

DYNAMIC MODEL OF ROTOR BLADE BEHAVIOUR

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ABSTRACT

There are more than 40 Ka-26 rotorcrafts today in Hungary. They have glass-fibre composite rotor blades had been constructed (at 1969) there were possibilities only for the static strengths analysis. Conversely the rotor blades are loaded by a lot of basically unsteady effects. For determination of them nowadays much more concinnity methods (theoretic examinations for example vortex theories; 1:1 rate wind tunnel tests; flight tests) are used. Unfortunately such methods are very expensive and they often give different results. For the successful calculation of dynamic loads of a rotor blade (mainly by a bottom blade of a coaxial system) with the possibilities are available for me in Hungary, I had to develop such method that has a satisfactory accuracy, take into consideration the unsteady effects, and easy realisable and usable with a PC. In this paper I presented analysis of aerodynamic-dynamic behaviour of the bottom rotor blade and the relation between the static and dynamic loads of the bottom rotor blade of coaxial rotor system using that aerodynamic-dynamic-aero elastic model. Results could give the base of the life time limit lengthen of that blades as validated by the present exploration.

1. INTRODUCTION

My aim was to establish a technical-mathematical model for write the aerodynamic-dynamic-aero elastic behaviour of coaxial rotor system in a steady linear flight. For reaching the goal I had to analyse the rigid and elastic blade motions, the flow area above the rotors and the aerodynamic forces acting on blades with taking into consideration the effect of top rotor and unsteady effects of variable flow too.

The base of calculation is the combined blade-element momentum theory with the ONERA model [1] for unsteady flow effects, with the effect of top blade tip vortices and the effect of control system too. By this way the induced velocity field and the unsteady effects can be calculated. In case of success, these results can be used by the calculation of helicopter performance, equilibrium states, and finally but not at least for the investigation of rotor blade's life time with the calculation of the loads. The combined blade element momentum theory (BEMT or CBEMT), is a well known theoretical method [2, 3]. The zero resulted effects of blade tip vortices can be taken into consideration with using of the vortex theory complement added by me, which missed from the original theory. The present calculation method could be checked by the application of the results of KA-26 helicopter investigations have been implemented at 1990 in a co-operation of Technical University Aachen and Technical University Budapest [4].

2. THE MODEL AND RESULTS

For reaching the aim I have had to consider my strongly limited computational capacity and measuring possibility as well as the relatively simple programming ability and satisfactory accuracy, I have chosen the base of model the combined blade element momentum theory supplemented with effect of trailing vortices. Increasing the accuracy I have considered three movements of rotor blade, the flow above the rotor, the aerodynamic forces on the blade, the effects of top rotor, the unsteady flow around the profiles, the elastic deformations and the effect of tip vortices. For the solution of problem I have developed the model of Tamás Gausz Ph.D. written in version 3.5 of Power-Basic [5] and based on the combined blade-element momentum theory for single rotor case. I have used the MATLAB too mainly for filtering of the results of measurements and Microsoft Excel for completions of those processes were not programmed, and for the graphics.

In case of using the momentum theory the cross section of stream tube of the coaxial rotor system, what I have given as a function of the place along the rotor disc. By the way on a coordinated place knowing the distant flow velocity, the pressure and the density, the induced velocity could be simply determined by using of momentum theory. Using the blade-element theory in case of bottom rotor we have to consider even the classical components of the flow or the normal and tangential induced velocities of top rotor, the velocities are induced by the tip vortex of top rotor on the bottom rotor disc, the effect of tip vortex on the lift near the tips (the lift coefficient was decreased to zero with a polynomial by the tips) and the effect of unsteady flow on the profile characteristic with the ONERA model. By considering of the effects of top rotor those area is on the bottom rotor disturbed by the flow of top rotor had to be determined in the function of advance ratio [6]. Here the setting back of the stream tube was considered.

The flapping and feathering motions were considered with their simplified classical differential equation by this way consider with the control law and the effect of flapping compensation. In the computation the bending deformation was considered with the linear combination of the first four free vibration with their azimuthally coefficients, those azimuthally coefficients were very necessary for the calibration of the model and for the strength analysis too.

The computation process have two parts: In the first part the program calculates the induced velocity-distribution, thrust, horizontal and side forces of the top rotor. In the second step the program considers the foregoing computed and conformal positioned induced velocities of the top rotor additionally with the velocities induced by the top rotor tip vortices. In both parts calculations shall be stopped when reaching generalised equilibrium state of rotor blades.

For the calibration of model I have used the results of a measurement already published in the [7] and was analysed in my previously papers [8] [9] [10]. Without detailing the base of the measurement was the signs of tensiometric stamps calibrated for unit-moment values on a bottom rotor blade of a Ka-26, flapping angle transmitter and rotation per minute transmitter were transmitted to the earth with a telemetric system during steady level flight with different advance ratio.

The differential equation of flexible chord can be easily solved numerically with the linear combination of the above mentioned azimuthally coefficients and free vibrations. So giving same operation parameters near the measured moment values could be calculated with the model, in a given azimuth and place along the rotor blade. For determination of the deviation between the measured and with a dipole Chebisev filtered and model computed moment values I have used a deviation function with the space of quadratic integral able functions, computed by scalar product and well usable in case of any constant approximation [11].

Table 1. shows the above mentioned deviations in case of $\mu=0,15$ advance ratio. On the base of results above I have

Table 1. Relative deviations of the two results on the measuring places

Meas. Places	No1	No2	No3	No4	No6	No7	No8
Deviation [%]	14,4	15,01	24,38	22,04	18,59	21,77	23,22

looked at the model as a valid one. The whole both the normal and tangential induced velocity field of the helicopter was calculated by different advance ratios as an aerodynamic application of model. One of these results (the induced velocity field of bottom rotor) is shown by the Figure 1.

The whole calculation of rotor blade's loads would be calculated with those movements were determined by the model so by this reason it would be possible the calculation of load on the base of static – with superposition of the external loads – and on the base of dynamic – calculation of the internal loads as to be in balance with external ones.

By the calculation of static bending load the following effects had been considered the moments and forces from the lift, the moments and forces from the lift centrifugal force, the moments and forces from the mass forces.

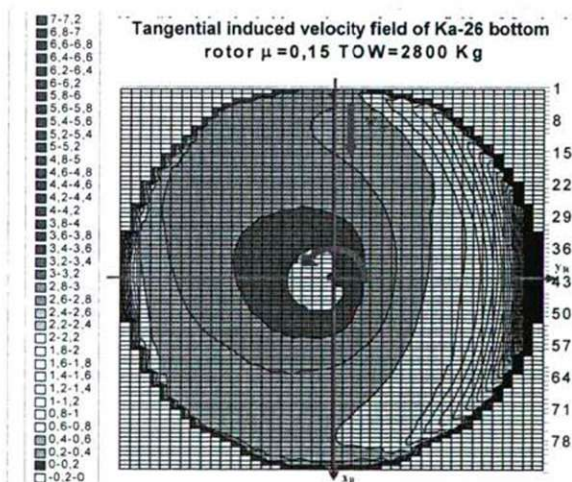
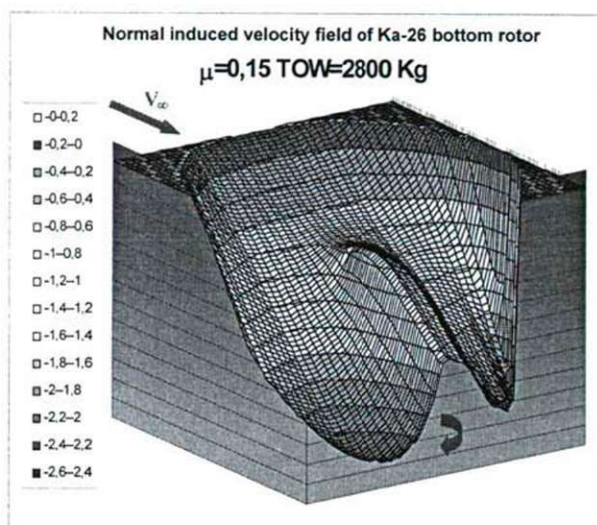


Figure 1. The normal and tangential induced velocity field of bottom rotor [m/s]

The internal stresses from the elastic and rigid bending motion were considered as the base of dynamic bending load. The following equations coming – from differential equation of flexible chord – were used to calculate the dynamic bending load as a bending moment:

$$(1) \quad M_{DIN}(x, \psi) = IE(x) Y''(x, \psi)$$

and from this moment the stress in the outermost cord of the bended structure – in this case the bottom outermost fibre of the spar of rotor blade – can be calculated with the following equation:

$$(2) \quad \sigma_{DEF} = \frac{\partial^2}{\partial x^2} \sum_{i=2}^4 \Phi_i(x) H_i(\Psi) E e(x)$$

The reduced stress values in the table 2. by both –dynamic and static too – cases were calculated with the following equation [12]:

$$(3) \quad \sigma_{red} = \sqrt{\sigma_r^2 + 4\tau_v^2}$$

where in static case σ_r is a summary of follows: the bending moment from lift force, the bending moment from centrifugal force, the bending moment from mass force, tensile stress from centrifugal force. In case if shear only the lift was considered and related to the shear strength.

Table 2. Relative stresses and elongations

Adv. Ratio	$\sigma_{dir}/\sigma_{stat}$	$\sigma_{redStat}/\sigma_B$	σ_{redDin}/σ_B	ϵ_{Stat} (m/m)	ϵ_{Din} (m/m)	τ_v/τ_B
$\mu=0,025$	12/85 (14,1%)	135/420 (32,14%)	56/420 (13,33%)	0,0045	0,0019	2,8/40 (7%)
$\mu=0,15$	15/180 (8,3%)	180/420 (42,85%)	60/420 (14,28%)	0,006	0,002	2,6/40 (6,5%)
$\mu=0,25$	19/325 (5,8%)	330/420 (78,57%)	66/420 (15,71%)	0,011	0,0022	3,2/40 (8%)

In dynamic case σ_r is a summary of follows: internal stresses from elastic deformations due to dynamic forces, tensile stress from centrifugal force as above.

Table 2. shows the absolute and relative values of the stresses and elongations. The strength properties of rotor blade material were sourced from the literature [13].

The figure 2 and 3 show the distributions of the static and dynamic reduced stresses along the rotor disc.

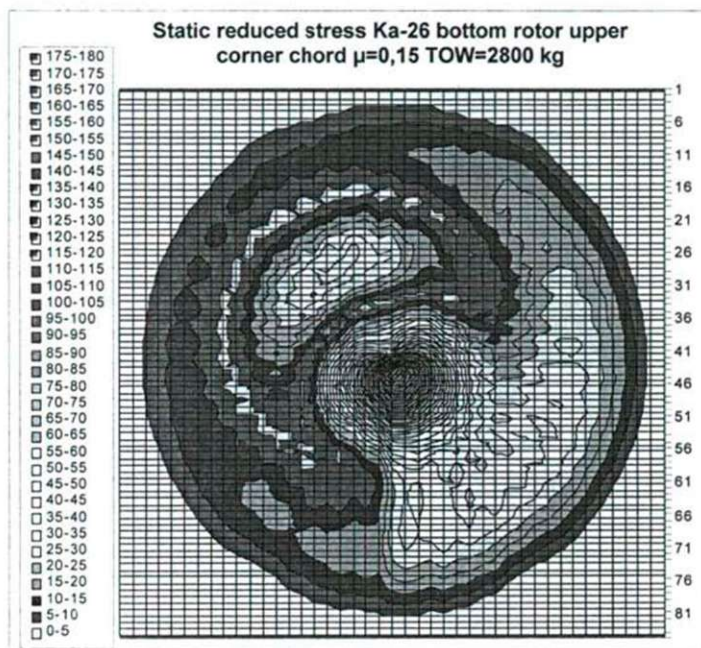


Figure 2. Distribution of static reduced stress [MPa]

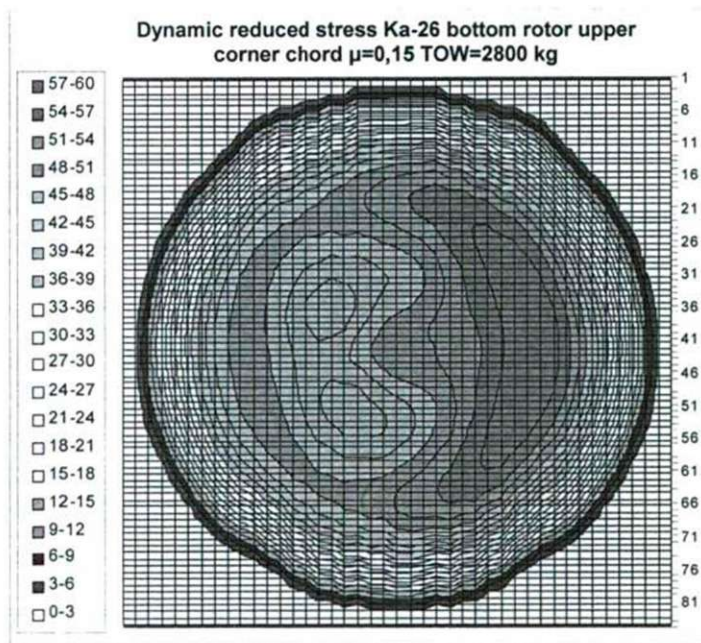


Figure 3. Distribution of the dynamic reduced stress [MPa]

3. CONCLUSIONS

Using this model the following could be state able:

1. The flow around the bottom rotor blades are not changed significantly due to the effect of induced velocity field of top rotor;
2. The diameter and place of the stream tube of top rotor is changed in the function of advance ratio and there is always an area to be not disturbed by the flow of top rotor;
3. The top blade's tip vortices act on the load of bottom blades only in case of medium advanced operation and the effect of the induced velocities is the higher in case of small advance or hanging. On the other hand in case of high speed operation the effects of top rotor on the loads of bottom one is insignificant. This figure 4 shows the effects of top rotor in the relative radius of 0,75 (is place is the place of No. 3 of the measure rotor blade) at the most often used advance ratio. The symbols in the figure are the follows:
 - No. 3 AERO: Results are calculated with the model considered with the most effects;
 - ÖN: Results are calculated with the model without the effect of top blade tip vortices;
 - FN: Results are calculated with the model without any effects of the top rotor.
4. It can be well seen on the base of values of the Table 2. that values calculated on the base of external loads and called for static are much more higher than those values are calculated on the base of deformations as internal stress (called dynamic) and really existing. This goes to show in real operation situation due to the fast change of loads the structure has no enough time to carry those loads were calculated on base of static point of view. Figure 5 as azimuthally intercepts well show the rate of static and dynamic stresses.

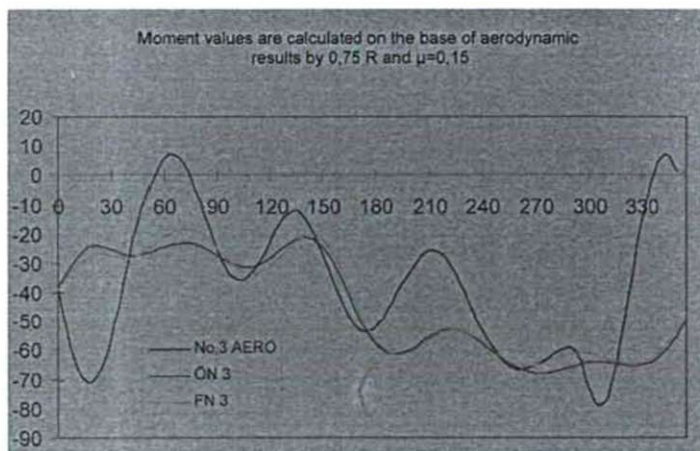


Figure 4. The effects of top rotor on the bending moment of bottom blades by medium advance

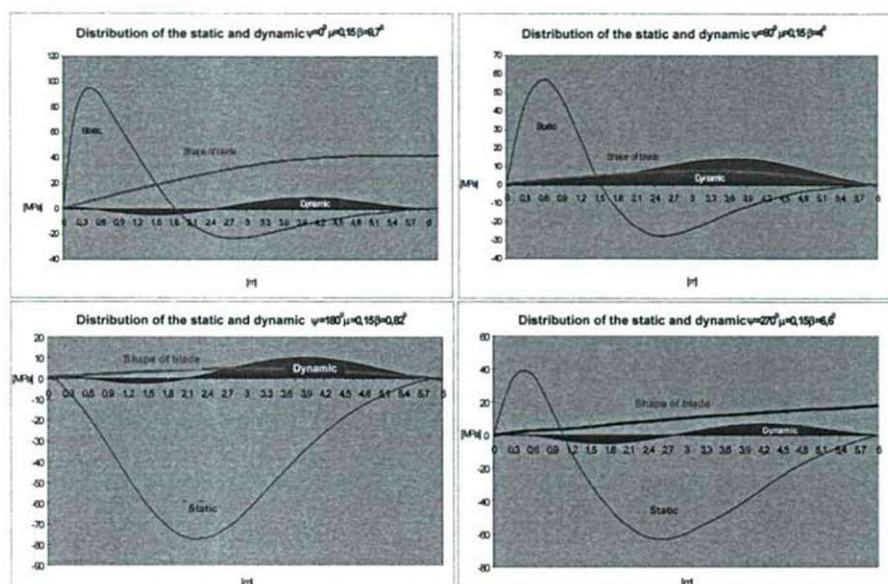


Figure 5. Azimuthally intercept of shape of blade and strength distributions

- By this reason the rotor blades are constructed on the base of static aspect (forasmuch as the rotor blade of Ka-26 rotorcraft was constructed at 1959 and then were not so computational background as were able to determine the dynamic loads) are exaggerated structures.
- Using dynamic loads new construction limits could be determined as a more economic solution or the life time of these structures could be lengthen on this base.
- It is ascertainable that the relative elongation of rotor blades of Ka-26 helicopter exceeds nowhere the 0,004 value [14] [15] [16] [17] so by this way the life time of blade goes to the infinite when the mechanic loads are considered only. On this base (considered with practical experiences in the subject [18] the life time of the blades would be not infinite due to the environmental effects, but it is expectable this life time will be very high.
- Presently we are working on the problem of environmental damage of the main spar performing deformation measures and destructive tests also. We have almost 100 results at every type of analysis based on Manufacturer's acceptance procedure. The freshest statistics show that the strength of this structure is basically in correlation with calendar time not with operation (hard) time. On the base of results of our present exploration expectable calendar limit of this rotor blades shall be more than 30 years instead of present 20 years, what was 6 years at the first step.

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