PAPER Nr.: 100

INFLUENCE OF THE CONTROL LAW ON THE PERFORMANCE OF A HELICOPTER MODEL ROTOR

BY

A. DESOPPER, P. LAFON, P. CERONI

OFFICE NATIONAL D'ETUDES ET DE RECHERCHES AEROSPATIALES
B.P. 72 - 92322 CHATILLON CEDEX, FRANCE

FIFTEENTH EUROPEAN ROTORCRAFT FORUM

SEPTEMBER 12 - 15, 1989 AMSTERDAM

INFLUENCE OF THE CONTROL LAW ON THE PERFORMANCE OF A HELICOPTER MODEL ROTOR

by A. DESOPPER, P. LAFON, P. CERONI

Office National d'Etudes et de Recherches Aérospatiales
B.P. 72 - 92322 CHATILLON CEDEX (France)

ABSTRACT

For several years, a model rotor test rig has been used at the ONERA S2 Chalais-Meudon wind tunnel to study the total performance of helicopter rotors and the local flow on different blade tip shapes. All these tests were performed with a free flapping rotor without any cyclic pitch control. In 1987 the rig was equipped with a cyclic pitch device and tests have been performed for several control laws.

This paper presents the influence of the control law on the test results : total performance obtained with a three bladed rotor equipped with rectangular and parabolic sweptback tips, blade loads and test enveloppe, blade tip shapes effect and local flows on the blade. These tests are performed for a given rotating tip Mach number and each configuration is obtained for given total lift, total propulsive force and advance ratio. The results obtained for three different control laws show a large effect of this parameter, in particular on the performance and on the local flow over the blade. Calculations performed with a performance code based on lifting line theory with a simple inflow model don't predict such large effects.

All these results show that the control law can be an important parameter in the performance of a helicopter rotor.

1 - INTRODUCTION

This paper presents the total performance results obtained with a three-bladed rotor equipped with rectangular and parabolic sweptback tips for three control laws :

- without cyclic (θ_{1c} and θ_{1s} are not exactly equal to zero due to a small pitch-flap coupling effect),
- θ_{1s}, θ_{1c} such that $\beta_{1c} = \beta_{1s} = 0$ ("American law")
- a "mixed" control law ($\theta_{1s} = \beta_{1c}$, $\beta_{1s} = 0$).

The cyclic (θ) and flapping angles (β) being defined by :

$$\theta = \theta_o - \theta_{1s} \sin \psi + \theta_{1c} \cos \psi$$

$$\beta = \beta_o + \beta_{1s} \sin \psi - \beta_{1c} \cos \psi$$

where ψ is the blade azimuth.

The influence of these control laws on the experimental results will be presented for the total performance, the blade loads and test enveloppe, the comparison between rectangular and parabolic sweptback tips performance and the local flows on the blade.

The results show a large control law effect, in particular on the performance and on the local flow over the blade. For the two control laws with cyclic pitch, the "mixed" law gives better rotor performance and larger test enveloppe with smaller blade root loads than the law $\beta_{1c} = \beta_{1s} = 0$.

Some calculations performed with a performance code based on lifting line theory with a simple inflow model are also presented. These calculations don't predict the important effect seen in the experiments.

All these results show that the control law is a parameter that has to be taken into account for performance and local flows studies on isolated rotor.

2 - EXPERIMENTAL RESULTS

For several years, a model rotor test rig has been used at the ONERA S2 Chalais-Meudon wind tunnel to study the total performance of helicopter rotors and the local flow on different blade tip shapes [1 - 3]. All these tests were performed with a free flapping rotor without any cyclic pitch control. In 1987 the rig was equipped with a cyclic pitch device and tests have been performed for several control laws.

For lifting rotor configurations, the experiments are performed 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 0.9) can be obtained. The total performance are measured with a six components balance and a torquemeter and local pressure with absolute unsteady pressure transducers in the three spanwise sections 0.85 R, 0.9 R and 0.95 R.

The tests are performed for a given rotating tip Mach number and each configuration is obtained for given total lift, total propulsive force and advance ratio. For the present results the rotating tip Mach number is $M_{\Omega R} = 0.61$, the propulsive force is (CdS) $f/S\sigma = 0.1$, the lift varies between $C_T/\sigma = 0.05$ and 0.09 and the advance ratio between 0.3 and 0.4.

Three different control laws have been studied

- without cyclic (θ_{1c} and θ_{1s} are not exactly equal to zero due to a small pitch-flap coupling effect),
- θ_{1s}, θ_{1c} such that $\beta_{1c} = \beta_{1s} = 0$ ("American law")
- a "mixed" control law ($\theta_{1s} = \beta_{1c}$, $\beta_{1s} = 0$).

2.1 - Influence of the control law on the total performance (Figs. 1 - 5)

Figures 1 and 2 show the large influence of the control law on the total performance of the rotor equipped with rectangular blades. The "mixed" control law is the one that gives the best performance with a power reduction of up to 8.7 % at an advance ratio of 0.4 compared to the control law with the flapping angles equal to zero.

Figures 3, 4 and 5 present the evolutions with total lift of the lateral and longitudinal cyclic angles, of the lateral and longitudinal flapping angles, of the rotor shaft angle (α_s) and of the tip path plane angle at an advance ratio of $\mu = 0.35$. The cyclic angles are larger for the law with flapping angles equal to zero than for the "mixed" control law (Fig. 3). If the variation in term of rotor shaft angle is large between the different laws (3 to 4 degrees larger for the "mixed" law than for $\beta_{1s} = \beta_{1c} = 0$), the difference between the tip path plane angles of the mixed and of the no flapping angles control laws which is quite small (Fig. 5) cannot explain the difference in performance (Fig. 1).

2.2 - Influence of the control law on the blade loads : (Figs. 6 - 8)

The pitch link load and the flap and lag bending moments at an inboard section (r/R = 0.3) are presented on figures 6 to 8. The peak-to-peak amplitude of the pitch link load and lag bending moment are reduced by up to 40 % by the mixed control law compared to the no flapping angles control law. This reduction which is particularly important at high advance ratio and lift (Fig. 8) explains why the test enveloppe is larger with the mixed control law than with the no flapping angles. For example no test point has been obtained above $C_L/\sigma = 0.075$ for the no flapping angles control law (Fig. 1).

2.3 - Influence of the control law on the comparison between rectangular and PF1 blades performance (Figs. 9 -11)

Among the different blade tip shapes studied on the S2 Ch wind tunnel test rig, PF1 combines a parabolic sweptback tip planform (Fig. 9) with an evolutive anhedral effect. Performance results obtained without cyclic pitch have already been compared with the ones for a rectangular blade [3].

Figures 10 and 11 show the results obtained with the different control laws studied. In the case of PF1 as well as for the rectangular blade the "mixed" control law is the one that gives the best performance (Fig. 10). The improvement obtained with PF1 compared to the rectangular blade depends on the control law used for the test (Fig. 11) : the benefit are quite similar for the two control laws with cyclic but significantly smaller than the one obtained without cyclic pitch. The study of the local flows on the blade will show large effects of the control law for both the advancing and the retreating blade sides.

2.4 - Influence of the control law on the local flows on the blade tip (Figs. 12 -15)

In order to understand these large effects of the control law on the performance, pressure measurements have been performed on the PF1 blade tip shape in the spanwise stations 0.85 R, 0.9 R and 0.95 R.

Figures 12 to 14 compare the experimental pressure results obtained with and without cyclic pitch control, on the upper surface of PF1 for the same configuration : C_L/σ = 0.0665, μ = 0.4 and (CdS)f/Sσ = 0.1. Figures 12 and 13 present the evolution with azimuth of the pressure coefficients at different chordwise locations of the span section 0.85 R. Figure 14 shows the upper surface pressure distributions at different azimuths of the retreating blade side.

With the cyclic law that cancels the flapping angles, the intensity of the unsteady transonic flows on the blade tip is larger in the first quadrant ($0 < \psi \leq 90°$) than in the second one ($90 < \psi \leq 180°$) (Fig. 13). It is the opposite when the experiments are performed without cyclic and the intensity of the transonic flows is stronger with well defined shocks. For the mixed control law, the intensity of the transonic flows is strongly reduced (Fig. 13) and this explains the performance improvements obtained with this control law (Fig. 1).

On the retreating blade side and in particular for $300 < \psi \leq 360°$, the large suction peak near the upper surface leading edge obtained with cyclic pitch (Fig. 14) indicates that the blade is more loaded with cyclic than without. This phenomenon is even more important for the control law with zero flapping than for the mixed control law. The azimuthal evolutions of the normal force coefficient (Fig. 15) confirm these blade loading differences.

These retreating blade phenomena observed with and without cyclic pitch are certainly accentuated by the fact that this model rotor is equipped with relatively heavy blades designed to be very stiff and to be instrumented with pressure transducers. However, similar effects of the influence of the control law have been obtained on the new helicopter rotor test rig in the large Modane wind tunnel [4]. Figure 16 shows the influence of the two cyclic control laws ("mixed" and zero flapping) on the performance of a more realistic (R/c = 15) rotor model than the one used in S2 Ch wind tunnel : a power reduction of 5.3 % is obtained with the "mixed" control law.

3 - RESULTS OBTAINED WITH A PERFORMANCE CODE BASED ON LIFTING LINE THEORY

Calculations have been performed with a basic performance code based on lifting line theory with 2D airfoil tables and with a simple inflow model (Drees model). Figure 17 presents the influence of the control laws on the calculated total performance for the same model rotor than the one tested in S2 Chalais-Meudon wind tunnel (Fig. 1).

At advance ratio lower than 0.35, the influence of the cyclic law ("mixed" or zero flapping) is the same than the experimental one with an improvement of the performance when the "mixed" control law is used. At higher advance ratio and C_L/σ smaller than 0.075, the calculated effect is opposite to the experimental one with the best calculated performance obtained for the zero flapping control law.

These computed results and the local flow measurements show that this large influence of the control law on the rotor performance is certainly due to some non linear effects like the three-dimensional unsteady transonic effects that occur on the advancing blade side and are not properly taken into account with a lifting line method. Three-dimensional unsteady calculations [5] and coupled dynamic 3D aerodynamic computations [6] need to be performed in order to better understand these phenomena.

4 - CONCLUSION

This paper presents the influence of the control law on model rotor test results for total performance measurements, blade loads and test enveloppe, blade tip shapes effect and local flow studies. The results obtained for three different control laws show a large effect of this parameter, in particular on the performance and on the local flow over the rotor blade. For the two control laws with cyclic pitch studied, the "mixed" law gives better rotor performance and larger test enveloppe with smaller blade root loads than the law $\beta_{1c} = \beta_{1s} = 0$. Calculations performed with a performance code based on lifting line theory with a simple inflow model don't predict such large effects.

All the results show that for performance and local flows studies on isolated rotor and for blade tip planform modifications, the control law is a parameter that has to be taken into account.

REFERENCES

[1] J.J. PHILIPPE, J.J. CHATTOT. Experimental and theoretical studies on helicopter blade tips at ONERA. 6th European Rotorcraft Forum, Bristol, September 1980.

[2] A. DESOPPER, P. LAFON, P. CERONI, J.J. PHILIPPE. 10 years of rotor flows studies at ONERA. State of the art and future studies. 42nd AHS Meeting, Washington D.C., 2-4 June 1986.

[3] A. DESOPPER, P. LAFON, J.J. PHILIPPE, J. PRIEUR. Effect of an anhedral sweptback tip on the performance of a helicopter rotor. 44th AHS Meeting, Washington D.C., 16-18 June 1988.

[4] M. ALLONGUE, J.P. DREVET. New helicopter rotor test rig in the large Modane wind tunnel. 15th European Rotorcraft Forum, Amsterdam, September 1989.

[5] H. BEZARD, M. COSTES. An improved method for the computation of unsteady transonic potential flow. Application for airfoil and blade performance prediction. 15th European Rotorcraft Forum, Amsterdam, September 1989.

[6] C.T. TRAN, A. DESOPPER. An iteration technique coupling 3D transonic small perturbation aerodynamic theory and rotor dynamics in forward flight. 14th European Rotorcraft Forum, Milano, September 1988.

Fig.1 - INFLUENCE OF THE CONTROL LAW ON THE PERFORMANCE

RECTANGULAR BLADE

$M\Omega R=0.61$ $(CdS)f/S\sigma=0.1$

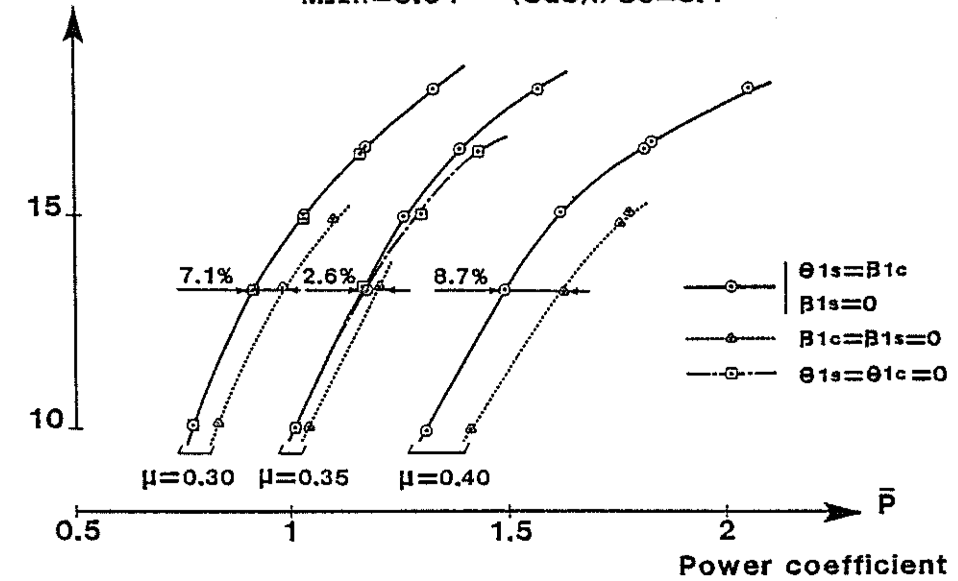

Fig.2 - INFLUENCE OF THE CONTROL LAW ON THE PERFORMANCE

RECTANGULAR BLADE

$M\Omega R=0.61$ $(CdS)f/S\sigma=0.1$

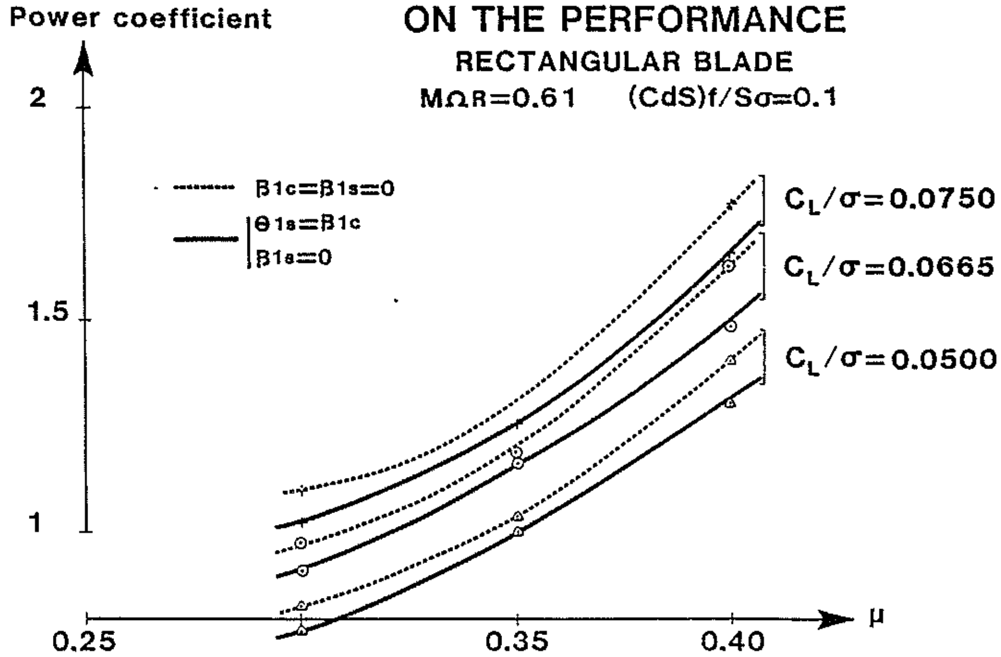

Fig.3 - INFLUENCE OF THE CONTROL LAW ON THE CYCLIC ANGLES

RECTANGULAR BLADE

MΩR=0.61 (CdS)f/Sσ=0.1 μ=0.35

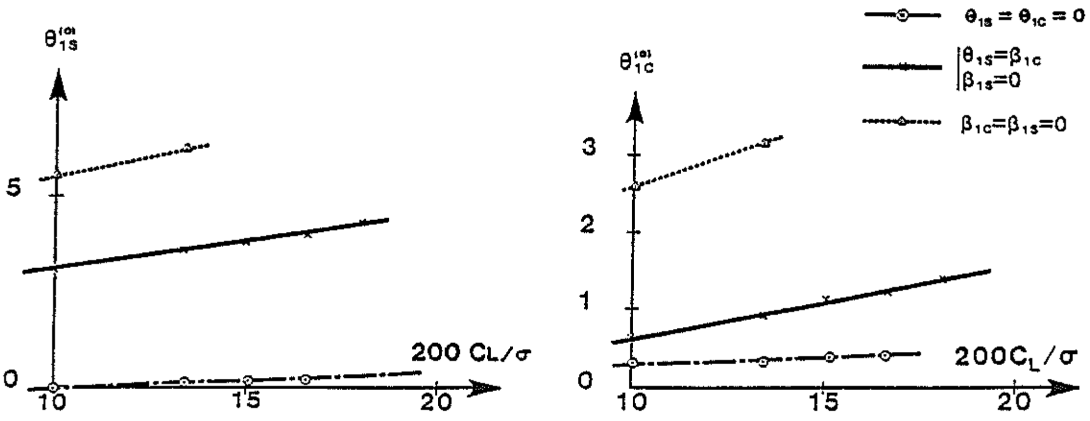

Fig.4 - INFLUENCE OF THE CONTROL LAW ON THE FLAPPING ANGLES

RECTANGULAR BLADE

MΩR=0.61 (CdS)f/Sσ=0.1 μ=0.35

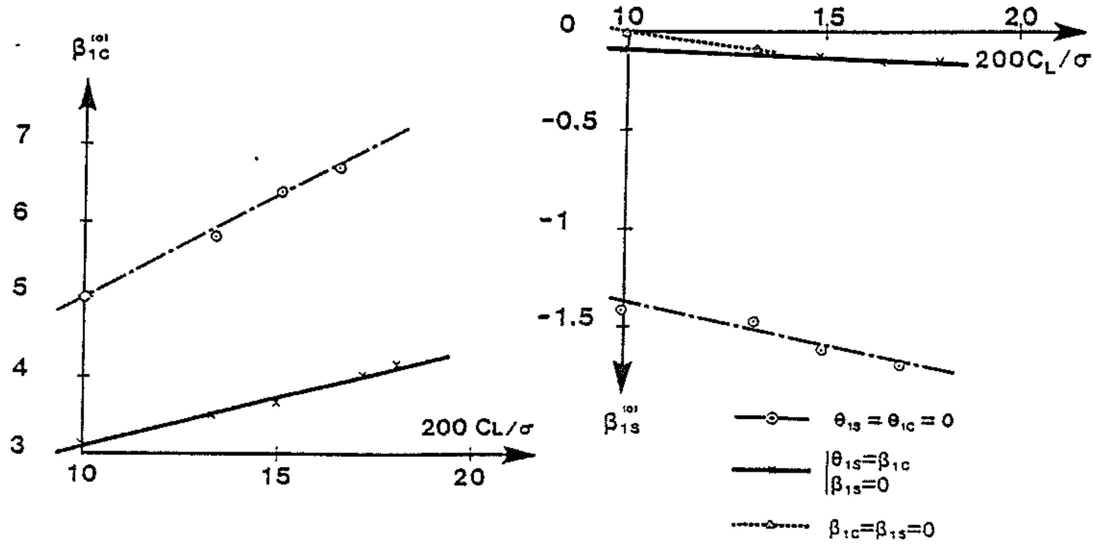

Fig.5 - INFLUENCE OF THE CONTROL LAW

RECTANGULAR BLADE

MΩR=0.61 (CdS)f/Sσ=0.1 μ=0.35

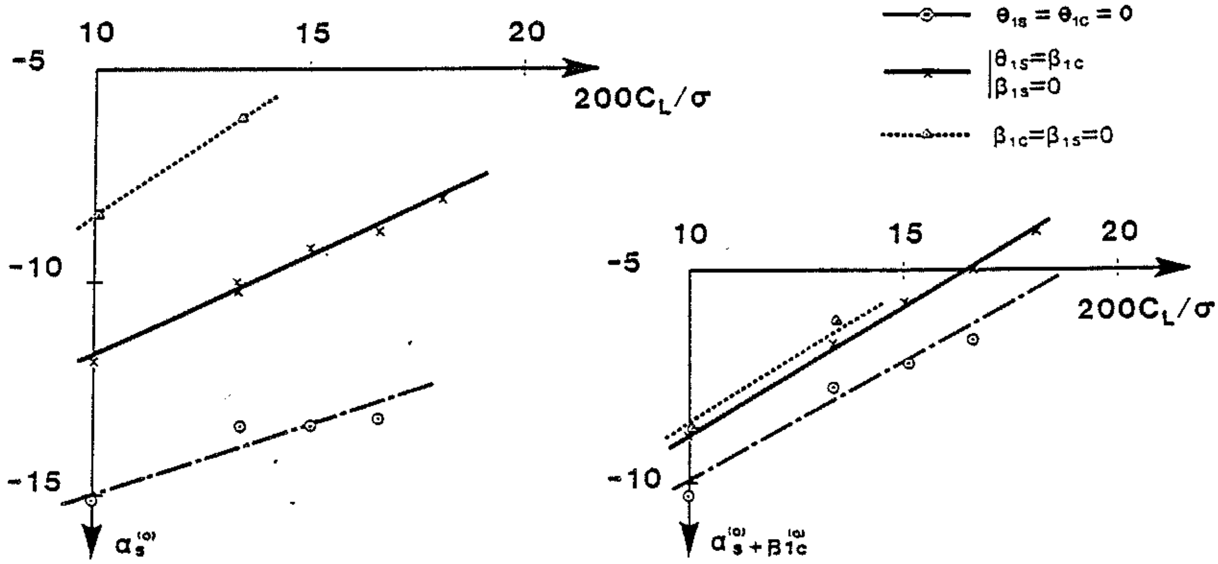

Fig.6 - INFLUENCE OF THE CONTROL LAW ON THE LOADS

Rectangular blade

MΩR=0.61 (CdS)f/Sσ=0.1 CL/σ=0.075

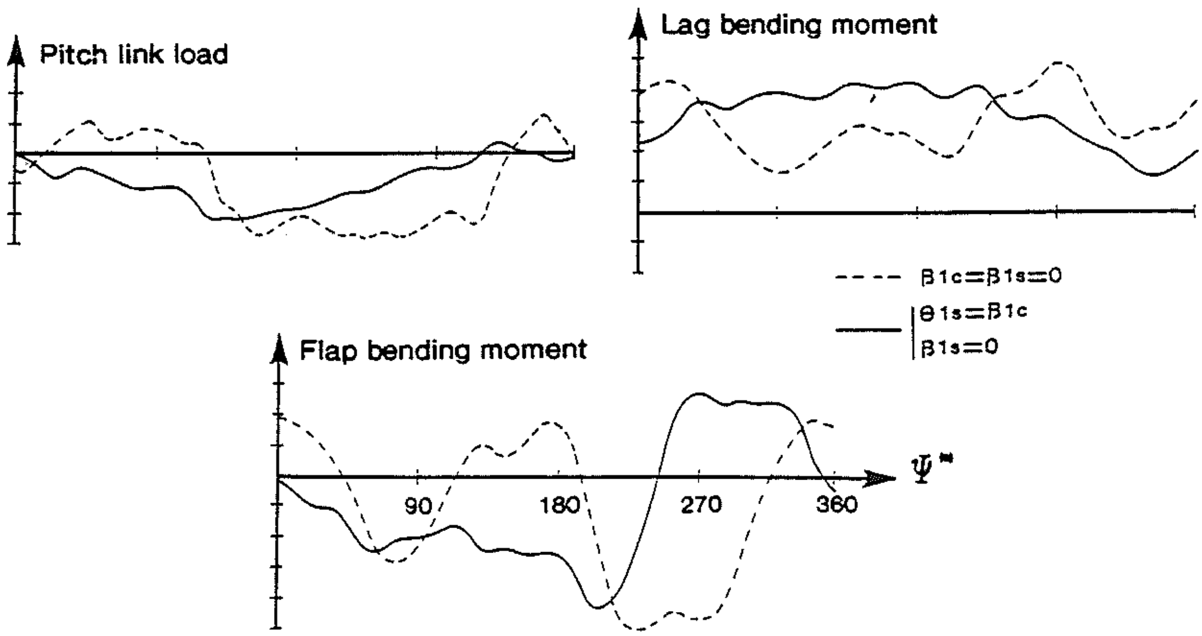

Fig.7 - INFLUENCE OF THE CONTROL LAW ON THE LOADS

Rectangular blade

$M_{\Omega R} = 0.61$ $(CdS)f/S\sigma = 0.1$ $C_L/\sigma = 0.0665$

Peak to peak amplitude

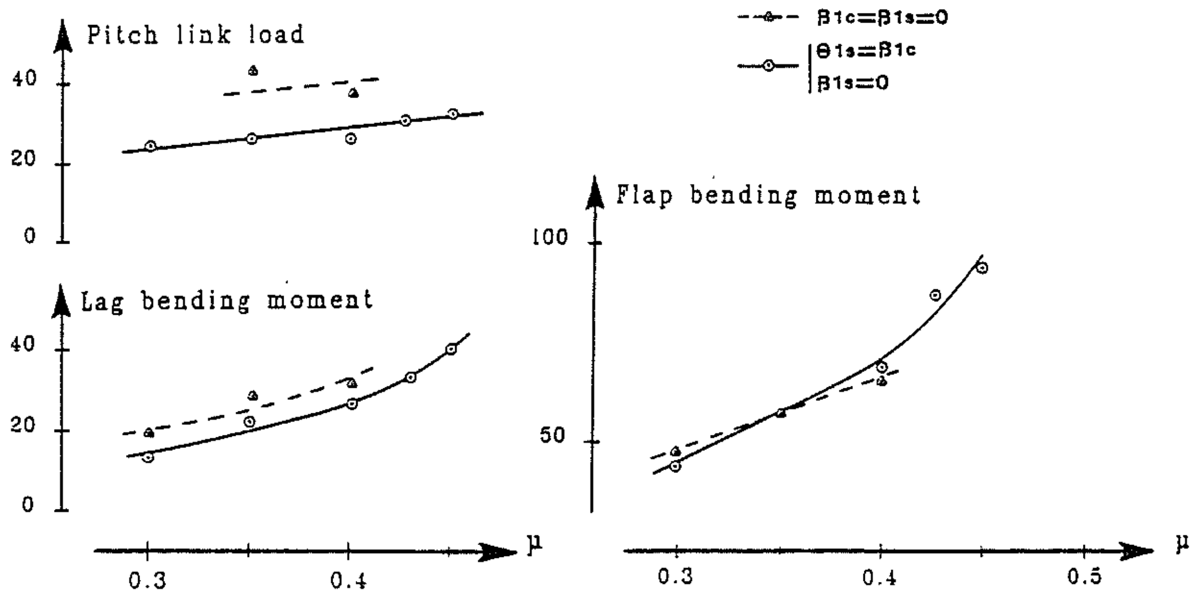

Fig.8 - INFLUENCE OF THE CONTROL LAW ON THE LOADS

Rectangular blade

$M_{\Omega R} = 0.61$ $(CdS)f/S\sigma = 0.1$ $\mu = 0.4$

Peak to peak amplitude

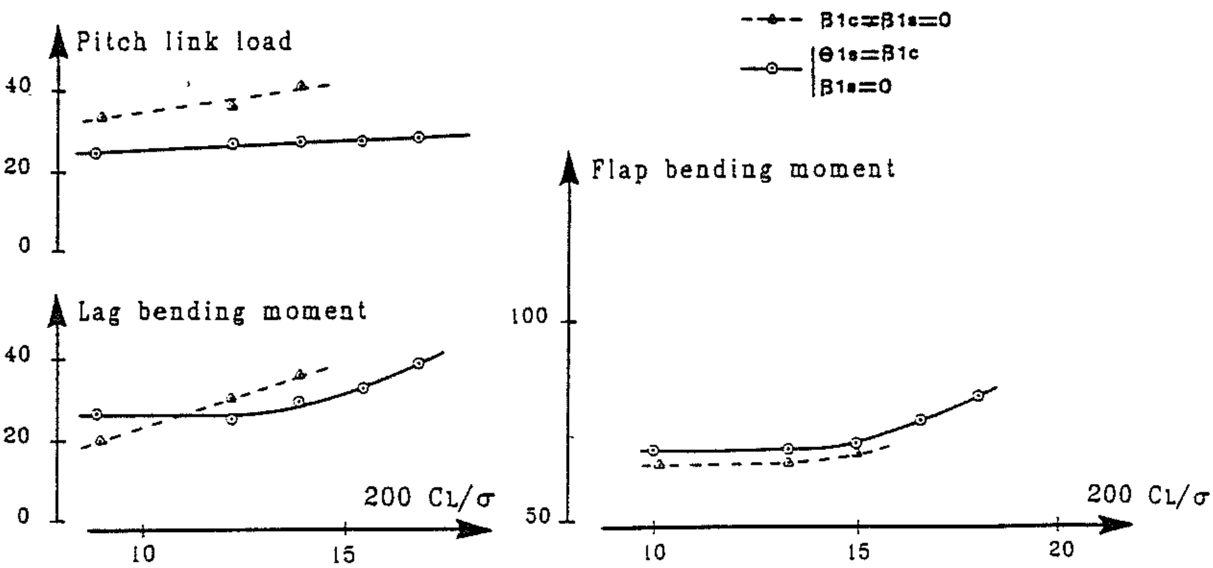

Fig.9 - PF1 BLADE TIP PLANFORM

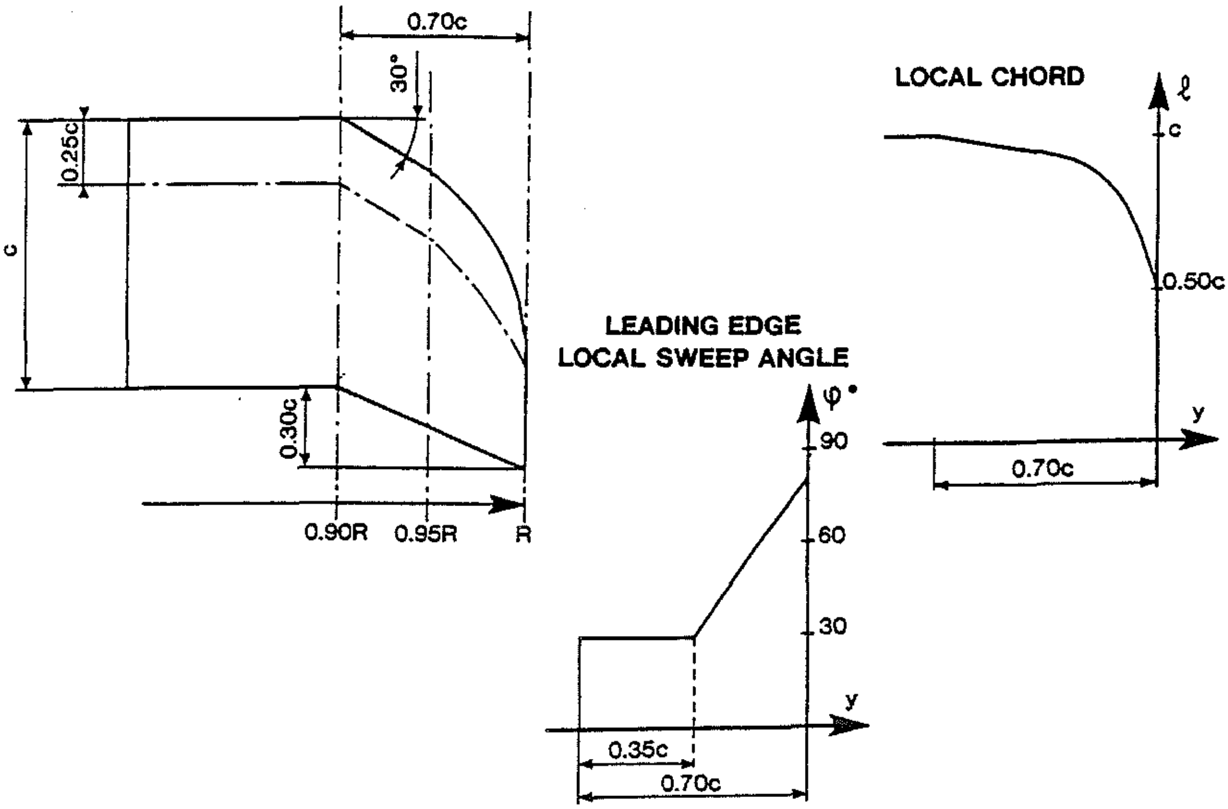

Fig.10 - INFLUENCE OF THE CONTROL LAW ON THE BLADE TIP SHAPE EFFECT

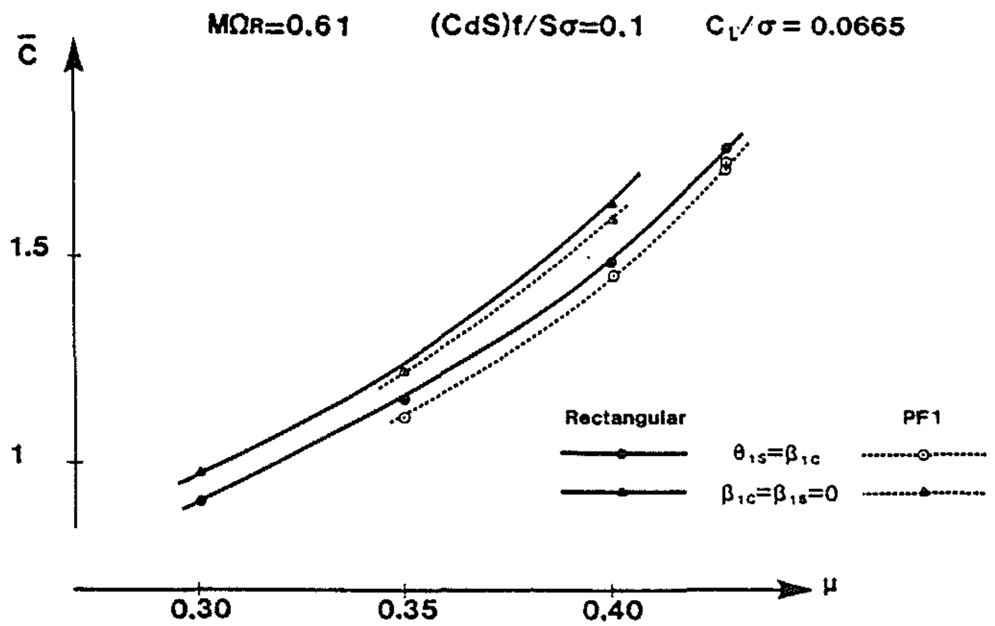

Fig. 11 – INFLUENCE OF THE CONTROL LAW ON THE BLADE TIP SHAPE EFFECT

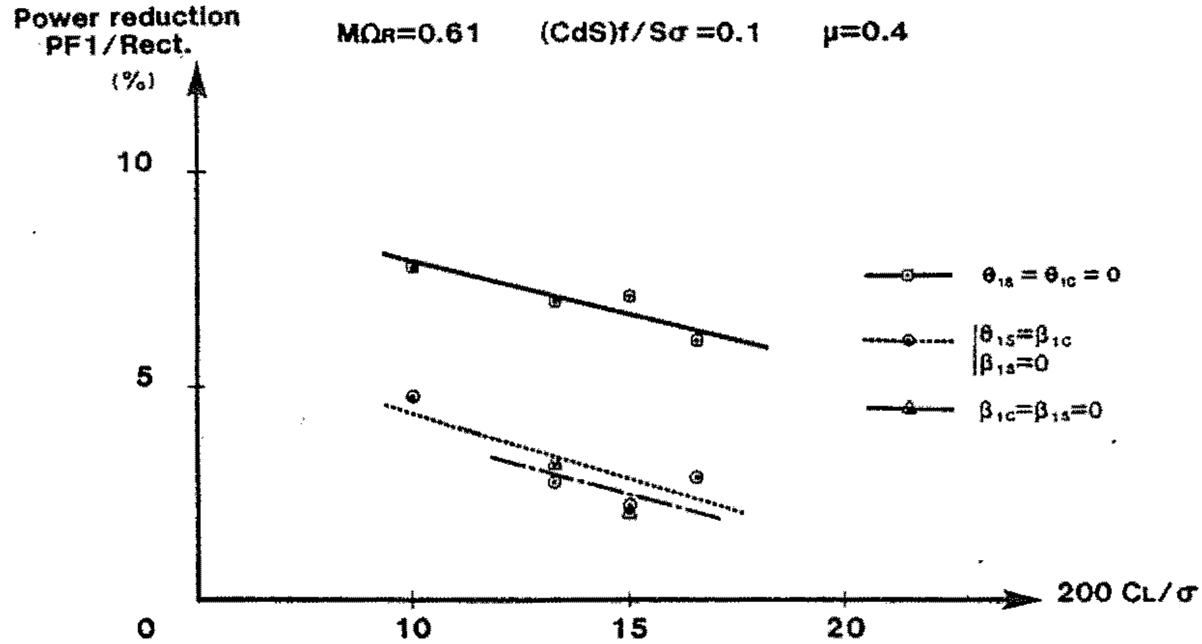

Fig. 12 – INFLUENCE OF THE CONTROL LAW ON THE LOCAL FLOW

PF1 blade Upper surface (CdS)f/Sσ =0.1 MΩR=0.61

r/R=0.85 C_L/σ =0.0665 μ=0.4

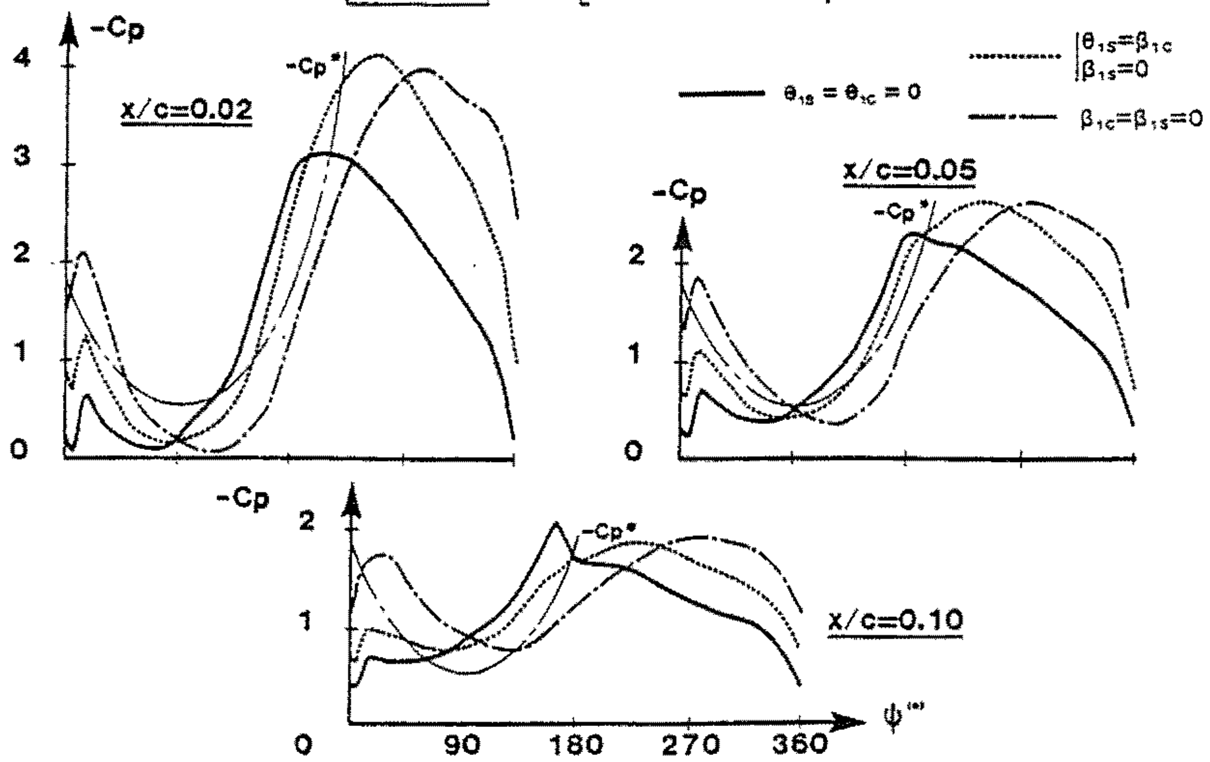

Fig.13 - INFLUENCE OF THE CONTROL LAW ON THE LOCAL FLOW

PF1 blade Upper surface MΩR=0.61 (CdS)f/Sσ=0.1

r/R=0.85 $C_L/\sigma=0.0665$ $\mu=0.4$

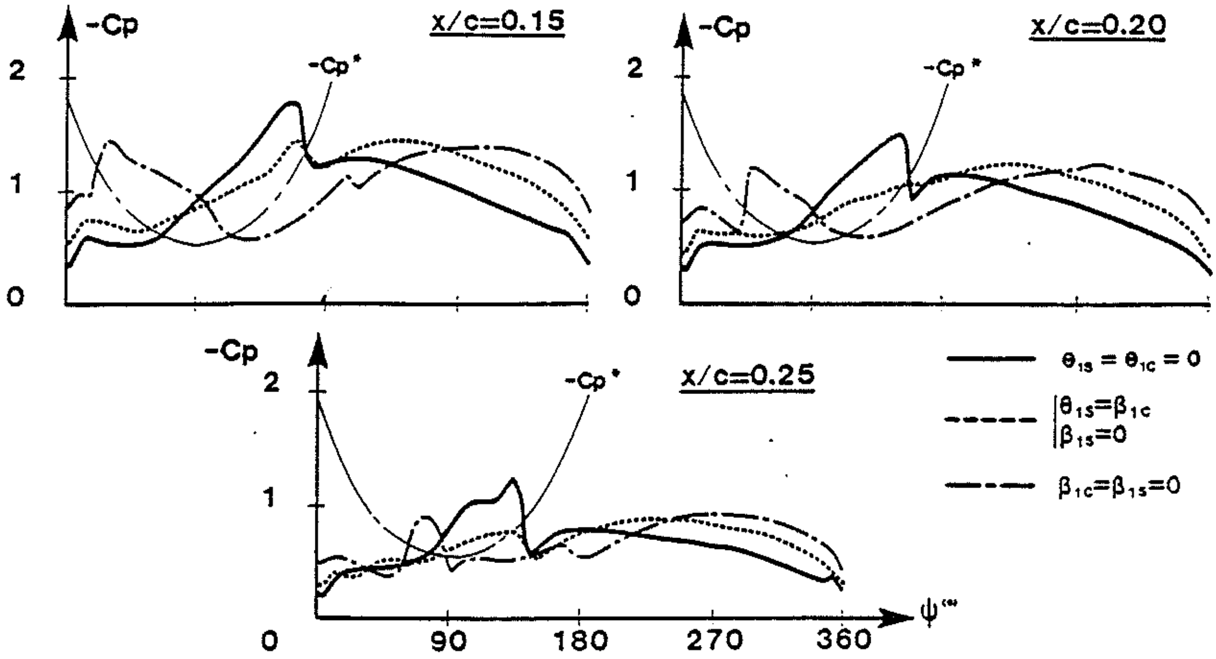

Fig.14 - INFLUENCE OF THE CONTROL LAW

PF1 blade Upper surface MΩR=0.61 (CdS)f/Sσ=0.1

r/R=0.85 $C_L/\sigma=0.0665$ $\mu=0.4$

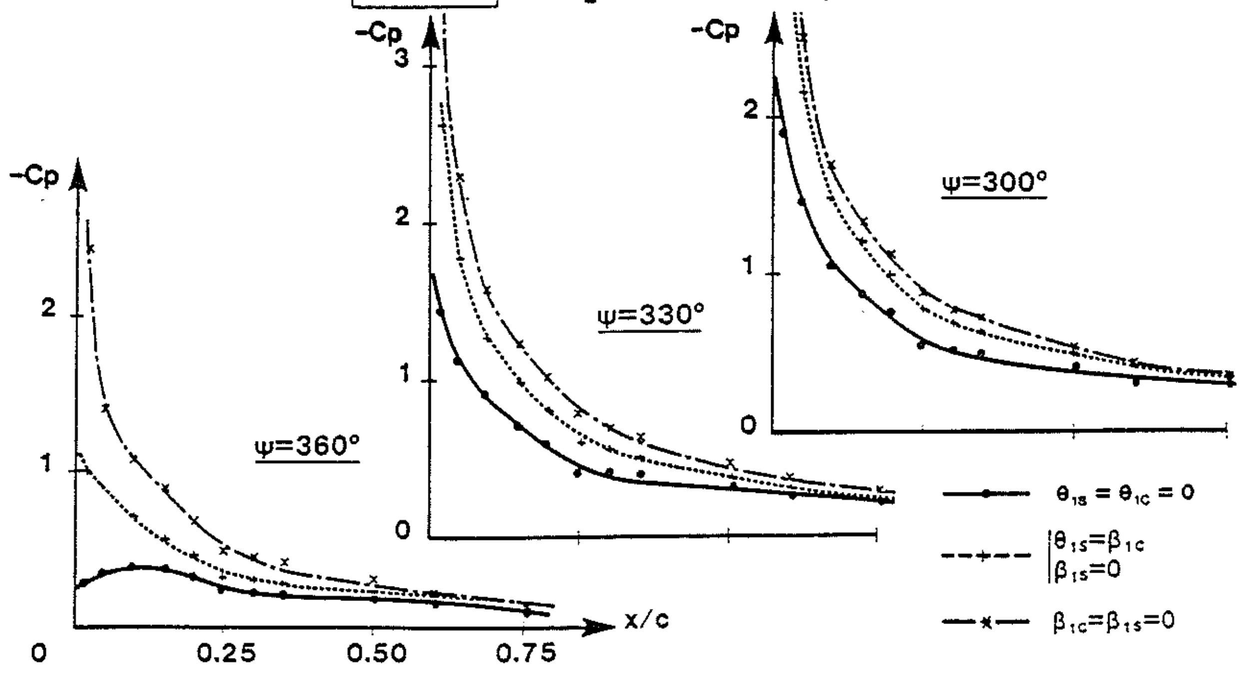

Fig.15 - INFLUENCE OF THE CONTROL LAW ON THE NORMAL FORCE COEFFICIENT

MΩR=0.61 (CdS)f/Sσ=0.1 C_L/σ=0.075

PF1 blade μ=0.4

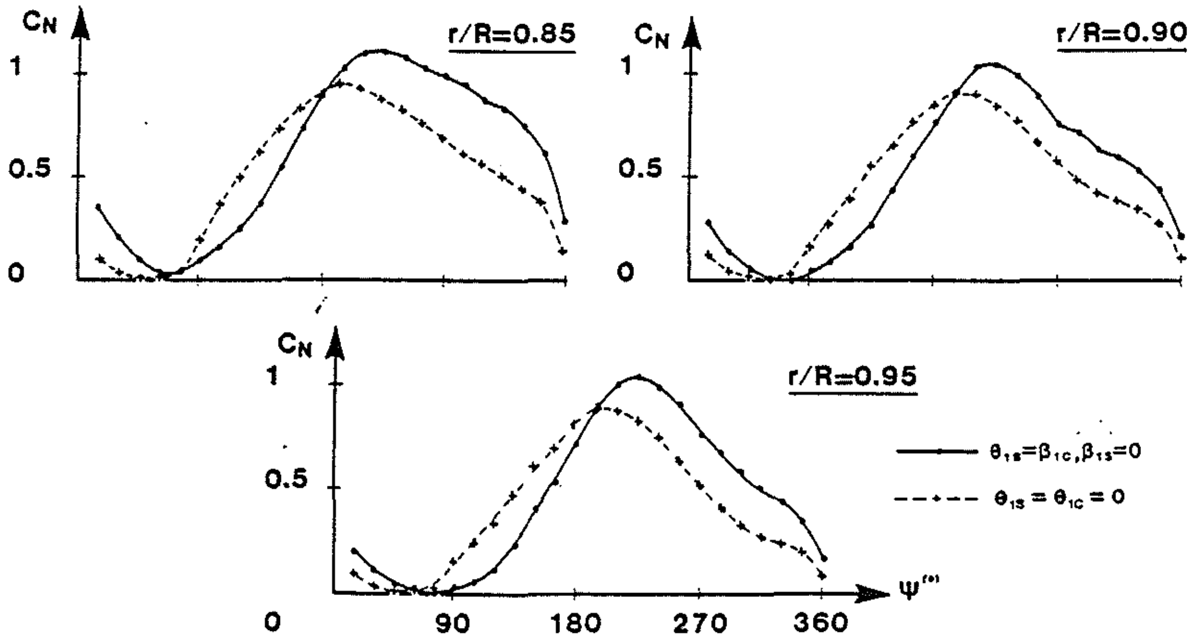

Fig.16 - INFLUENCE OF THE CONTROL LAW ON THE PERFORMANCE

Rotor 7AD1

MΩR=0.646 (CdS)f/Sσ=0.1

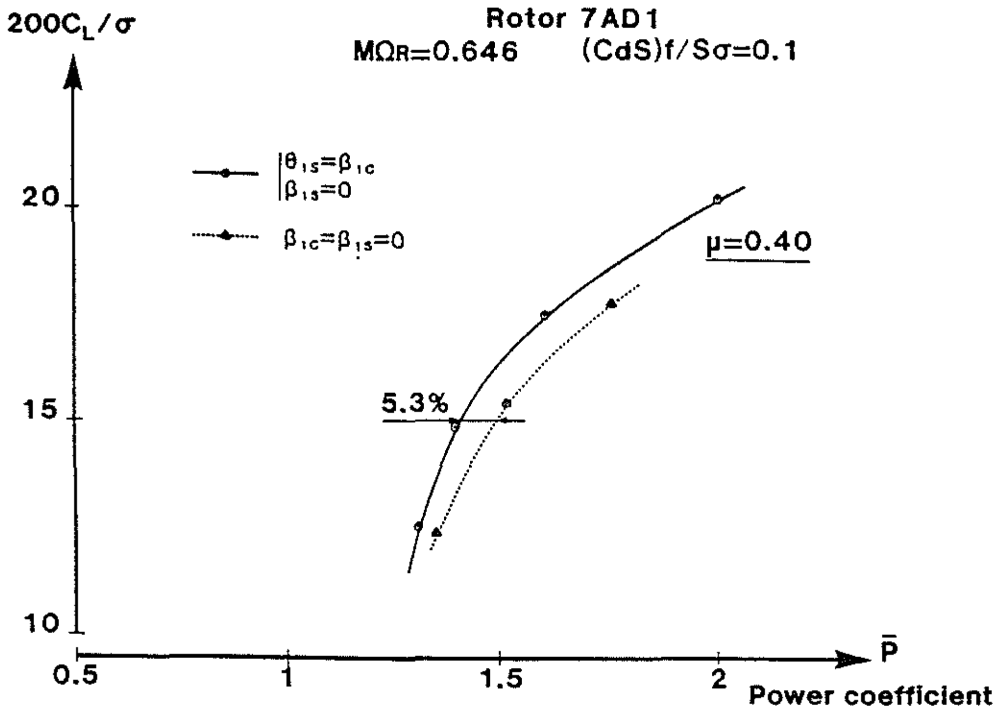

Fig.17 – COMPUTED INFLUENCE OF THE CONTROL LAW ON THE PERFORMANCE