Aircraft Design
Second Iteration

Aircraft Design Process

Seven Intellectual Pivot Points

1. Requirements
2. First estimate of aircraft weight
3. Critical performance parameters
4. Configuration layout
5. Better weight estimate
6. Performance analysis
   Does it meet the requirements?
7. Optimization
   Is it the best design?

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Aircraft Design Process

Seven Intellectual Pivot Points

5. Better Weight Estimate

Overall Size and Shape Determined

First Configuration Layout

Performance Parameters Understood

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Aircraft Design Process

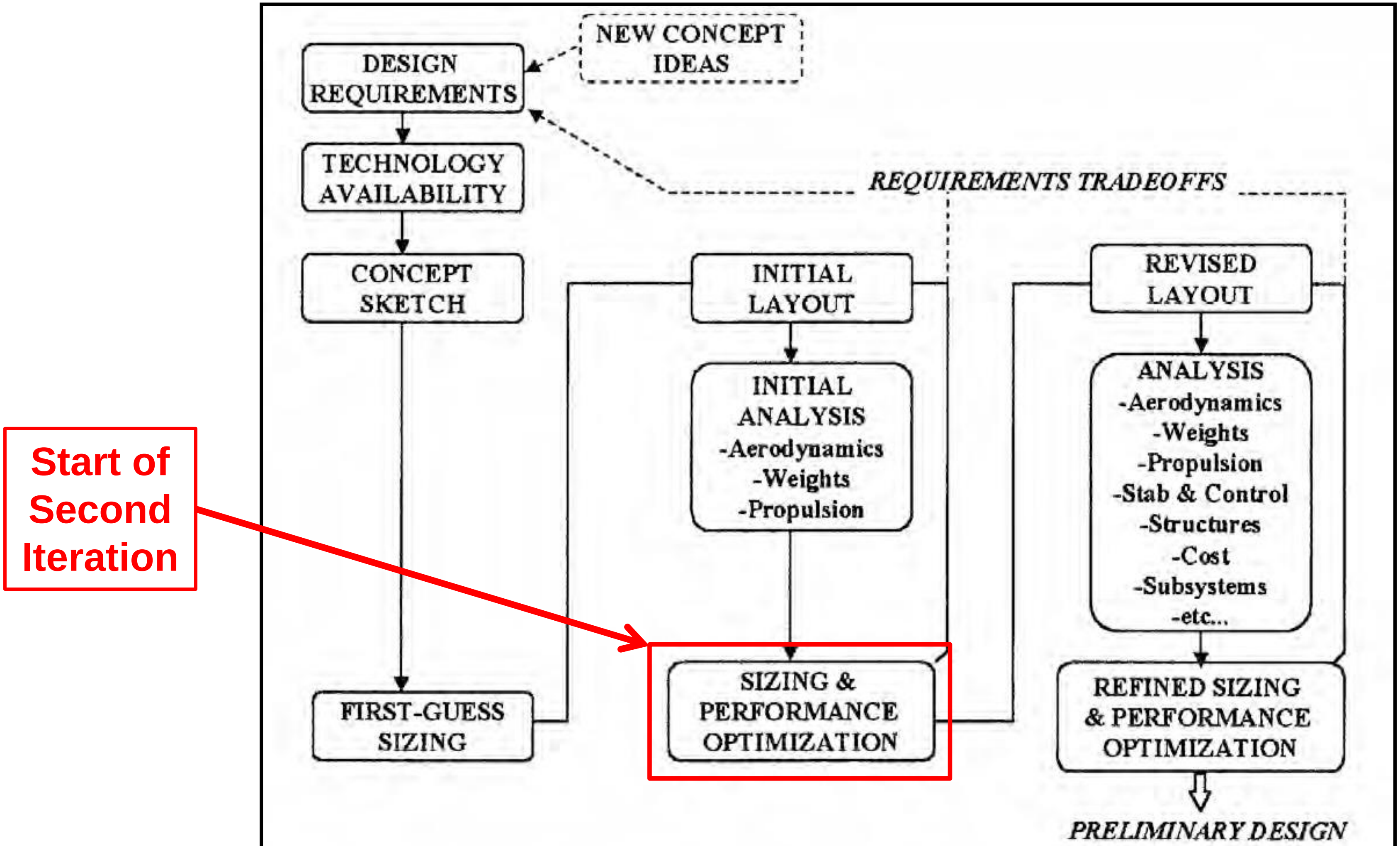

Fig. 2.4 Aircraft conceptual design process.

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

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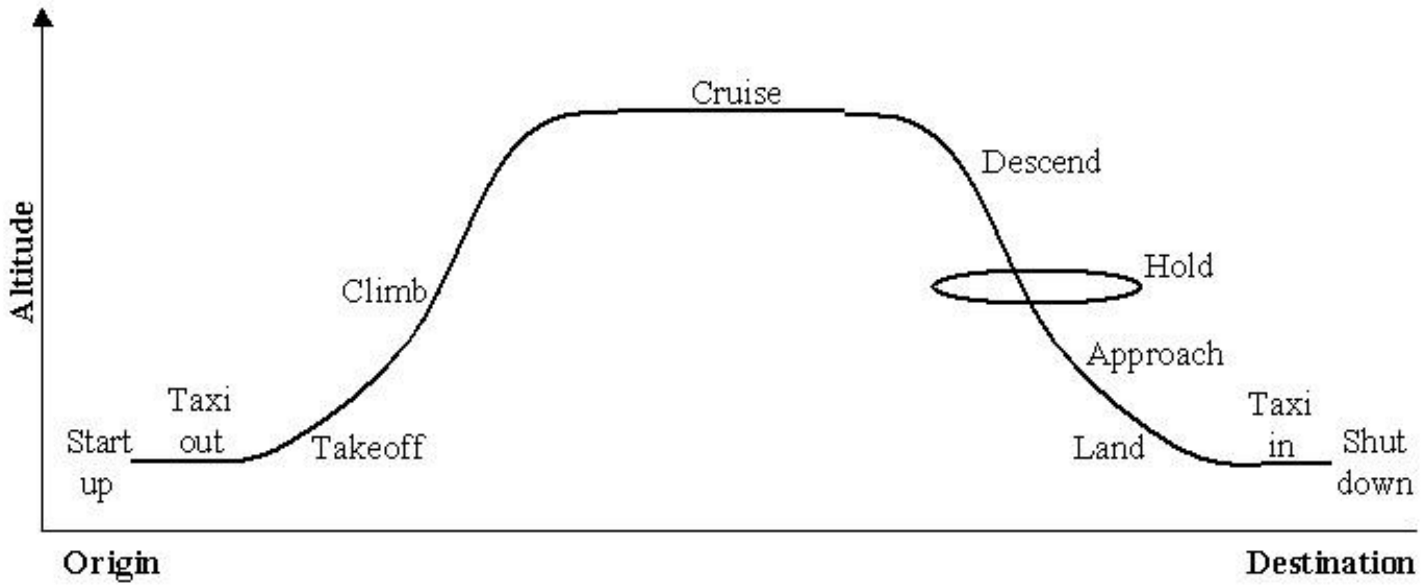
First Iteration



Requirements: **Range**
Payload
Cruise Mach Number
Takeoff and Landing Distance

First Iteration

Requirements:	**Range**
	Payload
	Cruise Mach Number
ITERTOW inputs:	**Mission Profile**
	Aspect Ratio
	Structure Factor
	Initial Takeoff Weight
ITERTOW outputs:	**Mission Segment Fuel**

First Iteration

WINGLOAD inputs:

- Takeoff C_{Lmax}
- Landing C_{Lmax}
- C_{D0}
- Wing Area
- Mission Segment Fuel

WINGLOAD outputs:

- Takeoff Distance
- Landing Distance
- Cruise Altitude

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First Iteration

WING inputs: Wing Leading Edge Sweep Angle
Wing Taper Ratio

WING outputs: Wing Span
Root Chord & Tip Chord
Trailing Edge Sweep Angle
MAC Length & Location (y_{MAC})
Wing Planform Shape

First Iteration

FUSELAGE inputs:
- **Fuselage Length (L_{fuse})**
- **Fuselage Diameter (D_{fuse})**
- **Fineness Ratio $(L/D)_{fuse}$**

FUSELAGE outputs:
- **Fuselage Shape**
- **Fuselage Wetted Area (S_{fuse})**

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First Iteration

TAIL inputs: Wing Planform data
Historical HT and VT data
- Aspect Ratio
- Taper Ratio
- Leading Edge Sweep Angle
- Tail Volume Coefficient
- Tail MAC c/4 to Wing MAC c/4

TAIL outputs: HT Span and VT Height
Root Chord & Tip Chord
Trailing Edge Sweep Angle
MAC Length & Location (y_{MAC})
Tail Shapes

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	Units	Value
REQUIREMENTS		
Range	NM	
Number of Passengers	#	
Passenger Payload	lb	
PERFORMANCE CAPABILITIES		
Takeoff Distance: 100% fuel @ SL	ft	
Landing Distance: 20% fuel @ SL	ft	
Cruise Altitude & Speed	ft / Mach	
AIRCRAFT WEIGHTS		
Takeoff Gross Weight	lb	
Fuel Capacity	lb	
Operating Weight Empty	lb	
Structure Factor	--	
PROPULSION		
Maximum Thrust	lb	
Cruise TSFC	lb/lb-hr	
WING		
Wing Area	ft^2	
Wing Span	ft	
Aspect Ratio	--	
Root Chord & Tip Chord	ft	
Taper Ratio	--	
Leading & Trailing Edge Sweeps	degrees	
M.A.C. length & y_{MAC} location	ft	
FUNDAMENTAL PARAMETERS		
Takeoff T/W	--	
Takeoff W/S	lb/ft^2	

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TAIL DESIGN		Units	Horizontal Tail	Vertical Tail	Main Wing
Leading Edge Sweep Angle	Λ_{LE}	degrees			
Trailing Edge Sweep Angle	Λ_{TE}	degrees			
Quarter-Chord Sweep Angle	$\Lambda_{c/4}$	degrees			
Root Chord	c_r	ft			
Tip Chord	c_t	ft			
Span	b	ft		X	
Height	h	ft	X		X
Taper Ratio	λ	--			
Surface Area	S	ft^2			
Aspect Ratio	AR	--			
MAC length	MAC	ft			
y_{MAC} location	y_{MAC}	ft			
Distance from tail's c/4 of MAC to wing's c/4 of MAC	l_{HT}	ft		X	X
Distance from tail's c/4 of MAC to wing's c/4 of MAC	l_{VT}	ft	X		X
Horizontal Tail Volume Coefficient	C_{HT}	--		X	X
Vertical Tail Volume Coefficient	C_{VT}	--	X		X
FUSELAGE DESIGN		**Units**	**Value**		
Fineness Ratio	$(L/D)_{fuse}$	--		X	X
Fuselage Length	L_{fuse}	ft		X	X
Fuselage Diameter	D_{fuse}	ft		X	X

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Block 1 Schedule – Ingredient Data

Week	Day	Date	Topics	Homework Due
1	Tuesday	Jan 12	Introduction Atmosphere	
	Thursday	Jan 14	Physics of Flight Aircraft Terms	
2	Tuesday	Jan 19	Aerodynamics	Atmosphere Model Aircraft Dimensions
	Thursday	Jan 21	Propulsion Aircraft Weights	Aerodynamics
3	Tuesday	Jan 26	Material Review Homework Review	Propulsion Aircraft Weights
	Thursday	Jan 38	Exam #1	

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Aircraft Weights

Structure

wings	*fuselage*	*engine mounts*
tails	*landing gear*	*air induction*

+ Propulsion

engines	*fuel tanks*	*engine cooling*
exhaust	*starters*	*engine controls*

+ Equipment

hydraulics	*avionics*	*flight controls*
electrical	*pneumatics*	*APU*
instruments	*armament*	*air conditioning*

= Weight Empty

Aircraft Weights

Structure

wings	*fuselage*	*engine mounts*
tails	*landing gear*	*air induction*

+ Propulsion

engines	*fuel tanks*	*engine cooling*
exhaust	*starters*	*engine controls*

+ Equipment

hydraulics	*avionics*	*flight controls*
electrical	*pneumatics*	*APU*
instruments	*armament*	*air conditioning*

= Weight Empty

Aircraft Weights

Weight Empty

structure ***propulsion*** ***equipment***

+ Operating Items

crew	***unusable fuel***	***fixed items***
oxygen	***engine oil***	***crew baggage***

= Operating Weight

+ Payload

passengers	***cargo***	***bombs***
luggage		***missiles***

+ Fuel

= Takeoff Gross Weight

Aircraft Weights

Wing (W_{wing})

+ Horizontal Tail (W_{HT})

+ Vertical Tail (W_{VT})

+ Fuselage (W_{fuse})

+ Main Landing Gear (W_{MLG})

+ Nose Landing Gear (W_{NLG})

+ Installed Engines (W_{eng})

+ Equipment + Operating Items (W_{equip})

= Operating Weight

Approximate Group Weights Method

Wing (W_{wing})	**$10 * S$**
+ Horizontal Tail (W_{HT})	**$5.5 * S_{HT}$**
+ Vertical Tail (W_{VT})	**$5.5 * S_{VT}$**
+ Fuselage (W_{fuse})	**$5 * S_{fuse}$**
+ Main Landing Gear (W_{MLG})	**$0.85 * 0.043 * W_{TO}$**
+ Nose Landing Gear (W_{NLG})	**$0.15 * 0.043 * W_{TO}$**
+ Installed Engines (W_{eng})	**$1.3 * W_{eng}$**
+ Equipment + Op Items (W_{equip})	**$0.17 * W_{TO}$**
= Operating Weight	

Statistical Group Weights Method

Wing (W_{wing})
+ Horizontal Tail (W_{HT})
+ Vertical Tail (W_{VT})
+ Fuselage (W_{fuse})
+ Main Landing Gear (W_{MLG})
+ Nose Landing Gear (W_{NLG})
+ Installed Engines (W_{eng})
+ Equipment + Operating Items (W_{equip})
= Operating Weight

Empirical equations based on dimensions (tailored for airliners)

Factors

Wing Weight

$$\mathbf{W_{wing} = 0.0051\,(n_z W_{TO})^{0.557}(S)^{0.649}(A)^{0.5}}$$
$$\mathbf{(t/c)^{-0.4}(1+\lambda)^{0.1}\left(\cos\Lambda_{c/4}\right)^{-1.0}(S_f)^{0.1}}$$

n_z	Design Load Factor (n_z = 3.5 g's)
W_{TO}	Maximum Takeoff Gross Weight
S	Wing Area
A	Wing Aspect Ratio
t/c	Wing Maximum Thickness Ratio
λ	Wing Taper Ratio
$\Lambda_{c/4}$	Wing Quarter-Chord Sweep Angle
S_f/S	Flapped Wing Area Ratio (= 0.60 for airliners)

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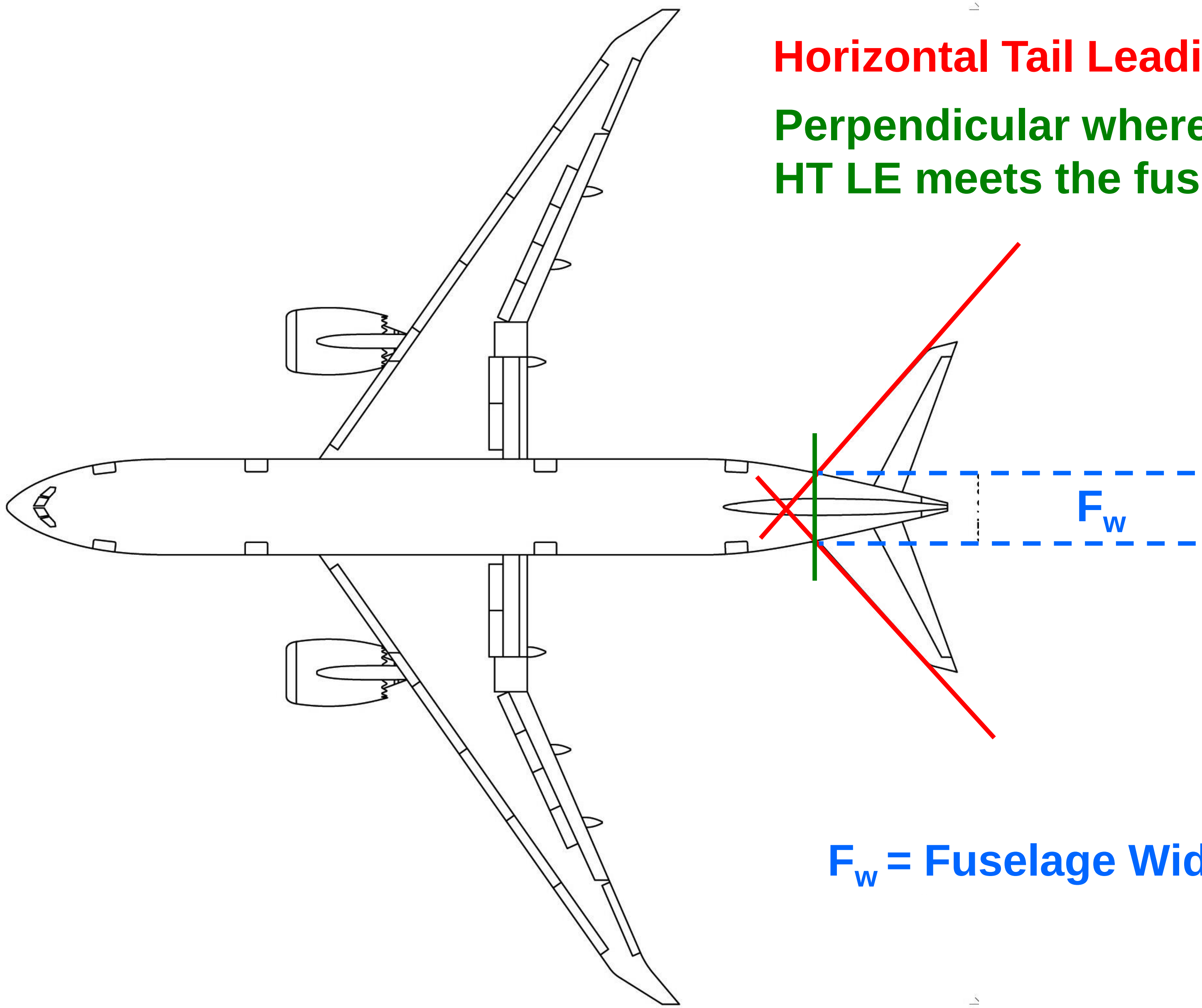
Horizontal Tail Weight

$$W_{HT} = 0.0379\,(1 + F_w/b_{HT})^{-0.25}(n_z)^{0.1}(W_{TO})^{0.639}(S_{HT})^{0.75}(l_{HT})^{-1.0}\,(K_y)^{0.704}\left(\cos\Lambda_{HT\ c/4}\right)^{-1.0}(A_{HT})^{0.166}$$

F_w	Fuselage Width at the HT's Intersection (next slide)
b_{HT}	Horizontal Tail Span
n_z	Design Load Factor (n_z = 3.5 g's)
W_{TO}	Maximum Takeoff Gross Weight
S_{HT}	Horizontal Tail Area
l_{HT}	Distance between Wing MAC c/4 to HT MAC c/4
K_y	Pitching Radius of Gyration (= 0.3 l_{HT})
$\Lambda_{HT\ c/4}$	Horizontal Tail Quarter-Chord Sweep Angle
A_{HT}	Horizontal Tail Aspect Ratio

Horizontal Tail Weight



Vertical Tail Weight

$$\mathbf{W_{VT} = 0.0026\,(1 + H_{HT}/H_{VT})^{0.225}(n_z)^{0.536}(W_{TO})^{0.556}\,(S_{VT})^{0.5}\,(l_{VT})^{0.5}\,(K_z)^{0.875}\left(\cos\Lambda_{VT\ c/4}\right)^{-1.0}(A_{VT})^{0.35}\left({}^{t}/_{c}\right)^{-0.5}}$$

H_{HT}/H_{VT}	Location of HT (= 0 for Conv Tail; = 1 for T-Tail)
n_z	Design Load Factor (n_z = 3.5 g's)
W_{TO}	Maximum Takeoff Gross Weight
S_{VT}	Vertical Tail Area
l_{VT}	Distance from Wing MAC c/4 to VT MAC c/4
K_z	Yawing Radius of Gyration (= l_{HT})
$\Lambda_{VT\ c/4}$	Vertical Tail Quarter-Chord Sweep Angle
A_{VT}	Vertical Tail Aspect Ratio
t/c	Vertical Tail Maximum Thickness Ratio

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Fuselage Weight

$$\mathbf{W_{fuse} = 0.3280\ K_{door}\ K_{lg}\ (n_z W_{TO})^{0.5} (L_{fuse})^{0.25}\ (S_{wet-fuse})^{0.302}\ (1 + K_{ws})^{0.04} (L_{fuse}/D_{fuse})^{0.10}}$$

K_{door}	= 1.00 for no cargo door; = 1.06 for one cargo door = 1.12 for two cargo doors
K_{lg}	= 1.00 for wing-mounted landing gear = 1.12 for fuselage-mounted landing gear
n_z	Design Load Factor (n_z = 3.5 g's)
W_{TO}	Maximum Takeoff Gross Weight
L_{fuse}	Fuselage Length
$S_{wet-fuse}$	Fuselage Wetted Area (from FUSELAGE.XLS)
K_{ws}	$= 0.75\ [(1 + 2\lambda)/(1 + \lambda)]\ (b_{wing} \tan(\Lambda_{wing\ c/4}) / L)$
$(L/D)_{fuse}$	Fuselage Fineness Ratio

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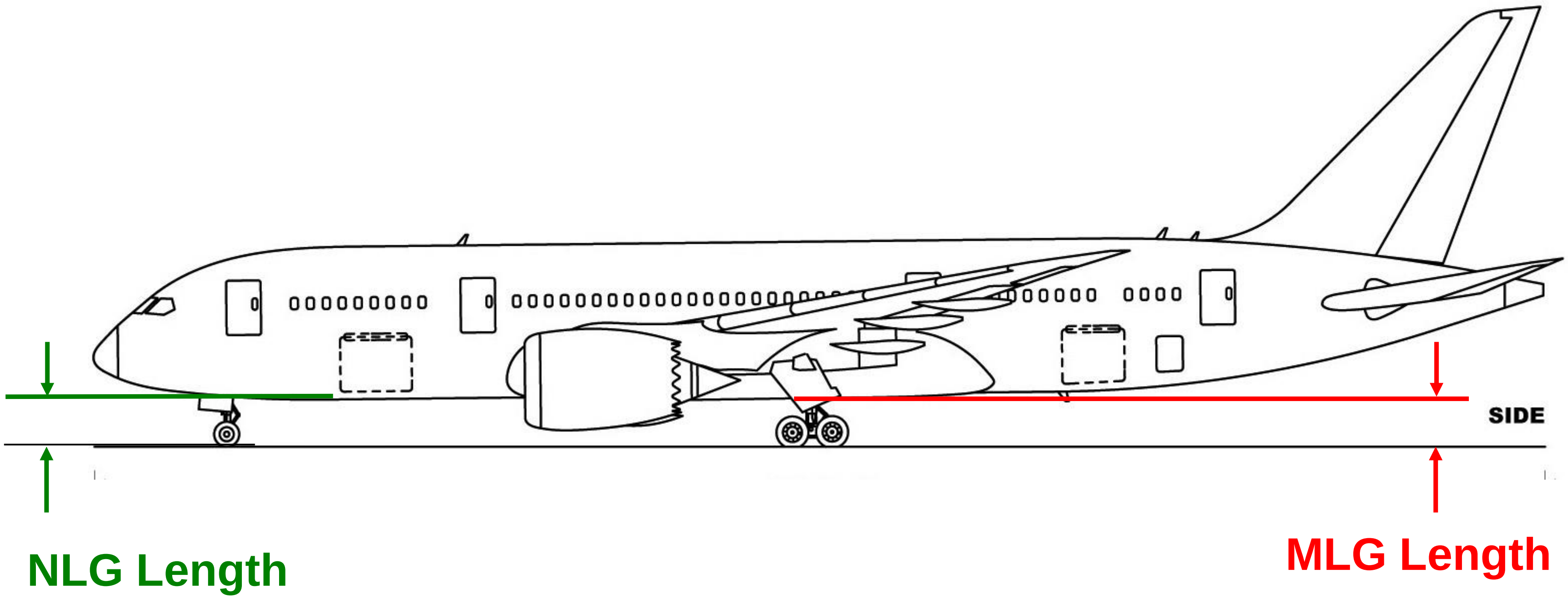
Main Landing Gear Weight

$$\mathbf{W_{MLG} = 0.0106\,(n_z)^{0.25}(W_{LND})^{0.888}\,(L_{MLG})^{0.4}\,(N_{mw})^{0.321}(N_{mss})^{-0.5}\,(V_{stall})^{0.1}}$$

n_z	Design Load Factor (n_z = 3.5 g's)
W_{LND}	Maximum Landing Gross Weight (= TOGW – 50% fuel)
L_{MLG}	Main Landing Gear Length (on next slide)
N_{mw}	Number of MLG Wheels
N_{mss}	Number of MLG Struts
V_{stall}	Stall Speed in Landing Configuration

Landing Gear Weight



Nose Landing Gear Weight

$$\mathbf{W_{NLG} = 0.0320\,(n_z)^{0.2}(W_{LND})^{0.646}\,(L_{NLG})^{0.4}\,(N_{nw})^{0.45}}$$

n_z	**Design Load Factor (n_z = 3.5 g's)**
W_{LND}	**Maximum Landing Gross Weight (= TOGW – 50% fuel)**
L_{NLG}	**Nose Landing Gear Length (on previous slide)**
N_{nw}	**Number of NLG Wheels**

Propulsion System Weight

$$\boxed{\mathbf{W_{prop} = 1.30\ x\ Weng}}$$

Engine Weight (W_{eng}) = Uninstalled Engine Weight x Number of Engines

Equipment Systems Weight

$$\boxed{\mathbf{W_{equip} = 0.17\ x\ Maximum\ Takeoff\ Gross\ Weight}}$$

Aircraft Weights

Wing (W_{wing})

+ Horizontal Tail (W_{HT})

+ Vertical Tail (W_{VT})

+ Fuselage (W_{fuse})

+ Main Landing Gear (W_{MLG})

+ Nose Landing Gear (W_{NLG})

+ Installed Engines (W_{eng})

+ Equipment + Operating Items (W_{equip})

= Operating Weight

Aircraft Wetted Area

Wing ($S_{wet-wing}$)

\+ Horizontal Tail (S_{wet-HT})

\+ Vertical Tail (S_{wet-VT})

\+ Fuselage ($S_{wet-fuse}$)

\+ Installed Engines ($S_{wet-eng}$)

= Aircraft Wetted Area (S_{wet})

Aero Surfaces: $S_{wet} = S\left(1.977 + 0.52 * {}^{t}/_{c}\right)$ $\quad {}^{t}/_{c} \cong 0.120$

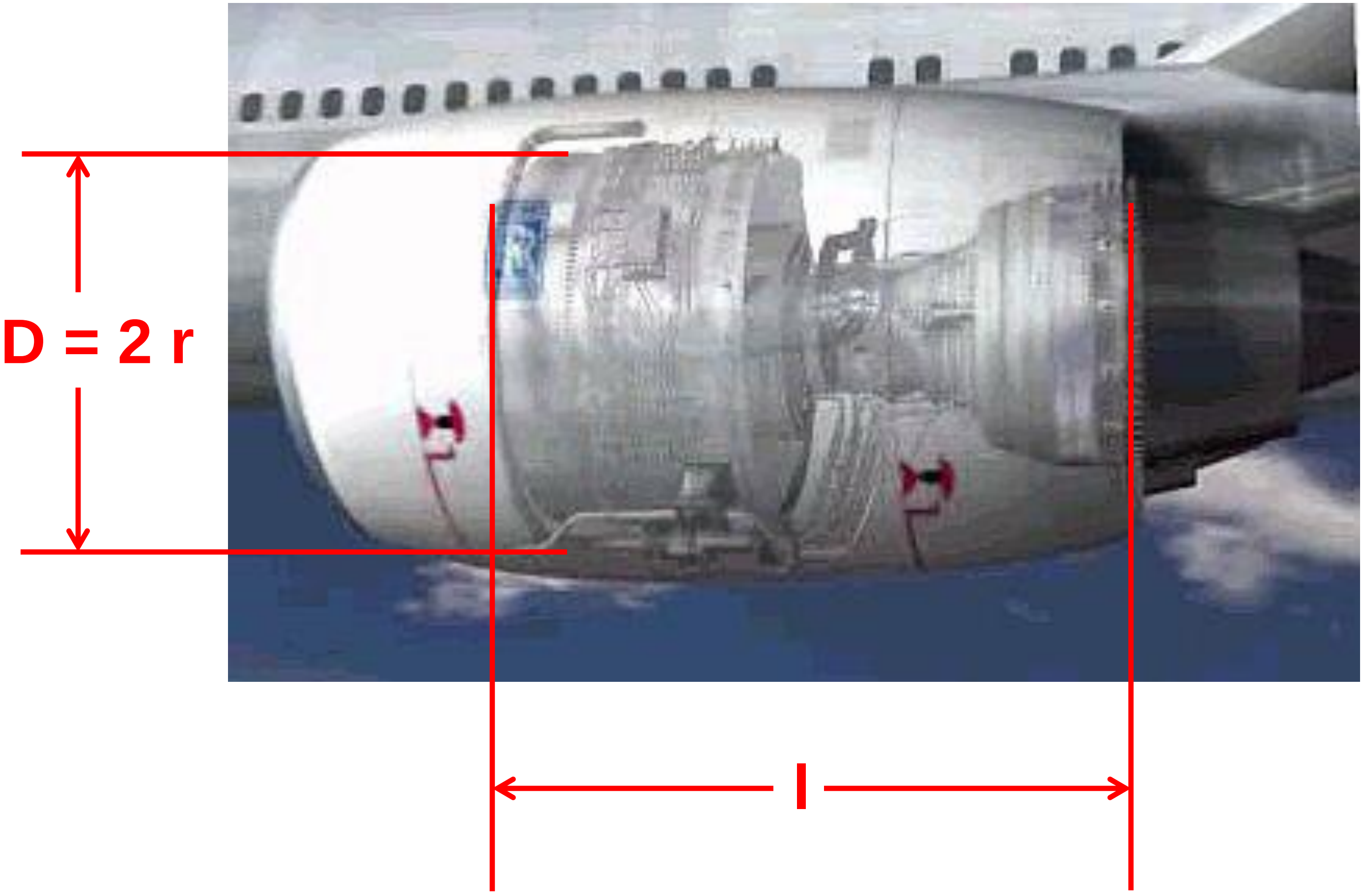
Fuselage: S_{wet} is calculated in FUSELAGE.XLS

Installed Engines: $S_{wet} = 2\,\pi\,r\,l$ (wetted area of a cylinder)

➡ calculate S_{wet} / S_{ref}

Aircraft Wetted Area

Installed Engines: $S_{\mathrm{wet}} = 2\,\pi\,\mathrm{r}\,\mathrm{l}$ **(wetted area of a cylinder)**



Factors:
1.25 * D
1.50 * l
1.30

Aircraft Drag

Wing ($C_{D0\text{-wing}}$)

\+ Horizontal Tail ($C_{D0\text{-HT}}$)

\+ Vertical Tail ($C_{D0\text{-VT}}$)

\+ Fuselage ($C_{D0\text{-fuse}}$)

\+ Installed Engines (bookkept in engine data)

= Aircraft Wetted Area (C_{D0})

Aero Surfaces: WING.XLS and TAIL.XLS

Fuselage: FUSELAGE.XLS

calculate $C_D = C_{D0} + k\, C_L^2$

Homework Assignments

HW #25 – Second Iteration
(due by 11:59 pm ET on Monday, April 12)
Submit Word file and Excel file

<u>HW Help Sessions</u>
Thursday 2:00 – 3:20 pm ET (class time)
Monday 1:00 – 2:00 pm ET

Posted to Canvas:
HW #25 assignment with instructions, tips, and checklist (Word file)
Excel file ITERATION2.XLS

Questions?