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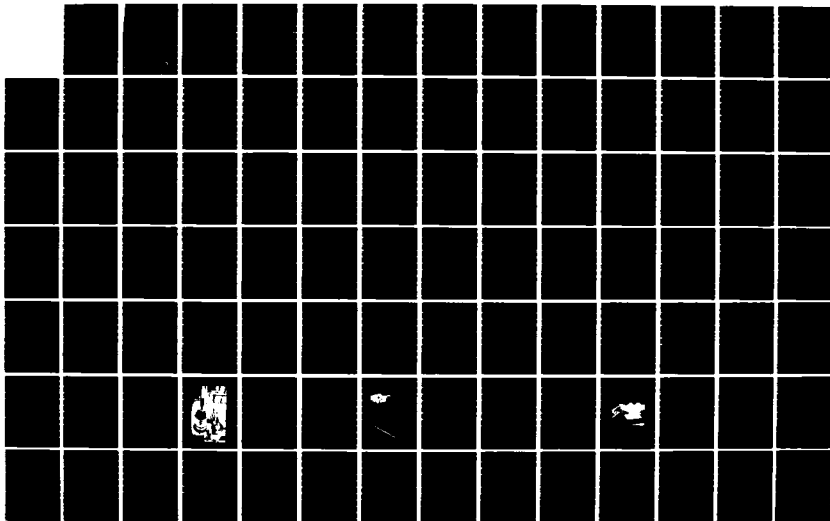
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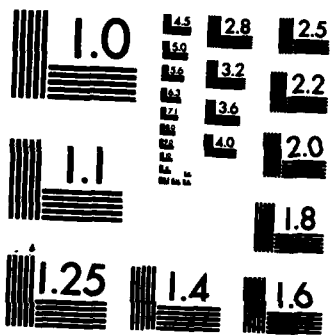
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THE EFFECT OF STRAKES ON VORTICAL FLOWS
APPLIED TO AIRCRAFT

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<p>→ The influence of strakes placed along vortical flows has been determined in order to define ways of drag reduction on wake-like flow fields present on aircraft afterbodies.</p> <p>Strakes of different aspect ratio and thickness were tested at different angles of incidence with respect to a vortex path in order to evaluate the best configuration which can reduce, or minimise, the cross flow kinetic energy, thus the vortex drag of a vortical flow.</p> <p>The flow field in the vicinity of the boattail of a scale cargo aircraft was studied. The aircraft was tested with and without strakes placed on its afterbody, the results confirm that when strakes are properly placed on the boattail, a reduction in drag is achievable.</p>			

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This technical report has been reviewed and is approved for publication.


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PROJECT REPORT 1983-22

JUNE 1983

THE EFFECT OF STRAKES ON VORTICAL FLOWS
APPLIED TO AIRCRAFT

GUSTAVO G. ORDONEZ

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This report is dedicated to my father who, among many things, taught me about love, hard work and the pursuit of self-satisfaction in life.

ABSTRACT

The influence of strakes placed along vortical flows has been determined in order to define ways of drag reduction on wake-like flow fields present on aircraft afterbodies.

Strakes of different aspect ratio and thickness were tested at different angles of incidence with respect to a vortex path in order to evaluate the best configuration which can reduce, or minimise, the cross flow kinetic energy, thus the vortex drag of a vortical flow.

The flow field in the vicinity of the boattail of a scale cargo aircraft was studied. The aircraft was tested with and without strakes placed on its afterbody, the results confirm that when strakes are properly placed on the boattail, a reduction in drag is achievable.

LIST OF SYMBOLS

AR	$\frac{b^2}{S}$, wing aspect ratio
b	wing span
BIR	$\frac{\sqrt{(P2-P4)^2 + (P1-P3)^2}}{(P5-\bar{P})}$, misalignment parameter
C_p	$\frac{P-P_\infty}{q}$, pressure coefficient
CP	$\frac{(PT-P5)}{q}$, total pressure parameter
CX	$\left[C_{pang} \left(\frac{\text{projected axial area}}{S} \right) \right]_{\text{forward facing}}$ $- \left[C_{pang} \left(\frac{\text{projected axial area}}{S} \right) \right]_{\text{rearward facing}}$
D	wake dimension, largest distance between contour points of 1.1 Pr
DCFKE	$\frac{v^2+w^2}{U_0^2}$, dimensionless cross flow kinetic energy
D_1	component of the drag of a vortex wake
H	$\frac{(H_S - H_{WLC})}{D}$
H_S	height of strake
H_T	total head
H_{WLC}	height of wake lower core (lowest portion of Pr = 1.1 isoline)
\bar{P}	$\frac{(P1+P2+P3+P4)}{4}$, average peripheral pressure
PD	$\frac{(P5-\bar{P})}{q}$, dynamic pressure parameter
P_r	$\frac{P_T}{q_\infty}$

P_s	static pressure
P_T	total pressure
P_1	
P_2	
P_3	circumferential pressure measured by five hole probe
P_4	
P_5	pressure measured by the central tube in the five hole probe
P_∞	free stream pressure
q	$\frac{1}{2} \rho V^2$, dynamic pressure
s	$\frac{b}{2}$, wing semispan
S	wing area
u	flow velocity component in the x-axis
U_0, U_∞	free stream velocity
v	flow velocity component in the y-axis
V	total velocity vector
w	flow velocity component in the z-axis
x	lateral axis of the wind tunnel + left (looking upstream)
y	vertical axis of the wind tunnel + upwards
z	longitudinal axis of wind tunnel + downstream

α	angle of attack
α_r	strake angle of attack with respect to a vortex path
α_S	angle of aircraft strake referenced to boattail wake path
γ	yaw angle
θ	misalignment angle, or pitch angle
ξ	x distance downstream of delta wing trailing edge / S
ρ	density of air
ϕ	roll angle

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1. INTRODUCTION

1.1 Previous investigation

Wind tunnel and flight test results have shown that when strakes are mounted in the afterbody part of an aircraft (or so called "boattail") a reduction in the overall drag may be obtained.

Previous researchers have investigated the flow on afterbodies of representative fuselages of high upswept angle. Different devices such as strakes and flow deflectors have been fitted to such configurations and qualitative conclusions from visualization experiments were drawn. In some cases the effect of applying suction along the boattail area was investigated and the effects on the afterbody induced wake was as well determined qualitatively.

Although helpful, no previous work done on aircraft afterbodies could define exactly what is the effect, and its reason, when a strake is placed along a wake-like flow, or vortical flow, like the ones induced by aircraft with a large unswept boattail angle.

This prompted the desire to carry out a series of experiments at the von Karman Institute in order to define the mechanisms of action of a strake in the presence of vortical flows and its application on aircrafts as a way of drag reduction. This report describes such results.

1.2 Research steps carried out

In order to carry out our proposed projects, several steps were followed.

First, we investigated the flow field existent in an aircraft where the fuselage-boattail combination induces a vortex field.

Secondly, using a delta wing placed at a high angle of attack, the flow field downstream of its trailing edge was studied. This was done since previous research (Ref. 16) has shown that the vortex field induced by aircraft afterbodies is similar to the downstream vortex induced by separation on lifting slender delta wings at high angles of attack.

By placing strakes of different configurations along the vortex path downstream of the delta wing trailing edge, and scanning the flow behind the strakes we determined the effect of strakes in a vortical flow, and most important, defined ways of drag reduction by defining which strake configuration minimizes the vortex cross flow kinetic energy.

The above information served us to know how strakes should be placed on aircraft afterbodies. This was done and the results were validated by measuring the static pressures along the aircraft afterbody surface.

2. THEORY

2.1 Determination of vortex drag

The analysis proposed by Maskell (Ref. 5) which is an extension of the theory due to Betz to calculate the drag of a wing of finite span from a wake survey in one plane downstream of the model was adopted, in order to define what parameters on the wake-drag equation could be minimized so that its drag could be reduced.

Consider the flow generated by a lifting wing of finite span in a closed wind tunnel, where u, v, w are the x, y, z components of velocity, P_s the static pressure, H_T the total head and D the total drag of the wing. If the flow is assumed steady, incompressible and irrotational outside boundary layers and wakes the conservation of momentum equation within a control surface bounded upstream and downstream of the wake requires that

$$D = \iint \left[P_{s1} + \rho u_1^2 \right] dS - \iint \left[P_{s2} + \rho u_2^2 \right] dS \quad (1)$$

This equation does not take into account the effect of pressure gradients between the control surfaces.

The total head formula is, by definition :

$$H = P_s + \frac{1}{2} \rho (u^2 + v^2 + w^2) \quad (\text{inside wake}) \quad (2)$$

and outside the boundary layer and wake of the wing

$$H_{T_\infty} = P_\infty + \frac{1}{2} \rho U_\infty^2 \quad (3)$$

where U_∞, P_∞ are the velocity and static pressure of the undisturbed stream.

Substituting equations (2) and (3) into (1) for the two control planes respectively we obtain :

$$D_1 = \iint_W (H_{T_1} - H_{T_2}) dS + \frac{1}{2} \iint (u_1^2 - u_2^2) dS \\ + \frac{1}{2} \rho \iint \left[(v_2^2 + w_2^2) - (v_1^2 + w_1^2) \right] dS \quad (4)$$

where \iint_W denotes the integral over the wake region.

Equation 4 implies that the drag of a wake is proportional to the sum of the cross flow velocity components squared at the control surface downstream of the wake. Also, as the value of the U_2 velocity component approaches the undisturbed stream velocity, the second term of the RHS equation (4) is kept to a minimum.

Note that D_1 does not contain all the terms found in a detailed vortex drag equation. Reference 14 details it including wall effects and blockage terms.

3. EXPERIMENTS

3.1 Data acquisition system and methodology

All measurements were acquired by means of the data acquisition system which can be seen in figure 1a. It consists of a floppy disk driver linked to a Commodore PET computer which acquires a signal at a predetermined lapse by means of a stepping motor-scanivalve combination. The data is digitized, stored in a digital cassette and reduced by the VKI central computing system. The data is reduced as well by the PET computer and some of the results are prompted during testing in order to check the validity of the data acquired. All pressures were checked against a Betz manometer. Figure 1c shows the data acquisition schematic used for our experiments. Depending on whether it was surface static pressures or velocity field plots that we searched for, pressure taps or a five hole probe were connected into a multiple portion scanivalve. A Validyne MP45-1 variable reluctance transducer measured the pressure difference with respect to the tunnel static pressure. The voltage signal reached an amplifier of sufficient gain to optimize the accuracy of measurements : an analog to digital converter was placed before the PET Commodore computer.

Figures 2a and 2b show the five hole probe used for our measurements. It was supported by a traversing mechanism fixed along one of the straight walls of the test section and flow field surveys were made by displacing the probe along surface planes perpendicular to the test section. The stem which encloses the probes was aligned with the longitudinal axes of the wind tunnel. A detailed view of the five hole probe can be seen in figure 3 and the support system is shown in figure 4.

The calibration curve for the pressure transducer is shown in figure 5 showing the linearity of the instrument; its deviation is 0.5%.

Appendix I includes the data acquisition program implemented in the PET computer which was used for our tests.

3.2 Measurements using a five hole probe

Flow field measurements were done by means of a five hole probe (Figs. 2a,3) in order to obtain a quantitative description of the three dimensional flow involved in our case. This is of prime importance since we deal with vortex flows where limiting streamline pattern, smoke injection and pressure plots at the surface are not sufficient to understand the flow behaviour.

The five hole probe method of measurement was used since it can be set in a non-nulling mode of operation (i.e., the probe is inserted into the flow in a fixed attitude), and physical quantities describing the flow can be deduced from the pressures recorded by the probe.

Small measurement errors in vortical flows are expected due to the finite probe size in flow gradients, unsteady effects and probe response time.

Disturbances produced by the probe own geometry are accounted for by calibrating it in a free stream of known speed and direction. The calibration speed was the same as test conditions with pitch angle limits higher than the expected in vortex flows.

3.2.1 Calibration of the five hole probe

This type of probe enables the total local pressure and velocity vector components to be deduced from the pressures sensed by the five tubes open to the flow in a configuration shown in figure 3.

The calibration was done following a combination of the methods described by Wickens (Ref. 10) and Meineke (Ref. 7). The parameters listed below are deduced from the pressures measured by the probe. These are :

$$PD = \frac{P5 - \bar{P}}{\frac{1}{2} \rho V^2} \quad \text{dynamic pressure parameter}$$

$$CP = \frac{PT - P5}{\frac{1}{2} \rho V^2} \quad \text{total pressure parameter}$$

$$PHI = \frac{P2 - P4}{P1 - P3} \quad \text{roll parameter}$$

$$BIR = \frac{\sqrt{(P2 - P4)^2 + (P1 - P3)^2}}{P5 - \bar{P}} \quad \text{misalignment parameter}$$

where P1-P4 are the pressures at the probe defined in figure 6B. These relations are sufficient to obtain a calibrated probe if the flow direction is given by the pitch angle θ , and the roll angle ϕ normal to the probe head. The actual roll flow angle can then be deduced from the relation $\tan^{-1} \frac{P2 - P4}{P1 - P3}$.

The pitch and roll angles and the flow direction quadrants are defined according to the convention shown in figure 6b. The calibration duct used for our probe is shown in figure 6a. By keeping its velocity constant and varying the pitch and roll angles covered by the different quadrants, the calibration data shown in figures 7-11 was finally obtained. These curves were approximated by a N degree polynomial (its degree was chosen depending on the data scatter) and input in the data reduction program. Each of the plots in figures 7-11 show the experimental data curves and points (dashed line) and the polynomial curve (solid line) which was used to approximate the data. The polynomial formulas used can be read from Table 1.

Figure 10 shows the agreement between the calculated roll angle and the one set in the calibration duct

The dynamic pressure parameter variation with respect to the roll angle can be seen in figure 11. Although not as symmetric as Wickens' results, its cyclic variation with quadrants variations is well defined.

3.2.2 Calculation of total pressure and flow velocity components

During tests, the central and circumferential pressures measured from the five hole probe were recorded. These results were used to calculate ϕ , deduce the quadrant from which the flow is coming, and the value for BIR. Knowing BIR, $|\theta|$ could be found from the calibration curves.

Secondly, the parameter PD could be obtained from the calibration polynomials. This allowed us to deduce the value of the local velocity vector using the following relation :

$$V = \sqrt{\frac{P5 - \bar{P}}{\frac{1}{2} \rho PD}}$$

The parameter CP was then found from the calibration plots. Finally, the total local pressure could be obtained by using $PT = P5 + \frac{1}{2} \rho V^2 CP$.

The probe axis system and the Cartesian system are shown in figure 6b. The transformation formulas used were :

$$\sin|\alpha| = \sin|\theta| \times \cos|\phi|$$

$$\cos|\gamma| = \frac{\cos|\theta|}{\sqrt{1 - \sin^2|\theta| \times \cos^2|\phi|}}$$

and vice versa

$$\tan|\phi| = \frac{\sin|\gamma|}{\tan|\alpha|}$$

$$\cos|\theta| = \cos|\alpha| \cdot \cos|\gamma|$$

Velocity component signs were given by knowing the flow quadrant. The quadrant numbering convention was defined as follows :

Quadrant I:	$\alpha > 0^\circ$	$\gamma > 0^\circ$
	$P1 > P3,$	$P4 > P2$

Quadrant II:	$\alpha > 0^\circ$	$\gamma < 0^\circ$
	$P1 > P3,$	$P2 > P4$

Quadrant III:	$\alpha < 0^\circ$	$\gamma < 0^\circ$
	$P3 > P1,$	$P2 > P4$

Quadrant IV:	$\alpha < 0^\circ$	$\gamma < 0^\circ$
	$P3 > P1,$	$P4 > P2$

Finally, the flow velocity components were calculated using the following relations :

$$u = V \times \cos\alpha \times \cos\gamma$$

$$v = V \times \cos\alpha \times \sin\gamma$$

$$w = V \times \sin\alpha$$

3.3 The VKI L-2A wind tunnel

The L-2A is an open return closed test section wind tunnel as shown in figure 12. The speeds at which all our measurements were taken was at 29 m/s (50 mm H₂O)). In order to ensure that the cross flow velocity irregularities present in the clean tunnel would not influence the accuracy of our experiments, two flow surveys were made at different test section stations; measurements of turbulence were carried out as well. Figure 13 shows the cross sectional view of the L-2A. The solid line bounds the area where the flow surveys were made and the dashed line is the boundary of the turbulence level measurements. All flow field and turbulent maps are shown looking upstream of the test section.

3.3.1 Flow quality

Figure 14 shows a flow field map of one of the test section stations surveyed. The magnitude of the cross flow velocities is of the order of 0.50 m/s, which gives an average flow angularity on the tunnel of about 1.0 degree. The rotational motion seen in figure 14 is thought to be inherent of tunnels of such classes. The magnitude of the cross flow velocities is small compared to the results of our experiments, therefore no large margin of error was expected. Isolines of total pressure are also shown across the test section. In case one is to compare the magnitude of the cross flow vectors by looking at the length of the arrow-vector itself, the reader should note that the cross flow vector plot of figure 14 is not plotted in the same proportion as the rest of the cross flow vector plots existing in this report.

3.3.2 Turbulence measurements

Figures 15a and 15b show turbulence levels and isolines found at the same station as the cross flow survey was done. The average percent of turbulence found at the center of the test section was of about 0.50%.

Figure 16 shows isolines of P_r , found in the L-2A test section.

Figures 17a and 17b show a schematic from the models tested during our research as they were positioned in the tunnel with the boundaries of flow quality survey and turbulence.

Geometric blockage calculations indicate that for the models tested their value was of 3%.

3.4 The aircraft model

In order to study the flow field in the vicinity of an aircraft afterbody, a 1/72 scale model of a Lockheed Hercules C-130 E was used. Figures 18a and 18b show the aircraft tested, the upswept angle at the fuselage-boattail junction is of approximately 25° and reaches values as high as 30° at the end of the boattail. Forty eight pressure taps were installed in a circumferential manner along the fuselage boattail on four different fuselage stations (12 orifices along each station) and their values measured by means of tubing installed through the aircraft wing (Fig. 57). All tests on the aircraft were done at zero degrees fuselage angle of attack. The Reynolds number of tests based on fuselage diameter was of 1.8×10^5 . Transition strips which consisted of sand of height dimensions varying between .420 and .590 mm were placed along the beginning of the fuselage and on the upper surface of the wing. The first one was placed in order to ensure having turbulent flow at the afterbody; the transition strip over the wing was placed to create the correct downwash angle of the wing along the boattail.

Figure 19 shows the experimental set up as the model was installed in the test section. For measuring the static pressures on the boattail, the 48 port scanivalve placed on the lower left corner was used. The traversing mechanism seen on the right was used to displace the five hole probe.

A three view picture of a C-130 model is seen in figure 20. The side view denotes the different fuselage stations where the flow field was surveyed. Fuselage station No. 1 is located at the fuselage-afterbody junction and No. 5 is at the end of the boattail whereas No. 6 is located one fuselage diameter downstream of No. 5.

Note that fuselage station 3 of the aircraft corresponds to the same wind tunnel longitudinal station at which the flow quality survey and turbulence measurements were made.

Pressure taps were installed along fuselage stations Nos. 1,2,3,4 and their positioning can be seen in figure 57.

3.4.1 Oil smoke visualization

By inserting oil smoke upstream of the aircraft the boattail induced wake could be visualized. Such is the case of figure 21 which was taken at fuselage station No. 3. Even though photographic quality is not the best since the pictures were taken with a camera outside the test section focused on a mirror inside, the wake could clearly be seen which also gave us an estimation of the measurement domain of our flow field surveys. The smoke flow visualization results agree qualitatively with the flow field surveys using the five hole probe.

3.4.2 Flow field surveys

In the case of the C-130 where there is a high surface curvature at the junction of the fuselage side panels and the afterbody lower area, the three dimensional boundary layer flow seems to leave the surface near this junction and roll up into trailing vortices which travel along the boattail as they are swept upwards. Such is the indication of the flow field surveys starting at fuselage stations No. 1 to No. 5. A complete wake can be deduced to exist at the end of the boattail area (No. 5)

and this is validated when the flow field is surveyed downstream of the aircraft (F.S. No. 6). The measurement domain could not go higher since the horizontal tail interfered with the probe stem.

Isolines of P_r indicate two areas of pressure loss at the end of the boattail as indicated by figure 26b. The first is along the side of the boattail and the second of slightly less loss, is a bluff wake which leaves the fuselage right behind it. When isolines of cross flow kinetic energy are plotted non dimensionalized with respect to the free stream velocity squared, the location of the wakes is more easily deduced, as shown in figure 26c.

The flow field survey downstream of the boattail (Fig. 27a) shows the final geometry of the wake as it leaves the aircraft in conjunction with other small wakes like the one near the vertical tail. Isolines of P_r (Fig. 27b) denote two areas of large pressure loss which probably are the boattail induced trailing vortex, and the bluff wake which leaves the aircraft through the corner of the end of the boattail.

Figure 27c agrees with the previous figure by locating the position of the boattail induced vortex with isolines of cross flow kinetic energy.

3.4.3 Limiting streamlines visualization

Limiting streamlines visualizations was done by mixing talc, oleic acid, titanium dioxide, gasoline and oil and placing small dots on the afterbody surface. Figure 28a shows the top view of the aircraft, where limiting streamlines traveling close together tend to separate in different directions. Figure 28b gives an idea of the embracing of the flow over the boattail as well as the downwash angle induced by the wing. Two separation lines can be seen, one at the side-panel-bottom junction and the other which is also seen in figure 28c,

corresponding to the bluff wake that leaves the boattail through the afterbody corner. Note on figure 28c the result of stagnated flow present on the upper end of the boattail; some of the mixture used to visualize the limiting streamlines did not move.

3.5 The delta wing

A delta wing of aspect ratio = 1.0 (Fig. 29) placed at 20° angle of attack was positioned on a flat plate and tested in the wind tunnel.

3.5.1 Flow field surveys downstream of it

Surveys were made in order to determine the position of the vortex path as it travels downstream. Figures 30a,b,c show the flow field, P_r and CFKE isolines of a plane $\xi = 0.625$ downstream of the trailing edge. Figures 31a,b show the cross flow field and CFKE values of a plane $\xi = 1.875$ downstream of the trailing edge.

Results of the flow field survey at $\xi = 2.5$ are shown in figures 32a,b and c. The control plane has been increased compared to the ones shown in figures 30 and 31.

The $\xi = 2.5$ station is the basis for our analysis when we will compare these results against the same control plane but having strakes placed before it.

3.5.2 Vortex core travel path

Figure 33 shows the travel path that the delta wing induced vortex follows as it leaves the trailing edge. Note that the helix makes an angle with respect to the momentum flow direction and that as it travels downstream it tends to curve referenced to the tunnel axis. The height of the vortex core is approximately constant as it moves downstream.

3.6 Strakes placed downstream of the delta wing

3.6.1 Thin strakes

Different strake configurations were placed downstream of the delta wing, and pivoted at $\xi = 1.25$, in order to change the angle of incidence with respect to the incoming vortex.

Figure 34 shows how strakes were placed on the flat plate and their position with respect to the wing. The flow field downstream of the strake was studied (at the $\xi = 2.50$ plane).

Measurements of static pressures on the strake surfaces were also done.

Figure 35 shows the different strake configurations that were tested. Water tunnel flow visualization studies were made by placing a delta wing of $AR = 1$ at 20° angle of attack and observing the vortex path and the field downstream of the strakes qualitatively. Figure 36 shows the set up used. The vortex formed by the delta wing leading edge separation as it travels downstream was observed and strakes were positioned along the path.

The height of the strake was chosen so that it would reach three different levels of H (as defined in figure 37). If we look upstream on the P_r isolines plot of figure 32b, wake dimension D is the distance from the vortex core to the $P_r = 1.1$ isoline (the largest). Therefore $H = 0$ when the strake reaches $P_r = 1.1$ on the lower side and 1.0 when it reaches the highest point along the curve, $H = 0.5$ when the height of the strake reaches the vortex core. The angle of attack sign can be defined in the conventional way. It is positive when the leading edge of the strake is moved right and negative when it moves left. The zero alpha position was when the strake is aligned and in the center of the vortex path.

Figure 38 shows that when the strake $H = 0$ is placed at a negative angle, as the helix moves along the strake the lower part of the vortex which cannot jump to the other side continues having a vortical type motion, but the flow coming out of the forward facing side is streamlined as a result of not having rotational energy or vorticity contributed by the flow on the opposite side of the strake.

The same sort of effect is present when $\alpha_r = 0$, although the streamlined flow has changed positions and the main vortex core has been displaced.

For positive incidence, the appearance of an opposite direction vortex field from the main appears in the lower right corner with small values for its cross velocities. For negative incidences, the values of the velocities are higher than for angles of zero or above.

The same trend is followed by strakes of ratio $H = 0.5$ (Figs. 41-43) although the magnitude of their cross flow velocities is smaller than for the $H = 0$ case, especially when $\alpha_r = 0$, which produces a streamlining effect clearly noticed.

At positive angles of attack, a double vortex is definitely present which reduces the magnitude of opposite direction velocities of the velocity vector integral, thus reducing the vortex energy loss.

Water tunnel visualization for $H = 0.5$ strake is shown in figure 44 which confirms the result shown by the cross flow velocity components plots : an existing vortex is still present at $\alpha_r = -15$ and is streamlined as $\alpha_r = 0$; at positive angles of attack, part of the vortex flow is redirected due to the influence of the strake presence and still maintains vortex motion, and the other plot "jumps over" (Fig. 44b) the strake with its core finding a new equilibrium position near the lower corner of the control plane.

Similar observations are found for strakes of $H = 1.0$ (Figs. 45-47) with the difference that the velocity components are higher than $H = 0.5$ and $H = 0$ expect for $\alpha_r = -15^\circ$. Strakes of $H = 1.0$ have a wider area of pressure loss where a vortex core is present. This can be observed on the P_r isoline plots.

Water tunnel visualization for strakes of different H and constant α is seen in figure 48. For the case of strake placed in the lower edge of the vortex, the wing induced vortex does not get influenced as much as the other two cases do. For the $H = 1.0$ case the vortex impinges on the forward facing surface and does create a more disorganized flow than the $H = 0.5$ case.

3.6.2 Thick strakes

In order to evaluate the effect of thickness on the cross flow kinetic energy, strakes of $H = 0.5$ ratio were tested at different angles of attack. The resultant flow field agrees in trend and in approximate magnitude with the thin strakes placed at similar incidences. Results show that at $\alpha_r = 0$ the flow field is much more streamlined than $\alpha_r = -15$ and that for $\alpha_r = 15^\circ$ a double vortex formation of opposite velocity direction occurs.

3.7 Pressure measurements on strakes

Figure 52 shows the three different thick strake configurations that were tested and where static pressure measurements were made on each surface. The reason for these measurements was to find out which strake configuration bends providing a reduction in CFKE, would at the same time create lift or favourable force along its axis.

Figures 53,54 and 55 show pressure distribution for $H = 0, 0.5, 1.0$ strakes at three different angles of attack.

The results are similar for the three strake configurations. This implies that the height of the strakes is irrelevant for its pressure sensed. When strakes are placed at angles of attack with respect to the incoming vortex of 0° or less, the net result is an increase in lift, which as a result provides an increase in thrust along the strake axis.

Calculations of lift integrals are not possible since the amount of pressure drop was not considered enough. The results, though, give an indication of how a strake works.

3.8 Aircraft model with strakes mounted on its boattail

3.8.1 Criteria for placing the afterbody strakes

Although it will be discussed in detail in the conclusion section, integrals of DCFKE for all strake configurations tested indicate that CFKE is lowest for strakes of $H = 0.5$ and for $\alpha_r = 15^\circ$.

In order to place strakes along the boattail of the aircraft, the location of the wake and its distance from the fuselage had to be found.

Figure 56a shows the wake path along the boattail area as it moves downstream. With that information at hand, a pair of strakes of the same height/length ratio as the ones tested were built whose height when positioned on the boattail, reached the afterbody wake core (Fig. 56b).

The strakes were placed at an $\alpha = 15$ with respect to the wake core and supported to the nearest pressure tap hole. This allowed us to check the pressure measured by the strake and compare that to the pressures obtained in the delta wing-strake combination set up. Besides, the static pressures along the boattail including strakes were measured as shown by figure 57.

Although the best overall configuration (lowest CFKE, highest lift) would be $H = 0.5$, $\alpha_r = 0$ strake, $\alpha_s = 15^\circ$ were used in order to validate the CFKE criteria on which our investigation was based.

The location along the fuselage where strakes were placed was arbitrarily chosen along the region where the primary separation line was found from the limiting streamlines visualization.

Figures 58a,b show how strakes were placed along the boattail and their angle with respect to the afterbody lines.

3.9 Limiting streamlines visualization

Limiting streamlines flow visualization of the aircraft with strakes is shown in figure 59. Figure 59a shows how the strake delays the primary separation line; figure 59b shows that the downwash angle along the boattail is reduced, streamlining the flow, probably due to the pressure field induced by the strake. Figure 59c compared to limiting streamlines without strakes shows that the flow is attached to the boattail as it reaches the end of the afterbody area, eliminating the pressure loss and wake induced by the afterbody alone.

3.9.1 Pressure measurements in the aircraft strake

The pressure measured by the strakes placed on the aircraft (Fig. 54c) agree with the results obtained from the pressure measurements study; that is, the strake feels a negative lift on its surface. Its value agree closely with the ones measured on the flat-plate-delta-wing-strake set up.

4. ANALYSIS OF RESULTS

4.1 On strakes

Besides the observations noted earlier on the flow fields some analysis is considered necessary by looking at figure 60. It shows the values of the cross flow kinetic energy obtained for different strake ratios H and different angles of attack. For all ratios of H , the CFKE is lowest at positive angle of attack.

The values of CFKE obtained with a thick strake of $H = 0.5$ are close to those obtained with a thin strake. Also the resultant flow field induced by a thick strake is similar in trends, and close in magnitude of velocity vectors to the one obtained by a thin strake. This allows us to conclude that the pressure distribution on strakes and their behaviour along a vortex is similarly independent of its thick ones.

4.2 On the pressure distribution along the boattail

The pressure distribution along the aircraft boattail with and without strakes is shown in figure 61. It shows that by properly placing strakes on it, the pressure on the afterbody increases. In other words an extra "push" or "thrust" is created due to the effect induced by the strakes on the surface. The extra axial force obtained when strakes are placed on the surface was found by multiplying the wedge pressure of each tap by the projected boattail area of each hole, which was chosen by drawing centerlines along mid distance points between taps. It was found to be 23% extra. This force is subtracted from the total drag of the aircraft. An estimated reduction in drag for a typical cargo aircraft would be of approximately 0.004 C_x under the conditions described in this section.

5. UNCERTAINTY ANALYSIS

Measurement errors as a result of instrumentation inaccuracies as well as test conditions fluctuations were deduced from calibration curves, and by monitoring deviations that occurred on certain test parameters.

5.1 Accuracy range of equipment used

All pressure measurements were calibrated against a Betz manometer whose accuracy is within ± 0.1 mm H₂O. The deviation of the pressure transducer used for the probe and surface pressures is of 0.5%.

Variations in the tunnel velocity were kept to ± 0.2 mm H₂O with set test conditions.

Pressure variations in the five hole probe tubes when being calibrated were of about 1.0 mm H₂O.

Angle settings in the calibration duct could be easily set within 0.2°.

5.2 Error margins in test data

From the five hole probe calibration data we can deduce its roll and pitch angle deviation. The accuracy of the roll angle is within 2.5° at low values of θ and of 0.89° at larger settings. The probe misalignment angle is as low as 0.4° and a maximum of 2.5°.

From flow quality measurements, the flow angularity of the wind tunnel was found to be of about 1°.

Static pressure coefficients measured on the aircraft boattail and on the strakes surfaces varied within ± 0.05 of C_p .

6. CONCLUSIONS

The main conclusions which can be drawn from this study are :

Aircraft which have a highly upswept afterbody induce a wake-like flow which leaves the boattail as it moves upward.

Strakes, when placed along the path of a vortex, streamline the flow, thus its cross flow kinetic energy is reduced.

When strakes are placed at positive incidence, the resultant flow field downstream of it includes two vortices of opposite direction. By that, the cross flow velocity components integral is reduced.

Strakes provide lift when placed at angles of attack of zero or lower than zero with respect to the vortex path. Therefore, a thrust is created.

When strakes are placed at angles of attack equal or greater than zero, a reduction in the cross flow kinetic energy occurs. Therefore, the vortex drag is also reduced.

Strakes placed properly on an airplane boattail reduce its overall drag by increasing the static pressure in the afterbody surface.

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Quadrant	Independent variable i.e. y	Dependent variable i.e. x	A ₀	A ₁	A ₂	A ₃	A ₄	A ₅	A ₆
I	θ	BIR	-0.8374	12.1226	2.3296	-3.2299	1.2841	-2.2683E-1	1.899E-2
	PD	θ	5.8333E-1	2.8778E-3	-1.6356E-4	-1.4225E-5	6.9290E-7	-8.8531E-9	
	CP	θ	7.5369E-4	- 8.1303E-4	-2.0669E-5	2.8294E-5	-4.9759E-7	2.3290E-9	
II	θ	BIR	-0.7472	21.5309	-13.9469	8.9530	-3.2487	5.9037E-1	-4.1485E-2
	PD	θ	5.9093E-1	8.1935E-4	- 6.7776E-5	-5.9604E-6	-1.5378E-7	1.6539E-8	-2.3476E-10
	CP	θ	9.7776E-4	- 3.2565E-3	1.2137E-3	-1.4361E-4	8.7681E-6	-2.1725E-7	1.9070E-9
III	θ	BIR	0.4942	17.2669	- 8.7556	5.7489	-2.1487	3.9653E-1	-2.8316E-2
	PD	θ	5.952E-1	7.5598E-5	1.5644E-4	-4.3459E-5	2.1625E-6	-4.3810E-8	3.2467E-10
	CP	θ	1.4027E-3	- 2.8369E-3	6.1998E-4	-3.4554E-5	1.6512E-6	-2.5172E-8	7.8316E-11
	θ	BIR	-1.2412	13.7286	- 2.1122E-1	-0.9420	2.9331E-1	2.6975E-2	
	PD	θ	5.8701E-1	4.46614E	- 3.9905E-4	-5.3629E-6	5.5383E-7	-7.4054E-9	
	CP	θ		7.0658E-4	- 3.0324E-4	4.8346E-5	-1.4304E-6	2.6121E-8	-2.3198E-10

i.e. $y = A_0 + A_1X + A_2X^2 + A_3X^3 + A_4X^4 + A_5X^5 + A_6X^6$

TABLE I - FIVE HOLE PROBE CALIBRATION COEFFICIENTS

TABLE II

T1 - Flow field velocity vectors tabulation for figure 32a
($\xi = 2.5$)

T2 - Flow field velocity vectors tabulation for figure 27a
(F.S. 6)

Note in all cases, figures are shown looking upstream.

The y-axis increases to the left, and z-axis increases upwards.

The data columns are tabulated in y,z,v,w order

Tl

a

μ¹⁰⁰

0.281246E-38	0.000000E+00	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	-0.489421E+01	0.185642E+01
0.500000E+01	0.000000E+00	-0.640392E+01	0.225254E+01
0.100000E+02	0.000000E+00	-0.890712E+01	0.307333E+01
0.150000E+02	0.000000E+00	-0.120001E+02	0.287519E+01
0.200000E+02	0.000000E+00	-0.151878E+02	0.139398E+01
0.250000E+02	0.000000E+00	-0.167753E+02	-0.145386E+01
0.300000E+02	0.000000E+00	-0.163984E+02	-0.391138E+01
0.350000E+02	0.000000E+00	-0.135386E+02	-0.656994E+01
0.400000E+02	0.000000E+00	-0.100448E+02	-0.681741E+01
0.450000E+02	0.000000E+00	-0.654021E+01	-0.608125E+01
0.500000E+02	0.000000E+00	-0.461764E+01	-0.605663E+01
0.550000E+02	0.000000E+00	-0.223438E+01	-0.568555E+01
0.600000E+02	0.000000E+00	-0.223429E-01	-0.567128E+01
0.600000E+02	0.500000E+01	0.846999E-01	-0.693252E+01
0.550000E+02	0.500000E+01	-0.199367E+01	-0.701752E+01
0.500000E+02	0.500000E+01	-0.437374E+01	-0.742911E+01
0.450000E+02	0.500000E+01	-0.676640E+01	-0.843786E+01
0.400000E+02	0.500000E+01	-0.987010E+01	-0.846009E+01
0.350000E+02	0.500000E+01	-0.146982E+02	-0.857110E+01
0.300000E+02	0.500000E+01	-0.174721E+02	-0.521012E+01
0.250000E+02	0.500000E+01	-0.170594E+02	-0.156419E+01
0.200000E+02	0.500000E+01	-0.164821E+02	0.261008E+01
0.150000E+02	0.500000E+01	-0.121142E+02	0.475672E+01
0.100000E+02	0.500000E+01	-0.862345E+01	0.462810E+01
0.500000E+01	0.500000E+01	-0.573374E+01	0.325824E+01
0.000000E+00	0.500000E+01	-0.410435E+01	0.295291E+01
0.000000E+00	0.100000E+02	-0.301761E+01	0.425467E+01
0.500000E+01	0.100000E+02	-0.447548E+01	0.555704E+01
0.100000E+02	0.100000E+02	-0.723234E+01	0.823891E+01
0.150000E+02	0.100000E+02	-0.107572E+02	0.942979E+01
0.200000E+02	0.100000E+02	-0.158725E+02	0.619174E+01
0.250000E+02	0.100000E+02	-0.174857E+02	-0.835138E+00
0.300000E+02	0.100000E+02	-0.160712E-03	0.682364E-04
0.350000E+02	0.100000E+02	0.815281E-01	-0.457475E-01
0.400000E+02	0.100000E+02	-0.898685E+01	-0.137215E+02
0.450000E+02	0.100000E+02	-0.566204E+01	-0.117244E+02
0.500000E+02	0.100000E+02	-0.342753E+01	-0.990621E+01
0.550000E+02	0.100000E+02	-0.155106E+01	-0.879629E+01
0.600000E+02	0.100000E+02	0.180791E-01	-0.888802E+01
0.600000E+02	0.150000E+02	-0.437092E+00	-0.101366E+02
0.550000E+02	0.150000E+02	-0.101356E+01	-0.104284E+02
0.500000E+02	0.150000E+02	-0.200848E+01	-0.116875E+02
0.450000E+02	0.150000E+02	-0.322539E+01	-0.146029E+02
0.400000E+02	0.150000E+02	-0.527455E+01	-0.176268E+02
0.350000E+02	0.150000E+02	0.000000E+00	0.000000E+00
0.300000E+02	0.150000E+02	-0.129704E-12	-0.120900E-12
0.250000E+02	0.150000E+02	-0.176122E+02	-0.194824E+00
0.200000E+02	0.150000E+02	-0.118382E+02	0.121132E+02
0.150000E+02	0.150000E+02	-0.638275E+01	0.138097E+02
0.100000E+02	0.150000E+02	-0.408354E+01	0.110528E+02
0.500000E+01	0.150000E+02	-0.265381E+01	0.700973E+01
0.000000E+00	0.150000E+02	-0.140799E+01	0.504675E+01
0.000000E+00	0.200000E+02	-0.328756E+00	0.536977E+01
0.500000E+01	0.200000E+02	-0.331271E+00	0.780777E+01
0.100000E+02	0.200000E+02	-0.878354E-01	0.111731E+02
0.150000E+02	0.200000E+02	0.545726E+00	0.154941E+02
0.200000E+02	0.200000E+02	0.130574E+01	0.155904E+02
0.250000E+02	0.200000E+02	0.328037E+00	0.137044E+02
0.300000E+02	0.200000E+02	0.000000E+00	0.000000E+00
0.350000E+02	0.200000E+02	0.263810E+00	-0.146234E+02
0.400000E+02	0.200000E+02	0.522187E+00	-0.175374E+02
0.450000E+02	0.200000E+02	0.157355E+00	-0.149822E+02

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0.500000E+02	0.200000E+02	-0.169765E+00	-0.122206E+02
0.550000E+02	0.200000E+02	0.159557E-01	-0.109306E+02
0.600000E+02	0.200000E+02	-0.974652E-01	-0.105231E+02
0.600000E+02	0.250000E+02	-0.117867E+00	-0.104715E+02
0.550000E+02	0.250000E+02	0.545277E+00	-0.107697E+02
0.500000E+02	0.250000E+02	0.149181E+01	-0.117404E+02
0.450000E+02	0.250000E+02	0.268634E+01	-0.138184E+02
0.400000E+02	0.250000E+02	0.531110E+01	-0.155393E+02
0.350000E+02	0.250000E+02	0.111047E+02	-0.129317E+02
0.300000E+02	0.250000E+02	0.000000E+00	0.000000E+00
0.250000E+02	0.250000E+02	0.133890E+02	0.657068E+01
0.200000E+02	0.250000E+02	0.120322E+02	0.136375E+02
0.150000E+02	0.250000E+02	0.684936E+01	0.116924E+02
0.100000E+02	0.250000E+02	0.325763E+01	0.923636E+01
0.500000E+01	0.250000E+02	0.218704E+01	0.652374E+01
0.000000E+00	0.250000E+02	0.599748E+00	0.498070E+01
0.000000E+00	0.300000E+02	0.138933E+01	0.411382E+01
0.500000E+01	0.300000E+02	0.283967E+01	0.481115E+01
0.100000E+02	0.300000E+02	0.530035E+01	0.566391E+01
0.150000E+02	0.300000E+02	0.959132E+01	0.597233E+01
0.200000E+02	0.300000E+02	0.139584E+02	0.683453E+01
0.250000E+02	0.300000E+02	0.174849E+02	0.380635E+01
0.300000E+02	0.300000E+02	0.167891E+02	-0.238385E+01
0.350000E+02	0.300000E+02	0.115837E+02	-0.767463E+01
0.400000E+02	0.300000E+02	0.710935E+01	-0.105896E+02
0.450000E+02	0.300000E+02	0.424939E+01	-0.108388E+02
0.500000E+02	0.300000E+02	0.237894E+01	-0.102314E+02
0.550000E+02	0.300000E+02	0.920225E+00	-0.984809E+01
0.600000E+02	0.300000E+02	0.786078E-01	-0.941791E+01
0.600000E+02	0.350000E+02	-0.119692E+00	-0.826670E+01
0.550000E+02	0.350000E+02	0.971023E+00	-0.872025E+01
0.500000E+02	0.350000E+02	0.251164E+01	-0.867117E+01
0.450000E+02	0.350000E+02	0.409627E+01	-0.860613E+01
0.400000E+02	0.350000E+02	0.626022E+01	-0.782527E+01
0.350000E+02	0.350000E+02	0.893235E+01	-0.492036E+01
0.300000E+02	0.350000E+02	0.108577E+02	-0.176532E+01
0.250000E+02	0.350000E+02	0.114386E+02	0.106939E+01
0.200000E+02	0.350000E+02	0.104665E+02	0.223992E+01
0.150000E+02	0.350000E+02	0.791230E+01	0.250389E+01
0.100000E+02	0.350000E+02	0.541070E+01	0.349615E+01
0.500000E+01	0.350000E+02	0.294009E+01	0.339104E+01
0.000000E+00	0.350000E+02	0.162448E+01	0.330198E+01
0.000000E+00	0.400000E+02	0.173825E+01	0.244061E+01
0.500000E+01	0.400000E+02	0.337346E+01	0.298856E+01
0.100000E+02	0.400000E+02	0.447207E+01	0.246509E+01
0.150000E+02	0.400000E+02	0.530318E+01	0.140004E+01
0.200000E+02	0.400000E+02	0.576823E+01	0.123306E+01
0.250000E+02	0.400000E+02	0.665331E+01	0.102358E+00
0.300000E+02	0.400000E+02	0.719962E+01	-0.157119E+01
0.350000E+02	0.400000E+02	0.620966E+01	-0.366107E+01
0.400000E+02	0.400000E+02	0.493597E+01	-0.545979E+01
0.450000E+02	0.400000E+02	0.349486E+01	-0.672558E+01
0.500000E+02	0.400000E+02	0.192274E+01	-0.689334E+01
0.550000E+02	0.400000E+02	0.739627E+00	-0.721178E+01
0.600000E+02	0.400000E+02	-0.411372E-01	-0.714743E+01

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F16

0.826541E-38	0.200000E+01	0.000000E+00	0.000000E+00
0.000000E+00	0.000000E+00	0.178925E+00	-0.715443E-01
0.500000E+01	0.000000E+00	0.273659E+00	-0.234614E+00
0.100000E+02	0.000000E+00	0.163090E+00	-0.163530E+00
0.150000E+02	0.000000E+00	0.193394E+00	-0.299370E+00
0.200000E+02	0.000000E+00	0.265782E+00	-0.379780E-01
0.250000E+02	0.000000E+00	0.484370E-01	0.650146E-07
0.300000E+02	0.000000E+00	0.250619E+00	-0.212269E+00
0.350000E+02	0.000000E+00	0.844825E-01	-0.842381E-01
0.400000E+02	0.000000E+00	-0.170995E+00	-0.274320E+00
0.450000E+02	0.000000E+00	-0.170326E+00	-0.272745E+00
0.500000E+02	0.000000E+00	0.000000E+00	0.000000E+00
0.550000E+02	0.000000E+00	0.000000E+00	0.000000E+00
0.600000E+02	0.000000E+00	0.000000E+00	-0.168856E+00
0.650000E+02	0.000000E+00	0.965328E-01	-0.803679E-01
0.650000E+02	0.500000E+01	-0.145915E+00	-0.182999E+00
0.600000E+02	0.500000E+01	0.113649E+00	-0.488356E-01
0.550000E+02	0.500000E+01	0.130455E+00	-0.327479E+00
0.500000E+02	0.500000E+01	0.203679E+00	-0.237738E+00
0.450000E+02	0.500000E+01	0.277649E+00	-0.493607E+00
0.400000E+02	0.500000E+01	0.263693E+00	-0.296661E+00
0.350000E+02	0.500000E+01	0.666144E-01	-0.340994E+00
0.300000E+02	0.500000E+01	-0.186278E+00	-0.528327E+00
0.250000E+02	0.500000E+01	0.273514E+00	-0.608200E+00
0.200000E+02	0.500000E+01	0.338728E+00	-0.796950E-01
0.150000E+02	0.500000E+01	0.160717E+00	-0.451041E+00
0.100000E+02	0.500000E+01	0.653488E-01	-0.426983E+00
0.500000E+01	0.500000E+01	0.386926E-01	0.406493E-01
0.000000E+00	0.500000E+01	0.268075E+00	-0.153316E+00
0.000000E+00	0.100000E+02	0.507260E+00	-0.202913E+00
0.500000E+01	0.100000E+02	0.113340E+00	0.148649E-06
0.100000E+02	0.100000E+02	0.154700E+00	-0.558033E+00
0.150000E+02	0.100000E+02	0.166579E+00	-0.367294E+00
0.200000E+02	0.100000E+02	0.320283E+00	-0.100151E+00
0.250000E+02	0.100000E+02	0.144492E+00	-0.217160E+00
0.300000E+02	0.100000E+02	0.371381E+00	-0.782406E-01
0.350000E+02	0.100000E+02	0.783698E-01	-0.473920E-01
0.400000E+02	0.100000E+02	0.000000E+00	0.000000E+00
0.450000E+02	0.100000E+02	0.279060E+00	-0.259382E+00
0.500000E+02	0.100000E+02	0.000000E+00	0.000000E+00
0.550000E+02	0.100000E+02	0.323259E-01	-0.278130E+00
0.600000E+02	0.100000E+02	0.133259E+00	-0.333197E+00
0.650000E+02	0.100000E+02	0.711294E-01	-0.252185E+00
0.650000E+02	0.150000E+02	-0.489784E-01	-0.505186E-01
0.600000E+02	0.150000E+02	0.224478E+00	-0.353085E+00
0.550000E+02	0.150000E+02	0.624406E-01	-0.506279E+00
0.500000E+02	0.150000E+02	-0.329392E-01	-0.477706E+00
0.450000E+02	0.150000E+02	-0.622688E-01	-0.567687E+00
0.400000E+02	0.150000E+02	0.186045E+00	-0.744313E-01
0.350000E+02	0.150000E+02	0.533755E-01	0.136391E-01
0.300000E+02	0.150000E+02	0.189901E+00	-0.133164E+00
0.250000E+02	0.150000E+02	0.000000E+00	0.000000E+00
0.200000E+02	0.150000E+02	0.000000E+00	-0.370044E-03
0.150000E+02	0.150000E+02	0.532369E-01	0.705946E-07
0.100000E+02	0.150000E+02	0.309865E-01	-0.626314E+00
0.500000E+01	0.150000E+02	0.249571E+00	0.383870E-01
0.000000E+00	0.150000E+02	0.232216E+00	-0.213021E+00
0.000000E+00	0.200000E+02	0.296470E+00	-0.329365E+00
0.500000E+01	0.200000E+02	0.116903E+00	0.167932E-01
0.100000E+02	0.200000E+02	0.103047E+00	-0.309419E+00
0.150000E+02	0.200000E+02	0.530428E-01	0.133912E-01
0.200000E+02	0.200000E+02	0.341360E+00	-0.527669E+00
0.250000E+02	0.200000E+02	0.234317E+00	-0.117278E+00

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0.300000E+02	0.200000E+02	-0.224998E+00	-0.450269E+00
0.350000E+02	0.200000E+02	0.455706E-01	-0.139265E+00
0.400000E+02	0.200000E+02	0.667254E-01	-0.400295E+00
0.450000E+02	0.200000E+02	-0.214383E+00	-0.644401E+00
0.500000E+02	0.200000E+02	-0.263764E+00	-0.329948E+00
0.550000E+02	0.200000E+02	-0.200042E+00	-0.333443E+00
0.600000E+02	0.200000E+02	-0.505497E-01	-0.516735E-01
0.650000E+02	0.200000E+02	0.901428E-01	0.151977E-01
0.650000E+02	0.250000E+02	-0.645090E-01	-0.421910E+00
0.600000E+02	0.250000E+02	-0.167118E+00	-0.313632E-01
0.550000E+02	0.250000E+02	0.000000E+00	0.000000E+00
0.500000E+02	0.250000E+02	0.235603E+00	-0.176977E+00
0.450000E+02	0.250000E+02	0.000000E+00	0.000000E+00
0.400000E+02	0.250000E+02	0.283724E+00	-0.409880E+00
0.350000E+02	0.250000E+02	0.326484E-01	0.110205E-01
0.300000E+02	0.250000E+02	0.000000E+00	0.373133E-01
0.250000E+02	0.250000E+02	0.000000E+00	-0.166445E-02
0.200000E+02	0.250000E+02	0.127721E+00	-0.127268E+00
0.150000E+02	0.250000E+02	0.000000E+00	0.000000E+00
0.100000E+02	0.250000E+02	0.000000E+00	0.000000E+00
0.500000E+01	0.250000E+02	0.250782E+00	-0.135267E+00
0.000000E+00	0.250000E+02	0.398080E+00	0.398086E-01
0.000000E+00	0.300000E+02	0.198978E+00	0.282090E+00
0.500000E+01	0.300000E+02	0.274497E+00	0.176514E+00
0.100000E+02	0.300000E+02	0.267873E+00	0.382694E-01
0.150000E+02	0.300000E+02	0.389238E+00	0.266418E+00
0.200000E+02	0.300000E+02	0.799297E-01	0.103443E+00
0.250000E+02	0.300000E+02	0.825003E-01	-0.165319E+00
0.300000E+02	0.300000E+02	0.721991E-01	-0.253500E+00
0.350000E+02	0.300000E+02	0.000000E+00	0.000000E+00
0.400000E+02	0.300000E+02	0.704415E-01	-0.284012E+00
0.450000E+02	0.300000E+02	-0.136529E+00	-0.684757E-01
0.500000E+02	0.300000E+02	-0.313472E-01	0.127957E-01
0.550000E+02	0.300000E+02	0.289129E+00	-0.385877E+00
0.600000E+02	0.300000E+02	0.000000E+00	-0.455047E+00
0.650000E+02	0.300000E+02	-0.262020E+00	-0.327769E+00
0.650000E+02	0.350000E+02	-0.908001E-01	-0.731660E+00
0.600000E+02	0.350000E+02	0.129160E+00	-0.485584E+00
0.550000E+02	0.350000E+02	0.155767E+00	-0.623426E+00
0.500000E+02	0.350000E+02	-0.403748E+00	-0.151440E+00
0.450000E+02	0.350000E+02	-0.127464E-01	-0.101192E-01
0.400000E+02	0.350000E+02	-0.294348E+00	0.232650E+00
0.350000E+02	0.350000E+02	0.000000E+00	0.136714E-01
0.300000E+02	0.350000E+02	-0.266765E-01	-0.151335E-01
0.250000E+02	0.350000E+02	-0.939202E-01	0.160806E+00
0.200000E+02	0.350000E+02	0.519784E-01	0.618914E-01
0.150000E+02	0.350000E+02	0.249560E+00	0.428160E+00
0.100000E+02	0.350000E+02	0.000000E+00	0.000000E+00
0.500000E+01	0.350000E+02	0.124507E+00	0.106928E+00
0.000000E+00	0.350000E+02	0.765597E-01	0.141150E+00
0.000000E+00	0.400000E+02	0.485108E-01	0.585320E-01
0.500000E+01	0.400000E+02	0.438788E+00	0.376048E+00
0.100000E+02	0.400000E+02	0.176510E-01	0.433415E+00
0.150000E+02	0.400000E+02	0.463101E-01	0.128322E+00
0.200000E+02	0.400000E+02	-0.598026E-01	0.418239E-01
0.250000E+02	0.400000E+02	-0.753788E-01	0.866844E-01
0.300000E+02	0.400000E+02	0.000000E+00	0.000000E+00
0.350000E+02	0.400000E+02	0.000000E+00	0.000000E+00
0.400000E+02	0.400000E+02	0.326085E-01	0.674491E-01
0.450000E+02	0.400000E+02	0.000000E+00	0.000000E+00
0.500000E+02	0.400000E+02	0.000000E+00	-0.228192E-02
0.550000E+02	0.400000E+02	0.368502E-01	-0.255035E-01
0.600000E+02	0.400000E+02	-0.373289E+00	-0.497668E+00

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0.650000E+02	0.400000E+02	-0.254133E+00	-0.413060E+00
0.650000E+02	0.450000E+02	0.000000E+00	0.000000E+00
0.600000E+02	0.450000E+02	0.000000E+00	0.000000E+00
0.550000E+02	0.450000E+02	0.000000E+00	0.000000E+00
0.500000E+02	0.450000E+02	0.000000E+00	0.000000E+00
0.450000E+02	0.450000E+02	0.000000E+00	0.000000E+00
0.400000E+02	0.450000E+02	-0.261614E+00	0.366644E+00
0.350000E+02	0.450000E+02	-0.268897E+00	0.209191E+00
0.300000E+02	0.450000E+02	-0.445123E-01	0.235653E+00
0.250000E+02	0.450000E+02	-0.175540E+00	0.239567E+00
0.200000E+02	0.450000E+02	0.848669E-01	0.214091E+00
0.150000E+02	0.450000E+02	0.238303E+00	0.306520E+00
0.100000E+02	0.450000E+02	-0.359145E-01	0.510713E+00
0.500000E+01	0.450000E+02	0.150073E+00	0.350163E+00
0.000000E+00	0.450000E+02	0.156981E+00	0.401541E+00
0.000000E+00	0.500000E+02	0.284512E+00	0.759118E+00
0.500000E+01	0.500000E+02	0.303374E+00	0.701910E+00
0.100000E+02	0.500000E+02	0.181905E+00	0.510203E+00
0.150000E+02	0.500000E+02	0.157735E-01	0.703242E+00
0.200000E+02	0.500000E+02	0.000000E+00	0.491593E+00
0.250000E+02	0.500000E+02	-0.396560E+00	0.414527E+00
0.300000E+02	0.500000E+02	-0.173786E+00	0.417305E+00
0.350000E+02	0.500000E+02	-0.278508E+00	0.278540E+00
0.400000E+02	0.500000E+02	-0.570025E+00	-0.142517E+00
0.450000E+02	0.500000E+02	-0.210694E+00	0.111655E+00
0.500000E+02	0.500000E+02	-0.947572E-01	-0.291542E-01
0.550000E+02	0.500000E+02	-0.259661E+00	-0.260110E+00
0.600000E+02	0.500000E+02	-0.219448E+00	-0.501350E+00
0.650000E+02	0.500000E+02	-0.539967E+00	-0.660062E+00
0.650000E+02	0.550000E+02	-0.367300E+00	-0.581927E+00
0.600000E+02	0.550000E+02	-0.207408E+00	-0.888996E+00
0.550000E+02	0.550000E+02	-0.365710E+00	-0.426770E+00
0.500000E+02	0.550000E+02	-0.438175E+00	-0.129875E+00
0.450000E+02	0.550000E+02	-0.492427E-01	-0.179661E-01
0.400000E+02	0.550000E+02	-0.486725E+00	-0.100699E+00
0.350000E+02	0.550000E+02	-0.296090E+00	0.249623E+00
0.300000E+02	0.550000E+02	-0.177732E+00	0.193148E+00
0.250000E+02	0.550000E+02	-0.237191E+00	0.566569E+00
0.200000E+02	0.550000E+02	-0.324275E+00	0.686895E+00
0.150000E+02	0.550000E+02	-0.248076E+00	0.783373E+00
0.100000E+02	0.550000E+02	0.135431E+00	0.738056E+00
0.500000E+01	0.550000E+02	0.311388E+00	0.759824E+00
0.000000E+00	0.550000E+02	0.285060E+00	0.665868E+00
0.000000E+00	0.600000E+02	0.366059E+00	0.867007E+00
0.500000E+01	0.600000E+02	0.191113E+00	0.937419E+00
0.100000E+02	0.600000E+02	-0.139178E+00	0.109705E+01
0.150000E+02	0.600000E+02	-0.200511E+00	0.104327E+01
0.200000E+02	0.600000E+02	-0.354564E+00	0.365399E+00
0.250000E+02	0.600000E+02	-0.485493E+00	0.699087E+00
0.300000E+02	0.600000E+02	-0.609247E+00	0.258512E+00
0.350000E+02	0.600000E+02	-0.423890E+00	0.220436E+00
0.400000E+02	0.600000E+02	-0.324656E+00	-0.103361E+00
0.450000E+02	0.600000E+02	-0.461290E+00	0.604944E-06
0.500000E+02	0.600000E+02	-0.458212E+00	-0.288540E+00
0.550000E+02	0.600000E+02	-0.329792E+00	-0.204161E+00
0.600000E+02	0.600000E+02	-0.332992E+00	-0.222009E+00
0.650000E+02	0.600000E+02	-0.447239E+00	-0.685977E+00
0.650000E+02	0.650000E+02	-0.717996E+00	-0.804167E+00
0.600000E+02	0.650000E+02	-0.679517E+00	-0.639571E+00
0.550000E+02	0.650000E+02	-0.306796E+00	-0.230295E+00
0.500000E+02	0.650000E+02	-0.497569E+00	-0.223087E+00
0.450000E+02	0.650000E+02	-0.698840E+00	-0.245550E+00
0.400000E+02	0.650000E+02	-0.563978E+00	-0.140993E+00

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0.350000E+02	0.650000E+02	-0.119769E+01	0.384863E+00
0.300000E+02	0.650000E+02	-0.974227E+00	0.656549E+00
0.250000E+02	0.650000E+02	-0.874505E+00	0.831914E+00
0.200000E+02	0.650000E+02	-0.805697E+00	0.113636E+01
0.150000E+02	0.650000E+02	-0.415964E+00	0.160181E+01
0.100000E+02	0.650000E+02	-0.812093E-01	0.116077E+01
0.500000E+01	0.650000E+02	0.142787E+00	0.141068E+01
0.000000E+00	0.650000E+02	0.389381E+00	0.141417E+01
0.000000E+00	0.700000E+02	0.366288E+00	0.159538E+01
0.500000E+01	0.700000E+02	0.151588E+00	0.171074E+01
0.100000E+02	0.700000E+02	-0.282256E+00	0.173767E+01
0.150000E+02	0.700000E+02	-0.523126E+00	0.161182E+01
0.200000E+02	0.700000E+02	-0.645476E+00	0.124942E+01
0.250000E+02	0.700000E+02	-0.121507E+01	0.131807E+01
0.300000E+02	0.700000E+02	-0.152508E+01	0.871487E+00
0.350000E+02	0.700000E+02	-0.139344E+01	0.522543E+00
0.400000E+02	0.700000E+02	-0.127271E+01	0.151002E+00
0.450000E+02	0.700000E+02	-0.844732E+00	-0.120689E+00
0.500000E+02	0.700000E+02	-0.618479E+00	-0.281161E+00
0.550000E+02	0.700000E+02	-0.432097E+00	-0.293946E+00
0.600000E+02	0.700000E+02	-0.485111E+00	-0.636617E+00
0.650000E+02	0.700000E+02	-0.323676E+00	-0.275144E+00
0.650000E+02	0.750000E+02	0.129813E+00	-0.553453E+00
0.600000E+02	0.750000E+02	-0.998372E-01	-0.464400E+00
0.550000E+02	0.750000E+02	-0.436204E+00	-0.560907E+00
0.500000E+02	0.750000E+02	-0.266645E+00	-0.250092E+00
0.450000E+02	0.750000E+02	-0.581726E+00	-0.498695E+00
0.400000E+02	0.750000E+02	-0.114205E+01	-0.153749E+00
0.350000E+02	0.750000E+02	-0.189939E+01	0.671737E+00
0.300000E+02	0.750000E+02	-0.187624E+01	0.181349E+01
0.250000E+02	0.750000E+02	-0.137185E+01	0.180086E+01
0.200000E+02	0.750000E+02	-0.920478E+00	0.194336E+01
0.150000E+02	0.750000E+02	-0.521295E+00	0.185621E+01
0.100000E+02	0.750000E+02	-0.611384E+00	0.181230E+01
0.500000E+01	0.750000E+02	-0.473704E-01	0.220377E+01
0.000000E+00	0.750000E+02	0.900717E-01	0.222527E+01
0.000000E+00	0.800000E+02	0.706555E-01	0.200790E+01
0.500000E+01	0.800000E+02	0.214508E-01	0.200372E+01
0.100000E+02	0.800000E+02	-0.398069E+00	0.205721E+01
0.150000E+02	0.800000E+02	-0.531843E+00	0.231931E+01
0.200000E+02	0.800000E+02	-0.955284E+00	0.286589E+01
0.250000E+02	0.800000E+02	-0.175114E+01	0.297034E+01
0.300000E+02	0.800000E+02	-0.217205E+01	0.214764E+01
0.350000E+02	0.800000E+02	-0.178515E+01	0.768611E+00
0.400000E+02	0.800000E+02	-0.896444E+00	-0.156877E+01
0.450000E+02	0.800000E+02	0.652973E+00	-0.108819E+01
0.500000E+02	0.800000E+02	0.103857E+01	-0.578200E+00
0.550000E+02	0.800000E+02	0.600445E+00	-0.480993E+00
0.600000E+02	0.800000E+02	0.774157E+00	-0.569230E+00
0.650000E+02	0.800000E+02	0.654998E+00	-0.935828E+00
0.650000E+02	0.850000E+02	0.923706E+00	-0.505842E+00
0.600000E+02	0.850000E+02	0.127862E+01	-0.157027E+00
0.550000E+02	0.850000E+02	0.123107E+01	0.165728E+00
0.500000E+02	0.850000E+02	0.168865E+01	0.511714E+00
0.450000E+02	0.850000E+02	0.372504E+01	-0.188875E+01
0.400000E+02	0.850000E+02	0.339183E+01	-0.522595E+01
0.350000E+02	0.850000E+02	-0.375401E+00	-0.249078E+01
0.300000E+02	0.850000E+02	-0.463005E+00	0.247870E+01
0.250000E+02	0.850000E+02	-0.346737E+00	0.365509E+01
0.200000E+02	0.850000E+02	-0.294410E+00	0.358058E+01
0.150000E+02	0.850000E+02	0.288231E+00	0.317063E+01
0.100000E+02	0.850000E+02	0.208449E-01	0.262212E+01
0.500000E+01	0.850000E+02	-0.954510E-01	0.187076E+01

T2 e

0.000000E+00	0.850000E+02	0.000000E+00	0.146773E+01
0.000000E+00	0.900000E+02	-0.827514E-01	0.138342E+01
0.500000E+01	0.900000E+02	0.185226E+00	0.174878E+01
0.100000E+02	0.900000E+02	0.708449E+00	0.269232E+01
0.150000E+02	0.900000E+02	0.901895E+00	0.315687E+01
0.200000E+02	0.900000E+02	0.116121E+01	0.305096E+01
0.250000E+02	0.900000E+02	0.234067E+01	0.349870E+01
0.300000E+02	0.900000E+02	0.331719E+01	-0.719769E+00
0.350000E+02	0.900000E+02	0.347469E+01	-0.595296E+01
0.400000E+02	0.900000E+02	0.430455E+01	-0.667319E+01
0.450000E+02	0.900000E+02	0.342321E+01	-0.103305E+01
0.500000E+02	0.900000E+02	0.209458E+01	0.172159E+01
0.550000E+02	0.900000E+02	0.142322E+01	0.993570E+00
0.600000E+02	0.900000E+02	0.113038E+01	0.688079E+00
0.650000E+02	0.900000E+02	0.889667E+00	-0.148114E+00
0.650000E+02	0.950000E+02	0.932721E+00	0.102602E+01
0.600000E+02	0.950000E+02	0.174199E+01	0.435495E+00
0.550000E+02	0.950000E+02	0.158439E+01	0.115228E+00
0.500000E+02	0.950000E+02	0.867759E+00	-0.542375E-01
0.450000E+02	0.950000E+02	0.986515E+00	-0.314451E+01
0.400000E+02	0.950000E+02	0.234217E+01	-0.507863E+01
0.350000E+02	0.950000E+02	0.373539E+01	-0.450163E+01
0.300000E+02	0.950000E+02	0.492347E+01	-0.123087E+01
0.250000E+02	0.950000E+02	0.369857E+01	0.211348E+01
0.200000E+02	0.950000E+02	0.217195E+01	0.264413E+01
0.150000E+02	0.950000E+02	0.195313E+01	0.323937E+01
0.100000E+02	0.950000E+02	0.140075E+01	0.315853E+01
0.500000E+01	0.950000E+02	0.148435E+01	-0.539769E+00
0.000000E+00	0.950000E+02	0.637903E+00	-0.179413E+01
0.000000E+00	0.100000E+03	0.143283E+01	-0.169941E+01
0.500000E+01	0.100000E+03	-0.488703E+00	-0.205278E+01
0.100000E+02	0.100000E+03	0.476261E+00	0.616345E+00
0.150000E+02	0.100000E+03	0.184303E+01	0.298138E+01
0.200000E+02	0.100000E+03	0.241574E+01	0.181182E+01
0.250000E+02	0.100000E+03	0.268505E+01	0.105296E+00
0.300000E+02	0.100000E+03	0.269304E+01	-0.110064E+01
0.350000E+02	0.100000E+03	0.228315E+01	-0.172314E+01
0.400000E+02	0.100000E+03	0.130242E+01	-0.237049E+01
0.450000E+02	0.100000E+03	0.230550E-01	-0.252723E+01
0.500000E+02	0.100000E+03	-0.361938E+00	-0.186521E+01
0.550000E+02	0.100000E+03	0.000000E+00	-0.104361E+01
0.600000E+02	0.100000E+03	0.395927E+00	-0.670036E+00
0.650000E+02	0.100000E+03	0.458540E+00	-0.639270E+00
0.650000E+02	0.105000E+03	0.406255E+00	0.580571E-01
0.600000E+02	0.105000E+03	0.631737E-01	-0.355672E+00
0.550000E+02	0.105000E+03	0.157248E+00	-0.408653E+00
0.500000E+02	0.105000E+03	-0.165815E+00	-0.127277E+01
0.450000E+02	0.105000E+03	0.123212E+00	-0.132286E+01
0.400000E+02	0.105000E+03	0.937963E+00	-0.138561E+01
0.350000E+02	0.105000E+03	0.116452E+01	-0.952841E+00
0.300000E+02	0.105000E+03	0.159039E+01	-0.126954E+00
0.250000E+02	0.105000E+03	0.128821E+01	-0.444216E-01
0.200000E+02	0.105000E+03	0.808709E+00	0.247003E+00
0.150000E+02	0.105000E+03	0.629689E-01	0.207643E+00
0.100000E+02	0.105000E+03	-0.667791E+00	-0.535057E+00
0.500000E+01	0.105000E+03	-0.861228E+00	-0.574163E+00
0.000000E+00	0.105000E+03	0.181684E+01	-0.493147E+00

APPENDIX I - COMPUTER PROGRAM LISTINGS

- A - Cassette digital data readout and implementation of pressure transducer coefficients
- B - Program for operating data blocks
- C - Program used to interchange data points
- D - Program for altering data
- E - Calculation of velocity vectors, preparation of streamlines, data matrix, and creation of pressure isolines block
- F - Calculation of velocity vectors and creation of cross flow kinetic energy isolines block
- G - PET Commodore program used for calibration of five hole probe
- H - PET Commodore program used for data acquisition into digital cassette (G and H require machine language program to relate scanivalve A at set intervals of time)

A1

```
C-----C
C  READ FILE CREATED BY CDX AND REWRITE IT AFTER APPLYING COEFFICIENTS  C
C
C      NAME      :      JEUS
C      AUTHOR    :      OTTE A.
C      DATE      :      10-MAY-83
C      SUBROUTINES CALLED : PARAM1, GETCDX
C-----C
C      PROGRAM JEUS
C
C      DIMENSION COEF(2),FC(5)
C      LOGICAL*1 YES
C
C      NCAN=5
C      CALL PARAM1 (COEF,2,1)
C
C      CALL GETCDX (NCAN,COEF,FC,FACT)
C
C      STOP
C      END
C-----C
C      SUBROUTINE GETCDX (NPTS,COEF,FC,FACT)
C      DIMENSION IVAL(50),IBUF1(256),IBUF2(256),COEF(2),FC(5)
C      LOGICAL*1 FILE1(15),FILE2(15),YES
C      IV1=1
C      IV2=1
C      FACT=1.          ! JEUSSETTE
C
C      TYPE 1
C      1  FORMAT(' RAW DATA FILENAME : ($)
C          CALL GETSTR (5,FILE1,14)
C          CALL ASSIGN (1,FILE1)
C          DEFINE FILE 1 (0,256,U,IV1)
C
C      TYPE 500
C      500  FORMAT(' NEW FILENAME      : ($)
C          CALL GETSTR (5,FILE2,14)
C          CALL ASSIGN (2,FILE2)
C          DEFINE FILE 2 (0,256,U,IV2)
C
C      IOUT=0
C      TYPE 1111
C      1111  FORMAT(' OUTPUT VERIFICATION ? [Y/N] : ($)
C          IF(YES()) IOUT=1
C
C      100  READ (1'IV1) IBUF1
C          WRITE (2'IV2) IBUF1
C
C      NCAN=IBUF1(2)
C      IF(NPTS.GT.0) GO TO 5
C      GO TO 6
C      5  IF(NCAN.NE.NPTS) NCAN=NPTS
C      6  NREC=IBUF1(3)
C          IF(NPTS.GT.IBUF1(2)) NREC=NREC/NCAN*IBUF1(5)
C          IREC=0
C      10  J1=1
C          J2=NCAN
C      11  READ (1'IV1) IBUF1
C      15  I=0
C      20  DO 25 J=J1,J2
C          I=I+1
C          IF(IBUF1(J).EQ.0) GO TO 4000
C          ! JEUS
```

A2

```
25 CONTINUE
   IREC=IREC+1
   IGO=1
   IF(IREC.NE.NREC) GO TO 1000
60   IF(IREC.EQ.NREC) GO TO 40
30   J1=J2+1
   IF(J1.EQ.257) WRITE (2,IV2) IBUF2
   IF(J1.EQ.257) GO TO 10
   J2=J1+NCAN-1
   IF(J2.LE.256) GO TO 15
   I=0
   DO 35 J=J1,256
   I=I+1
   IVAL(I)=IBUF1(J)
35 CONTINUE
   IGO=2
   GO TO 1000
70 WRITE (2,IV2) IBUF2
   J1=1
   J2=J2-256
   GO TO 11
C
1000 K=0
   JE=J2
   IF(IGO.EQ.2) JE=256
   DO 3000 JJ=J1,JE
   K=K+1
   FC(K)=COEF(1)
   DO 2000 II=2,2
   FC(K)=FC(K)+COEF(II)*FLOAT(IVAL(K))**(II-1)
2000 CONTINUE
   IBUF2(JJ)=FC(K)/FACT
3000 CONTINUE
   IF(IOUT.EQ.1) TYPE 9999,J1,J2,(IVAL(N),N=1,5),(IBUF2(N),N=J1,JE)
9999 FORMAT(2I6,' ! ',5I6,' ',5I6)
   GO TO (60,70),IGO
C
4000 DO 5000 JJJ=J,256
5000 IBUF2(JJJ)=0
40 CONTINUE
   WRITE (2,IV2) IBUF2
   CALL CLOSE (1)
   CALL CLOSE (2)
   RETURN
   END
```


B2

```
0
4   TYPE 1
1   FORMAT(/' RAW DATA FILENAME : '$)
    CALL GETSTR (5,FILE,14)
    CALL ASSIGN (1,FILE)
    DEFINE FILE 1 (0.256,U,IV1)

0
100  READ (1'IV1) IBUF
     NCAN=IBUF(2)
     IF(NPTS.GT.0) GO TO 5
     GO TO 6
5   IF(NCAN.NE.NPTS) NCAN=NPTS
6   NREC=IBUF(3)
     IF(NPTS.GT.IBUF(2)) NREC=NREC/NCAN*IBUF(5)
7   IREC=0
10  J1=1
     J2=NCAN
     READ (1'IV1) IBUF
15  I=0
20  DO 25 J=J1,J2
     I=I+1
     IVAL(I)=IBUF(J)
     IF(IVAL(I).EQ.0) GO TO 40
25  CONTINUE
     IREC=IREC+1
     IDEB=1
     IF(IREC.NE.NREC) RETURN
     GO TO 40
30  J1=J2+1
     IF(J1.EQ.257) GO TO 10
     J2=J1+NCAN-1
     IF(J2.LE.256) GO TO 15
     I=0
     DO 35 J=J1,256
     I=I+1
     IVAL(I)=IBUF(J)
35  CONTINUE
     READ (1'IV1) IBUF
     J1=1
     J2=J2-256
     GO TO 20
40  IDEB=0
     CONTINUE
     IF(INFILE.EQ.0) CALL CLOSE (1)
     K=-1
     RETURN
     END
```

```

PROGRAM UPDATE
DIMENSION IVAL(5),JVAL(5)
LOGICAL*1 NAME1(15),NAME2(15),YES
10  TYPE 20
20  FORMAT(' NAME OF FILE TO BE UPDATED : '$)
    CALL GETSTR (5,NAME1,14)
    CALL ASSIGN (1,NAME1)
    DEFINE FILE 1 (0,5,U,IV1)
30  TYPE 40
40  FORMAT(' RECORD NUMBER TO BE REPLACED : '$)
    ACCEPT 50,IR1
50  FORMAT(15)
    IF(IR1.EQ.0) GO TO 999
60  TYPE 70
70  FORMAT(' NAME OF FILE TO PICK UP RECORD : '$)
    CALL GETSTR (5,NAME2,14)
    CALL ASSIGN (2,NAME2)
    DEFINE FILE 2 (0,5,U,IV2)
75  TYPE 80
80  FORMAT(' RECORD NUMBER TO PICK UP : '$)
    ACCEPT 50,IR2
    IF(IR2.EQ.0) GO TO 888
    READ(1,IR1) IVAL
    TYPE 1000,IVAL
1000 FORMAT(5I10)
    READ(2,IR2) JVAL
    TYPE 1000,JVAL
    TYPE 2000
2000 FORMAT(' RECORD O.K.? [Y/N] : '$)
    IF(.NOT.YES()) GO TO 75
    WRITE(1,IR1) JVAL
    CALL CLOSE (2)
    GO TO 30
888  CONTINUE
    CALL CLOSE (2)
999  CONTINUE
CCC  CALL CLOSE (1)
    TYPE 4000
4000 FORMAT(' DO YOU WANT TO DELETE RECORDS ? [Y/N] : '$)
    IF(.NOT.YES()) GO TO 5000
C
    TYPE 4010
4010 FORMAT(' NUMBER OF RECORDS TO BE DELETED : '$)
    ACCEPT 50,NRDEL
    TYPE 4020
4020 FORMAT(' START DELETING FROM RECORD NUMBER : '$)
    ACCEPT 50,ISTART
C
    JR=ISTART+NRDEL
    JW=ISTART
4030 READ(1,JR,END=5000,ERR=5000) IVAL
    TYPE 6000,JW,JR,IVAL
6000 FORMAT(7I8)
    WRITE(1,JW) IVAL
    JR=JR+1
    JW=JW+1
    IF(IVAL(1).NE.0) GO TO 4030
C
5000 CALL CLOSE (1)
C
    TYPE 3000
3000 FORMAT(' DO YOU WANT TO CONTINUE ? [Y/N] : '$)
    IF(YES()) GO TO 10
STOP
END

```


D1

```
C      PROGRAM BIN
C      AUTHOR: GUS ORDONEZ AR'82-83
C      PGM REPLACES VALUE FOUND IN RAW DATA FROM DIGITAL CASSETTE
C      TO VALUE ASSIGNED BY THE USER
      DIMENSION IBUF(256)
      LOGICAL NAME1(15)
10     TYPE 20
20     FORMAT(' INPUT FILENAME: '$)
      CALL GETSTR(5,NAME1,14)
      CALL ASSIGN(1,NAME1)
      DEFINE FILE 1(0,256,U,IV1)
      IV1=1
      TYPE 30
30     FORMAT(' BLOCK NUMBER TO BE MODIFIED: '$)
      ACCEPT 50,N
50     FORMAT(15)
      N=N+1
      NR =N
      READ(1'N) IBUF
      TYPE 40
40     FORMAT(' NUMBER OF VALUE IN BLOCK: '$)
      ACCEPT 50,K
      TYPE 100
100    FORMAT (' ENTER NEW VALUE: '$)
      ACCEPT 50,IYAL
      IBUF(K)=IYAL
      WRITE (1'NR) IBUF
      CALL CLOSE(1)
      STOP
      END
```

E1

```

C     PREPARE A DATA FILE FOR STREAMLINES PLOTTING PROGRAM AND ISOLINES
C     NAME      :      NPMGUS
C     GUS ORDOÑEZ AR'82-83
C     DATE      :      26-MAY-83
C     PGM CALCULATES CROSS FLOW VELOCITY COMPONENTS AND TOTAL PRESSURE
C     AND PREPARES DATA FOR STREAMLINES PLOTTING AND ISOLINES OF
C     TOTAL PRESSURE
C     PROGRAM NPMGUS
C     COMMON XP(50),YC(50),WC(50),IVAL(5),PC(5),XPLISD(50)
C     COMMON XPR(50),YR(50),WR(50),TITLE(20),NX,NY
C     LOGICAL*1 NAME1(15),NAME2(15),NAME3(15),YES

C
C     G=9.806356
C     TYPE 100
100   FORMAT(' NUMBER OF POINTS ON X-AXIS : ($)')
C     ACCEPT 110,NX
110   FORMAT(I5)
C     TYPE 120
120   FORMAT(' NUMBER OF POINTS ON Y-AXIS : ($)')
C     ACCEPT 110,NY
C     TYPE 130
130   FORMAT(' INITIAL VALUE FOR X : ($)')
C     ACCEPT 140,XI
140   FORMAT(F10.0)
C     TYPE 150
150   FORMAT(' INITIAL VALUE FOR Y : ($)')
C     ACCEPT 140,YI
C     TYPE 155
155   FORMAT(' STEP FOR X/Y : ($)')
C     ACCEPT 140,STEP

C
159   TYPE 160
160   FORMAT(' DATA INPUT FILENAME : ($)')
C     CALL GETSTR (5,NAME1,14)
C     CALL ASSIGN (1,NAME1)
C     DEFINE FILE 1 (0,5,U,IV1)
C     IV1=1

C
C     N=NX*NY      ! TOTAL NUMBER OF POINTS
C     NNN=N
C     NI=N+1
C     CALL ASSIGN (2,'STREAM.OUT')
C     DEFINE FILE 2 (0,8,U,IV2)

C
C     TYPE 500
500   FORMAT(' OUTPUT FILENAME FOR ISOLINES : ($)')
C     CALL GETSTR (5,NAME3,14)
C     CALL ASSIGN (3,NAME3)
C     TYPE 510
510   FORMAT(' TITLE FOR ISOLINES PLOT : ($)')
C     ACCEPT 520,TITLE
520   FORMAT(20A4)
C     WRITE(3,525) TITLE      ! RECORD 1 FOR PLIS
525   FORMAT(1X,20A4)
C     WRITE(3,*) NX,NY      ! RECORD 2
C     XP(1)=0.
C     DO 530 I=2,NX
530   XP(I)=XP(I-1)+STEP
C     WRITE(3,*) (XP(K),K=1,NX) ! RECORD 3 - X-COORD.
C     XP(1)=0.
C     DO 540 J=2,NY
540   XP(J)=XP(J-1)+STEP

```

E21

```

C
WRITE(2,1) N,O,O
IV2=2
YP=YI-STEP
1000 TYPE 1010
1010 FORMAT(' ATMOSPHERIC PRESSURE ',F4)
ACCEPT 140,PAT
TYPE 1020
1020 FORMAT(' TEMPERATURE ',F4)
ACCEPT 140,TO
TYPE 1030
1030 FORMAT(' DYNAMIC PRESSURE (MM H2O) ',F4)
ACCEPT 140,DPHH
CTE=DPHH*G
XP(1)=XI-STEP
C
DO 30 J=1,NY
JL=J
YP=YP+STEP
SIG=1
IF(MOD(JL,2).EQ.0) SIG=-1
C
XMIN=XI
XMAX=STEP*FLOAT(NX-1)+XI
C
1040 IF(MOD(JL,2).EQ.0) XP(1)=XMAX+STEP
IF(MOD(JL,2).NE.0) XP(1)=XMIN-STEP
C
DO 20 I=1,NX
XP(I)=XP(I)+STEP*SIG
IF(I.GT.1) XP(I)=XP(I-1)+STEP*SIG
READ (1,IV1) IVAL
DO 180 K=1,5
P(K)=FLOAT(IVAL(K))
180 CONTINUE
C
CALL CALCUL (P,VARG,MARG,PAT,TO,BT)
C
V(I)=VARG
W(I)=MARG
XPR(I)=BT/CTE
C
20 CONTINUE
C
DO 210 K=1,NX
WRITE(2,IV2) XP(K),YP,W(K),M(K)
210 CONTINUE
C
IF(MOD(JL,2).EQ.0) GO TO 400
KR=0
DO 300 K=NX,1,-1
KR=KR+1
300 XPLISOCK(K)=XPR(K)
WRITE(3,*) (XPLISOCK),K=1,NX) ! RECORD 5
TYPE 1111,(XPLISOCK),K=1,NX)
1111 FORMAT(5F12.3)
GO TO 30
400 WRITE(3,*) (XPR(K),K=1,NX) ! RECORD 5
TYPE 1111 (XPR(K),K=1,NX)
C
30 CONTINUE
CALL CLOSE (1)
CALL CLOSE (2)

```

E3

```

CALL CLOSE (3)
CALL ASSIGN (1,NAME3)
CALL ASSIGN (2,'ISOLINES OUT ')
READ(1,525) TITLE
READ(1,*) NX,NY
READ(1,*) (XPR(K),K=1,NX)
READ(1,*) (XPR(K),K=1,NY)

```

```

C
DO 9999 J=1,NY
READ(1,*) (XPLISO(K),K=1,NX)
WRITE(2,2222) (XPLISO(K),K=1,NX)
2222 FORMAT(1X,10F12.3)
C

```

```

9999 CONTINUE
CALL CLOSE (1)
CLOSE(UNIT=2,DISP='PRINT')
C

```

```

CALL REVERS
C

```

```

STOP
END

```

C DATA REDUCTION ROUTINE FOR UPDATED DATA.
C CROSS FLOW VELOCITY COMPONENTS AND TOTAL PRESSURE ARE CALCULATED
C SUBROUTINE CALCUL (P,V,W,PAT,PO,PT)
C DIMENSION P(1)

```

CCC ASIN(X)=ATAN(X/SQRT(1.-X*X))
CCC ACOS(X)=ATAN(SQRT(1.-X*X)/X)
C

```

```

PMDY = (P(1)+P(2)+P(3)+P(4))*0.25

```

```

P(2)=P(2)+18

```

```

P(1)=P(1)+10

```

```

DD = P(2)-P(4)

```

```

EE = P(1)-P(3)

```

```

ADD = ABS(DD)

```

```

AEE = ABS(EE)

```

```

FF = AEE - ADD

```

```

IF (EE.EQ.0.) GO TO 2

```

```

GG = ABS(DD/EE)

```

```

FIR = ATAN(GG)

```

```

FI = 180.*FIR/3.14159

```

```

GO TO 3

```

```

2 FI = 90.0

```

```

FIR = 3.14159/2.0

```

```

3 RA = DD*DD+EE*EE

```

```

BI = SQRT(RA)

```

```

BIR = BI/ABS(P(5)-PMDY)

```

```

IF (FF.LE.0.005) GO TO 4

```

```

IF (EE.GE.0.01) GO TO 5

```

```

T1 = 13.72858*BIR+(-2.112228E-1)*BIR**2-(-.9420486)*BIR**3+

```

```

1 (-2.933134E-1)*BIR**4

```

```

T2 = -(2.697529E-2)*BIR**5

```

```

TH = T1 + T2 - 1.241217

```

```

D1 = (5.870109E-1)+(4.466144E-3)*TH+(-3.990502E-4)*TH**2

```

```

D2 = (-5.362912E-6)*TH**3+(5.538313E-7)*TH**4

```

```

D3 = (-7.405356E-9)*TH**5

```

```

C
PD = (D1+D2+D3)*1.0

```

```

C1 = (7.065830E-4)*TH+(-3.032390E-4)*TH**2+(4.834588E-5)

```

```

1 *TH**3

```

```

C2 = (-1.430398E-6)*TH**4+(2.612108E-8)*TH**5-(-2.319786E-10)

```

```

1 *TH**6

```

E4

```

10  RHT = PAT/(287.0*TO)
    AV  = ABS((P(5)-PMOY)*2./CPD*RHT)
    AV  = SQRT(AV)
    BT  = P(5)+CP*RHT*AV**2*0.5
    IF ((P(1).GE.P(3)).AND.(P(4).GE.P(2))) QU = 1.
    IF ((P(1).GE.P(3)).AND.(P(2).GE.P(4))) QU = 2.
    IF ((P(1).LE.P(3)).AND.(P(2).GE.P(4))) QU = 3.
    IF ((P(1).LE.P(3)).AND.(P(4).GE.P(2))) QU = 4.
    TH  = TH*3.14159/180.0
    IF (CP.LT.0.) CP = 0.0
    IF (TH.LT.0.) GO TO 832
        SSTH=SIN(TH)
        SSFIR=COS(FIR)
    SAL = SIN(TH)*COS(FIR)
    CTE=1.-SAL*SAL
    CGA=COS(TH)/SQRT(CTE)

C
CCC   CGA = COS(TH)/(SQRT(ABS(1.-SAL*SAL)))
    CAL=SQRT(1.-SAL*SAL)
    SGA=SQRT(1.-CGA*CGA)
CCC   TYPE ,TH,FIR,SSTH,SSFIR,SAL,CGA,CTE
CCCC  FORMAT('TH,FI,STH,CFI,SAL,CGA,CTE'/7F10.4)
    UU=CAL*CGA*AV
    V=CAL*SGA*AV
    W=SAL*AV
    IF(QU EQ.1..OR.QU EQ.4.) V=-V
    IF(QU EQ.1..OR.QU EQ.2.) W=-W
    GO TO 833

832  V=0.
    W=0.
    UU=AV
833  RETURN
4    IF (DO.LE.0.01) GO TO 6
    T1 = 21.53083*BIR-13.94688*BIR**2
    T2 = +8.953023*BIR**3-3.248728*BIR**4
    T3 = (5.903704E-1)*BIR**5-(4.148470E-2)*BIR**6
    TH = T1 + T2 + T3 - .7471644
    D1 = (5.9093289E-1)+(8.193470E-4)*TH-(6.777613E-5)*TH**2
    D2 = (-5.960415E-6)*TH**3+(-1.537824E-7)*TH**4
    D3 = (1.653859E-8)*TH**5+(-2.347760E-10)*TH**6
    PD = (D1+D2+D3)*1.0
    C1 = (-3.258468E-3)*TH+(1.213657E-3)*TH**2-(1.436069E-4)*
1    TH**3
    C2 = (8.769080E-6)*TH**4+(-2.172509E-7)*TH**5+(1.907005E-9)
1    *TH**6
    CP = C1+C2+9.777586E-4
    GO TO 10

5    T1 = 17.26694*BIR-8.755824*BIR**2
    T2 = 5.748909*BIR**3-(2.148792)*BIR**4
    T3 = (3.965276E-1)*BIR**5-(2.831693E-2)*BIR**6
    TH = T1+T2+T3+0.4941921
    D1 = (5.95200E-1)+(7.559778E-5)*TH+(1.564457E-4)*TH**2
    D2 = (-4.345895E-5)*TH**3+(2.162540E-6)*TH**4
    D3 = (-4.380951E-8)*TH**5+(3.246741E-10)*TH**6
    PD = (D1+D2+D3)*1.0
    C1 = (-2.836868E-3)*TH+(6.199820E-4)*TH**2-(3.455378E-5)*TH**3
    C2 = (1.651172E-6)*TH**4+(-2.517231E-8)*TH**5+(7.831602E-11)
1    *TH**6
    CP = C1+C2+1.402665E-3
    GO TO 10

6    T1 = 12.12255*BIR+(2.329591)*(BIR**2)-3.229866*BIR**3+
1    (1.284068)*BIR**4
    T2 = (-2.268258E-1)*BIR**5+(1.488891E-2)*BIR**6
    TH = T1+T2-0.4941921
    D1 = (5.95200E-1)+(7.559778E-5)*TH+(1.564457E-4)*TH**2
    D2 = (-4.345895E-5)*TH**3+(2.162540E-6)*TH**4
    D3 = (-4.380951E-8)*TH**5+(3.246741E-10)*TH**6
    PD = (D1+D2+D3)*1.0
    C1 = (-2.836868E-3)*TH+(6.199820E-4)*TH**2-(3.455378E-5)*TH**3
    C2 = (1.651172E-6)*TH**4+(-2.517231E-8)*TH**5+(7.831602E-11)
1    *TH**6
    CP = C1+C2+1.402665E-3
    GO TO 10

```

E5

```
TH = T1+T2-0.8373914
D1 = (5.833296E-1)+(2.877764E-3)*TH+(-1.635622E-4)*TH**2
D2 = (-1.422516E-5)*TH**3+(6.928993E-7)*TH**4
D3 = (-8.953081E-9)*TH**5
PD = (D1+D2+D3)*1.00
C1 = (-8.130340E-4)*TH-(2.066893E-5)*TH**2+(2.829430E-5)*TH**3
C2 = (-4.975929E-7)*TH**4+(2.329037E-9)*TH**5
CP = C1+C2+7.536941E-4
GO TO 10
END
```

```
C-----
C SUBROUTINE USED TO PLOT CROSS FLOW VELOCITIES ON PDP PLOTTER
C SUBROUTINE REVERS
C COMMON XP(50),Y(50),W(50),IVAL(5),P(5),XPLISO(50)
C COMMON XPR(50),YR(50),WR(50),TITLE(20),NX,NY
C
C CALL ASSIGN (2,'STREAM.OUT')
C DEFINE FILE 2 (0,8,U,IV2)
C IV2=1
C CALL ASSIGN (3,'STREAMP.OUT')
C DEFINE FILE 3 (0,8,U,IV3)
C IV3=1
C
C READ(2'IV2) N,NZ,RNZ
C WRITE(3'IV3) N,NZ,RNZ
C
C DO 40 J=1,NY
C DO 10 I=1,NX
C READ(2'IV2) XP(I),Y,V(I),W(I)
10 CONTINUE
C
C L=0
C DO 20 K=NX,1,-1
C L=L+1
C YR(L)=-V(K)
C WR(L)=W(K)
20 CONTINUE
C
C DO 30 K=1,NX
C WRITE(3'IV3) XP(K),Y,YR(K),WR(K)
30 CONTINUE
40 CONTINUE
C CALL CLOSE(2)
C CALL CLOSE(3)
C RETURN
C END
```

FI

```

C     PREPARE A DATA FILE FOR ISOLINES
C     NAME      :      NEW PROBE AND VELOCITIES KINETIC (HPVKINET)
C     MODIFIED FOR CROSS FLOW KINETIC ENERGY INTEGRAL - G.ORDONEZ
C     DATE      :      26-MAY-83
C     PGM PREPARES DATA FOR KINETIC ENERGY ISOLINES AND
C     CALCULATES CPOS FLOW KINETIC INTEGRAL NONDIMENSIONALIZED WRT
C     MAINSTREAM VELOCITY
C     PROGRAM HPVKINET
C     DIMENSION XPC(50),YPC(50),WPC(50),IVAL(5),PC(5),KPLISOC(50),CFKEL(50)
C     DIMENSION XPRC(50),YRC(50),WRC(50),TITLE(20),BCFKEL(50)
C     LOGICAL*1 NAME1(15),NAME2(15),NAME3(15),YES
C
C     RHOAIR=1.225
C     RHOWAT=1000.
C     G=9.806356
C     TYPE 100
100   FORMAT(' NUMBER OF POINTS ON X-AXIS : '$)
C     ACCEPT 110,NX
110   FORMAT(15)
C     TYPE 120
120   FORMAT(' NUMBER OF PDINTS ON Y-AXIS : '$)
C     ACCEPT 110,NY
C     TYPE 130
130   FORMAT(' INITIAL VALUE FOR X : '$)
C     ACCEPT 140,XI
140   FORMAT(F10.0)
C     TYPE 150
150   FORMAT(' INITIAL VALUE FOR Y : '$)
C     ACCEPT 140,YI
C     TYPE 155
155   FORMAT(' STEP FOR X/Y : '$)
C     ACCEPT 140,STEP
C
C     TYPE 160
160   FORMAT(' DATA INPUT FILENAME : '$)
C     CALL GETSTR (5,NAME1,14)
C     CALL ASSIGN (1,NAME1)
C     DEFINE FILE 1 ((0,5),U,IV1)
C     IV1=1
C
C     N=NX*NY          ! TOTAL NUMBER OF POINTS
C     NNN=N
C     NI=N+1
C
C     TYPE 300
300   FORMAT(' OUTPUT FILENAME FOR ISOLINES : '$)
C     CALL GETSTR (5,NAME3,14)
C     CALL ASSIGN (3,NAME3)
C     CALL ASSIGN(4,('KINER.OUT'))
C     DEFINE FILE 4 ((0,8),U,IV4)
C     IV4=2
C     TYPE 510
510   FORMAT(' TITLE FOR ISOLINES PLOT : '$)
C     ACCEPT 520,TITLE
520   FORMAT(20A4)
C     WRITE(3,525) TITLE          ! RECORD 1 FOR PLIS
525   FORMAT(1X,20A4)
C     WRITE(3,*) NX,NY          ! RECORD 2
C     XPC(1)=0.
C     DO 530 I=2,NX
530   XPC(I)=XPC(I-1)+STEP
C     WRITE(3,*) (XPC(K),K=1,NX) ! RECORD 3 - X-COORD.

```

F2

```

540      DO 540 J=2,NY
        XPC(J)=XPC(J-1)+STEP
        WRITE(3,*) (XPC(K),K=1,NY)          ! RECORD 4 - Y-COORD.
C
        YP=YI-STEP
1000     TYPE 1010
1010     FORMAT(' ATMOSPHERIC PRESSURE : ($)
        ACCEPT 140,PAT
        TYPE 1020
1020     FORMAT(' TEMPERATURE           : ($)
        ACCEPT 140,TO
        TYPE 1030
1030     FORMAT(' DYNAMIC PRESSURE (MM.H2O) : ($)
        ACCEPT 140,DPMH
        VELSQ=(2.*RHDWAT*DPMH)/(RHOAIR*1000.)
        CTE=DPMH*G
        XPC(1)=XI-STEP
C
        DCFKET=0.
C
        DO 30 J=1,NY
          JL=J
          YP=YP+STEP
          SIG=1.
          IF(MOD(JL,2).EQ.0) SIG=-1
C
          XMIN=XI
          XMAX=STEP+FLOAT(NX-1)+XI
C
1040     IF(MOD(JL,2).EQ.0) XPC(1)=XMAX+STEP
          IF(MOD(JL,2).NE.0) XPC(1)=XMIN-STEP
C
          DO 20 I=1,NX
            XPC(I)=XPC(I)+STEP*SIG
            IF(I.GT.1) XPC(I)=XPC(I-1)+STEP*SIG
            READ (1,IV1) IVAL
            DO 180 K=1,5
              PCK)=FLOAT(IVAL(K))
180      CONTINUE
C
          CALL CALCUL (P,VARG,WARG,PAT,TO )
C
          VC(I)=VARG
          WK(I)=WARG
          DCFKEL(I)=(VC(I)**2+WK(I)**2)
          DCFKEL(I)=DCFKEL(I)/VELSQ
          DCFKET=DCFKET+DCFKEL(I)
          TYPE 1111,DCFKET
          XPR(I)=DCFKEL(I)
C
          CONTINUE
          IF(MOD(JL,2).EQ.0) GO TO 400
          KR=0
          DO 300 K=NX,1,-1
            KR=KR+1
300      XPLISQ(KR)=XPR(K)
            WRITE(3,*) (XPLISQ(K),K=1,NX)          ! RECORD 5
            DO 250 I=1,NX
              WRITE (4,IV4) VC(I),WK(I),DCFKEL(I),DCFKET
250      CONTINUE
          TYPE 1111, (VC(I),WK(I),DCFKEL(I),VELSQ,DCFKET,I=1,NX)
          FORMAT(5F12.2)

```


F 3

```

100  WRITE(3,*) (PERIOD, K=1, NN)
110  DO 200 I=1, NN
120  READ(4,*) (V(I), W(I), P(I), Q(I), R(I), S(I), T(I), U(I))
130  WRITE(5,*)
140  WRITE(1,*) (V(I), W(I), P(I), Q(I), R(I), S(I), T(I), U(I))
150  CONTINUE
160  CALL CLOSE(1)
170  CALL CLOSE(2)
180  CALL CLOSE(3)
190  CALL ASSIGN(1, N)
200  CALL ASSIGN(2, I)
210  READ(1,*) TITLE
220  READ(1,*) UNIT
230  READ(1,*) (PERIOD, K=1, NN)
240  READ(1,*) (PERIOD, K=1, NN)
250
260  DO 9999 J=1, NY
270  PERIOD(J,*) = CARLISB(K), K=1, NN
280  WRITE(2,*) (CARLISB(K), K=1, NN)
290  FORMAT(10, 10F12.3)
300
310  CONTINUE
320  CALL CLOSE(1)
330  CLOSE(UNIT=2, DISK='PRINT')
340  STOP
350  END

```

```

-----
C  CALCULATION OF VELOCITY VECTOR, PRESSURE, AND PRESSURE CALIBRATION
C  POLYNOMIALS AND MISALIGNMENT PRESSURE. GO TO SUBROUTINE CORR/83
C  SUBROUTINE CALCUL (P, V, W, P, Q, R, S, T, U)
C  DIMENSION PC(1)
000  BIRN2=BI*IAN(X/SQRT(1-X**2))
010  BIRK=BI*IAN(X/SQRT(1-X**2))
020
030  PHOY = (PC(1)+PC(2)+PC(3)+PC(4))+0.25
040  PC(2) AND PC(1) WILL BE CORRECTED VALUES MEASURED BY PROBE
050  PC(2)=PC(2)+18.
060  PC(1)=PC(1)+10.
070  DD = PC(2)-PC(4)
080  EE = PC(1)-PC(3)
090  ADD = ABS(DD)
100  AEE = ABS(EE)
110  FF = AEE - ADD
120  IF (EE EQ 0) GO TO 2
130  GG = ABS(DD/EE)
140  FIR = ATAN(GG)
150  FI = 180 *FIR/3.14159
160  GO TO 3
170  FI = 90.0
180  FIR = 3.14159/2.0
190  RA = DD*DD+EE*EE
200  RI = SQRT(RA)
210  BIR = 61/ABS(PC(5)-PHOY)
220  IF (FF.LE.0.005) GO TO 4
230  IF (EE.GE.0.01) GO TO 5
240  T1 = 13.72856*BIR+C-2.112226E-11**IR**2-(.9420486)*BIR**3+
250  (.2933134E-1)*BIR**4
260  T2 = -(2.697529E-20)*BIR**5
270  TH = T1 + T2 - 1.241217
280  DI = (5.870109E-1)+(4.466144E-3)*TH+(-3.990502E-4)*TH**2

```


F5

```
C1 = (-2.636668E-3)*TH+(6.197820E-4)*TH**2+(3.465379E-5)*TH**3
C2 = (-1.251172E-6)*TH**4+(2.517031E-3)*TH**5+(7.931692E-11)*
*TH**6
CP = C1+C2+1.402665E-3
GO TO 10
6 T1 = (2.12256481R**2-322581.3481R**3)+3.222668*B1R**3
1 C1 28494.97481R**4
T2 = (-2.069259E-10)*B1R**5+(1.413981E-2)*B1R**6
TH = T1+T2-2.9372914
D1 = (5.833294E-11)*T2-8.777844*TH**3+(1.835821E-4)*TH**2
D2 = (-1.422018E-3)*TH**3+(1.422018E-3)*TH**4
D3 = (-8.653081E-9)*TH**5
PD = (D1+D2+D3)+1.09
C1 = (-8.130340E-4)*TH+(2.066393E-5)*TH**2+(2.829439E-5)*TH**3
C2 = (-4.975929E-7)*TH**4+(2.321737E-9)*TH**5
CP = C1+C2+7.536941E-4
GO TO 10
END
```

G1

```

1 OPEN 1,4
2 OPEN 4,4,4
5 POKE 848,5
6 POKE 851,1
7 POKE 853,1
8 POKE 852,4
10 PRINT#4:REM ENABLES ERROR DIAGNOSTICS
20 DIM I(8),X(5),Y(5),P(5)
30 DIM CF(5),YC(5)
55 ST(1)=0
60 READ R
70 DATA 287
80 FOR I=1TO5:READ CF(I):NEXT
90 DATA 133.32,9.806356,9.80665E+04,6894.8,1
100 INPUT"DATE":I(3),I(4),I(5)
110 POKE 852,4
120 INPUT"NUMBER OF TRANSDUCERS TO CALIBRATE,0 TO END":NT
130 IF NT=0 THEN 1000
140 POKE 850,1
180 INPUT"WHEN READY TYPE 1":KK
190 IF KK>1 THEN 180
200 NP=0
210 INPUT"VALUE OF POINT AND UNIT INDEX":RP,IX
220 IF IX=0 THEN 325
230 NP=NP+1
240 REM CLEAR AND INITIALIZE STORE
250 SYS(32017)
280 Y(NP)=RP*CF(IX)
310 V=PEEK(860)*256+PEEK(861)-2048
320 X(NP)=V:PRINT V:GOTO 210
325 GOSUB 5000:REM LINEAR REGRESSION
330 PRINT#1,"CALIBRATION OF CHANNEL"
340 PRINT#1
350 PRINT#1,"PRESSURE","DIGITS","CALCULATED PRESSURE"
355 ER=0
360 FOR J=1TO NP
363 YC(J)=A0+A1*X(J)
365 ER=ER+ABS(YC(J)-Y(J))*100/Y1
370 PRINT#1,Y(J);"PA",X(J),YC(J);"PA":NEXT
380 PRINT#1
400 IF ER<1.00 THEN 420
410 PRINT#1,"POSSIBLE ERROR IN CALIBRATION OF CHANNEL"
420 PRINT#1,"REGRESSION COEFFICIENTS ":A0,A1
440 PRINT#1,"MEAN ERROR":ER:PRINT#1
450 GO TO 110
1000 POKE 850,0
1012 INPUT"P-ATM,CONV:1 FOR HG,2 FOR H2O":PAT,IC
1013 PAT=PAT*CF(IC)
1014 INPUT"P-DYN IN MM H2O":P1
1015 P1=P1*CF(2)
1017 INPUT"ANGLE OF ATTACK":AL
1020 INPUT "TRAVERSE A":I(2)
1030 POKE 02,123
1031 POKE 01,123 :REM INI USR ADD
1032 INPUT "TEST NUMBER":I(1)
1033 FOR J=1TO5
1034 A=USR(I(J))
1035 NEXT J
1040 A=USR(-1)
1090 INPUT"TOTAL TEMP IN DEG-C":T0
1092 T0=T0+273.15
1095 RHT=PAT/(R*T0)
1096 U1=SQR(2*P1/RHT)

```

```
1200 PRINT#1,"DATE":I(3):I(4):I(5):PRINT#1
1202 PRINT#1,"TESTS CONDITIONS":PRINT#1
1203 PRINT#1,"ATM PRESSURE":PAT:"PA"
1204 PRINT#1,"TEMP TOTALE":T0:"K"
1205 PRINT#1,"TRAVERSE A":I(2):"FS"
1206 PRINT#1,"TUNNEL SPEED":U1:"M/S"
1207 PRINT#1,"PR. DYN":P1:"PA"
1208 MU=1.4962E-06*T0↑1.5/(T0+120)
1209 RE=RHT*U1*.062/MU
1210 PRINT#1,"RE NO.":RE:PRINT#1
1211 PRINT#1,"TEST NUMBER":I(1):PRINT#1:PRINT#1:PRINT#1:PRINT#1:PRINT#1
1290 POI=0
1300 INPUT"EQUILIBRATION DELAY":ED
1310 POKE 849,ED
1320 POKE 59459,252:REM VIA DDR PINS 0,1 INPUT
1330 POKE 59471,12:REM PUTS 1 TO OUTPUT PINS 2&3
1345 POI=POI+1
1350 FOR J=1T05
1370 SYS(32017)
1380 POKE 59471,4:FOR K=1T095:NEXT
1390 POKE 59471,12:FOR K=1T0500:NEXT
1400 SYS(31945)
1430 V=PEEK(860)*256+PEEK(861)-2048
1440 P(J)=A0+A1*V
1442 A=USR(V)
1443 NEXT
1446 PRINT#1,"POINT":POI,"XS":XS,"YS":YS:PRINT#1
1455 PMOY=(P(1)+P(2)+P(3)+P(4))/4
1460 PDP=(P(5)-PMOY)/P1
1465 DD=P(2)-P(4) :HH=P(1)-P(3)
1468 ADD=ABS(DD) :AEE=ABS(HH) :FF=AEE-ADD
1469 IF DD=0 THEN 1475
1470 GG=ABS(HH/DD) :FIR=ATN(GG) :FI=180*FIR/3.14159 :GO TO 1480
1475 FI=90
1480 RA=DD*DD+HH*HH
1484 BI=SQR(RA)
1485 BIR=BI/ABS(P(5)-PMOY)
1486 CP=1-(P(5)/P1)
1527 IF P(1)>=P(3)ANDP(4)>=P(2) THEN QU=1
1528 IF P(1)>=P(3)ANDP(2)>=P(4) THEN QU=2
1529 IF P(1)<=P(3)ANDP(2)>=P(4) THEN QU=3
1530 IF P(1)<=P(3)ANDP(4)>=P(2) THEN QU=4
1541 PRINT#1,"P1":P(1):"PA", "P2":P(2), "P3":P(3):"PA":PRINT#1
1542 PRINT#1,"P4":P(4):"PA", "P5":P(5):"PA", "IF1":FI:"CP":CP:PRINT#1
1543 PRINT#1,"BIR":BIR,"PDP":PDP,"PMOY":PMOY:PRINT#1:PRINT#1:PRINT#1
1550 GO TO 1850
1710 GO TO 1525
1850 PRINT"ACQUISITION SUSPENDED.FOR NEXT POINT.TYPE 1"
1860 INPUT KK
1870 IF KK=1 THEN 1310
1900 SYS(31862)
1910 PRINT"ACQUISITION SUSPENDED.TO RESUME.TYPE 1"
1920 INPUT KK
1930 IF KK=1 THEN 110
1960 GO TO 2200
2200 END
5000 X1=0:Y1=0:XY=0:X2=0:Y2=0
5010 FORJ=1TONP
5020 X1=X1+X(J):Y1=Y1+Y(J)
5030 XY=XY+X(J)*Y(J)
5040 X2=X2+X(J)^2:Y2=Y2+Y(J)^2:NEXT
5050 DN=X2-X1*X1/NP
5060 A1=(XY-X1*Y1/NP)/DN
5070 A0=(Y1-A1*X1)/NP
5080 B2=A1*A1*(X2-X1*X1/NP)/(Y2-Y1*Y1/NP)
```

G 2

```
5100 RETURN
8000 INPUT "NUMBER CHANNEL";N
8020 POKE 40970,0
8030 POKE 40971,0
8040 A=PEEK(40972):IF NOT A AND 128 THEN 8040
8050 A=PEEK(40973):IF NOT A AND 128 THEN 8070
8060 A=A-248:GO TO 8080
8070 A=A+8
8080 A=A*256+PEEK(40974)-2048
8090 PRINT "ON CHANNEL NUMBER";1..A;"DIGITS"
8100 GO TO 8000
READY.
```

G3

HI

```
1 OPEN 1,4
2 OPEN 4,4,4
5 POKE 848,5
6 POKE 851,1
7 POKE 853,1
8 POKE 852,4
10 PRINT#4:REM ENABLES ERROR DIAGNOSTICS
20 DIM I(8),X(5),Y(5),P(5)
30 DIM CF(5),YC(5)
55 ST(1)=0
60 READ R
70 DATA 287
80 FOR I=1TO5:READ CF(I):NEXT
90 DATA 133.32,9.806356,9.80665E+04,6894.8,1
100 INPUT"DATE";I(3),I(4),I(5)
110 POKE 852,4
120 INPUT"NUMBER OF TRANSDUCERS TO CALIBRATE,0 TO END";NT
130 IF NT=0 THEN 1000
140 POKE 850,1
180 INPUT"WHEN READY TYPE 1";KK
190 IF KK<>1 THEN 180
200 NP=0
210 INPUT"VALUE OF POINT AND UNIT INDEX";RP,IX
220 IF IX=0 THEN 325
230 NP=NP+1
240 REM CLEAR AND INITIALIZE STORE
250 SYS(32017)
280 Y(NP)=RP*CF(IX)
310 V=PEEK(860)*256+PEEK(861)-2048
320 X(NP)=V:PRINT V:GOTO 210
325 GOSUB 5000:REM LINEAR REGRESSION
330 PRINT#1,"CALIBRATION OF CHANNEL"
340 PRINT#1
350 PRINT#1,"PRESSURE","DIGITS","CALCULATED PRESSURE"
355 ER=0
360 FOR J=1TO NP
363 YC(J)=A0+A1*X(J)
365 ER=ER+ABS(YC(J)-Y(J))*100/Y1
370 PRINT#1,Y(J);"PA",X(J),YC(J);"PA":NEXT
380 PRINT#1
400 IF ER<1.00 THEN 420
410 PRINT#1,"POSSIBLE ERROR IN CALIBRATION OF CHANNEL"
420 PRINT#1,"REGRESSION COEFFICIENTS ";A0,A1
440 PRINT#1,"MEAN ERROR";ER:PRINT#1
450 GO TO 110
1000 POKE 850,0
1012 INPUT"P-ATM,CONV:1 FOR HG,2 FOR H2O";PAT,IC
1013 PAT=PAT*CF(IC)
1014 INPUT"P-DYN IN MM H2O";P1
1015 P1=P1*CF(2)
1017 INPUT"ANGLE OF ATTACK";AL
1020 INPUT "TRAVERSE A";I(2)
1030 POKE 02,123
1031 POKE 01,123 :REM INI USR ADD
1032 INPUT "TEST NUMBER";I(1)
1033 FOR J=1TO5
1034 A=USR(I(J))
1035 NEXT J
1040 A=USR(-1)
1090 INPUT"TOTAL TEMP IN DEG-C";T0
1092 T0=T0+273.15
1095 RHT=PAT/(R*T0)
1096 U1=SQR(2*P1/RHT)
```

H 2

```

1200 PRINT#1,"DATE";I(3);I(4);I(5):PRINT#1
1202 PRINT#1,"TESTS CONDITIONS":PRINT#1
1203 PRINT#1,"ATM PRESSURE";PAT;"PA"
1204 PRINT#1,"TEMP TOTALE";T0;"K"
1205 PRINT#1,"TRAVERSE A";I(2);"FS"
1206 PRINT#1,"TUNNEL SPEED";U1;"M/S"
1207 PRINT#1,"PR.DYN";P1;"PA"
1208 MU=1.4962E-06*T0↑1.5/(T0+120)
1209 RE=RHT*U1*.062/MU
1210 PRINT#1,"RE NO.":RE:PRINT#1
1211 PRINT#1,"TEST NUMBER";I(1):PRINT#1:PRINT#1:PRINT#1:PRINT#1:PRINT#1
1290 POI=0
1300 INPUT"EQUILIBRATION DELAY";ED
1310 POKE 849,ED
1320 POKE 59459,252:REM VIA DDR PINS 0,1 INPUT
1330 POKE 59471,12:REM PUTS 1 TO OUTPUT PINS 2&3
1345 POI=POI+1
1350 FOR J=1T05
1370 SYS(32017)
1380 POKE 59471,4:FOR K=1T095:NEXT
1390 POKE 59471,12:FOR K=1T0500:NEXT
1400 SYS(31945)
1430 V=PEEK(860)*256+PEEK(861)-2048
1440 P(J)=A0+A1*V
1442 A=USR(V)
1443 NEXT
1446 PRINT#1,"POINT";POI,"XS";XS,"YS";YS:PRINT#1
1455 PMOY=(P(1)+P(2)+P(3)+P(4))/4
1464 P(2)=P(2)+18 :P(1)=P(1)+10
1465 DD=P(2)-P(4) :HH=P(1)-P(3)
1468 ADD=ABS(DD) :AEE=ABS(HH) :FF=AEE-ADD
1469 IF HH=0 THEN 1475
1470 GG=ABS(DD/HH) :FIR=ATN(GG):FI=180*FIR/3.14159 :GO TO 1480
1475 FI=90
1480 RA=DD*DD+HH*HH
1484 BI=SQR(RA)
1485 BIR=BI/ABS(P(5)-PMOY)
1490 IF FF<=0.005 THEN 1650
1495 IF HH>=0.01 THEN 1600
1497 T1=13.72858*BIR-(2.11223E-1)*BIR↑2-(0.942049)*BIR↑3+(2.933134E-1)*BIR↑4
1498 T2=-(-2.697529E-2)*BIR↑5
1510 TH=T1+T2-1.2412170
1515 D1=(5.870109E-1)+(4.46614E-3)*TH+(-3.990502E-4)*TH↑2
1516 D2=(-5.36291E-6)*TH↑3+(5.538313E-7)*TH↑4
1517 D3=(-7.405356E-9)*TH↑5
1518 PD=(D1+D2+D3)*1.00000
1520 C1=(7.065830E-4)*TH-(3.03239E-4)*TH↑2+(4.834588E-5)*TH↑3
1521 C2=(-1.43039E-6)*TH↑4+(2.612108E-8)*TH↑5-(2.319786E-10)*TH↑6
1522 CP=C1+C2
1525 MV=ABS((P(5)-PMOY)*2/(RHT*PD)):MV=SQR(MV)
1526 BT=P(5)+CP*RHT*MV*MV/2
1527 IF P(1)>=P(3)ANDP(4)>=P(2) THEN QU=1
1528 IF P(1)>=P(3)ANDP(2)>=P(4) THEN QU=2
1529 IF P(1)<=P(3)ANDP(2)>=P(4) THEN QU=3
1530 IF P(1)<=P(3)ANDP(4)>=P(2) THEN QU=4
1531 PP=BT/P1
1541 PRINT#1,"P1";P(1);"PA","QUADRANT";QU,"[THETA]";TH;"DEGRES":PRINT#1
1542 PRINT#1,"P2";P(2);"PA","[FI]";FI;"DEGRES":PRINT#1
1543 PRINT#1,"P3";P(3);"PA","PD";PD,"VELOCITY";MV;"M/S":PRINT#1
1544 PRINT#1,"P4";P(4);"PA","CP";CP,"PR.TOT.LOC";BT;"PA":PRINT#1
1545 PRINT#1,"P5";P(5);"PA","PMOY";PMOY;"PA","PP";PP:PRINT#1:PRINT#1:PRINT#1
1550 GO TO 1850
1600 T1=21.53083*BIR-13.94689*BIR↑2
1601 T2=8.953023*BIR↑3-(3.248728)*BIR*BIR*BIR*BIR
1602 T3=(5.903704E-1)*BIR↑5-(4.14847E-2)*BIR↑6

```


H3

```

1620 D1=(5.909329E-1)+(8.193470E-4)*TH-(8.777613E-5)*TH^2
1621 D2=(-5.960415E-6)*TH^3-(1.537824E-7)*TH^4
1622 D3=(1.653859E-8)*TH^5-(2.34768E-10)*TH^6
1623 PD=(D1+D2+D3)*1.0
1625 C1=(-3.25646E-3)*TH+(1.213657E-3)*TH^2-(1.436869E-4)*TH^3
1626 C2=(8.768088E-5)*TH^4-(2.172509E-7)*TH^5+(1.987005E-9)*TH^6
1629 CP=C1+C2+9.777586E-4
1630 GO TO 1525
1650 IF DD<=0.01 THEN 1685
1660 T1=17.26694*BIR-8.755624*BIR^2
1661 T2=5.748909*BIR^3-2.148792*BIR^4
1662 T3=(3.965276E-1)*BIR^5-(2.831603E-2)*BIR^6
1663 TH=T1+T2+T3+0.4941921
1670 D1=(5.952E-1)+(7.559778E-5)*TH+(1.564457E-4)*TH^2
1671 D2=(-4.345895E-5)*TH^3+(2.162540E-6)*TH^4
1672 D3=(-4.38095E-8)*TH^5+(3.246741E-10)*TH^6
1673 PD=(D1+D2+D3)*1.0
1675 C1=(-2.83687E-3)*TH+(6.199820E-4)*TH^2-(3.455378E-5)*TH^3
1676 C2=(1.651172E-6)*TH^4-(2.517231E-8)*TH^5+(7.831602E-11)*TH^6
1677 CP=C1+C2+1.402665E-3
1680 GO TO 1525
1685 T1=12.12255*BIR+(2.329581)*(BIR^2)-3.229866*BIR^3+(1.284068)*BIR^4
1686 T2=(-2.268258E-1)*BIR^5+(1.48998E-2)*BIR^6
1687 TH=T1+T2-0.8373914
1700 D1=(5.833296E-1)+(2.877764E-3)*TH+(-1.635622E-4)*TH^2
1701 D2=(-1.422516E-5)*TH^3+(6.928993E-7)*TH^4
1702 D3=(-8.853089E-9)*TH^5
1703 PD=(D1+D2+D3)*1.00
1705 C1=(-8.130340E-4)*TH-(2.066893E-5)*TH^2+(2.829438E-5)*TH^3
1706 C2=(-4.975929E-7)*TH^4+(2.329037E-9)*TH^5
1707 CP=C1+C2+7.536941E-4
1710 GO TO 1525
1850 PRINT"ACQUISITION SUSPENDED.FOR NEXT POINT,TYPE 1"
1860 INPUT KK
1870 IF KK=1 THEN 1310
1900 SYS(31862)
1910 PRINT"ACQUISITION SUSPENDED.TO RESUME,TYPE 1"
1920 INPUT KK
1930 IF KK=1 THEN 110
1960 GO TO 2200
2200 END
5000 X1=0:Y1=0:XY=0:X2=0:Y2=0
5010 FORJ=1TONP
5020 X1=X1+X(J):Y1=Y1+Y(J)
5030 XY=XY+X(J)*Y(J)
5040 X2=X2+X(J)^2:Y2=Y2+Y(J)^2:NEXT
5050 DN=X2-X1*X1/NP
5060 A1=(XY-X1*Y1/NP)/DN
5070 A0=(Y1-A1*X1)/NP
5080 R2=A1*A1*(X2-X1*X1/NP)/(Y2-Y1*Y1/NP)
5090 R2=SQR(ABS(R2))
5100 RETURN
8000 INPUT"NUMBER CHANNEL":N
8020 POKE 40970.0
8030 POKE 40971.0
8040 A=PEEK(40972):IF NOTA AND 128 THEN 8040 8040
8050 A=PEEK(40973):IF NOTA AND 128 THEN 8070 8070
8060 A=A-248:GO TO 8080
8070 A=A+8
8080 A=A*256+PEEK(40974)-2048
8090 PRINT"ON CHANNEL NUMBER":1,A;"DIGITS"
8100 GO TO 8000

```

READY.

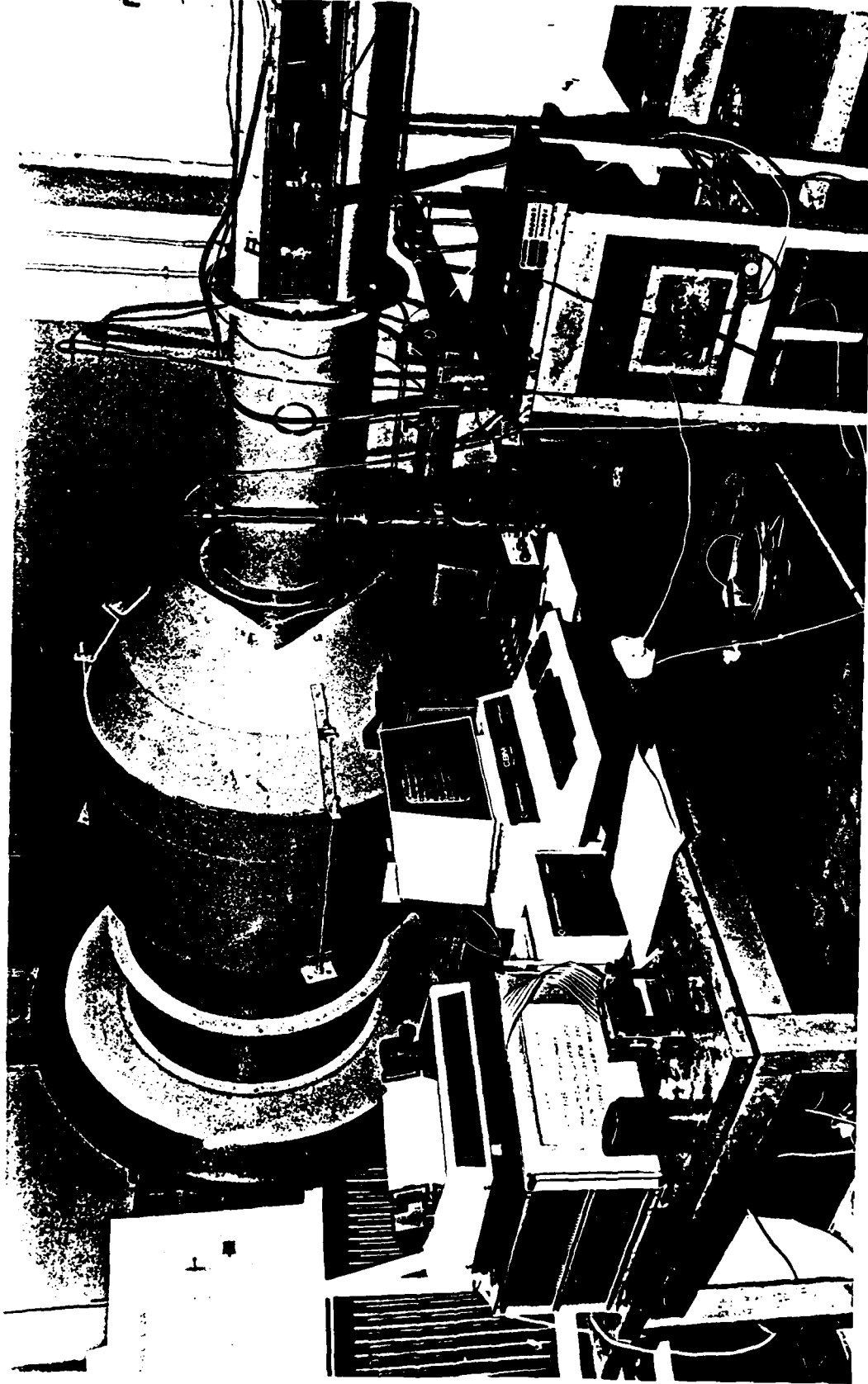


FIG. 1A - DATA ACQUISITION SYSTEM SET UP

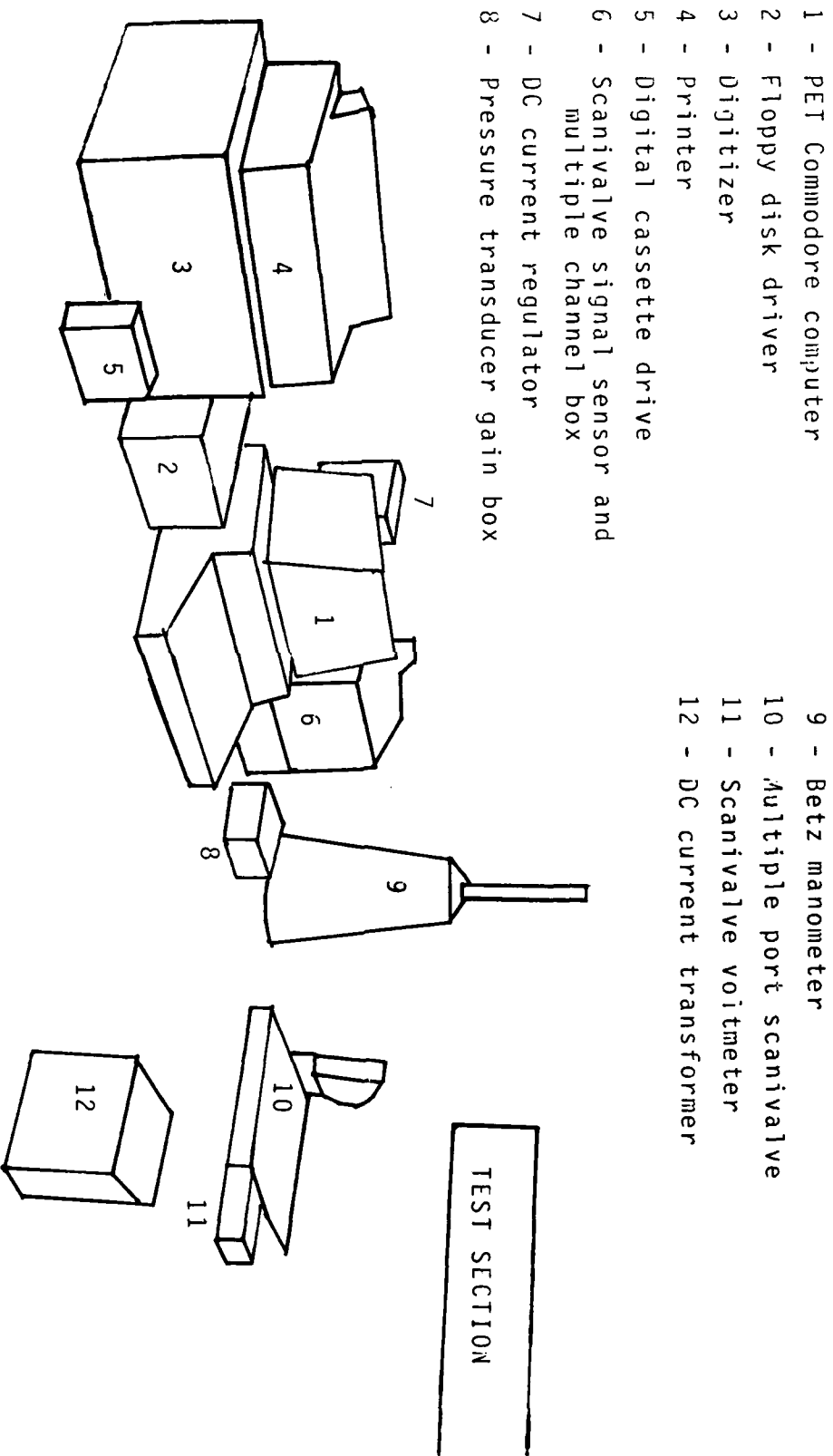
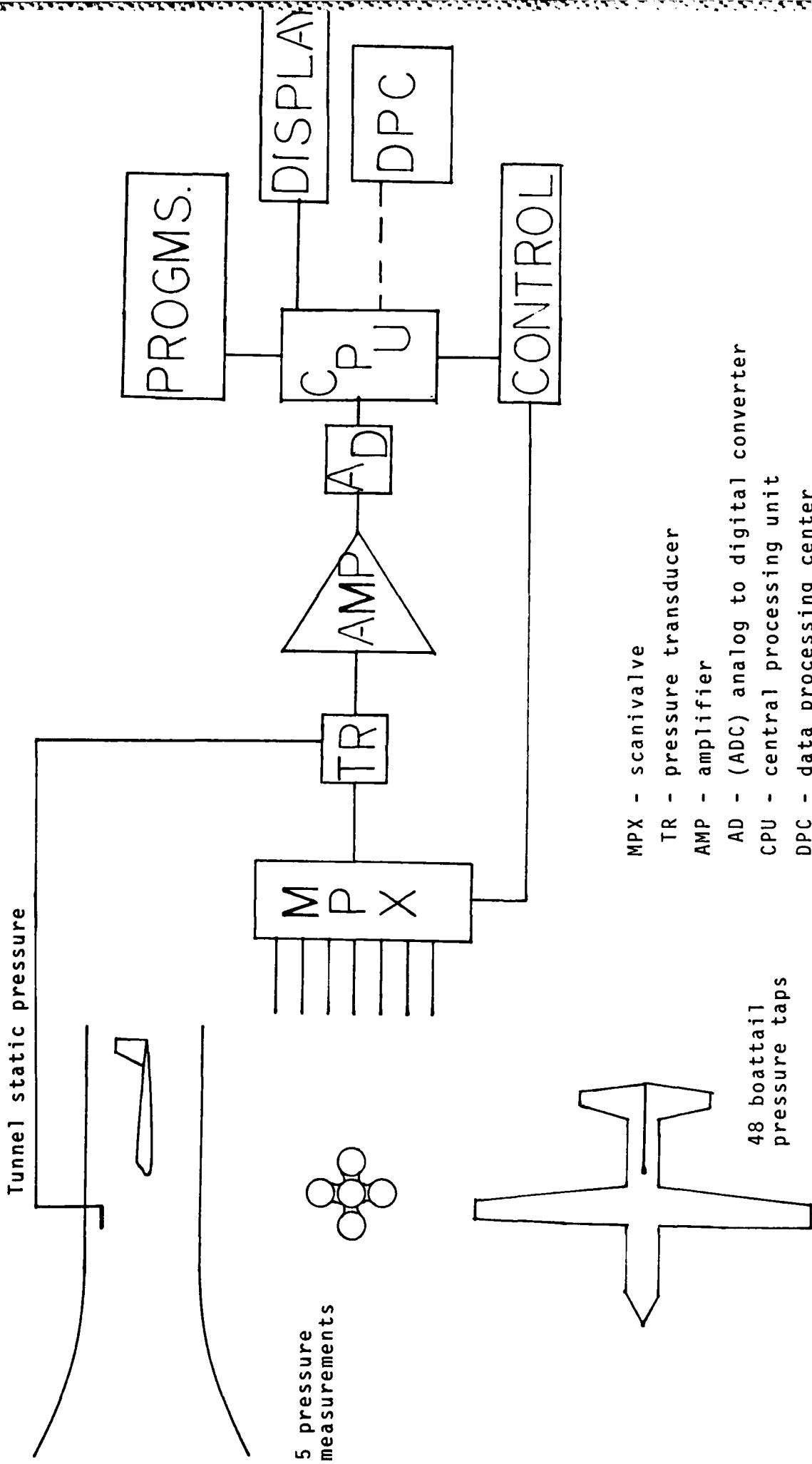


FIG. 1B - TEST INSTRUMENTATION DESCRIPTION



- MPX - scanivalve
- TR - pressure transducer
- AMP - amplifier
- AD - (ADC) analog to digital converter
- CPU - central processing unit
- DPC - data processing center

FIG. 1C - DATA ACQUISITION SYSTEM SCHEMATIC



FIG. 2A - FIVE HOLE PROBE VIEW

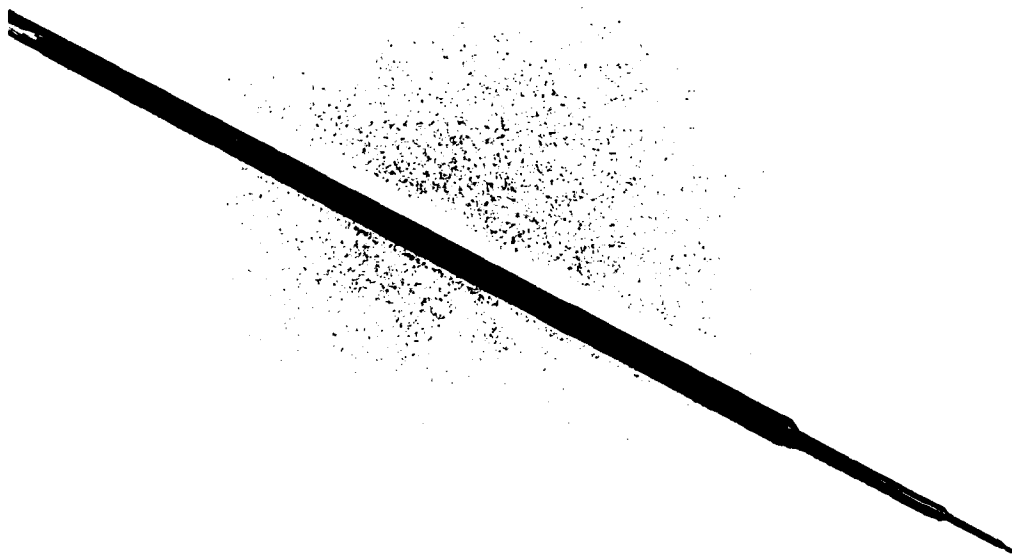


FIG. 2B - SUPPORT STEM FOR FIVE HOLE PROBE

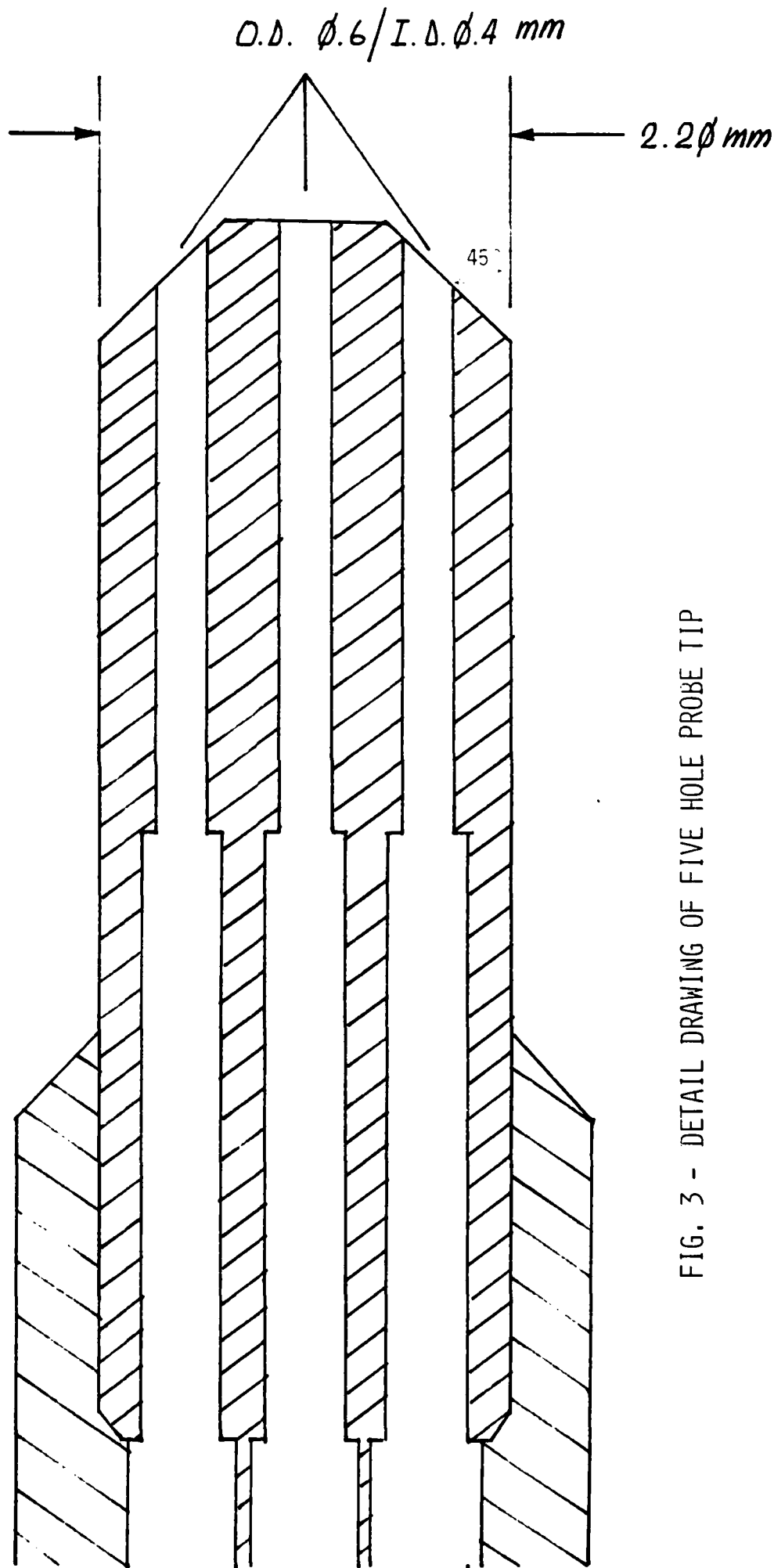
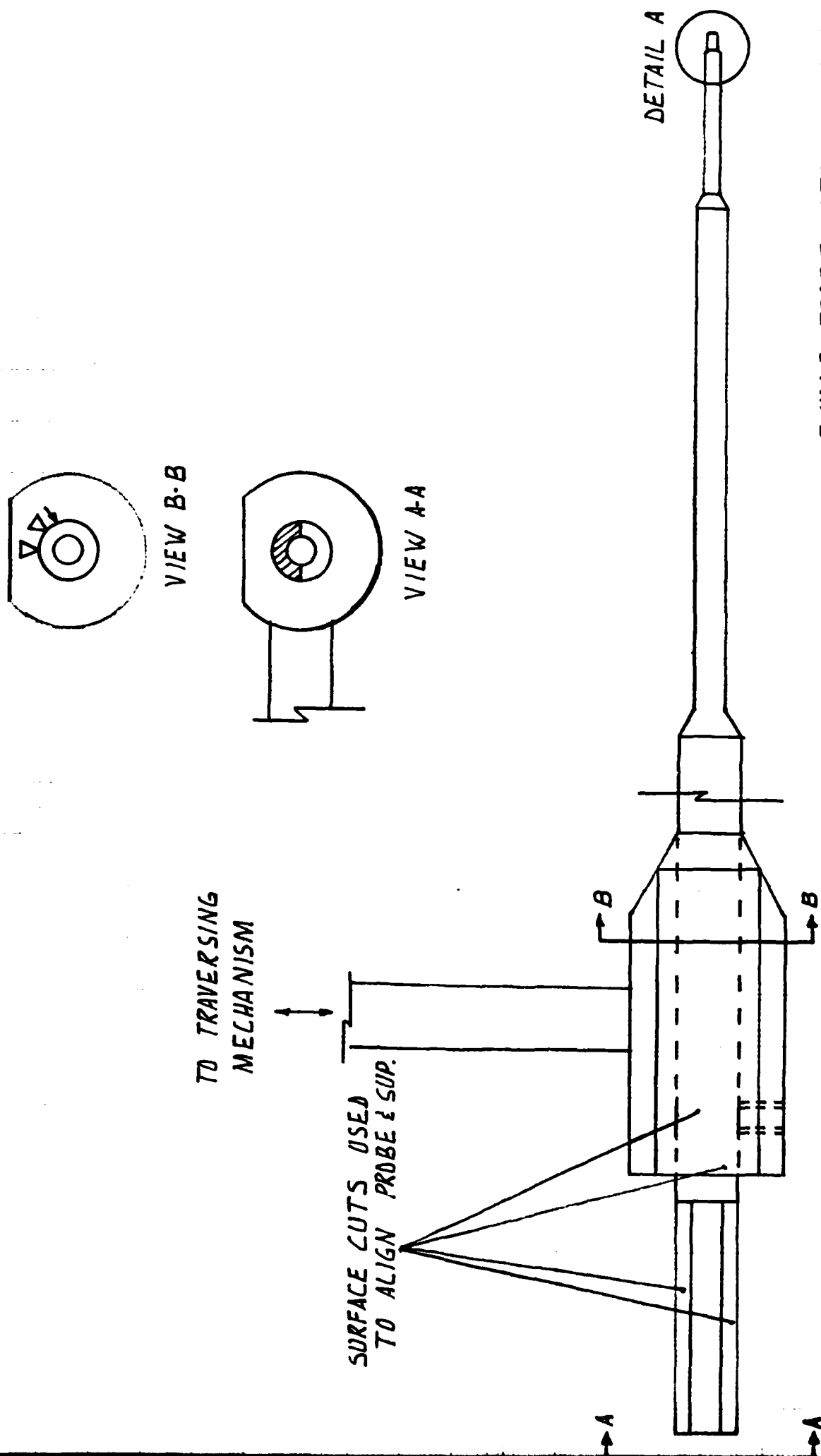


FIG. 3 - DETAIL DRAWING OF FIVE HOLE PROBE TIP



5 HOLE PROBE - STEM - SUPPORT

FIG. 4 - FIVE HOLE PROBE - STEM - TRAVERSING MECHANISM LINKAGE DRAWING

PRESSURE VS. SIGNAL OUTPUT OF
 VALDYNE MP45-1 S-N. 49675 TRANSDUCER
 RANGE ± 0.5 PSI DIFFERENTIAL

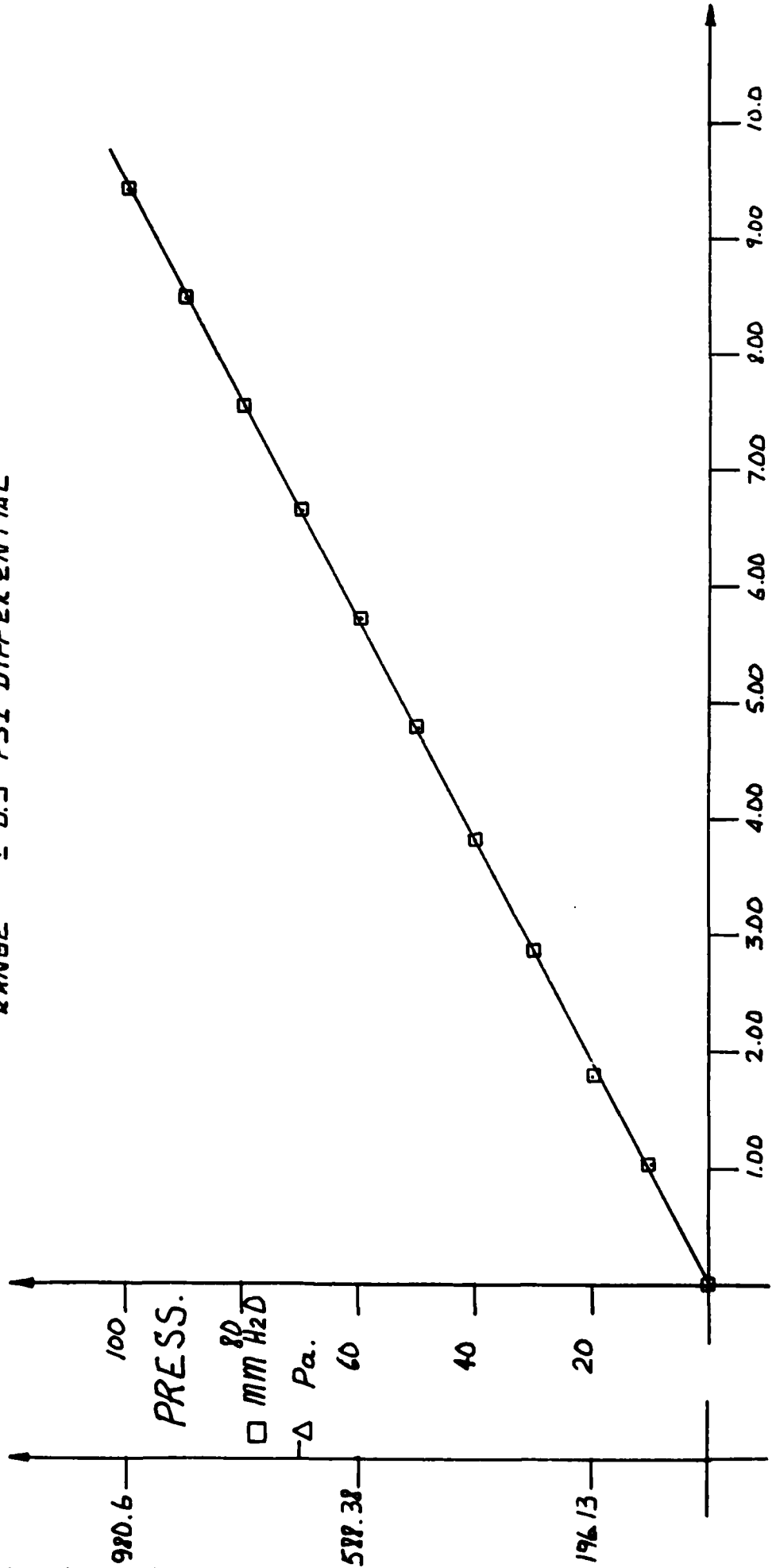


FIG. 5 - CALIBRATION CURVE FOR PRESSURE TRANSDUCER VOLTS, V

ORDONEZ 7/83

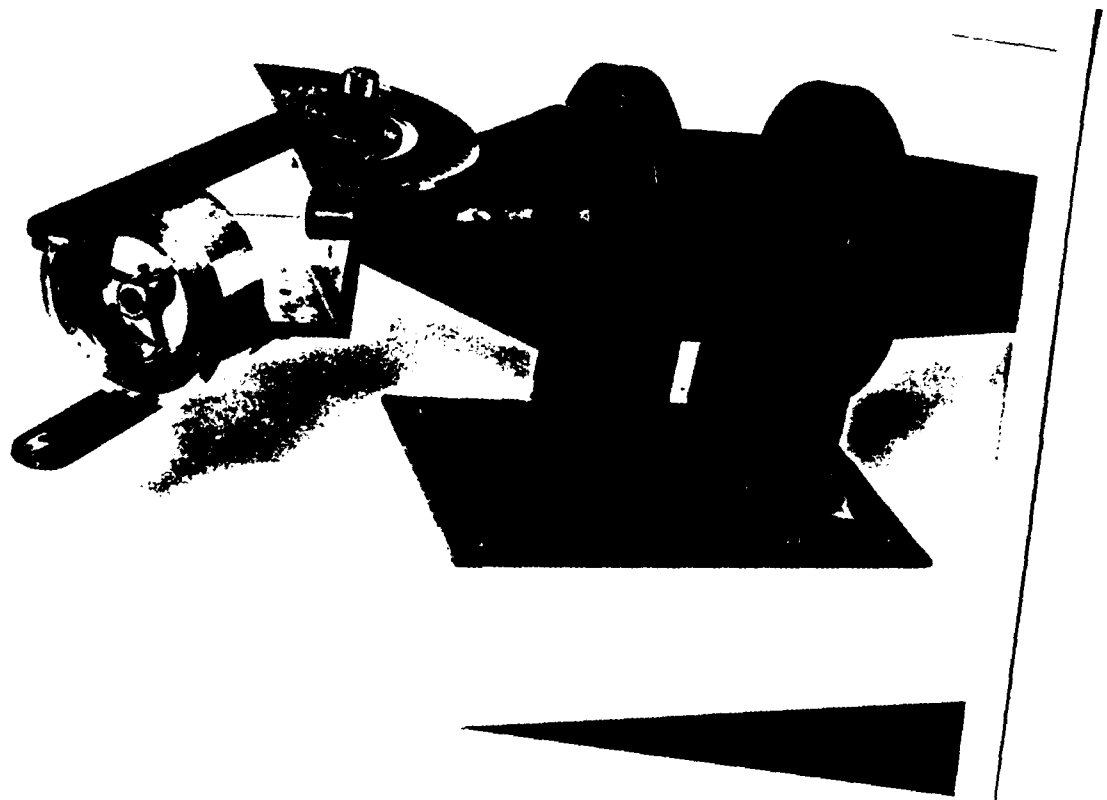


FIG. 6A - FIVE HOLE PROBE CALIBRATION DUCT

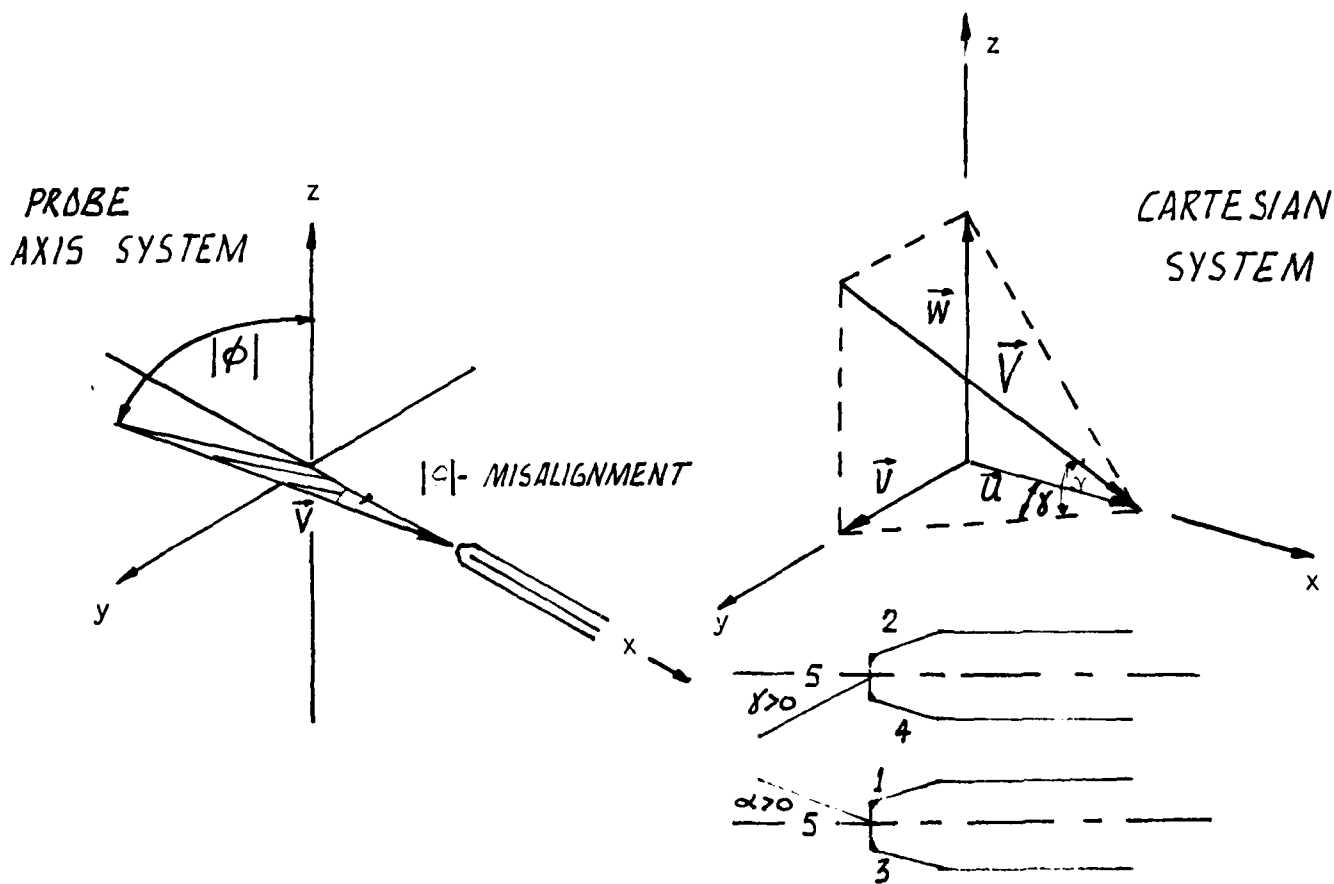
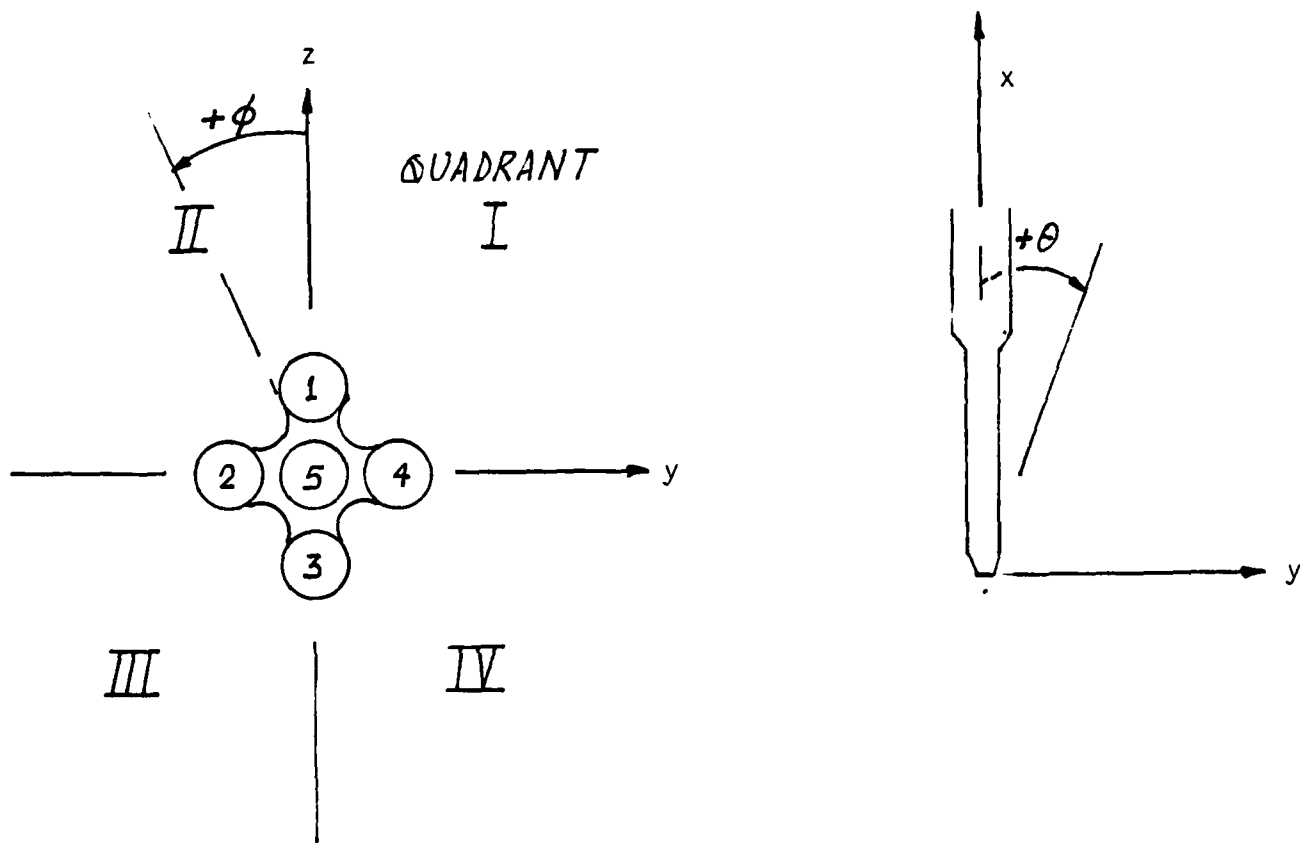


FIG. 6B - AXIS SYSTEM AND QUADRANT DEFINITION

BIR VERSUS θ CALIBRATION CURVES FOR FIVE HOLE PROBE

FIG. 7A
QUADRANT 1

— \square — EXP. DATA
 — POLYNOMIAL APPROXIMATION

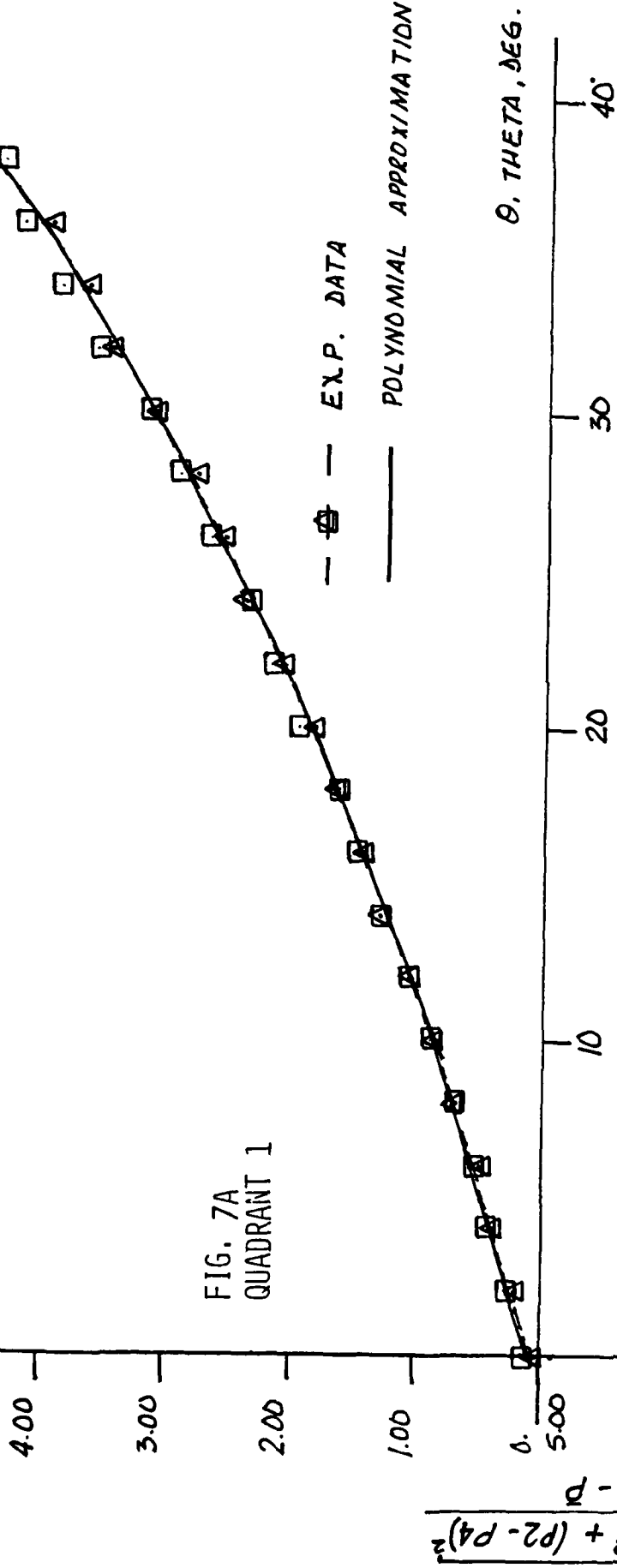
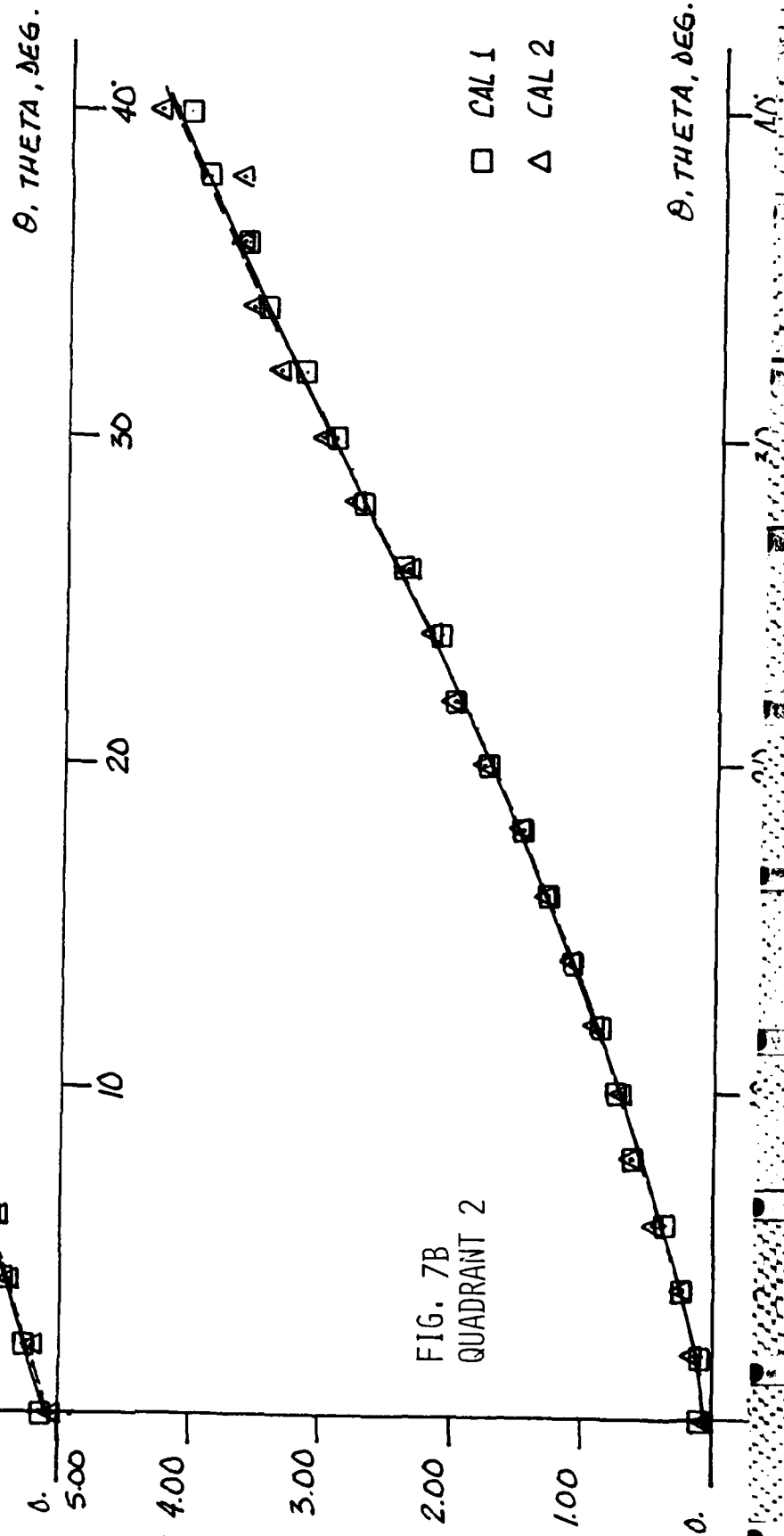


FIG. 7B
QUADRANT 2

\square CAL 1
 \triangle CAL 2



BIR VERSUS θ CALIBRATION CURVES FOR FIVE HOLE PROBE

FIG. 7C
QUADRANT 3

θ , THETA, DEG.

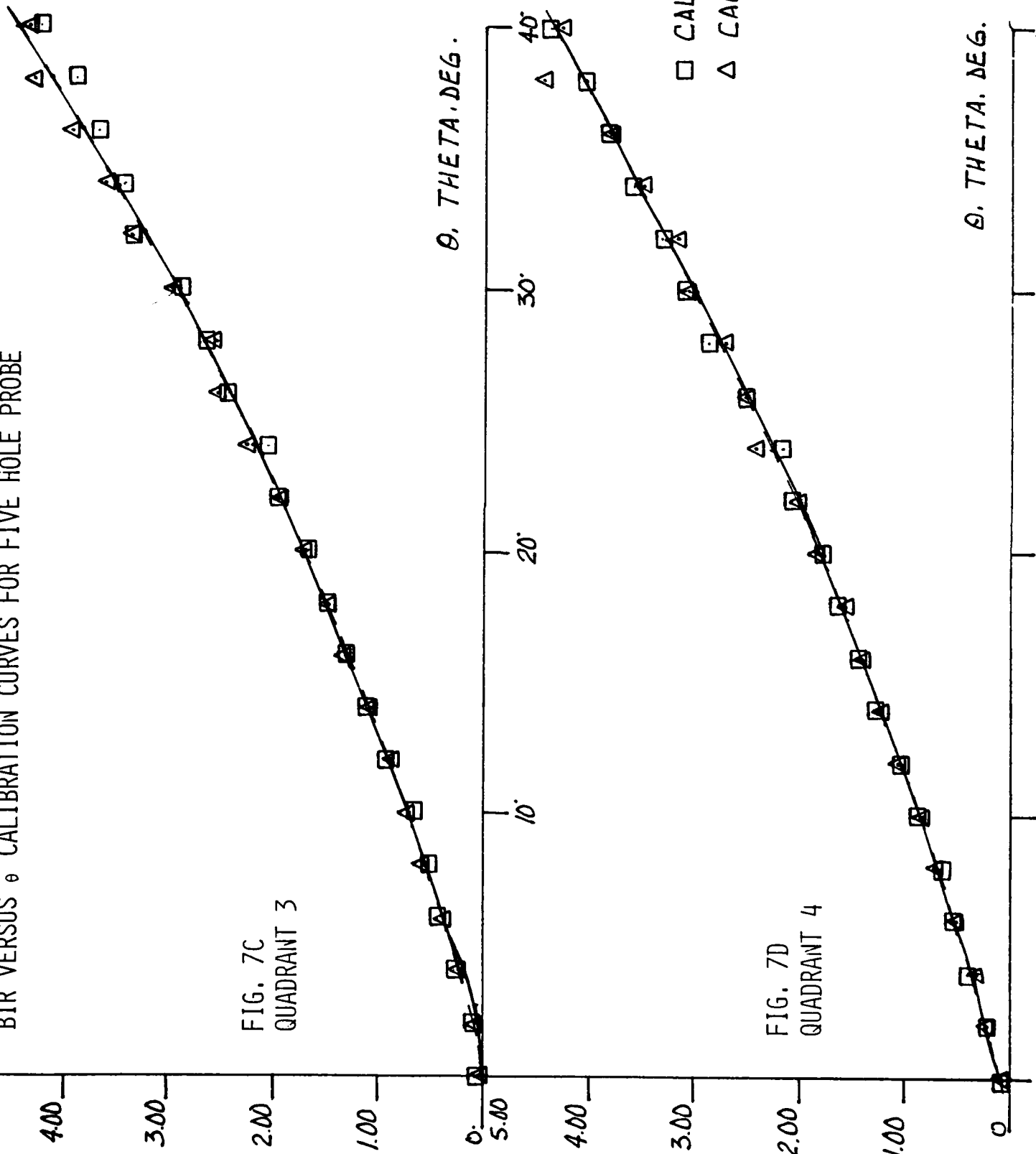
□ CAL 1
△ CAL 2

FIG. 7D
QUADRANT 4

θ , THETA, DEG.

$$\sqrt{(P1-P3)^2 + (P2-P4)^2}$$

P5 - P



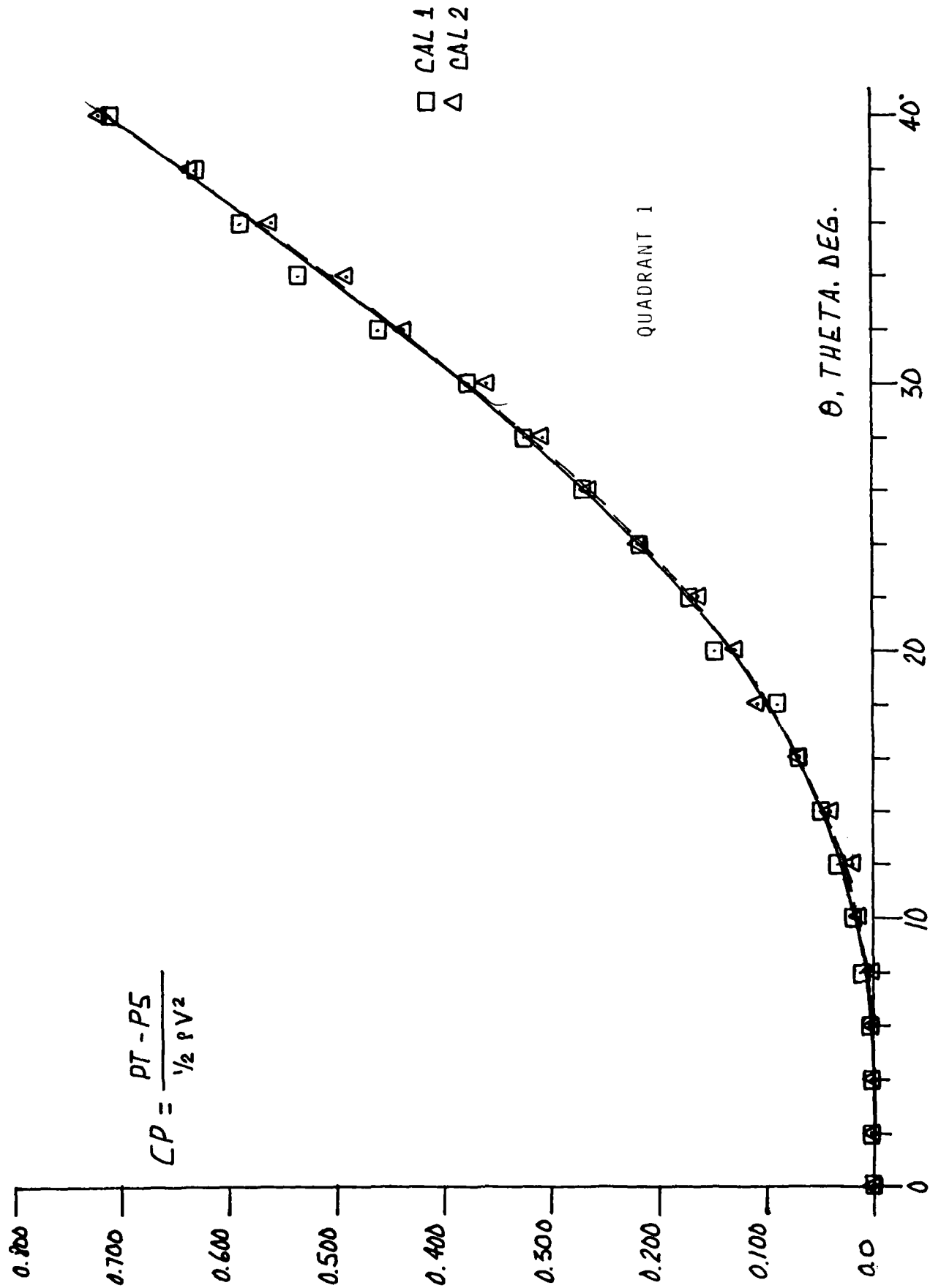


FIG. 3A - CP VERSUS θ CALIBRATION CURVES FOR FIVE HOLE PROBE

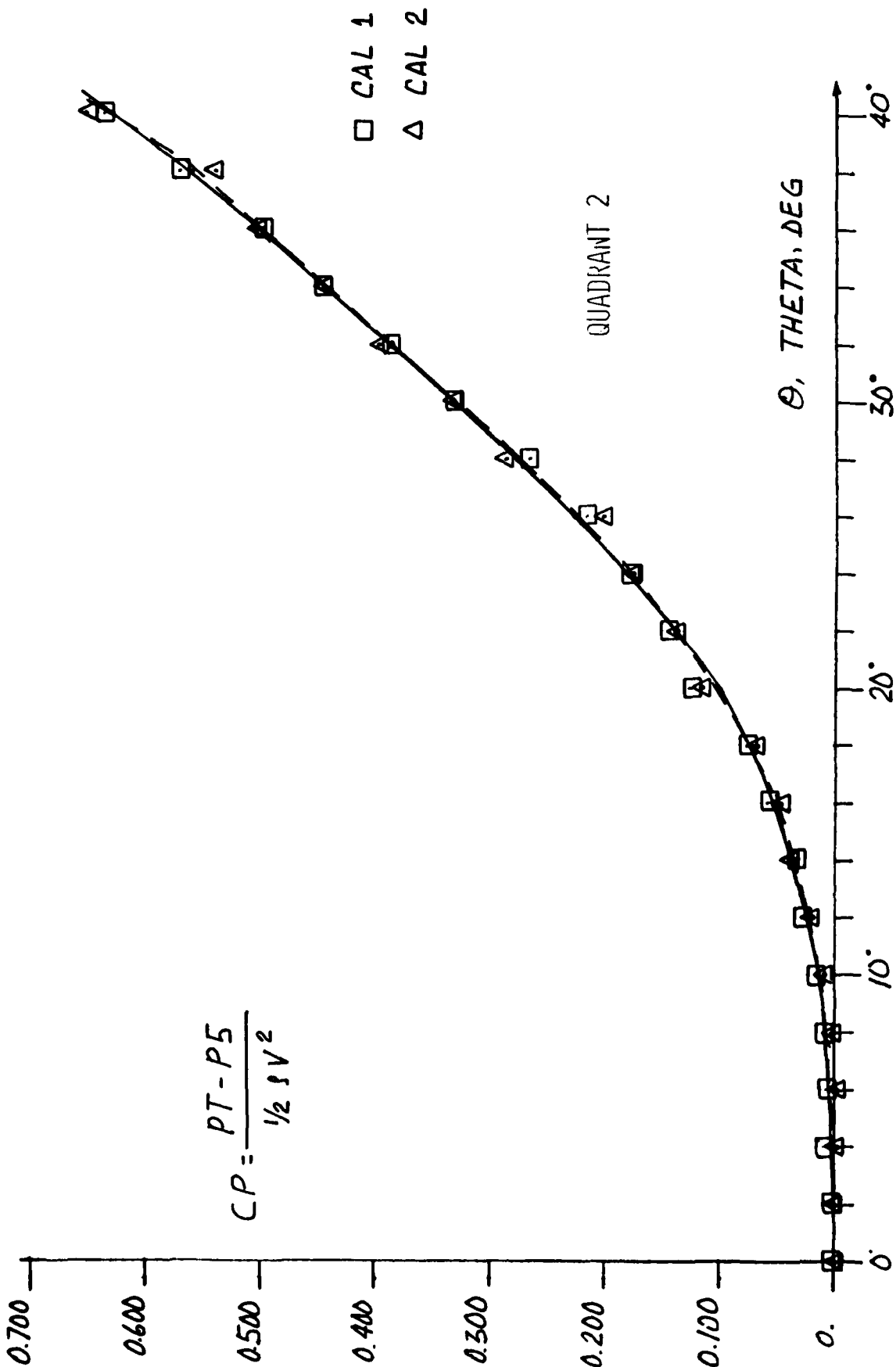


FIG. 8B - CP VERSUS θ CALIBRATION CURVES FOR FIVE HOLE PROBE

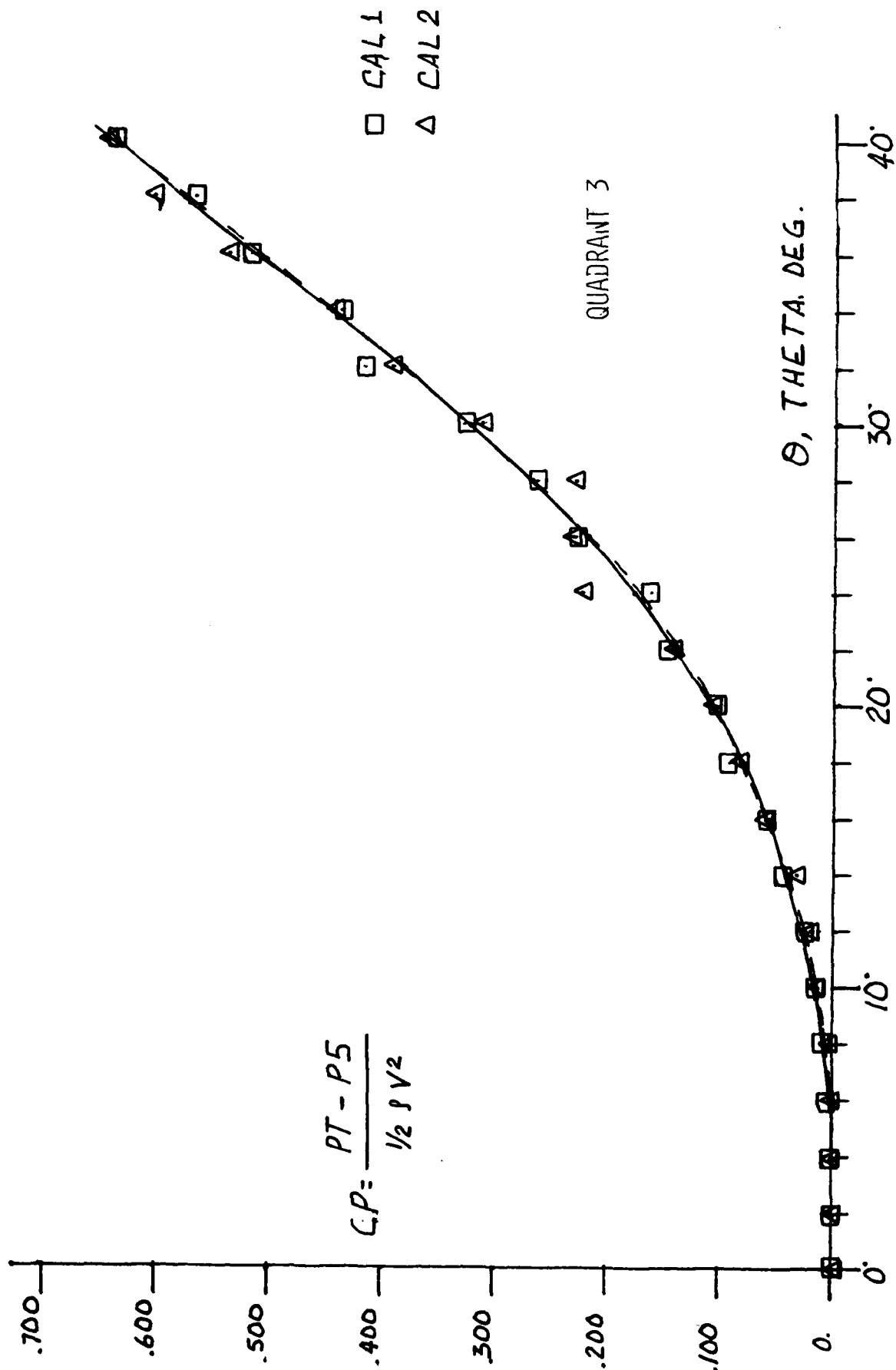


FIG. 8C - CP VERSUS θ CALIBRATION CURVES FOR FIVE HOLE PROBE

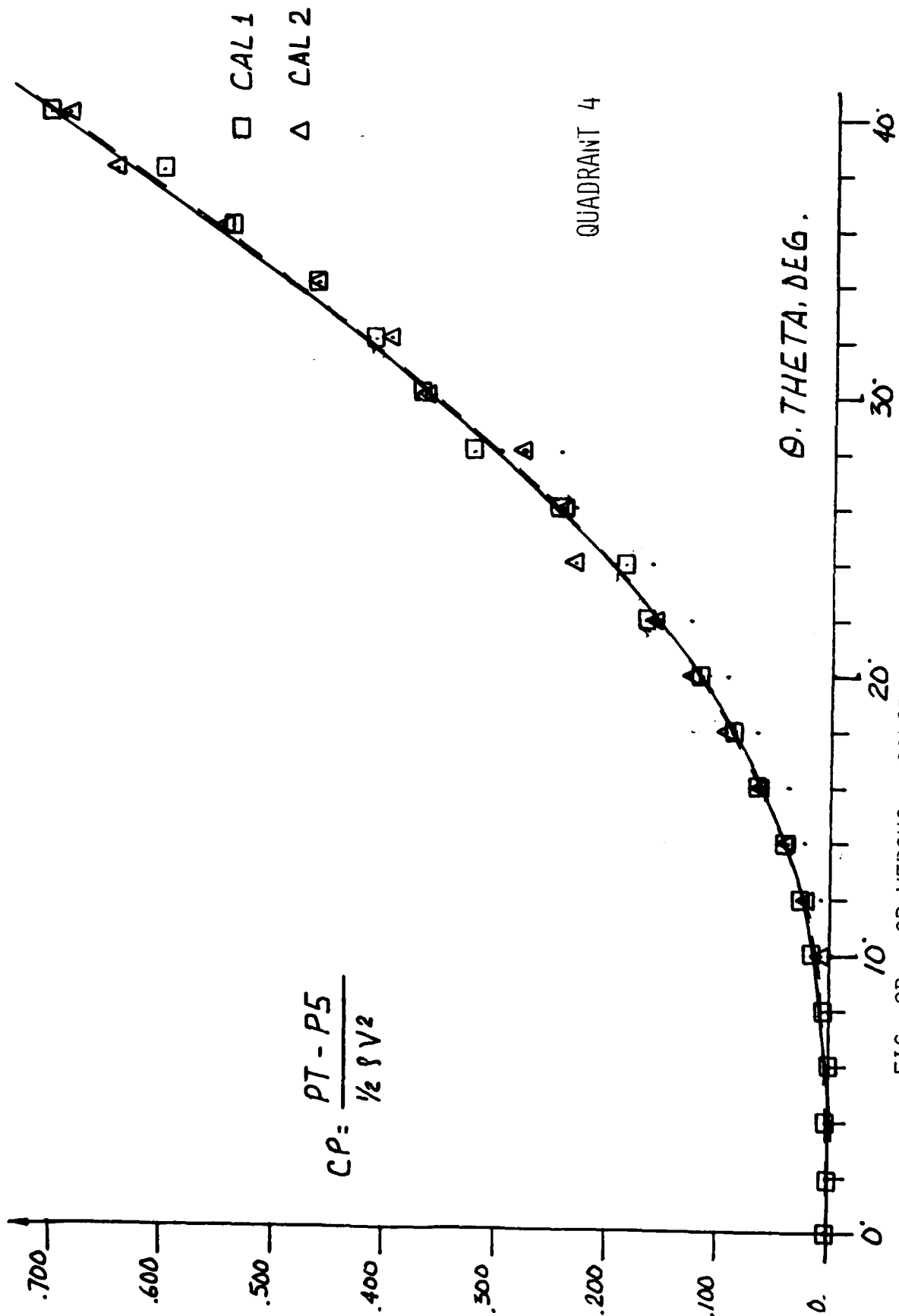
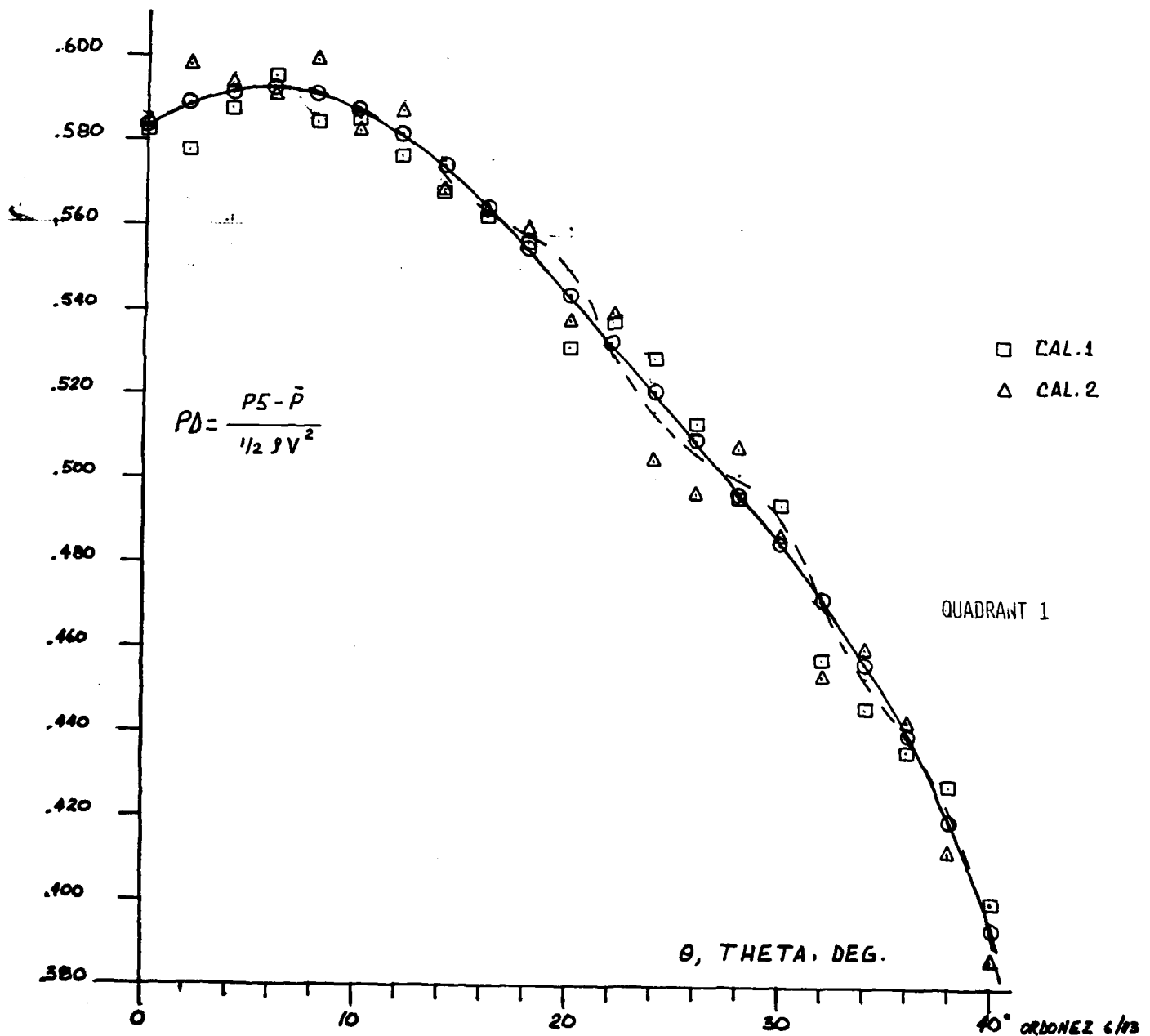


FIG. 8D - CP VERSUS θ CALIBRATION CURVES FOR FIVE HOLE PROBE

FIG. 9A - PD VERSUS θ CALIBRATION CURVES FOR FIVE HOLE PROBE



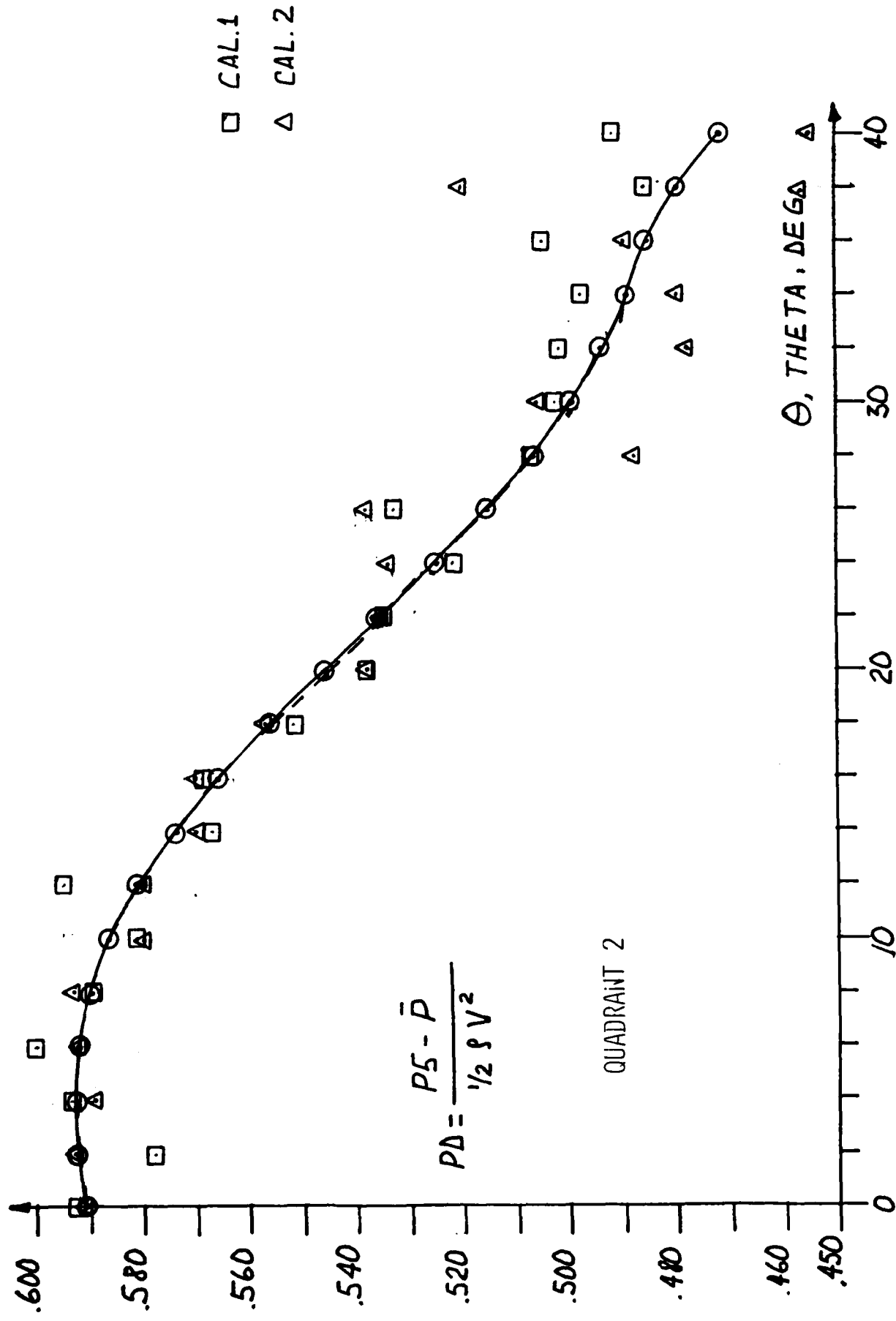


FIG. 9B - PD VERSUS θ CALIBRATION CURVES FOR FIVE HOLE PROBE

FIG. 9C - PD VERSUS θ CALIBRATION CURVE FOR FIVE HOLE PROBE

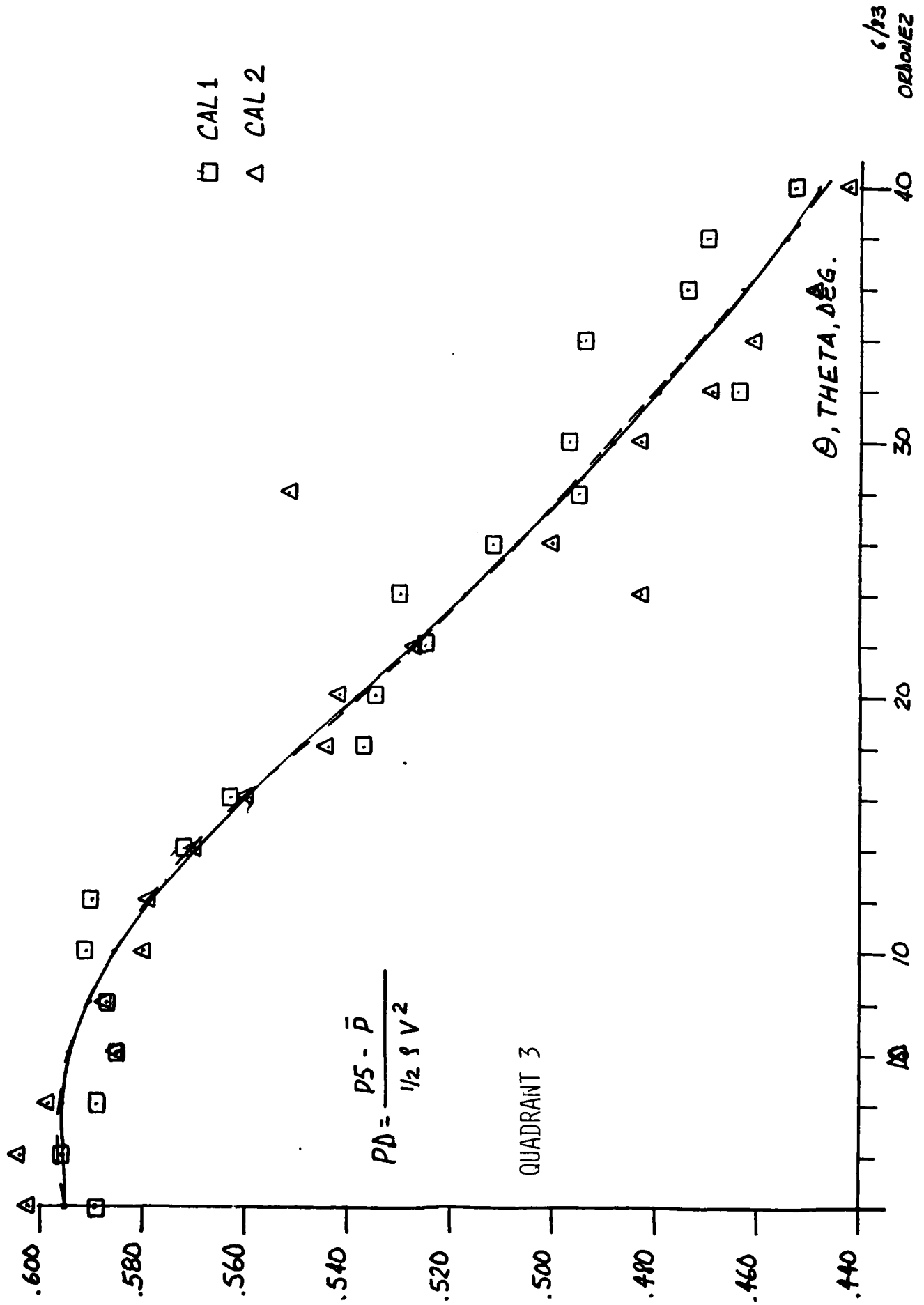


FIG. 9D - PD VERSUS θ CALIBRATION CURVES FOR FIVE HOLE PROBE

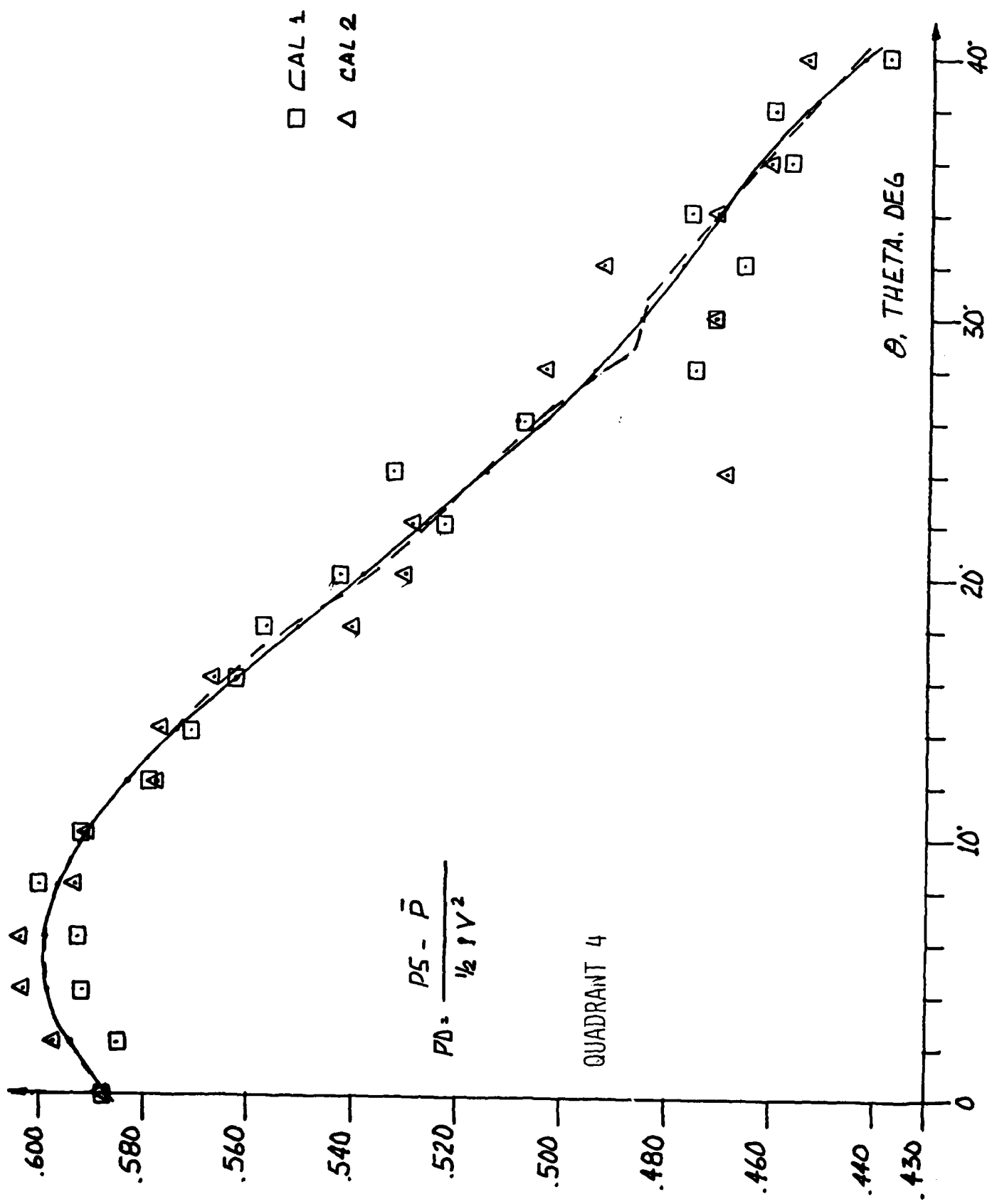
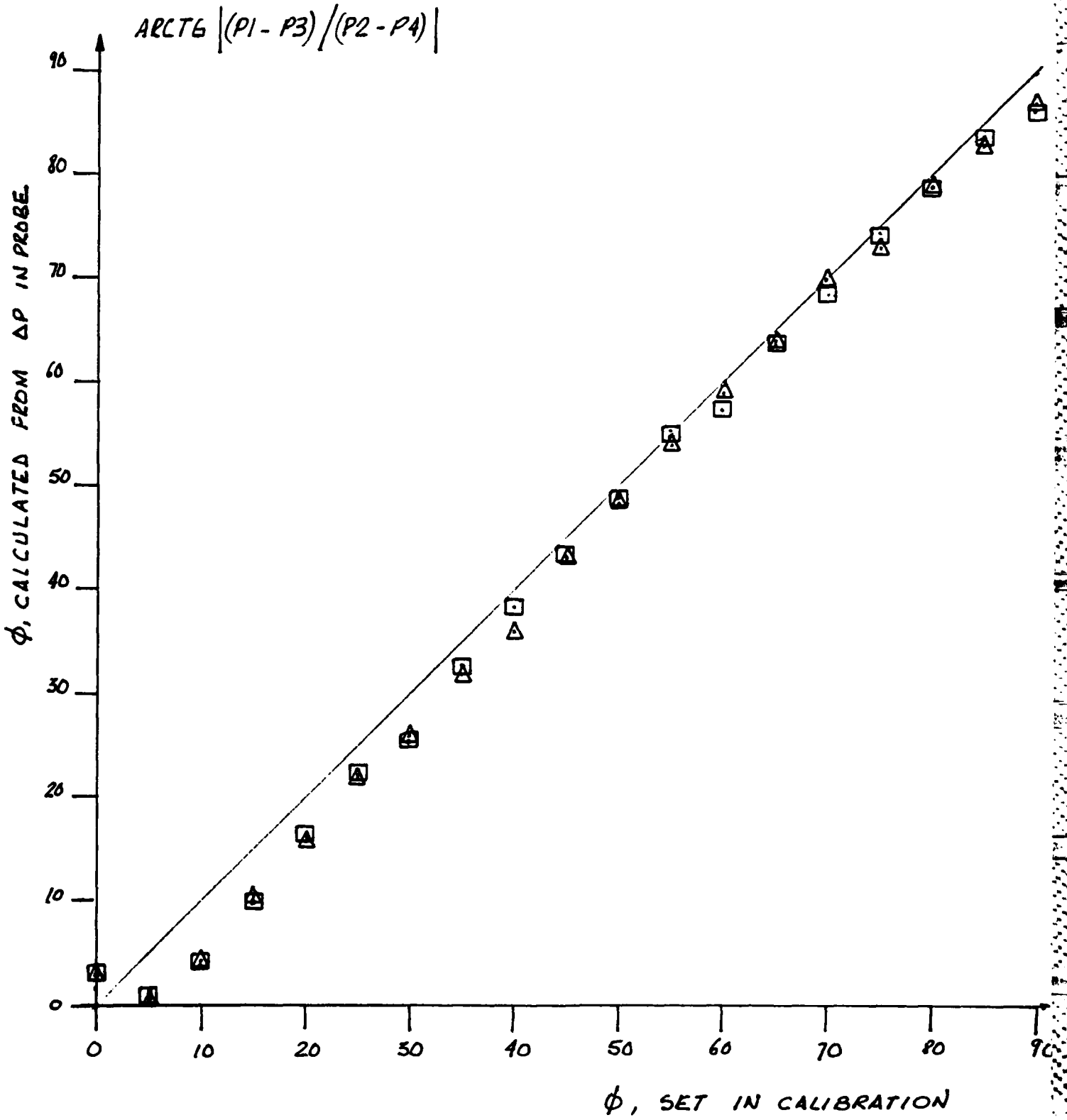


FIG. 10 - CALCULATED ROLL ANGLE VERSUS MEASURED ROLL ANGLE
USING FIVE HOLE PROBE



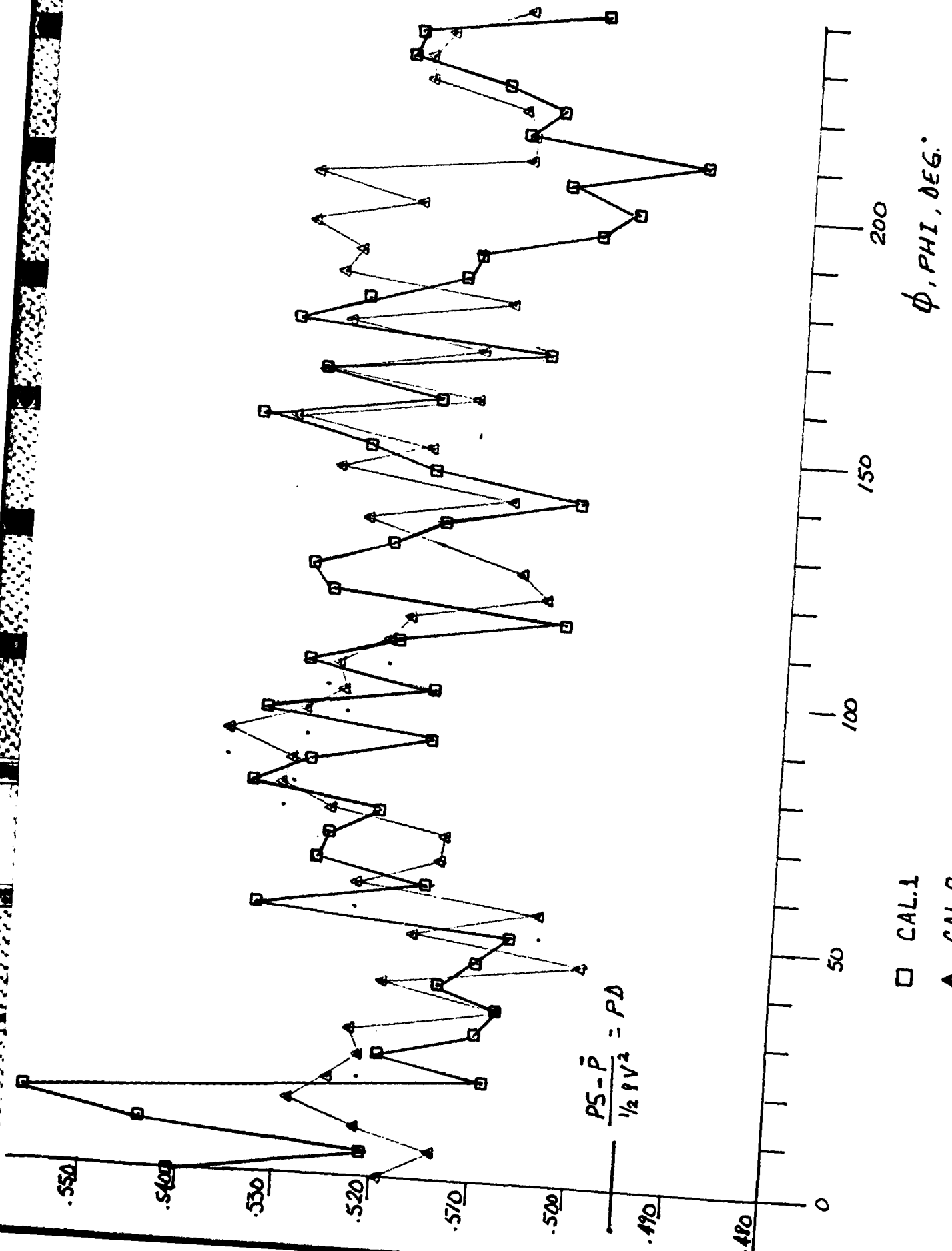


FIG. 11 - PD VERSIJS & CURVE FOR IJSDN FIVE HOIF PROBE

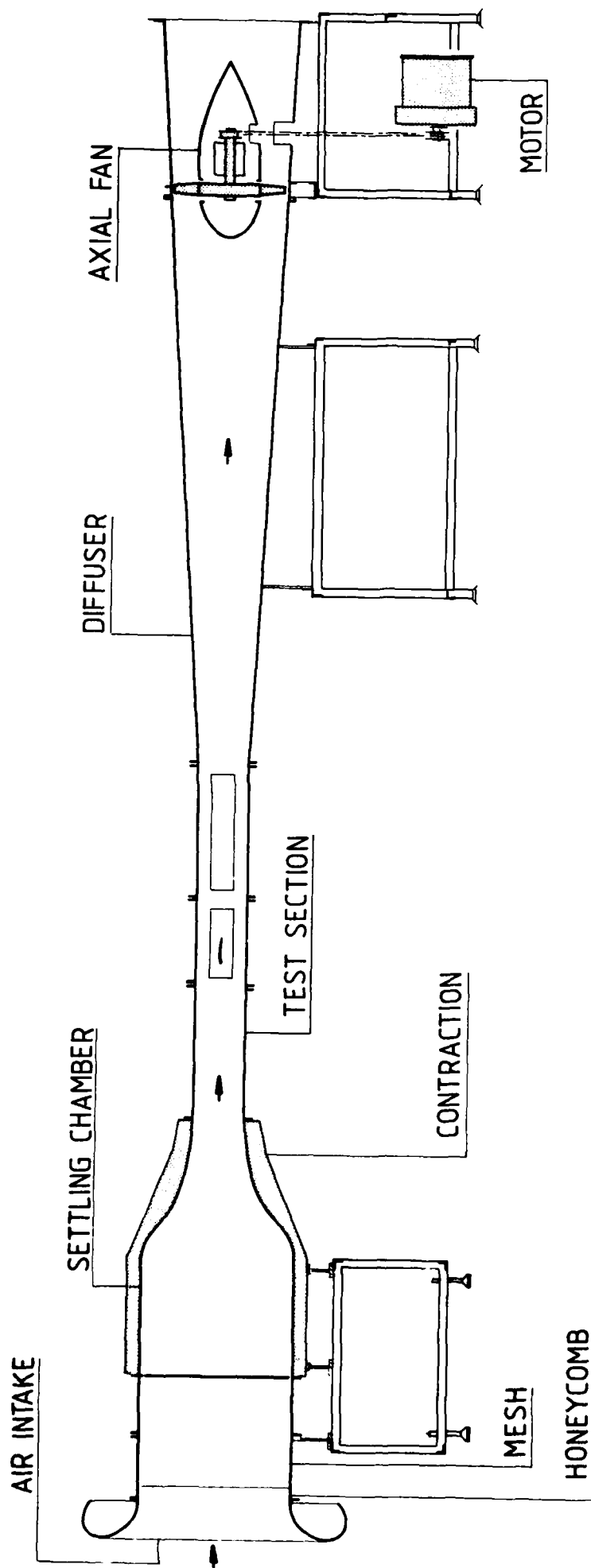


FIG. 12 - LOW SPEED WIND TUNNEL L-2A

VKI LOW SPEED TUNNEL L2A

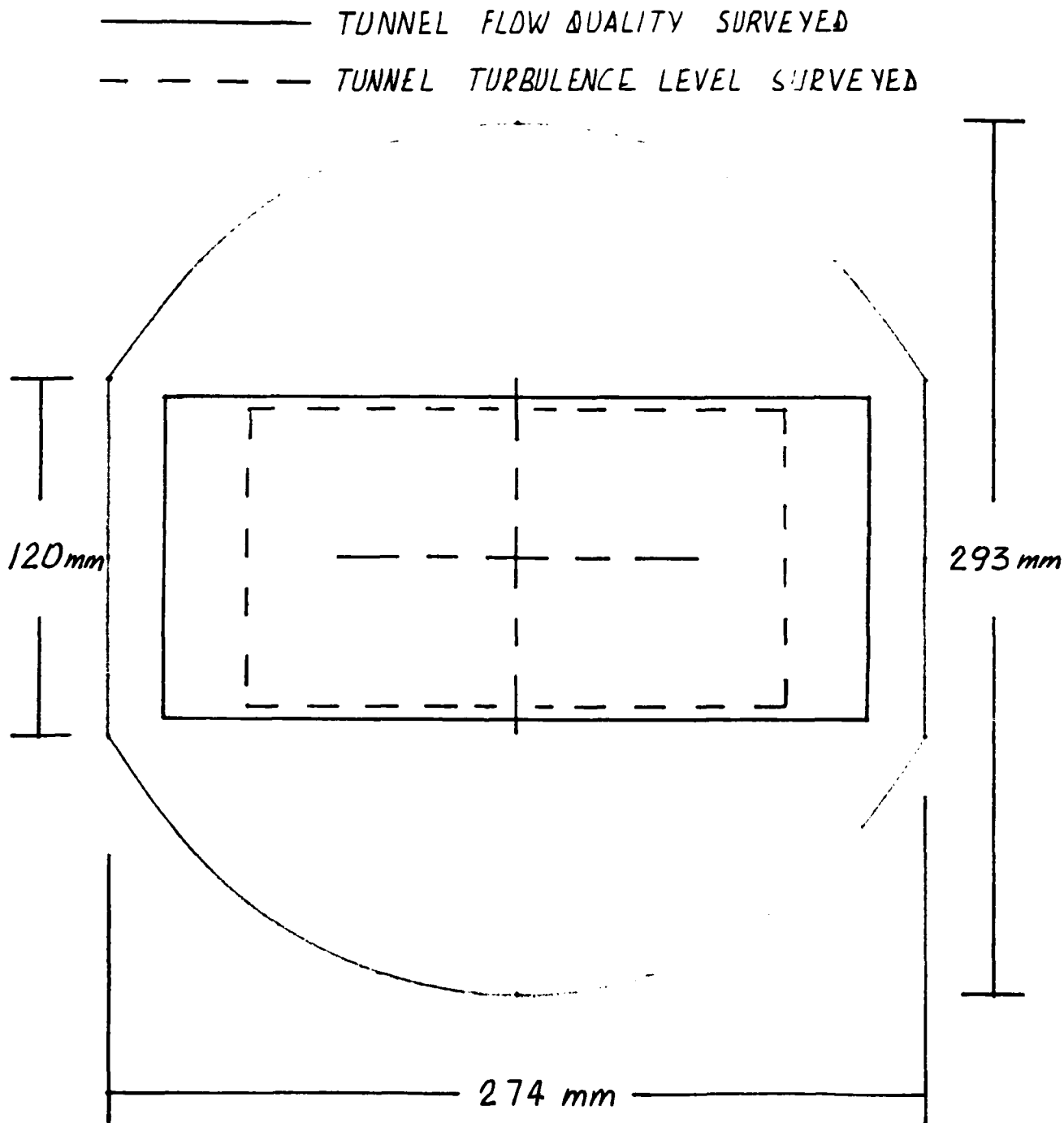
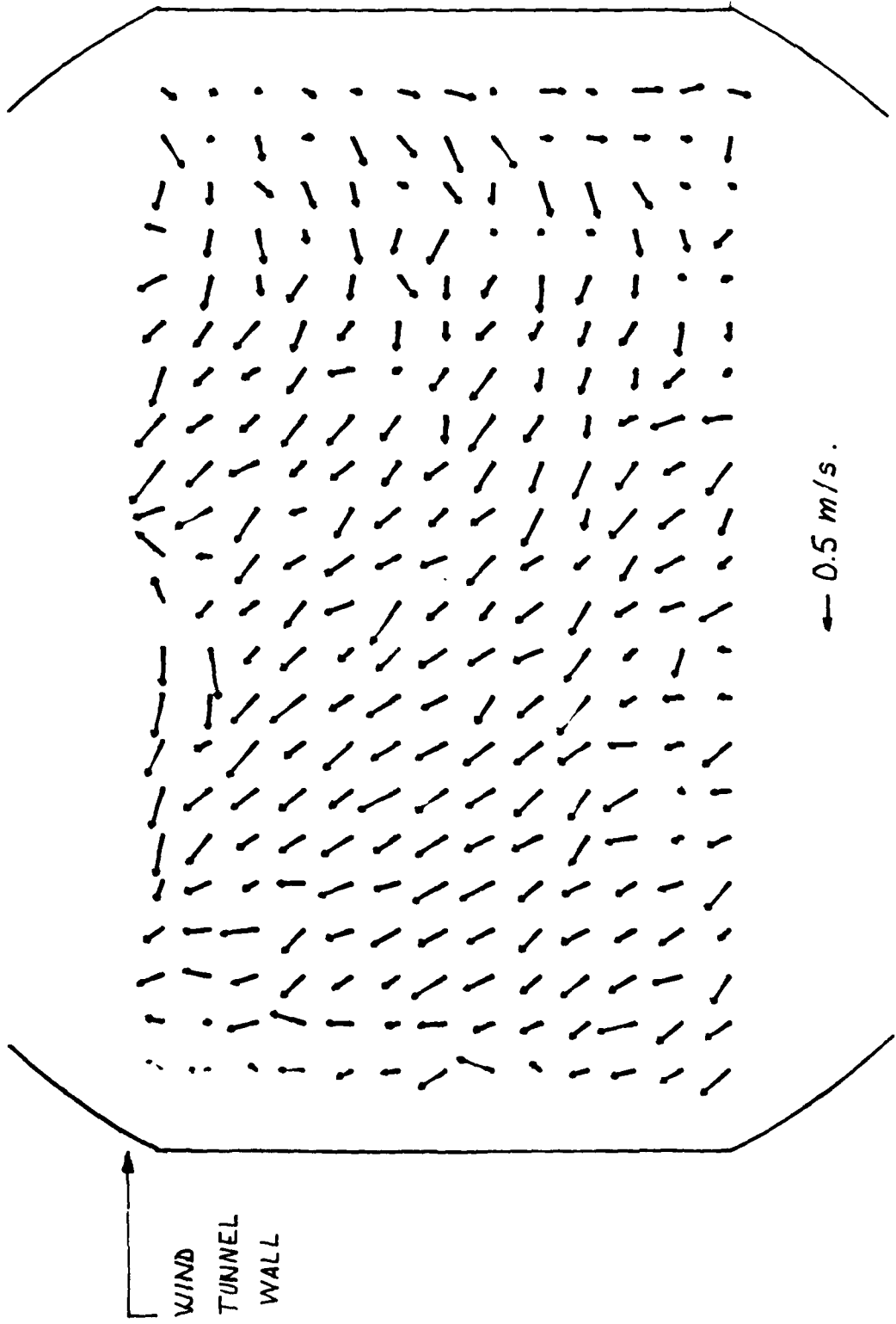


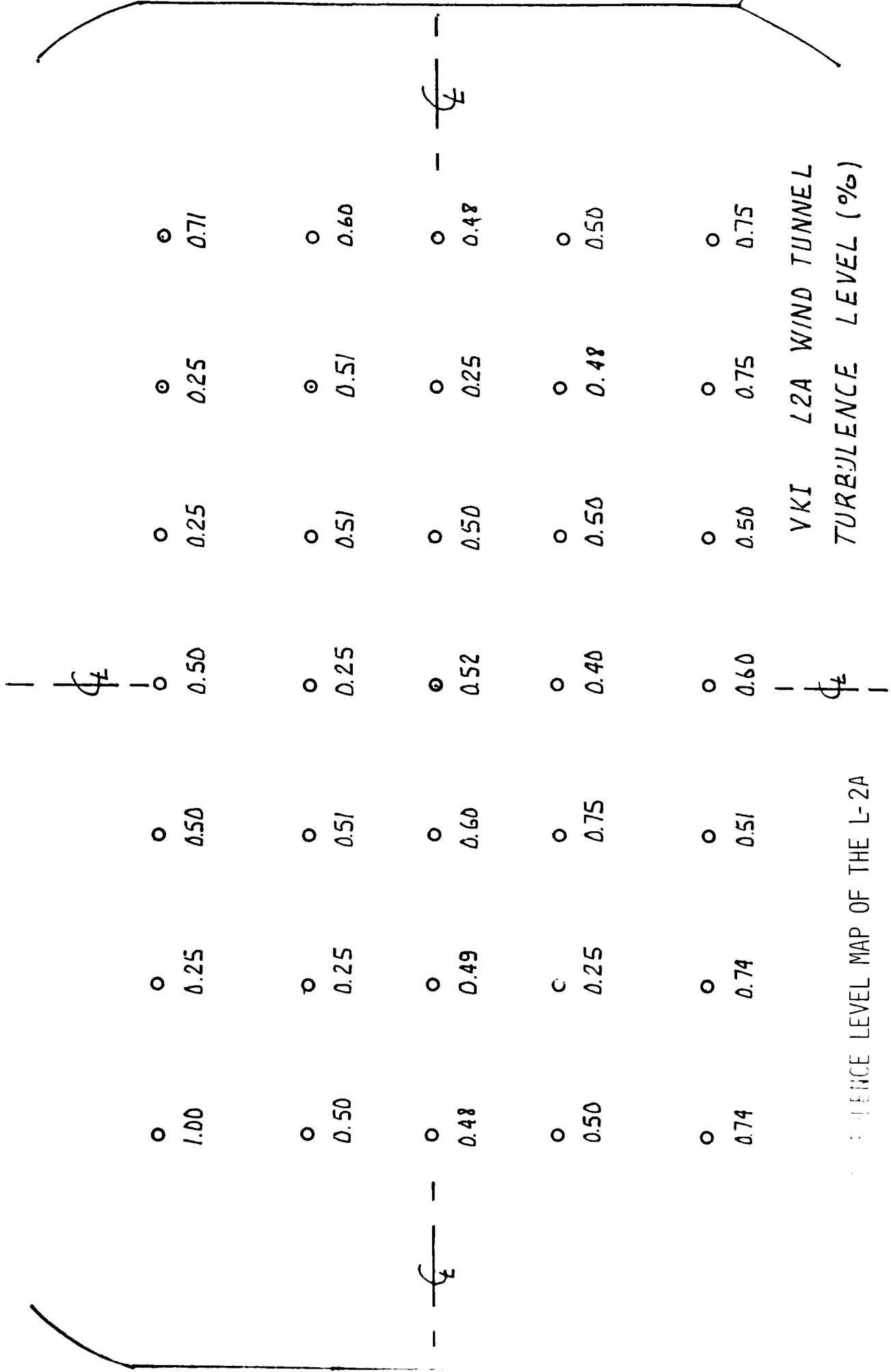
FIG. 13 - CROSS SECTION VIEW OF L-2A TUNNEL WITH MEASUREMENT REGIONS

$U_{\infty} = 29.8 \text{ m/s}$



← 0.5 m/s.

FIG. 14 - FLOW FIELD EXISTING AT A CLEAN TEST SECTION
STATION OF THE L-2A



TURBULENCE LEVEL MAP OF THE L-2A

VKI L2A WIND TUNNEL
TURBULENCE LEVEL (%)

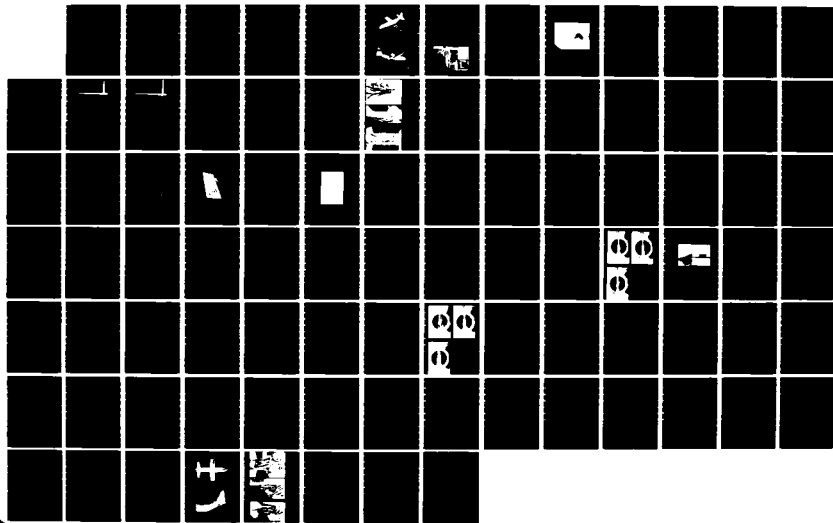
AD-A139 989

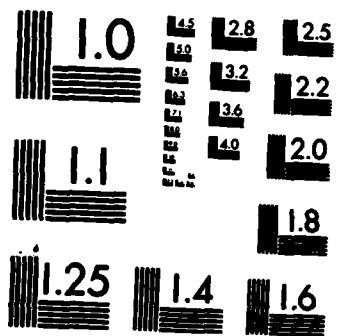
THE EFFECT OF STRAKES ON VORTICAL FLOWS APPLIED TO
AIRCRAFT. (U) VON KARMAN INST FOR FLUID DYNAMICS
RHODE-SAINT-GENESE (BELGIUM) G G ORDONEZ 31 MAR 84
VKI-PR-1983-22 EOARD-TR-84-14 AFOSR-83-0126 F/G 20/4

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MICROCOPY RESOLUTION TEST CHART
 NATIONAL BUREAU OF STANDARDS-1963-A

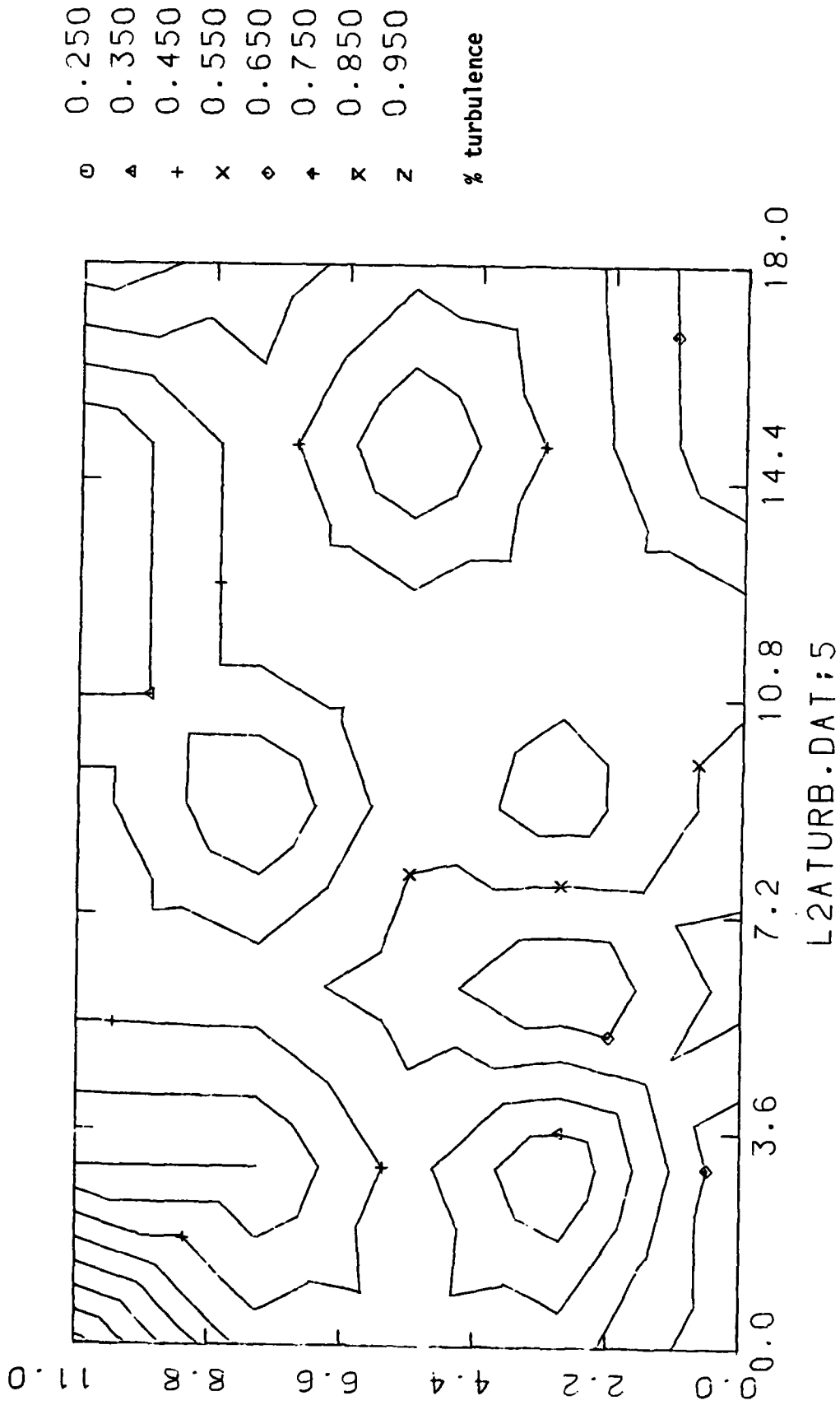


FIG. 15B - TURBULENCE LEVEL ISOLINES ALONG TEST SECTION OF L-2A TUNNEL

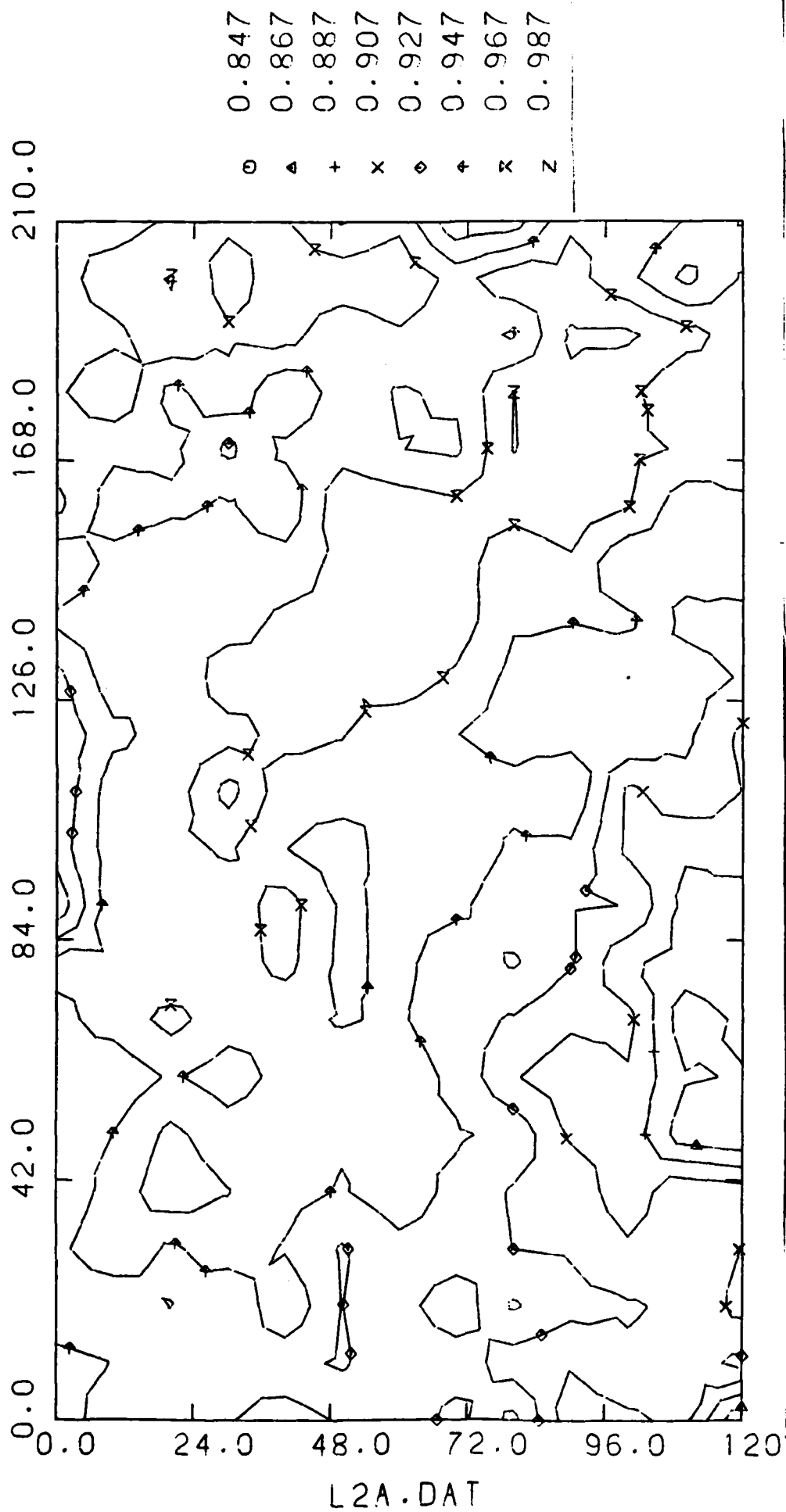


FIG. 16 - TOTAL PRESSURE / DYNAMIC PRESSURE ISOLINES ALONG TEST SECTION OF L-2A TUNNEL

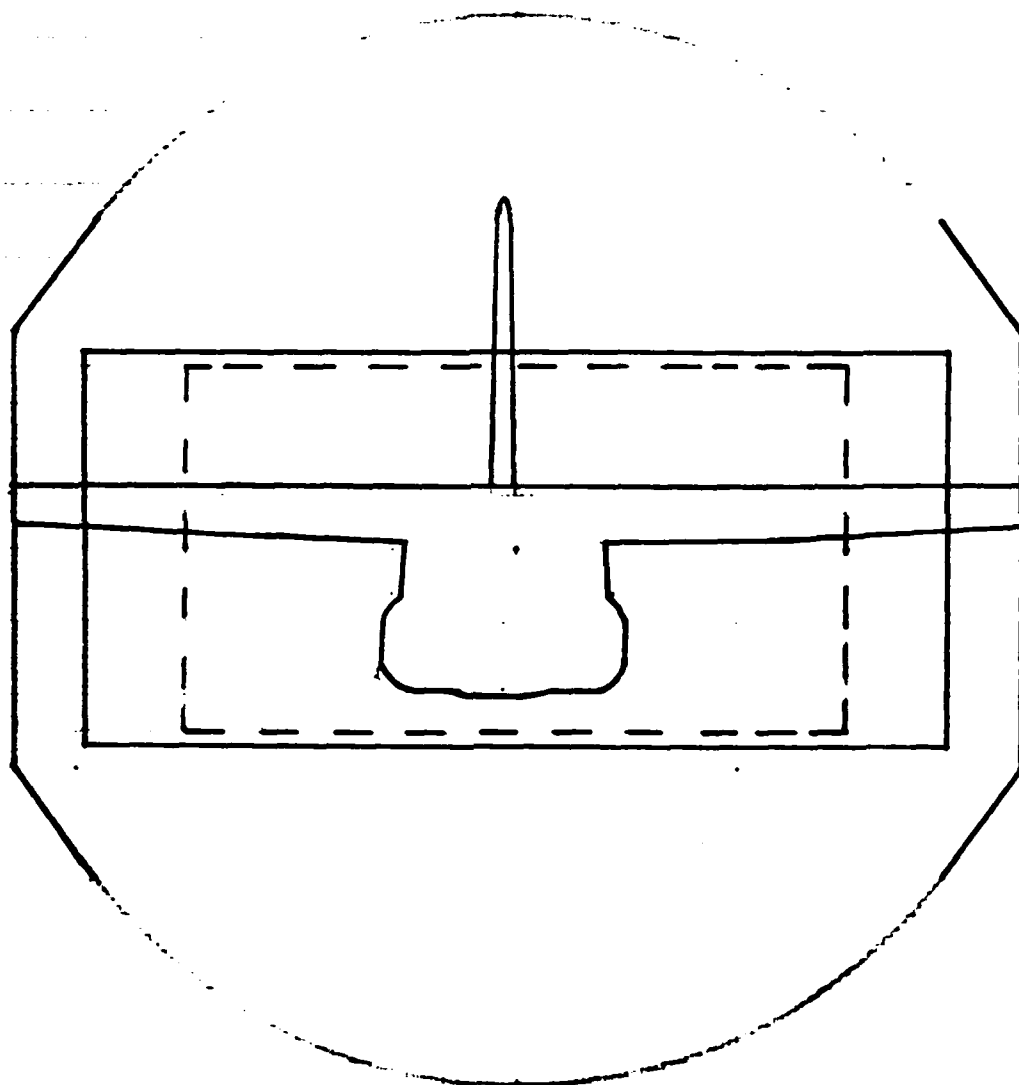


FIG. 17A - L-2A CROSS SECTION WITH G-130 AND MEASUREMENT REGIONS

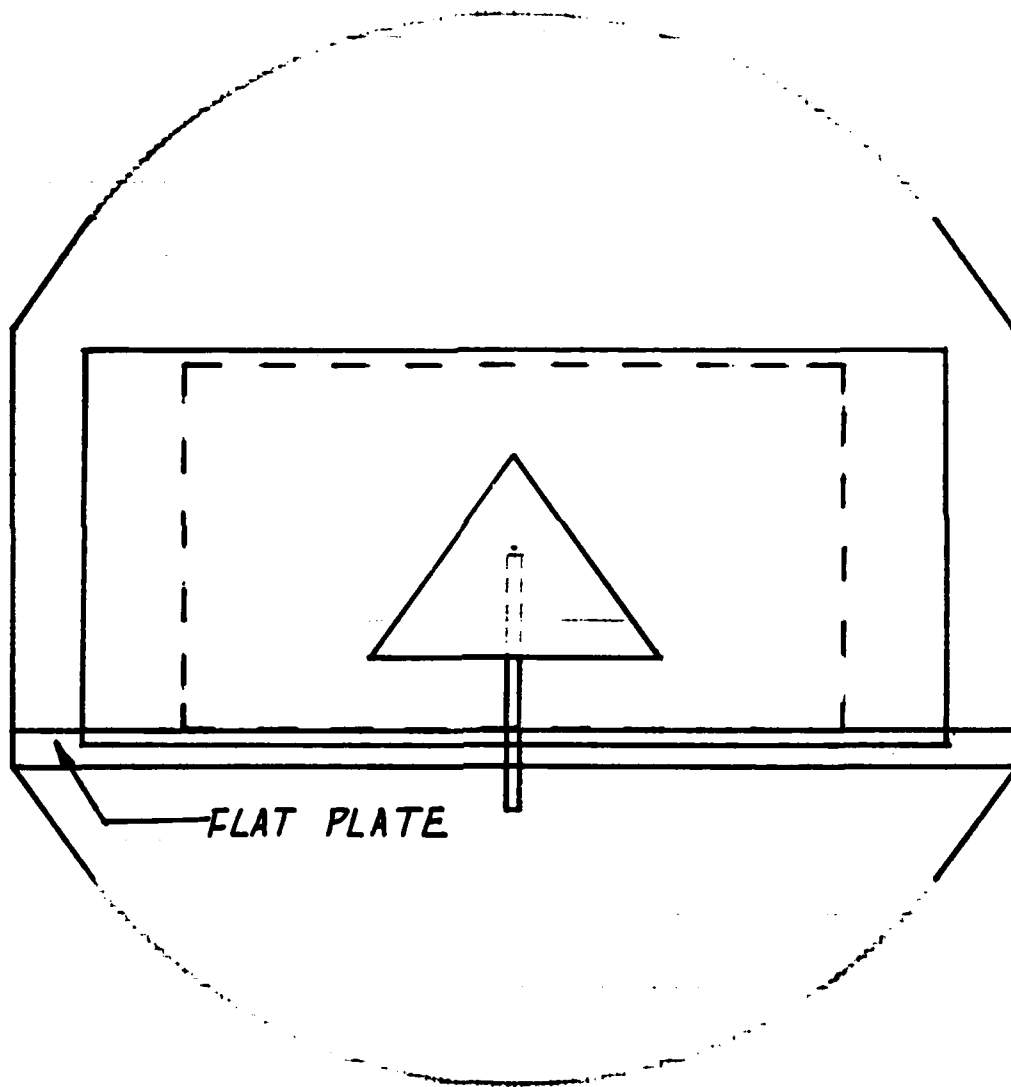


FIG. 17B - L-2A CROSS SECTION WITH DELTA WING
AND MEASUREMENT REGIONS



FIG. 18A - GENERAL VIEW OF 1/72 SCALE MODEL OF THE LOCKHEED HERCULES C-130 AIRCRAFT USED

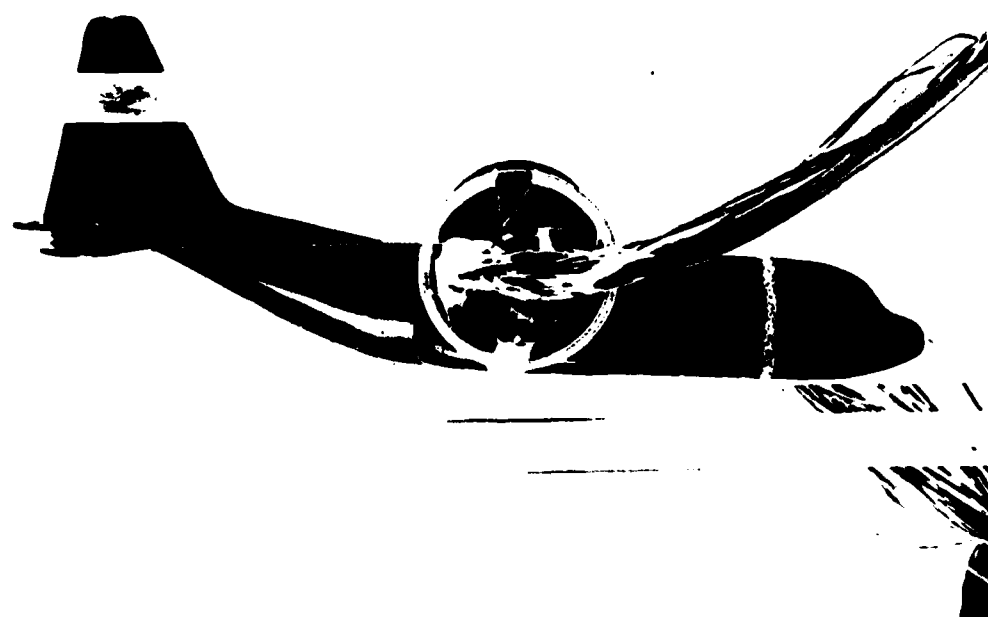


FIG. 18B - SIDE VIEW AND CONNECTING PRESSURE MEASUREMENT TUBES IN THE C-130 AIRCRAFT

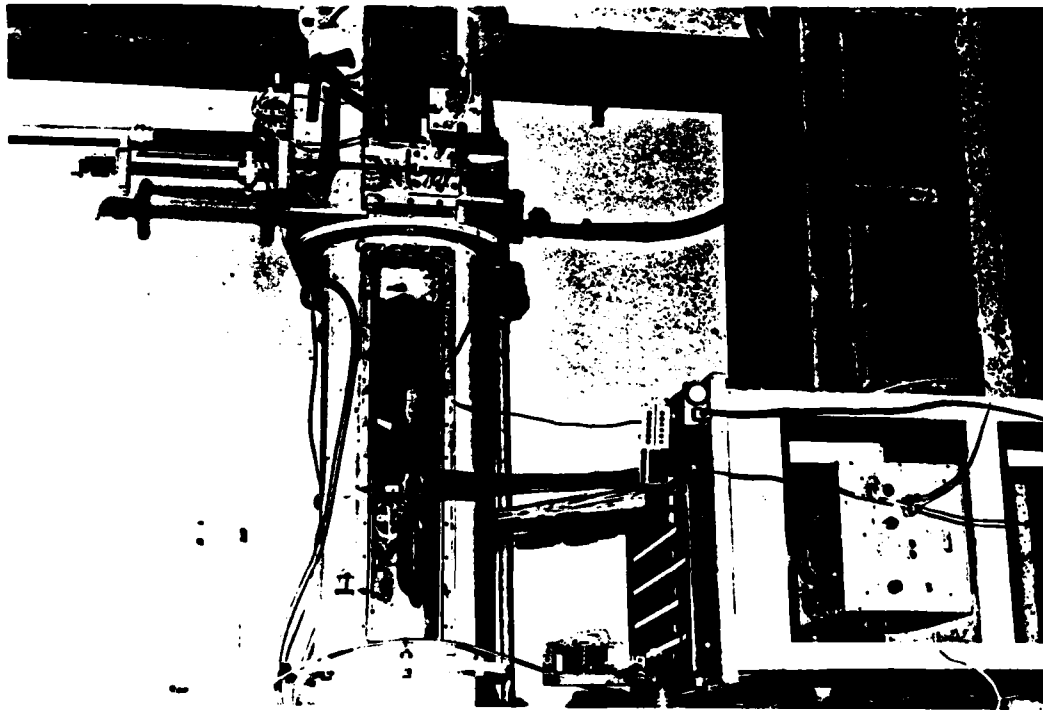


FIG. 19A - WIND TUNNEL TEST SECTION AND MEASUREMENT INSTRUMENTATION

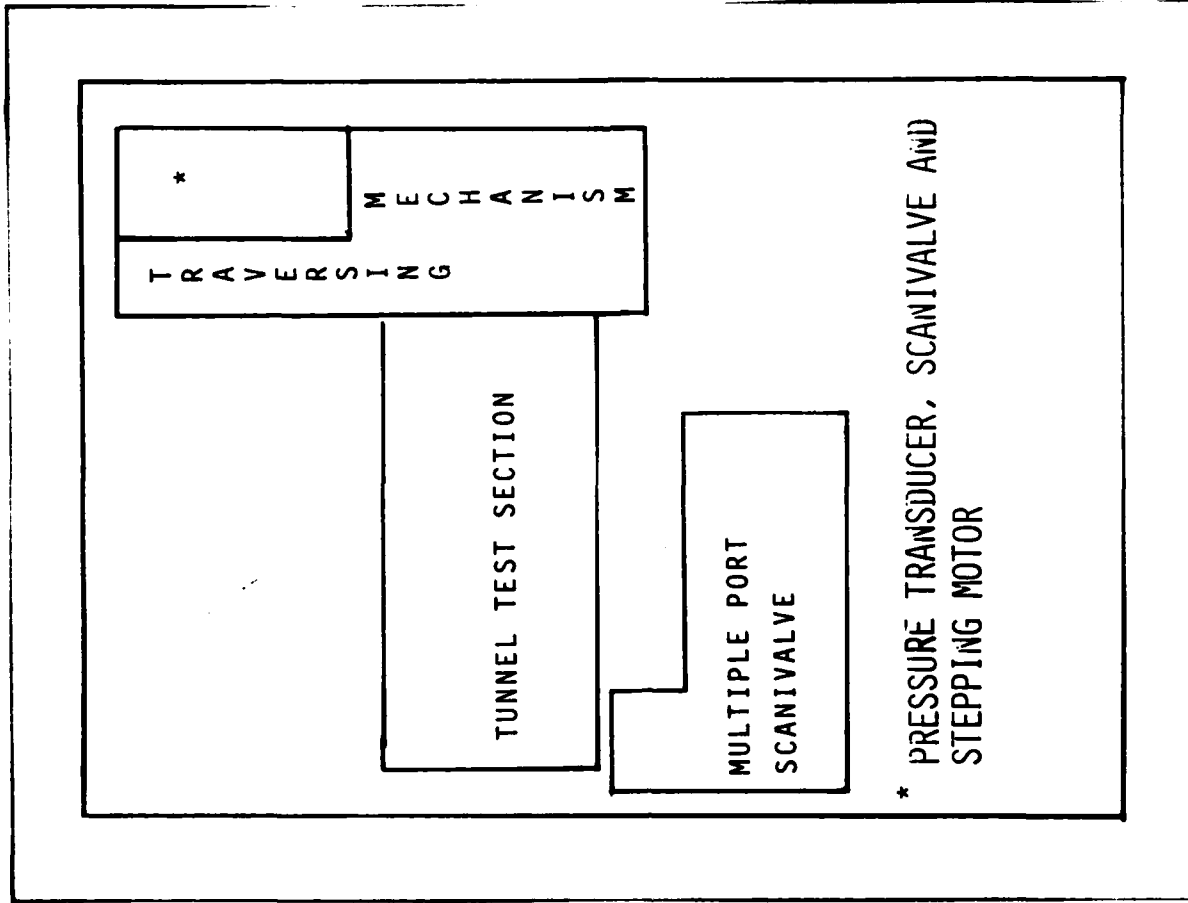


FIG. 19B - DESCRIPTION OF EQUIPMENT

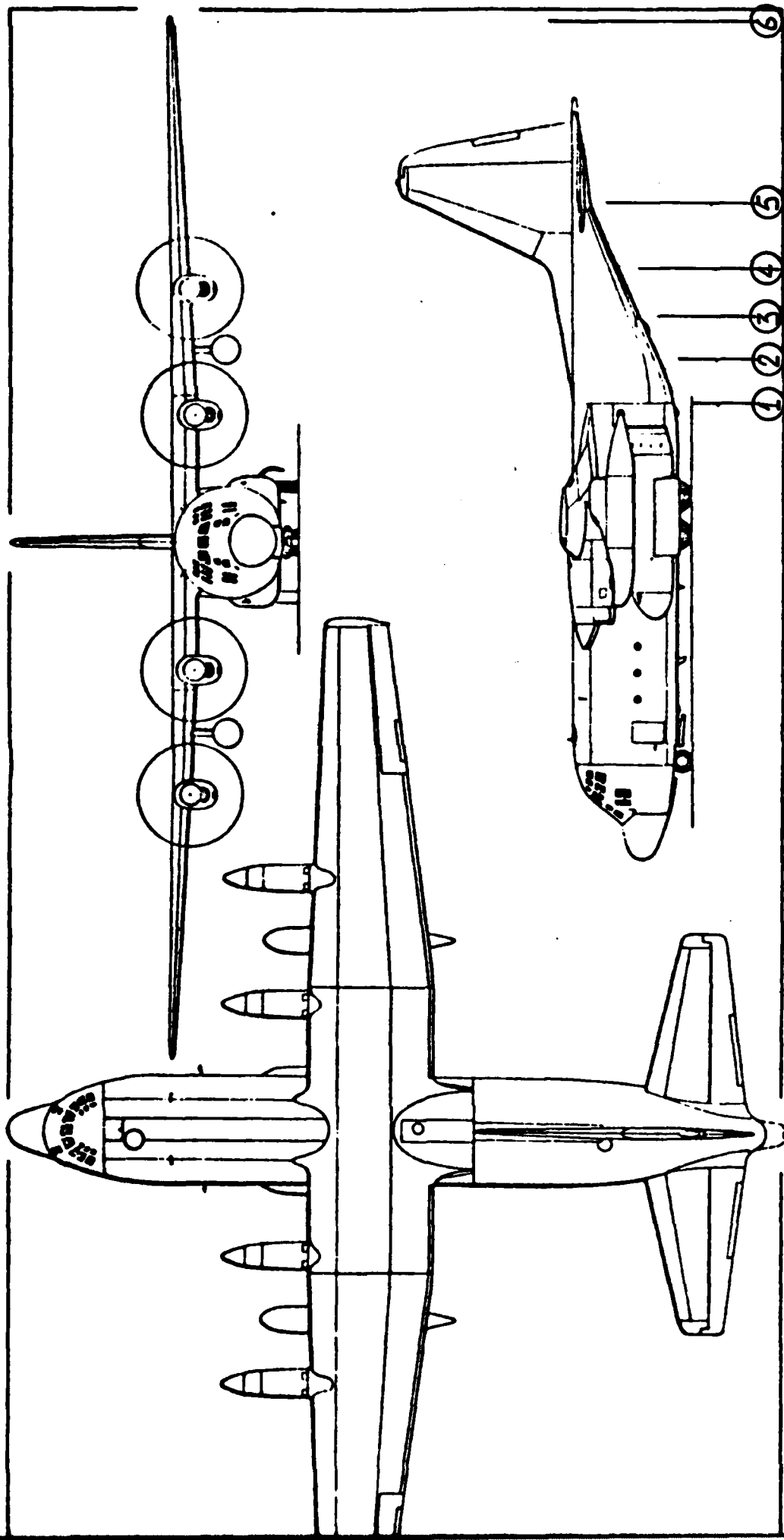


FIG. 20 - THREE VIEW DRAWING OF HERCULES G-130 AIRCRAFT AND FUSELAGE STATIONS WHERE PRESSURES AND FLOW FIELD MEASUREMENTS WERE TAKEN

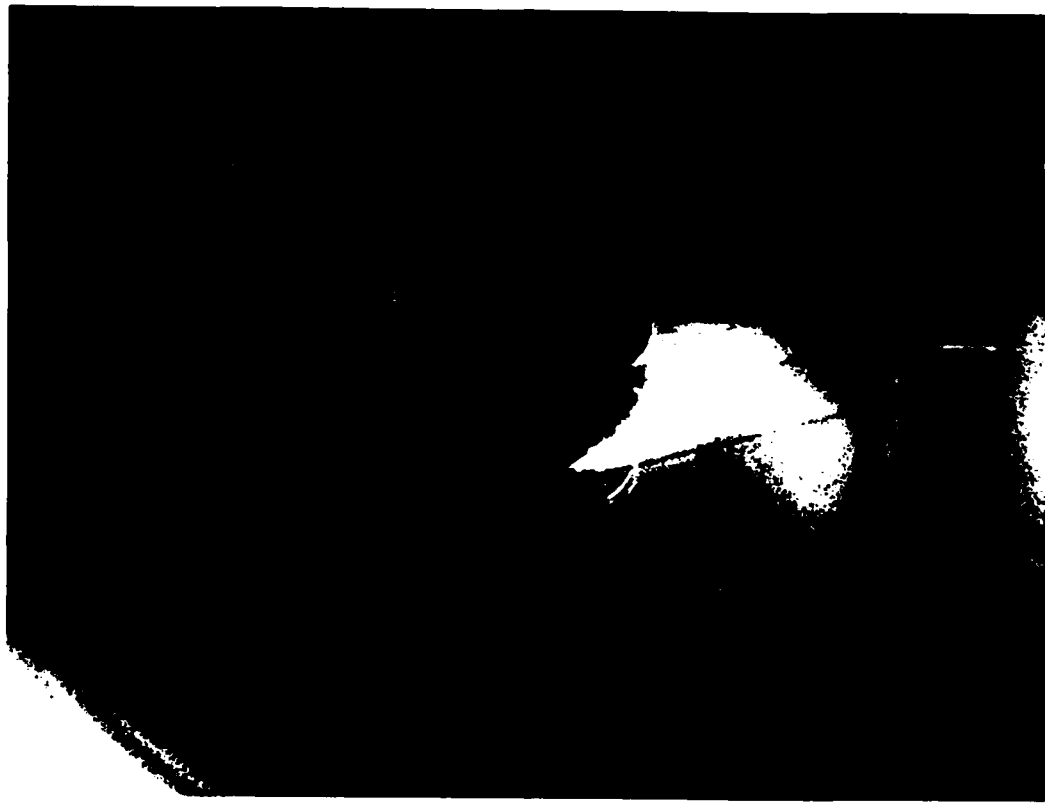


FIG. 21 - SMOKE FLOW VISUALIZATION ALONG FUSELAGE STATION 3
OF THE BOATTAIL OF C-130

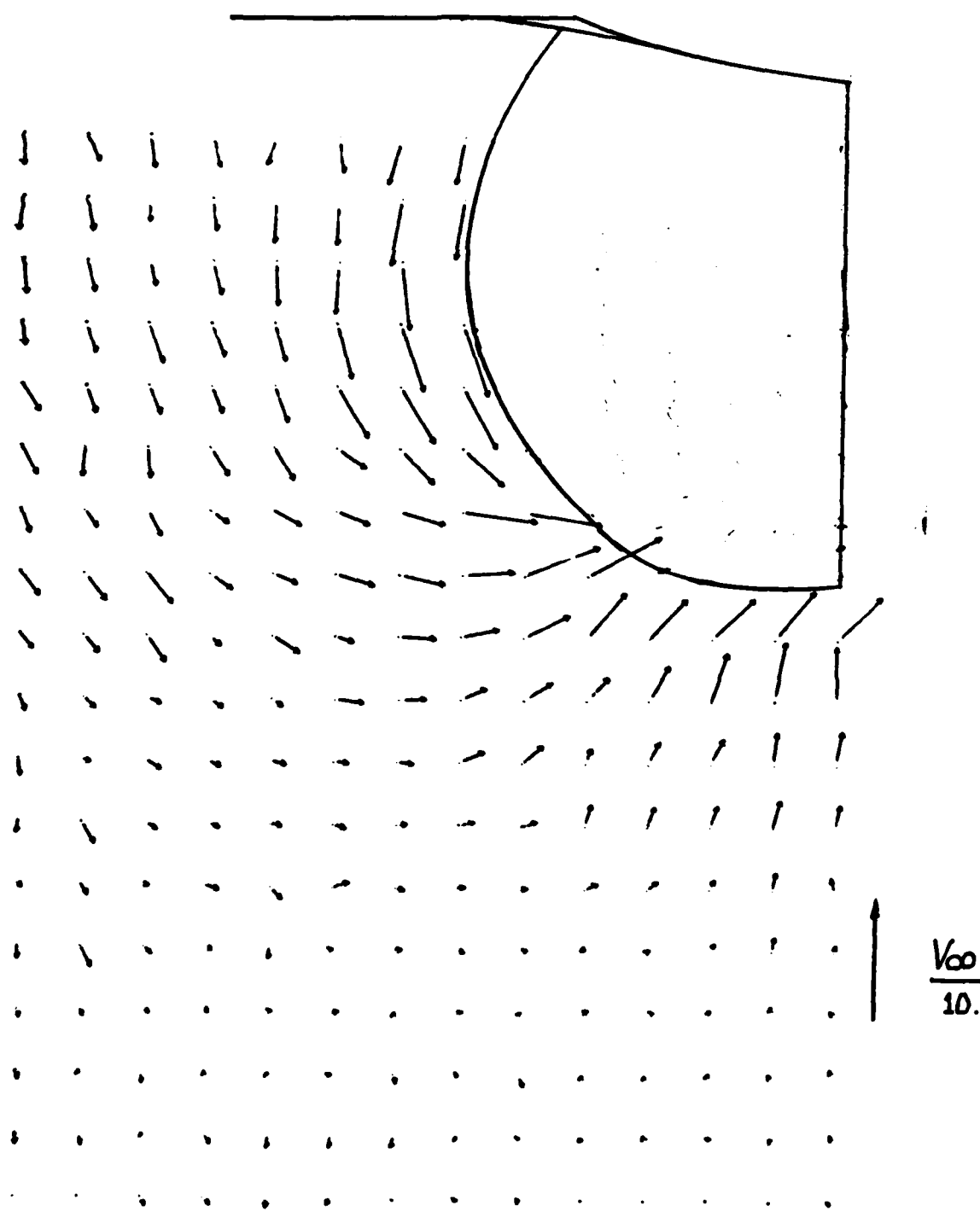


FIG. 22 - FLOW FIELD MAP OF FUSELAGE STATION 1 ALONG BOATTAIL OF C-130

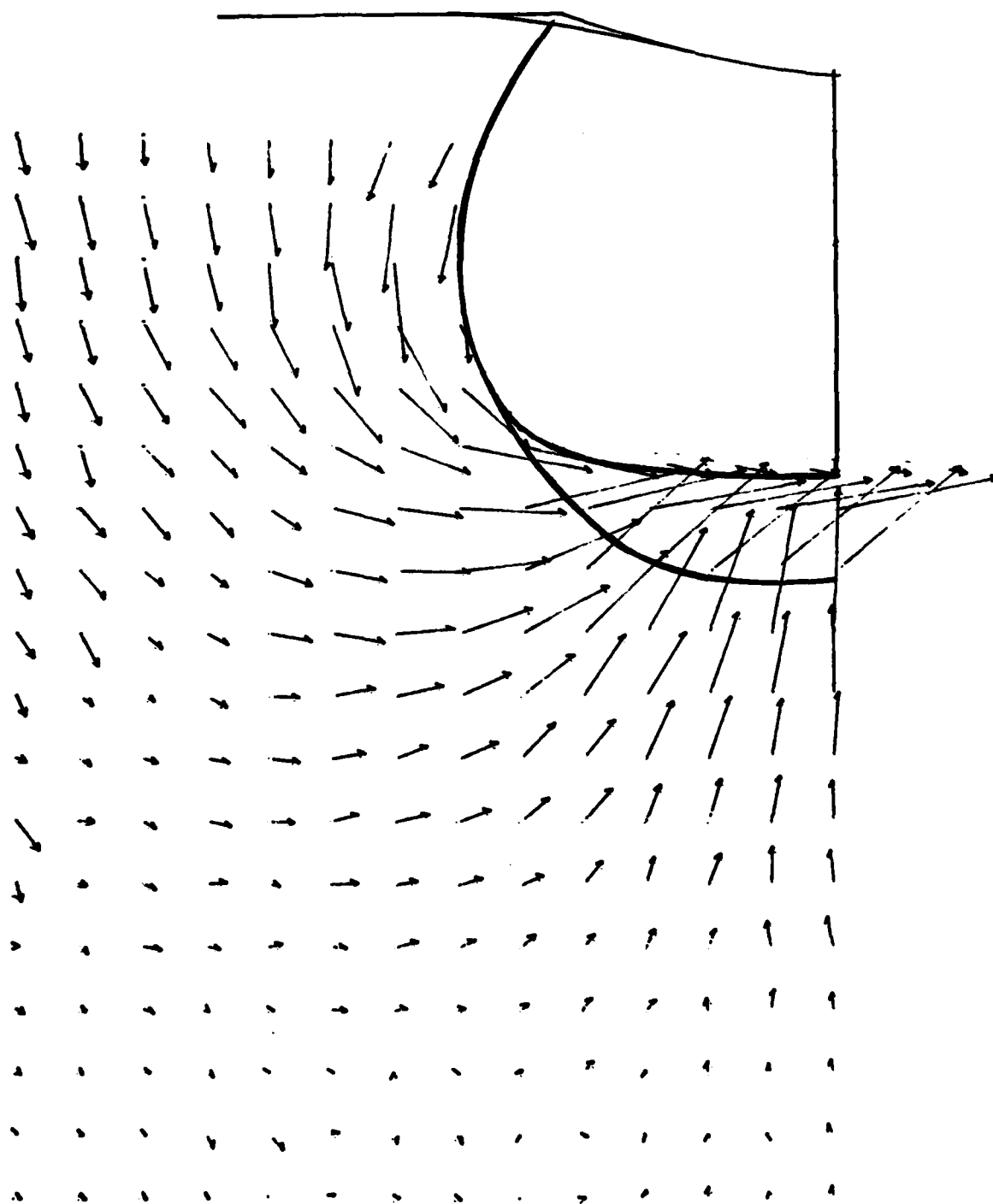


FIG. 23 - FLOW FIELD MAP OF FUSELAGE STATION 2 ALONG
BOATTAIL OF C-130

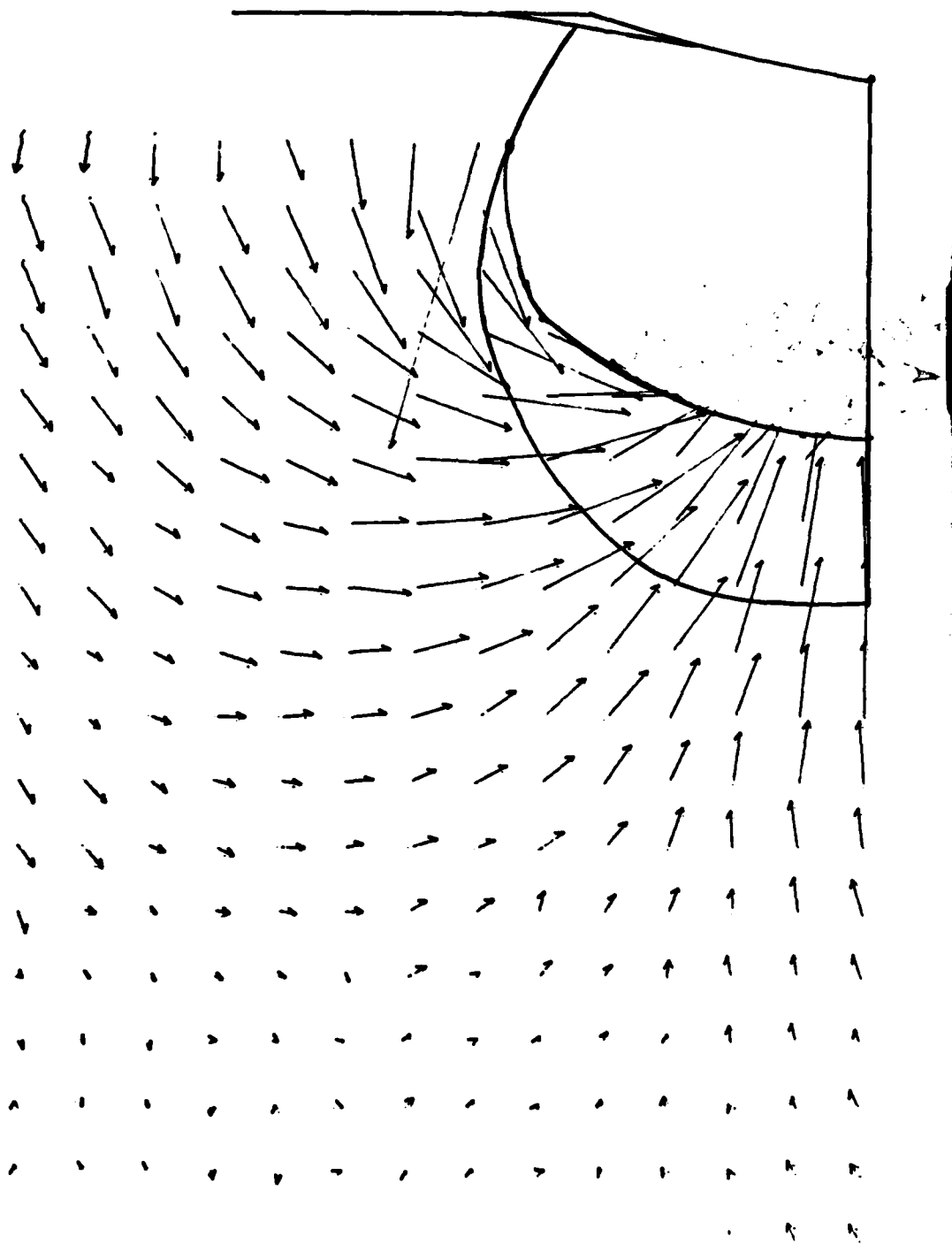


FIG. 24 - FLOW FIELD MAP OF FUSELAGE STATION 3 ALONG
BOATTAIL OF C-130

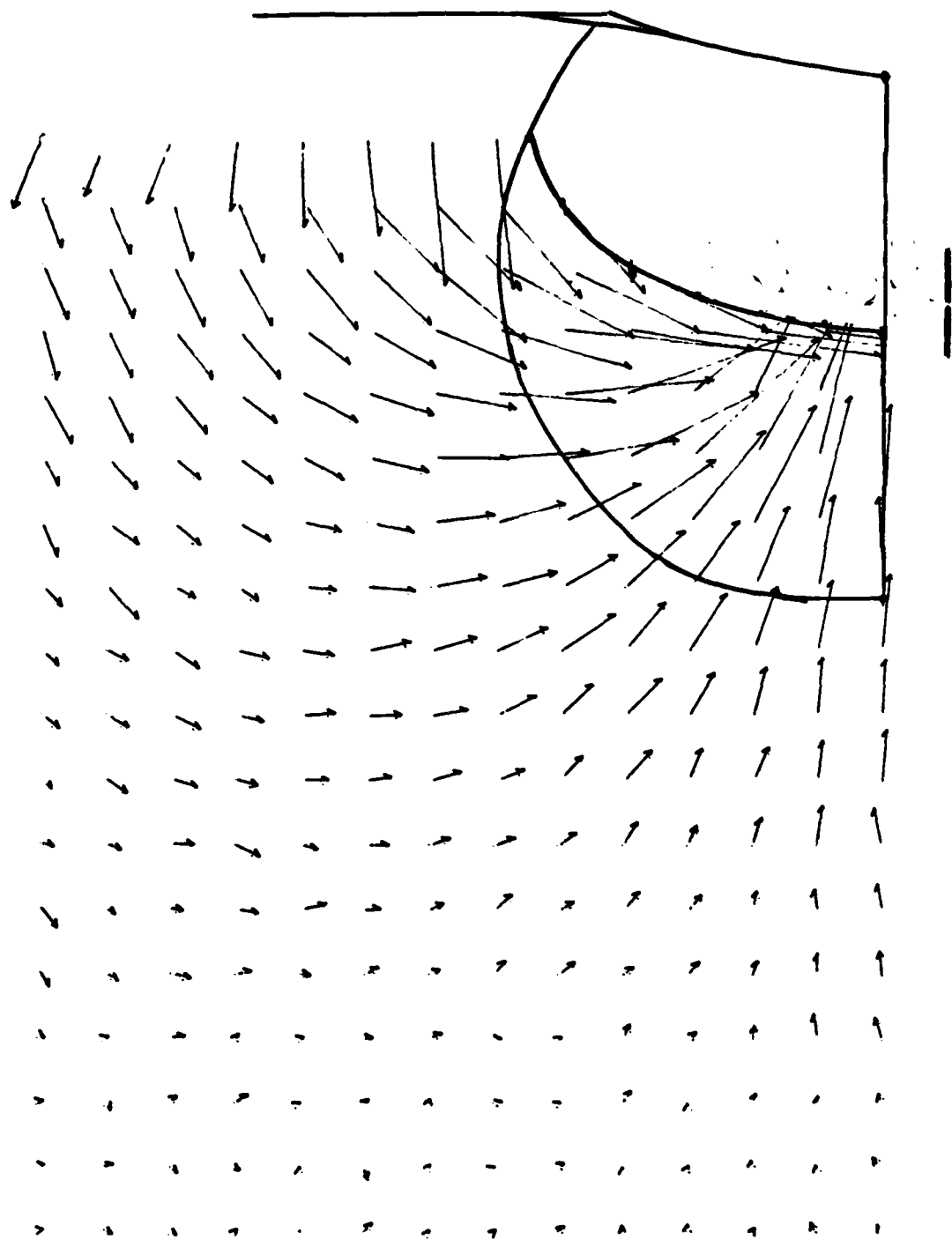


FIG. 25 - FLOW FIELD MAP OF FUSELAGE STATION 4 ALONG
BOATTAIL OF C-130

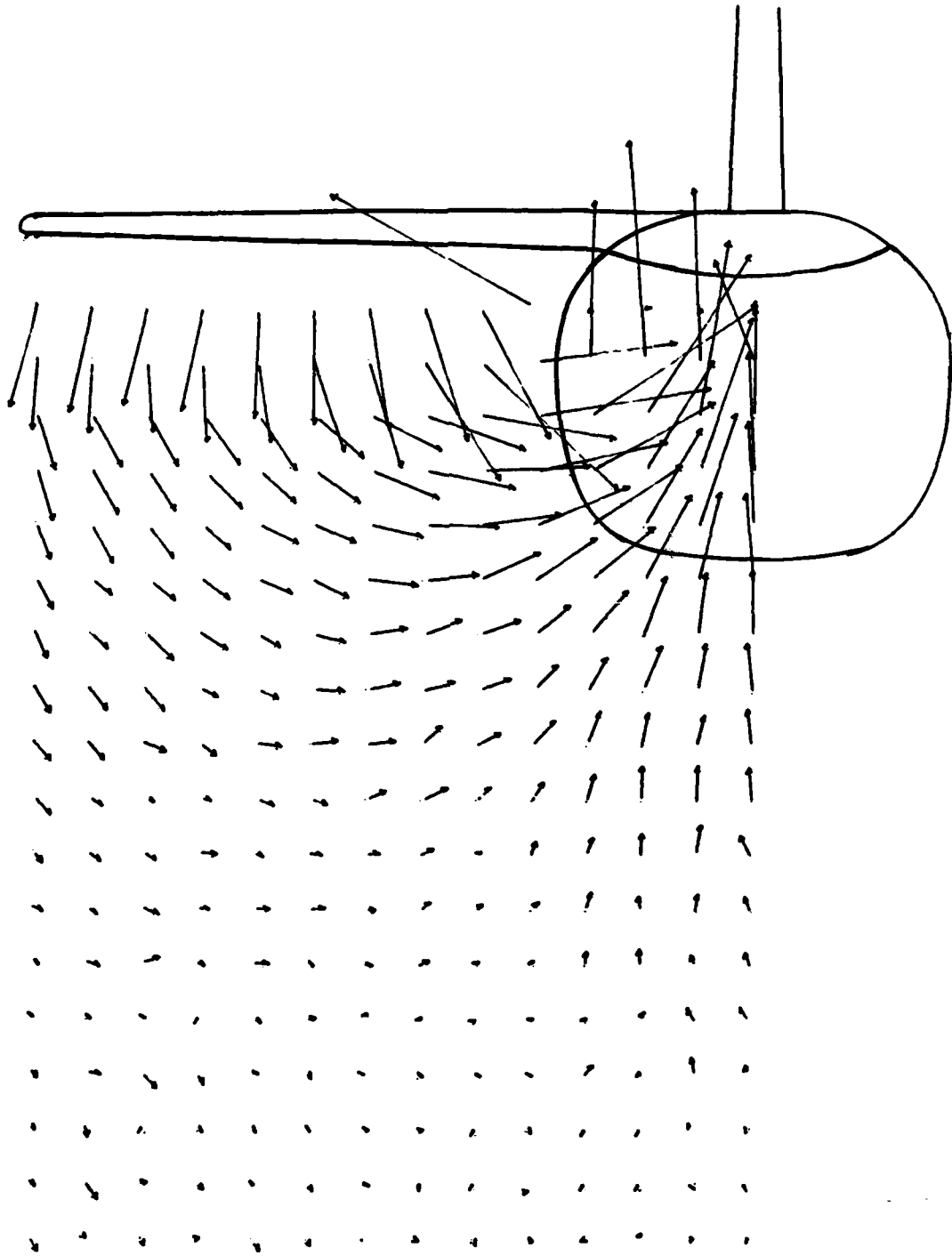
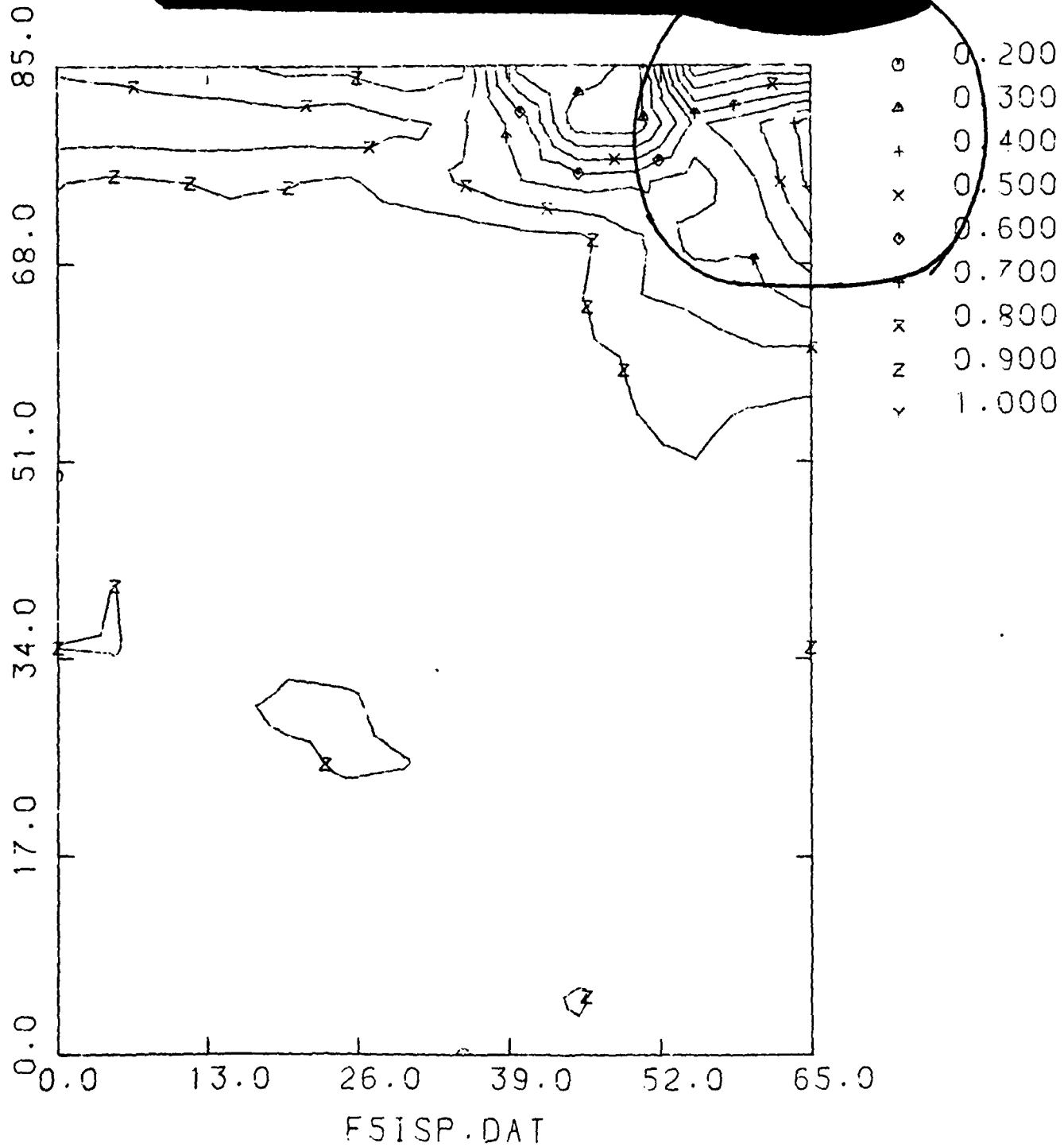


FIG. 26A - FLOW FIELD MAP OF FUSELAGE STATION 5 ALONG
BOATTAIL OF C-130



FIB. 26B - ISOLINES OF TOTAL PRESSURE/DYNAMIC PRESSURE
 ON FUSELAGE STATION 5

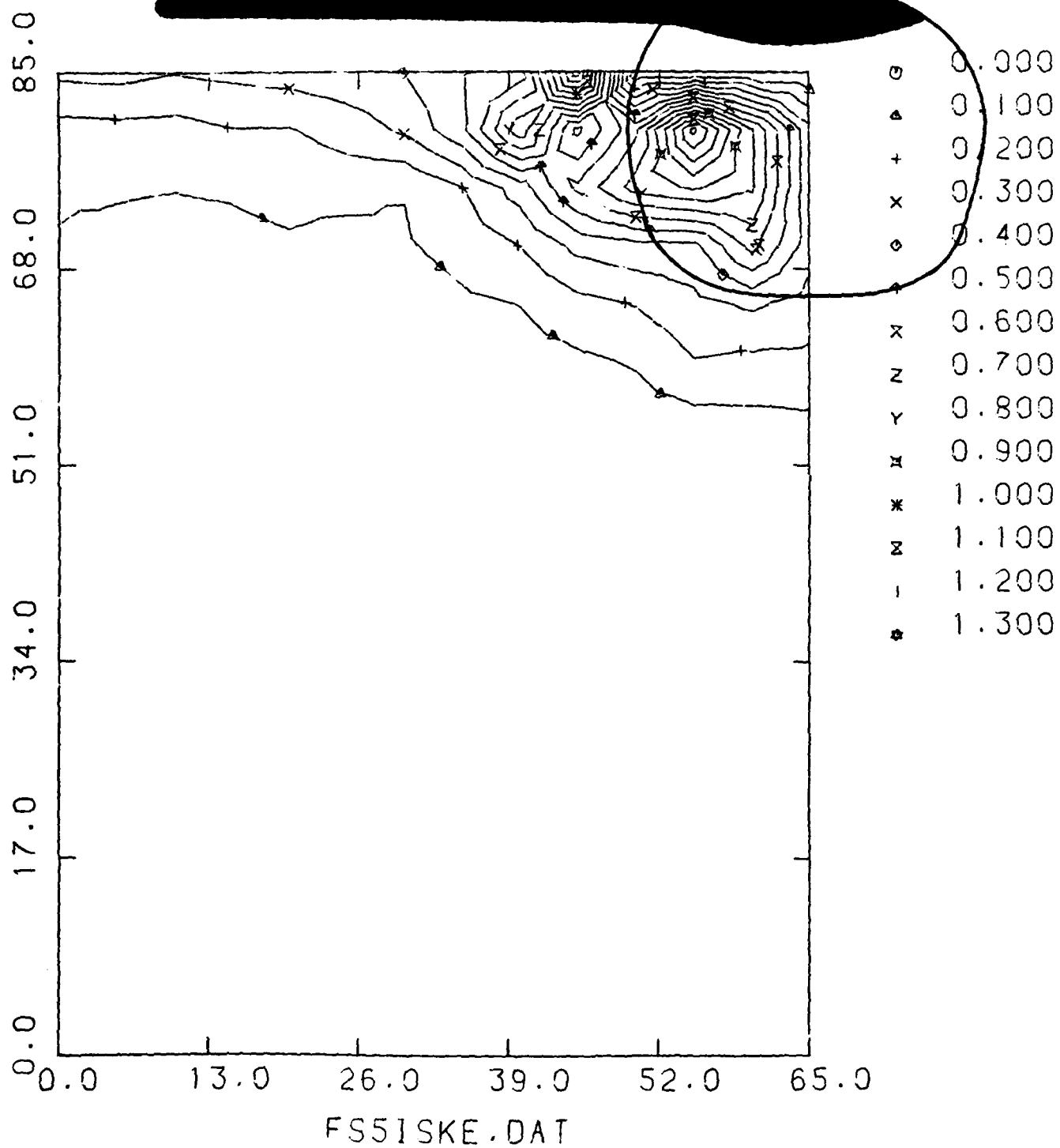


FIG. 26C - ISOLINES OF CROSS FLOW KINETIC ENERGY AT FUSELAGE STATION 5

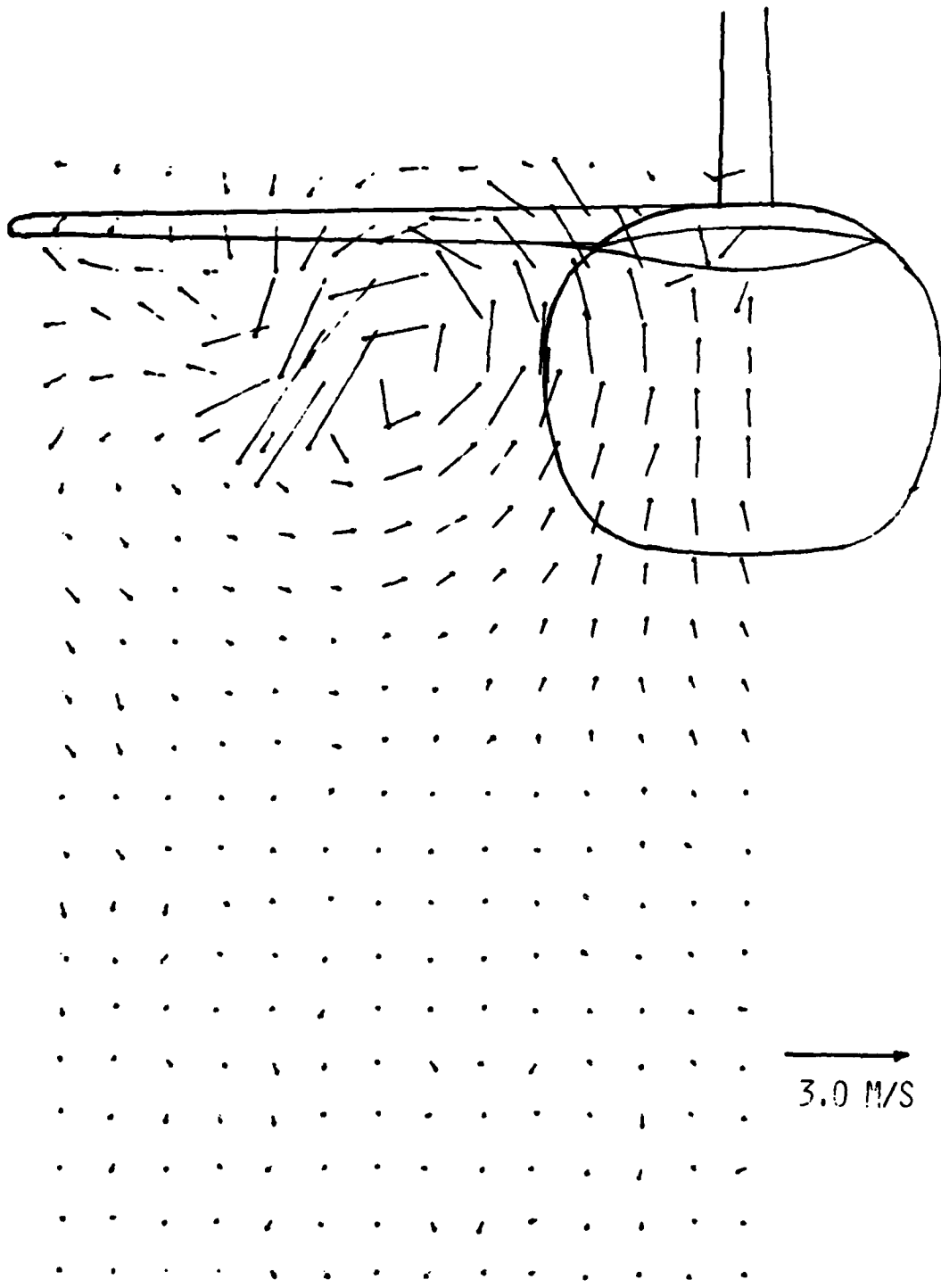
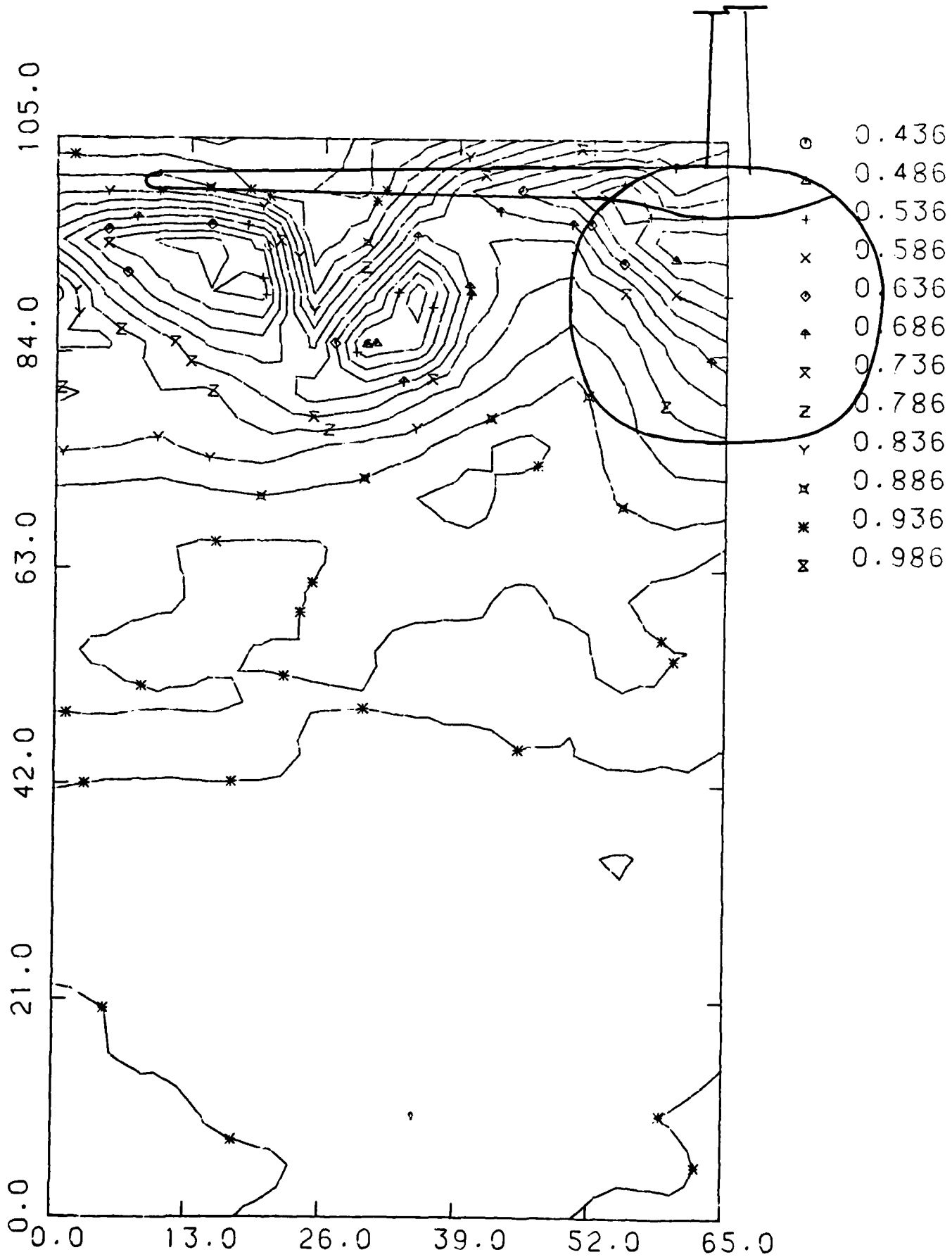


FIG. 27A - FLOW FIELD MAP OF FUSELAGE STATION 6
(DOWNSTREAM OF G-130)

FIG. 27B - ISOLINES OF TOTAL PRESSURE/DYNAMIC PRESSURE ON FUS. STA. 6

- CHARACTERISTIC ISOLINES OF PRESSURE LOSS DUE TO WAKE INDUCED BY AIRCRAFT BOATTAIL.

- MEASUREMENTS TAKEN AT 1 FUSELAGE DIAMETER DOWNSTREAM OF FUSELAGE



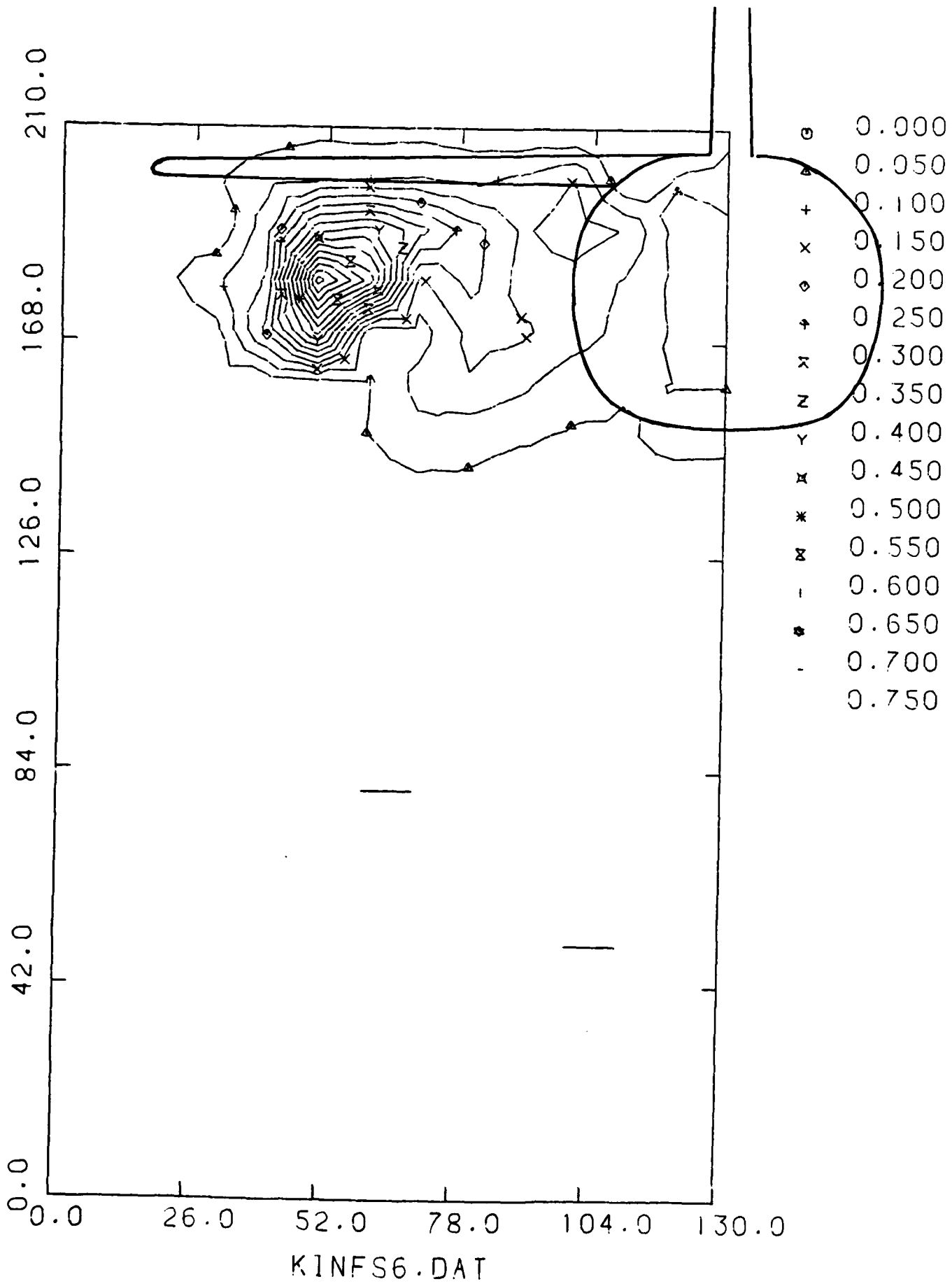


FIG. 27C - ISOLINES OF CROSS FLOW KINETIC ENERGY AT FUSELAGE STATION 6



A



B

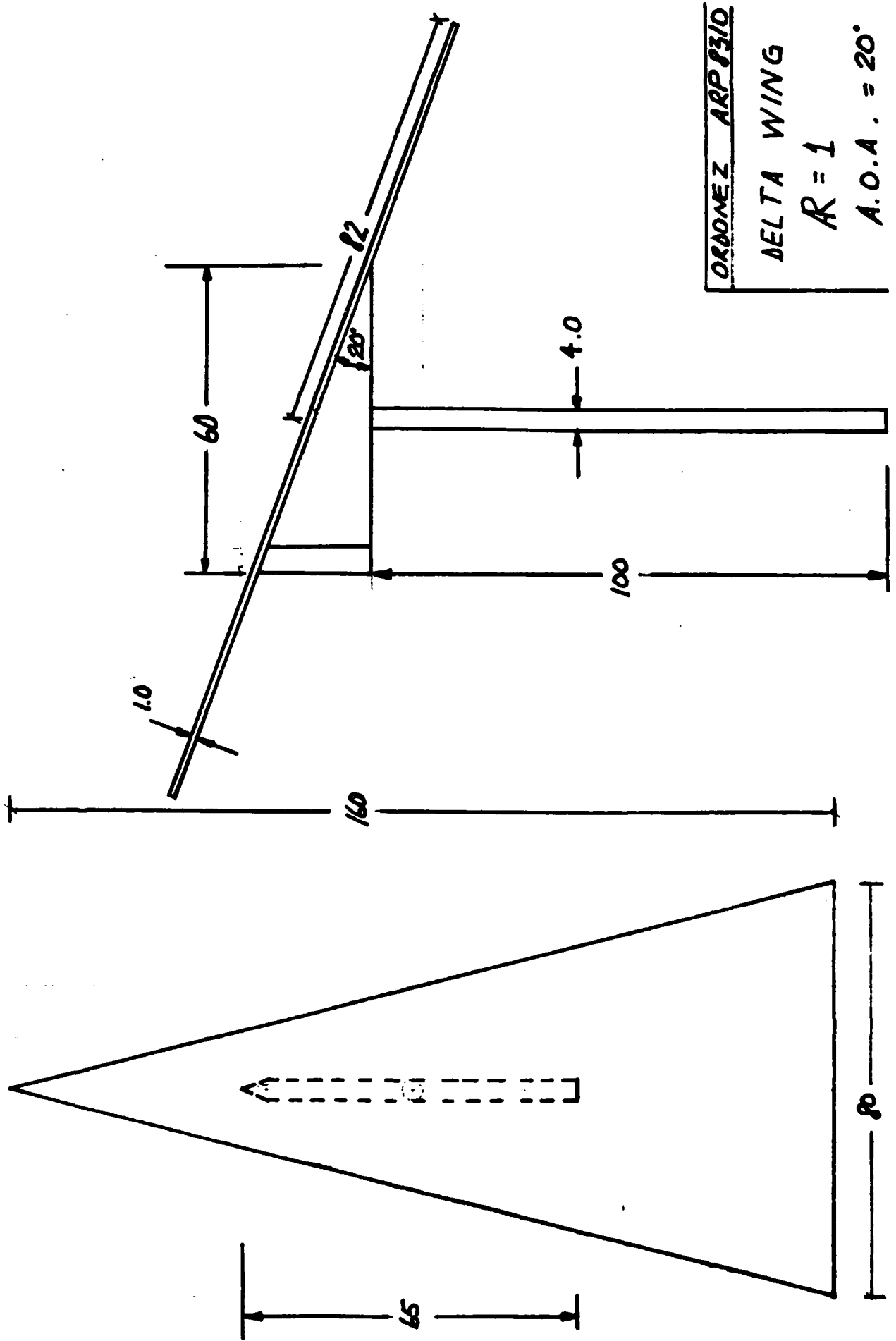


C

FIGS. 28A,B,C - LIMITING STREAMLINES VISUALIZATION ON G-130 (TOP, SIDE AND BOTTOM VIEWS)



FIG. 29 - TOP AND SIDE VIEW DRAWING OF DELTA WING USED FOR EXPERIMENTS



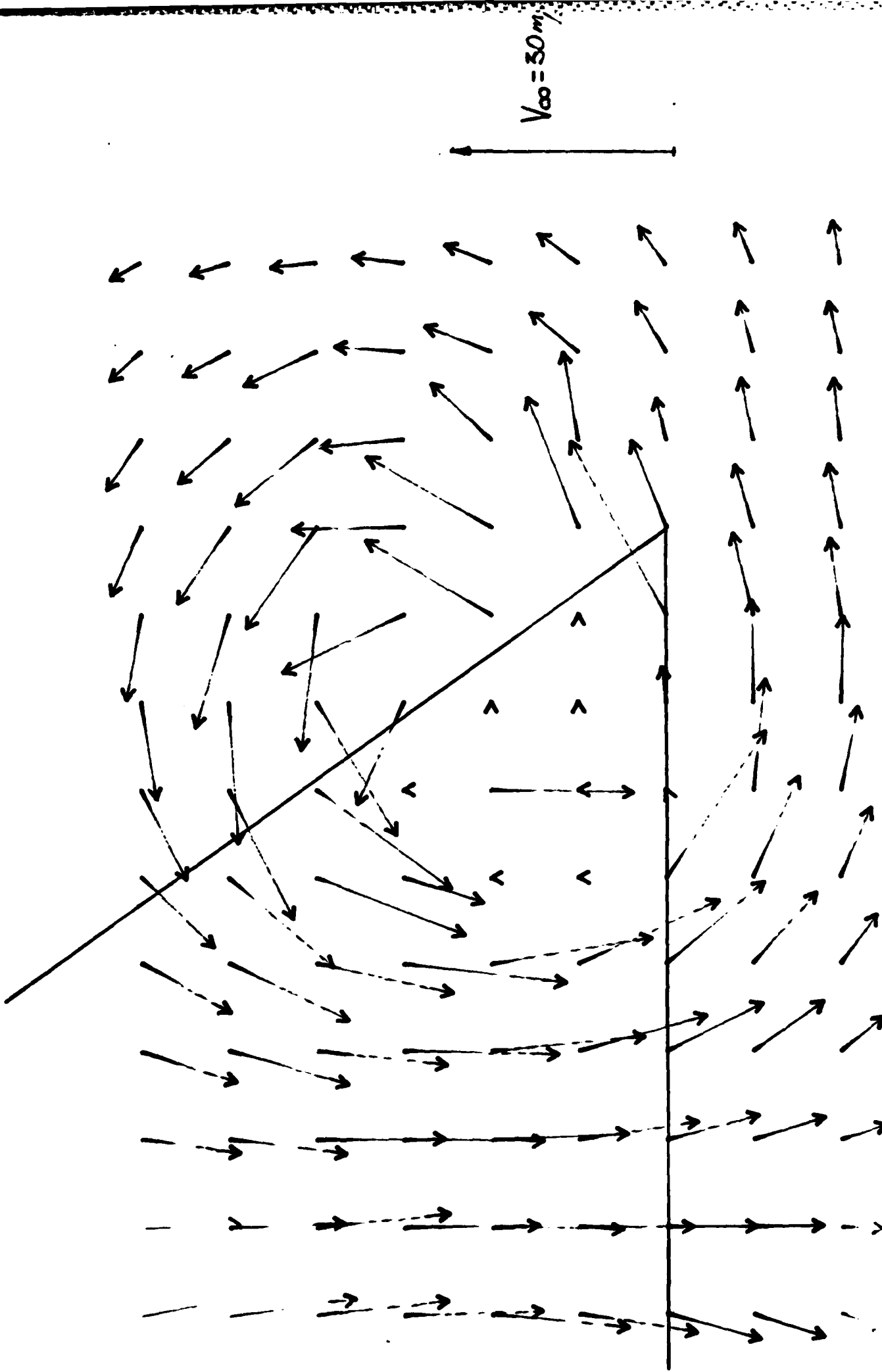


FIG. 30A - FLOW FIELD AT $\epsilon = 0.625$ DOWNSTREAM OF DELTA WING

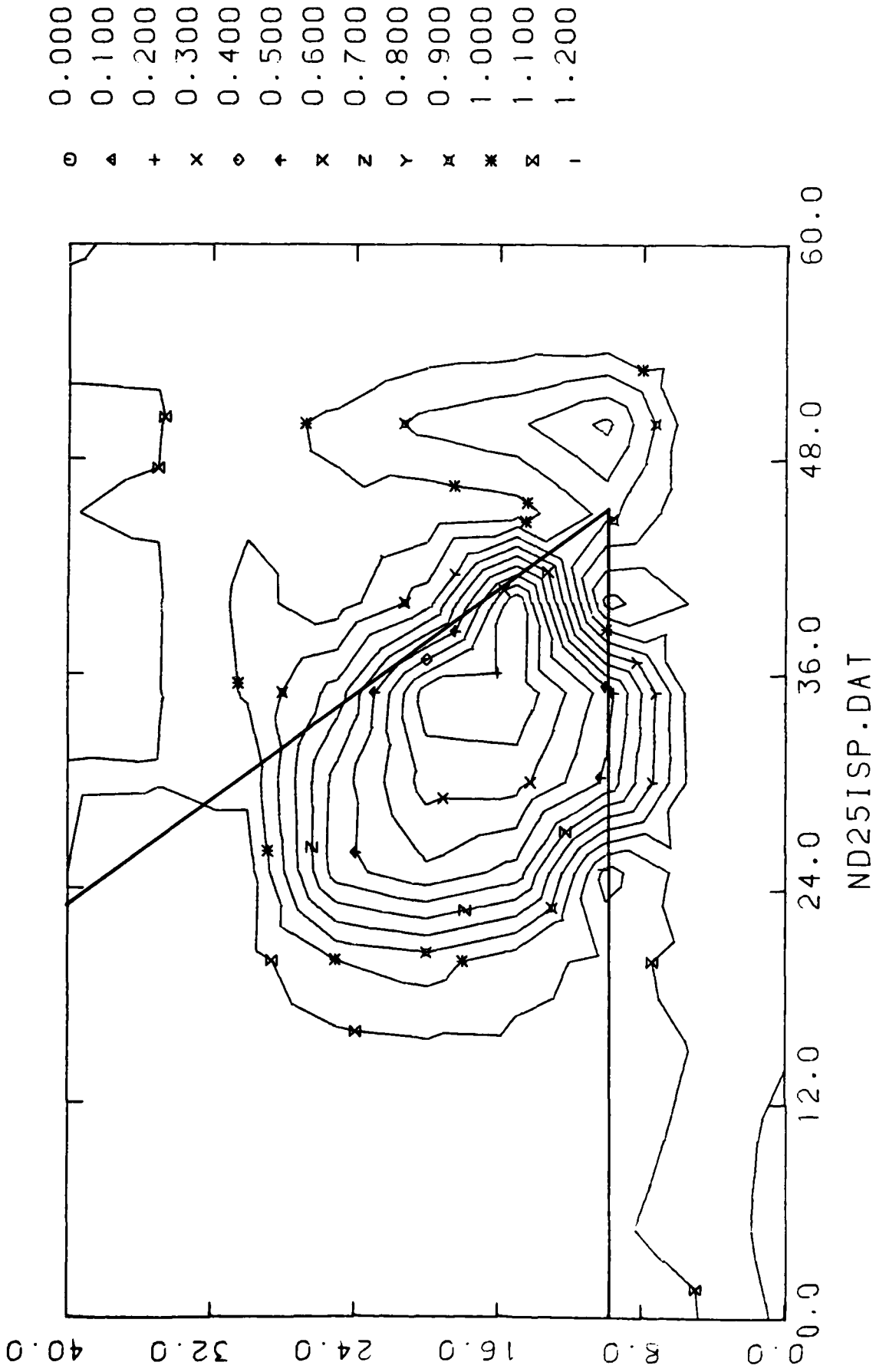


FIG. 30B - ISOLINES OF TOTAL PRESSURE/DYNAMIC PRESSURE AT $\epsilon = 0.625$
DOWNSTREAM OF DELTA WING

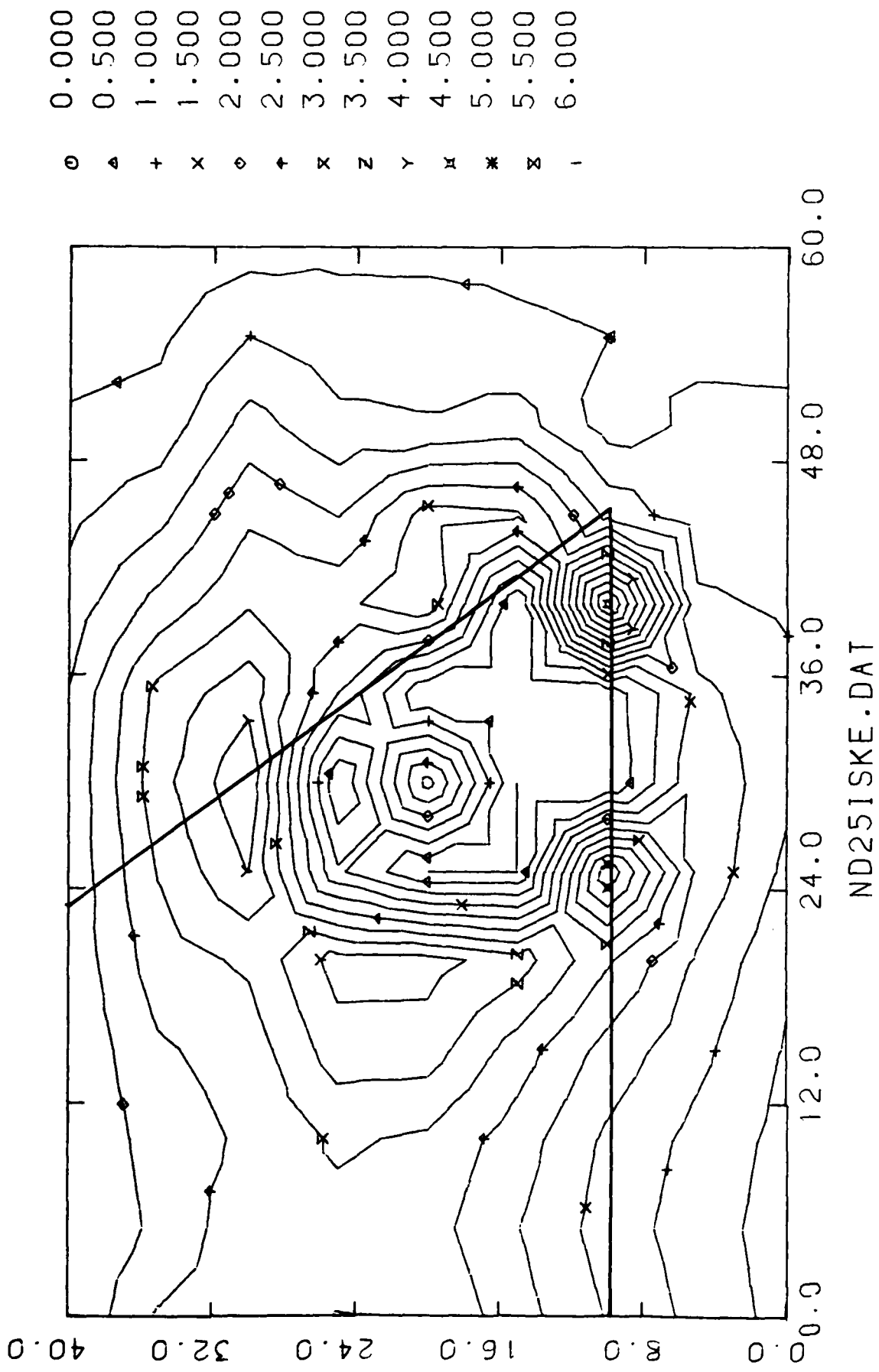


FIG. 30C - ISOLINES OF DIMENSIONLESS CROSS FLOW KINETIC ENERGY AT $\epsilon = 0.625$ DOWNSTREAM OF DELTA WING

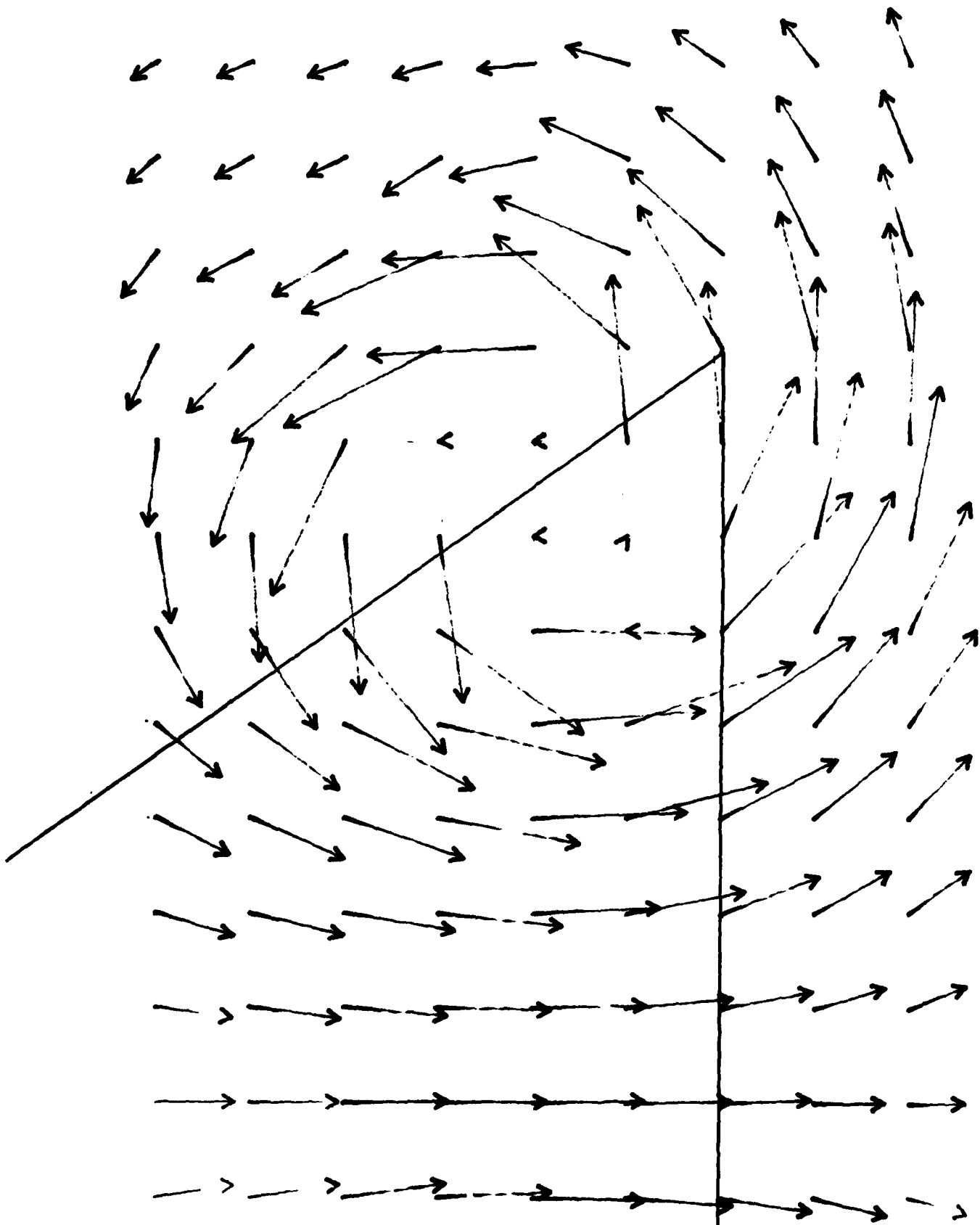


FIG. 31A - FLOW FIELD AT $\epsilon = 1.875$ DOWNSTREAM OF DELTA WING

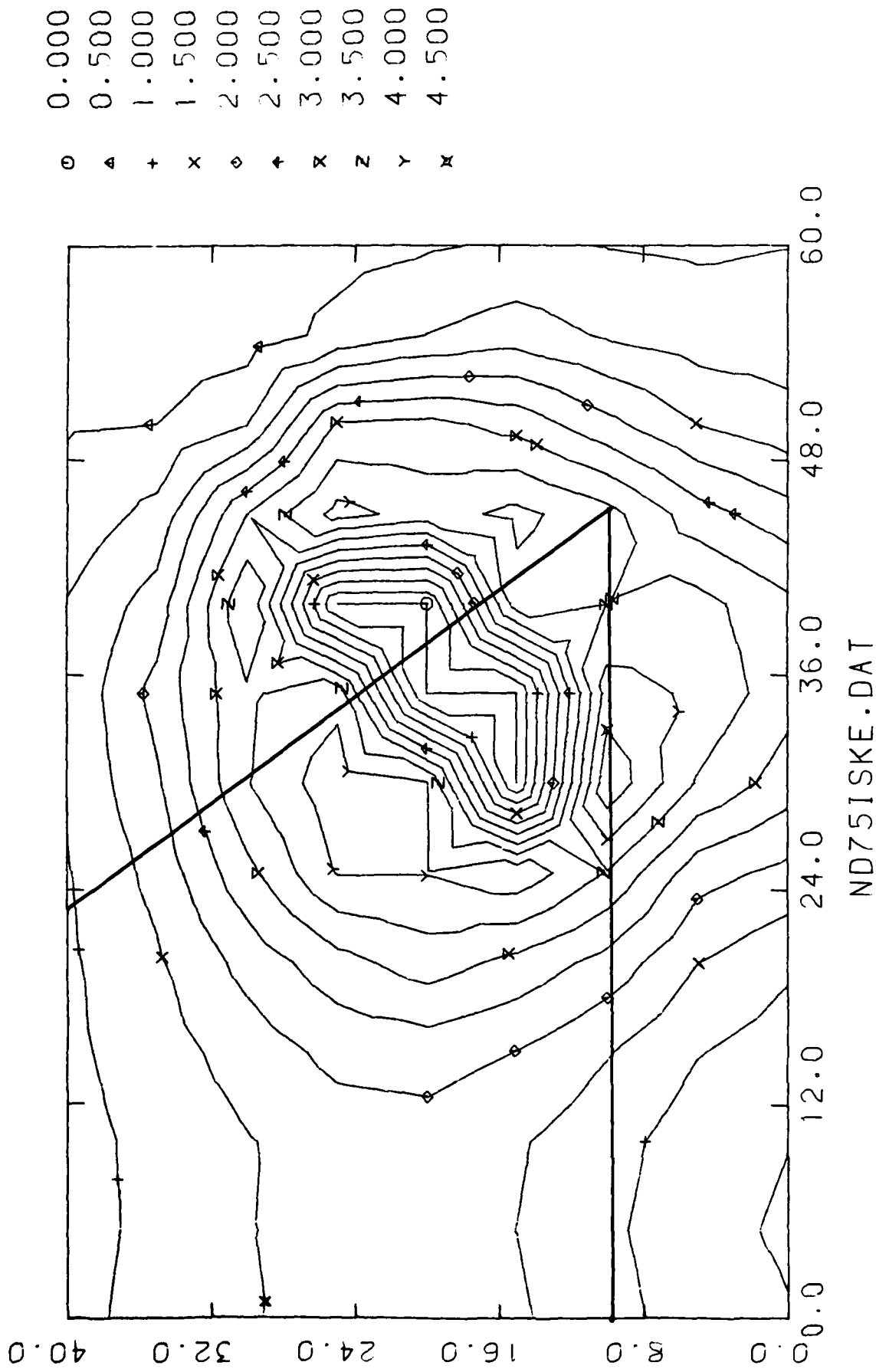


FIG. 31B - ISOLINES OF DIMENSIONLESS CROSS FLOW KINETIC ENERGY AT $\epsilon = 1.875$ DOWNSTREAM OF DELTA WING

VORTEX FIELD INDUCED BY DELTA WING WITHOUT STRAKES PLACED IN ITS VICINITY.

- MEASUREMENTS TAKEN AT 1.2 WING SPAN DOWNSTREAM OF TRAILING EDGE
- ANGLE OF ATTACK OF DELTA WING = 20°

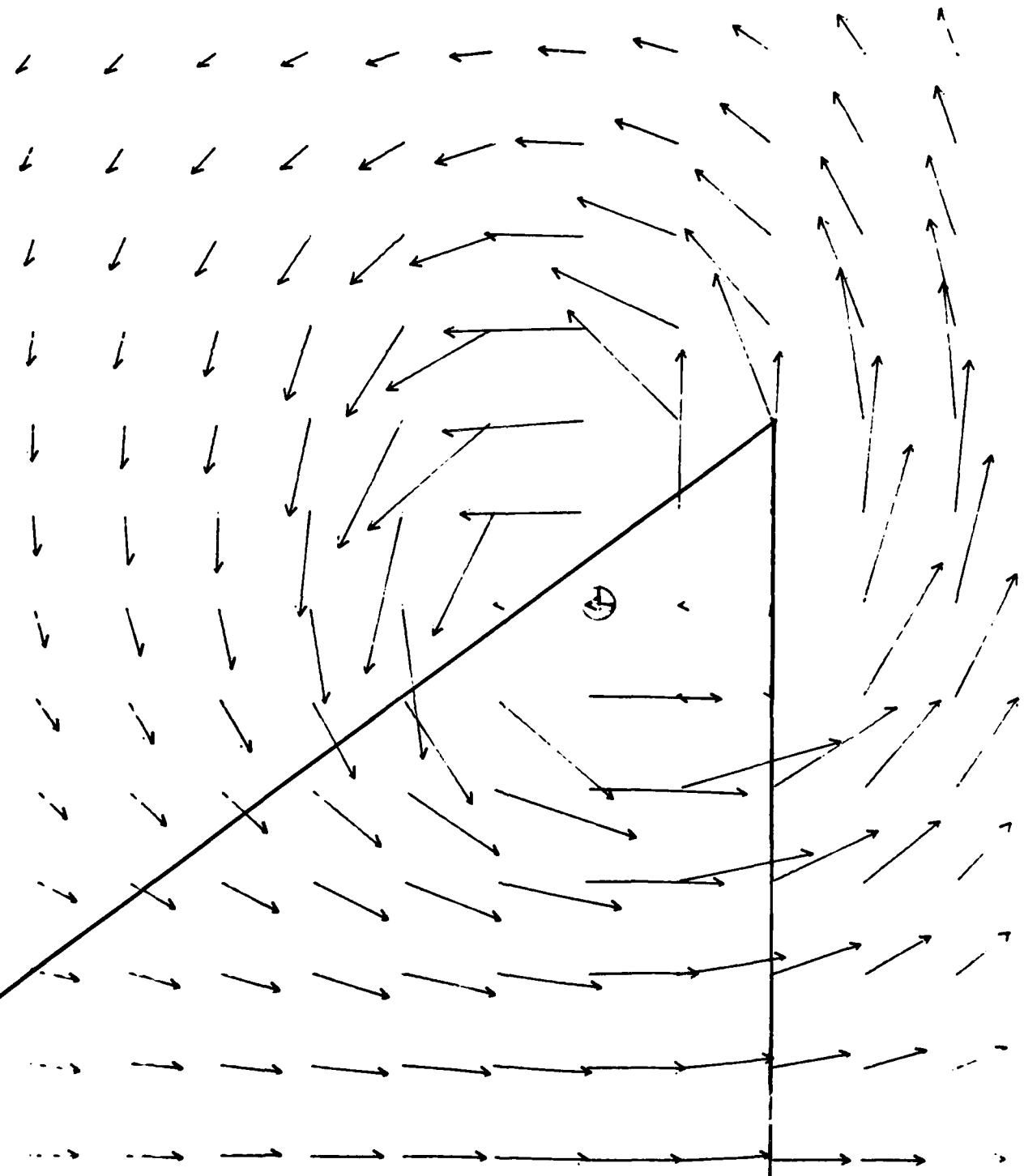
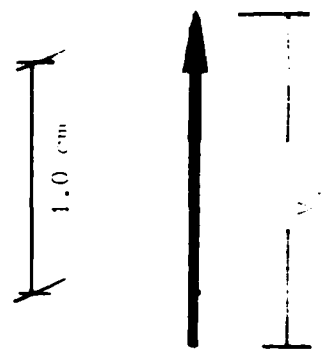


FIG. 32A - FLOW FIELD AT $x = 2.50$ DOWNSTREAM OF DELTA WING

ISOLINES OF $\frac{\text{TOT. LOC. PRESSURE}}{\text{DYNAMIC PRESSURE}}$ FOR A VORTEX AT 1.2 WING SPAN DOWNSTREAM OF TRAILING EDGE, ($\epsilon = 2.5$)

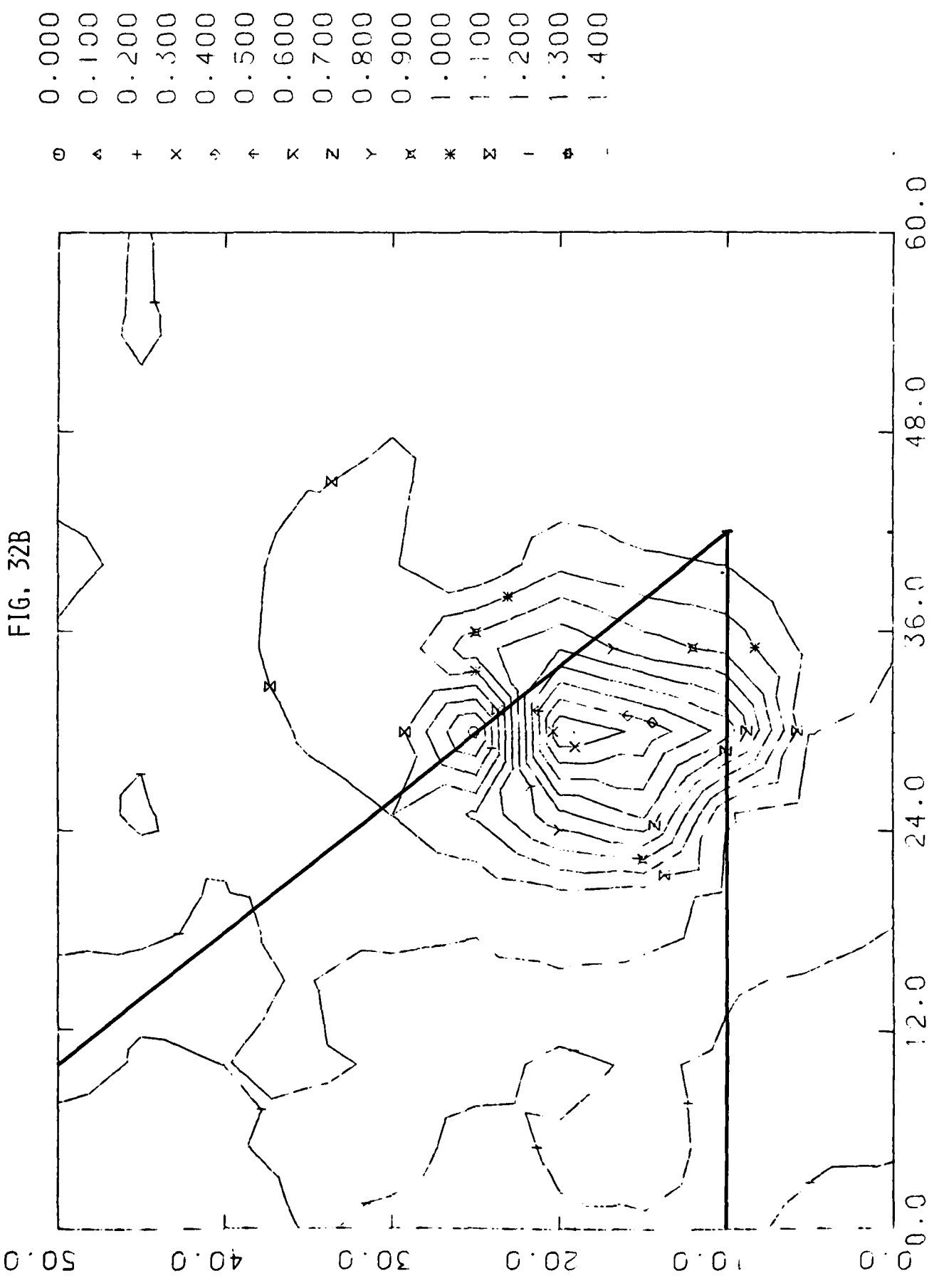
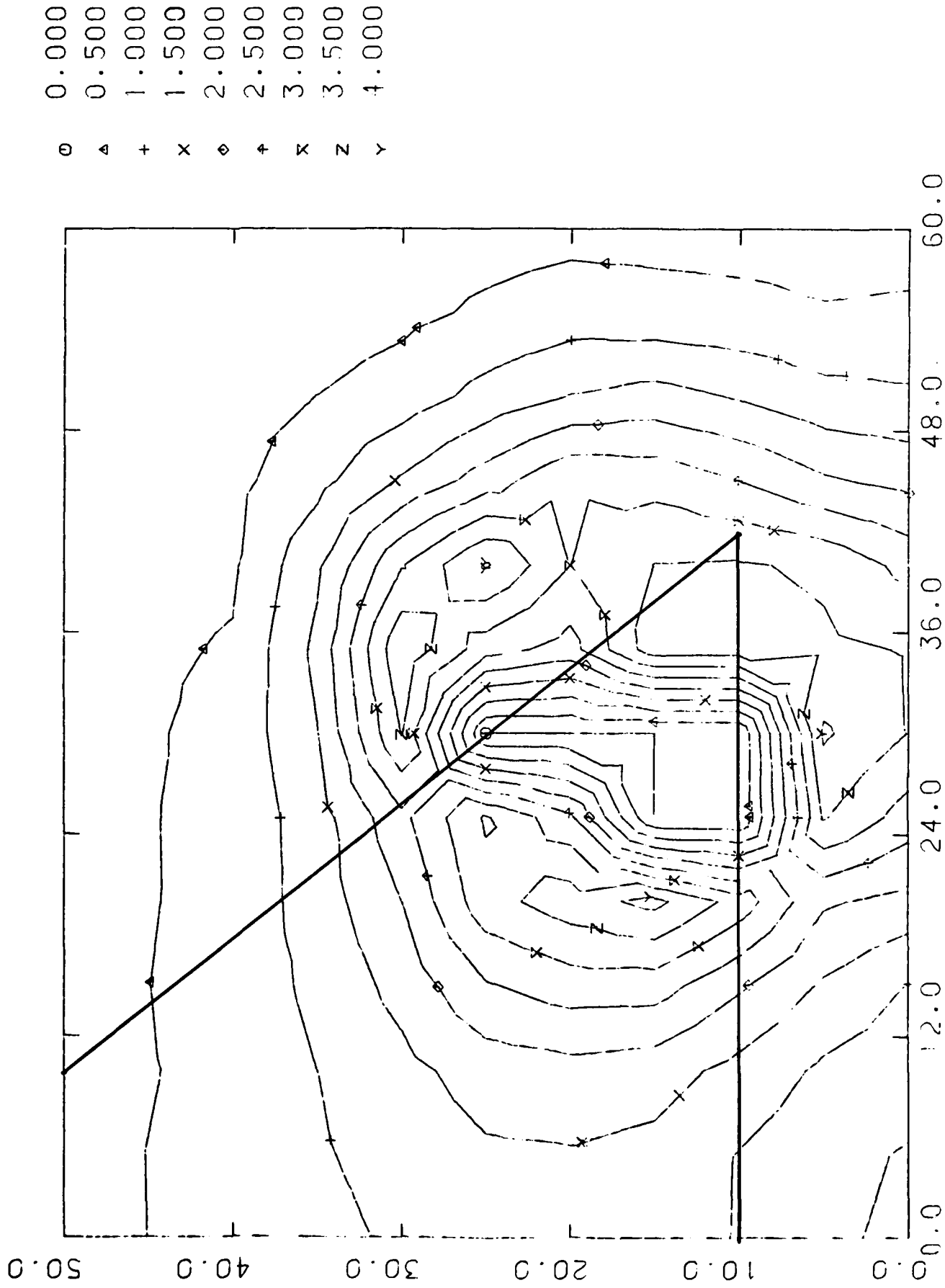
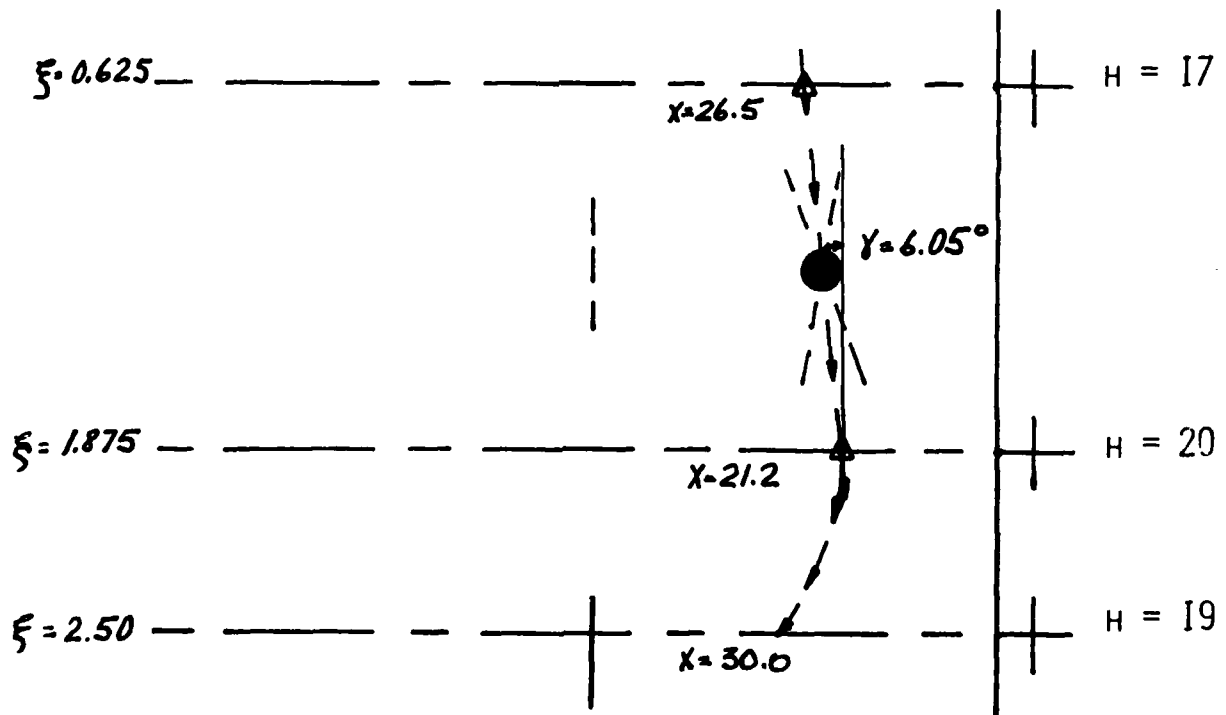
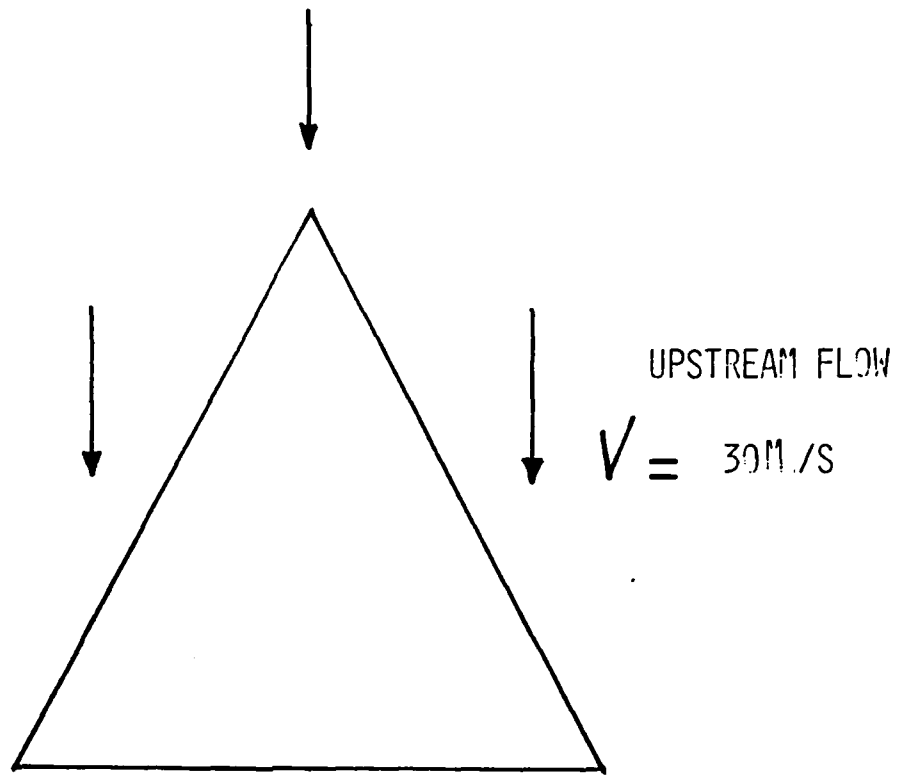


FIG. 32C - ISOLINES OF DCFKE AT $\epsilon = 2.5$ DOWNSTREAM OF DELTA WING





HEIGHT OF VORTEX CORE



DISTANCE DOWNSTREAM

DELTA WING TRAILING EDGE

FIG. 27. VORTEX CORE PATH SCHEMATIC

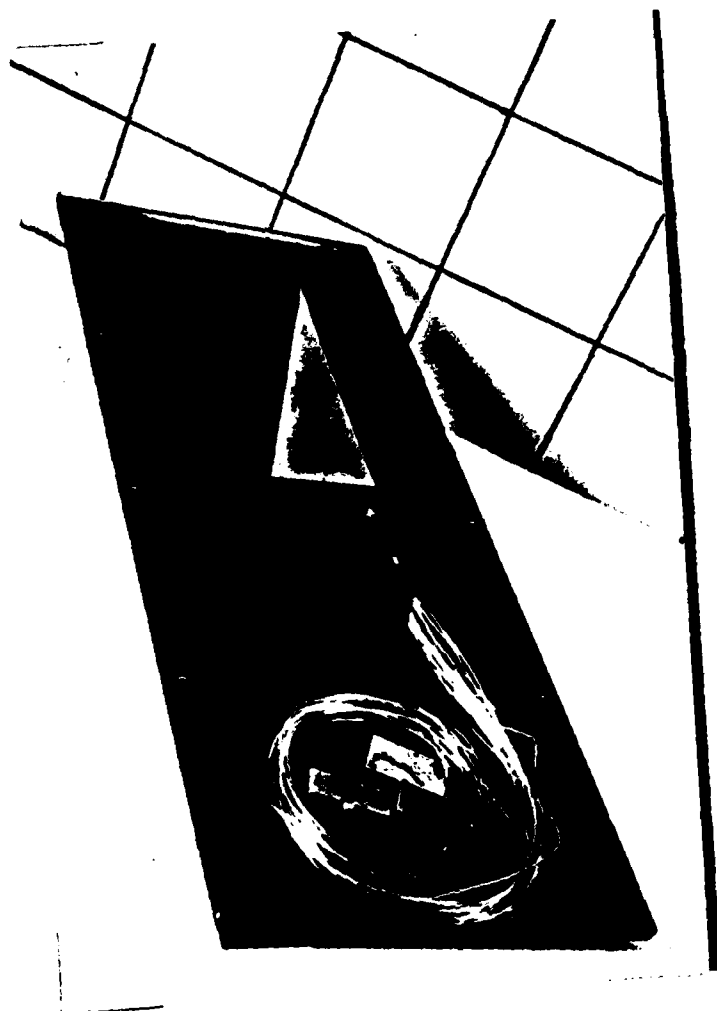
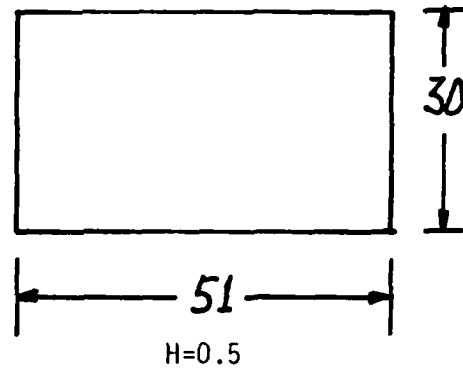
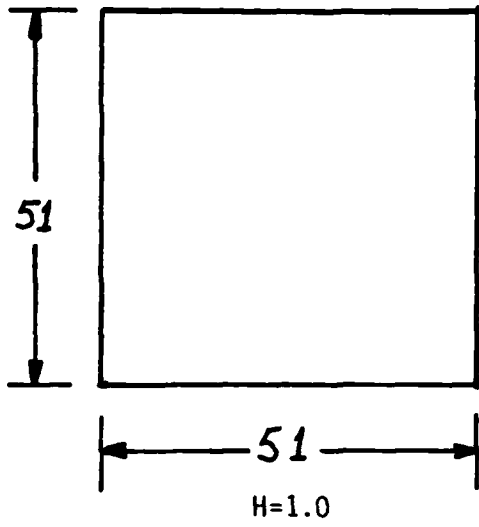
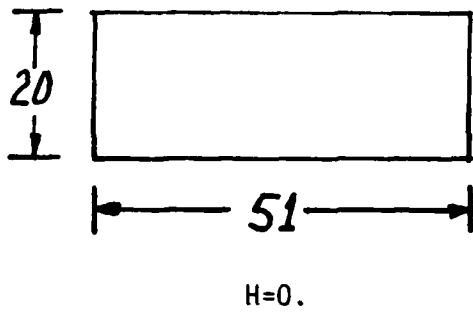


FIG. 34 - DELTA WING AND STRAKES EXPERIMENTAL SET UP IN L-2A

THIN STRAKES
(DIMENSIONS IN MM.)



STRAKES THICKNESS
= 0.80 mm.



THICK STRAKE

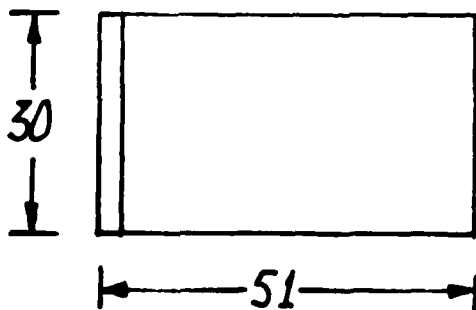


FIG. 35 - STRAKES CONFIGURATIONS (H = 0, 0.5, 1.0)

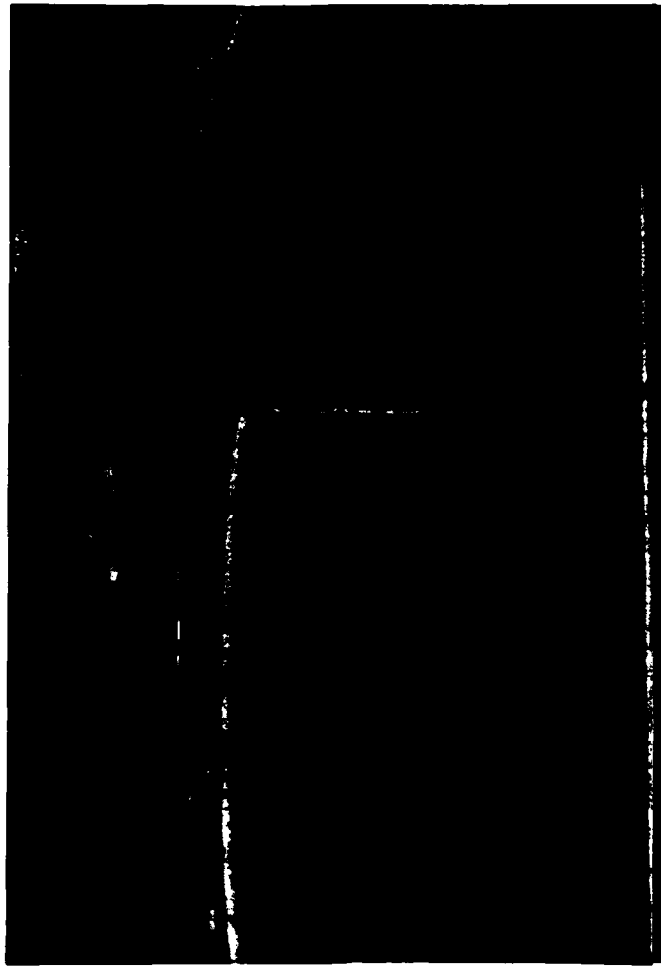
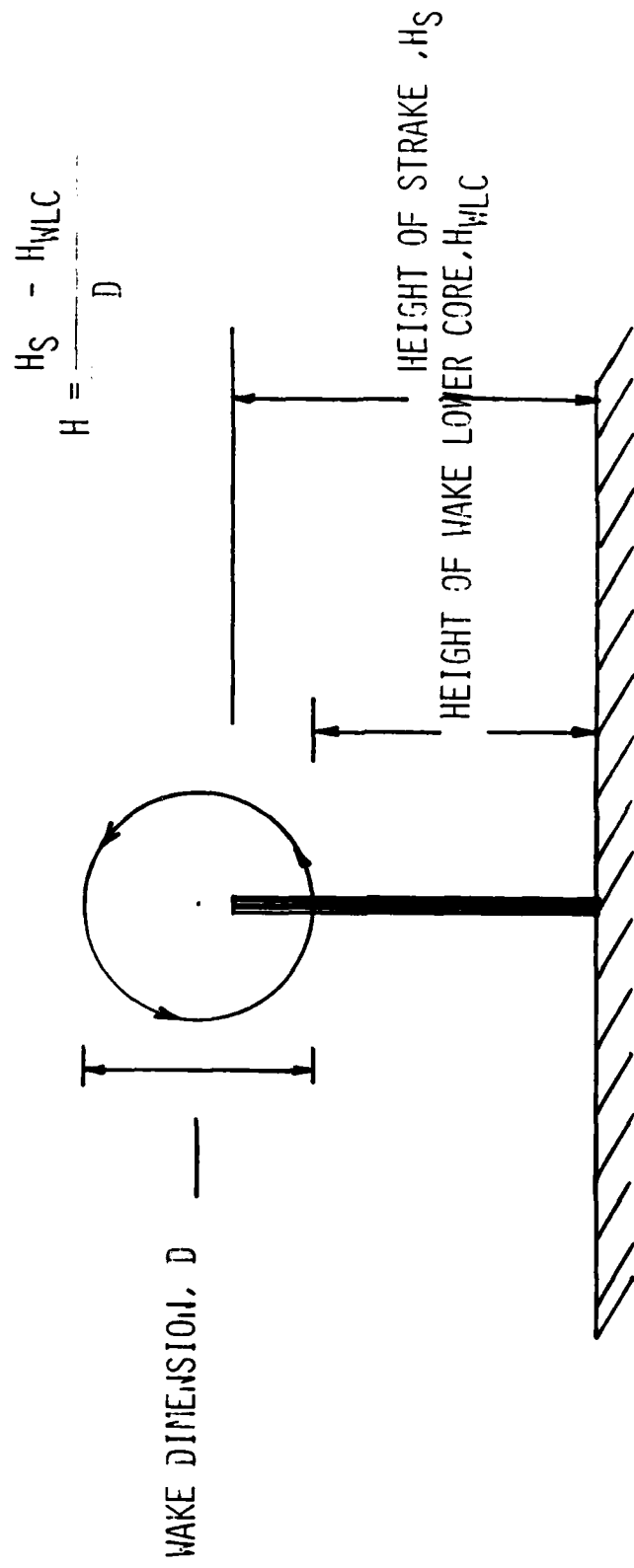


FIG. 36 - WATER TUNNEL DELTA WING - STRAKE SET UP

FIG. 37 - PARAMETRIC DEFINITION



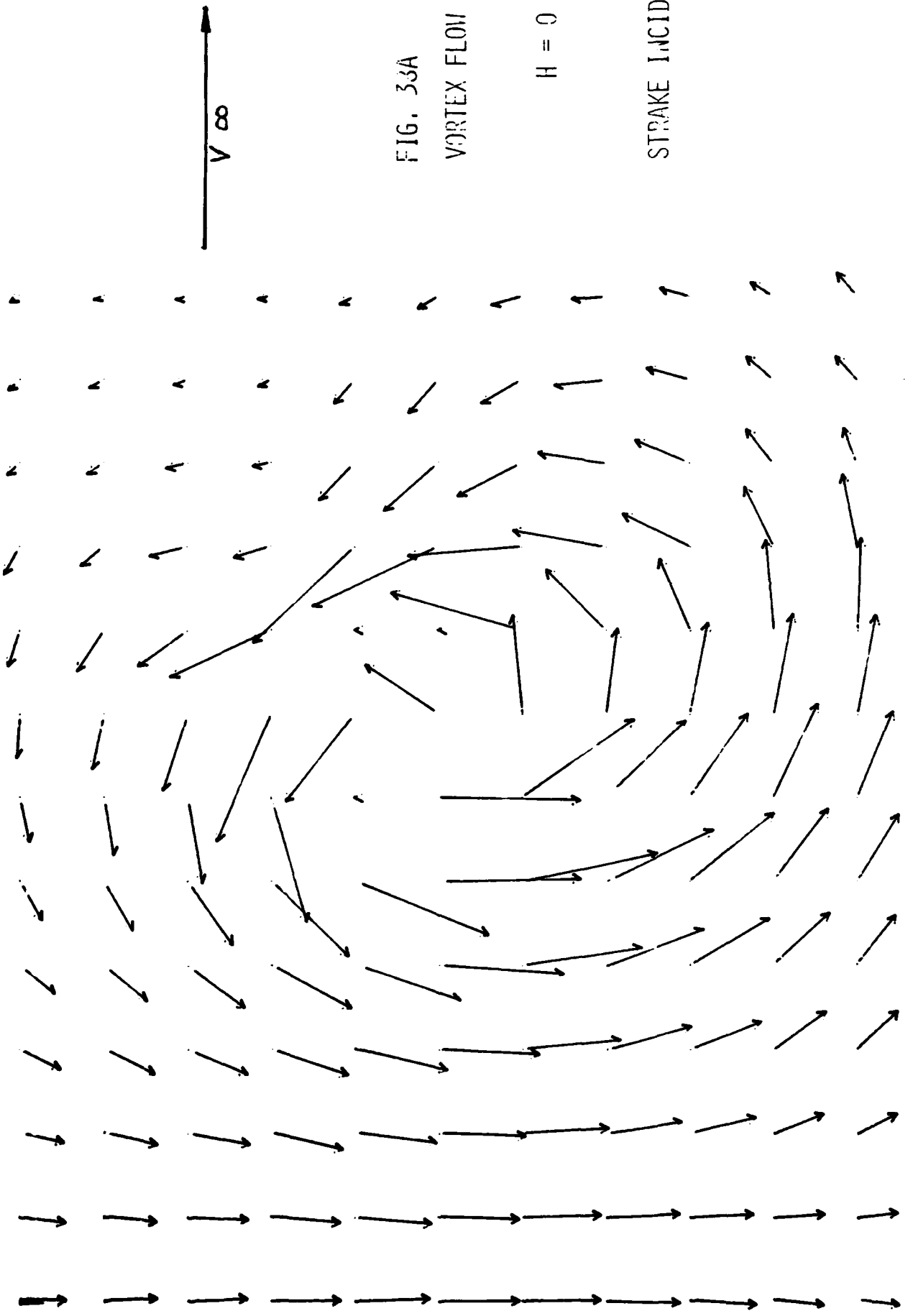


FIG. 33A

VORTEX FLOW FIELD FOR

$$H = 0$$

STRAKE INCIDENCE = -10°

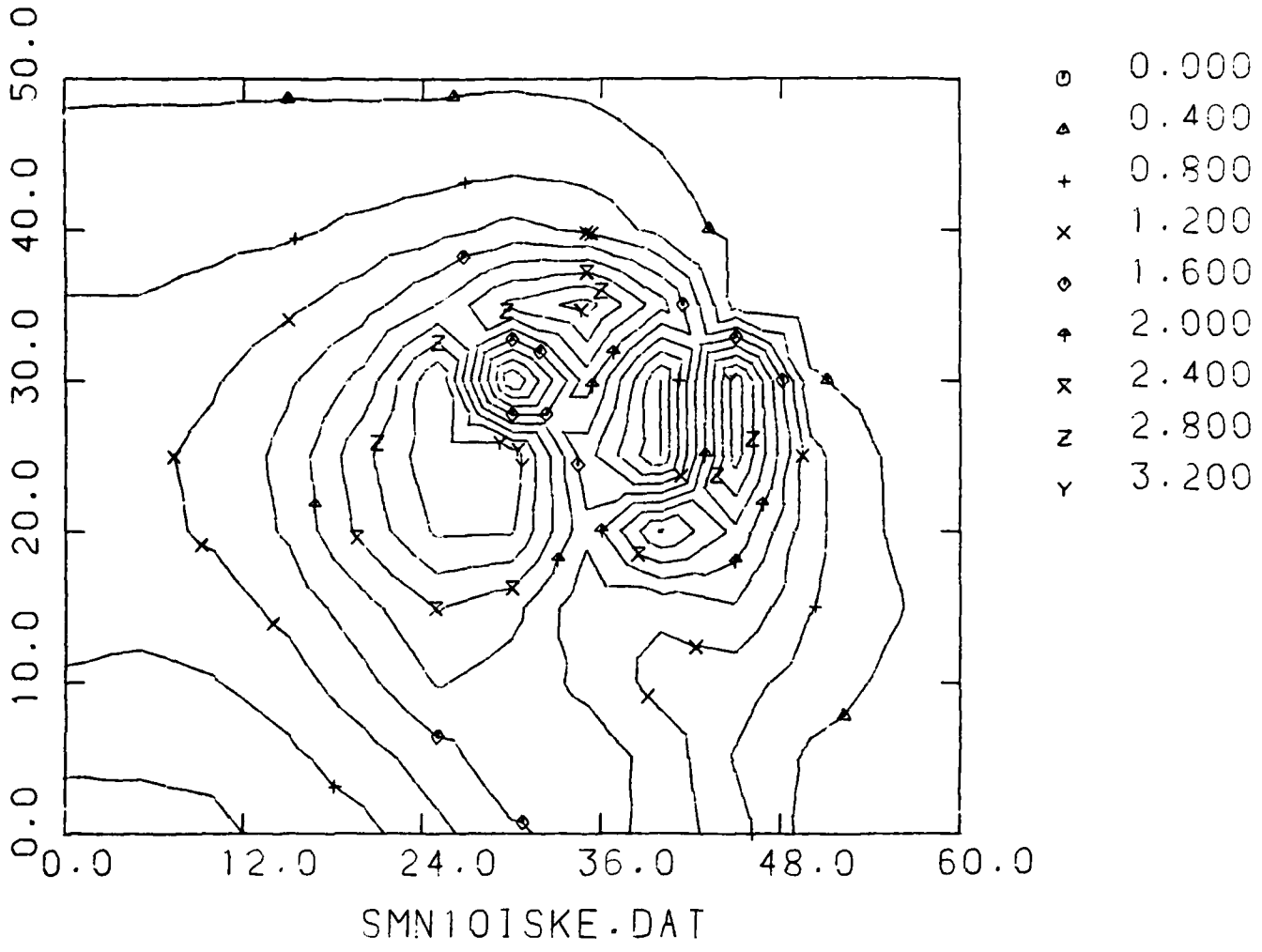


FIG. 38B - ISOLINES OF DIMENSIONLESS CROSS FLOW KINETIC ENERGY (DCFKE) DOWNSTREAM OF $H = 0$, $\alpha_R = -10$ THIN STRAKE

FIG. 39A
FLOW FIELD DOWNSTREAM
OF $h = 0$, THIN STRAKE
AT $r_R = 0$

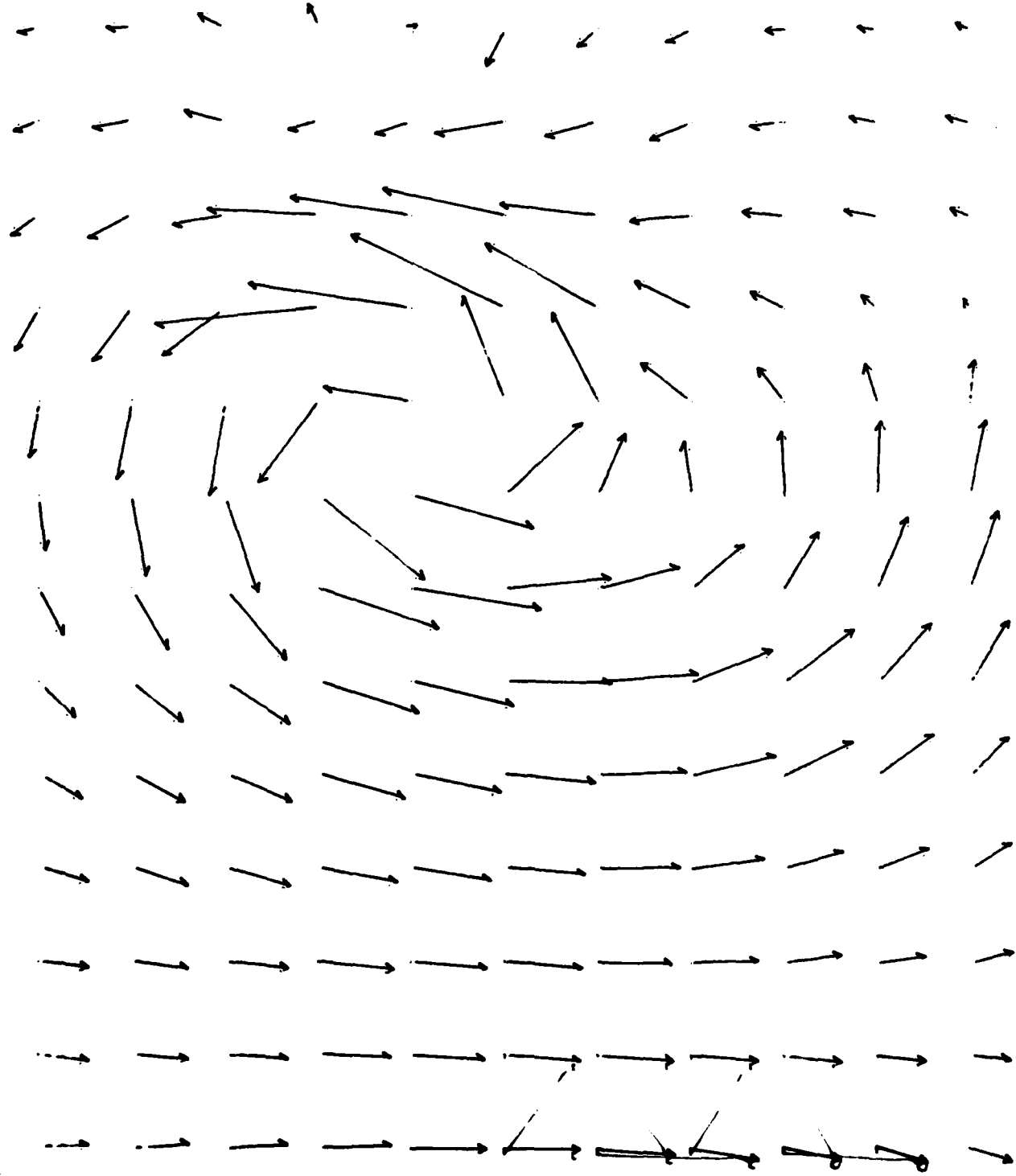
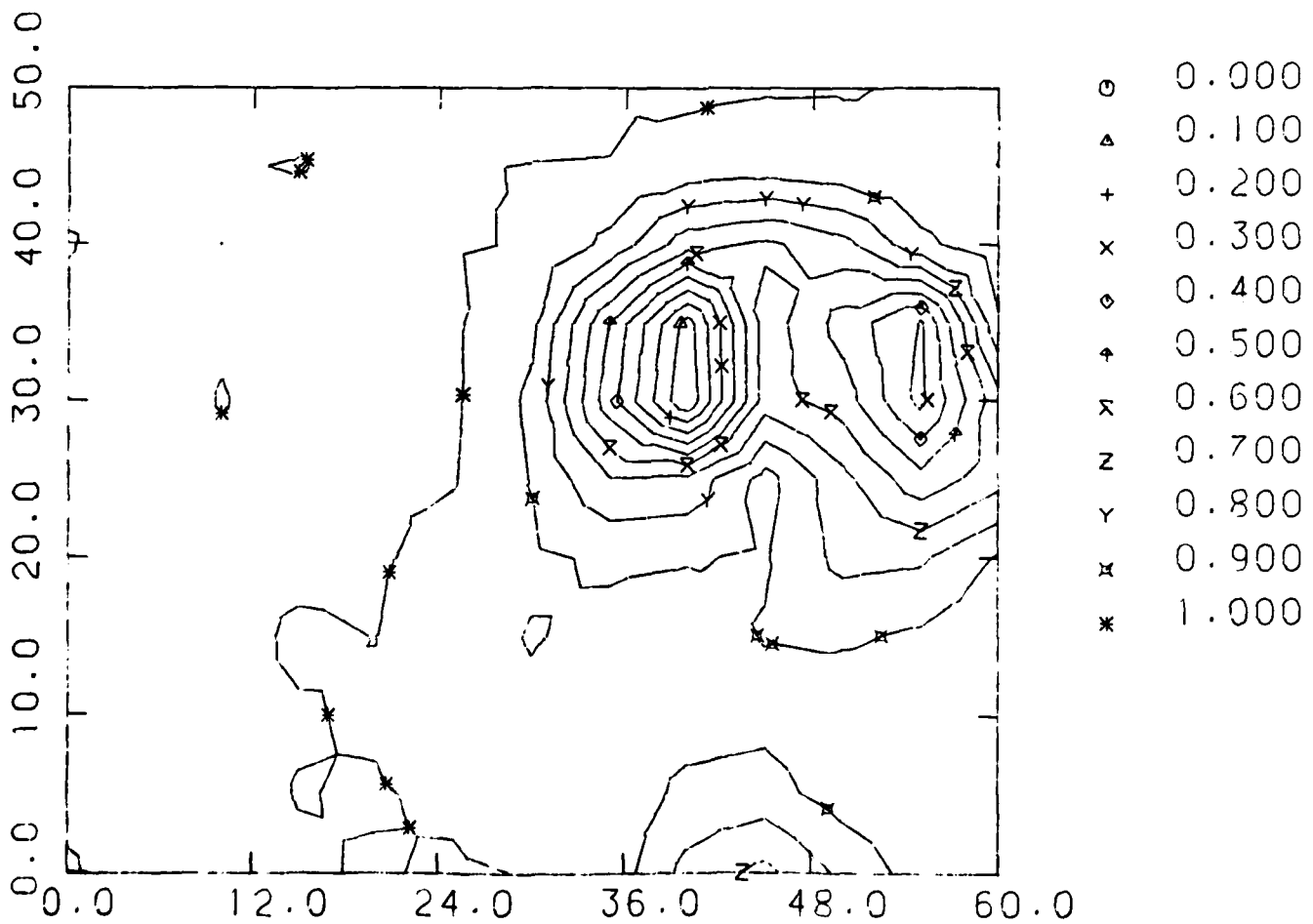


FIG. 39B

ISOLINES OF TOTAL LOCAL PRESSURE / DYNAMIC PRESSURE FOR

$$H = 0.$$

$$\alpha_R = 0, \text{ THIN STRAKE}$$



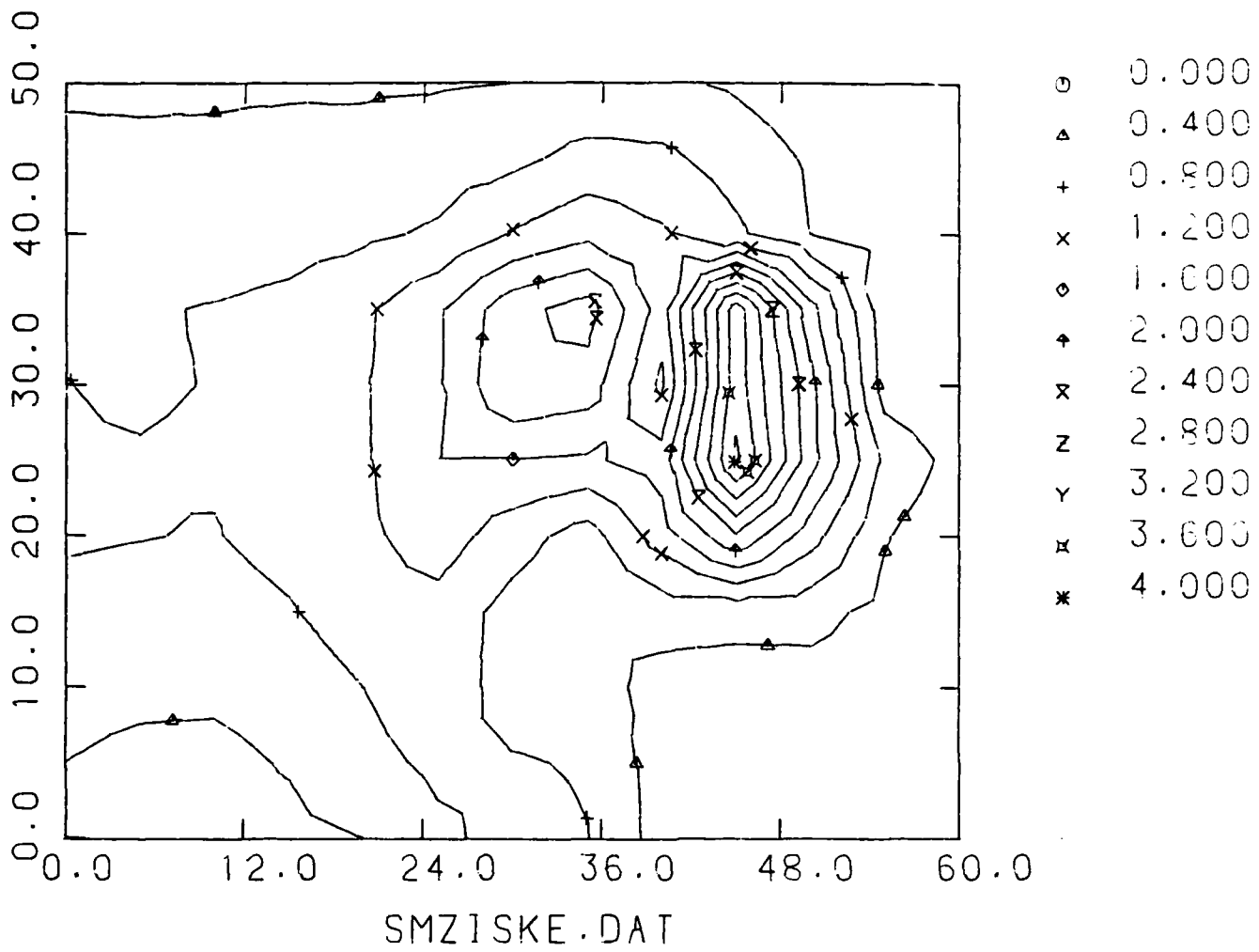
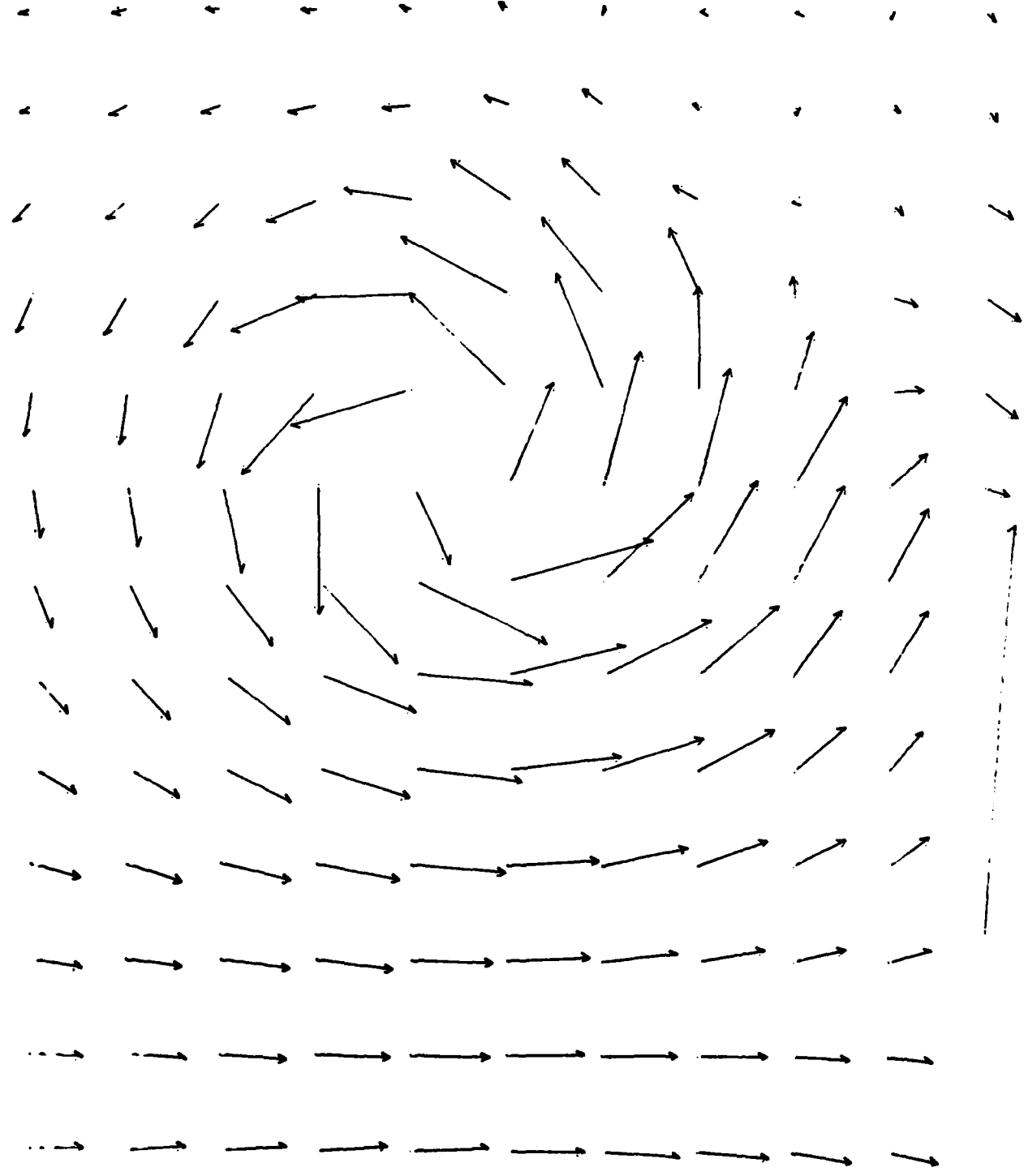


FIG. 39C - ISOLINES OF DCFKE DOWNSTREAM OF $H = 0$, $\alpha_R = 0$ THIN STRAKE

FIG. 40A

RESULTANT FLOW FIELD
DOWNSIDE OF STRAKE OF
RATIO = 0
AT POSITIVE INCIDENCE
W.R.T. INCOMING VORTEX
 $\alpha_R = 15$ THIN STRAKE



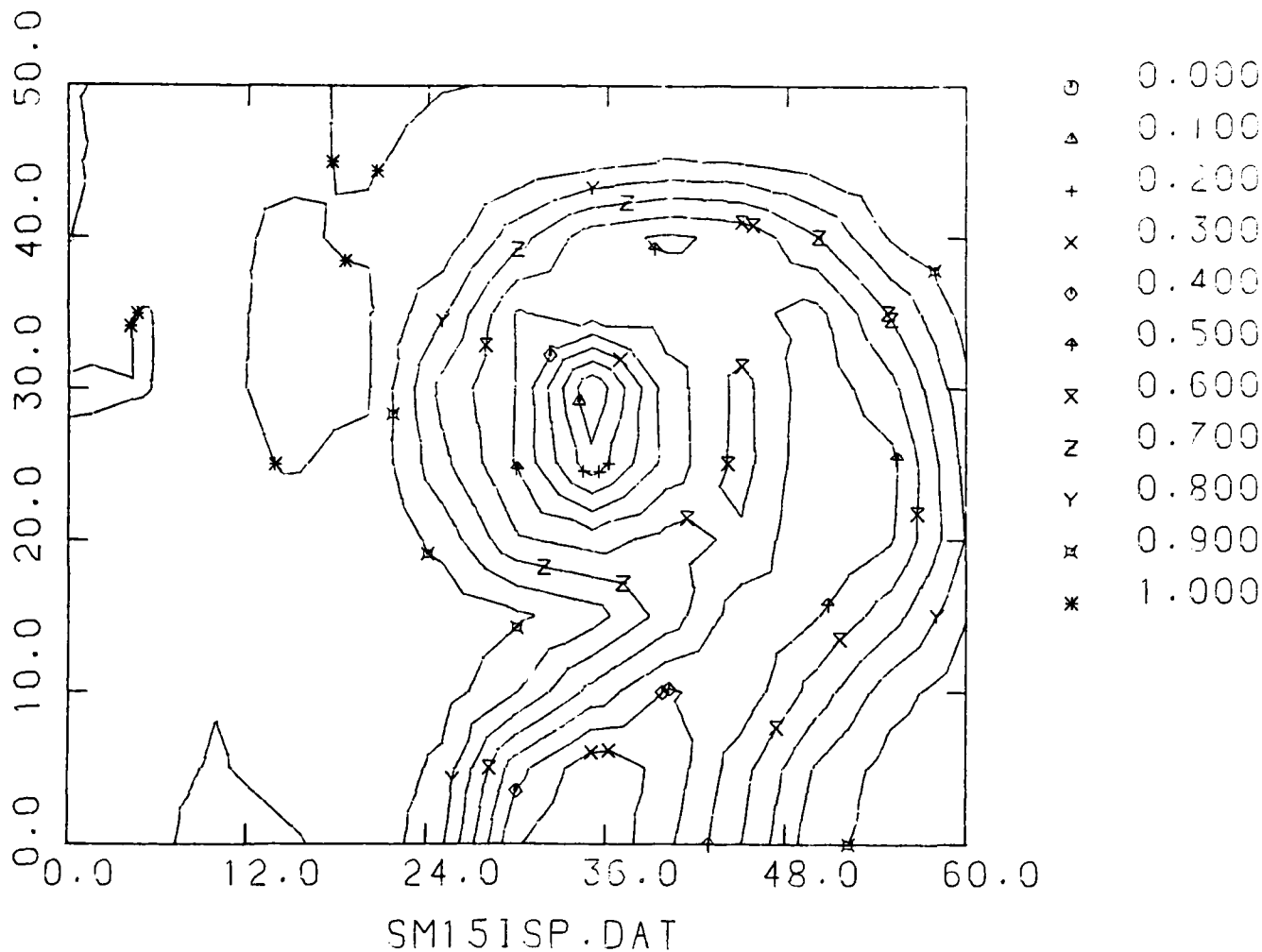


FIG. 40B - ISOLINES OF P_R DOWNSTREAM OF $H = 0$, $\alpha_R = 15$ THIN STRAKE

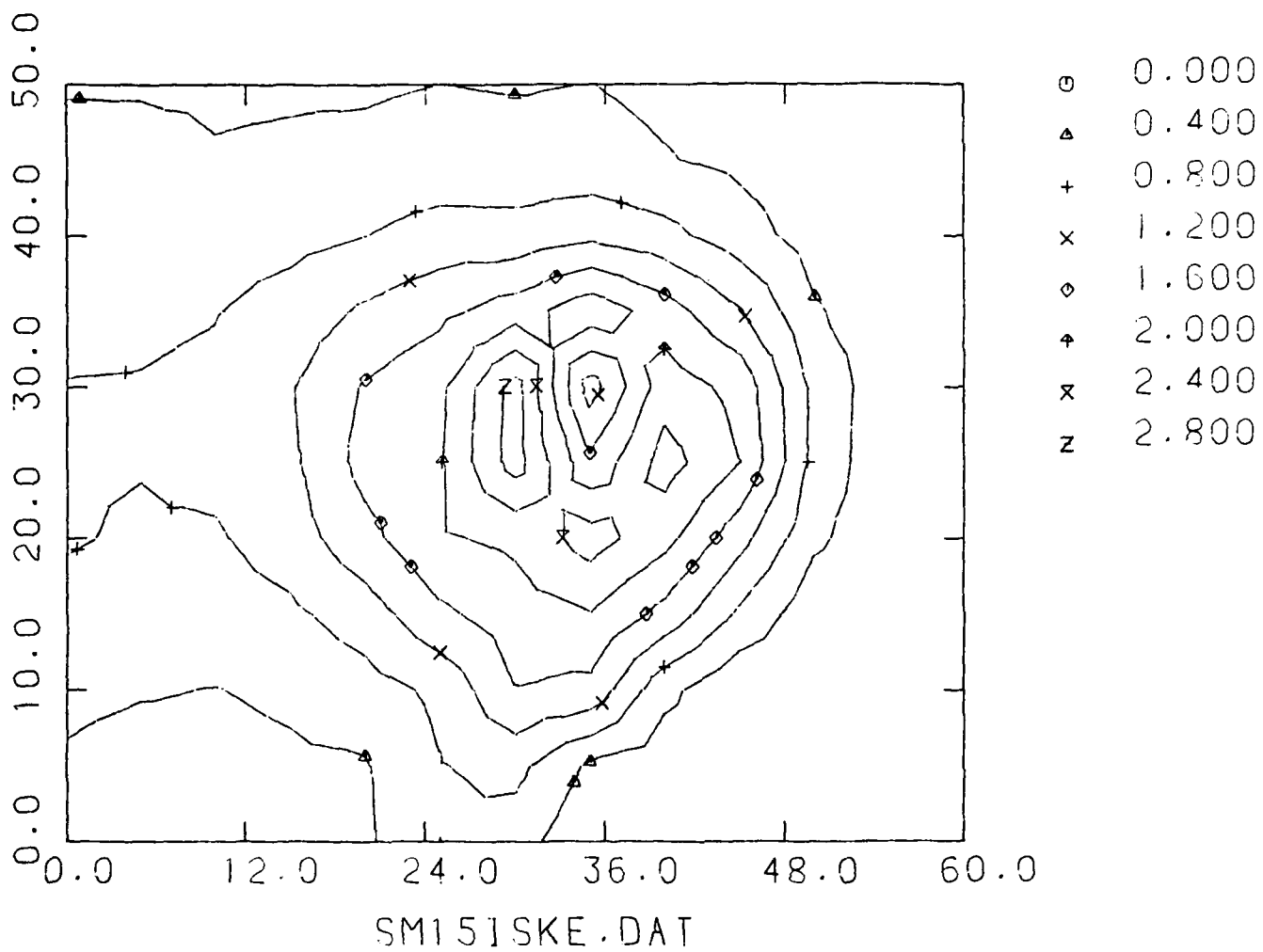


FIG. 40C - ISOLINES OF DCFKE DOWNSTREAM OF $H = 0$, $\alpha_R = 15$ THIN STRAKE

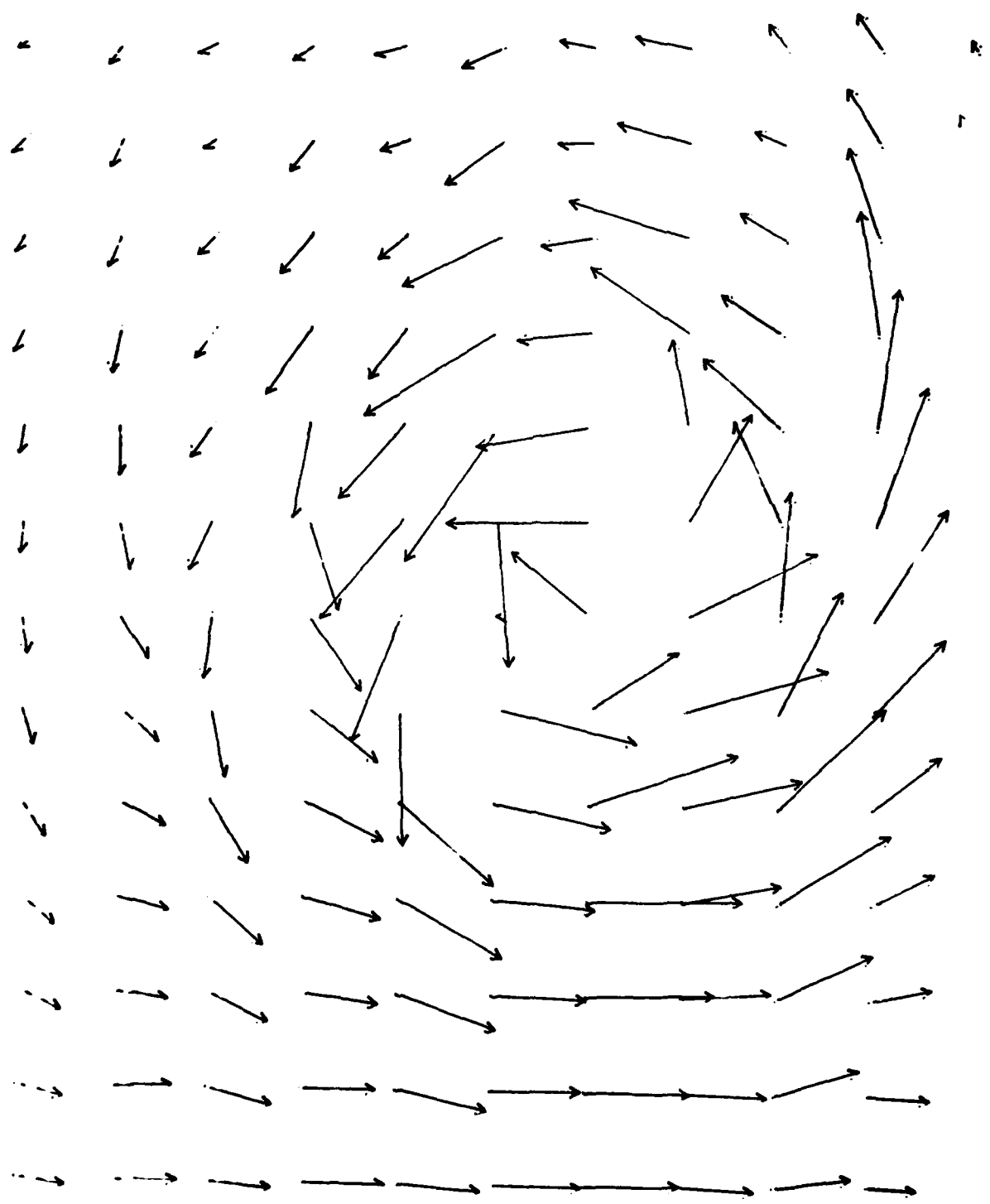


FIG. 41A

RESULTANT VORTEX WHEN
STRAKE OF RATIO

$\alpha_R = -15, H = 0.5$ IS PLACE

AT A NEGATIVE INCIDENCE

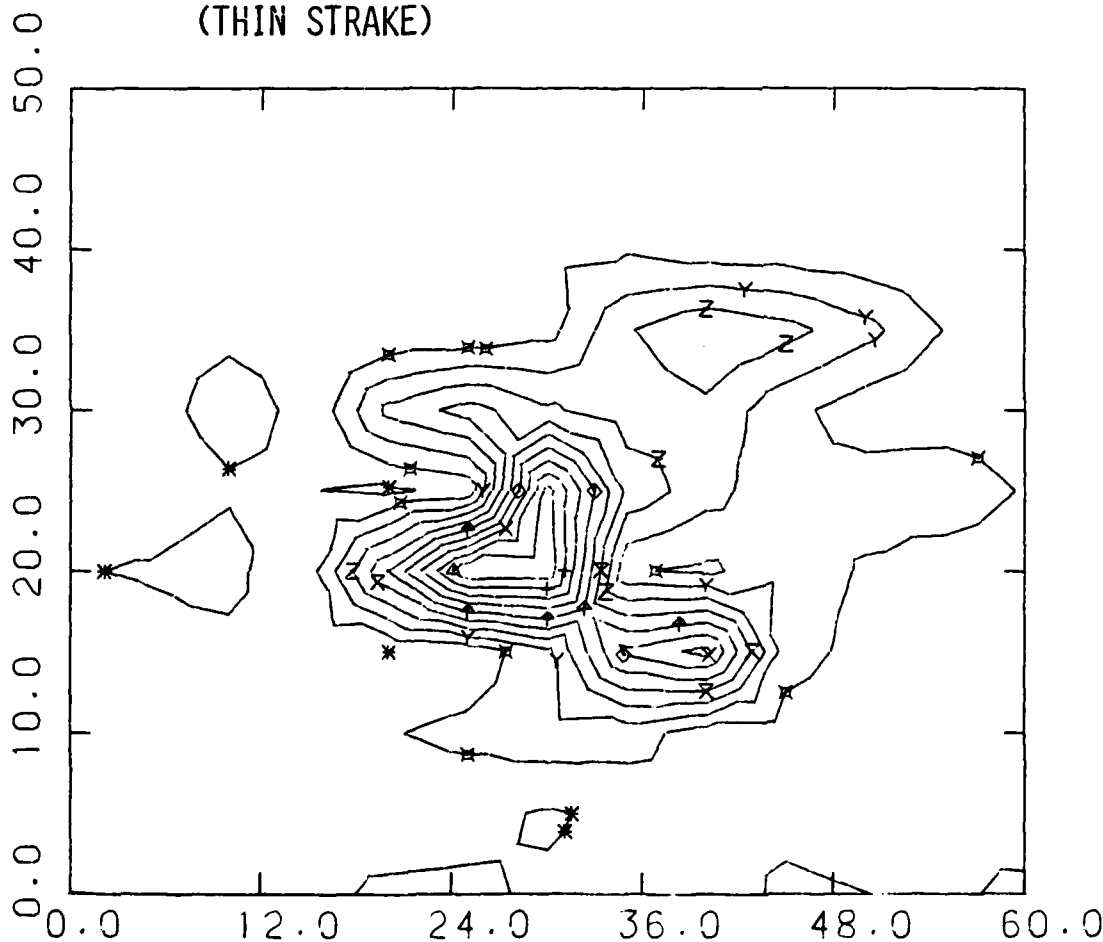
(THIN STRAKE)

FIG. 41B

TOTAL PRESSURE
DYNAMIC PRESSURE

RATIO FOR A FLOW FIELD DOWNSTREAM OF A STRAKE OF

RATIO $H = 0.50$ AT NEGATIVE ANGLE OF ATTACK. ($\alpha_R = -15$)
(THIN STRAKE)



MN151SP.DAT

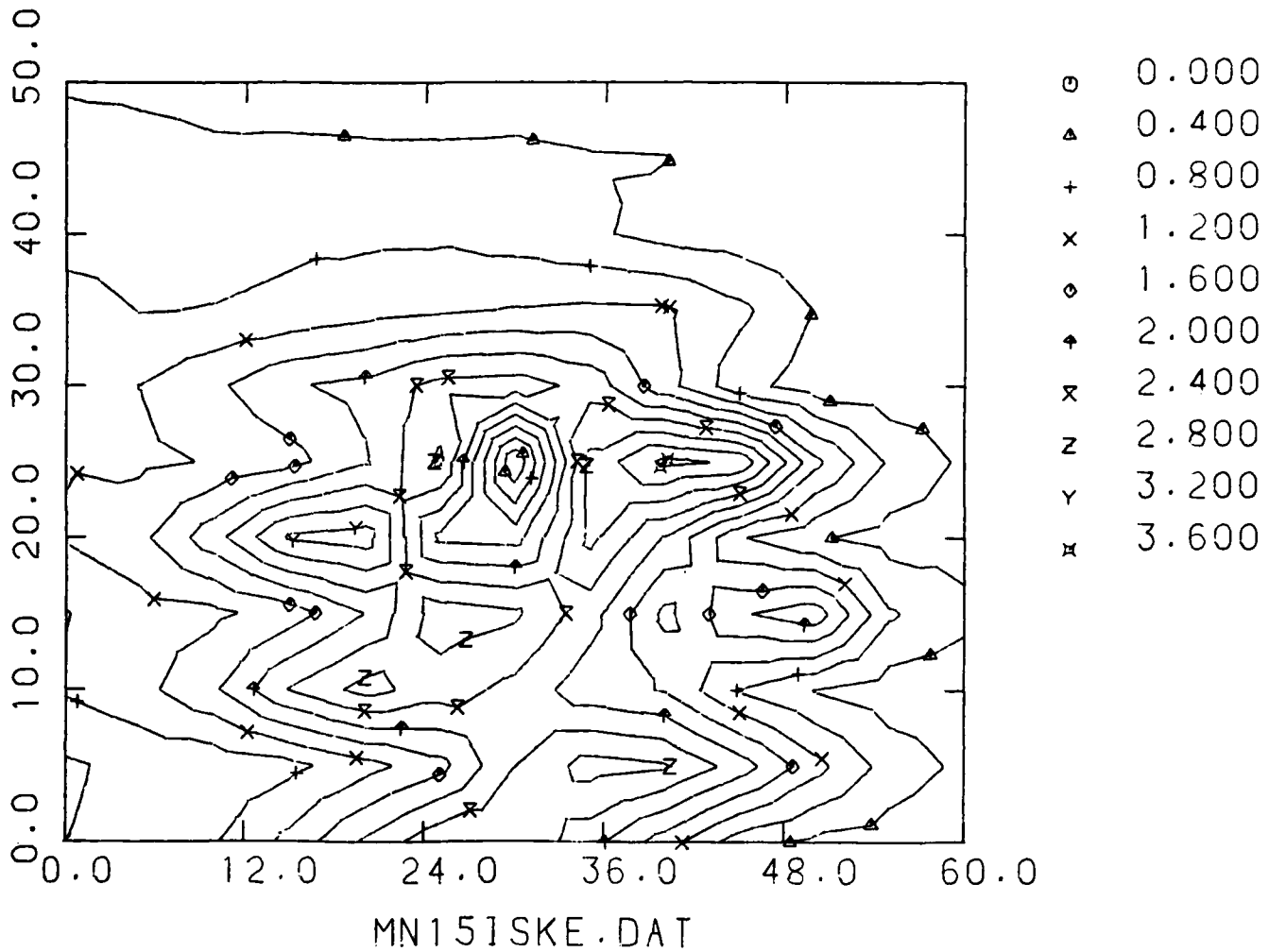


FIG. 41C - ISOLINES OF DCFKE DOWNSTREAM OF $H = 0.5$, $\alpha_R = -15$
THIN STRAKE

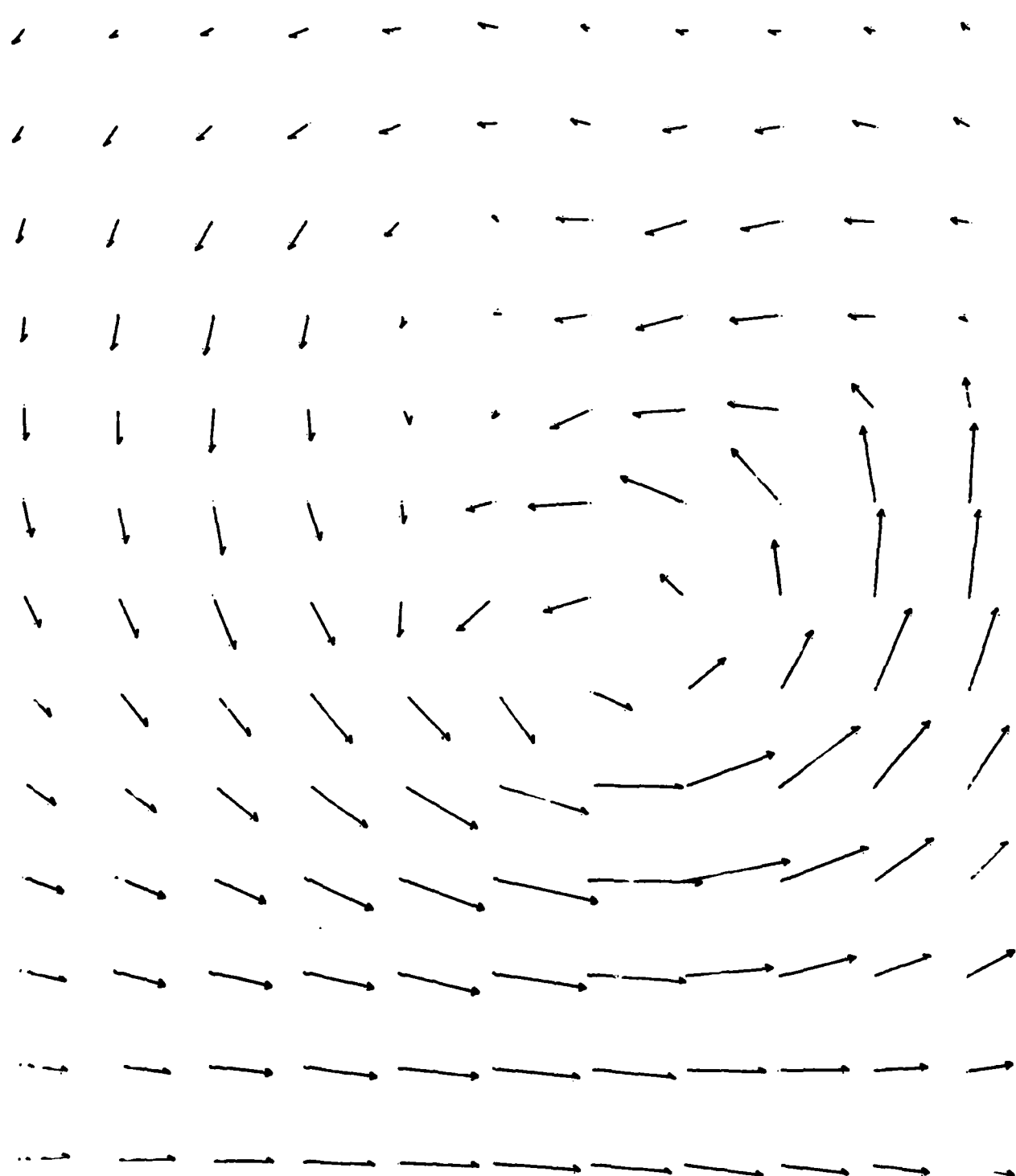


FIG. 42A

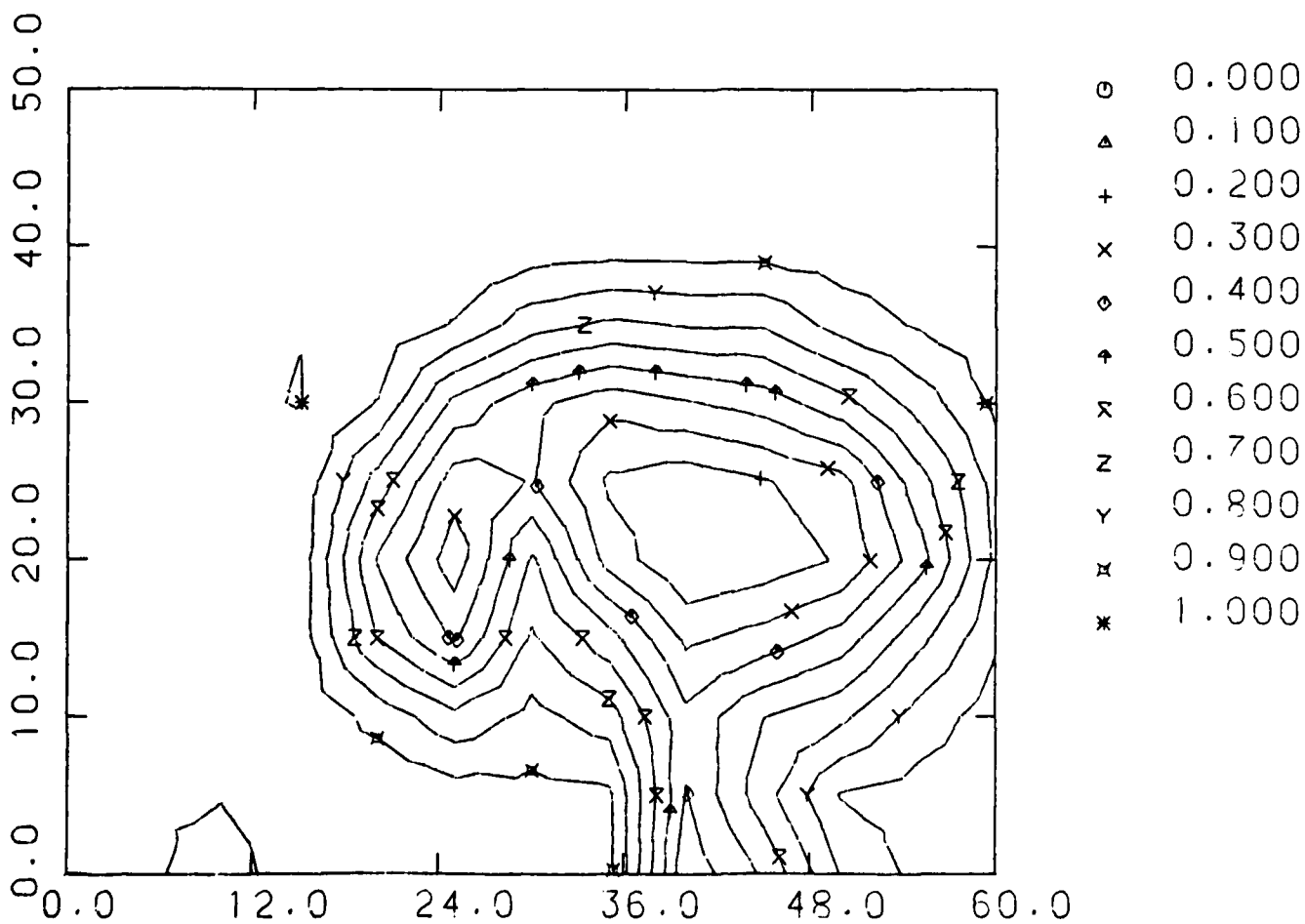
"STREAMLINING" EFFECT
PRODUCED BY PLACING A
STRAKE OF RATIO

$$H = 0.5$$

IN VERTICAL FLOW AT 0
INCIDENCE

FIG. 42B

ISOLINES OF $\frac{\text{TOTAL LOCAL PRESSURE}}{\text{DYNAMIC PRESSURE}}$ WHEN STRAKE OF $H = 0.5$
AT ZERO INCIDENCE ALONG THE VORTEX PATH



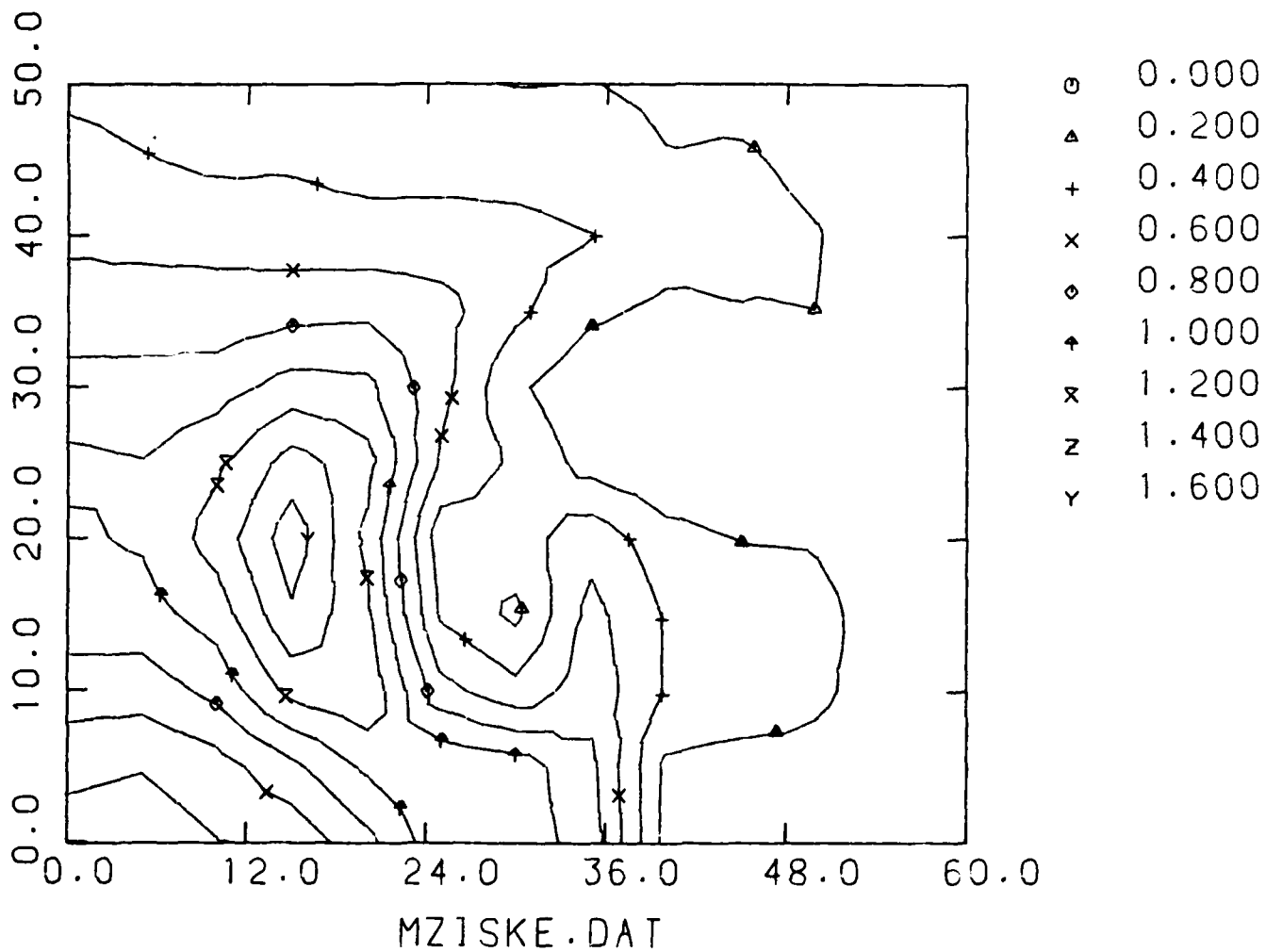


FIG. 42C - ISOLINES OF DCFKE DOWNSTREAM OF $H = 0.5$, $\alpha_R = 0$ THIN STRAKE

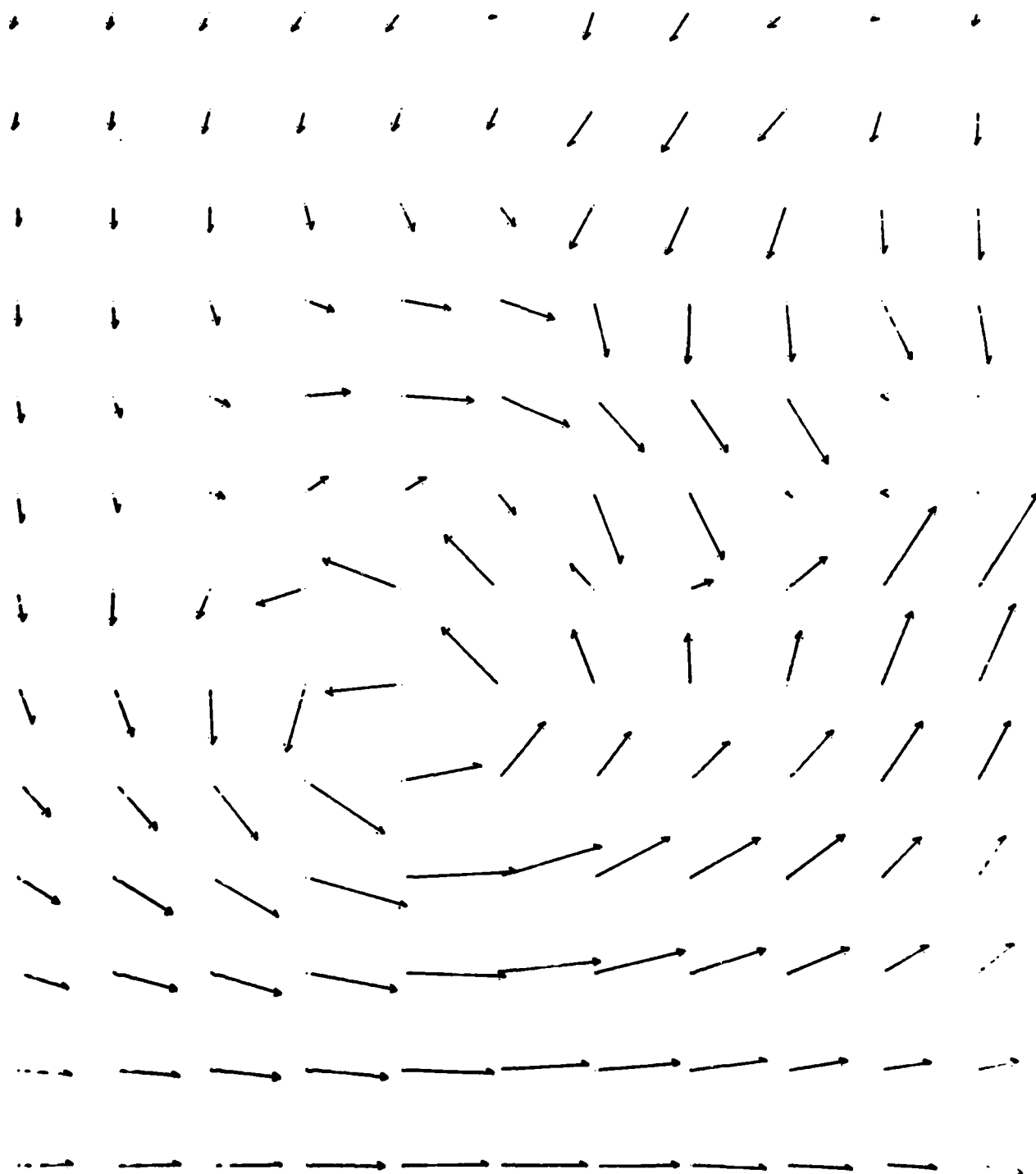


FIG. 43A

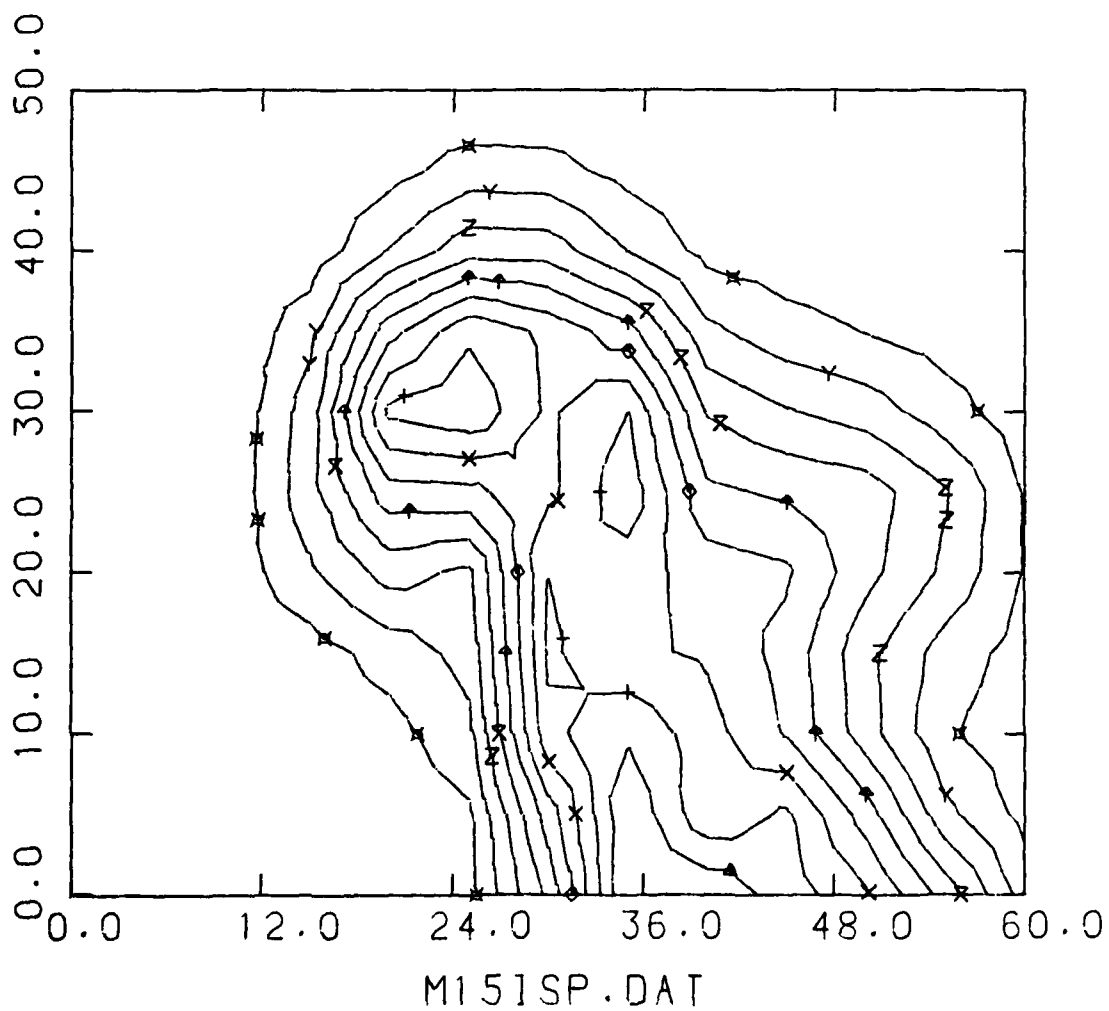
"DOUBLE VORTEX" OF OPPOSITE
MAGNITUDE EFFECT CREATED BY
LOCATING STRAKE OF

$H = 0.5$ RATIO AT
POSITIVE INCIDENCE, $\alpha_R = 15$
NET RESULT IS A DECREASE IN
CROSS FLOW KINETIC ENERGY

FIG. 43B

BIFURCATION OF VORTICAL FLOW WHEN A STRAKE OF RATIO
IS PLACED ALONG THE VORTEX CORE PATH AT $\alpha_R = 15^\circ$

H = 0.5



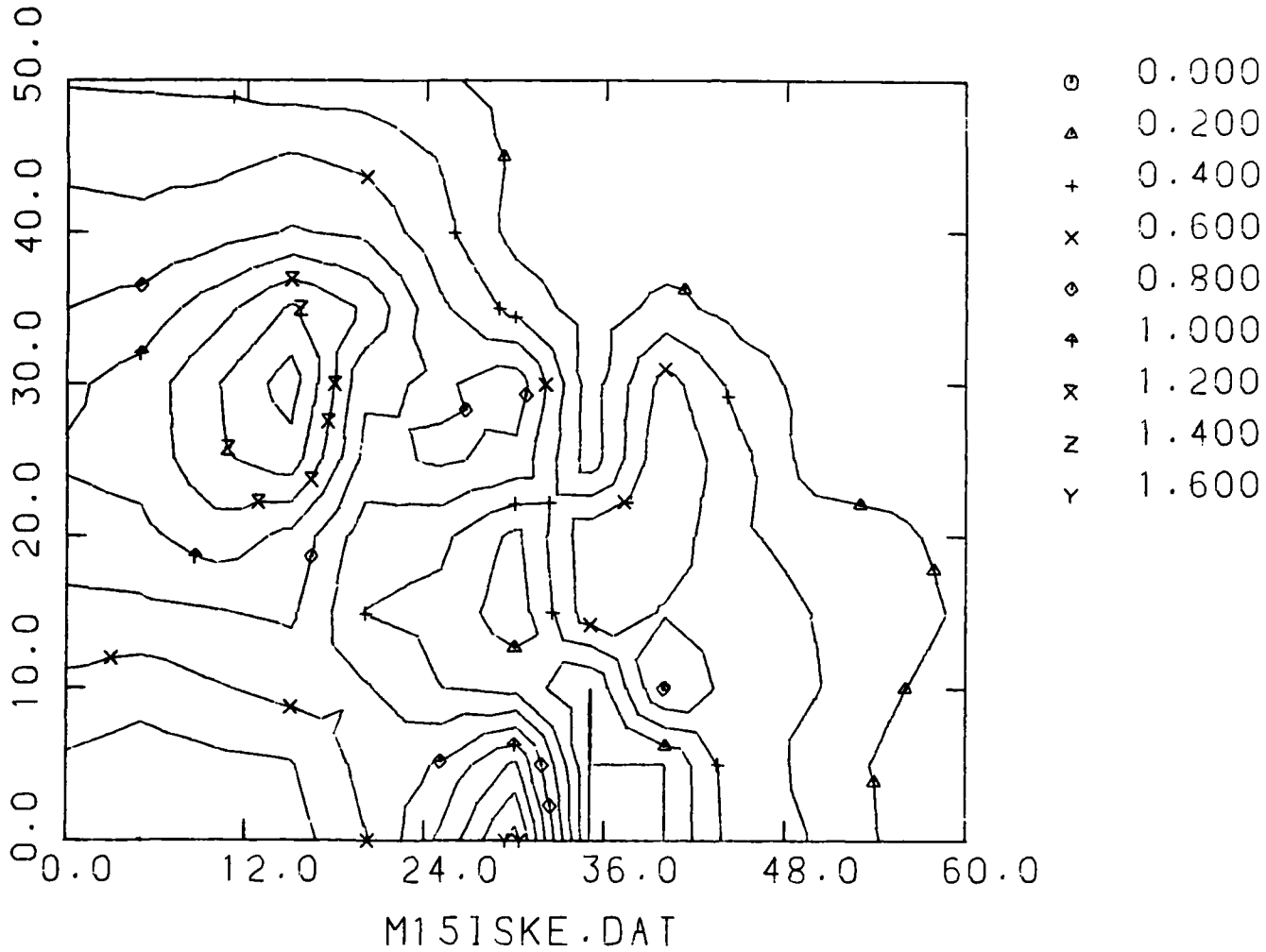
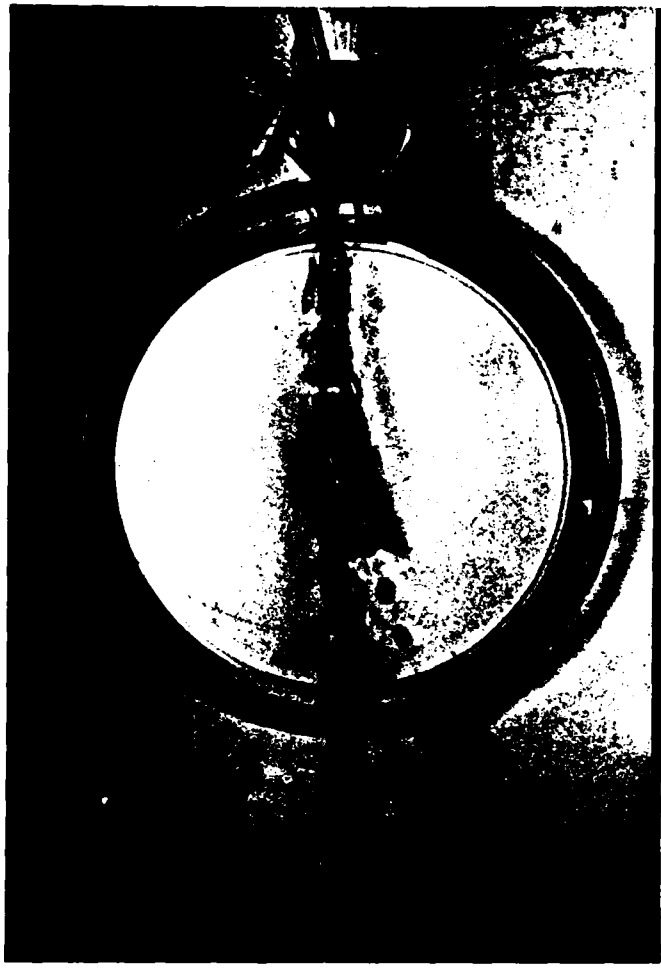


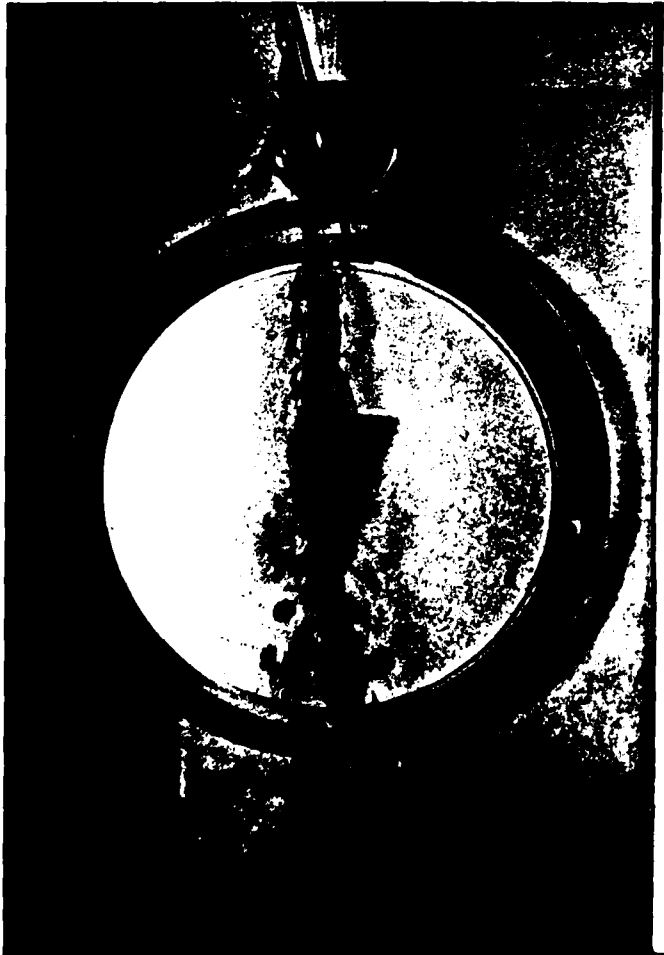
FIG. 43C - ISOLINES OF DCFKE DOWNSTREAM OF $H = 0.5$, $\alpha_R = 15$ THIN STRAKE



(A) $\alpha_R = -15$



(B) $\alpha_R = 0$



(C) $\alpha_R = 15$

FIG. 44 - WATER TUNNEL
VISUALIZATION FOR $H = 0.5$
THIN STRAKE DOWNSTREAM OF
DELTA WING

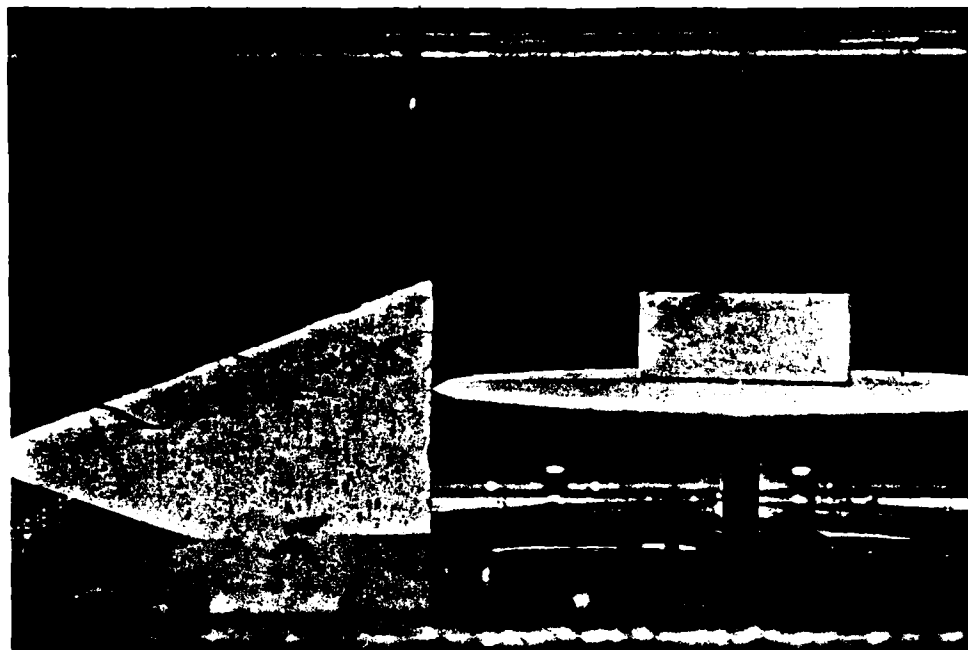


FIG. 44D - WATER TUNNEL VISUALIZATION (SIDE VIEW)
FOR $H = 0.5$, $\alpha_R = 15^\circ$ THIN STRAKE

FIG. 45A - FLOW FIELD DOWNSTREAM
OF $H = 1.0$, $\alpha_R = -15$ THIN STRAKE

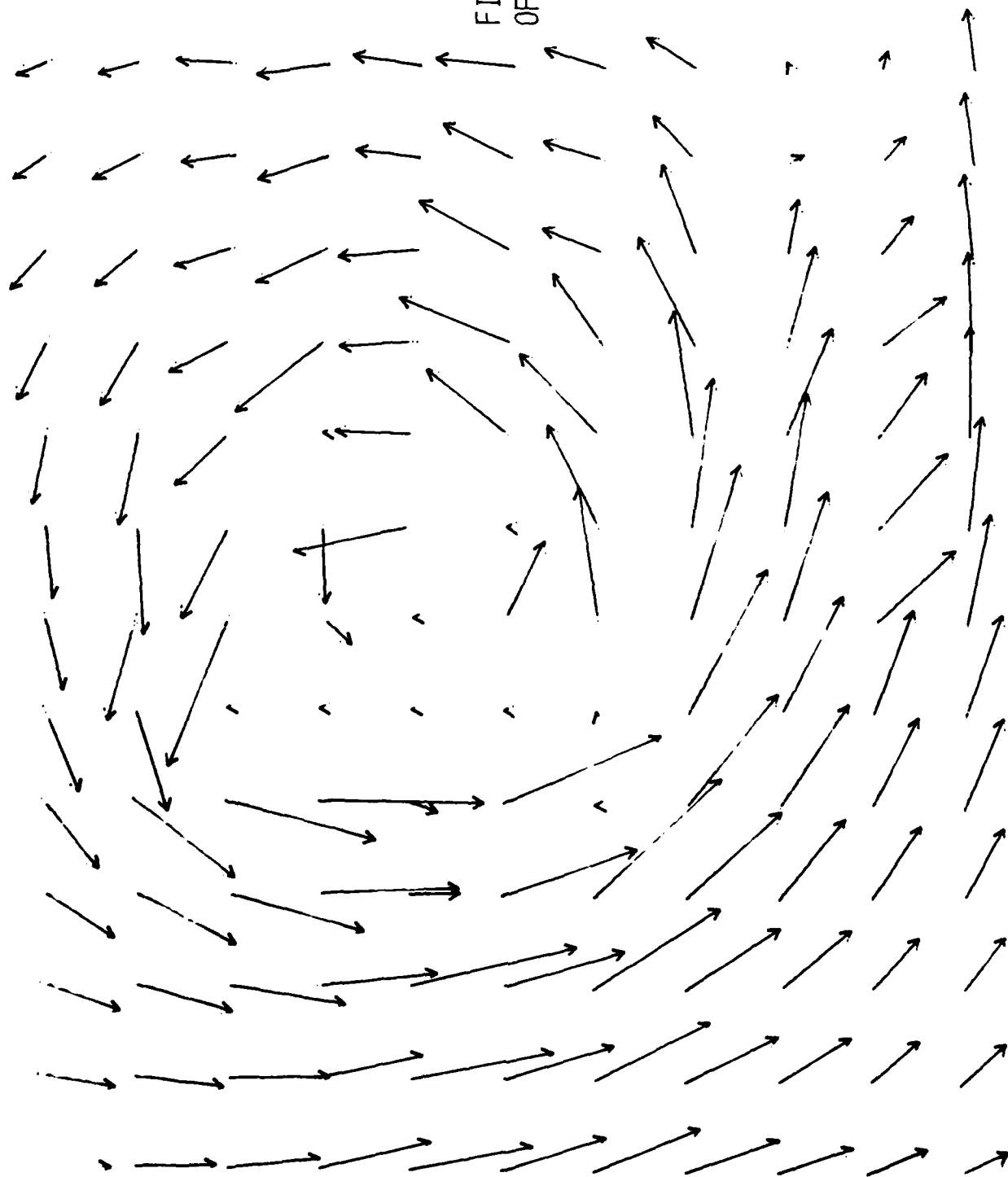
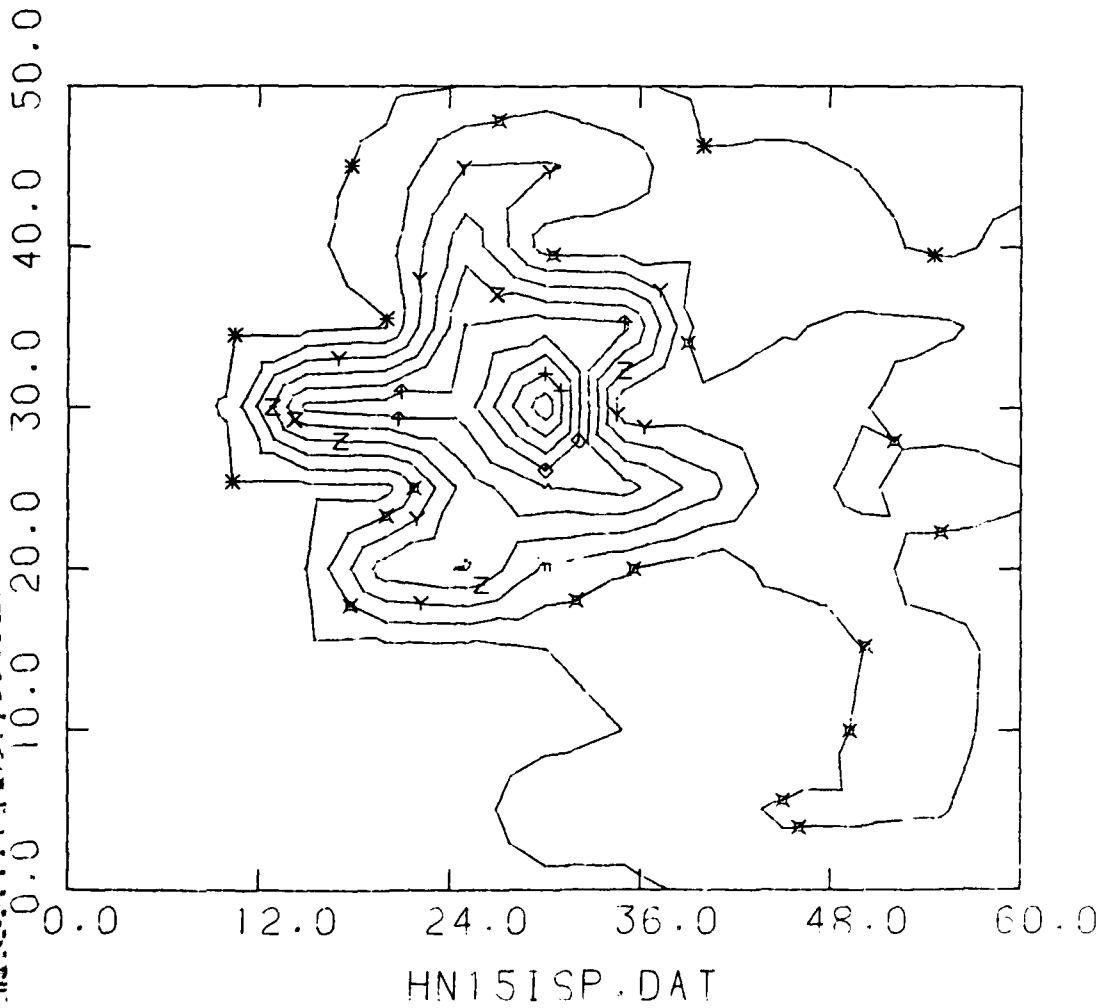


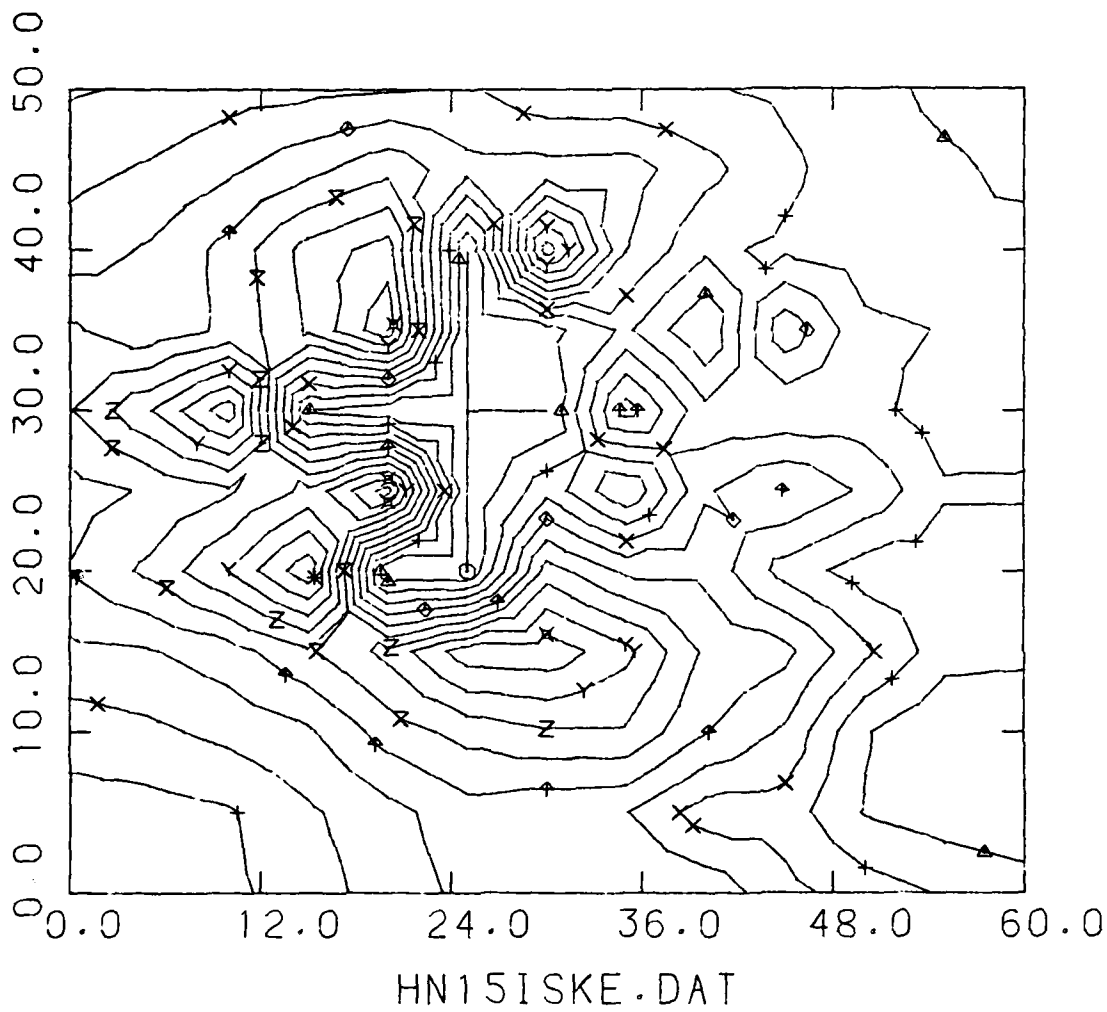
FIG. 45B

ISOLINES OF $\frac{\text{TOTAL LOCAL PRESSURE}}{\text{DYNAMIC PRESSURE}}$ DOWNSTREAM OF A STRAKE OF

RATIO $\frac{H \text{ WAKE}}{H \text{ STRAKE}} = 1.0$

STRAKE ANGLE OF ATTACK = - 15°





- 0.000
- △ 0.400
- + 0.800
- x 1.200
- ◇ 1.600
- ⋈ 2.000
- ⊗ 2.400
- z 2.800
- γ 3.200
- ⊘ 3.600
- * 4.000

FIG. 45C - ISOLINES OF DCFKE DOWNSTREAM OF $H = 1.0$, $\alpha_R = -15$ THIN STRAKE

FIG. 46A— FLOW FIELD DOWN-
STREAM OF $h = 1.0, \alpha_R = 0$
THIN STRAKE

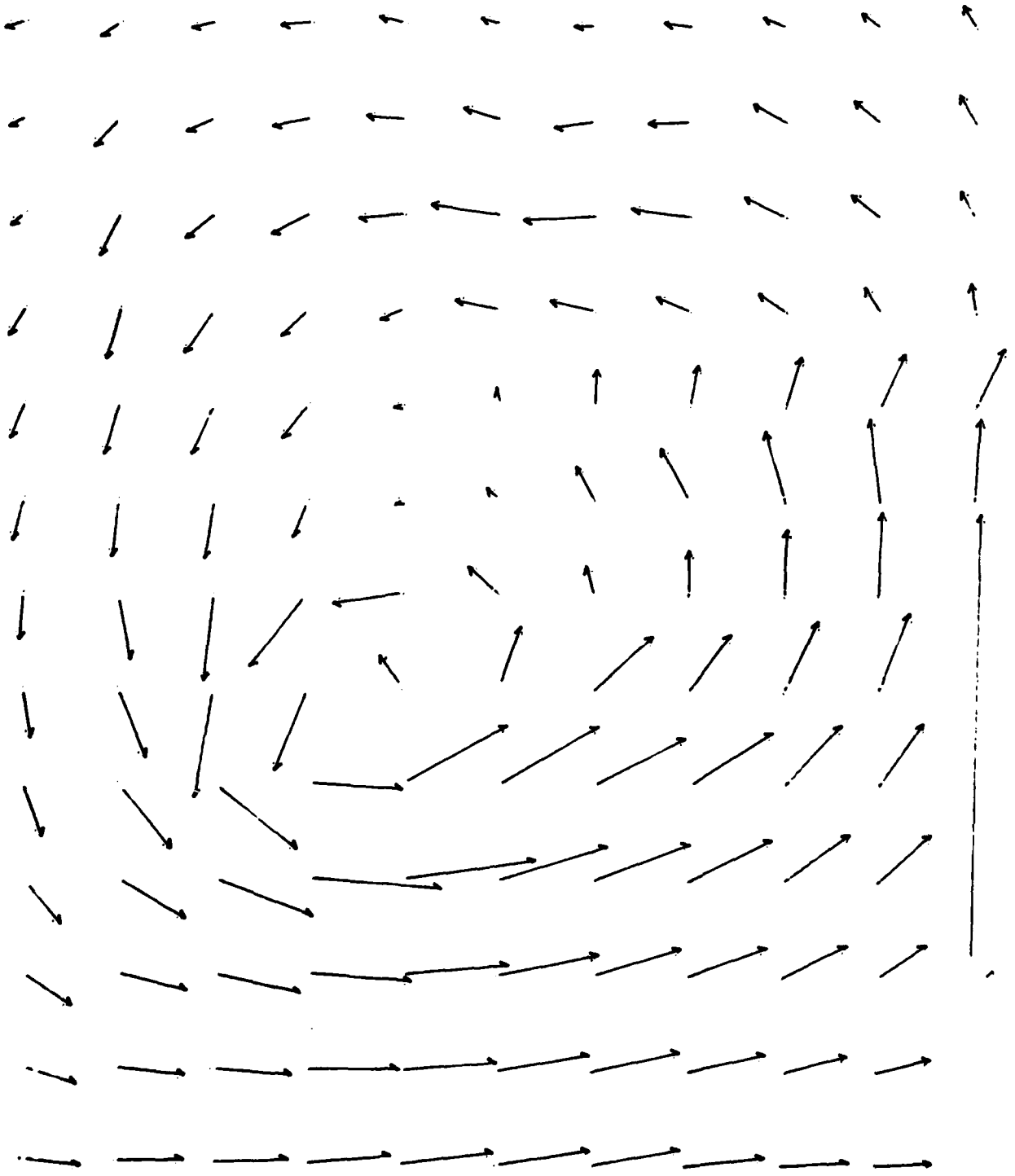
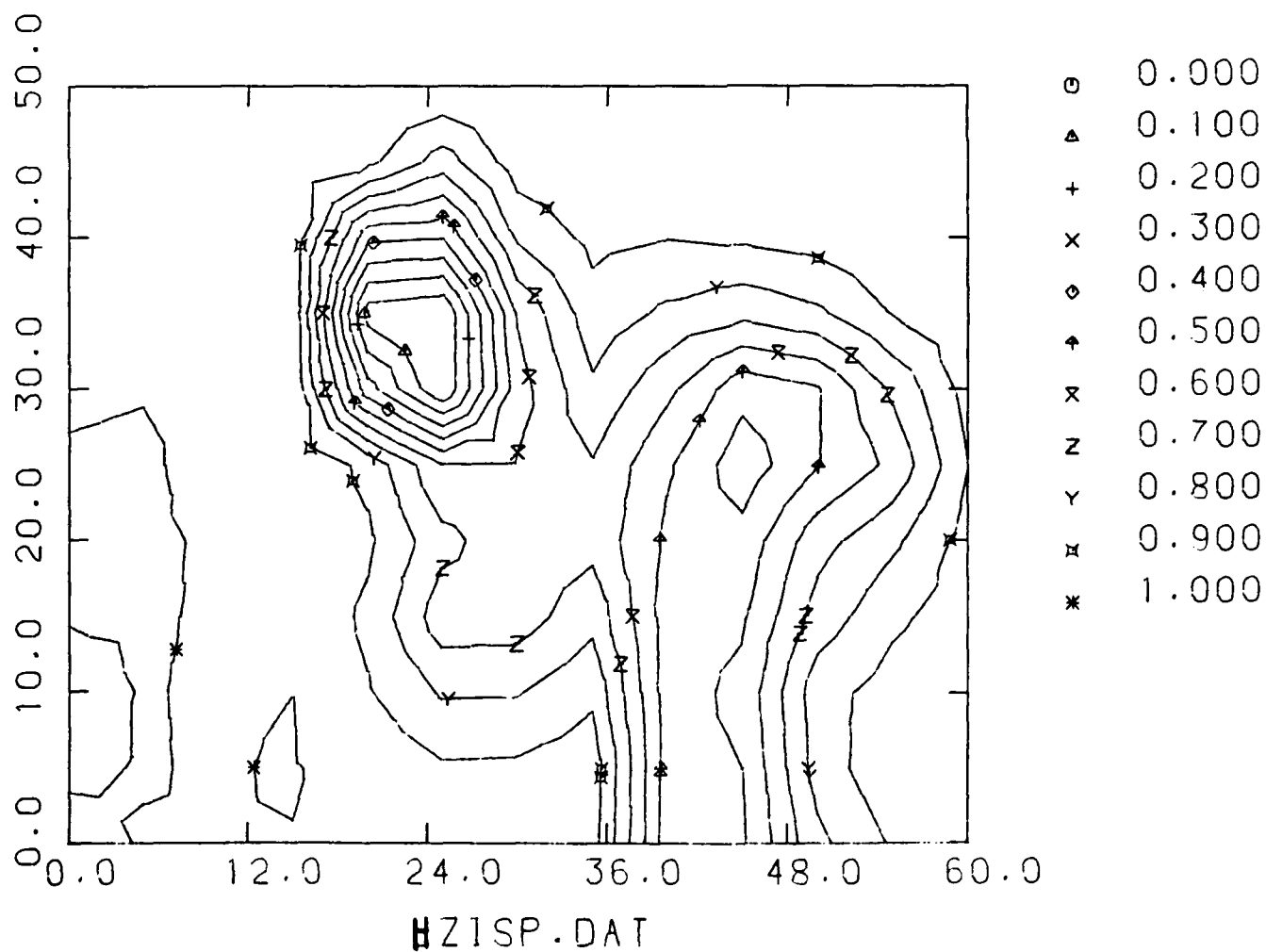


FIG. 46B

BIFURCATION OF VORTICAL FLOW WHEN A STRAKE OF RATIO

$H = 1.0$

IS PLACED ALONG THE VORTEX CORE. ($\alpha_R = 0$)



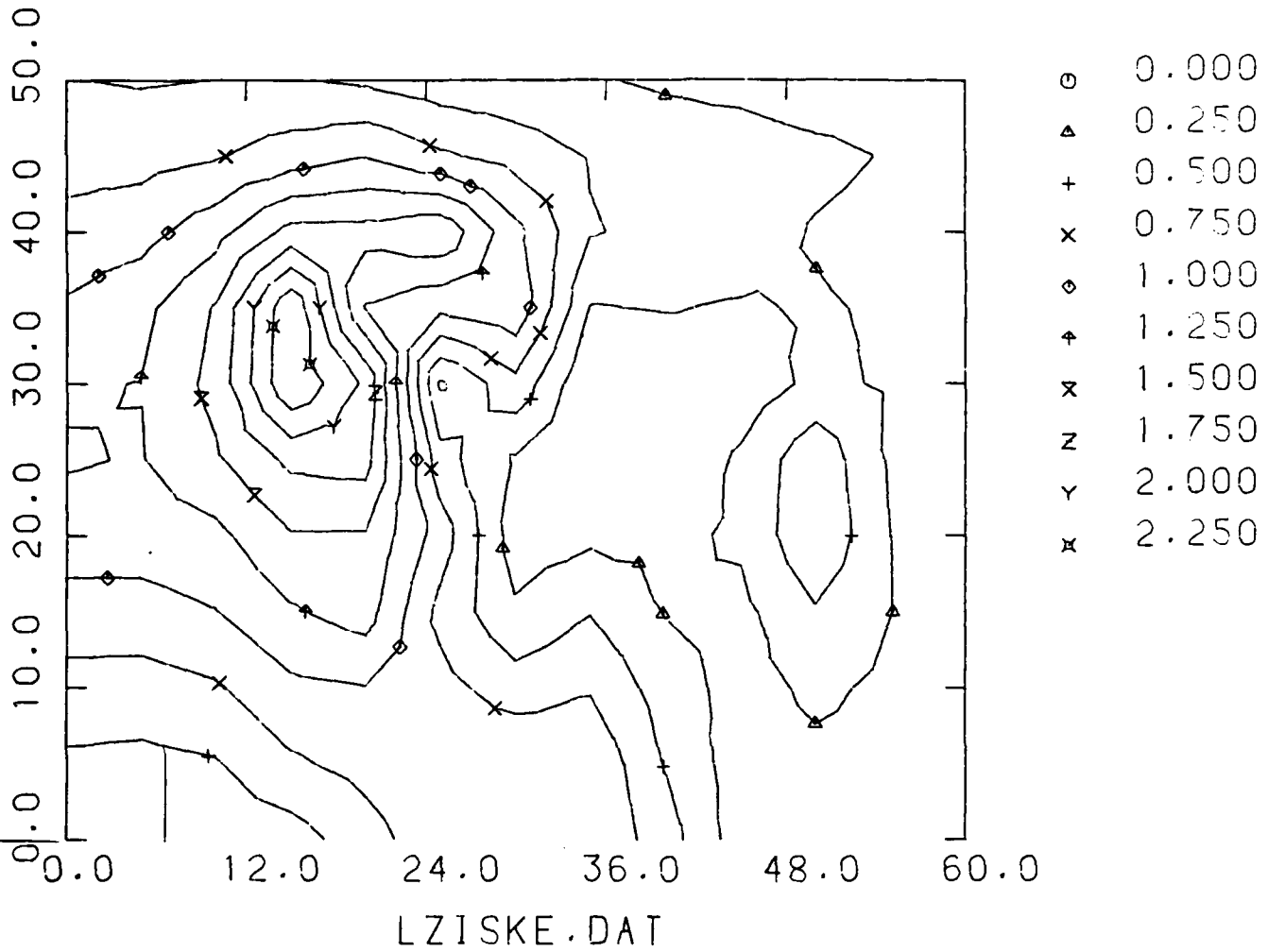


FIG. 46C - ISOLINES OF DCFKE DOWNSTREAM OF $H = 1.0$, $\alpha_R = 0$ THIN STRAKE

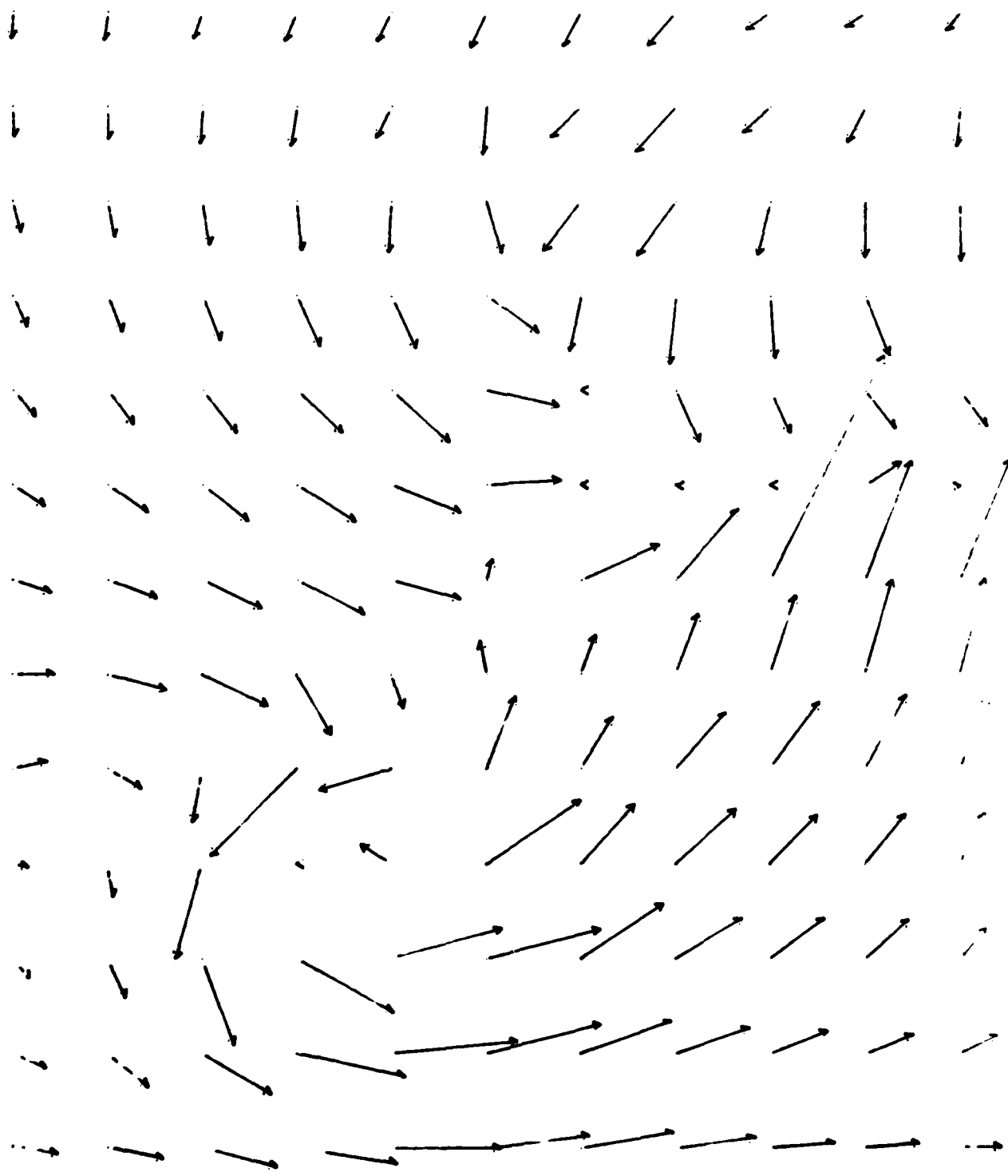


FIG. 47A

FLOW FIELD DOWNSTREAM OF
STRAKE OF RATIO

$$H = 1.0$$

AT POSITIVE INCIDENCE
 $\alpha_R = 15$ THIN STRAKE

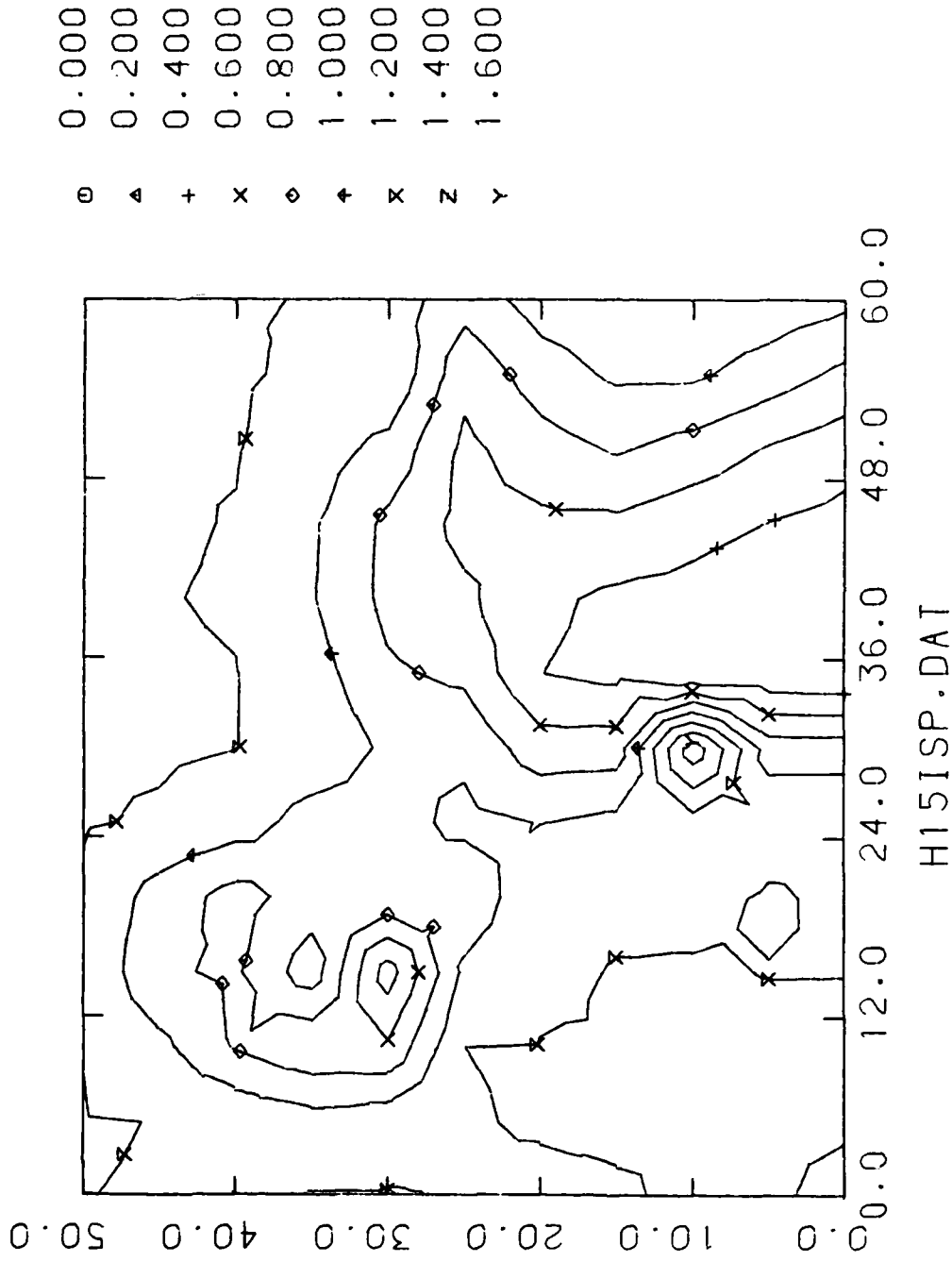


FIG. 47B - ISOLINES OF P_R DOWNSTREAM OF $H = 1.0$, $\alpha_R = 15$ THIN STRAKE

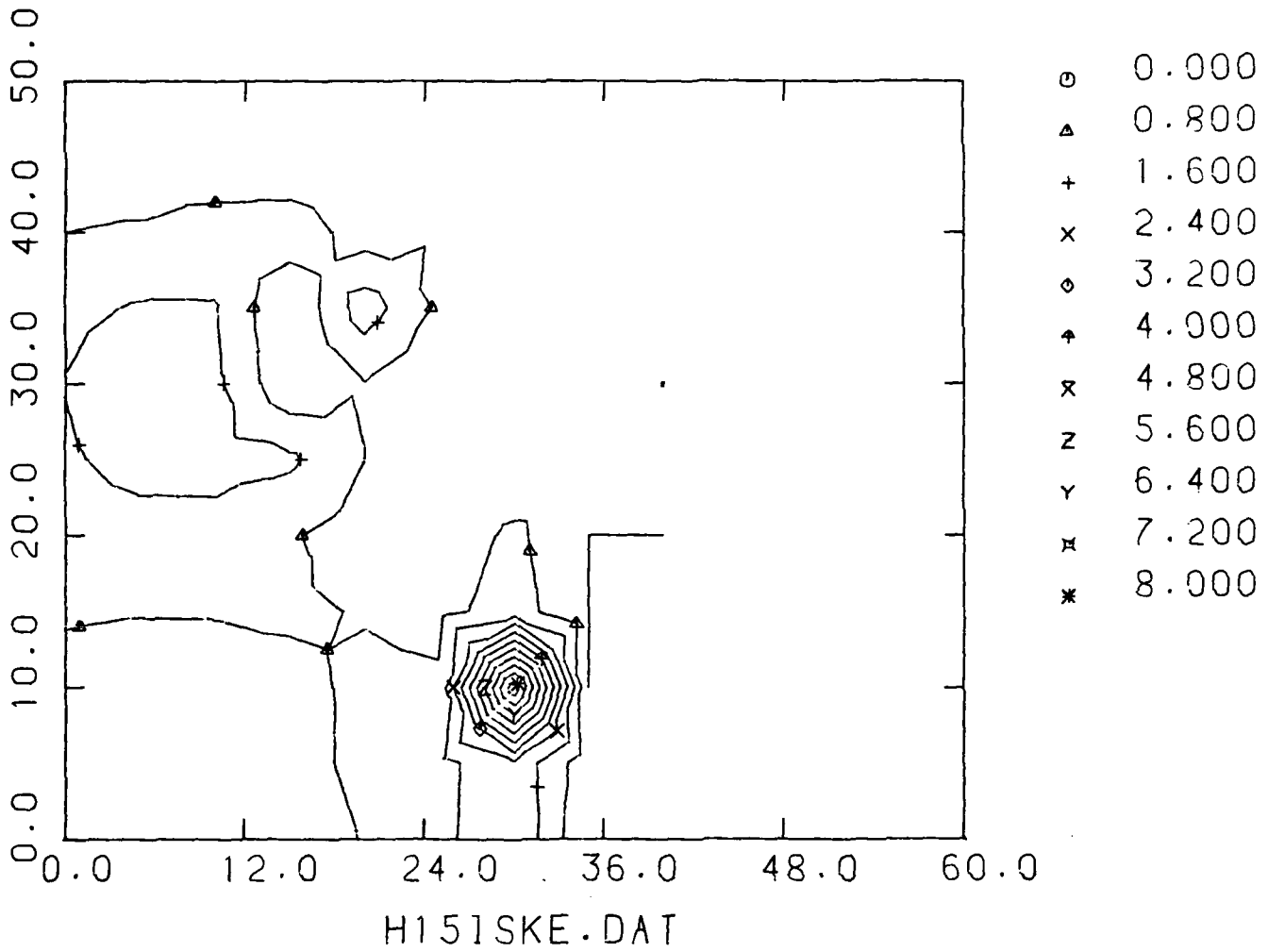
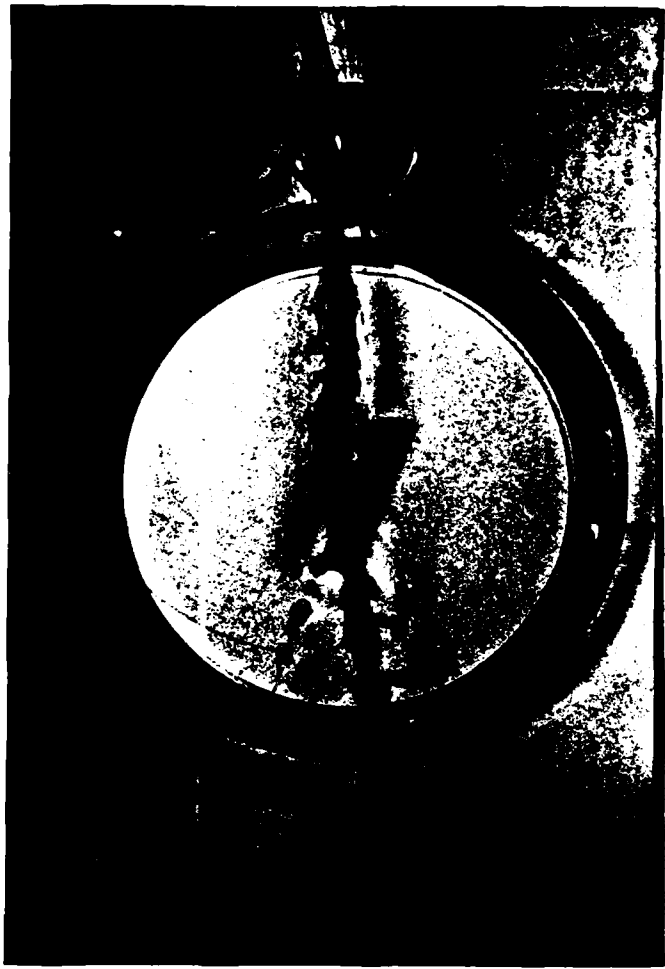
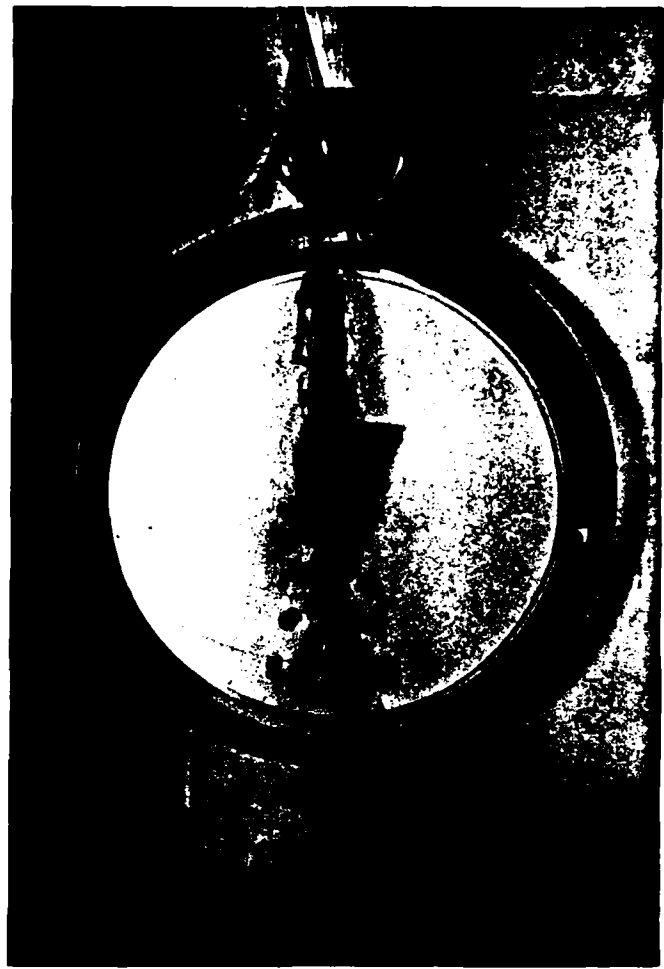


FIG. 47C - ISOLINES OF DCFKE DOWNSTREAM OF $H = 1.0$, $\alpha_R = 15$ THIN STRAKE



H = 0



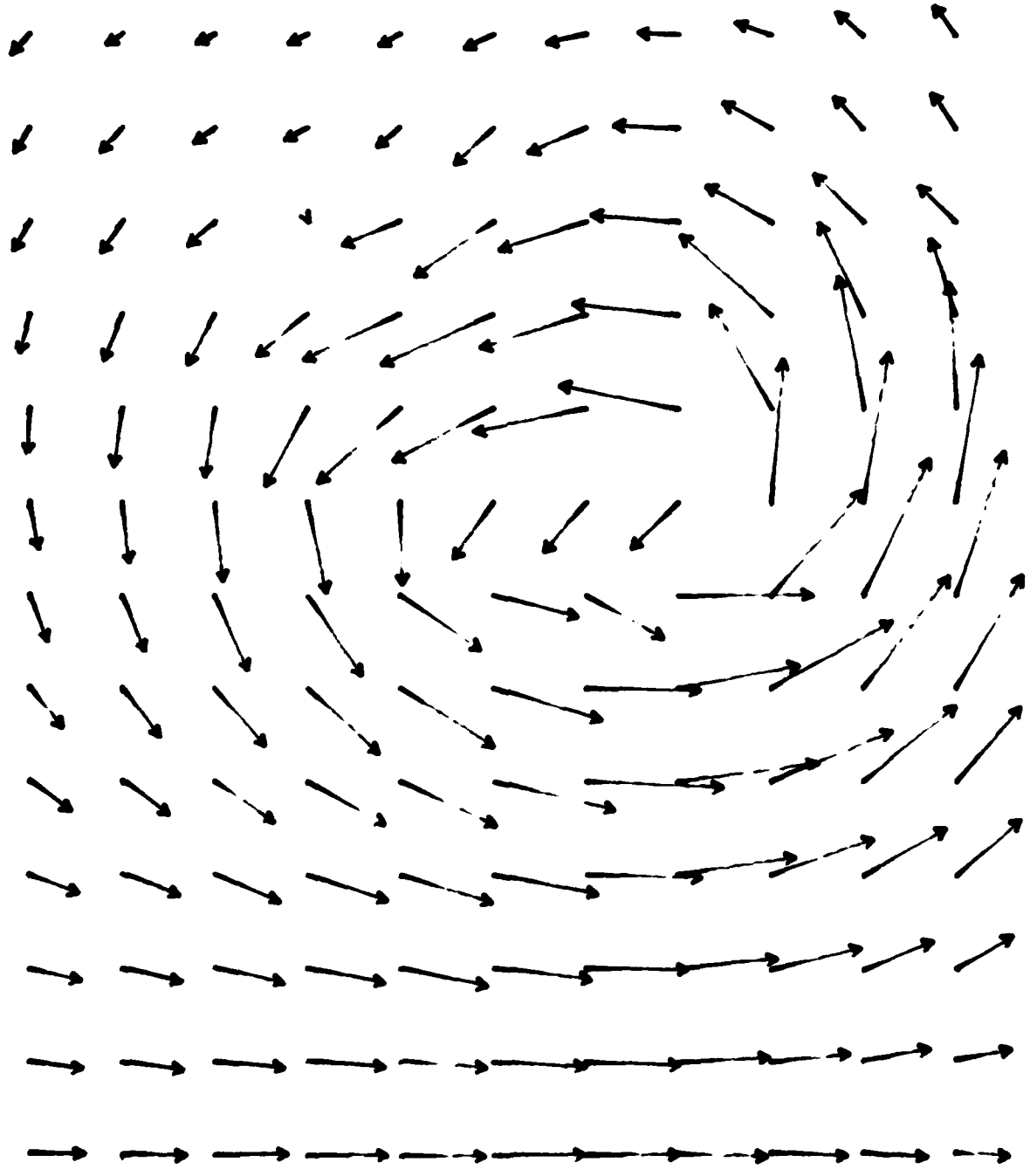
H = 0.5



H = 1.0

FIG. 48 - WATER VISUALIZATION
FOR THIN STRAKE AT
 $\alpha_R = 15$ DOWNSTREAM OF
DELTA WING

FIG. 49A - FLOW FIELD DOWNSTREAM
OF $H = 0.5$, $\alpha_R = -15$ THICK STRAKE



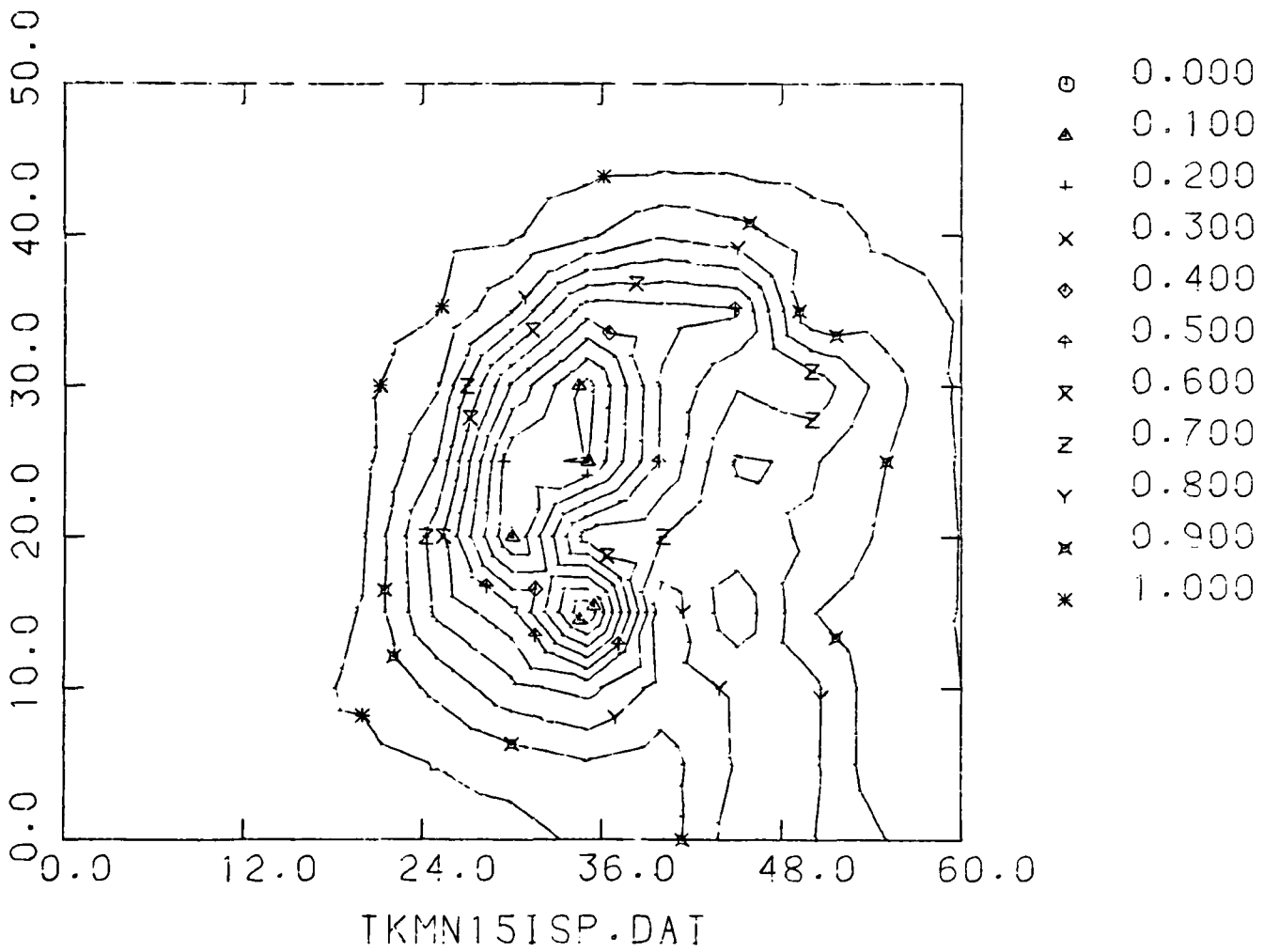
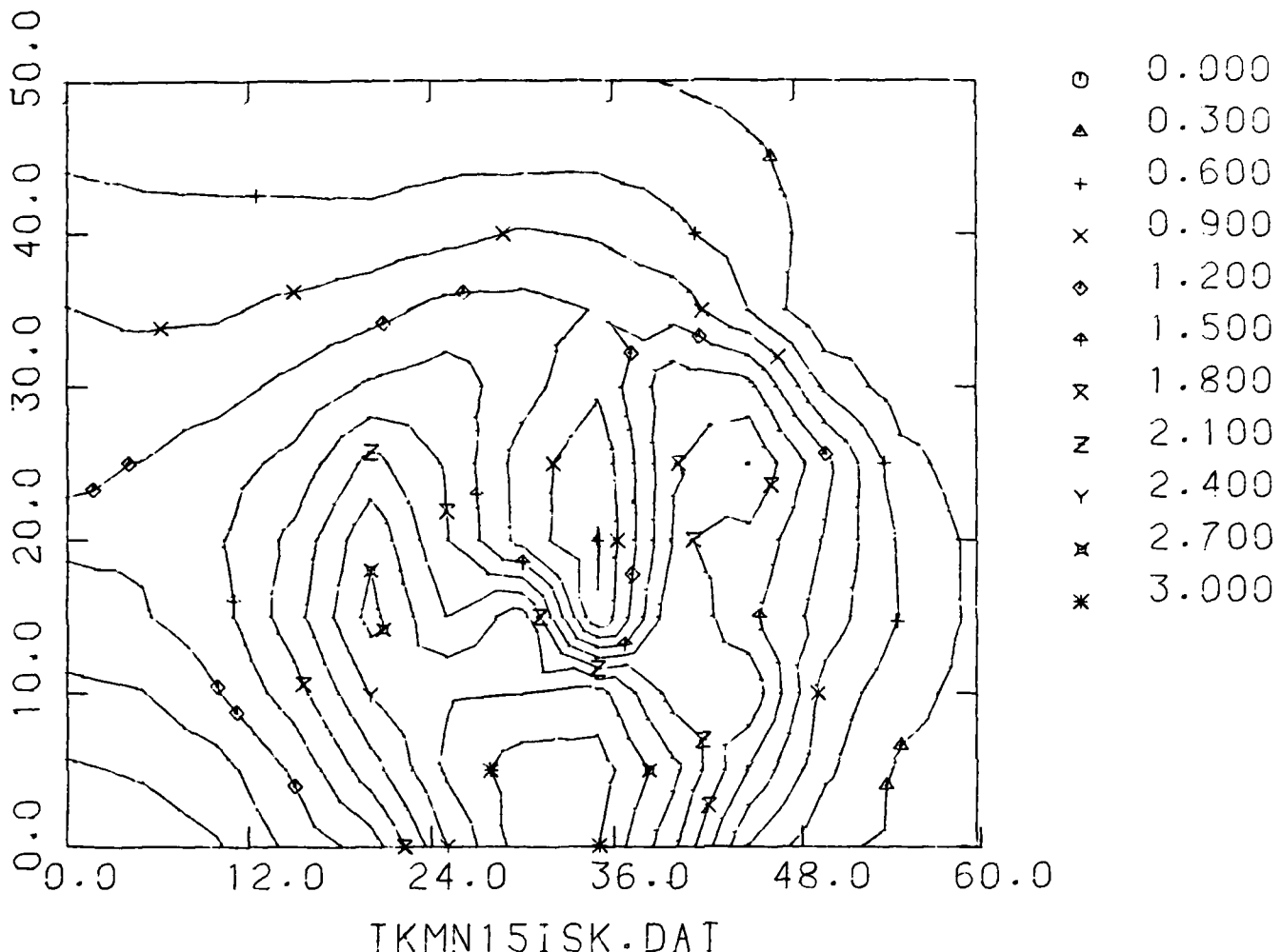


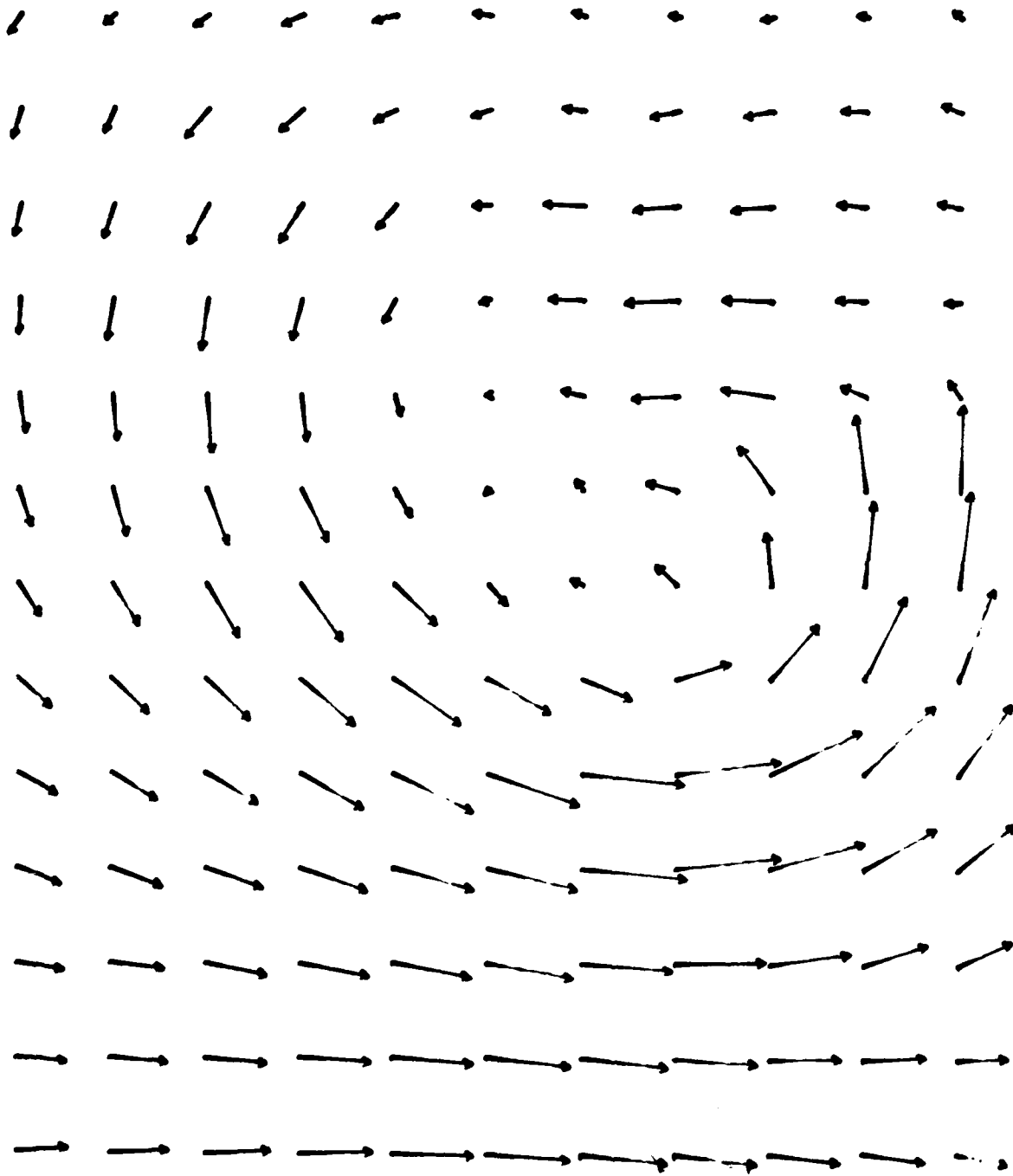
FIG. 49B - ISOLINES OF P_R DOWNSTREAM OF $H = 0.5$, $\alpha_R = -15$ THICK STRAKE



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FIG. 49C - ISOLINES OF DCFKE DOWNSTREAM OF $H = 0.5$, $\alpha_R = -15$ THICK STRAKE

FIG. 50A - FLOW FIELD DOWNSTREAM
OF $H = 0.5$, $\alpha_R = 0$ THICK STRAKE



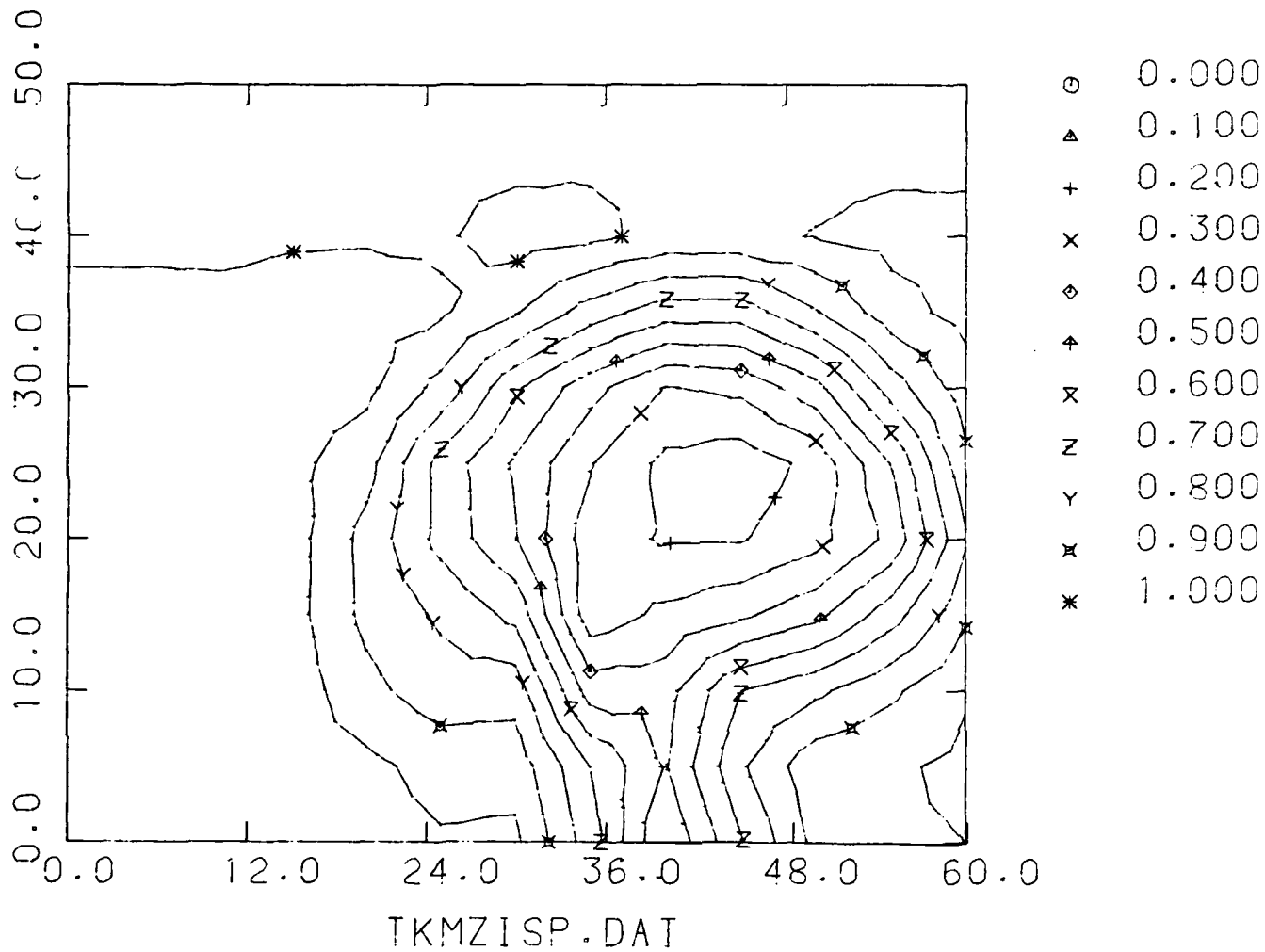


FIG. 50B - ISOLINES OF P_R DOWNSTREAM OF $H = 0.5$, $\alpha_R = 0$ THICK STRAKE

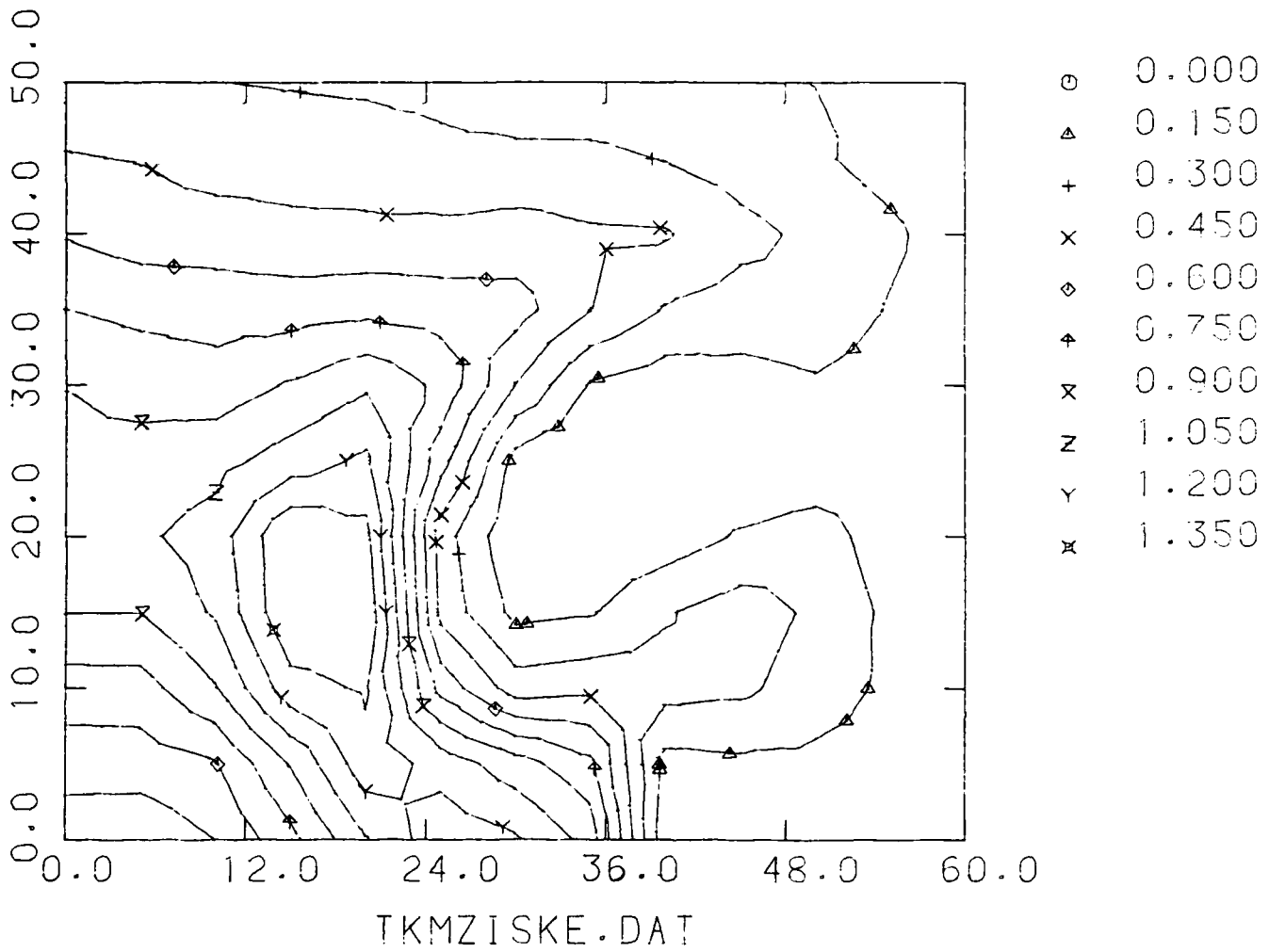
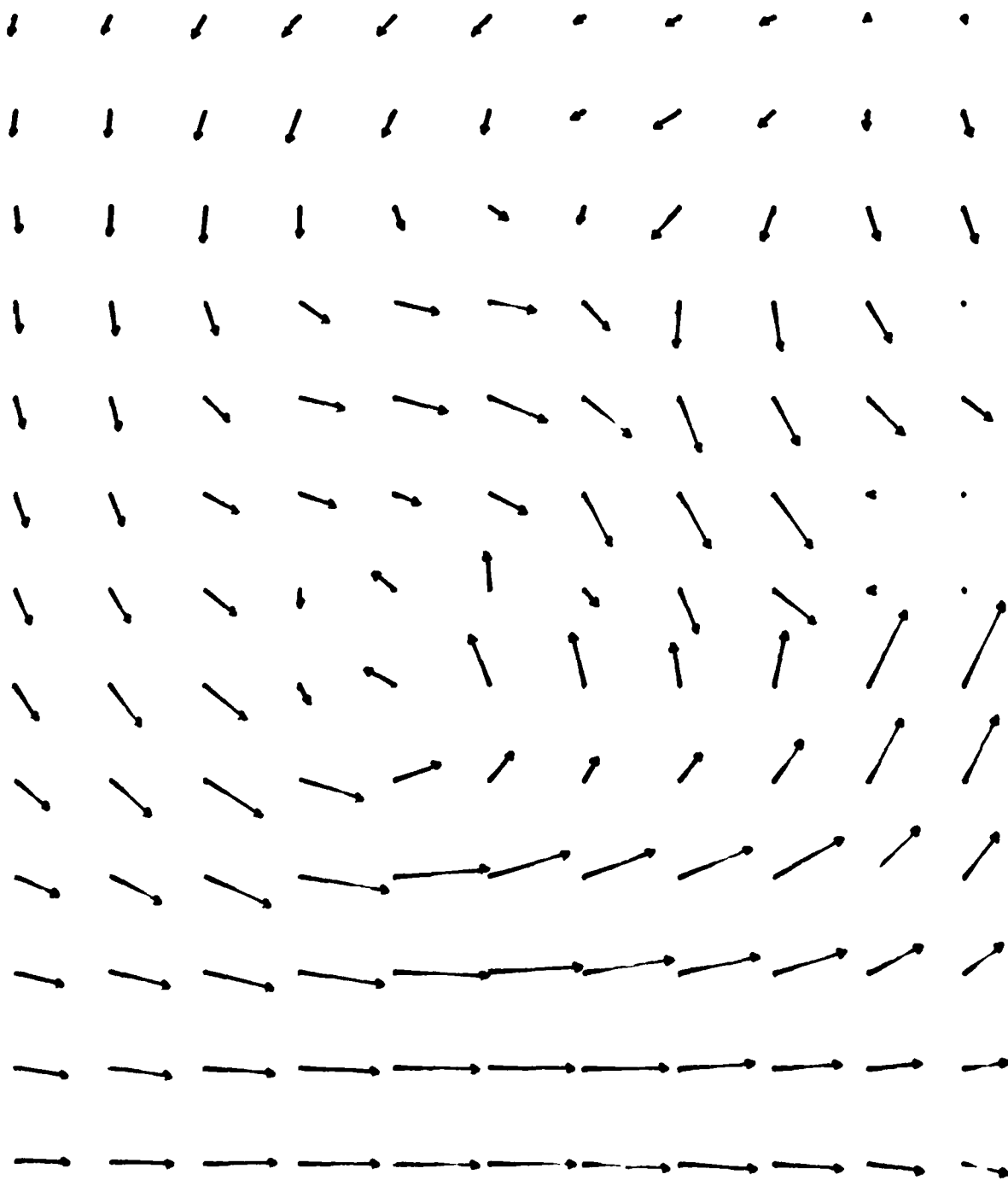


FIG. 50C - ISCLINES OF DCFKE DOWNSTREAM OF $H = 0.5$, $\alpha_R = 0$ THICK STRAKE

FIG. 51A - FLOW FIELD DOWN-
STREAM OF $H = 0.5$, $\alpha_R = 15$
THICK STRAKE



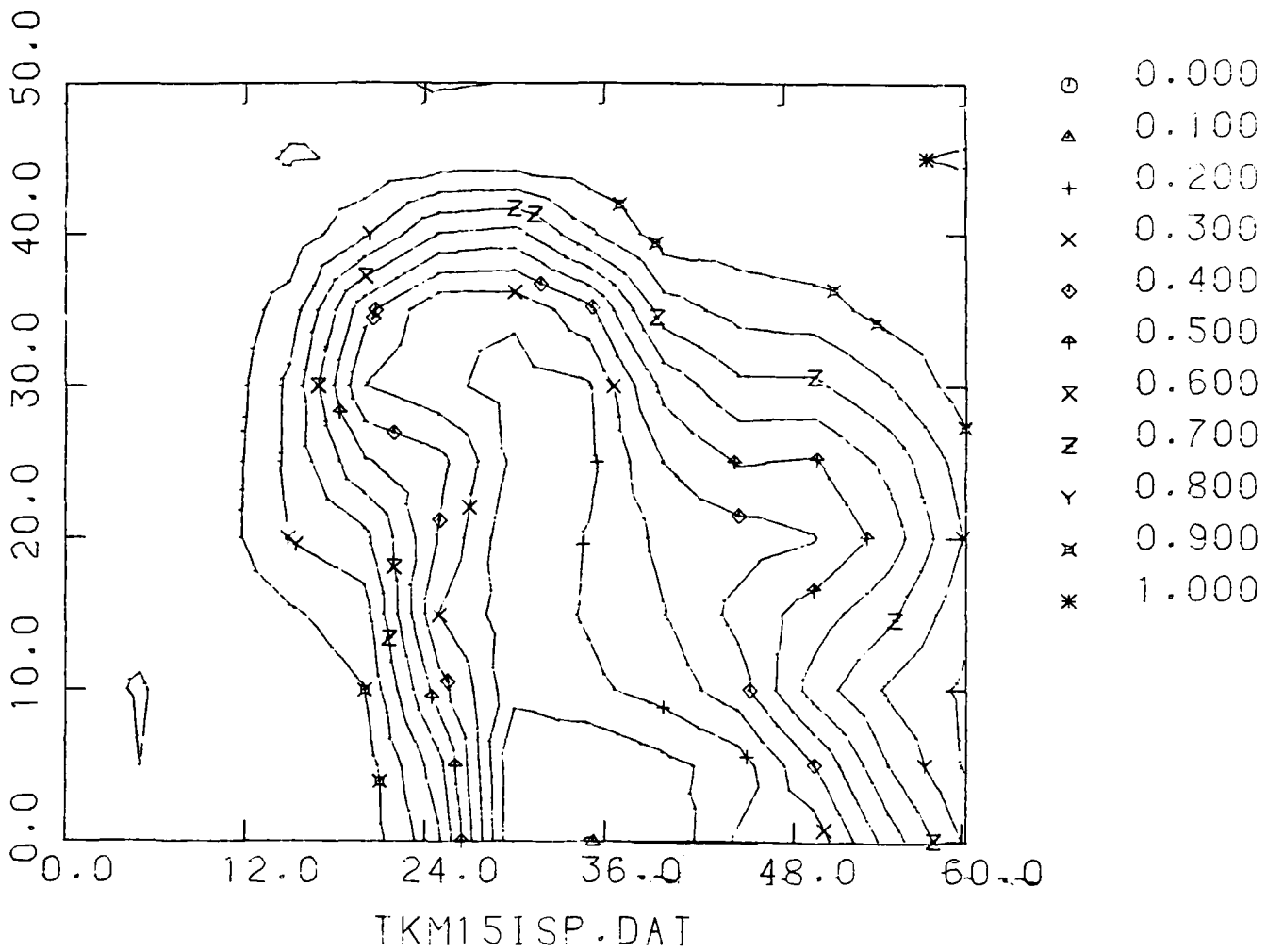


FIG. 51B - ISOLINES OF P_R DOWNSTREAM OF $H = 0.5$, $\alpha_R = 15$ THICK STRAKE

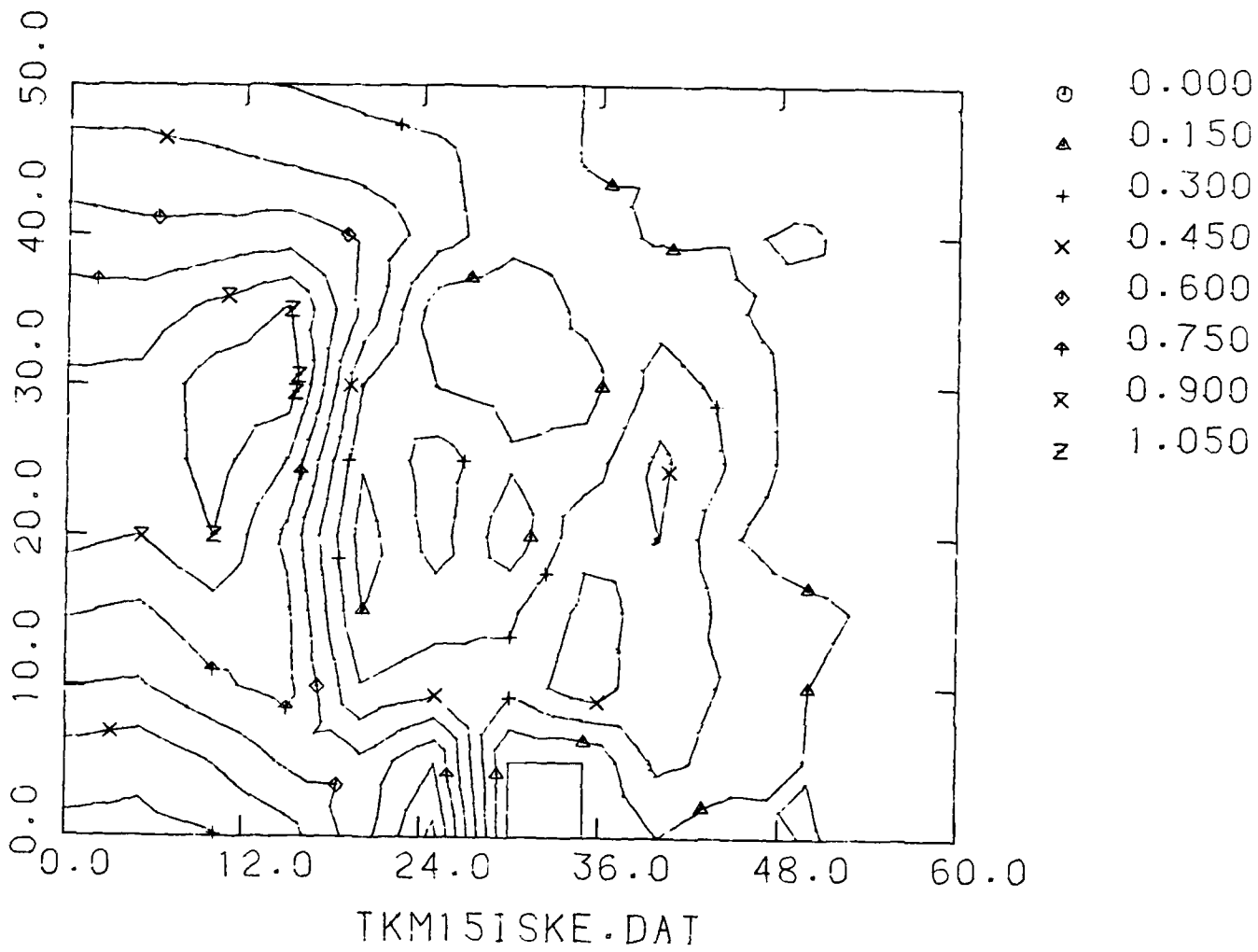


FIG. 51C - ISOLINES OF DCFKE DOWNSTREAM OF $H = 0.5$, $\alpha_R = 15$ THICK STRAKE

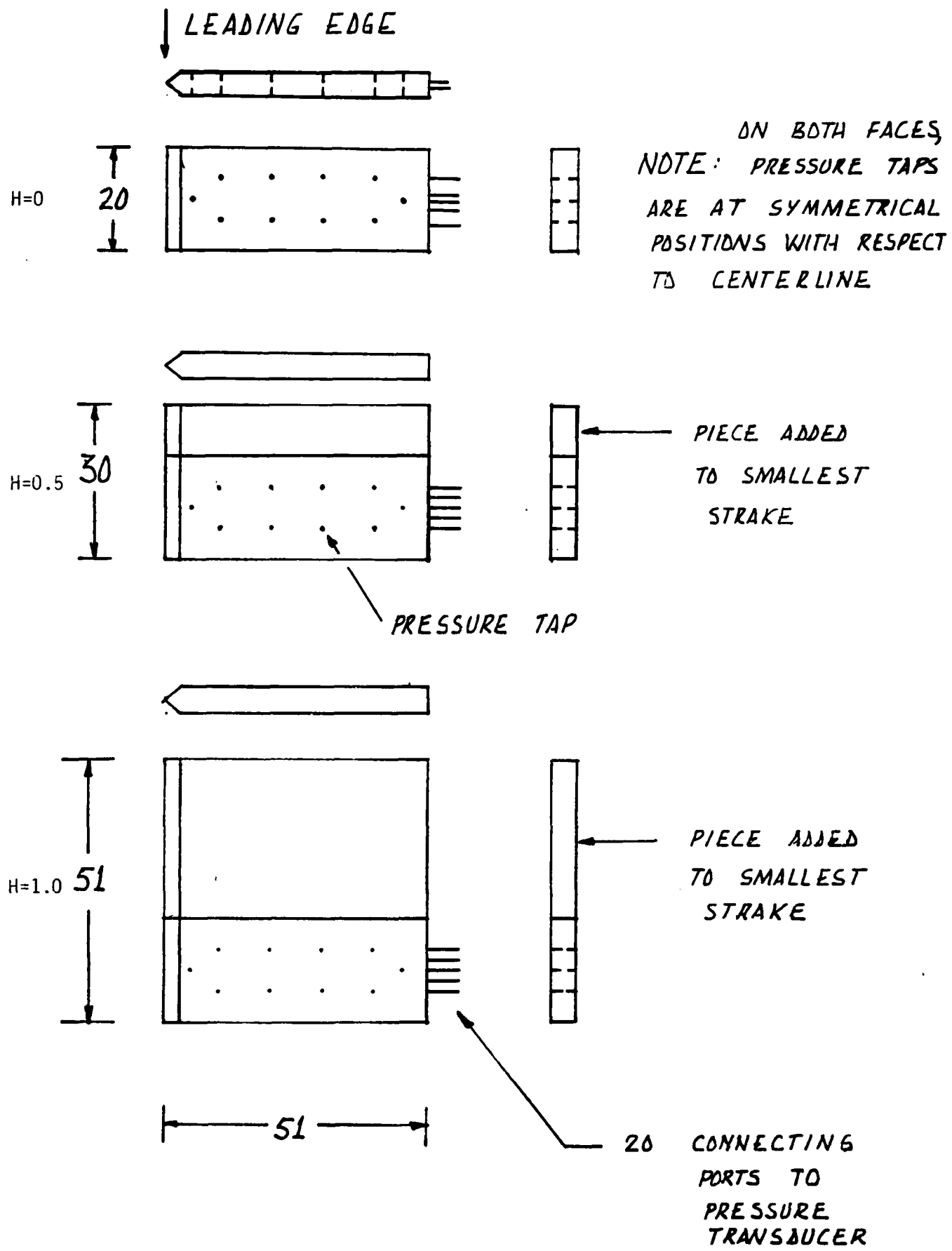


FIG.52A - STRAKES WITH PRESSURE TAPS TESTED

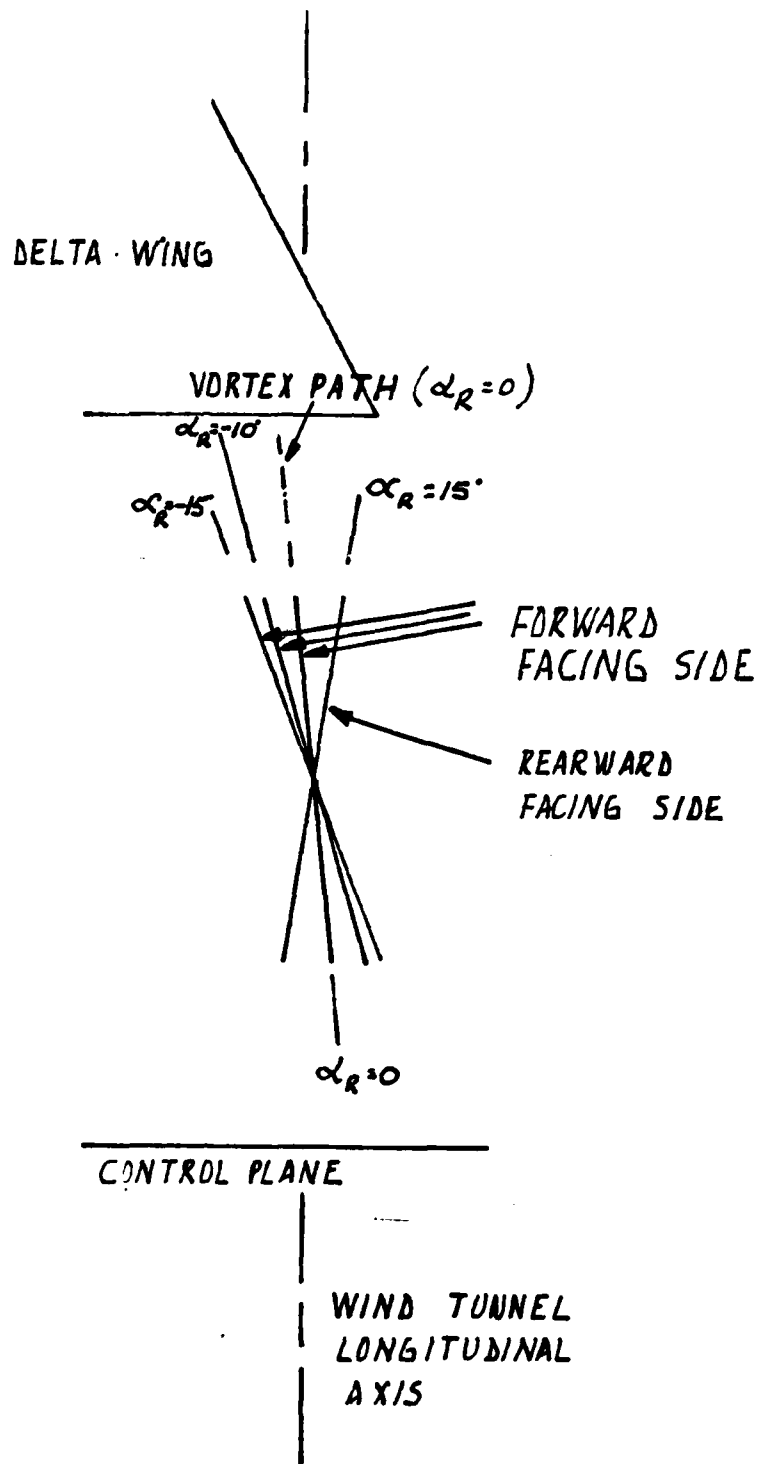


FIG. 52B - VORTEX PATH AND STRAKE WALLS ORIENTATION AT THE α_R TESTED

$$H = 0.0 \quad \alpha = -10^\circ$$

- FWD FACING
- - - REARWD FACING
 Δ $h = 0.12 c$ OVER FLAT PLATE
 \circ $h = 0.70 c$ " " "

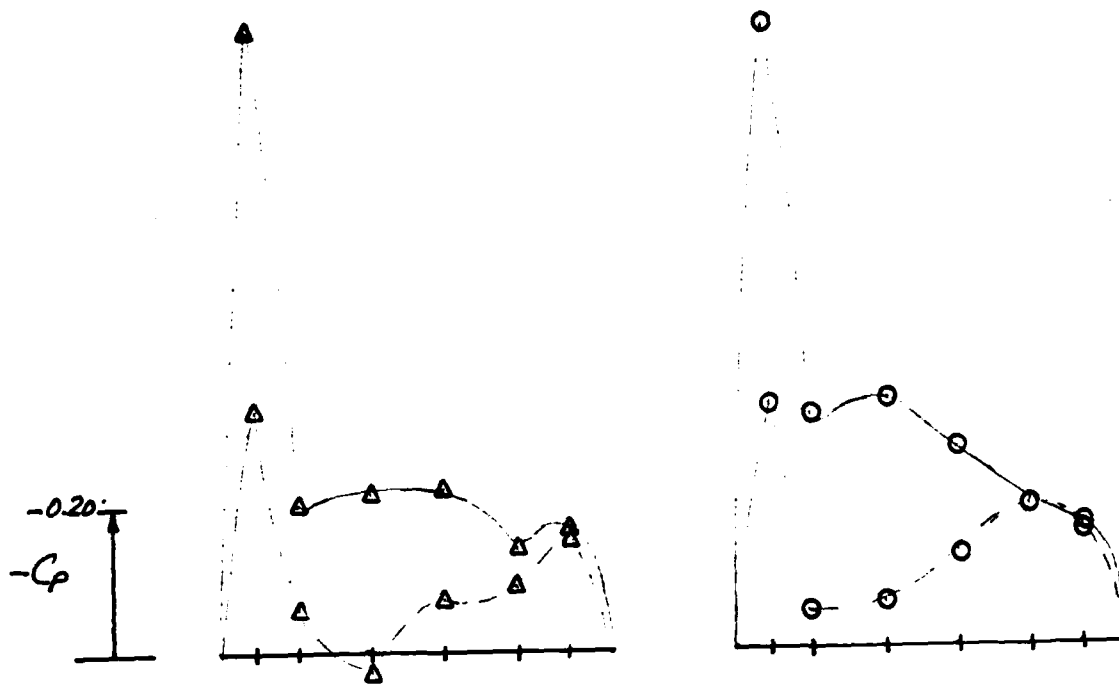


FIG. 53A - PRESSURE DISTRIBUTION ON STRAKE TESTED

$H = D.D \quad \alpha = 0^\circ$

— FWD FACING
- - - REARWD. FACING

Δ $h = 0.12 C$ OVER FLAT PLATE
 \circ $h = 0.70 C$ OVER FLAT PLATE

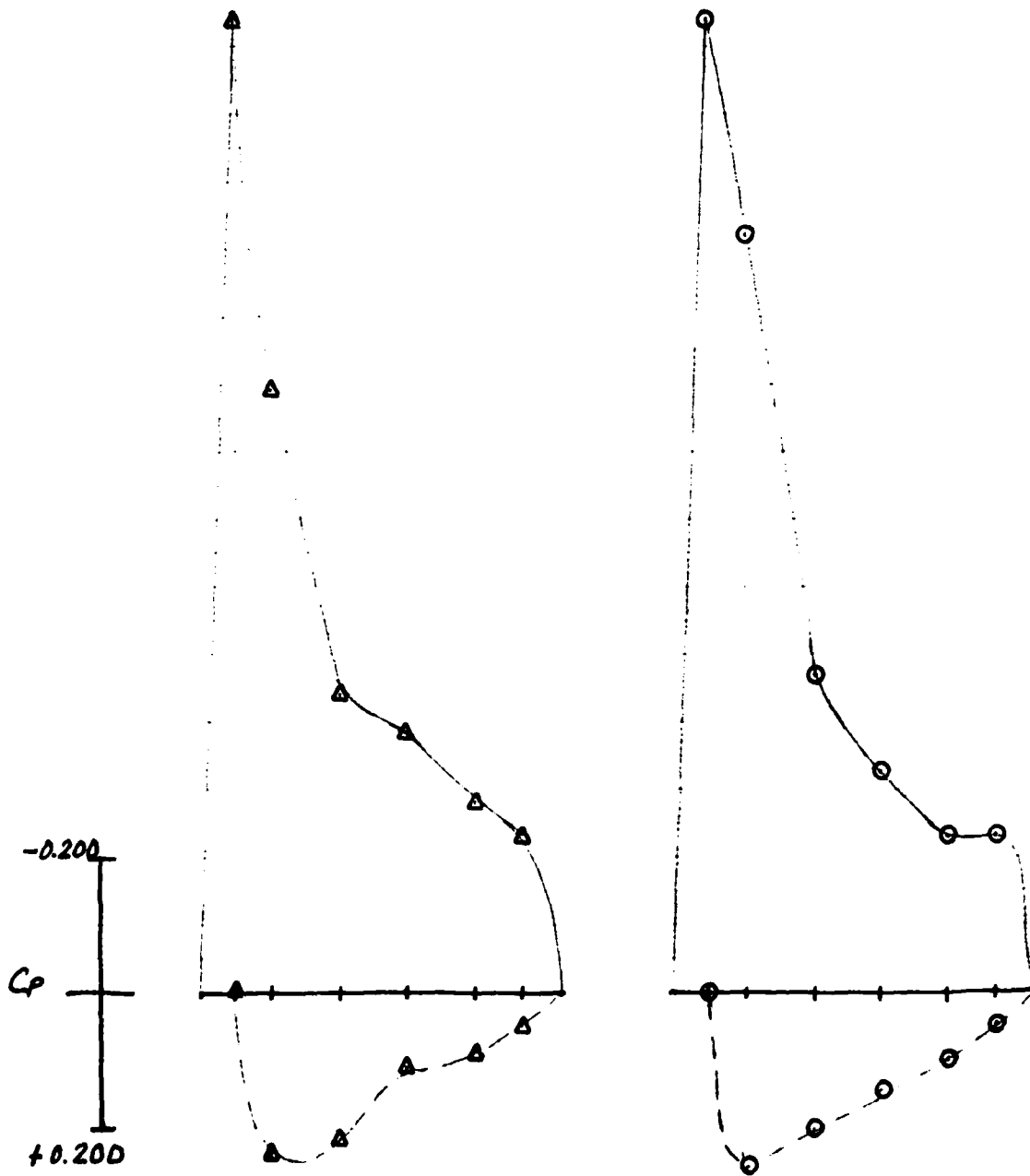


FIG. 53B - PRESSURE DISTRIBUTION ON STRAKE TESTED

$H = 0.0$ $\alpha = 15^\circ$

———— FWD. FACING

----- REARWD. FACING

Δ $h = 0.12 c$ OVER FLAT PLATE

\circ $h = 0.70 c$ OVER FLAT PLATE

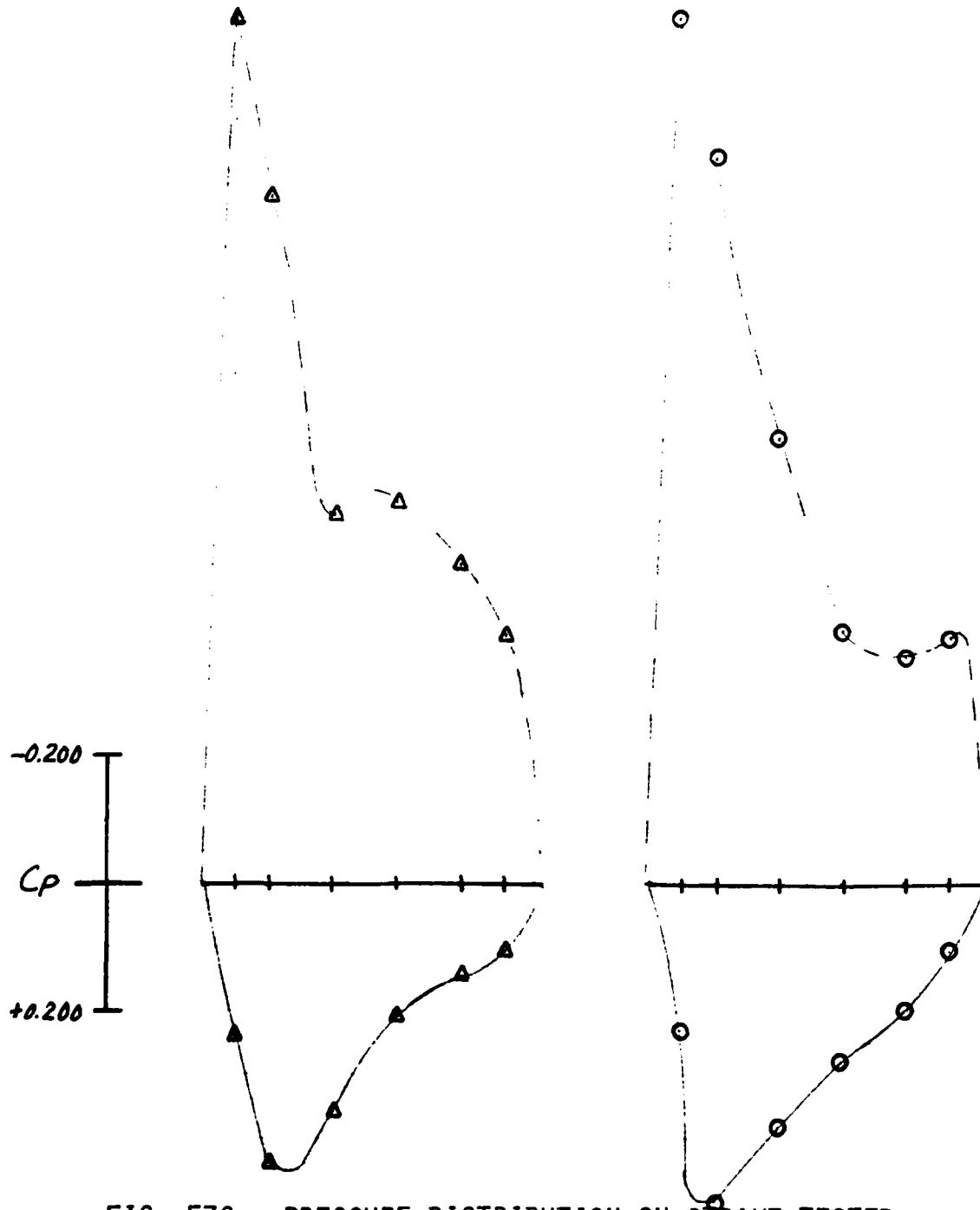


FIG. 53C - PRESSURE DISTRIBUTION ON STRAKE TESTED

$$H = 0.5 \quad \alpha = -15^\circ$$

———— FW/D. FACING

----- REARWD. FACING

Δ $h = 0.12c$ OVER FLAT PLATE

\circ $h = 0.70c$ OVER FLAT PLATE

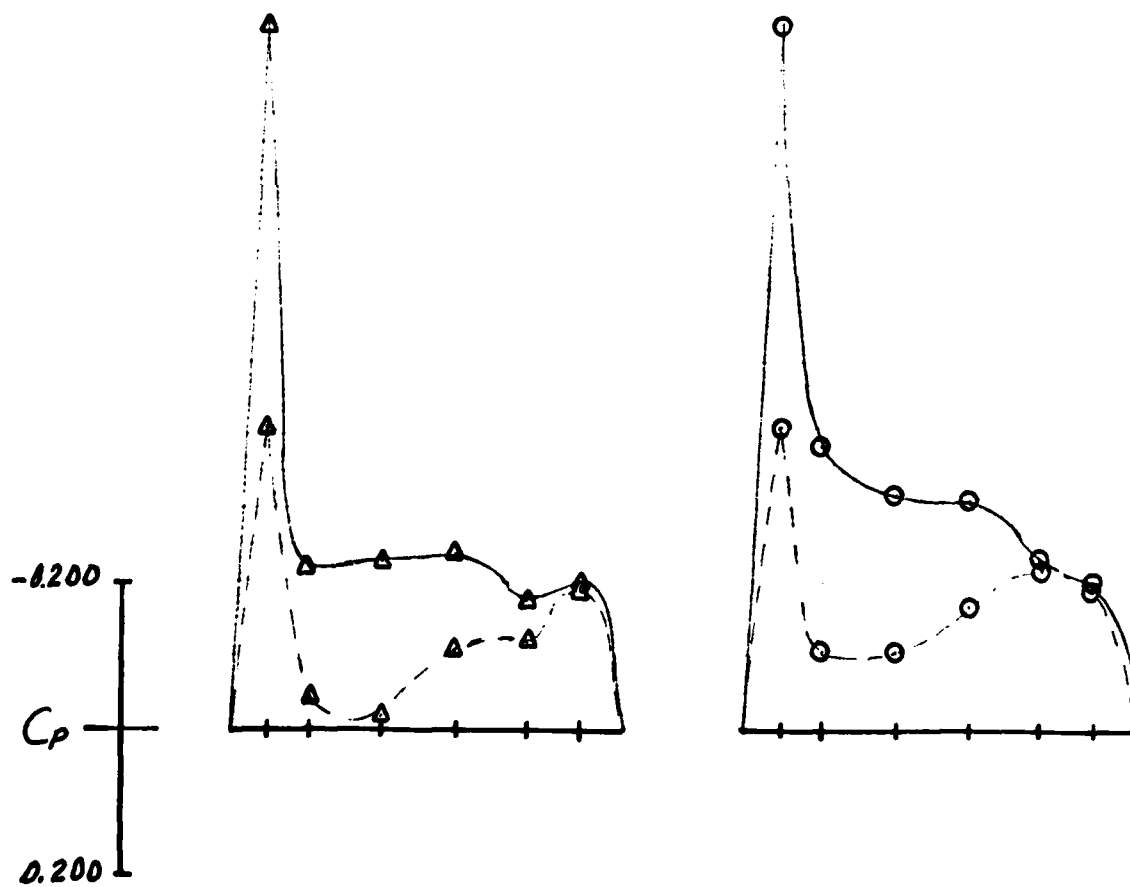


FIG. 54A - PRESSURE DISTRIBUTION

$H = 0.5$ $\alpha = 0^\circ$

———— FWD. FACING

----- REARWD. FACING

Δ $h = 0.12 c$ OVER FLAT PLATE

\circ $h = 0.70 c$ OVER FLAT PLATE

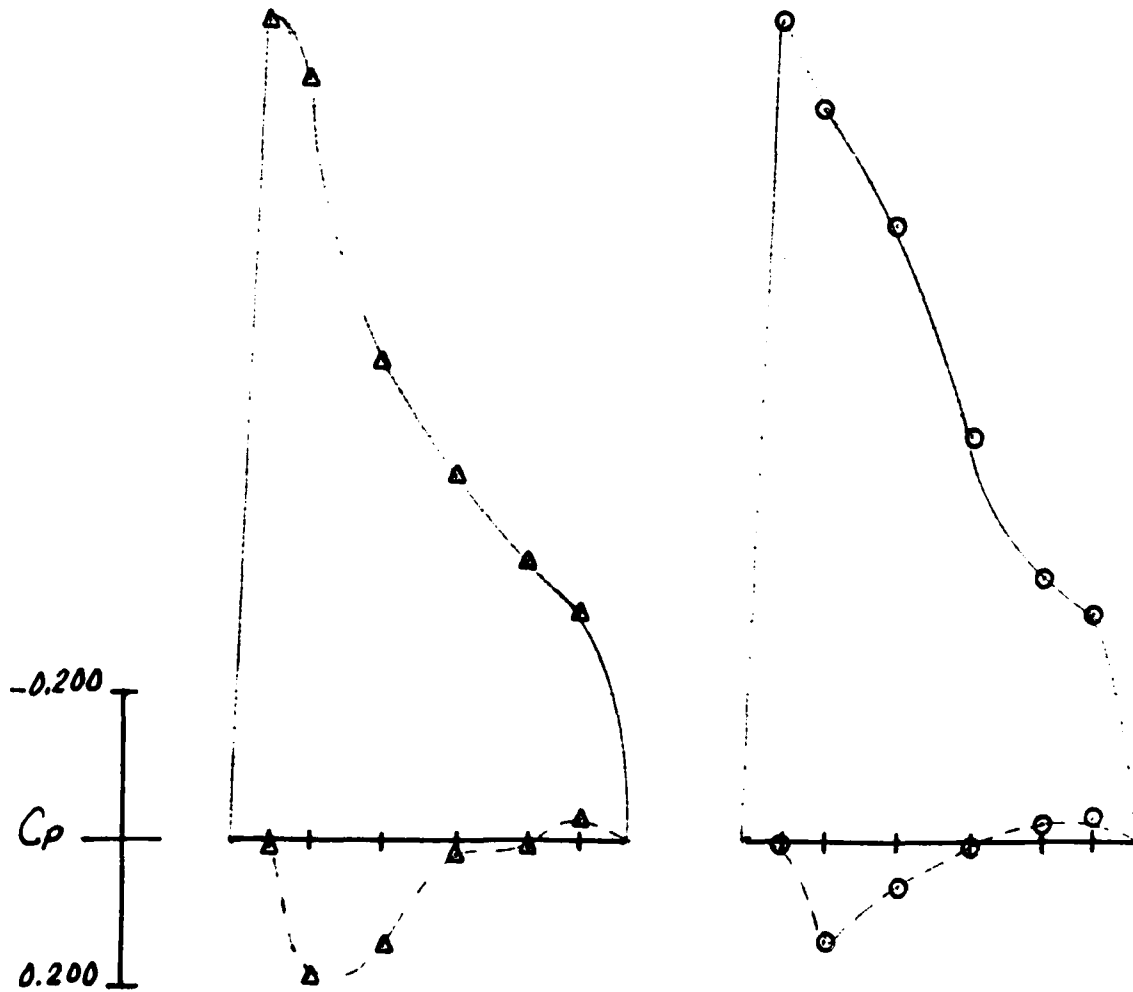


FIG. 54B - PRESSURE DISTRIBUTION

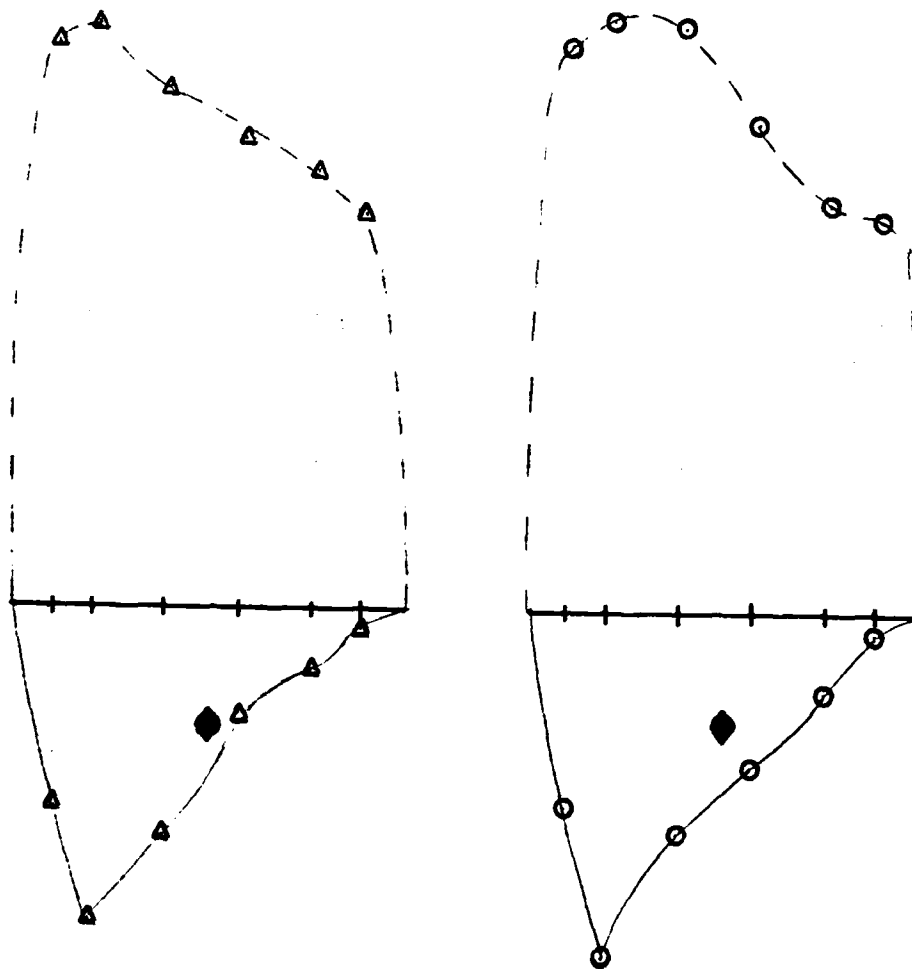
$H = 0.5$ $\alpha = 15^\circ$

———— FWD FACING

----- REARWD. FACING

Δ $h_s = 0.12 c$ OVER FLAT PLATE

\circ $h_s = 0.70 c$ OVER FLAT PLATE



NOTE : BLACK DIAMOND DATA POINT DENOTES
PRESSURE MEASURED BY THIN STRAKE PLACED
ON AIRCRAFT AFTERBODY AT $H = 0.5$ $\alpha = 15^\circ$
PLACED AT FUSELAGE STATION 3 - SEE FIG. 56 A

FIG. 54C - PRESSURE DISTRIBUTION

$H=1.0$ $\alpha = -15^\circ$

———— FWD. FACING

- - - - REARWD. FACING

Δ $h = 0.12c$ OVER FLAT PLATE

\circ $h = 0.70c$ " " "

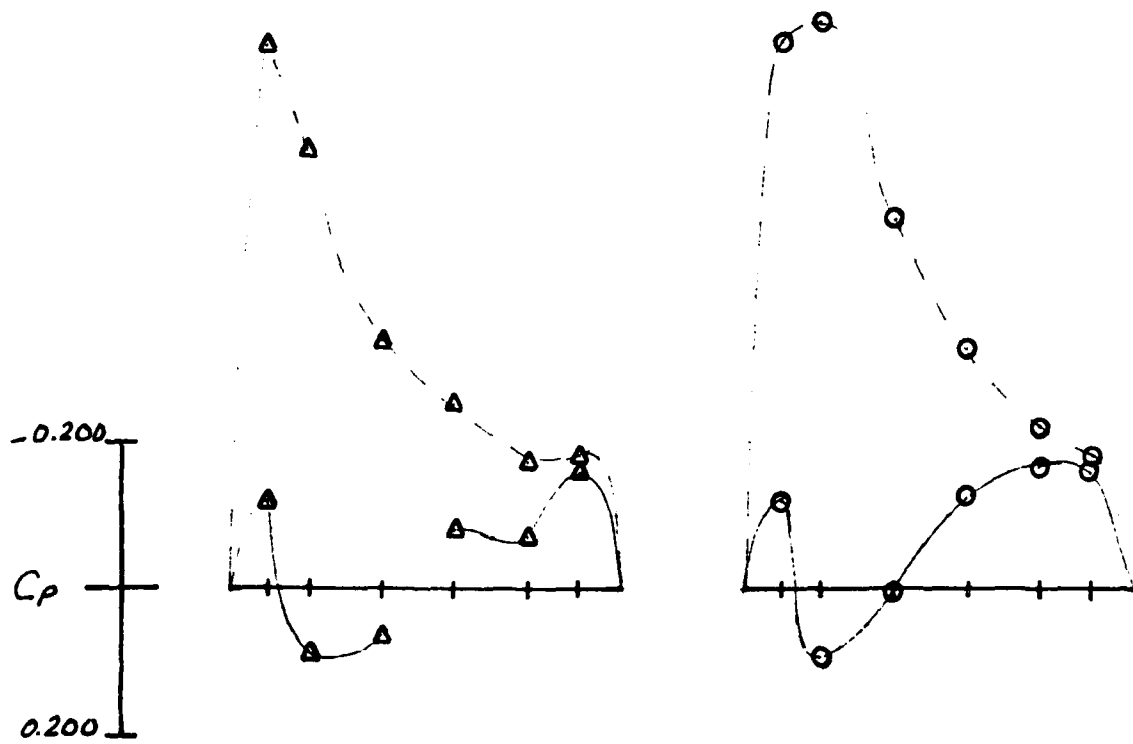


FIG. 55A - PRESSURE DISTRIBUTION

$$H=1.0 \quad \alpha=0^\circ$$

- FWD. FACING
- - - REARWD. FACING
 Δ $h=0.12c$ OVER FLAT PLATE
 \circ $h=0.70c$ OVER FLAT PLATE

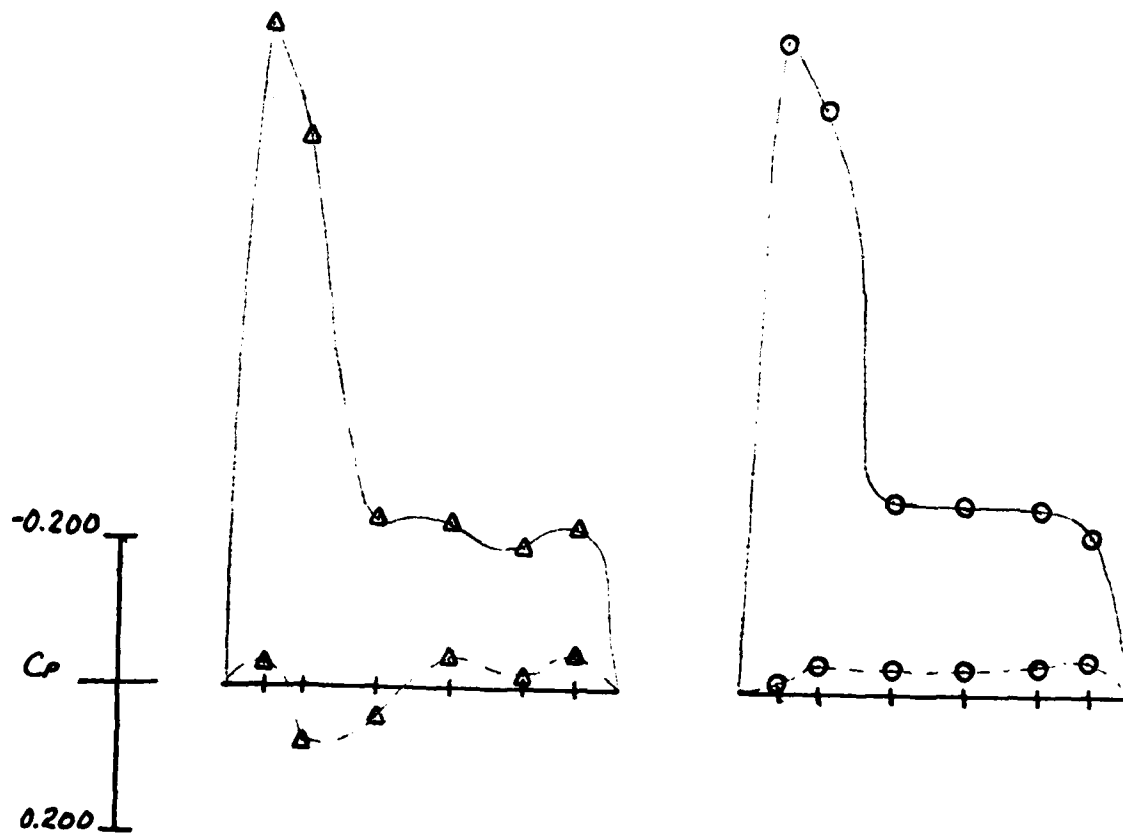


FIG. 55B - PRESSURE DISTRIBUTION

$H = 1.0$ $\alpha = 15^\circ$

- FWD FACING
- - - REARWD. FACING
- Δ $h = 0.12c$ OVER FLAT PLATE
- \circ $h = 0.70c$ OVER FLAT PLATE

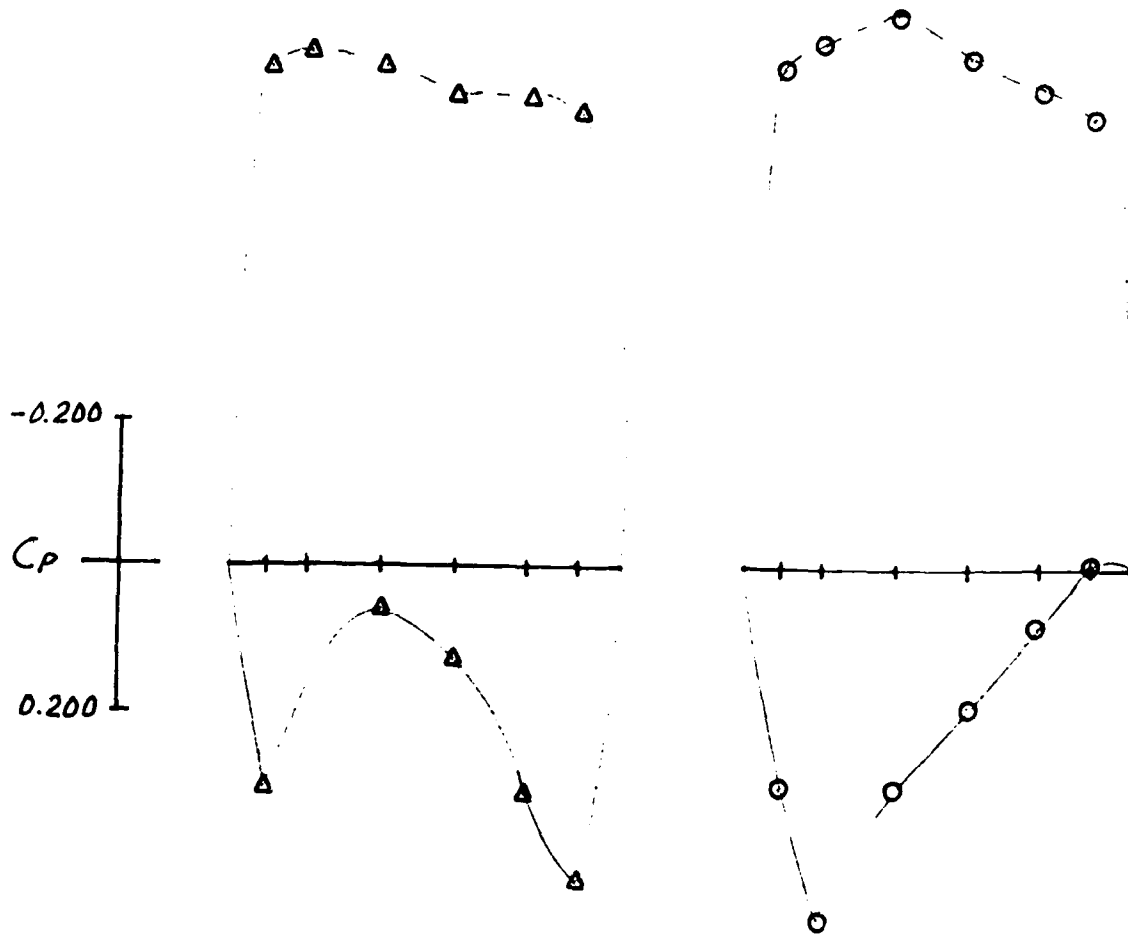


FIG. 55C - PRESSURE DISTRIBUTION

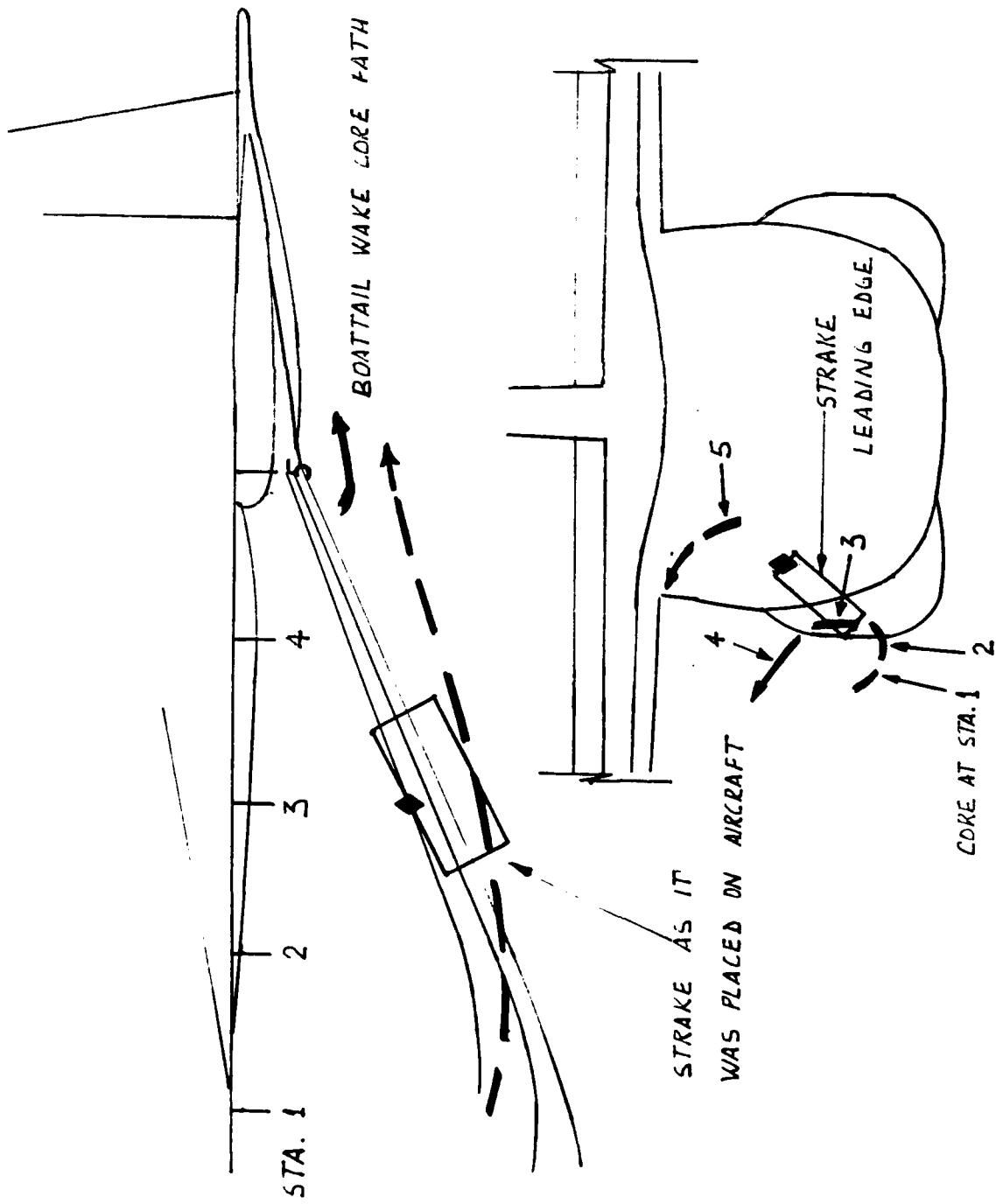
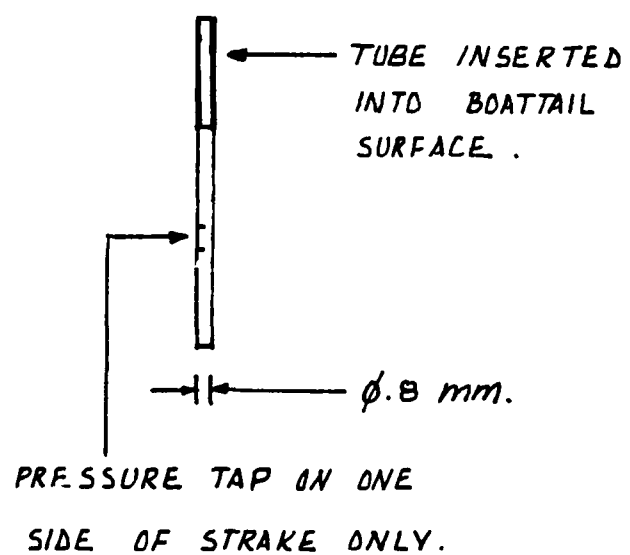
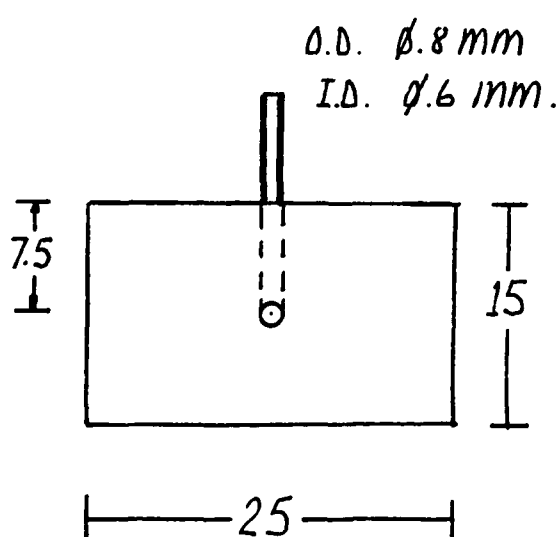
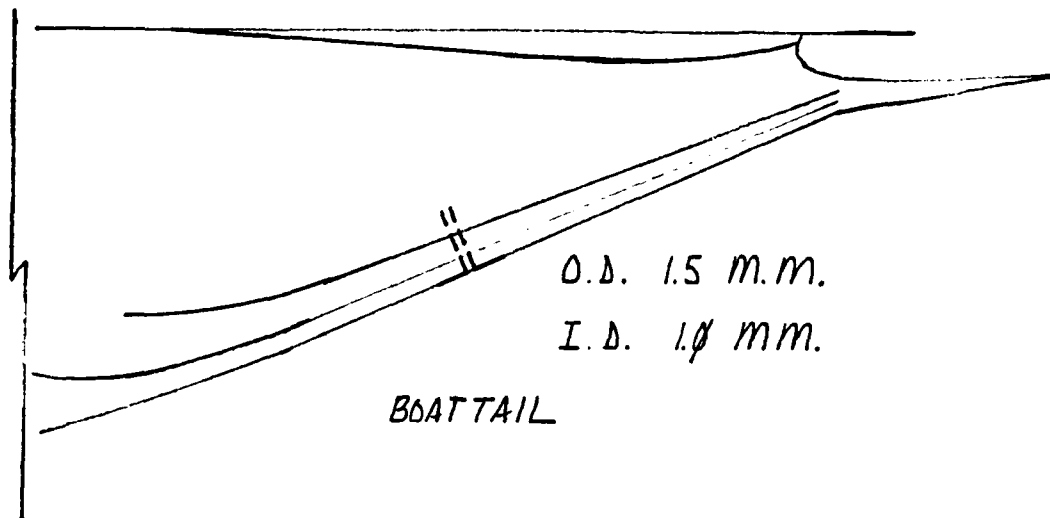


FIG. 56A - SCHEMATIC OF BOATTAIL INDUCED WAKE PATH



AIRCRAFT STRAKE

FIG. 56B - STRAKE CONFIGURATION TESTED ON C-130 BOATTAIL

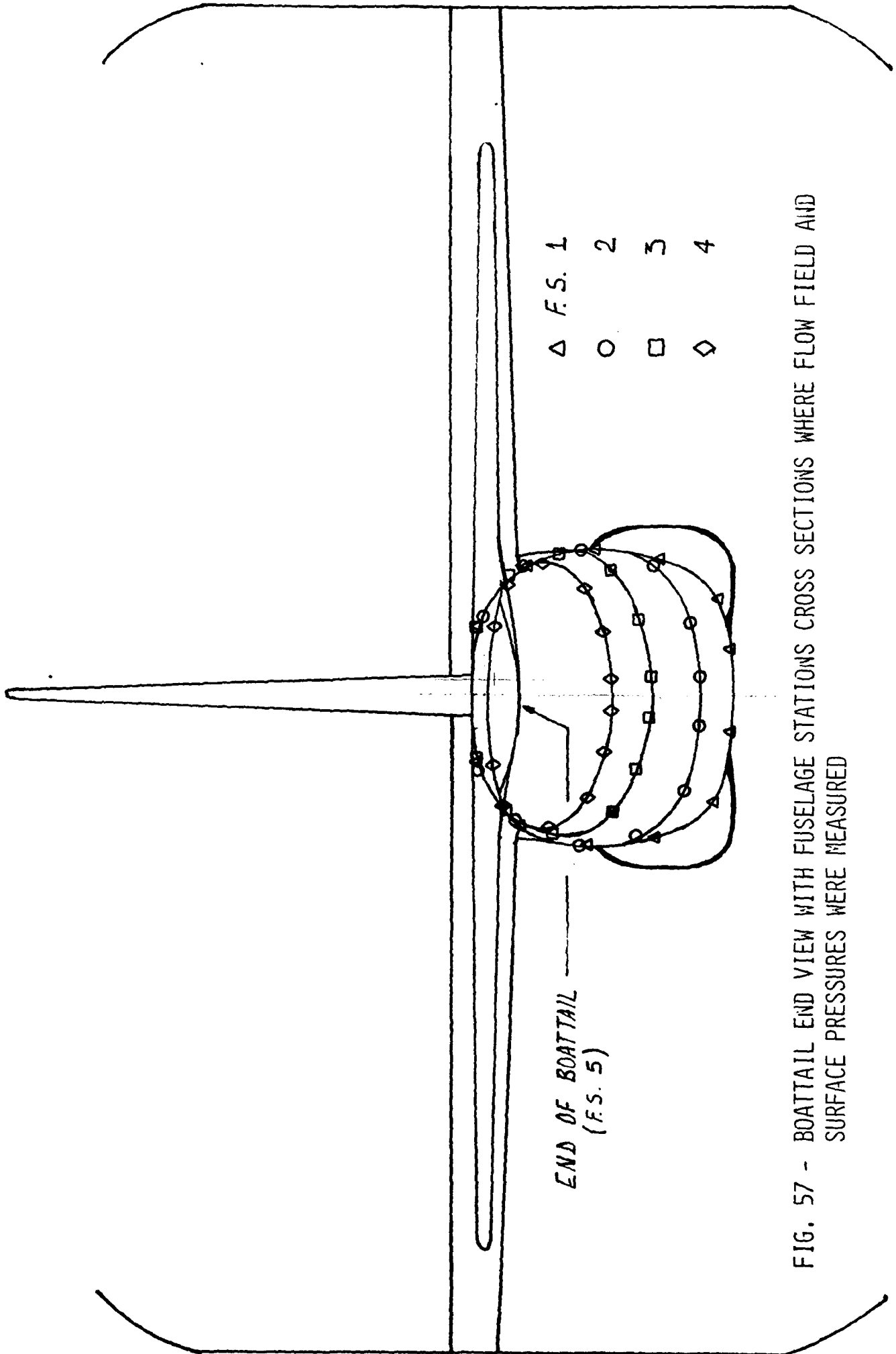
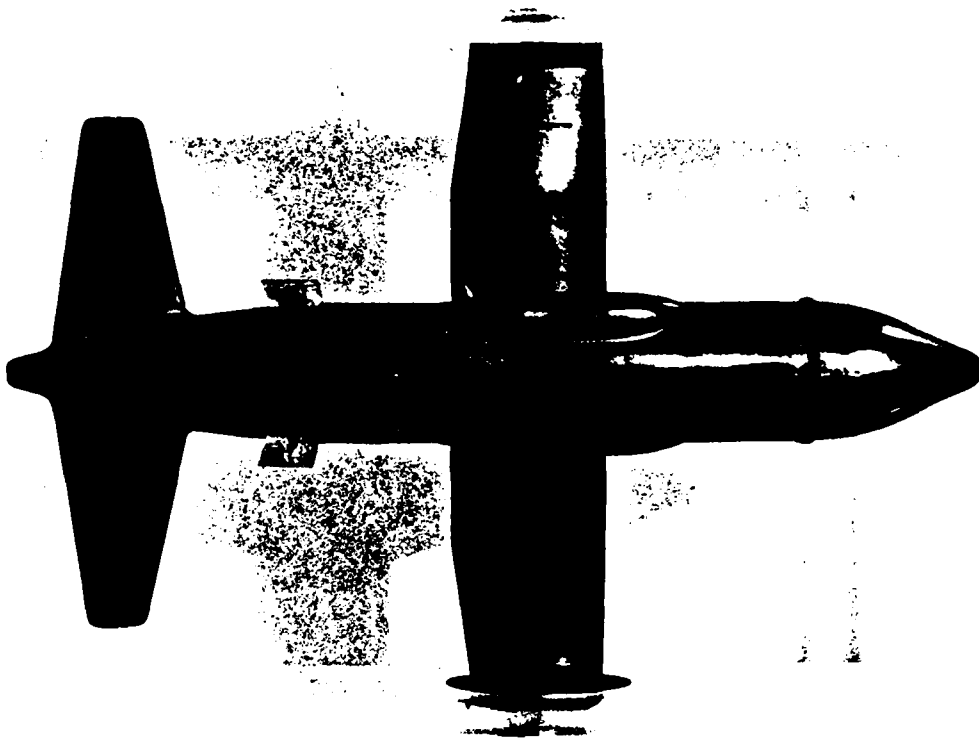


FIG. 57 - BOATTAIL END VIEW WITH FUSELAGE STATIONS CROSS SECTIONS WHERE FLOW FIELD AND SURFACE PRESSURES WERE MEASURED



A



B

FIG. 58A,B - VIEWS OF C-130 AIRCRAFT WITH STRAKES PLACED ON IT



A



B



C

FIG. 59 - LIMITING STREAMLINES VISUALIZATION ON C-130 WITH STRAKES

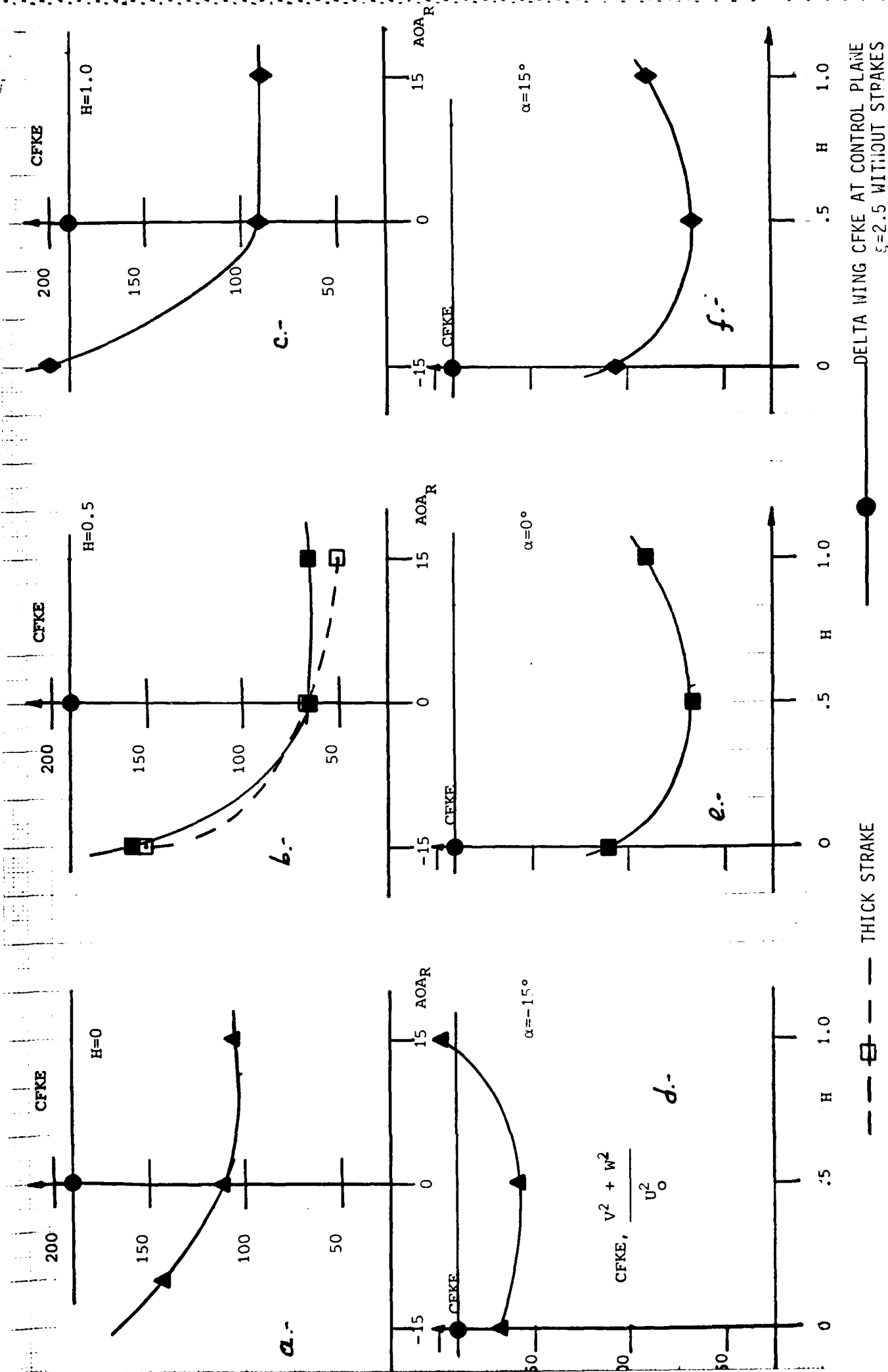
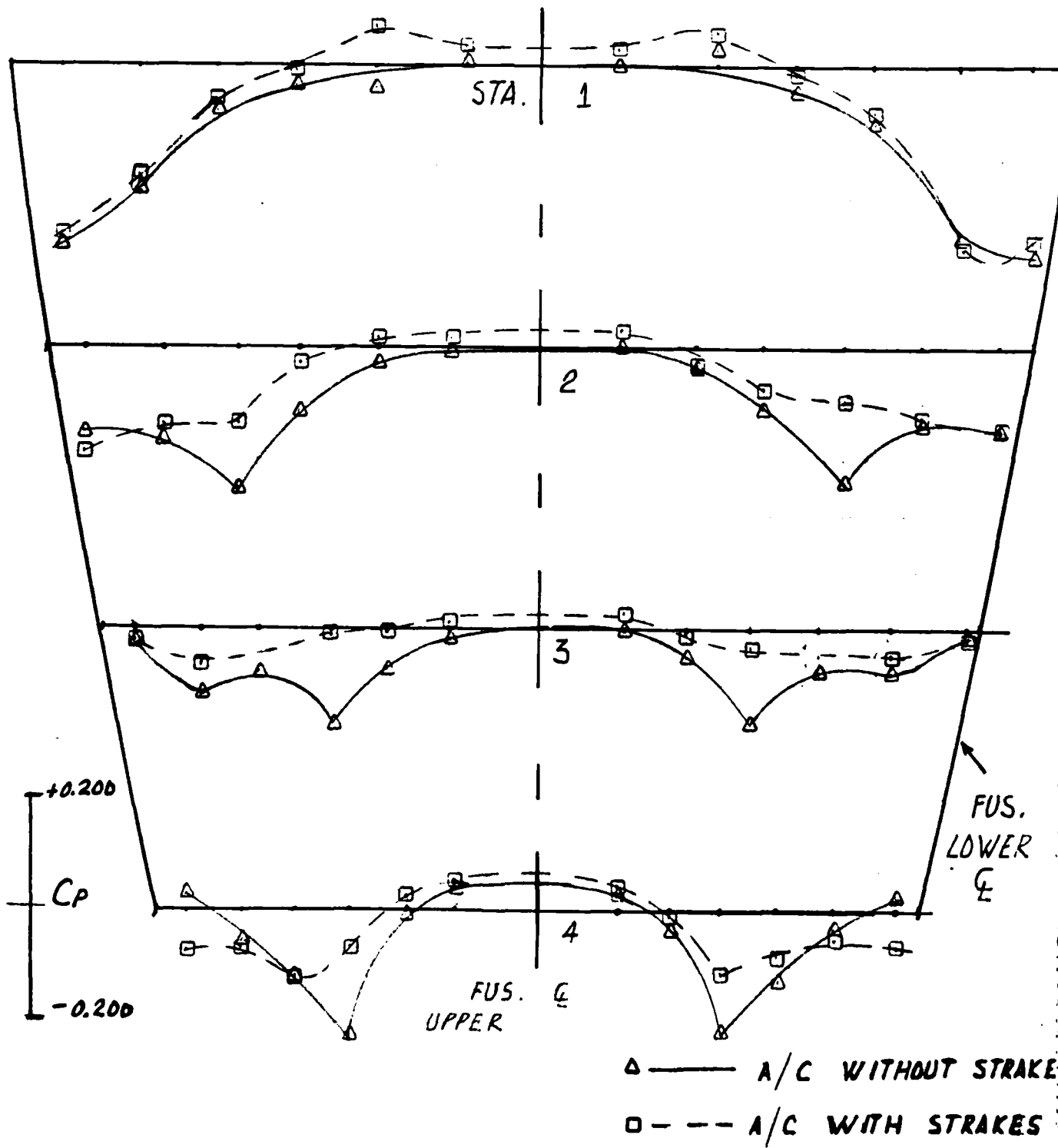


FIG. 60 - PLOTS OF DCFKE INTEGRATED DOWNSTREAM OF STRAKES OF DIFFERENT H, α R

FIG. 61

PRESSURE DISTRIBUTION ON C-130 BOATTAIL WITH AND WITHOUT STRAKES



END

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