ANALYTICAL INVESTIGATION OF ROTOR WAKE FORMATION AND GEOMETRY

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During the six months from April to October, 1985, progress was made with both the Euler code calculation task and the rotor optimization task as briefly described below.

EULER CODE TASK

During this period a number of refinements in the computer code were worked out and tested. Three codes have been written to date. One program is for an isolated wing and is being used to compare with data for the vortex wake (Weston). The second code is for an isolated wing with a streamwise vortex passing above it. This program is being used to validate the computational procedure for incorporating the vortex into the Euler equation calculations. The third program is the hovering rotor code which is the overall objective of the research. In this six month period, attention has been given mostly to the first two of these three programs. An attached abstract submitted to the AIAA 4th Applied Aerodynamics Conference in San Diego in June describes our progress on these programs.

We plan to turn our attention to the third program to get it updated during January 1986, and then to perform the final calculations of the study during February 1986. A more detailed description of our progress is being written and will be available during the next period.

ROTOR OPTIMIZATION TASK

The optimization calculations for a hovering helicopter rotor have been completed and are being prepared in a thesis by Song Young Chung which will be submitted later.

ORIGINAL PAGE IS OF POOR QUALITY

Abstract Submittal Form

Abstract Submittal Form

Print or type all information

I wish to submit an abstract for (conference/meeting): AIAA 4th Applied Aerodynamics Conf.

Place: San Diego, CA **Date:** June 9-11, 1986

Session/organizer (this information appears in the call): Marvin M. Walters

Reminders:

1/ AIAA has first publication rights to all papers presented at its meetings. Manuscripts accepted for the meeting will be evaluated for publication in the appropriate AIAA publication, if the author requests it. If a Progress Series book is planned, papers from relevant sessions will be held for the book.

2/ Authors must inform each organizer if abstract is submitted to more than one session topic organizer.

3/ All program participants and authors will be charged a registration fee (AIAA member rate) at the meeting.

4/ Authors of accepted papers will be expected to submit a 100-word abstract (12 weeks before a meeting) and a photo-ready manuscript (6 weeks before a meeting). Authors desiring journal publication should send 4 copies of their photo-ready manuscript directly to the Editor in Chief of the journal of their choice (see inside front cover of each journal for correct address), along with a covering letter, before the meeting, if they wish to accelerate the review procedure. Government Program Monitors/Security Officers should be alerted as soon as authors receive formal acceptance of their paper.

Paper title (this title will be published in the Program):

Euler Solutions for the Flow Around a Hovering Helicopter Rotor

Author/s' name and title, AIAA membership grade, company, full mailing address, telephone number:

1 Author presenting paper	2
Thomas W. Roberts, Member M.I.T. 37-354 Cambridge, MA 02139	Earll M. Murman, Assoc. Fellow M. I. T. 33-217 Cambridge, MA 02139
3	4

Abstract due date: November 19, 1985

Draft of paper included? ☐ Yes ☒ No

Similar results been presented or published elsewhere? ☐ Yes ☒ No

Concise statement of problem (its genesis and objective covered):

See attached abstract

Scope and methods of approach, with statement of contribution to the state-of-the-art or an application of existing analytical techniques and theories to a problem:

See attached abstract

Summary of important conclusions:

See attached abstract

Statement of data used to substantiate conclusions, and freehand sketches of major figures to be used (no more than two typed pages):

Euler Solutions for the Flow Around a Hovering Helicopter Rotor

Thomas W. Roberts
Earll M. Murman

1 Introduction

In recent years, computational fluid dynamics technology has been highly developed for fixed wing aircraft configurations. The same cannot be said for rotary wing aircraft. In the case of a helicopter rotor in hovering flight, which may be treated as steady in the frame of reference of the rotor, an important effect is the interaction of the tip vortex trailed from one blade with the following blade. This interaction results in large variations in the loading at the blade tip. Furthermore, the semi-infinite vortex wake of the rotor has a significant influence on performance and must be included. The need to include these effects poses quite a challenge for existing computational techniques.

The computation of aerodynamic flows using the compressible Euler equations allows the "capturing" of vortical wakes trailed from lifting surfaces. However, due to grid stretching and numerical viscosity, the wake vorticity is diffused as it is convected downstream. For this reason, an Euler calculation around a complete rotor configuration is impractical, as the tip vortex of each rotor blade will be quite diffuse by the time it reaches the following blade. The steep spanwise gradients in the aerodynamic loading near the tip due to the blade/vortex interaction will not be correctly computed. Also, a model for that part of the semi-infinite wake that lies outside the computational domain is required if accurate values for the thrust, induced power, and the initial radial contraction of the wake are to be obtained.

In the proposed paper, we will solve for the flow field around a hovering helicopter rotor using an approach that contains the following features:

1. an Euler calculation of the near field of a rotor blade, including the formation and roll-up of the attached vortex wake;
2. treatment of the tip vortex of the preceeding blade such that the vortex is not destroyed by numerical diffusion; and
3. inclusion of the influence of the semi-infinite wake.

2 Technical Approach

The basic scheme for solution of the Euler equations for the flow around the rotor blade is a finite volume, multi-stage algorithm based on the work of Jameson and Baker [1]. An O-O mesh topology is used to get good resolution of the tip, leading edge, and trailing edge regions of the blade (fig. 1). The semi-infinite vortex wake is treated using by the free wake model of Miller [2,3]. The coupling of the free wake and the near field blade calculations will be performed in a fashion similar to the approach used by Roberts and Murman [3] for a lifting line representation of the blade, and is outlined below.

To account for the close encounter between the rotor blade and the tip vortex from the preceeding blade a prescribed vortex, or perturbation, approach will be used to include this vortex without the attendant numerical diffusion problems. This perturbation approach has been applied to the unsteady 2-D blade/vortex interaction problem by Srinivasan and his co-workers [4]. The implementation of the approach here consists of freezing the wake geometry, including the position of the tip vortex of the preceeding blade, during the Euler iterations. The state vector of the wake flow field, $\mathbf{U_0} = (\rho, \rho u, \rho v, \rho w, \rho E)$ is then computed. The finite volume flux balance and and artificial viscosity operator are applied to this flow field. The residuals of the flow field $\mathbf{U_0}$ are subtracted from the residuals of the total flow field $\mathbf{U}$ at each time step of the Euler iteration. In this way, the truncation error of the scheme is corrected for the influence of the tip vortex of the preceeding rotor blade such that the vortex remains well defined, even near the outer boundary of the computational domain where the resolution of the grid is quite coarse.

With the new Euler solution, the strengths of the wake vortices are re-computed, and the wake geometry is updated through the free wake iteration procedure. After updating the wake geometry, the new geometry is used to re-compute the prescribed flow field $\mathbf{U_0}$, and the Euler solution is updated. This coupled iteration procedure is continued until convergence.

3 Results

Euler solutions have been obtained for fixed wing geometries. A comparison of solutions obtained with this code and experimental data for the ONERA M6 wing at $\alpha = 3.06°, M_\infty = .84$ are shown in figure 2. The calculations were performed on a grid of $96 \times 20 \times 20$ finite volume cells, and comparisons of surface pressure coefficient for 3 span stations are shown.

The code has also been used to compute the flow about an unswept, untapered wing with a NACA 0012 airfoil section tested at NASA-Langley Research Center by Weston [5]. The purpose of this calculation is to compare the vortical wakes computed by the Euler equations with experimental data. The calculation was performed on a $128 \times 32 \times 32$ grid at $\alpha = 8°, M_\infty = .1425$. Surface pressures are shown in figure 3. In figure 4 are shown contours of constant total pressure and vorticity at 1/2 chord behind the trailing edge. The computed wake is qualitative similar to experimental data, indicating that the Euler equations do capture the vortical structure of the wake. Quantitative comparisons with experiment will be performed to ascertain the ability of the Euler equations to capture realistic vortex wake structures.

The use of the perturbation approach for computing the interaction of a streamwise vortex with a semispan wing is shown in figures 5 and 6. The geometry of the configuration is sketched in figure 5a; the wing has a semispan to chord ratio of 2:1, a NACA 0006 airfoil section, and the free stream Mach number is .3. The vortex passes 1/2 chord above the wing and 1/2 semispan from the plane of symmetry. A $96 \times 20 \times 20$ grid was used around the wing. The spanwise distribution of lift coefficient C_l is shown in figure 5a for the perturbation approach, while figure 5b shows the results for the standard Euler solver. The steeper gradients at the 1/2 semispan section for the perturbation approach due to the better resolution of the vortex are apparent. In figure 6, contours of vorticity are shown in a vertical plane passing through the mid-chord of the wing. The contour levels are identical in figures 6a and b. Note that the vortex is well defined with the perturbation approach, while for the non-perturbation scheme it has virtually vanished. This calculation illustrates the ability of the perturbation scheme to overcome the problems of coarse grid resolution near the outer boundary and the diffusion of vorticity due to artificial viscosity. This is a preliminary calculation; further comparisons with the experimental data of reference [6] for this configuration will be undertaken.

For the proposed paper, the current perturbation scheme will be applied to the case of a hovering helicopter rotor. The Euler code for a hovering rotor has been written. Preliminary results for the hover case have been presented by the authors [7] using an earlier version of the perturbation scheme now being developed. (In reference [7], only the smoothing operator and not the flux operator was applied to the wake flow field $\mathbf{U}_0$.) The position of the tip vortex passing near the rotor blade will be found from a free wake calculation. The free wake and Euler computations will be coupled such that the strengths of the free wake vortices will be determined from the Euler calculation. In this fashion, the correct representation of the tip vortex of the preceeding blade within the Euler computational domain as well as the influence of the entire semi-infinite wake will be included in the calculations.

4 Summary

A prescribed vortex or perturbation scheme for the Euler equations around a hovering helicopter rotor is being developed. For the rotor case, this approach will provide several advantages over existing hover performance prediction methods. First, the scheme will allow the interaction between the rotor blade and the tip vortex of the preceeding blade to be computed. Second, the formation and roll-up of the near trailing vortex wake attached to the blade will be captured by the Euler solver. Finally, by fully coupling the Euler solution of the near field of the blade with a free wake analysis, the proper influence of the complete semi-infinite wake will be accounted for.

5 References

1. Jameson, A., and Baker, T.J., "Solution of the Euler Equations for Complex Configurations," AIAA paper 83-1929CP, *Proc. AIAA Computational Fluid Dynamics Conference*, 1983.

2. Miller, R.H, "Simplified Free Wake Analyses for Rotors,", FFA (Sweden) TN 1982-7, 1982.

3. Roberts, T.W. and Murman, E.M., "A Computational Method for Helicopter Vortex Wakes," AIAA paper 84-1554, 1984.

4. Srinivasan, G.R., McCroskey, W.J., and Baeder, J.D., "Aerodynamics of Two-Dimensional Blade-Vortex Interaction," AIAA paper 85-1560, 1985.

5. Weston, R., private communication.

6. Smith, W.G., and Lasseroni, F.A., "Experimental and Theoretical Study of a Rectangular Wing in a Vortical Wake at Low Speed," NASA TN D-339, 1960.

7. Roberts, T.W., and Murman, E.M., "Solution Method for a Hovering Helicopter Rotor Using the Euler Equations," AIAA paper 85-0436, 1985.

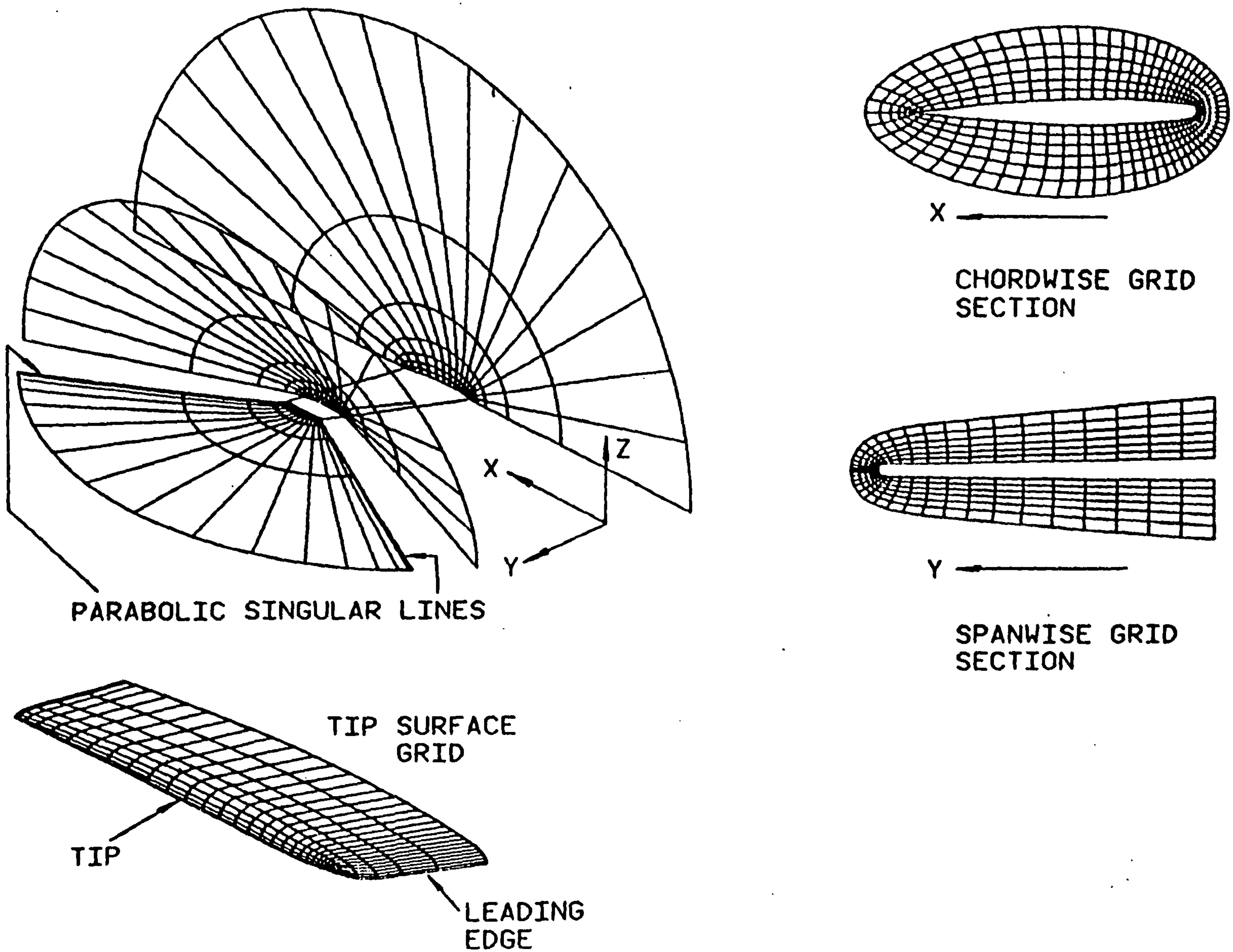


Figure 1 - O-O Mesh Features

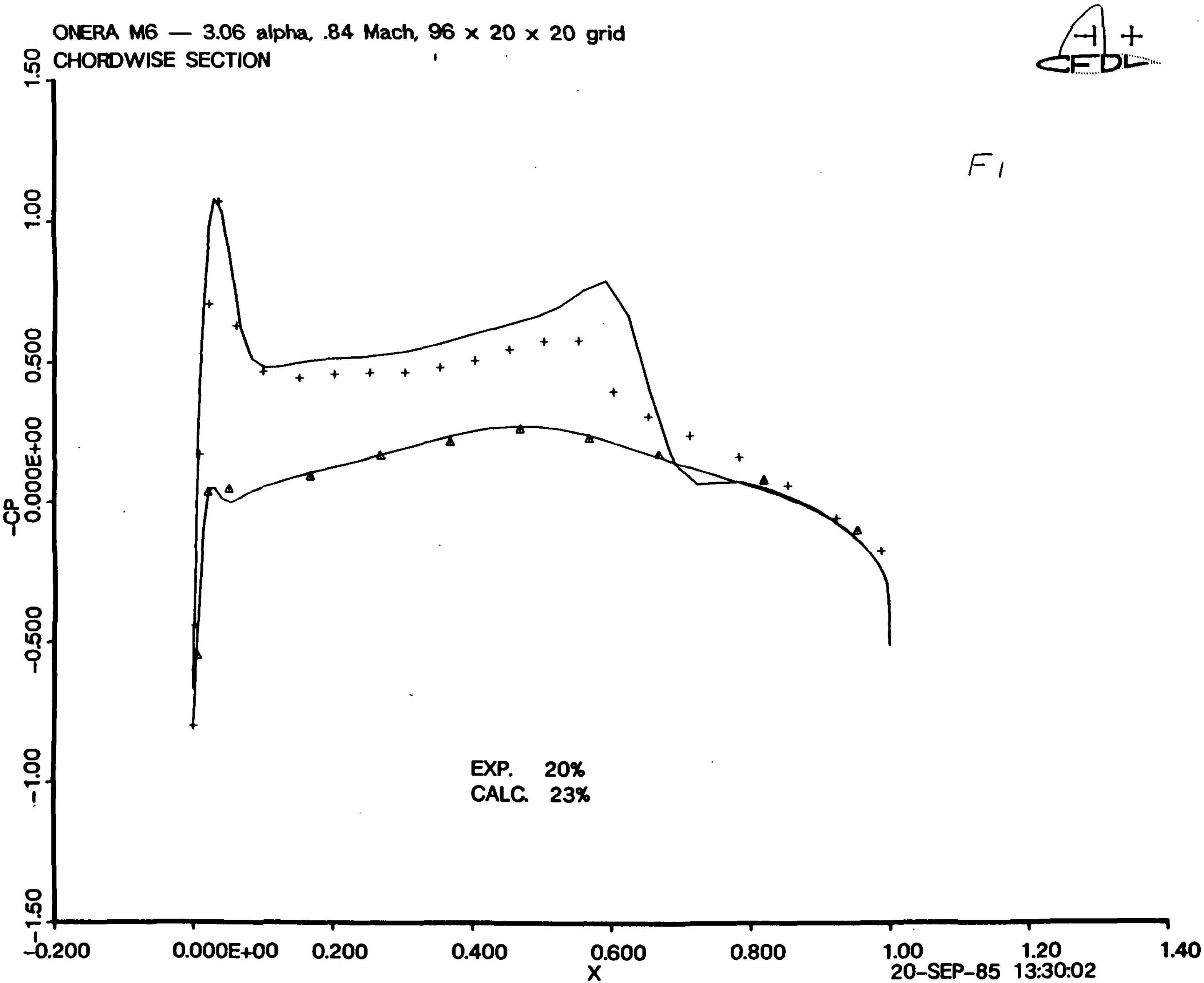


Figure 2a - C_p Comparisons for ONERA M6 Wing – 20% span

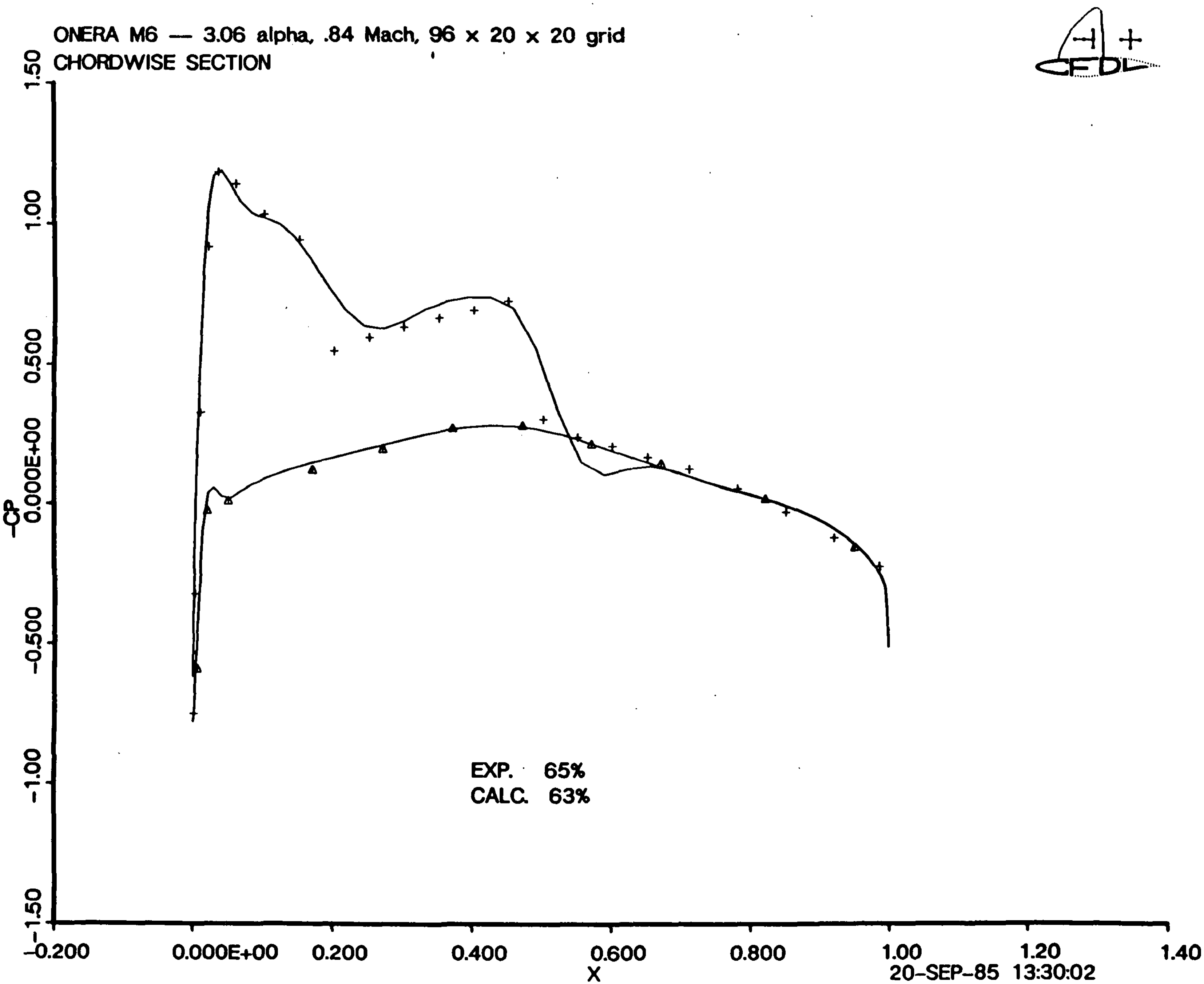


Figure 2b - C_p Comparisons for ONERA M6 Wing – 65% span

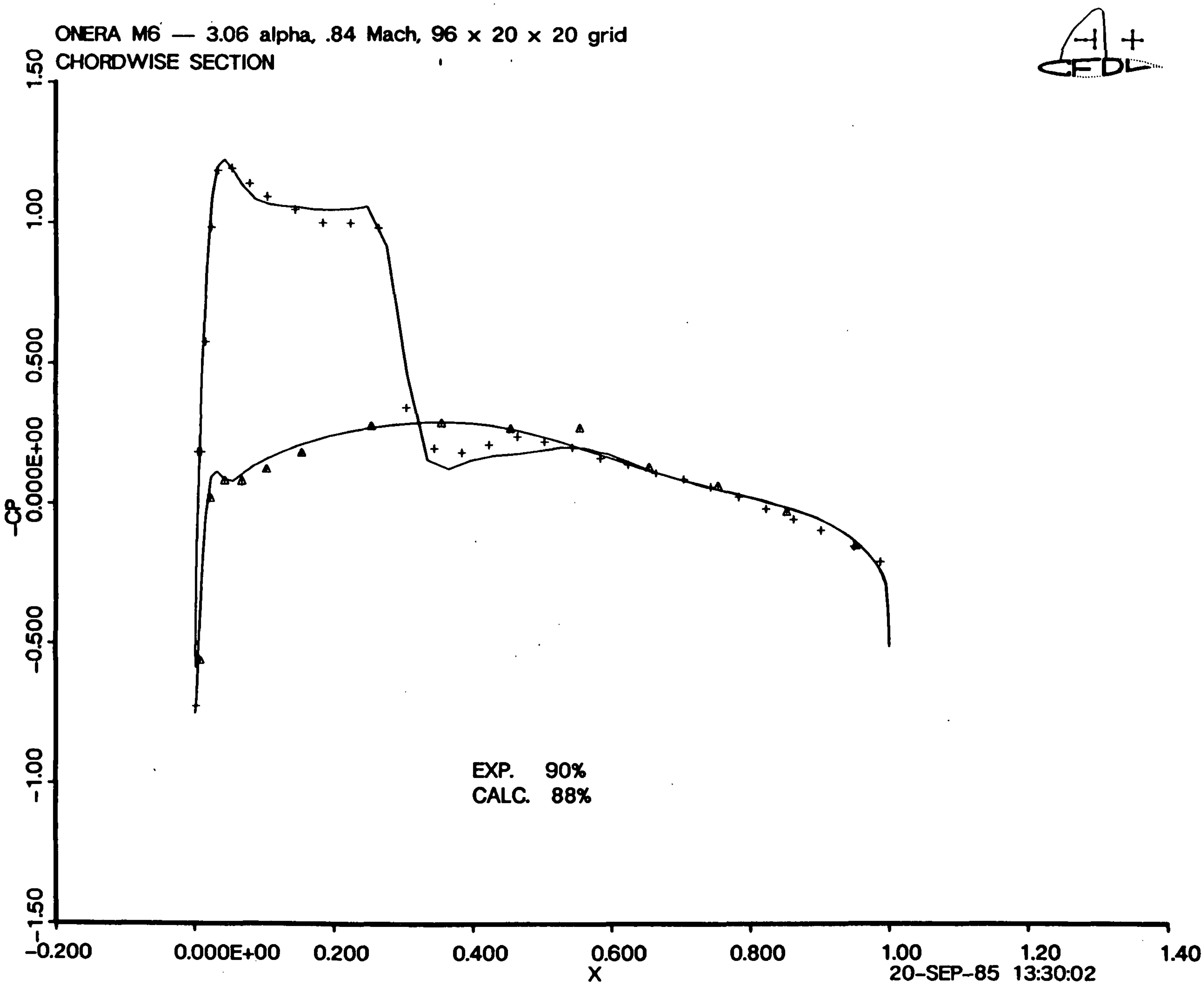


Figure 2c - C_p Comparisons for ONERA M6 Wing – 90% span

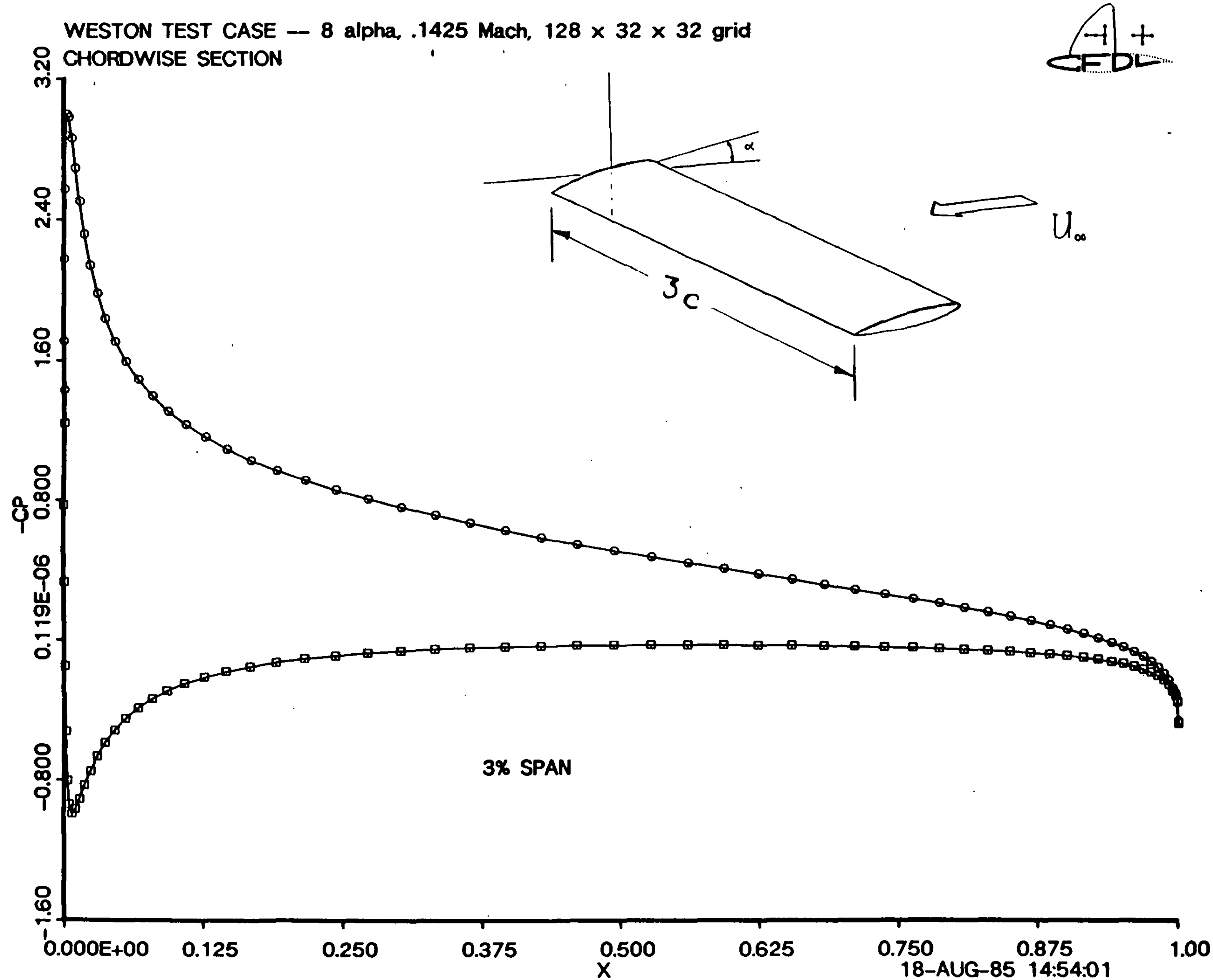


Figure 3a - C_p for Plain, Unswept Wing - 3% span

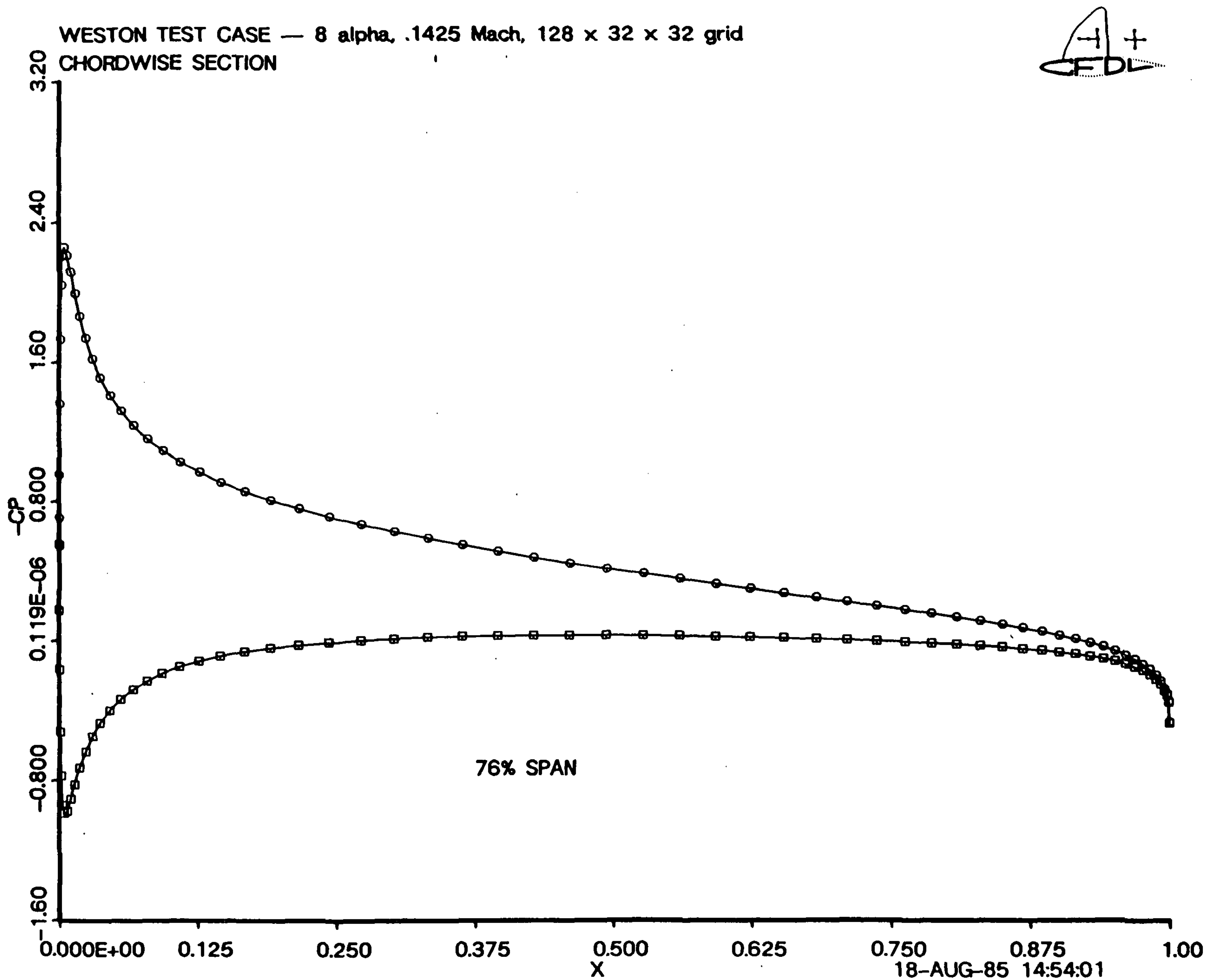


Figure 3b - C_p for Plain, Unswept Wing - 76% span

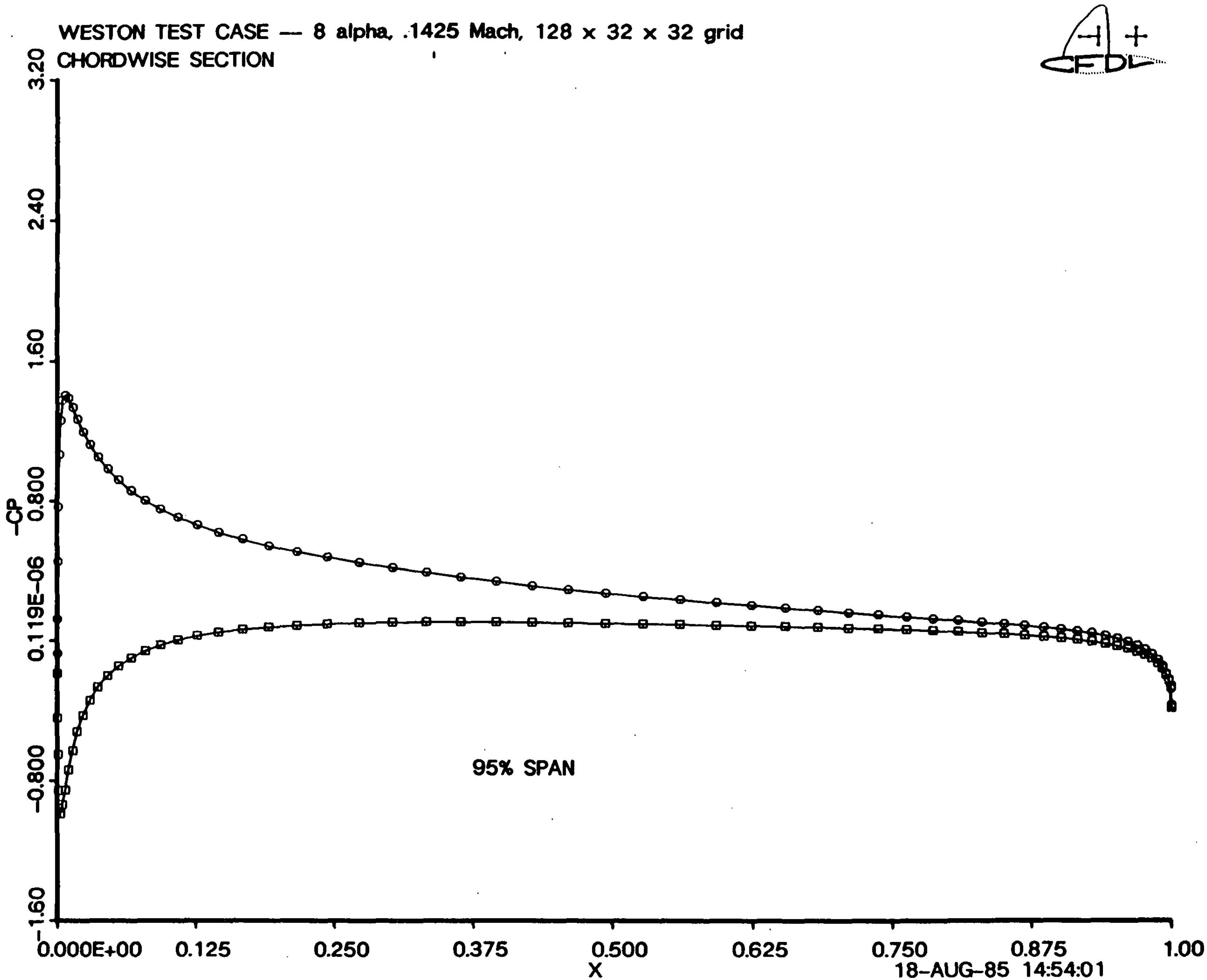


Figure 3c - C_p for Plain, Unswept Wing – 95% span

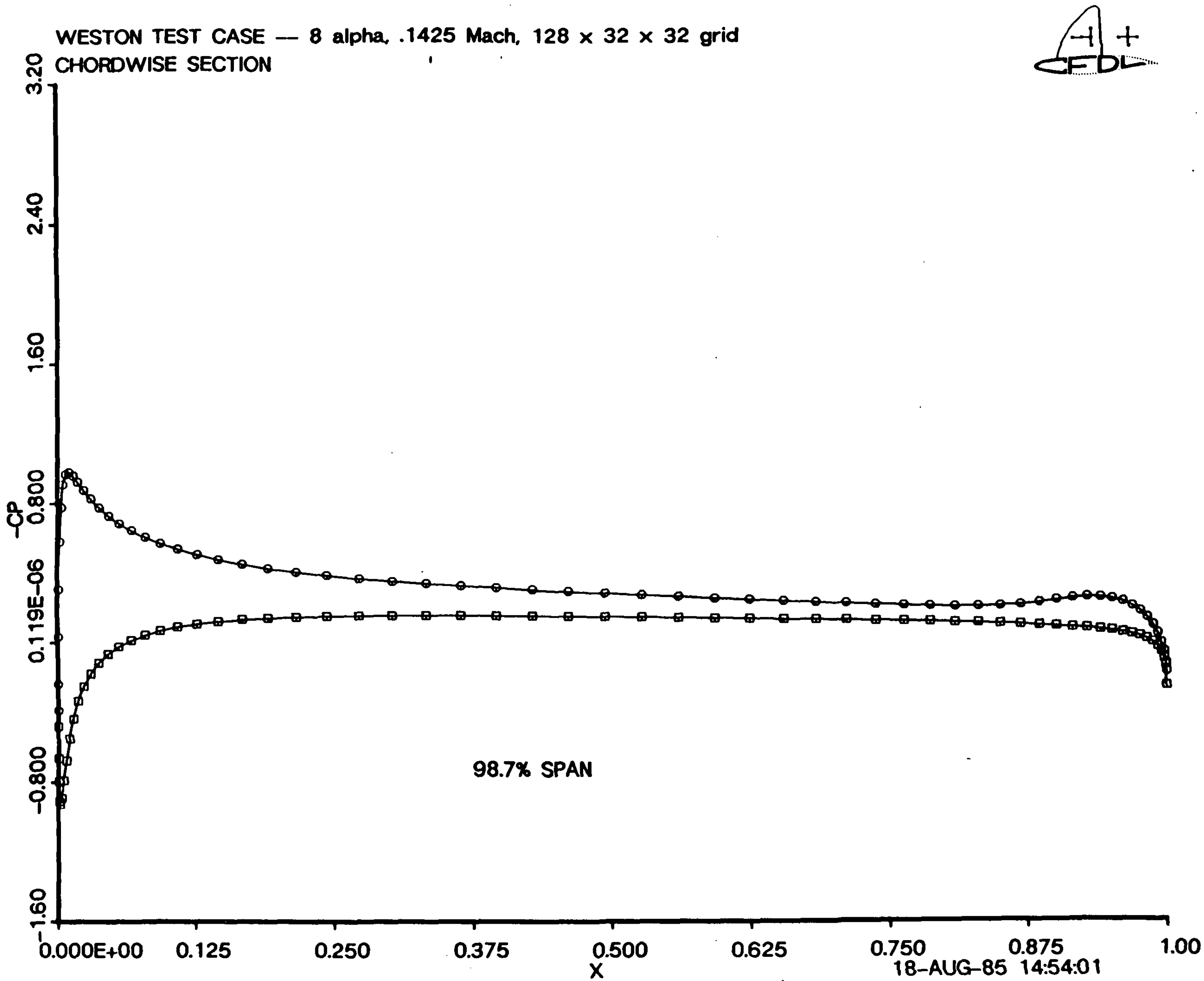


Figure 3d - C_p for Plain, Unswept Wing – 99% span

$C_L = .6423$
$\Delta P_0 = .0036$

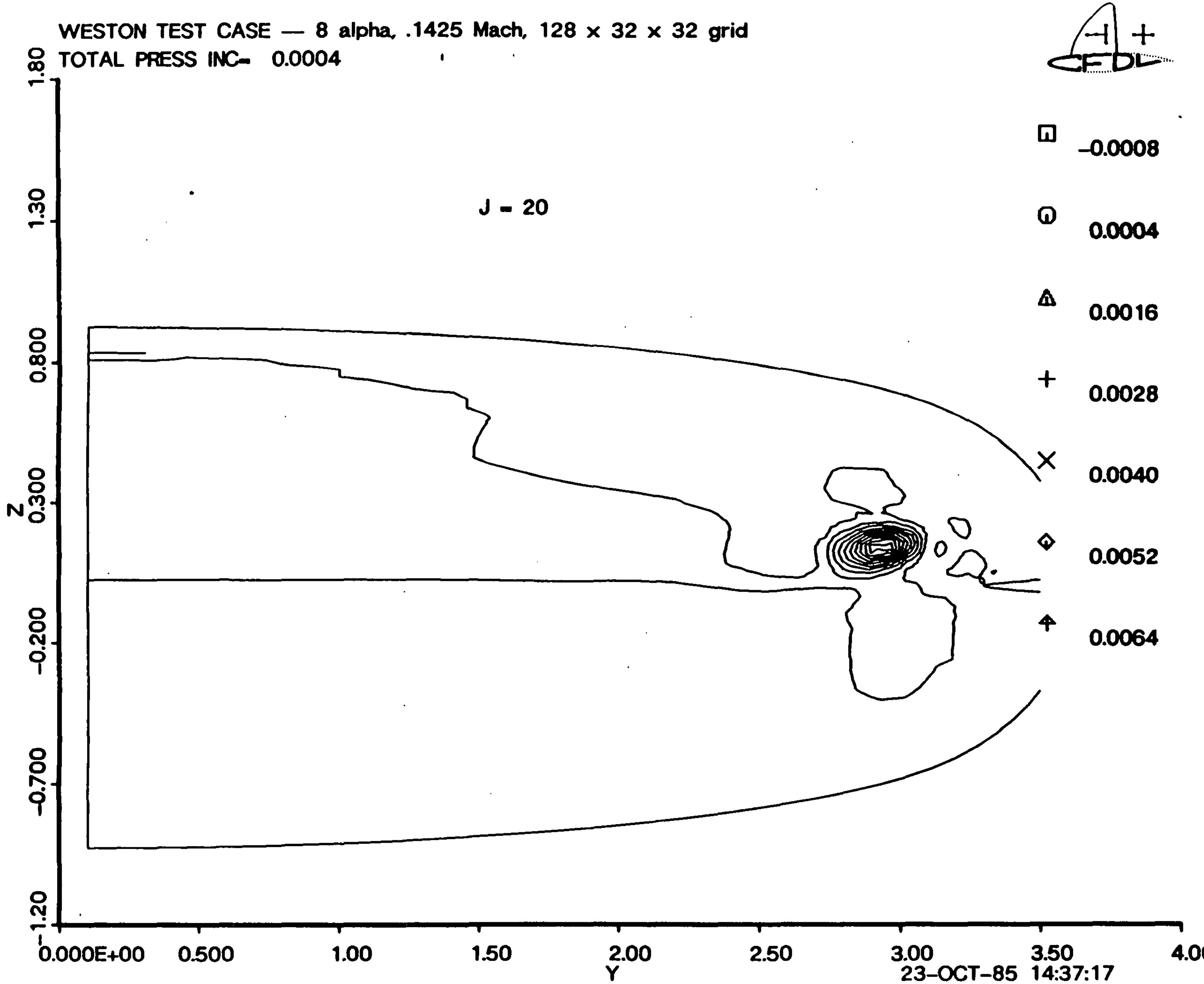


Figure 4a - Total Pressure Loss, $\frac{1}{2}$ Chord Behind Wing

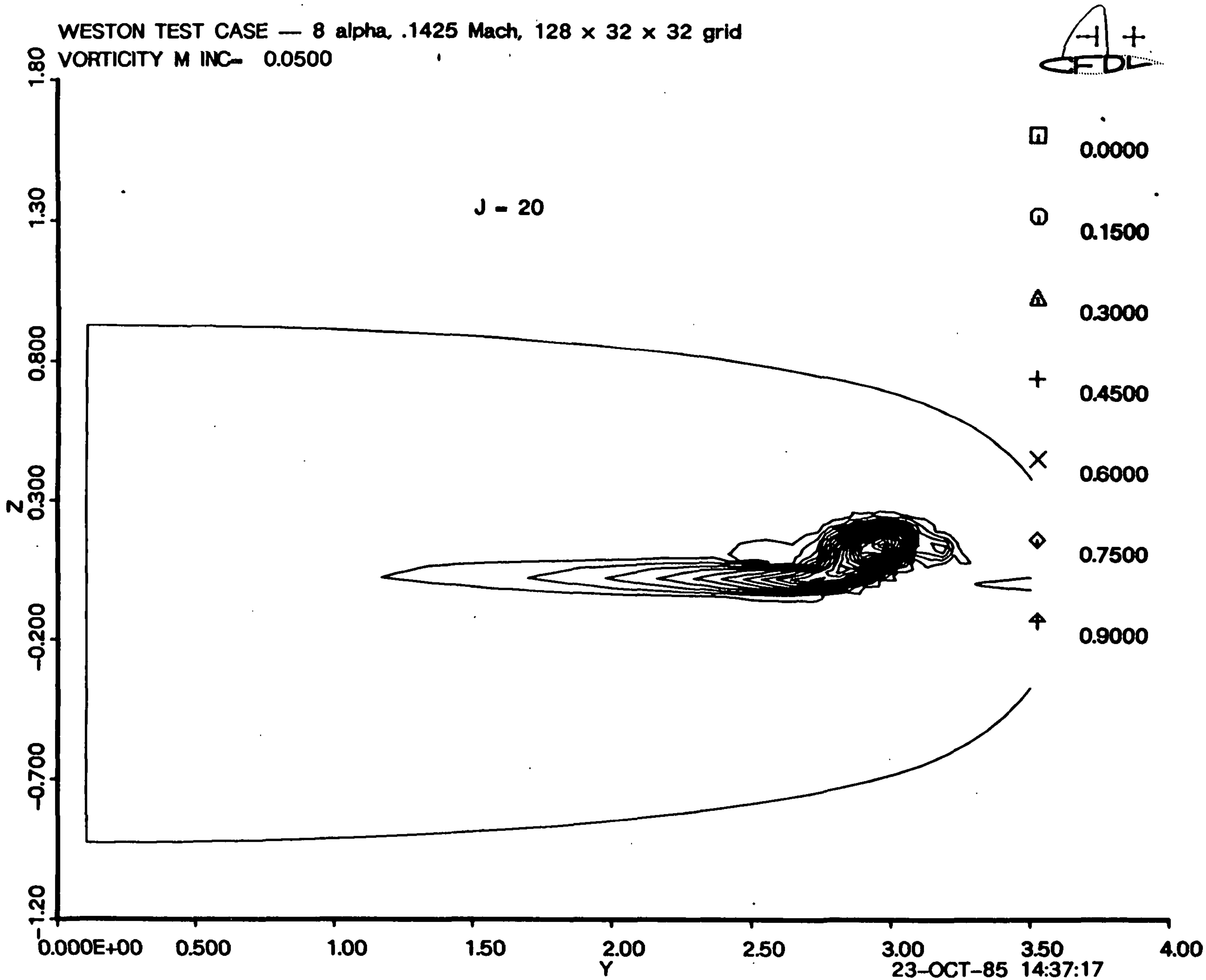


Figure 4b - Vorticity, $\frac{1}{2}$ Chord Behind Wing

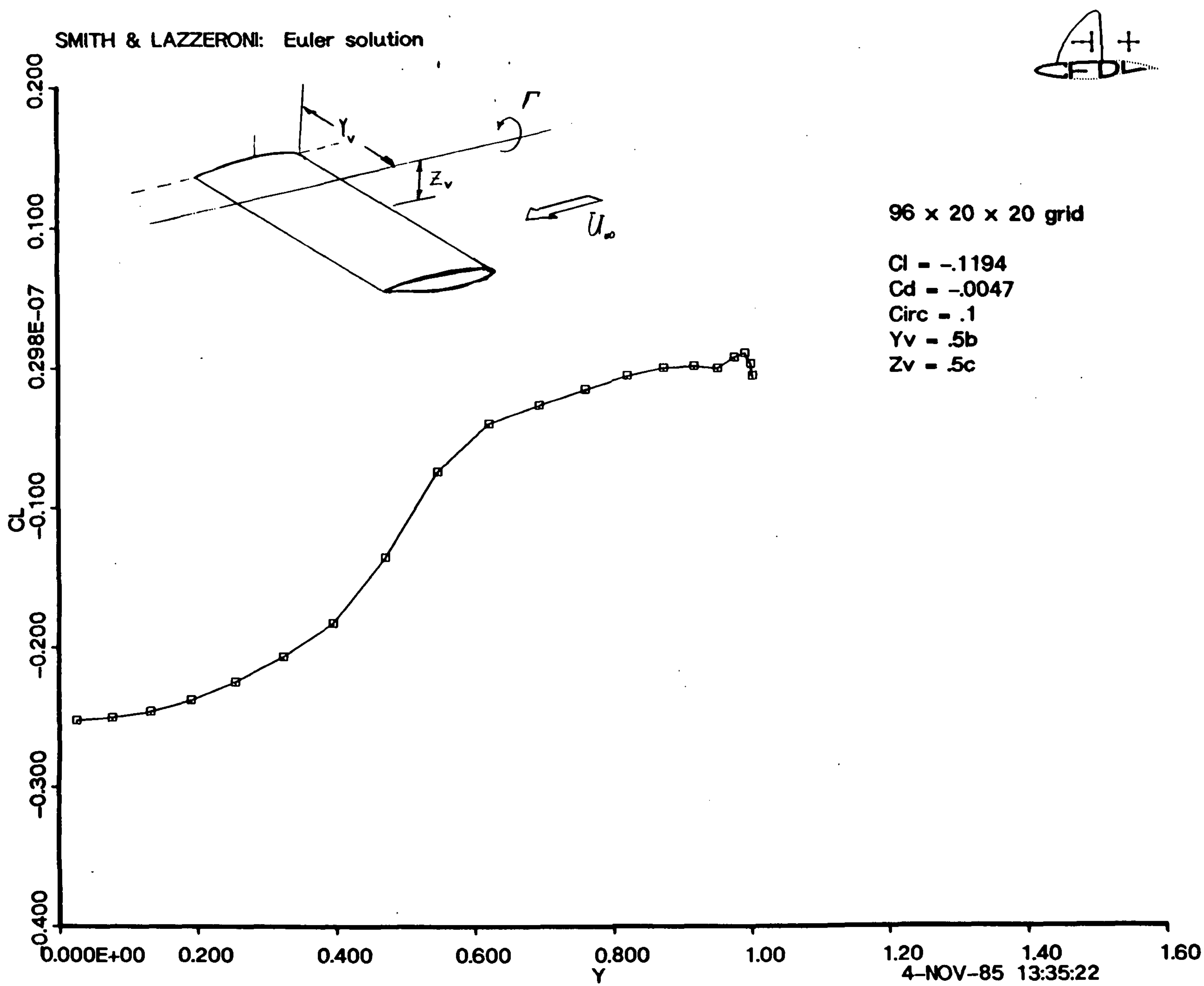
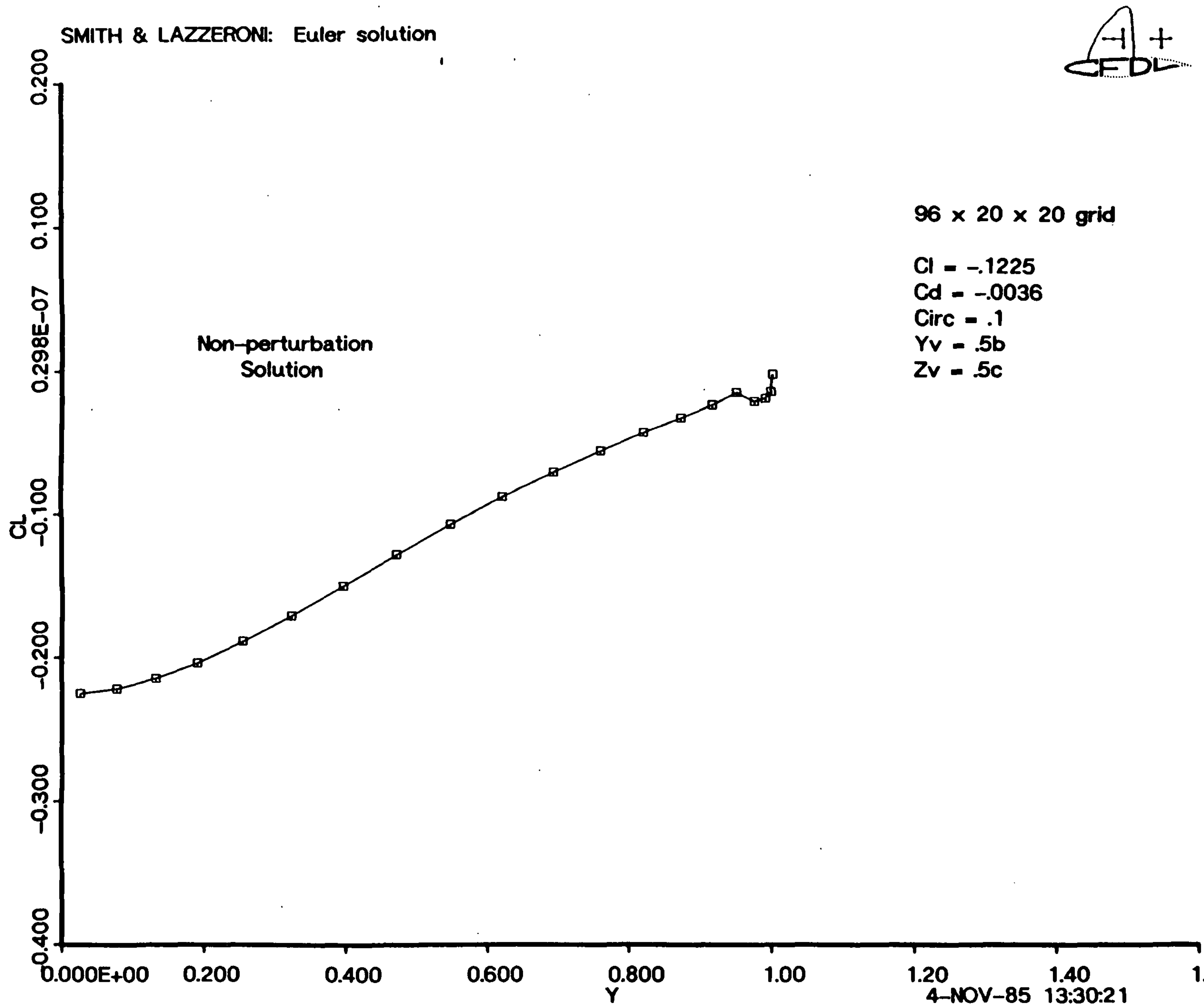


Figure 5 - Spanwise C_l Distribution, Wing/Vortex Interaction
a - Perturbation Scheme



b - Standard Euler Scheme

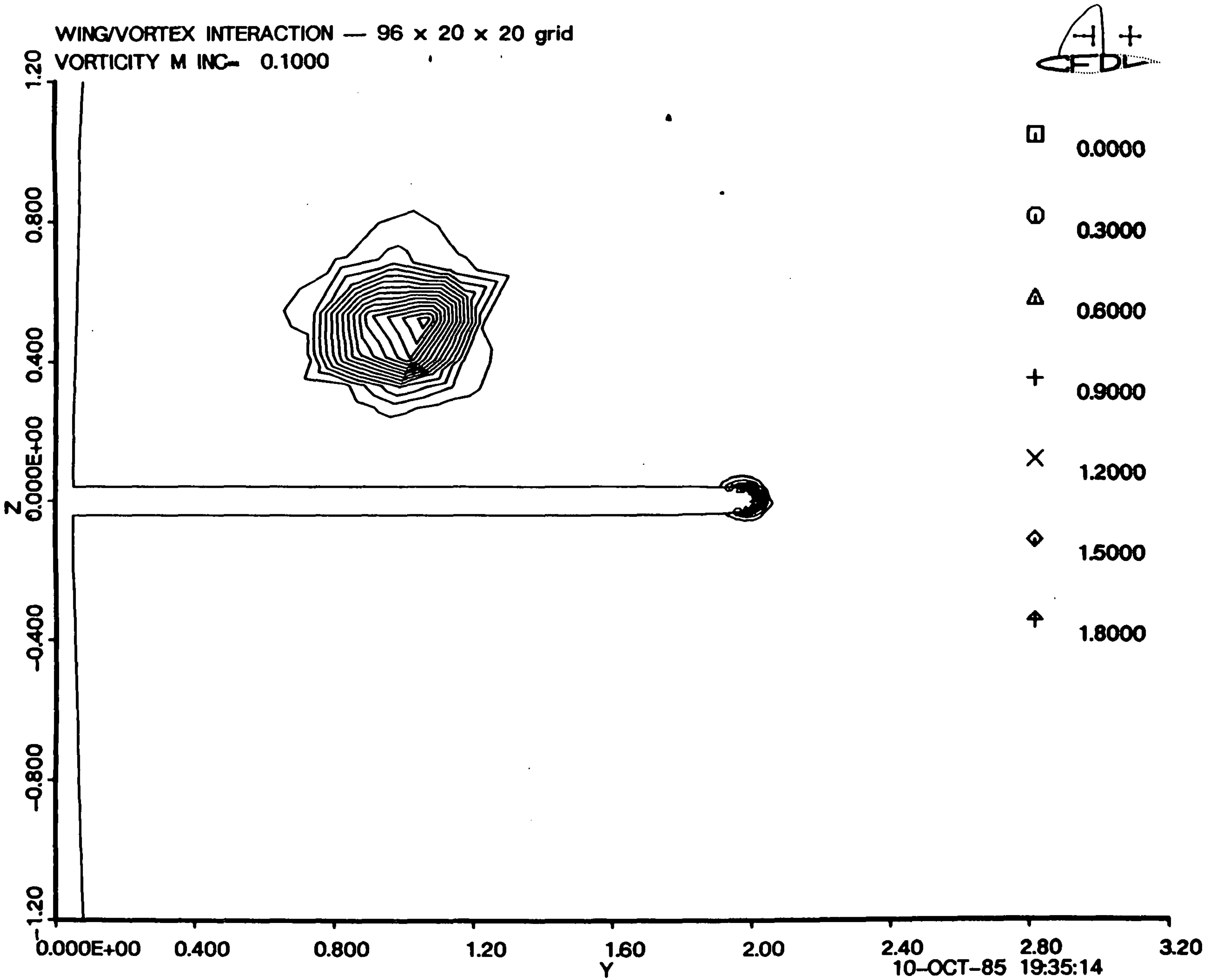
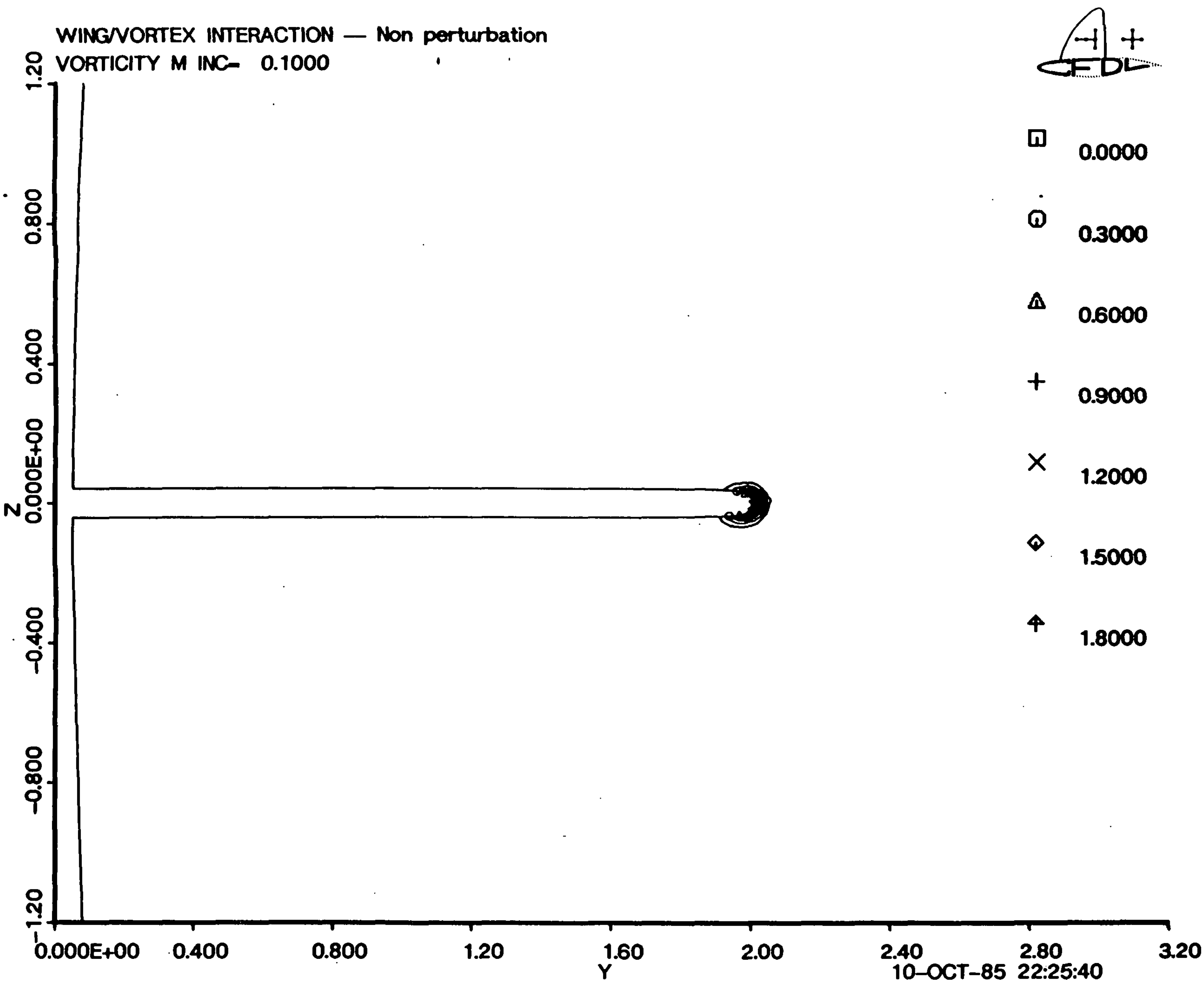


Figure 6 - Vorticity Contours, Wing/Vortex Interaction
a - Perturbation Scheme



b - Standard Euler Scheme