FLIGHT TESTS OF A SWEPTBACK PARABOLIC TIP ON A DAUPHIN-365 N

by

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Abstract

ONERA has designed a sweptback parabolic tip in order to delay the appearance of shockwaves or to reduce their strength in the advancing blade sector. Its geometry and its theoretical justification are given. The new tip was first tested on a small scale rotor model in a wind-tunnel. The results obtained were judged encouraging enough for Aerospatiale to build a full scale blade with this new tip planform and to fly it on a 365 N Dauphin helicopter.

This tip is compared to a thinned straight tip during the same flight test campaign. The results obtained show significant performance improvements in favour of sweptback parabolic tips in hover and stabilized forward flight. The influence of this tip on aircraft behaviour under load factor is analyzed as concerns servo-unit limitations and pitch-link responses. Acoustic measurements are also briefly presented, and it is shown that a reduction of noise levels perceived on the ground is obtained with the sweptback parabolic tip.

Through aerodynamic and radiated noise computations considerations it is finally attempted to explain the experimental results regarding the increase of performance and the noise level reductions obtained.

1. Introduction

In order to delay the appearance of shockwaves or to reduce their strength on the advancing side of the rotor disk, ONERA has designed a sweptback parabolic tip. The main objectives of the flight tests described in this paper were to confirm the interest of such a design, proved previously by computations or by small scale rotor tests only. If increase of performance and reduction of noise were expected, it remained however necessary to ascertain the eventual penalties associated with the use of such tips. For that reason, we compare the results of the sweptback parabolic tip to those obtained with a thinned straight tip tested during the same flight test campaign.

2. Sweptback parabolic tip design

2.1. Planform definition

Some years ago [1] ONERA studies had shown that a standard 30° swept tip can reduce the power required by the rotor, but that there exist on the external edge of this tip strong expansions of the flow which may be penalizing, in regard to aerodynamic drag and noise when they lead to the formation of a shock. To prevent the formation of such expansion, it is necessary to increase the sweep angle of the leading-edge line of the tip.

With this idea in mind and with the analysis of tests on half-wing with parabolic tip, [2], a sweptback parabolic tip called PF2, was designed. Its main characteristics are (Fig. 1) :

- a span of 0.7 chord of the rectangular inboard part of the blade.

- a leading-edge line with a constant 30° swept angle on 0.35 chord and with a parabolic line on the last 0.35 chord which allows the sweep angle to increase quasi-linearly from 30° to 79°8.

- a global taper in chord of 0.5, but this tapering being important only on the last part of the blade (between R - 0.35 c and R).

- a straight trailing edge line with 23°2 swept back angle.

2.2 Preliminary computations

The figures 2 and 3 for which a non-lifting case is considered only, confirm the theoretical interest of the sweptback parabolic tip PF2 : at 90° azimuthal position indeed, there is no shock on this tip, while there is a strong shock on the straight tip (rectangular) and a large expansion zone remains on the 30° standard swept tip (F30).

The maximum local Mach numbers (Ml max) are much lower on the PF2 tip than those on the rectangular tip, and also than those on the F30 tip. The iso-Mach lines map reveal that the domain of supersonic flows is considerably reduced by the sweptback parabolic design. These results have been obtained with a computer code solving the low frequency transonic small disturbance equation for rotor blades of nearly arbitrary planform that J.J. Chattot [3] developed with the help of US Army RTL at Ames.

2.3 Experimental verification in wind-tunnel

The PF2 tip was tested in ONERA S2 Chalais wind-tunnel on a basic research 3-blade rotor with - 12° twisted but rigid blades, that have a low aspect ratio (7.0) and a high solidity ratio (0.137).

The figure 4 shows that the PF2 tip has made possible a significant reduction (5 to 8 %) in the power required by the rotor. These tests proved that an "optimization" of the working aerodynamic conditions of a tip in the advancing blade area is able to increase the total performance of a rotor.

These first results were judged sufficiently encouraging for Aerospatiale to build a full scale blade with a PF2 tip planform and to fly it on a 365 N Dauphin helicopter.

3. Blades description

Figure 5 shows first the reference blade equipped with a thinned straight tip. This tip extends from 0.94 R (where we have the profile OA 209) to R (where we find the profile OA 207). The thickness of the profiles decreases linearly between these two profiles. The profiles OA (ONERA - Aerospatiale) are described in [4] for example. The tip is removable from 0.94 R and it allows the study of different tips.

Figure 5 shows also the blade equipped with the sweptback parabolic tip that we have described more in 2.1. This tip (0.7 chord span) extends from 0.96 R to R. We have to note that for this blade the profile is the same (OA 209) from the root to the tip, while it equips the reference blade up to .94 R only.

The twist from .29 R to .94 R is equal to - 1,39°/m but, for both type of tips (i.e. from .94 R to R) there is no supplementary twist.

The blades are built with composite materials and are quite soft in torsion. The first torsional mode is located between 3 and 4 Ω. The blades are mounted on a Starflex hub which equips the 365 N Dauphin aircrafts [5]. However, the blades used for these tests have a 0.35 m chord and the radius of the rotor is 5.84 m. These two dimensions are different from the actual ones of the Dauphin (.385 m $<$ c $<$ .405 m ; R = 5.965 m). The blades with the sweptback parabolic tips can be seen on figure 6. Additional weights were fixed at 0.45 R in order to have a good dynamic adaptation of the second lead-lag mode of the blades. The same weights were also fixed on the rectangular reference blades.

4. Flight test results

4.1. Performance in hover

Figure 7 shows the performance in hover of the main rotor equipped with the two different blade tips. This figure represents the reduced main rotor power W/δ (total engine power minus fenestron power obtained from tail rotor control pedal test position) as a function of the reduced mass M/δ or of the mean blade loading coefficient C_{zm}. The parameter δ is defined by : $\delta = \rho/\rho_o$ where ρ and ρ_o are the actual and reference densities respectively.

For each blade tip, the curve passing through the test points has been obtained using a least mean square method.

For the same main rotor power, the sweptback parabolic tip (PF2) allows a take-off weight increase of 70 to 80 kg (154 to 176 Lbs), that is 2.2 % of the total take-off weight for a blade loading mean coefficient C_{zm} of 0.44. The latter value would represent the necessary mean value of C_{zm} for the SA 365 N at its max. take-off weight (4000 kg) . Inversely, for the same mean blade loading coefficient C_{zm} of 0.44, the reduction of the main rotor power is 3.2 %.

On figure 7, the maximum reduced gross weight M/δ tested with PF2 blade tip is only 3560 kg (7860 Lbs) instead of 3680 kg (8125 Lbs) for the thinned straight tip. Indeed, the PF2 planform, being sweptback, makes the aerodynamic center of the tip move back, which creates a nose-down moment leading to an overtwist of this rather flexible blade as far as torsion is concerned. This blade overtwist is illustrated on figure 8 : for the same weight, the collective pitch at blade root is about one degree greater with PF2 tip than with the thinned straight tip.

4.2. Helicopter performance in level flight

The flight test envelope of both tips is described on figure 9 which represents total helicopter power versus cruise speed.

The collective pitch control range did not allow high test speeds for the two following reasons :

- no blade root counter-twist on the tested blades,

- afore-mentioned overtwist due to PF2.

On the other hand, additional weight on the blade, necessary to a good dynamic adaptation, brings 2 or 3 % loss of speed for the same power.

The total helicopter power reduction due to sweptback parabolic tip (figure 10) is an increasing function of the cruise speed for a given value of C_{zm} and also an increasing function of the blade loading mean coefficient C_{zm} for a given flight speed, and ranges from 1 to 6 % in the flight test envelope.

This total power reduction can be transformed into a decrease of fuel consumption per hour or an increase of the range. For example, PF2 on a Dauphin 365 N at 4000 kg weight (8830 Lbs or $C_{zm} = 0.42$) and 270 km/h cruise speed (146 Kts), will reduce at $Z = 0$ the fuel consumption by 3.5 % and will increase the range by 7 %.

For the same aircraft flying now at Z = 2500 m (8200 ft) and 220 /h(120 Kts) (C_{zm}= 0.54), the fuel consumption is reduced by 6 % and the nge is increased by 5 %.

Figure 11 shows the speed increase owing to sweptback parabolic tip compared to thinned straight tip for the same total helicopter power. For e different blade loading coefficients varying ranging from 0.42 to 0.54, e max. speed increase is as high as 5 to 8 km/h (1.8 to 3.5 %).

Another illustration of good performance of sweptback parabolic tip shown on figure 12 which represents profile drag mean coefficient (C_{xp}) a function of blade loading coefficient (C_{zm}) for different values of vance ratio (μ). This profile drag coefficient is calculated using profile wer formula ($\dot{W}_{prof} = \frac{\rho}{8} S \sigma U^3 C_{xp}$)

duced from the following formula (splitting of the necessary power into s different terms) :

$$\dot{W}_{tot} = \dot{W}_{ind} + \dot{W}_{prof} + \dot{W}_{fus} + \dot{W}_{tr} + \dot{W}_{loss}$$

ere :

$\dot{}_{ind}$: induced power = $k.Mg.V_i$

$\dot{}_{fus}$: power dissipated by fuselage drag = $\frac{1}{2} \rho C_x S.V^3$

$\dot{}_{tr}$: fenestron power.

$\dot{}_{loss}$: power losses in main gearbox.

It is assumed that the fenestron powers are equal for both tips hich is true up to C_{zm} = 0.5), and that power losses in main gearbox presents 5 % of the total helicopter power.

The profile drag coefficients are nearly equal at low advance ratio, d become significantly different as the advance ratio or the blade loading an coefficient increases.

The unusual high level of the profile drag coefficient results from e weight added on the blades.

4.3. Loads on servo-control and pitch link rods

Collective and cyclic pitch controls use three servo-units. The right rward and left rearward servo-units take loads from collective and lateral clic pitch. The left forward servo-unit takes loads from longitudinal clic pitch.

On figure 13 static loads for two servo-units (left rearward and ght forward) are plotted versus cruise speed in level flight (loads on the ft forward servo-unit are low).

Static loads on the right forward servo-unit are much more important 700 N) for sweptback parabolic tip than for thinned straight tip. On the ft rearward servo-unit, this drawback only appears above 125 Kts.

This static load increase on the right forward servo-unit is due to gher loads on pitch link rods (static and 1 P component).

This phenomenon can be seen on figure 14 in stabilized flight conditions with load factor (210 km/h, 115 Kts). In this case, the static component due to PF2 increases significantly as well as 1 P component. However, the excitation of the first torsional mode, which is comprised between 3 and $4\,\Omega_{MR}$ does not seem to be increased by a sweptback parabolic tip.

4.4. Noise

Flight tests were also conducted to evaluate the helicopter noise level in the flight procedures selected by ICAO for the helicopter noise certification.

One of the procedures, illustrated in figure 15, is the horizontal flyover with acoustic pressure signals recorded with three microphones on the ground. For each tip, different speeds were tested.

Figure 16 shows the mean value noise level (in Effective Perceived Noise decibel) for different values of speed.

The reduction of the noise level due to sweptback parabolic tip is equal to 1.25 EPN dB, in spite of the fact that the relative thickness of the sweptback parabolic tip (9 %) is higher than that of the straight tip (7 %).

These results prove a better aerodynamic flow condition on the sweptback parabolic tip and confirm the test results obtained on other aircraft with different tips [6].

5. Computations relative to the flight condition

We can try to explain some of the good results obtained in flight through computational analysis. Aerodynamic prediction tools become now sufficiently accurate to furnish a good idea of the pressure distributions we can expect on such blades, without taking into account the elastic deformations of the blades, especially when we have such a complex swept tip. Aerodynamicists are also able to give to acoustic people the flow field on and around the blades in order to estimate the magnitude of the quadrupolar sources terms generating impulsive noise in fast level flight.

5.1. Predictions of pressure distributions on the blades

Although the computations are performed on an isolated blade, the presence of the other blades and their wakes are taken into account by using J. Drees's formulation for the induced velocities following the technic described in [7, 8]. By prescribing the flight conditions for the collective and cyclic pitch angles and the motions of the blades at V = 136 knots, A. Desopper has obtained results which can explain, at least partly, the improvements due to the PF2 tip. In these computations, the blade is equipped with the profile OA 209 for both tips.

In figure 17, we see the evolution of the pressure distributions at 0.98 R versus the azimuth. We see clearly that we have less severe flows on the PF2 tip than on the straight tip especially from 30° to 150°.

If now, we plot in the figure 18 the spanwise distribution of the maximum local Mach numbers on each of the blades at different azimuthal positions, we have a good confirmation of the possibility, by using the PF2 tip, to delay the appearance of transonic flows and to limit their developments (in particular the penalyzing shock waves) over quite a large azimuthal sector of the advancing blade.

So, these computations confirm that we need less power for the rotor ɿuipped with the PF2 tip than for the rotor equipped with the rectangular ꜫference blades.

5.2. Acoustic computations

J. Prieur from the acoustics division of ONERA has developed a method) evaluate the intensities of the quadrupolar noise sources from the ıowledge of the local speeds on and around the blades. He has in particular ılculated , using the Transonic Small Perturbations code, the flow field ɔr the rectangular blade and for the same blades equipped with the PF2 tip ; 90° azimuth position and for non-lifting case. The iso-Mach lines ılculated in the coordinate system related to the rotating blade are shown ı figure 19. We see that for the rectangular blade we have almost a ɔnnection between the supersonic flow area on the blade and the equivalent ıter flow. For the PF2 tip there is a large "buffer" zone of subcritical .ow between the transonic area on the blade and the sonic circle, the ıterest of which is to prevent shock waves to extend out to infinity and so) create severe impulsive noise.

This description of the flows explains well the intensities of the ılculated quadripolar sources (proportional to the square power of the ıordwise perturbation velocity), the values of which are plotted section by ꜫction in figure 20. If the favourable tendency presented here at a given :imuth could be confirmed regardless of the blade azimuth, then the PF2 ɔuld appear to be able to reduce the impulsive noise of a helicopter.

. Conclusions

For several years, studies have been conducted in cooperation ꜫtween ONERA and Aerospatiale for aerodynamic design of advanced rotors .th new tip shapes [9]. This cooperation has led to a flight test campaign ' a sweptback parabolic tip on a SA Dauphin - 365 N in 1983.

The results obtained during this campaign are very encouraging as far ı performances are concerned. Indeed, the sweptback parabolic tip, as ɔmpared to a thinned straight tip allows :

more than 2 % take-off weight increase ;

1 to 6 % total power reduction in level flight, which can be converted ıto a 3 to 6 % reduction of the fuel consumption and 5 to 7 % increase of ıe range.

These new tips decrease also the helicopter effective perceived noise ꜫvel by an amount of 1.25 EPN dB, and correspond to a better aerodynamic ꜫhaviour as compared to the thinned straight tips.

But the aerodynamic center move back of the sweptback tip creates a ɔse-down moment resulting in :

higher static loads on servo-control units ;

torsional deformation of the blade (overtwist due to the blade exibility) in this present test.

The good results obtained on a Dauphin - 365 N and the good ediction methods at our disposal lead ONERA and Aerospatiale to follow on e efforts, in order to design optimized tip shapes.

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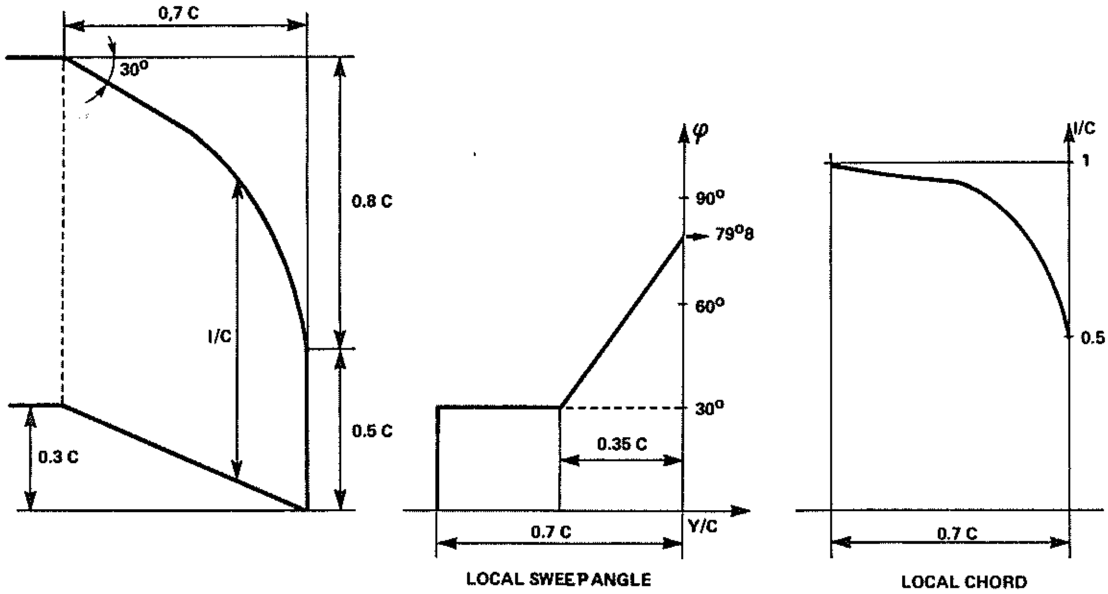

Fig. 1 PF2 TIP

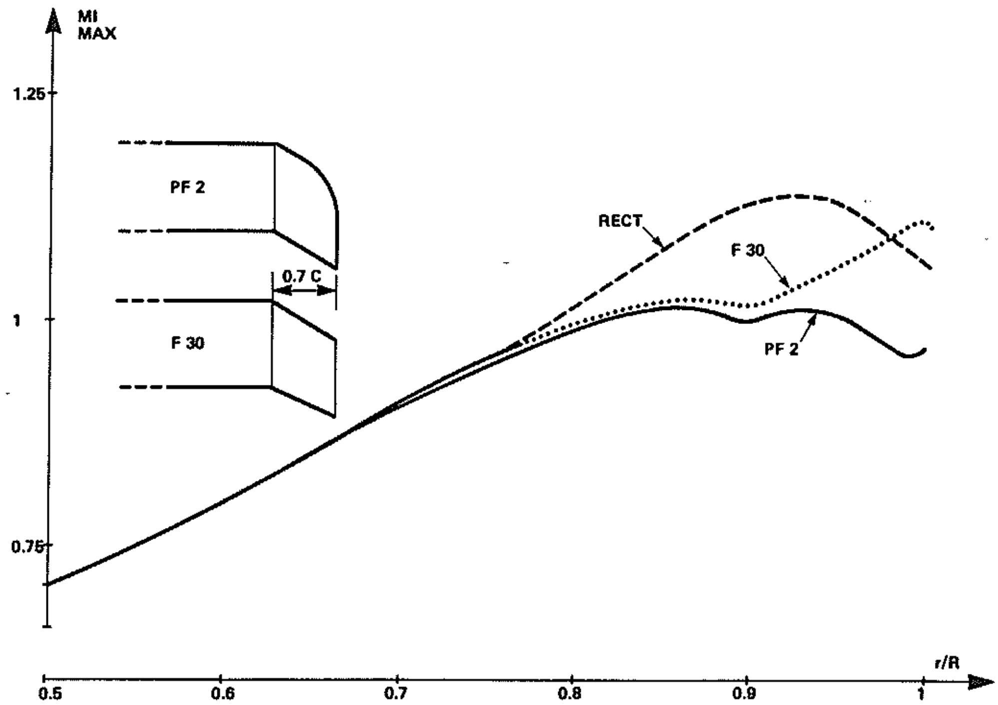

Fig. 2 MAXIMUM LOCAL MACH NUMBERS
μ=0.4 $M\omega R$=0.64 Q–S COMPUTATION ψ=90°

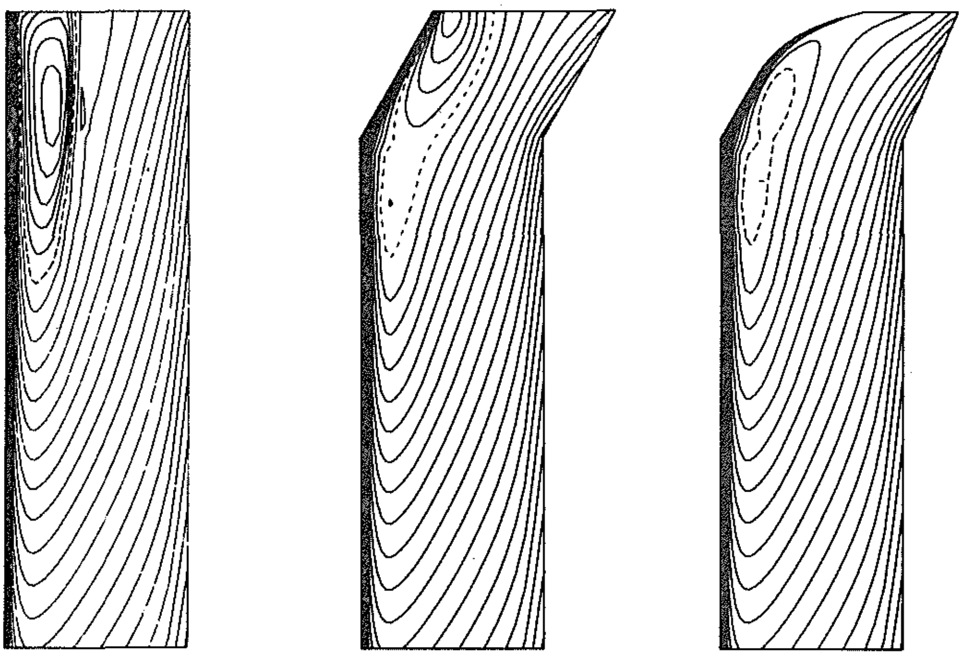

Fig. 3 ISO-MACH LINES

$\mu = 0.4$ $M_{\omega R} = 0.64$ $\psi = 90°$ --- $M_l = 1$

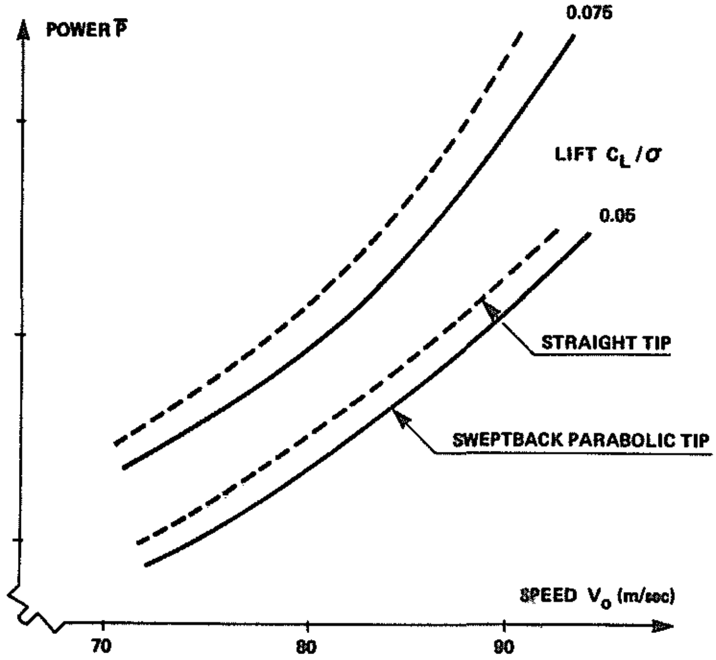

Fig. 4 ONERA S2 CHALAIS WIND-TUNNEL TESTS

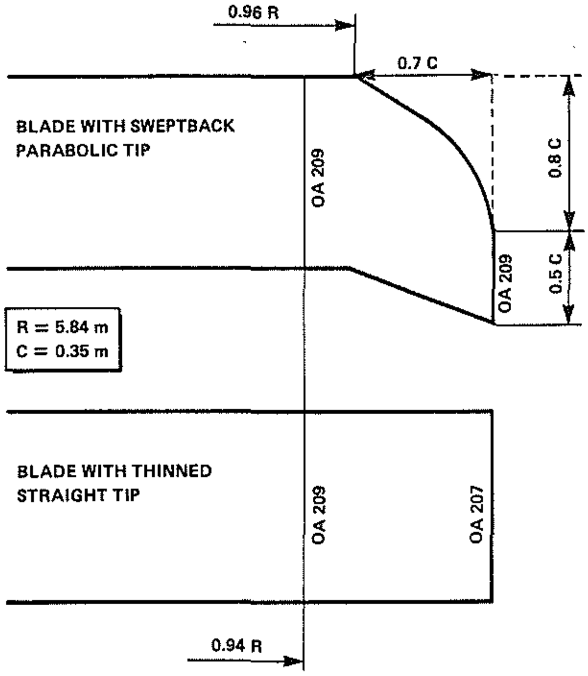

Fig. 5 MAIN ROTOR BLADE GEOMETRY

Fig.6

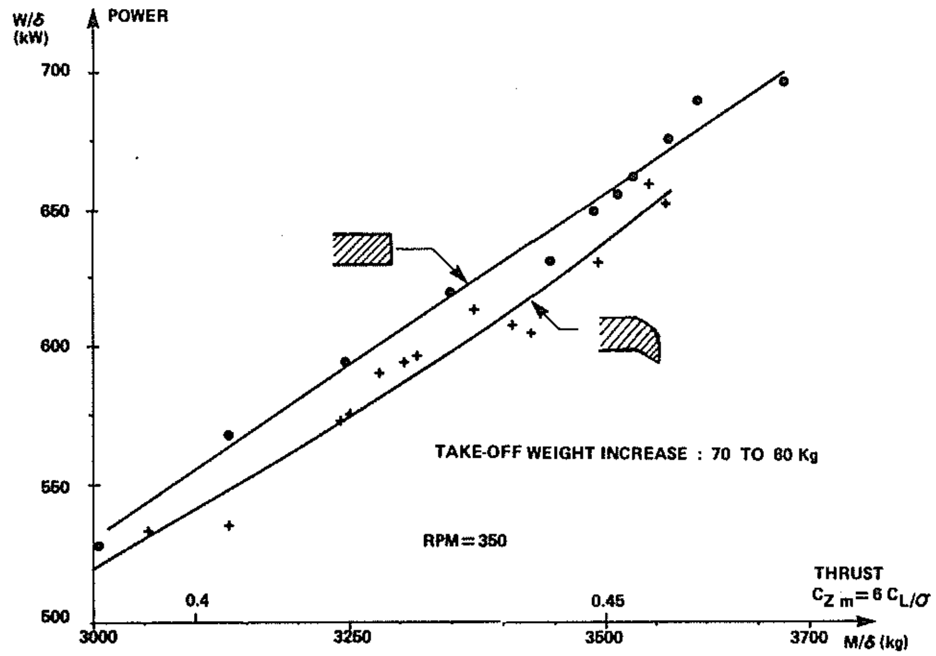

Fig. 7 MAIN ROTOR PERFORMANCE COMPARISON IN HOVER

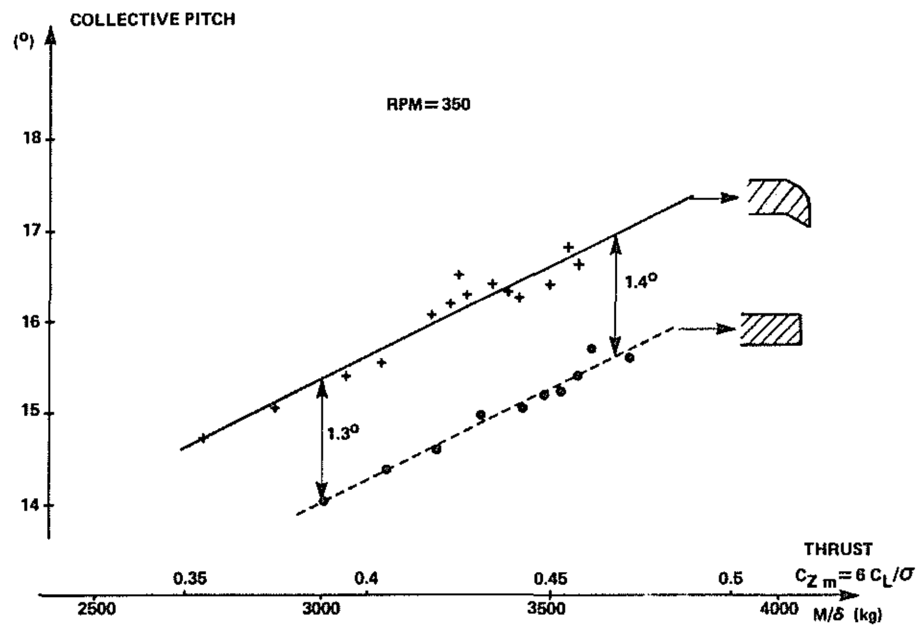

Fig. 8 COLLECTIVE PITCH AT BLADE ROOT IN HOVER

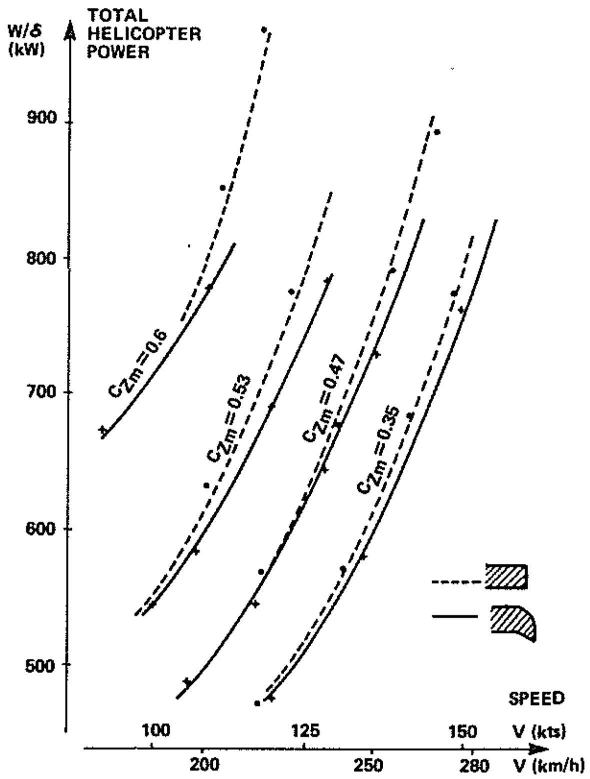

Fig. 9 HELICOPTER PERFORMANCE IN LEVEL FLIGHT RPM = 358

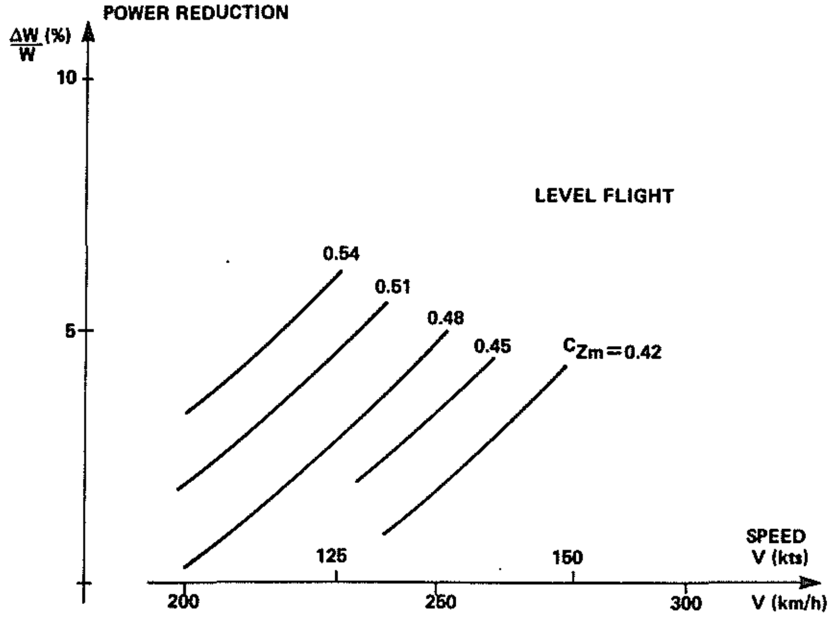

Fig. 10 TOTAL HELICOPTER POWER REDUCTION DUE TO SWEPTBACK PARABOLIC TIP AS A FUNCTION OF CRUISE SPEED FOR DIFFERENT VALUES OF BLADE LOADING COEFFICIENT

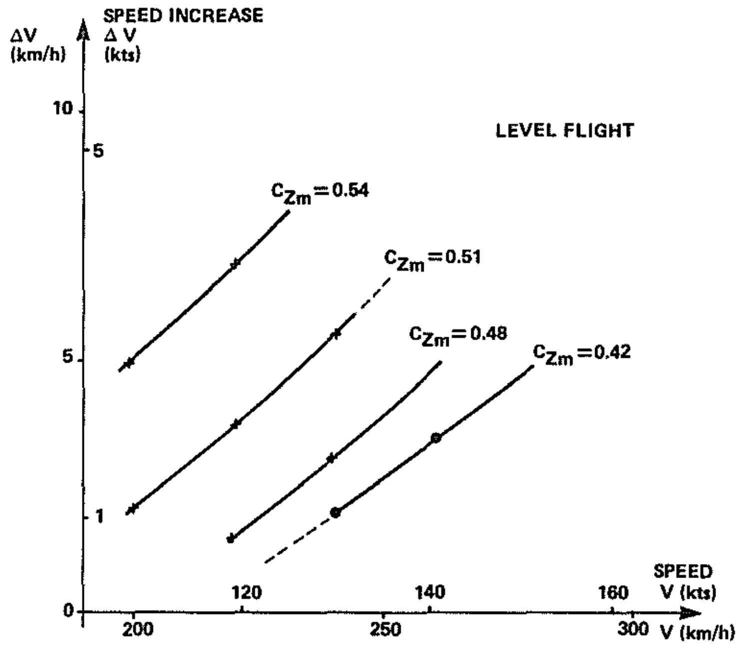

Fig. 11 SPEED INCREASE DUE TO SWEPTBACK PARABOLIC TIP FOR DIFFERENT VALUES OF THE BLADE LOADING COEFFICIENT (SAME TOTAL HELICOPTER POWER)

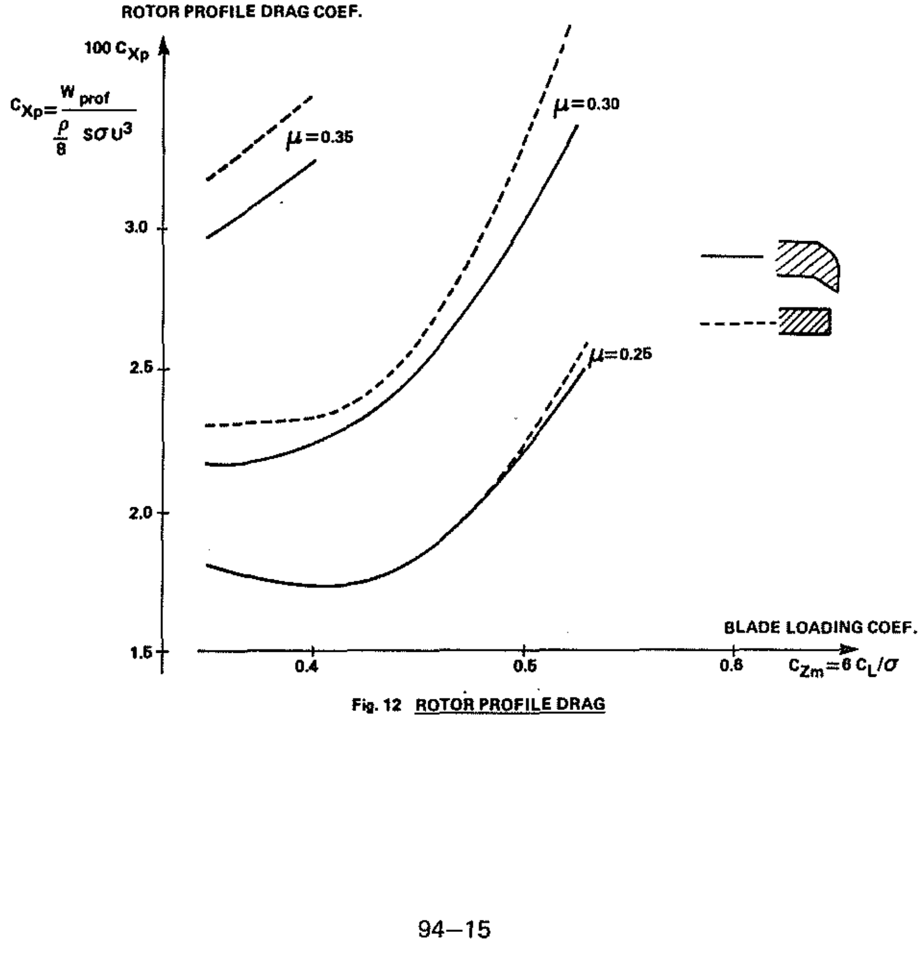

Fig. 12 ROTOR PROFILE DRAG

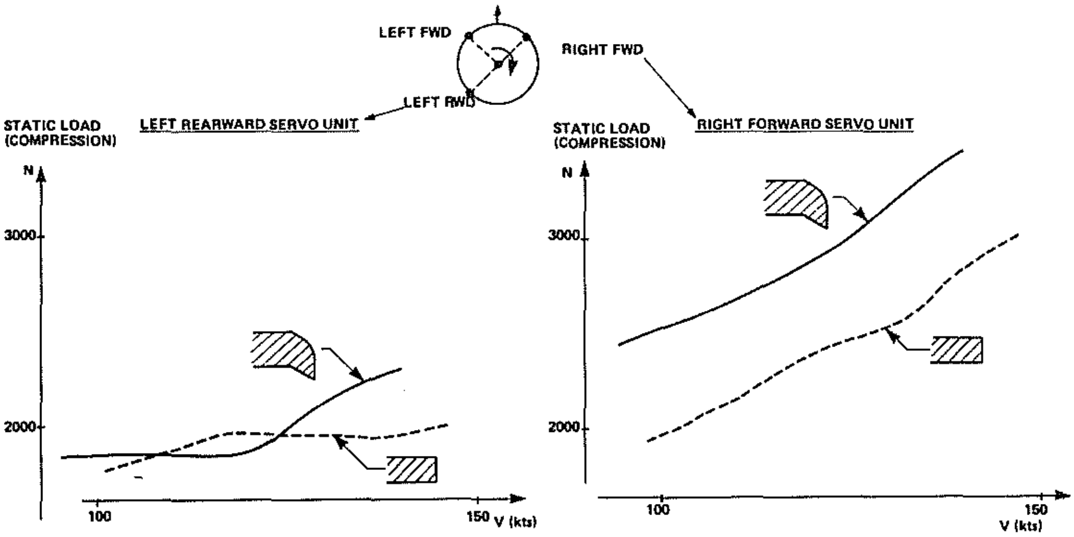

Fig. 13 STATIC LOADS ON SERVO CONTROL-UNITS – M = 3820 kg

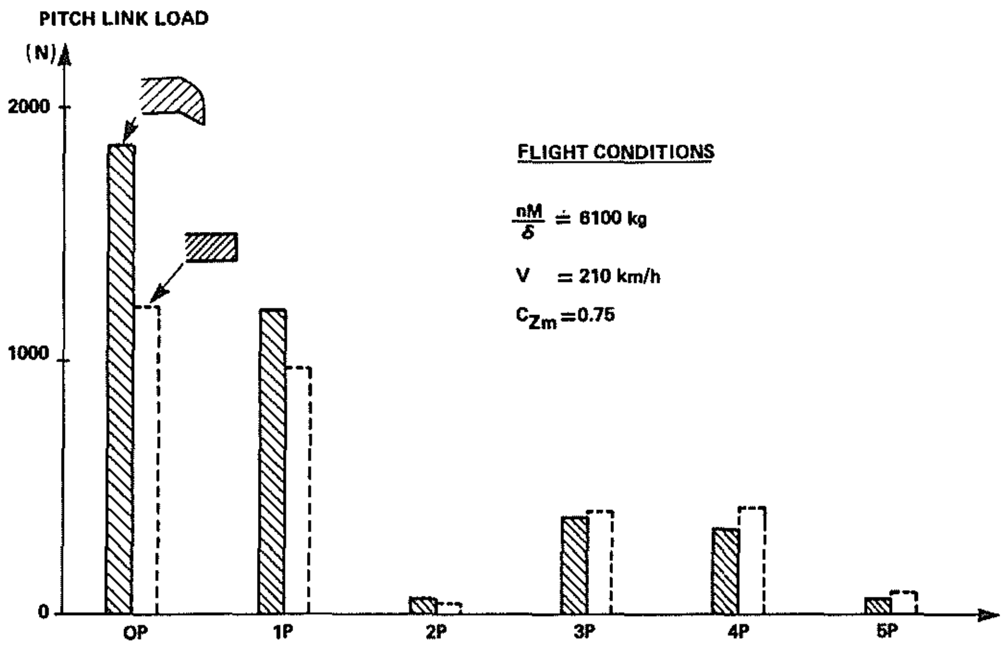

Fig. 14 LOADS ON THE PITCH LINK ROD
(STATIC LOAD AND FIVE FIRST HARMONICS)

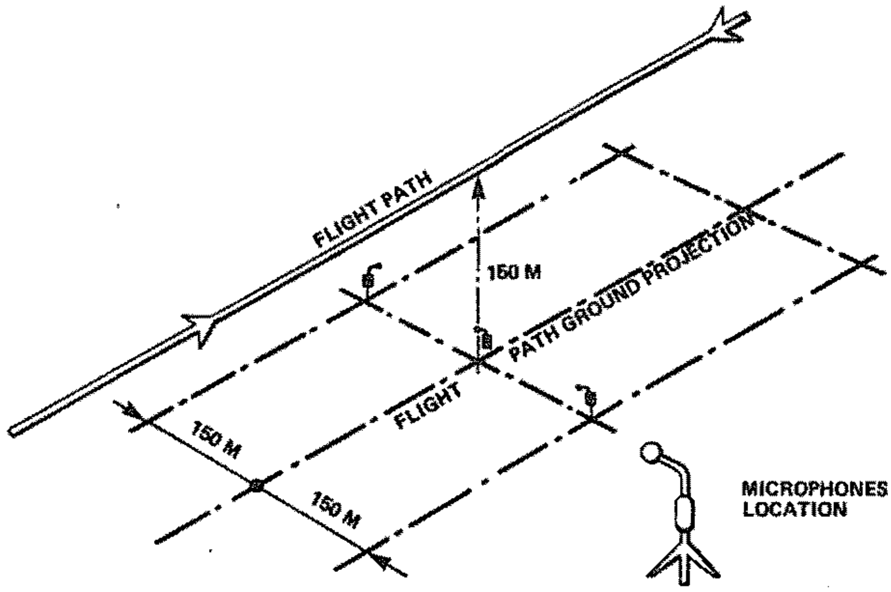

Fig. 15 HORIZONTAL FLYOVER
(ICAO FLIGHT PROCEDURES)

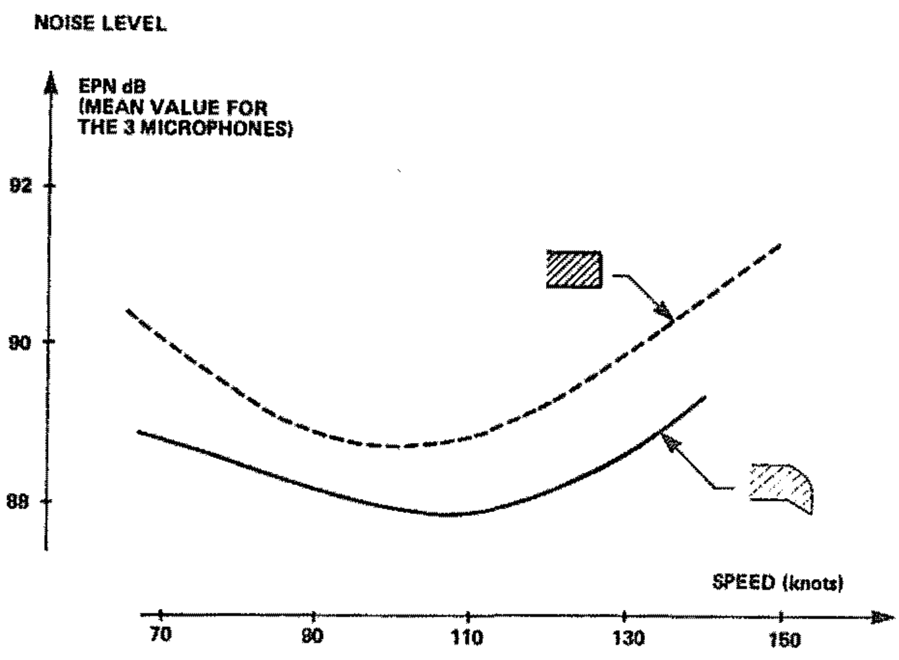

Fig. 16 REDUCTION OF THE HELICOPTER MEAN EFFECTIVE PERCEIVED NOISE LEVEL DUE TO SWEPTBACK PARABOLIC TIP

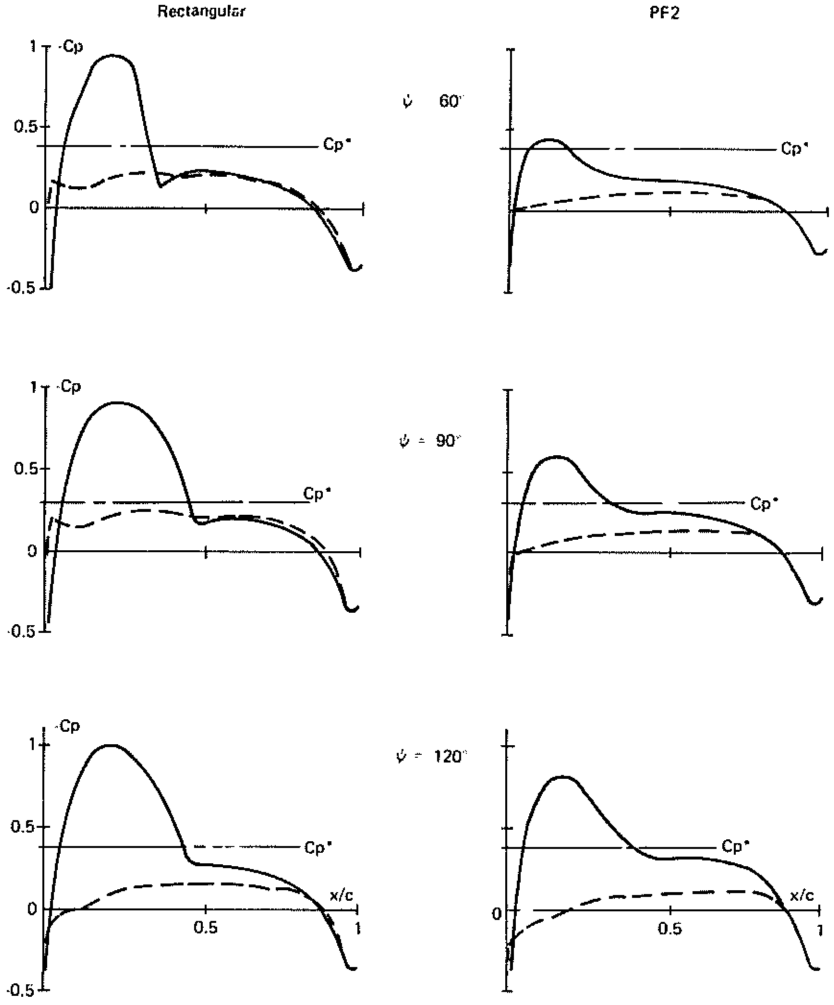

Fig. 17 CALCULATED PRESSURE DISTRIBUTION AT r/R 0.98

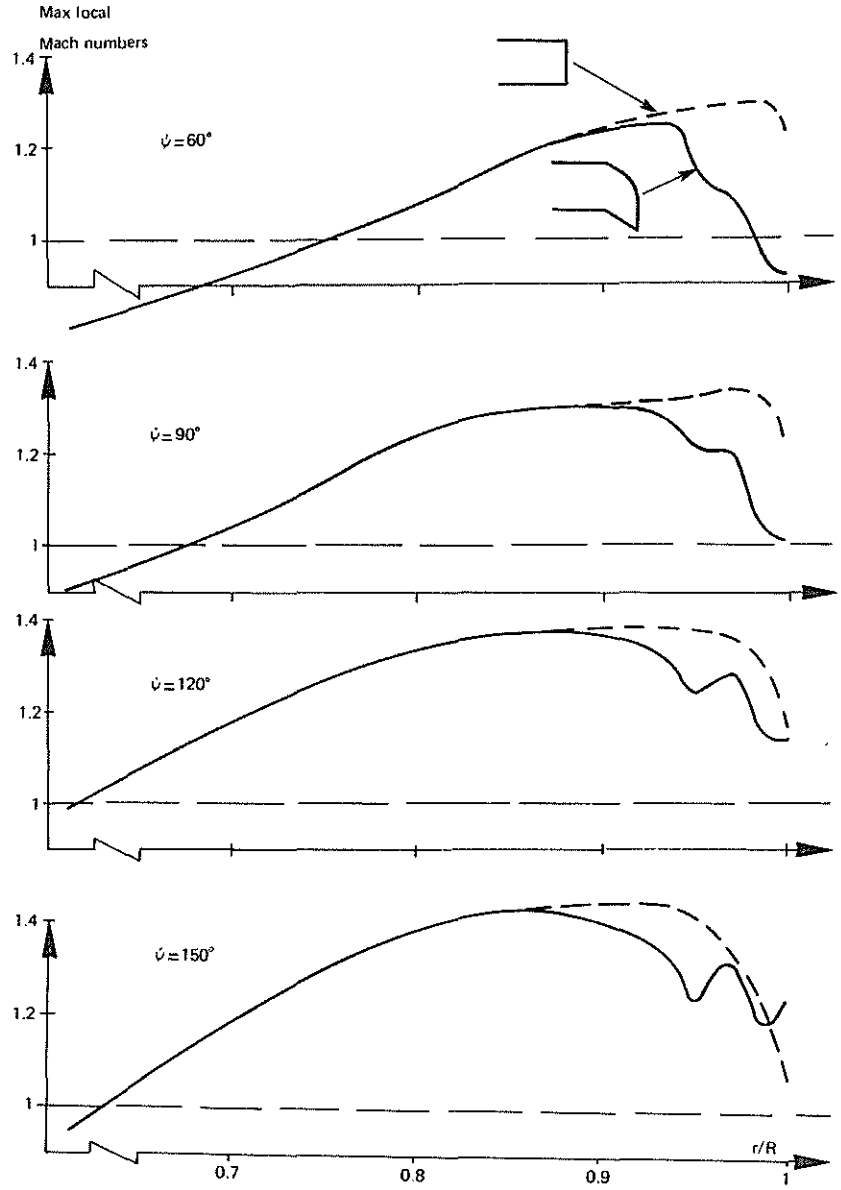

Fig. 18 EVALUATION OF THE MAXIMUM LOCAL MACH NUMBERS ON RECTANGULAR BLADE AND ON BLADE WITH PF2 TIP

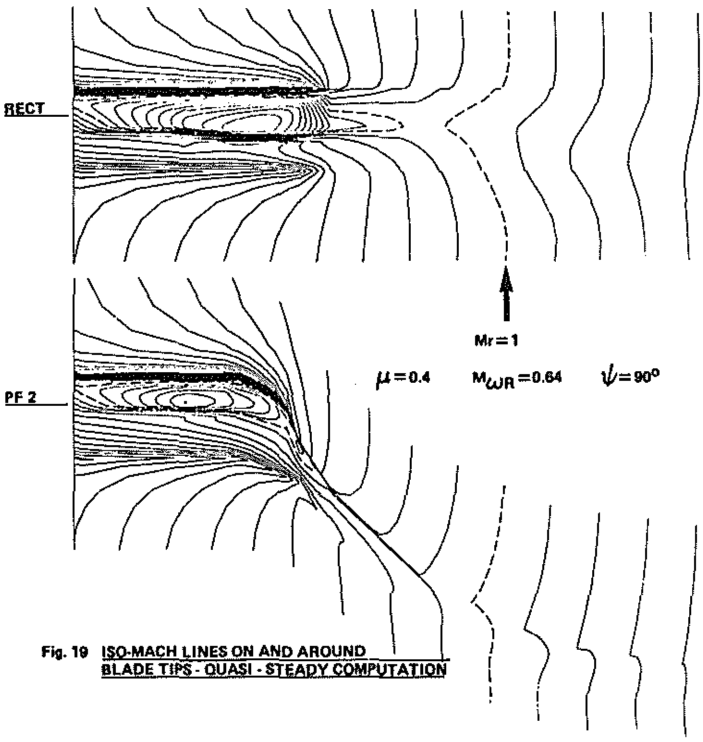

Fig. 19 ISO-MACH LINES ON AND AROUND BLADE TIPS - QUASI - STEADY COMPUTATION

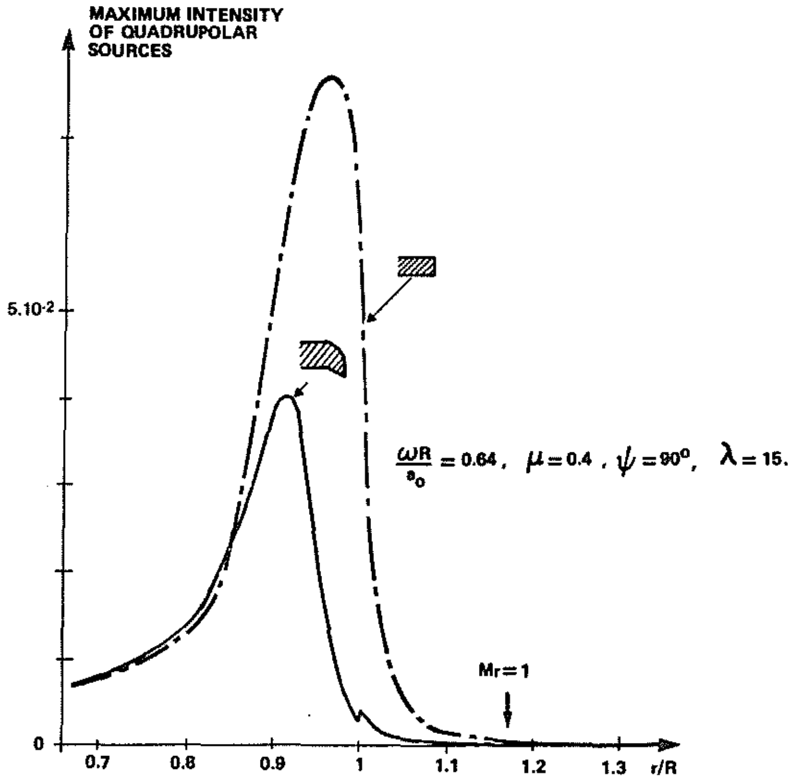

Fig. 20 MAXIMUM INTENSITY OF QUADRUPOLAR SOURCES FOR DIFFERENT HELICOPTER BLADE TIPS AT $\psi = 90^o$