Introduction to Aerospace Propulsion

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Lecture No - 28

Propeller Fundamentals

- A propeller is an interface between an engine and an aircraft.
- It creates thrust for flying an aircraft.

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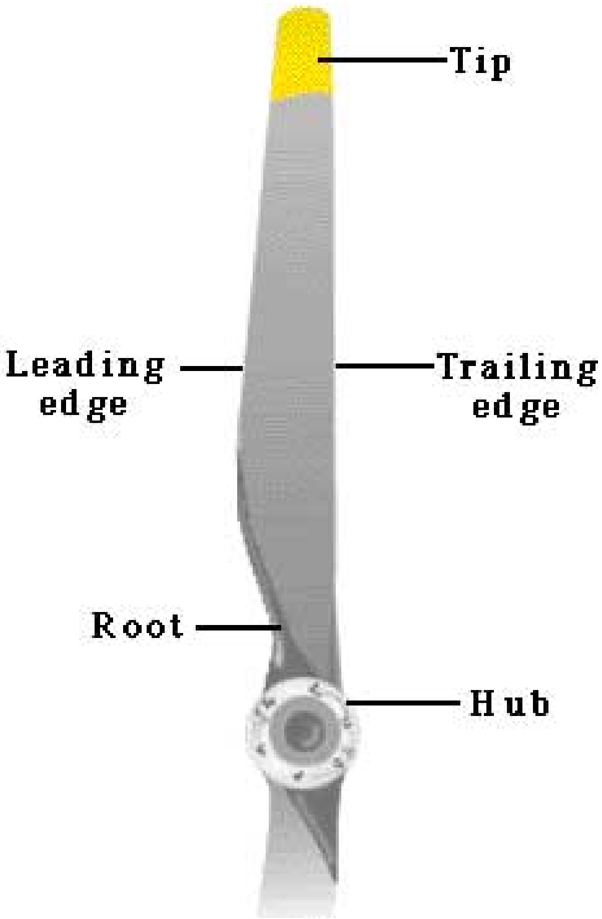
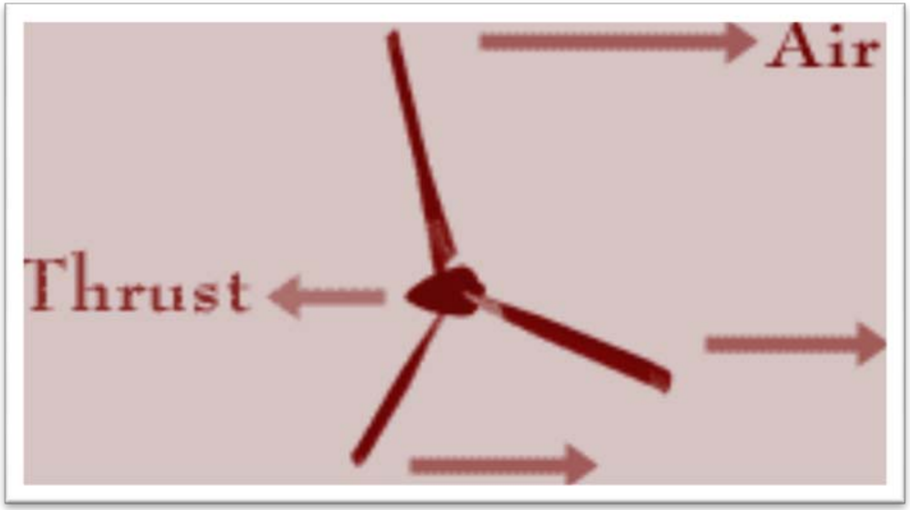
Propeller blade





4-bladed propeller

3-bladed propeller

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- All propulsors moving in air produce propulsive force, called thrust, by effecting a net change in momentum to a propulsive fluid in the direction of motion.
- Propellers create thrust by introducing a small change in velocity to a relatively large mass of air, compared to those of various jet propulsion devices.

$$T_{net} = \dot{m}.(V_e - V_a)$$

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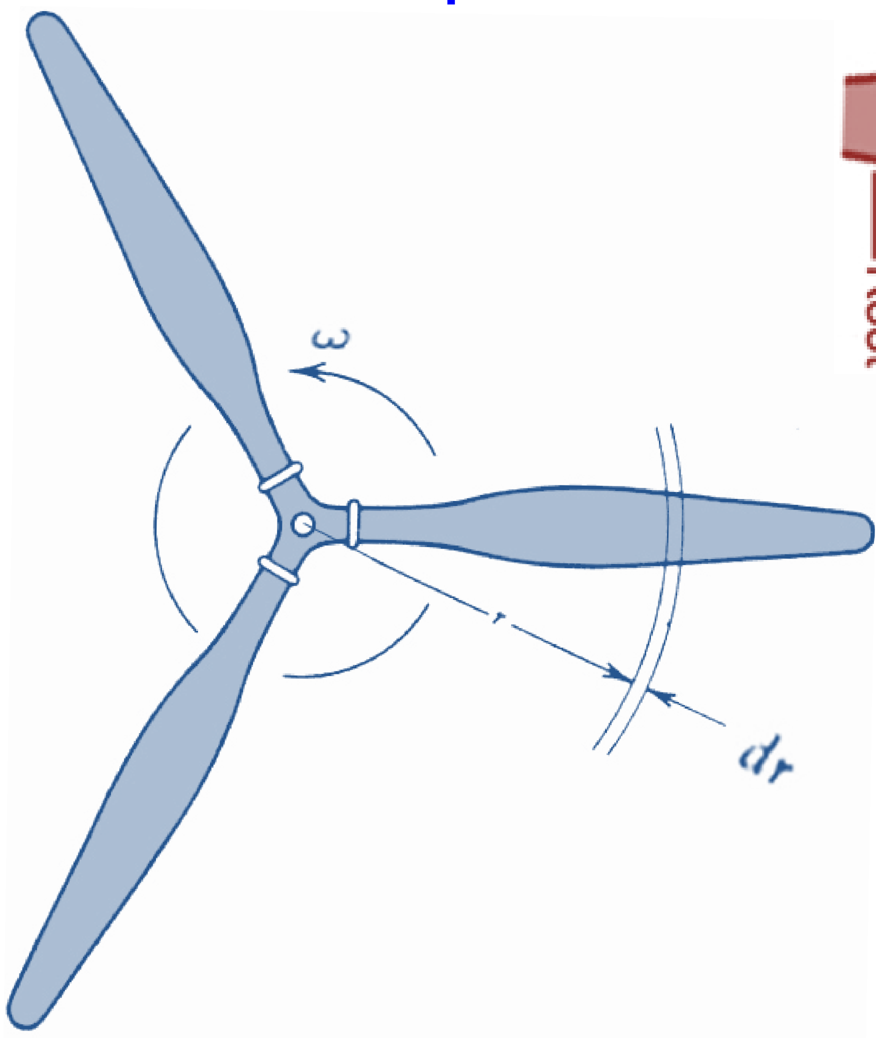
Propeller blades for Thrust



Propellers have 2 or more exactly similar blades, each of which is built up by stacking of airfoil sections radially from the root to the tip

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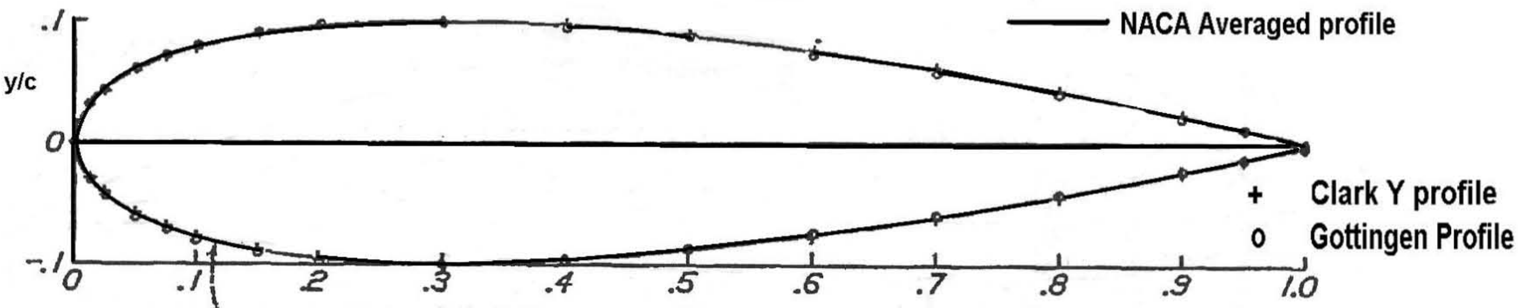
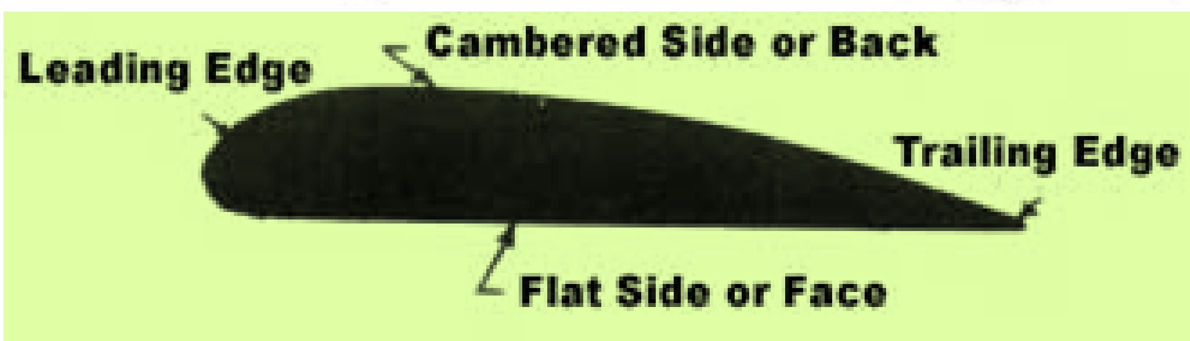
Basic shape (symmetrical) of typical propeller airfoils



$$\pm y = 0.29690\sqrt{x} - 0.12600x - 0.35160x^2 + 0.28430x^3 - 0.10150x^4$$

Basic ordinates of N.A.C.A. family airfoils (percent of chord) *L.E. Radius 4.40 % C*

x/c (%)	0	1.25	2.5	5.0	7.5	10	15	20	25	30	40	50	60	70	80	90	95	100
y/c (%)	0	3.157	4.358	5.925	7.000	7.805	8.909	9.563	9.902	10.003	9.672	8.823	7.606	6.107	4.372	2.413	1.344	0.210



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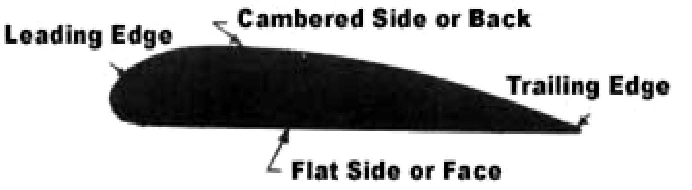
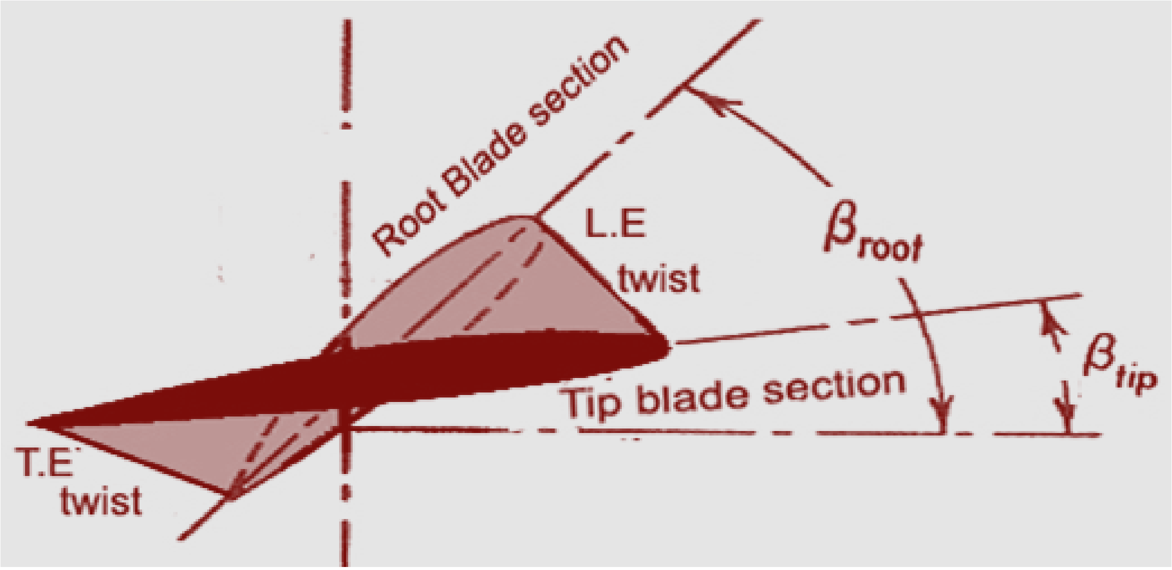
Propeller Airfoil Data

Flat Undersurface Airfoils

	Clark Y		Gö 436		Gö 623		RAF 6E
x	y_U	y_L	y_U	y_L	y_U	y_L	y
0	2.99	2.99	2.50	2.50	3.25	3.25	1.15
1.25	4.66	1.65	4.70	1.00	5.45	1.95	3.19
2.5	5.56	1.26	5.70	0.20	6.45	1.50	4.42
5.0	6.75	0.80	7.00	0.10	7.90	0.90	6.10
7.5	7.56	0.54	8.10	0.05	9.05	0.35	7.24
10	8.20	0.36	8.90		9.90	0.20	8.09
15	9.14	0.13	10.05		10.95	0.10	9.28
20	9.72	0.03	10.25		11.55	0.05	9.90
30	10.00		11.00		12.00		10.30
40	9.75		10.45		11.70		10.22
50	9.00		9.55		10.65		9.80
60	7.82		8.20		9.15		8.98
70	6.28		6.60		7.35		7.70
80	4.46		4.60		5.15		5.91
90	2.39		2.45		2.80		3.79
95	1.27		1.25		1.60		2.58
100	0.10		0		0.30		0.76
LE rad.							1.15
TE rad.							0.76





The blade shaping gives a radial twist which gives a local air angle of attack for each blade section at the 'design' operation. The final blade shape and blade setting are optimized between the 'design point' , various 'off-design points', and an aircraft's flight schedule.

Propeller fundamentals

- The performance of a propeller is dependant on the local aerodynamics on the blade elements, integrated over the blade length.

- For efficient operation each blade element should be at an Angle of Attack, **α,** optimized to a value near the maximum elemental lift to drag (L/D) ratio.

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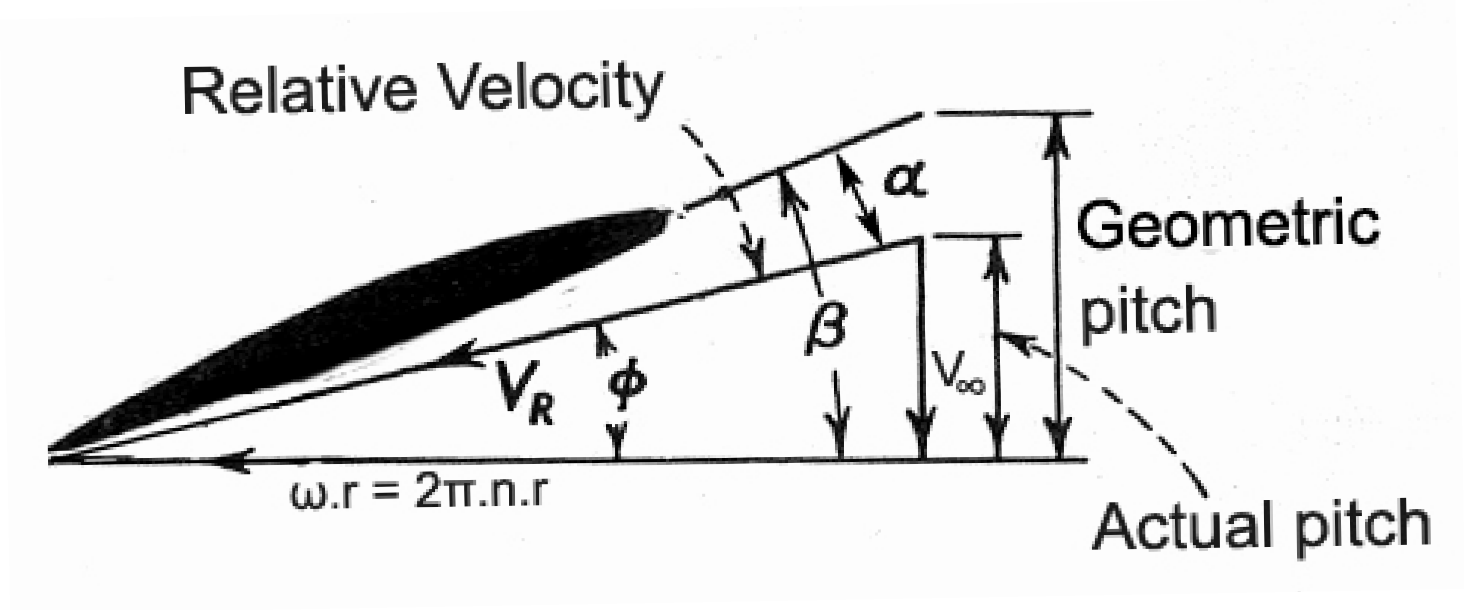
Propeller blade --- sectional geometry and local flow details



$$\textit{Geometric Pitch}, \quad p = 2\pi r.\tan\beta$$

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Propeller fundamentals

- The AoA (**α**) is a function of the blade element geometric pitch (blade setting) angle, β and effective pitch angle (flow angle) ϕ.
- The rotational speed, (**$U = \omega . r$**) of each blade element is different, but as the forward speed, **V_a**, is same, the pitch setting needs to be varied from hub to tip so as to maintain the best AoA for each blade element.

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- The blade section in fig shows that the section makes an angle **β** with the rotational direction, is known as pitch angle (blade setting angle) , defined with respect to either (i) zero lift line, or (ii) chord line, or (ii) the flat undersurface of the blade section.

- The "pitch" refers to the forward movement of the propeller for one revolution of the blade (section).

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- Theoretically, each section of the propeller may have its own pitch value.
- However, <u>since all the blades sections of each blade of a propeller are assembled into one solid body</u>, all the sections must move forward by the same amount per revolution of the propeller.
- Thus, a difference between the <u>*geometric pitch*</u>, ***p*** , for a blade section, and the <u>*actual pitch*</u>, for the same section (when the body of the propeller moves forward) arises.

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- The lift and the drag of a blade element are perpendicular and parallel respectively to the relative wind direction coming on the blade element.

- These may be projected to the forces : *Tangential force* (for **Torque**) and *axial force* (**Thrust**), in the planes normal and parallel respectively to the axis of rotation of the propeller.

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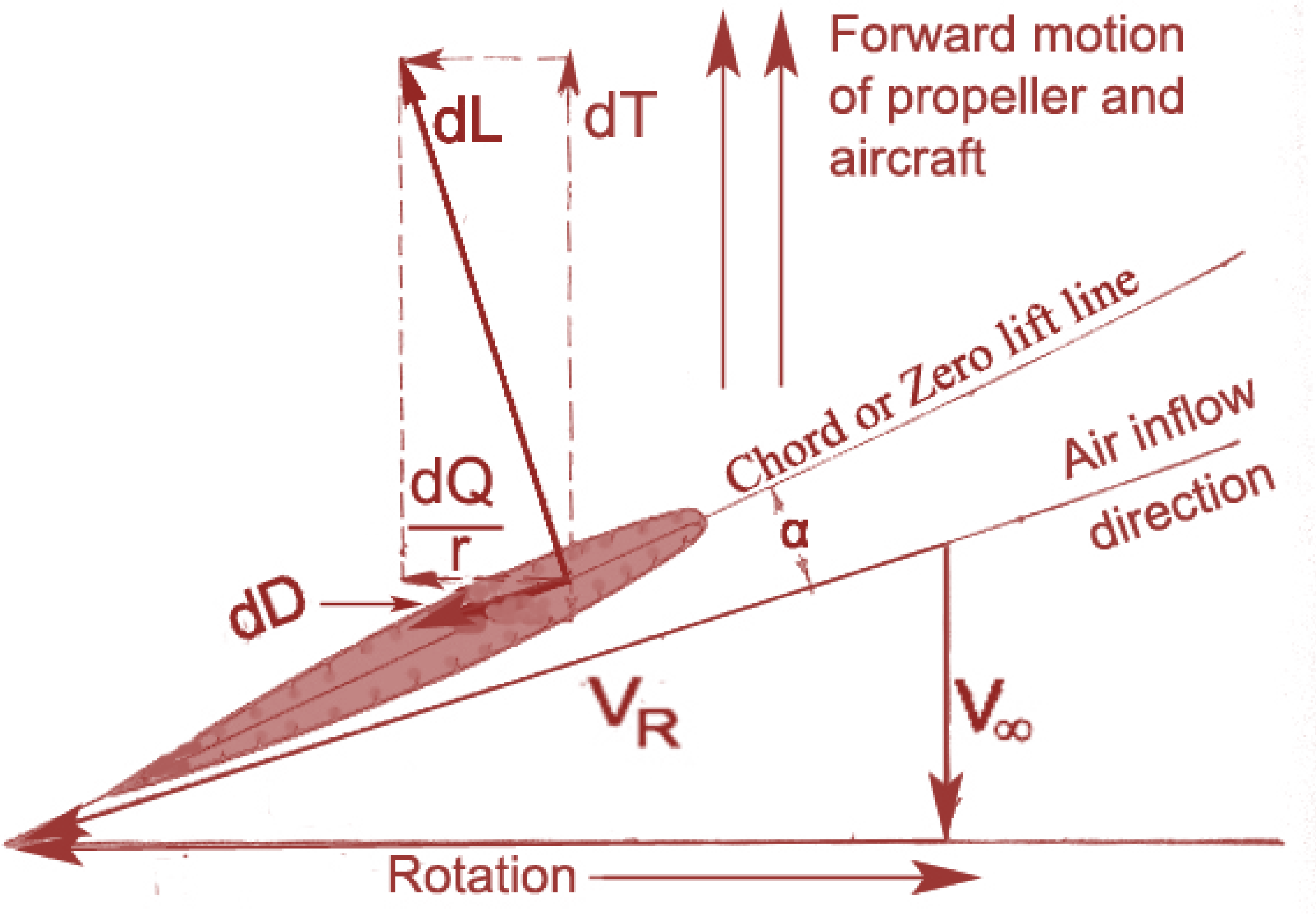
Blade section geometry , local flow details and aerodynamic forces created



L - Lift
D – Drag
T – Thrust
Q – Torque
V_∞ – Forward velocity
V_R – Relative velocity
r – radius
α - angle of attack

There are three Pitch setting arrangements:

- A *fixed pitch propeller*, in which the geometric pitch cannot be varied, must be matched to the various operating conditions of the engine and of the aircraft.
- A *variable pitch propeller*, either variable manually, or through hydro-mechanical control system, usually offer at least two or more blade settings, one fine and the other coarse, to maximize the propeller efficiency, during take-off and during cruise respectively.

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The third Pitch setting arrangement is:

- A *constant speed propeller* --- automatically changes propeller pitch according to a built in control law (floating pitch) so as to maintain proper torque such that the speed of the propeller shaft is maintained constant with the help of a governor and a electro-hydro-mechanical control system. Most modern propellers are constant speed propellers.

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Propeller performance parameters

The *Advance ratio, J* is defined as:

$$J = V_\infty / (n.D)$$

where, V_∞ - Forward speed (of aircraft) m/s,

n - Rotational speed, rps; and

D - Propeller diameter, m.

It effectively captures the forward motion per unit rotational speed.

This goes with the general perception that a propeller executes a screw motion through the working medium and is often referred to as an *airscrew*.

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Propeller performance parameters

The main performance parameters thrust T,, torque, Q and power, P may be defined as follows,

$$T = \rho . n^2 \cdot D^4 . C_T$$
$$Q = \rho . n^2 \cdot D^5 . C_Q$$
$$P = \rho . n^3 \cdot D^5 . C_P$$

where, C_T, C_Q, C_P are the thrust, torque and power coefficients of the propeller, and are the characteristics of the propeller. These are derived using dynamic similarity theories (Pi theorem), much the same way as lift and drag coefficients of an aerofoil are defined.

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Propeller performance parameters

The propeller efficiency is given by the usual output power to input power ratio,

$$\eta_P = (T.V_\infty)/P = (T.V_\infty)/(2.\pi.n.Q)$$

Thus, $\eta_P = J.C_T / C_P$

Where, $C_P = 2.\pi.C_Q$

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Propeller performance parameters

The propeller tip speed is given by,

$$V_{tip,\ helical} = \sqrt{(\{\pi nD\}^2 + V_\infty^2)}$$

- At high tip speeds, compressibility and shocks come in to effect; the shock losses reduce lift and increase drag for the blade elements, unless they are designed for it.
- Metal propellers are limited to M_{tip} of 0.85, and wooden ones are limited to M_{tip} of 0.75.
- Propellers made of carbon composites have crossed the sonic barrier ($M_{tip} > 1.0$) at the tip, with transonic airfoil profiles.

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Propeller Theories