Lift generation of forward flying helicopters/rotors

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1 Introduction

The basic difference between helicopter and fixed-wing aircraft is that the the generation of lift, thrust and control is strictly separated for fixed-wing aircraft. In contrast to that the rotor of a forward flying helicopter has to fulfill all three functions [1]:

- generate vertical lift force
- generate horizontal propulsion force
- generate moments and forces to control attitude and position

Nevertheless, the general concept to use airfoils to generate these forces is basically the the same. However, the incident flow is created by the rotation of the rotor blades and not by a straightforward movement through air [2]. This article concentrates on the question how the lift is generated by the rotor, how it can be calculated and which effects this has on the helicopter.

2 Aerodynamics of helicopters

A good way to analyze the aerodynamics of helicopters is to differentiate the various flight regimes. The most basic ones are hover, climb and descent and and forward flight which are explained more detailed in the following. All other complex maneuvers can be obtained by a combination of these. [1]

2.1 Hover flight

As there is only an axis-symmetric flow through the rotor the hover flight is the easiest of the defined flight regimes [1]. Assuming a simplified one-dimensional, quasi steady, incompressible and inviscid flow through the rotor a control volume can be obtained to calculate the flow through the rotor. This control volume is shown in Figure 1. In the hovering regime there is an equilibrium of thrust T and weight W. For the hovering flight applies additionally $T = L$, so that the thrust equal to the lift. With the help of the mass conservation and conservation of fluid momentum one can obtain equation (1).

$$T = W = L = 2 \cdot \rho \cdot A \cdot {v_0}^2 \tag{1}$$

where v_0 is the velocity of the air-stream in hovering flight [3].

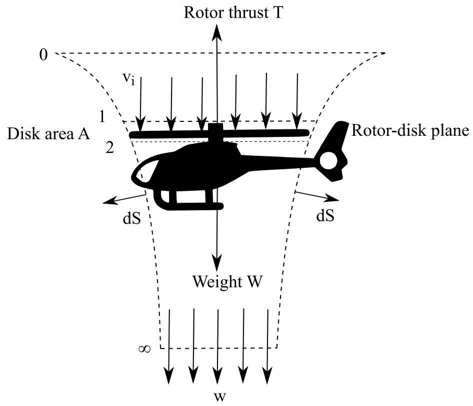

Fig. 1 . Flow model for momentum theory analysis of a rotor in hovering flight adapted from [1]

2.2 Axial climb and descent

By adding a vertical speed V_C (climb) or V_D (descent) to the previous analysis of hovering, the aerodynamics can be analyzed rather easily as axis symmetry is still present. Thrust is, when climbing or descending with constant speed, still equal to the lift. This results in the equations (2). Where v_i is the initial velocity of the air-stream in flight (so just before the air passes the rotors).

$$\begin{aligned} T = W = L = 2 \cdot \rho \cdot A \cdot (V_C \cdot v_i + v_i^2) \\ T = W = L = 2 \cdot \rho \cdot A \cdot (V_D \cdot v_i - v_i^2) \end{aligned} \tag{2}$$

From this it all seems rather easy, but this is just theoretical. In reality vortex flows are present and affect the aerodynamics heavily. Mostly when descending slowly, problems arise since the vortices form and stay around the tips of the blade. This creates vibrations which make controlling the helicopter even harder.

2.3 Forward flight

During forward flight two main differences can be seen in comparison to the hover flight and axial climb and descent situation. The rotors blades have to generate aside from the lifting force also a propulsion force. This propulsion is parallel to the rotors blades. As a result, the blades should be tilted at a certain angle (Angle of attack α). Furthermore, the helicopter experiences a free stream velocity (V_∞) as a result of going forward. Both can be seen in figure 2 and have an influence on the lift calculation as discussed before.

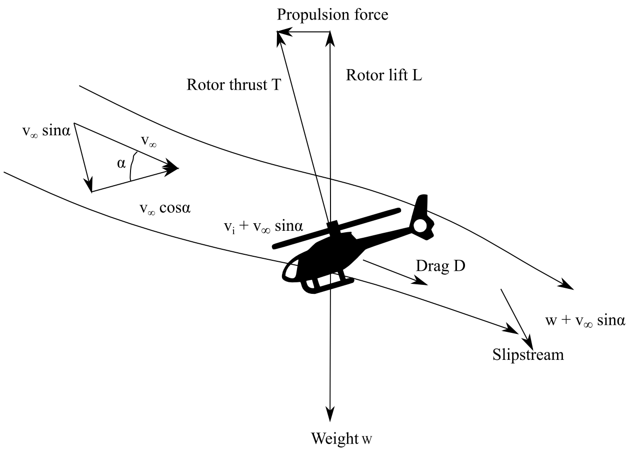

Fig. 2 . Flow model for the momentum analysis of a rotor in forward flight adapted from [1]

To calculate the generated thrust by the rotor blades (3), the local stream velocity (U) at the rotor blades has to be estimated first. The velocity can be determined by equation (4)

$$T = 2 \cdot \rho \cdot A \cdot U \cdot v_i \tag{3}$$

$$U = \sqrt{V_\infty^2 + 2 \cdot V_\infty \cdot v_i \cdot sin\alpha + v_i^2} \tag{4}$$

In comparison to the situation discussed before, the total thrust is not only used to generate lift but also for the propulsion force. The vertical part of the generated thrust is equal to the lift. The horizontal part of the thrust is equal to the propulsion force (figure 2). As a result, the rotor blades need to generate more thrust, as in a hover situation, to maintain the helicopter at a constant height.

3 Ground effects

Concerning the lift generation of a rotor there occur two different forms of lift generation during normal flight and near the ground. These are presented in the schematic sketches in Figure 3 and discussed briefly in the following. Near the ground the air-stream is deflected by the ground. This causes an increasing pressure and a resulting lower velocity in the flow area. Because of the fact that this is an induced velocity there is a less power needed to generate it. This has advantages for take off. [2, 4]

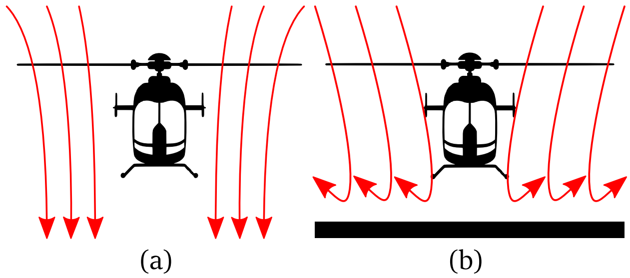

Fig. 3 . Lift generation in normal flight (a) and lift generation near the ground (b)

4 Conclusion

The described effects are only the basic principals of lift generation of forward flying helicopters. The theoretical calculation of the aerodynamics of a real helicopter are considerably more complex than this [1]. At this point for example vortexes of the rotor, rotor flapping or the resulting swinging movements should be noted. See the referred literature for further detailed information.

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