Aircraft Weights

Aircraft Weights & CG

Why do we worry about the weight of the aircraft?

Sizes the aircraft landing gear

Runway restrictions

Heavier weight = less performance capability

- **Longer takeoff distance**
- **Less rate of climb**
- **Less cruise efficiency**
- **Lower maneuver capability**
- **Higher approach speeds**

Weight ≅ Acquisition Cost

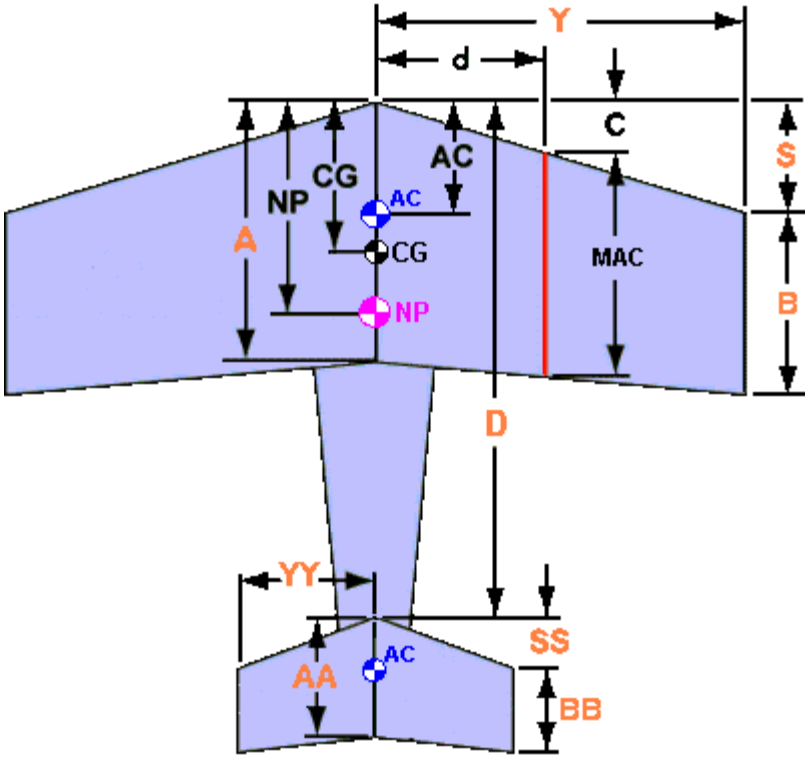
Aircraft Weights & CG

Why do we worry about the aircraft's center of gravity?

The CG needs to be the right range for stable flight

Want the CG near the wing's aerodynamic center

Want the CG in front of the Neutral Point



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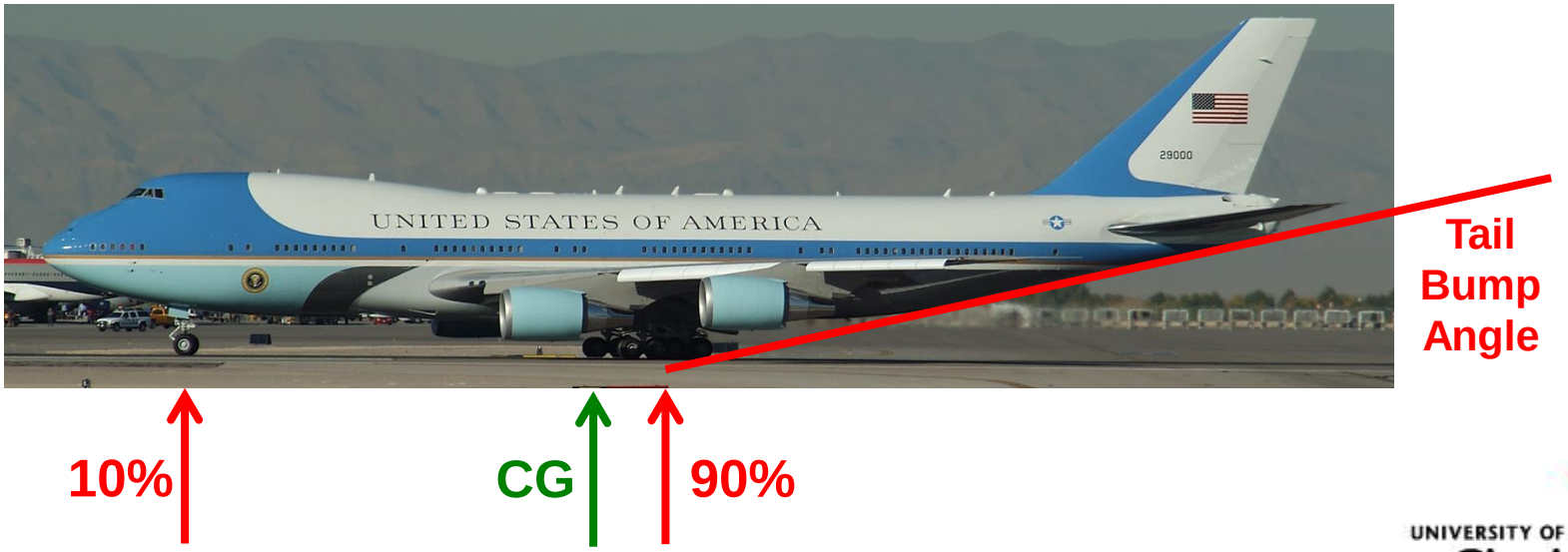
Aircraft Weights & CG

Why do we worry about the aircraft's center of gravity?

The CG needs to be the right range on the ground

- **Want the CG between the nose & main landing gear**
- **Want the CG just in front of the main landing gear**
- **Weight on nose gear ≅ 10% to 15%**
- **Weight on main landing gear ≅ 90% to 85%**



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Aircraft Weights & CG

Why do we worry about the aircraft's center of gravity?

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Aircraft Weights & CG

Society of Allied Weight Engineers

Aircraft weight and balance
Mass properties management
Weight estimating
Weight control

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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

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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

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Aircraft Weights

Takeoff Gross Weight

- Expended Payload
(bombs, missiles, paratroopers, cargo drop)

- Mission Fuel Used

= Landing Weight (including reserve fuel)

Aircraft Weights

Takeoff Gross Weight (TOGW)

Usable Fuel

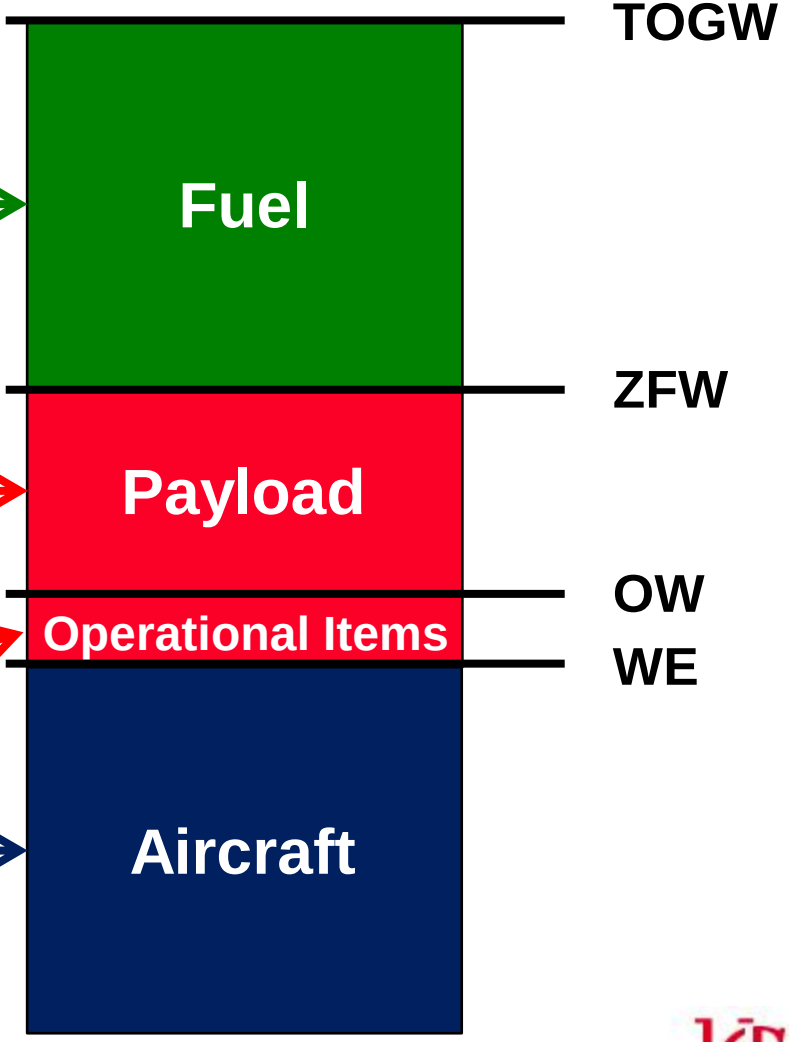
Zero Fuel Weight (ZFW)

Payload – includes stores, bombs, missiles, and other expendables

Operating Weight (OW)

Operational Items– includes unusable fuel, engine oil, crew, suspension equipment

Weight Empty – the weight of the aircraft including structure, propulsion, flight controls, avionics, subsystems, etc



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Aircraft Weights

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

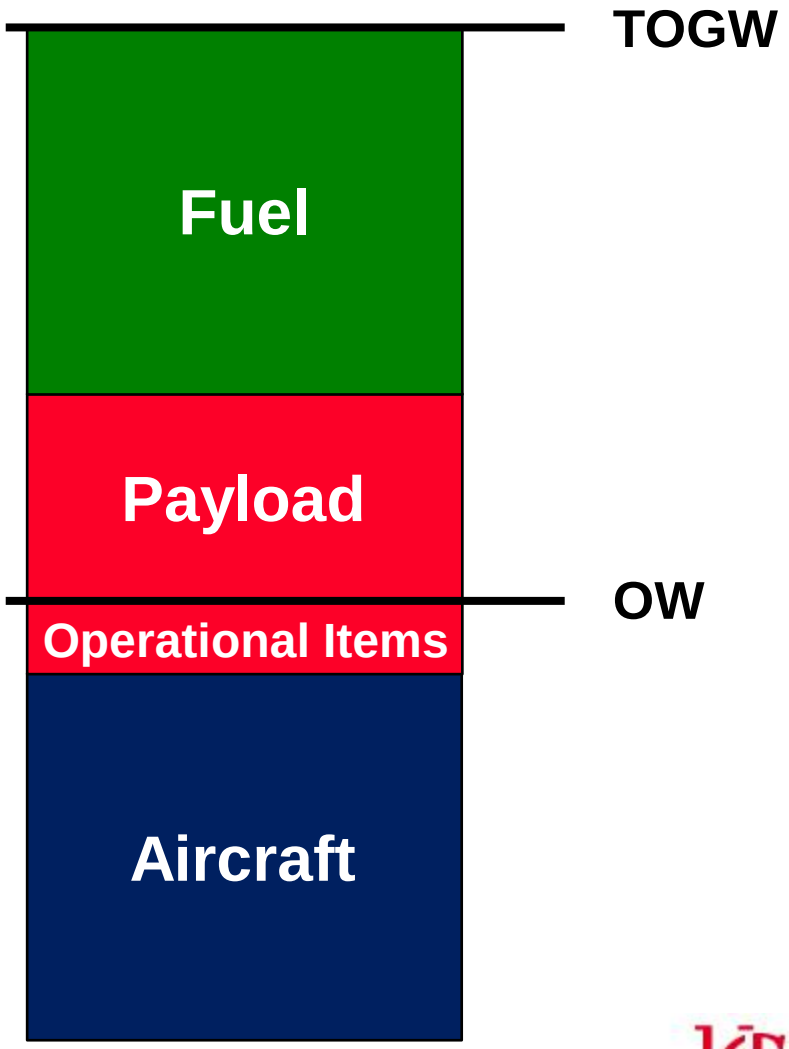
Maximum Fuel – full capacity
Mission Fuel – specific mission capability

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

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

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

Aircraft Weights

Example – 777-200ER

Operating Weight Empty	**304,500 lbs**	
Maximum Fuel Capacity	**303,000 lbs**	
Maximum Payload	**96,000 lbs**	**(400 passengers)**
Maximum TOGW	**656,000 lbs**	

1 passenger = 180 lbs + 60 lbs of baggage

How many passengers can the 777-200ER carry if it carries all of its fuel capacity?

How much fuel can the 777-200ER carry if it is a full flight with 400 passengers? How much fuel would it need to offload to not exceed its Maximum TOGW?

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Aircraft Weights

1st Example – 777-200ER

Operating Weight Empty	**304,500 lbs**	
Maximum Fuel Capacity	**303,000 lbs**	
Maximum Payload	**96,000 lbs**	**(400 passengers)**
Maximum TOGW	**656,000 lbs**	

1 passenger = 180 lbs + 60 lbs of baggage

Full Fuel: **656,000 Maximum TOGW**
- 304,500 Operating Weight
- 303,000 Maximum Fuel
= 48,500 for passengers + baggage
➡ 48,500 / 240 = 202 passengers

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Aircraft Weights

2nd Example – 777-200ER

Operating Weight Empty	**304,500 lbs**	
Maximum Fuel Capacity	**303,000 lbs**	
Maximum Payload	**96,000 lbs**	**(400 passengers)**
Maximum TOGW	**656,000 lbs**	

1 passenger = 180 lbs + 60 lbs of baggage

Full Flight: **656,000 Maximum TOGW**
- 304,500 Operating Weight
- 96,000 400 passengers
= 255,500 Fuel Quantity
303,000 – 255,500 = 47,500 lbs offloaded

Convention: all weight values are positive numbers

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Aircraft Weights

2nd Example – 777-200ER

Crew Weight	-	Crew Weight	-
Payload Weight	96,000	Payload Fraction	14.6%
Fuel Weight	255,500	Fuel Fraction	38.9%
Empty Weight	304,500	Empty Weight Fraction	46.4%
Sum	656,000	Formula	100.0%

2017 UC Aerocats

Crew Weight	-	Crew Weight	-
Payload Weight	37	Payload Fraction	69.8%
Fuel Weight	-	Fuel Fraction	0.0%
Empty Weight	16	Empty Weight Fraction	30.2%
Sum	53	Formula	100.0%

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Aircraft Weights

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

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

A check of the math ...

Crew Weight	-	Crew Weight	-
Payload Weight	48,500	Payload Weight	48,500
Fuel Weight	303,000	Fuel Fraction	0.461890
Empty Weight	304,500	Empty Weight Fraction	0.464177
Sum	656,000	Formula	656,000

Crew Weight	-	Crew Weight	-
Payload Weight	96,000	Payload Weight	96,000
Fuel Weight	255,500	Fuel Fraction	0.389482
Empty Weight	304,500	Empty Weight Fraction	0.464177
Sum	656,000	Formula	656,000

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Review of Center of Gravity Definitions

Weight and Balance – the process to ensure that the aircraft is within the allowable weight limits and center of gravity limits for safe flight

Center of gravity limits – specified longitudinal and lateral boundaries that the center of gravity must be located within during taxi and flight (CG range)

Ballast – removable weight specifically used to bring the center of gravity into the allowable range

Review of Center of Gravity Definitions

Reference datum – the reference plane that allows accurate and uniform measurements to any point on the aircraft

Moment arm – the chordwise distance from the datum to any point on the aircraft

Moment – the measure of force that results from an object's weight acting at a distance from the datum

Mean Aerodynamic Chord (MAC) – weighted average chord calculated by:

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

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

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Homework Assignment

HW #5 – Aircraft Weights
(due by 11:59 pm ET on Monday)

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

<u>Posted on Canvas</u>
HW #5 Assignment with instructions, tips, and checklist
HW #5 Template for data table in Excel

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Questions?