

MILITARY TECHNICAL COLLEGE CAIRO - EGYPT

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DYNAMIC STALL EFFECTS ON HELICOPTER PERFORMANCE

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ABSTRACT

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Dynamic stall constitutes a major limiting factor for helicopter's forward speed. Calculations of rotor airloads and helicopter limiting speeds introducing the blade pitching oscillations effects, translate the real case into a reasonable analytical model. The present technique offers a reliable mean for calculating the rotor airloads with the unsteady effects. The method is extended to determine the limiting forward speed of helicopter.

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INTRODUCTION

In forward flight regime of helicopters the rotor blades are usually subjected to conditions of dynamic separations and reattachments. The term "dynamic stall" expresses an ensemble of aerodynamic Phenomena that occured when an airfoil is experienced by aerodynamic conditions variable with time. The dynamic stall behaviour of blade airfoils can limit to a great extent the flight speed and the lifting capability of contemporary helicopters. Consequently the dynamic stall effects in rotor blade analyses must by incorporated. Halfman et al. (1) had outlined the practical means for prediction of dynamic stall characteristics and set a procedure that has been followed by subsequent dynamic stall investigators (2-4) . The methods theoritical and empirical ones predicting the airloads during dynamic stall (5) explain the general features of this stall in terms of vortex-shedding phenomenon based on potential, boundary layer theories and Navier stokes calculations. Variety of these methods fall into three broad types :-

- Substantially analytic methods with emphasis on flow details and hence it requires substantial computation.
- 2. Semi-analytic methods wherein test data are mathematically modelled using the qualitative unsteady features of data and simple approximation to those features.
- 3. Substantially experimental methods wherein a quantative unsteady data are reduced and tabulated withen an analytic framework.

Furthermore the details of dynmaic stall depend on some main physical features as observed in oscillating airfoil tests (5) These features can be simulated by an alternative set of dynamic parameters used for prediction of dynamic stall onset and determination of the unsteady airloads.

Blade element theory as one of the existing methods calculating rotor characteristics in static conditions is considered a suitable base to be extended for real dynamic conditions . The present technique computes the dynamic airloads of helicopter rotor, based on B.E.T. by accurate pridiction of the unsteady acrodynamic coefficients of blade sections at each blade azimuth.

SUMMARY OF THE METHOD:

The computational procedure of rotor airloads is performed by using B.E.T. Knowing for each blade section its relative velocity, the induced velocity and the value of pitch angle, the sectional angles of attack and Mach numbers are calculated. The aerodynamic coefficients $^{\rm C}{\rm LS}$, $^{\rm C}{\rm DS}$ of each section are obtained from test data according the predetermined values of $\alpha_{\rm r}$, M. Consequently the unit loads are computed as : $\frac{dt}{d\bar{\rm r}} = (^{\rm C}{\rm LS} \cdot \bar{\rm U}_{\rm X} + ^{\rm C}{\rm DS} \cdot \bar{\rm U}_{\rm Y})\bar{\rm U}\bar{\rm D}$ - were $\bar{\rm U}$ is the dimensionless

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value of the relative velocity of the flow past the blade section and \bar{U}_χ , \bar{U}_y are its horizontal and vertical components.

From equilibrium of moments of forces acting on blade-element the flapping equation in dimensionless form will be : $\beta' + (\cos\beta - \frac{Lh.h}{I}) \sin\beta = \frac{\gamma}{a} m_{h.h} \cdot \frac{g \cdot Sh.h.}{I_{h.h.}2}$ where : $\frac{\gamma}{a} = \frac{\beta \cdot b_{0.7} R^4}{2 \cdot I_{h.h.}}, m_{h.h} = \int_{I_{h.h}}^{1} \frac{dt}{dr} (\bar{r} - \bar{L}_{h.h.}) \cdot \frac{1}{L_{h.h.}}$

Integrating the unit loads of sections allover the blade length forces and moments of one blade at certain azimuthal position Ψ are obtained. On mapping these forces in plane of rotation on the longitudinal and transverse axes of the rotor and integrating again for all positions of the blade the average forces (t,h) per revolution could be determined.

The lift and drag coefficients of rotor are determined by changing from body fixed system axes to velocity system :

 $C_y = t \cos \alpha - h \sin \alpha$ $C_x = t \sin \alpha + h \cos \alpha$

The dynamic effects are introduced in calculation of the airloads by introducing the unsteady aerodynamic coefficients when calculating the unit loads of blade sections.

MODELLING OF UNSTEADY AERODYNAMIC COEFFICIENTS

The airloads of rotor blades in dynamic conditions depend on the precise determination of the unsteady coefficients C_{LU} , C_{DU} corresponding to the angle of attack α_r and Mach mumber M of the blade section. Test parameters such as mean angle of attack α_m , amplitude and reduced frequency (K = Ω b/2U) alter the ammount of hystersis and the shape of loops of the relations ($C_{LU} - \alpha_r$), ($C_{DU} - \alpha_r$). As a result the synthes-ized unsteady aerodynamic coefficient can be expressed as(6):

 $C_{LU} = C_{LS} (\alpha_{r} - \Delta \alpha_{1} - \Delta \alpha_{2}) + \Delta C_{L1} + \Delta C_{L2}$ $C_{DU} = C_{DS} (\alpha_{r} - \Delta \alpha_{2}) + \Delta C_{D}$

Values of these increments in sectional angle of attack and aerodynamic coefficients are function of some dynamic parameters :

$$\Delta \alpha_{1} = (P_{1}A + P_{2}\alpha_{w} + P_{3})\alpha_{ss}$$

$$\Delta \alpha_{2} = (\alpha_{w} + \delta_{2})\alpha_{ss}$$

$$\Delta C_{L1} = Q_{1}A + Q_{2}\alpha_{w} + Q_{3}(\alpha_{r}/\alpha_{ss}) + Q_{4}(\alpha_{r}/\alpha_{ss})^{2}$$

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$$\Delta C_{L2} = Q_5 \delta_1 + Q_6 \Delta \alpha_2$$

$$\Delta C_D = J_1 A + J_2 \alpha_w + J_3 (\alpha_r / \alpha_{ss}) + J_4 \delta_1 + J_5 \Delta \alpha_2$$

The value of dynamic parameter α depends on the reduced frequency K, Mach mumber M, the mean angle of attack of blade section and the nondimentional pitch rate A. It can be written analytically as (6):

$$\alpha_{w} = \delta_{1} (K,M) A + \delta_{2} (K,M) (\alpha_{r} - \alpha_{m})$$

$$\delta_{1}(K,M) = \frac{0.165 (1-M^{2}) (0.0455)}{K^{2} + (1-M^{2})^{2} (0.0455)^{2}} + \frac{0.335 (1-M^{2}) (0.03)}{K^{2} + (1-M^{2})^{2} (0.03)^{2}}$$

$$\delta_{2}(K,M) = \frac{0.165 K^{2}}{K^{2} + (1-M^{2})^{2} (0.0455)^{2}} + \frac{0.335 K^{2}}{K^{2} + (1-M^{2})^{2} (0.03)^{2}}$$

The values of δ_1 , δ_2 depends on the static stall angle α_{ss} , dynamic moments stall angle $_{\rm DM}$ and can be evaluated as:

$$\delta_{1} = \begin{bmatrix} 0 & \text{for} & \alpha_{r} \leqslant \alpha_{ss} \\ (\frac{\alpha_{r}}{\alpha_{ss}} - 1) & \text{for} & \alpha_{ss} \leqslant \alpha_{r} \leqslant \alpha_{DM} \end{bmatrix}$$

$$\delta_{2} = \begin{cases} 0 & \text{for} & \alpha_{r} \leqslant \alpha_{ss} \\ (\frac{\alpha_{r}}{\alpha_{ss}} - 1) & \text{for} & \alpha_{ss} \leqslant \alpha_{r} \leqslant \alpha_{DM} \\ (\frac{\alpha_{DM}}{\alpha_{ss}} - 1) & \text{for} & \alpha_{r} \leqslant \alpha_{DM} \end{cases}$$

The airfoil shape and the values of M,K, α_m , are used for adopting the aerodynamic coefficients loops which will be taken for computing the empirical constants P_s , Q_s , J_s using least square curve fitting of the equation of unsteady lift coefficient. Values, of α_m , at each section and position of the blade are evaluated due to their periodic variation during each cycle (revolution) by two functions: $\alpha_m = f_1(r)$, $\bar{\alpha} = f_2(r)$. Fig. (1):shows the calculation procedure block diagram of computing the synthesized unsteady oerodynamic coefficients

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of blade sections. The method programmed firstly started calculation by assigned values of β , $\beta = 0$ at $\Psi = 0$ and the pitch angle θ_o . equalls C_y . The calculation is performed at certain revolution in two loops, an inner loop for obtaining values of β , β and an outer one for the value of C_y Iterations continued till the difference in two successive revelutions in values of β , β and C_y will be in an acceptable accuracy. The difference $\Delta C_y = |Cy_{Obt} - Cy_{as}|$ is used for refining the assigned value of θ_0 in each iteration.

At the end of calculations thrust and flapping angle coefficients of fourier series are computed as :

 $t_{\psi} = t + \sum_{n=1}^{5} (t_{1n} \cos n\psi + t_{2n} \sin n\psi)$

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 $\beta = a_0 - \sum_{n=1}^{5} (a_n \cos n\psi + b_n \sin n\psi)$

ANALYSIS OF RESULTS

Having established a practical model for the unsteady aerodynamic characteristics of the airfoils of rotor blades, this methodology was applied to predict the rotor airloads in static and unsteady conditions. for this purpose a general computer program was developed and accurately computes these loads applying B.E.T. , then the program goes through time varying changes of \mathcal{Q}_m , $\overline{\mathcal{Q}}$ and introduces the evaluated values of the unsteady aerodynamic coefficients in the module of B.E.T. The program has been developed in such a way that it can calculate the limiting forward speeds according the different payloads of the helicopter.

The distribution of sectional angles of attack calculated by B.E.T. at $\overline{V} = 0.3$, $\theta_{*} = 4.9^{\circ}$ Cy = 0.149 are shown in Fig. (2) and the distributions calculated by this methods in the same conditions are presented in Fig. (3), comparing these different distributions, it can be seen how the increment of flapping angle resulted due to the augmentation of blade loading in the dynamic case leads to higher values of angles of attack than that obtained by B.E.T. The flapping angle variations with azimuth angle calculated by both methods are show in Fig. (4) where the derivatives are represented in Fig. (5) which reflex the increment of dynamic loading on the blades leading to increase the flap angle

APPLICATION OF THE METHOD TO TEST DATA

The technique mentioned has been developed for computing the critical values of rotor lift coefficient at different velocity ratios V. Consequently, the maximum values of rotor lift force could be determined for corresponding forward velocities.

The method was applied to full scale test data of Gazelle helocopter . Comparison of the present method and B.E.T. with real values of Gazelle helicopter can be seen in Fig.. (6) : It should be mentioned that the deviation of calculated results by the present method is far short from the test data of the helicopter whereas the dynamic effects are much more pronounced when the forwaredspeed of helicopter is increased.

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Figure (2): Distribution of angles of attack over rotor disc calculated by B.E.T. (Gazelle Helicopter-Horizontal flight $0_0 = 4.9^\circ$ & Cy = 0.149).



Figure [3]: Distribution of angles of attack over rotor disc calculated by the present method (Gazelle Helicopter-Horizonta) flight, $\Theta_0 = 4.9^\circ$ & Cy = 0.18)





Figure (4): Variation of flapping angle as a function of Azimuth angle (Gazelle)



Figure (5): Azimuthal derivatives of flapping angle versus blade azimuth.

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Fig. (6): Comparison of calculated critical rotor lift coefficients by B.E.T. and Present method with Gazelle Helicopter (livel flight sea level).

CONCLUSION

The results presented are acceptable especially at moderate velocity ratios. Better accuracies could be obtained if the flapping oscillations are introduced as well as the pitching one.

The present technique computes with good accuracy the rotor airloads with the effect of dynamic stall . In general good agreement was shown between the calculated maximum forward velocities and the data values of Gazelle helicopter. So far the method gives good base for the study of the blade dynamic loading with the inclusion of blade elasticity.

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NOMENCLATURE

nondimensional pitch rate (A= $\alpha_{p}b/2.U$) blade chord ($\overline{b} = b/R$), $b_{0.7}$ is the chord at section А b r = 0.7 CDS, CLS Static drag and lift coefficients of blade section. CDU, CLU Synthesized drag and lift coefficients of blade section. rotor drag and lift coefficients. Cv С_х, gravitational acceleration. g longitudinal force coefficient. h moment of inertia forces of flapping. lhh empirical constant for Cdu Js reduced frequency (K = $\Omega \tilde{b}/2U$) Κ Stagges of flapping hinges Lh.h Mach number thrust moment coefficient_relative to flapping hinge Μ mh.h empirical constants for CLU P's,Q's radius of rotor. R radius of blade section $(\bar{r} = r/R)$ mass static moment of the inertia forces of flapping Sh.h rotor thrust coefficient. t relative velocity of blade section. U path velocity of helicopter ($\tilde{V} = V/R$). V angle of attack of rotor. α amplitude. ā mean angle of attack. æm instantaneous angle of attack of blade section. time rate of change of blade element angle of attack ar flapping angle of blade and its lst and 2nd derivaar B, B, B' tives, with respect to Ψ air density. p blade azimuth blade pitch for section \bar{r} = 0.7 at /3 = 0 Y θ, rotor angular relocity 2 incremental drag coefficient. △CL1,CL2 incremental lift coefficients. shifts in angle of attack. Da, , Da,

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SUBSCRIPTS

as	assigned	
CT	critical	
obt	obtained	
	denotes the azimuthal position.	
S	Indicates number of dynamic empirical	constants

ABBREVIATIONS

B.E.T. blade element theory.