ERF91-36

Paper No 91-36

EXPERIMENTAL AND THEORETICAL STUDIES ON HELICOPTER ROTOR FUSELAGE INTERACTION

N. BETTSCHART, R. HANOTEL, D. ILBAS, A. DESOPPER

OFFICE NATIONAL D'ETUDES ET DE RECHERCHES AEROSPATIALES
CHATILLON, FRANCE

SEPTEMBER 24-26, 1991

Berlin, Germany

Deutsche Gesellschaft für Luft- und Raumfahrt e.V. (DGLR)
Godesberger Allee 70, 5300 Bonn 2, Germany

EXPERIMENTAL AND THEORETICAL STUDIES ON HELICOPTER ROTOR FUSELAGE INTERACTION

N. Bettschart, R. Hanotel, D. Ilbas, A. Desopper
Châtillon, France

Abstract

Experimental and theoretical studies are presently under development at ONERA on helicopter rotor/fuselage interactional aerodynamics.

From the experimental point of view, a test was conducted in the ONERA S2 Chalais subsonic wind tunnel to measure the unsteady velocity field around an Aerospatiale powered helicopter model (Dauphin 365 scaled 1/7.7) in forward flight ($\mu = .20$). The unsteady measurements were performed with a three components laser doppler velocimeter.

From the theoretical point of view, an iterative coupling method has been developed for rotor fuselage calculations. This method is based on a panel method (source and doublet singularities) for the fuselage and on a lifting line code for the rotor. These two codes are coupled in an iterative approach through an azimuth marching technique.

The experimental results are analyzed and comparisons between experimental and computed results are presented for both the U.S. Army Langley and the ONERA tests. These comparisons show that the fuselage effects have to be taken into account in particular for the rotor wake geometry and for the flow conditions on the inboard part of the blade.

Future tests planned with the powered model as well as improvements of the computational method are also briefly described.

1. Introduction

Fore more than fifteen years now, at the Aerodynamics Department of ONERA, detailed experimental and theoretical aerodynamic studies have been performed on isolated helicopter rotor and in the last five years, on isolated fuselage in order to improve the capability to perform accurate measurements as well as to predict the characteristics of the flow around a helicopter blade or a helicopter fuselage. Now, ONERA is developing experimental and theoretical approaches on helicopter rotor fuselage interactional aerodynamics. This paper presents the work already performed on this subject and what is planned for the future.

From the experimental point of view, a test was conducted in the ONERA S2 Chalais subsonic wind tunnel to measure the unsteady velocity field around an Aerospatiale powered helicopter model. The powered model used for these tests is a very realistic and a very complete one. It is a Dauphin scaled 1/7.7, built by Aerospatiale under fundings from the French Ministry of Defense ("Direction des Recherches et Etudes Techniques"). A threedirectional Laser Doppler Velocimeter has been used to perform unsteady velocity field measurements in two planes perpendicular to the forward velocity direction.

From the theoretical point of view, an iterative coupling method has been developed for rotor fuselage calculations. This method is based on:

- a fuselage code developed at ONERA; it is a panel method using source and doublet singularities,
- a lifting line rotor code with a vortex wake modelisation developed at Aerospatiale (METAR code); in this method, the wake geometry used is the classical helical wake.

The iterative coupling between METAR and the fuselage code is based on a quasi-steady approach and has been realized by an azimuth marching technique.

Calculations have been performed on both the configuration tested at NASA Langley Research Center and the one of the Dauphin powered model. The comparisons between experimental and calculated results show that the fuselage effects have to be taken into account to improve the predictions, in particular for the flow characteristics on the inboard part of the rotor disk and for the rotor wake geometry.

2. Tests with the Dauphin powered model

Tests on a Dauphin powered model (scaled 1/7.7) have been performed in the ONERA S2 Chalais-Meudon wind tunnel. Unsteady velocity field measurements around the fuselage and the rotor in two different transversal planes (perpendicular to the fuselage plane of symmetry) using a threedirectional Laser Doppler Velocimeter, have been done.

2.1. Experimental set-up

The powered model used for these tests is a very realistic and a very complete one. It has been built by Aerospatiale under fundings from the French Ministry of Defense ("Direction des Recherches et Etudes Techniques"). The fuselage length is about 1.5 m, the rotor diameter is 1.5 m and the rotating tip speed is 100 m/s. A view of the model inside the S2Ch wind tunnel is presented on figure 1.

The Laser Doppler Velocimeter used in this experiment is described in detail in [1, 2]. Results already obtained for an isolated rotor can be found in [3, 4].

The main characteristics are as follows:
1) a fringe mode operation; 2) two 15 W argon laser as light sources; 3) use of Bragg cells to have the sign of the velocity components and 4) two Cassegrain telescopes to collect the scattered light.

It can be used in back or forward scattered mode with the whole system mounted on one (or two) very rigid table allowing precise (synchronized) and automated displacements along three orthogonal axes. The main elements of the data acquisition and processing unit are three laser Doppler signal processors (DISA counters) connected to a mini-computer.

In this experiment, the velocimeter works at a distance of 1.5 m.

The unsteady velocity measurements have been performed in two different transversal planes $x=0$ and $x=315$ mm (0.4 R) (relatively to the rotor shaft) and for the advancing blade side (x being parallel to the forward velocity V_∞, y perpendicular to V_∞ and to the fuselage plane of symmetry in the direction of the advancing blade side and z perpendicular to V_∞ , in the fuselage plane of symmetry). These measurements are performed every 4° in azimuth; this means 90 different slots to describe one rotor revolution, each slot has a width of 1° in azimuth and for each slot the measurements are averaged over 100 samples. Typical results are presented for one point in space on figure 2.

The configuration studied during these tests corresponds to an advance ratio of 0.2 and a simulated mass of 4 000 kg.

2.2. 3D LDV results obtained

The instantaneous vertical velocities for different points located slightly above the rotor disk (fig. 3) show that outside the rotor disk ($y/R>1$) the velocity fluctuations are very small and the mean value positive (upwash) whilst inside the rotor disk ($y/R<1$) the fluctuations due to the blades passage are important and the mean value negative (downswash).

When you move away from the rotor plane level (fig. 4) these fluctuations decrease as well as the mean values.

The mean velocity field (V, W) (fig. 5 and 6) shows the rotor disk mean "edge vortex". The mean vertical velocity component (fig. 6) decreases away from the rotor disk.

All these unsteady measurements show that a 3D LDV system is a very useful experimental tool to study the velocity field around a helicopter powered model.

Experiments with steady and unsteady pressure measurements on the fuselage are going to be performed in order to complete this data base on powered model.

3. Iterative coupling method for rotor/fuselage interactional aerodynamics

3.1. Isolated fuselage code

A low order panel method has been developed at ONERA based on the hypothesis of inviscid, steady, incompressible 3D flow [5]. The bodies are discretized with quadrilateral panels of constant source and doublet distributions. Calculations with a fuselage wake of prescribed shape can also be performed (fig. 7). For the present calculations no fuselage wake was considered.

3.2. Isolated rotor code (METAR)

ONERA uses a method developed at Aerospatiale [6]. It is a lifting line method and the rotor wake is discretized by a lattice of linear vortex segments. For the calculations presented here, the wake geometry is prescribed with the conventional cycloidal trajectories, the induced velocity at each control point on the blade is computed by the Biot and Savart law and the lift is obtained through 2D airfoil tables (fig. 8).

3.3. Coupled method

A computational method of rotor/fuselage configuration is under development at ONERA by coupling the isolated fuselage and isolated rotor methods.

This iterative coupling between METAR and the fuselage code is based on a quasi-steady approach and has been realized by an azimuth marching technique (fig. 9). At each azimuth (or time step), the velocities induced by the rotor and its wake are introduced in a fuselage calculation whose results are then taken into account to evaluate the velocities at the blade level and the rotor wake geometry for the rotor calculation at the next time step (the new rotor wake geometry is computed with only the velocity field due to the fuselage).

For the calculations performed up to now the convergence of this procedure is obtained after two or three rotor revolutions.

4. Comparisons between experimental and theoretical results

Calculations have been performed with the isolated rotor code and the coupled method for an experimental configuration studied at the NASA Langley Research Center and for the Dauphin powered model.

4.1. U.S. Army Langley tests

An experimental investigation was conducted in the 4.3×6.7 meter wind tunnel at NASA Langley Research Center to measure the rotor inflow of a model helicopter in forward flight using a powered model with a ROBIN fuselage and a 1.72 m diameter four bladed rotor [7-10]. Two velocity components were measured 76 mm above the tip path plane with a laser velocimeter. Three flight conditions: $\mu=0.15$ - 0.23 - 0.30 have been studied [8-10] but only $\mu=0.30$ for a classical rectangular planform will be presented in this paper.

Calculated and experimental pressure distributions on the fuselage lateral line are compared on figure 10 for an isolated fuselage configuration. The calculations are performed with 2 756 panels.

Comparisons between experimental and computed mean and instantaneous vertical induced velocities one chord above the rotor disk are presented on figures 11 and 12 ($\mu=0.3$). Two calculations are considered: isolated rotor and coupled rotor/fuselage.

At this advance ratio the mean induced inflow is positive (velocity upwards) on a large portion of the front part of the rotor disk (fig. 11). The isolated rotor calculation underestimates this phenomenon. The coupled calculation shows a clear improvement with the zero-inflow line retreating up to the blade root (fig. 11). These results are simular to the ones obtained by Hoad & al. [10] and by A. Dehondt and F. Toulmay [6].

The instantaneous vertical induced velocities (fig. 12) for a measurement point at the azimuth $\psi_m = 180°$ show that the two predicted velocity distributions versus rotor azimuthal locations are in phase with the experimental one. When the fuselage effect is taken into account, the comparison is improved, in particular for the inboard station. The calculations slightly overestimate the peak to peak amplitude of the velocity fluctuations, in particular at $r/R = 0.78$ and $r/R = 0.98$.

The calculations being inviscid, the fuselage effect becomes deteriorating downstream of the upper cowlings and hub where separation can occur as found also by A. Dehondt and F. Toulmay [6].

The fuselage effect is also to modify the tip vortex trajectories (fig. 13) and this could be quite important for the flow conditions on the fuselage rear parts.

4.2. ONERA tests

The mesh of the very complete Dauphin fuselage is presented on figure 14.

Figures 15-17 show the comparisons between experimental and computed mean vertical and radial velocities. A better agreement is obtained on the mean vertical velocities in the more downstream plane (fig. 17) than in the plane $x/R = 0$ (fig. 15). For these measurements in two planes perpendicular to the fuselage plane of symmetry the difference between the isolated rotor calculation and the coupled calculation is very small. However some differences occur near the blade root in particular for the mean radial velocities (fig. 16).

Instantaneous vertical and radial velocities are presented on figures 18 and 19 for measurement points located at different z/R, near the blade root ($y/R = 0.13$) in the plane $x/R = 0.42$. For these points located not far from the fuselage the differences between the isolated rotor calculation and the coupled one are relatively large, in particular for the radial velocities (fig. 19). The correlation with the experimental results is improved for the radial velocities when the fuselage effect is taken into account (coupled calculations, fig. 19). For the instantaneous vertical velocities the agreement between experimental and calculated results is not good (fig. 18); above the rotor disk ($z/R = 0.079$, $\simeq .5$ cord above the rotor disk) the calculations are in phase with the experiment but the amplitude of fluctuations is underpredicted and below the rotor disk ($z/R < -0.014$) the correlation becomes worse (neither the phase nor the amplitude of fluctuations are well predicted).

The calculated results obtained for both the Langley and the Dauphin configurations show a relatively good agreement with the experiment above the rotor disk. Below the rotor, the main reason for the discrepancy obtained for the Dauphin with the present coupled calculations on the instantaneous velocities is certainly due to the fact that the rotor wake is not a complete free wake. The wake geometry is computed with the fuselage velocity field taken into account but not with the self induced velocities. The complete free rotor wake approach is going to be undertaken.

5. Concluding remarks

Experimental and theoretical studies have been undertaken at ONERA on helicopter rotor/fuselage interactional aerodynamics.

An experimental investigation has been conducted using a 3D Laser Doppler Velocimeter to study the flow around a Dauphin powered helicopter model. The results obtained show that the LDV technique is a very powerful tool for measurements around such a complex configuration with moving surfaces.

From the theoretical point of view, an iterative coupling method based on a panel method for the fuselage and on a lifting line code for the rotor has been developed.

Calculations have been performed for both the U.S. Army Langley and the Dauphin tests. The comparisons with the experimental results show that the fuselage effects have to be taken into account for the flow characteristics on the inboard part of the rotor disk and for the rotor wake geometry.

The experimental work will be completed with steady and unsteady pressure measurements on the fuselage. The computational approach has to be improved with a complete free rotor wake calculation, a close vortex-body interaction technique and with unsteady pressure predictions on the fuselage.

6. References

1. A. BOUTIER. Two-dimensional laser velocimeter 20M61. Data sheet 1981-4.

2. A. BOUTIER, E. HAZIZA, D. LEFEBVRE, J. LEFEVRE. New applications of laser velocimetry in ONERA wind tunnels. 10th ICIASF, Saint-Louis (September 1983).

3. J.M. POURADIER, E. HOROWITZ. Aerodynamic study of a hovering rotor. 6th European Rotorcraft and Powered Lift Aircraft Forum, Bristol (1980).

4. A. DESOPPER. Rotor wake measurements for a rotor in forward flight. International Conference on Rotorcraft Basic Research, Research Triangle Park, North Carolina (February 19-21, 1985).

5. J. RYAN, G. FALEMPIN, T.H. LE. Rotor plane velocities by a helicopter fuselage. 2nd International Conference on Basic Rotorcraft Research. College Park, Maryland, February 16-18, 1988.

6. A. DEHONDT, F. TOULMAY. Influence of fuselage on rotor inflow performance and trim. 15th European Rotorcraft Forum, Amsterdam (September 12-15, 1989).

7. C.E. FREEMAN, J.C. WILSON. Rotor-body interference (ROBIN) - Analysis and Test. 36th Annual Forum of the American Helicopter Society Washington D.C., 1980.

8. J.W. ELLIOTT, S.L. ALTHOFF, R.H. SAILEY. Inflow measurement made with a laser velocimeter on a Helicopter model in forward flight. Volumes I, II, III, NASA Technical Memoranda 100541 to 100543 (1988).

9. A.E. PHELPS III and J.D. BERRY. Description of the U.S. Army Small-Scale 2 meter rotor test system. NASA Technical Memorandum 87762 (1987).

10. D.R. HOAD, S.L. ALTHOFF, J.W. ELLIOTT. Rotor inflow variability with advance ratio. 44th Annual Forum of the American Helicopter Society, Washington D.C., 1988.

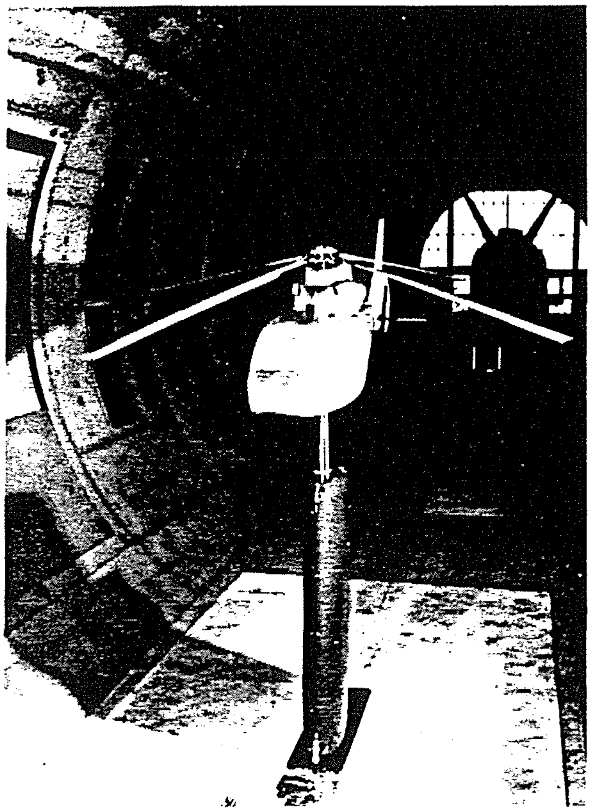


Fig. 1 – Dauphin powered model.

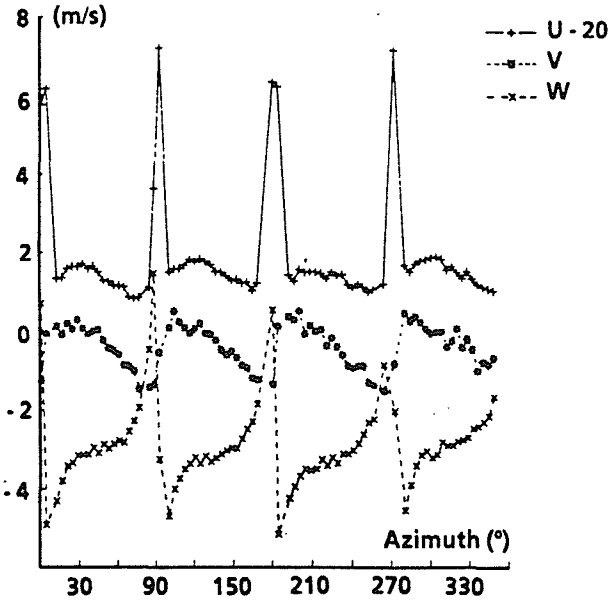


Fig. 2 – 3D LDV measurements.

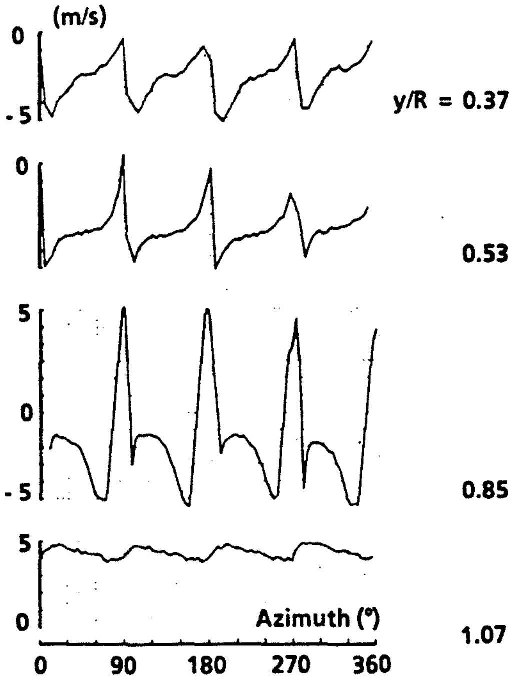


Fig. 3 – Dauphin powered model
Vertical velocities: x/R = 0; z/R = 0.066

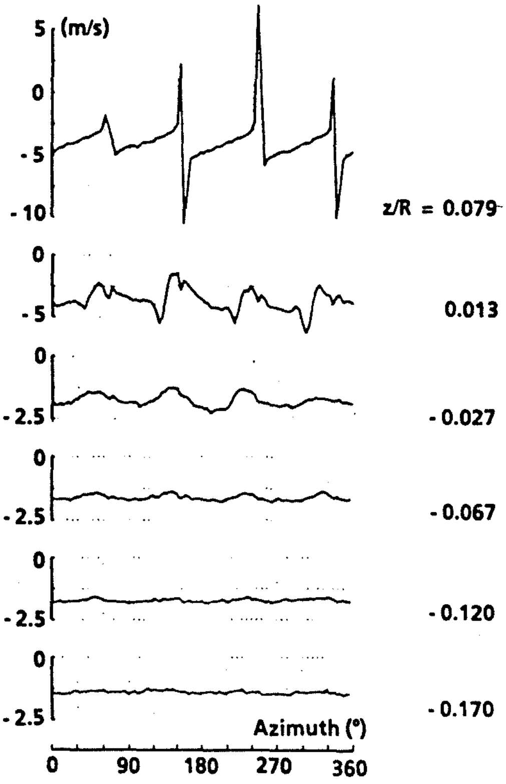


Fig. 4 – Dauphin powered model
Vertical velocities: x/R = 0.42; y/R = 0.80.

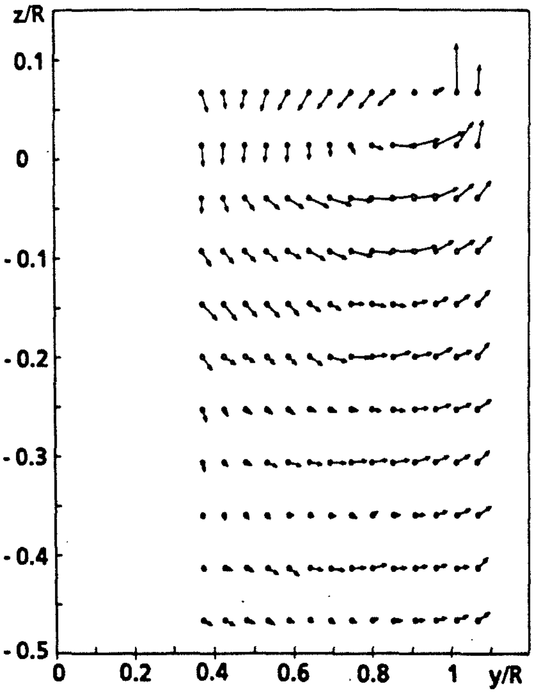


Fig. 5 – Dauphin powered model
Mean velocities: x/R = 0.

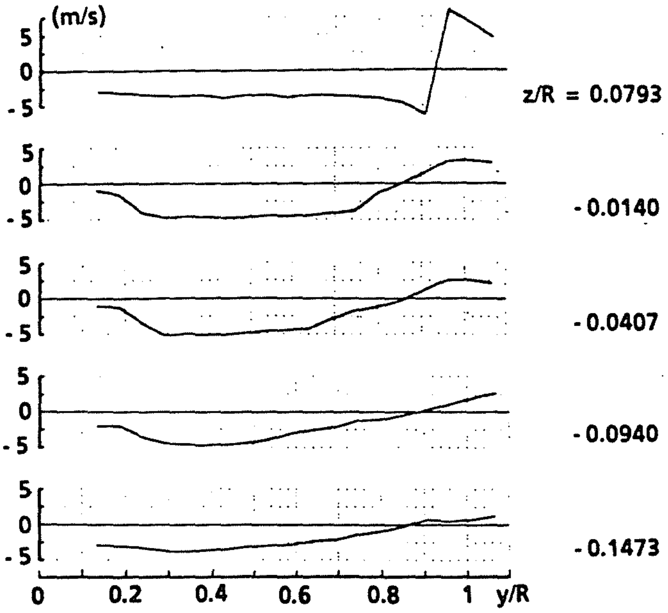
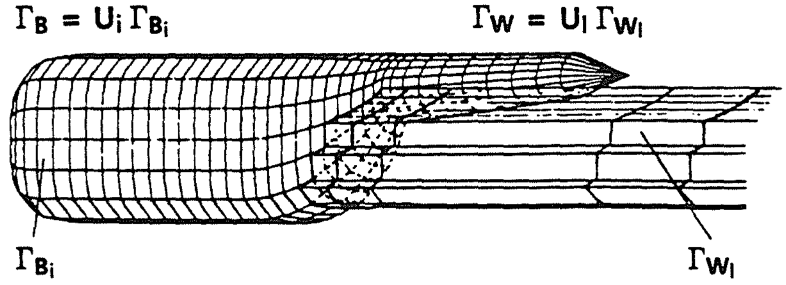


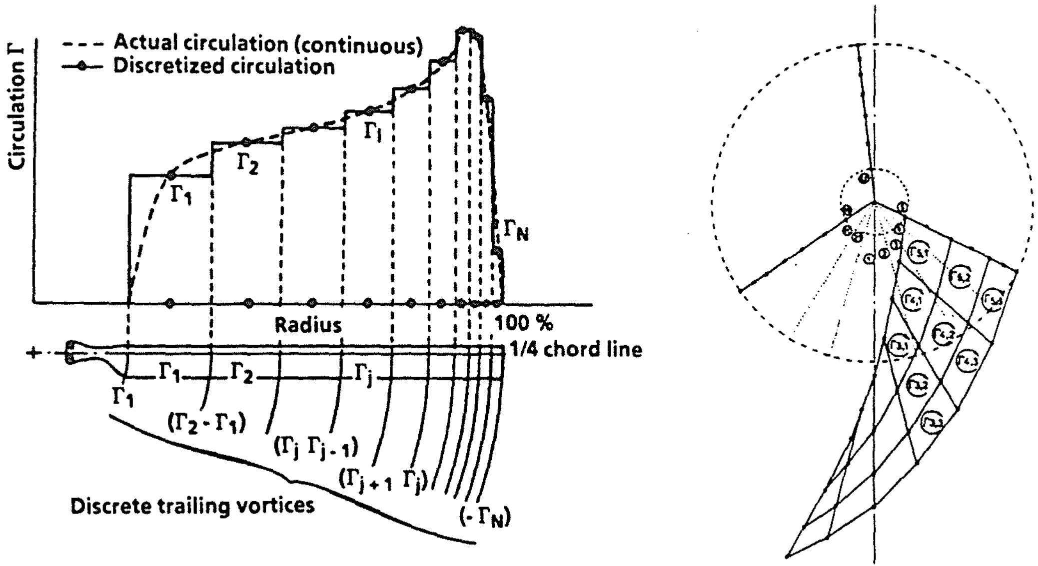
Fig. 6 – Dauphin powered model
Mean vertical velocities: x/R =042.

Fig. 7 – Discretisation.



Source and doublet distribution intensity constant per panel

$$2\pi\phi_i - \Sigma a_{ij}\phi_j = b_i$$



Spanwise discretization of circulation

Rotor wake modeling

Fig. 8 – Rotor code developed by Aérospatiale.

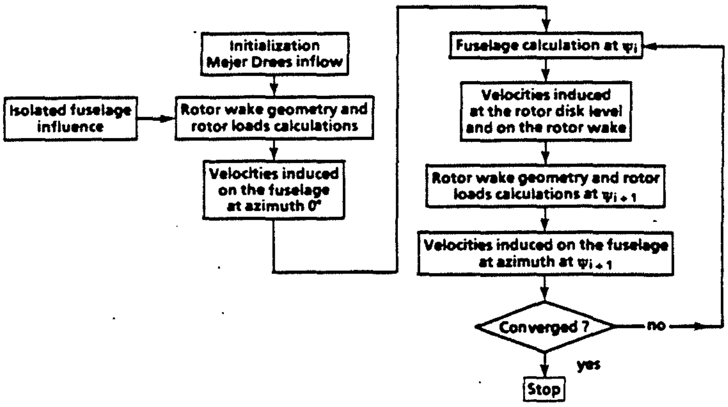


Fig. 9 – Coupled calculations.

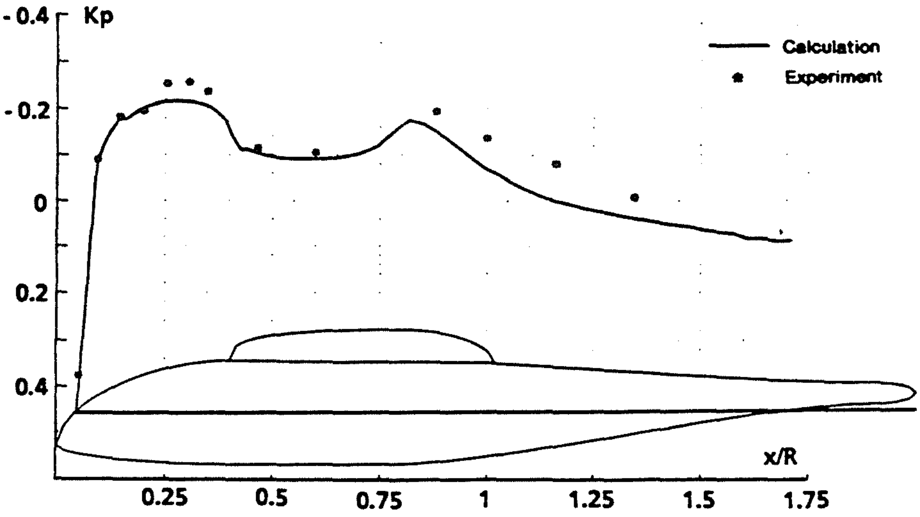
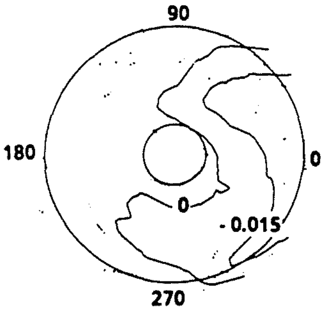
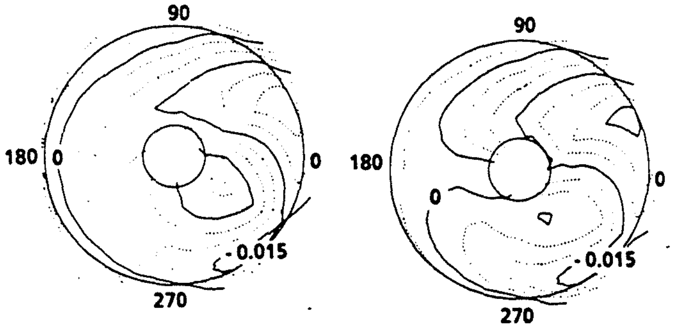


Fig. 10 – Isolated fuselage calculation
Pressure distribution on lateral
$z=0 \quad \alpha=0° \quad \beta=0°$.



Experiment



Calculation without fuselage   Coupled calculation

Fig. 11 – Mean induced inflow
ratio distribution
$\bar{v}_i / V_{tip}$ *(positive up)*
$\mu=0.3$.

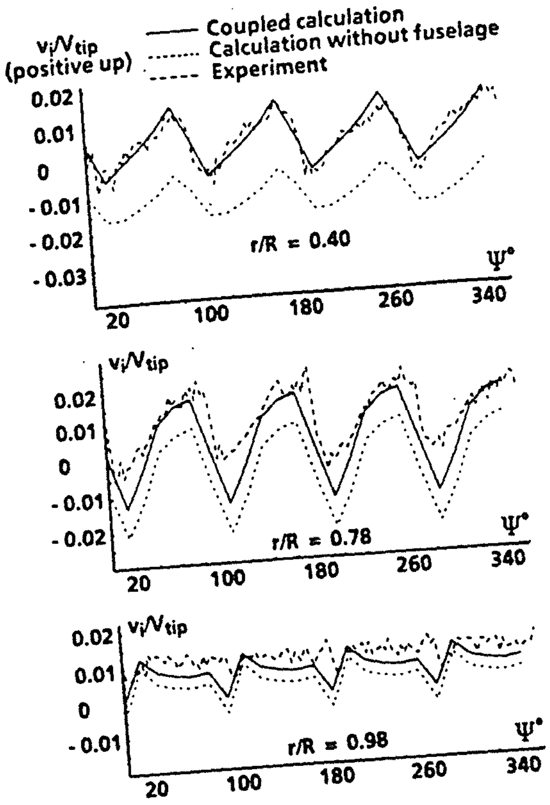


Fig. 12 – Induced inflow ratio
Measurement azimuth: $\psi_m = 180°, \mu = 0.3$.

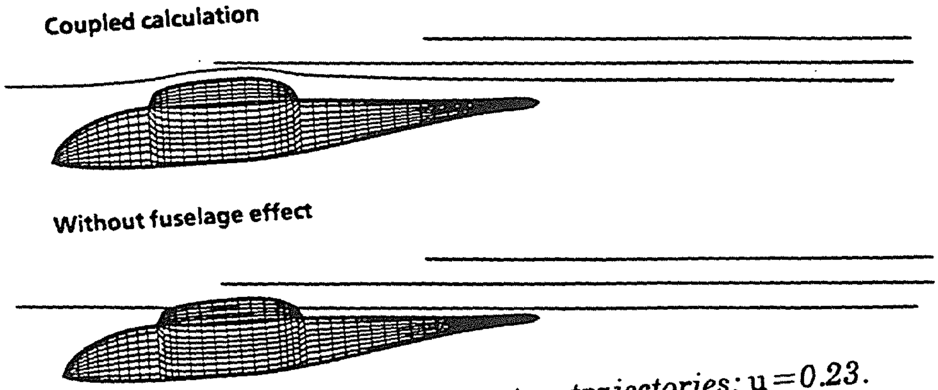


Fig. 13 – Rotor wake geometry: trajectories; $\mu = 0.23$.

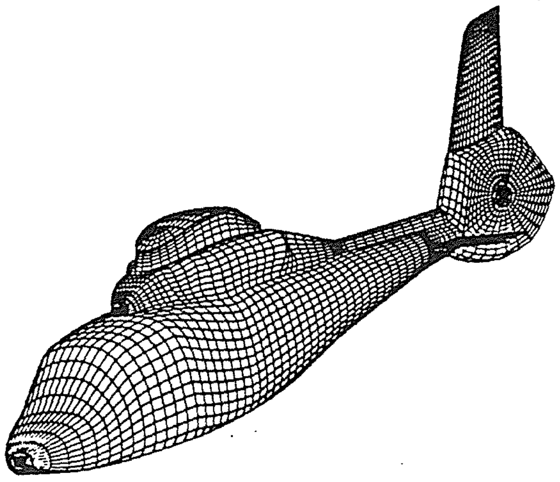


Fig. 14 – Mesh of the Dauphin fuselage.

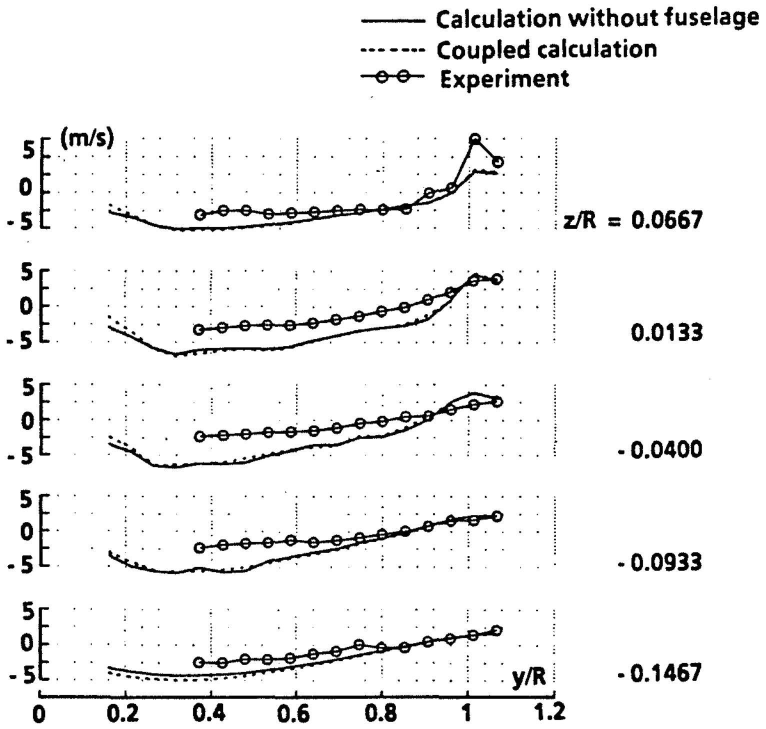


Fig. 15 – Dauphin powered model
Mean vertical velocities: x/R = 0.

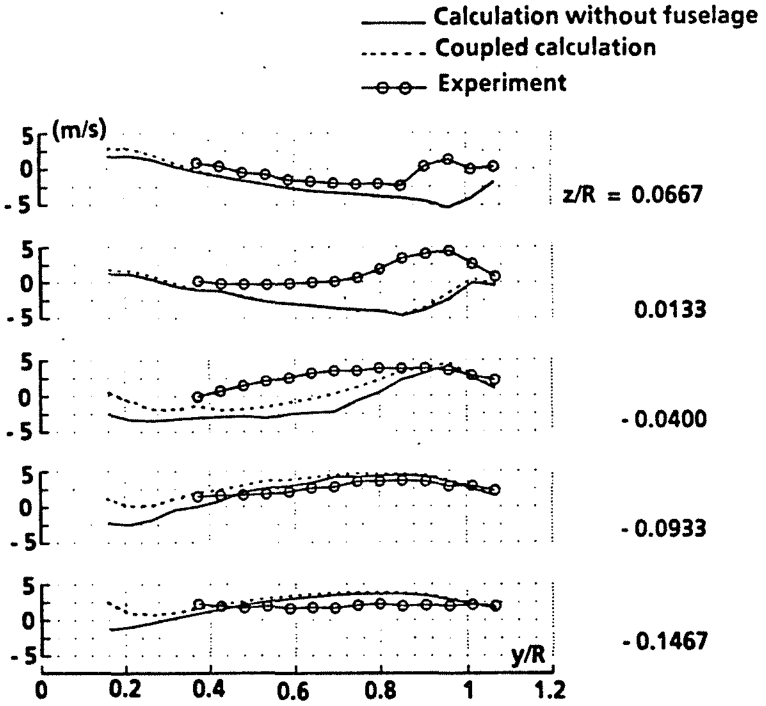


Fig. 16 – Dauphin powered model
Mean radial velocities: x/R = 0.

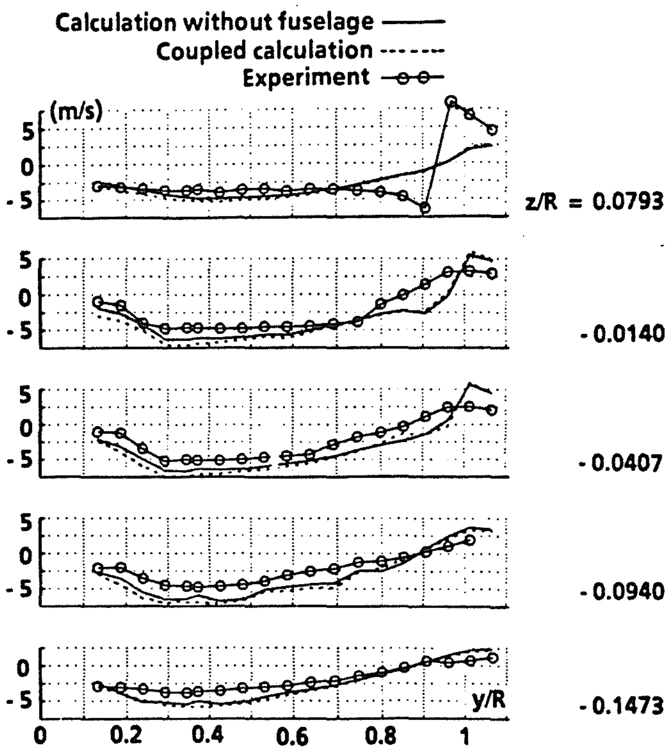
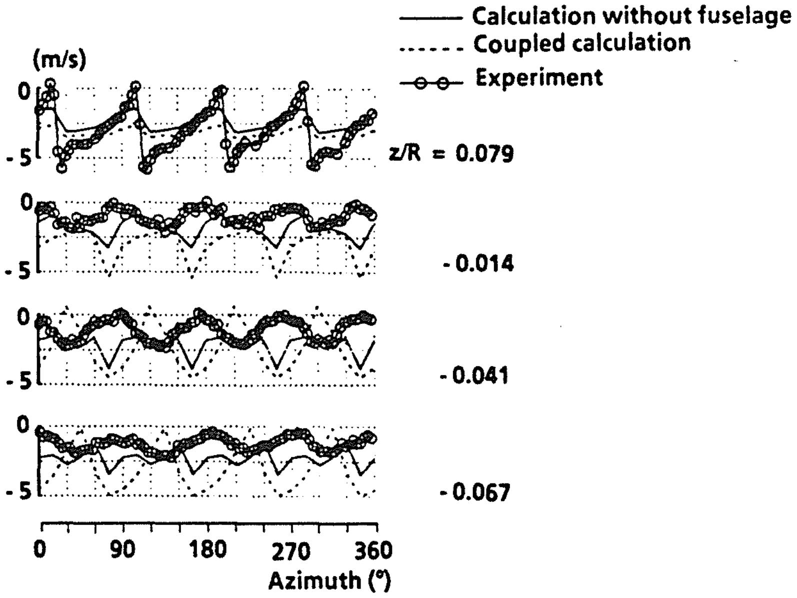


Fig. 17 – Dauphin powered model Mean vertical velocities: x/R = 0.42.

Fig. 18 – Dauphin powered model Instantaneous vertical velocities: x/R = 0.42; y/R = 0.13.



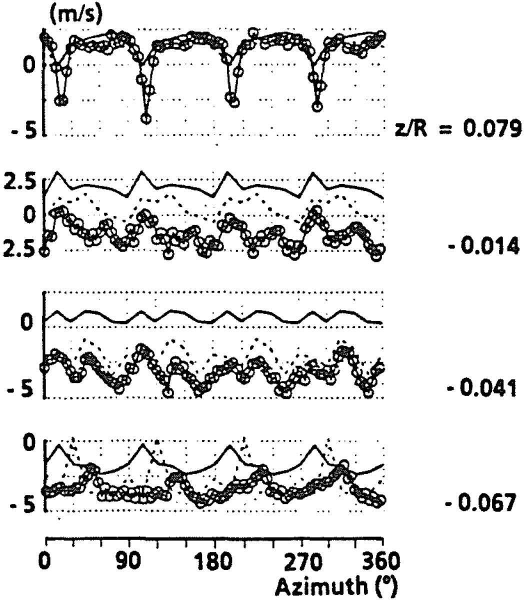


Fig. 19 – Dauphin powered model Instantaneous radial velocities: x/R = 0.42; y/R = 0.13.