Study of soft-in-torsion blades : ROSOH operation

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Summary

This paper presents the ROSOH operation (SOft ROtor for Helicopters). Experimental results in the ONERA S2CH wind tunnel on a soft and a rigid rotor are analyzed. The influence of tab deflection, advance ratio and lift coefficient on global performance (torque) and local coefficients (torsional deformations ...) is studied more specifically. Some computations made with the Eurocopter code R85/METAR are compared with experiment : they show good correlations. Measurements on a flexible rotor with swept PF1 blades should be of high interest to complete the database obtained herein.

1 INTRODUCTION

Notations

b .... number of blades

c .... mean chord

R .... rotor radius

$S=\pi R^2$ .... surface of rotor disk

V_∞ .... freestream velocity

Ω .... rotational speed

M .... local Mach number

p .... local pressure

ρ .... local density

F_x .... global drag

F_z .... global lift

ψ .... blade azimuth

r/R ..... radial position

x/c ..... chordwise position

θ_0 ...... collective pitch

θ_{1s} .... lateral cyclic pitch

β_0 ...... collective flapping angle

β_{ic}, β_{is}. cyclics of flapping angle

Q .... global torque

δ .... tabs deflection

Cz ...... airfoil lift coefficient

Cm .. airfoil moment coefficient

$K_p=(p-p_\infty)/(1/2\rho V_\infty^2)$ .... local pressure coefficient

$\sigma=bcR/(\pi R^2)$ .... rotor solidity

$\mu=V_\infty/(\Omega R)$ .... advance ratio

$\bar{Z}=200C_T/\sigma=100F_z/(1/2\rho S\sigma(\Omega R)^2)$... global lift coefficient

$\bar{C}=200C_Q/\sigma=100Q/(1/2\rho S\sigma R(\Omega R)^2)$. global torque coefficient

The blades used on real helicopters have been assumed to be very rigid for quite a long time. The main reason for this is that metallic materials used to build the blades had high elastic moduli.

The systematic use of composite materials by helicopter manufacturers has changed this point of view. Composite materials can have much smaller elastic moduli. Furthermore, the way blades are made (succession of plies oriented in

different directions) can create couplings between the different degrees of freedom of the blades (torsion–flapping or torsion–extension coupling for example).Ref [1]. It means that the torsional response of the blade can be amplified. The consequence is a modification of local incidences depending on the azimuthal and radial position of the section considered. If the incidences change, the total power needed to ensure a given lift at a given speed may also change : but the question is to know whether this change will be beneficial.

This was approximatively the context in which ROSOH (SOft ROtor for Helicopters) started on some years ago. The French Aerospace Research Center (ONERA) and the French manufacturer AEROSPATIALE (now Eurocopter France) are associated in this operation with the financial support of DRET and STPA.

The possible interests of this study could be a power reduction by the use of soft blades, a reduction of the vibrations (Ref [2]) or even a noise reduction by decreasing BVI using elastic couplings. Furthermore, in the field of optimization, the blade flexibility is an important parameter (Ref [3]). Prior to this, it is necessary to ensure that the codes used can reproduce correctly the experimental trends : the main goal of ROSOH is to create a database for the validation of torsion computations.

2 EXPERIMENTAL PART

2.1 Description of wind tunnel tests

In order to study the blade flexibility, it was first decided to build two sets of blades : "rigid" blades and "soft-in-torsion" blades having the same geometric characteristics. But this was not sufficient to model very different torsional behaviours ; one way to achieve this is to add small "tabs" sticked at the blades trailing edge in order to simulate nose–up (or nose–down) aerodynamic pitching moments (just by deflecting the tabs at different angles). Moreover, being aware of the importance of the phenomenas occuring at the tip, it seemed important to think of a database with blades having complex shapes (swept tips). Finally, it was decided to use a rotor with a low aspect ratio in order to amplify the possible elastic couplings.

Considering all these aspects, three sets of blades were built : rigid PF1 blades (reference blades), soft rectangular blades and soft PF1 blades. Removable tips (rectangular or PF1 : fig. 1) are assembled on the same current part. The main features of rotors are summarized in fig.2.

Blade instrumentation

The rigid PF1 rotor (reference rotor) was not instrumented : only global parameters (performance) used to trim the rotor will be measured. The soft blades (PF1 and rectangular) were instrumented with :

– 72 unsteady pressure transducers distributed in 4 different sections located at 50%, 75%, 85% and 95 % of the rotor radius ; these transducers measure local pressure coefficients Kp,

– 30 strain gauges regularly distributed along the blades ; they are used to measure elastic deformations using the SPA (*Strain Pattern Analysis*) method developped by the Structures Department at ONERA. Ref. [4]

S2CH wind tunnel

Measurements are made in the S2 CHalais wind tunnel of ONERA. The diameter of the test section is 3 m. The rotor is hung upside down so that the rotor disk is at a distance of 1.25 m from the floor. The rotor is rotated by a hydraulic engine. The axis of the rotor can move continuously during the tests (variation of shaft angle α_q). The test section is protected by removable panels which are removed for hover configurations.

Flight domain

The main configurations studied are the following :

$\mu = 0$, 0.30 , 0.35 , 0.40

$C_T/\sigma =$ 0.050 , 0.075 , 0.090 ($\bar{Z} = 10$, 15 , 18)

$\delta =$ 0, +6 , +12 degrees

The rotor is trimmed according to the "Modane law" which consists of the following relations : $\beta_{1s} = 0$ and $\beta_{1c} = \theta_{1s}$ ($\beta>0$ for the blade up).

The tabs are generally deflected up to 90% of the radius. For rectangular blades, some points at μ=0.4 were tested with the tabs deflected all along the blades. The positive values of δ are chosen to create nose-up pitching moments. A value of –6° for δ was tested only for the rigid PF1 rotor.

The ROSOH operation is still under way and results relative to the soft PF1 blades are not yet available. For this reason only the two first rotors will be studied in the paper.

2.2 Study of experimental results

The aim of this part is to analyse the results obtained in S2CH wind tunnel. It will be achieved by the study of the influence of the deflection of tabs δ, the advance ratio μ and the lift coefficient C_T/σ on global and local parameters.

2.2.1 Influence of tabs

The influence of tab deflection on $\bar{C}$ coefficient is quite clear on the two rotors : the global power is increased (fig. 3), especially for the soft rotor. This effect is particularly important for high values of lift coefficient where the torque increase between the tabs deflected at 0 and 12 degrees can reach 26 % for μ=0.35 and C_T/σ=0.09 (tab. 1)

μ=0.35	rigid blades	soft blades
CT/σ=0.050	0 %	7 %
CT/σ=0.075	13 %	22 %
CT/σ=0.090	18 %	26 %

Tab. 1 Increase of power between δ=0° and δ=12° for different C_T/σ

The torque increment when the tabs are deflected is also more important when the advance ratio increases (mostly from μ=0.3 to μ=0.35).

It is interesting to compare the evolution of $\overline{C}$ for the tabs deflected to 90% and all along the blades : there is a torque increase by more than 11 % for C_T/σ=0.075 and δ=12°, which emphasises the importance of blade tip effects (high Mach numbers).

In order to understand better the reasons why the deflection of tabs is detrimental to rotor performance, the aerodynamic local coefficients of the soft rotor will now be studied.

Fig. 4 shows the −Kp coefficient versus the chord at azimuth 120°. It is clear that there is a decrease of lift at the trailing edge when the tabs are deflected : on the upper surface, the velocity decreases, the pressure increases and −Kp decreases ; on the lower surface, it is the opposite : −Kp increases. At 95 %, there is no important difference at the trailing edge between the two tab deflections because the tabs are deflected up to 90 %. The closer a leading edge is to the blade tip, the greater the effect of tab deflection on this leading edge.

The trends described above logically create an important nose−up pitching aerodynamic moment (before 90 %) illustrated in fig. 5. There is also a large difference in the loads distribution when the tabs are deflected : the lift becomes higher at the tip and, by compensation, lower closer to the axis of the rotor. Moreover, airfoil tables for the tabs deflected provide higher drag coefficient.

As expected, the torsional response of the blade changes substancially : the amplitude of deformations increases (fig. 6 : 5 degrees for δ=12°). There are large positive deformations on the advancing side.

2.2.2 Influence of advance ratio

In this part, the influence of μ on the blade response is analyzed. The lift coefficient is supposed to be constant and no tab deflection is applied.

When μ increases, the lift on the advancing blade becomes smaller in order to avoid having too high loads at the tip (fig. 7). Conversely, this creates an important lift increase at the front side of the rotor (ψ=180°) in order to ensure the same global C_T/σ.

Consequently, the amplitudes of torsional deformations become larger (tab. 2). The most important effects appear after 90° : the torsional angles become more and more negative (nose−down deformations), as illustrated by fig. 8. The effects are also important near 300°.

μ	0.30	0.35	0.40
$\Delta\theta_{torsion}$ at tip	1.5°	1.8°	2.7°

Tab. 2 Amplitudes of torsional deformations at tip (soft blade) C_T/σ=0.075

2.2.3 Influence of lift coefficient C_T/σ

As could be expected, the increase of C_T/σ creates an increase in the surface between −Kp on the upper surface and −Kp on the lower surface curves for any radial or azimuthal position (fig. 9) : the CzM^2 coefficient becomes higher to ensure the right global lift.

But there is no significant effect on the torsional response of the blade for $\delta=0°$. For higher values of δ, the effect of C_T/σ is just a little more important.

2.2.4 Comparisons between soft and rigid blades

Presently, it is possible to compare globally the rectangular soft blades and the PF1 rigid blades.

When no deflection δ is applied, rigid blades give better performance for hover conditions but soft blades give better performance for advancing flight configurations (fig. 10).

For $\delta=12°$, the rigid rotor provides the best performance under all configurations.

This means that deflecting the tabs tends to excite the torsion modes and it is not beneficial for a soft rotor whose incidences on the rotor disk increase too much. The value $\delta=12°$ is probably too high.

3 COMPUTATIONAL PART

3.1 Description of the codes used

The curves presented in this part are the results of computations made with a performance code R85 coupled with an aerodynamic wake code METAR, both developed by Eurocopter France. Ref [5]. These codes have been modified at ONERA and the results shown here are those obtained with the ONERA version of the codes.

The performance code trims the rotor, computes its dynamic (quasi−steady) response and elastic deformations in torsion, flap and lag. Lagrange's equations (1) are used :

$$\frac{d}{dt}\frac{\partial T}{\partial qi} - \frac{\partial T}{\partial qi} + \frac{\partial U}{\partial qi} = Qi \qquad (1)$$

where T is the kinetic energy, U the elastic energy, qi the generalized coordinates and Qi the generalized loads terms.

The elastic energy U is directly written as a function of the unknown deformations using a linear beam model. The unknowns are written as a linear combination of eigenmodes computed in the rotating frame.

The aerodynamic model is based on 2D airfoil tables (lifting line method) and METAR simulates a vortex wake with a prescribed geometry.

3.2 Results on soft blades

The torque coefficient $\overline{C}$ is fairly well predicted for the deflection $\delta=0°$ (fig. 11) ; for $\delta=12°$ the prediction is less accurate but is still acceptable.

The computation of CzM^2 is also good (fig. 12) from r/R=50 to 85 %. At 95 %, experiment shows positive CzM^2, which is unusual on the advancing blade, whereas computations show slightly negative lift.

The evolution of torsional angle when the tabs are deflected is presented in fig. 13 : the same trends were observed in experiment in Fig. 6 (positive deformations on the advancing side). The computation tends to have a static torsional deformation lower than that obtained with the SPA method : further work is needed to explain this difference .

The evolution of CzM^2 when μ increases is also very close to experiment.

4 CONCLUSION

From the experimental point of view, the ROSOH database is very interesting to study the torsional behaviour of rotor blades. The following conclusions can be drawn :

– deflecting the tabs bas an important effect on torsion but is detrimental to performance (increase of incidences), particularly for the soft rotor,

– the amplitude of torsional response of the blade is significantly affected by an increase of μ,

– the increase of C_T/σ has little influence on torsion.

Pressure and elastic measurements on a rotor with soft PF1 blades will be of high interest to complete this study. At the present time, the soft rectangular rotor has greater performance only for the deflection $\delta=0°$.

Computations made with R85/METAR show good agreement with experiment : the trends are well predicted by the code.

Finally, it should be interesting to use a CFD code (a full potential code for example) in order to analyze in greater detail the flowfield, to validate the pressure computation and improve the model (3D Cm for example).

References

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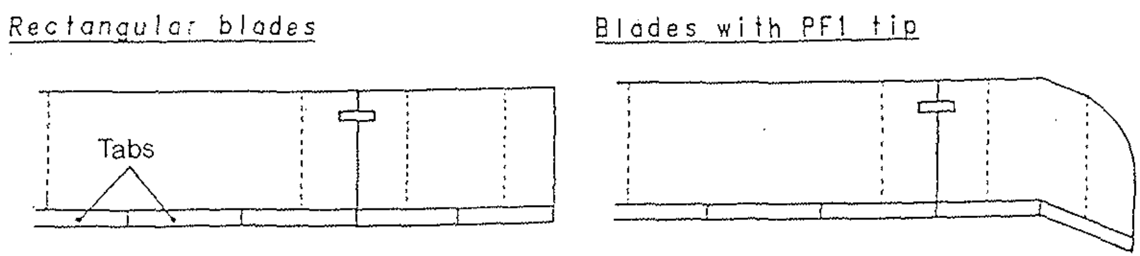

Fig.1: BLADES FOR ROSOH OPERATION

Fully articulated rotor	
Rotor radius	0.857 m
Number of blades	3
Mean chord	0.123 m
Solidity	0.137
Rotational speed	2247 rpm
Mach at tip	0.610
Airfoil	OA209 + tabs
Geometric twist	-14.1 °/m

Fig.2: MAIN FEATURES OF ROSOH BLADES

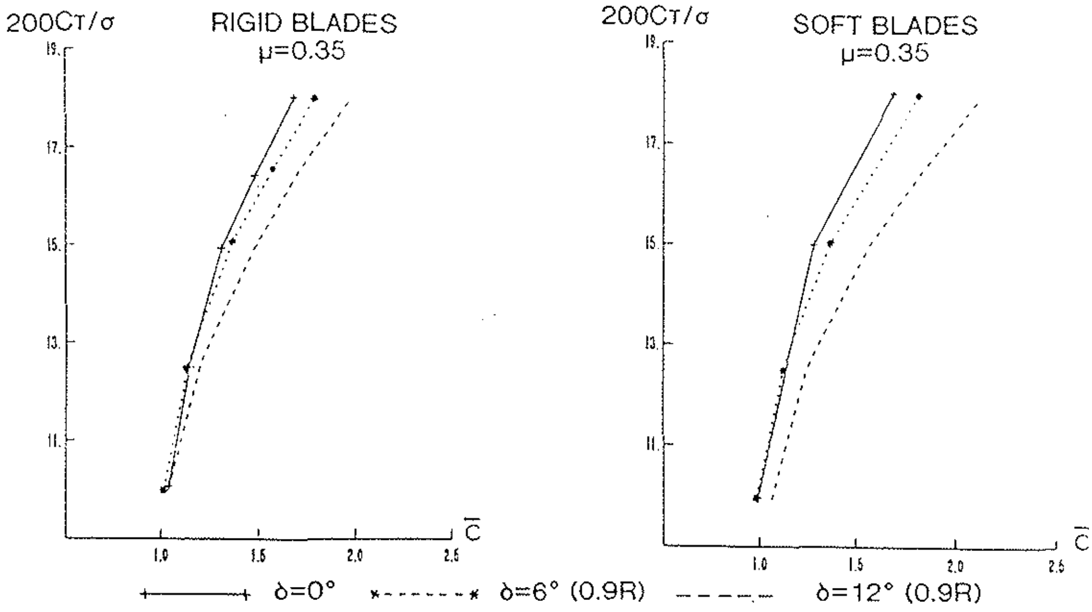

Fig.3: INFLUENCE OF BRACKING OF TABS ON TORQUE COEFFICIENT

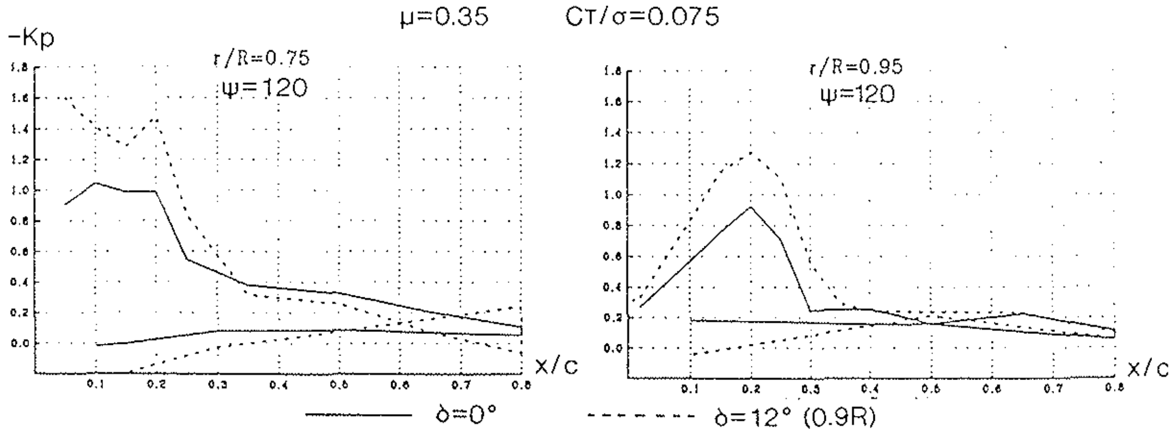

Fig.4: INFLUENCE OF BRACKING OF TABS δ ON LOCAL PRESSURE

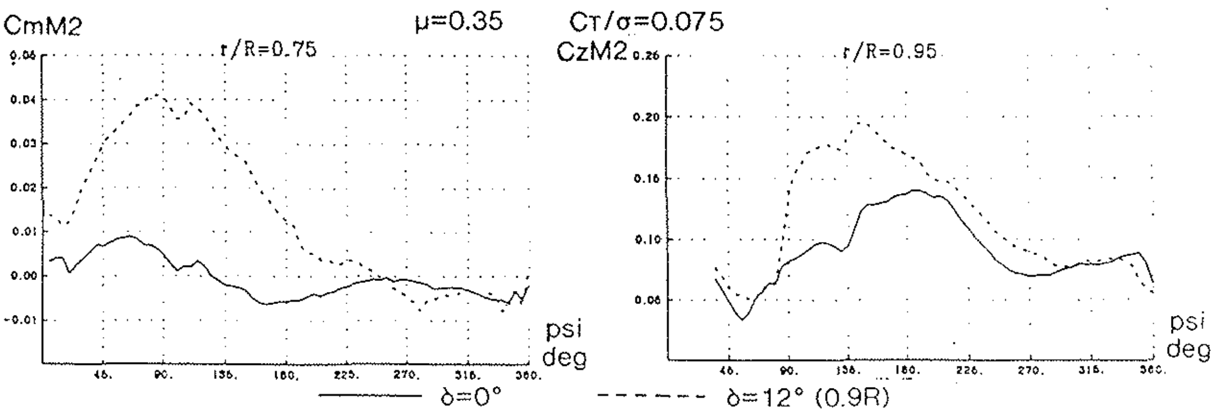

Fig.5: INFLUENCE OF BRACKING OF TABS δ ON CmM2 AND CzM2

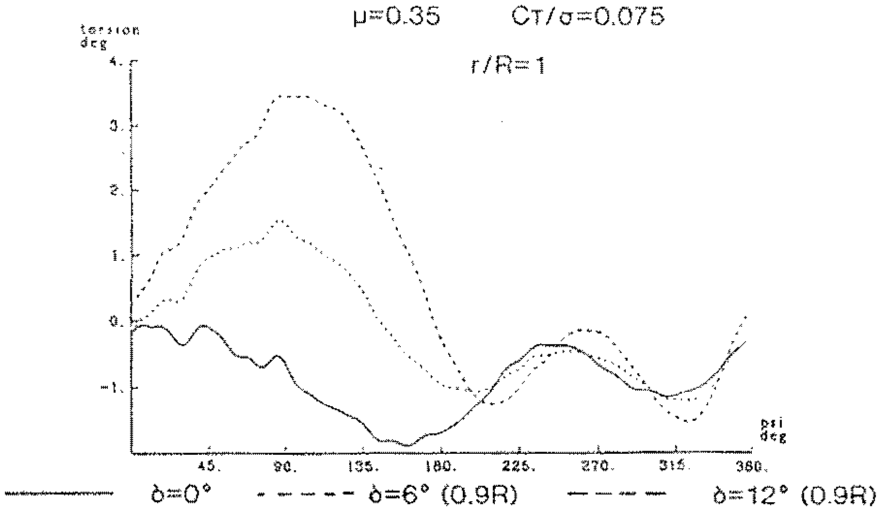

Fig.6: INFLUENCE OF BRACKING OF TABS δ ON TORSIONAL DEFORMATION

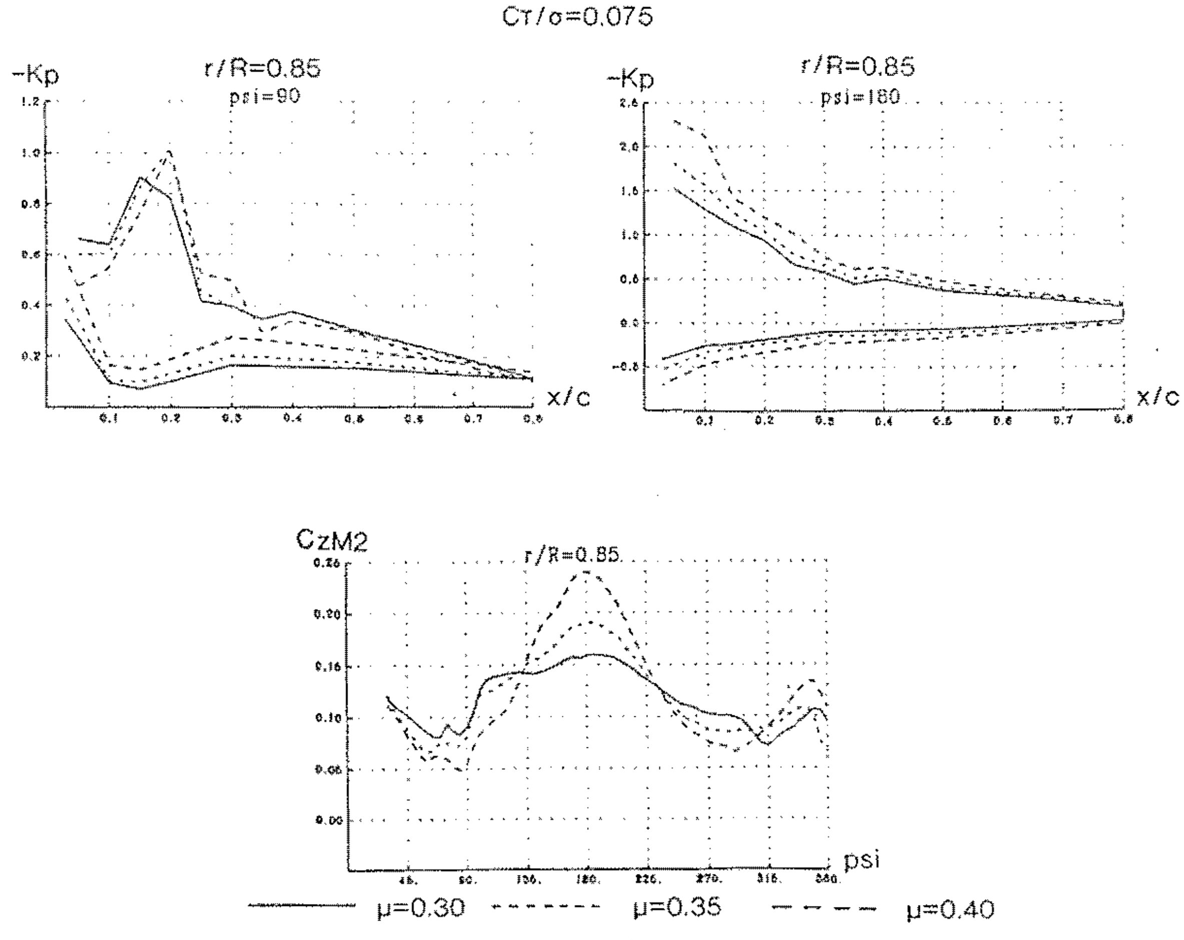

Fig.7: INFLUENCE OF ADVANCE RATIO μ ON Kp AND CzM2

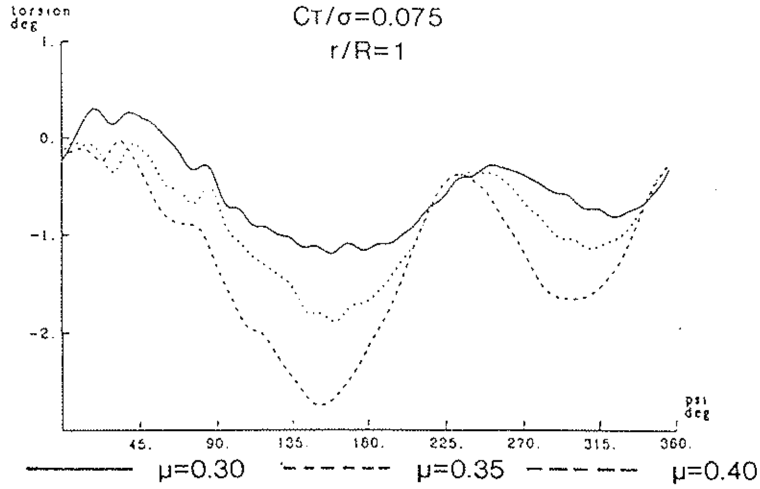

Fig.8: INFLUENCE OF ADVANCE RATIO μ ON TORSIONAL DEFORMATION

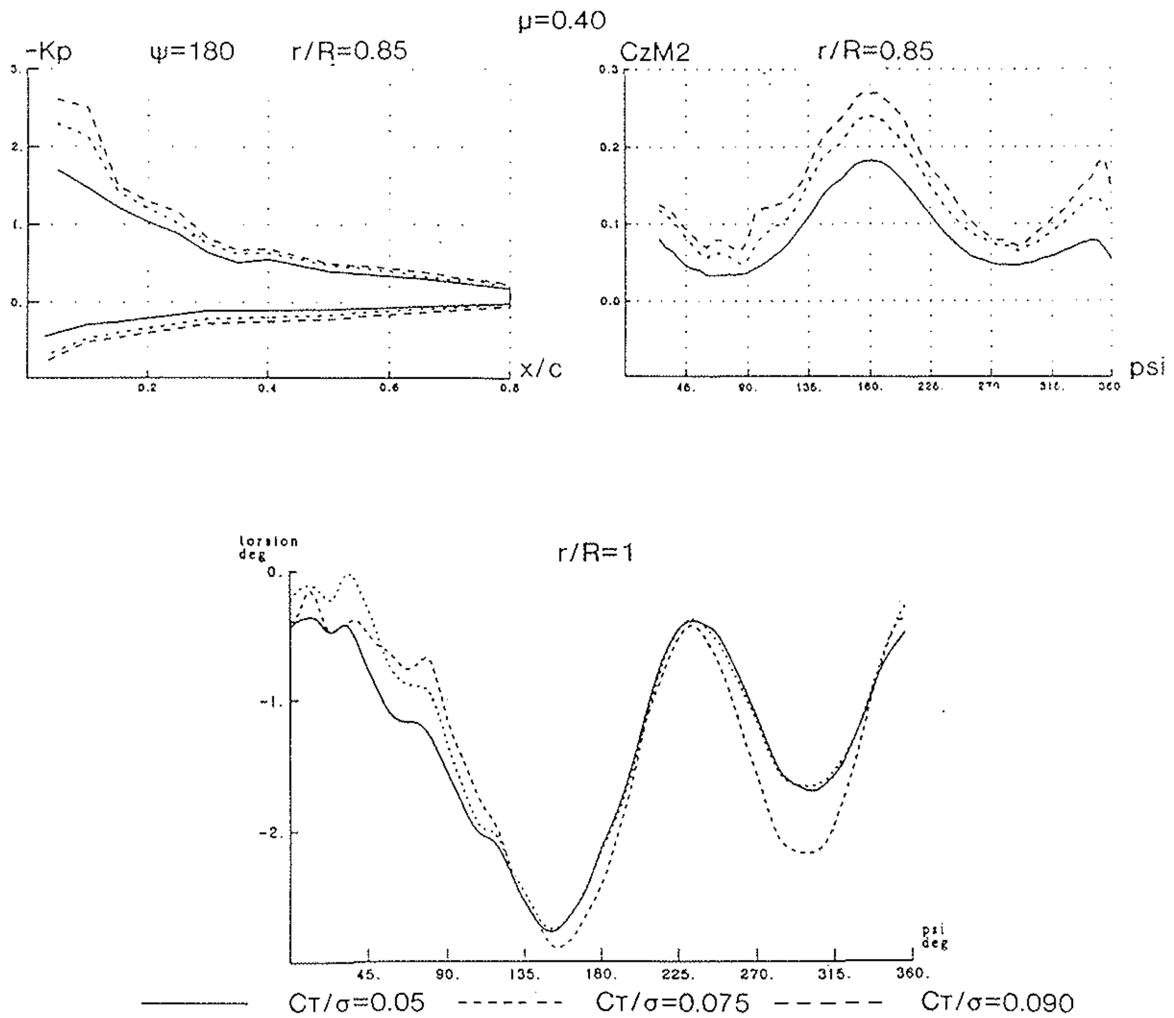

Fig.9: INFLUENCE OF LIFT COEFFICIENT ON Kp,CzM2 AND TORSIONAL DEFORMATION

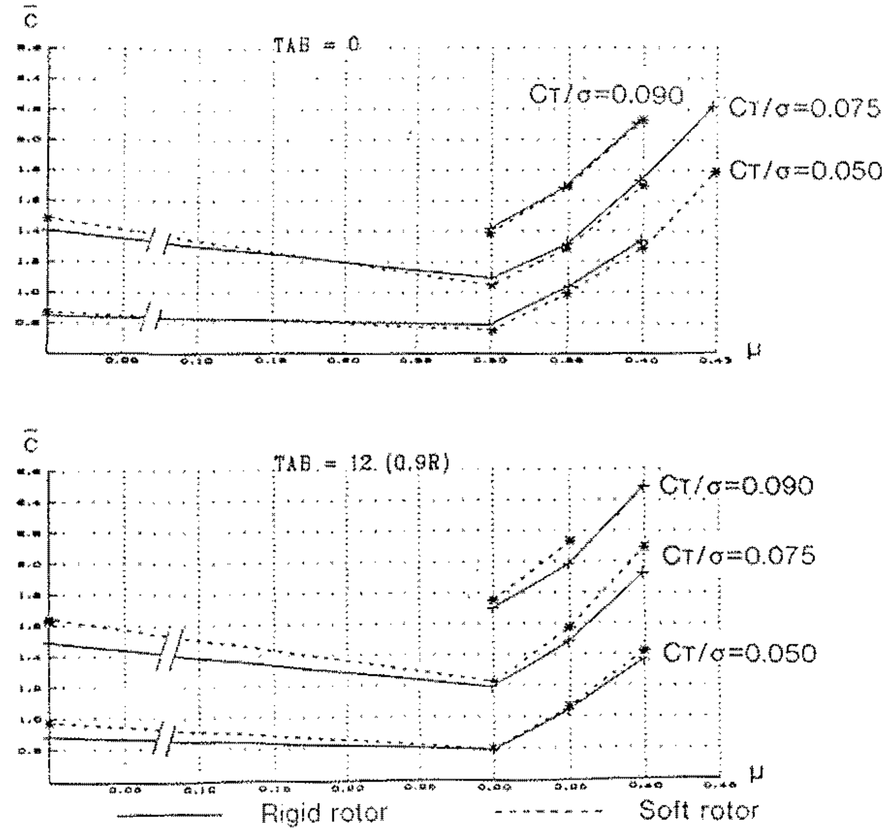

Fig.10: COMPARISON BETWEEN THE SOFT AND THE RIGID ROTOR

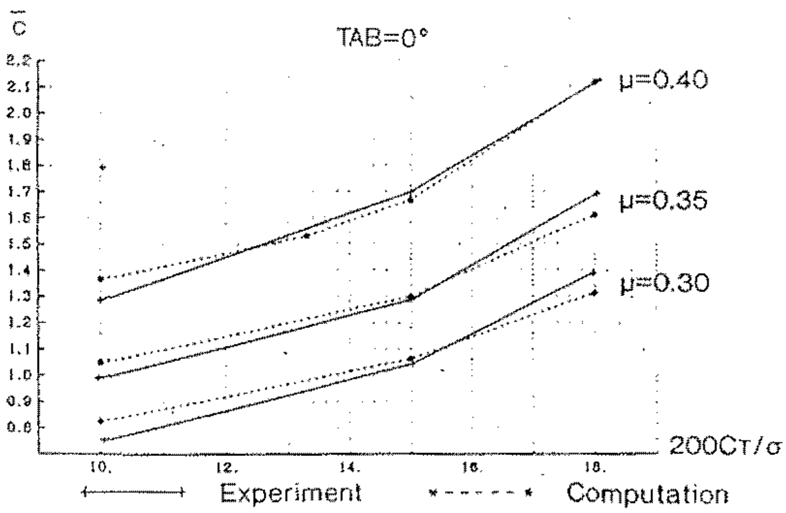

Fig.11: COMPUTATION OF TORQUE COEFFICIENT

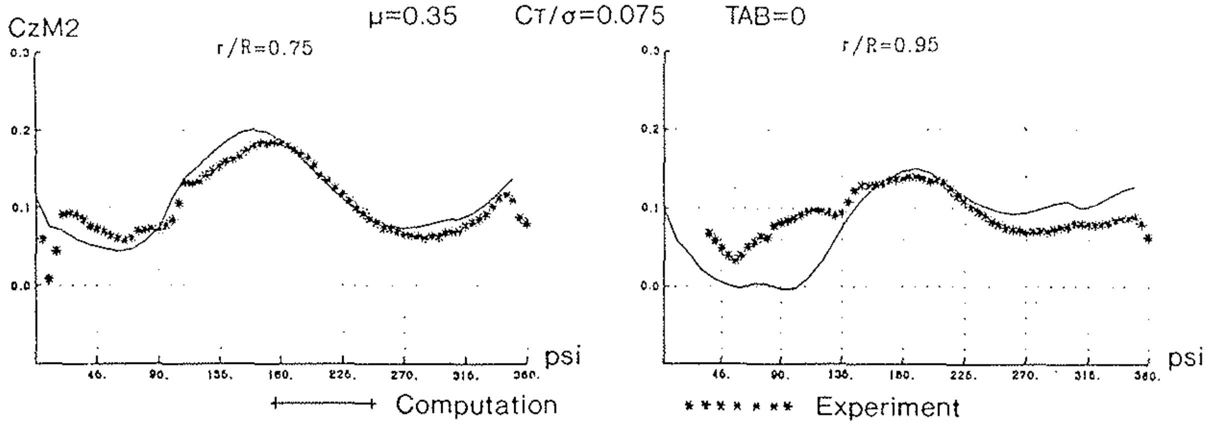

Fig.12: COMPUTATION OF LOCAL LIFT COEFFICIENT CzM2

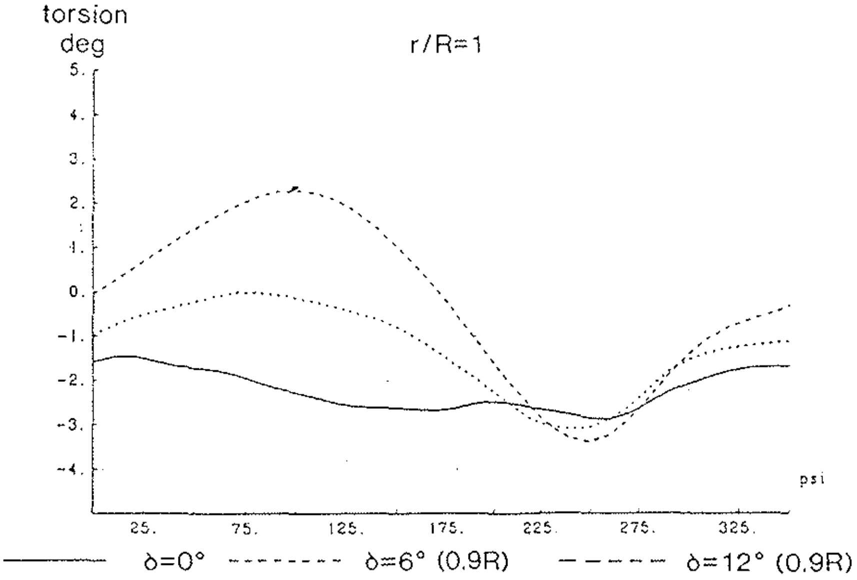

Fig.13: COMPUTATION OF TORSIONAL DEFORMATION