PROPULSION THEORY

In order to understand the propeller operation, it is simpler to perform the analysis at propeller level rather than at airfoil level.

First, the third Newton law assess : *"If a part A applies a force FA on a part B, The part B applies a force FB on the part A. FB has the same value than FA, the same line of action but the opposite direction".* This law is summarized by "action = reaction" principle.

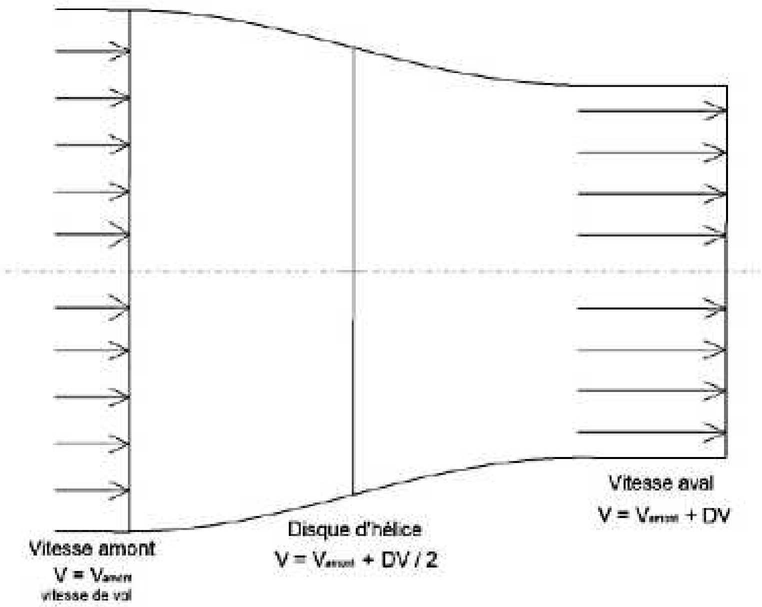
If we want our propeller A use a forward force, it must apply on "B" a backward force. For the aircraft, "B" is the air mass going though the blades swept disc. It is not really a mass but a mass air flow. This "mass air flow" is equal to "disc surface" x "air speed" x " air density".

To apply a force on the mass air flow, blades are like wings. Blade airfoils allow propeller to apply lift forces on air flow. The propeller applies a force on the air flow so the air flow speed is modified.

The difference between the upstream air speed and the downstream air speed is calculated as followed
Delta Velocity (upstream/downstream) = pull / mass air flow
DV = P / dm

from the second Newton law : F = d(m.v)/dt

This speed variation induced by the pull is applied half upstream and half downstream.



Mass air flow is so equal to : Dm = mvo x Sdisc x (Vflight + DV/2)
With :
- mvo : air density (kg/m^3)
- S disc : blades swept disc (m^2)
- Vflight : Flight speed

Some power calculations can be carried out :
- usefull power delivered by the propeller to the aircraft : Pu = Pull x Vflight
- absorbed power : Pa = Pull x (Vflight + DV/2)

So propulsion efficiency factor : rp = Pu / Pa
=> propulsion efficiency factor is an absolute limit which is the design goal for the propeller designer.

Choice of a small diameter for the propeller leads to mediocre performances. And this becomes worst with a low flight speed.

Number of blades may allow reducing the performance loss (see after in the text). But this cannot be enough to reach the performances with an adapted diameter.

Propulsion phenomenon power losses cannot be decreased by the propeller designer. But he must take care not to increase them with a bad pull distribution along the propeller disc. So he must chose the right pitch, chord and airfoil distribution in order to get the optimum lift distribution.
Unfortunately, others energetic losses exist : losses linked to blade drag. Blades are like wings and generate lift and drag.
This drag consists of 2 parts : **friction drag** and **lift induced drag.**

A/ Friction drag on blade airfoils

Drag = 0.5 x Mvo x S x CD x V^2
Blade case is more complex than wing one, because speed is variable from foot to tip of the blade.

At blade foot :
Low speed and small chord lead to ridiculous Reynolds number => airfoil performances are mediocre (high CD and low Clmax)

At blade tip :
High speed and very small chord => Reynolds number remains small.
But as the speed is close to sound one, Mach number is high. High Mach leads to airfoil characteristics degradation. With a small curvature or incidence defect, airflow may become supersonic and so generate noise and degrade performances.

B/ Lift induced drag

The wing has a finite span and so lift generate induced drag. Air speed is constant along the span. Induced drag can be calculated easily at wing level.

For the propeller blade, induced drag modeling is not easy because of the variable speed along the span. For this drag assessment, Helices E-Props engineers don't find adapted calculation method in specialized press or in labs studies reports. So the team has implemented a new and efficient calculation method. Calculation duration is quite long : 90% of the airflow modeling duration is used to define induced effects on blades linked to iterative documentation.

This chapter has listed causes of propeller propulsion energetic losses. Trigonometric aspects of the modeling have not been presented because they are out of scope of this simplified explanation of the modeling process.