1. Publication Nº	2. Version	3. Date	5. Distribution
INPE-4132-PRE/1043		*Feb., 1987*	☐ Internal ☒ External
4. Origin: *DMC*	Program: *ATDMC*		☐ Restricted

6. Key words - selected by the author(s)

AERODYNAMICS — *PRESSURE DISTRIBUTIONS*
PANEL METHODS — *WIND TUNNEL WALL*

7. U.D.C.: *629.7.018.1*

8. Title *INPE-4132-PRE/1043*

COMPARING AND IMPROVED 1st ORDER PANEL METHOD WITH RESULTS WIND-TUNNEL MEASUREMENTS FOR A COMPLETE AIRPLANE CONFIGURATION

10. Nº of pages: *15*

11. Last page: *14*

12. Revised by

Wolodymir Boruszewski

Wolodymir Boruszewski

9. Authorship *Francisco Leme Galvão*

Responsible author Francisco L. Galvão

13. Authorized by

Marco Antonio Raupp
Director General

14. Abstract/Notes

A numerical computation of pressure distribution over a complete comercial airplane configuration, using an improved first order panel method, is made and results are compared with experimental measurements obtained for the same configuration with a 1/14 model at the ONERA's Modane wind-tunnel.

15. Remarks

Proposed to be presented in Boundary Element Technology Congress - BETECH-Rio/87, 2-4 June 1987.

COMPARING AN IMPROVED 1st ORDER PANEL METHOD RESULTS WITH WIND-TUNNEL MEASUREMENTS FOR A COMPLETE AIRPLANE CONFIGURATION

Galvão, Francisco L.

Departamento de Engenharia Mecânica Espacial, Instituto de Pesquisas Espaciais, 12201 São José dos Campos, SP, Brasil.

1 - SUMMARY

A numerical computation of pressure distribution over a complete comercial airplane configuration, using an improved first order pannel method, is made and results are compared with experimental measurements obtained for the same configuration with a 1/14 model at the ONERA's Modane wind-tunnel.

It is shown that for subcritical Mach numbers and attached flow angles of attack, a fair agreement can be found between computed and measured pressure values and also that wind-tunnel and nacelle internal flows can be correctly simulated.

2 - NUMERICAL CODE DESCRIPTION

2.1 - Original Code

The original numerical code adopted was the Aerospatiale's AM37 FORTRAN program, which basically consists of a first order panel method using constant strength source sink and doublets plane panels (Yermia and Bousquet[1]) similar to those described in (Krauss[2]) and (Labrujere et al.[3]).

The code used is limited to 2000 panels that can be grouped into 17 different elements, 5 of which can be assumed to be of the "lifting type" elements, each one containing a group of lifting strips.

Each lifting strip is composed of a closed surface source panel strip enveloping an internal doublet panel strip, that is made continuous through the trailing edge, generating a wake of constant doublet intensity.
The total number os lifting strips is limited to 30.

To remove the solution redundancy of the resulting Laplace's equation containing sources and doublets, the doublet intensities inside lifting strips are supposed to be proportional to the strip thickness derivative as in the Krauss[2] approach, and its trailing edge value is determined by a "Kutta condition".

Option to use two different "Kutta conditions" is provided, allowing a choice between zero normal velocity at a point situated just "outboard" the trailing edge panels (linear K-condition) or a pressure equality on trailing edge's upper and lower panels (nonlinear K-condition).

The resulting complete equation system is in the form:

$$\left[\begin{array}{c|c} S_S & T_S \\ \hline S_D & T_D \end{array}\right]\left[\begin{array}{c} \sigma \\ \hline \Gamma \end{array}\right] + \left[\vec{V}_\infty, \vec{n}\right] = \left[\, 0 \,\right]$$

where:

S are the source panels influence coefficient matrices and T the complete doublet strip influence coefficient matrices, σ being source and Γ the doublet strengths.

The system is solved by a Gauss-Sidel block reiteration scheme with the S matrices solved by direct inversion.

An option is also included for extending the wake doublet strips to infinity in the incident flow direction or to compute in an iterated fashion a wake strip that is parallel, at each wake panel, to the local flow direction. In the latter case the reiteration can [or not] include a new singularity strength computation [at will].

To account for the compressibility effects, the "Goethert" rule is applied to the surface defining points, changing their geometry while original surface control points and normal directions are kept unchanged to compute the "Neumman" boundary condition: $\vec{V}_\infty \cdot \vec{n}$.

Compressible pressure coefficients are computed as:

$$C_p = 2\left[\left(1 + \frac{\gamma-1}{2} \cdot M_\infty^2 \cdot (1-V^2)\right) \cdot \frac{\gamma}{\gamma-1} - 1\right] / \gamma . M_\infty^2$$

where: $V = V_\infty + V'/\beta$, V' being the perturbation velocity and $(1+M^2)^{0,5} = \beta$.

2.2 - Code Modifications

The original basic code was modified, first to include a nonzero normal velocity condition at user designated control points, as necessary to the engine's nacelle and wind-tunnel simulation models adopted (see ϕ 5).

Then, it was included the possibility of changing the doublet law inside lifting strips since the original code showed to be very sensitive to panel spacing specially for thinner wing shapes.

A first attempt was made using as doublet law the doublet distribution resulting from a stripwise integration of vortex intensities computed for the same geometry with a Woodward[4] vortex lattice code.

The results obtained were not satisfactory, probably due to the high peaks of vortex strengths typical of the thin-wing approach for nonadpated local angles (see fig. 4).

A final satisfactory approach was obtained with doublet strength derivatives proportional to velocity differences on upper and lower surface corresponding panels, and computed in an iterated manner so that for each iteration step we have:

$$\left\{\frac{\gamma(x)}{\gamma_{x=c}}\right\}_n = \left\{\frac{\int_0^x (V_x^u - V_x^\ell)\,dx}{\int_0^c (V_x^u - V_x^\ell)\,dx}\right\}_{n-1}$$

V_x^u and V_x^ℓ being the stripwise velocity computed on upper and lower surface in the previous step.

3.1 - Panelling

The panel geometry used was rather coarse in order to detect any method sensibility to panelling and also to reduce computation times. It also represents the author's lack of experience with such geometrical problems.

Considering that even physically ill-posed problems may give reasonable results, provided that fine panelling is used to impose boundary conditions practically everywhere, a coarse panelling was preferred.

Figure 1 to 3 give an idea of the mesh used.

Care was taken to obtain control points and normals coincident with the wind-tunnel model pressure taps.

In the fuselage, this objective led to the 14 longitudinal strips division adopted and in the engine nacelle to a 7 strip division.

3.2 - Internal Flow Simulation

To simulate wind-tunnel wall effects an additional element consisting of a closed box surface containing only source panels was fitted to the wind-tunnel test-section geometry, having inward oriented normals.

At inlet and outlet test-section surfaces, uniform normal velocities $V_n = V_\infty$ and $V_n = - V_\infty$, respectively, were imposed.

Although, in the author's knowlededge, most wall correction schemes utilize vortex-lattices and open surfaces, the proposed closed surface source-only one was expected to work and also, although not attempted in this study, source panels seem to be more adequate to represent porous or slotted wall effects.

To simulate the engine cowling or nacelle, a closed surface of source panels was chosen due to a reasoning similar to that used for the tunnel simulation.

Previous simulations with closed anular-wing type lifting strip elements have been extensively used with the AM37 code at Aerospatiale, but for the case in study it was thought that the source-only scheme would be adequate to simulate the "natural flow" the nacelle wind-tunnel model has been designed for (no jet).

Also a closed surface constant doublet plume resulting from an anular wing lifting surface seemed to be a meaningless and costly model with no effects outside its boundaries.

3.3 - Engine Pylon

The engine pylon was divided into one "lifting" and another "nonlifting" sections, the nonlifting one consisting of 2 panel strips (with some zero surface panels) corresponding to the front dorsal fin and to the pylon portion covered by the nacelle out-flow (see fig. 3).

These parts seemed not prone to generate strong "lift effects", the fin provided that no vortex shedding or separation were present and the rear lower pylon by the orientating effect of engine's nacelle out-flow.

4. WIND-TUNNEL TESTS

Wind-tunnel measurements were carried out at the ONERA's high subsonic 2 meter section wind-tunnel at Modane (Avrieux) using a 1/14 scale model having 840 pressure taps.

Scanivalves inside the model provided complete pressure measurements in a 180 sec. cycle!

Runs were made for one complete and 3 other partial model configurations in longitudinal and transverse angle sweeps covering:

Pitch angles : $-4^\circ \leqslant \alpha < 4^\circ$
Yaw angles : $-9 \leqslant \beta \leqslant 9^\circ$
Speed range : $0{,}3 \leqslant \text{Mach} \leqslant 0{,}91$

5. RESULTS

5.1 - Doublet Law

In fig. 4 it is shown the effect over a midwing section obtained by different doublet laws in comparison with measured pressure values.

The corresponding doublet laws resulting from the iterative scheme are shown in fig. 5.

At the second iteration (started from the original law) the doublet law changes are already very small and due to the sources predominance over doublets on control points, the effects on velocity and pressure are even smaller.

A third iteration showed negligible variations unless global force coefficients were compared, so results of the 2nd iteration were considered to be satisfactory for the precision level of this study.

The most impressive effect of doublet law change is shown in fig. 6, where spanloadings are compared.

5.2 - Internal Flows

In fig. 7 it is shown the wind-tunnel effects over spanloading both presented cases computed with the original doublet-law for a simpler airplane configuration without engines and pylons.

Although no numerical comparison with other wall correction methods has been made, the effect obtained was qualitatively correct and the agreement of measured pressures at isoangle of attack seem to justify the wind-tunnel simulation adopted.

In fig. 8 it is shown the computed and measured pressure distributions obtained for the nacelle.

The failure of computation to reproduce the suction peaks at nacelle's inlet can be better attributed to a large internal separation with reduced mass flow in the experimental set-up than to a computational model failure.

Indeed external inlet peaks have been obtained in the computation model by reducing the internal flow and corresponding inlet and outlet imposed velocities

5.3 - Other Results

In fig. 10 the wing root, middle and tip sections computed and measured pressures are shown for 0° angle of attack and also for 4° for the middle section (fig. 11).

A fair agreement is obtained everywhere, except in the upper leading edge for 4° angle of attack where critical conditions of sonic flow are attained.

Viscous effects are weak, except in upper surface trailing edges where thick boundary layer can explain the pressure discrepancies.

Fig. 12 shows the computed and measured pressure distributions obtained for the horizontal tail, also indicating a failure of the theoretical model to reproduce the correct flow direction at tail location.

It seems that this failure can be caused by the use of constant doublet panels which correspond to discrete vortex lines at panel strips intersections in the wake.

Also the lack of simulation of the vortex viscous decay can be a factor.

6 - CONCLUSIONS

The case study carried out with this modified first order panel method code indicates that:

- Wing-body-tail complete airplane configuration analysis methods using external surface source panels and internal doublet panels can be improved by doublet determination procedures more in accordance with the rotational physical phenomena in 3D flows and wing surface theories.

An example is the doublet law scheme adopted in this study. (see also Hess[5]).

- Nonzero normal velocities in conjunction with closed surface plane source panels seem to be useful tools for internal flow simulations including wind-tunnel flows.

- The comparison of computed and measured pressure distributions indicates that first order panel methods, as described in this study, are adequate to obtain theorical pressure distributions to be used in connection with load calculations (or other) for subcritical and separation free flow conditions, provided that tail and fuselage load and moments are adjusted to stability and control wind-tunnel or better to flight tests measurements.

7 - ACKNOWLEDGMENTS

This work[6] was done during an eight month training the author made in 1980 at Aerospatiale's Toulouse "Bureau d'Étude" under the joint sponsorship of CNPq, CEFI and EMBRAER. He is particularly grateful to the help of ingénieurs Yermia, M and Bousquet, J.

8 - REFERENCES

1. M. Yermia & J. Bousquet. (1977) Calculs d'ecoulements potentiels subcritiques autor de corps tridimensionnels par une méthode des singularités. AEROSPATIALE - Note Technique DIV-1004

2. Werner Krauss. (1976) Panel Methods in Aerodynamics. Von Karman Institute - VKI. Lecture Series 87

3. E. Labrujere, W. Loeve and J.W. Sloof. (1970) An Approximate Method for the Calculation of Pressure Distribution on Wing-Bodies Combinations at Subcritical Speeds. National Aerospace Laboratory - N.L.R. - M.P. 70014 U

4. Woodward F.A. (1968) Analyses and Design of Wing-Body Combinations, at Subsonic and Supersonic Speeds. Journal of Aircraft Vol 5

5. John L. Hess. (1972) Calculation of Potential Flow About Arbitrary Three Dimensional Lifting Bodies. Douglas Aircraft Co. - NTIS AD 755480

6. Galvão F.L. (1981) Rapport de stage. AEROSPATIALE - Note Technique 443-537/81.

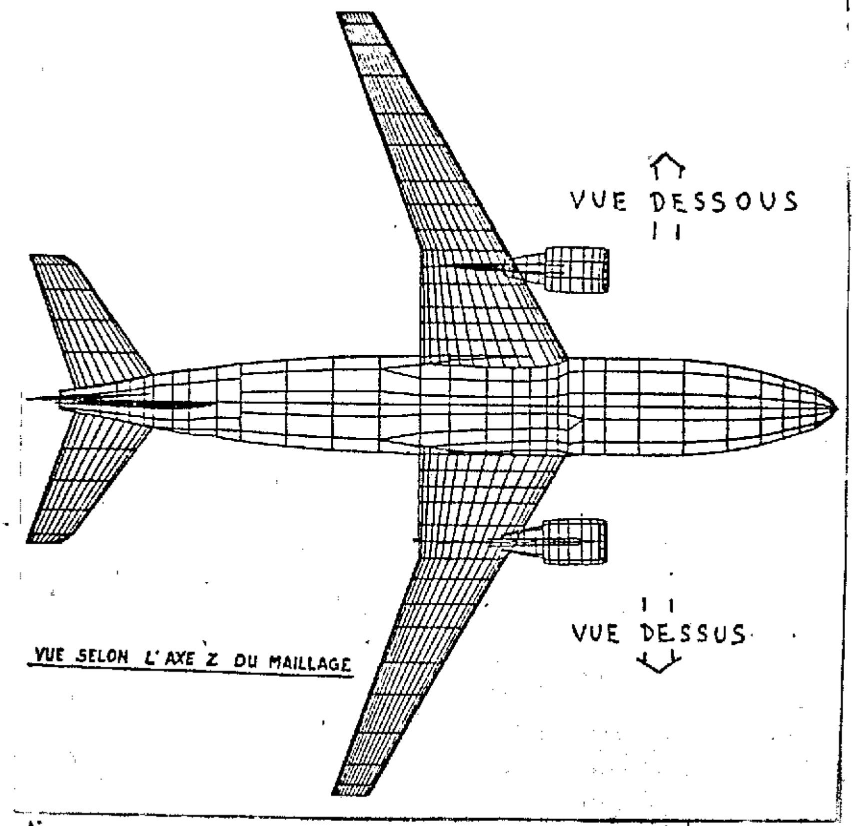

Fig. 1 - Z Axis views of panelling

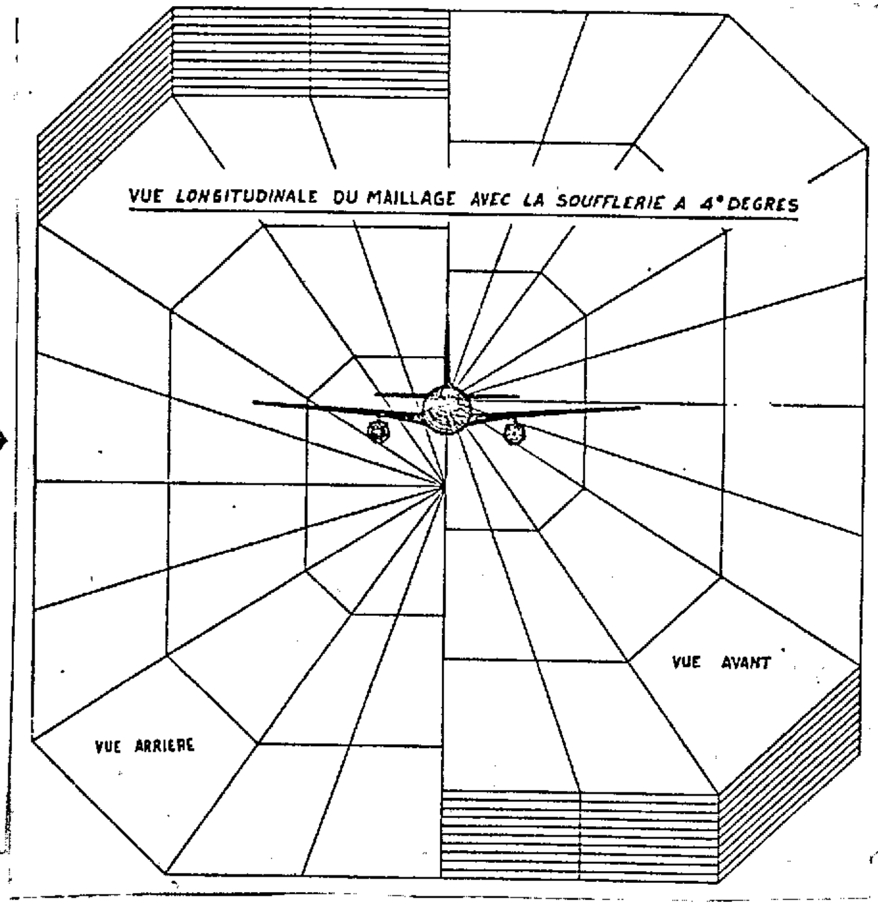

Fig. 2 - Longitudinal panelling view.
(with wind-tunnel at 4^{o})

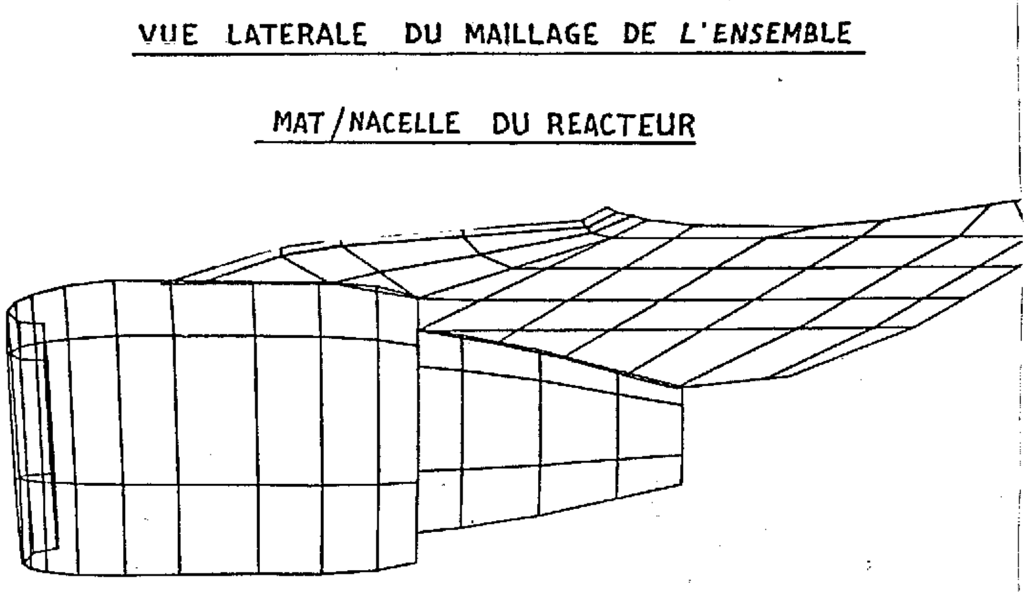

Fig. 3 - Pylon and cowling panelling lateral view.

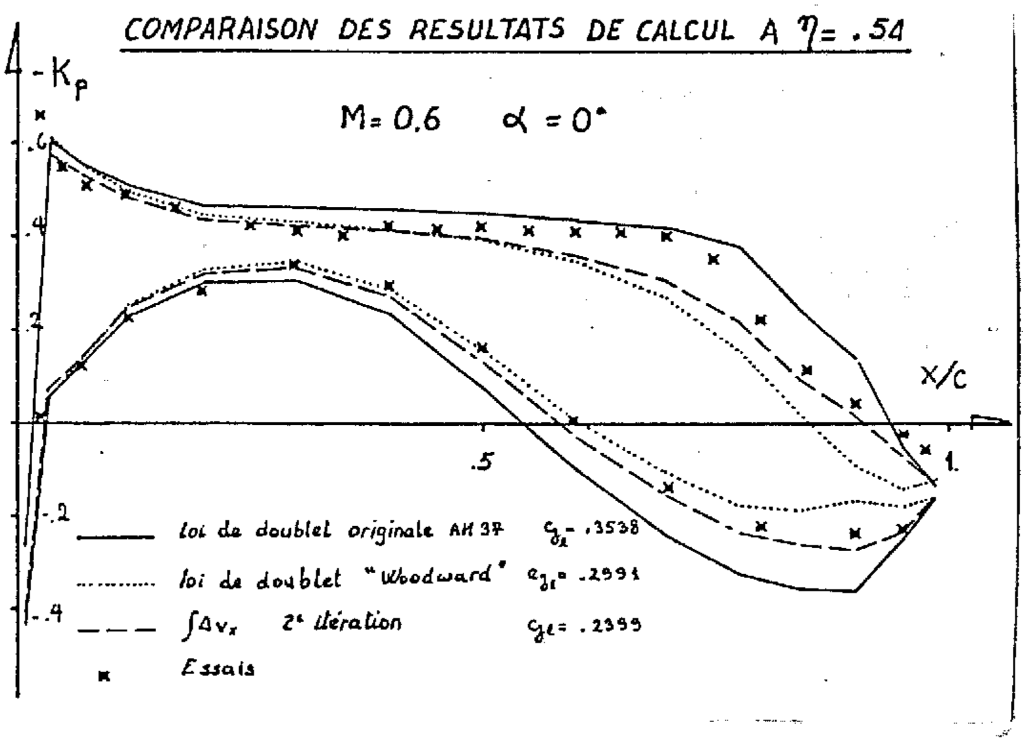

Fig. 4 - Mid span computation and test results.

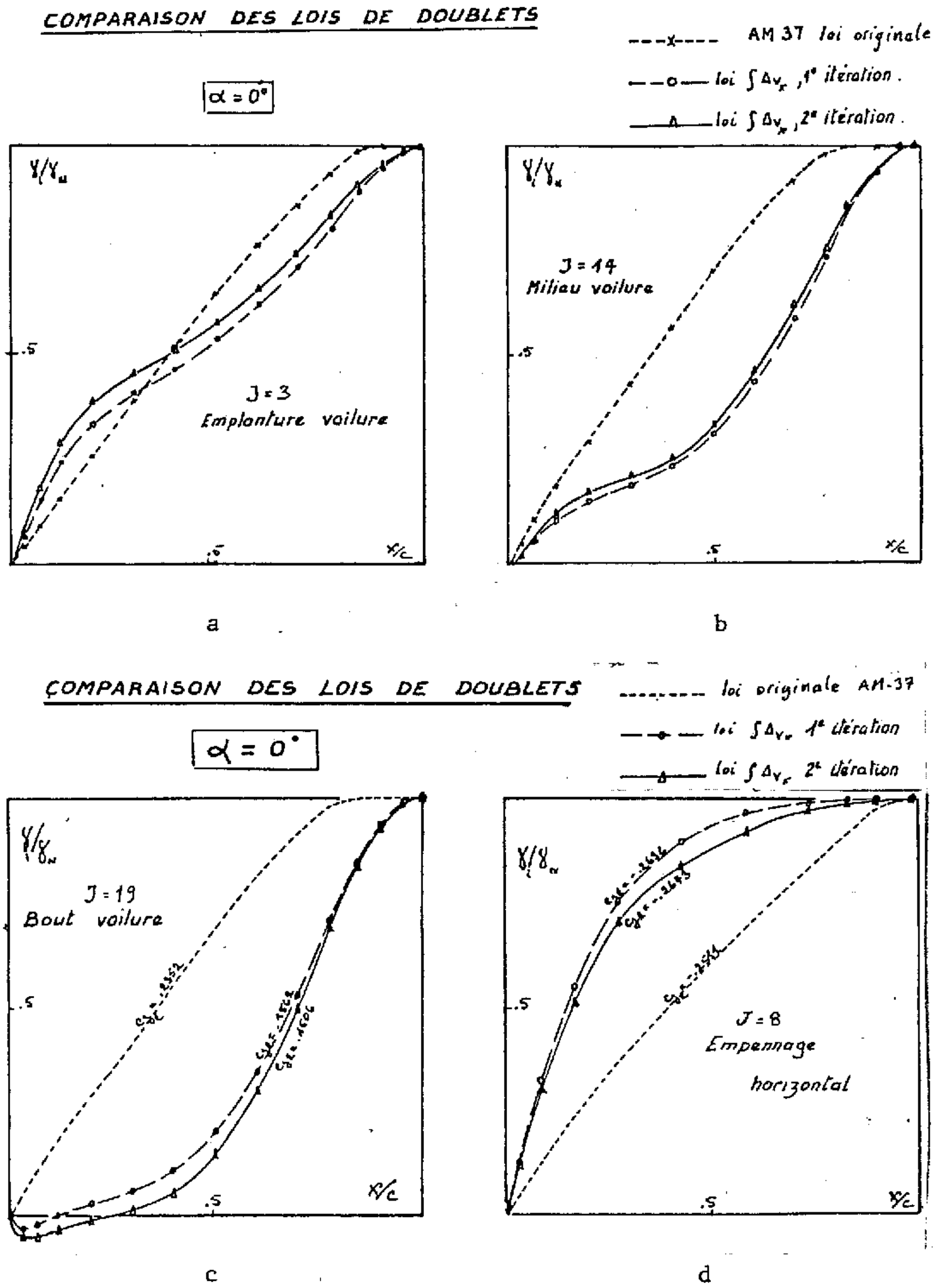

Fig. 5 - Doublet laws comparison.

a - wing root b - midwing
c - wing tip d - tail-plane

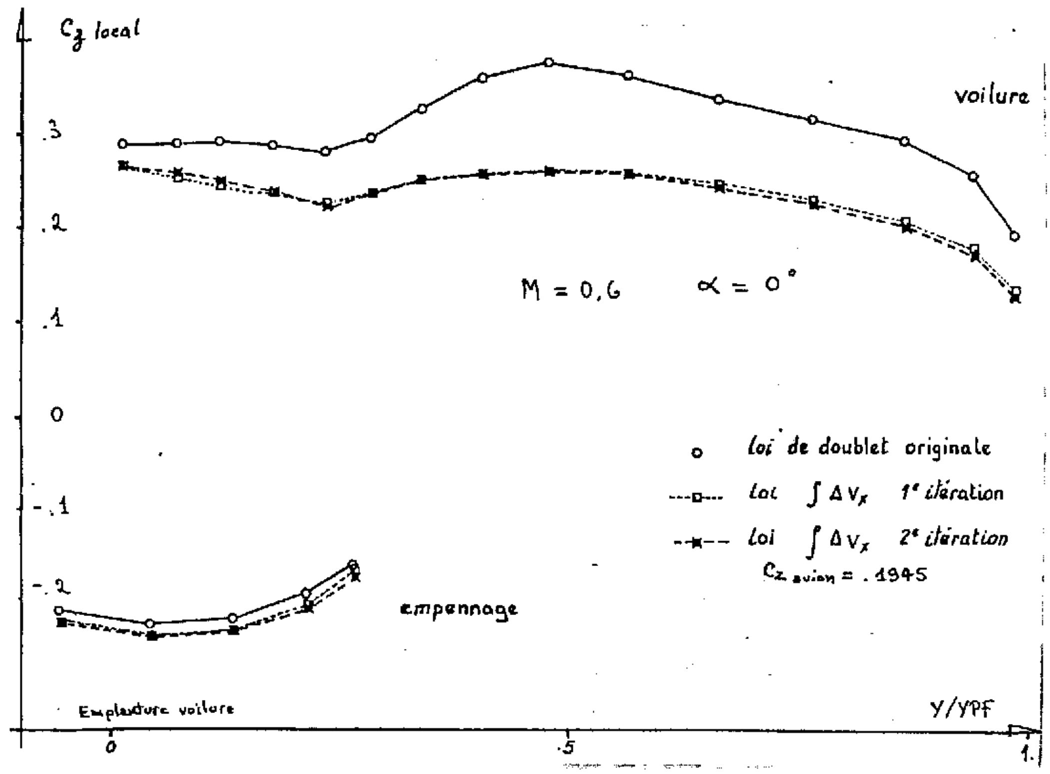

Fig. 6 - Span loadings comparison.

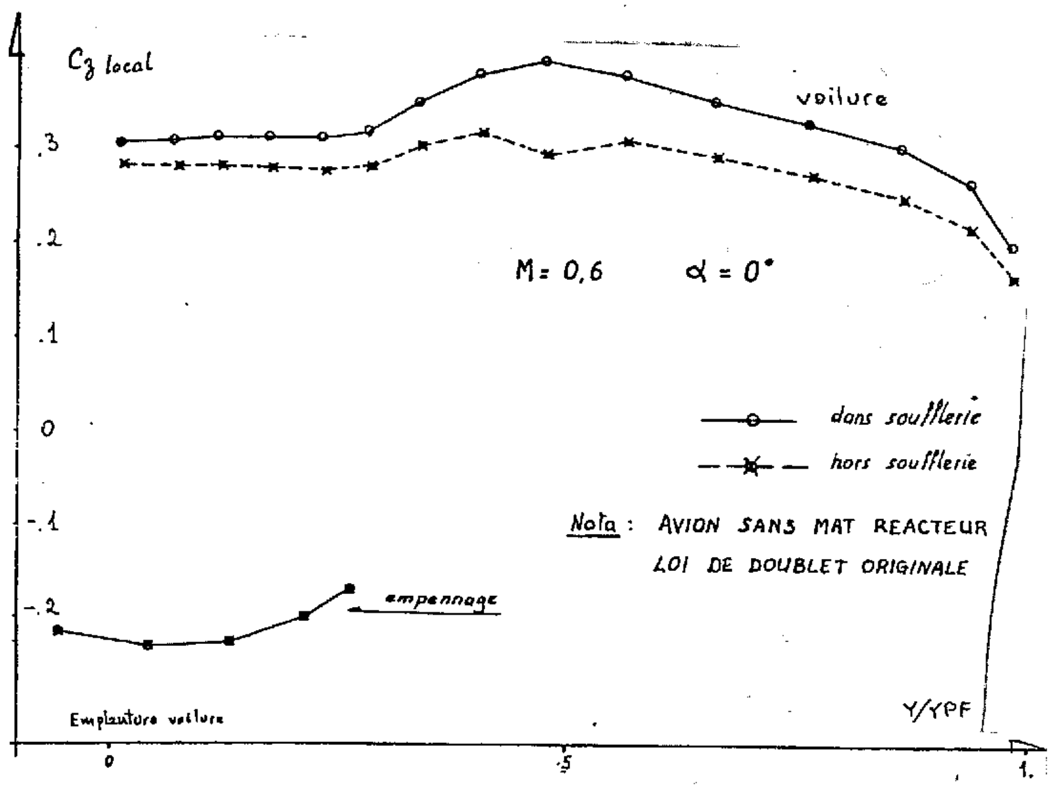

Fig. 7 - Wind-tunnel wall effects on span loading.

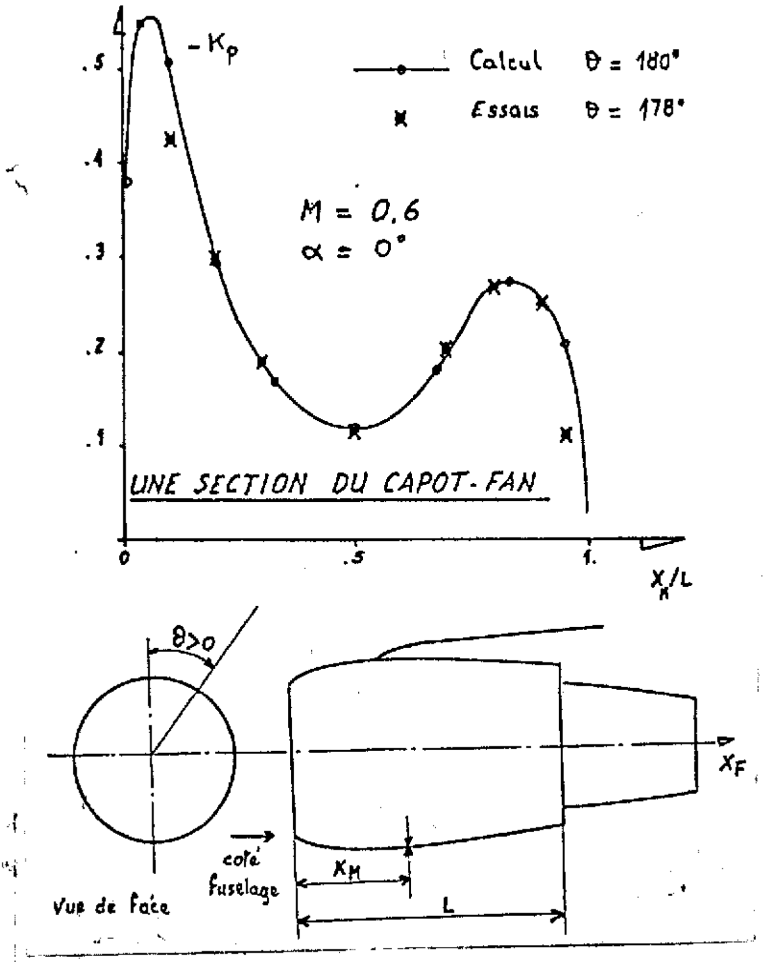

Fig. 8 - Lower fan section pressures comparison

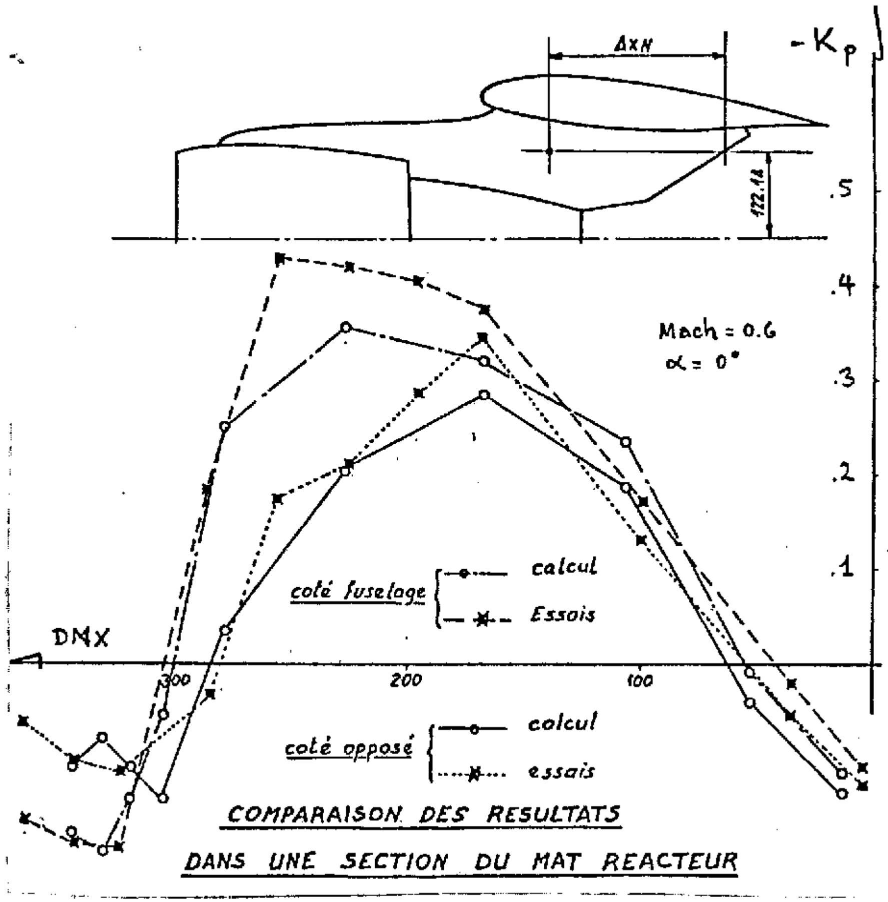

Fig. 9 - Pylon section pressures comparison.

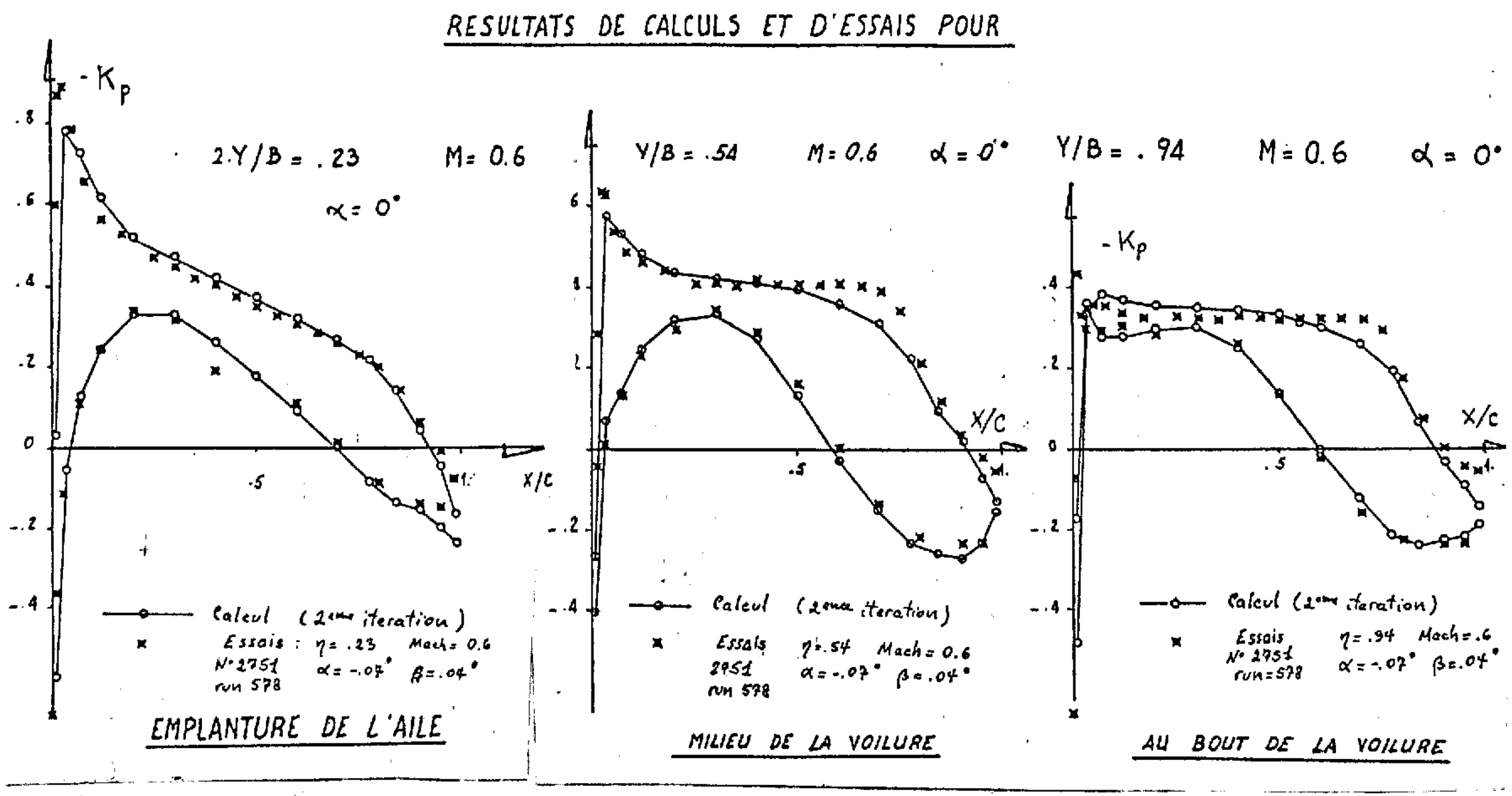

Fig. 10 - Comparison of wing section computed and measured pressures.

a) wing root b) mid span c) wing tip

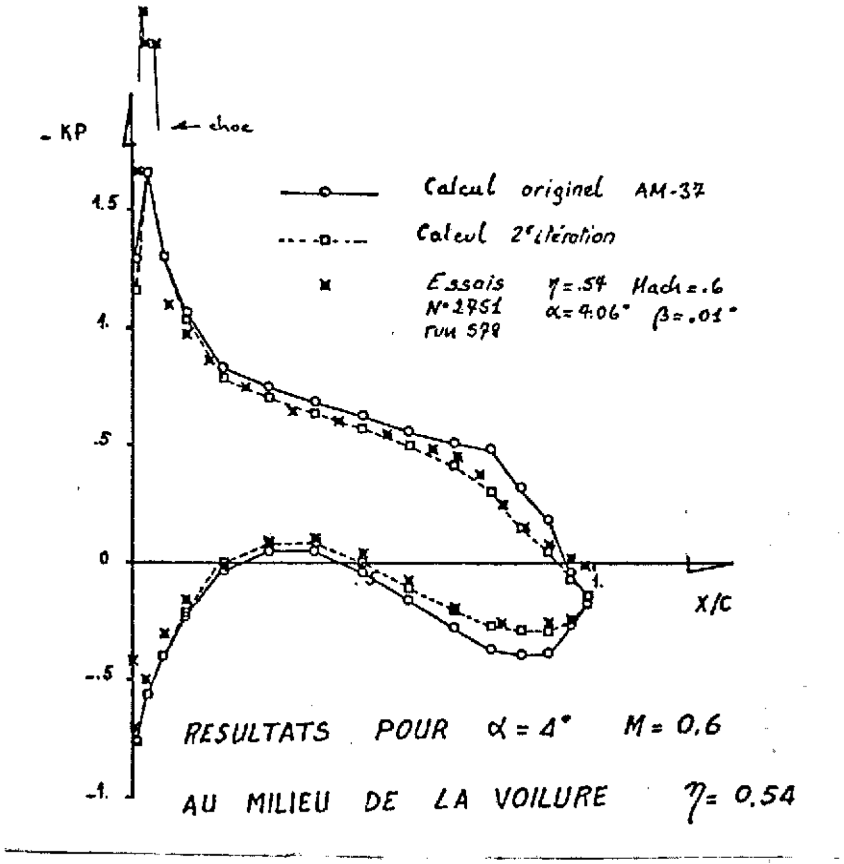

Fig. 11 - Wing mid section pressure comparison for $\alpha = 4^{o}$, M=0,6

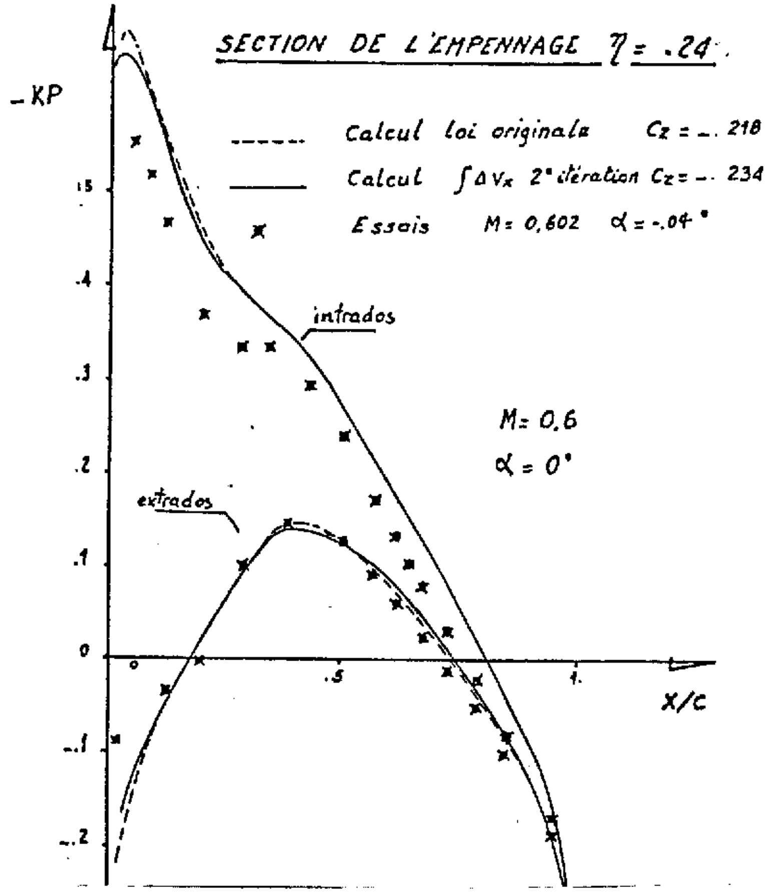

Fig. 12 - Tailplane section pressure comparison.

CONSELHO NACIONAL DE DESENVOLVIMENTO CIENTÍFICO E TECNOLÓGICO
INSTITUTO DE PESQUISAS ESPACIAIS

PROPOSTA PARA PUBLICAÇÃO

DATA: 30.01.87

IDENTIFICAÇÃO

TÍTULO: COMPARING AN IMPROVED 1ST ORDER PANNEL METHOD WITH WIND-TUNNEL MEASUREMENTS FOR A COMPLETE AIRPLANE CONFIGURATION:

AUTORIA: Francisco Leme Galvão

PROJETO/PROGRAMA: ____

DIVISÃO: ____

DEPARTAMENTO: EME

DIVULGAÇÃO [X] EXTERNA [ ] INTERNA MEIO: BETECH/RIO/87

REVISÃO TÉCNICA

REVISOR TÉCNICO: Wolodymir Boruszewski

RECEBI EM: ____ REVISADO EM: ____

OBSERVAÇÕES: [ ] NÃO HÁ [ ] VER VERSO

DEVOLVI EM: 25/01/87 ASSINATURA: Wolodymir Boruszewski

APROVAÇÕES

APROVADO: [ ] SIM [ ] NÃO [ ] VER VERSO

DATA ____ CHEFE DIVISÃO ____

APROVADO: [X] SIM [ ] NÃO [ ] VER VERSO

DATA: 30/01/87 P/ CHEFE DEPARTAMENTO: [signature]

REVISÃO DE LINGUAGEM

Nº: 16 PRIORIDADE: 1

DATA: 02.02.87

REVISADO [ ] COM [ ] SEM CORREÇÕES [ ] VER VERSO

POR: Maria do Carmo S. Soares

DATA: 2-2-87 ASSINATURA: [signature]

DATILOGRAFIA

O(S) AUTOR(ES) DEVE(M) MENCIONAR NO VERSO, OU ANEXAR NORMAS E/OU INSTRUÇÕES ESPECIAIS

RECEBIDO EM: ____

CONCLUÍDO EM: ____

DATILÓGRAFA: ____

ASSINATURA ____

PARECER

FAVORÁVEL: [ ] SIM [ ] NÃO [ ] VER VERSO

DATA ____ RESPONSÁVEL/PROGRAMA ____

EM CONDIÇÕES DE PUBLICAÇÃO EM: 5/02/86

AUTOR RESPONSÁVEL: FGalvão

AUTORIZO A PUBLICAÇÃO: [ ] SIM [ ] NÃO

DIVULGAÇÃO [ ] INTERNA [ ] EXTERNA MEIO: ____

OBSERVAÇÕES: ____

DATA ____ DIRETOR ____

SEC

PUBLICAÇÃO: 4132PRE/1013 PÁGINAS: ____ ÚLTIMA PÁGINA: ____

CÓPIAS: ____ TIPO: ____ PREÇO: ____