PAPER Nr.: 77

THE FLIGHT CHARACTERISTIC ANALYSIS OF HELICOPTER DURING THE DASH STOP MANEUVER

BY

R. L. CHEN

UNIVERSITY OF NANJING AERONAUTICS AND ASTRONAUTICS
NANJING, P. R. CHINA

TWENTIETH EUROPEAN ROTORCRAFT FORUM
OCTOBER 4 - 7, 1994 AMSTERDAM

Printed by the Technical Highschool Haarlem

THE FLIGHT CHARACTERISTICS ANALYSIS OF HELICOPTER DURING THE DASH STOP MANEUVER

BY
R.L. CHEN
NANJING UNIVERSITY OF AERONAUTICS AND ASTRONAUTICS
NANJING, P.R. CHINA

Abstract

The dash stop flight at extreme condition is the primary interest in this study. the paper describers the process of research to the flight characteristics of helicopter in dash stop. A set of equations which gover the dash stop is developed. a method which determine the acceleration and deceleration is proposed . Formulas are then developed which relate the aircraft angular rates and pitch and roll attitudes to flight speed, angle of attack and acceleration or deceleration . Finally the helicopter " DOLPHIN" is taken as an example to calculate its acceleration/deceleration capability, pilot control and aircraft attitudes in space. It was found that the results are reasonable.

Notation

a	aircraft acceleration or deceleration
a_{HOVER}	aircraft acceleration in hover
T_{MAX}	rotor maximum thrust in hover
T, H	rotor thrust and hind force
W	aircraft gross weight
C_Q, C_T, C_H	rotor thrust, hind force and torque coefficient
q	dynamic pressure
α_{TPP}	angle of attack of the tip path plane
α	angle of attack with respect to air mass.

f	equivalent plane area
A_b, A'_b	the blades area and their calculating area
V_I	speed of flight with respect to earth
μ	nondimensional value of V_I
v_x , v_y , v_z	components of velocity in the body axes system
p , q , r	components of angular velocity in the body axes system
I_x , I_y , I_z	inertia about body x-axis, y-axis, z-axis
I_{xy} , I_{yz} , I_{xz}	cross coupling inertia
γ , θ	aircraft Euler angles with respect to X_I , Z_I
θ_0 , θ_c , θ_s , θ_p	collective pitch, lateral cyclic pitch, longitudinal cyclic pitch and paddle pitch.

1. Introduction

With the development of armed helicopter for their expended roles in missions sush as ground attack and air to air combat, the question of helicopter maneuverability is receiving increased attention. Better analytical methods are needed to achieved a reliable prediction of the rotor thrust limits and aircraft performance, thereby permitting an accurate simulation of the trajectory and the orientation of the aircraft in maneuvering flight, especially those flights involving extreme conditions. Efforts have been and are still being made to meet this need. Improved flight test techniques are also needed to evaluate and substantiate the actual maneuvering limitations of the helicopter.

Basic to the flight evaluation of helicopter maneuvering capability is dash stop. This maneuver is a flight of changing the horizontal position in space form hover to hover, and is often used in the case of motion in which aircraft flies from one obstacle aeras to another one. It is the combination of three diffirent maneuver, i. e., a helicopter makes an accelarating flight rapidly from hover to maximum speed, then flies with that speed across an open terrain area and finally decelarate to hover as soon as possible.

Obeviously, the pilot who has been asked to demonstrate the extreme capability of a helicopter will build up the maneuver until he reaches one of the following limits:

(a). Maximum engine power.

(b). Maximum stick displacement.

(c). Unacceptable level of vibration.

(d). High nose-up attitude or pitch rate from which recovery is uncertain.

(e). Indication of abnormally high loads in the rotor or the controlsystem.

(f). Aircraft instability.

(g). Ominous change in noise level.

(h). Sudden rotor out-of-track condition.

Accurate knowledge of aircraft attitudes is necessary in planing, conducting, and interpreting the flight experiment. A more importment requirement (but less emphasized) is the knowledge of the angular rates of the helicopter in a dash stop. The angular rates about the body axes can exert a significant impact on the performance and handing characteristics of the aircraft. The effect of pitch rate on alleviation of stall of the main rotor is well known. Roll rate has a direct couplingg to the thrust of rotor system in forward flight because of the asymmetry in dynamic pressuree on the advancing and the retreating sides of the rotors.

The objetives of this research are therefore: (1) to discussion the extreme condition for a helicopter in dash stop, (2) determine the maximum acceleration and deceleration capability of helicopter during the dash stop,(3) to develop a set of equations govering the flight of dash stop to evaluate the pilot control and aircraft attitudes in space.

2. Discussion of Extereme Condition for A helicopter in Dash Stop

The limits of a helicopter flight condition is mentioned above section. Obviously, when it's flight condition reaches one or more of these limits the helicopter operates in the extereme cndition. In all of these limits, some, such as reaching maximum engine power, are straightforward and can be predicted by methods alreadly developed. Others,however, are a function of the structural and dynamic characteristics of the rotor, the control system, and the remainder of the helicopter and the pilot's willingness to subject himself to uncomfortable and potentially dangerous flight conditions. There is as yet no way to predict the maximum attainable load factor when these latter considerations are involved, but there is enough experimental data from wind tunnel and flight testing to provide some insight into the problem. figure 1 shows A convenient nondimensional representation of the maximum thrust capability.

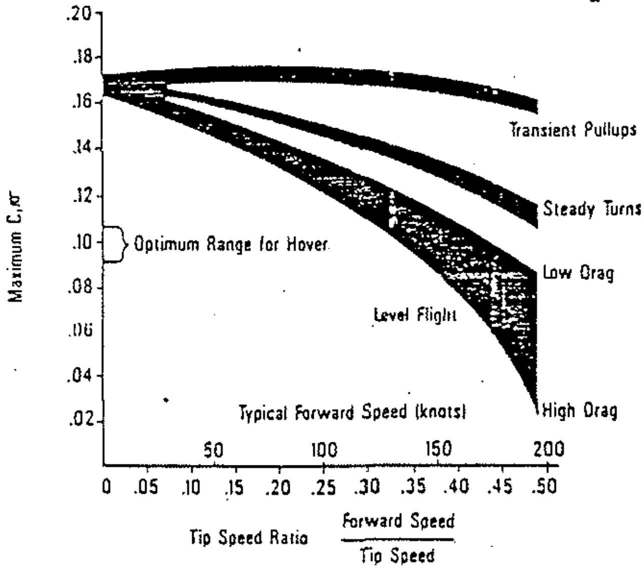


Fig. 1 Maximum rotor thrust Capability

The pilot has three boundaries depending on the flight condition. The transient boundary can be achieved momentarily in flight or continuously in a wind tunnel at high rotor angles of attack. Test results indicat that it is in the neighborhood of 0.17 which is equivalent to an averageblade element lift coefficient of about 1. Other boundaries represent turning and level flight. The level flight envelope is bounded by retreating blade stall conditions. High drag makes a helicopter fly very nose down, especially on the retreating side. Thus a high drag helicopter runs into stall at higher than the steady flight boundary because cyclic pitch is being used to precess the rotor nose-up. These increases the angle of attack on the advancing side and lowers it on the retreating side thus providing a margin for generating more thrust before stall.

3. The Determination of Acceleration and Decelaration in Dash Stop

(1). acceleration

The ability to increase speed rapidly is important for many types of operations. The maximum level flight acceleration capability is primarily a function of the excess power available. At hover, the maximum acceleration is achieved when the maximum available rotor thrust is tilted until the vertical component is eqqual to the gross weight. For this situation, the acceleration is:

$$a_{HOVER} = \sqrt{\left(\frac{T_{MAX}}{W}\right)^2 - 1} \qquad (3.1.1)$$

where the maximum thrust is taken as equal to the maximum hover gross weight in a hover ceiling. from hover, the equation can be used for accelerations rearward and sideward as well as forward. the acceleration capability in forward flight varies from the hover value to zero at maximum speed. For speed between hover and maximum speed, the acceleration capability can be computed with the following procedure:

(1). Assume $C_T/\sigma = C_W/\sigma$

(2). For every values of tip speed ratio, find θ_0 at the value of the torque/solidity coefficient corresponding to the maximum power available.

(3). Find the angle of attack of the tip path plane form the equation:

$$\alpha_{TPP} = \frac{f}{A_b}\frac{\mu^2/2}{C_T/\sigma} \qquad (3.1.2)$$

(4). Calculate

$$C_T/\sigma = \frac{C_W/\sigma}{\cos\alpha_{TPP}} \qquad (3.1.3)$$

(5). Find new θ_0 and C_Q/σ

(6). Find f/A_b corresponding to C_T/σ and θ_0

(7). Convert tip speed ratio into forward speed and dynamic pressure.

(8). Calculate the acceleration capability from the equation:

$$a = \frac{(f/A_b' - f/A_b)}{W} \qquad (3.1.4)$$

Figue 2 show the acceleration capability of the example helicopter

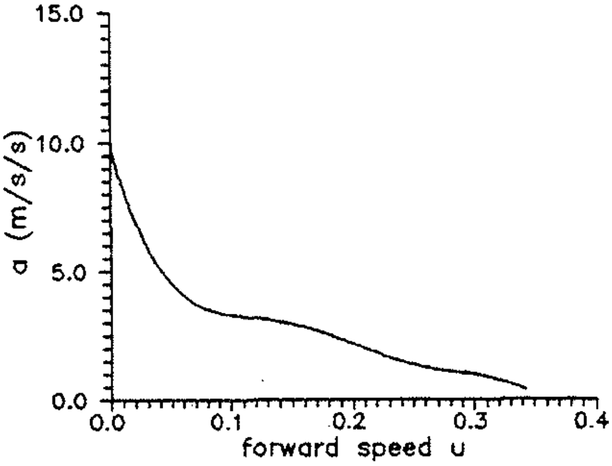


Fig. 2 the acceleration capability of the examble helicopter.

(2) deceleration

at speed near hover, the deceleration capability is equal and opposite to the acceleration capability but in high speed flight, the capability may be limited by rotor autorotation at some overspeed limit usually specified by structural design. The proceedure for calculating the deceleration capability is follow:

(1). Assume $C_T/\sigma = C_W/\sigma$

(2). For every values of tip speed ratio, find θ_0 at $C_Q/\sigma = 0$

(3). Find the angle of attack of the tip path plane (with equation 3.1.3).

(4). Calculate

$$C_T/\sigma = \frac{C_W/\sigma}{\cos\alpha_{TPP}} \qquad (3.2.1)$$

(5). Find new θ_0 at $C_Q/\sigma = 0$

(6). Convert C_T/σ , C_H/σ to T and H

(7). Convert tip speed ratio into forward speed and dynamic pressure.

(8). Calculate the deceleration capability:

$$a = \frac{(fq + H + T\alpha_{TPP})}{W} \tag{3.2.2}$$

Figure 3 shows the deceleration of the example helicopter.

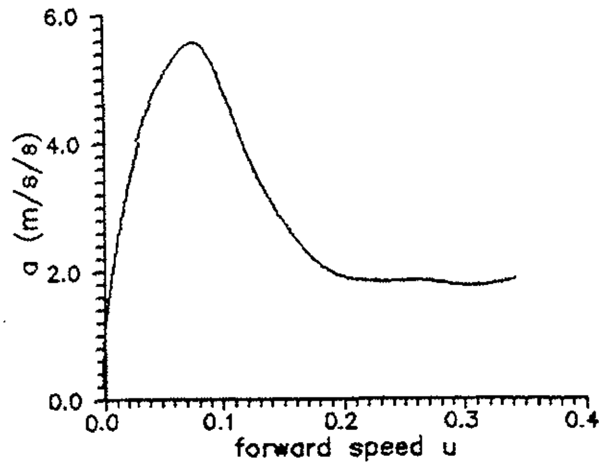


Fig. 3 the deceleration capability of the example helicopter.

4. Helicopter Angular Rates and Attitudes in Dash Stop

The aircraft angular rates about the body axes have significant influence on the thrust capability and stall characteristics of both the main rotor and the tail rotor. Therefore , it is important to examine the effects of flight papametery such as α , ψ ,and V on angular rates of the helicopter in a dash stop.

The helicopter pitching velocity, for example, has a well-known effect on the thrust capability of rotor. A positive pitching velocity, such as that which exists during a dash stop, has been shown to provide an increased thrust or g-capability due to loading of the advancing blade and unloading of the retreating blade, thereby providing a stall-alleviating effect for a lifting rotor. The principal mechanism causing this effect is due to a gyroscopic moment acting on the rotor system. Conversely, a negative pitching velocity will aggravate stall of the rotor system. As a corollary, yaw ratee has a siginficant effect on the stall characteristics of the tail rotor. In fact, it is an important factor to be considered in the design of the tail rotor system. The helicopter roll rate couples directly to the thrust of the main rotor system. The effect is due primarily to the change in the rotor inflow distribution. As such, it is primarily an aerodynamic rather than an inertia effects, as is the case for the pitching velocity discussed previously.

The angular rates in dash stop around the helicopter body axes are given as follows:

$$
\begin{aligned}
p &= \frac{a \sin\theta \sin\gamma}{v_y} \\
q &= \frac{a(1 - \cos\theta\cos\alpha - \sin\theta\sin\alpha\sin\gamma)}{v_x + v_y} \qquad (4.1) \\
r &= 0
\end{aligned}
$$

5. The Pilot Control and Helicopter Attitudes During Dash Stop

The helicopter attitudes in space are variable during the dash stop. Therefore, in order to make a helicopter fly horizontally, pilot must adjust theposition of sticks. It is the interesting of this section how to determine the pilot control and helicopter attitudes in dash stop. Because the dash stop is level flight the change of height and yaw can be omit. Consquiently,the sideslip can also be omit, i. e.,

$$(\frac{dv_y}{dt})_t = (\frac{dv_z}{dt})_t = 0$$

The Eular equations reduce to

$$\Sigma X = W(\frac{dv_x}{dt} - qv_y + rv_z)$$

$$\Sigma Y = W(\frac{dv_y}{dt} - pv_z + qv_x)$$

$$\Sigma Z = W\left(\frac{dv_z}{dt} - qv_x + pv_y\right)$$

$$\Sigma L = -I_{yz}(q^2 - r^2) - I_{xz}pq + I_{xy}rp - (I_y - I_z)rq \qquad (5.1)$$

$$\Sigma M = -I_{xz}(r^2 - p^2) - I_{xy}qr + I_{yz}pq - (I_z - I_x)rp$$

$$\Sigma N = -I_{xy}(p^2 - q^2) - I_{yz}rp + I_{xz}qr - (I_x - I_y)pq$$

The force components ΣX , ΣY , ΣZ and the there moment components ΣL , ΣM , ΣN are functions of the fligft parameters V_t , α ; helicopter attitudes in space θ , γ ; angular velocity p , q , r ; and cntrol positions θ_0 , θ_c , θ_s , θ_t . Symbolically

$$\Sigma X = f(V_t, \alpha, \theta, \gamma, p, q, r, \theta_0, \theta_c, \theta_s, \theta_t) \qquad (5.2)$$

with similar functional relationships for ΣY , ΣZ , ΣL , ΣM , ΣN .

Assume the aircraft flightpath angle ψ, the relationship between V_t and α, α and θ can be obtained as follow respectively,

$$v_x = V_t \cos\alpha$$

$$v_y = V_t \sin\alpha \qquad (5.3)$$

$$\alpha = \theta - \psi$$

Clearly, for a given set of ψ, V_t ,α , the nine equations completely determine the nine unknown trim value in dash stop, that is, Euler attitudes θ , γ ; angular rates p , q , r ; and four control variables of the aircraft θ_0 , θ_c , θ_s , θ_t .

Figure 4 and figure 5 show the pilot controls and attitudee of the example helicopter DOLPHIN from hover to maximum formard speed and from maximum forward speed to hover. In order to compare with the steady level flight condition Figure 6 shows the responsible results.

6. Concluding Remarks

1)The extreme condition is discussed according with the helicopter structure and pilot' s feeling and prescribes some method, which is not only suitable to the dash stop maneuver but also suitable to the other extreme flight after updating, determine the extreme condition.

(2) A method is systematically provided of determining the aircraft acceleration and deceleration capability accoding to the engine power, aircraft configuration and flight condition.

(3) New formulas that explicitly relate aircraft angular rates and pitch and roll attitudes to the flight parameters have been obtained. These formulas simplifying the computation of kinematics for the helicopter in dash stop flight.

(4)A set of nine equations which govern a dash stop have been developed. The sults according to these equations are reasonable.

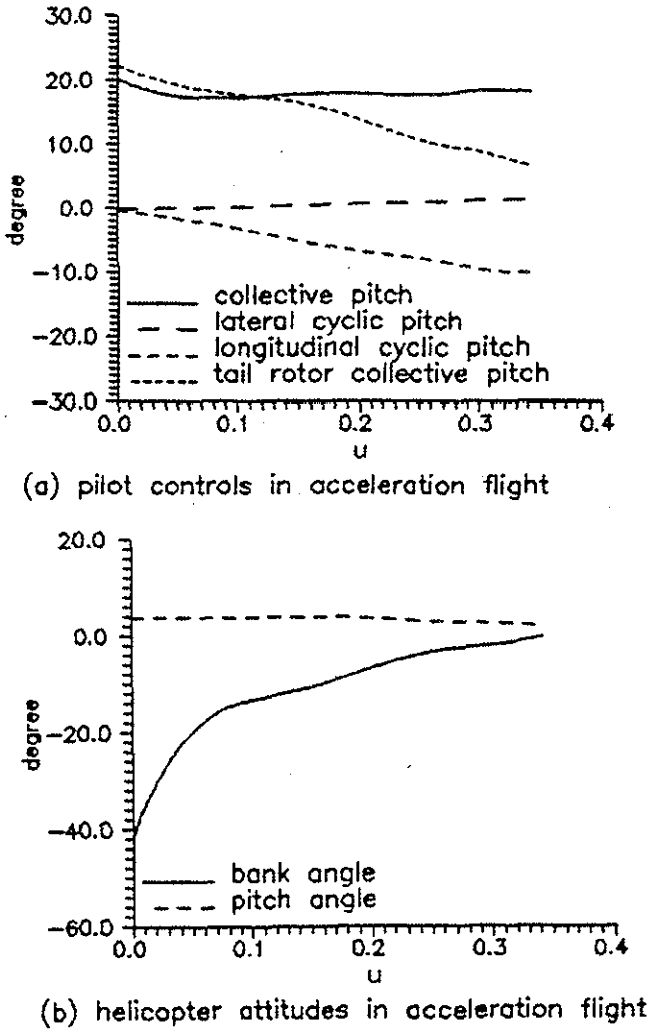
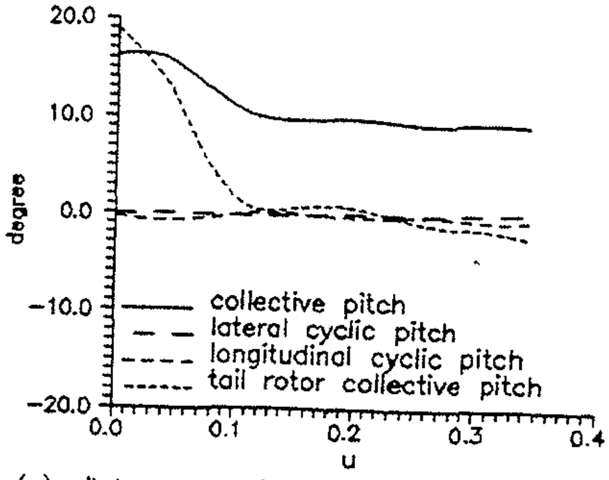
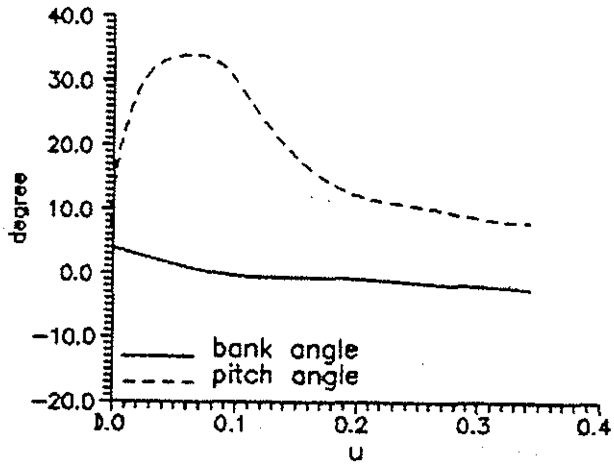


Fig. 4The Pilot Controls and Attitudes of helicopter DOLPHIN from hover to maximum speed

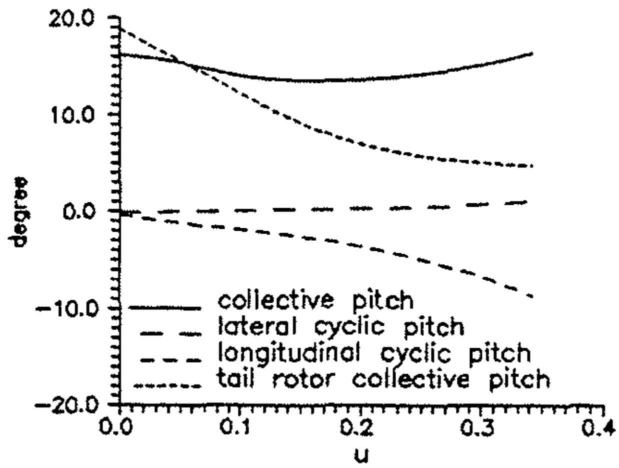


(a) pilot controls in deceleration flight



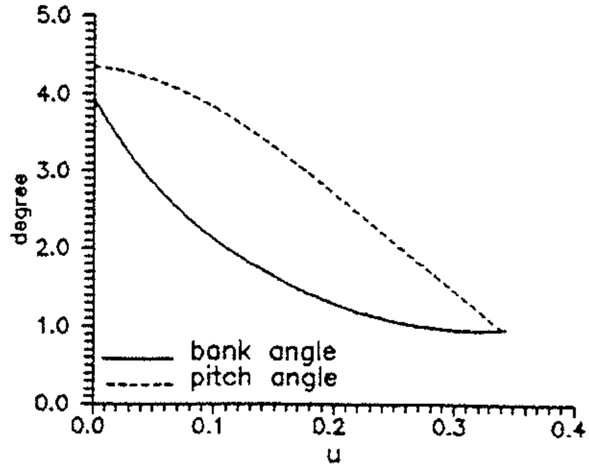
(b) helicopter attitudes in deceleration flight

Fig. 5The Pilot Controls and Attitudes of helicopter DOLPHIN from maximum speed to hover



(a) pilot controls in steady level flight

Fig. 6The Pilot Controls and Attitudes of helicopter DOLPHIN in steady level flight



(b) helicopter attitudes in steady level flight

Fig. 6 (continue) The Pilot Controls and Attitudes of helicopter DOLPHIN in steady level flight

7. References

1) C.D. Wells and T.L. Wood, Maneuverability—Theory and Application. American Helicopter Society J. vol. 18 no. 1, Jan, 1973.

2) C.N. Keys, Rotory—Wing Aerodynamics Vol. —Performance Prediction of Helicopter, NASA CR—3083, Jan. 1979.

3) R.B. Lewis, Hueycobra Maneuvering Investigations. paper presented at 26th Annual National AHS Forum, 1970.

4) R.T Chen, A Simplified Rotor System Mathematical Model for Pilot Flight Dynamic Simulation, NASA TM—78575, 1979.