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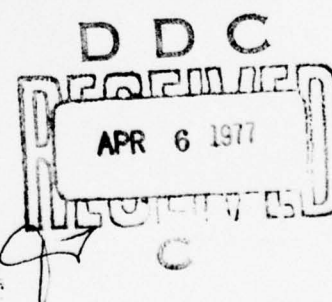
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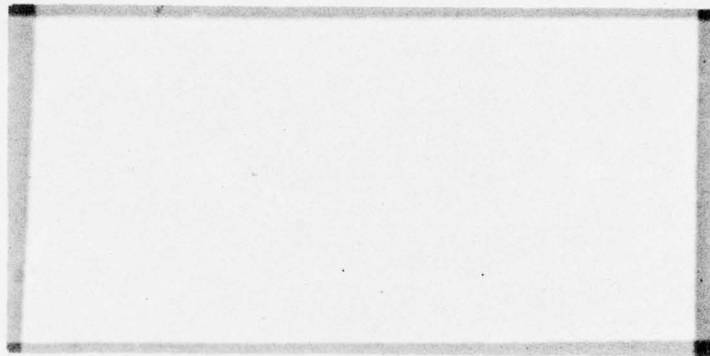
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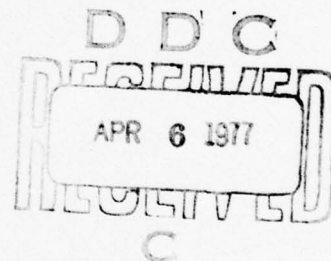
WORKING PAPER NO. 145-13  
NOVEMBER 1976

FINAL REPORT  
RESEARCH ON PARACHUTE OPENING

BY  
PETER R. PAYNE  
AND  
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FOR  
AIR FORCE OFFICE OF SCIENTIFIC RESEARCH  
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CONTRACT NO. F44620-76-C-0020



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# ABSTRACT

This report summarizes work carried out under contract number F44620-76-C-0020 in connection with parachute opening theory. Contributions were made in the following areas.

- (a) Prediction of fabric porosity effects.
- (b) Calculation of the external and internal pressure fields during inflation.
- (c) Calculation of the canopy shape and stress distribution during inflation.

These three elements, taken together, cover the problem, but they were not integrated into a complete predictive methodology because of lack of time.

The analogous problem of the opening of a two-dimensional hinged plate was also studied, both experimentally and theoretically. The problem of the inviscid flow field inside such an inflating wedge was solved exactly, in closed form, and agreed well with experiment.

Most of the reports written during this study will be published in the open literature.

## DISCUSSION

### Fabric Porosity

In Reference 1\* it was shown that existing methods of predicting the flow through a fabric or gauze were unsatisfactory (the "coefficients" are not constants) because they ignored viscosity. It was shown that the available experimental data rather follows a law first enunciated by Osborne Reynolds; namely

$$\Delta p = K_1 U^2 + K_2 U \quad (1)$$

where  $\Delta p$  = the pressure drop across the cloth  
 $U$  = volume flow/cloth area  
 $K_1$  = the dynamic pressure coefficient  
 $K_2$  = the viscous pressure coefficient

Reference 1 presents equations for  $K_1$  &  $K_2$ . Figure 1 shows how  $K_1$  varies with the fabric's geometric porosity  $\alpha_G$ , through six orders of magnitude. Figure 2 shows how the viscous coefficient varies with the parameter

$$\left( \frac{n\ell}{A} \right) \frac{1}{\alpha^2}$$

where  $n/A$  = number of holes per unit area  
 $\ell$  = cloth thickness  
 $\alpha$  = aerodynamic porosity =  $1/(1 + \sqrt{2K_1/\rho})$

Figure 3 shows the relationship between geometric porosity  $\alpha_a$  and the aerodynamic porosity  $\alpha$  to be roughly one to one at the values of interest to parachute designers.

The analysis of Reference 1 is also shown to be applicable to thick felt filters multi-layer sintered gauzes, and similar materials.

### The Pressure Fields Inside & Outside an Inflating Canopy

Reference 2\* computes the unsteady inviscid flow field inside an inflating canopy of idealized (cylindrical) shape, and obtains a closed form solution which compares well with the meager experimental data available. Streamlines for the simple solution of constant cavity length (for which normalized streamlines are constant) are shown in Figure 4.

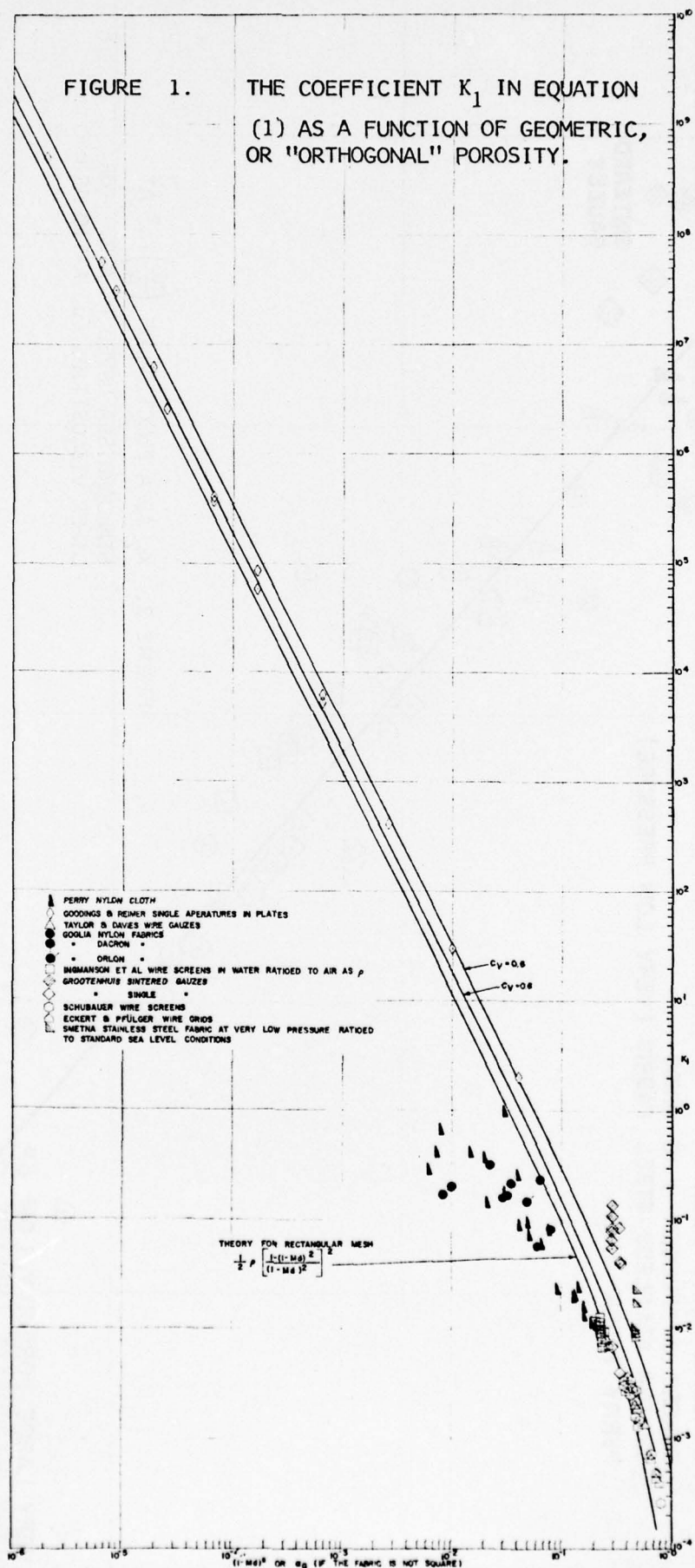
The problem of the external pressure field is solved approximately in Reference 3, by the use of a time-varying, three-dimensional, sink-source pair to develop the canopy shape. Figure 5 shows the general flow field developed. Figure 6 is developed from some experimental observations by Klimas, during inflation of a model canopy, and Figure 7 shows that the theory gives generally similar results.

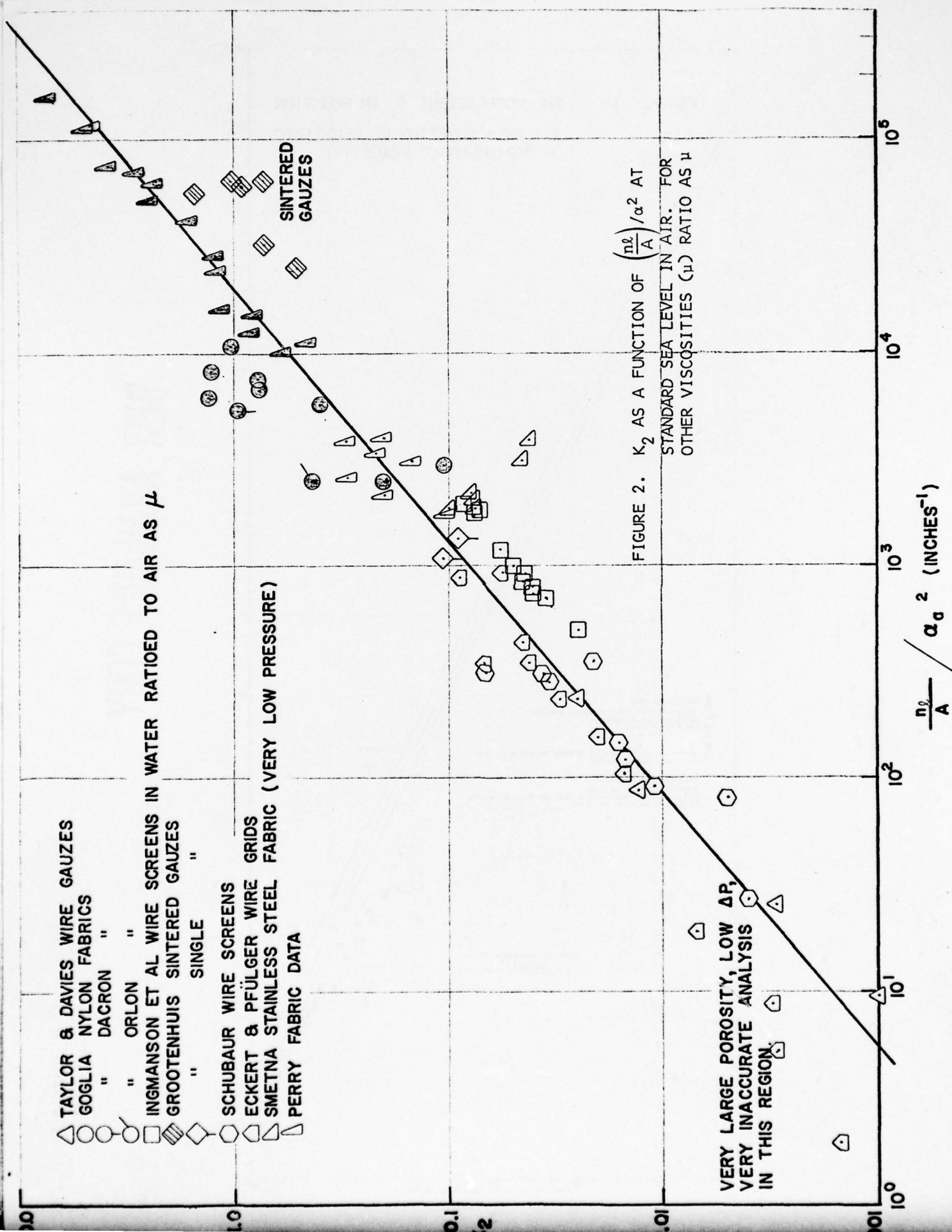
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\*To be published in the AIAA Journal of Aircraft.

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FIGURE 1. THE COEFFICIENT  $K_1$  IN EQUATION (1) AS A FUNCTION OF GEOMETRIC, OR "ORTHOGONAL" POROSITY.





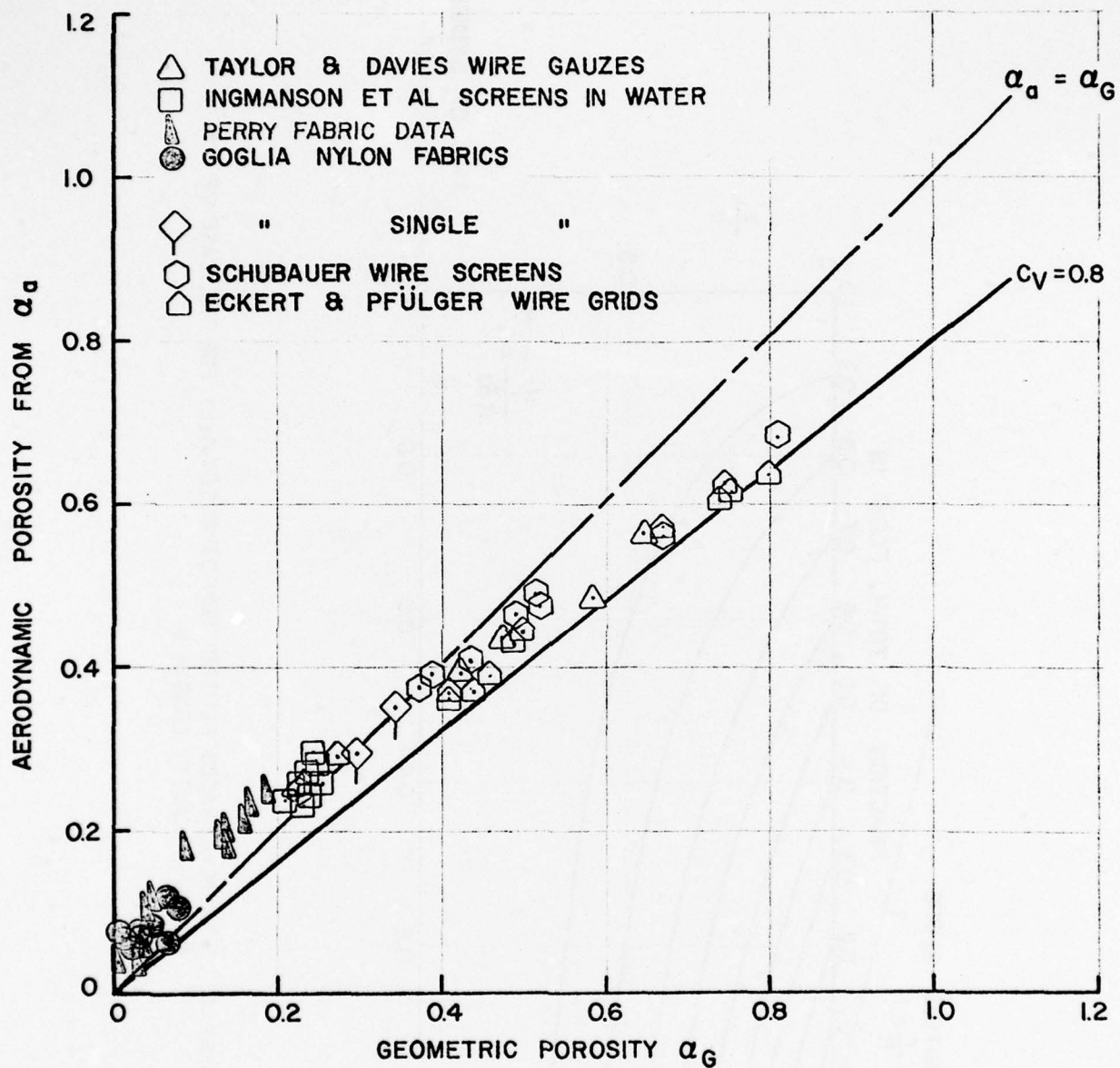


FIGURE 3. COMPARISON BETWEEN GEOMETRIC POROSITY AND THE VALUE DEDUCED FROM

$$\alpha_a = 1 / \left( 1 + \sqrt{\frac{2}{\rho} K_1} \right)$$

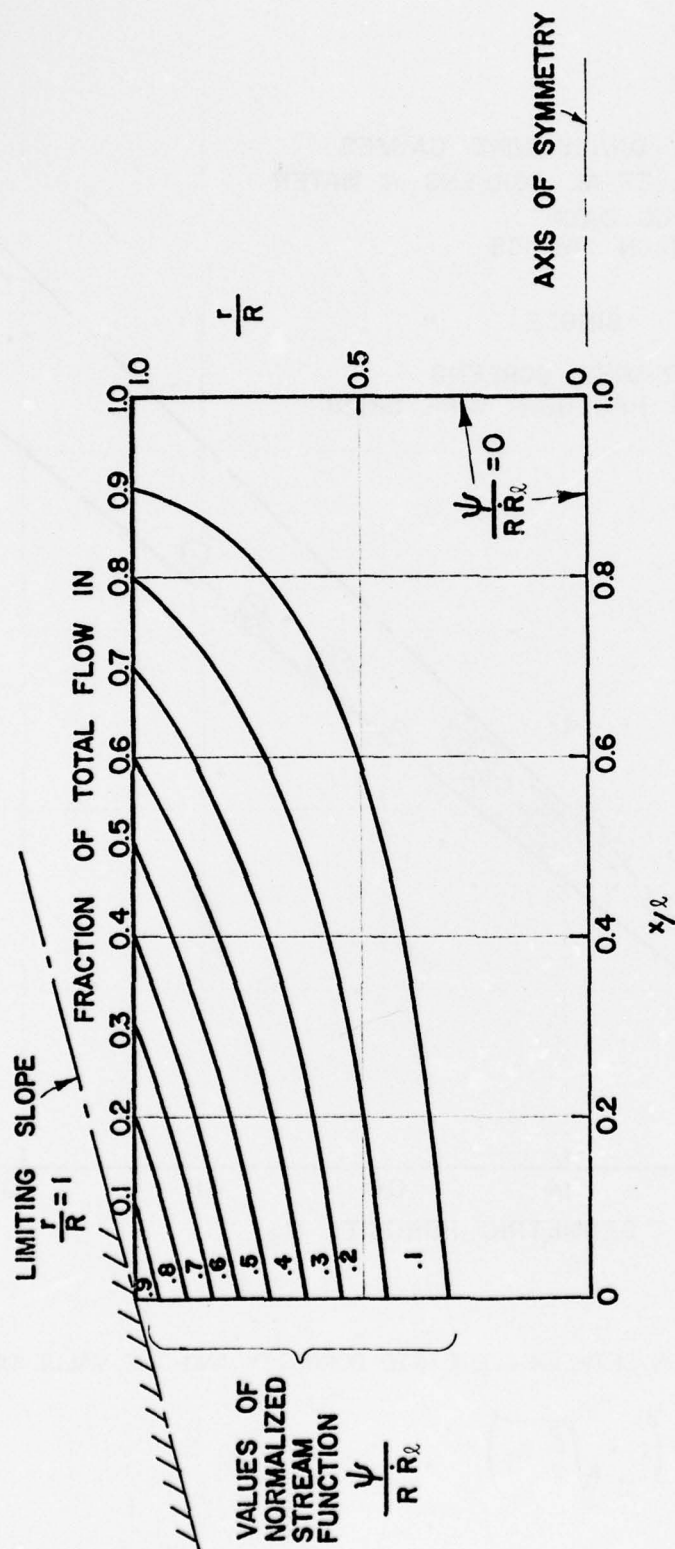


FIGURE 4. STREAM SURFACES PLOTTED NON-DIMENSIONALLY FOR THE CASE OF CONSTANT CAVITY LENGTH  $\ell$

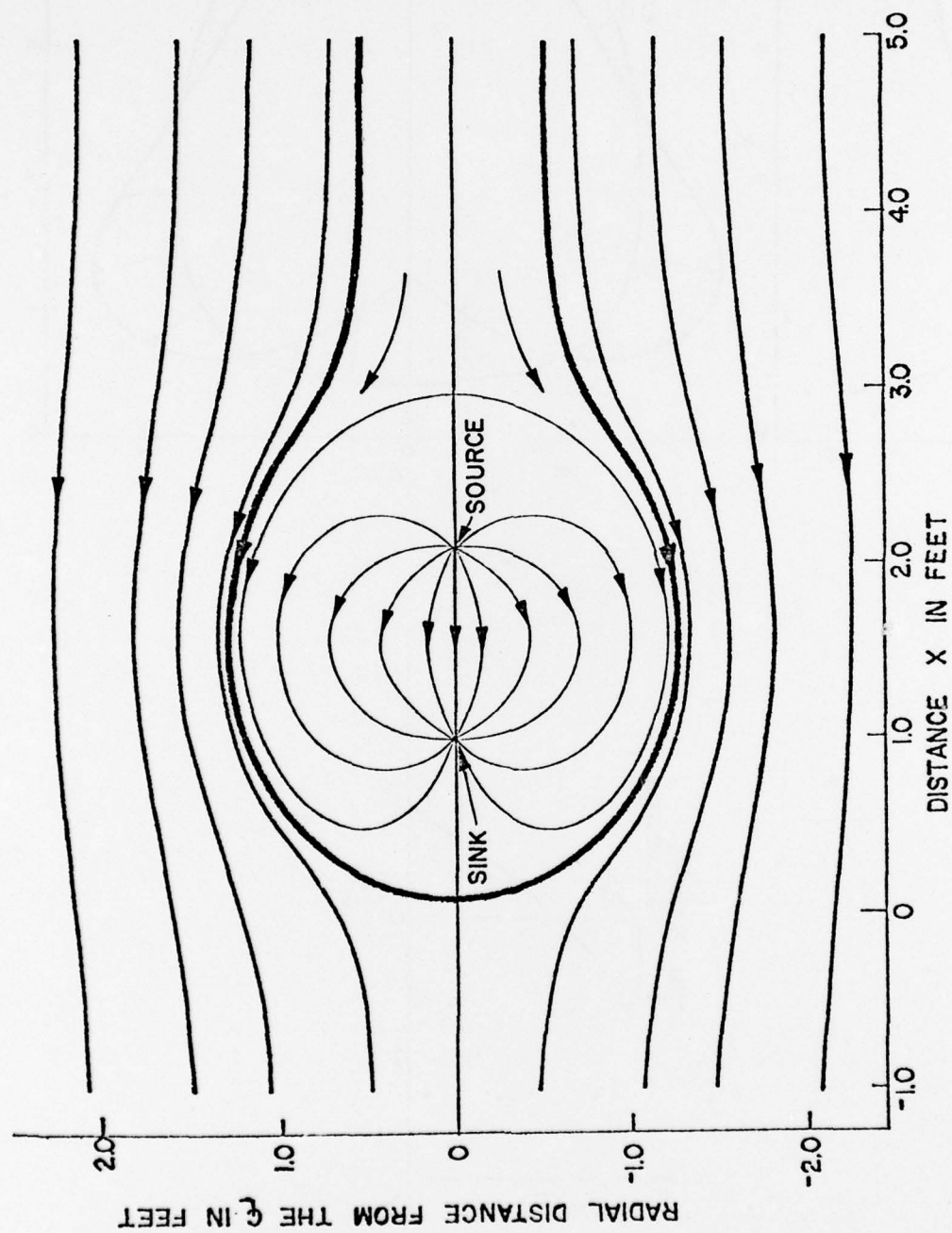


FIGURE 5. STREAMLINES AROUND AN OPENING CANOPY, MODELED WITH AN UNEQUAL SOURCE AND SINK PAIR, OF VARIABLE INTENSITY.

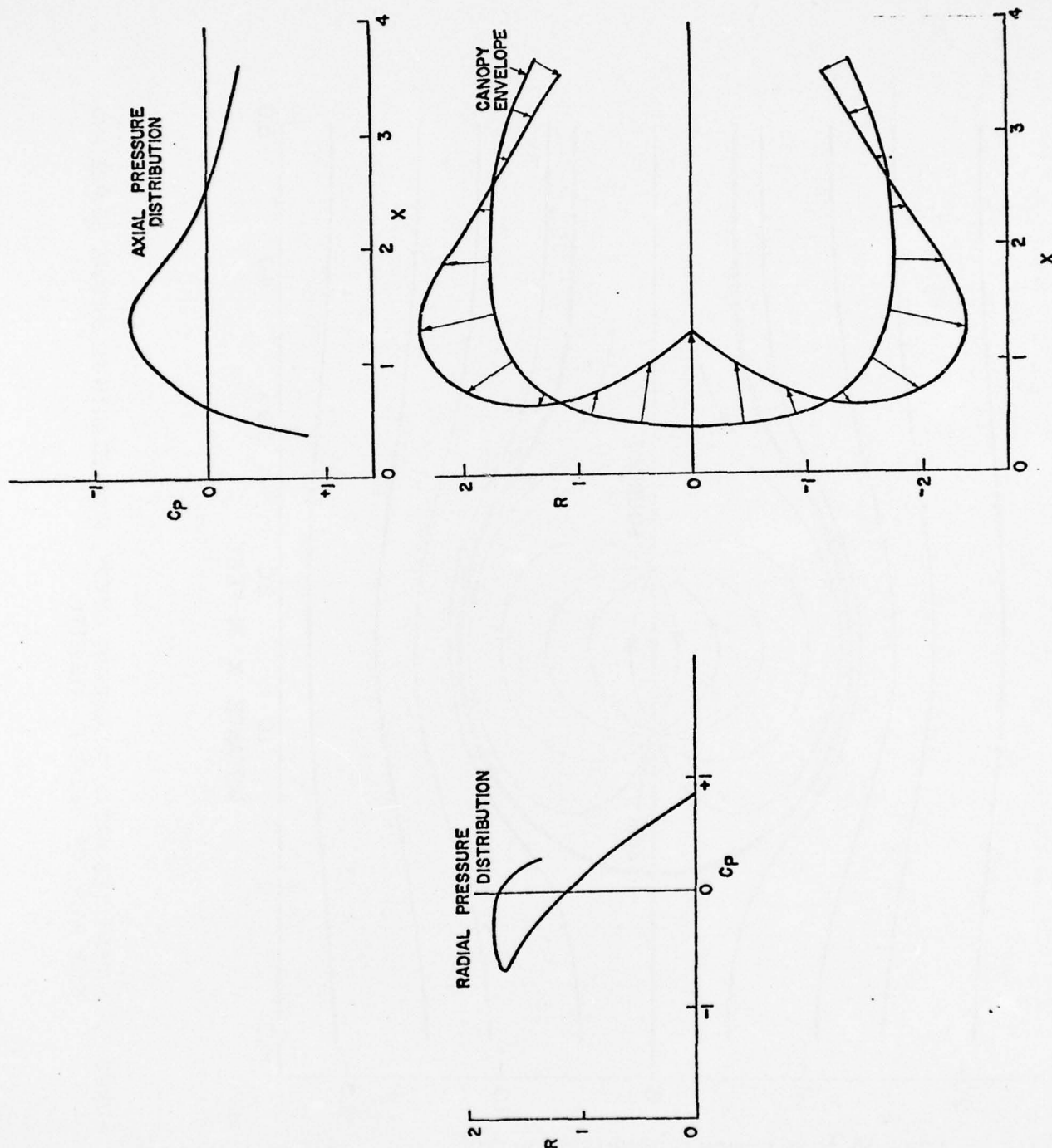


FIGURE 6. COMPUTED PRESSURE DISTRIBUTION OVER AN EXPANDING CANOPY AT  $T = .05$  SEC. FOR THE EXPERIMENTS OF KLIMAS<sup>4</sup>.

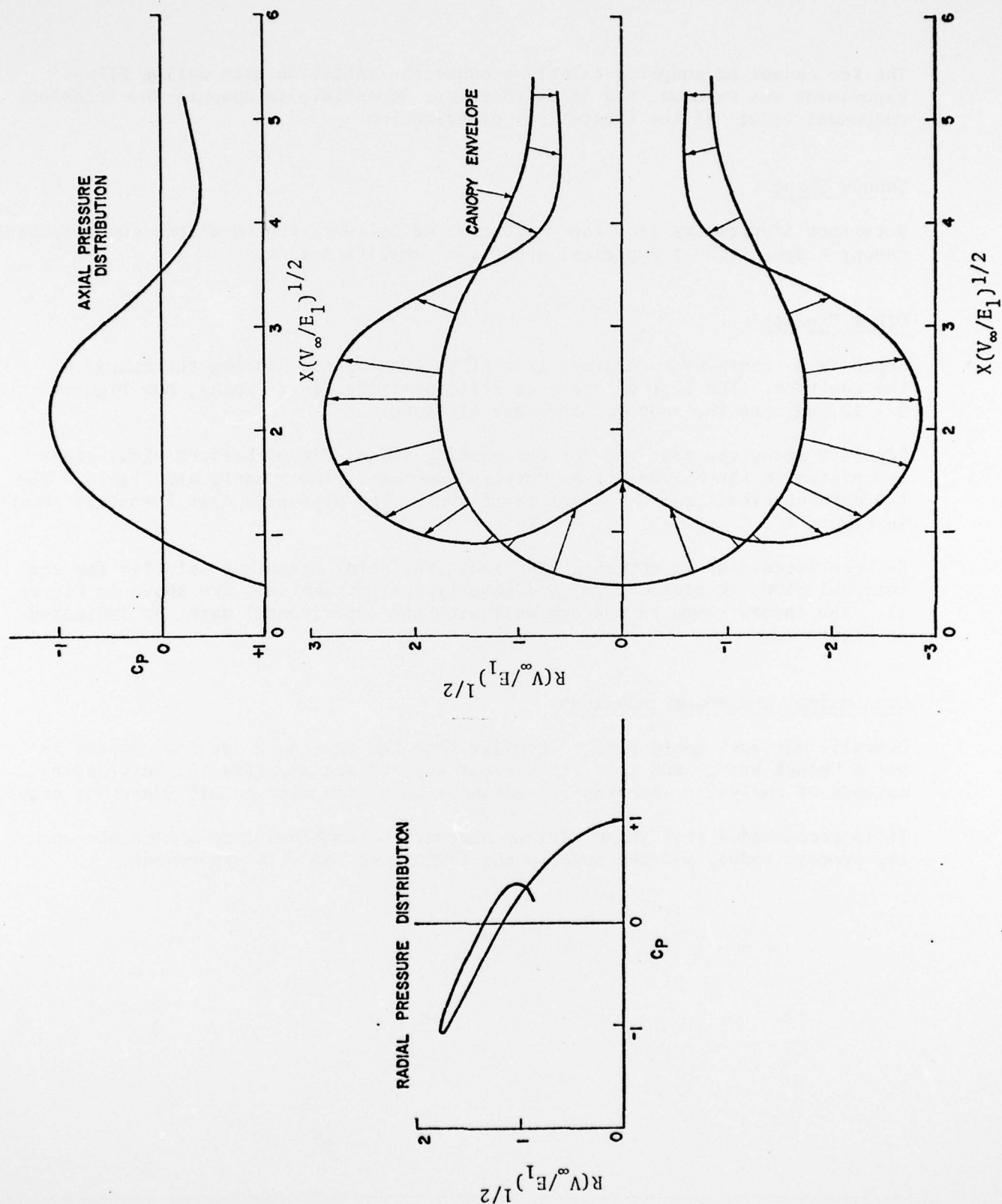


FIGURE 7. STATIC PRESSURE DISTRIBUTION OVER "BEST" GENERATED SHAPE IN INVISCID FLOW FOR COMPARISON WITH FIGURE 6.

The two cannot be compared exactly because the inflation rate during Klimas' experiment was unknown, and it is therefore impossible to compute the transient component  $\partial\phi/\partial t$  of the theoretical distribution.

### Canopy Shape

Reference 5\* presents (for the first time we believe) the equations for computing canopy shape, without empirical geometric simplifications.

### Other Studies

Appendix A contains a complete list of reports written during the course of the contract. The last of these is still awaiting final typing, but Figures 8 - 12 indicate the scope of the investigation.

Figure 8 shows the test rig for the opening wedge, rigged between plexi-glass end plates in the University of Maryland subsonic wind tunnel, and Figure 9 the raw data obtained from a typical experiment. The processed data format is shown in Figure 10.

We were successful in obtaining an exact (inviscid) transient solution for the internal flow, in closed form, and some typical streamlines are shown in Figure 11. The theory seems to conform well with the experimental data, as indicated in Figure 12.

### Conclusions and Recommendations

Overall, our work would seem to confirm that the parachute opening process is not a "black art", and that its various aspects are amenable to the classic methods of analysis. Substantive advances have been made in all important areas.

It is recommended that these various elements be combined into a complete opening process model, and the model predictions compared with experiment.

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\*Submitted for publication.

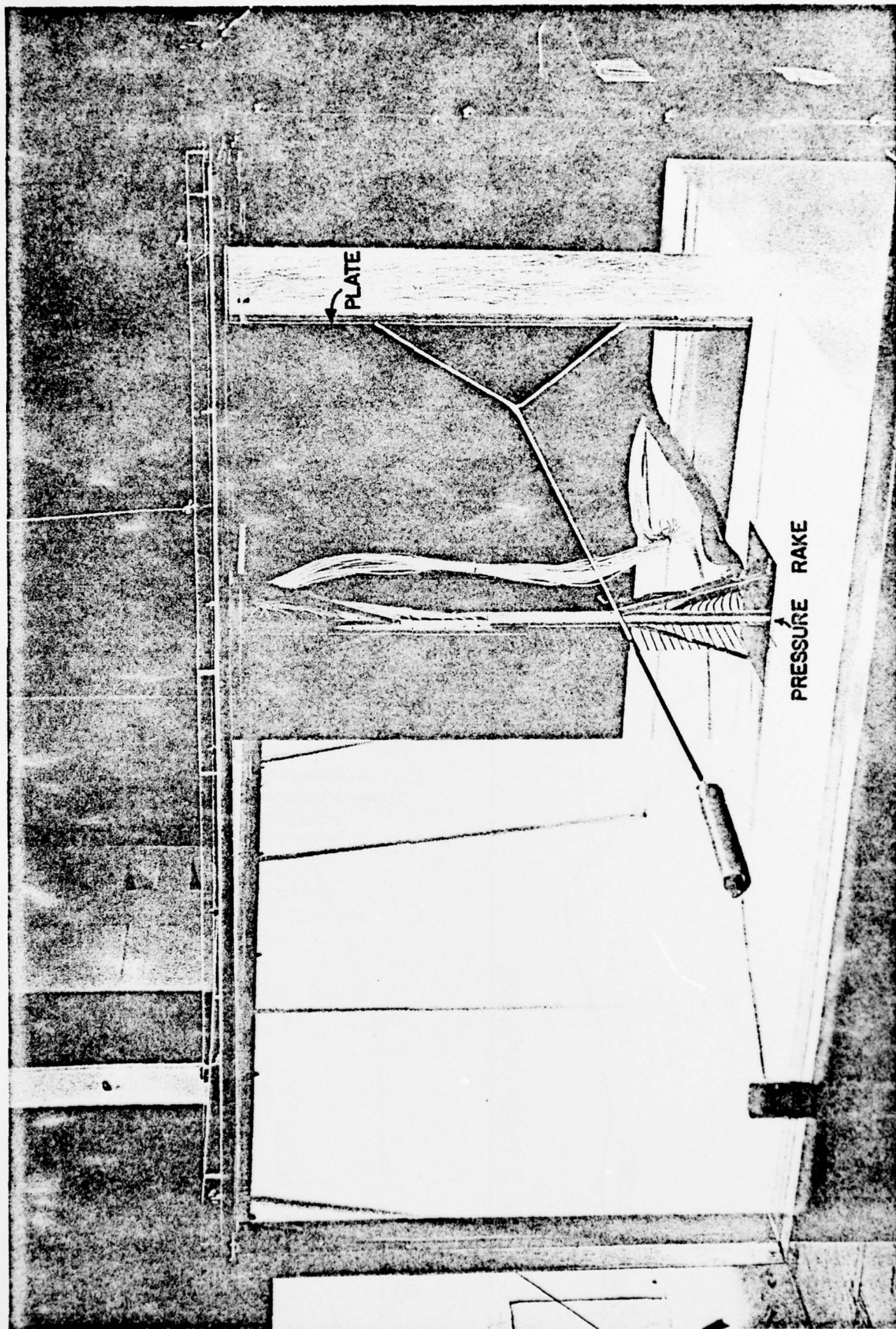


Figure 8. Two-Dimensional Test Section Showing Experimental Set Up and Pressure Survey Rake.

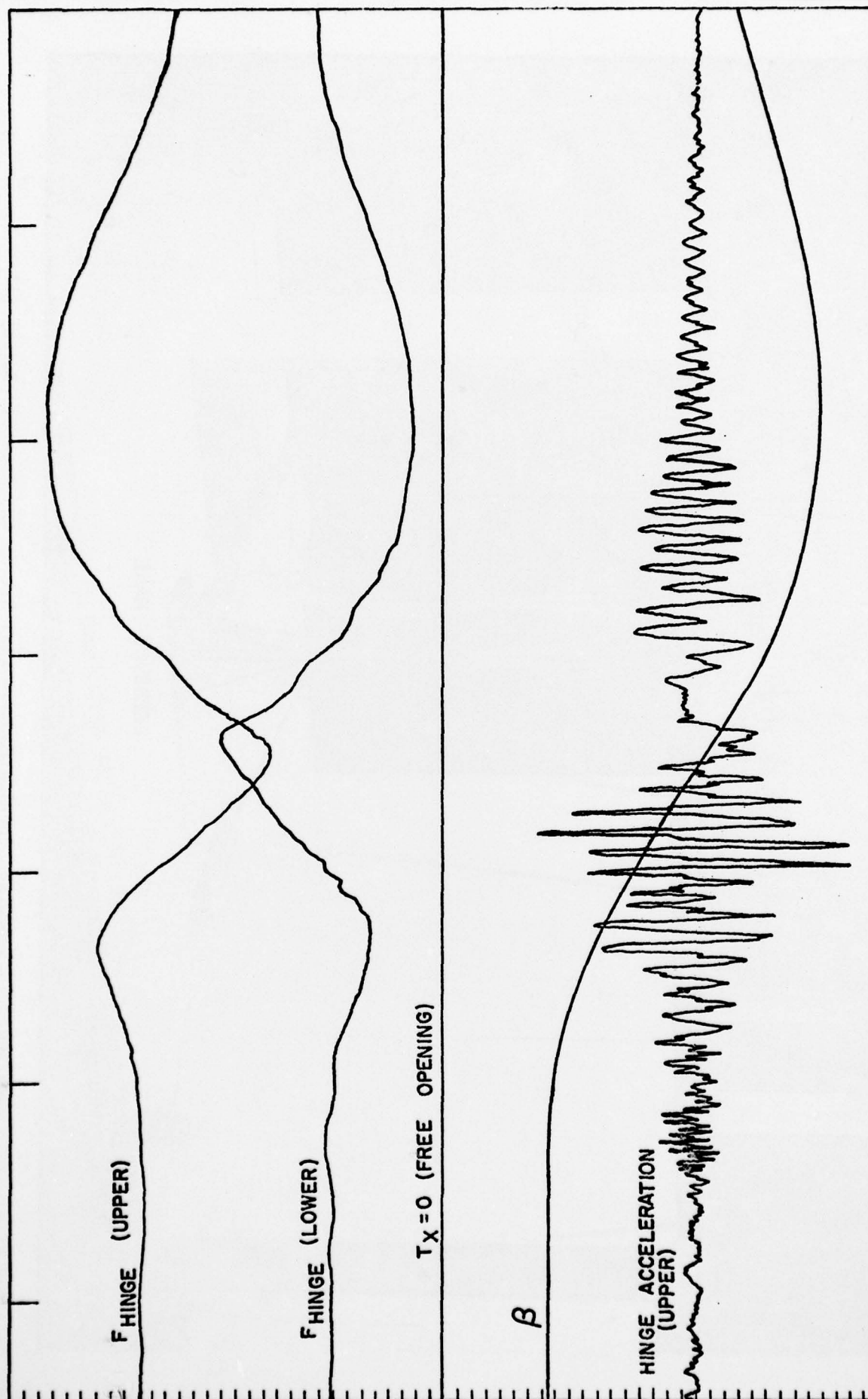


FIGURE 9. RAW DATA FOR THE FREE-OPENING, UNVENTED CASE,  $\beta = 10^\circ$ ,  $V = 50.0$  FPS

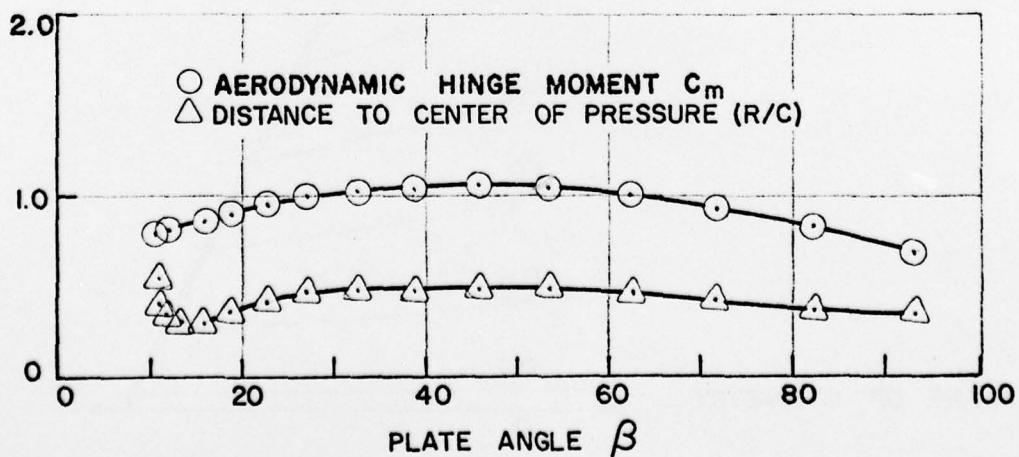
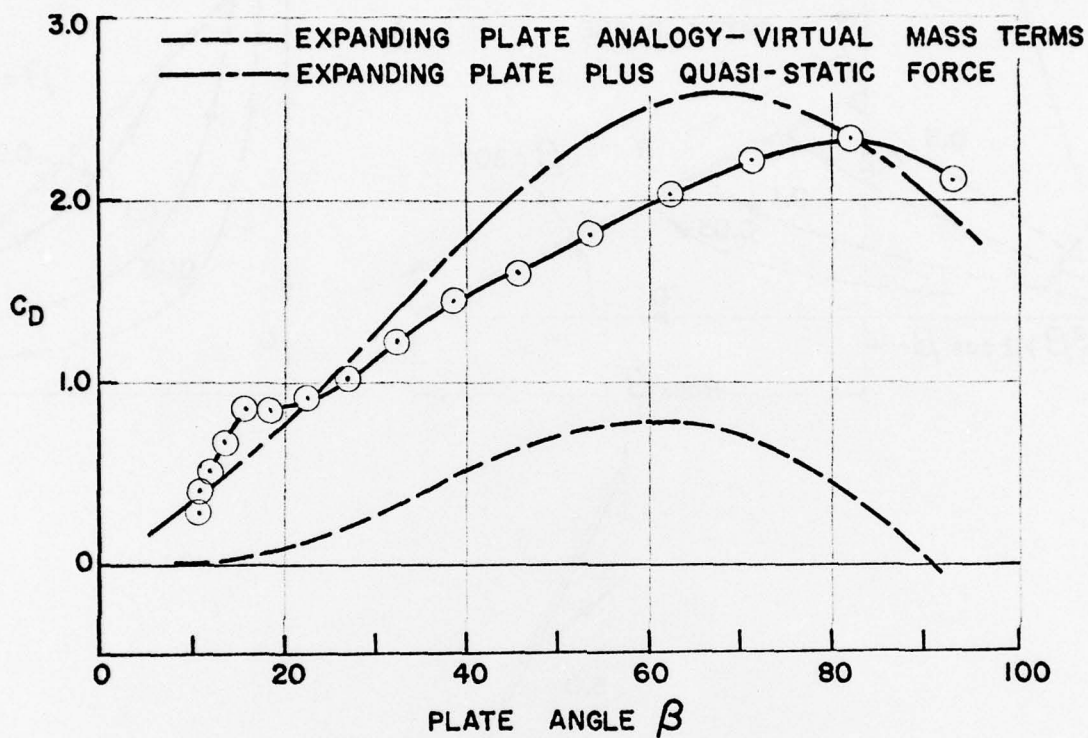


FIGURE 10. TRANSIENT DRAG OF A FREELY OPENING PLATE, BASE VENTED, 50 FPS TUNNEL SPEED, INITIAL ANGLE =  $10^\circ$ .

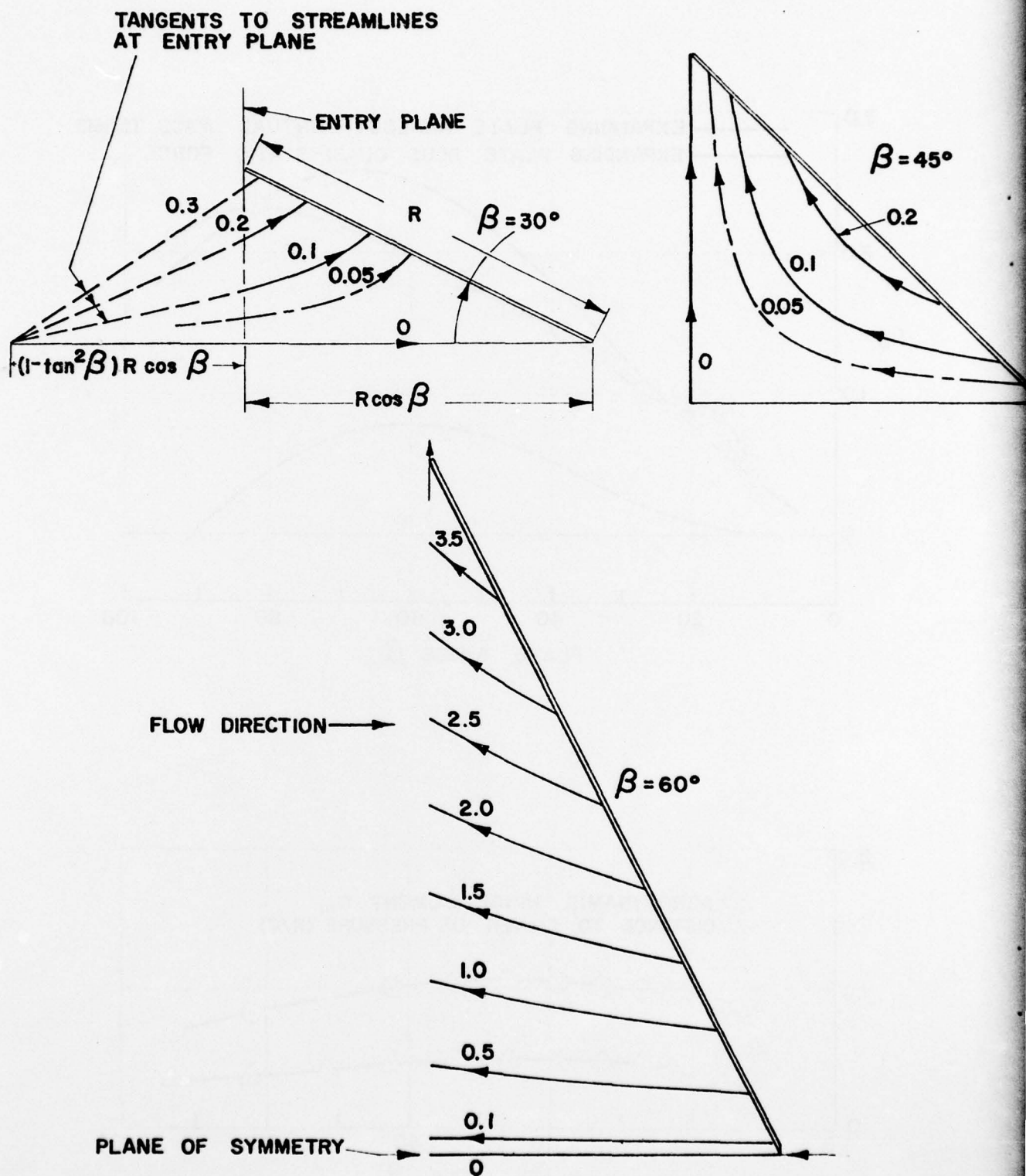


FIGURE 11. STREAMLINES IN A GUTTER WHEN THE FORWARD EDGE IS CONSTRAINED FORE AND AFT, AND THE VERTEX IS FREE TO MOVE ALONG THE AXIS. IN THE PLOTS  $R \cos \beta$  IS TAKEN AS UNITY AND THE VALUES ON THE CURVES ARE  $C/R^2 \cos^2 \beta$

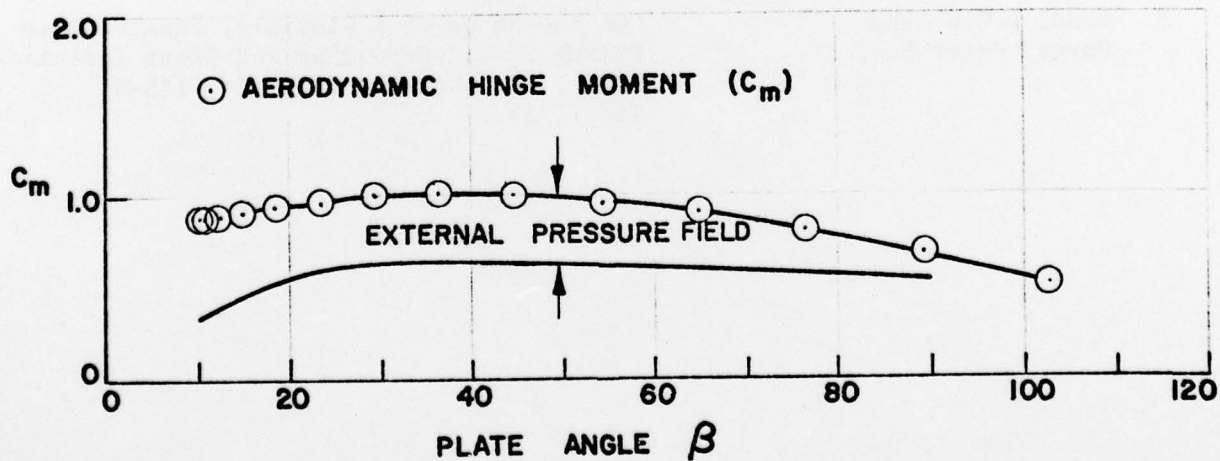
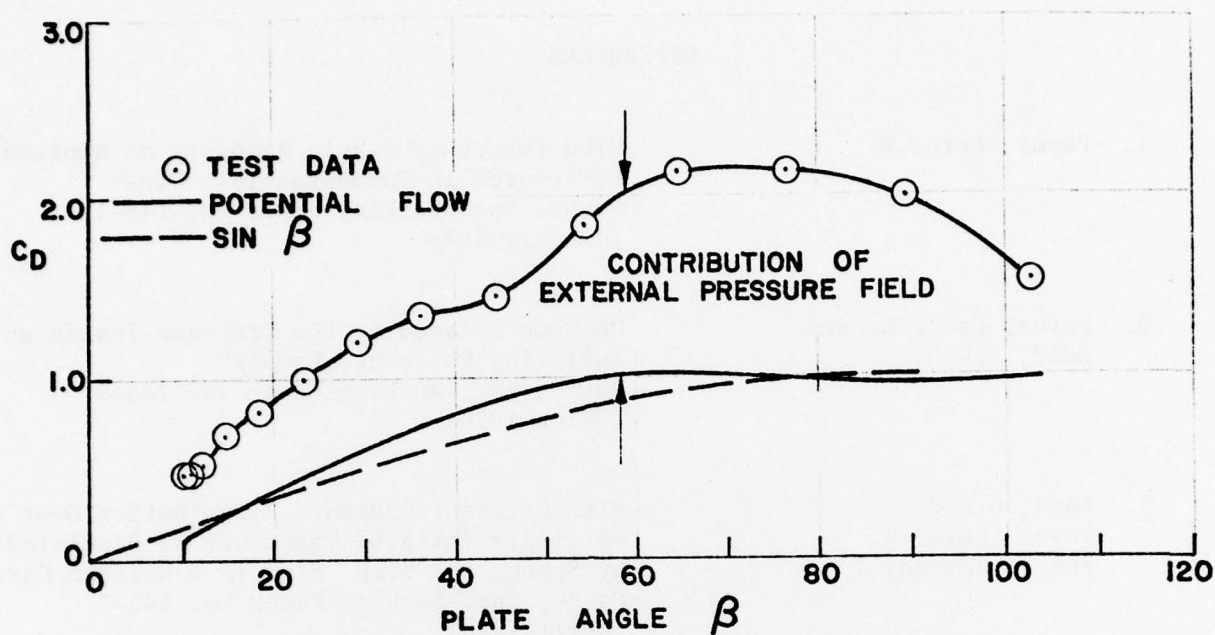


FIGURE 12. THE INTERNAL POTENTIAL FLOW SOLUTION COMPARED WITH THE WIND TUNNEL MEASUREMENTS

#### REFERENCES

1. Payne, Peter R. "The Theory of Fabric Porosity as Applies to Parachutes in Incompressible Flow"  
Payne, Inc. Working Paper No. 145-1  
(January 1976)
2. Payne, Peter R. and Band, E.G.U. "A Note Related to the Pressure Inside an Inflating Parachute Canopy"  
Payne, Inc. Working Paper No. 145-9  
(March 1976)
3. Band, E.G.U.  
Payne, Peter R.  
Euler, Anthony J "The External Pressure Distribution Over a Partially Inflated Parachute as Simulated by Source and Sink Flow in a Uniform Stream"  
Payne, Inc. Working Paper No. 145-3  
(April 1976)
4. Klimas, Paul C. and Rogers, David F "Helium Bubble Survey of a Parachute Opening Flowfield Using Computer Graphics Techniques"  
for U.S. Army NATICK Laboratories, (May 1975)  
Also published as AIAA Paper No. 75-1368  
(November 1975)
5. Band, E.G.U. and Payne, Peter R. "On the Shape of a Flexible, Inextensible Parachute Canopy During and After Inflation"  
Payne, Inc. Working Paper No. 145-5  
(April 1976)

APPENDIX

SIGNIFICANT REPORTS GENERATED  
UNDER CONTRACT NO. F44620-76-C-0020  
TO DEVELOP THE THEORY OF PARACHUTE OPENING

| <u>Working<br/>Paper No.</u> | <u>Author(s)</u>                        | <u>Title</u>                                                                                                                                        |
|------------------------------|-----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| 145-1                        | P.R. Payne                              | The Theory of Fabric Porosity as Applied to Parachutes: Part I - Incompressible Flow, November 1975.                                                |
| 145-3                        | A.J. Euler<br>E.G.U. Band<br>P.R. Payne | The External Pressure Distribution Over a Partially Inflated Parachute as Simulated by Source and Sink Flow in a Uniform Stream, April 1976.        |
| 145-5                        | P.R. Payne<br>E.G.U. Band               | On the Shape of a Flexible, Inextensible Parachute Canopy During and After Inflation, December 1975.                                                |
| 145-6                        | P.R. Payne                              | The Total Head Loss Due to the Suspension Lines of an Inflating Parachute Canopy in Incompressible Flows, January 1976.                             |
| 145-7                        | P.R. Payne                              | Notes on the Taylor Parachute Shape Equation, January 1976.                                                                                         |
| 145-8                        | P.R. Payne                              | On a Class of Nonlinear Second Order Equations, February 1976.                                                                                      |
| 145-9                        | P.R. Payne                              | A Note Related to the Pressure Inside an Inflating Parachute Canopy, March 1976.                                                                    |
| 145-10                       | P.R. Payne                              | A Note on the Quasi-Static Flow into a Parachute Canopy, January 1976.                                                                              |
| 145-11                       |                                         | A Bibliography Related to Parachute Opening, March 1976.                                                                                            |
| 145-12                       | P.R. Payne<br>F.W. Hawker               | The Fluidynamic Forces Acting on a V-Gutter, Free to Open About a Pivot at its Vertex: A Theoretical and Experimental Investigation, November 1976. |
| 145-13                       | P.R. Payne<br>E.G.U. Band               | Final Report - Research on Parachute Opening, November 1976.                                                                                        |

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| 7. AUTHOR(s)<br>Peter R. /Payne<br>E. G. U. /Band                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                       | 9. PERFORMING ORG. REPORT NUMBER<br>Working Paper 145-13                               |  |
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