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EFFECT OF AN ANHEDRAL SWEPTBACK TIP ON THE PERFORMANCE OF A HELICOPTER ROTOR

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EFFECT OF AN ANHEDRAL SWEPTBACK TIP ON THE PERFORMANCE OF A HELICOPTER ROTOR

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ABSTRACT

This paper presents some experimental and theoretical results dealing with total performance and local aerodynamics of helicopter rotor blades in high-speed forward flight.

Experimental results obtained with a rig without cyclic pitch control concern a rectangular blade, a blade with a parabolic sweptback tip (PF) and a blade combining an evolutive anhedral shape with the same parabolic sweptback tip (PF1). They show an increase in total performance for the PF1 blades which is due to a decrease of the transonic flow intensity on the advancing blade side. Acoustic measurements show a noise reduction for these PF1 blades. The aerodynamic results are confirmed by calculations with a transonic small disturbances code. These calculations show that some benefit can be obtained by combining anhedral and sweep effects for the design of blade tip shapes.

The rotor test rig has just been equipped with a cyclic pitch device and the results obtained with cyclic are compared with the previous ones. These comparisons show that the piloting law of the rotor has a quite large effect on the local flow over the blade, in particular for the transonic flows development on the advancing blade side.

1 INTRODUCTION

The experimental an analytical study of aerodynamics, dynamics and acoustics of helicopter rotor blades in high-speed forward flight is a very difficult problem involving unsteady, transonic, viscous and highly non-linear phenomena.

During the last ten years, experimental and theoretical research studies have been performed at the Aerodynamics Department of ONERA in order to improve the capability to perform accurate measurements, to predict the characteristics of the flow around a helicopter blade and to define new blade tip shapes that improve the performance of a rotor. These aerodynamic studies have been more particularly focused on the unsteady transonic flows that occur on the advancing blade side for high-speed forward flight.

Experimental and theoretical results concerning different blade tip planforms have already been published [1],[2],[3]. Total performance and pressure measurements have been performed on a very rigid 3 bladed model rotor equipped with these different blade tip planforms. Of all the blade tip shapes tested, PF1, which combines an evolutive anhedral shape with a parabolic sweptback tip, is the one which has given the best performance to the model rotor.

This paper will present aerodynamic and acoustic experimental results obtained with the model rotor test rig, without cyclic pitch control, for a rectangular blade, for a blade with a parabolic sweptback tip (PF) and for PF1. The aerodynamic experimental results will be compared with analytical ones obtained with a transonic small disturbances code.

The rotor test rig has just been equipped with a cyclic pitch device and the results obtained with cyclic will be compared with the previous ones and with predictions.

2 EXPERIMENTAL STUDIES (without cyclic pitch control)

For about 10 years now, experimental studies concerning helicopter rotor flows have been performed at the Aerodynamics Department of ONERA. For lifting rotor configurations, the experiments are performed in the ONERA S2 Ch wind tunnel on a basic research 3-bladed rotor ($R = 0.857$ m, $R/c = 7$) with -12° twisted rigid blades. In this wind tunnel (3 m in diameter) and with the rotor test rig used, realistic rotating tip Mach number and advancing tip Mach number (M_{AT} up to .9) can be obtained.

From the aerodynamic point of view, total performance measurements with a six components balance and local pressure measurements in the three spanwise sections 0.85 R, 0.9 R and 0.95 R have been performed. Results concerning different blade tip planforms (Fig. 1) have already been published [1,2,3]. Among these different blade tips studied two of them have the same sweptback parabolic planforms (PF and PF1) ; the last blade tip tested (PF1) combines an evolutive anhedral shape with this planform effect (Fig. 2-3).

In order to perform joint aerodynamic and acoustic testings, the test section of the S2 Ch wind tunnel was equipped with a removable acoustic lining in 1984-1985.

2.1 Aerodynamic results

The total performance of the model rotor have been significantly improved by the use of these PF and PF1 blade tip shapes when compared to the performance obtained for a standard rectangular blade (Fig. 4-5). A decrease of 7 % in hover (Fig. 4) and up to 10 % in forward flight (Fig. 5) has been obtained for the power required to drive the rotor when it is equipped with the PF1 tip compared to the power needed for the rectangular blade. The comparison of the results between the PF and the PF1 shapes shows that the anhedral effect improves the performance more particularly when $C_T/\sigma > .070$ in hover (Fig. 4) and when $C_T/\sigma > 0.065$ and $\mu > .40$ ($V_0 \simeq 84$ m/s) in forward flight (Fig. 5).

In hover the improvement obtained with PF1 is certainly the result of the modification of the load distribution over the tip due to the planform (the tip is unloaded by the effect of the taper in chord) and to the anhedral effect which decreases the blade vortex interaction phenomena by increasing the distance between a blade and the vortex of the preceeding blade.

In forward flight, the analysis of the local pressure measurements on the blade tip have pointed out that the benefit obtained with PF1 was due to the decrease of the supercritical flow intensity on the upper surface of the blade for a large azimuthal sector of the advancing blade side, in particular at the azimuth $\psi = 90°$ (Fig. 6).

The sweptback parabolic tip (PF) has also been flight tested on a 365 N Dauphin helicopter[4]. In this case the parabolic tip (.7 chord span) extends from .96R to R only. A total helicopter power reduction ranges from 1 to 6 % in the flight test envelope has been obtained with this PF tip (Fig. 7).

2.2 Acoustic results

For acoustic experiments the test section of the S2 Ch wind tunnel can be equipped with a removable lining adequate for measurements of model rotor impulsive noise. Some tests were conducted for rectangular and PF1 blades with flush mounted microphones located upstream of the rotor. Details concerning the experimental set up and the main results obtained can be found in reference [5].

Figure 8 shows that PF1 blades are slightly less noisy than the rectangular ones by 1 dB for a microphone located upstream of the rotor at 2.5 R from the hub in the horizontal plane of symmetry of the wind tunnel (in this direction the noise mainly results from thickness and compressibility effects).

The flight tests with the sweptback parabolic tip (PF) have also proved a reduction of the noise level due to such a tip [4].

All these experimental aerodynamic and acoustic results prove a better aerodynamic flow condition on PF and PF1 tips that are confirmed by aerodynamic analytical results.

3 ANALYTICAL STUDIES

A three-dimensional unsteady transonic small disturbances (TSD) code for rotor blades of arbitrary planform, developed in cooperation between US Army at Ames and ONERA within the framework of a M.O.U. on helicopter aeroelasticity [6] has been used for these aerodynamic calculations.

This method can be used for non-lifting and lifting calculations. For lifting calculations, the influence of the complex wake system has to be taken into account. As this study concerns high advance ratio forward flight configurations (μ >.3), where the induced downwash is small, on angle of attack approach has been adopted.

The unsteady lifting calculations are performed on an isolated blade with an angle of attack prescribed along the blade for each azimuthal location. The experimental values are used for the rotor shaft angle, the pitch angle, the blade twist angle and the flapping angle. The induced incidence is computed using the Drees downwash model [7]. More details concerning this angle of attack approach and results for different blade tip shapes can be found in references [2,3,8].

Unsteady lifting calculations for the advancing blade side and comparisons with experimental results are presented on figures 9, 10 for the rectangular blade and on figures 11, 12, 13, 14 for PF1. The three-dimensional unsteady and transonic flows are relatively well predicted by the calculations ; in particular the development of a strong shock on the upper surface of the rectangular blade between $\psi = 70^\circ$ and $\psi = 160^\circ$ (Fig. 10) and a phase shift of the supercritical flow towards the second quadrant of the advancing blade side on PF1 (Fig. 12 and 14). The unsteady effects of an anhedral tip for the advancing blade side is to increase the lift in the first quadrant and to decrease it in the second one and therefore to slightly increase the transonic flow intensity on the upper surface before 90° and to decrease it after 90° azimuth (Fig. 15).

The pressure measurements as well as these unsteady analytical results show that the decrease of the transonic flows intensity for azimuts $\psi < 140°$ in the advancing blade side, on such a highly-swept tip with anhedral effect, is certainly the main reason for the improvement in the performance and for the benefit on quadripolar noise obtained with the PF1 tip (Fig. 4-5-8).

4 RESULTS OBTAINED WITH A CYCLIC PITCH CONTROL

4.1 Experimental results

Up to now, all the experiments for blade tip planform studies in the ONERA S2 Ch wind tunnel have been performed with a test rig without cyclic pitch device. This limits the retreating blade phenomena that can be tested on this model rotor equipped with relatively heavy blades designed to be very stiff and to be instrumented with pressure transducers. In particular due to the blade dynamic characteristics, the flapping is not sufficient to give the high incidences usually associated with the retreating side of the rotor disk.

A cyclic pitch control device has just been designed and experiments with PF1 in these new conditions have just begun. The cyclic law used for these very first tests, is the one that cancel the first harmonic of the flapping angle.

Figures 16 to 19 compare the experimental pressure results obtained with and without cyclic pitch control, on the upper surface of PF1 for the same configuration : $C_T/\sigma = 0.0067$, $\mu = .4$ and $(Cx.S)_f/S\sigma = 0.1$. Figures 16 and 17 present the evolution with azimuth of the pressure coefficients at different chordwise locations of the span sections .85R and .95R. Figures 18 and 19 show the upper surface pressure distributions at different azimuts of the advancing blade side (Fig. 18) and of the retreating blade side (Fig. 19).

With the cyclic law used in these tests, the intensity of the unsteady transonic flows on the blade tip is larger in the first quadrant $(0 < \psi \leqslant 90°)$ than in the second one $(90 < \psi \leqslant 180°)$ (Fig. 16, 17, 18). It is the opposite when the experiments are performed without cyclic.

On the retreating blade side and in particular for $270° \leqslant \psi \leqslant 360°$, the large suction peak near the upper surface leading edge obtained with cyclic pitch (Fig. 19) indicates that the blade is more looded with cyclic than without. This phenomenon is more important in the inboard section (.75R) than in the outboard one (.95R).

Sharp increases of the local velocity near the upper surface leading edge of the section .95R appear for azimuts between 270° and 330° (Fig. 17). They are certainly due to some vortex flow phenomena generated on this highly swept blade tip in a part of the cycle where the local angle of attack is large.

These comparisons of the experimental results obtained with and without cyclic pitch show a change in the blade loading resulting from a modification of the local angle of attack variation with azimuth. With the cyclic pitch device, more realistic configurations with dynamic stall phenomena on the retreating blade side, can now be studied.

Tests are going to be performed to study the influence of blade tip planform modifications on dynamic stall and to study the effect of different cyclic laws on the local flow and on the total performance of a helicopter rotor.

4.2 Analytical results

The three dimensional unsteady transonic small disturbances code have been used to perform calculations with the experimental cyclic pitch law. Comparisons with the test results are presented on Figure 20 for the upper surface pressure distributions at different azimuts of the advancing blade side in the span locations .85R and .95R.

Although the calculation under predicts the transonic flow intensity at $\psi = 60°$, it shows, as well as the experiment that with cyclic pitch, the intensity of the supercritical flow is larger at $\psi = 60°$ than at $\psi = 120°$ (Fig. 20) ; without cyclic pitch it is the opposite (Fig. 11, 18).

Calculations with an unsteady full potential code [9] are going to be perform for the full cycle (advancing and recreating blade sides) and for the different cyclic laws that will be tested in the wind tunnel.

These first experimental and calculated results obtained with a cyclic pitch variation show that the piloting law of the rotor has a quite large effect on the local flow over the blade for our model rotor equipped with relatively heavy blades. This effet has to be considered in the study of blade tip planform modifications design for improving the total performance of a rotor.

5 CONCLUSIONS

For several years, experimental and theoretical studies have been performed at the Aerodynamics Department of ONERA in order to obtain detailed and accurate measurements, to predict the characteristics of the flow on and around a helicopter blade and to define new blade tip shapes that improve the performance of a rotor.

Total performance and pressure measurements have been performed on a 3 bladed model rotor equipped with very rigid blades for different blade tip planforms. The last blade tip studied, PF1, combines an evolutive anhedral shape with a parabolic sweptback tip. Thanks to a removable acoustic lining, joint aerodynamic and acoustic experiments can be performed.

Of all the blade tips tested, PF1 is the one which has given the best performance to the model rotor. A decrease of 7 % in hover and up to 10 % in forward flight has been obtained for the power required to drive the rotor when it is equipped with this PF1 tip compared to the power needed for the rectangular blade. From the acoustics point of view, a noise reduction of the order of 1 dB (between 1 and 2 dBA when scaled to a real helicopter) is obtained in the conditions of experiments.

These improvements appear to be the consequences of the decrease of the transonic flow intensity on the advancing blade side due to high sweep and anhedral effects. This has been shown by pressure measurements and confirmed by unsteady, transonic flowfield calculations.

The rotor test rig of S2 Ch wind tunnel has just been equipped with a cyclic pitch device and therefore more realistic configurations with dynamic stall phenomena on the retreating blade side can now be studied. The comparison of the results obtained with and without cyclic shows that the piloting law of the rotor has a significant effect on the local flow over the blade for this model rotor equipped with relatively heavy blades.

Future studies are planned to take the flexibility of the blades into account in order to approach the difficult problem of aeroelastic optimization : 1) The design and the tests of a three bladed model rotor equipped with soft in torsion blades ; 2) The "coupling" of 3D aerodynamic code and dynamic one[10].

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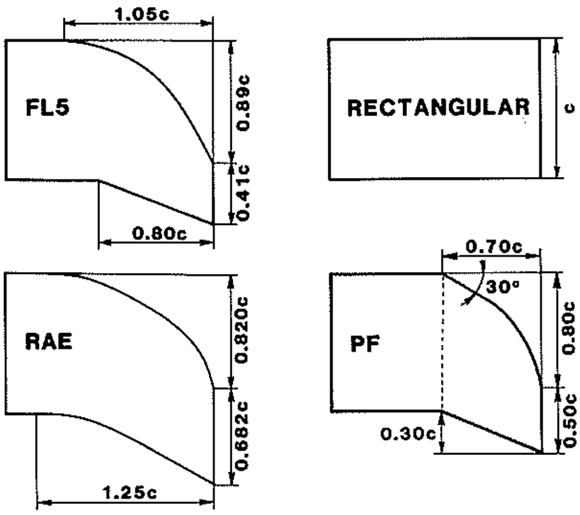

Fig.1 **BLADE TIP SHAPES**

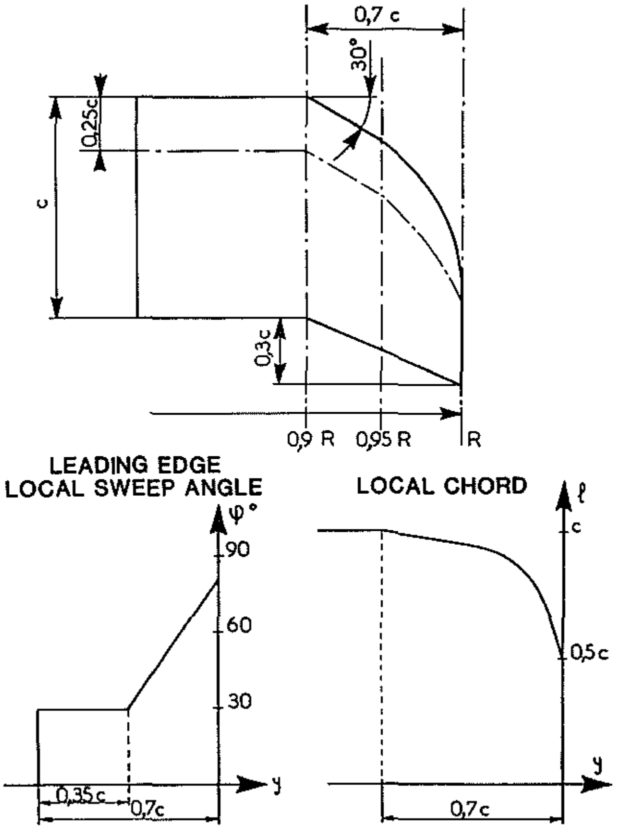

Fig.2 **BLADE TIP PLANFORM** ►

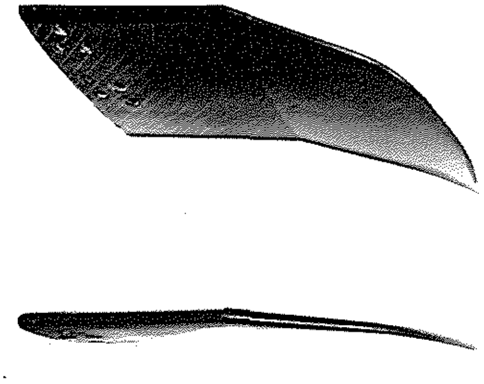

Fig.3 **PARABOLIC SWEPTBACK TIP PF1**

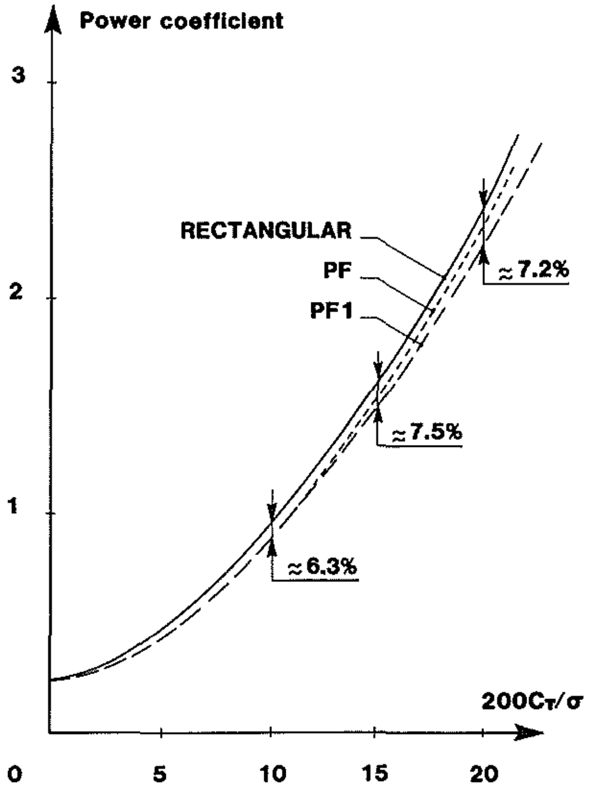

Fig.4 **HOVER CONFIGURATION** ►

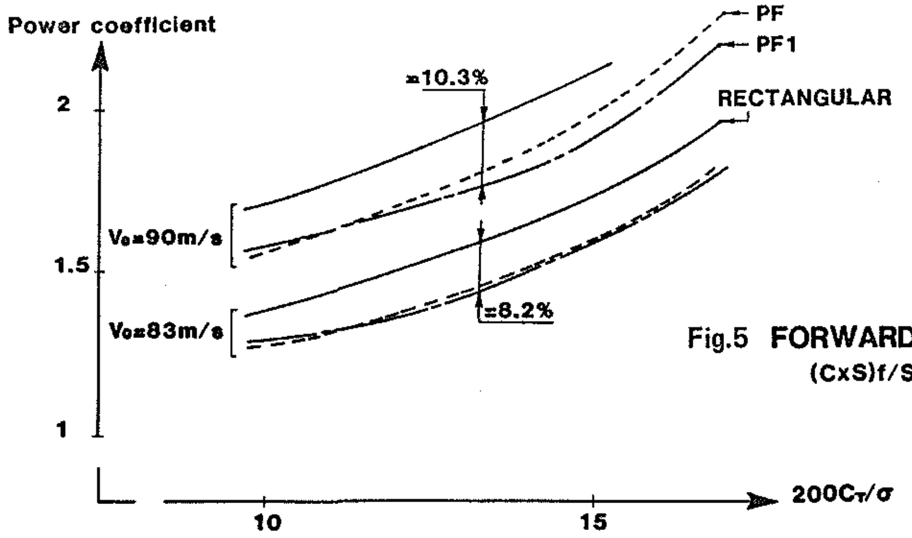

Fig.5 **FORWARD FLIGHT CONFIGURATION**

$(C_xS)f/S\sigma = 0.1$ $\Omega R = 210$ m/s

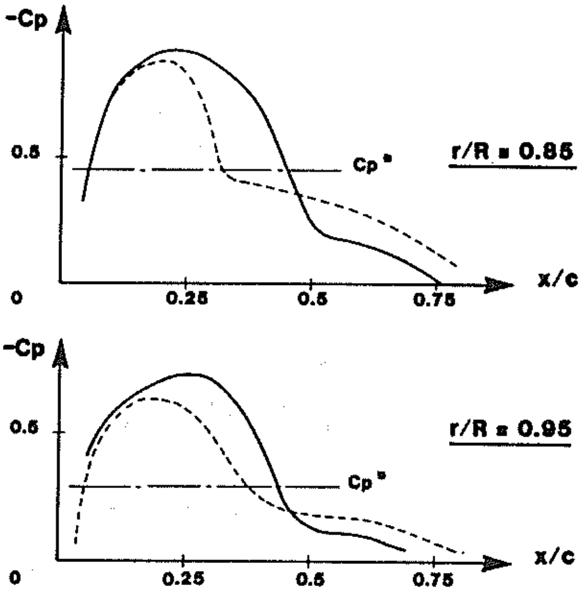

Fig.6 **PRESSURE DISTRIBUTIONS**

$C_T/\sigma = 0.0665$ $V_0 = 93$ m/s $(C_xS)f/S\sigma = 0.1$

Upper surface $\psi = 90°$

——— RECTANGULAR -----PF1

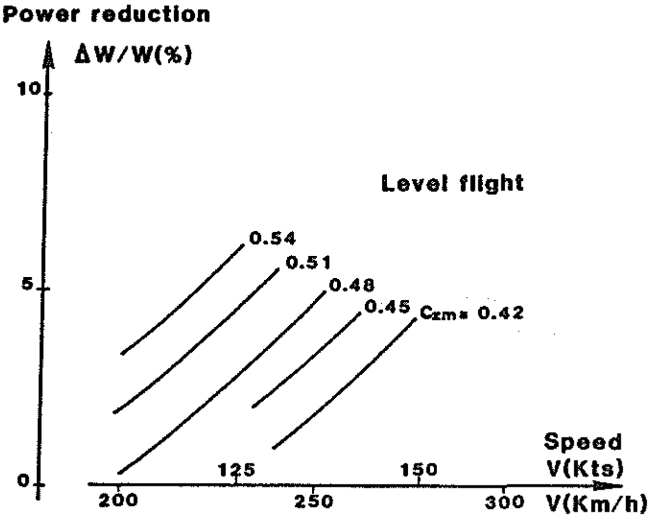

Fig.7

TOTAL HELICOPTER POWER REDUCTION DUE TO SWEPTBACK PARABOLIC TIP

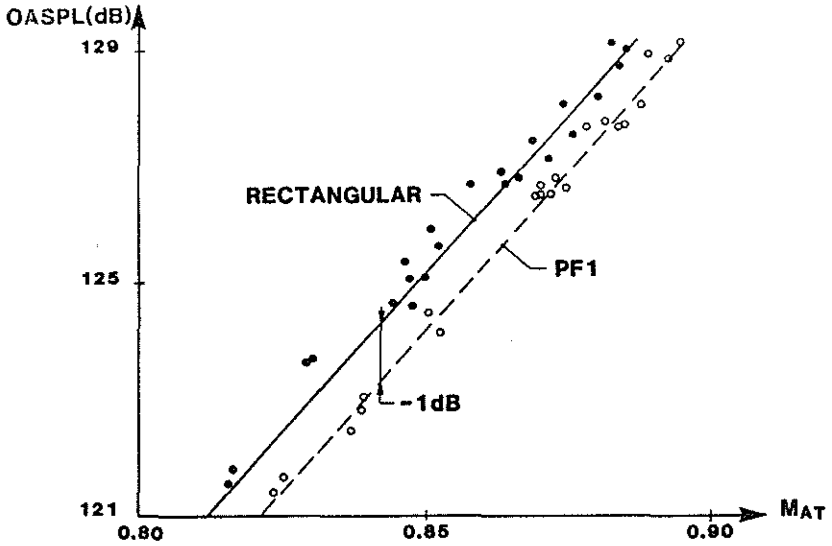

Fig.8 **ACOUSTIC COMPARISON**

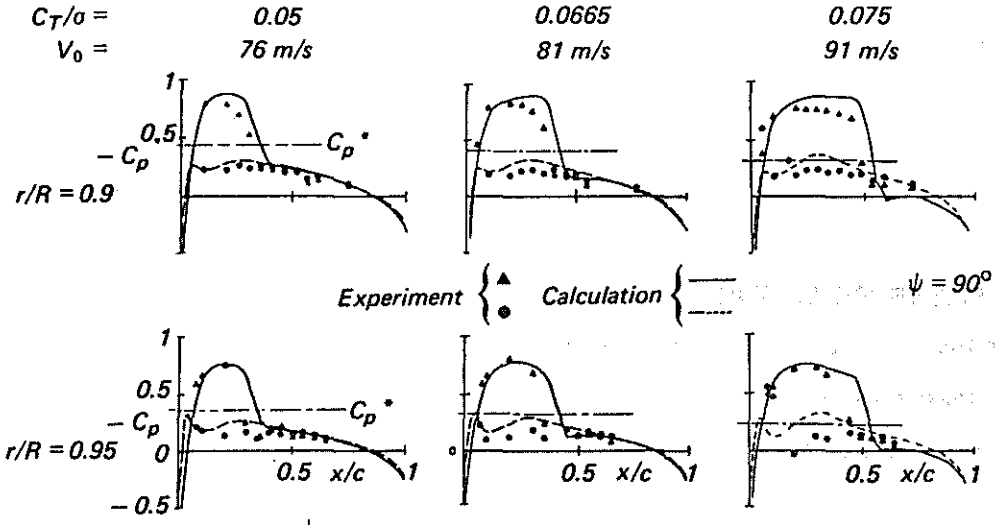

Fig.9 LIFTING UNSTEADY CALCULATION .
RECTANGULAR BLADE .

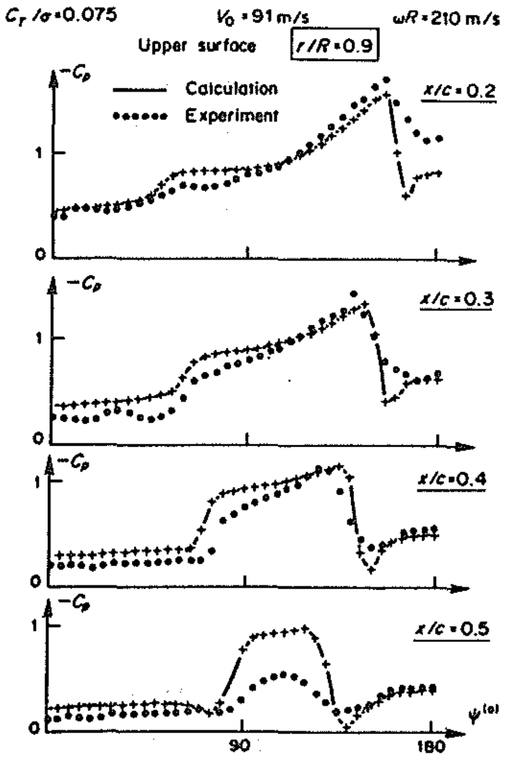

Fig.10

LIFTING UNSTEADY CALCULATION
RECTANGULAR BLADE

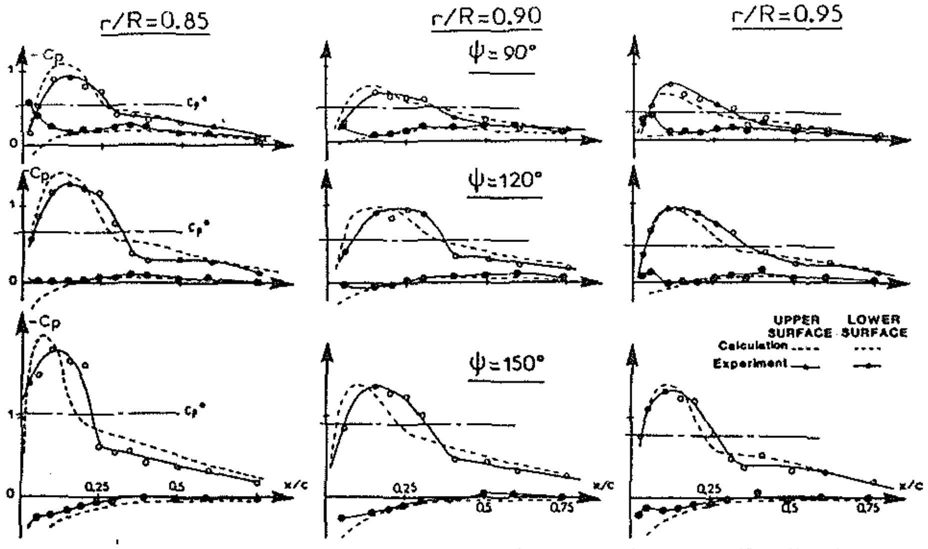

Fig.11 LIFTING UNSTEADY CALCULATION - PF1 BLADE

$C_T/\sigma=0.0665$ $V_0=84m/s$

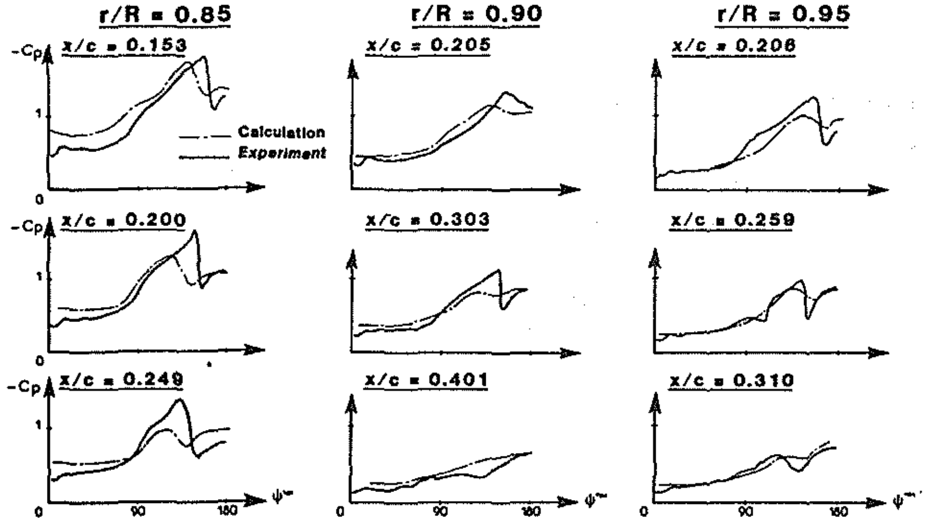

Fig.12 LIFTING UNSTEADY CALCULATION - PF1 BLADE

$C_T/\sigma = 0.0665$ $V_0 = 84m/s$

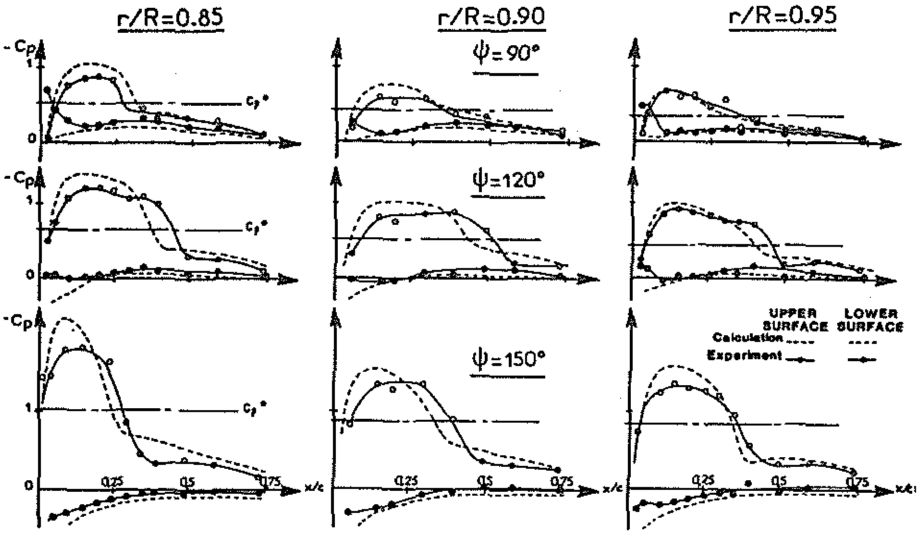

Fig.13 LIFTING UNSTEADY CALCULATION - PF1 BLADE

$C_T/\sigma=0.0665$ $V_0=93m/s$

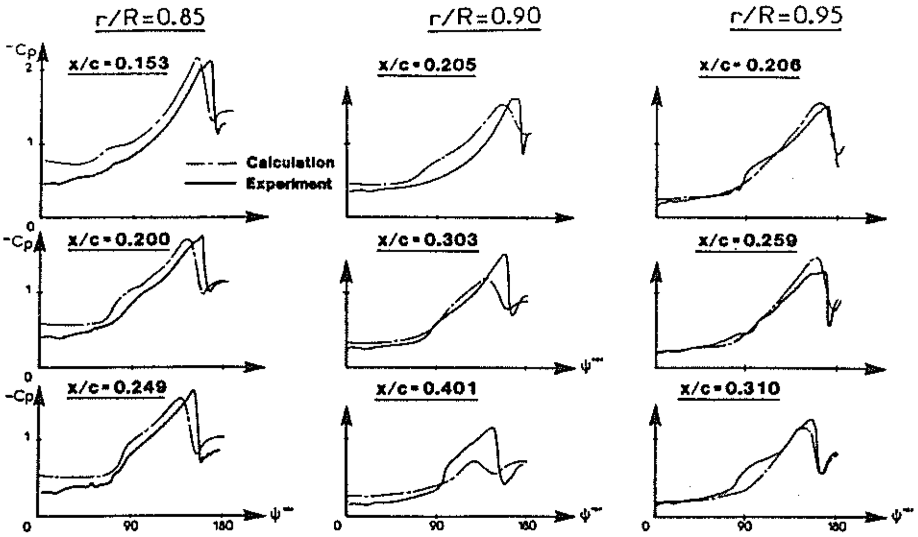

Fig.14 LIFTING UNSTEADY CALCULATION – PF1 BLADE

C_T/σ=0.0665 V_0 =93m/s

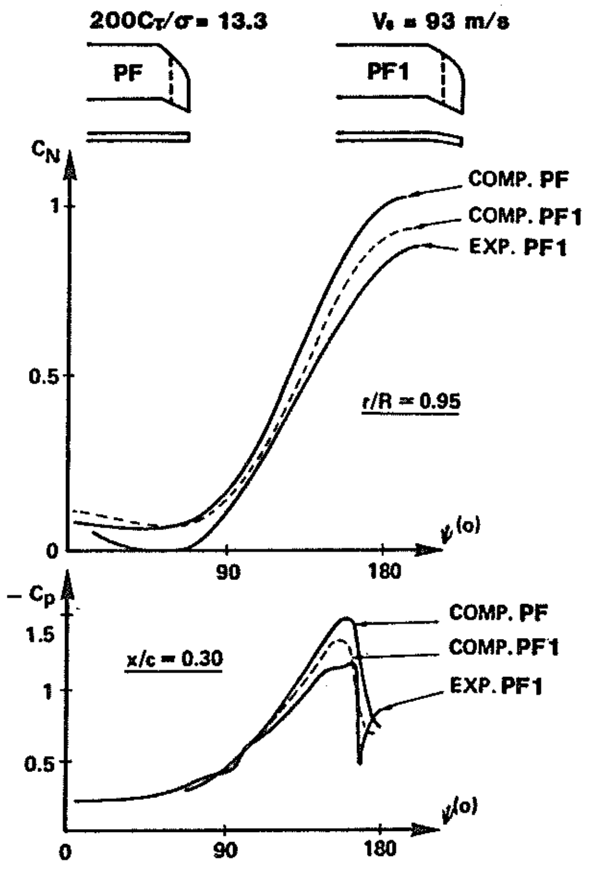

Fig.15 SWEPTBACK PARABOLIC TIP

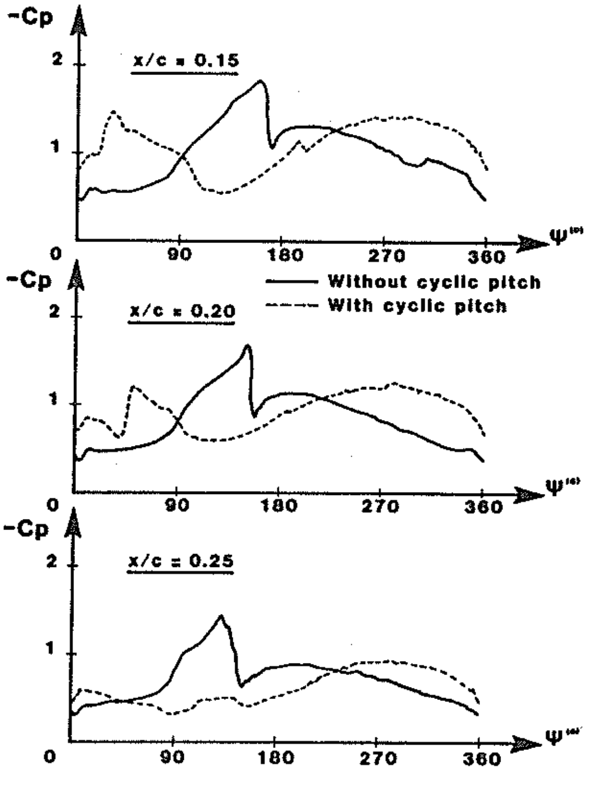

Fig.16 EXPERIMENTAL RESULTS ON PF1

C_T/σ = 0.067 μ = 0.4 $M_{\Omega R}$ = 0.61

Upper surface

r/R = 0.85

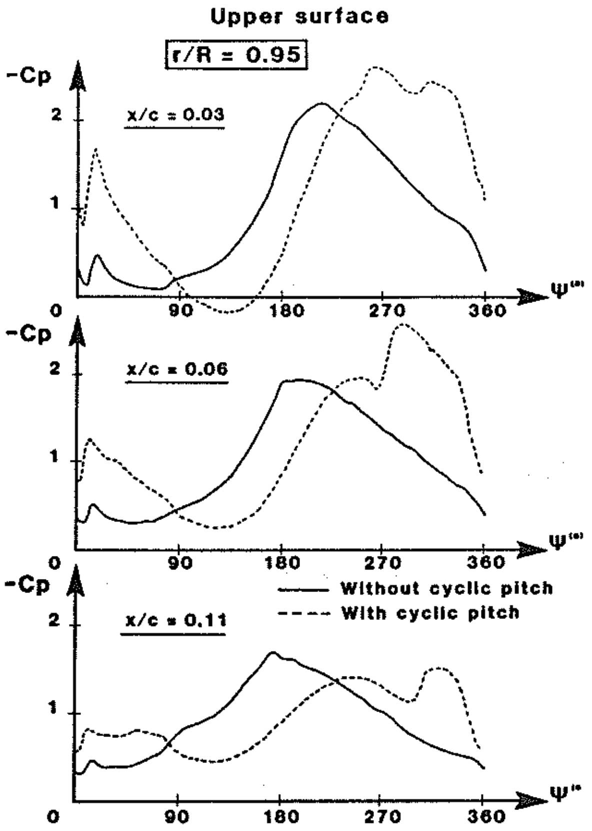

Fig.17 EXPERIMENTAL RESULTS ON PF1

$C_T/\sigma = 0.067$ $\mu = 0.4$ $M_{\Omega R} = 0.61$

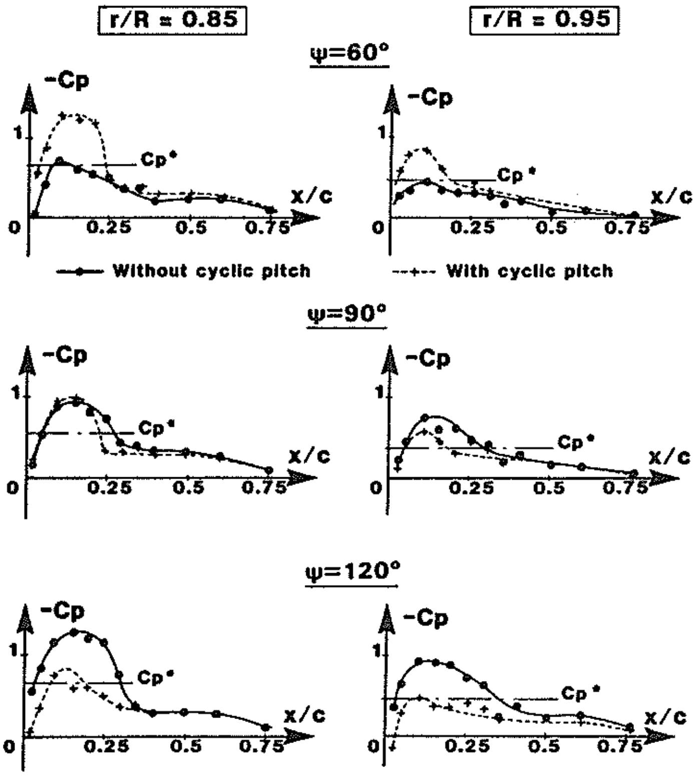

Fig.18 EXPERIMENTAL RESULTS ON PF1

$C_T/\sigma = 0.067$ $\mu = 0.4$ $M_{\Omega R} = 0.61$ Upper surface

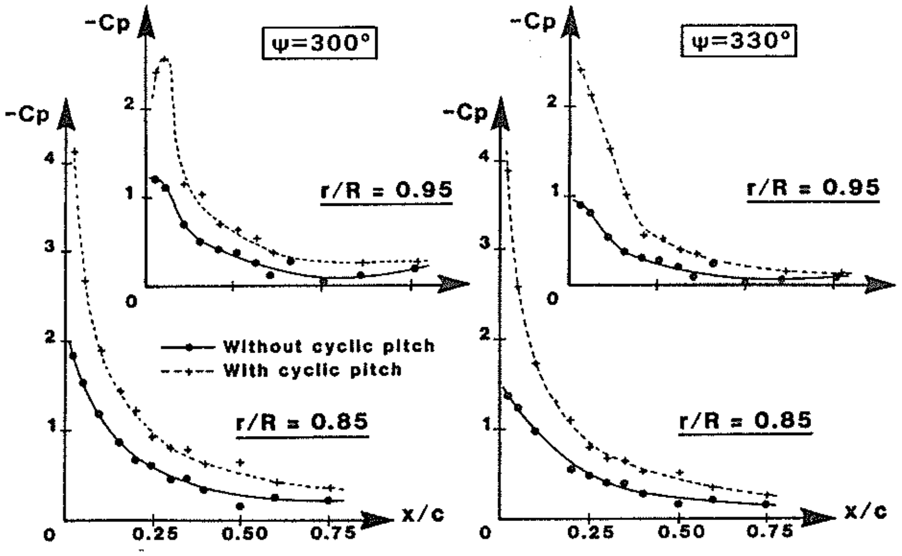

Fig.19 EXPERIMENTAL RESULTS ON PF1

$C_T/\sigma = 0.067$ $\mu = 0.4$ $M_{\Omega R} = 0.61$ Upper surface

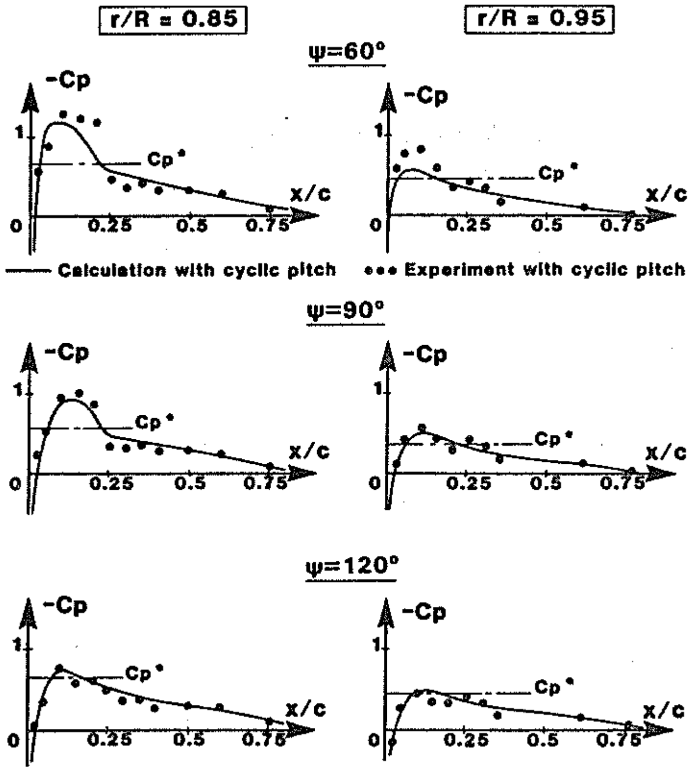

Fig.20 LIFTING UNSTEADY CALCULATION
PF1 BLADE

$C_T/\sigma = 0.067$ $\mu = 0.4$ $M_{\Omega R} = 0.61$ Upper surface