Performance

1. Power, thrust
2. Loading
3. Endurance

6A: Aircraft performance

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In this lecture you will learn:

- Aircraft performance and efficiency

Power consumption in flight

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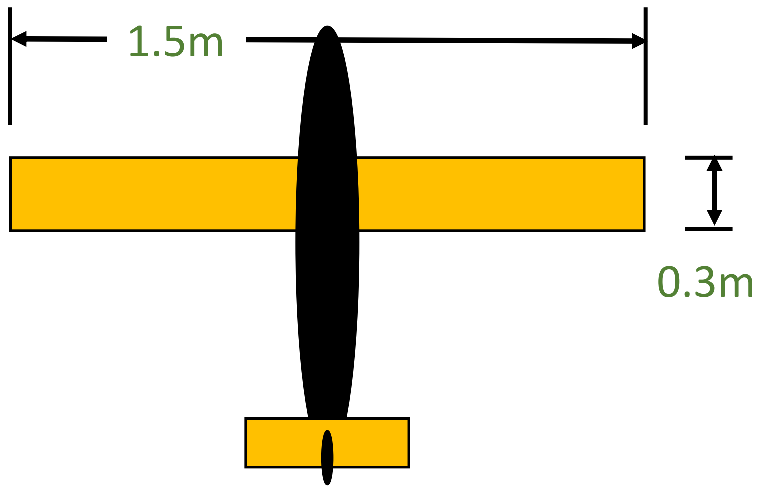
- The power that is consumed by the drone is a direct function of the **drag force** and **speed** of the aircraft
  - The normal definition for power is $P = Force\ x\ Velocity$
- In our case, this force is *thrust* from the motor, and is equal to the *drag force D*
- For example, if the drag on an aircraft is 4.85N and it is flying at 20m/s, the power consumed is:

$$P = D\ x\ V = 4.85N\ x\ 20\frac{m}{s} = 97\frac{Nm}{s} = \mathbf{97W}$$

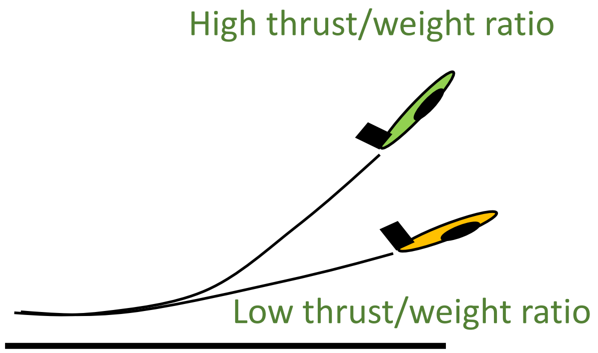
- Note that this is an *ideal* calculation of power required – in reality, all systems are less than 100% efficient and so an efficiency factor should be used to compute the actual power consumption by the system

We will discuss more about power systems tomorrow



Thrust/weight ratio

- Another useful parameter is the thrust (T) / weight (W) ratio
- The T/W ratio gives an understanding of what performance we may expect from the aircraft
  - A high T/W ratio means the aircraft will climb quickly
  - The penalty is a heavier motor and perhaps more motor drag in cruise that would reduce the range of the aircraft
  - A larger motor may also consume more power in cruise than a smaller motor designed for the cruise power settings it requires



The takeoff performance is directly affected by the T/W ratio

Thrust/weight ratio

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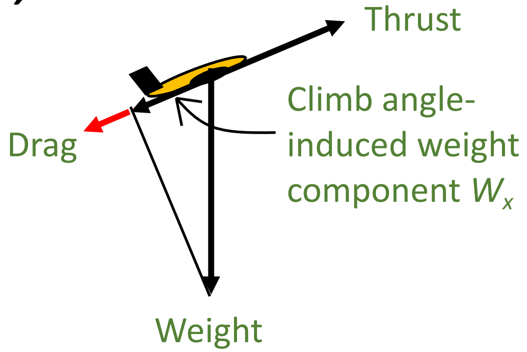
- Using the geometry shown for the climbing aircraft:

$$T = D + W sin\theta$$

$$\theta = sin^{-1}\left(\frac{T-D}{W}\right)$$

- Assuming an aircraft has a weight of 10*N*, a thrust of 8*N* and a drag force of 2*N*, determine the angle of climb:

$$\theta = sin^{-1}\left(\frac{8-2}{10}\right) = 37^o$$



Climb angle illustrated

Power/weight ratio

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- Another valuable metric to use in evaluating aircraft design is the power/weight ratio
  - Power/weight is a common metric to evaluate the aerodynamic efficiency of the aircraft
  - Metrics used in the general classes of fixed wing and VTOL are useful for comparing performances in those categories

EcoSoar power/weight

$$Wt = 1.25\ kg$$
$$P = 40\ W$$
$$\frac{P}{Wt} = \frac{40}{1250} = 0.032\, {}^{W}/_{g}$$

DJI Mavic Pro

$$Wt = 740\ g$$
$$P = 109\ W$$
$$\frac{P}{Wt} = \frac{109}{740} = 0.147\, {}^{W}/_{g}$$

Power/weight ratio

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- The power to fly EcoSoar at cruise speed is **30%** of the power to operate the Mavic 2
- This is typical: fixed wing aircraft are much more efficient that VTOL / rotary wing aircraft which is why their endurance is much longer
- We will look at how VTOL aircraft operate next…

$$\frac{P}{Wt} = 0.032\, {}^{W}/_{g}$$

$$\frac{P}{Wt} = 0.108\, {}^{W}/_{g}$$

Flight performance, planning and loading

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- All flights must comply with the laws of physics!
- The following rules should be followed to launch a successful mission:
    1. Loading of the aircraft should not exceed the design limits as the performance is directly related to the weight carried
    2. In mission planning, it is important to validate the aircraft will have adequate range and endurance to complete the mission
    3. Environmental conditions directly affect aircraft performance and must be evaluated carefully

VTOL aircraft loading

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- Weight has a direct impact on aircraft performance, and keeping the payload loading of the aircraft within its design limits is critical to safe flight performance
- Payload **weight that changes** during flight, such as **sprayer payloads**, need to consider both aircraft weight and balance during the mission
- Balance of the aircraft is just as important as the weight - **the flight control system assumes that the center of gravity is near the center of the airframe**
  - Any exceedances of center of gravity position can result in an inability of the flight controller to maintain stable flight

Aircraft loading considerations: density altitude

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- Density altitude is a strong factor in aircraft performance and is always determined and used in the flight planning process
- The density altitude is an effective altitude for a “standard day” (T = 20°C, P = 1.01E^5 N/m^2) and the actual atmospheric conditions which include altitude, humidity and temperature
- Density altitude is calculated using the ideal gas equation to find a corrected density due to the measured temperature: $\rho = \frac{p}{RT}$

Aircraft loading considerations: density altitude

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- When flying in hot conditions (above standard temperature), the density altitude can be much higher than the actual altitude
- Since lift is a direct function of air density, a **decrease in density** will result in a **decrease in lift**
  - This will reduce the payload you are able to carry on the aircraft
- In addition to reducing lift that is generated by the wings or propeller, internal combustion engines will also suffer a power loss as the air density decreases

Aircraft loading considerations: density altitude

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- Compute the density altitude in Lilongwe on a 35°C day:

  Altitude = **1100m**

  Standard day pressure = ***p* = 8.879E^4 *N/m^2***

  $$\rho = \frac{p}{RT} = \frac{8.879x10^4}{287\ (308.15K)} = 1.004\ kg/m^3$$

- Looking up this density in the standard day atmospheric charts shows that the corresponding altitude would be ***h = 2000m***
- Therefore, the aircraft thinks it is flying at a much higher altitude due to this much higher temperature

Aircraft loading considerations: density altitude

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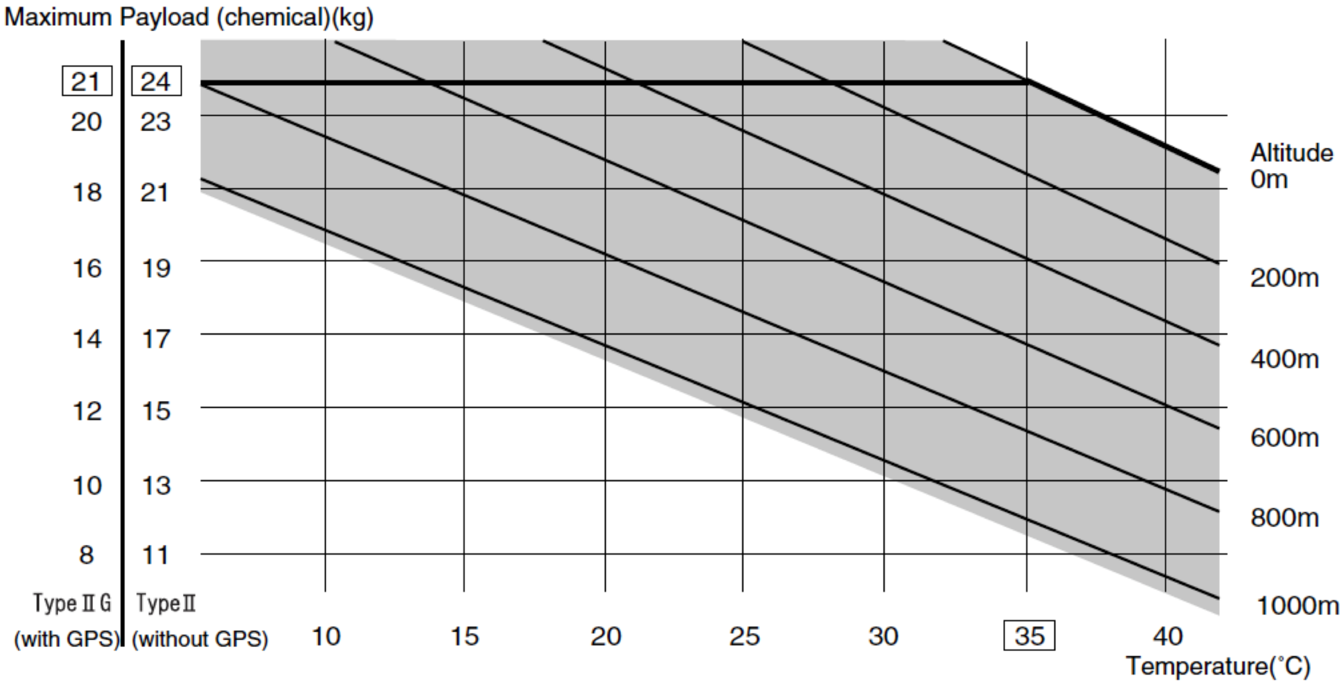
- Some aircraft manufacturers will specify payload loading as a function of altitude and temperature
- The chart shown for the Yamaha RMAX is typical of a density altitude loading chart that will guide the operator to safe loading of the aircraft
- If a chart does not exist, then approximate effects of density altitude can be determined by assuming looking at the prop thrust equation…



Aircraft loading considerations: density altitude

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- Propeller thrust, like lift and drag, can be described by a non-dimensional thrust coefficient: $T = C_T \rho n^2 d^4$

Here, C_T is the thrust coefficient
ρ is the air density, n is the rotational speed in cycles/sec, and d is the propeller diameter

- Since the thrust is directly proportional to air density, it is obvious that if the **air density decreases by 10%**, then the **thrust or lifting capacity of the aircraft will also decrease by 10%**

Validate that the aircraft has necessary range and endurance

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- As part of the flight planning activity, the aircraft range and time aloft should be estimated so that it is reasonably assured the aircraft will be able to complete its mission
- Time aloft estimate: based on the mission plan estimate of completion time for the mission
  - Note that the flight plan may not account for takeoff and landing that should be factored into an overall endurance estimate
- An accurate aircraft endurance estimate is based on past experience
  - If the temperature is significantly different, then that will either add or subtract to the endurance estimate

Validate that the aircraft has necessary range and endurance

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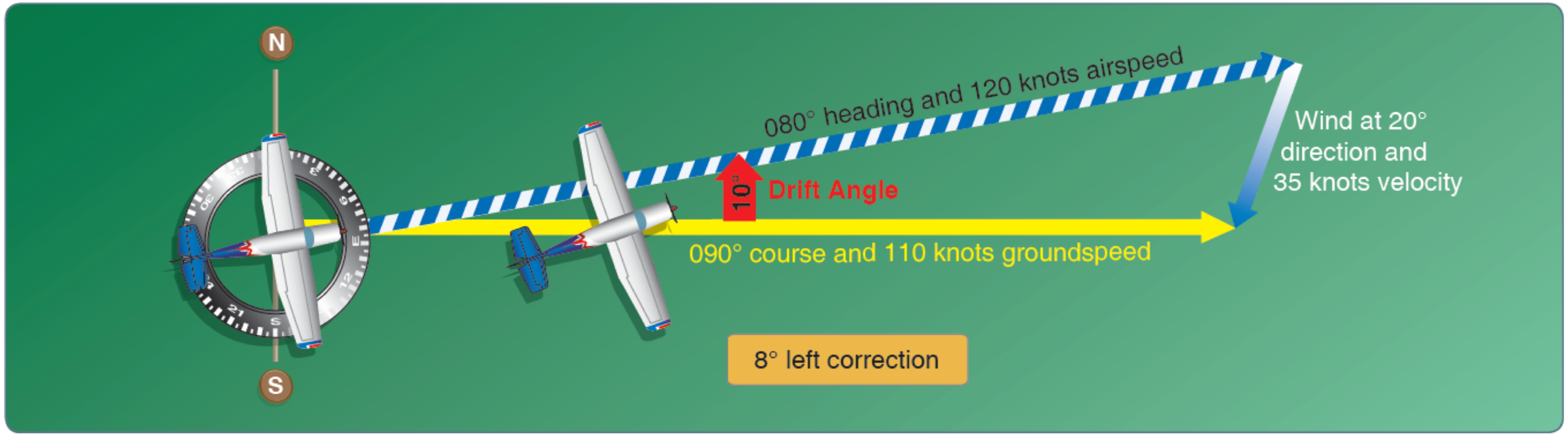
- With fixed wing aircraft that are traveling at a much higher speed at higher altitude, it is advisable to consider the winds aloft when determining how long the flight will take



An effective groundspeed is determined once a wind triangle has been drawn to find the drift component and the compensating flight heading to maintain course

Computing the crosstrack correction and groundspeed will provide accurate mission times to determine feasibility

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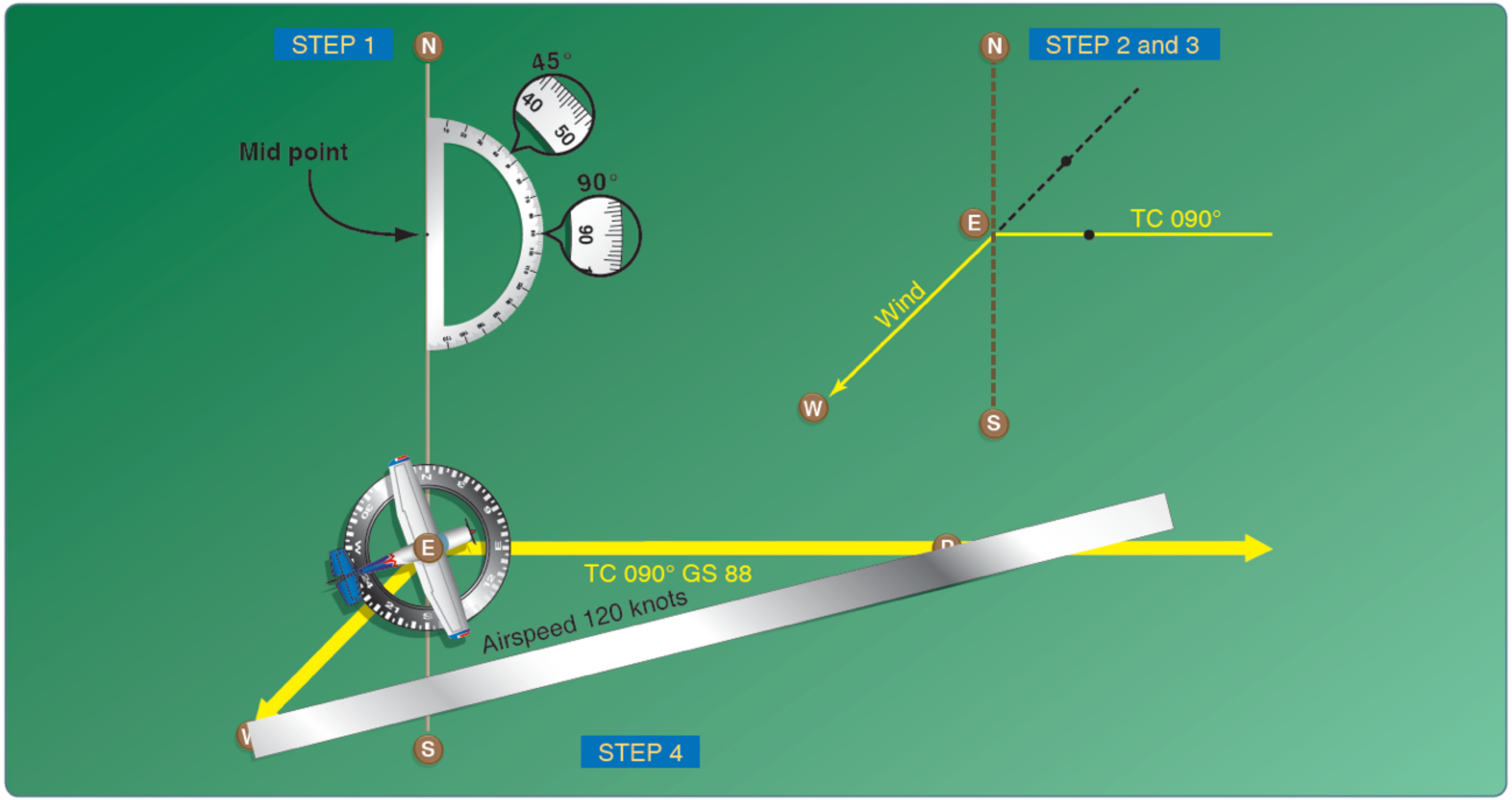

To determine aircraft groundspeed, plot the wind vector and the aircraft vector to find the flight heading + groundspeed over the desired track. Check endurance with battery capacity