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VALIDATION OF R85/METAR ON THE PUMA RAE FLIGHT TESTS *

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I INTRODUCTION

Rotorcraft codes developped to predict dynamic response and loads in forward flight are more and more sophisticated, both in the fields of Dynamics and Aerodynamics. To predict loads on a rotor disk is not an easy task: for low advance ratio, the wake is very important and for high advance ratio the blade dynamic modelling becomes crucial. Aerodynamic phenomena are very complex because of unsteady effects, transonic flow on the advancing blade and dynamic stall on the retreating blade. Dynamic phenomena are also complex because of blade flexibility.

Most of computational methods used to solve this aeroelastic problem use a lifting line theory as aerodynamic model. Many efforts are also made on the wake modelling: some codes use half-vortex rings (RAE/WHL for example), other use straight vortex elements (CAMRAD, CAMRAD/JA); the wake geometry is most of the time prescribed. For the elastic model, flexibility of blades is often represented by modes which are previously calculated assuming the blade to be a straight beam, rotating or not. The modes obtained can be fully coupled in flap, lag and torsion or not.

R85/METAR code belongs to this kind of codes using a lifting line theory. In a former version, a linear inflow model was used; a more realistic model was then introduced through the coupling with the METAR code which uses straight vortex elements and a prescribed wake geometry. Rotational fully coupled modes aré computed to model flexibility. Lagrange equations are solved, the elastic energy being expressed as a function of modal curvatures. Formulae used are those of a beam undergoing flap, lag and torsion; only linear terms are kept. In the basic version, no unsteady aerodynamic correction is made and the blade is supposed to be straight (no curvature of the quarter-chord line).

II PRESENTATION OF THE PUMA RAE FLIGHT TESTS

Flight tests were performed at RAE Bedford on an Aerospatiale AS330 Puma helicopter. The rotor was equipped with four swept tip blades (fig 1). One blade was instrumented with pressure transducers on the suction side and on the lower side located at 92%, 95%, and 98% of the span. Another blade was instrumented with strain gauges to measure flatwise bending, edgewise bending and torsion moments (ref 1).

The rotor speed was approximately 254 rev/mn. Measurements were performed for five different advance ratios : $\mu=0.098$, $\mu=0.181$, $\mu=0.307$, $\mu=0.362$ and $\mu=0.402$. In the paper, only the extreme values of μ will be studied ($\mu=0.098$ and $\mu=0.402$).

All computations presented here are run until convergence on the right C_t/σ, shaft angle α_q, and first harmonic flapping angles β_{1s}, β_{1c}. The experimental values are given below.

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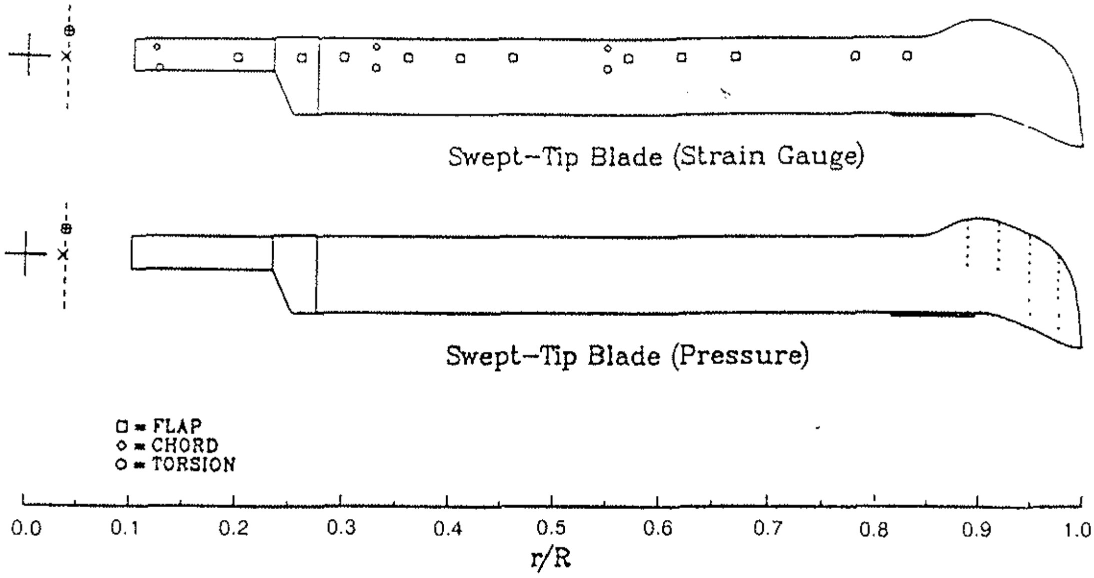

Fig 1. Puma blade instrumentation.

Case	μ	C_T/σ	αq	$\beta 1c$	$\beta 1s$
1	0.098	0.073	-1.0	0.223	0.319
2	0.402	0.070	-8.9	-0.437	-0.222

Tab. 1 Experimental values for trim

III COMPARISONS BETWEEN COMPUTATIONS AND EXPERIMENTS

3.1 Basic results

In a former version of R85, the blade is assumed to be rigid, straight and a linear inflow model (Meijer-Drees) is used to compute the induced velocities. The aerodynamic coefficients Cl, Cd, Cm are directly read into 2D airfoil tables. Then, they are corrected for Reynolds influence and non-orthogonal local aerodynamic wind, according to the azimuth and the radial position of the airfoil on the blade.

As seen in fig. 2 below, correlations on the local lift distribution (ClM2) are poor both for high advance ratio (μ= 0.402) and low advance ratio (μ= 0.098). Meijer-Drees model is a second order empirical harmonic function. Therefore, it is unable to predict higher order harmonic phenomena such as the lift on a swept tip rotor blade in forward flight. Moreover, since it is a global method, it cannot predict local interactions like blade vortex interactions.

Therefore, a step towards improvement was made by changing the induced velocities model: the METAR vortex lattice method with a prescribed wake was substituted to the linear inflow model.

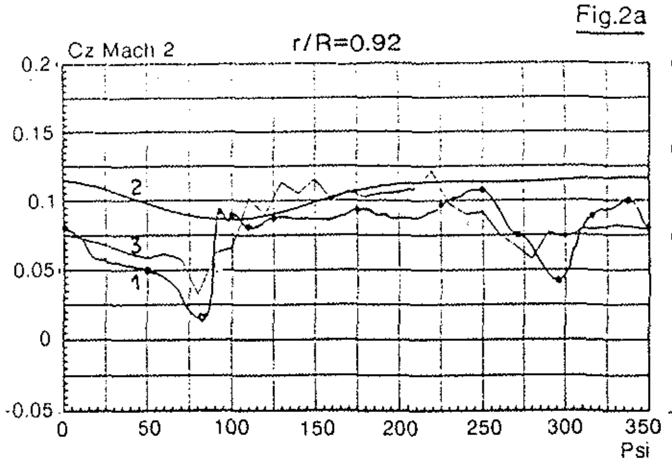
Fig.2a

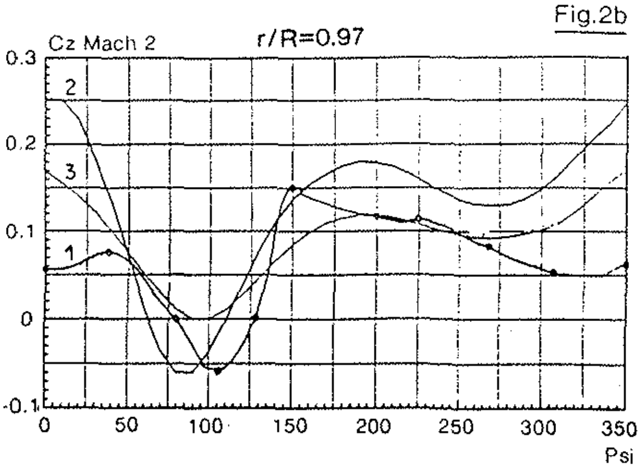
Fig.2b

1 ○——○ Experiment μ=0.098 C_T/σ=0.073

1 ○——○ Experiment μ=0.4 C_T/σ=0.07

2 ——— computation with Meijer-Drees

3 - - - - - computation with Metar

3.2 Introduction of a prescribed wake

Coupling between R85 and METAR

As seen before, linear Meijer-Drees model is not realistic to predict the lift near the tip of the blade (over estimation of the amplitude of lift at 98%). The main reason for that is that Meijer-Drees model does not take into account the vortical structure of the wake, particularly important at the tip.

This is why a coupling was achieved between R85 code and METAR code. METAR models the wake with straight vortex lines. The wake geometry is prescribed, depending on the trim of the rotor. The code uses a Biot&Savart formulation: an influence matrix is computed (taking into account the whole wake on a number of revolutions just greater than the one needed to let the tip vortex leave the rotor disk area), and the induced velocities at each point of the rotor disk is obtained by multiplying this matrix with the circulation vector (ref 2).

The trim of the rotor is given by R85. METAR computes new values of the induced velocities. A new position of trim is computed with these velocities. This is repeated until convergence on the mean value of the induced velocities between one iteration and the next one. A relaxation technique is used to prevent the process from diverging.

The scheme of this coupling for R85 rigid computations is shown in fig. 3. For soft computations, one starts with a rigid convergence as explained before. The induced velocities obtained at the end of the rigid iterations are directly used in the soft computation, without any coupling (weak coupling), for computational time reasons.

New results

Fig. 2a) and b) (§3.1) show comparisons on the CIM2 between Meijer-Drees model and METAR for μ= 0.098 at 92%R and μ= 0.402 at 97%R. If the comparisons with experiments are much better with METAR, specially at μ= 0.098 (rich in high harmonics and able to predict the "90° and 270°"blade vortex interaction), there remains a particular problem on the advancing blade: the negative peak of lift recorded on the advancing blade at 97%R during the experiments is not at all predicted by METAR for μ= 0.4, as far as amplitude and phase are concerned. Therefore, in the following, we will mainly focus on solving this problem.

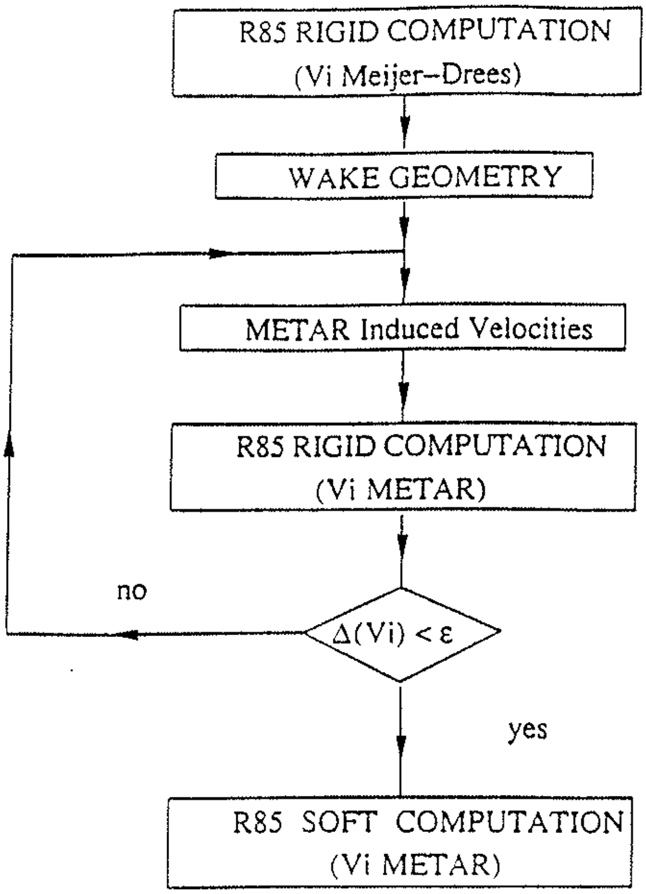

Fig. 3

3.3 Introduction of soft blade modelization

Since blades encounter strong external (aerodynamics) and internal (centrifugal forces) force fields, they can exhibit deformations which are not at all neglectable on such slender beams. It was therefore logical to introduce an elastic model in R85. The approach chosen is an energetic one, by solving Lagrange equations, expressed in function of modal curvatures (ref 3). Only a few modes are used (eight generally, including one torsion mode at least) for time computationing reasons. These modes are previously calculated for a straight blade in rotation.

New results

The introduction of elasticity in the model, and more specially torsion effects, leads to the following comparative results (Fig.4 and 5):

As seen above, the phase of the peak is now relatively correct but still no improvement is obtained on its amplitude.

Although the code is now able to predict for example the excitation of the blade in torsion due to high harmonics in the aerodynamic input, via the coupled METAR vortex lattice method, which is highly necessary to better correlate with experiments on signals such as the local lift, the results obtained here on a swept tip rotor blade are rather deceiving! Consequently, it is decided to introduce sweep and anhedral effects.

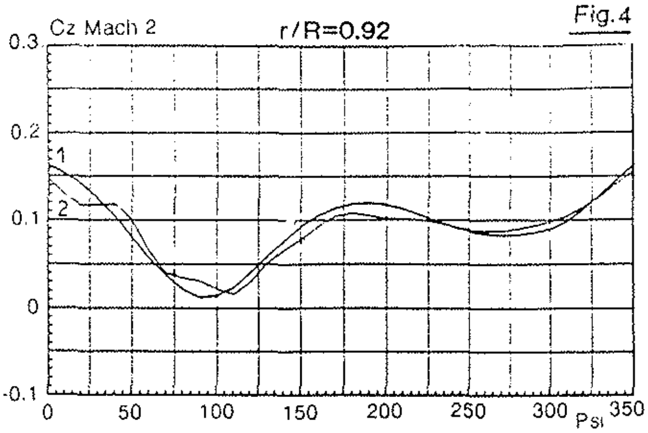

Fig.4

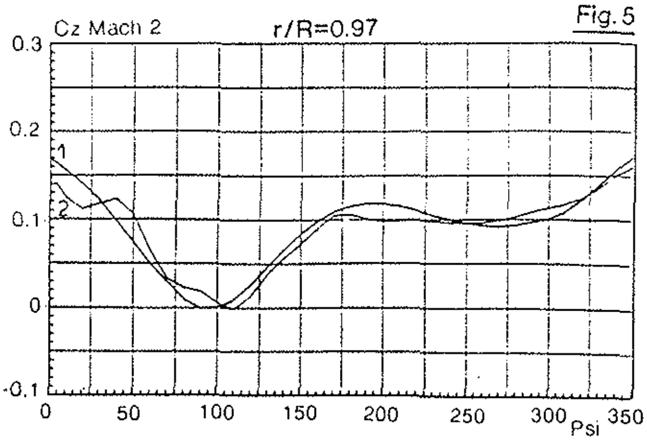

Fig.5

1 ——— Soft computation with Metar
2 ------ Soft computation (Including torsion) with Metar

3.4 Introduction of geometric curvature

This is achieved by modelizing the sweep and anhedral offsets of the quarter-chord line, where aerodynamic forces and torsion rotations of the blade are applied (ref 4).

New results

Running calculations show this time the expected peak of negative lift on the advancing side. But the phase of the peak sets again back to 90°. Before attributing that improvement to the modelization of sweep and anhedral alone, an interesting simulation is to run calculations without torsion, but with curvature effects.

The results of both computations are shown below (fig. 6 and 7).

Note that the peak of ClM2 is also predicted by the second calculation (no torsion) but it is less sharp. This remarkable result confirms that a no-straight tip blade not only modifies local aerodynamic loads just because of different aerodynamic input but also amplifies this phenomenon via high harmonic torsion coupling. Moreover, the change of dynamic response due to an offset of the torsion axis can lead to dramatic increase of pitch link loads. It is therefore necessary to computationaly control torsion effects for developing advanced rotors

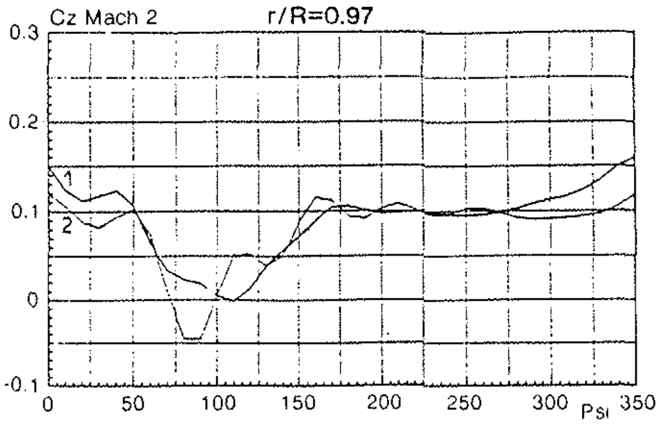

Fig. 6

1 ——— *Soft computation (Including torsion) with Metar*
2 ------- Soft computation (Including torsion) with Metar and curvature

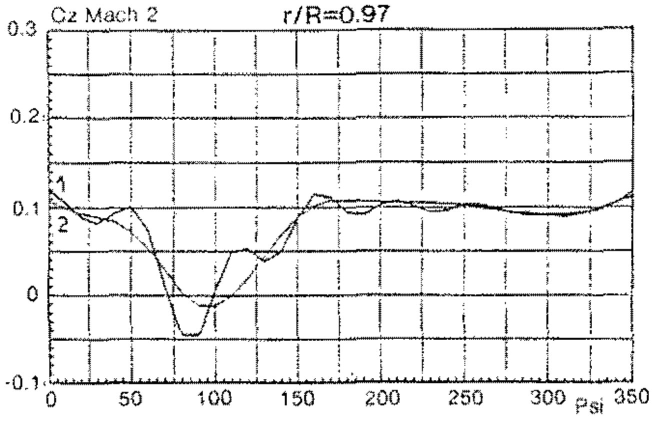

Fig. 7

1 ——— Soft computation (Including torsion) with Metar and curvature
2 ------ Soft computation (Without torsion) with Metar and curvature

3.5 Unsteady effects

To end, in order to improve the phase of the negative peak, an attempt is made by introducing some unsteady effects on the aerodynamic coefficients (ref 4).

New results

Fig. 8 and 9 show results on the CIM2, obtained when taking into account the linear part of Theodorsen's unsteady terms for the pitching moment coefficient Cm. No unsteady effects have been introduced on the Cl.

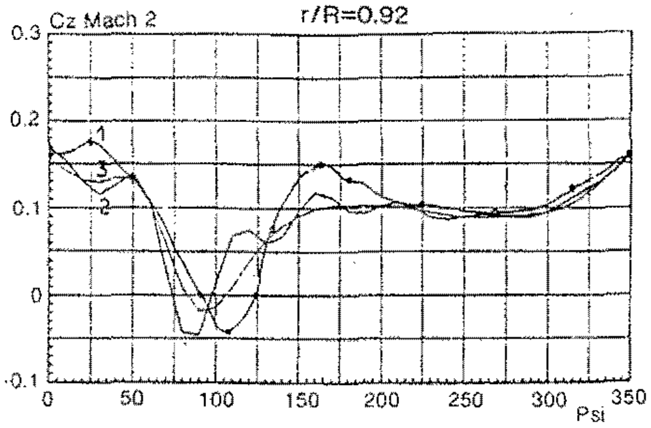

Fig. 8

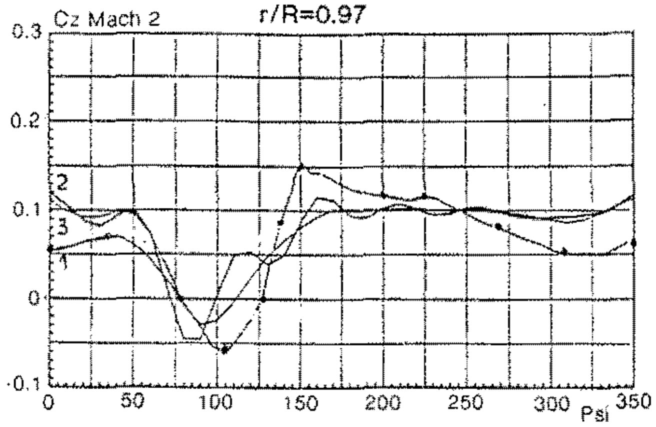

Fig. 9

1 o——o Experiment $\mu=0.4$ $C_T/\sigma=0.07$
2 ——— Soft computation (Including torsion) with Metar and curvature
3 ------ Soft computation (Including torsion) with Metar , curvature and unsteady effects

It is interesting to note that some phase lag emerges from unsteady computations like in experiments. However, this lag in the interaction between the wake and the advancing blade is not important enough.

Full unsteady aerodynamics seems necessary to really correlate well with experiments on this phenomenon. Some research undergoes at ONERA on this subject and preliminary results agree with.

3.6 Overall results. Synthesis

To measure the improvements brought from a basic version (Meijer-Drees induced velocities model + soft blade calculations) to a sophisticated one (METAR + geometrical curvature effects + unsteady effects), some results dealing with the local lift distribution on the blade are reminded below:

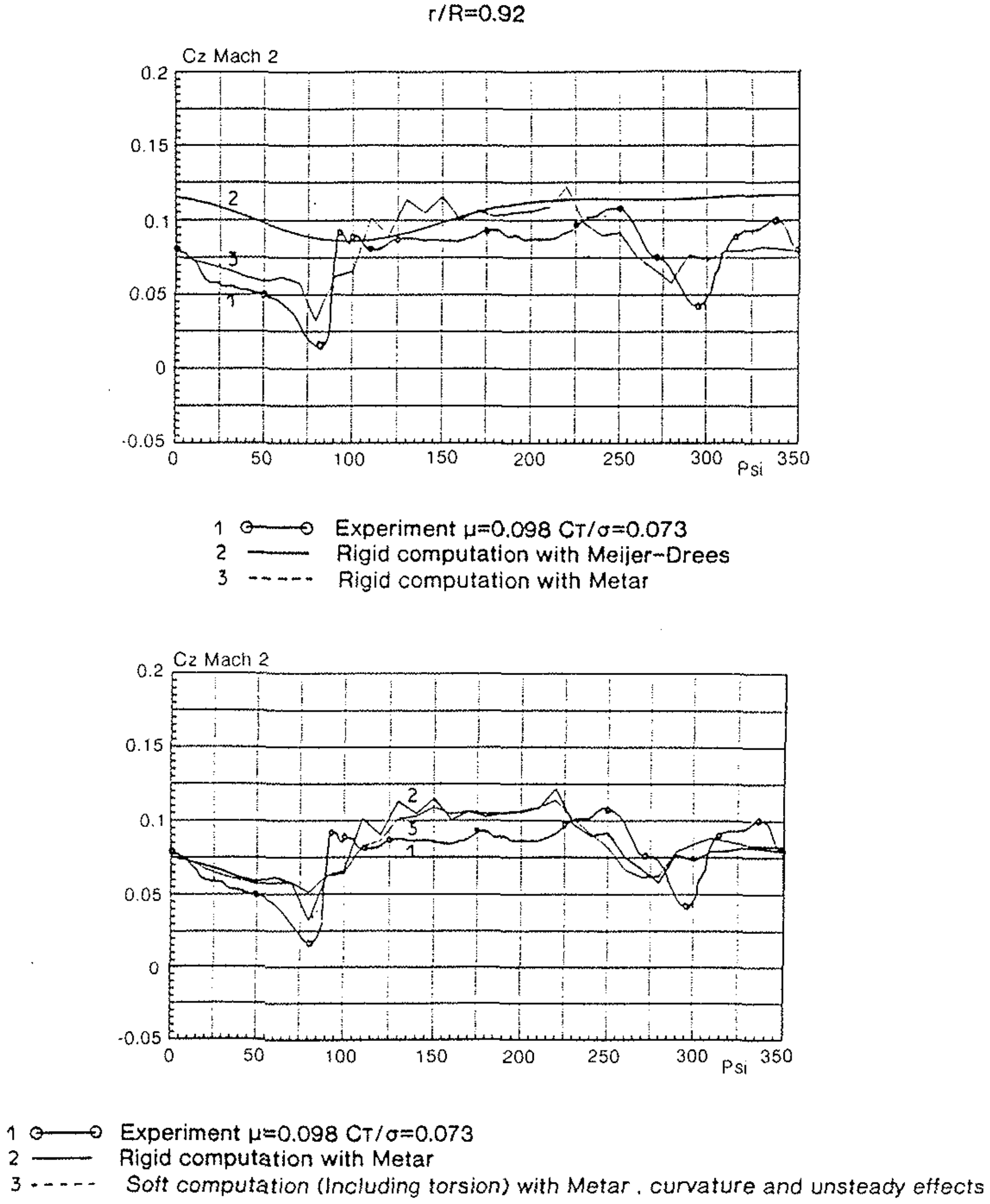

Fig.10

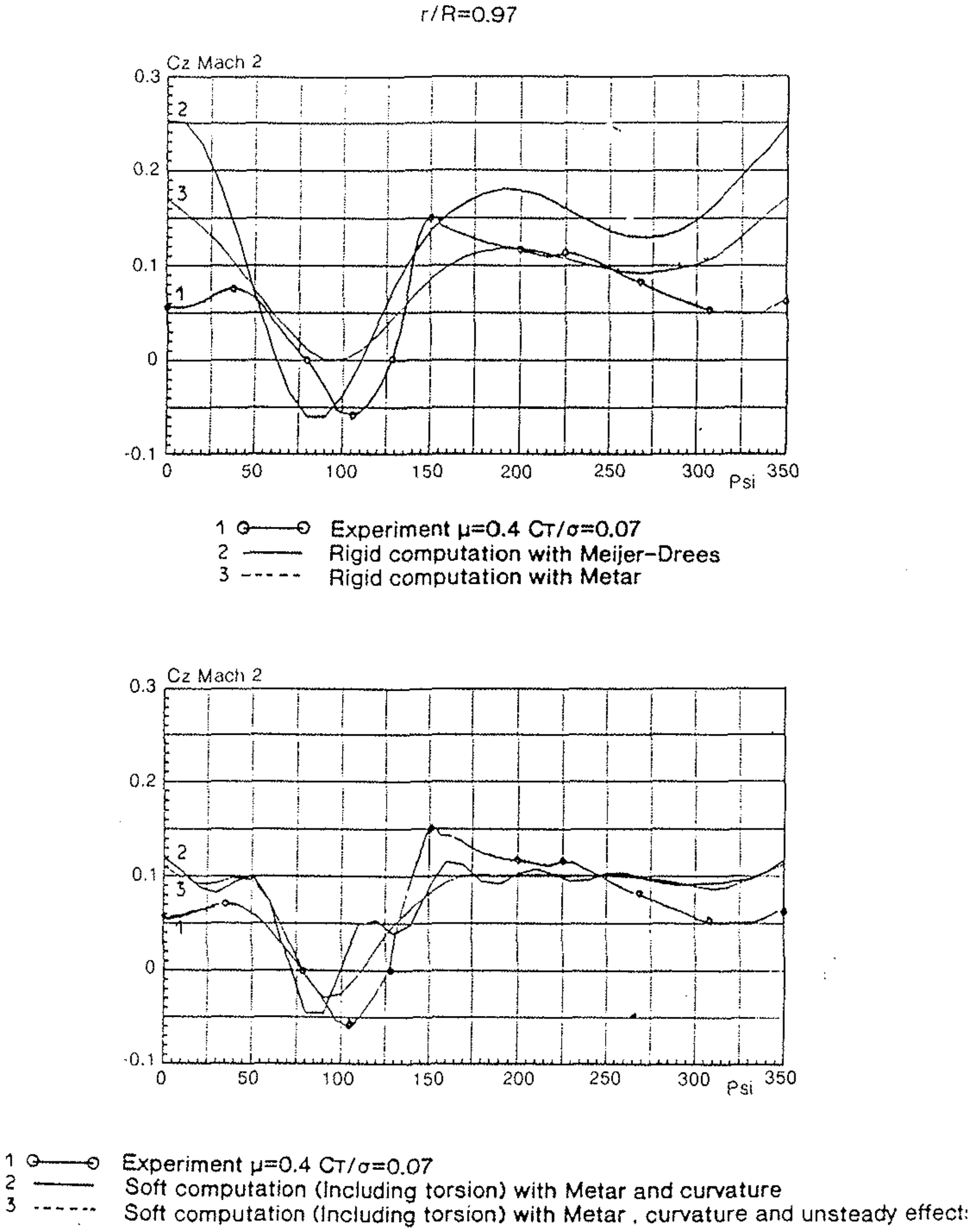

Fig.11

As seen above, some problems remain:

- bad phase prediction for the peak of ClM2 on the advancing side at μ= 0.4: unsteady effects? Transonic effects?
- bad prediction on the retreating side: stall?
- coarse overall prediction for low advance ratio: wake model?

Finally, overall results on the flatwise and chordwise bending moments and on the torsion moment are illustrated below for μ= 0.4 at 56.9%R, 55%R, and 55%R respectively. (Fig.13,14 and 12)

These comparisons between the fully coupled model (R85/METAR) and the soft blade calculation run with the basic Meijer-Drees inflow model justify by themselves the necessity to use a sophisticated code to correlate local parameters recorded during complex rotor experiments.

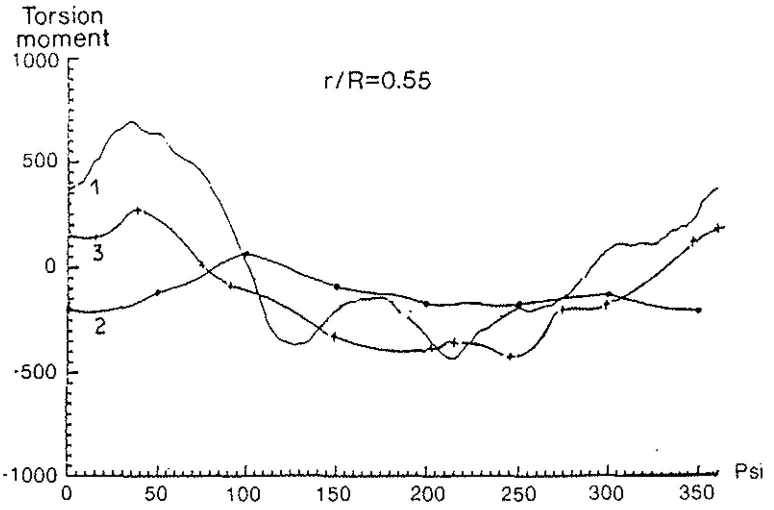

Fig. 12

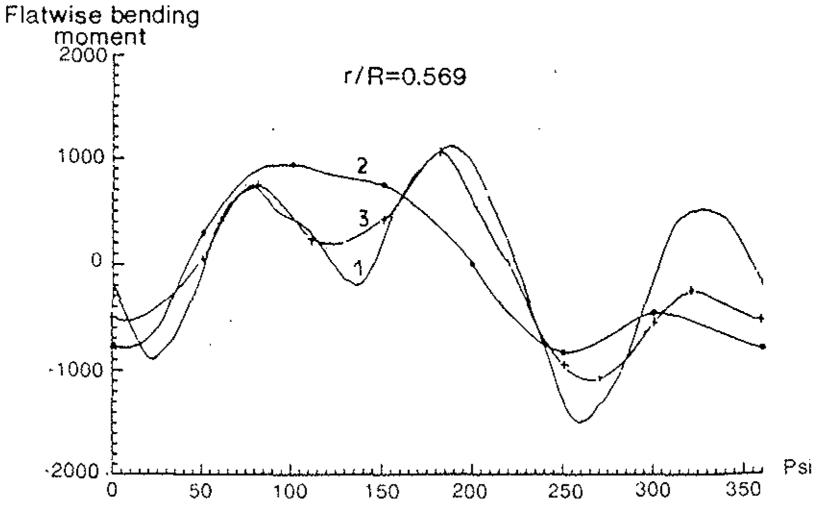

Fig. 13

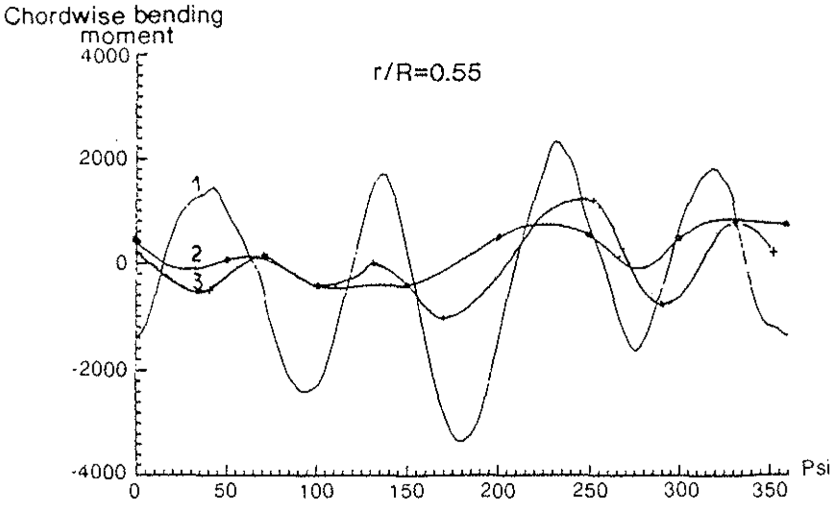

Fig. 14

1 ——— Experiment μ=0.4 C_T/σ=0.07

2 ⊖——⊖ Soft computation with Meijer-Drees.

3 +——+ Soft computation (Including torsion) with Metar , curvature and unsteady effects

IV CONCLUSIONS

This study outlines the fact that all improvements presented here are necessary to get good correlations: it is impossible to obtain good results without an accurate model for the wake (at least a prescribed wake for high advance ratio); introduction of torsion is also an important feature; curvature of the blade must also be introduced in calculations and unsteady effects may play an important role. R85/METAR has now all these improvements and correlations show that predictions are accurate enough for industrial developments.

At present time, three main limitations have been encountered: for low advance ratio, a free wake model seems necessary to account for strong blade-vortex interactions and for high advance ratio, the introduction of 3D effects at blade's tip could be a way towards improving the results obtained herein. Finally, unsteady aerodynamics would improve local correlations, specially for Cl predictions.

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