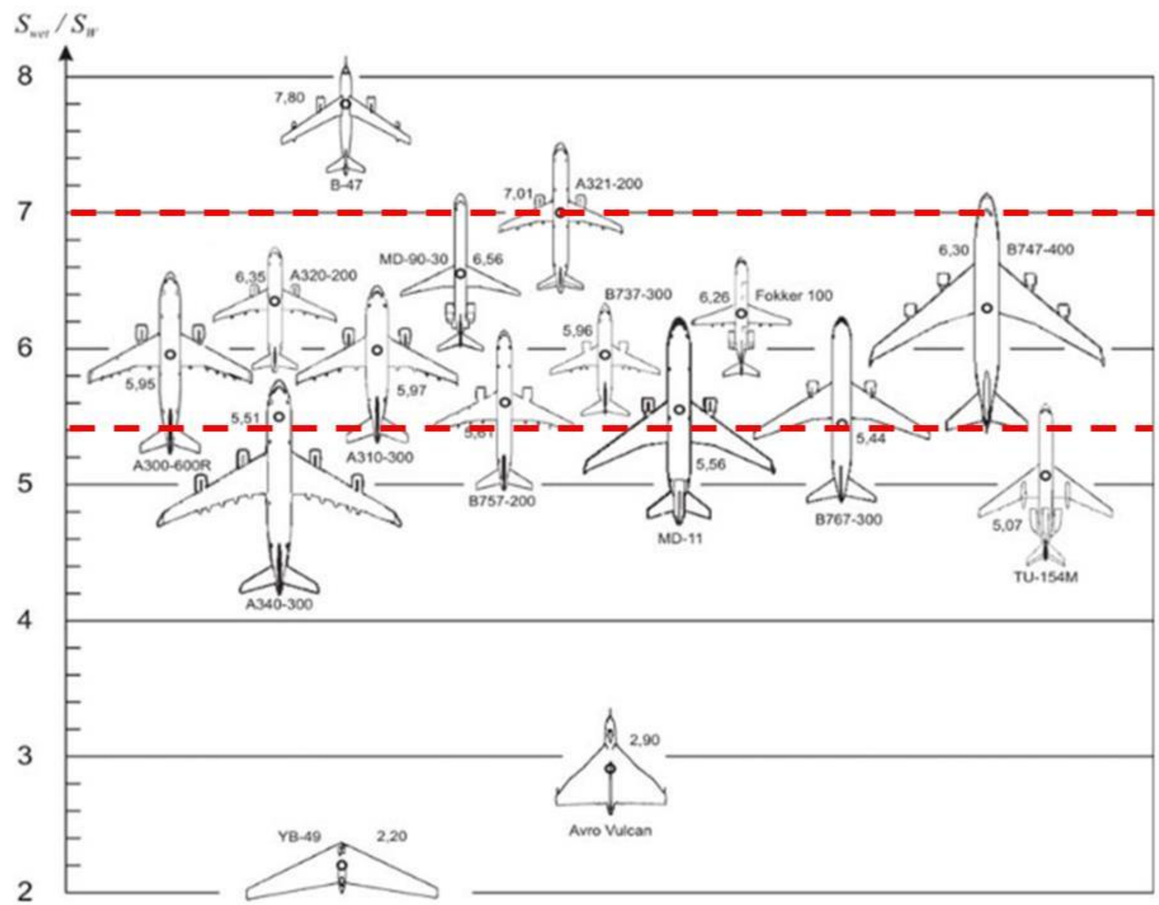
Wing Loading (W/S)

	C_{fe} - subsonic
Bomber and Civil Transport	**0.0030**
Military Cargo	**0.0035**
Air Force Fighter	**0.0035**
Navy Fighter	**0.0040**
Clean Supersonic Cruise	**0.0025**
Light Aircraft – Single Engine	**0.0055**
Light Aircraft – Twin Engine	**0.0045**

$$C_{D_0} = \frac{S_{wet}}{S_{ref}} C_{f_e}$$



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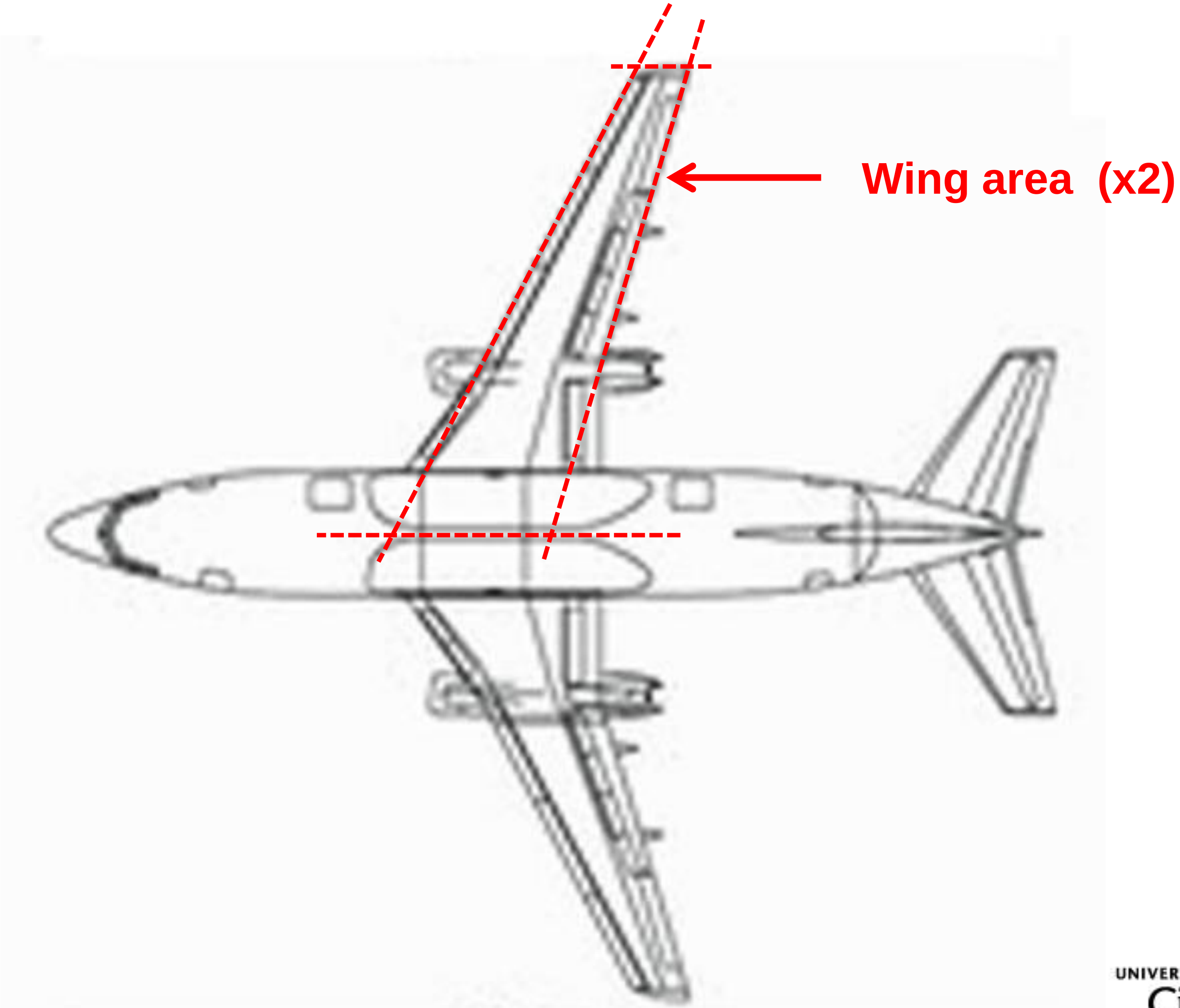

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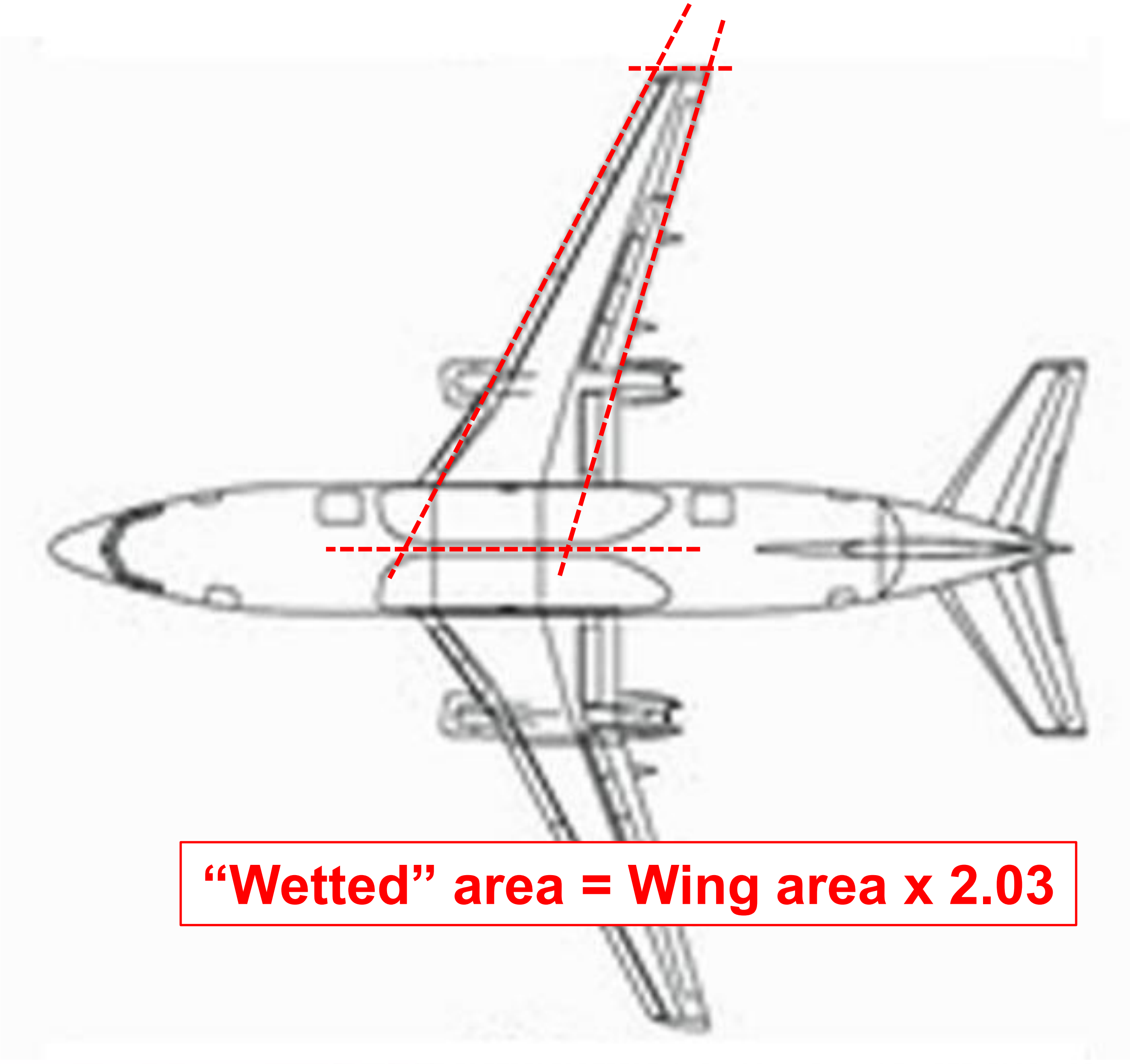
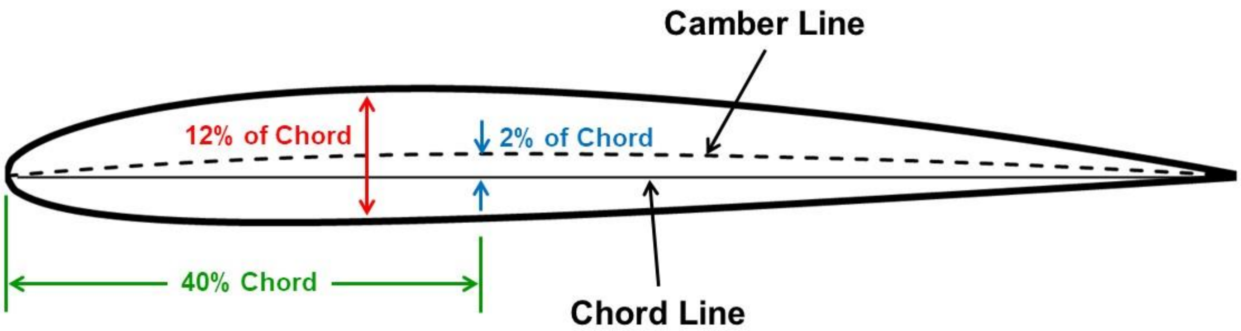
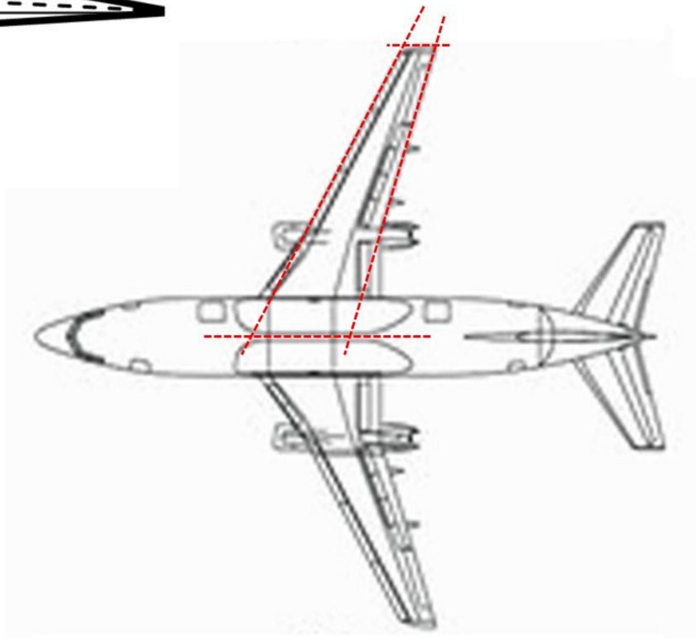


"Wetted" area = Wing area x 2.03

Aircraft Wing Dimensions





Wetted Area Equation
for Wing's max t/c < 0.05

$$S_{wet} = S_{ref} * 2.003$$

Wetted Area Equation
for Wing's max t/c > 0.05

$$S_{wet} = S_{ref} * \underbrace{[1.977 + 0.52\,(t/c)]}_{\cong 2.03}$$

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HW #22 – Wing Design

Design Parameters

M	0.8000	
S_{ref}	1994	ft^2
S_{trap}	1797	ft^2
AR_{ref}	7.8110	
AR_{trap}	8.6672	
Λ_{LE}	28.0	deg
λ	0.2298	
W c-start	257,658	lb
W c-end	222,376	lb
q c-start	388.33	lbf/ft^2
q c-end	335.15	lbf/ft^2
Cl c-start	0.3327	
Cl c-end	0.3327	

Airfoil Data

Name	*NACA 64A204*	
Cl_{max}	1.03	
Cl_{α}	0.11	1/deg
a.c.	0.253	c
α_{0L}	-1.33	deg
Cd0	0.004	
r_{le}	0.0024	c
Cl_{minD}	0.1 - 0.3	
(t/c)max	0.40	c
t/c	0.04	

Air Properties

Cruise Alt.	24,714	ft
V	815.98	f/s
ρ	0.037561	lbm/f^3
q	388.3342	lbf/f^2
μ	1.07E-05	lbm/(f-s)
ν (cruise)	0.000285	f^2/s

WING.XLS

"Design of Aircraft" - Thomas C. Corke

Calculations

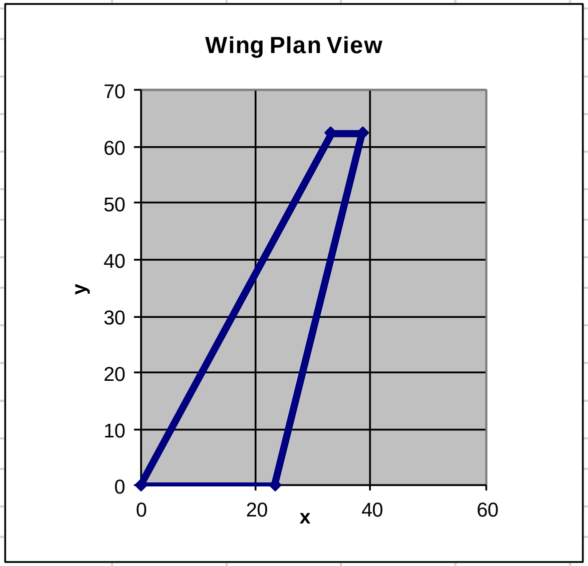
b	124.8	ft
M_{eff}	0.71	
c_r	23.4	ft
c_t	5.4	ft
MAC	**16.3**	ft
y_{mac}	24.7	ft
β	0.71	
$C_{L\alpha}$	**0.098**	1/deg
C_{Lo}	0.13	
α_{trim}	**2.1**	deg
C_{Ltrim}	0.3327	
k	0.05094	
C_D	**0.0118**	
L/D	**28.16**	
Total Drag	**9149.534**	lbf

Sweep Angles

	x/c	$\Lambda_{x/c}$ (deg)
LE	0.00	28.0
1/4C	0.25	24.7
a.c	0.25	24.6
(t/c)max	0.40	22.6
TE	1.00	13.6

Viscous Drag

V_eff	720.4657	f/s
q_eff	302.744	lbf/f^2
Re_mac	4.12E+07	
sqrt(Re)	6417.001	
Cf	2.31E-03	
S_wet	3993.982	ft^2
F	1.334637	
Q	1	
C_{D0}	**0.006177**	



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Input data from fact sheet and three-view drawing measurements

Input data from WINGLOAD cruise climb data

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HW #22 – Wing Design

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Check data against your own calculations and information

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Use these values later!!

Questions?

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