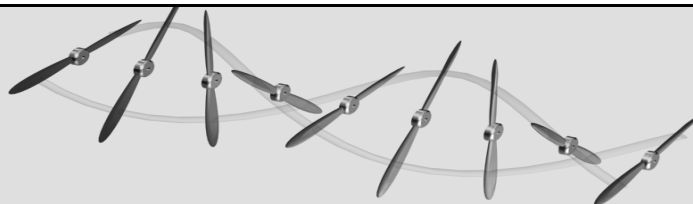


More Propellers

Article from John McGregor



David Charity's articles in the BRA Magazine⁽¹⁾, plus the fact that my neighbour's fourteen year old son, who wants to become an engineer in the R.A.F., has started to ask me awkward questions, prompted me to read more about propellers.

The main reason for my reading further was my failure to comprehend the formula for calculating "Pitch.", or, as Kermode⁽²⁾, (pp 130-133), explained, somewhat belatedly : "Geometric Pitch" Why, in the formula :

$$2\pi r \cdot \tan \theta = p$$

was " $2\pi r$ " used ? To calculate "p" it would be necessary to know the value of θ . To calculate $\tan \theta$ one would need to know the values of p and r. This seemed a circular argument. How would one obtain these values? Martin Simonds⁽³⁾ gives the same diagram but seems to imply that it is simply a useful guide for designing a propeller. Kermode, however, states the formula is "true". It is correct, trigonometrically, but he does not explain what is meant by "true".

Glauert⁽⁴⁾, who wrote in 1926, used the same formula as Kermode :-

"If the airscrew moved through the air as through a solid medium, the advance per revolution would be $2\pi r \cdot \tan \theta$ and this quantity would define the pitch of the screw."

However, like Kermode, he did not say how to determine the value of " θ " nor why use the formula for the circumference of a circle. So, in an attempt to find answers to my questions, I tried to construct a model, which might clarify matters.

I started with a definition of the helix. Clearly the paths of the different parts of a rotating propeller can be shown as helices. A helix can be described (5) as:-

"A twisted curve whose tangent always makes a constant angle with a fixed line, called the axis of the helix."

It is clear that, the Chord Line of a propeller's aerofoil acts tangentially to the path of the helix. Barnard & Philpott⁽⁶⁾, illustrate this:

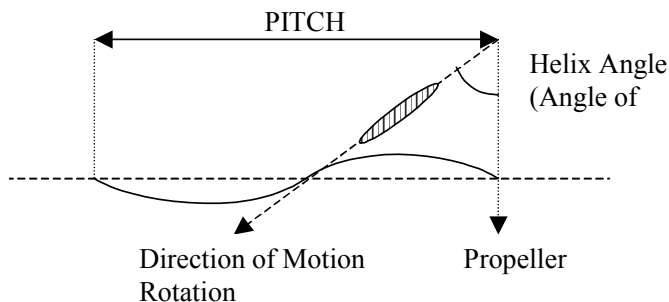
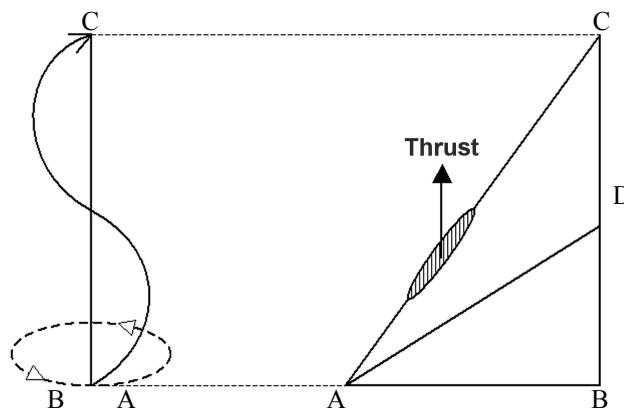


Diagram 1.

This shows the Helix Angle and the actual Direction of Motion of the propeller. (c/f Kermode p130.). I concluded that Zero Angle of Attack should be used, as this would represent Geometric Pitch. (See later.) .

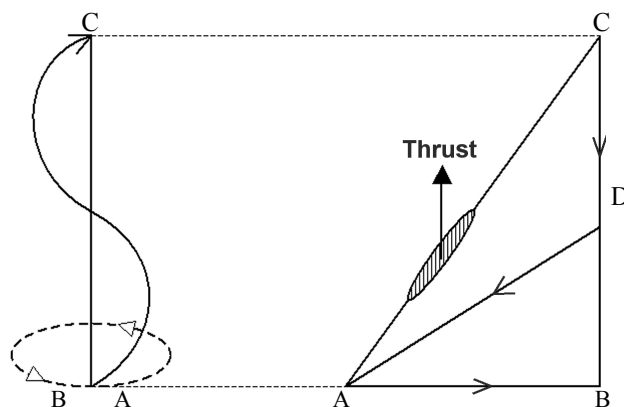
I drew two diagrams (see Diagrams 2a & 2b.), and adopted the following definitions, all gleaned from my Notes⁽⁷⁾.



AB= Blade Circle ($2\pi r$) CAD= Angle Of Attack
AC= Path Of Helix DAB= Angle Of Advance (Helix Angle)
BC= Pitch CAB= Blade Angle

Diagram 2a.

Remembering that the distance a propeller moves forward, in one revolution, depends upon the rotational velocity and the forward, or translational velocity :-



AB= Rotational Velocity CAD= Angle Of Attack
AC= Path Of Helix DA= Relative Airflow
BC= Forward Velocity BD= Advance Per Rev.

Diagram 2b.

GEOMETRIC PITCH :

The distance that a propeller will advance, in one revolution, at zero degrees angle of attack.

(Zero angle of attack is, presumably, a datum point, as aerofoils can generate lift at negative angles of

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attack.)(Glauert wrote :- *".....it is customary to define as the geometrical pitch of the airscrew the value of $2\pi r \tan \theta$ at a radial distance of 70 per cent. of the tip radius."*)

WORKING PITCH :

The distance that a propeller will advance, in one revolution, at normal working angle of attack.

EXPERIMENTAL PITCH :

The distance that a propeller will advance, in one revolution, under conditions of zero thrust.

Constructing the diagrams and adopting these definitions helped my limited understanding of how a propeller works.

Having redrawn the blade circle and helix path as straight lines (see Diagrams 2a and 2b.), I understood why Kermode and Glauert used the formula for calculating the circumference of a circle. However, it did not solve my problem of how to discover the value of the angle θ .

I concluded that the value must have been derived either experimentally or from previous knowledge of the properties of a particular aerofoil. From reading Darrol Stinton⁽⁸⁾ and bearing in mind that characteristics such as pitch, angle of attack and thrust could change, in flight, it was clear that designing anything to do with aircraft was a complex process, involving a series of compromises after having defined a range of desired factors.

Years ago, I asked a man: "Which is the road to Downpatrick?". He replied: " If I were you, I wouldn't start from here! ". Perhaps he designed propellers.

In general, there was a surprising lack of standard terminology. "Relative Airflow " in one book became " Relative Wind " in another. " Angle of Attack " in some could become "Geometric" or "Aerodynamic Angle" in the others. "Blade Angle" became "Blade Pitch" or "Conventional (Rated) Pitch" and "Geometric Pitch" became "Built in Angle of Incidence". Darol Stinton used "Blade Pitch" for "Blade Angle".

The use of the word "Pitch" was particularly confusing. Given that "Pitch" is defined⁽⁹⁾ as (and see Diagrams.) :-

"(Aero.) The distance forward in a straight line travelled by a propeller in one revolution at zero slip...."

it would seem illogical to regard "Pitch" as an "Angle". However, the same reference does go on to say that "Pitch" is :-

".... often colloquially though wrongly applied to the blade incidence."

There was, on the other hand, a high degree of similarity between the diagrams illustrated in the books. But, although the lines might be identical, the words used were, often, not.

However, I did learn a number of other, interesting, facts. I learned, for example, from Martin Simons⁽³⁾, that

Rankine (1820-72) and Froude (1810-79) had, apparently, developed the main principles, in the mid 1800s, while researching into ships' water screws. Surprisingly, Rankine, a Scot, and the Scots are well-known for their dourness, also wrote humorous and patriotic songs.

On the other hand, the American author, J D Anderson Jnr.⁽¹⁰⁾, recently seen on TV, wrote:-

".....marine propellers, which had been extensively developed by 1900 for steamships, were strictly empirical in their design and at best had efficiencies on (sic) the order of 50 percent. There existed no rational hydrodynamic or aerodynamic theory for propeller design at the turn of the century."

He went on to describe how the Wright brothers developed a theory, including the reason for :

".....the necessity for twisting the blade in order to account for the varying relative airflow velocity from the hub to the tip."

It would seem that the brothers had realised the need to maintain the same angle of attack along the whole length of the propeller blade. Interestingly, Anderson noted that, Wilbur Wright carved two propellers, using "a hatchet and a drawknife", which achieved an efficiency of 70 percent.

It might be argued that the ordinary pilot does not need to know such technical details. Personally, I learned a lot from my short search. I hope that those members of the BRA, who know about these things, will set me right. If we do not ask questions, we would still believe that the world is flat.

Which we do.....

Don't we?

John McGregor.

REFERENCES.

Not a comprehensive list, These books were easily available to me.

1. BRA Magazines - March / April and June / July 2003.
2. Mechanics of Flight. - A C Kermode.
3. Model Aircraft Aerodynamics. - Martin Simons.
4. The Elements of Aerofoil & Airscrew Theory. - H. Glauert.
5. The Penguin Dictionary of Mathematics.
6. Aircraft Flight. - R H Barnard & D R Philpott.
7. Various personal notes.
8. The Anatomy of the Aeroplane. - Darrol Stinton.
9. Chambers Science and Technology Dictionary.
10. Introduction to Flight. - John D. Anderson Jnr.

"John McGregor is wrestling manfully with the concept and the mathematics of propeller design - good for him!and good for his neighbour's son too!

To encourage us all, simple propeller design theory should not stretch the maths of an educated fourteen-year-old. We'll have another article on this topic in the next issue of GyroFlight."

- GyroFlight Technical Editor