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MAIN ROTOR L/D RATIO, LIFT AND PROPULSIVE COEFFICIENTS

BY

ALEXANDRE S. BRAVERMAN

MIL MOSCOW HELICOPTER PLANT

TWENTIETH EUROPEAN ROTORCRAFT FORUM
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Alexandre S.Braverman
Mil Moscow Helicopter Plant

Abstract

It is proposed in the paper to define main rotor aerodynamic characteristics as a function of rotor propulsive power versus power consumed by it.These functions are described with sufficient accuracy by linear equations.Coefficients contained in these equations fully comply with aircraft wing L/D ratio and propulsor efficiency in terms of their physical sense and numerical value. That is why they are named "L/D ratio" and "propulsive coefficient" of the rotor . Using these terms the universal formulas for single- and multi-rotor helicopters, compound helicopters with wing and propulsor and for airplanes were obtained.

In hovering and at low flight speed the meaning of the rotor or wing L/D ratio loses its sense. Thus, for such a flight conditions the other coefficient is used, namely the main rotor "lift coefficient" . It defines the power and hourly fuel consumption required to create a unit of the main rotor lift.

The paper shows formulas for definition of the coefficients mentioned, presents the data on L/D ratio, lift and propulsive coefficients of the ideal and real rotors.

1.List of symbols

R, (T,H), (L,D) -Main rotor aerodynamic forces resultant vector and its components in body-axis and wind-body coordinate systems;

t_R,(t,h),(t_L,t_D) -main rotor forces dimensionless coefficients (divided by $(1/2)\rho(\omega R)^2 \sigma A$);

A - rotor disk area;

mg - helicopter weight;

Q - helicopter parasitic drag;

P_{pr} - helicopter propulsor force;

N - main rotor power;

m_K - main rotor power dimensionless coefficient (divided by $(1/2)\rho(\omega R)^3 6A$);

ξ - engine power utilisation factor (ξ=N/N_e);

V, (V_x,V_{yg}) - flight speed and its components in body-axis and terrestrial coordinate systems;

v - main rotor average induced velocity;

M_t - blade tip average Mach number (M_t=$\omega R/c$);

α - main rotor angle of attack;

$\Delta\alpha_i$ - angle of downwash at the i-th element of the helicopter lift system;

τ - angle between the normal to flight speed vector and R vector;

K - main rotor L/D ratio;

η - main rotor propulsive coefficient;

N_o^T - main rotor lift coefficient.

Indexes

h - helicopter;

w - wing;

pr - propulsor;

p - profile drag;

id - ideal;

e - engine;

ef - effective;

LF - level flight.

hov - hovering.

2. Introduction

Let's consider the deficiency of coefficients used as main rotor aerodynamic efficiency criteria. In level flight, at high enough speed, a term of "main rotor L/D ratio" is used. It is determined using convention drag, assumd to be equal to (N/V-D). When V,T and M_t are constant, the value of this force depend on design point selection i.e. on N and corresponding force D. Thus, the value of L/D=K is numerically indeterminate. Besides, such K value can be compared with K of the wing only roughly, because the wing drag is comparable with rotor drag in autorotation conditions only. This will be demonstrated below.

Main rotor aerodynamic efficiency in hovering condition is characterised by relative efficiency factor η_o , which is ideal rotor power divided by real rotor power. Therefore, it doesn't directly describe power expendtures or hourly fuel consumption per unit of thrust, which is the most important in aircraft efficiency analysis. For the modern values of main rotor tip speed, the η_o factor also can't be directly used to define the main rotor optimal parameters (Ref.[1]).

Main rotor has the second function: it is a helicopter propulsor. Therefore, it defines helicopter dynamic characteristics as vertical climb rate and acceleration $\dot{V}$. This main rotor function should also be described.

And finally, coefficients describing the main rotor and helicopter in general should be definable through all flight conditions, but not only at high speeds and hover.

This paper presents other coefficients free from the deficiency described above. Owing to that fact they have much wider field of application and can be used in particular for determination and analysis of helicopter flight performance.

3.A Method of the Main Rotor Aerodynamic Characteristies Interpretation

The purpose of this paper was to define the coefficients which can offer the following possibilities:

- to define the value of helicopter operational effectiveness criteria,such as,for example,fuel consumption per the unit of useful work or fuel consumption per flight time unit;
- to analyse the advisability of installation on the helicopter of a wing or a propulsor;
- to define helicopter flight performance for various helicopter configurations. In order to determine the coefficients which give such a possibilities we propose to define the main rotor aerodynamic characteristics as a function of rotor propulsive power (a product of propulsive force D and flight speed V) versus power N consumed by it (fig.1). Comparison of various methods of the rotor aerodynamic characteristics presentation (like those in Ref.[1,3], for instance) has shown that the method proposed has a number of

advantages:

-it is applicable for all flight speeds and conditions including hovering, vertical flight and low speed steep trajectory flight;

-functions are close to linear which makes possible their approximation ;

-functions are the same for various swashplate inclination angles, as, when R=const and V =const, main rotor effective angle of attack α_{ef}, force D and power N remain the same;

-functions are easy to recalculate when the main rotor solidity ratio σ changes (according to the theories of rotors with infinite number of blades).

The first two features of the functions proposed will be examined in the paper; correctness of the others is easy to check using availble literature, Ref. [1] for exaample.

4. Ideal rotor

Let's determine the ideal rotor propulsive power DV, when certain values of N_{id} and $V\cos\tau$ are known. To define resultant flow velocity through the main rotor V', we will use the following equation (fig.2):

$$V' = \sqrt{(V\cos\tau)^2+(V\sin\tau-v)^2} \qquad (1)$$

Here V' is defined from the triangle on fig.2. From the formula of ideal rotor theory

$$R=2\rho AV'v; \qquad N_{id}=Rv-DV$$

using equation (1), it is easy to derive the following formulae:

$$\tilde{v}=1/\sqrt{(\tilde{V}\cos\tau)^2 + \tilde{N}_{id}^2} \quad , \qquad (2)$$

$$\tilde{D}\tilde{V}= \tilde{V}\sin\tau= \tilde{v}-\tilde{N}_{id} \quad , \qquad (3)$$

where

$\tilde{v}=v/v_{hov}$; $v_{hov}=\sqrt{R/2\rho A}$; $\tilde{V}=V/v_{hov}$; $\tilde{N}=N/Rv_{hov}$; $\tilde{D}=D/R$; (4)

Let us note,that when velocity $\tilde{V}\cos\tau$ and $\tilde{N}_{id}$ are defined we can determine the induced velociti using a simpe formula (2) instead of solving a well- know fourth order equation $\tilde{v}=f(\tilde{V},\tau)$. The plot of the function of interest is presented on fig.3. For ideal rotor it embraces all flight conditions. The point with coordinate DV=0 on the $V\cos\tau=0$ curve correspond to hovering flight conditions. Other points of the same curve correspond to vertical climb (fig.4: $\tau=-90^0$; $\tilde{D}=-1$, i.e. $D=-R$; $L=\cos\tau=0$; $\tilde{V}=-\tilde{D}\tilde{V}$) or vertical descent ($\tau=90^0$; $\tilde{D}=1$,i.e. $D=R$; $L=0$; $\tilde{V}=\tilde{D}\tilde{V}$). Other curves on fig.3 when $V\cos\tau=0$ correspond to non-vertical trajectories with any speeds. When $\tilde{V}\cos\tau>3$ ($\tilde{V}=0.13...0.2$ depending on main rotor disc loading R/A) the value of $(\tilde{V}\cos\tau)^2$ is much greater than $\tilde{N}_{id}^2$, so

$$(\tilde{D}\tilde{V})_{id} = 1/\tilde{V}\cos\tau - \tilde{N}_{id}. \quad (5)$$

When $V\cos\tau$ is constant the function $DV=f(N)$ is linear and

$$-d(DV)_{id} / dN_{id} = 1. \quad (6)$$

The function being considered has the greatest curvature when $V\cos\tau=0$,but even at this trajectory in the interval of practcal interest ($1<\tilde{N}_{id}<1.3$), it may be substituted for a straight line. In this case the maximum error is within 3% of hover inducedv velocity: 0.25...0.5m/sec [$\delta(\tilde{D}\tilde{V})=0.03$]. Thus, the functions being examined may be considered linear with accuracy sufficient for helicopter flight performance determination and can be described by one of the two following formulae (fig.1):

$$N=N_o-DV/\tan\varphi = N_o - DV/\eta \ , \quad (7)$$

$$N=[(DV)_a-DV]/\eta \ . \quad (8)$$

Index "id" is omitted in the formulae because they are also correct for a real main rotor. When should this or that formula be used? Most tipical helicopter flight conditions are indiceted by points on fig.5. They are - cruise flight (point

1),flight with minimum power required for level flight or maximum endurance flight conditions (point 2),hovering (point 3).Helicopter operetional efficiency is characterised by a number of criteria [Ref.2].However all the criteria defining transport capabilities contain the ratio $N_{e.LF}/mV$. For instans,fuel amount (m_f) required to transport a unit of cargo (m_c) to a unit of distance (L):

$$q^* = m_f/m_c L = N_{e.LF} C_e t/m \bar{m}_c L = (N_{e.LF}/mV) C_e/\bar{m}_c.$$

Here t - flight endurance; C_e-engine specifie fuel consumption; $\bar{m}_c = m_c/m$ - helicopter weight efficiency by usefyll cargo.

Other criteria characterising flight endurance contain the ratio $N_{e.LF}/m$. For example, fuel amount required for flight with a unit of cargo, during a unit of flight time

$$t^* = m_f/m_c t = N_{e.LF} C_e t/m \bar{m}_c t = (N_{e.LF}/m) C_e/\bar{m}_c.$$

Thus, at low flight speed $\bar{V}_x \leqslant 0.2$ (hover and minimum power conditions) helicopter aerodynemic quality and,hence,main rotor perfection is defined by ($N_{e.LF}/m$) ratio and at higher speed, $\bar{V}_x > 0.2$ (cruise conditions) - by ($N_{e.LF}/mV$) ratio. Accordingly, when $\bar{V}_x \leqslant 0.2$, a transformed formula (7) should be used:

$$N/T = N_o/T - (D/T)V/\eta = N_o^T - (D/T)V/\eta \text{ ,} \qquad (9)$$

and for $\bar{V}_x > 0.2$ - a transformed formula: (8)

$$N/TV = (1/K - D/T)/\eta \qquad (10)$$

N_o^T ratio and tangent of straight lines angle of inclination φ let's name correspondingly the "lift" and the "propulsive" coefficients:

$$N_o^T = N_o/T \qquad (11)$$

$$\eta = \tan\varphi \qquad (12)$$

and K - aerodynamic efficiency:

$K=D_a/T=D_a/L$ (13)

K and η coefficients have the same phisical sense as a wing L/D ratio K_w and propeller efficieny η_{pr}. Actually, the main rotor may be represeted as a device combining a wing with drag D_a and a propeller with (D_a-D) propulcive forc (fig.6). Coefficients K and K_w, η and η_{pr} are comporable with each other by their value which will be evident from formula (18) below.

Let's revert to an ideal rotor. The function of $N_{o.id}$, η_{id}, K_{id} and $(DV)_{a.id}$ is presented on fig.7. The table on the same figure shows an interval of N_{id} where the value of these coefficients is correct.Propulsive coefficient is defined using an average value of $(v-v_o)/V\sin\tau$ in the power interval being considered:

$$\eta=1/[1-(v-v_o)/V\sin\tau]$$

One can see that during vertical flight in the interval $1<\tilde{N}_{id}<1.3$ the propulsive coefficient is equal to $\eta=1.87$. From a well-known formula

$$V_y=2(N - N_{hov})/mg$$

follows that $\eta=2$.Such angle of inclination $V\cos\tau$ curve has at hovering flight conditions.This value of η may be used in the interval of $1<N_{id}<1.15$ with the possible error shown above.

The fact that η is greater than the efficiency factor of other propulsors dosn't mean that the main rotor consumes less power than the other propulsors. Total power of ideal rotor is $N_{id}=N_{o.id}+(N_{id}-N_{o.id})=N_{o.id}-DV/\eta_{id}=R(V+v)$. Any other ideal propulsors have the same power. It is advisable to devide the power N into N_o and $N_{pr}=-DV/\eta$ only in the case of skewed airflow conditions (fig.6).

Propulsive coefficient is defined not as a ratio of useful and consumed power, but as a ratio of their increments. Therefor it can be equal 1 and greater or less than 1.

In skewed airflow on the main rotor with $V\cos\tau>3$ propulsive coefficient $\eta_{id}=1$, as it was shown in the equation (6). At these speeds the propulsive coefficient is greater than efficiency factors of other propulsors because in order to create the propulsive force the main rotor axis, which is almost vertical, should be inclined forward by small angle (as T>>D). The values of R and v change slightli, so the required power increas is only δN_{id}=-DV. This means that there are no additional power losses in generating of propulsive force by a lifting rotor. Other propulsors do have power losses equal to -Dv.

Let's propose some useful formulae. At hovering: $N_o^T{}_{.id}=v_{hov}$; at $\tilde{V}>3$: $\tilde{v}=1/\tilde{V}$; $N_o^T{}_{id}=v_{hov}/\tilde{V}$; $K_{id}=\tilde{V}^2$

5.Real rotor

In order to difine m_o^t, η , K coefficients using the rotor wind-tunnel test data or calculated data the function $t_D\overline{V}=f(m_K,t)$ is plotted (fig.1). This function, as said above, can be derived for all flight speeds. In particular cases it is identical to the following function: $t\overline{V}_y=f(m_K,t)$ in vertical motion (fig. 8); $t_D\overline{V}=f(m_K,t)$ or $t_D=f(m_K,t)$ at a speed $\overline{V}_x>0.2$, as at this speeds $V_x=V$, $t_R=t_L=t$. These functions ara linearized. Then straight lines inclination angle φ and characteritie point m_o, $(t_D\overline{V})_a$ are defined and m_o^t , K, η are determined. m_o^t, K, η coefficients give the possibility to represent in compact manner the rotor aerodynamic coefficients. Complete characteristic is given on fig.9. In the interval t=0.14-0.17 at $\overline{V}_x$=0.15-0.2 the lifting coefficient N_o^T=9-11 W/N and in hover N_o^T=20-26W/N.Under the same thrust coefficients at $\overline{V}_x$=0.3-0.4, M_t=0.65 the rotor K is maximum and equal to 8-10. Propulsive coefficient η=1.87 at V_x=0; η=1.5 at $\overline{V}_x$=0.05; η=1.1-1.2 at $\overline{V}_x$=0.1. At $\overline{V}_x>0.2$ η=1...0.95 and η=0.9-0.8 at the near stall conditions. Besides, fig.9 shows the diagram of the main rotor effective angle of attack at autorotation $\alpha_{ef.a}$ which is required to define α at any m_K:

$$\alpha_{ef}= \alpha_{ef.a} - m_K\, \eta/t_L\overline{V}_x = \alpha_{ef.a} - 1/K + t_D/t_L \qquad (14)$$

$$\alpha = \alpha_{ef} - D_1\delta_B - D_2\delta_K \qquad (15)$$

Here δ_B, δ_K - longitudinal and lateral swachplate inclination angles; D_1, D_2 -flight control system gear rations.

The rotor K is about 2 times less than the wing K_W. It may be mainly explained by the fact that at the same flight speed the helicopter blade effective aerofoil sections velocities are higher than wing cross-section velocities. Thus, the rotor profil drag is higher than that of the wing. The rotor induced drag is also 10...15% higher. That is why rotor N_o^T is high. However the hourly fuel consumption $N_o^T C_e$ is 7...10 lover than VTOL fixed-wing aircraft have. That way the helicopter hovering endurance is much greater then VTOL possible.

Real rotor propulsive coefficient η is not the same as η_{id} because the rotor profil losses depend on the rotor propulsive force (on the α):

$$1/\eta = 1/\eta_{id} + 1/\tan\varphi_p \qquad (16)$$

The value of $\tan\varphi_p$ encreases with the $\overline{V}_x$, M_t, t increas. It makes η value smaller from $\eta_{id}=1$ to $\eta=0.9...0.8$. Real rotor K is not the same as K_{id} because there are profil and additional induces losses:

$$1/K = 1/K_{id} + m_{p.o}\ \eta/t\overline{V} + (I-1)\overline{V}_o\ \eta\ /\overline{V},$$

as $m_K = m_{K.id} + m_{p.o} + (I-1)t\overline{V}$ $\quad (I=m_{ind}/t\overline{V};\ I = 1.15...1.1)$.

It was mentioned in the Introduction about K used by some authors. Let's desighnate it as K_{ef} and show its interconnection with the proposed coefficients:

$$1/K_{ef} = 1/K\eta + (D/L)(1-1/\eta)$$

In particular case when the rotor has $\eta=1$, than $K_{ef}=K$.

6. Helicopter flight performance definition using N_o^T, K and η coefficients

To make the case more general, the formulae are drawn for a twin rotor helicopter with a wing and propulsor (propeller). The resuitant vector of all the forces projections on flight direction line is:

$$D_1+T_1\Delta\alpha_1+D_2+T_2\ \Delta\alpha_2+D_W+L_W\ \Delta\alpha_W+Q-P_{pr}+mg(V_{yg}/V+\dot{V}/g)=0$$

Using this equation and formulae (9,10) we will have:

$$N_{LF}/mg = [\bar{T}_1(N_o^T)_1+\bar{T}_2(N_o^T)_2+V(\bar{T}_1\Delta\alpha_1+\bar{T}_2\Delta\alpha_2)+$$

$$+\bar{L}_W V(1/K_W+\Delta\alpha_W)+\bar{Q}V-\bar{P}_{pr}V(1-\eta\xi/\eta_{pr}\xi_{pr})]/\eta \qquad (17)$$

$$N_{LF}/mgV = [\bar{L}_1(1/K_1+\Delta\alpha_1)+\bar{L}_2(1/K_2+\Delta\alpha_2)+\bar{L}_W(1/K_W+\Delta\alpha_W)+\bar{Q}-$$

$$-\bar{P}_{pr}(1-\eta\xi/\eta_{pr}\xi_{pr})]/\eta \qquad (18)$$

$$V_{yg}/V+\dot{V}/g = (N-N_{LF})\eta/mgV \qquad (19)$$

Indexes 1 and 2 in the formulae correspond to the first and the second rotors, symbols with a dash above are the values devided by helicopter weight, $\Delta\alpha$ are the angles of downwash. Formula (17) is used at low flight speeds. If η and N_o^T are known, using this formula we can define flight performance and effectiveness criteria for those helicopters which often fly at 20...50km/p.h speed, such as agricultural, tug- helicopters and others.
Formulae(17-19) are correct for every aircraft. For a fixed-wing aircraft with $P_{pr}=L_W/K_W+Q$:

$$N_e = P_{pr}V / \eta_{pr}\xi_{pr}$$

The value in brackets in formula (18) is an inverse aerodynamic efficiency characteri of the helicopter $1/K_h$.
N_o^T, K_h and η coeffficients may be determined in helicopter flight testing. Choosing the flight speed, rotor r.p.m., helicopter mass and flight altitude we can satisfy the conditions: $\bar{V}_x$=const, t=const, M_t=const. Maintaining these conditions in climb, level flight, descent various helicopter propulsive force values D_h are determined:

$$D_h = -mgV_{yg} / V. \qquad (20)$$

Using these data, the function of interest is plotted (fig.10) and characteristical points, needed to define $(N_o^T)_h$, K_h and η are found. If we have dependable data regarding the values contained in formulae (17) and (18), we can compute main rotor coefficients.

Formula (18) gives the possibility to conclude in general whether the installation of helicopter wing and propulsor expedient, or not. If $\eta_\xi > \eta_{pr} \zeta_{pr}$ than the installation of propulsor is not advisable. This condition is fulfiled for the speed below 370...400km/p.h, i.e. for helicopters with power-to-weight ratio 300...370 W/N. If the value of $[1/K + \Delta\alpha + (L_W/L)(1/K_W+\Delta\alpha_W)]/\eta$ is less with a wing, installation of the wing will result in required power reduction.

Below there are some examples of formula (18) use. Let's define K_h coefficients of various helicopter configurations (table 1).

Table 1: $\overline{V}$=0.3; M_t=0.65; Q/mg=0.057

	Rotor			L/mg*	Wing			L /mg*	
Configur.	L/mg	K	$\Delta\alpha$	$(1/K+\Delta\alpha)$	L/mg	K	$\Delta\alpha$	$(1/K+\Delta\alpha)$	K_h
Singl.rot.	1	8	-	0.127	-	-	-	-	5.5
Sin.rot.+wing	0.8	8	0.0066	0.108	0.2	18.4	0.0235	0.016	5.6
Side-by-side twin rot.+w.	0.76	7.6	-0.012	0.091	0.2	22.8	0.044	0.026	6.1

The single rotor helicopter aerodynamic efficiency is K_h=5.5. In case of single rotor helicopter with a wing, the wing efficiency is much higher than rotor efficienci , however the helicopter aerodynamic efficiency didn't change much due to rotor-wing interaction. Side-by-side twin rotor helicopter aerodynamic efficiency is higher due to positive interaction of the two rotors ($\Delta\alpha$ <0).

Let's consider the example regarding hovering conditions. At helicopter hovering ceiling 2000m ($T/A=620N/m^2$) the coefficient N_o^T contains the follwing components:

$$N_o^T=[Iv+c(m_pM_t/t)]T=[1.15*16.9+332(0.00373*0.683/0.175)]1.03=$$
$$= [19.2+4.8]1.03=25.6 \text{ W/N}$$

If it might be possible to reduce the induction coefficient I by 1%, m_pM_t/t by 8%, the value of $\overline{T}$=T/mg by 1% (through the reduction of thrust losses caused by main rotor airflow over the airframe) then N_o^T would be redueced by 3.5%. This example illustrates numerically the possibility of helicopter aerodynamic characteristies improvement.

The value of the coefficients proposed depend on $t, \overline{V}, \sigma$ and M_t. To make the helicopter coefficients with different $t, \overline{V}$ σ and M_t comparable with each other it is necesary to recalculate them to some specific value of $\overline{V}$, t, σ , M_t (for example, in cruise flight: $\overline{V}$=0,3, t=0.16, σ=0.09, M_t=0.65). Publication of such a data would undoubtedly stimulate the works on helicopter aerodynamic improvement.

7. Conclusions

1. It is proposed to describe main rotor aerodynamic efficiency by the L/D ratio, lifting and propulsive coefficients. These coefficients directly define the value of the helicopter operational effectiveness criteria.

2. By its physical meaning the coefficients proposed concur with the wing L/D ratio, propeller efficiency and N/T ratio (or hourly fuel consumption $N^T * C_e$ per unit of thrust) of VTOL fixed-wing aircraft. They are comporable with the latter by numerical value.

3. In contrast to the similar coefficients described by other autors, the coefficiets proposed are defined using linearised functions $t_D\overline{V}=f(m_k,t)$ when $\overline{V}_x$=const, M_t=const. That is why they may be used for any flight speed including low speeds, vertical trajectories, hovering.

4. $t_D\overline{V}=f(m_k,t)$ function can be derived from flight test experimental data.

5. Main rotor aerodynamic performance are recommend to be presented as a function of the coefficients proposed versus t, M_t, $\overline{V}_x$.

6. The proposed coefficients enable to determine flight performance of rotory-wing aircraft of various configuration. Computation scheme is very obvious, so the analysis of the results is simplified.

7. New formulae for induced velocity and propulsive force definition were obtained within the ideal rotor theory. The values of the coefficients under consideration were defined for

ideal rotor. At hovering and vertical climb $(N_o^T)_{id}=v_{hov}$, $\eta_{id}=1.87$; at $\tilde{V}>3$ $K_{id}=\tilde{V}^2$, $\eta_{id}=1$, $(N_o^T)_{id}=v_{hov}/\tilde{V}$.

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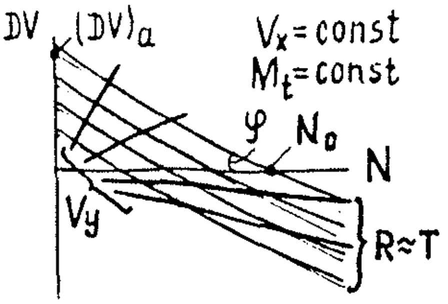


Fig.1:Rotor propulsive power versus power consumed by it(D>0 drag;D<0 propulsiv force)

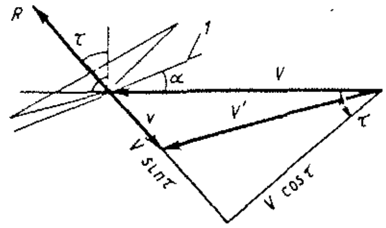


Fig.2:Airflow velocity V' determination (1–rotor plane)

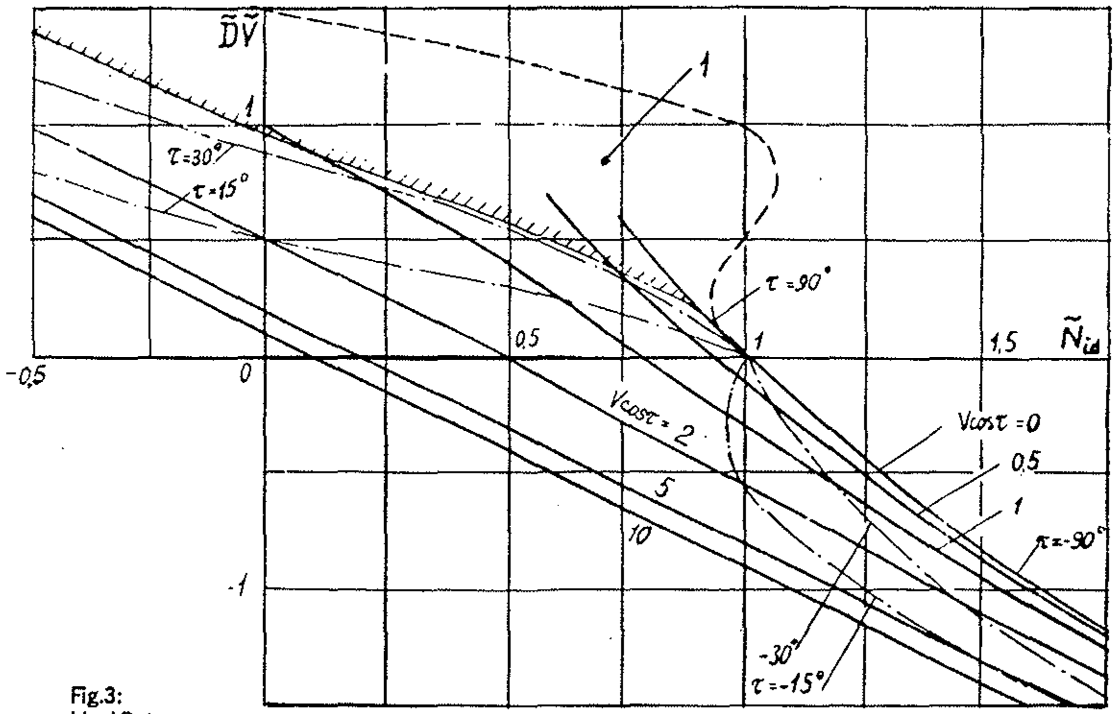


Fig.3:
Ideal Rotor
propulsive pover versus power consumed by it (1–vortex ring condition area)

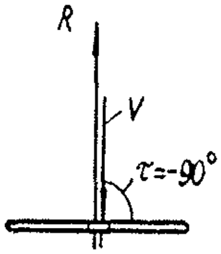


Fig.4:Resultant rotor force and airflow velocity in vertical climb (D=–R=–T; DV=–TVy)

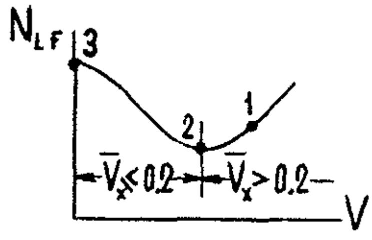
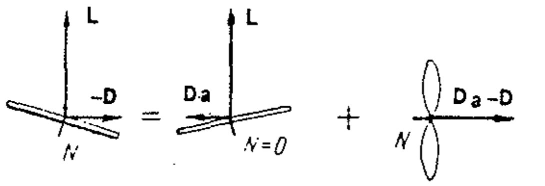


Fig.5:Helicopter level flight required power versus flight speed



$K = L/Da \qquad \eta = (Da - D)V/N$

Fig.6:Main rotor representation as a wing and propulsor combination

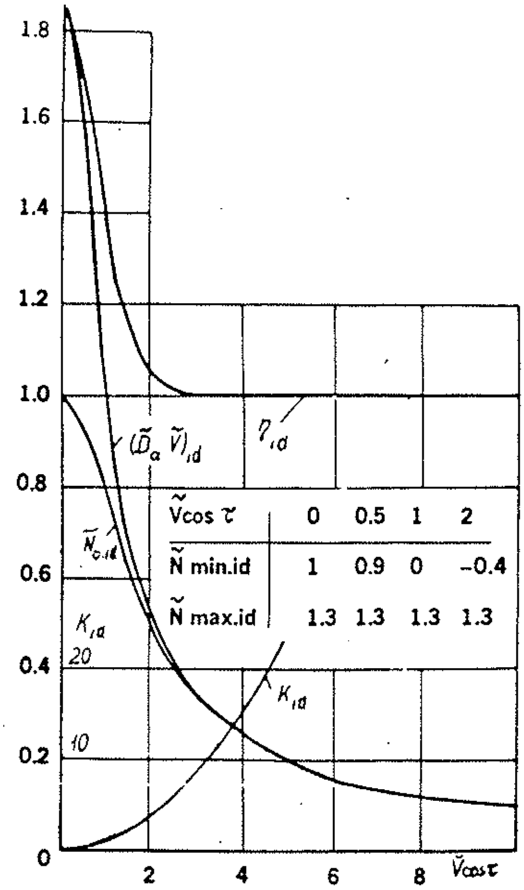


Fig.7:Ideal rotor coefficients versus
$\tilde{V}\cos\tau$ speed component

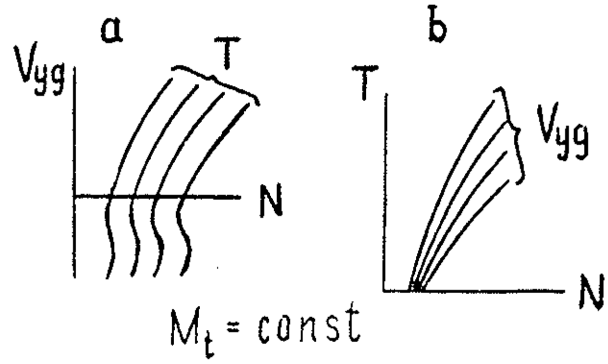


Fig.8:Main rotor characteristics
in vertical airflow conditions (Vx=0)

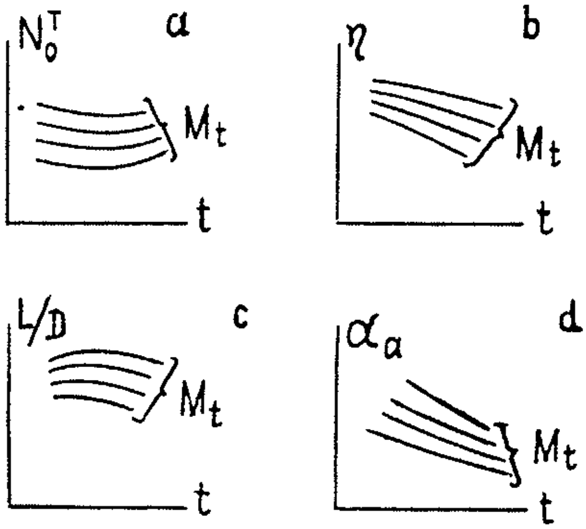


Fig.9:Main rotor coefficiets versus t and M (Vx=const;
a–for $\overline{V}$x<0.2;b–for all $\overline{V}$x;c,d–for $\overline{V}$x>0.2)

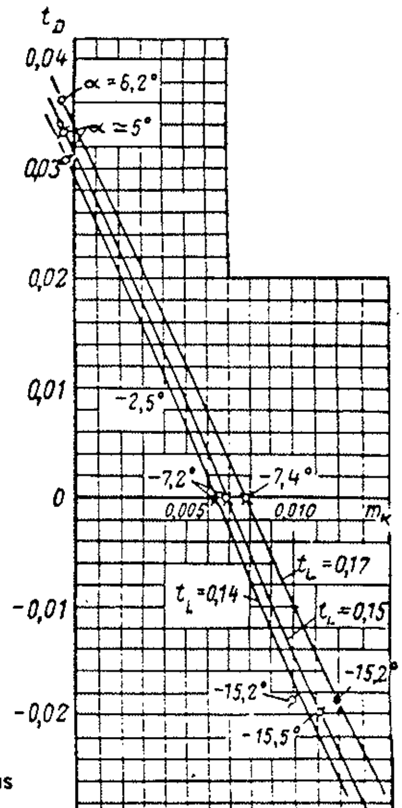


Fig.10:Propulsive force coefficient versus
helicopter consumed power coefficient;
$\overline{V}$x=0.2 (flight test)