CPL Theory
Aircraft Systems (CSYA)

CSYA 6 – Propellers & Constant Speed Units

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3. Disclaimer

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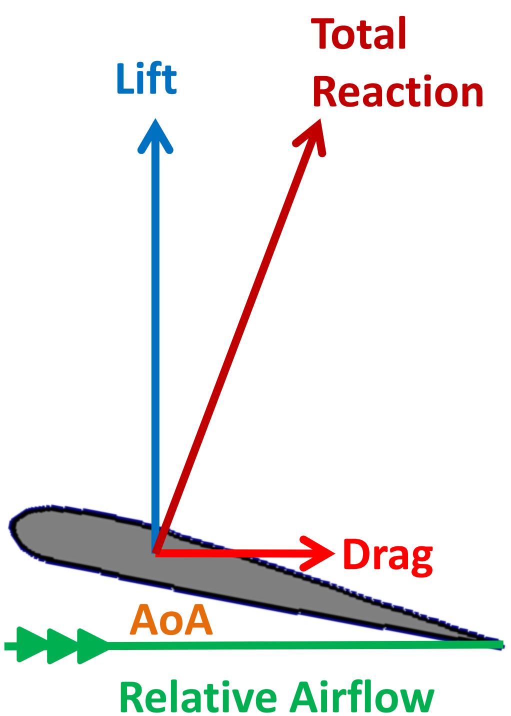
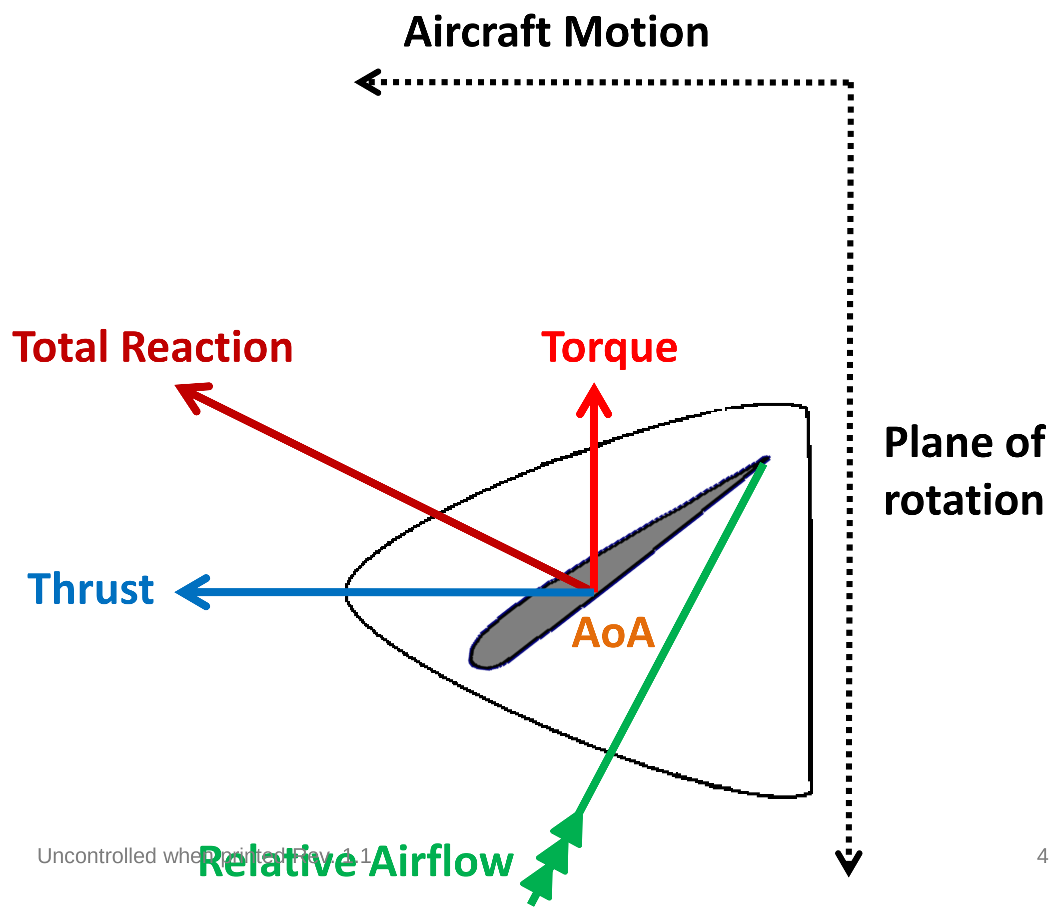
PROPELLER FORCES

Propeller Forces

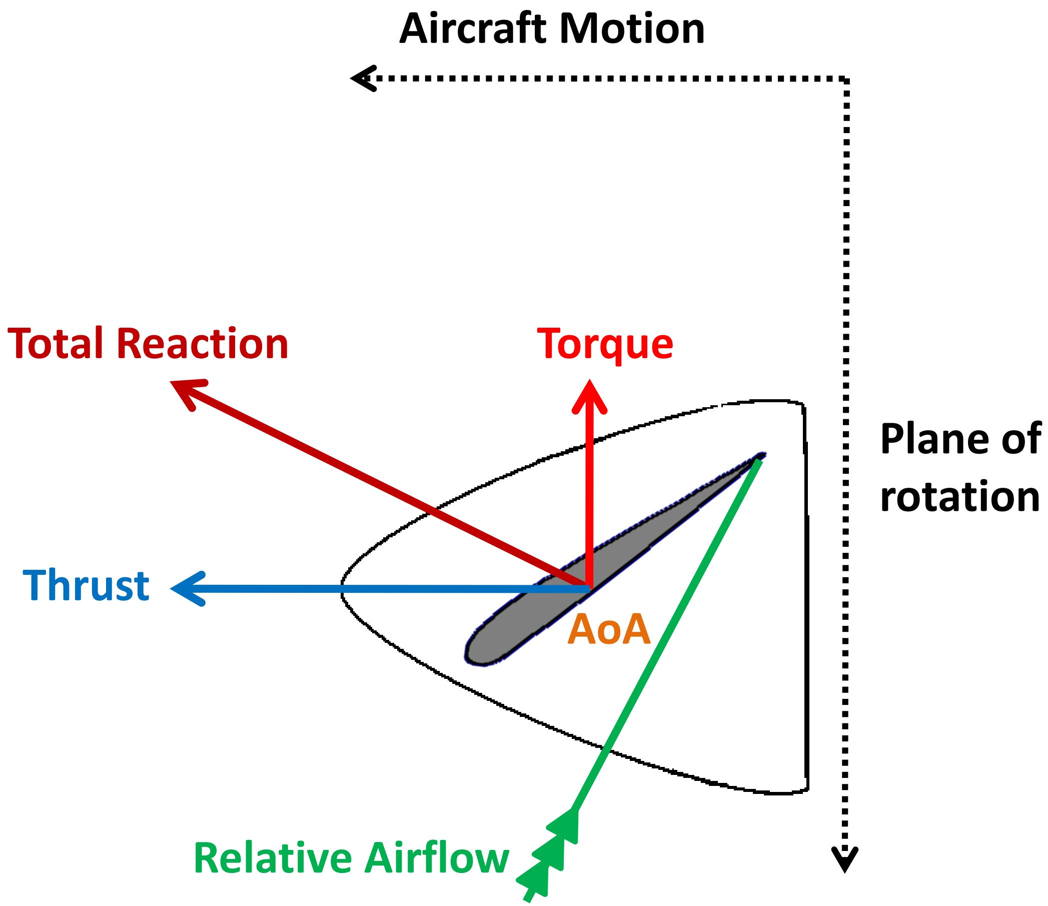
- A propeller blade is essentially a rotating wing
- Just like a wing, it is a cambered aerofoil which is presented to the relative airflow at an angle of attack





Propeller Forces

- **Thrust** acts parallel to the propeller shaft and provides the force required to overcome total drag in flight
- **Propeller Torque** is the resistance to motion in the plane of rotation (tries to stop the blades rotating)
- **Engine Torque** overcomes Propeller Torque and allows the blades to continue to rotate
- When Engine Torque = Propeller Torque, a **constant RPM** is maintained



DEFINITIONS AND TERMS

Definitions and Terms

Blade
An aerofoil which converts engine power into thrust

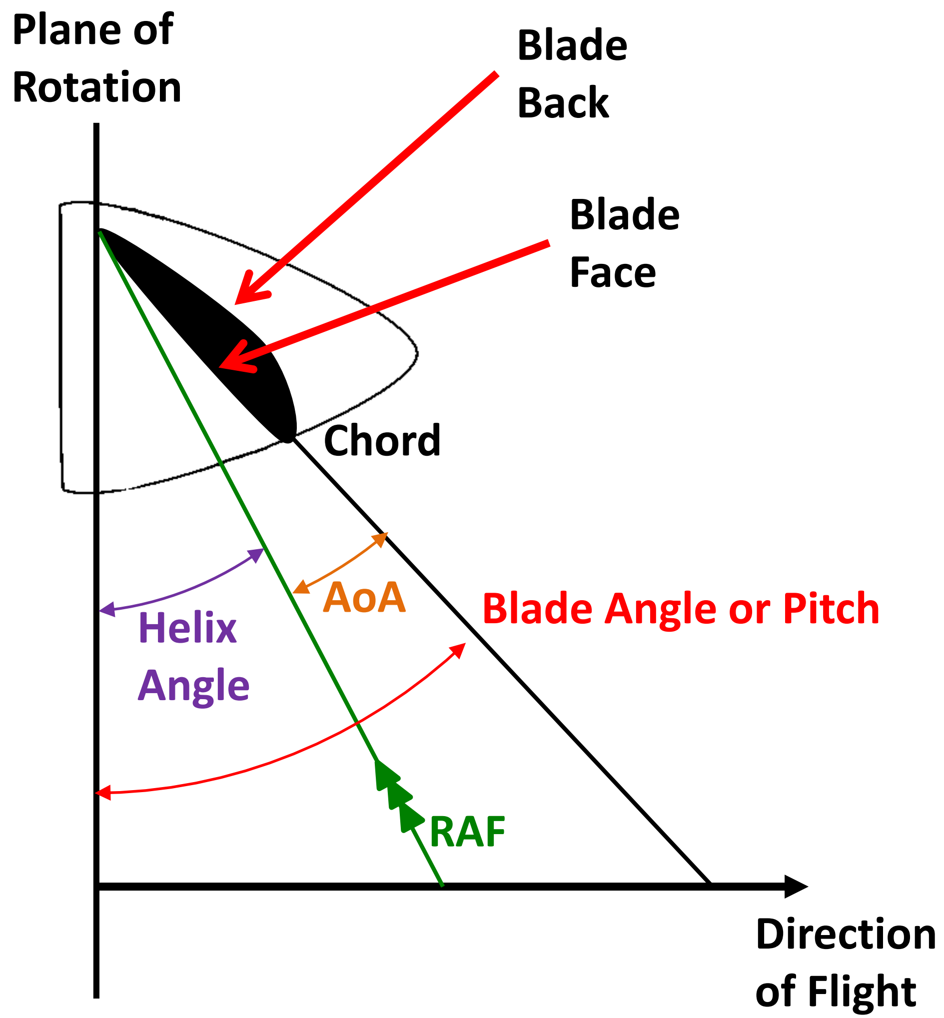
Blade Back
The cambered side of the blade

Blade Face
The flat side of the blade

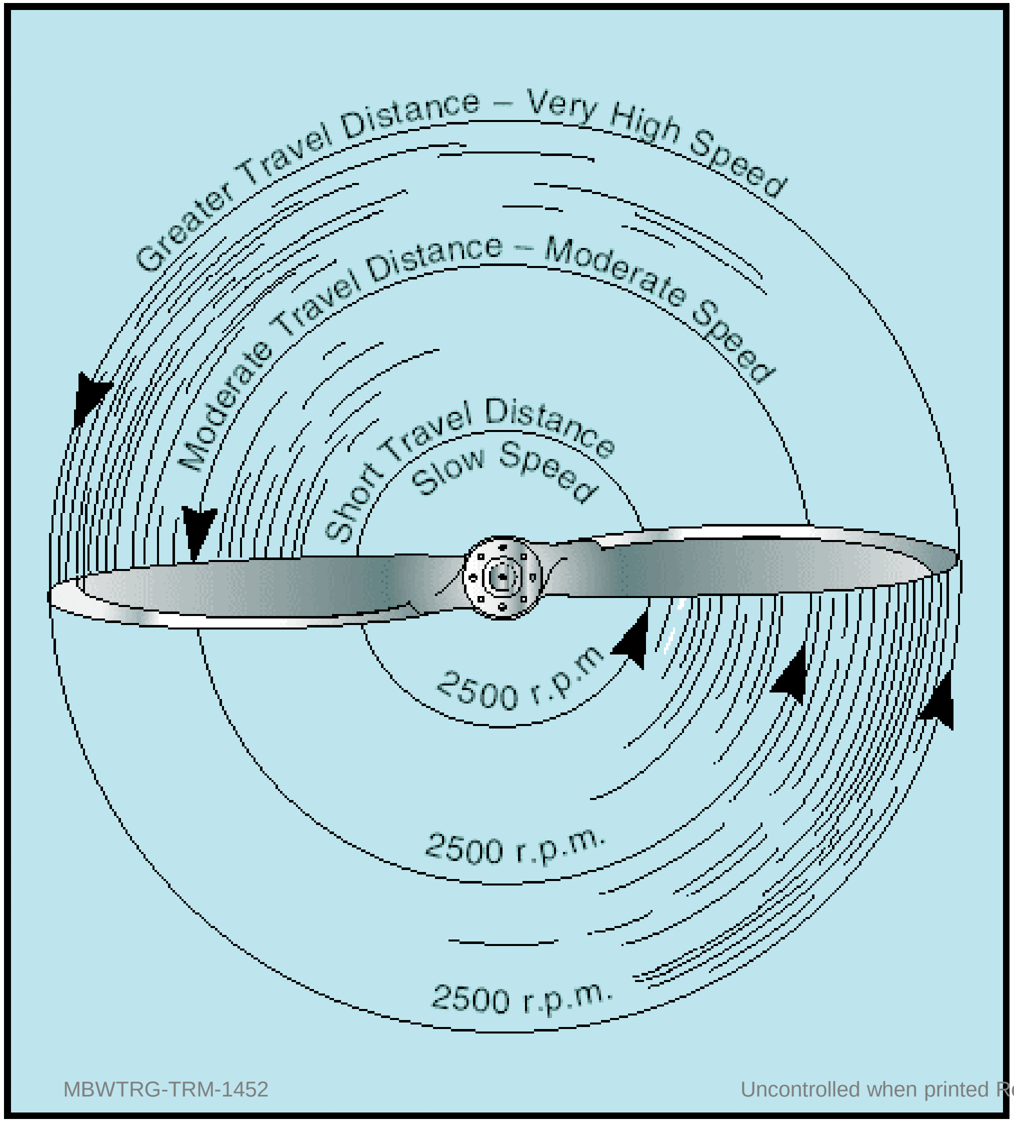
Blade Angle
The angle between the blade chord line and the plane of rotation

Angle of Attack
The angle between the chord line of the blade and the relative airflow

Helix Angle (Angle of Advance)
The angle between the resultant velocity of the blade and the plane of rotation

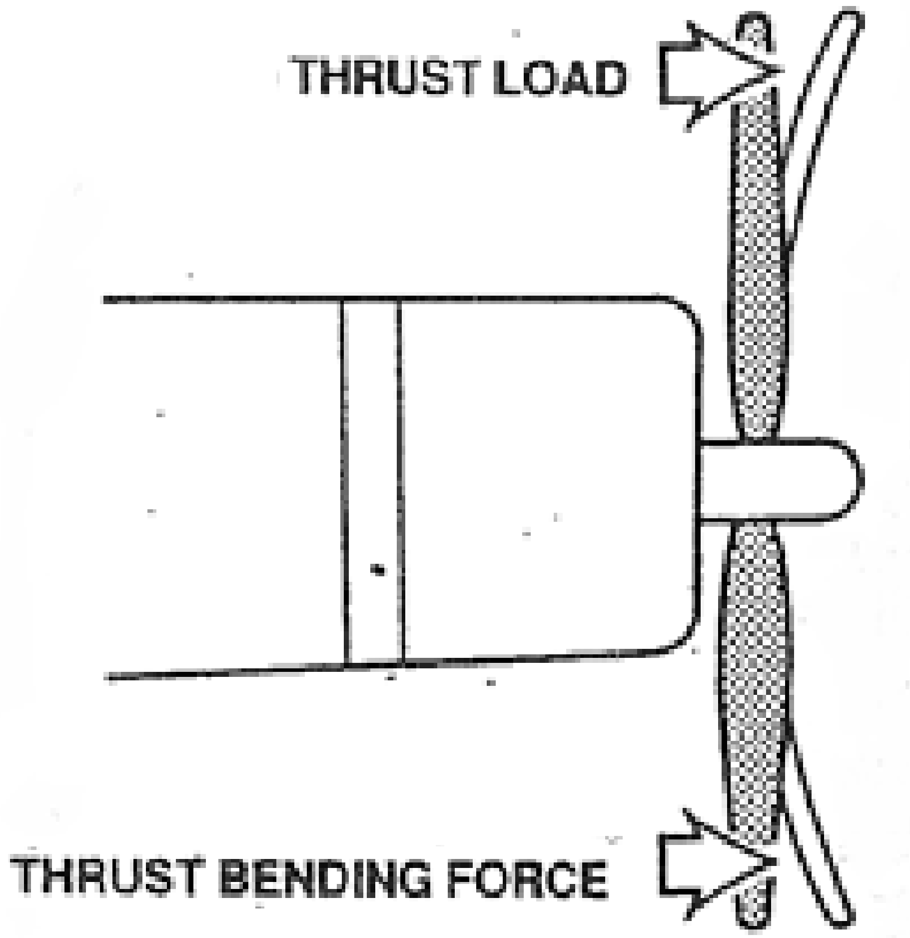


Definitions and Terms



- When the propeller rotates, the blade tip travels faster than the blade root, due to the greater distance travelled in the same amount of time
- This would lead to an increase in thrust developed at the tip, which would cause bending along the blade

Definitions and Terms



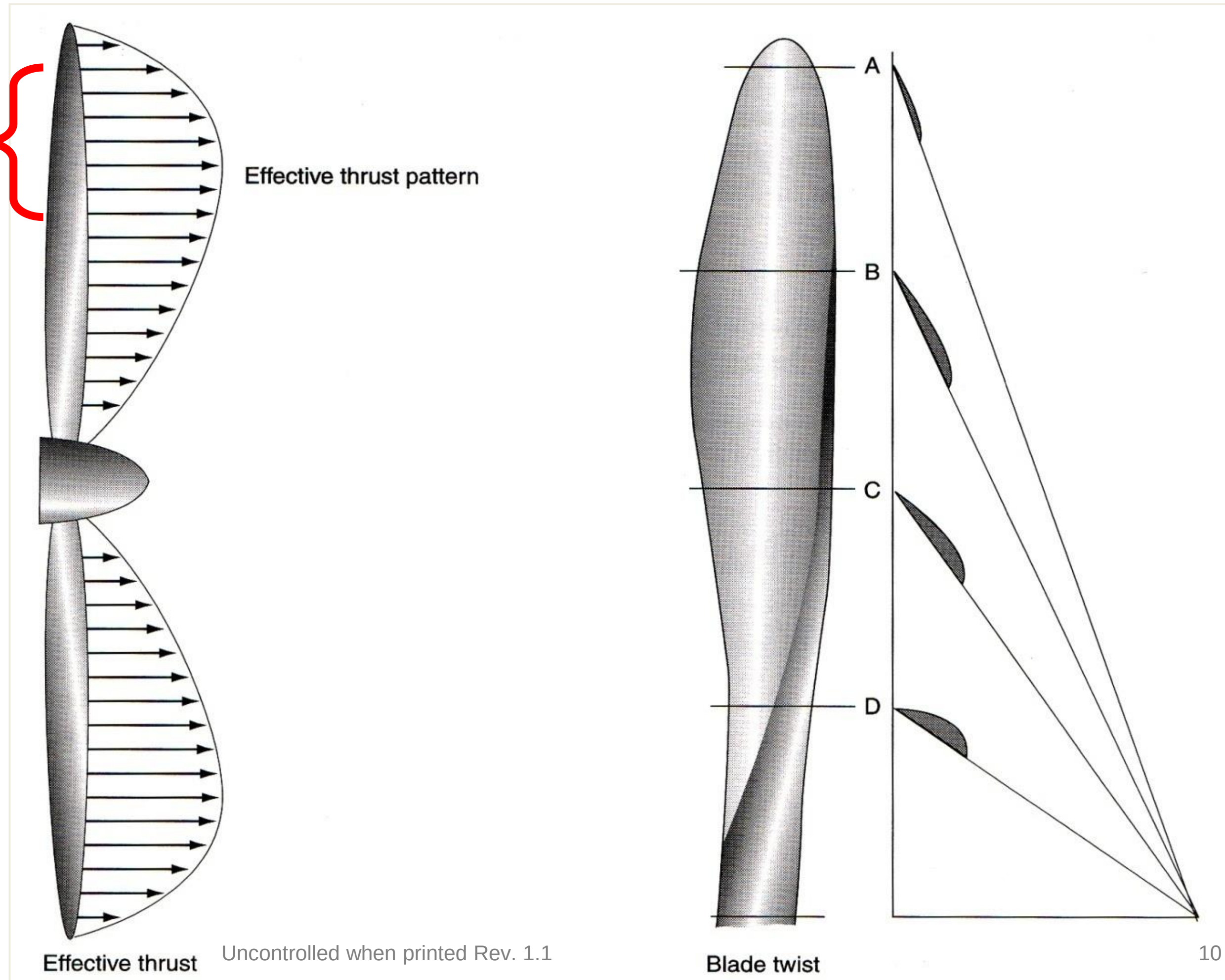
- When the propeller rotates, the blade tip travels faster than the blade root, due to the greater distance travelled in the same amount of time
- This would lead to an increase in thrust developed at the tip, which would cause bending along the blade

Definitions and Terms

- To even out the forces, the blade is twisted to compensate. The **blade twist** means that the blade angle at the hub is much greater than the blade angle at the tip

- **Most effective part of the propeller is between 60 and 90% of the distance from the hub**

- **The most efficient point is at 75%**

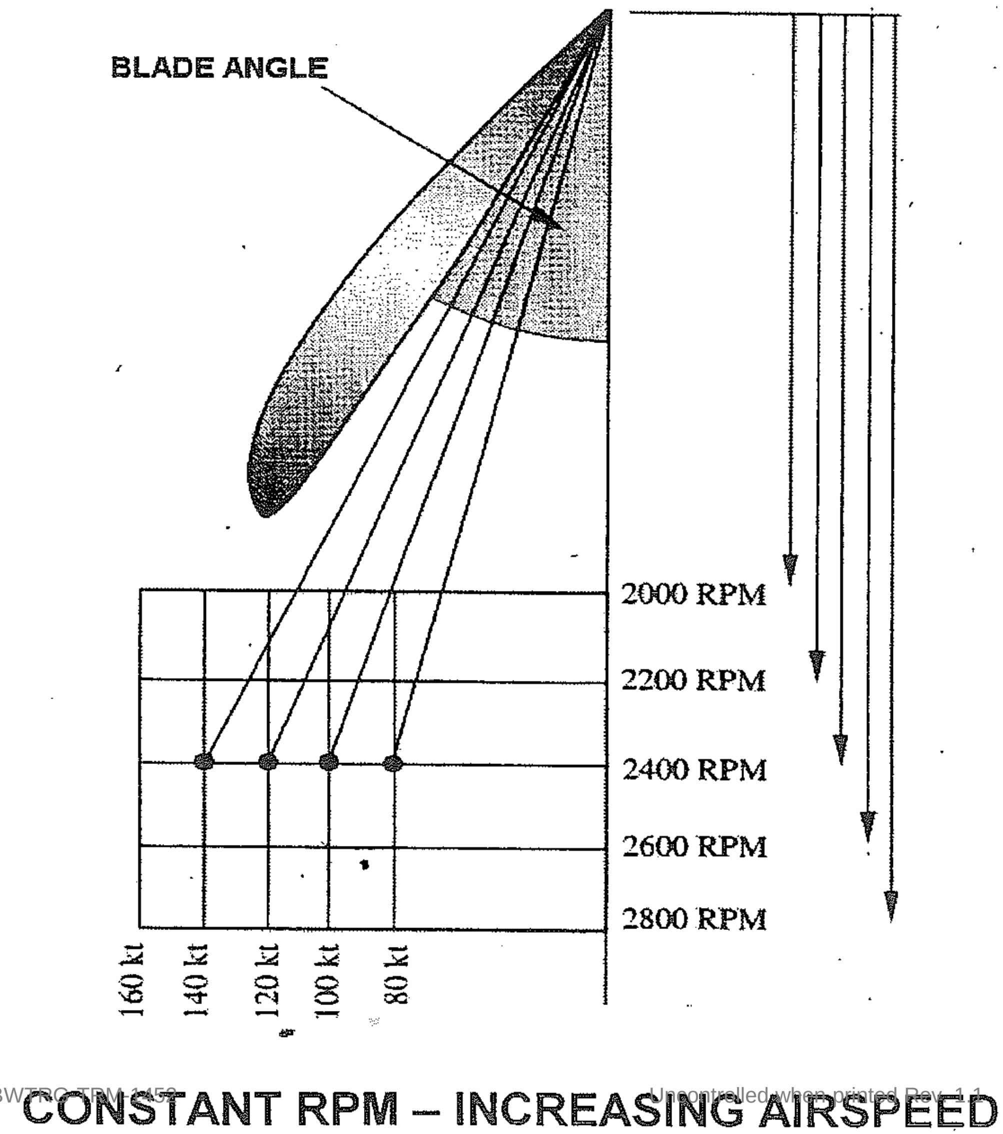


PROPELLER EFFICIENCY

Propeller Efficiency

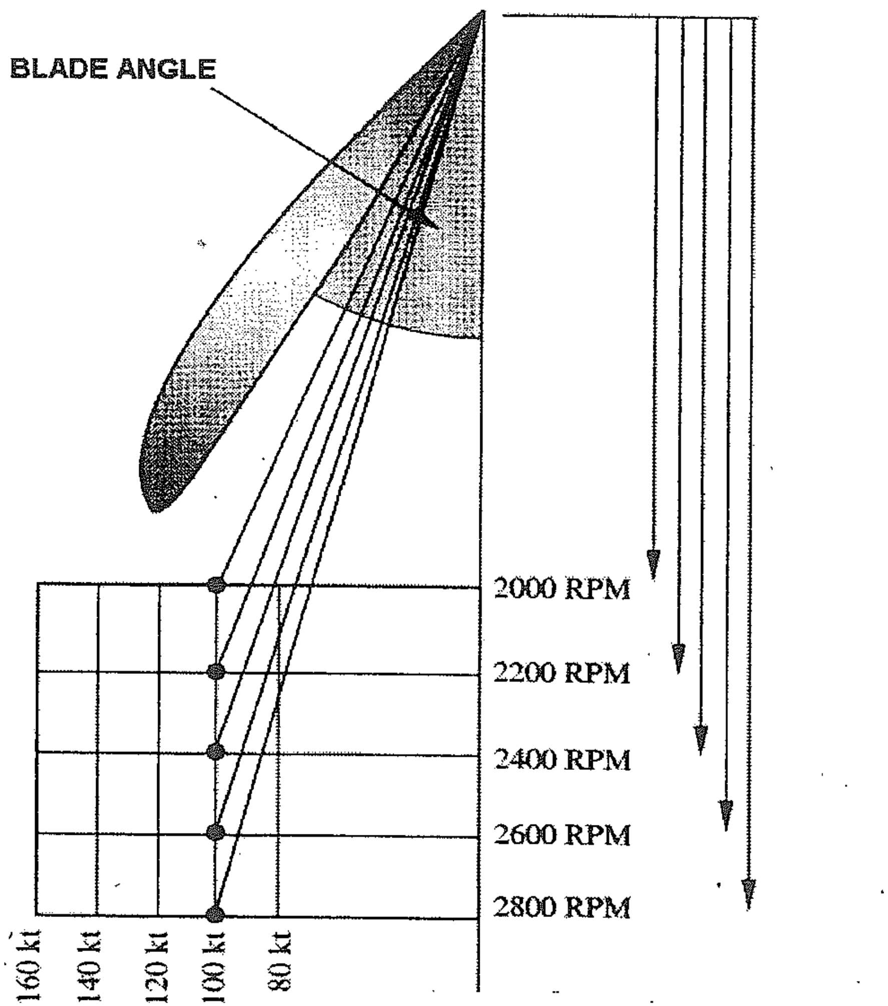
- In a fixed pitch propeller aircraft, the blade angle remains constant
- The Angle of Attack, however, varies with RPM and TAS
- This will contribute to propeller efficiency
- Before we examine this further, let’s look at how Angle of Attack varies with RPM and TAS

Propeller Efficiency



- In a fixed pitch propeller aircraft, the blade angle remains constant (shaded)
- For any given RPM, the Angle of Attack decreases as the TAS increases

Propeller Efficiency



INCREASING RPM – CONSTANT AIRSPEED

- In a fixed pitch propeller aircraft, the blade angle remains constant (shaded)
- For any given TAS, the Angle of Attack increases as RPM increases

Propeller Efficiency

- On a wing, there is only **one** Angle of Attack that produces the **best Lift/Drag Ratio**
- Similarly, there is only **one** Angle of Attack on a propeller blade that produces the **best Thrust/Torque Ratio**
- In other words, there is one Angle of Attack at which we are producing the greatest amount of thrust for the least amount of propeller torque
- Like wings, this is around about 4^0 Angle of Attack
- Since most aircraft cruise at a particular RPM setting, there is actually only **one TAS** at which this efficiency is achieved

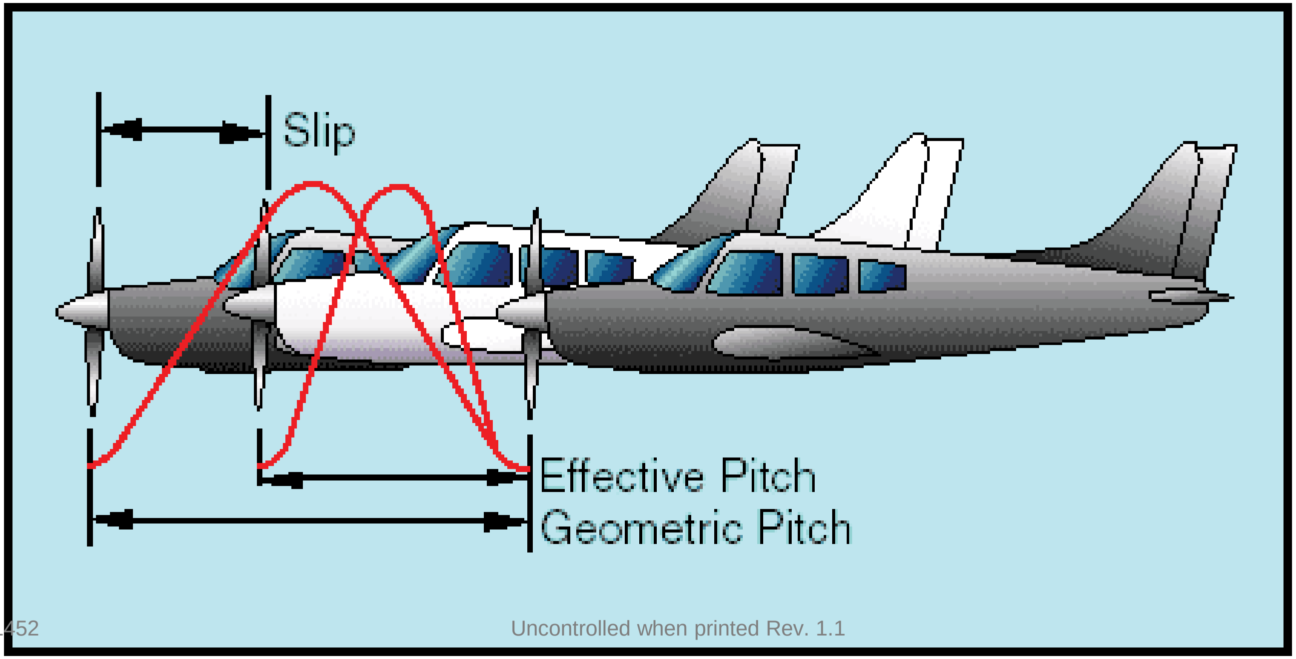
Propeller Efficiency

Geometric Pitch:

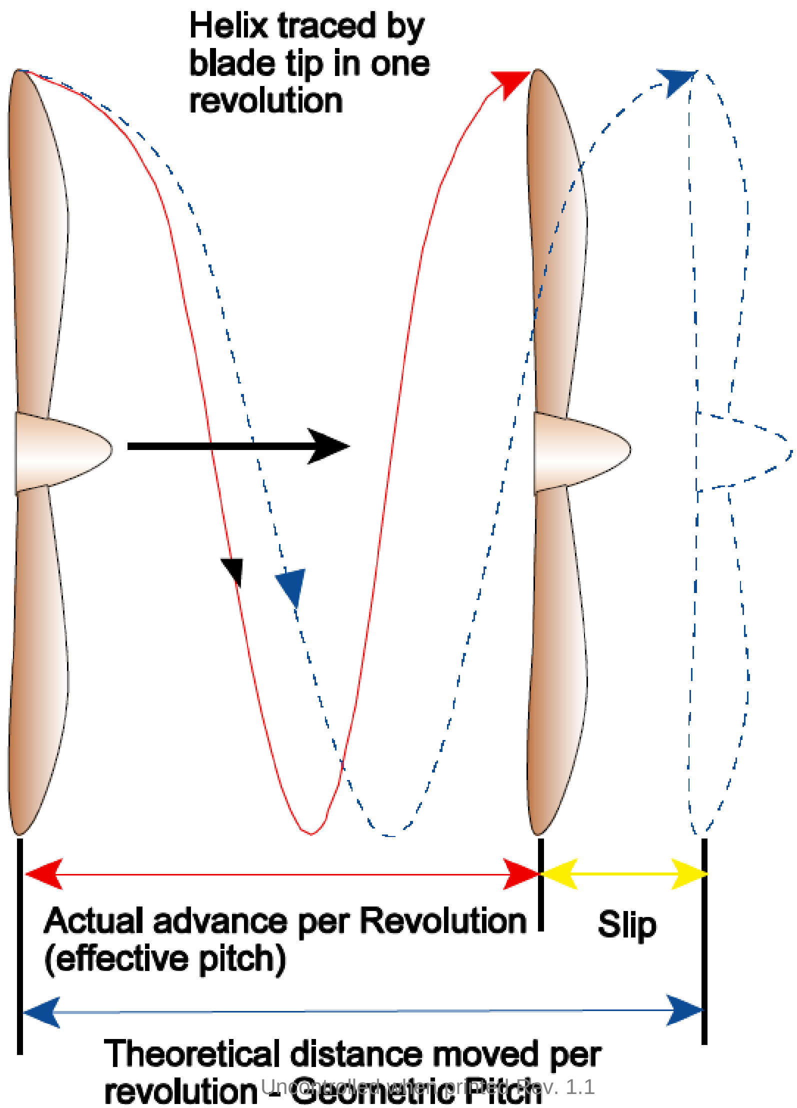
The theoretical distance the blade would move forward in one revolution (if at the most efficient Angle of Attack)

Effective Pitch:

The actual distance the blade moves forward in one revolution (depending on RPM and TAS). **Slip** is the difference between the two and accounts for the reduction in efficiency



Propeller Efficiency



FIXED vs. VARIABLE PITCH PROPELLERS

Fixed vs. Variable Pitch Propellers

- We can see now that a fixed pitch propeller (fixed blade angle) is quite ineffective as maximum efficiency can only be achieved at one TAS for any given RPM

- In order to maintain an efficient Angle of Attack over a large range of RPM and TAS values, we need to be able to change the pitch (change the blade angle)

- This is known as a **Variable Pitch Propeller**

- Variation of pitch is usually achieved via a **Constant Speed Unit (CSU)** which allows the pilot to vary the blade angle and therefore maintain efficiency across a range of airspeeds for any one RPM

Fixed vs. Variable Pitch Propellers

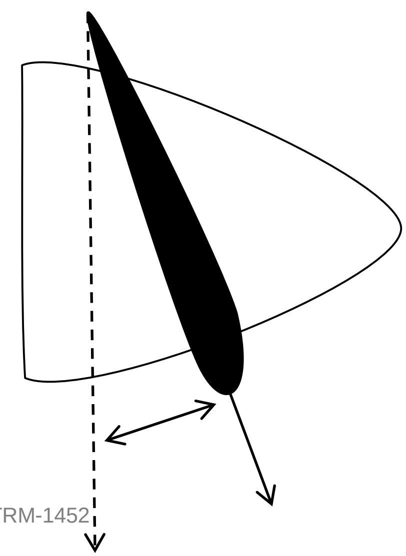
- A variable pitch propeller can range from "fine pitch" to "coarse pitch"

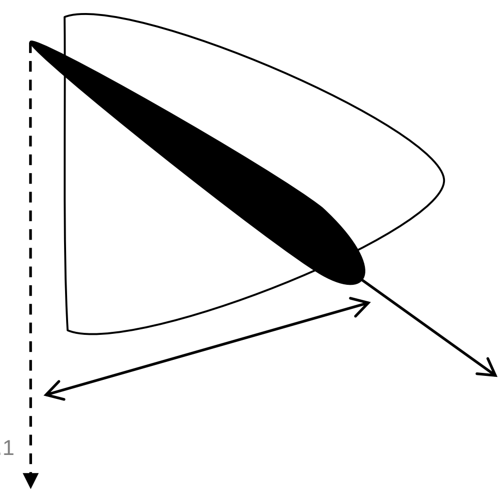
Fine Pitch

- Small Blade Angle
- Fine Pitch Stop approx. 22°
- Small Geometric Pitch
- Suitable for Low Airspeeds
- "Climb Propeller"

Coarse Pitch

- Large Blade Angle
- Coarse Pitch Stop approx. 57°
- Large Geometric Pitch
- Suitable for High Airspeeds
- "Cruise Propeller"
- C172 has this type
- Fixed pitch aircraft can have either a climb, cruise or usually a compromise propeller fitted





Fixed vs. Variable Pitch Propellers

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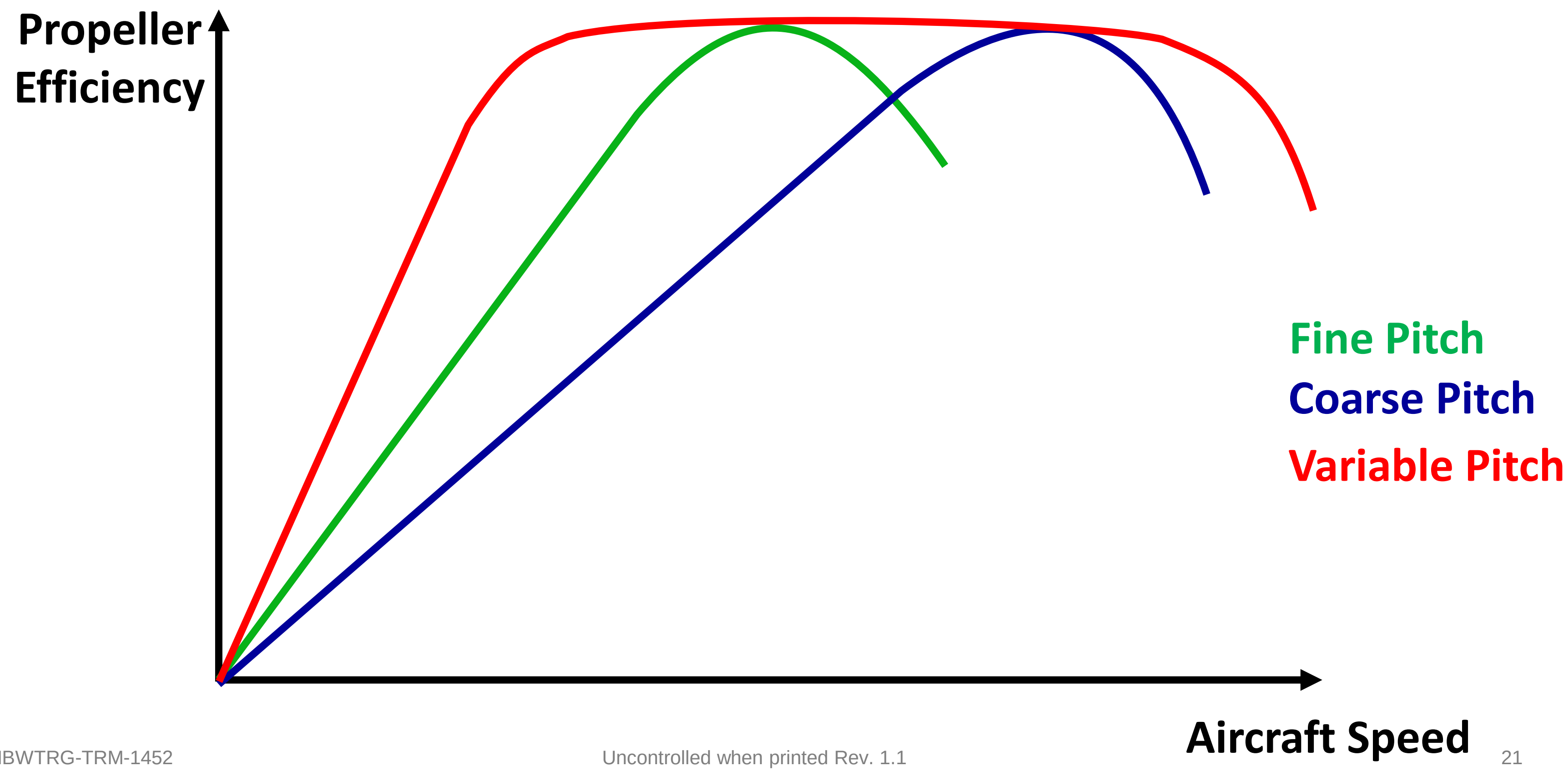


Fixed vs. Variable Pitch Propellers

- This image shows the right engine propeller in **coarse pitch**
- Some aircraft may have a **“feathering”** capability
- If the blade angle can reach 90° then the propeller will stop – it is **feathered**
- When flying multi-engine aircraft, feathering a failed engine will **reduce drag** and increase asymmetric control (one-engine operative control)

ADDITIONAL PROPELLER FORCES

Additional Propeller Forces

- Before we examine the CSU in further detail, we need to be aware of some further forces acting on a propeller blade during normal operation:

1. Aerodynamic Twisting Moment (ATM)

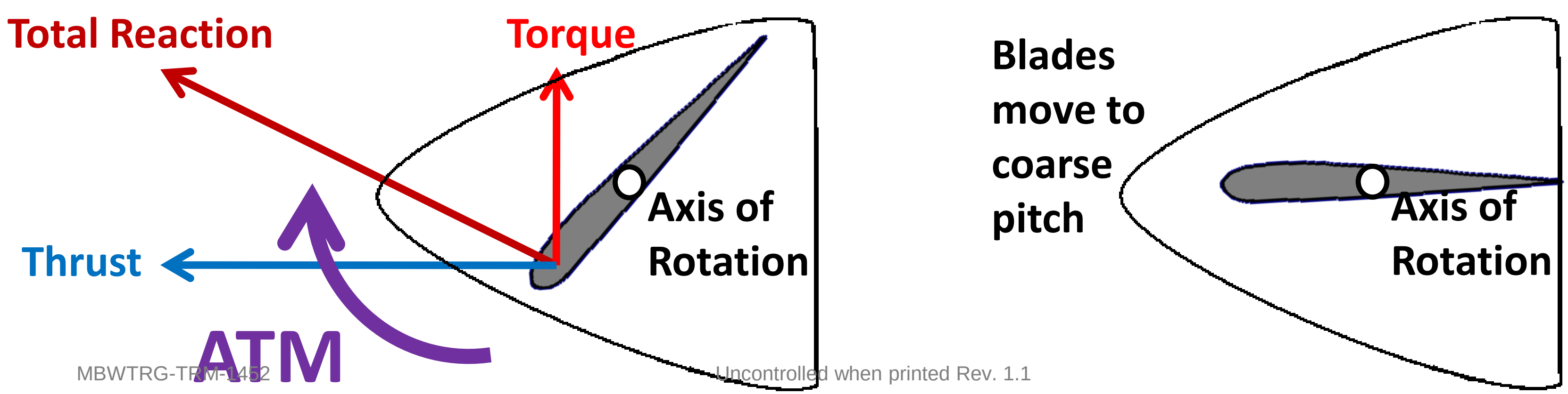
2. Centrifugal Twisting Moment (CTM)

3. Centrifugal Force

Additional Propeller Forces

Aerodynamic Twisting Moment (ATM)

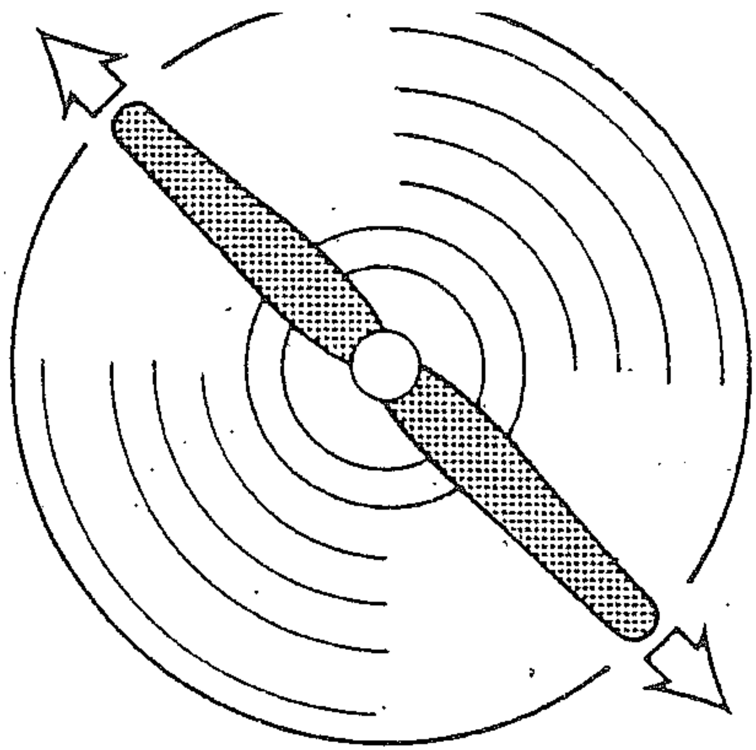
- As the relative airflow passes over the surface of the blade, a **total reaction force** is produced
- Just like on a wing, this force acts from the **centre of pressure**
- On a propeller blade, the centre of pressure is **forward of the axis of rotation** of a variable pitch propeller
- This produces a twisting moment - the blades want to rotate towards **coarse pitch**



Additional Propeller Forces

Centrifugal Force

- As the propeller rotates at high RPM, a tensile load on the blade is produced which tries to stretch the blades longitudinally (away from the crankshaft)

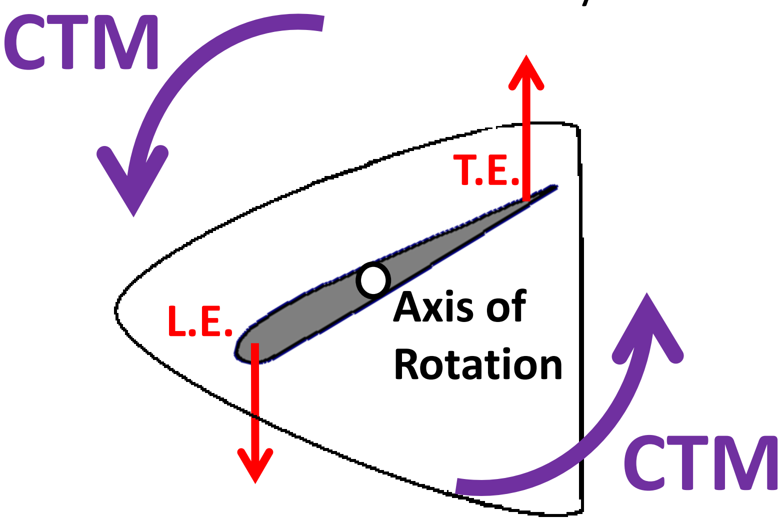


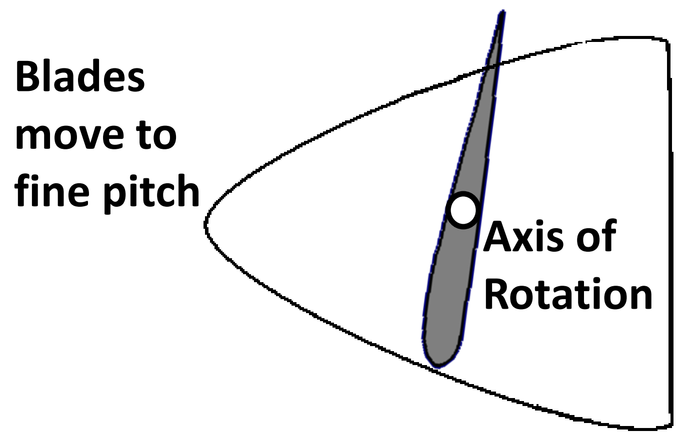
A. CENTRIFUGAL FORCE

Additional Propeller Forces

Centrifugal Twisting Moment (CTM)

- The centrifugal force also means that the Leading and Trailing Edges of the blade will also be stretched away from the axis of rotation





- This produces a twisting moment – the blades want to rotate towards **fine pitch**
- The heavy blades rotating at high RPM mean that **CTM will be much stronger than ATM**
- Therefore, a propeller blade will **naturally** want to adopt a **fine pitch** position

CSU OPERATION

CSU Operation

- A CSU varies the blade angle to maintain a desired RPM across a range of airspeeds

If the airspeed is increased:

- The RPM will start to increase
- The CSU senses this overspeed and rotates the blades to **coarse**
- This **increases the blade angle** and also **increases propeller torque**
- The increased blade angle maintains an efficient AoA at a now higher airspeed
- The increased propeller torque slows the RPM back to its original value

If the airspeed is decreased:

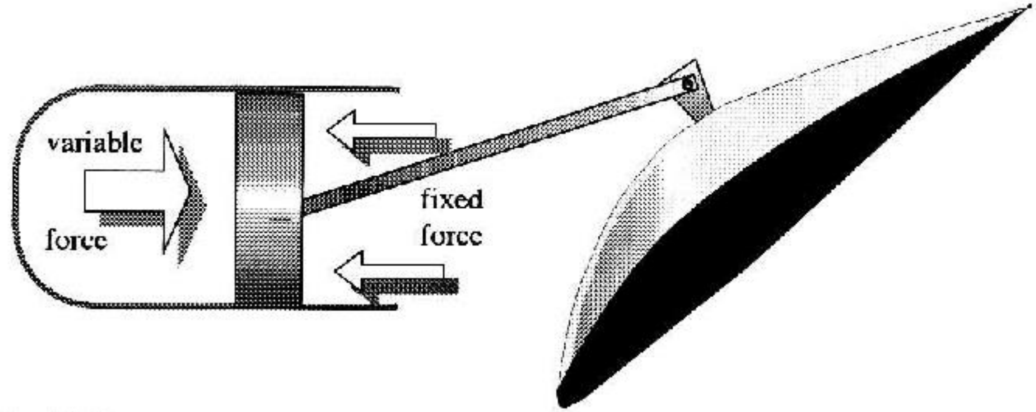
- The RPM will start to decrease
- The CSU senses this underspeed and rotates the blades to **fine**
- This **decreases the blade angle** and also **decreases the propeller torque**
- The decreased blade angle maintains an efficient AoA at a now lower airspeed
- The decreased propeller torque allows the RPM to increase back to its original value

CSU Operation

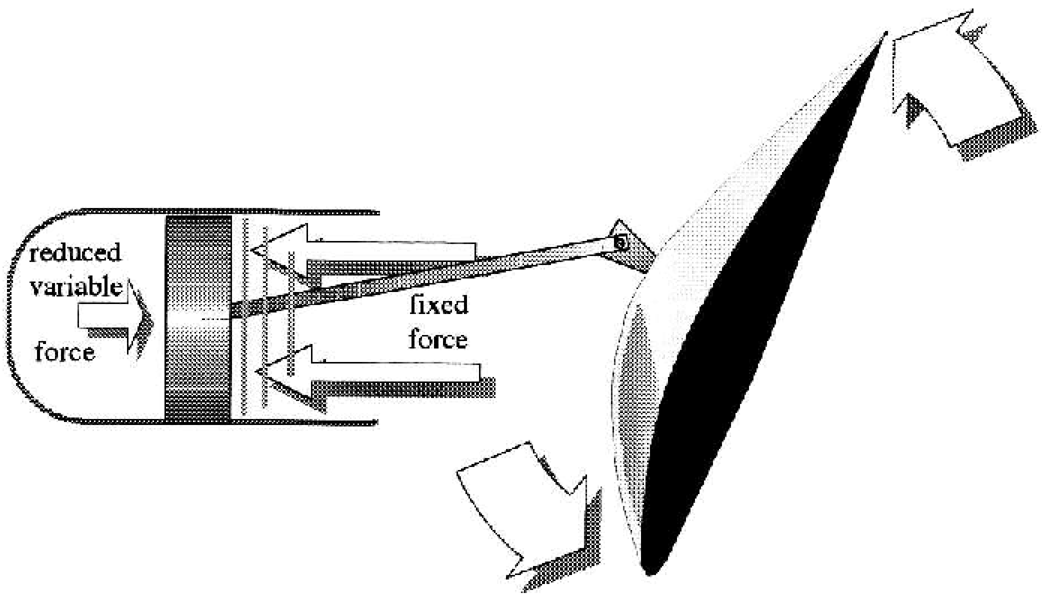
- To actuate this change in pitch, a moveable **piston** inside the **propeller hub** is used
- The piston is subject to two forces – the blade angle will depend on their balance
- The propellers we are talking about are **single-action** propellers – meaning that oil pressure delivered from the engine can only drive one side of the piston
- This oil pressure is a **variable force** that is controlled by the **propeller governor**
- The force acting on the opposite side of the piston is a **fixed force**
- This fixed force is usually supplied by a spring but may also be supplied by compressed gas or weights

CSU Operation

- In the diagram right, we can see that the balance between the variable force and the fixed force sets the blade at a specific pitch



- If the variable force is reduced (oil inside the hub is reduced), the blade will rotate towards fine pitch



- This is a common set-up, but individual CSUs may be set up differently

CSU Operation

- So in short, the pitch is controlled by the strength of the variable force – the amount of oil inside the hub acting on the piston

- The amount of oil flowing into or out of the hub is controlled by the **propeller governor**

Remember:

- If oil flows into the hub, then the propeller moves to coarse pitch

- If oil flows out of the hub, then the propeller moves to fine pitch

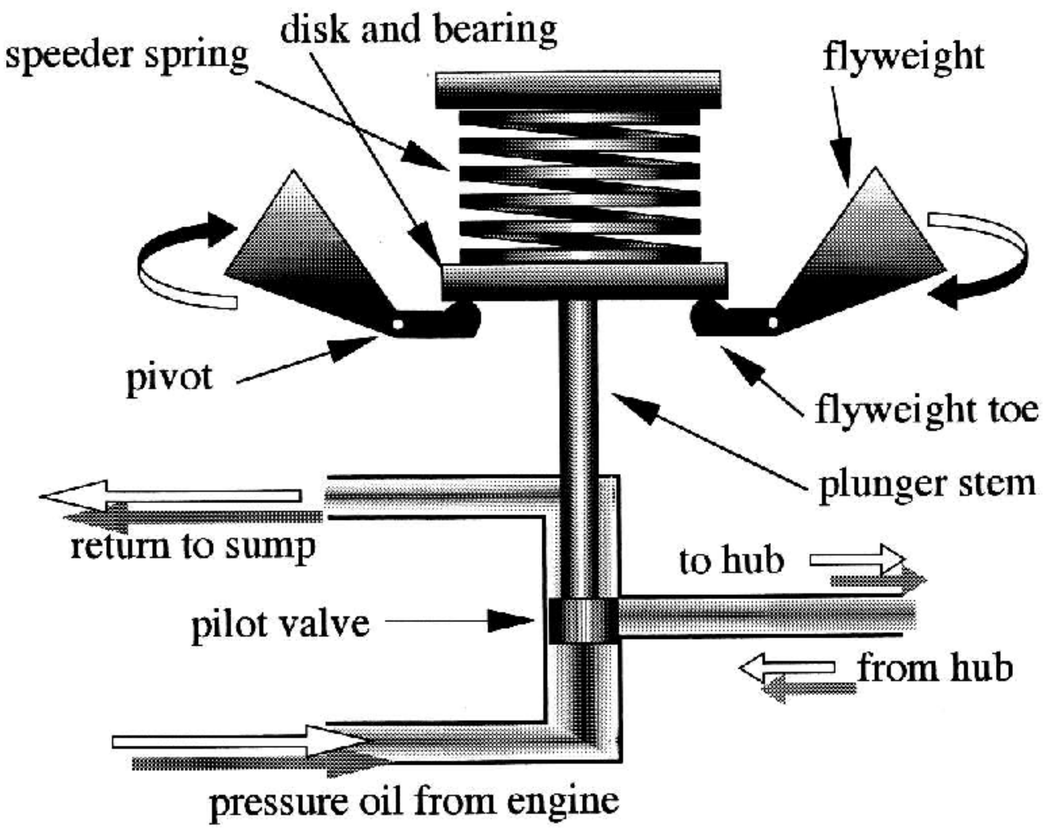
CSU Operation

- Inside the governor, there are three main components:

1. Pilot Valve

2. Speeder Spring

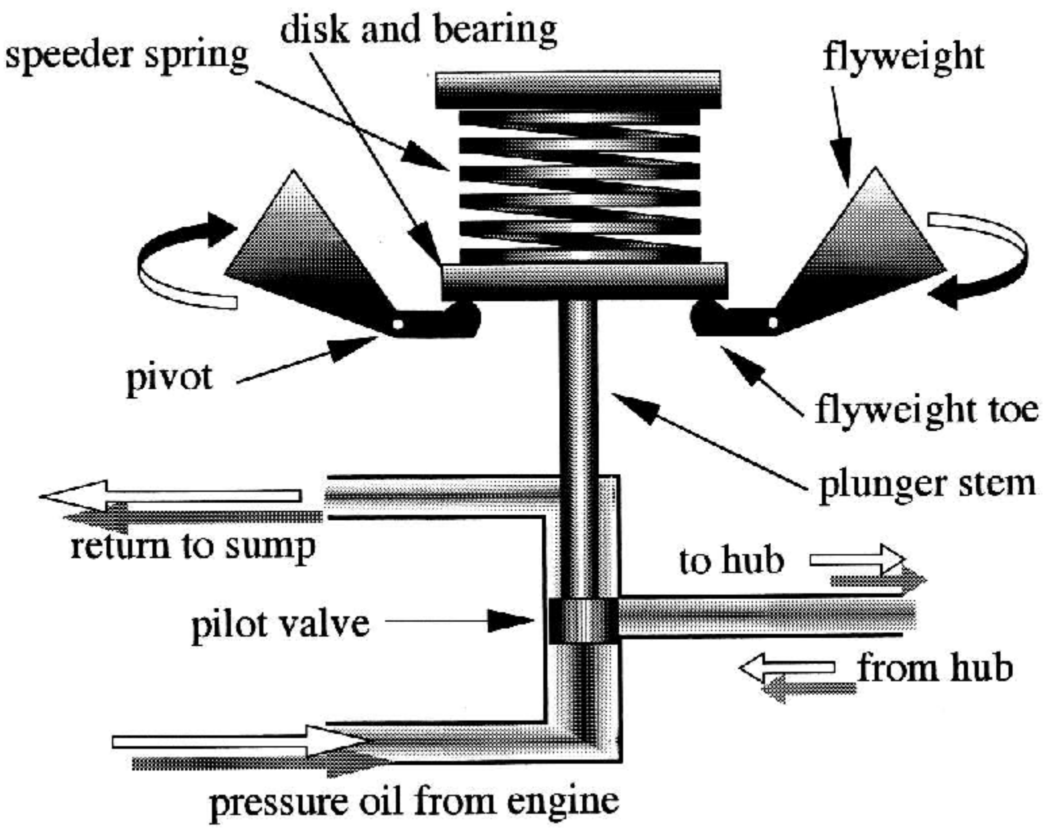
3. Flyweights



- The pilot valve is connected to the speeder spring via a plunger stem
- The speeder spring wants to extent, pushing the pilot valve down
- This would allow oil to drain from the hub back to the oil sump
- The blades would move to **fine pitch**

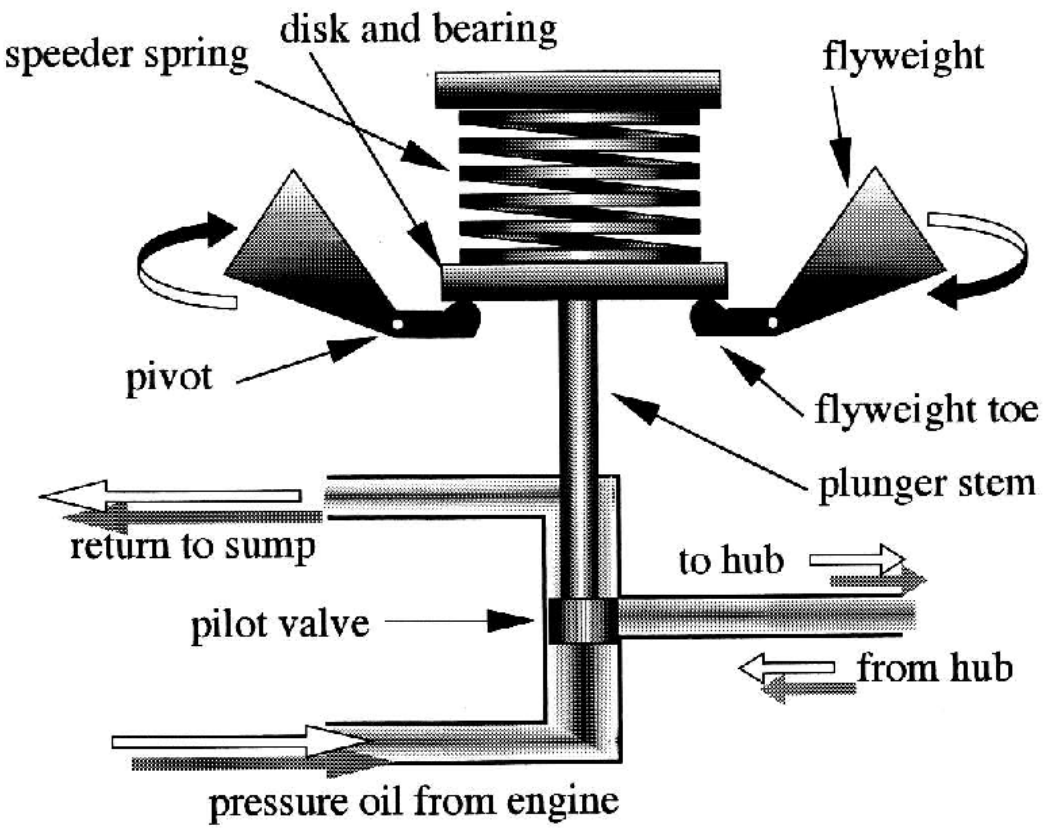
CSU Operation

- Opposing the speeder spring are the flyweights
- The flyweights actually rotate around the spring at an RPM based on centrifugal force
- The higher the airspeed, the higher the centrifugal force
- If the force is high, the weights will pivot outwards and their toes will press up on the spring
- This will raise the pilot valve and allow oil to flow into the hub
- The blades would move to coarse pitch



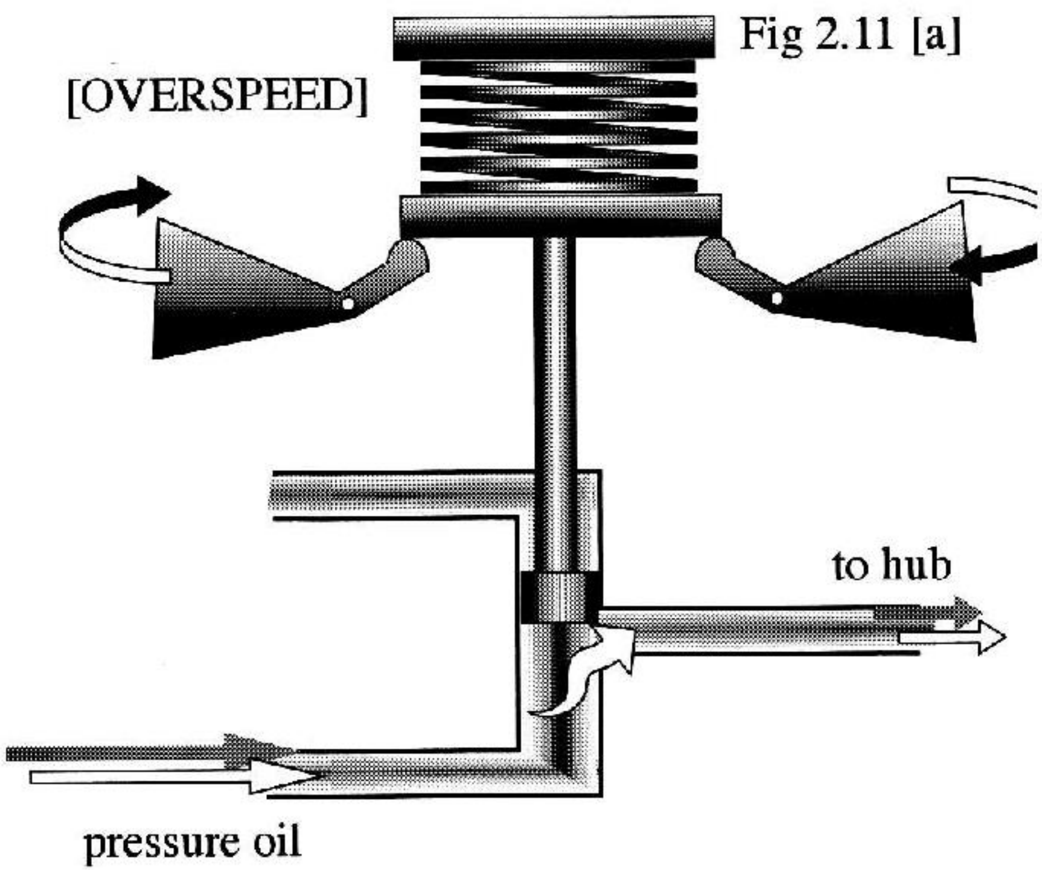
CSU Operation

- In this image, the strength of the speeder spring is balancing the strength of the centrifugal force
- When the forces are balanced, the pilot valve remains over the inlet to the hub
- This means that no oil can flow into or out of the hub
- This keeps the blade at a constant angle
- The forces will be balanced with the RPM is constant
- This is known as the "on-speed" condition



CSU Operation

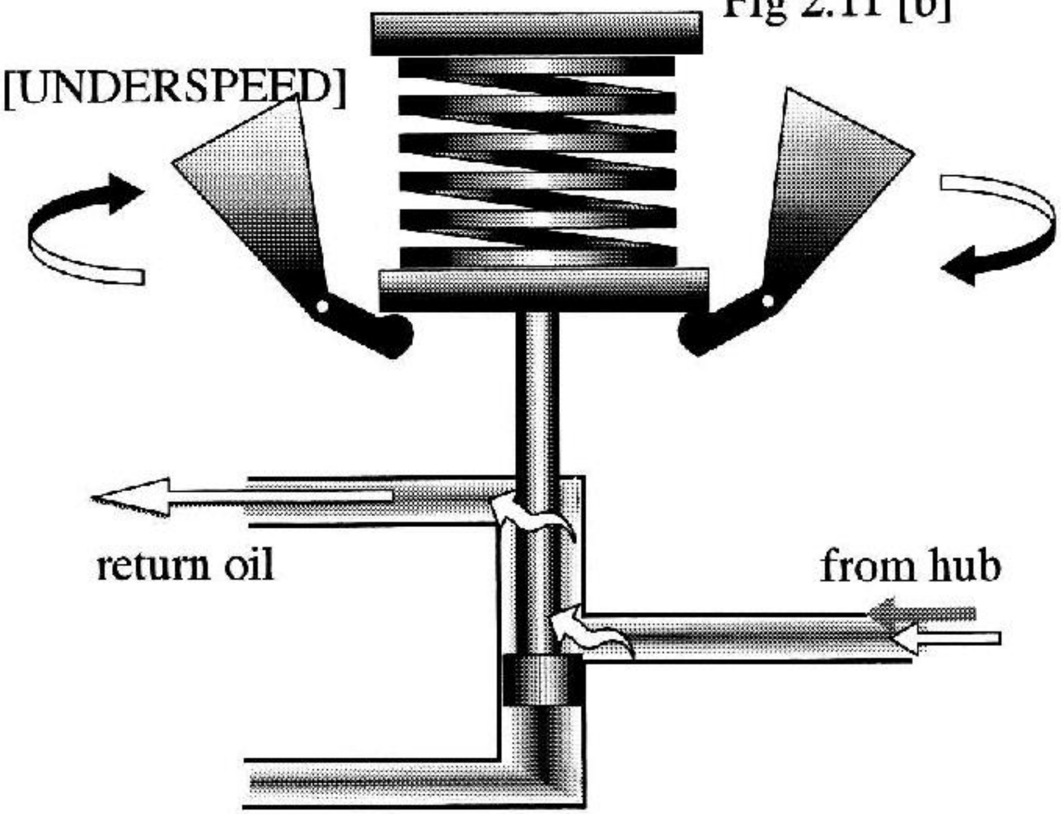
- If RPM begins to increase, then centrifugal force will increase
- This causes the flyweights to move outwards
- This causes the flyweight toes to press up on the speeder spring
- This compressed the speeder spring and raises the pilot valve
- Oil now flows into the hub, moving the blades to coarse
- This increases the propeller torque, slowing down the RPM and returning it to normal value



CSU Operation

- If RPM begins to decrease, then centrifugal force will decrease
- This causes the flyweights to move inwards
- This causes the flyweight toes to move downwards and allows the speeder spring to extend
- This lowers the pilot valve, allowing oil to exit the hub
- This moves the blades to fine pitch
- This decreases the propeller torque, increasing the RPM and returning it to normal value

Fig 2.11 [b]



CSU Operation

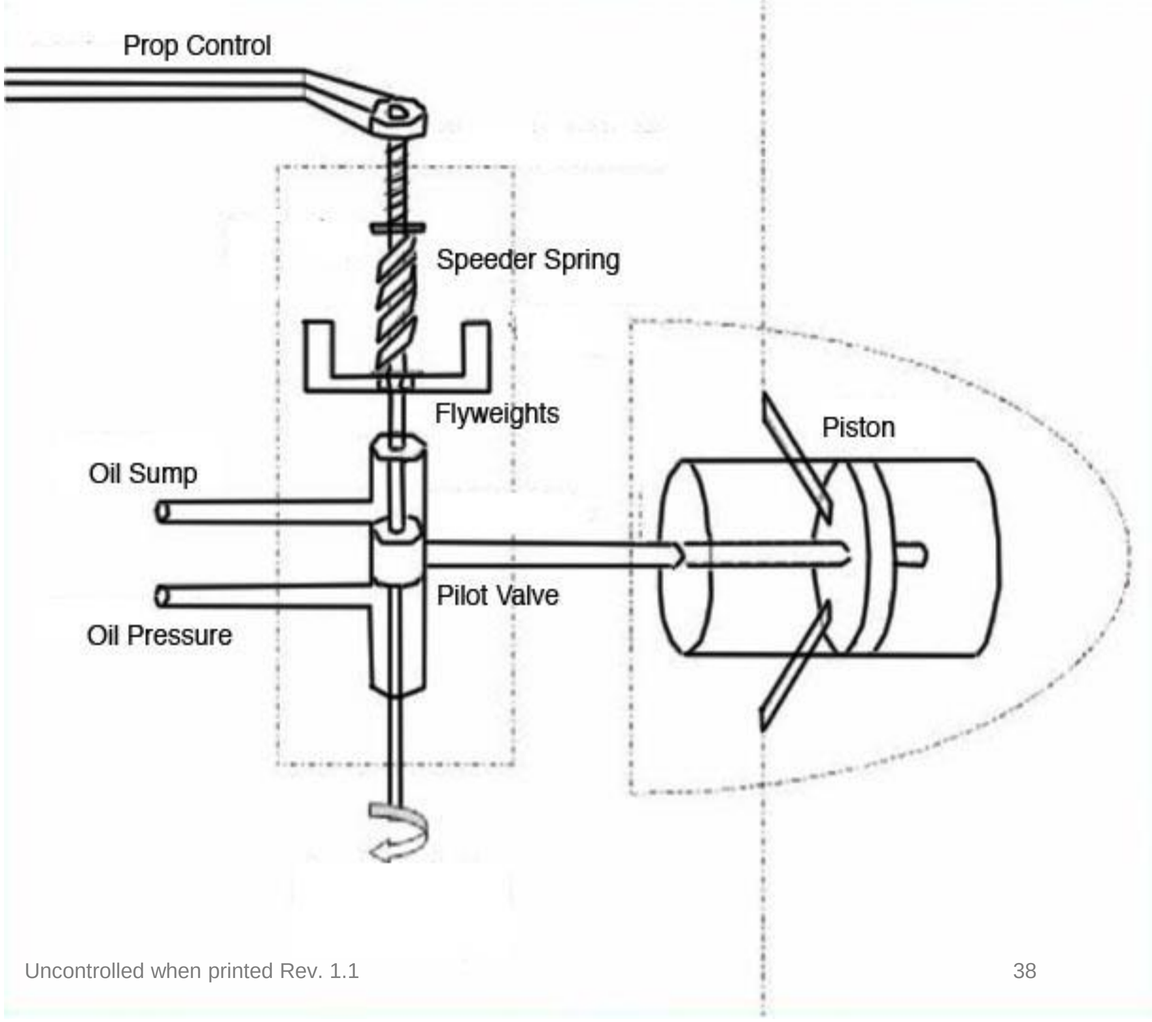
- You can see that it is actually the extension or compression of the speeder spring that dictates the change in blade angle

- The pilot has a control called the **pitch lever** that is directly coupled to the speeder spring

- The pilot uses the lever to set the desired tension on the spring and therefore set the quantity of oil in the hub

- This sets the pitch and RPM

- The governor then maintains this RPM using the system we have just seen



CHANGING POWER WITH A CSU

Changing Power with a CSU

- In an aircraft fitted with a fixed pitch propeller:

  1. Power is changed using the throttle

  2. Power is selected using the Tachometer (RPM Gauge)

- The Tachometer is actually showing rate of rotation of the engine's crankshaft

- Because this is usually coupled directly to the propeller, it also tells us propeller RPM

- If the airspeed increases too much, the propeller may **overspeed** unless the throttle position is reduced

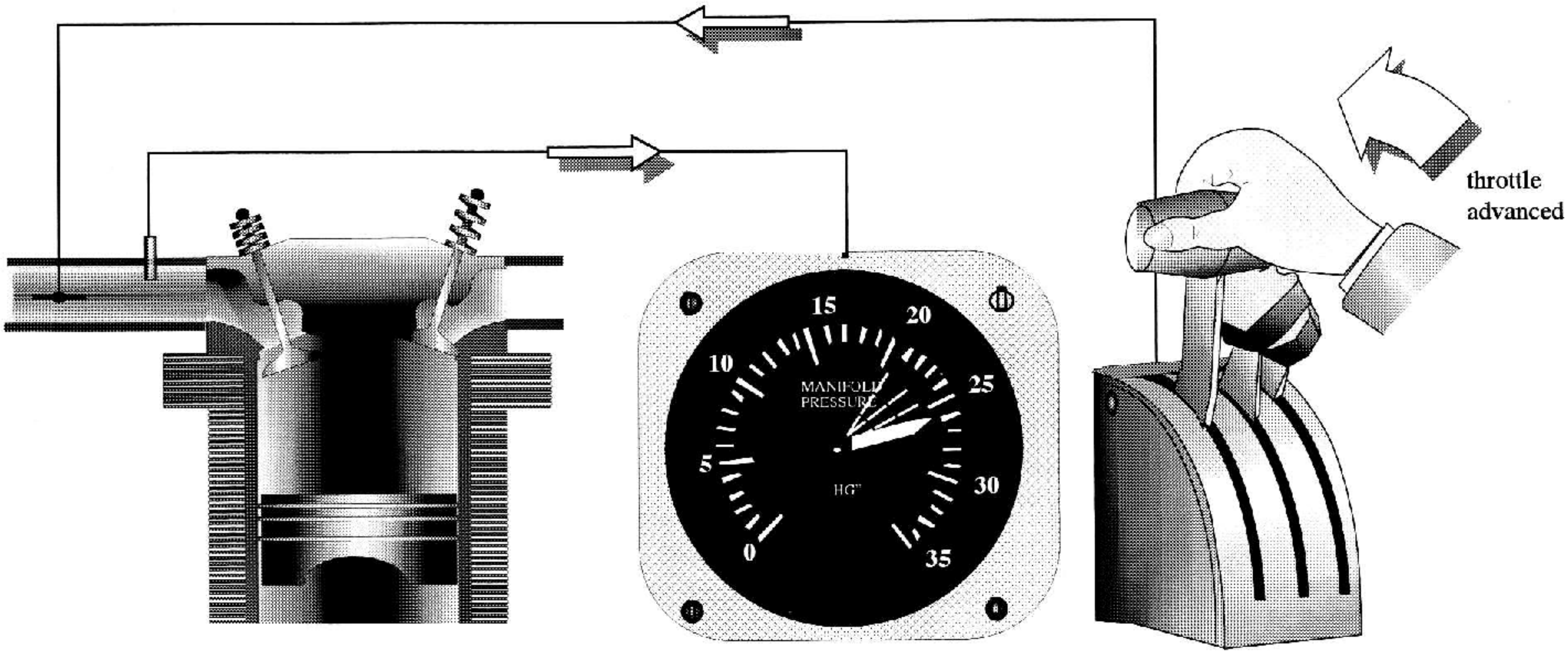
Red Line – Maximum Permissible RPM

- Leads to excessive wear on engine components
- May reduce engine life

Changing Power with a CSU

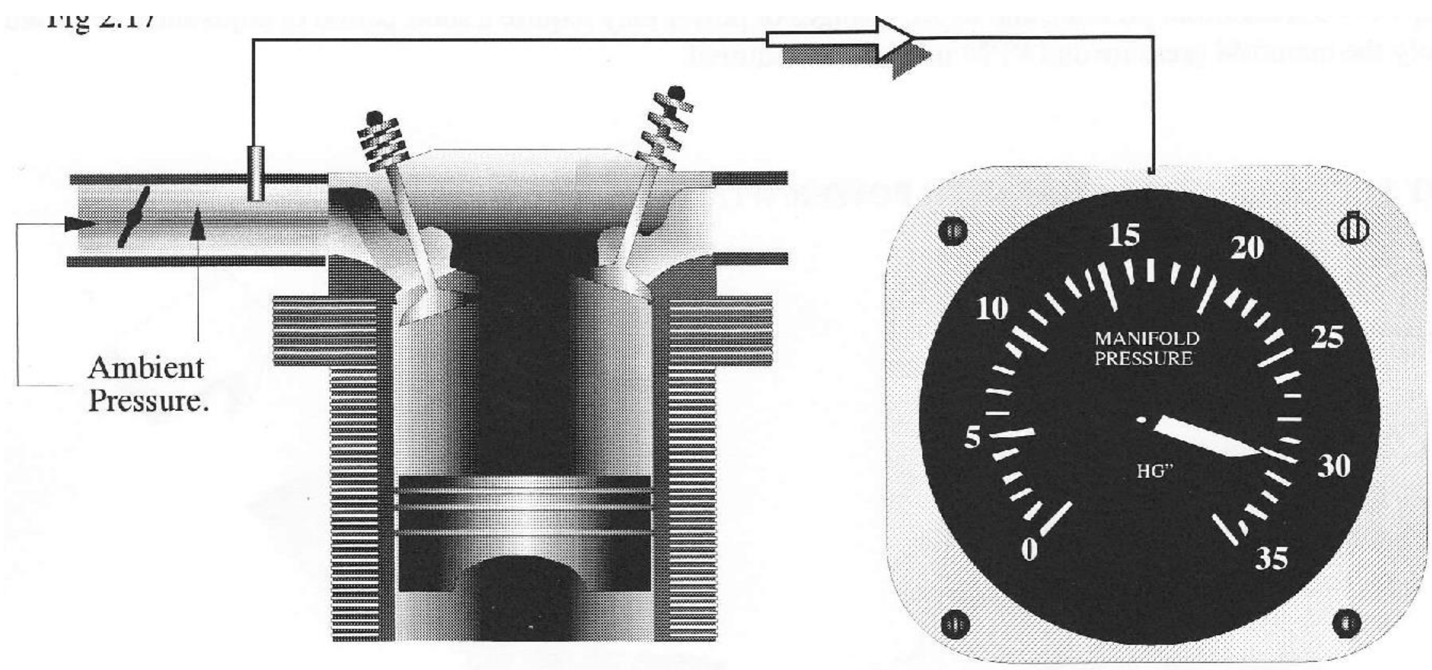
- However, for aircraft fitted with a variable pitch propeller, the CSU will maintain a selected RPM using a propeller governor
- We can therefore no longer rely on RPM for an indication of engine power output
- To overcome this, an extra gauge is fitted, known as a **Manifold Pressure Gauge (MAP)**
- This measures the pressure in the **inlet manifold** between the **throttle butterfly** and the **inlet valve**
- This is an excellent indicator of power as MAP decides how much fuel-air mixture will enter the cylinder when the inlet valve opens
- The higher the MAP, the more mixture will be sucked into the cylinder during the induction stroke

Changing Power with a CSU



Changing Power with a CSU

- MAP is measured in **inches of mercury ("Hg)**
- Normal MSL Pressure (1013.25hPa) is equal to **29.92''Hg**
- Therefore, when the aircraft is on the ground at sea level with the engine inoperative, the MAP gauge should read approx. 30''Hg

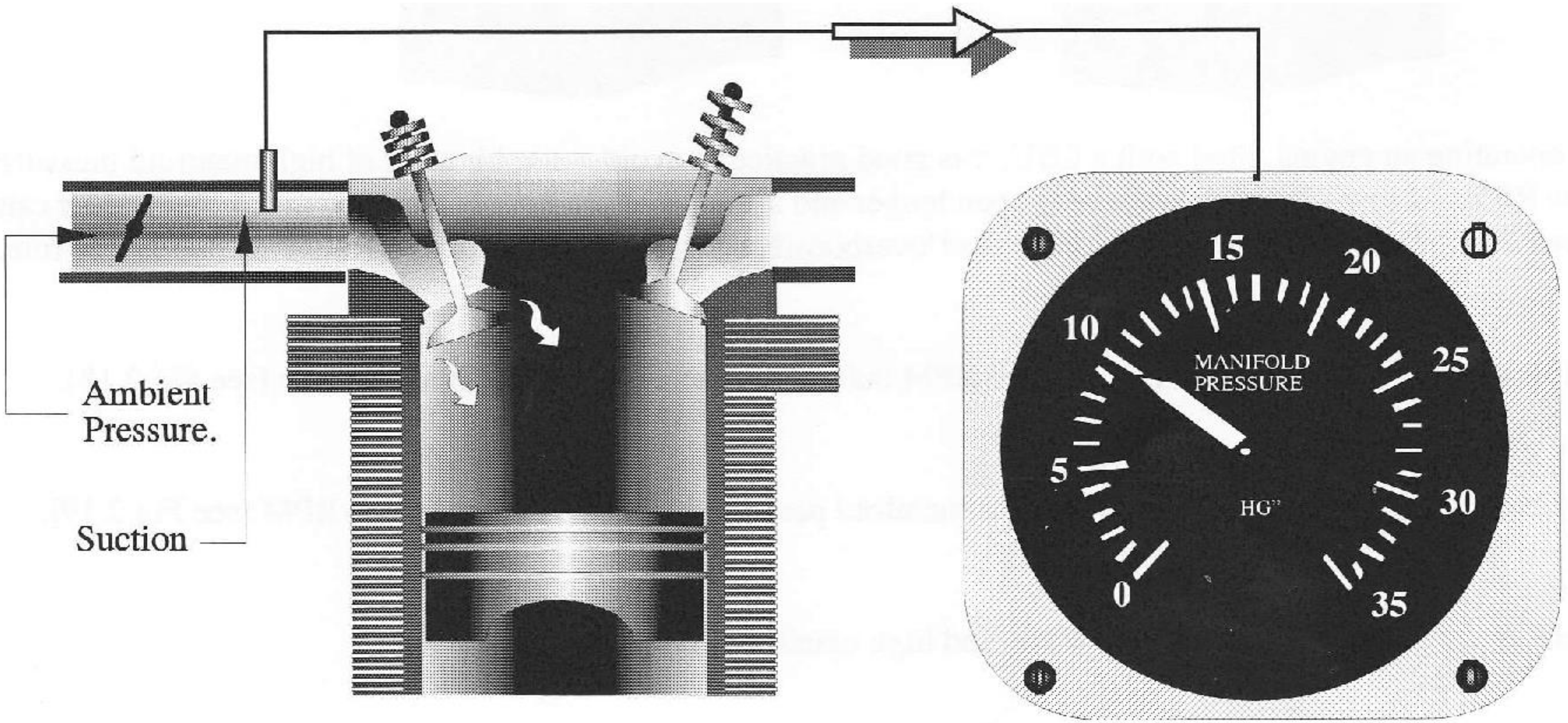


- Note that pressure decreases at approximately 1''Hg per 1000ft
- Therefore, a normal MAP gauge reading on the ground at an elevation of 4000' would be approximately 26''Hg

Changing Power with a CSU

- If the engine is started, the downward moving pistons create a low pressure inside the cylinders – creating suction to draw in fuel-air mixture

- A normal MAP gauge indication will be around 10 or 11 ''Hg




MAN IN
27.3
10
35
PROPELLER
PUSH
INCR
RPM
MIXTURE
PULL
LEAN
FULL
NOSE
DOWN
NOSE
UP
NOSE
LEFT
NOSE
RIGHT

Changing Power with a CSU

- So, in an aircraft fitted with a variable pitch propeller:

  1. **Power is changed using the throttle**

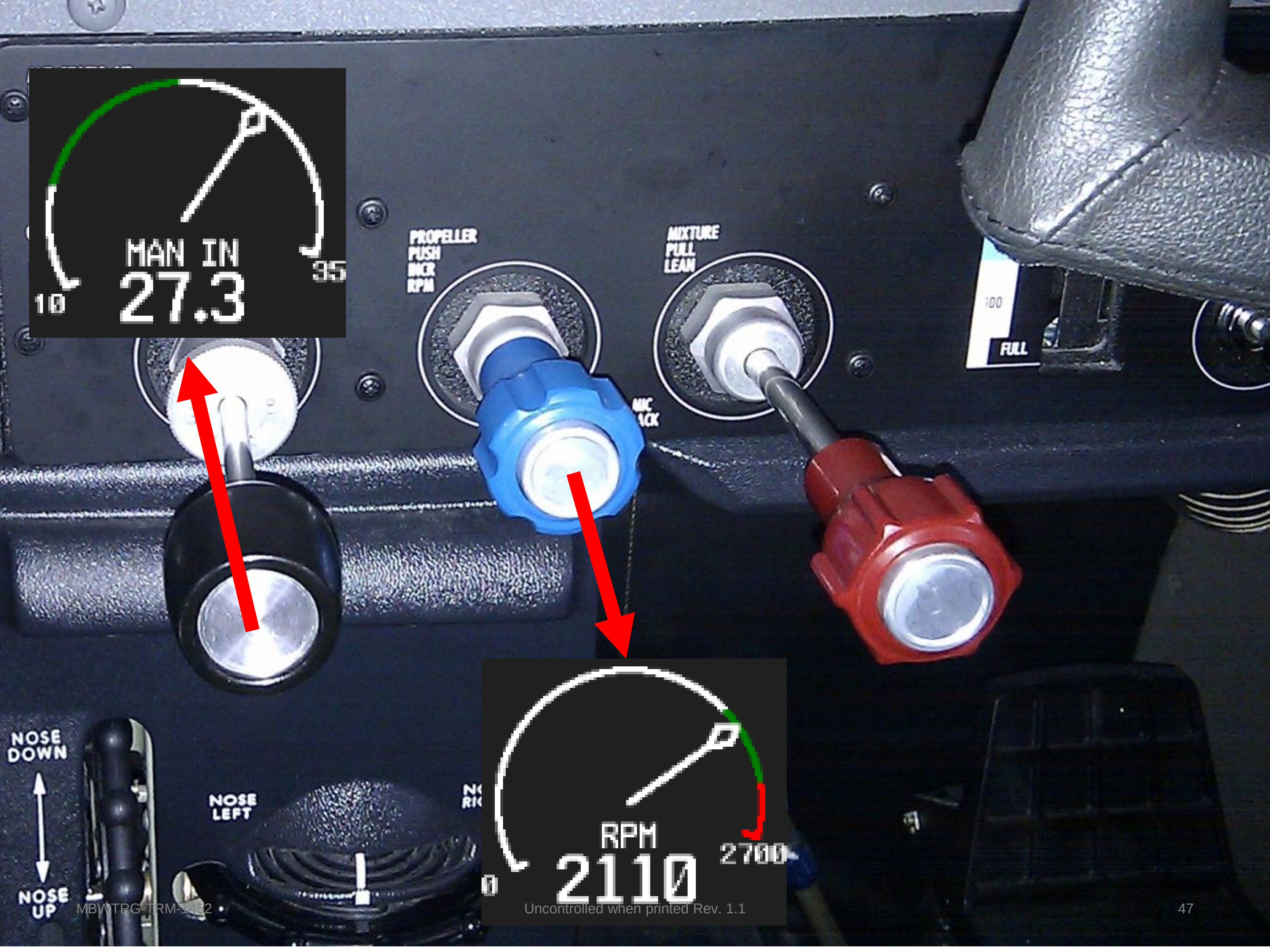
  2. **Power is set using the MAP Gauge**

- The pilot may also wish to select a desired RPM

- To achieve this, an extra cockpit control is added between the throttle and the mixture levers – known as the **pitch lever**

- Note that using the lever will still change the rate of rotation of the crankshaft and therefore the propeller

- Once the RPM has been set, the CSU will vary the blade angle to maintain that RPM


MAN IN
27.3
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35
PROPELLER
PUSH
INCR
RPM
MIXTURE
PULL
LEAN
FULL
RPM
2110
0
2700
NOSE DOWN
NOSE UP
NOSE LEFT

Changing Power with a CSU

- Pushing the pitch lever all the way forwards will lock the propeller into the smallest blade angle – this is known as **pitch fully fine**
- When the pitch is fully fine (at the pitch stop), the propeller behaves just like a fixed pitch type – in other words, RPM changes whenever engine power changes
- When on the ground, we set pitch fully fine when carrying out pre take-off checks such as magnetos and carburettor heat
- Pitch fully fine also allows the propeller to produce **maximum thrust** at low airspeed and as such is used for **take-off** (and on **landing** in case of a go-around)
- Pulling the pitch lever all the way backwards will lock the propeller into the largest blade angle – this is known as **pitch fully coarse** (or sometimes fully feathered)
- Note that this would also cause the propeller to behave like a fixed pitch type
- However, except for multi-engine aircraft when feathering a failed engine, this pitch setting is rarely used

Changing Power with a CSU

- The advantage of the CSU is that the pilot now has two controls:

  1. The throttle to control power output

  2. The pitch to control propeller efficiency

- When the throttle is increased, and MAP will increase and therefore the flow of fuel-air mixture into the cylinders will increase

- When the pitch is moved towards coarse, the RPM will reduce and this enables the valves to remain open longer during the induction stroke, improving the flow of mixture into the cylinders

- Therefore, the **best volumetric efficiency** will be achieved when a **low RPM** is used in conjunction with a **high MAP**

- Are there any limitations to this?

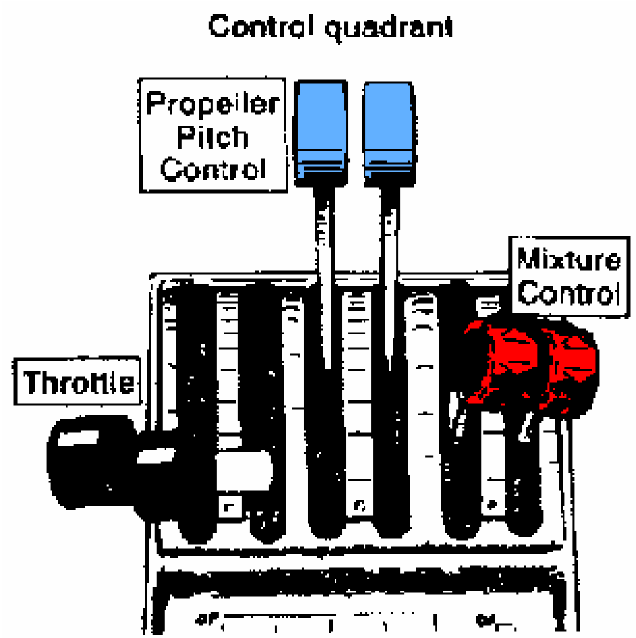
Changing Power with a CSU

- Unfortunately, if an excessively high MAP is used with an excessively low RPM, too much fuel-air mixture may be forced into the cylinders

- This is known as **overboosting** and can even lead to detonation

When increasing power – Increase RPM before MAP

1. "Mix Up"
2. "Pitch Up"
3. "Power Up"



When decreasing power – Decrease MAP before RPM

1. "Power Down"
2. "Pitch Down"
3. "Mix Down"

- In the cruise, you should also only use recommended combinations of MAP and RPM to avoid overboosting

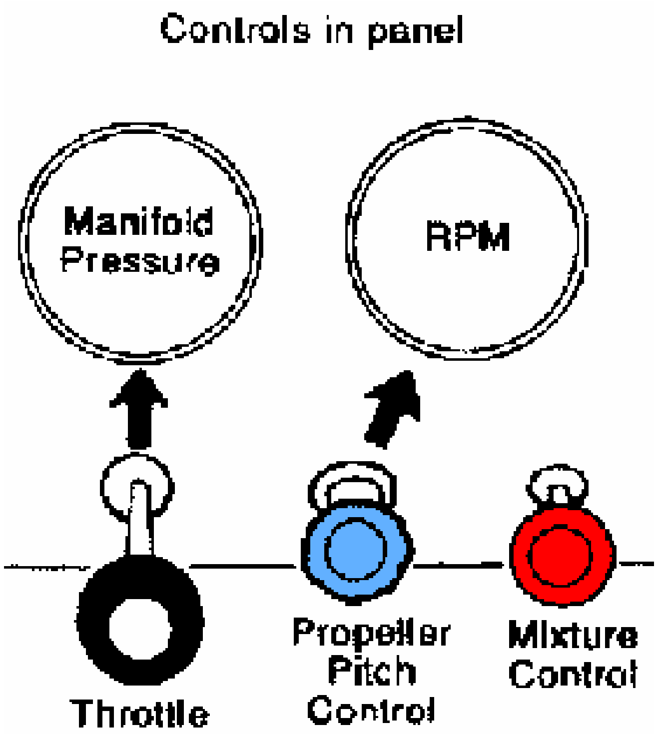
Changing Power with a CSU

- You may notice during flight that when the pitch lever is used to vary RPM, the MAP also varies even though no change has been made to the throttle position

When RPM is decreased, MAP will slightly increase

- This is because at lower RPM, the valves stay open for longer
- Therefore, they are opening fewer times per minute
- This reduces the rate of flow into the cylinders
- The reduced flow results in a build up of pressure in the inlet manifold
- The opposite effect occurs when RPM is increased

When RPM is increased, MAP will slightly decrease



CARBURETTOR ICE & THE CSU

Carburettor Ice & the CSU

- Just like a fixed pitch propeller aircraft, the presence of carburettor icing is indicated by **an apparent reduction in power (just like closing the throttle)**

- This means that if icing is present:

  1. The MAP will drop

  2. RPM will remain the same

- If carburettor heat is applied:

  1. An initial drop in MAP as the mixture becomes more rich

  2. A subsequent rise in MAP as the ice melts

  3. RPM will remain the same

PROPELLER LIMITATIONS

Propeller Limitations

- Remember that the CSU can only maintain RPM within the limitations of the:

  1. Coarse Pitch Stop (Blade Angle approx. 57°)

  2. Fine Pitch Stop (Blade Angle approx. 22°)

- Once the blades reach a pitch stop, they behave like a fixed pitch propeller and will vary with changes in power and airspeed

Example: If a dive is entered with power on, what will be the effect on the propeller?

- As the airspeed increases, the CSU will move the pitch to coarse to maintain RPM
- If the airspeed continues to increase, the blades will reach the coarse pitch stop
- When this occurs, the propeller acts like a fixed pitch type and RPM will increase
- If nothing is done, red-line RPM will be exceeded and overspeed will occur
- Fortunately, this would be at a speed above Vne in most light aircraft

PROPELLER MALFUNCTIONS

Propeller Malfunctions

- The two most common malfunctions that occur in CSUs are:

  1. Failure of the Speeder Spring in the Propeller Governor

  2. Loss of oil pressure in the Propeller Hub

- To understand the effects of these malfunctions, we must first understand the type of CSU being used

- The two main types of single-acting, non-feathering CSUs:

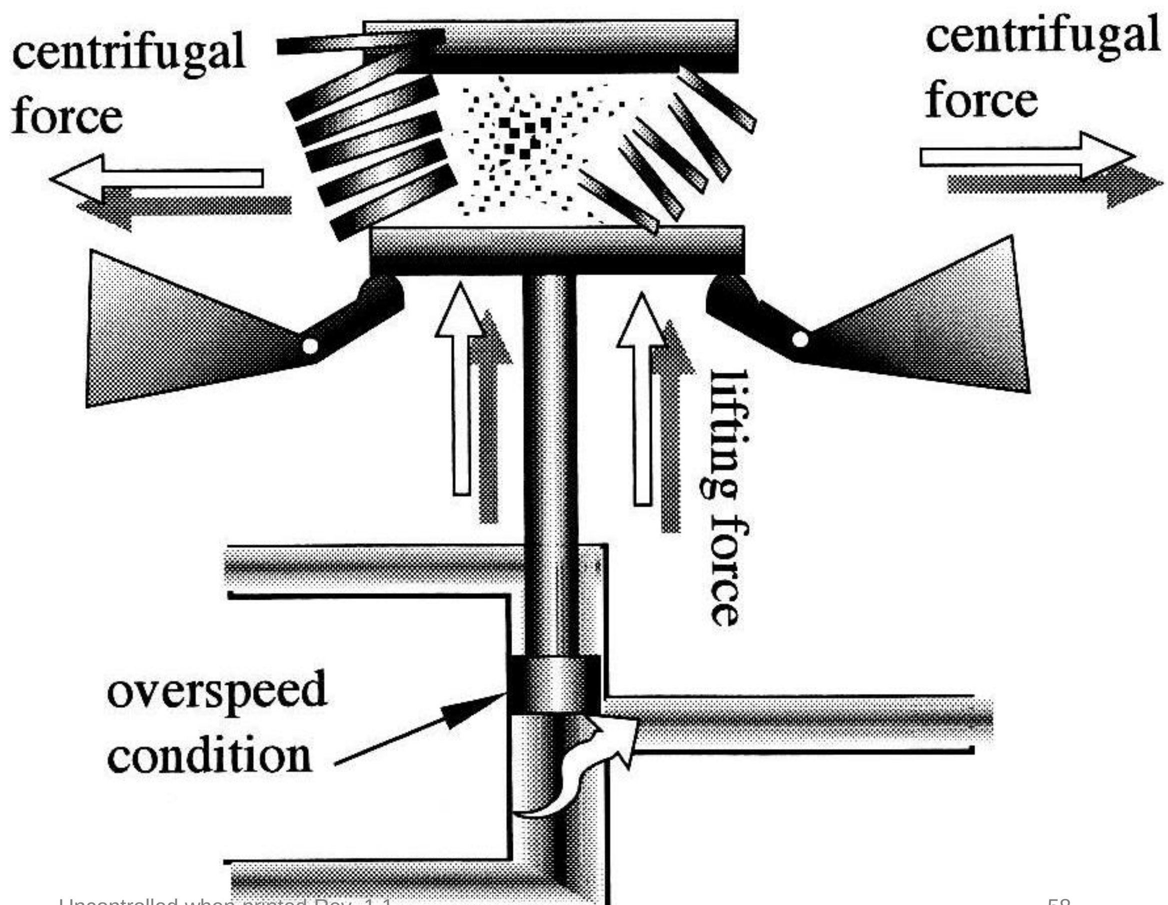
  1. Mc Cauley Type (non-counterweight)

  2. Hartzell Type (counterweight)

Propeller Malfunctions – Failure of Speeded Spring

Mc Cauley Type AND Hartzell Type

- If the speeder spring were to fail, then there would be no resistance against the centrifugal force of the flyweights
- This means the propeller would falsely assume an "overspeed"
- The pilot valve would move upwards and oil would flow into the propeller hub
- This will move the blades to coarse pitch, resulting in a rapid **drop in RPM** and **degraded performance**



Propeller Malfunctions – Loss of Oil Pressure in the Hub

Mc Cauley Type

- **CTM** plus a **spring in the hub** want to rotate the blades towards **fine pitch**

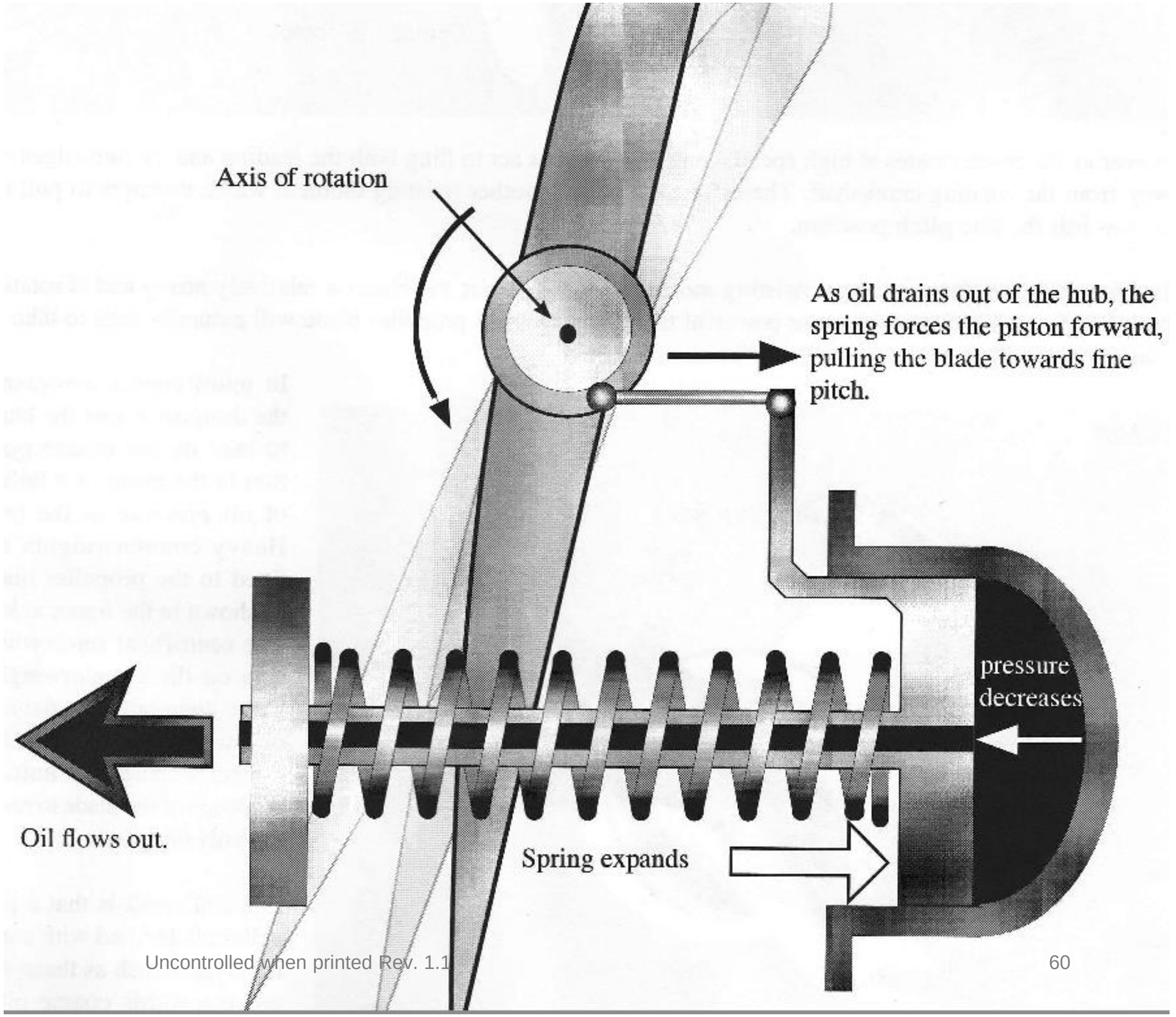
- **ATM** plus **oil pressure in the hub** want to rotate the blades towards **coarse pitch**

- This type is often found on single engine aircraft

Propeller Malfunctions – Loss of Oil Pressure in the Hub

Mc Cauley Type

- If oil pressure is lost, CTM plus the force of the spring in the hub rotate the blades towards **fine pitch**
- This would cause a rapid increase in RPM – leading to a "runaway propeller"
- To avoid overspeed, reduce power and airspeed immediately



Propeller Malfunctions – Loss of Oil Pressure in the Hub

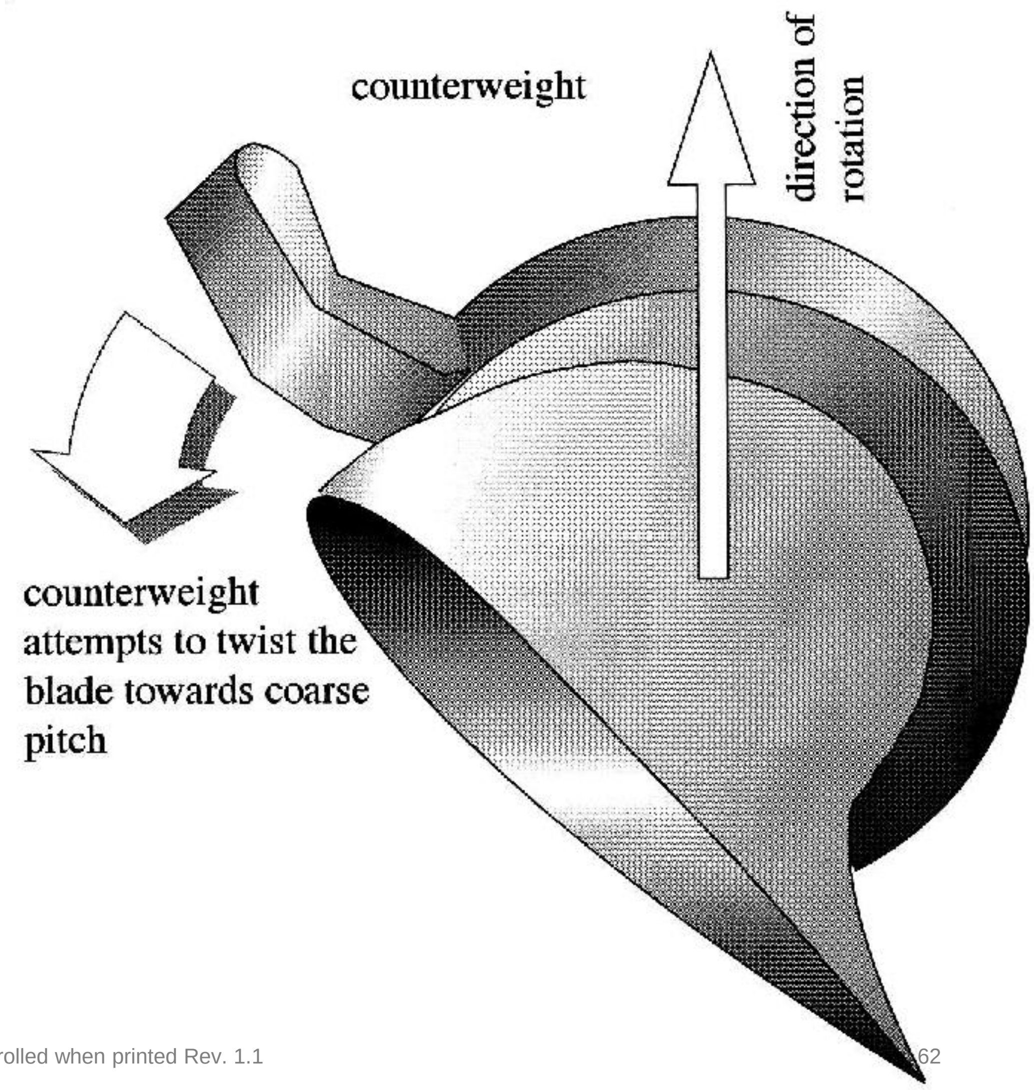
Hartzell Type

- **CTM** plus **oil pressure in the hub** want to rotate the blades towards **fine pitch**
- **ATM** plus **counterweights on the blades** want to rotate the blades towards **coarse pitch**
- This type is often found on multi-engine aircraft

Propeller Malfunctions – Loss of Oil Pressure in the Hub

Hartzell Type

- If oil pressure is lost, CTM will try to rotate the blades towards fine pitch
- However, the counterweights attached to the propeller blades are designed to overcome CTM
- ATM plus the counterweights will overcome CTM and the blades will rotate towards **coarse pitch**



Feathering

- **In multi-engine aircraft** with a **feathering** capability, the system is always set up so that an **oil pressure failure** in the hub will move the blades towards **coarse pitch** (just like the Hartzell Type)

- If one engine fails in a multi-engine aircraft, the **"dead engine"** produces h**igh amounts of drag** whilst it is still spinning, making control sometimes impossible

- The propeller's rotation can be stopped by "feathering" – moving the pitch to fully coarse and into the feather position

- The blades will rotate so that the chord line is parallel to the relative airflow, causing the propeller to stop **"windmilling"** and remain stationary

- This will reduce drag and make asymmetric control possible

https://www.youtube.com/watch?v=HCaTefEODiE