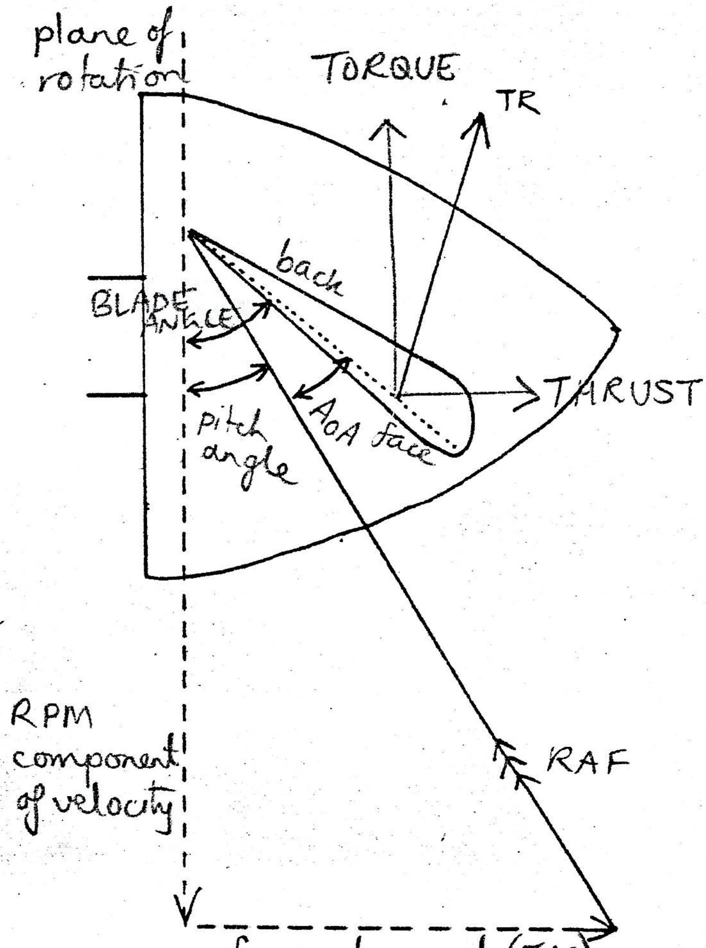
Unit Nine: Propellers

A propeller blade is an aerofoil, with a chordline, camber, angle of attack to the relative airflow etc. It produces a total reaction force as a result of the redistribution of static pressure.

Because the propeller blade passes through the air in a helical (corkscrew) manner so the velocity has a forward component and a rotational component (RPM). This gives a relative airflow as shown.

The total reaction is resolved into a component perpendicular to the plane of rotation; THRUST and one parallel to the plane of rotation; TORQUE.



Angle of Attack Angle between chordline & relative airflow

Blade Angle Angle between chordline & plane of rotation. Fixed if fixed pitch prop. Varied by governor if CSU.

Pitch Angle (helix angle) Angle between relative airflow & plane of rotation.

Pitch distance a blade section moves thru the air in one rotation.

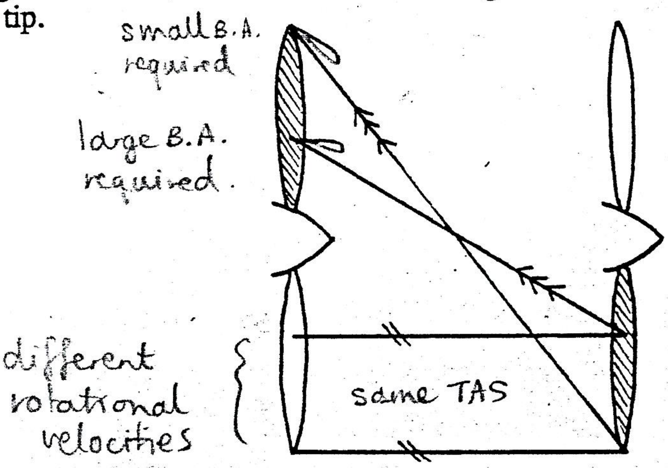
- geometric pitch: theoretical. AoA = 0° ie blade angle = pitch angle
- effective pitch: actual distance moved thru air: always less than G.P. (unless windmilling) G.P. − E.P. = slip.

Efficiency of Thrust Production

Most thrust is produced by the blade section between 60 and 90% of the tip radius. Peak thrust production occurs at the 75% station.

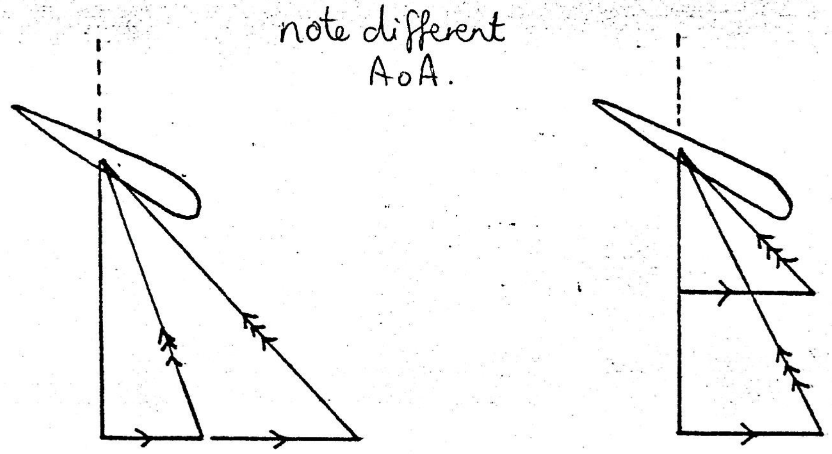
Reason: tips approach speed of sound & compress the air → ↓thrust
hub – thick & close to cowling

Because the different sections of the blade at different radii from the hub have different rotational velocities they have different relative airflows and thus different angles of attack. In order to maintain an efficient (small positive) angle of attack along the blade length the blade is twisted so the blade angle at the hub is greater than the blade angle at the tip.



Propeller efficiency varies with forward speed, RPM and blade angle. For a given blade angle, the variation of angle of attack with forward speed and RPM is as shown:

(a) same RPM, different forward speed (b) same forward speed, different RPM



In either case, when forward speed is small compared with RPM, angle of attack is large.

Unless Blade angle can be altered as RAF changes, AoA will vary a lot.

Power absorbed by a propeller depends on the following factors:

1. Aerofoil section ie thickness, camber etc. Fixed by designer.

2. Number of blades Thrust increases as blade no. increases, up to about 5 blades per shaft - then airflows interfere with each other.

3. Diameter - high aspect ratio → more efficient thrust production - but problems with ground clearance & tip speed.

4. Blade chord As chord ↑ prop can absorb more power, but CTM increases & aspect ratio decreases.

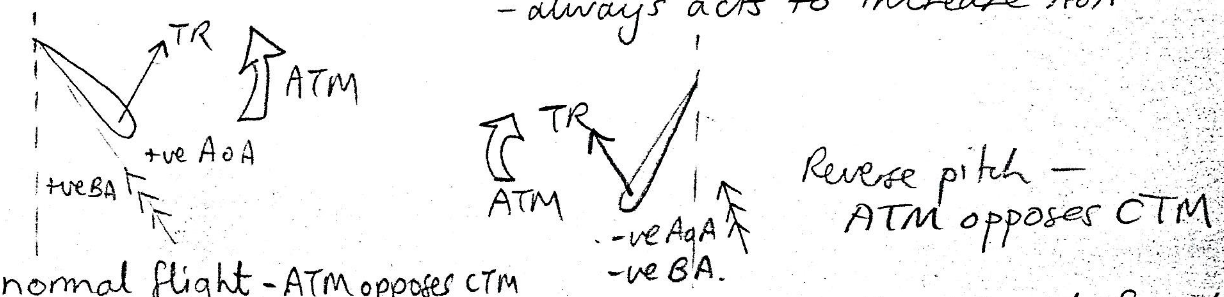
5. RPM Limited by tip speed & centrifugal & torsional loads

6. Blade angle need efficient AoA with respect to R.A.F.

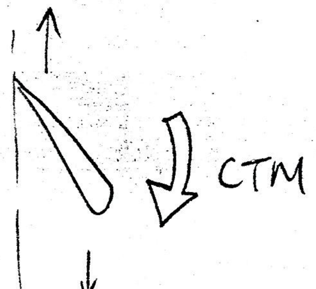
pilot can vary (5, 6)

Forces Acting on the Propeller

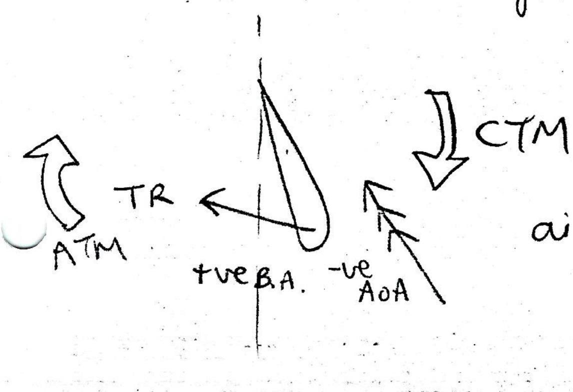
Aerodynamic Twisting Moment (ATM) - due to total reaction (lifts & drags back) - always acts to increase AoA



Centrifugal Twisting Moment (CTM) - due to stretching action of centrifugal force - always acts to reduce BA. to fine pitch.



Windmilling Pitch too fine for airspeed: R.A.F. strikes blade back. ATM reinforces CTM making pitch finer → situation worsens



airflow drives prop.

The coarser the pitch, the less severe the effect of windmilling.

Fixed Pitch Propellers

A fixed pitch propeller has a blade angle which cannot be varied. Therefore the angle of attack varies with TAS and RPM.

A fixed pitch propeller is most efficient at only one RPM-airspeed combination. The propeller is chosen to fit the tasks for which the aircraft is designed, ie its most efficient RPM/airspeed combination is matched to the aeroplane.

Variable Pitch Propellers

The blade angle can be changed by the pilot while the aircraft is in flight, in order to produce an optimum angle of attack. With no constant speed unit, when a certain blade angle is selected, changes in RPM will occur whenever speed or power is altered, ie there is no automatic control of RPM.

Fine pitch high RPM
low torque
small blade angle
advance pitch lever

"frequent small bites"

Coarse pitch low RPM
high torque
large blade angle
retard pitch lever

"fewer, larger bites"

CONSTANT SPEED PROPELLERS

Constant speed propellers are a type of variable pitch propeller with a governor which regulates blade angle automatically to maintain the RPM selected by the pilot.

The blade angle can take up any position between two in-flight limits at the fine and coarse ends of its range. The set RPM is maintained irrespective of power (throttle) or airspeed changes. Provided the pilot conforms with the recommended throttle and pitch settings this will result in high propeller efficiency (efficient angle of attack) in most stages of flight.

If RPM increases, the governor increases blade angle to bring the RPM back down.
If RPM decreases, the governor decreases blade angle to bring the RPM back up.

If a new, higher RPM is selected, the blade angle is automatically reduced to bring the speed up to this new value.
If a new, lower RPM is selected, the blade angle is automatically increased to bring the speed down to this new value.

If power is increased (throttle opened) blade angle will be increased to take a bigger "bite" of the air, to absorb the extra power whilst keeping the RPM constant.
If power is decreased (throttle closed) blade angle will be reduced, to keep the "bites" small and maintain RPM.

If speed is increased for constant power (eg a powered dive) the governor increases the blade angle to prevent overspeeding due to a reduced AoA; the prop then takes bigger "bites" of the air.
If speed is decreased at constant power, the governor decreases the blade angle.

The mechanism by which the blade angle is actually changed, under the direction of the governor, varies with the manufacturer.

Constant Speed Units

1. Single acting: oil pressure is used to alter blade angle in one direction only; other forces (centrifugal, counterweights) alter the blade in the opposite direction.

   * (a) non-counterweight type - centrifugal twisting moment alters blade angle to fine, when oil pressure is relieved
     - high pressure oil alters the blade angle to coarse

     Examples: McCauley & Hartzell props on most modern CSU aircraft.

   (b) counterweight type - high pressure oil and CTM together alter blade angle to fine
     - counterweights alter blade angle to coarse when oil pressure is relieved

     Examples: Decathlon. (better to go to coarse due to oil pressure failure if doing aerobatics)

2. Double acting: a piston is moved within a closed cylinder, with oil pressure applied to one side the piston moves the blade to coarse; applied to the other side it moves the blade to fine, assisted by CTM.

   Examples: Hamilton standard hydromatic propeller - radial engines.

CSU Governors (single-acting, non-counterweight type)

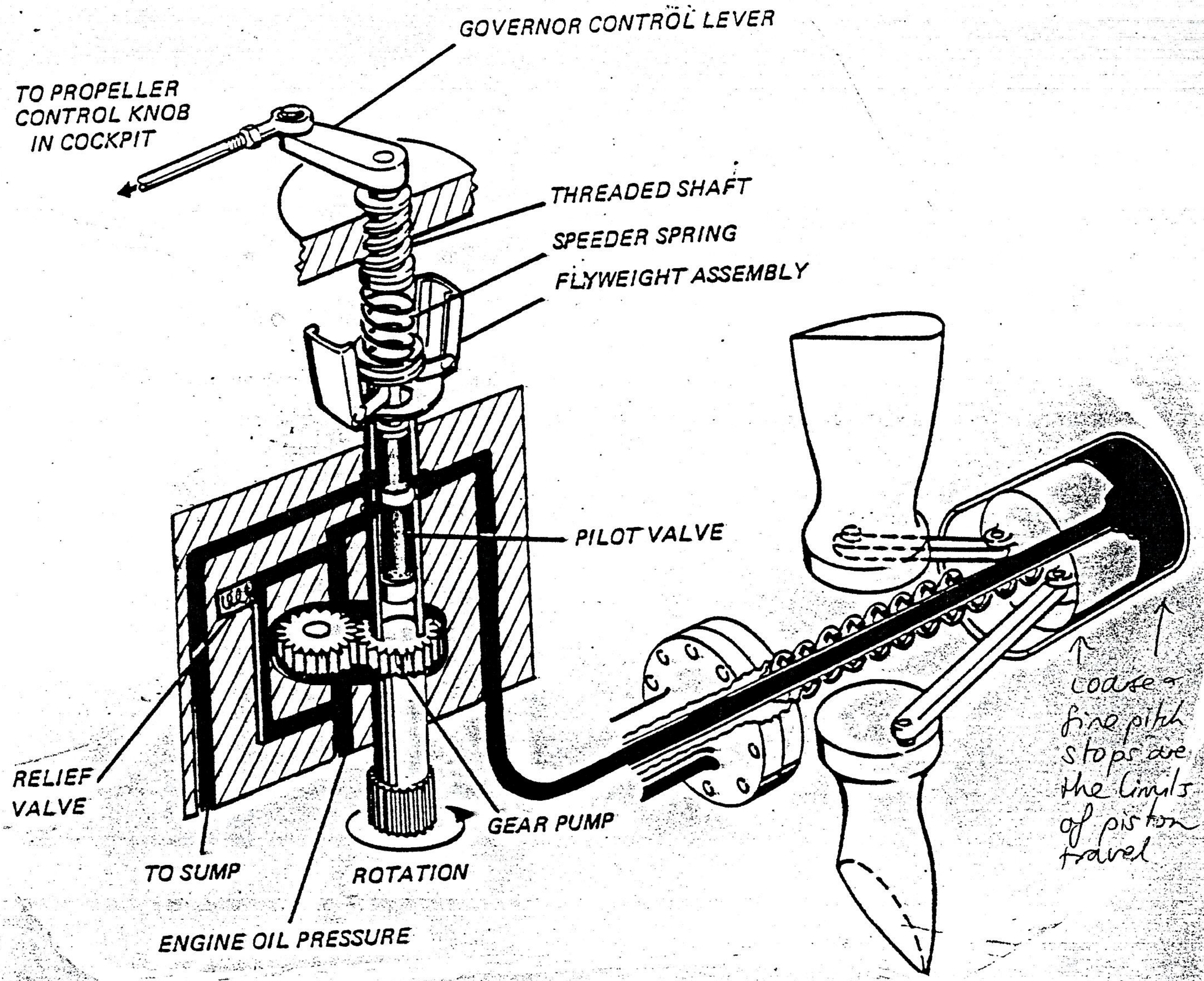
The governor is an RPM sensing device which responds to changes in engine RPM by directing oil pressure out to or releasing it from the propeller to change the blade angle. The governor is set for a specific RPM by the cockpit prop control.

The governor is mounted on and geared to the engine. The engine drives the governor oil pump and flyweight assembly. The rotational speed of the flyweights assembly varies directly with engine speed and and controls the position of the pilot valve. The position of the pilot valve determines whether oil flows to or from the prop to change the blade angle.

The centrifugal force of the spinning flyweights is opposed by a spring force. When the flyweights spin very fast, their centrifugal force is greater than the spring force and the pilot valve moves up to direct oil to the prop to coarsen the blade angle and decrease the RPM. When flyweight RPM decreases, the spring force becomes stronger, pushing the pilot valve down to release oil from the prop. This allows CTM to reduce blade angle to a finer position.

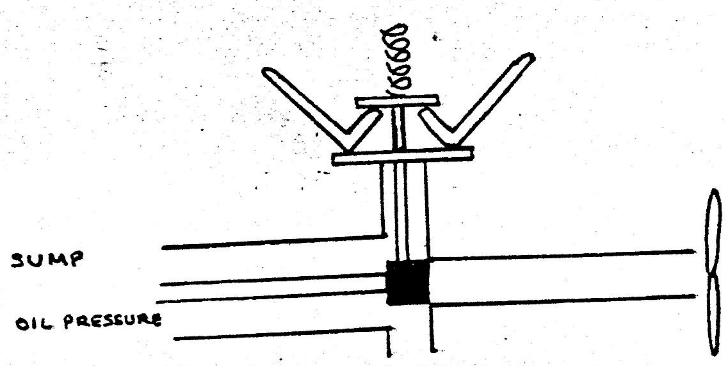
The cockpit control sets the desired RPM by adjusting the spring compression.

Diagram of a CSU governor



The Onspeed Condition

When the engine torque exactly balances the propeller torque, at constant RPM, the propeller blades have been positioned so that they absorb the engine power at the RPM selected. The force of the flyweights equals the spring force. No oil flows to or from the propeller.

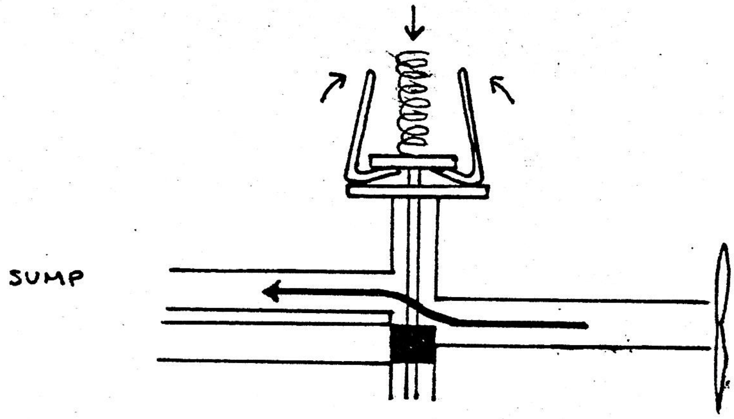


The Underspeed Condition

Caused by - a reduction in forward speed
- a reduction in power
- the initial effect of advancing the prop control

Blade angle is too great; increased RPM is required.

1. Reduced RPM causes a drop in flyweight RPM.
2. The spring force causes the pilot valve to move down.
3. Oil flows from the propeller
4. With the reduction in oil pressure, CTM settle the blade into a finer pitch.
5. The finer pitch enables the RPM to increase to the set value.

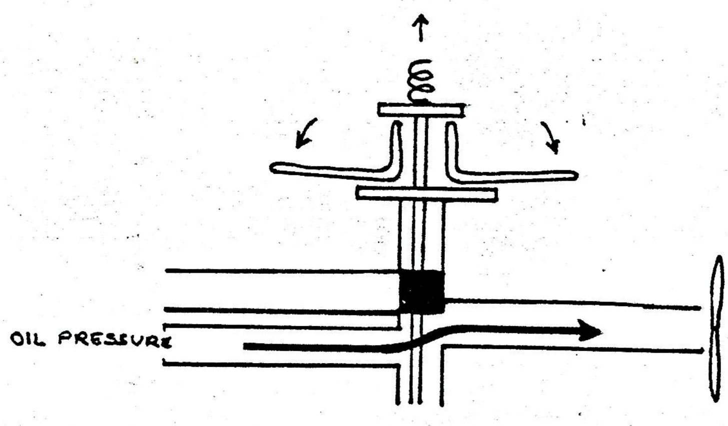


The Overspeed Condition

Caused by - an increase in forward speed
- an increase in power
- the initial effect of retarding the prop control

Blade angle is too small; decreased RPM is required.

1. Increased RPM causes an increase in flyweight RPM.
2. The flyweights raise the pilot valve
3. Oil flows to the propeller
4. Oil pressure moves the blades to a coarser pitch
5. The coarser pitch reduces the RPM to the set value



CSU Applications and Handling

The horsepower which an engine develops is a function of MP and RPM (the P and N parts of PLANK) For constant horsepower, if RPM is decreased, MP must increase. If RPM is increased, MP must decrease. However, with a CSU, for a given pitch lever setting, RPM remains fixed when MP is varied.

Therefore, to increase power: ↑RPM first (MP drops slightly) then ↑MP

to decrease power ↓MP first (to slightly less than desired) then ↓RPM (MP rises slightly.

Throttle	Pitch control	horsepower	MP	RPM	blade angle
set	advance	no Δ	↓	↑	↓ fine
set	retard	no Δ	↑	↓	↑ coarse
advance	set	↑	↑	no Δ	↑ coarse
retard	set	↓	↓	no Δ	↓ fine

Fine pitch stop fully fine used for takeoff, ground handling & runups. Also on final in preparation for go-around. When prop fully fine, changes in RPM can be used for runups to assess mags etc.

Coarse pitch stop

Used for glide approaches to minimise drag from windmilling

Loss of governor oil pressure non-counterweight pitch reverts to fine due to CTM. If counterweighted → reverts to coarse (exam Q)

Propeller Synchroniser used in twins. Off for takeoff & landing.

Feathering – twins. To reduce drag of failed engine.

Reverse pitch for braking, ground run only. Negative B.A. Turboprops.

Preflight Inspection and Propeller Maintenance – chips & nicks will result in cracks. Have them filed.

- Report prop. strikes.
- Care in taxiing over rough ground.