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ENGINE POWER INFLUENCED BY VERTICAL TIP WINGS AT ROTOR BLADES

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Summary

This paper describes a preliminary study on an improvement to descrease the helicopter engine power requirements. Such improvement consists of the application of vertical placed wing at each tip of the main rotor blades, hereafter called "VTW" (Vertical Tip Wing).

The presented theoretical and numerical analysis show the relation between the aerodynamic characteristics of the VTW and the ratio of the peripheral velocity at the rotor tip to the free flight velocity, the peripheral position, and the ratio of the rotor blade radius to the VTW chord, that suggest the advantage to use the VTW for the savings in engine power.

The way for more theoretical and experimental investigation on the VTW conclude the paper.

List of Symbols

C	VTW chord length
C_L	$= L/(0.5\ \rho\ W^2\ S_R)$, lift coefficient of the VTW
C_D	$= D/(0.5\ \rho\ W^2\ S_R)$, drag coefficient of the VTW
C_m	$= M/(\rho\ U_\infty^2\ \pi\ R^3)$, saving torque coefficient due to one VTW
C_p	$= P/(0.5\ \rho\ U_\infty^3\ \pi\ R^2)$, saving power coefficient due to one VTW
C_t	$= T/(0.5\ \rho\ U_\infty^2\ \pi\ R^2)$, thrust coefficient of the VTW
D	VTW drag
H	VTW height

L	VTW lift
M	saving torque due to one VTW
P	saving power due to one VTW
R	rotor blade radius
S_R	reference area of the VTW
T	thrust of the VTW
$\vec{U}_\infty$	free flight velocity
$\vec{W}$	VTW onset flow velocity (see fig. 2)
α	VTW effective angle of attack
Θ	angular reference position of the VTW
λ	$= R\,\omega/U_\infty$, ratio of the rotor tip peripheral velocity to the free flight velocity
ρ	free stream density
ω	angular velocity of the rotor rotation

1 - INTRODUCTION

Nowadays the modern helicopter and its associated propulsion system is highly sophisticated. But, agreed with other authors, still many problems exist. Therefore and because of the increasing use of such helicopters, it is required to make research on further understanding of the physical phenomena and consequently on further improvements in the design and in the technology of their assemblage.

For the reasons above the present paper describes a preliminary study on an improvement to decrease the helicopter engine power requirements. This improvement consists of the application of a vertical placed wing at each tip of the main rotor blades, fig. 1, hereafter called "VTW" (Vertical Tip Wing).

During the helicopter flight the VTW is subjected to the free flight velocity as well as to the peripheral velocity at the rotor tip. Therefore, the VTW act at an angle of attack α and produces lift, L, and drag, D, fig. 2. Such forces have a component, T, in the rotor blade plane and in the direction of the movement of this VTW. It is this aerodynamic driving force that will decrease the engine power requirements.

The presented theoretical and numerical studies show the relation between the aerodynamic characteristics of the VTW and the ratio λ of the peripheral velocity at the rotor tip to the free flight velocity, the peripheral position, Θ , and the ratio R/C of the rotor blade radius to the VTW chord, that suggest the advantage to use the VTW for the savings in engine power.

The way for more theoretical and experimental investigation on the VTW conclude the paper.

2 - THEORETICAL PRELIMINARY INVESTIGATION

An example of the application of the VTW at the tip of each blade of a main rotor of three blades is shown in fig. 1. In this figure Θ gives the angular reference position of the VTW under consideration.

Considering that the VTW are of small maximum thickness, the variation of the peripheral velocity $R\omega\vec{\tau}$ ($\vec{\tau}$ is the unit versor) over its surface is neglected. Therefore, as fig. 1 and fig. 2 illustrate, because of the angular velocity of the rotor rotation, ω, and of the free flight velocity, U_∞, the VTW is subjected to an onset velocity, $\vec{W}$, and to an angle of attack, α , at every its position Θ. The values of these W and α, are given by the expressions:

$$\left\{\begin{aligned} W &= U_\infty\sqrt{\lambda^2 + 2\lambda\cos\Theta + 1} \\ \alpha &= tg^{-1}[\sin\Theta/(\lambda + \cos\Theta)] \end{aligned}\right. \qquad (1)$$

where λ is the ratio of the rotor tip peripheral velocity to the free flight velocity.

Owing to the above incidence α, each VTW develop a lift, L, and a drag, D, fig. 2, that have a component T in the rotor blade plane and in the peripheral direction of its movement. Assuming that this thrust T is positive in the advancing direction of the VTW, the value of its coefficient is:

$$C_t = (W/U_\infty)^2 (C_L \sin\alpha - C_D \cos\alpha)\, S_R/(\pi R^2) \qquad (2)$$

The above thrust produces at the axis of the rotor a saving torque and a saving power which coefficients are:

$$\begin{cases} C_m = C_t/2 \\ C_p = C_t\,\lambda \end{cases} \tag{3}$$

Following this simple theoretical model that is descripted in a more detail in Ref. [1], for the present preliminary theoretical investigation it is assumed a rectangular VTW of small aspect ratio and of section NACA 0012.

Neglecting: a) the interference between the VTW and the rotor blades; b) any transonic effect of the flow; c) the strong unsteady phenomena that can be calculated by the method descripted in Ref. [2]; d) the interference between the VTW of each rotor blade, the aerodynamic coefficients C_L and C_D of the VTW are calculated from the coefficients C_L and C_D of the two-dimensional airfoil NACA 0012, assumed from the Ref. [3] and reported in fig. 3.

Fig. 4 presents the angle of attack, α, at which the VTW works at its position Θ and for every value of λ. From this figure and from fig. 3 derives that the considered VTW works under the stall angle for $\lambda > 4$.

Fig. 5 illustrates the instantaneous saving power coefficient producted by the VTW in relation to the number and to the radius of the rotor blades, for $\lambda = 13$. From this figure it can be remarked that the saving power coefficient is almost constant when the number of the rotor blades are more than two. This is due to the equilibrium of the forces developed by all the VTW.

Fig. 6 shows the values of the main saving power and of the main saving torque coefficient, in a complete blades run, vs λ, that each VTW develop for various values of the rotor blades radius. From this figure derives that the maximum values of C_p and C_m, for the assumed VTW, are obtained for $\lambda = 12.6$ and for $\lambda = 5.5$. From the same figure it is also denoted that from the hovering condition the VTW gives very quickly a positive power that decrease the engine power requirements.

Finally, in fig. 7 it is reported the limit of the saving power coefficient vs the radius of the rotor blades that each of the considered VTW can develop.

3 - EXPERIMENTAL INVESTIGATION

An experimental investigation should be executed not only to verify the theoretical investigation on the influence of the VTW on the engine power, but also to measure the physical phenomena caused by the VTW rotor-blade combination. The shape of the VTW tip is also an item to investigate.

Such investigation should not only present aerodynamic but also acoustic results, because helicopter operations in terminal-areas are submitted to commercial noise regulations. The helicopter main and tail rotor are mainly responsible for the noise. The main rotor impulsive noise is created by shock waves at high forward speeds or by blade-vortex interaction at near hover ($\lambda \rightarrow \infty$) or descent conditions, Ref. [4]. These phenomena take place at the outer part of the rotor diameter and at the tip to which the VTW is attached. To investigate the effect of the VTW itself and the VTW-tip shape on the engine power and on the physical phenomena the VTW must be detachable from the rotor tip. A possible wind-tunnel set-up and some technical aspects involved will be discussed.

The scaled model rotor must satisfy to several requirements to obtain similarity with full-scale conditions. The model rotor must be geometrically scaled down. The rotational tip Mach number and the advance ratio ($1/\lambda$) should be duplicated because it plays an important role in the aerodynamic flow field and is a dominant factor in the contribution of the acoustis pressures. It is favourable to duplicate the Reynolds number or else be as close as possible to the full-scale number. If the wind tunnel is not a pressurized but an atmospheric one the Reynolds number is unavoidably affected. Then it is important that the scale-down factor of the model rotor is not too large. To fulfil the Reynolds number at the advancing but also at the retreating side of the rotor disk the minimum chord length of the model rotor should be at least 0.10 m to 0.14 m, based on a tip Mach number of 0.64 in hover and on a high advance ratio of 0.35 ($\lambda = 2.86$), Ref. [5]. It is also important to duplicate the dynamical characteristics of the rotor blades, the rotor head and especially the VTW's to find out the dynamical interference between VTW and rotor blade. The VTW is an extra wing with its characteristics at the end of the rotor tip. A propor distribution of mass and stiffness must be applied. This together with the aerodynamic behaviour of the rotor blade and VTW, caused by the acting forces, may result in an increase of rotor chord length, Ref. [6].

The model rotor will have at least two rotor blades. One rotor blade will be instrumented with a number of miniature pressure-transducers at radial and chordwise rotor stations, with a higher concentration at the leading edge and rotor tip, at the transition of the rotor blade to the VTW and at the VTW itself. The other blade will be instrumented with strain gauges and miniature accelerometers to measure respectively the radial and chordwise bending and blade torsion, and the radial or chordwise accelerations. In the same blade a three-component strain-gauge balance will be placed in the rotor tip to measure the aerodynamic forces and moments of the VTW and to be aware of the constructional forces and moments inside the future rotor-blade caused by the VTW.

The test stand which supports the model rotor must contain the hydraulic drive system, the six-component rotor balance, the power-consumption device, the rotor-control system and the transmitter to send the signals of the rotor-located instuments to the data-acquisition system, Ref. [6]. It must be at least possible to vary the tip-path-plane angle of the rotor to match several flight and out-of-flight conditions. The test stand must faired with noise-absorbing material to minimize the rotor-drive system noise and the rotor noise-reflections off the fairing. The spacings for shaft and hub rotations will be a sound source and has a negative input on the contribution in noise absorbtion. Therefore their effect must be determined through a transmission loss-test, Ref. [7]. The rotor balance will be used to measure the overall stationary and instationary rotor forces and moments. The power-consumption device will measure the power needed to rotate the rotor with and without the VTW. Some microphones on struts, faired with noise-absorbing material, have to be located around the rotor disk in in-flow and out-of-flow conditions to measure the noise in the near and far field and to be able to correct the noise data because of the reflections and tunnel shear-layer transmissions.

Finally we need a test facility which is appropriate for aeroacoustic testing of not too large scale-down helicopter rotors. The Duits-Nederlandse Windtunnel (German-Dutch Windtunnel) DNW could be such a facility, Ref. [8]. The DNW is a closed-return-type, subsonic atmospheric wind-tunnel with three interchangeable, closed-test-section configurations and one open-jet aeroacoustic configuration. The open-jet configuration consists of a 6 m by 8 m nozzle, a usable length of 20 m between the nozzle and the collector, and a 9.5 m by 9.5 m collector. The open jet is surrounded by a acoustically treated testing-hall of 45 m long, 30 m wide and 20 m high. The maximum flow velocity of 85 m/s (165 knots) covers the speed range of modern helicopters. Before testing the aerodynamic and acoustic characteristics of the tunnel should be known, Ref. [5, 8]. The aerodynamic characteristics of the clean open-jet configuration can be determined by flow quality calibrations like velocity uniformity, flow angularity and turbulent levels. The acoustic characteristics of the open-jet configuration affected by the rotor test-stand can be determined by background noise measurements and by impuls calibrations. The first method consists of running the tunnel at several speeds with a clean test stand without the rotor and VTW. The second method consists of firing of small explosive charges in the plane of the rotor disk to determine the acoustic reflections. Now a possible wind tunnel set-up and some technical aspects involved were described. The DNW wind tunnel and the DLR rotor-stands are known existing elements to which, after some simple modifications, we see possibilities to add the present VTW's, fig. 8. Therefore the verification of the influence of the VTW on the engine power would not occupy much tunnel time.

4 - CONCLUSIONS

Vertical Tip Wings, "VTW", at the main rotor blades have been applied to decrease the helicopter engine power.

The preliminary theoretical investigation on the aerodynamic characteristics of rectangular VTW of section NACA 0012 shows that the using of these VTW are convenient for rotors with more than two blades and only during the helicopter flight if such VTW are fixed at the tip of the main rotor blades.

Because of the good obtained results, a more detailed investigation on:

a) the interference between the VTW and the rotor blades;
b) any transonic effect of the flow;
c) the strong unsteady phenomena;
d) the interference between the VTW of each rotor blade,

is necessary to establish the advantages of the VTW using.

The shape of the VTW tip is also an item to investigate.

After or during the theoretical investigation, an experimental investigation must be done following the indications given in chapter 3 that permit to minimize the time and the costs of this activity.

5 - REFERENCES

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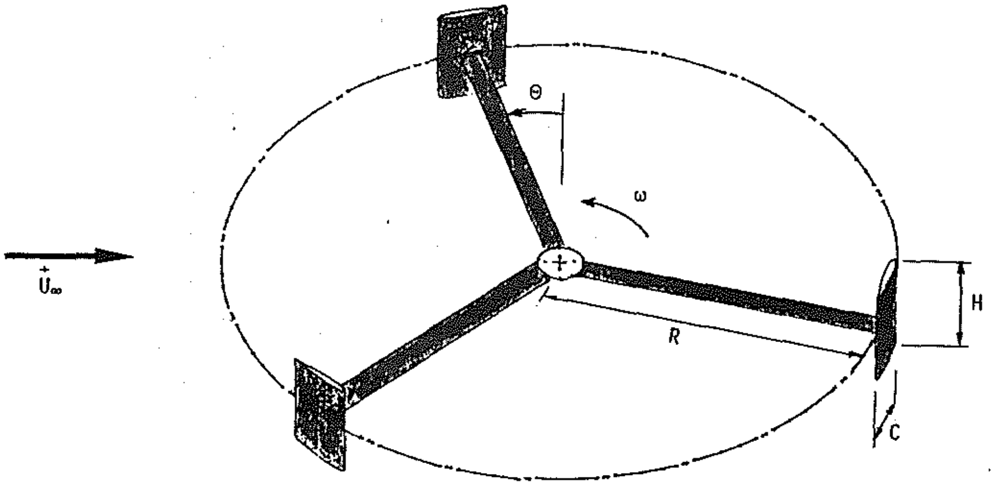


Fig. 1 - Rotor blades - VTW.

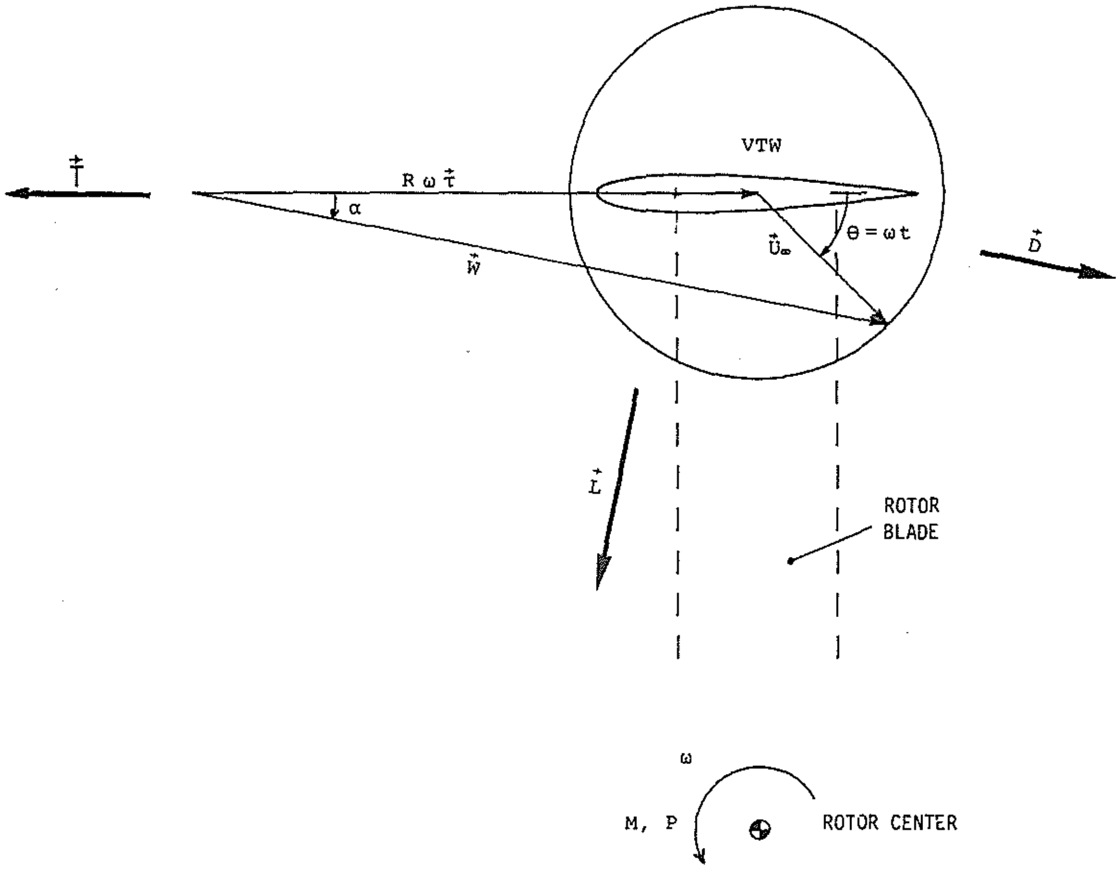


Fig. 2 - Aerodynamic responce of the VTW.

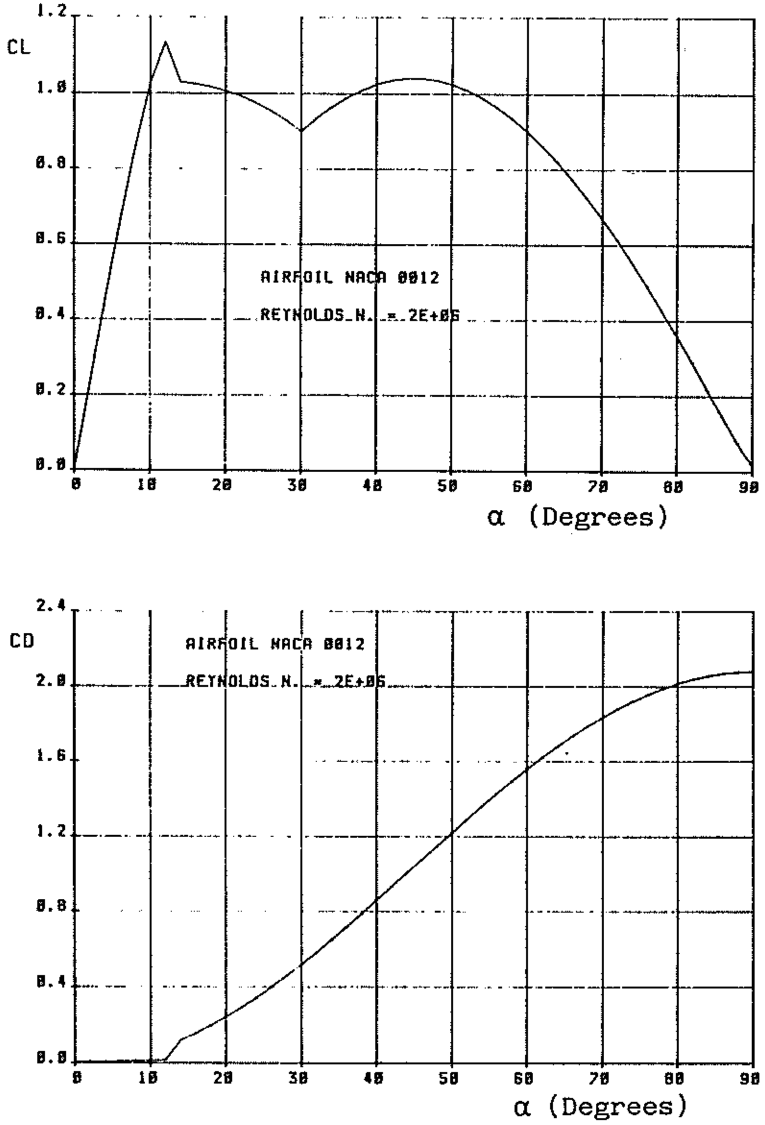


Fig. 3 - Lift and drag coefficients vs angle of attack of the airfoil NACA 0012, Ref. [3].

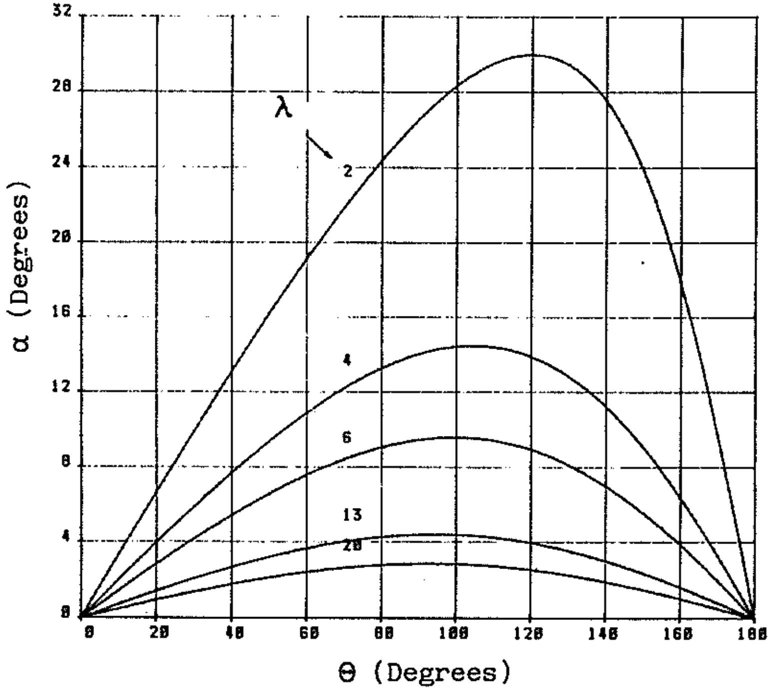
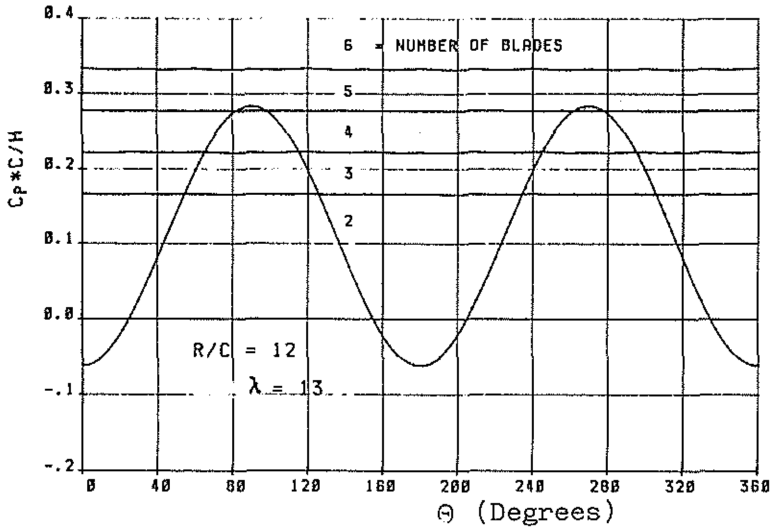


Fig. 4 - Effective angle of attack of the VTW in relation to the angular position Θ and to the ratio λ.



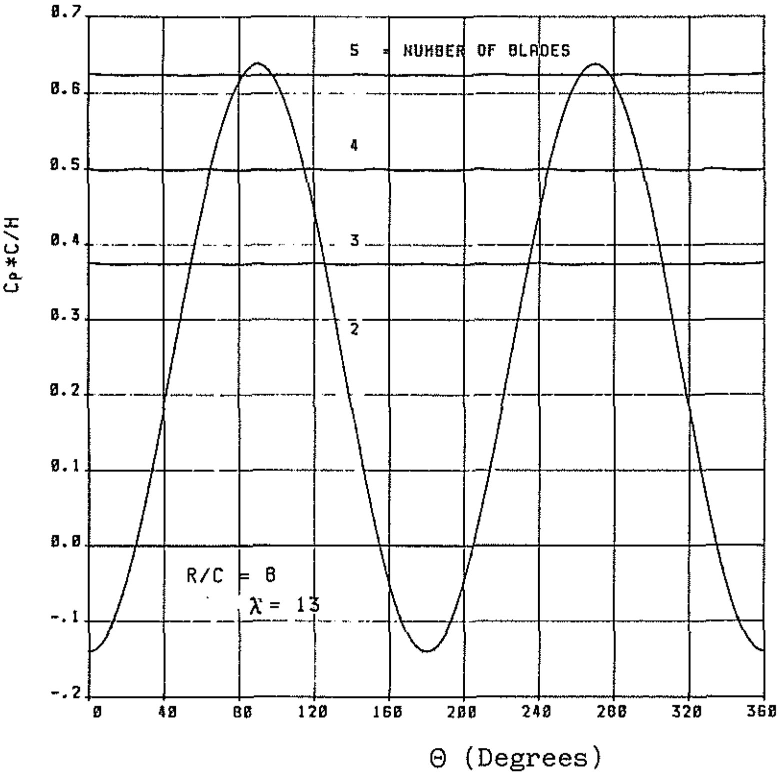
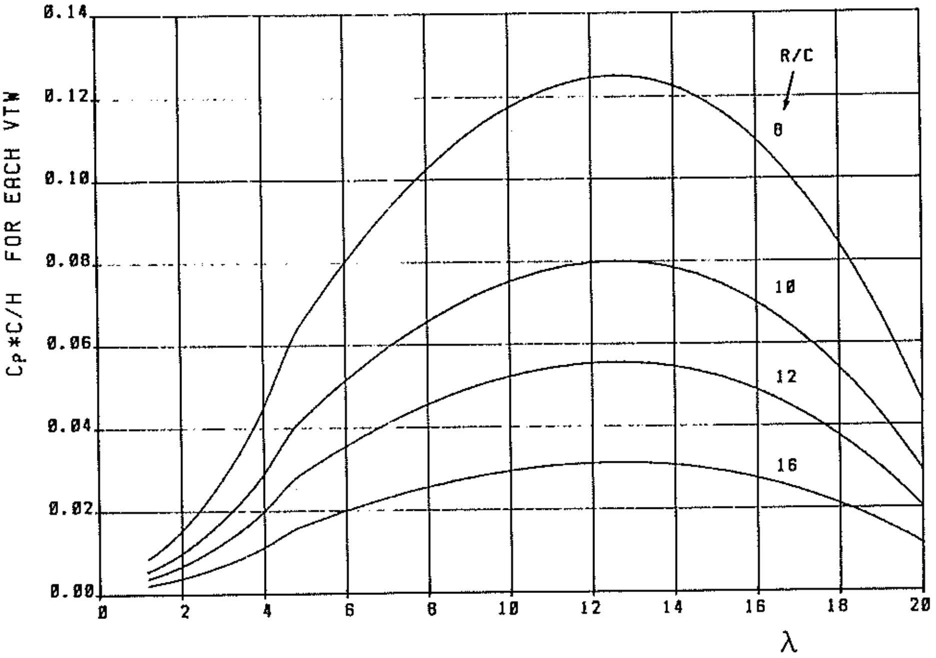


Fig. 5 - Azimuthal power coefficient produced by the VTW as function of the number of the rotor blades, for $\lambda = 13$ and for $R/C = 12$ and 8.



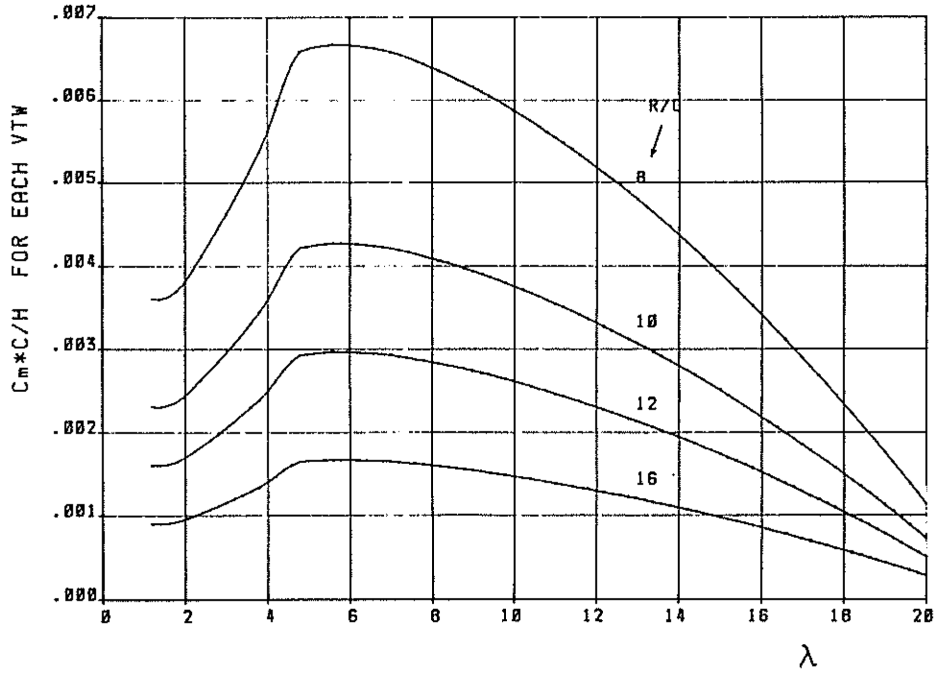


Fig. 6 - Main saving power and main saving torque coefficients of each VTW in function to the R/C and to the ratio λ.

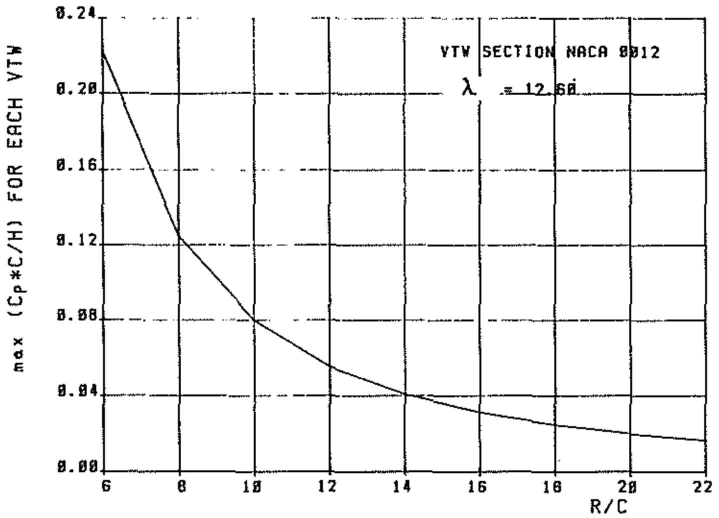


Fig. 7 - Limit of the main saving power coefficient of each VTW vs R/C.

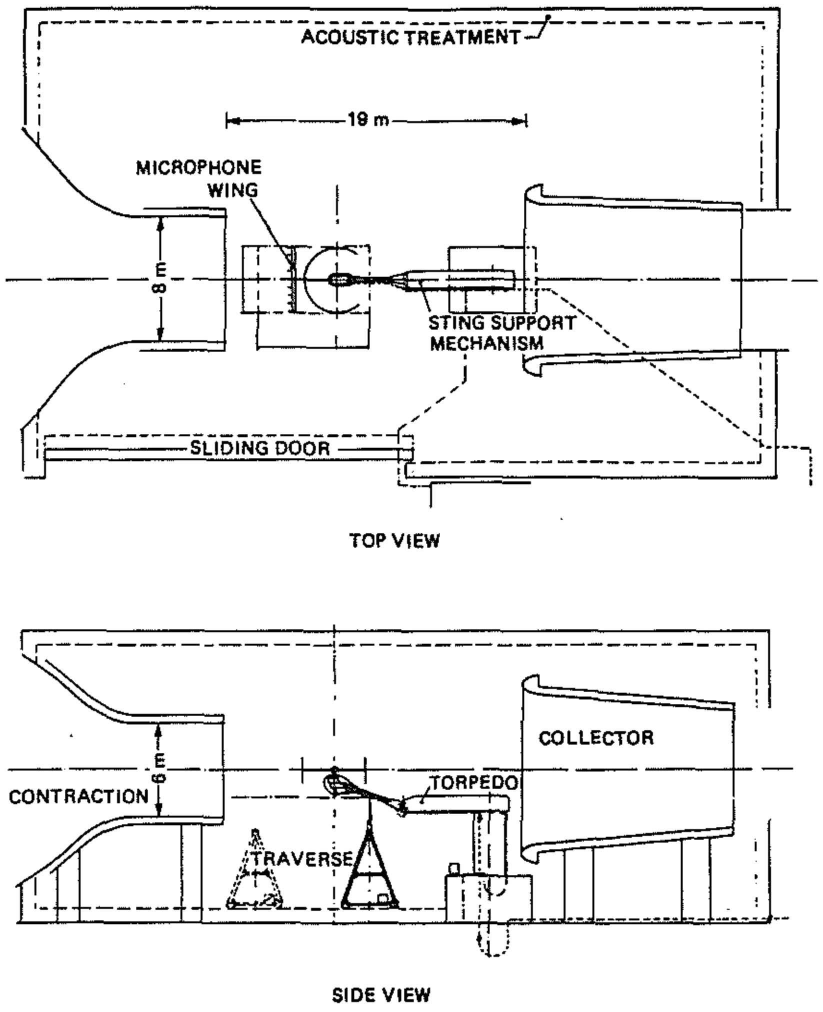


Fig. 8 - DNW Open Jet Configuration, Ref. [5].