(NASA-CR-174105) PHYSICS ON AIRCRAFT WAKES Progress Report, 15 May - 14 Nov. 1984 (North Carolina State Univ.) 14 p HC A02/MF A01 CSCL 01A

N85-12871

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G3/02 24629

NASA COOPERATIVE AGREEMENT NCCI-84

PHYSICS OF AIRCRAFT WAKES

Progress Report No. 1

For the Period May 15, 1984 to November 14, 1984

Prepared by

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The progress report consists of the enclosed Abstract which was submitted to the AIAA 18th Fluid Dynamics, Plasma Dynamics and Lasers Conference.

Abstract Submittal Form

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I wish to submit an abstract for (conference/meeting): AIAA 18th Fluid Dynamics, Plasma Dynamics and Lasers

Place: Cincinnati **Date:** July 16-18, 1985

Session/organizer (this information appears in the call): Dr. Tony Lin

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

Roll-up of a Vortex Sheet

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

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4

Abstract due date: Dec. 24, 1984

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

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

Summary of important conclusions:

See Attached

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

See Attached

ROLL-UP OF A VORTEX SHEET*

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Abstract

The roll-up of a vortex sheet is analyzed by two approaches. The first is based on the exact compressible Euler equations while the second is based on the exact incompressible Navier-Stokes equations. The inviscid calculations for the two-dimensional problem do not indicate any roll-up of the sheet. On the other hand, the viscous calculations capture the dynamics of the roll-up rather well. This suggests that the generally held views regarding the roll-up process of aircraft wakes, namely, that it be treated as an inviscid process, may not be completely accurate.

Introduction and Approach

This research represents the results of the first phase of a research effort dealing with aircraft wakes. An excellent review of this problem is given by Donaldson and Bilanin.[1] According to Reference 1, understanding aircraft wakes entails the understanding of four problems. These are: roll-up, interaction and stability, aging and atmospheric effects.

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*Supported in part by NASA Cooperative Agreement NCCI-84.

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The object of this investigation is the roll-up region. Its length scale is of the order of the aspect ratio over the lift coefficient times the span length. As indicated in Reference 1, processes in this region are essentially inviscid. Because of this, we felt that an approach based on the exact Euler equations should reproduce the experimentally observed features of this region. Such an approach has a distinct advantage over other approaches reviewed in Reference 1 because the generality of the equations permits first, detailed study of the relevant dynamics processes and second, observation of the downstream evolution of vortical structures in their proper spatial and temporal relationships.

Although we are dealing with low Mach numbers, the compressible form of the Euler equations is employed. This is a crucial aspect of the formulation because the problem is dominated by boundary conditions, Figure 1. One does not know before hand whether inflow or outflow conditions should be imposed at a given boundary. Therefore, without employing a procedure that selects the proper boundary condition at a given instant and a given point one cannot hope to achieve an accurate solution. The proper boundary conditions for the compressible Euler equations, which are hyperbolic, are determined from the method of characteristics[2] and these have been implemented here.

The calculation of the development of a vortex wake from a flat sheet, Figure 2, is considered. This problem, which is characterized as "formidable" in Reference 1, is analyzed using the fourth-order Runge-Kutta method of Jameson et al.[3] Use of this method of solution brings up another crucial aspect of the formulation, namely, numerical damping. It is extremely important that the effects of numerical damping be reduced to a minimum in order not to mask the relevant physics of the problem. There are three types of damping that are employed in Reference 3: second-order, fourth-order and enthalpy. Because the stagnation enthalpy is not constant for the problem under consideration, enthalpy damping cannot be used here. Second-order damping mimics viscous effects and, therefore, was not used. Therefore, only fourth-order damping was employed in this formulation.

When one employs the compressible equations to study a phenomenon where the compressibility effects are small, the system of equations becomes stiff. The stiffness is a result of the disparity in the eigenvalues of the system. Matrix preconditioning[4,5] may be employed to alleviate the problem. Therefore, a secondary objective of this investigation is to evaluate the utility of such schemes.

Because of the inability of the Euler equations to predict the physics of the roll-up problem, the code that was developed in Reference 6 to study shear layers was employed. The code employs a vorticity-velocity formulation of the incompressible Navier-Stokes equations. Further details of the method are given in Reference 6.

Results and Discussion

The problem considered is that shown in Figure 2. At time t = 0, the velocity difference between the two streams occurs across one computational cell with the result that, at t = 0, the vorticity is zero everywhere except at that cell. Because enthalpy damping could not be used to speed up the convergence to the steady state, the matrix preconditioning (M.P.) procedure of Turkel[5] was employed. Figure 3 shows the convergence history of the solution based on the Euler equations in the absence and presence of matrix preconditioning. It is seen from the figure that M.P. helps speed up the convergence.

Figure 4 shows the vorticity contours that result from calculations based on the Euler equations with N indicating the number of iterations. The total number of iterations employed corresponds to the number of iterations needed to allow a disturbance moving with the lowest velocity to propagate across the computational domain. No roll-up is indicated in the figure. Figure 5 shows the vorticity contours based on the Navier-Stokes equations. It is seen that the results indicate roll-up.

In conclusion, the above results suggest that the physics of vortex roll-up is best described by the Navier-Stokes equations. It appears that if we hope to understand the behavior of aircraft wakes then we must rely exclusively on the Navier-Stokes equations.

References

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2. Whitfield, D. L. and Janus, J. M., "Three-Dimensional Unsteady Euler Equations Solution Using Flux Vector Splitting," AIAA Paper No. 84-1552, June 1984.

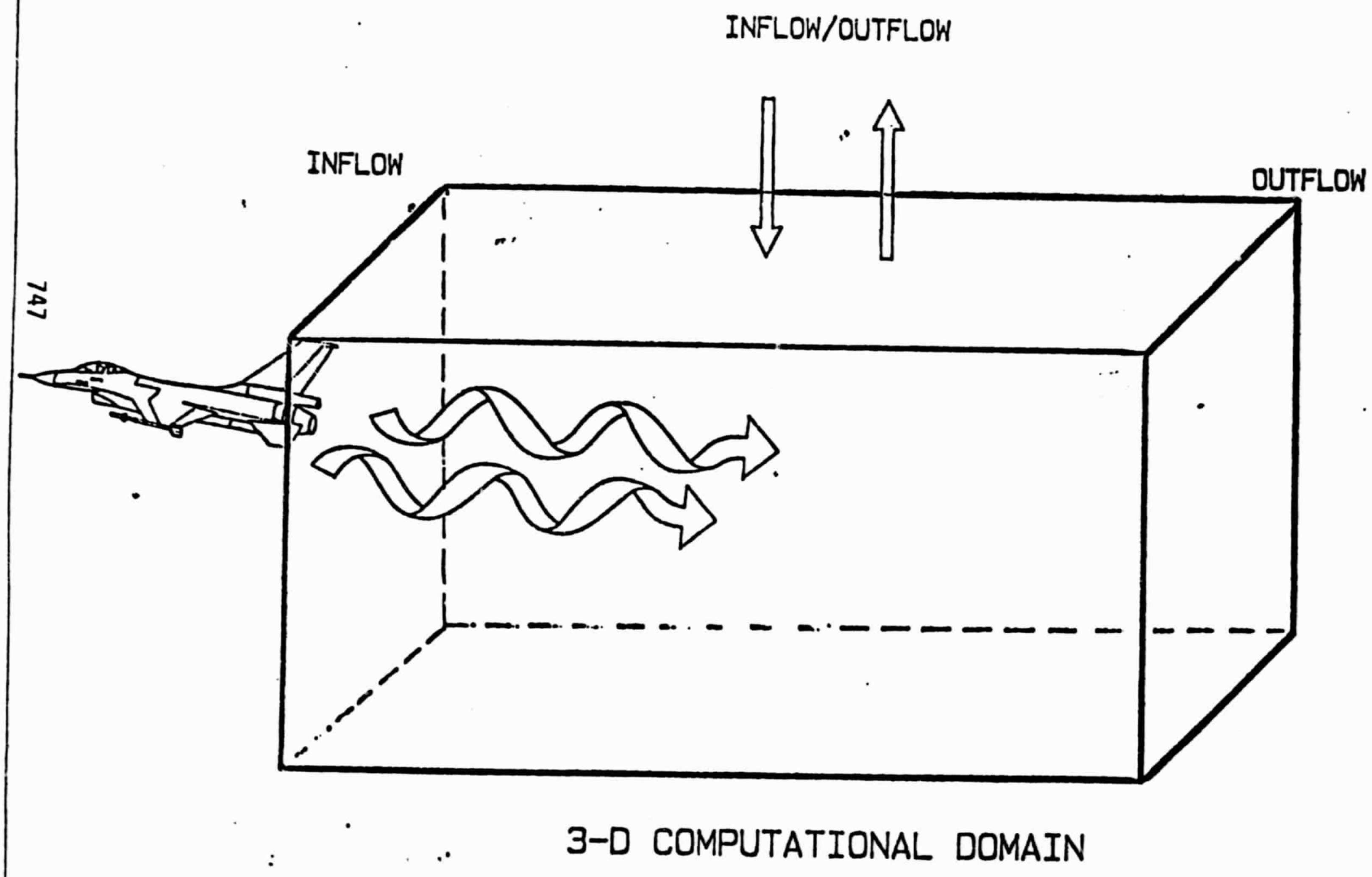
3. Jameson, A., Schmidt, W., and Turkel, E., "Numerical Solutions of the Euler Equations by Finite Volume Methods Using Runge-Kutta Time Stepping Schemes," AIAA Paper No. 81-1259, June 1981.

4. Briley, W. R., McDonald, H. and Shamroth, S. J., "A Low Mach Number Euler Formulation and Application to Time-Iterative LBI Schemes," AIAA Journal, Vol. 21, October 1983, pp. 1467-1469.

5. Turkel, E., "Acceleration to a Steady State for the Euler Equations," NASA CR-172398 and ICASE Report No. 84-32, July 1984.

6. McInville, R. M., Gatski, T. B. and Hassan, H. A., "Embedded Shear Layer Computations for Increased Drag Reduction," AIAA Paper No. 84-0349, 1984.

figure 1 FLOWFIELD SCHEMATIC



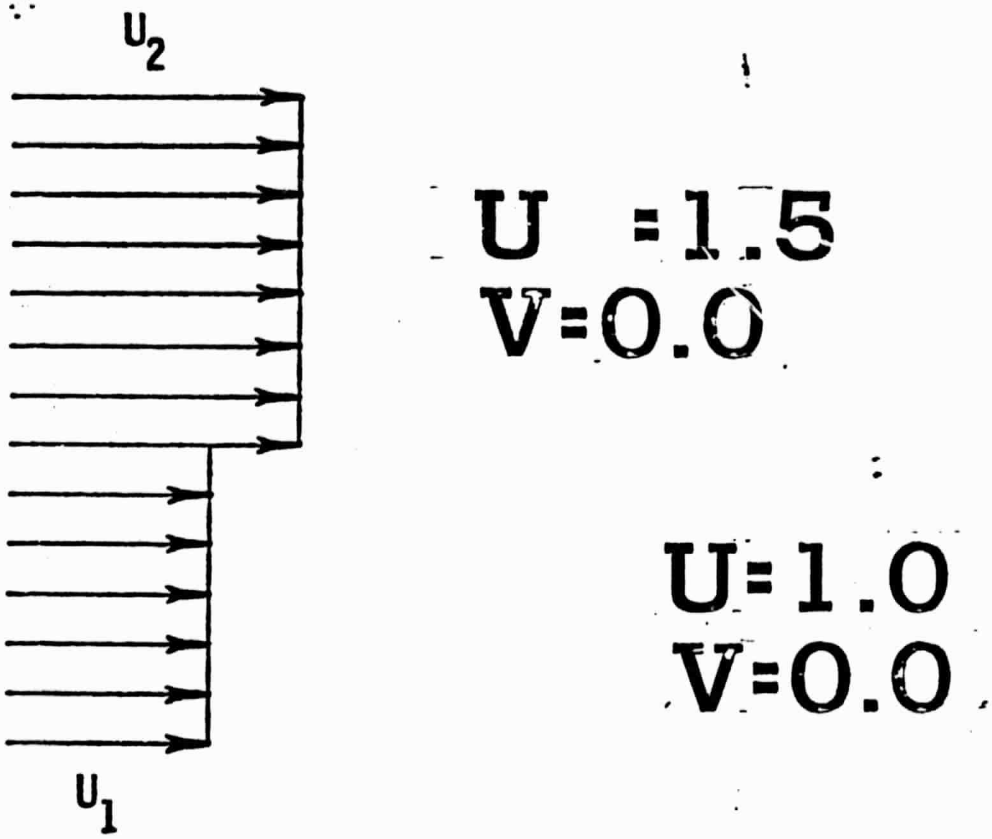


figure 2 inital velocities

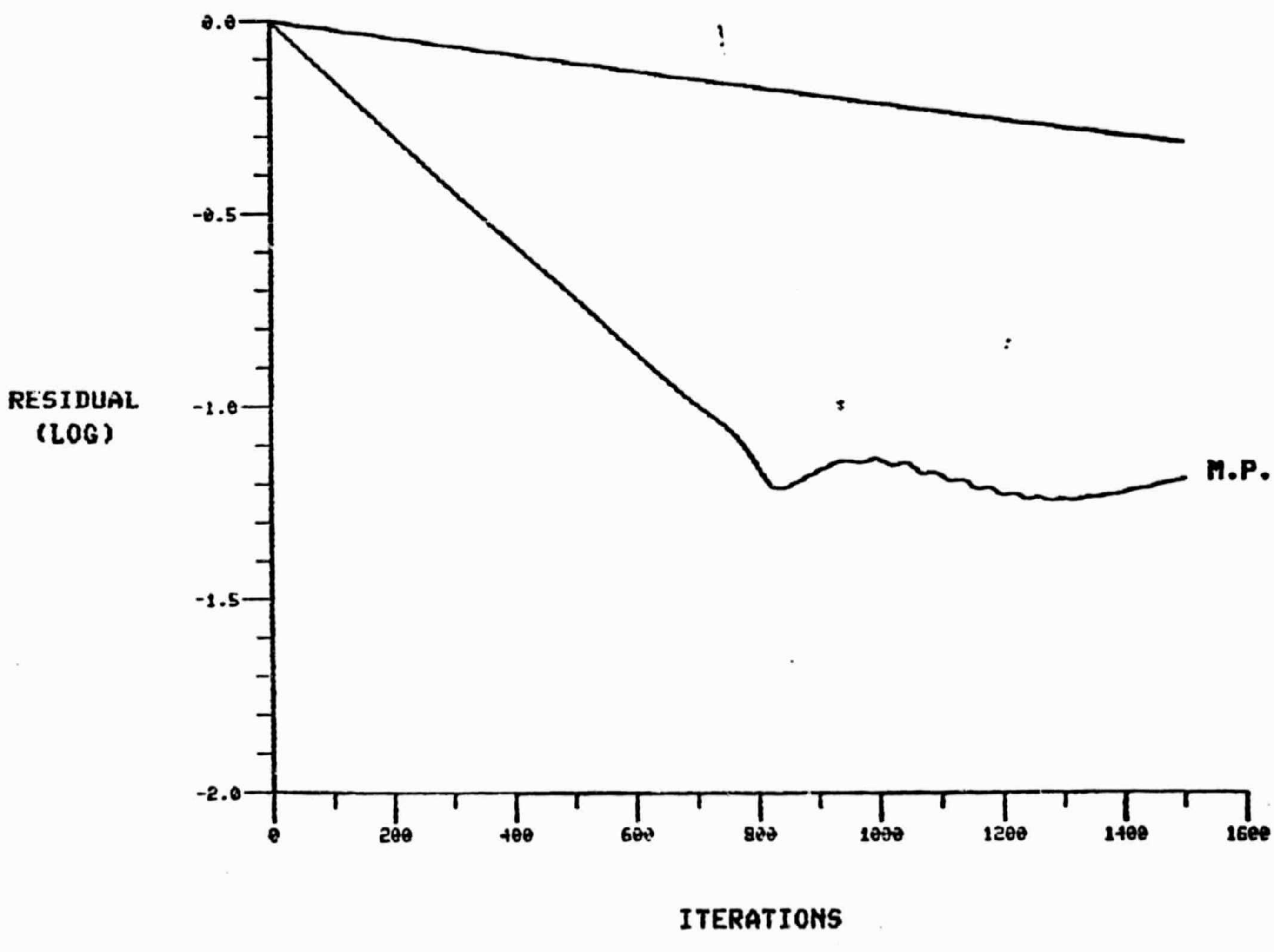


figure 3 convergence comparison

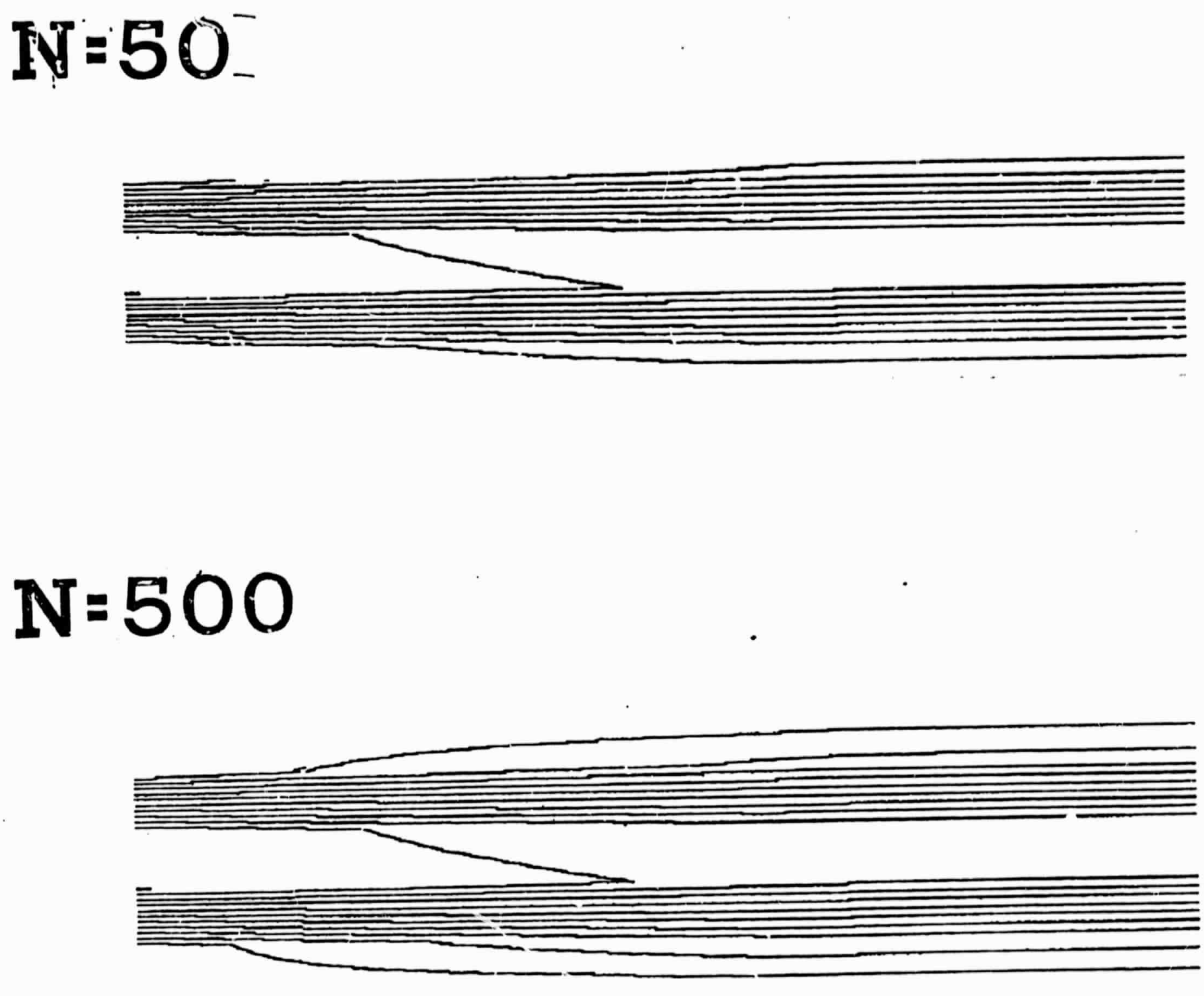
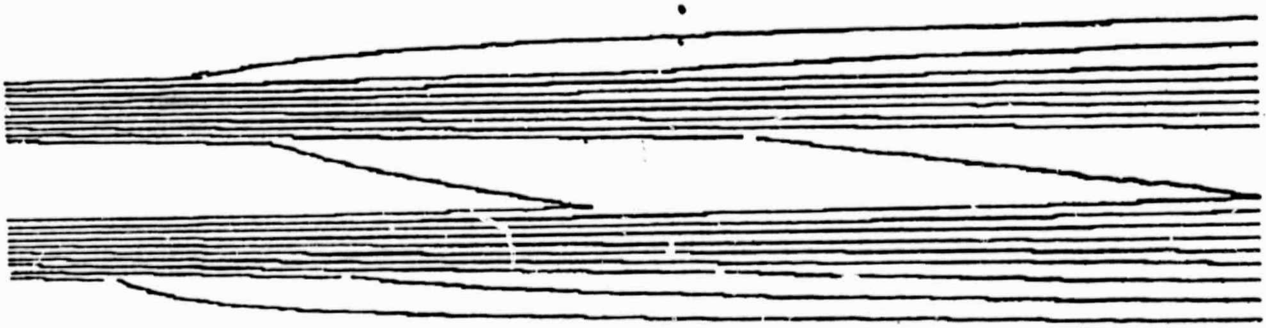


figure 4a vorticity evolution (inviscid)

N=1000



N=1500

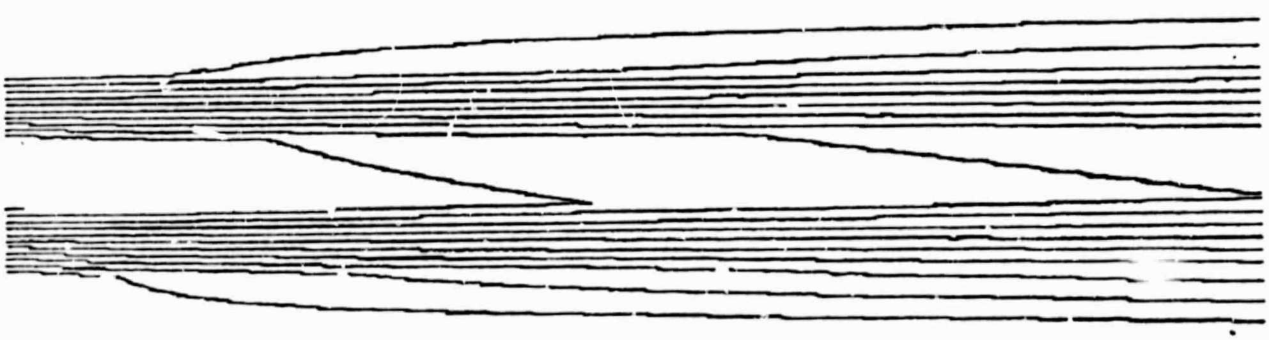


figure 4b vorticity evolution (inviscid)

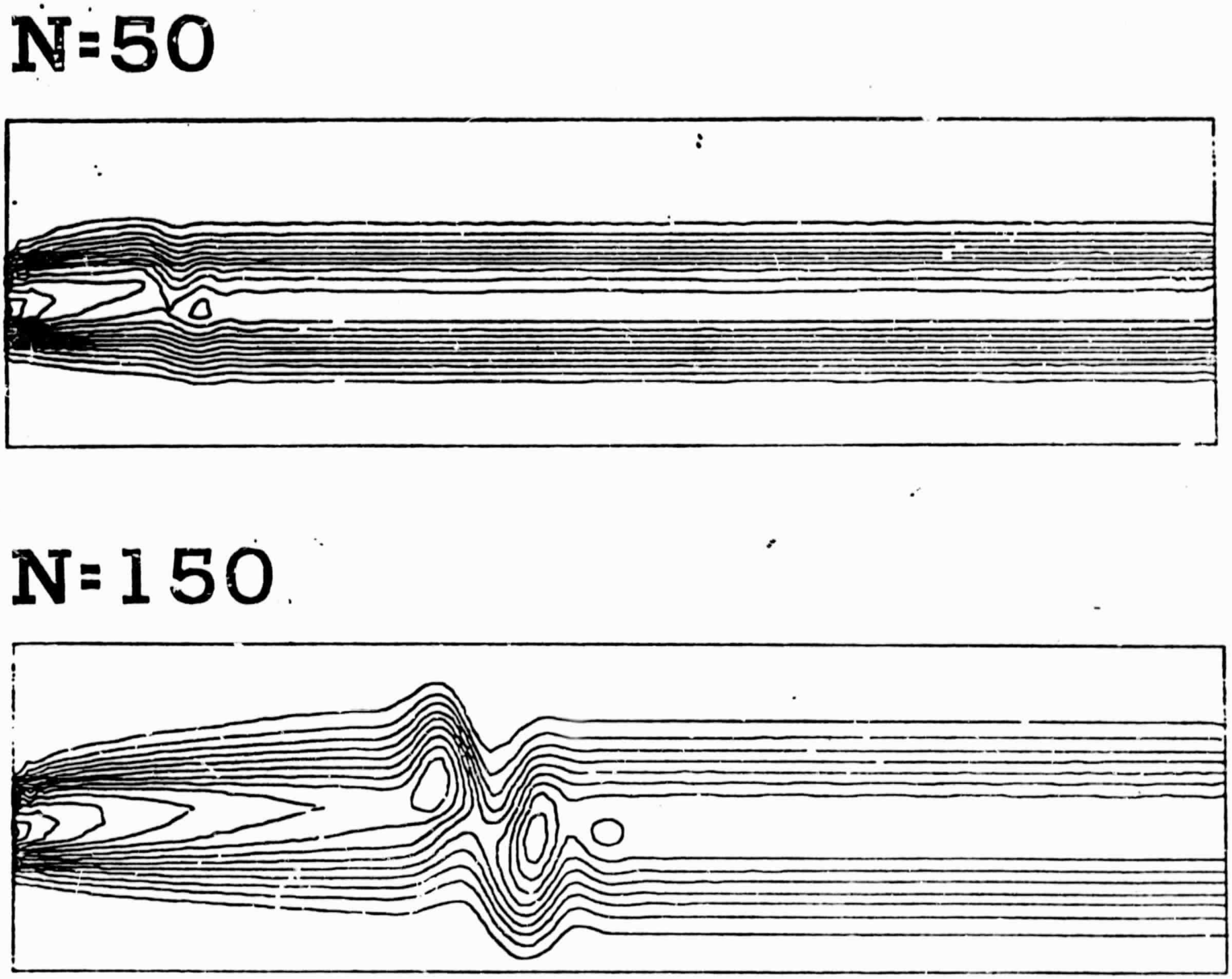
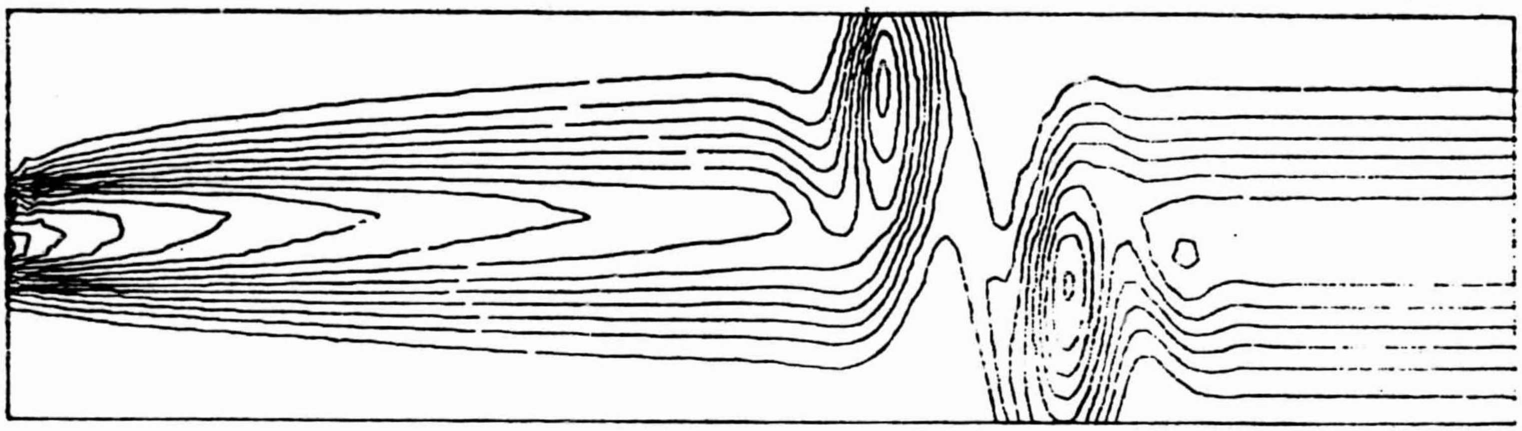


figure 5a : vorticity evolution (viscous)

N=250



N=300

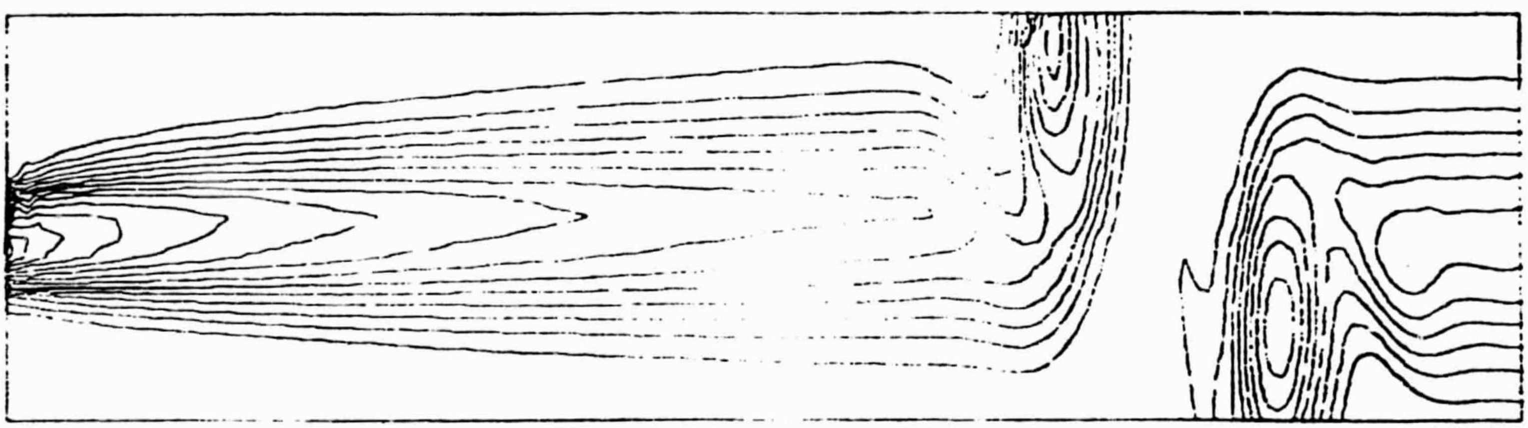


figure 5b vorticity evolution (viscous)