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HELICOPTER BLADE TIPS

R. Lyothier

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16. Abstract

Methods of improving helicopter performance and vibration level by proper shaping of helicopter blade tips are considered. The principle involved consists of reducing the extent of the supersonic zone above the advancing tip and of the turbulent interaction. For stationary and advancing flight, the influence of the rotor and the problems posed by blade tips are reviewed. The theoretical methods of dealing with the two types of flight are briefly stated, and the experimental apparatus is described, including model triple and quadruple rotors. Different blade tip shapes are shown and briefly discussed. The theoretical results include an advancing speed of 309 km/h and a blade tip rotational speed of 215 m/s. The experimental values are advancing speed of 302 km/h and blade tip Mach number 0.86 for both types of rotor.

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HELICOPTER BLADE TIPS*

**/1

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SUMMARY

A substantial gain in the vibrational level performance of a helicopter can be brought about by using blade tips of particular shape.

The principle consists of reducing the extent of the supersonic area which appears over the advancing blade as well as reducing the effects of vortex interaction. After first selecting the shapes by calculation, performance and force measurements were performed in a wind tunnel on a rotor model.

1. INTRODUCTION

Research has been performed over several years in order to improve the performance and comfort of helicopters. Two important results have been achieved (Puma 330J and Dauphin 365C):

- increase in the liftable mass for stationary flight
- increase in the maximum speed.

These gains were obtained by using new blade profiles (OA family, resulting from a SNIAS-ONERA collaboration.

New phenomena appeared which were related to the increase in velocity, both for flight and altitude and for the payload factor.

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Depending on the flight conditions, this affects the power consumed by the rotor, the loads and the vibration level. This is the result of two main causes:

- the appearance of a super-critical regime at the extremity of the advancing blade, whose Mach number can reach 0.9. This results in a torsion excitation and an increase in drag.
- the vortex interaction which comes from an encounter of the blade extremity region with the wake of the preceding blade, which can lead to flow separation.

An additional refinement of the extremity profiles would be desirable, but is not feasible technologically (as an example, the relative thickness can already reach 6% at the extremities of the blades of Dauphin N). In addition, this does not solve the problem of vortex interaction. Therefore, it seems necessary to find a solution in the modification of the plan form of the blade extremities.

2. GENERAL REMARKS ABOUT THE ROTOR

Problems associated with the blade extremities appear in two distinct operational ranges of the rotor (references [1] and [3]):

- stationary flight, for which the aerodynamic conditions remain stationary and the Mach numbers are moderate (on the order of 0.6).
- forward flight for which the flow is unsteady and can reach the critical speed.

2.1 Stationary flight

The loads on the blades are independent of their azimuth, except for a small cyclical command which provides for equilibrium of the craft. The rotor is symbolized by a lifting disk (Figure 1) and the loads have the distribution indicated in Figure 2.

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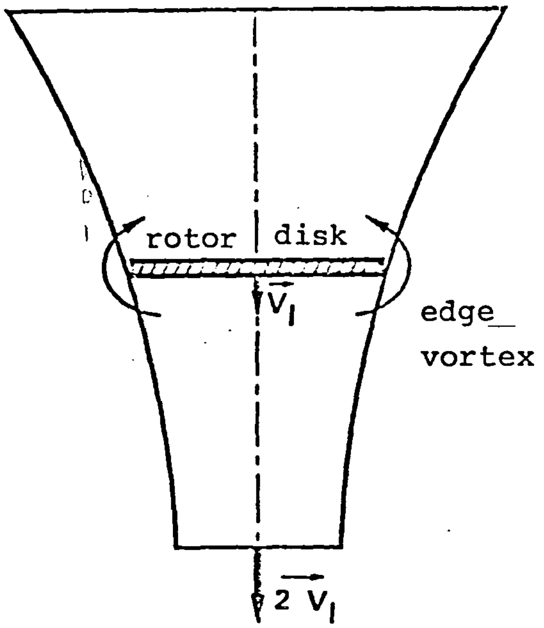

Figure 1. Stationary flight

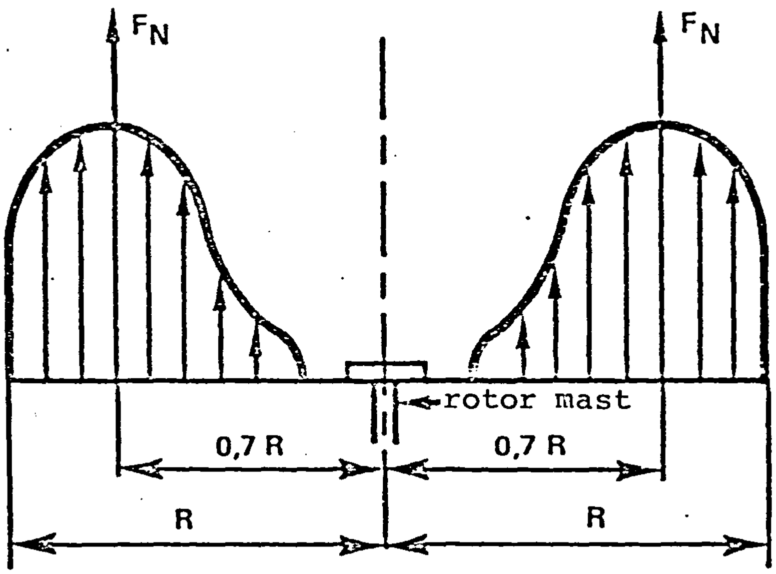

Figure 2. Stationary flight loads

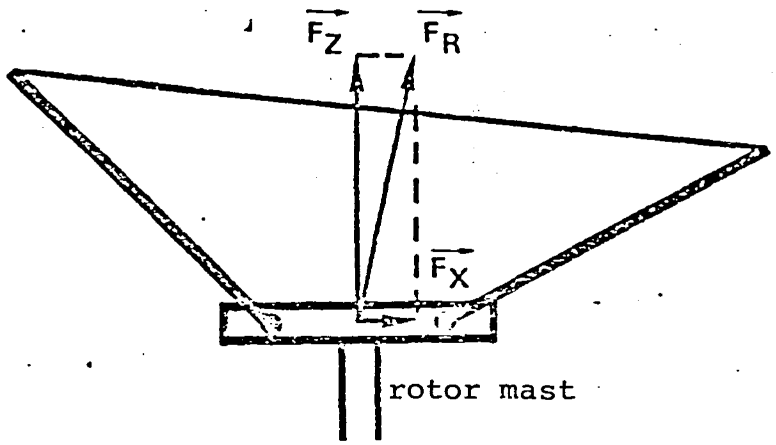

Figure 3. Inclination of the rotor disc during forward flight.

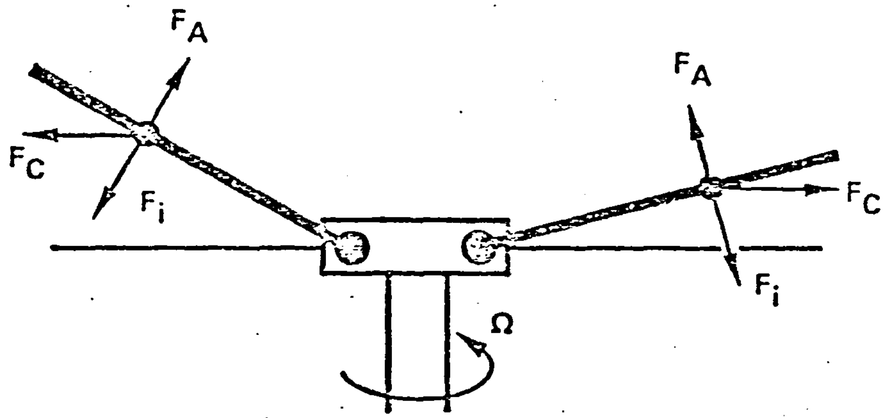

Figure 4. Dynamic equilibrium of the blades.

F_A aerodynamic force

F_C centrifugal force

F_i inertial force

The lift is a maximum in the extremity area and the resultant FN is applied at about 0.7R. This induces a vortex sheet and an edge vortex which interferes with the other blades.

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2.2 Forward flight

The rotor provides a resulting force whose components FZ and FX respectively provide the lift and the propulsion of the craft (Figure 3). The component FX is created by inclining the rotor disk in the desired direction. This is the result of a cyclical variation of the step and the composition of the translation and velocity compositions. The blades have a flapping degree of freedom and this leads to a mechanical system which responds to this excitation at the rotation frequency. This is equivalent geometrically to a balancing of the disk.

The forces involved (Figure 4) are the following:

- aerodynamic forces, modulated by the cyclical nature and composition of the speeds,
- the inertia forces,
- the centrifugal force. /4

Figure 5 shows the variation of the load distributions as a function of blade azimuth.

The response of a blade to cyclical excitation occurs with a phase delay of 90° (close to resonance). In order to obtain the inclination of the rotor disk in the forward direction required for propulsion, the incidence has to be a minimum over the advancing blade and a maximum over the regressing blade. The aerodynamic excitation resulting from the composition of the speeds acts in a similar manner.

3. PROBLEMS CAUSED BY THE EXTREMITIES /5

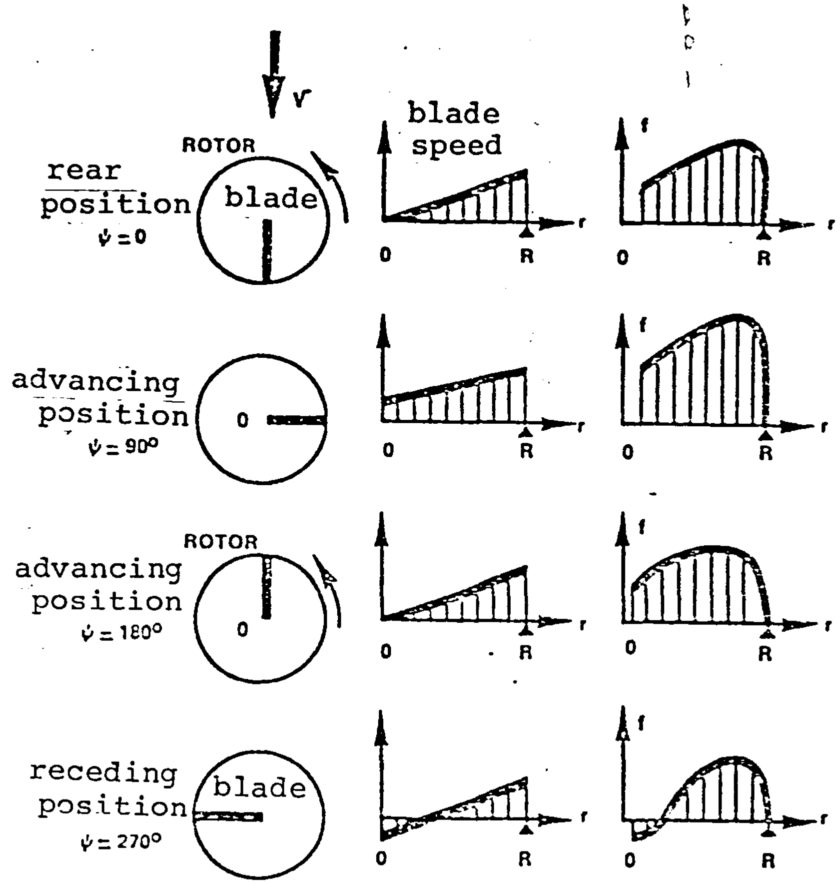

Figure 5. Behavior of the rotor discs in translation flight.

The problems caused by the blade extremities are essentially the result of the following:

- supercritical phenomena (the appearance of shockwaves) on the advancing blade,
- from the vortex interaction which by increasing the incidence of the extremity can lead to flow separation when the Mach number is sufficiently large.

3.1 Stationary flight

The problems encountered over the extremities are caused

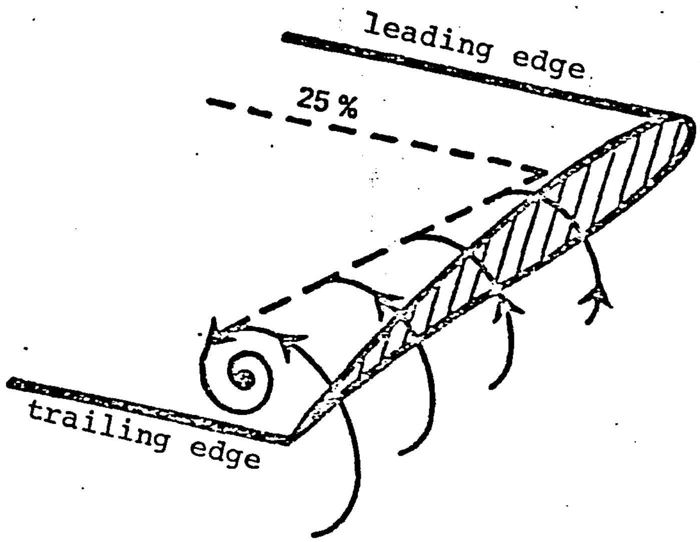

Figure 6

/5

essentially by the attached vortex. It starts at about 25% of chord and passes above it along the top side (Figure 6) and therefore creates a depression or an additional lift (reference [4]).

However, the passage of the vortex below the following blade increases the incidence angles over the extremity and decreases them over the interior part of the blade (references [5] and [6]). This is translated into a reduction in lift of the blade for a given step and an increase in the drag with a given lift.

Finally, since the extremity is subjected to large dynamic pressures, the last 10% of the blade provide 25-30% of the lift (reference [4]).

This is also the zone where the Cz values are maximum. This leads to two important consequences:

- the extremity has the tendency to separate before the rest of the blade,
- the incident Mach number is on the order of 0.6, and shockwaves appear because of the increased incidence angle.

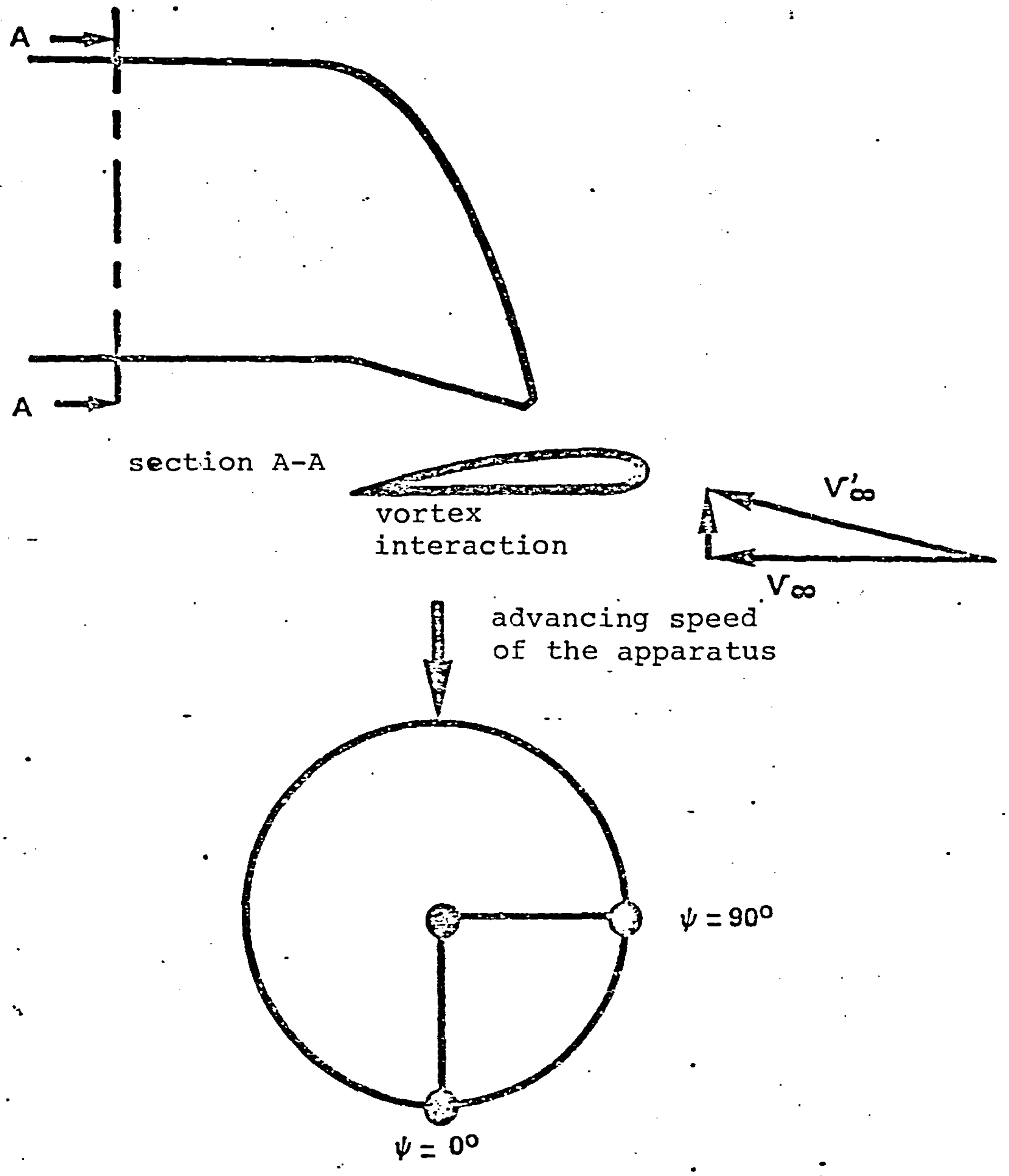
A
A
section A-A
vortex
interaction
V'∞
V∞
advancing speed
of the apparatus
ψ = 90°
ψ = 0°

Figure 7

3.2 Forward flight

The functioning of the extremities has been studied by many authors (references [7], [8], [9], [10]).

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These studies have allowed one to distinguish various problems related to the blade extremities.

- compressibility (shocks) over the advancing blade,
- vortex interaction of the rear blade.

The vortex interaction which is produced on the rear blade of a four-blade rotor under certain conditions of flight can lead to flow separation near the extremity (reference [7]) which is the case for steady flight.

Transsonic phenomena which appear on the advancing blade extremity, whose Mach number can reach 0.9, are aggrevated by an increase in the incidence due to the vortex interaction, as shown in Figure 7 (see reference [10]).

The appearance of shockwaves is translated into an increase in drag and noise and induces large variations in the torsion moments.

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4. STUDY MEANS

These are both experimental and theoretical.

4.1 Theoretical means

Complete methods for studying the case of forward flight or stationary flight are not available, in spite of substantial efforts. Only partial aspects of problems can be studied.

4.1.1 Stationary flight

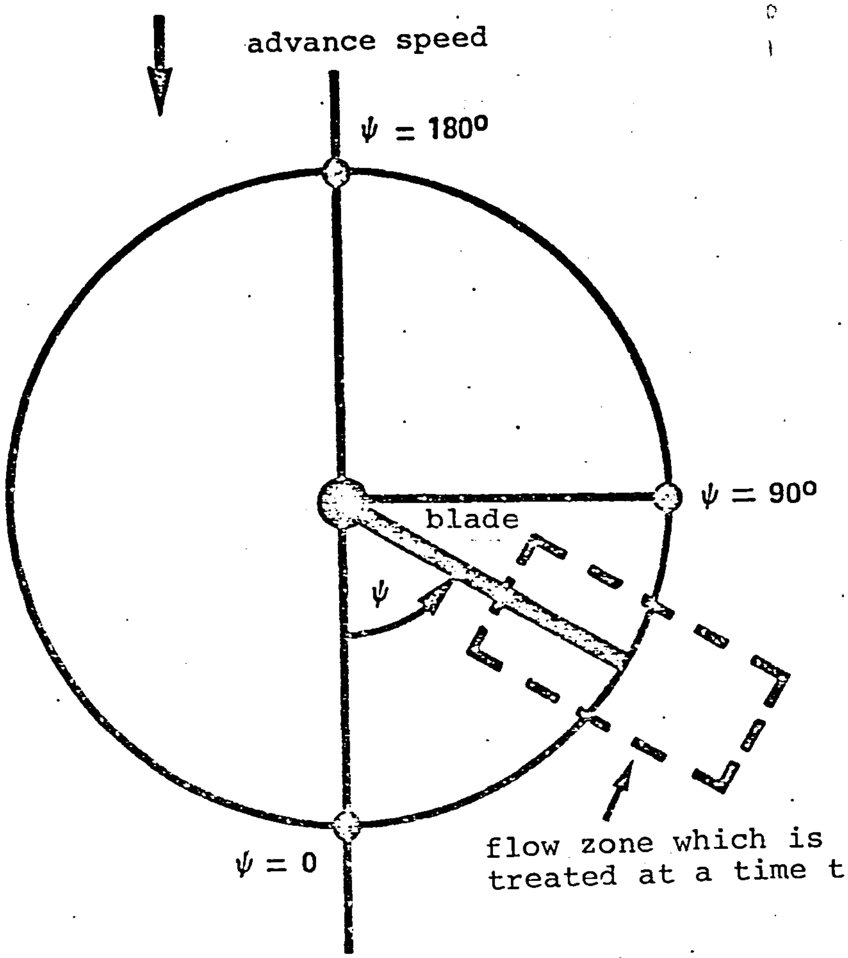

Figure 8

The load distribution over a rotor blade for stationary flight is obtained by a vortex method (work of M. Hirsch reference [11]).

The blade is represented by a lifting line with a circulation distribution similar to that of Prandtl for a finite span wing.

Nonlinear effects and compressibility effects are induced by corrections made from the polars of the profiles used.

The balancing of the wake is done using an iteration process whose convergence is acquired when the velocity induced is tangential with the vortex wake.

4.1.2 Forward flight

The flow over the extremity of a helicopter blade in forward flight is three-dimensional, unsteady and supercritical, a problem which has not been solved up to the present:

The available calculation methods only take into account partial aspects of the problem. This includes three aspects.

- Three dimensional calculations for a supercritical type wing.

The flow is steady and the reference speed is constant. This is a large perturbation method which predicts shockwaves. This allows one to estimate the geometric shape (thickness law and extremity).

- Finite elements

At the present time, it is applied for the same conditions as above. The representation of the shape of the extremity is more refined. It is possible to introduce a reference speed which varies linearly with span in order to closely approach the conditions of the helicopter blade.

- Three dimensional unsteady calculation with no lift for a helicopter type situation.

This method considers three dimensional effects and introduces unsteady effects (Figure 8). It uses the hypothesis of small perturbations. In spite of its limitation to the non-lifting case, it is useful to research shapes and this eliminates supersonic areas caused by the sweep back effect.

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4.2 Experimental means

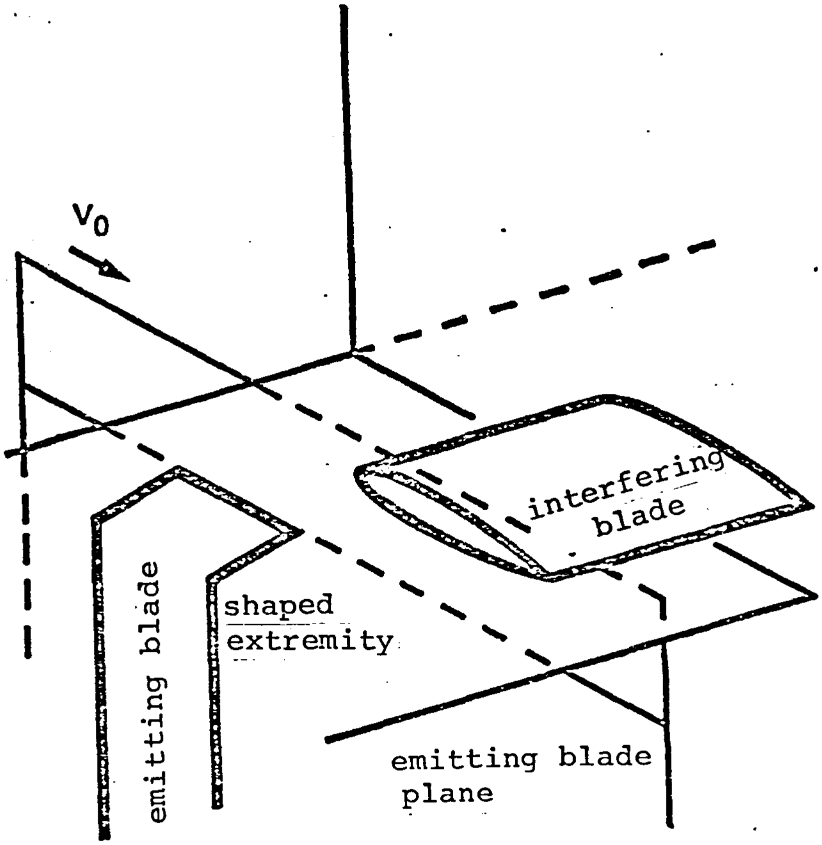

Figure 9. Wing-vortex interaction

4.2.1 Wing-vortex interaction

Above we discussed the importance of the influence of the extremity vortices on a blade.

In order to better understand these phenomena, tests were performed by ONERA in the S3 wind tunnel at Chalais Meudon (reference [15]). The principle is summarized in Figure 9.

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We wish to observe the influence on pressure distribution over a blade, of the variation intensity and position of an edge vortex coming from a preceding blade, using two half wings at the wall. The vortex intensity value is modified by varying the lift of the

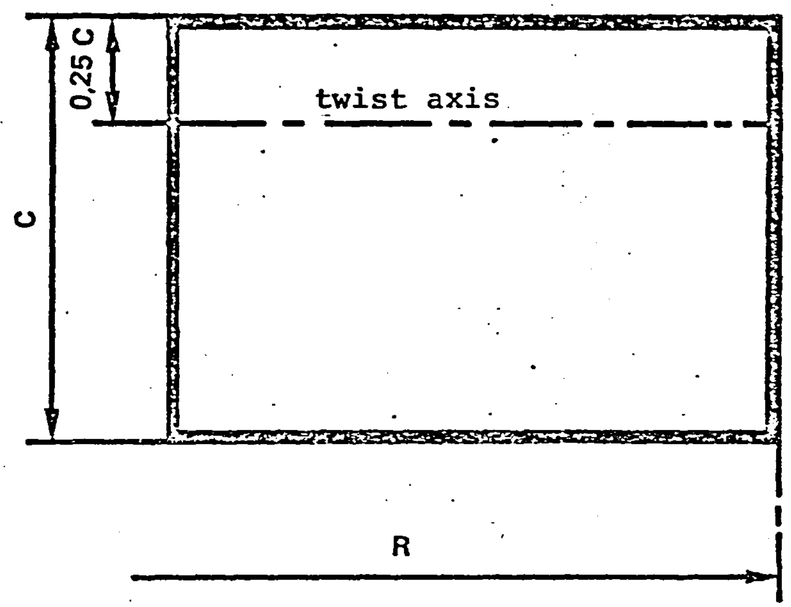

Figure 10. Rectangular extrimity

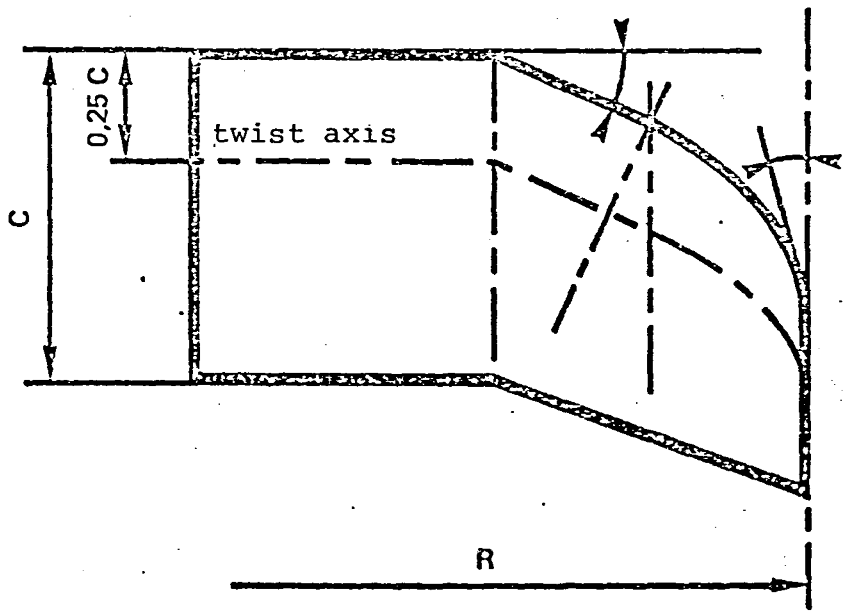

Figure 11. Parabolic extremity with sweep back

emitting blade. The blade is equipped with pressure transducers.

4.2.2 Rotors-model

These are test devices developed by the S2 of the ONERA at Chalais-Meudon. A fixed component balance allows one to measure performance. The velocity range extends from steady flight up to a forward speed parameter of 0.5. The geometrical parameters are the following:

- a collective step, inclination of the rotor axis.

After being used to study the influence of profiles and the laws of twist, this installation is used in order to analyze the operation of blade extremities. Two types of rotors are tested.

- Three blade ONERA rotor

The purpose is to perform fundamental studies on the extremities. They can be detached at 0.8 R. The chord dimension allows one to install pressure transducers. The rotor diameter is on the order of 1.700 m and the chord is 0.123 m. For the test performed, only the influence of the plan form is examined, the twist and the profiles are retained. The shapes studied are the following: rectangular extremity, parabolic extremity with sweep back (Figures 10 and 11). The latter has the purpose of producing shockwaves which appear on the advancing blade, using the sweep back effect. /11

- Four-blade SNIAS rotor

The purpose is to study performance. The hub used is articulated for flapping and drag, and has a damper. The blades are made of composite material (reference [18]). The dimensions of the chord (0.05 m) do not allow the installation of the pressure transducers, but load measurements are performed on the rotor. The parameters studied are the following:

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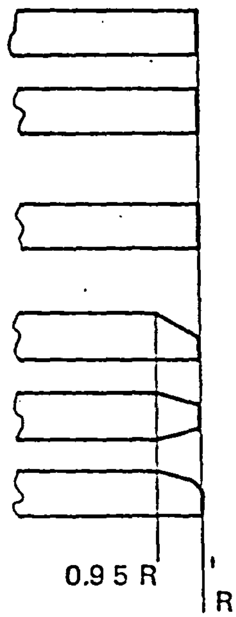
ROTOR NUMBER	TWIST	PLAN FORM	PROFILE
1	– 8°		BV 23010 - 1,58
2	– 14°		BV 23010 - 1,58
3 } 7	– 8°.3 linear and nonlinear		OA 209
4	– 8°.3		OA 209
5	– 8°.3		OA 209
6	– 8°.3		OA 209



- the fineness, the twist and the plan form of the extremity.

The configurations which were tested are given in the table above.

5. CLASSIFICATION OF EXTREMITY SHAPES

The first tests performed showed the influence of the following parameters:

- relative profile thickness
- twist
- plan form.

Numerous studies were performed on ingots with various plan forms.

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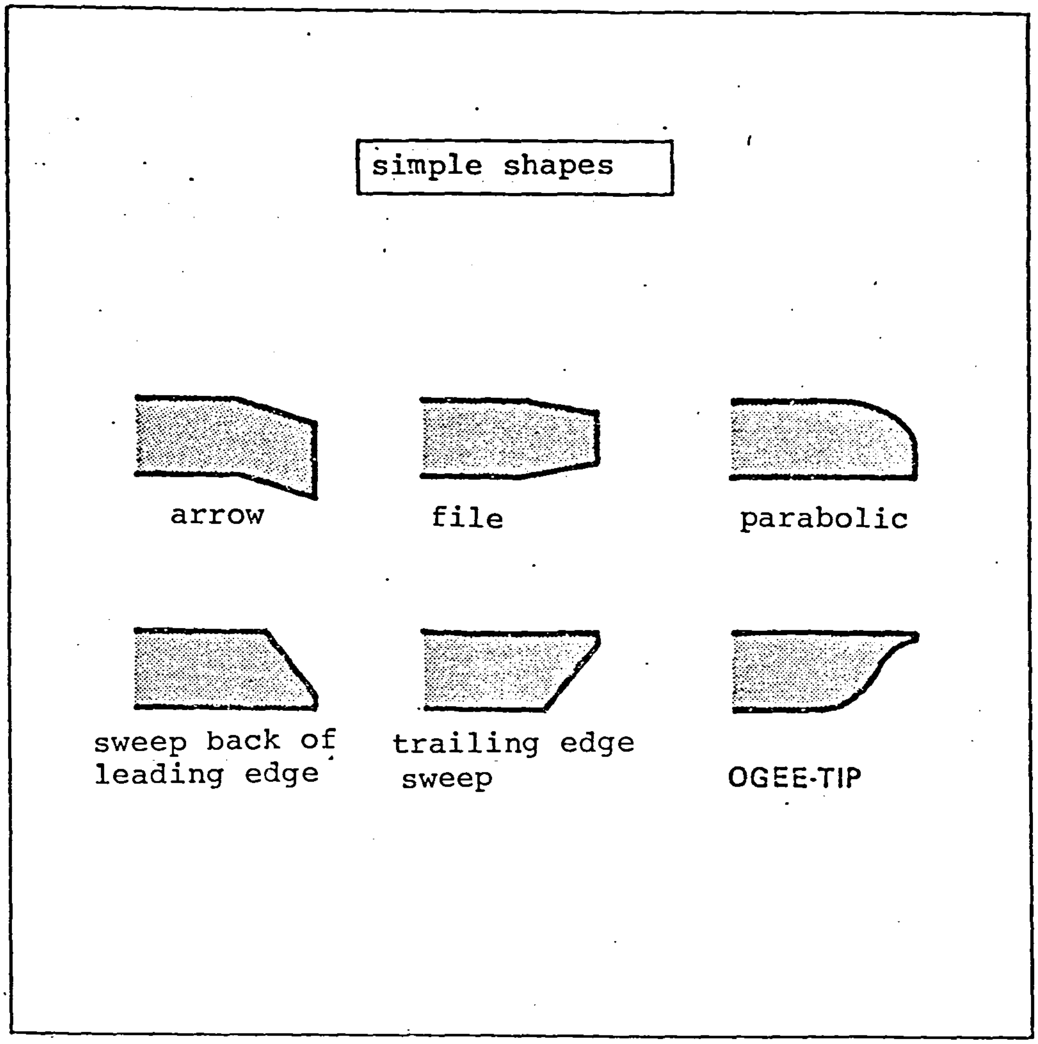

Figure 12. Ingot shaped examples

- Simple shapes (Figure 12)

There are two types, those where the leading edge is modified with respect to a straight extremity (sweep back, file, parabola, sweep back of the leading edge) and those which have a modification to the trailing edge (sweep back of the trailing edge, ogee tip). The former tend to modify the flow by reducing the over-velocity caused by a sweep back effect. The second ones are of interest because of vortex interaction. This allows one to calibrate the extremity vortex and to accelerate dilution.

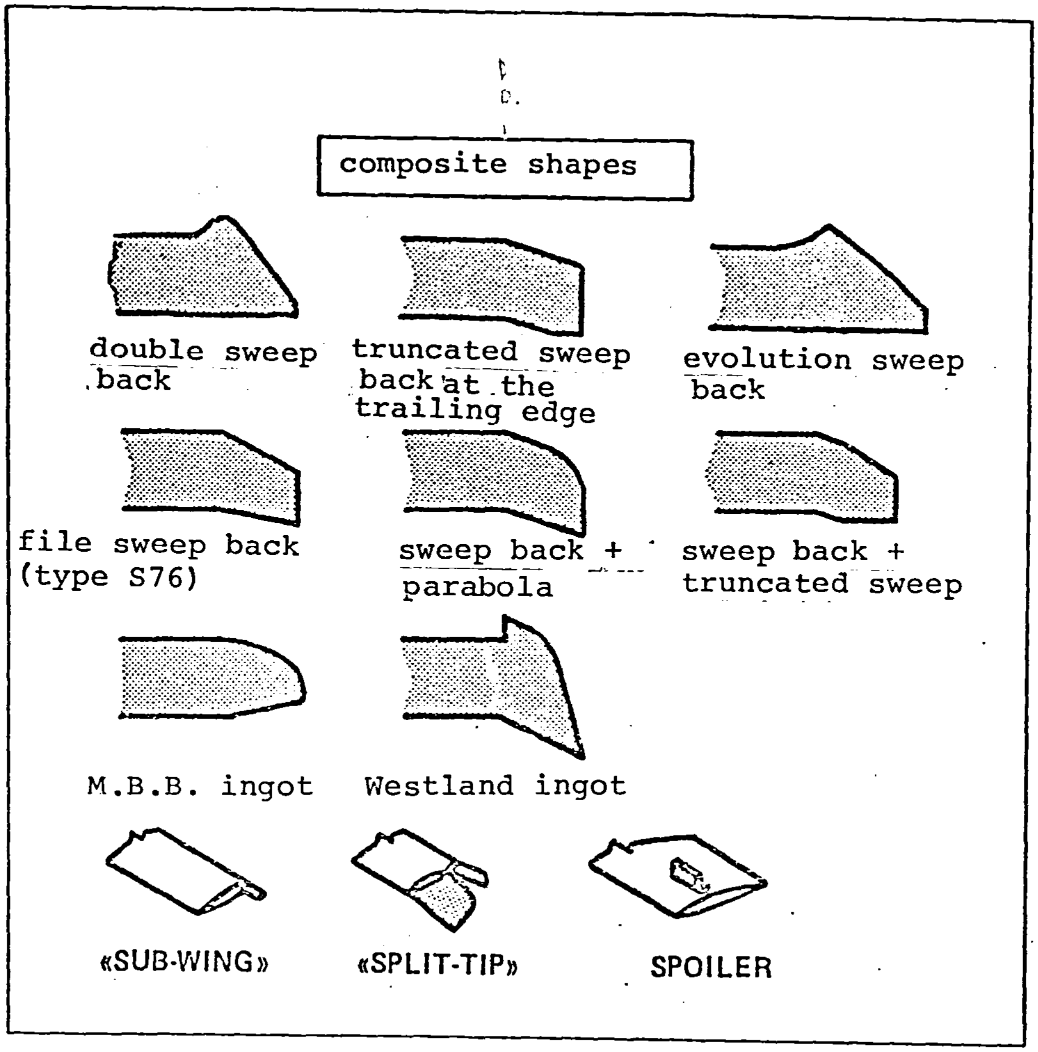

Figure 13. Ingot shaped examples

- Composite shapes (Figure 13).

They tried to combine the advantages of various simple shapes. This is a case for example of a swept back extremity--file shape which adds the effect of reducing the over-velocity caused by sweep back, with an effect of lowering the vortex intensity at the extremity, caused by a reduction in the chord.

In addition to these complex shapes, we have those which have external elements (SUBWING, SPLIT-TIP). These tend to accelerate the dilution of the extremity vortex by a velocity composition effect.

6. RESULTS

6.1 Theoretical results

Only the unsteady three-dimensional program at the present time gave results which could be exploited. We give an example in Figure 14. This is a comparison of the isomach line distribution over two extremities with different shapes. The calculation conditions are the following:

- quasi-stationary (the terms which depend on time are made zero) /14
- azimuth of 90°
- forward speed 309 Km/h
- rotation rate at the blade extremity is 215 m/s.

Over the rectangular shape the supersonic zone is bordered by very close lines which allows one to conclude that there is a shock-wave there.

This phenomenon disappears when the leading edge is swept back.

6.2 Experimental results

6.2.1 Three-blade rotor (ONERA)

The most interesting results were obtained using a swept back extremity whose leading edge is partially in the shape of a parabola (see Figure 11).

The results shown in Figure 15 were obtained for the following conditions:

- forward speed 302 Km/h
- Mach number at the blade extremity: 0.86.

/14

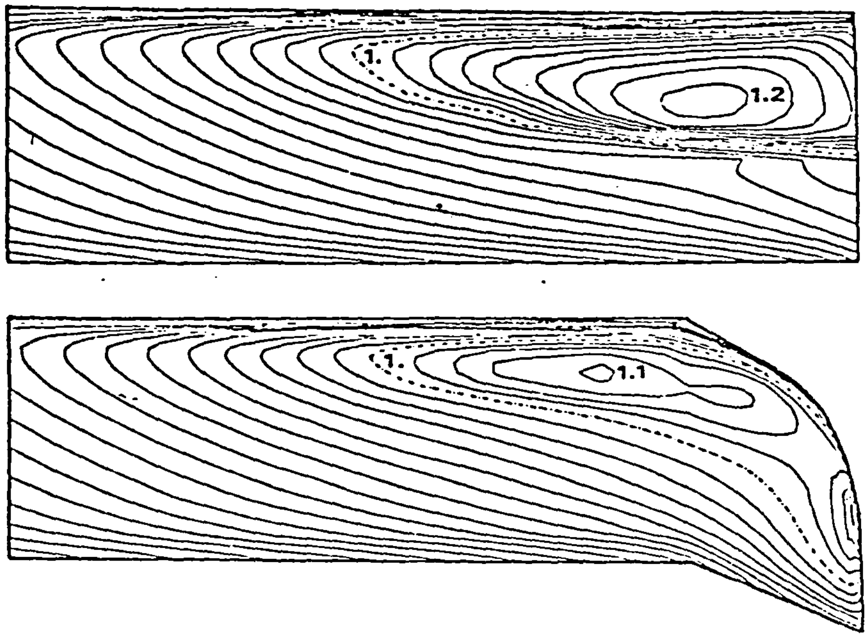

Figure 14. Velocity map

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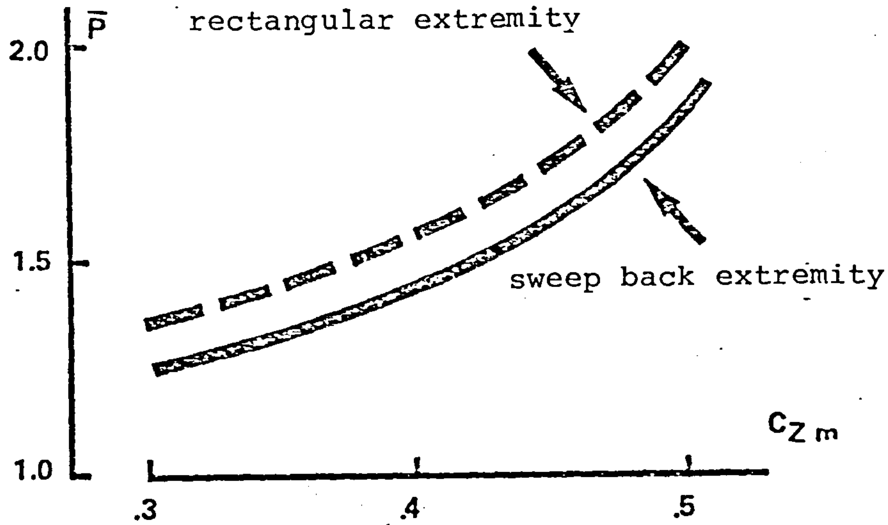


Figure 15. Three blade rotor

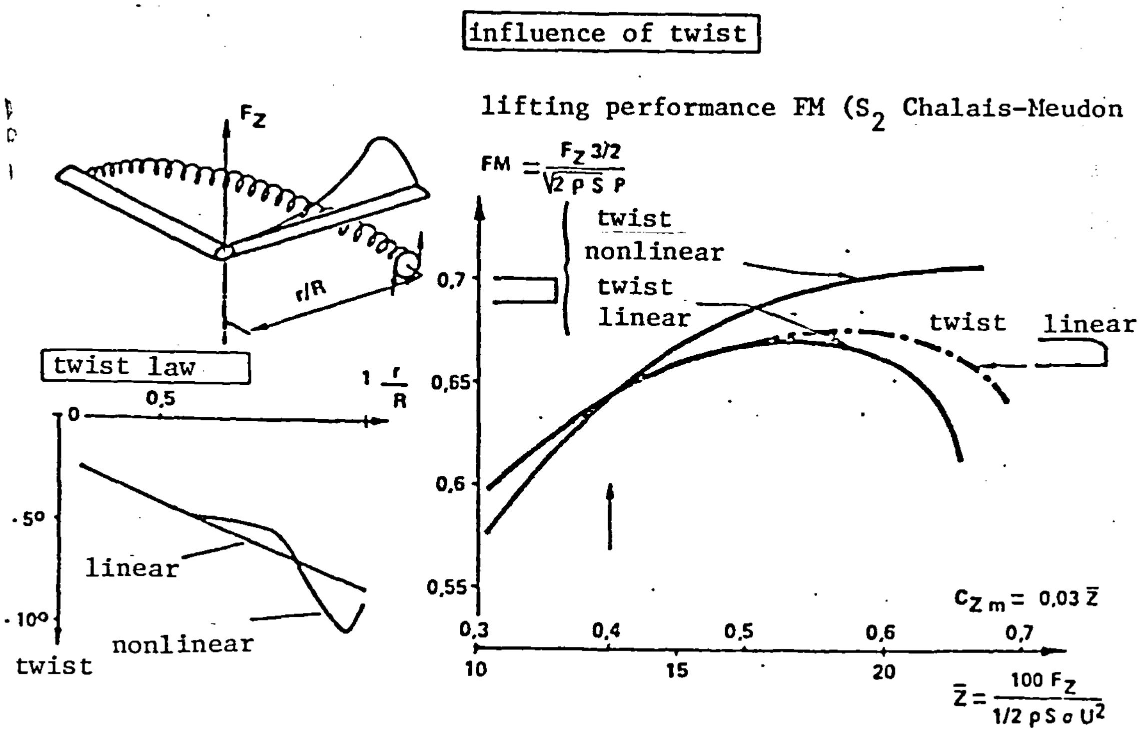


Figure 16. Stationary flight performances

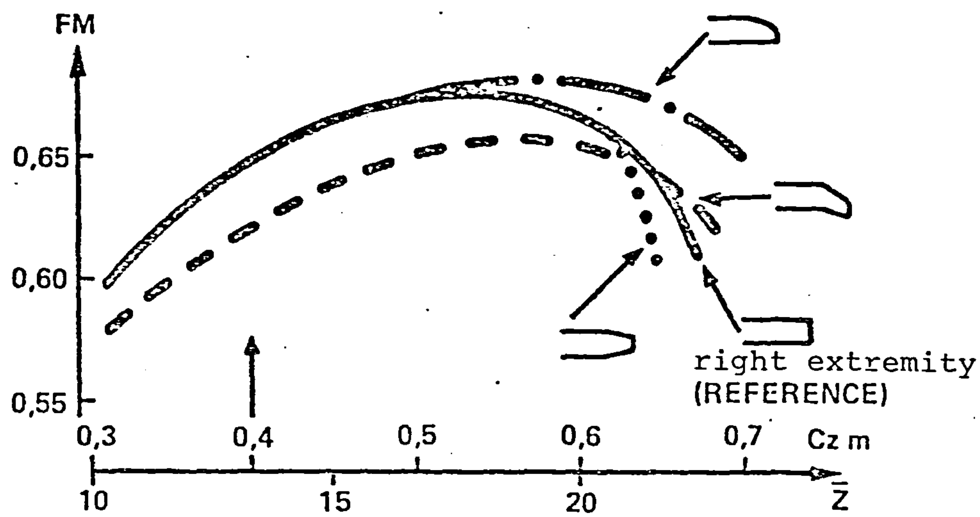
The gain over a classical extremity (rectangular) is on the order of 7% for the reduced power, for an average lift of 0.48. By considering the case of the Dauphin 365 N, the possible increase in speed would be on the order of 8 Km/h and the increase in take-off weight would be 60 Kg (references [19] and [20]).

6.2.2 Four-blade SNIAS rotor

In order to show the influence on performance of the twist and the plan form for stationary flight, Figures 16 and 17 show the variation of the figure of merit (ratio of the power supplied by the rotor to the FROUDE power derived from the theory of the induced velocity) as a function of average Cz. The nonlinear twist (Figure 16), by reducing the influence of the vortex interaction, allows one to increase the figure of merit. Also, the four plan forms are shown in Figure 17 but only the parabolic extremity gives a substantial gain.

S_2 Chalais-Meudon wind tunnel

4-blade SNIAS rotor $\sigma = \frac{bl}{\pi R} = 0{,}085$ $\emptyset = 1{,}474$ m $\theta_{vr} = -8{,}3^o$



3-blade ONERA rotor $\sigma = 0{,}137$ $\emptyset = 1{,}714$ m $\theta_{vr} = -12$

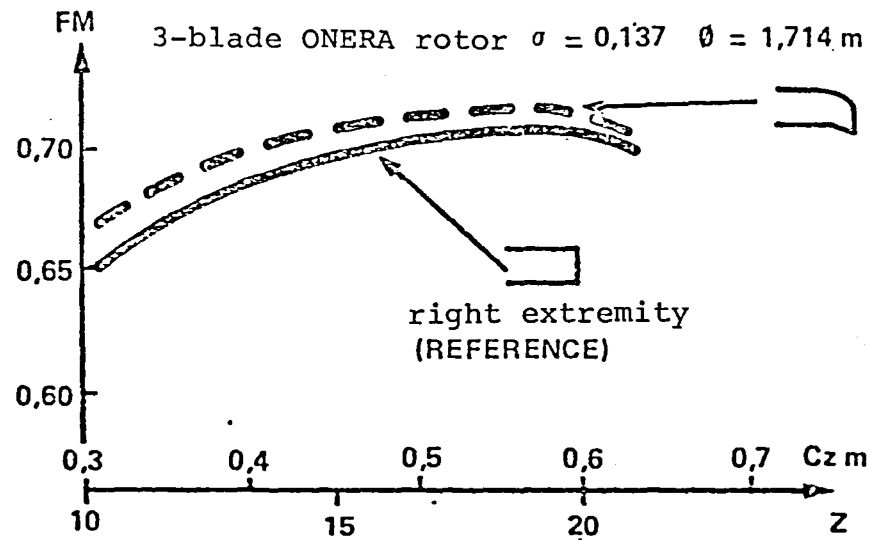


Figure 17. Influence of the shape of the extremity of the blade on the lifting performance for stationary flight.

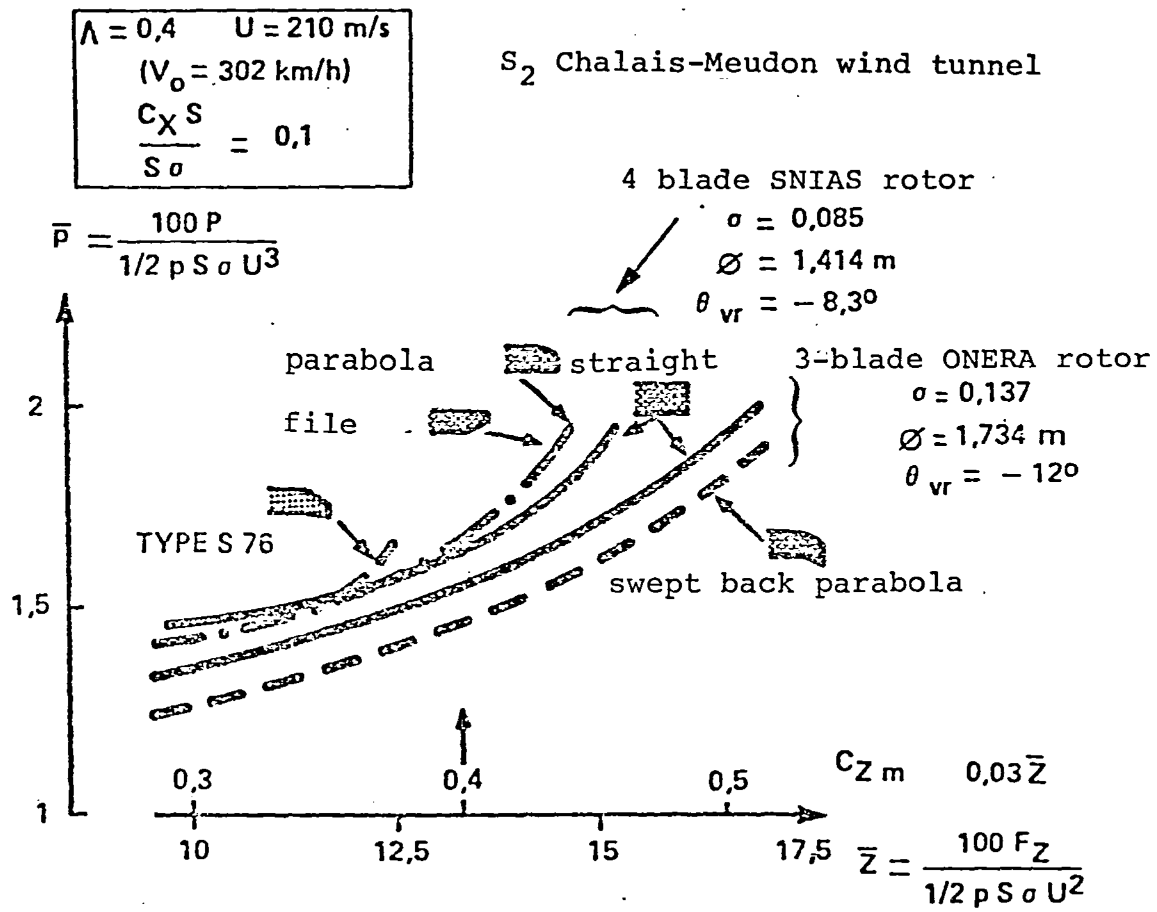


Figure 18. Cruise performance

For forward flight, the tests were carried out for a reduced /17
drag of the craft of

$$\frac{CxS}{S1\sigma} = 0.125$$

(S master couple, σ ratio of blade area to area S1 of the rotor disk).

The forward speed was 302 Km/h and the Mach number at the blade extremity was 0.86. Figure 18 shows the various results obtained for the four extremities. We can see that for a large load, the straight extremity remains the best. However, for Czm less than 0.4, the parabolic extremity gives a slight gain.

These latter conclusions only apply to the four-blade rotor. Tests on the three-blade rotor show an advantage of the parabolic extremity with sweep back for the entire range considered. The same holds true for stationary flight for the two rotors. Therefore, it is this extremity which gives the best compromise. It is used for confirmation in flight using the Dauphin N helicopter.

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7. CONCLUSION

After making substantial improvements to helicopter rotors by defining specific profiles, especially the OA family, the adaptation of extremity shapes can be considered in order to exploit their characteristics in the best way.

The sensitive parameters are the following:

- the plan form, in order to limit the supersonic zone and to attenuate shockwaves,
- the twist law and the tapering law, in order to reduce the vortex interaction effects.

The gains obtained primarily involve the increase in performance (takeoff weight and maximum speed) and a reduction in the vibration level. They were demonstrated by wind tunnel tests of rotor models having small dimensions, as well as by flight tests.

The theoretical means for studying the problem are still being developed and at the present time only allow treatment of partial problems. The importance of knowing the aerodynamic field and criteria of selection, however, can be used for the examples mentioned above.

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