Calculation of helicopter maneuverability in forward flight based on energy method

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Abstract

A new method for calculating helicopter maneuverability in forward flight is proposed. Empirical equations for evaluating rotor required power are employed. Using energy method, an algorithm to calculate the available overloads, rate of climb and flight trajectory is given. The maneuver performance of AH-1G helicopter is investigated and three kinds of maneuvers including level acceleration, deceleration turning and turning climb followed by accelerating climb are calculated and analysed. Numerical results indicate that the method is effective and feasible, even for three dimensional maneuvering problems. In addition, the method can be applied to predict flight trajectory during forward flight.

Keywords: Helicopter, Maneuverability, Energy Method

1 Introduction

With the development of aviation technology, plenty of new roles and missions are assigned for helicopter. Sometimes helicopters were required for rescues and aid in an unknown, dynamic and potentially hostile environment. In order to finish the specified task successfully, helicopters should equip collision avoidance system, which demands real-time and accurate helicopter maneuverability and flight trajectories [1].

Due to the complex helicopter aerodynamics, the maneuvering process need much more time based on the existing method. To obtain the designed performance, energy method is used by a lot of researchers to investigate two-dimensional (2-D) helicopter maneuver flight problems. Basic studies about helicopter required power were conducted in detail [2-4]. Helicopter performances were investigated using energy balance method [5, 6]. Some maneuver characteristics were studied by Xu [7] and Mikhailov [8-10]. Aerobatic maneuvers were analysed in detail based on mathematical description by Cao [11] and Hu [12, 13].

However, there are few researches on helicopter 3-D maneuver using energy method. In this paper, an algorithm based on energy method is described. Using the data of AH-1G helicopter, three kinds of maneuvers are analysed, including level acceleration, decelerating turn, turning climb followed by accelerating climb.

2 Mathematical model

The energy state of a helicopter can be written as:

$$E = \frac{1}{2}mV^2 + mgh + \frac{1}{2}I\Omega^2 , \qquad (1)$$

where m is mass of helicopter, I is total rotor inertia, Ω is rotor rotational speed. By taking the partial derivative with respect to time of equation 1, the energy rate is expressed as:

$$\frac{dE}{dt} = \Delta P = mV\frac{dV}{dt} + mg\frac{dh}{dt} . \qquad (2)$$

2.1 REQUIRED POWER

The rotor power required in forward flight is given by the sum of parasite power, induced power, rotor blade profile power, compressibility power, stall power and climb power [14].

$$\begin{aligned} P_{req,rotor} &= 0.5 f\rho V^3 + TV_i \\ &+ 0.125\delta bcR(1+4.6\mu^2)\rho(\Omega R)^3 \\ &+ \rho\Omega^3\pi R^5\Delta M^3[0.0033 - \Delta M(0.022 - 0.11\Delta M)] \\ &+ \kappa^{1.5}(t_c - t_{cdiv})^{1.5} + mgV_h , \end{aligned} \qquad (3)$$

where f is equivalent flat-plate drag area, ρ is air density, T is rotor thrust, V_i is induced velocity, δ is coefficient of blade drag, b is number of blades, c is blade chord, R is rotor radius, μ is advance ratio, ΔM is the amount by which advancing blade tip Mach number exceeds drag divergent Mach number, κ is a constant coefficient, t_c is thrust coefficient, t_{cdiv} is

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thrust coefficient at which stall power occurs and V_h is vertical velocity. The total power required is obtained by rotor power and overall efficiency factor (η) and

$$HP_{req,total} = \eta HP_{req,rotor} . \tag{4}$$

2.2 PERFORMANCE

Changes in horizontal velocity (V_l) for energy rate (ΔP_1) is determined form the following:

$$\frac{dV_l}{dt} = \frac{\eta_1 \Delta P_1}{mV_l} , \tag{5}$$

where $\eta_1 = \begin{cases} 1 & , \text{when } \Delta P_1 \geq 0 \\ 0.8 & , \text{when } \Delta P_1 < 0 \end{cases}$

The relationship between normal load factor (n_n) and the turn rate ($\dot{\theta}$) is given by:

$$\dot{\theta} = \frac{gn_n}{V_l} . \tag{6}$$

Energy rate (ΔP_2) influences vertical velocity as follows:

$$V_h = \frac{\eta_2 \Delta P_2}{m\frac{dV_h}{dt} + mg} , \tag{7}$$

where $\eta_2 = \begin{cases} 1 & , \text{when } \Delta P_2 \geq 0 \\ 0.8 & , \text{when } \Delta P_2 < 0 \end{cases}$

2.3 ROTOR THRUST LIMITS

The maximum thrust of main rotor is restricted by the available power and maximum thrust coefficient.

$$t_c = \frac{T}{0.5 \rho bc \Omega^2 R^5} \leq t_{c\max} , \tag{8}$$

$$\Delta P_1 + \Delta P_2 + (P_{req,total} - \eta mgV_h) \leq P_{ava} , \tag{9}$$

where $t_{c\max}$ and P_{ava} is maximum thrust coefficient and available power.

2.4 KINEMATIC EQUATIONS

The kinematic equations can be written as follows:

$$\begin{cases} \dot{x} = V_l \cos\theta \\ \dot{y} = V_l \sin\theta \\ \dot{z} = V_h \end{cases} \tag{10}$$

3 Calculation algorithm

Figure 1 presents the algorithm of calculating the maneuverability and flight trajectory. The required data for this algorithm are properties of helicopters, engine output power and control laws.

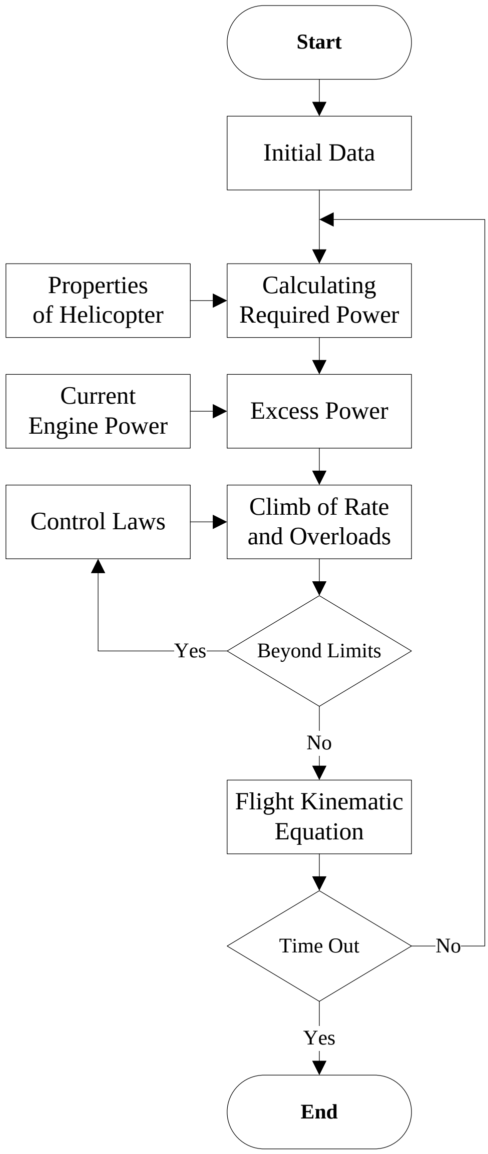

FIGURE 1 Calculation algorithm for maneuverability

4 Examples and results

A program is completed in MATLAB to calculate AH-1G helicopter maneuverability. The properties of AH-1G helicopter [15], which are used in program are presented in Table 1. Three kinds of maneuvers are analysed as follows.

TABLE 1 Properties of AH-1G helicopter

Parameter (unit)	Value	Parameter (unit)	Value
m (kg)	3400	Ω (s^{-1})	34
R (m)	6.71	f (m^2)	1.82
b (-)	2	κ (-)	736
c (m)	0.69	δ (-)	0.0075

4.1 LEVEL ACCELERATION

Level acceleration is a very necessary and integral component of the maneuver capability of a helicopter. It is very important to predict acceleration in danger situations. In the present example, the engine is at the maximum power output condition and the initial velocity is 25.7 m/s. Figure 2 shows the computed trajectory of the helicopter in 10 seconds. Figure 3 and Figure 4 demonstrate the time histories of the helicopter speed and power for the acceleration maneuver. It can be seen from the figures that the excess power is maximum at the velocity about 32 m/s.

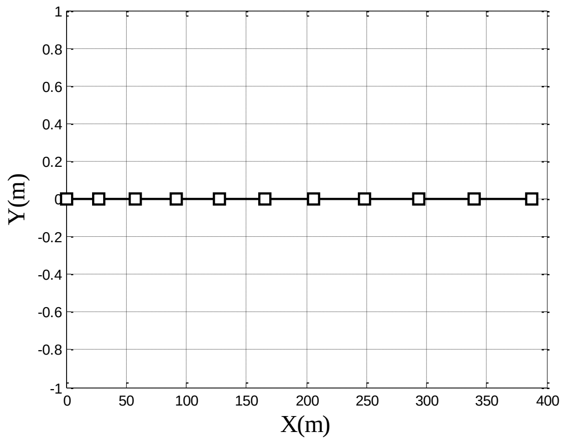

FIGURE 2 Acceleration trajectory

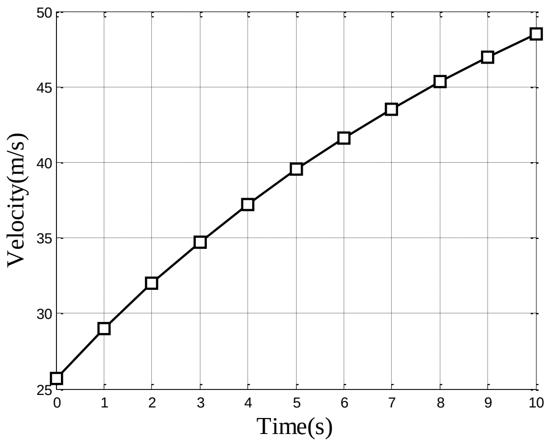

FIGURE 3 Time history of velocity for acceleration maneuver

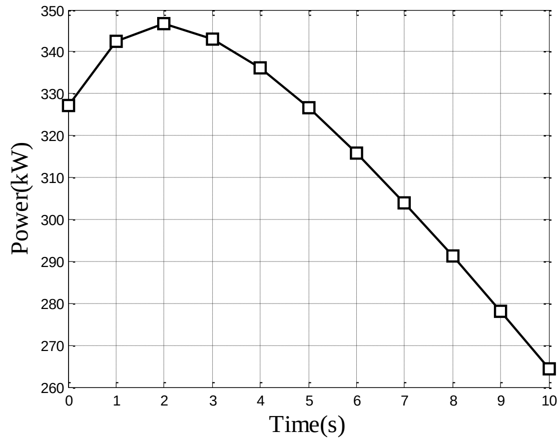

FIGURE 4 Time history of excess power for acceleration maneuver

4.2 DECELERATING TURN

The pilots often choose decelerate at constant altitude in order to supply more power for a 180 degree turn. Figure 5 presents an example of a decelerating turn at 1.72-g overload.

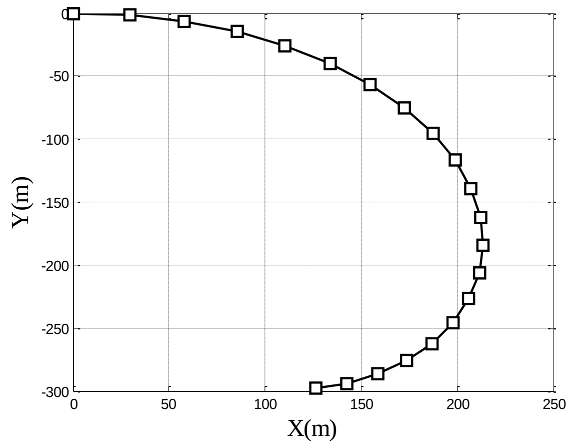

FIGURE 5 Turning trajectory

The time histories of the helicopter speed and power in this maneuver are given in Figure 6 and Figure 7. In a decelerating turn, the helicopter must maintain engine idle speed [16]. Therefore, the value of excess power is always below zero, shown in Figure 7. The maximum excess power is at the velocity about 37 m/s.

4.3 TURNING CLIMB FOLLOWED BY ACCELERATING CLIMB

A complex maneuver is presented in which a turning climb is following by an accelerating climb. The rate of climb is 5 m/s in whole maneuver. The helicopter maintains engine idle speed in climbing turn and the engine work at the maximum power output condition in accelerating climb.

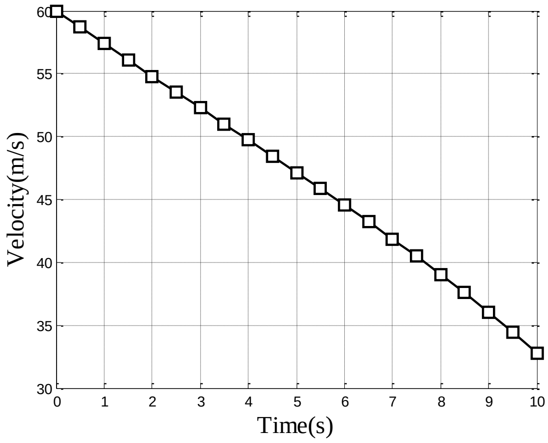

FIGURE 6 Time history of velocity for turning maneuver

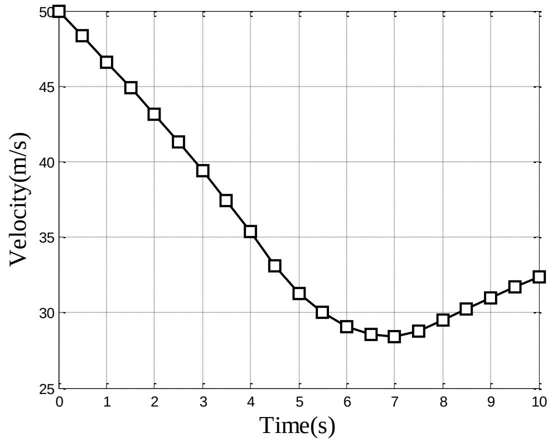

FIGURE 9Time history of velocity for 3-D maneuver

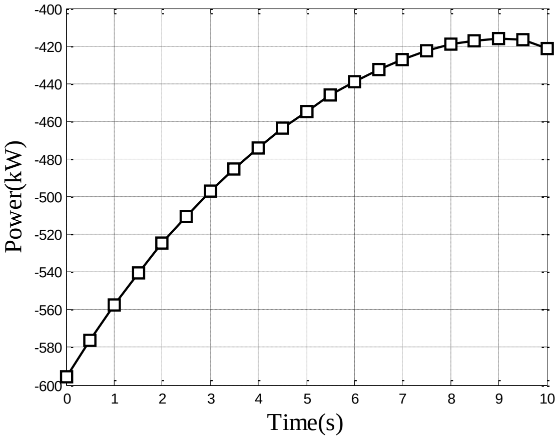

FIGURE 7 Time history of power for turning maneuver

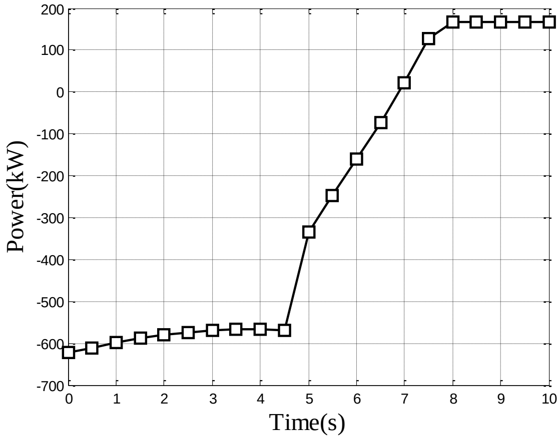

FIGURE 10 Time history of power for 3-D maneuver

There is a transitional period between these two conditions. Figure 8 shows the flight trajectory of this maneuver. Figure 9 demonstrates the time history of the helicopter speed. It can be seen from figure 10 that there is a transitional period about 3 seconds.

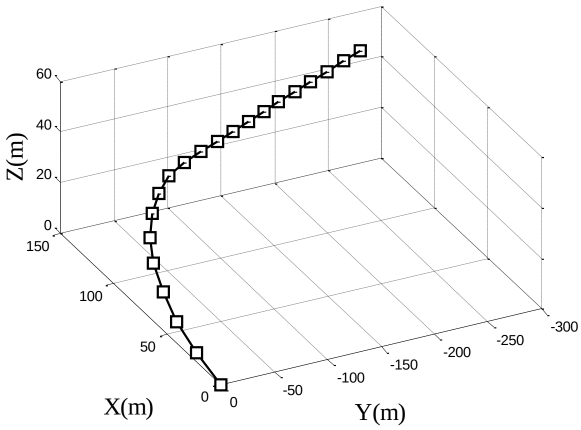

FIGURE 8 3-D flight trajectory

5 Conclusions

This paper proposed a fast and accurate approach to evaluate helicopter maneuverability in forward flight. A three dimensional complex maneuver of AH-1G helicopter is presented, and some important characteristics including maneuver time, trajectory, excess power and velocity are obtained. The results indicate that this method is feasible and effective for helicopters during forward flight. In order to get a fast calculation algorithm, some empirical studies which are only appropriate for forward flight situation are employed in mathematical model. Future research would focus on the rapid method for evaluating maneuverability of the helicopter in hover or vortex ring state.

Acknowledgments

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