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Abstract

This paper deals with the wake modelling for a helicopter fuselage. This modelling consists in a base flow model (i.e. equipressure zone with low velocity) to represent the broad wake at the rear part of the fuselage. Calculations are performed with such a model on a test case for which experiments have been carried out at the F2 wind tunnel.

1 Introduction

In the prediction of aerodynamic drag coefficient on helicopter fuselage the main problem is due to the occurrence of separated flows [1-3]. Aerodynamic theory even within the framework of inviscid flow is still very approximate and wake models need to be improved. In this paper is introduced a fixed wake model, bounding a dead-air region, with a linear distribution of the doublet intensity. This wake model is implemented in an existing 3-D panel code developed at ONERA.

2 Theoretical model

2.1 Continuous problem

To model the broad wake behind the fuselage Ω , the following hypotheses are assumed :

- 1) the velocity field is potential outside vortex sheets
- 2) the wake is a semi-infinite area Ω_w bound by a surface of tangeant velocity discontinuity Γ_w aligned with the stream direction (see fig.1). In Ω_w , velocities are supposed practically null, therefore Ω_w is a quasi equipressure zone.

The flow being inviscid, incompressible and steady, the potential given by hypothesis 1) must be solution of the following problem P0:

$$(P0) \left\{ \begin{array}{l} \Delta\Phi = 0 \text{ in } \Omega' \setminus \Gamma_W \\ \frac{\partial\Phi}{\partial n} \Big|_{\Gamma_B} = 0 \text{ slip condition} \\ \left[\frac{\partial\Phi}{\partial n} \right] \Big|_{\Gamma_W} = 0 \text{ and } [\Phi] \Big|_{\Gamma_W} \text{ such that } |\nabla\Phi|_{\Omega_W} \text{ minimum} \\ \Phi \xrightarrow{|x| \rightarrow \infty} \Phi_\infty \\ |x| \rightarrow \infty \end{array} \right.$$

where :

$\Omega' = C_\Omega$ is the fluid domain

n exterior unit normal

Φ_∞ freestream potential ($V_\infty = \nabla\Phi_\infty$)

$\Gamma_B = \partial\Omega$ boundary of body Ω

$[f] \Big|_{\Gamma_W}$ jump of variable f through Γ_W

$|\cdot|_{\Omega_W}$ is a norm on Ω_W

The condition that $|\nabla\Phi|_{\Omega}$ should be minimum is given by hypothesis 2). This problem on the total potential can be split into two simpler problems in order to separate the effect of the body and that of the wake. Φ is written as $\Phi = \phi_B + \phi_W + \phi_\infty$ where ϕ_B is a perturbation potential and ϕ_W the wake induced potential

and ϕ_B and ϕ_W are solution of the following problems

$$(P_{\phi_B}) \left\{ \begin{array}{l} \Delta\phi_B = 0 \text{ in } \Omega' \\ \frac{\partial\phi_B}{\partial n} \Big|_{\Gamma_B} = -V_\infty \cdot n \\ \phi_B \xrightarrow{|x| \rightarrow \infty} 0 \\ |x| \rightarrow \infty \end{array} \right. \quad (P_{\phi_W}) \left\{ \begin{array}{l} \Delta\phi_W = 0 \text{ in } \Omega' \setminus \Gamma_W \\ \frac{\partial\phi_W}{\partial n} \Big|_{\Gamma_W} = 0 \\ \phi_W \xrightarrow{|x| \rightarrow \infty} 0 \\ |x| \rightarrow \infty \end{array} \right.$$

with $[\phi_B + \phi_W] \Big|_{\Gamma_W} = [\phi_W] \Big|_{\Gamma_W}$ (as $[\phi_B] \Big|_{\Gamma_W} = 0$) such that $|\nabla\Phi|_{\Omega_W}$ minimum. Thus ϕ_B and ϕ_W are connected by the minimum velocity condition in Ω_W . (This condition can be seen as a consequence of the

general fluid mechanic principle for which the established velocity field of an ideal fluid must be such that kinetic energy is minimum everywhere [4]). Using Bernoulli's 2nd theorem and pressure continuity, hypothesis 2) of an equipressure zone implies that the potential jump across Γ_W of ϕ_W ($\left[\phi_W \right]_{\Gamma_W}$) must be linear along the stream direction.

$\left[\phi_W \right]_{\Gamma_W} = \left[\phi_W \right]_{\Gamma_W}^0 + \alpha d$ where d is a curvilinear distance on Γ_W and α is a constant. $\left[\phi_W \right]_{\Gamma_W}^0$ and α are completely determined by the condition of minimum velocity.

2.2 Formulation

By use of Green's integral representation, solving problem P0 after splitting Φ into $\phi_B + \phi_W + \phi_\infty$ is equivalent to solving the following problem:

$$(P) \left\{ \begin{array}{l} (1) \forall x \in \Gamma_B \\ 2\pi \phi_B(x) - \int_{\Gamma_B} \phi_B(y) \frac{\partial}{\partial n_y} \frac{1}{r} d\gamma(y) - \int_{\Gamma_B} \frac{V_\infty \cdot n(y)}{r} d\gamma(y) = 0 \\ \\ (2) \forall x \in \Gamma_B \\ 2\pi \phi_W(x) - \int_{\Gamma_B} \phi_W(y) \frac{\partial}{\partial n_y} \frac{1}{r} d\gamma(y) - \int_{\Gamma_W} \left[\phi_W \right]_{\Gamma_W} \frac{\partial}{\partial n_y} \frac{1}{r} d\gamma(y) = 0 \\ \\ (3) \forall x \in \Gamma_W \quad \left[\phi_W \right]_{\Gamma_W}(x) = \left[\phi_W \right]_{\Gamma_W}^0(x) + \alpha d(x) \\ \\ \text{where } \alpha \text{ and } \left[\phi_W \right]_{\Gamma_W}^0 \text{ are such that } \left| \nabla(\phi_B + \phi_W + \phi_\infty) \right|_{\Omega_W} \text{ is minimum.} \\ (r = |x - y|) \end{array} \right.$$

condition 3) is a linear condition on $\left[\phi_W \right]_{\Gamma_W}^0$ and α for a quadratic norm on Ω_W , therefore ϕ_B and ϕ_W are connected by a linear relation.

2.3 Discretisation

To discretise P, equation (1) is satisfied at a finite number m of points of Γ_B (collocation points) and the solutions of the m resulting equations are computed by a low order panel method. The resulting equations are:

$$\forall x_i, i = 1, m \quad (x_i \in \Gamma_B, \text{ collocation points}) \\ 2\pi \phi(x_i) - \sum_1^m \phi(x_j) \int_{\Gamma_{B_i}} \frac{\partial}{\partial n_y} \frac{1}{r} d\gamma(y) = \sum_1^m V_\infty \cdot n(x_j) \int_{\Gamma_{B_i}} \frac{1}{r} d\gamma(y)$$

where Γ_B is discretised by $U_1^m \Gamma_{B_i}$, and Γ_{B_i} are panels on which ϕ_B is supposed constant and equal to ϕ .

$\int_{\Gamma_B} \frac{\partial}{\partial n_y} \frac{1}{r} d\gamma(y)$ and $\int_{\Gamma_B} \frac{1}{r} d\gamma(y)$ are computed analytically by the Hess and Smith formulae [5]. The wake Γ_W is approximated by a prescribed surface in alignment with the freestream direction on which $\left[\phi_W \right]_{\Gamma_W}$ is also supposed linear with respect to d . Γ_W is then discretised by $N \times L$ panels (L panels in the freestream direction) and

$$\begin{cases} \forall n, n = 1, N \\ \forall l, l = 1, L \end{cases} \left[\phi_W \right]_{\Gamma_W}(x_{n,l}) = \left[\phi_W \right]_{\Gamma_W}(x_{n,1}) + \alpha d(x_{n,l})$$

$x_{n,l}$ is the barycentre of panel $\Gamma_{W_{n,l}}$ and the unknown parameters are λ_n and α

$$(\lambda_n = \left[\phi_W \right]_{\Gamma_W}(x_{n,1})) \quad n = 1, N$$

In fact, as the problem is linear, the discretised potential ϕ_W can be written as $\phi_W = \sum_N \lambda_n \phi_W^n + \alpha \phi_d$ where $\left[\phi_W^n \right]_{\Gamma_W}$ is equal to 1 on $U_1^L \Gamma_{W_{n,l}}$ and zero elsewhere and $\left[\phi_d \right]_{\Gamma_W} = d$.

So for any $n=1, N$, ϕ_W^n is solution of

$$\begin{cases} 2\pi \phi_W^n(x_i) - \sum_1^m \phi_W^n(x_j) \int_{\Gamma_B} \frac{\partial}{\partial n_y} \frac{1}{r} d\gamma(y) = - \sum_1^L \int_{\Gamma_{W_{n,l}}} \frac{\partial}{\partial n_y} \frac{1}{r} d\gamma(y) \\ (\forall x_i \in \Gamma_B) \end{cases}$$

and ϕ_d is solution of

$$\begin{cases} 2\pi \phi_d(x_i) - \sum_1^m \phi_d(x_j) \int_{\Gamma_B} \frac{\partial}{\partial n_y} \frac{1}{r} d\gamma(y) = - \sum_1^N \sum_1^L d(x_{n,l}) \int_{\Gamma_{W_{n,l}}} \frac{\partial}{\partial n_y} \frac{1}{r} d\gamma(y) \\ (\forall x_i \in \Gamma_B) \end{cases}$$

The norm $\left| \nabla \phi \right|_{\Omega_W}$ is approximated by $\left(\sum_1^N (\nabla \phi(x_n))^2 \right)^{1/2}$ where $x_n \in \Gamma_B \cap \Gamma_W$

$(\lambda_i)_{i=1, N}$ and α are determined by minimising the following functional

$$\sum_1^N \left[\nabla \phi_B(x_n) + \sum_1^N \lambda_j \nabla \phi_W^j(x_n) + \alpha \nabla \phi_d(x_n) \right]^2$$

which is a quadratic expression in λ_j and α .

3 Application

In order to evaluate such a model, the above mentioned method was applied to a helicopter fuselage with sharp aft contraction. This particular configuration has been tested as a complete model in the F2 windtunnel and many experimental data were available [6]. At 0° angle of attack, tunnel results shown that the established flow has the characteristics of a base flow within compass of the model: i.e. the wake structure is that of an eddy flow and in the area of the aft contraction downstream of the separation line, velocities are low and pressure is practically constant (C_p 0.05). For the computation, because of the configuration symmetry (no yaw), only half the fuselage is meshed (410 panels for the half fuselage and 240 panels for the half wake). With such a discretisation, the developed code (OA118) working on a CRAY XMP cost 30 seconds of CPU time. The separation line given by the experiments is approximated by a line based on the body mesh (see fig. 3). From this line starts the discontinuity surface modelling the wake. On figure 3, is also shown location of points used for minimising the kinetic energy.

4 Results

Computations are performed without and with wake modelling. Results obtained with this model show that the quasi equipressure zone with low velocity has been well represented and pressure values computed below the separation line are similar to those given by the experiments (fig. 4). On fig. 5 are shown pressure distribution along the lower symmetry line computed with and without wake compared with the experimental data. Presence of the wake has improved the results at the second velocity peak. This is good proof of the influence of the wake not only over the whole rear part but also upstream of the aft contraction. There still remains a slight underevaluation of the velocity in that area, most likely due to the unsophisticated definition of the separation line situated in a region of sharp gradient velocities. The tailboom being slightly conical, the wake represented by a cylinder generated by lines parallel to the freestream direction is not closed on to the boom. This gap in the geometry is responsible for the high velocities on the side of the tailboom (see fig. 4). This cylindrical wake topology also implies that all the lower part of the tailboom is situated in the equipressure zone, though experimentally the flow in that area is close to being a potential flow. This explains the discrepancy of the pressure values at the end of the lower symmetry line (fig. 5).

5 Conclusion

Within the framework of potential inviscid flow, a wake model has been developed that provides accurate pressure values at the aft contraction, downstream of the separation line. Improvements still remain necessary in order to obtain precise pressure distribution over the whole of the fuselage so as to be able to compute the pressure drag. Further work will consist in:

- a better definition of the separation line, adapting the mesh so as to provide a smoother wake avoiding too broken a topology
- a wake geometry that excludes the tailboom from the equipressure zone
- implementing a wake equilibrium treatment.

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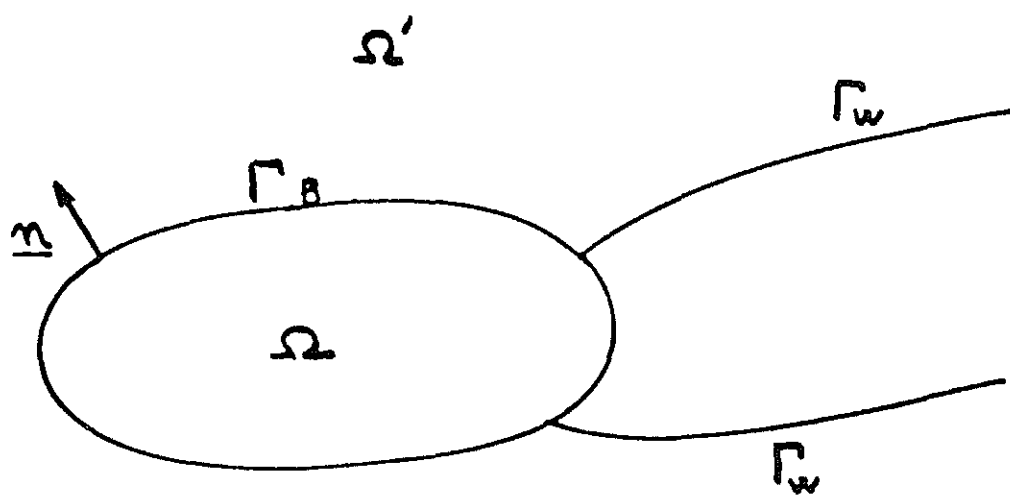


Fig. 1. Fluid domain and boundaries

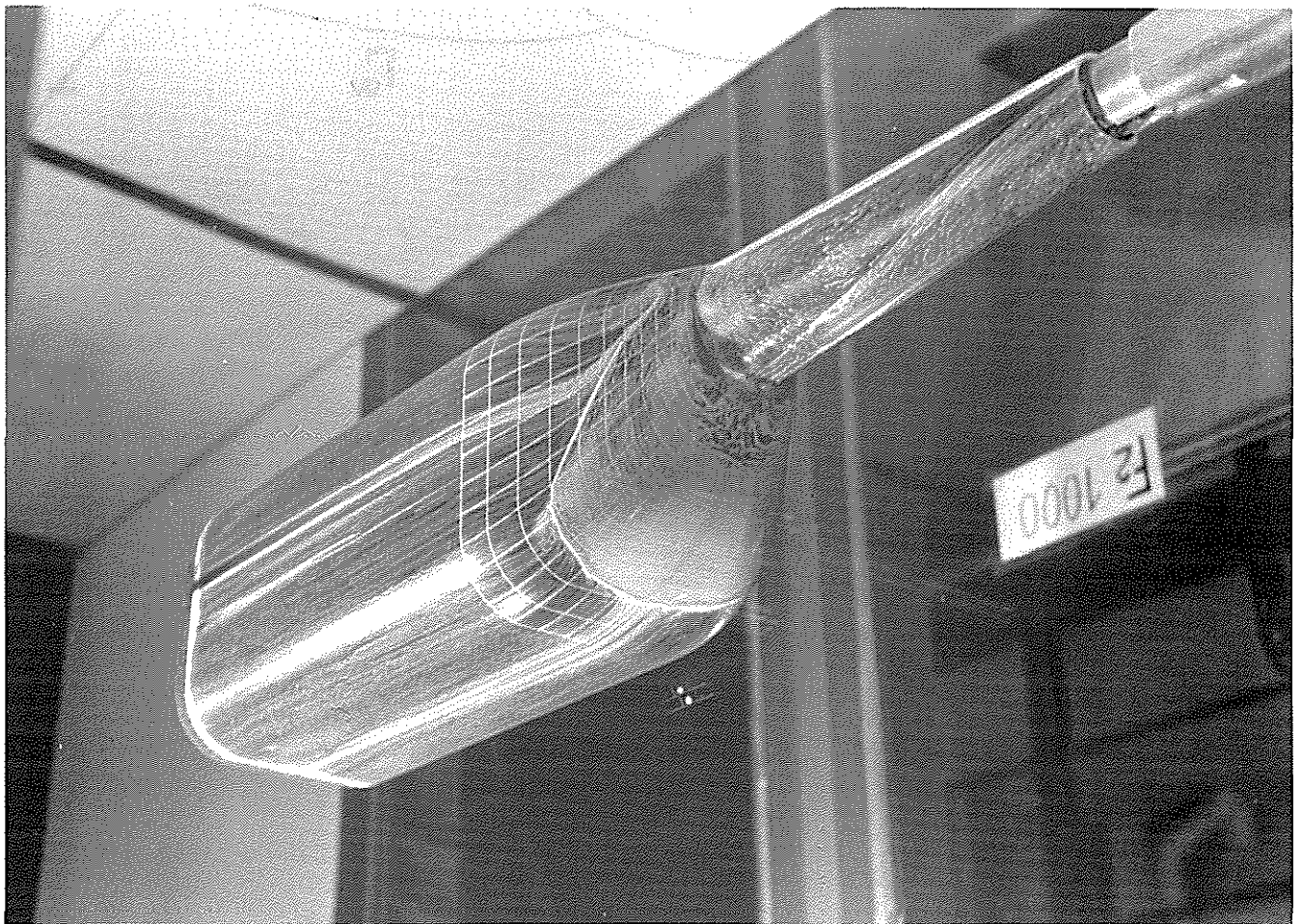
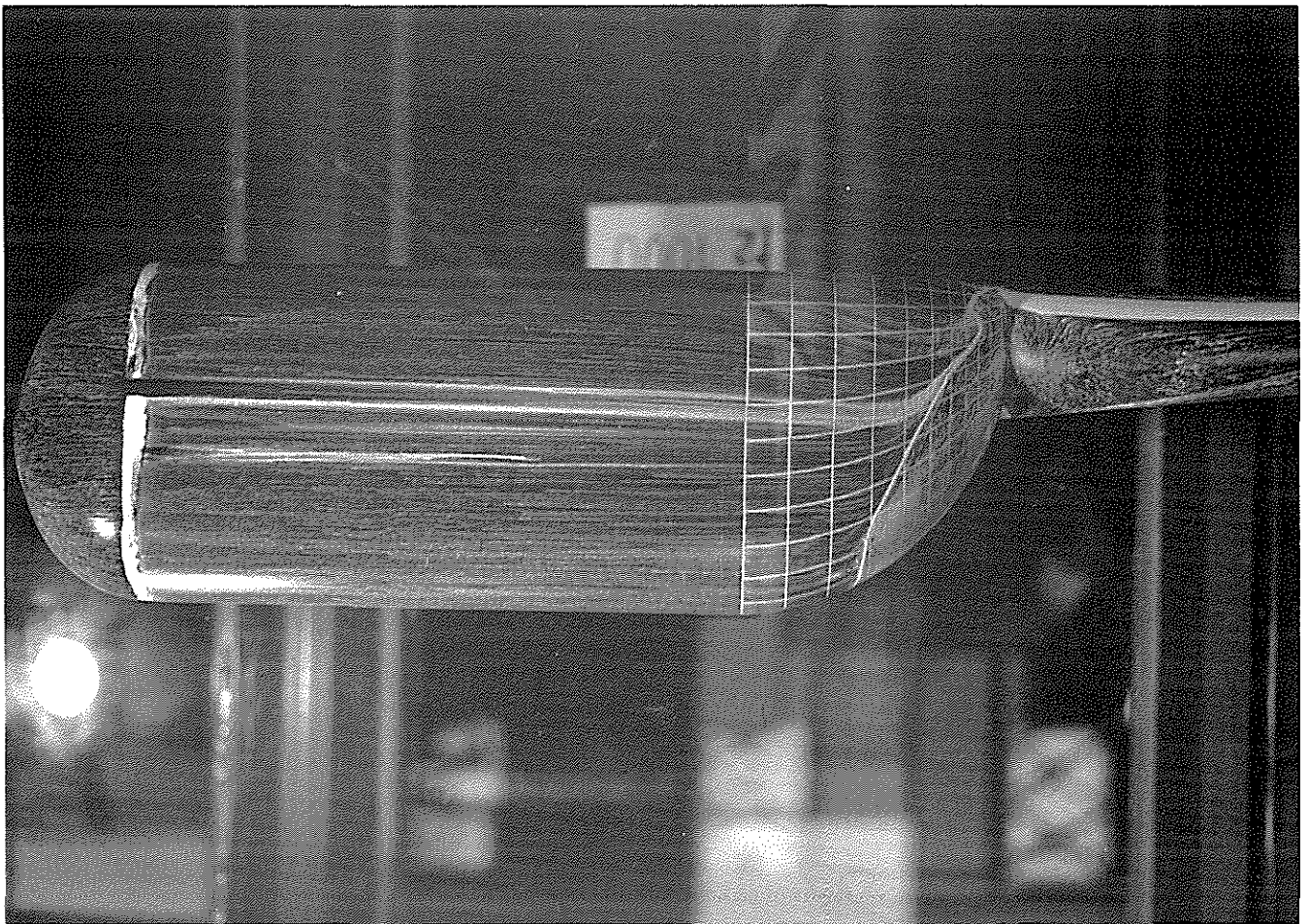


Fig. 2. Oil flow visualisation at 0° angle of attack

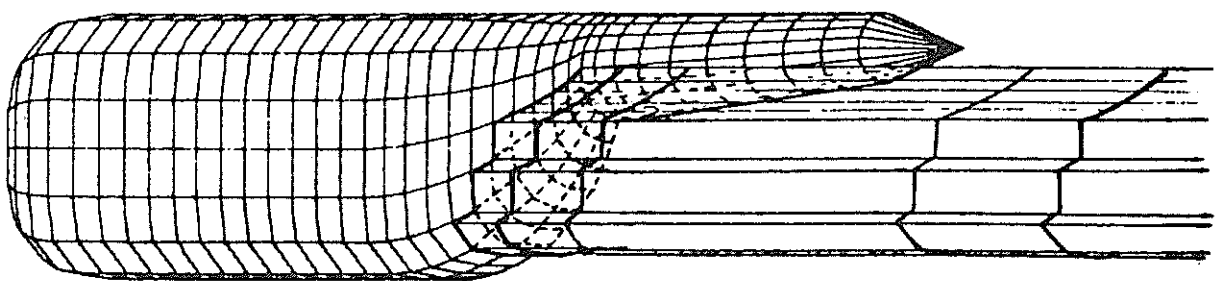
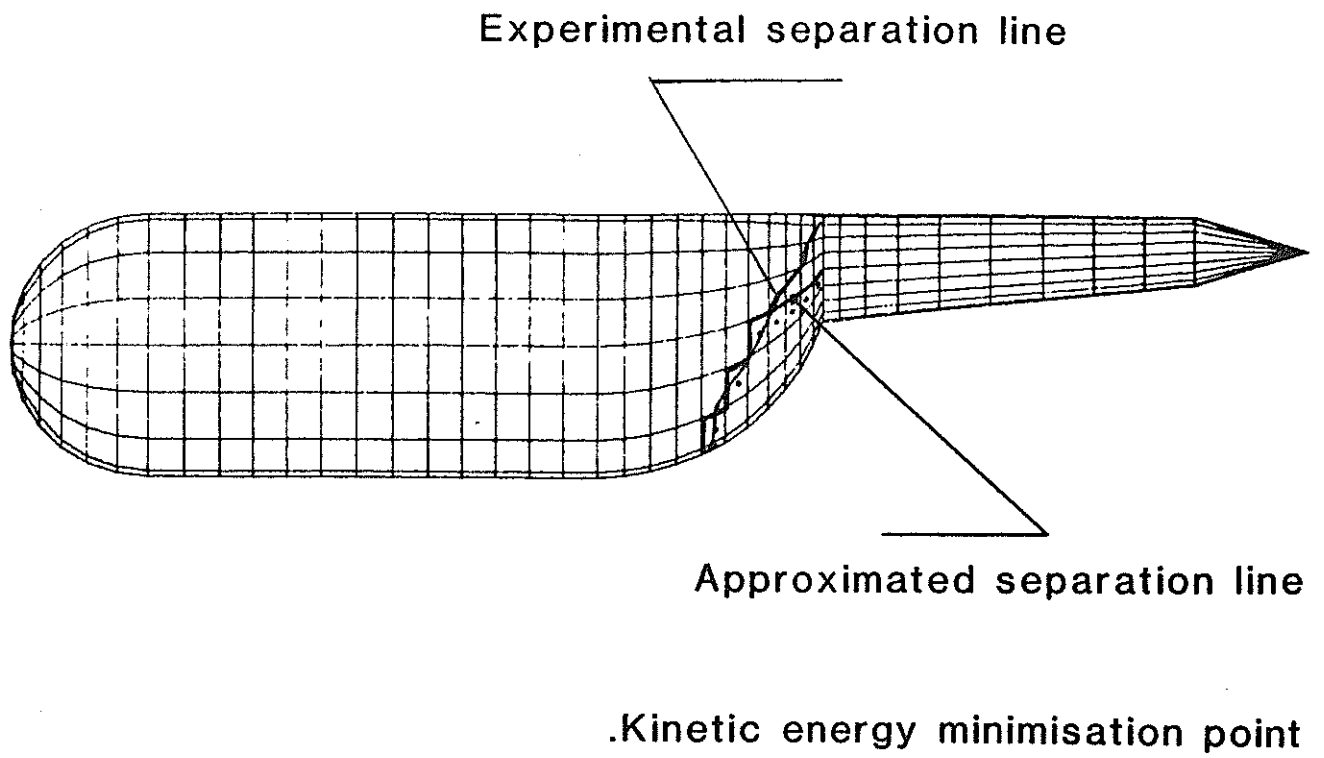


Fig. 3. Grid view and wake location

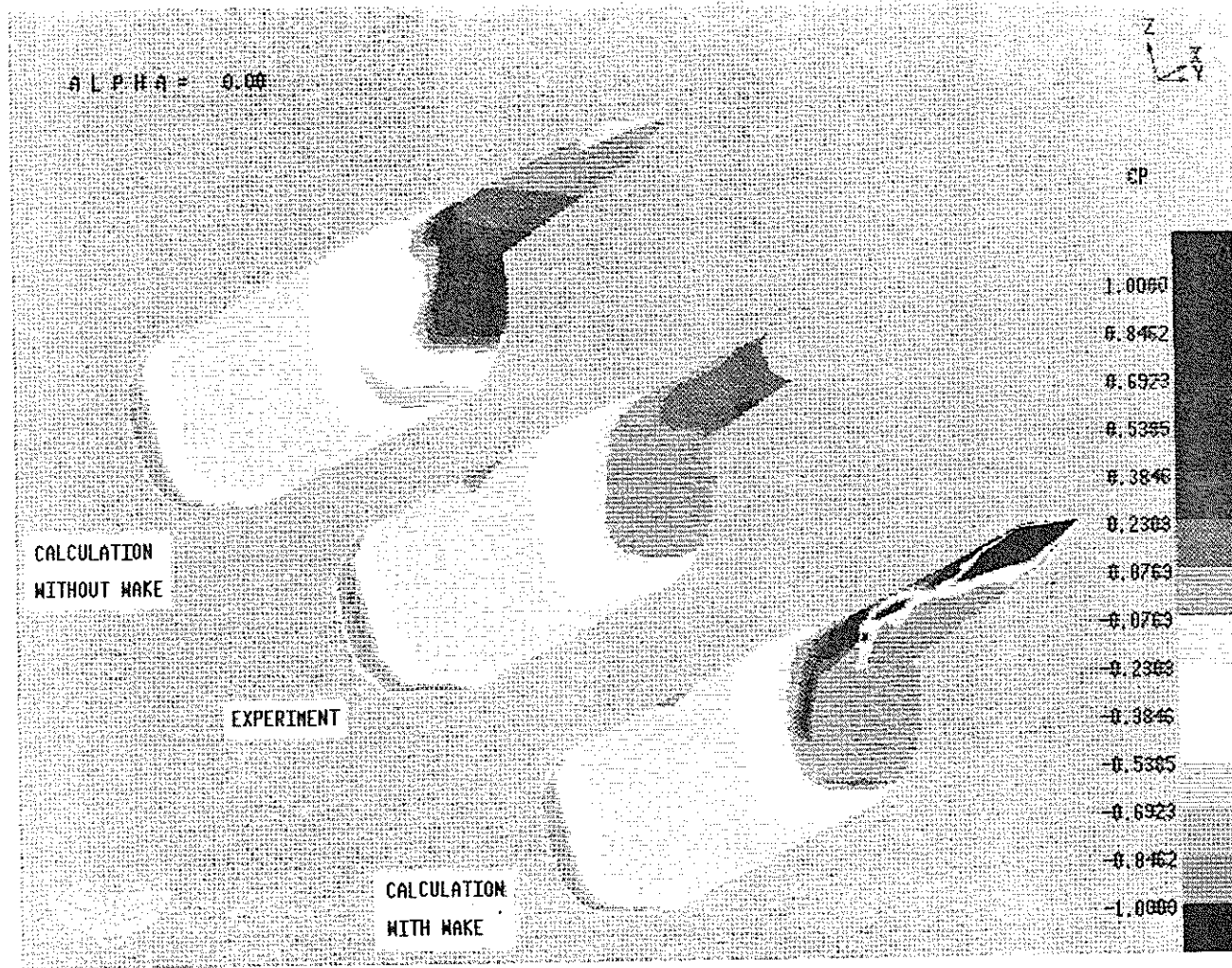


Fig. 4. Pressure distribution

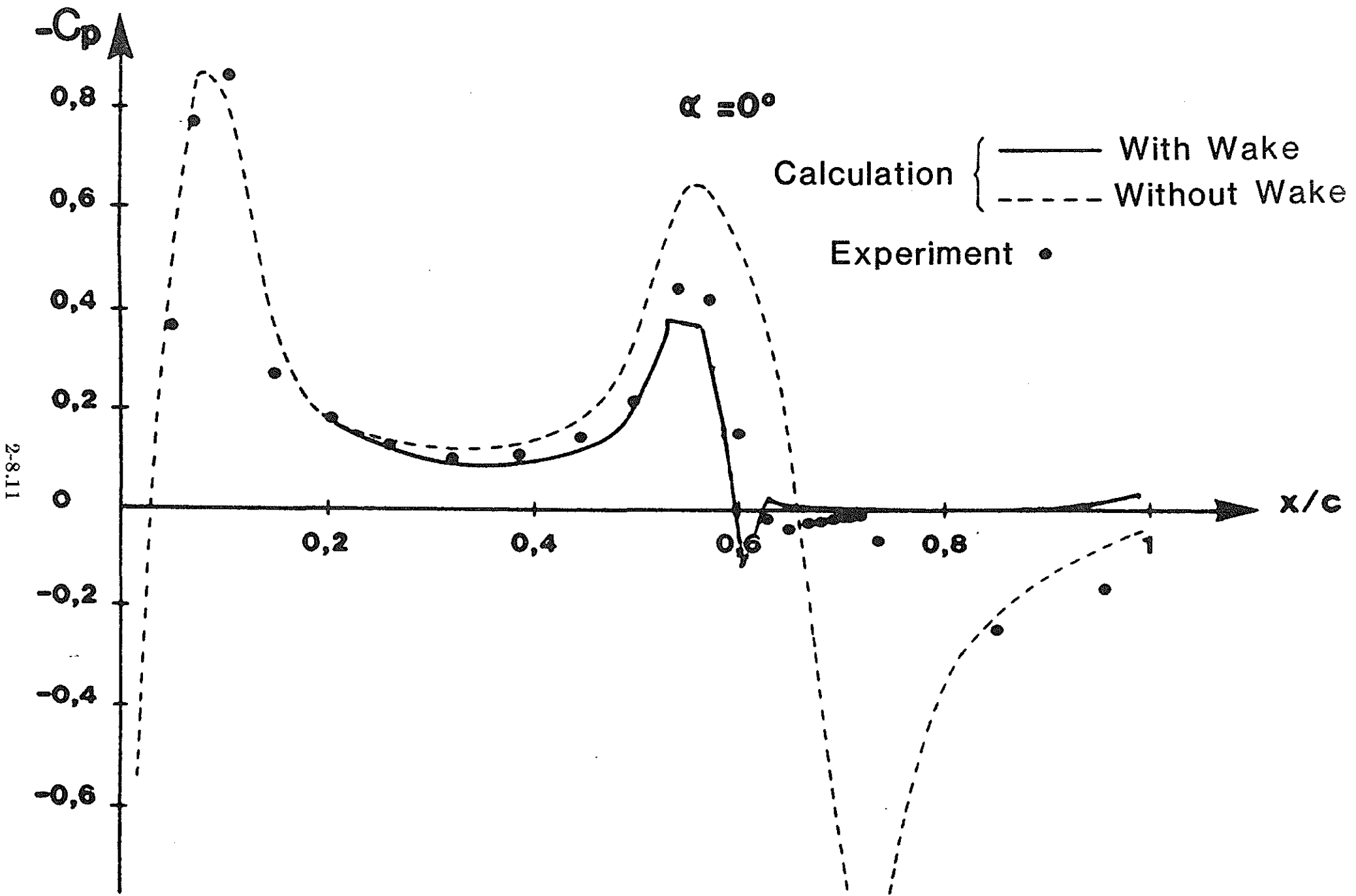


Fig. 5. Pressure distribution on lower symmetry line