CHAPTER 9 – PROPELLERS

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PROPELLERS – How lift is generated

Lift Generation

Lift is produced by air passing over the aerofoil cross section of a wing.

The aerofoil shape is deeper on top and thinner underneath; the shape of the wing varies for the type of aircraft it is fitted to. Generally, thicker wings are used for relatively slow flying transport aircraft, thinner wings are used for high speed combat type aircraft.

The air passing over the top surface travels further than the air travelling underneath the aerofoil, therefore it has to travel faster. Faster moving air has a lower pressure.

The lower pressure above the wing compared to the pressure below the wing forces the wing upwards, this is called LIFT.

All that is required is the design of the wing aerofoil and the speed it passes through the air provides enough lift to overcome the weight of the aircraft.

Keep the aircraft moving forward and it flies.

Aerofoil Angle

Lift is increased when the aerofoil is inclined upwards at the front. Typically, a deep transport type aerofoil shape produces more lift (i.e. is more efficient) when inclined upwards by approximately 4 degrees.

The difference between the direction of travel (flat when flying straight and level) and the inclined angle (measured at the chord line – the longest distance between the leading edge and the trailing edge in a straight line) is called to ANGLE of ATTACK.

It is important to maintain the most efficient Angle of Attack for fuel economy during long flights.

Decreasing the Angle of Attack at a set speed means the aircraft will sink.

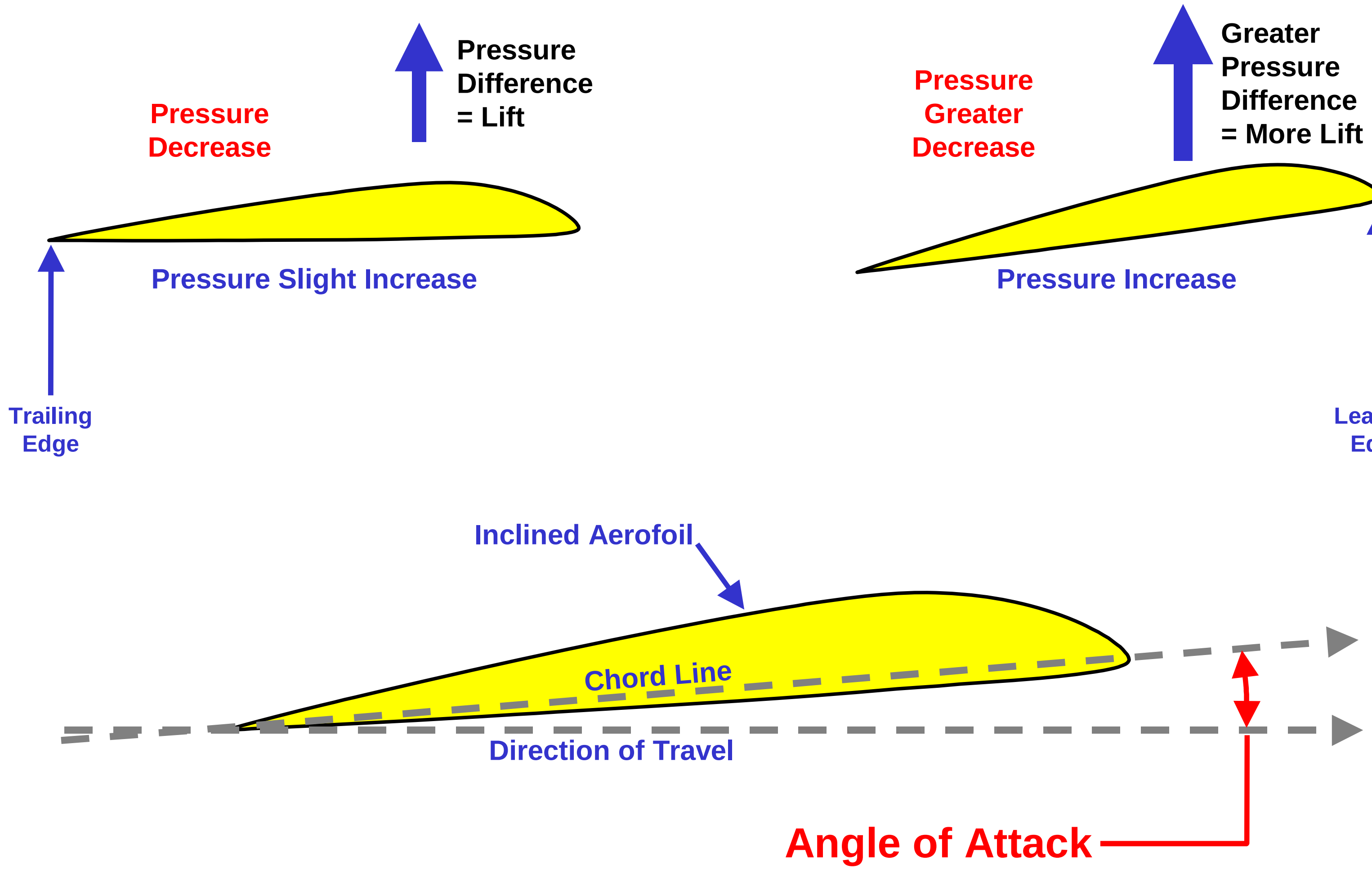
Increase the Angle of Attack too far and the airflow over the wing will break away causing the lift to reduce drastically to almost zero; this is called STALL, in this condition the aircraft will literally fall out of the sky.

How does all the foregoing apply to Propeller Blades?

A propeller blade produces lift exactly the same way as a wing, except it is called THRUST, i.e. the force which propels the aircraft forward.

It needs to be kept operating (flying) in the most efficient angle of attack, just the same as a wing, in order to produce the most thrust.

The direction of flight, however, is slightly more complicated, because the propeller spins in the vertical attitude *as well as* flying in the same direction as the aircraft – the direction of travel for a propeller blade is called a HELIX.



How lift is produced by a Wing

PROPELLER SYSTEM

PROPELLERS – Helix Angle

How the Helix Angle is produced

As the aircraft is pulled forward the propeller blade spins at high speed, this can be around 1000 rpm.

The resulting path the blade tip cuts through the air is like a coil spring or screw thread. This spiral curve shape is called a HELICAL.

Three features effect the helical shape: -

1. Aircraft forward speed.
2. Propeller rpm.
3. Propeller diameter.

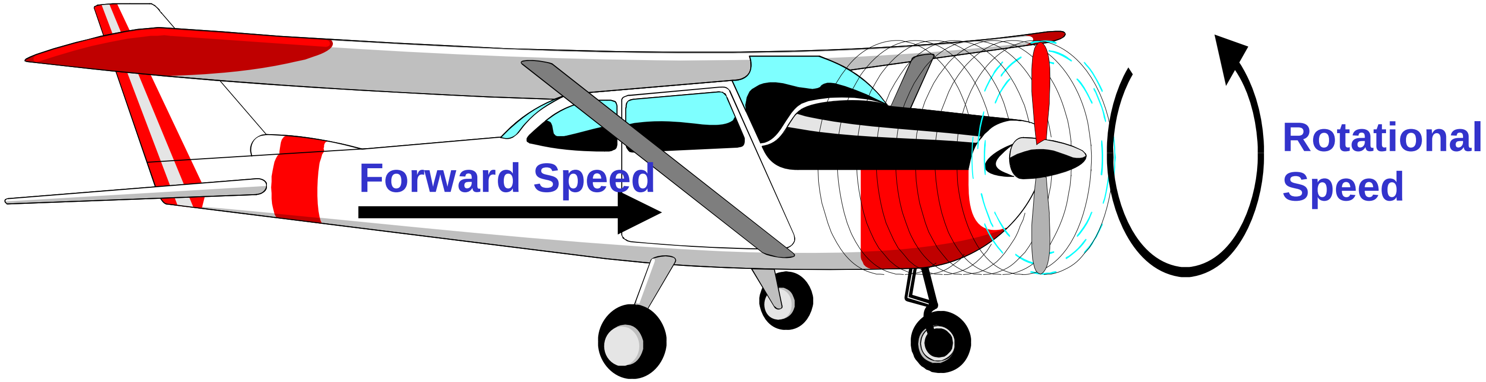
The Helix Angle

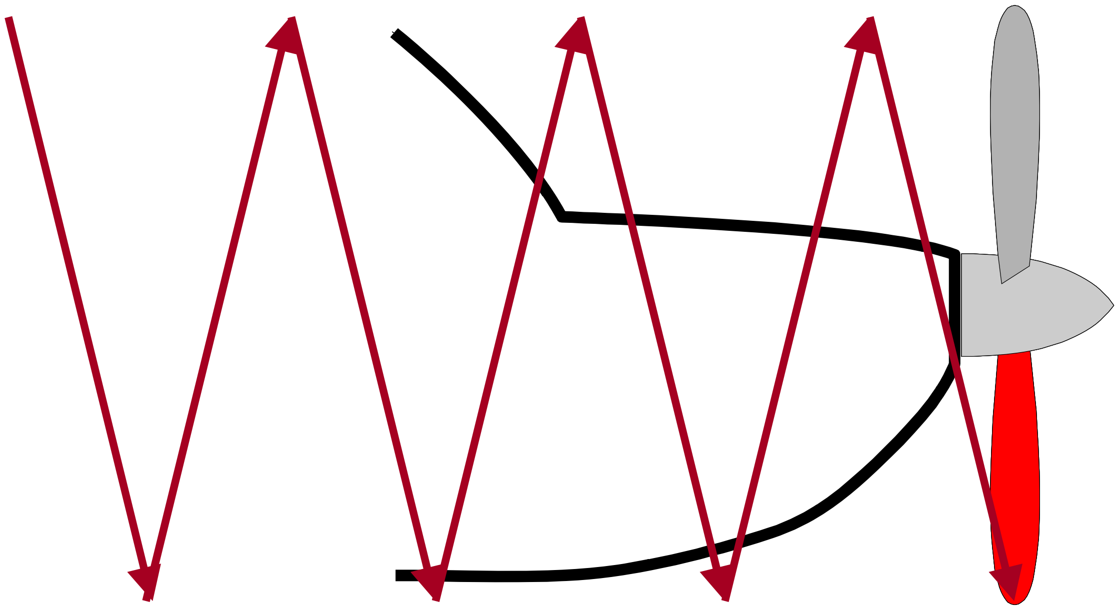
If the helical shape is viewed from the side, it can be seen that in the time it takes for the blade tip to travel from the top to the bottom of its rotation, it will also have travelled forward by a small amount.

Note: Although the blade tip is used in this (and most explanations), this principal is the same for any part along the length of the blade.

The Helix angle is a straight line drawn to illustrate the path of the blade tip compared to the static (i.e. no forward speed) vertical rotation line.

The helix path is actually the direction of travel for the propeller blade aerofoil, just as the line of flight is the direction of travel for the aircraft wing.





How the blade tip travel produces the HELIX ANGLE

PROPELLER SYSTEM

PROPELLERS – Blade Angle of Attack and Helix Angle Changes

Angle of Attack

The propeller blade needs to be set at the correct Angle of Attack to ensure maximum thrust (lift) is produced for the minimum fuel consumption.

The Angle of Attack can be changed by changing the rpm or the forward speed.

Note: Although the propeller diameter effects the Angle of Attack at the tip of the blade, it is fixed by design i.e. there are no *variable diameter* propellers, so this feature is regarded as a fixed dimension.

Changes to the Helix Angle

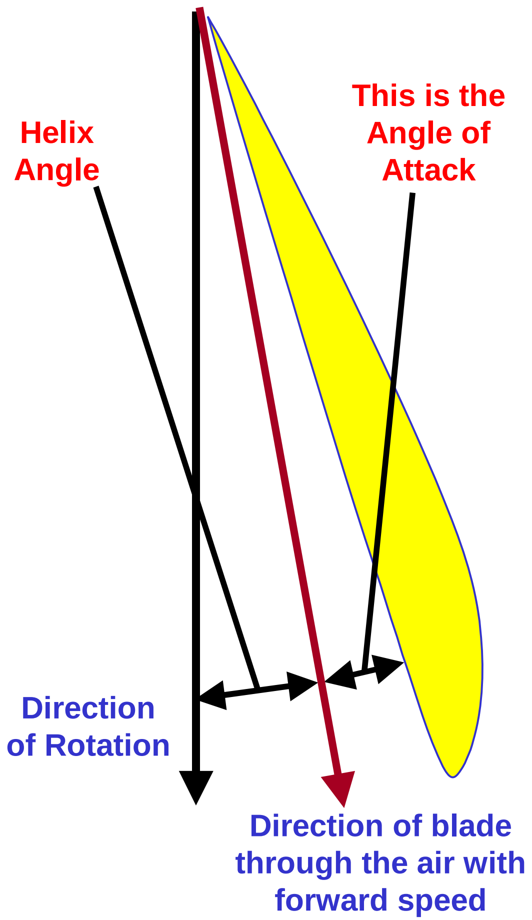
It can be seen from the graphs on the right in the diagram below that, at an rpm the helix angle is as shown by the red arrows. If rpm is increased, it can be seen that the helix angle has been reduced.

Similar effects happen at a fixed rpm, when changes in forward speed occur. Forward speed can be changed simply by going into a diving or climbing manoeuvre.

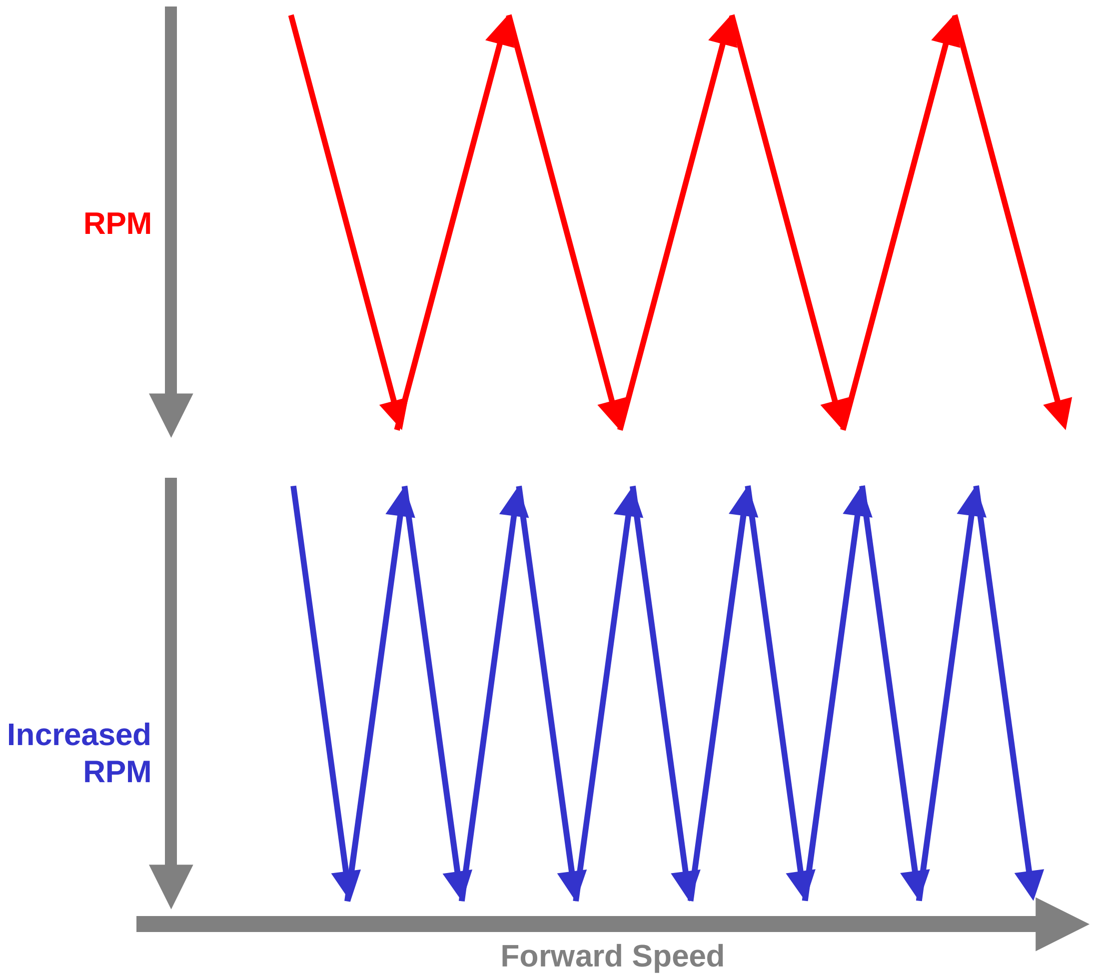
Fixed Pitch and Variable Pitch propellers

With fixed pitch propellers, changing the rpm or forward speed will change the Angle of Attack, but unfortunately the blade does not pass through the air at the correct angle. Therefore inefficient operation occurs i.e. either increase in drag or a stall results.

Variable pitch propellers were introduced the alleviate this problem, and provide other advantages.



How lift is produced by a Propeller Blade



How an increase in RPM changes HELIX ANGLE

PROPELLER SYSTEM

PROPELLERS – Variable Blade Angle Mechanism

Description

The variable pitch propeller is a mechanism by which all the blades on a propeller hub can be rotated about the blade centre axis, whilst the propeller is spinning.

All the blades on the hub are connected to a piston by connecting links so that as the piston moves, all the blades rotate by the same amount. The links are adjusted so that all the blade angles, at any point in the rotation of the blades, is identical.

The piston, mounted centrally in the propeller hub, can be moved manually directly from a lever in the cockpit through a slip ring mechanism, or it can be moved automatically by hydraulic pressure as in the case of the 'Constant Speeding Variable Pitch Propeller' system. This is described in the section CP02 PCU.

Propeller 'Stops'

For flight safety reasons, mechanical stops are designed into the mechanism to prevent the propeller pitch going into a dangerous pitch angles for various stages of the flight.

For instance, it would be catastrophic for the flight if a propeller moved to either a fine pitch (top diagram below) or a coarse pitch (bottom diagram).

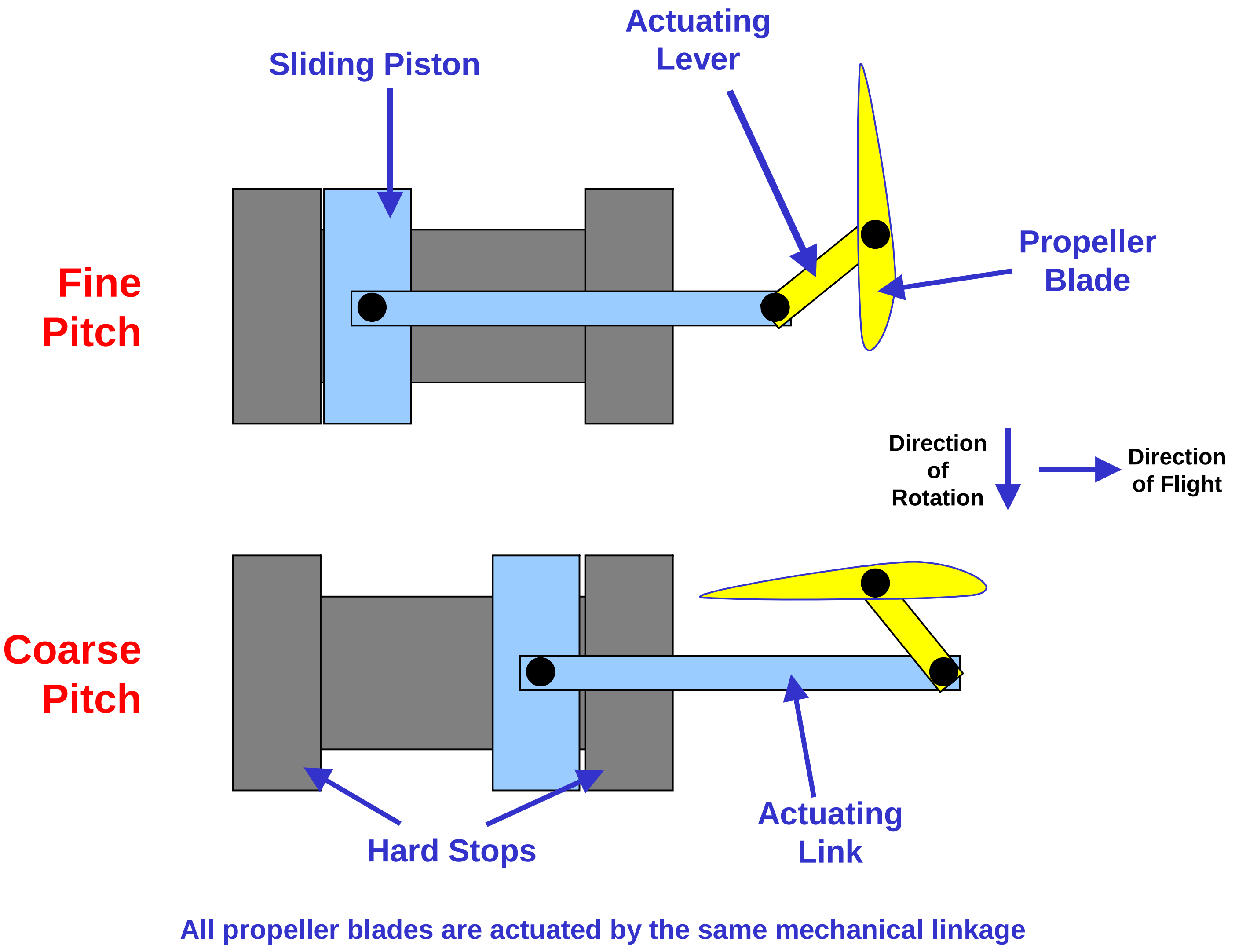
At a cruise rpm throttle setting, a sudden move to fine pitch would cause the engine to overspeed and be in danger of disintegrating.

At the same throttle setting, a sudden move to a coarse pitch would cause the engine to slow down losing thrust, and risk burning out the turbine in the case of the turboprop.

The mechanical stops or of two types: -

Hard stops which are fixed limits, and not removable.

'Soft' stops. These are mechanical stops which will limit piston movement but can be disengaged by automatic or manual control to allow further movement.



PROPELLER SYSTEM

PROPELLERS – Blade Angles

Various Pitch Angles

The angles the blade turns to are called Pitch Angles, and are shown on the illustration below, with descriptions listed here.

Fine Pitch – Minimum Pitch or Ground Fine Pitch

Controlled by a hard stop, this angle ideal for starting as there is little resistance to rotation, but not ideal for flight as there would be maximum resistance to forward motion.

Flight Fine Pitch

The minimum angle the propeller is allowed to go to during flight. At this position, particularly during descent with the throttle at idle, pitch angle is limited to prevent maximum drag that would occur at full fine pitch. It also allows faster acceleration of the engine during refused landing (go-around).

Controlled by a soft stop which is usually disengaged automatically by the 'weight-on-wheels' switch; a switch activated by final touchdown on landing. After landing the propeller is then allowed to go to fine pitch – also referred to as 'Ground Fine Pitch'.

Cruise Pitch

Can be limited by a soft stop on some systems for similar reasons described above but at higher forward speeds. In such systems the soft stop would be removed by moving the throttle back to idle.

On systems without soft stops this pitch angle represents the minimum angle the blade will be during the cruise phase of the flight.

Coarse Pitch, Maximum pitch or Feathered

In this position there is minimum resistance to forward motion, therefore should in-flight engine failure occur, this is the ideal angle.

The blade is pushed to feathered either automatically and/or manually via a control button on the flight deck. In the engine failed in flight situation, feathering the blade causes the propeller and therefore the engine to stop rotating, thereby minimizing any potential damage.

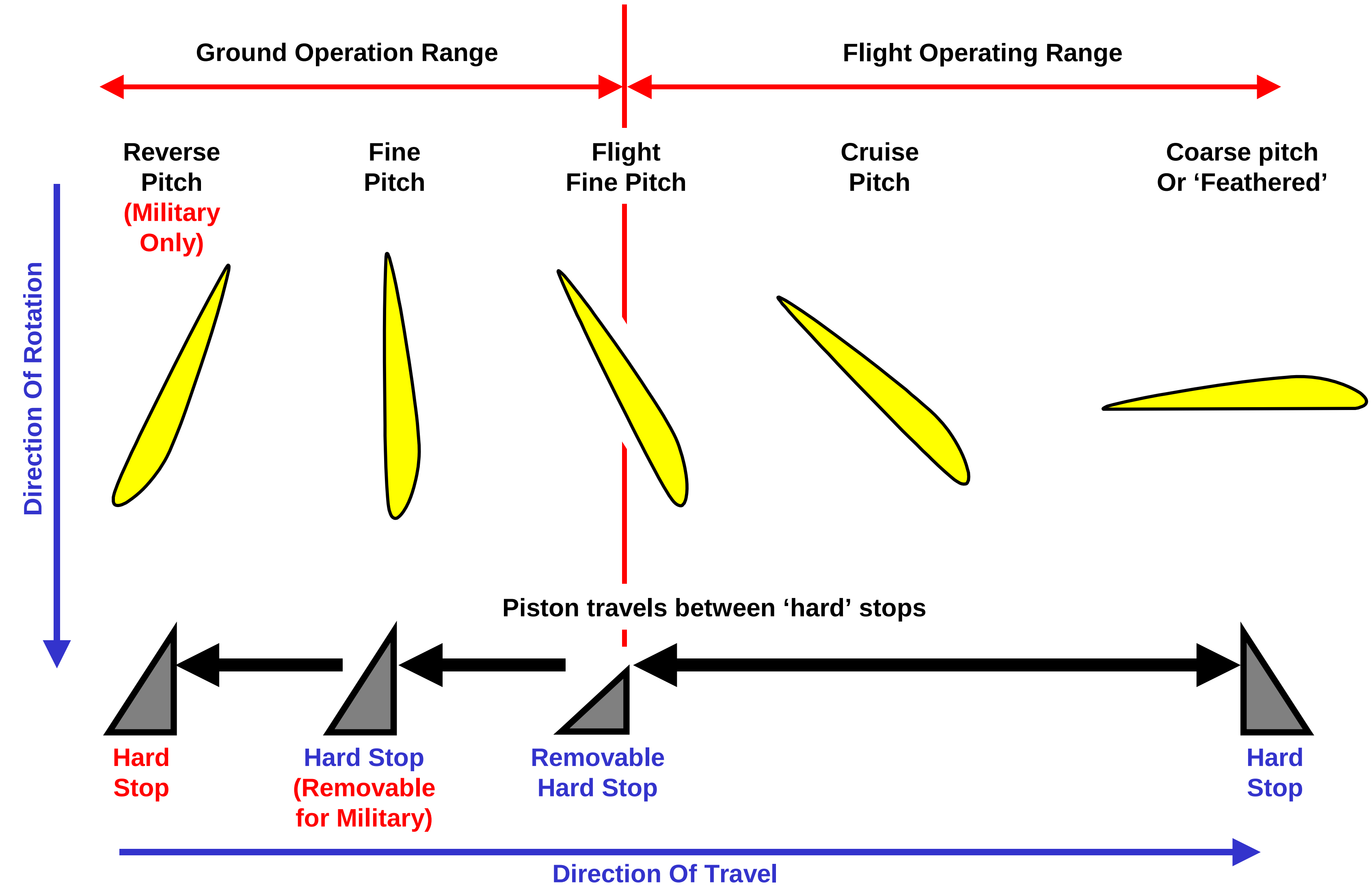
Coarse pitch is not ideal for starting as there is maximum resistance to rotation. Some systems however, the blade automatically goes to this angle on shut down, and is of course there during start initiation. However the blades soon move to the fine position just after rotation occurs.

Reverse Pitch

This is used mainly by military variants to provide short landing roll out. The ground fine pitch stop (i.e. a soft stop) is removed manually by a lever on the flight deck (and released by the weight on wheel switches), and the pitch then goes past fine pitch to provide a reversed flow of thrust, thus increasing the braking effect.

The weight on wheel switch function prevents inadvertent selection of reverse thrust in flight, which could be catastrophic.

Note:- *Hard* stops = not removable
Soft stops = hard stops which *are* removable



Note: - blade angle is relative to piston travel

PROPELLER SYSTEM

PROPELLERS – Blade Twist

Description

The shape of the blade is not constant along the blade length.

The aerofoil is thicker near the root for strength, there is enormous centrifugal forces applied to the root from the weight of the rest of the blade during rotation. Most of the blade is an efficient aerofoil section, with an aerofoil thickness suited for the speed each section travels through the air.

The distance the blade travels during rotation is different at various blade sections along its span. A section at the root will travel less distance than the tip. Consequently the speed, and therefore the direction of travel through the air and the angle of attack, will be different at the root and tip.

The solution is to vary the blade angle progressively from root to tip, i.e. the twist is designed to ensure the direction of travel and angle of attack are correct throughout the span.

Without the twist, a section of the blade such as the mid span position, may have the correct angles for the rotational speed, but: -

A. The tip which is travelling faster will have a negative angle of attack which would cause reverse thrust,

AND

B. The root which is travelling slower would have too great an angle of attack which would cause stalling and drag.

So, any forward thrust produced would be cancelled by the reverse thrust, with the remainder of the blade causing drag i.e. the aircraft wouldn't go anywhere. Any part of the blade not producing thrust efficiently is simply useless excess weight.

Designing blades with twist has been common practice since powered flight began with the Wright brothers. All propeller blades have a twist in them, a 'coarse' angle at the root, and a progressively smaller blade angle, a 'fine' angle towards the tip.

This 'blade twist' allows the blade to maintain an efficient angle of attack along the full length of the propeller blade.

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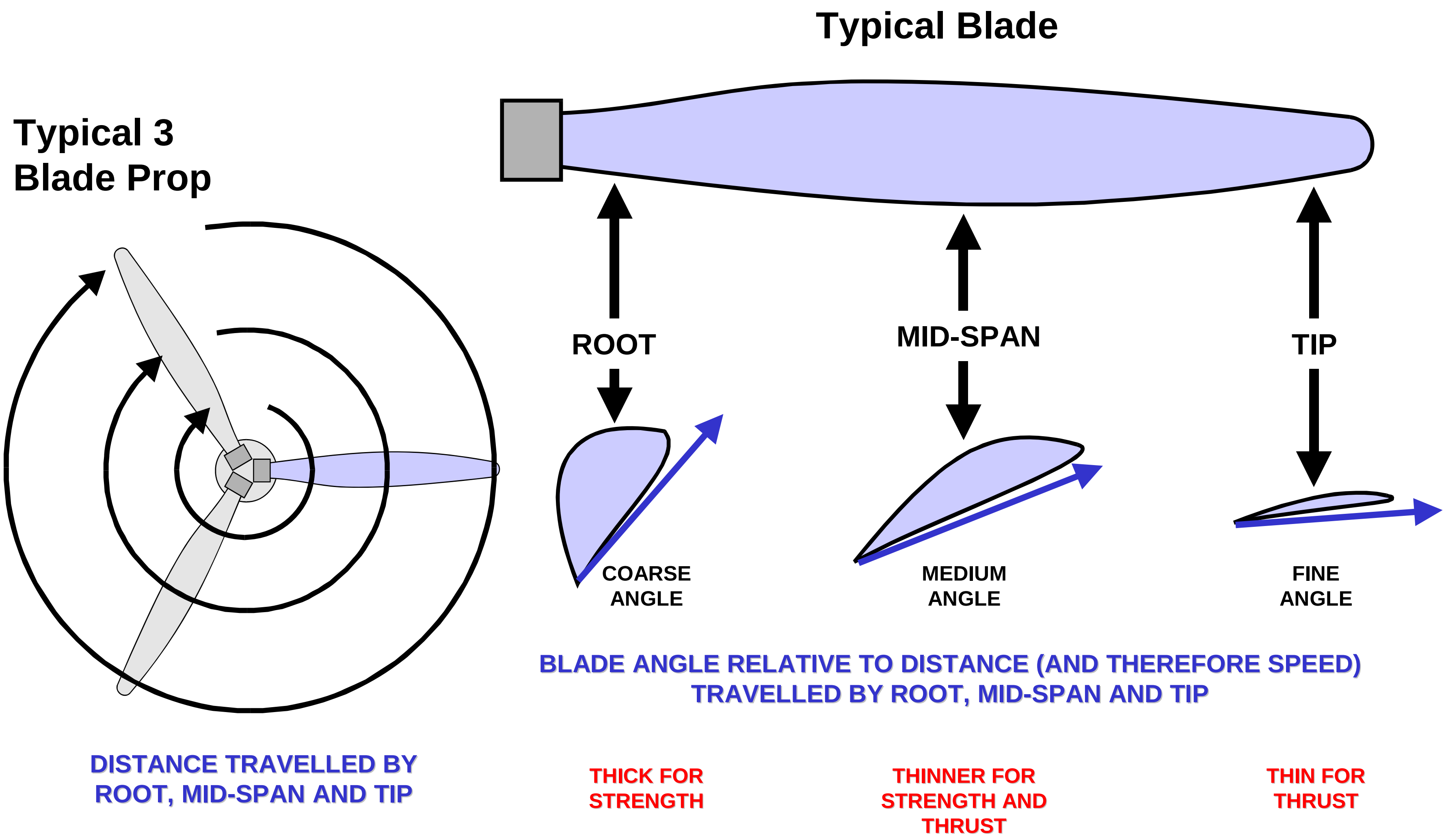

Blade Twist

PROPELLER SYSTEM