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Static Structural Analysis of a Helicopter Rotor Blade

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Abstract: **The aerospace industry deals from the beginning with structures with special requirements as extreme lightweight and withstanding to a big number of load cases. Aerodynamics constraints lead to supplementary restrictions, the results being the complex shape to sustain the fuselage, the rotor blades or the wings skin. This paper presents a static structural analysis of the main rotor blade for the light helicopter. To simulate the mechanical behaviour of the blade, a finite elements method was used. A case of hovering flight mode and steady state was considered.**

Keywords: **finite element method, hovering flight mode, rotor blade, structural analysis, ANSYS.**

I. INTRODUCTION

A helicopter can be defined as any flying machine using rotating wings (i.e., rotors) to provide lift, propulsion, and control forces that enable the aircraft to hover relative to the ground without forward flight speed to generate these forces. The thrust on the rotor(s) is generated by the aerodynamic lift forces created on the spinning blades. To turn the rotor, power from an engine must be transmitted to the rotor shaft. It is the relatively low amount of power required to lift the machine compared to other vertical takeoff and landing (VTOL) aircraft that makes the helicopter unique. [6]

II. LITERATURE SURVEY

The blades of a helicopter are “wings” which produce aerodynamic force, when are exposed at relative motion of air on their surface. The relative motion of the engine hub, produce this relative movement, both forward, sideways and back. The blades are designed to geometry adapted to different flight conditions.

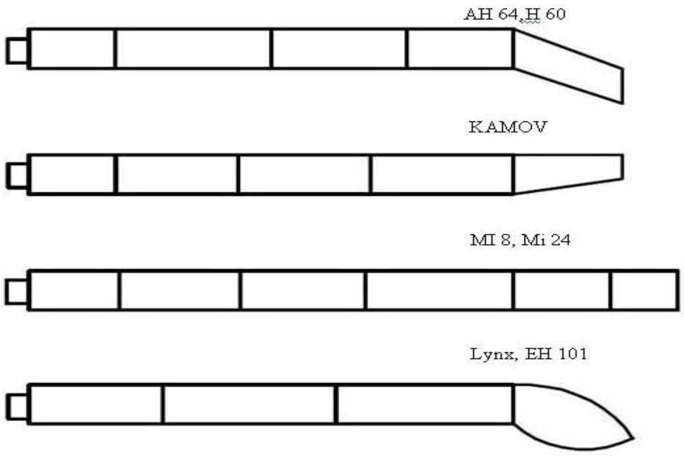


Fig 1: Types of blades.

A regular flight operation consists of take-off, climb, cruise, turn, maneuver, descent, approach and landing. Basically, the airfoil's optimum function is in cruise, that an aircraft spend much of its flight time in this flight phase. At a cruising flight, lift (L) is equal to aircraft weight (W), and drag (D) is equal to engine thrust (T). Thus the wing must produce sufficient lift coefficient, while drag coefficient must be minimum. Both of these coefficients are mainly coming from airfoil section. Thus two governing equations for a cruising flight are:

$$L=W=1/2\rho V^2 S C_L = mg \tag{2.1}$$

$$D=T=1/2\rho V^2 S C_D = nT_{max} \tag{2.2}$$

$$D=T=1/2\rho V^2 S C_D = \frac{n\eta_P P_{max}}{V_c} \tag{2.3}$$

Usually, there is no unique airfoil that that has the optimum values for all above-mentioned requirements. For example, you may find an airfoil that has the highest $C_{l_{max}}$, but not the highest $\left(\frac{C_l}{C_d}\right)_{max}$. In such cases, there must be compromise through a weighting process, since not all design requirements have the same importance. Hence NACA0012 airfoil is considered for design and analysis as it is reliable and widely useful and simple to generate.

III. DESIGN AND ANALYSES

Helicopter hover performance is expressed in terms of power loading or figure of merit (FM). In this study we assume that the rotor thrust and helicopter weight is equal. Therefore, the required hover power should be made as small as possible.

The airfoil shape is represented by CST function coefficients. These coefficients are also the design variables of the examined optimization problem. Considering the above-mentioned factors, this approach gives the induced and profile power as functions of twist, taper ratio, point of taper initiation, blade root chord, and coefficients of the airfoil distribution function. [1][2][3]

The CST method follows the process shown in Fig. 2. First, the given data points are converted to non-dimensional values. Second, the class function exponents and the degree of the shape function are defined. Then, shape function coefficients are calculated by the fitting process. Finally, by multiplying the shape function and the class function, the distribution function is obtained.

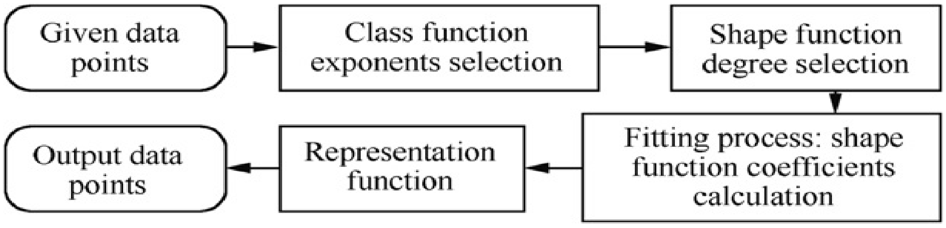


Fig 2: Representation procedure using CST method

In this study, the airfoil baseline was chosen as NACA0012. With the given data coordinate points in Cartesian coordinate space, a curve fitting was generated using fourth order Bernstein polynomials. The class function for the airfoils is CðxÞ ¼ x0:5ð1 _ xÞ The airfoil distribution functions defined as upper and lower curves are presented sequentially as

y1ðxÞ ¼ CðxÞ½Al0ð1 _ xÞ4 þ Al14xð1 _ xÞ3 þ Al26x2ð1 _ xÞ2 þAl34x3ð1 _ xÞ þ Al4x4_

yuðxÞ ¼ CðxÞ½Au0ð1 _ xÞ4 þ Au14xð1 _ xÞ3 þ Au26x2ð1 _ xÞ2 þAu34x3ð1 _ xÞ þ Au4x4_

where Au_0= 0.1718; Au_1= 0.15; Au_2 = 0.1624; Au_3 =0.1211;

Au_4 = 0.1671; A_{l0} =_0.1718; A_{l1} = _0.15; A_{l2} =_0.1624;

A_{l3} =_0.1211; A_{l4} =_0.1671.

Changes in the coefficients A0 and A4 in the CST method are sufficient for airfoil shape modification. These coefficients are also the design variables of the examined optimization problem.

Four coefficients of the airfoil distribution function are defined as the initial input data of the design process after obtaining the fitting curve of the airfoil baseline NACA0012. Then, airfoil coordinate points are generated by the CST function.

ANALYSIS:

Rotor blades can be broadly classified as metallic and composite. Fiber reinforced plastics (FRP) such as glass; carbon and Kevlar-epoxy combinations are being extensively used as structural materials in modern helicopter rotor blades and hubs. The important basic advantages are their higher fatigue strength, good damage tolerance and soft failure modes. The mechanical properties are shown in the table below.

Table 1: Material Properties of composites used

	Steel	Aluminium	Fiber Reinforced Plastic	Glass/Epoxy
Density Kg/mm^3	$7.84*10^{-5}$	$2.67*10^{5}$	$1.86*10^{-5}$	$2.49*10^{-5}$
Young's Modulus N/mm^2	$2.080*10^{5}$	$68.3*10^{3}$	$E_{11}=1.59*10^{5}$ $E_{22}=9655.8$	$E_{11}=38623.2$ $E_{22}=8276.4$
Poisson's Ratio	0.3	0.34	0.338	0.261
Shear Modulus N/mm^2	-	-	5034.81	4138.2

There are 12 number of components in this rotor blade design. Modelling is done using CATIA V5 version software as per the dimensions. (I.e. considering the design parameters) The length of the rotor blade is 12m and chordlength is 3m.

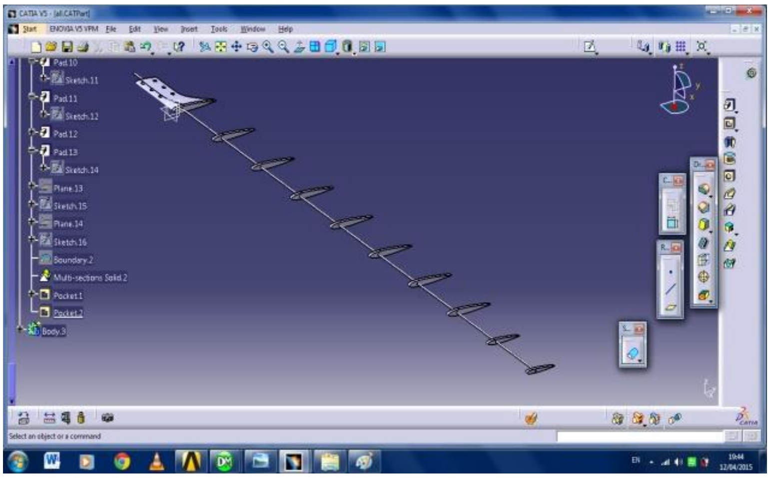
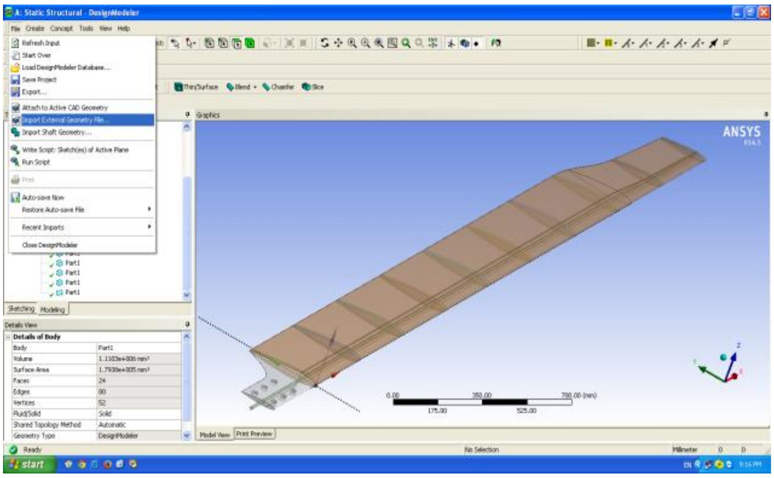


Fig 3: Rotor Blade design modelling



Details View

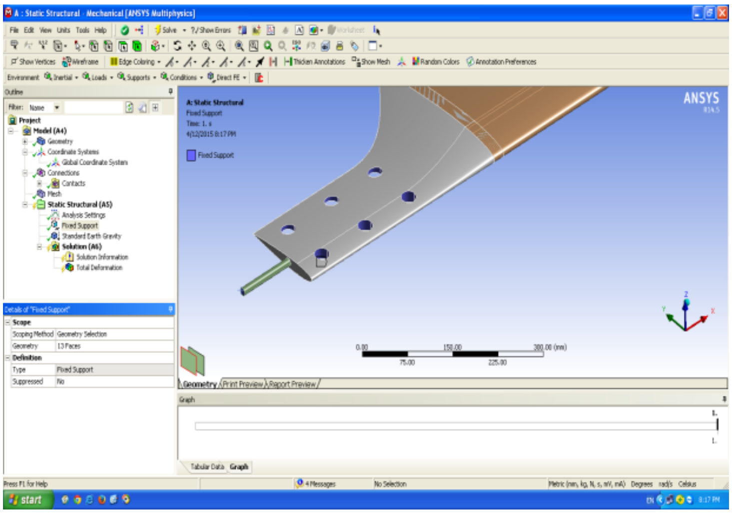
Details of Body	
Body	Part1
Volume	1.1103e+006 mm³
Surface Area	1.7930e+005 mm²
Faces	24
Edges	80
Vertices	52
Fluid/Solid	Solid
Shared Topology Method	Automatic
Geometry Type	DesignModeler

Fig 4: Importing CAD file in ANSYS Workbench

No. of nodes and elements for this product are: nodes: 179757, Elements: 79448

We can observe maximum stresses at some sections i.e., where we have some cross section area

Where stress= force/c.s area



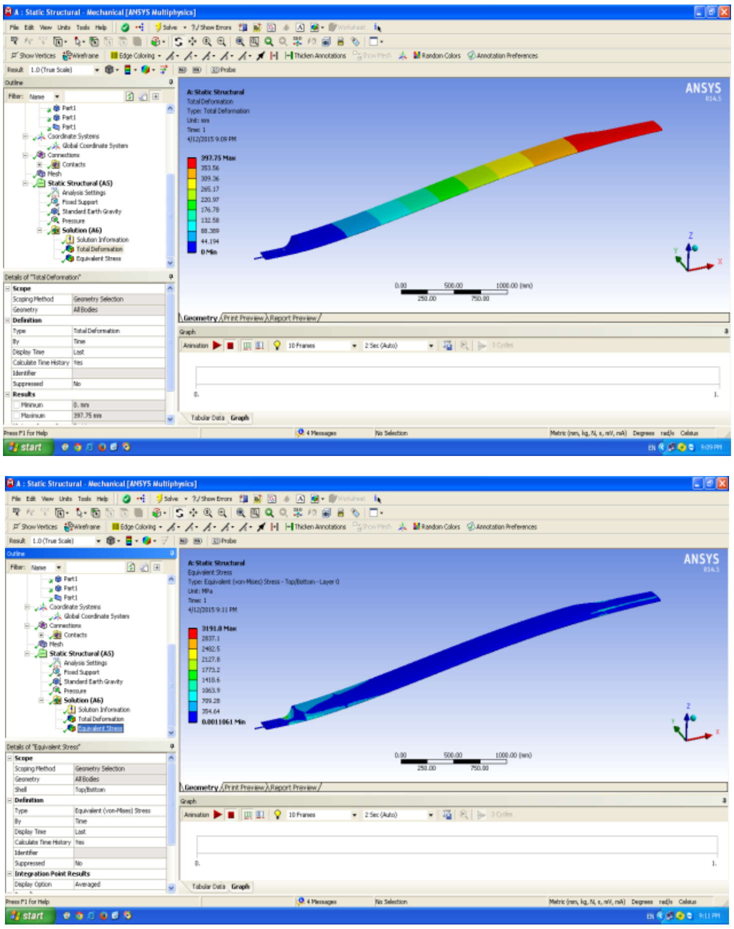
A : Static Structural - Mechanical [ANSYS Multiphysics]

A: Static Structural
Fixed Support
Time: 1. s
4/12/2015 8:17 PM

Details of "Fixed Support"

Scope	
Scoping Method	Geometry Selection
Geometry	13 Faces
Definition	
Type	Fixed Support
Suppressed	No

Fig 5: Self-weight and gravity loads in static condition



A : Static Structural - Mechanical [ANSYS Multiphysics]

A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
4/12/2015 9:09 PM

Details of "Total Deformation"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Total Deformation
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Suppressed	No
Results	
Minimum	0. mm
Maximum	397.75 mm

A : Static Structural - Mechanical [ANSYS Multiphysics]

A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress - Top/Bottom - Layer 0
Unit: MPa
Time: 1
4/12/2015 9:11 PM

Details of "Equivalent Stress"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Shell	Top/Bottom
Definition	
Type	Equivalent (von-Mises) Stress
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Suppressed	No
Integration Point Results	
Display Option	Averaged

Fig 6: Max Deflection and stresses observed

From above figures, we can observe max deflection and stresses are higher than material ability.

IV. RESULTS

This shows that in static structural analysis, we observe the alternating stresses and position of rotor blade.

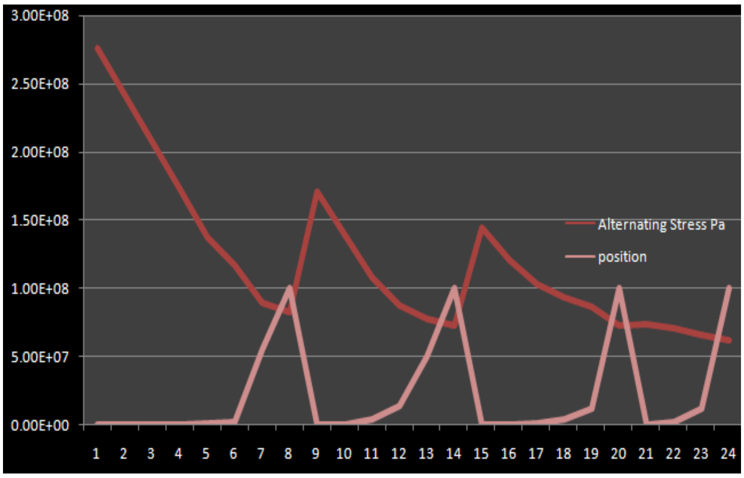


Fig 7: Rotor Blade graph stresses with position

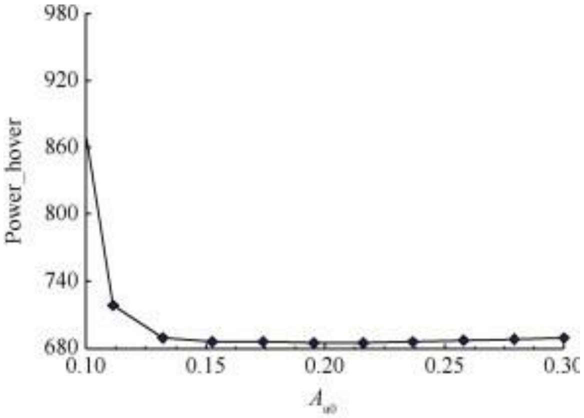
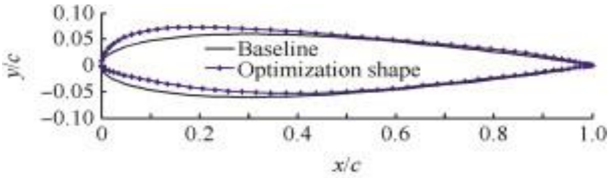
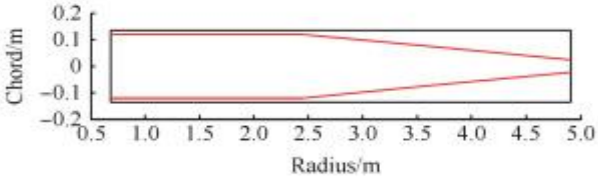


Fig 8: Sensitivity analysis of design variables

Optimization Problem: These analyses reveal that the coefficients obtained by the airfoil distribution function have an important role in the performance of the rotor. Therefore, this study has demonstrated that airfoil shape should be considered as a design variable. This optimization problem is applied to the rotor blade of a Bo 105 LS helicopter.



(a) Airfoil coordinate



(b) Blade planform

Fig 9: Optimum results

The optimum results in which the objective function decreases by 7.4% and Figure of Merit increases by 6.5%.

V. CONCLUSION

1. This study is performed for the hover case only. We can see that the optimum taper ratio and position of the taper are on the boundary of these design variables.
2. The local blade chord must vary hyperbolically with span and can be adequately approximated by a linear taper over the outer part of the blade.[4] Therefore, each section of the blade operates at optimum lift-to-drag ratio.
3. The optimum results in which the required hover power decreases by 7.4% and FM increases by 6.5% are good values for rotor blade design.

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