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AN INVESTIGATION OF THE ROTOR WAKE CHARACTERISTICS OF AN AXIAL
FLOW COMPRESSOR WITH CLEAN AND DISTORTED INLET FLOWS

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ABSTRACT

Three-dimensional velocity components and six stress tensor components have been obtained experimentally inside the rotor wake of an axial flow compressor. The measurements were made using a Hot-wire assembly with a micro-electronic closed system. Measurements were taken in a clean flow and in a flow with imposed inlet sine wave pressure distortion.

The set of wake data in the distortion flow mode, presented in this thesis, are probably the first reported comprehensive measurements taken to discern the effect of inlet sine wave pressure distortion on rotor wake behavior.

The mechanism by which the loading variation affects the wake characteristics radially, from the hub to the tip, has been studied.

A suite of rotor wake analysis programs has been developed. The suite includes programs dealing with self-similarity and preservation, decay and width variation, flow thicknesses, and harmonic decomposition of the rotor wake.

A mathematical model for the wake width/decay characteristics based on preceding work has been improved. The model uses the integral momentum technique. The improvements allow the inclusion of pressure terms, turbulence terms and the radial flow outside the wake edge in the final solution.

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NOMENCLATURE :

CHAPTER 1 :

A_1	CONSTANT IN DECAY EQUATION. (1.1)
A_2	CONSTANT IN DECAY EQUATION. (1.1)
m_1	POWER CONSTANT IN EQUATION (1.1)
m_2	POWER CONSTANT IN EQUATION (1.1)
X	NON-DIMENSIONAL AXIAL DISTANCE.
X_0	VIRTUAL ORIGIN IN EQUATION (1.1).
V_d	VELOCITY DEFECT IN THE WAKE CENTRE LINE.
V_o	VELOCITY IN THE OUTSIDE OF THE WAKE REGION.

CHAPTER 2 AND FIG. 1

G	NON-DIMENSIONAL PARAMETER TO DESCRIBE THE TANGENTIAL VELOCITY COMPONENT IN THE PITCH-WISE DIRECTION.
H	NON-DIMENSIONAL PARAMETER TO DESCRIBE THE RADIAL VELOCITY COMPONENT IN THE PITCH-WISE DIRECTION
F	NON-DIMENSIONAL PARAMETER TO DESCRIBE THE AXIAL VELOCITY COMPONENT IN THE PITCH-WISE DIRECTION.
I	NON-DIMENSIONAL PARAMETER TO DESCRIBE THE TURBULENCE INTENSITY IN THE RADIAL DIRECTION
J	NON-DIMENSIONAL PARAMETER TO DESCRIBE THE TURBULENCE INTENSITY IN THE TANGENTIAL DIRECTION.
K	NON-DIMENSIONAL PARAMETER TO DESCRIBE THE TURBULENCE INTENSITY IN THE AXIAL DIRECTION
P_e P_c	STATIC PRESSURE IN THE WAKE OUTER EDGE AND CENTRE RESPECTIVELY
q	PARAMETER TO REPRESENT ANY VELOCITY COMPONENT.
r	RADIAL DIRECTION. , RADIUS.
U_o	RADIAL VELOCITY IN THE WAKE OUTER EDGE.
V_o	TANGENTIAL VELOCITY IN THE WAKE OUTER EDGE.
W_o	AXIAL VELOCITY IN THE WAKE OUTER EDGE.
u_c	RADIAL VELOCITY IN THE WAKE CENTRE.
v_c	TANGENTIAL VELOCITY IN THE WAKE CENTRE.
w_c	AXIAL VELOCITY IN THE WAKE CENTRE.
u_d	RADIAL VELOCITY DEFECT.
v_d	TANGENTIAL VELOCITY DEFECT.
w_d	AXIAL VELOCITY DEFECT.

u	FLUCTUATING PART OF THE RADIAL VELOCITY
v	" " TANGENTIAL VELOCITY.
w	" " AXIAL VELOCITY.
x	AXIAL DIRECTION CO-ORDINATE.
z	RADIAL DIRECTION CO-ORDINATE.
η	NON-DIMENSIONAL PARAMETER FOR THE TANGENTIAL CO-ORDINATE.
δ	WAKE HALF-WIDTH DEFINED AS $(r (\theta_s - \theta_c))$.
ν_e	EDDY VISCOSITY
Ω	ANGULAR SPEED

CHAPTERS 4 , 5 and 6

A	HARMONIC COEFFICIENT IN FOURIER SERIES.
B	" " " " " " .
	AND COEFFICIENT IN KING'S LAW.
C	BLADE CHORD.
C_{it}	ISOTROPY COEFFICIENT.
C_d	CROSS SECTION DRAG COEFFICIENT.
E	OUTPUT VOLTAGE FROM THE HOT WIRE.
H	SHAPE FACTOR ACROSS THE WAKE.
K_{ij}	DIRECTIONAL SENSITIVITY MATRIX COEFFICIENTS.
M	MOMENTUM THICKNESS ACROSS THE WAKE.
n	POWER COEFFICIENT IN King'S LAW.
Q	EFFECTIVE COOLING VELOCITY.
R	NON-DIMENSIONAL RADIAL DISTANCE.
S	STREAM-WISE.
$T_{o.d}$	OVERALL DISTURBANCE LEVEL.
$T_{f.s.}$	FREE STREAM TURBLANCE LEVEL.
$T_{u.s.}$	UNSTEADINESS LEVEL.
U	VELOCITY COMPONENT IN THE AXIAL DIRECTION.
u	FLUCTUATING PART OF THE AXIAL VELOCITY COMPONENT.
V	RELATIVE TANGENTIAL VELOCITY COMPONENT.
v	FLUCTUATING PART OF THE TANGENTIAL VELOCITY.
w	RADIAL VELOCITY COMPONENT.
w	FLUCTUATING PART OF THE RADIAL COMPONENT.
U_s	STREAM WISE VELOCITY COMPONENT.
U_n	NORMAL TO STREAM WISE VELOCITY COMPONENT.
U_{smax}	MAXIMUM STREAM WISE VELOCITY IN THE OUTER EDGE OF THE WAKE.
V_{tot}	RELATIVE TOTAL VELOCITY IN THE TURBOMACHINERY FRAME OF REFERENCE

x, y, z	TURBOMACHINERY CO-ORDINATE SYSTEM (AXIAL , TANG. AND RRADIAL).
K.T.E.	KINETIC TURBULENT ENERGY.
ρ	FLUID DENSITY.
β	FLOW AIR ANGLE
θ	FLOW ABSOLUTE ANGLE
α	FLOW RADIAL ANGLE
δ	FLOW DEVIATION ANGLE AND DISPLACMENT THICKNESS.
r	NON DIMENSIONAL TANGENTIAL DISTANCE.

CHAPTER 1 : INTRODUCTION

1.1 GENERAL

The new generation of turbomachinery is characterised by the choice of compressor blading design, lower aspect ratio and higher loading - Bigger and fewer blades - being the main feature of the designs. The need for shorter and lighter engines requires one to minimize the spacing between the rotor and stator rows of the axial flow compressors used. A distance of $1/4$ and $1/2$ chord length is currently a common practice. The study of the flow in the downstream region of the rotor and stator rows is therefore essential for improving the performance and efficiency, as well as the acoustic characteristics of axial flow compressors. In most compressor design procedures the stator rows are assumed to be far enough from the rotor rows so that a redistribution of the flow exists and the design of the stator rows can take place in a clean steady flow. This assumption is not true and it is obvious from the even further proximity of the newly designed compressor stages. An aerodynamic interaction of the rotor wake with the associated unsteadiness brought into the stators inlet flow is inevitable; hence there is a need to accurately map the flow field in this area and define its mean and turbulent structure.

Understanding the flow structure in a wake region is not only essential for compressor designers but also important for other applications. For example, the design of leading edge slats and flaps can be improved by carefully examining the interaction between the wake and the boundary layer developed. Also, the performance of a diffuser can be greatly affected by

the decay characteristics of the inlet wake from the upstream structure.

Unlike the single aerofoil or cascade the rotor wake is most complicated for the following reasons;

1- The rotor wake is three dimensional . The three dimensionality is brought about by the induced centrifugal and coriolis forces. The imbalance between these forces and the pressure gradients inside the shear layer create a spanwise radial flow.

2- The rotor wake is turbulent , and the turbulence structure is anisotropic as will be seen later.

3- The rotor wake is asymmetrical within the trailing edge and the near wake regions . The asymmetry is due to the past history of the flow (the different development of the boundary layer on both the suction and the pressure sides of the rotor blade).

4- The compressor rotor wake has several zones of complex mixing flow such as, the interaction between the rotor wake and the hub wall boundary layer , the interaction between the wake and the annulus wall boundary layer, and that between the tip leakage flow and scraping vortices. The flow in these zones is responsible for nearly half the losses in an axial flow compressor.

5- The main feature of the complex rotor wake is the secondary flow. This flow is a result of an intially deflected shear layer. The cross flow developing contains a vortex aligned in the stream wise direction.

The parameters which affect the development of the three dimensional turbulent wakes are many. Among these are,

- 1- Upstream flow conditions.
- 2- Blade geometry and profile shape.
- 3- Hub to tip ratio and blade spacing.
- 4- Radial and axial pressure gradients.
- 5- Speed of rotation.
- 6- Flow coefficient and loading.
- 7- Lift coefficient.
- 8- Distance from the blade trailing edge.
- 9- Intake structural design.
- 10- Free stream turbulence level.
- 11- Inviscid and compressibility effects.

The understanding of the different mechanism that controls the decay and spread characteristics of the axial flow compressor rotor wake is of some interest. Investigations of this field have already been reported on, specially during the course of this investigation as will be seen in the literature survey.

1.2 LITERATURE SURVEY

The work on the flow wake region started in the early twenties of this century. Most of the researches were carried out on simple shapes such as a flat plate , cylinder , single aerofoil and cascades of aerofoils. The work on wakes started by considering the laminar flow wake and shortly afterwards work

was started on the more realistic turbulent wake. Most of the ideas which arose in those early days are still useful and applied even up till now. For example the single aerofoil model by Silverstein (1939) Ref.(2) is still used for simple applications. A comprehensive review of this excellent early work can be found in any of the texts (e.g. Berger(1971) Ref.(3).) Most of the original work was done by Townsend Refs.(4,5 and 6) ,Goldstein Ref.(7) and LeiblLein and Roudebush Ref(8). These and other works concentrated on the two dimensional wake behind solid bodies. The equations which correlate the decay of this wake are still used and prove to be invaluable even for the most complicated three dimensional turbulent wake. A relation of the sort

$$V_d/V_o = A_1 (\tilde{x} - \tilde{x}_o)^{m_1} + A_2 (\tilde{x} - \tilde{x}_o)^{m_2}$$

is still used for the decay of the 3-D turbulent wake with different powers.

In fact , the work on flat plate and single aerofoil turbulent wakes still attracts the attention of some aerodynamicists (Alber (1980) Ref.(9) and c.Hah (1980) Ref.(10)) In this review , attention is mainly concentrated on the investigations concerning the three dimensional turbulent wakes.

Steiger and Bloom (1962) Ref.(11) had examined the velocity field of three dimensional viscous wakes analytically using the boundary layer approximation along with the Oseen's linearization to demonstrate the decay characteristics. Reynolds (1962) Ref.(12) has established the similarity in

swirling wakes by defining length and velocity defect scales. Kerrebrock and Mikolajczack (1970) Ref.(14) have studied theoretically and experimentally the intra-stator transport of rotor wakes. They used a simple model which considers the transport of energy by the rotor wakes passing through the stator. They also measured the distorted stagnation temperature profile inlet to the stator. Whitfield, Kelly and Barry (1972) Ref.(15) have used a single slanted hot wire to measure the three dimensional flow downstream of the rotor. The measurements were aimed at mapping the blade to blade distribution of the mean velocity components. Walker and Oliver (1972) Ref.(16) have studied one of the most important influences of the rotor wakes, namely the noise generation. They concluded that the axial and circumferential positioning of the the stator rows has an important effect on the level of the noise generated.

The most acknowledged work in the field of turbomachinery aerodynamics is the work pioneered by Prof. Lakshminarayana and his colleagues. Although the work by Lakshminarayana started in the 60's, extensive study of wakes in general did not start till the 70's in the Pennsylvania state university. Most of the work on the particular subject of axial flow compressor three dimensional turbulent wake has been concurrently published during the course of this investigation i.e. (1980 to 1983). Because of the particular interest in the work of this group a separate review is made here.

Raj and Lakshminarayana (1973) Ref.(17) have studied the

characteristics of the wake behind a cascade of aerofoils. In this investigation semi-theoretical expressions were given for the wake profile and decay characteristics. A comparison was also made with the wake of flat plate, cylinder and symmetrical aerofoils. The comparison shows the slower decay of the cascade wake centre line velocity.

References (17 to 24) are all by Lakshminarayana et al. , and the outcome was the establishment of a technique used for the three dimensional mean and turbulent measurements inside a three bladed rocket inducer pump. The technique developed uses a triple sensor hot wire probe stationary and rotating with the machinery. The same technique was followed in all the measurements made afterwards for the rotor wakes. B. Lakshminarayana reviewed all the work made on the inducers in a collective paper published in 1982 Ref.(25). Raj and Lakshminarayana (1976) Ref.(26) investigated analytically and experimentally the turbulent wake characteristics behind an axial flow compressor rotor. The authors of this paper provide some empirical formulae for the decay of the velocity components and for the normal and shear stresses decay. The generality of these formulae is doubtful especially for the different radial locations downstream of the rotor blade trailing edge.

Lakshminarayana (1976) Ref.(27) adopted the integral momentum technique for predicting the decay and width variations of the free vortex designed compressor rotor wake. This analytical model has been developed in (1979) Ref.(28) by Reynolds and Lakshminarayana . The development included the addition of the turbulent stress to the governing equations

although it had not been used to obtain the final solution. An attempt is made here to develop further this model to include the radial flow outside the wake as well as the turbulence stresses modeled in the final solution. The analysis and the method of solution are presented in chapter (2).

Reynolds and Lakshminarayana Refs(29 and 30) measured the near wake of a lightly loaded compressor rotor. The measurements included both the mean and the turbulent quantities. The decay of the mean velocity components were correlated with the blade section drag coefficient. This correlation was denied by Dring et al.(1982) Ref.(31). This correlation had been thoroughly investigated here and is explained in chapter 5.

In a series of papers Ravindranath and Lakshminarayana (1980-1982) (Refs(32-37)) studied experimentally the mean and turbulent characteristics of the rotor wake of a moderately loaded compressor rotor blade using a triple sensor hot wire probe (Refs(32,33 and by a set of conventional low response probes Ref.(34). They also studied the wake mixing effects downstream of the compressor rotor. The attention in this paper was focussed on the radial gradients of the velocity and turbulence intensity components at the trailing edge and in the near wake region. In Ref.(37) 1982, the authors studied the interaction of compressor rotor blade wake with the wall boundary layer/vortex in the end wall region. The results concluded a slower decay rate and larger width in this region. These have been verified by this investigation.

The work on the wake mixing region has been continued by

Davino and Lakshminarayana Ref(38) to study the turbulent aspects of the mixing zone. In Ref.(35) a conclusion was drawn by the authors that the normal and the stream wise turbulence intensity profiles would decay to a much lower value downstream the rotor blade trailing edge in the tip region (at Z/C the nondimensional axial distance > 0.45) . This result is different to the one reported in this investigation where the turbulence and the mean velocity profiles had a very slow decay rate in this region. By superimposing the published results , of the turbulence profiles at several axial stations ,of Davino's paper, it was found that the decay of the turbulence profiles is completely arrested in this region.

Davino , Pouagare and Lakshminarayana Refs(39 and 40) had investigated the flow within the blade passage at tip region. Both the mean and turbulence structure have been measured. The investigation helped to understand the mechanism that controls tip leakage flow and scraping vortices. The authors concluded the existence of very high turbulence intensities ($>90\%$) . The same level of turbulence are reported here in the tip wake centres. The high production of turbulence energy is the main factor responsible for the high losses in this region.

Davino and Lakshminarayana Ref. (41) have used a single hot wire probe to determine the mean velocity component distributions inside the wake of a stator and inlet guide vane. They reported a different decay rate for different velocity components . They also reported static pressure gradients across the trailing edge and the near wake of both the stator and the inlet guide vane.

Hah Ref(42) and Hah and lakshminarayana Refs(43 to 45) studied numerically the two and three dimensional turbulent wake propagation. The numerical scheme uses a rotating curvilinear coordinates system . This analysis is the only reported numerical scheme for predicting the local profile shape of the axial flow compressor rotor wake. The effect of stream line curvature and rotation is included. C.Hah uses three different turbulence modelled in his numerical scheme. The first model is comprised of transport equations for the turbulent kinetic energy and the rate of energy dissipation. The second model uses the rate of turbulent kinetic energy dissipation and the Reynolds stress equation, the effects of convection and diffusion are handled collectively. In the third model , the author uses both the turbulent kinetic energy dissipation and Reynolds stresses equations in nearly the exact form. The author reported accurate predictions from the second and third models, but the second model is faster than the third one.

The effect of rotation and blade loading on the rotor wake characteristics was investigated by Lakshminarayana , Govindon and Reynolds (1982) Ref.(46) and (1983) and Ref.(47) . The effect of loading on the rotor wake characteristics was one of the main features of our investigations . Some of the conclusions reported in these investigations were later verified by their research, especially the ones concerned with the reverse trend of the loading effect from the hub to the tip on the mean velocity component defect.

In all the references mentioned , the investigations of the rotor wake took place in a clean inlet flow. The

experimentation made in this investigation is the first reported attempt to study the rotor wake behaviour in a sine wave circumferential pressure distortion regime.

Of the other notable work on turbomachinery aerodynamics in general and on the rotor wake in particular was published by Dring et al. (Refs(50 and 51) ,Hirsch et al.(Refs. 52 and 53) and Colpin et al. (Ref. 54). In the last three references, the authors used a slanted single hot wire to measure the three dimensional mean velocity components downstream of the rotor of an axial flow compressor. The single hot wire had to be rotated to three different positions in order to obtain the three dimensional picture of the flow. No turbulence measurements were made in these investigations. Okiishi and Schmidt Ref.(55) used a similar technique in order to measure the mean flow distribution inside the wake of a multistage axial flow compressor. The experiments were aimed at defining the periodic unsteadiness of the flow. Refs(56 to 83) are listed only as a bibliography . They are included since they have an indirect relationship with the field of turbomachinery rotor wake and they give a very good background information.

1.3 THE OBJECTIVES AND SCOPE OF THIS INVESTIGATION

The objectives of this investigation are:

1- To establish an experimental technique based on the latest developments in microprocessor technology by which an accurate picture of the mean flow and turbulent quantities inside the axial flow compressor rotor wake can be obtained.

The proposed technique uses a hot wire assembly with a micro-electronic closed system. The method is capable of measuring the three dimensional mean flow and the six stress tensor components (three normal stresses and three shear-Reynolds- stresses).

2- To provide a data bank of information for the axial flow compressor rotor wake in clean and distorted flow regimes. The complete set of data has been stored on a VAX 11/782 computer with easily accessible codes. This is the first reported attempt to measure the rotor wake flow in an inlet pressure distortion regime.

3- to develop a suite of rotor wake analysis programs concerned with the different aspects of correlations and characteristics . The suite includes programs dealing with self similarity and preservation , decay and width variations correlations , flow thickness distributions inside the wake (displacement, momentum and energy thickness) and the Fourier decomposition of the rotor wake.

4- to develop a mathematical model for the wake width/decay characteristics using the integral momentum technique. The integral momentum technique has the advantages of providing the gross properties of the wake flow .This is extremely important for the preliminary design and analysis of the flow. It correlates the inviscid flow in the blade passage to the effect of the wake shear thin layer. It also allows one to incorporate several effects such as rotation and turbulence structure.

It was also of extreme importance to carry out some preliminary experiments using different types of probes such as

the conventional five hole probe, three hole "built in " pressure transducer probes and a single hot wire probe. These experiments provided a measure of the order of magnitude of the flow. They also provided very important information concerning the flow radial distribution and the distribution downstream of the distortion screen. The single hot wire probe experiments helped to discern the effect of periodic unsteadiness from that of the random flow fluctuations. This will be explained in due course.

The particular choice of the hot wire assembly as the main probing instrument for this investigation is fully explained in ref.(1).

The mathematical model is presented in the next chapter (2).

An effort was made to generalise the model as much as possible so that any further development can be easily incorporated. The instruments and probes used in this investigation are explained and specified in chapter 3. The blade strobe unit which was especially designed for the purpose of wake measurements and linked to the microprocessor , is fully explained in this chapter.

In chapter 4 , the phases of the experimental programme are presented. The objectives of each test , the conditions and locations of measurements , the experimental techniques , the methods of analysis and the error estimations are all explained in this chapter.

In chapter 5 , The results of all the experimental phases

are presented . A coefficient is suggested in this chapter to estimate the level of anisotropy in the three dimensional turbulent flow. Also , the results of the rotor wake and flow distributions behind the sine wave pressure distortion screen . are also presented.

In chapter 6 , the different correlations and empirical formulae are presented. Also , a comparison with the theoretical predictions are made in this chapter.

The conclusions and the recommendations for future work are presented in chapter 7.

Due to limited space neither the mathematical derivation of the experimental technique or the mathematical model is fully presented. However the terms of the equations can be extracted from the computer program listings. The computer programs used in this investigation are all independent of on any library of mathematical program and they can be used on any machine. The Newton Raphson iterations and the different least square analysis are fully generalised. Several general subroutines were made and a master segment was written using collection of these subroutines to perform the particular analysis.

CHAPTER 2 : ROTOR WAKE MATHEMATICAL MODEL

ROTOR WAKE DECAY/WIDTH MATHEMATICAL MODEL

2.1 GENERAL

This chapter describes an attempt to modify the analytical technique developed by B.Lakshminarayana (Ref.27) and further modified by B.Reynolds and B.Lakshminarayana (Ref. 28).

The assumptions which were given in both the original and the modified version have been improved to include the variation of flow properties along the radial direction and the existence of radial flow outside the wake.

Although the previous two models did not provide a complete quantitative solution, the proposed solution algorithm presented here sets out to do this. The method used is that of Galerkin (Ref.77). It is a weighted residual method and is one of the most powerful methods for supplying a controlled convergency scheme. The set of non-linear algebraic equations, which was the result of using the Galerkin method, is solved by a general Newton Raphson iteration technique. The technique is fully explained in Appendix (1). For comparative purposes the same symbols are used for different velocity components as those used in Ref (28).

Because of the nature of the rotor wake observed it was decided to use the integral momentum technique. This method involves integrating the momentum equations across the wake. The resulting set of integrals can then be used globally as non-dimensional parameters describing the behaviour of the rotor wake in the pitch-wise plane. This then eliminates one of the dimensions.

The analysis can only be completed by using numerical methods. The program (Appendix 2) was generalised as much as possible to allow for further improvements.

The co-ordinate system used in this analysis is shown in fig (1).

The momentum equations in the rotating cylindrical co-ordinate system for incompressible flow (neglecting viscous stresses and including the turbulent ones) can be written as :

for r -direction:

$$\begin{aligned} & \frac{V}{r} \frac{\partial U}{\partial \theta} + U \frac{\partial U}{\partial r} + W \frac{\partial U}{\partial Z} - \frac{(V + \Omega r)^2}{r} \\ = & - \frac{1}{\rho} \frac{\partial p}{\partial r} - \frac{\partial}{\partial r} \overline{u'^2} - \frac{1}{r} \frac{\partial}{\partial \theta} \overline{(u'v')} - \frac{\partial}{\partial Z} \overline{(u'w')} - \frac{\overline{u'^2}}{r} + \frac{\overline{v'^2}}{r} \end{aligned}$$

... (2.1)

for θ -direction:

$$\begin{aligned} & \frac{V}{r} \frac{\partial V}{\partial \theta} + U \frac{\partial V}{\partial r} + W \frac{\partial V}{\partial Z} + \frac{UV}{r} + 2 \Omega U \\ = & - \frac{1}{\rho} \frac{1}{r} \frac{\partial p}{\partial \theta} - \frac{\partial}{\partial r} \overline{u'v'} - \frac{1}{r} \frac{\partial}{\partial \theta} \overline{(v'^2)} - \frac{\partial}{\partial Z} \overline{(v'w')} - 2 \frac{\overline{u'v'}}{r} \end{aligned}$$

... (2.2)

and for Z -direction

$$\begin{aligned} & \frac{V}{r} \frac{\partial W}{\partial \theta} + U \frac{\partial W}{\partial r} + W \frac{\partial W}{\partial Z} = - \frac{1}{\rho} \frac{\partial p}{\partial Z} - \frac{\partial \overline{u'w'}}{\partial r} - \frac{1}{r} \frac{\partial}{\partial \theta} \overline{(v'w')} \\ & - \frac{\partial}{\partial Z} \overline{(w'^2)} - \frac{\overline{u'w'}}{r} \end{aligned}$$

... (2.3)

The Continuity Equation (conservation of mass) becomes :

$$\frac{1}{r} \frac{\partial V}{\partial \theta} + \frac{\partial W}{\partial Z} + \frac{\partial U}{\partial r} + \frac{U}{r} = 0 \quad \dots (2.4)$$

In the previous equations the components of velocity U , V and W in the rotor wake analysis represent the difference between the free stream velocity components and the defect components. The following assumptions were incorporated into the equation.

1 - the velocity components are:

$$\left. \begin{aligned} V &= V_0(r) - v_d(\theta, Z) \\ W &= W_0(r) - w_d(\theta, Z) \\ U &= U_0(r) - u_d(\theta, Z) \end{aligned} \right\} \quad \dots (2.5)$$

In the previous group of equations (2.5), the assumption that the velocity defect does not vary along the radial direction was included. This assumption will not affect the result as long as the application of the analysis will be for one radius at a time.

Also the defects were assumed zero in the outer sides of the wake. The radial velocity (U_0) was observed to exist outside the wake and was therefore included.

2 - The pressure distribution is a function of all the co-ordinates

$$\text{i.e.} \quad p = p(r, \theta, Z) \quad \dots (2.6)$$

3 - A similarity in the velocity and turbulent wake profiles was assumed to exist. However the similarity laws which were used in this solution were different to those quoted in Ref. (28); these laws are explained in detail in Chapter 6 (Section 6.1).

The foregoing assumptions were the only ones used to develop the mathematical equations. Any further assumptions leading to the neglect of some parameters (such as radial variations of turbulence or eddy stresses) were left as options in the solution algorithm. (Described in Chapter 6).

In order to integrate the conservation of mass and momentum equations across the wake, Lakshiminarayana (Ref. 27) defined several integrations.

- (a) Consider the quantity (q) as a general component of velocity defect, the integration of the rate of change of " q " across the wake would be

$$\int_{\theta_c}^{\theta_o} \frac{\partial q}{\partial \theta} d\theta = q|_{\theta_o} - q|_{\theta_c} = - q|_{\theta_c}, \text{ where } q|_{\theta_o} = 0 \text{ (a)}$$

- (b) In order to define the integration of (q) itself consider the quantity $G(\theta, Z)$

$$\delta G = \frac{\partial G}{\partial \theta} \delta \theta + \frac{\partial G}{\partial Z} \delta Z$$

Assume $Z = Z(t)$, $\theta = \theta(t)$,

$$\text{then } \frac{dG}{dt} = \frac{\partial G}{\partial \theta} \frac{d\theta}{dt} + \frac{\partial G}{\partial Z} \frac{dZ}{dt} .$$

If $t = z$

$$\text{then } \frac{dG}{dt} = \frac{\partial G}{\partial \theta} \frac{d\theta}{dz} + \frac{\partial G}{\partial z} \quad (b.1)$$

consider now,

$$\begin{aligned} \int_{\theta_c}^{\theta_o} q(z, \theta) d\theta &= G_o(z, \theta_o) - G_c(z, \theta_c) \\ \frac{d}{dz} \int_{\theta_c}^{\theta_o} q(z, \theta) d\theta &= \frac{d}{dz} G_o(z, \theta_o) - \frac{d}{dz} G_c(z, \theta_c) \\ &= \frac{\partial}{\partial z} G_o(z, \theta_o) + \frac{\partial}{\partial \theta} G_o(z, \theta_o) \frac{d\theta}{dz} - \frac{\partial}{\partial z} G_c(z, \theta_c) - \frac{\partial}{\partial \theta} G_c(z, \theta_c) \frac{d\theta}{dz} \\ &= \frac{\partial}{\partial z} [G_o(z, \theta_o) - G_c(z, \theta_c)] + \frac{\partial}{\partial \theta} G_o(\theta_o, z) \frac{d\theta}{dz} - \frac{\partial}{\partial \theta} G_c(\theta_c, z) \frac{d\theta}{dz} \end{aligned}$$

Hence we can write,

$$\begin{aligned} \frac{d}{dz} \int_{\theta_c}^{\theta_o} q(z, \theta) d\theta &= \frac{\partial}{\partial z} \int_{\theta_c}^{\theta_o} q(z, \theta) d\theta + q_o \frac{\partial \theta_o}{\partial z} - q_c \frac{\partial \theta_c}{\partial z} \\ &= \int_{\theta_c}^{\theta_o} \frac{\partial}{\partial z} q(z, \theta) d\theta + q_o \frac{\partial \theta_o}{\partial z} - q_c \frac{\partial \theta_c}{\partial z} \quad (b.2) \end{aligned}$$

and

$$\frac{\partial \theta_c}{\partial z} \approx - \frac{1}{r} \left(\frac{V_o - v_c}{W_o - w_c} \right)$$

(c) Consider the non-dimensional parameter

$$\eta \equiv \frac{\theta - \theta_c}{\theta_o - \theta_c} \quad (c.1)$$

which takes the value 0, 1 at $\theta = \theta_c$ and $\theta = \theta_o$ respectively. We also define δ as the wake full width (which is found more realistic to use than the semi-wake width (see Chapter 6 Section 6.4)).

$$\delta = r(\theta_o - \theta_c) \quad (c.2)$$

Using c.1 and c.2, we can describe the similarity profiles as

$$q = q'_c(z) q(\eta) \quad (c.3)$$

$$\begin{aligned} \int_{\theta_c}^{\theta_o} q d\theta &= \int_{\theta_c}^{\theta_o} q'_c(z) q(\eta) d\theta \\ &= q'_c(z) (\theta_o - \theta_c) \int_0^1 q(\eta) d\eta \end{aligned}$$

$$\int_{\theta_c}^{\theta_o} q d\theta = \frac{\delta}{r} q'_c(z) Q \quad (c.4)$$

The reader might notice here the disappearance of the co-ordinate " θ " in (c.3) which is the outcome of using the similarity rule. The parameter Q in (c.4) was used in our development in different

form to that used in Ref (27), as will be shown in Chapter 6 Sections 6.1 and 6.2 .

- (d) By considering the assumptions in Section "c" above we can rewrite (b.2) as

$$\int_{\theta_c}^{\theta_o} \frac{\partial}{\partial z} q(z, \theta) d\theta = \frac{d}{dz} \int_{\theta_c}^{\theta_o} q(z, \theta) d\theta - \frac{q_c}{r} \left(\frac{v_o - v_c}{w_o - w_c} \right)$$

$$\int_{\theta_c}^{\theta_o} \frac{\partial}{\partial z} q(z, \theta) d\theta = \frac{d}{dz} \left(\frac{\delta q'_c}{r} \right) \left[\int_0^1 q(\eta) d\eta \right] + q_c \frac{1}{r} \left(\frac{v_o - v_c}{w_o - w_c} \right)$$

where $q'_c / (Q_o - q_c) = Q / \int_0^1 q(\eta) d\eta$

hence,
$$\int_{\theta_c}^{\theta_o} \frac{\partial}{\partial z} q(z, \theta) d\theta = \frac{d}{dz} \frac{\delta}{r} \left(Q_o - q_c \right) Q - \frac{q_c}{r} \left(\frac{v_o - v_c}{w_o - w_c} \right) \quad \dots (2.d)$$

- (e) The following non-dimensional parameters have been used in the development of the final set of equations, the parameters were changed from those of Ref (27) to include the freestream radial flow and to conserve the radial profile to be similar to that of axial profiles (which was found from experimental observations).

$$g(\eta) = v_d/v_o - v_c$$

$$G = \int_0^1 g(\eta) d\eta$$

$$h(\eta) = u_d/v_o - u_c$$

$$H = \int_0^1 h(\eta) d\eta$$

$$f(v) = w_d/w_o - w_c$$

$$F = \int_0^1 f(\eta) d\eta$$

$$i(\eta) = \overline{u'^2}(\eta)/\overline{u'^2}_c$$

$$I = \int_0^1 i(\eta) d\eta$$

$$\overline{p} = \frac{\delta}{r} \int_0^1 p d\eta \quad (E)$$

$$j(\eta) = \overline{v'^2}(\eta)/\overline{v'^2}_c$$

$$J = \int_0^1 j(\eta) d\eta$$

$$k(\eta) = \overline{w'^2}(\eta)/\overline{w'^2}_c$$

$$K = \int_0^1 k(\eta) d\eta$$

Using the previous assumptions 1, 2 and the integration (2.d) the conservation of mass and momentum equations are integrated as follows.

2.2.1 Radial Momentum Equation:

The momentum equation in the radial direction is :

$$\begin{aligned}
 & \frac{(V_o - v_d)}{r} \frac{\partial (U_o - u_d)}{\partial \theta} + (U_o - u_d) \frac{\partial (U_o - u_d)}{\partial r} \\
 & + (W_o - w_d) \frac{\partial (U_o - u_d)}{\partial z} - \frac{1}{r} (V_o - v_d + \Omega r)^2 \\
 & = - \frac{1}{\rho} \frac{\partial p}{\partial r} - \frac{\overline{\partial u'^2}}{\partial r} - \frac{\overline{u'^2}}{r} + \frac{\overline{v'^2}}{r} - \frac{\overline{\partial(u'v')}}{r \partial \theta} - \frac{\overline{\partial(u'w')}}{\partial z} \dots (2.7)
 \end{aligned}$$

Carrying out the integration of equation (2.7) across the wake term by term yields,

$$\begin{aligned}
 & \int_{\theta_c}^{\theta_o} \frac{(V_o - v_d)}{r} \frac{\partial (U_o - u_d)}{\partial \theta} d\theta = \int_{\theta_c}^{\theta_o} \left(\frac{V_o}{r} - \frac{v_d}{r} \right) \left(- \frac{\partial u_d}{\partial \theta} \right) d\theta \\
 & = - \int_{\theta_c}^{\theta_o} \frac{V_o}{r} \frac{\partial u_d}{\partial \theta} d\theta + \int_{\theta_c}^{\theta_o} \frac{v_d}{r} \frac{\partial u_d}{\partial \theta} d\theta \approx - \int_{\theta_c}^{\theta_o} \frac{V_o}{r} \frac{\partial u_d}{\partial \theta} d\theta = - \frac{V_o}{r} u_c \\
 & \int_{\theta_c}^{\theta_o} (U_o - u_d) \frac{\partial (U_o - u_d)}{\partial r} d\theta = \int_{\theta_c}^{\theta_o} (U_o - u_d) \left(\frac{\partial U_o}{\partial r} - \frac{\partial u_d}{\partial r} \right) d\theta
 \end{aligned}$$

$$= \int_{\theta_c}^{\theta_o} (U_o - u_d) \frac{\partial U_o}{\partial r} d\theta = \int_{\theta_c}^{\theta_o} U_o \frac{\partial U_o}{\partial r} d\theta - \int_{\theta_c}^{\theta_o} u_d \frac{\partial U_o}{\partial r} d\theta$$

$$= U_o \frac{dU_o}{dr} \frac{\delta}{r} - \frac{dU_o}{dr} \frac{\delta}{r} (U_o - u_c) H$$

$$\int_{\theta_c}^{\theta_o} (W_o - w_d) \frac{\partial (U_o - u_d)}{\partial z} d\theta = \int_{\theta_c}^{\theta_o} (W_o - w_d) \left(- \frac{\partial u_d}{\partial z} \right) d\theta$$

$$= - \int_{\theta_c}^{\theta_o} (W_o) \frac{\partial u_d}{\partial z} d\theta = - W_o \left[\frac{d}{dz} \frac{\delta}{r} (U_o - u_c) H \right.$$

$$\left. - \frac{u_c}{r} \frac{V_o - v_c}{W_o - w_c} \right]$$

$$\int_{\theta_c}^{\theta_o} - \frac{1}{r} (V_o - v_d + \Omega r)^2 d\theta = \int_{\theta_c}^{\theta_o} - \frac{1}{r} \left[(V_o - v_d)^2 + \Omega^2 r^2 + 2\Omega r (V_o - v_d) \right] d\theta$$

$$= \int_{\theta_c}^{\theta_o} - \frac{1}{r} \left[V_o^2 - 2V_o v_d + v_d^2 + \Omega^2 r^2 + 2\Omega r V_o - 2\Omega r v_d \right] d\theta$$

$$= - \frac{1}{r} \left[\int_{\theta_c}^{\theta_o} V_o^2 d\theta - 2 \int_{\theta_c}^{\theta_o} V_o v_d d\theta + \int_{\theta_c}^{\theta_o} v_d^2 d\theta + \int_{\theta_c}^{\theta_o} \Omega^2 r^2 d\theta \right.$$

$$+ 2 \Omega \int_{\theta_c}^{\theta_0} r v_o d\theta - 2 \int_{\theta_c}^{\theta_0} \Omega r v_d d\theta \Big]$$

$$= -\frac{1}{r} \left[v_o^2 \frac{\delta}{r} - 2 v_o \frac{\delta}{r} (v_o - v_c) G + \Omega^2 r^2 \frac{\delta}{r} + 2 \Omega r \right. \\ \left. v_o \frac{\delta}{r} - 2 \Omega r \frac{\delta}{r} G (v_o - v_c) \right]$$

$$\int_{\theta_c}^{\theta_0} -\frac{1}{r} (v_o - v_d + \Omega r)^2 d\theta = -\frac{v_o^2}{r^2} \delta + 2 \frac{v_o^2}{r^2} G \delta$$

$$- 2 \frac{v_o}{r^2} G \delta v_c - \Omega^2 \delta + 2 \frac{\Omega v_o}{r} G \delta - 2 \frac{\Omega}{r} G \delta v_c - 2 \frac{\Omega}{r} v_o \delta$$

$$\int_{\theta_c}^{\theta_0} -\frac{1}{\rho} \frac{\partial p}{\partial r} d\theta = -\frac{1}{\rho} \frac{\partial}{\partial r} \left(\bar{p} \frac{\delta}{r} \right) - \frac{1}{\rho} (p_c - p_e) \frac{\partial \theta_c}{\partial r}$$

$$+ \frac{1}{\rho} p_e \left(-\frac{\delta}{r^2} + \frac{1}{r} \frac{\partial \delta}{\partial r} \right)$$

Turbulence terms:-

$$1. \int_{\theta_c}^{\theta_o} - \frac{\overline{\partial u'^2}}{\partial r} d\theta$$

These terms are typified as representing the variation of turbulent quantity gradient in the spanwise direction. In the final algorithm the choice was left between either neglecting them or considering a local change in the slope between the centre line and the outer edge as described by

$$\int_{\theta_c}^{\theta_o} - \frac{\overline{\partial u'^2}}{\partial r} d\theta = - \left[\frac{\overline{\partial u'^2}}{\partial r} \Big|_{\theta_o} - \frac{\overline{\partial u'^2}}{\partial r} \Big|_{\theta_c} \right] \quad (T.1)$$

These variations are further discussed in Chapter 6 Section 6.5.

$$\int_{\theta_c}^{\theta_o} - \frac{\overline{u'^2}}{r} d\theta = - \frac{1}{r} \frac{\delta}{r} I \overline{u'^2_c}$$

$$\int_{\theta_c}^{\theta_o} \frac{\overline{v'^2}}{r} d\theta = \frac{1}{r} \frac{\delta}{r} J \overline{v'^2_c} = \frac{\delta}{r^2} J \overline{v'^2_c} .$$

$$2. \int_{\theta_c}^{\theta_o} - \frac{1}{r} \frac{\overline{\partial u'v'}}{\partial \theta} d\theta \quad \text{For this kind of term, the choice was again}$$

left open in the algorithm between applying the same ratios which were

obtained from the Experimental Results in the form of

$$- \frac{1}{r} \left[\overline{u'v'}_o - \overline{u'v'}_c \right], \text{ OR applying the Boussinesq's Concept (Ref. 78)}$$

in the form,

hence

$$\begin{aligned}
 & -\overline{u_i u_j} = v_t \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \\
 & \int_{\theta_c}^{\theta_o} -\frac{1}{r} \frac{\partial \overline{u'v'}}{\partial \theta} d\theta = -v_t \frac{\delta}{r^3} (V_o - v_c) G \\
 & \int_{\theta_c}^{\theta_o} -\frac{\partial \overline{u'w'}}{\partial z} d\theta = -v_t \frac{d}{dz} \left\{ \int_{\theta_c}^{\theta_o} \left(\frac{\partial U}{\partial z} + \frac{\partial W}{\partial r} \right) d\theta \right\} \\
 & = -v_t \frac{d}{dz} \left\{ \int_{\theta_c}^{\theta_o} \left(\frac{\partial (U_o - u_d)}{\partial z} + \frac{\partial (W_o - w_d)}{\partial r} \right) d\theta \right\} \\
 & = -v_t \frac{d}{dz} \int_{\theta_c}^{\theta_o} \left(-\frac{\partial u_d}{\partial z} + \frac{\partial W_o}{\partial r} \right) d\theta = -v_t \frac{d}{dz} \left\{ \int_{\theta_c}^{\theta_o} -\frac{\partial}{\partial z} u_d d\theta + \int_{\theta_c}^{\theta_o} \frac{\partial W_o}{\partial r} d\theta \right\} \\
 & = v_t \frac{d}{dz} \left\{ \frac{d}{dz} \left(\frac{\delta}{r} (U_o - u_c) H \right) - \frac{u_c}{r} \left[\frac{V_o - v_c}{W_o - w_c} \right] + \frac{\delta}{r} \frac{dW_o}{dr} \right\} \\
 & = v_t \left\{ \frac{d^2}{dz^2} \left(\frac{\delta}{r} (U_o - u_c) H \right) - \frac{d}{dz} \left(\frac{u_c}{r} \left[\frac{V_o - v_c}{W_o - w_c} \right] \right) + \frac{d}{dz} \left(\frac{\delta}{r} \frac{dW_o}{dr} \right) \right\} \\
 & = v_t \left\{ \frac{d^2}{dz^2} \left(\frac{\delta}{r} (U_o - u_c) H \right) - \frac{V_o}{r W_o} \frac{du_c}{dz} + \frac{d}{dz} \left(\frac{\delta}{r} \frac{dW_o}{dr} \right) \right\}
 \end{aligned}$$

By summation of the previous terms, the Conservation of momentum equation in the radial direction reads,

$$\begin{aligned}
 & - \frac{V_o}{r} u_c + U_o \frac{dU_o}{dr} \frac{\delta}{r} - \frac{dU_o}{dr} \frac{\delta}{r} U_o H + \frac{dU_o}{dr} \frac{\delta}{r} u_c H - W_o \frac{d}{dz} \left(\frac{\delta}{r} \right. \\
 & (U_o - u_c) H) + W_o \frac{u_c}{r} \left(\frac{V_o - v_c}{W_o - w_c} \right) - \frac{V_o^2}{r^2} \delta + \frac{2V_o^2}{r^2} G \delta - \frac{2V_o}{r^2} G \delta v_c \\
 & - \Omega^2 \delta - 2 \Omega / r V_o \delta + 2 \Omega \frac{V_o}{r} G \delta - 2 \frac{\Omega}{r} G \delta v_c \\
 & + \frac{1}{\rho} \frac{\partial}{\partial r} (\bar{p} \delta / r) - \frac{1}{\rho} (p_e - p_c) \frac{\partial \theta}{\partial r} - \frac{1}{\rho} P_e \left(- \delta / r^2 + \frac{\partial \delta}{r \partial r} \right) \\
 & + (T \cdot 1) + \frac{\delta}{r^2} I \overline{u_c'^2} \\
 & - \frac{\delta}{r^2} J \overline{v_c'} + \left\{ \frac{1}{r} (\overline{u'v'}_o / - \overline{u'v'}_c) \quad \text{OR} \quad - v_T \frac{\delta}{r^3} (V_o - v_c) G \right\} \\
 & - v_T \left\{ \frac{d^2}{dz^2} \left(\frac{\delta}{r} (U_o - u_c) H \right) - \frac{V_o}{r W_o} \frac{du_c}{dz} + \frac{d\delta}{dz} \frac{1}{r} \frac{dW_o}{dr} \right\} = 0 \\
 & \dots (2.8)
 \end{aligned}$$

2.2.2 Tangential Momentum Equation:

The momentum equation in the θ -direction applying assumptions (2.5, 2.6) is,

$$\begin{aligned} & \frac{(V_o - v_d)}{r} \frac{\partial (V_o - v_d)}{\partial \theta} + (U_o - u_d) \frac{\partial (V_o - v_d)}{\partial r} + (W_o - w_d) \\ & \frac{\partial (V_o - v_d)}{\partial z} + \frac{(U_o - u_d)(V_o - v_d)}{r} + 2 \Omega (U_o - u_d) = -\frac{1}{\rho} \frac{1}{r} \frac{\partial p}{\partial \theta} \\ & - \frac{1}{r} \frac{\partial \overline{v'^2}}{\partial \theta} - 2 \left(\frac{\overline{u'v'}}{r} \right) - \frac{\partial (\overline{u'v'})}{\partial r} - \frac{\partial (\overline{v'w'})}{\partial z} \dots (2.9) \end{aligned}$$

Integrating equation (2.9) across the wake term by term gives;

$$\int_{\theta_c}^{\theta_o} \left(\frac{V_o}{r} - \frac{v_d}{r} \right) \frac{\partial (V_o - v_d)}{\partial \theta} d\theta = - \int_{\theta_c}^{\theta_o} \left(\frac{V_o}{r} - \frac{v_d}{r} \right) \frac{\partial v_d}{\partial \theta} d\theta$$

$$= - \int_{\theta_c}^{\theta_o} \left(\frac{V_o}{r} \frac{\partial v_d}{\partial \theta} \right) d\theta + \int_{\theta_c}^{\theta_o} \left(\frac{v_d}{r} \frac{\partial v_d}{\partial \theta} \right) d\theta = \frac{V_o}{r} v_c$$

$$\int_{\theta_c}^{\theta_o} (U_o - u_d) \frac{\partial (V_o - v_d)}{\partial r} d\theta = \int_{\theta_c}^{\theta_o} (U_o - u_d) \frac{\partial V_o}{\partial r} d\theta$$

$$= \frac{\delta}{r} U_o \frac{dV_o}{dr} - \frac{dV_o}{dr} \int_{\theta_c}^{\theta_o} u_d d\theta = \frac{\delta}{r} U_o \frac{dV_o}{dr} - \frac{dV_o}{dr} \frac{\delta}{r} (U_o - u_c) H$$

$$\int_{\theta_c}^{\theta_o} (w_o - w_d) \frac{\partial (v_o - v_d)}{\partial z} d\theta = \int_{\theta_c}^{\theta_o} (w_o - w_d) \left(\frac{\partial v_o}{\partial z} - \frac{\partial v_d}{\partial z} \right) d\theta$$

$$= \int_{\theta_c}^{\theta_o} (w_o - w_d) \left(- \frac{\partial v_d}{\partial z} \right) d\theta = - \int_{\theta_c}^{\theta_o} w_o \frac{\partial v_d}{\partial z} d\theta$$

$$= - w_o \left\{ \frac{d}{dz} \left(\frac{\delta}{r} (v_o - v_c) G \right) - \frac{v_c}{r} \left(\frac{v_o - v_c}{w_o - w_c} \right) \right\}$$

$$\int_{\theta_c}^{\theta_o} \frac{1}{r} (u_o - u_d) (v_o - v_d) d\theta$$

$$= \int_{\theta_c}^{\theta_o} \frac{1}{r} \left\{ u_o v_o + u_d v_d - v_o u_d - u_o v_d \right\} d\theta$$

$$= \frac{1}{r} \left\{ \frac{u_o v_o}{r} \delta - v_o \int_{\theta_c}^{\theta_o} u_d d\theta - u_o \int_{\theta_c}^{\theta_o} v_d d\theta \right\}$$

$$= \frac{1}{r} \left\{ \frac{u_o v_o}{r} \delta - \frac{v_o \delta}{r} (u_o - u_c) H - \frac{u_o \delta}{r} (v_o - v_c) G \right\}$$

$$\int_{\theta_c}^{\theta_o} 2\Omega (u_o - u_d) d\theta = \int_{\theta_c}^{\theta_o} 2\Omega u_o d\theta - \int_{\theta_c}^{\theta_o} 2\Omega u_d d\theta$$

$$= 2 \int_{\theta_c}^{\theta_o} \Omega u_o d\theta - 2 \int_{\theta_c}^{\theta_o} \Omega u_d d\theta$$

$$= 2\Omega u_o \frac{\delta}{r} - 2\Omega \frac{\delta}{r} (u_o - u_c) H$$

$$\int_{\theta_c}^{\theta_o} - \frac{1}{\rho} \frac{1}{r} \frac{\partial p}{\partial \theta} d\theta = - \frac{1}{\rho} \frac{1}{r} (p_e - p_c)$$

Turbulence Terms:

$$1. \int_{\theta_c}^{\theta_o} -\frac{1}{r} \frac{\partial(\overline{v'^2})}{\partial \theta} d\theta = -\frac{1}{r} \left\{ \overline{v_o'^2} - \overline{v_c'^2} \right\}$$

$$-2 \int_{\theta_c}^{\theta_o} \left(\frac{\overline{u'v'}}{r} \right) d\theta = -2 \int_{\theta_c}^{\theta_o} \frac{1}{r} v_t \left(\frac{\partial V}{\partial r} + \frac{1}{r} \frac{\partial U}{\partial \theta} - \frac{V}{r} \right) d\theta$$

$$= -2 \int_{\theta_c}^{\theta_o} \frac{1}{r} v_t \left(\frac{\partial(V_o - v_d)}{\partial r} + \frac{1}{r} \frac{\partial(U_o - u_d)}{\partial \theta} - \frac{(V_o - v_d)}{r} \right) d\theta$$

$$= -2 \int_{\theta_c}^{\theta_o} \left[\frac{v_t}{r} \left(\frac{\partial V_o}{\partial r} - \frac{\partial v_d}{\partial r} + \frac{1}{r} \left(-\frac{\partial u_d}{\partial \theta} \right) - \frac{V_o}{r} + \frac{v_d}{r} \right) \right] d\theta$$

$$= -2 \frac{v_t}{r} \left[\frac{\delta}{r} \frac{dV_o}{dr} + \frac{1}{r} u_c - \frac{V_o \delta}{r^2} + \frac{1}{r^2} \delta (V_o - v_c) G \right]$$

$$2. \int_{\theta_c}^{\theta_o} -\frac{\overline{\partial u'v'}}{\partial r} d\theta : \text{This term is treated in the same way as that used for (T.1) (T.2)}$$

$$\int_{\theta_c}^{\theta_o} -\frac{\overline{\partial v'w'}}{\partial z} d\theta = - \int_{\theta_c}^{\theta_o} v_t \frac{d}{dz} \left(\frac{1}{r} \frac{\partial w}{\partial \theta} + \frac{\partial V}{\partial z} \right) d\theta$$

$$= -v_t \frac{d}{dz} \left[\int_{\theta_c}^{\theta_o} \frac{1}{r} \frac{\partial w}{\partial \theta} d\theta + \int_{\theta_c}^{\theta_o} \frac{\partial v}{\partial z} d\theta \right]$$

$$= -v_t \frac{d}{dz} \left[\int_{\theta_c}^{\theta_o} \frac{1}{r} \left(-\frac{\partial w_d}{\partial \theta} \right) d\theta + \int_{\theta_c}^{\theta_o} \frac{\partial(-v_d)}{\partial z} d\theta \right]$$

$$= -v_t \frac{d}{dz} \left[-\frac{1}{r} \int_{\theta_c}^{\theta_o} \left(\frac{\partial w_d}{\partial \theta} \right) d\theta - \int_{\theta_c}^{\theta_o} \frac{\partial v_d}{\partial z} d\theta \right]$$

$$= -v_t \frac{d}{dz} \left[-\frac{1}{r} (-w_c) - \left[\frac{d}{dz} \frac{\delta}{r} (V_o - v_c) G - \frac{v_c}{r} \left[\frac{V_o - v_c}{W_o - w_c} \right] \right] \right]$$

$$= -v_t \frac{d}{dz} \left[\frac{w_c}{r} - G \frac{d}{dz} \left\{ \frac{\delta}{r} (V_o - v_c) \right\} + \frac{v_c}{r} \left(\frac{V_o - v_c}{W_o - w_c} \right) \right]$$

$$= -v_t \left\{ \frac{d}{dz} \frac{w_c}{r} - G \frac{d^2}{dz^2} \left\{ \frac{\delta}{r} (V_o - v_c) \right\} + \frac{V_o}{r W_o} \frac{dv_c}{dz} \right\}$$

By summation of the previous terms the Conservation of momentum in the tangential direction reads:

$$\frac{V_o}{r} v_c + \frac{\delta}{r} U_o \frac{dV_o}{dr} - \frac{dV_o}{dr} \frac{\delta}{r} (U_o - u_c) H - W_o \left\{ \frac{d}{dz} \frac{\delta}{r} (V_o - v_c) \right.$$

$$\left. G - \frac{v_c}{r} \left[\frac{V_o - v_c}{W_o - w_c} \right] \right\} + \frac{1}{r} \left\{ \frac{U_o V_o}{r} \delta - \frac{V_o \delta}{r} (U_o - u_c) H - \frac{U_o \delta}{r} \right.$$

$$\begin{aligned}
& (V_o - v_c) G \left\{ + 2 \Omega \frac{U_o}{r} \delta - 2 \Omega \frac{\delta}{r} (U_o - u_c) H + \frac{1}{\rho} \frac{1}{r} \right. \\
& (P_e - P_c) + \frac{1}{r} (V_o'^2 - v_c'^2) + 2 \frac{v_t}{r} \left[\frac{\delta}{r} \frac{dV_o}{dr} + \frac{1}{r} u_c - \frac{V_o \delta}{r^2} \right. \\
& \left. + \frac{1}{r^2} \delta (V_o - v_c) G \right] + (T+2) + v_t \left\{ \frac{d}{dz} \frac{w_c}{r} - G \frac{d^2}{dz^2} \left(\frac{\delta}{r} (V_o - v_c) \right) \right\} \\
& \left. + \frac{V_o}{r W_o} \frac{dv_c}{dz} \right\} = 0 \quad \dots (2.10)
\end{aligned}$$

2.2.3 Axial Momentum Equation:

The momentum equation in the axial direction is :

$$\begin{aligned}
& \frac{(V_o - v_d)}{r} \frac{\partial (W_o - w_d)}{\partial \theta} + (U_o - u_d) \frac{\partial (W_o - w_d)}{\partial r} + (W_o - w_d) \frac{\partial (W_o - w_d)}{\partial z} \\
& = - \frac{1}{\rho} \frac{\partial p}{\partial z} - \frac{\partial (\overline{w'^2})}{\partial z} - \frac{\partial}{\partial r} (\overline{u'w'}) - \frac{\overline{u'w'}}{r} - \frac{1}{r} \frac{\partial (\overline{v'w'})}{\partial \theta} \quad \dots (2.11)
\end{aligned}$$

Integration of Equation (2.11) term by term yields,

$$\int_{\theta_c}^{\theta_o} \frac{(V_o - v_d)}{r} \frac{\partial (W_o - w_d)}{\partial \theta} d\theta = \int_{\theta_c}^{\theta_o} \left(\frac{V_o}{r} - \frac{v_d}{r} \right) \left(- \frac{\partial w_d}{\partial \theta} \right) d\theta$$

$$= \int_{\theta_c}^{\theta_o} - \frac{V_o}{r} \frac{\partial w_d}{\partial \theta} d\theta = \frac{V_o}{r} w_c$$

$$\int_{\theta_c}^{\theta_o} (U_o - u_d) \frac{\partial (W_o - w_d)}{\partial r} d\theta = \int_{\theta_c}^{\theta_o} U_o \frac{\partial W_o}{\partial r} d\theta - \int_{\theta_c}^{\theta_o} u_d \frac{\partial W_o}{\partial r} d\theta$$

$$= U_o \frac{dW_o}{dr} \frac{\delta}{r} - \frac{dW_o}{dr} \frac{\delta}{r} (U_o - u_c) H$$

$$\int_{\theta_c}^{\theta_o} (W_o - w_d) \frac{\partial (W_o - w_d)}{\partial z} d\theta = \int_{\theta_c}^{\theta_o} W_o \left(- \frac{\partial w_d}{\partial z} \right) d\theta$$

$$= - W_o \left\{ \frac{d}{dz} \left(\frac{\delta}{r} (W_o - w_c) F \right) - \frac{w_c}{r} \left(\frac{V_o - v_c}{W_o - w_c} \right) \right\}$$

$$\int_{\theta_c}^{\theta_o} - \frac{1}{\rho} \frac{\partial p}{\partial z} d\theta = - \frac{1}{\rho} \left\{ \frac{\partial (\bar{p} \delta / r)}{\partial z} + \frac{p_c}{r} \left(\frac{V_o - v_c}{W_o - w_c} \right) \right.$$

$$\left. - P_e \frac{1}{r} \left(\frac{V_o - v_c}{W_o - w_c} \right) + \frac{1}{r} \frac{\partial \delta}{\partial z} \right\}$$

Turbulence Terms :-

$$1) \int_{\theta_c}^{\theta_o} - \frac{\overline{\partial(w'^2)}}{\partial z} d\theta = - \left\{ \frac{d}{dz} \frac{\delta}{r} \overline{w'_c{}^2} K - \frac{\overline{w'_c{}^2}}{r} \left(\frac{V_o - v_c}{W_o - w_c} \right) \right\}$$

$$2) \int_{\theta_c}^{\theta_o} - \frac{\overline{\partial(u'w')}}{\partial r} : \text{ This term treated in the same manner as}$$

before (T-1), (T-2) (T.3)

$$\begin{aligned} \int_{\theta_c}^{\theta_o} - \frac{\overline{u'w'}}{r} d\theta &= - \int_{\theta_c}^{\theta_o} \frac{1}{r} v_t \left(\frac{d}{dz} \left(\frac{\partial U}{\partial z} + \frac{\partial W}{\partial r} \right) \right) d\theta \\ &= - \frac{v_t}{r} \frac{d}{dz} \left\{ \int_{\theta_c}^{\theta_o} \frac{\partial(U_o - u_d)}{\partial z} d\theta + \int_{\theta_c}^{\theta_o} \frac{\partial(W_o - w_d)}{\partial r} d\theta \right\} \\ &= - \frac{v_t}{r} \frac{d}{dz} \left\{ - \frac{d}{dz} \left(\frac{\delta}{r} (U_o - u_c) H \right) + \frac{u_c}{r} \left[\frac{V_o - v_c}{W_o - w_c} \right] + \right. \\ &\quad \left. \frac{dW_o}{dr} \frac{\delta}{r} \right\} \\ &= + \frac{v_t}{r} \left\{ \frac{d^2}{dz^2} \left(\frac{\delta}{r} (U_o - u_c) H \right) - \frac{V_o}{rW_o} \frac{du_c}{dz} - \frac{dW_o}{dr} \frac{d\delta/r}{dz} \right\} \end{aligned}$$

$$\int_{\theta_c}^{\theta_o} -\frac{1}{r} \frac{\overline{\partial v'w'}}{\partial \theta} d\theta = -\frac{1}{r} \int_{\theta_c}^{\theta_o} \frac{\overline{\partial v'w'}}{\partial \theta} d\theta = -\frac{1}{r} \left[\overline{v'w'}_o - \overline{v'w'}_c \right]$$

By summation of all the foregoing terms, the Conservation of momentum equation in the axial direction reads:

$$\begin{aligned} & \frac{V_o}{r} w_c + U_o \frac{dw_o}{dr} \frac{\delta}{r} - \frac{dw_o}{dr} \frac{\delta}{r} (U_o - u_c) H - W_o \left\{ \frac{d}{dz} \left(\frac{\delta}{r} \right. \right. \\ & \left. \left. (W_o - w_c) F \right) - \frac{w_c}{r} \left(\frac{V_o - v_c}{W_o - w_c} \right) \right\} + \frac{1}{\rho} \left\{ \frac{\partial(\bar{p}(\delta/r))}{\partial z} + \frac{p_c}{r} \left(\frac{V_o - v_c}{W_o - w_c} \right) \right. \\ & \left. - p_e \frac{1}{r} \left(\frac{V_o - v_c}{W_o - w_c} \right) + \frac{1}{r} \frac{\partial \delta}{\partial z} \right\} + \left\{ \frac{d}{dz} \frac{\delta}{r} \overline{w'^2_c} K - \frac{\overline{w'^2_c}}{r} \right. \\ & \left. \left(\frac{V_o - v_c}{W_o - w_c} \right) \right\} + (T.3) - \frac{v_t}{r} \left\{ \frac{d^2}{dz^2} \frac{\delta}{r} (U_o - u_c) H - \frac{V_o}{rW_o} \frac{du_c}{dz} \right. \\ & \left. - \frac{dw_o}{dr} \frac{d}{dz} \frac{\delta/r}{dz} \right\} + \frac{1}{r} (\overline{v'w'}_o - \overline{v'w'}_c) = 0 \quad \dots (2.12) \end{aligned}$$

2.2.4 Continuity Equation:-

$$\frac{1}{r} \frac{\partial(V_o - v_d)}{\partial \theta} + \frac{\partial(W_o - w_d)}{\partial z} + \frac{\partial(U_o - u_d)}{\partial r} + \frac{(U_o - u_d)}{r} = 0$$

by applying assumptions (2-5)

$$-\frac{1}{r} \frac{\partial v_d}{\partial \theta} - \frac{\partial w_d}{\partial z} + \frac{\partial U_o}{\partial r} + \frac{U_o}{r} - \frac{u_d}{r} = 0$$

Integration of the conservation of mass equation term by term gives

$$\begin{aligned}
 -\frac{1}{r} \int_{\theta_c}^{\theta_o} \frac{\partial v_d}{\partial \theta} d\theta &= \frac{1}{r} v_c \\
 -\int_{\theta_c}^{\theta_o} \frac{\partial w_d}{\partial z} d\theta &= -\frac{d}{dz} \left(\frac{\delta}{r} (w_o - w_c) F \right) + \frac{v_c}{r} \left(\frac{v_o}{w_o} - \frac{v_c}{w_o} - \frac{v_o w_c}{w_o^2} \right) \\
 \int_{\theta_c}^{\theta_o} \frac{\partial u_o}{\partial r} d\theta &= \frac{\delta}{H} \frac{du_o}{dr} \\
 -\int_{\theta_o}^{\theta_c} \frac{u_d}{r} d\theta &= -\frac{1}{r} \frac{\delta}{r} (u_o - u_c) H
 \end{aligned}$$

The Continuity Equation then yields,

$$\begin{aligned}
 \frac{1}{r} v_c - \frac{d}{dz} \left(\frac{\delta}{r} (w_o - w_c) F \right) + \frac{v_c}{r} \left(\frac{v_o}{w_o} - \frac{v_c}{w_o} - \frac{v_o w_c}{w_o^2} \right) \\
 + \frac{\delta}{r} \frac{du_o}{dr} - \frac{H}{r} \frac{\delta}{r} (u_o - u_c) = 0 \quad \dots (2.13)
 \end{aligned}$$

Equations (2.8), (2.10), (2.12) and (2.13) control the behaviour of the wake along the axial and the radial direction. The non-dimensional parameters (E) control the behaviour of the wake in the third co-ordinate.

The inclusion of eddy viscosity " ν_t " in the previous equations can be substituted for by several formulae. The eddy viscosity is said to be dependent on the flow turbulent characteristics, although all the given formulae do not contain any direct dependency, but the formulae are very descriptive for a flow of homogenous turbulence distribution and it is difficult to model the exact distribution of the eddy viscosity for a flow of high non-isotropic turbulent nature. As an approximation.

Ref (79) and Ref (80) quote the following formulae for wake flows

$\nu_T = ct (U_\infty - U_m) b_x$ where b is the wake semi-width and U_m is the wake centreline velocity and U_∞ is the free stream velocity. Ref (81) gives the following relation for the wake eddy viscosity $\nu_T = ct \int_0^\infty (U_\infty - u) dy$.

In the present analysis we adopted the last relation for the following reasons:

- 1 - it is simple to incorporate into this particular analysis because it does not contain the width or the centreline velocity. However, the effect of both was taken collectively into account as a function of the displacement thickness across the wake. This displacement thickness is well established from the experimental results.
- 2 - the first relation includes the width and wake centreline velocity both of which are unknown at this stage, and the inclusion of them would have led to high order non-linear equations. This higher order would risk the control over the resultant roots of the equations.
- 3 - inclusion of (b_x) , which is defined as the semi-wake width, cannot be doubled to obtain the full width as defined before. As known from the experimental evidence the wake has exponential decay characteristics along the pitchwise direction, which further complicates the modelling.

In the previous works, Refs (27 ,28) the eddy viscosity distribution was not considered because all the turbulence and pressure terms were neglected in the derivation of the functional solution.

2.3 Solution Technique

Because of the very lengthy analytical derivation, which was applied on the equation (2.8, 2.10, 2.12 and 2.13) to solve them for the unknowns u_c , v_c , w_c and δ , we shall only describe the technique and the final set of equations are presented in Appendix 3 .

Equations 2.8, 10, 12 and 2.13 can be written as :

$$L_i (\delta, u_c, v_c, w_c) = 0 \quad \text{where } i = 1, 2, 3, 4 \quad \dots (2.14)$$

From critical observation of the experimental results and the available literature (Refs 29 to 41) we assume the following functional solutions :

$$\left. \begin{aligned} \tilde{u}_c &= A_1 \phi_1(Z) + A_2 \phi_2(Z) \\ \tilde{v}_c &= A_3 \phi_3(Z) + A_4 \phi_4(Z) \\ \tilde{w}_c &= A_5 \phi_5(Z) + A_6 \phi_6(Z) \\ \tilde{\delta}_c &= A_7 \phi_7(Z) + A_8 \phi_8(Z) \end{aligned} \right\} \quad \dots (2.15)$$

where A_i , $i = 1, 8$ are the unknown parameters to be obtained by the solution algorithm

$$\phi_i(Z) = (Z - Z_0)^{m_i} \quad (i = 1, 8)$$

This function $\phi_i(Z)$ should be chosen to satisfy the physical boundary conditions, by substituting the functional solution (approximate solution) (2.15) into the differential equations (2.14). We obtain the Residual function $R_j(Z)$ given by

$$R_J(Z) = L_J (\tilde{\delta}, \tilde{u}_c, \tilde{v}_c, \tilde{w}_c) \quad (J = 1, 2, 3, 4).$$

From Galerkin's method, in order to obtain a solution with a minimum error, the following integrations must be zero :

$$\int_{Z_1}^{Z_2} \phi(Z) \frac{R_J(Z)}{(2J-1)} = 0$$

where $J = 1, 2, 3, 4$

$$\int_{Z_1}^{Z_2} \phi(Z) \frac{R_J(Z)}{2J} = 0 \quad \dots (2.16)$$

Application of these integrations (2.16) will lead to a set of non-linear algebraic equations (8 equations) which can be written in general as :

$$f_i(x_1, x_2, \dots, x_n) = \sum_{r=1}^{m_i} C_{i,r} \left(\prod_{s=1}^n x_s^{P_{i,s,r}} \right) \dots (2.17)$$

These set of equations can then be solved by a general Newton-Raphson iteration to obtain the roots which are the constant A 's. The differentiation of equations (2.17) is :

$$\frac{\partial f_i}{\partial x_t} = \sum_{r=1}^{m_i} C_{i,r} \left(\prod_{s=1}^n x_s^{P_{i,s,r}} \right) P_{i,t,r} x_t^{P_{i,t,r}-1},$$

and the final set of equations are presented in Appendix (3).

The description of the computer program to solve the equations is in Chapter 6 . Comparisons are also made with the experimental results in that chapter.

CHAPTER 3 : EXPERIMENTAL RIG AND INSTRUMENTATIONS

3.1.1 EXPERIMENTAL RIG AND PERIPHERAL INSTRUMENTATIONS

3.2 EXPERIMENTAL RIG:

The axial flow compressor used for this research was a lightly loaded single stage unit designated C134 compressor. It had a constant annulus cross section with hub/tip ratio of 0.5, tip diameter of .5m. The compressor was driven by a variable speed 5HP electric motor at speeds up to a max. of 1500 r.p.m.

3.1.1 BLADING

All the blades had a C4 profile, with a circular camber line.

The detailed geometry and the blade section characteristics are shown in table(1). The chord length was constant along the radial direction and it was 48.3 mm; this relatively short chord length made the measurement of the wake in the trailing edge region difficult. The nearest location of the measurements, with the set-up of hot wire used, was at 0.9mm (the equivalent non-dimensionlized distance was $Z/C = .01863$, the average Reynolds number were 1.0×10^5 and the aspect ratio was 2.618).

3.2 CONVENTIONAL MEANS OF MEASUREMENTS

3.2.1 SPHERICAL PRESSURE TUBE

The spherical pressure tube was of the (type 601, plate 1) consisted mainly of the spherical head with five apertures, arranged in two meridians at right angles enclosing an angle of 45 degrees in its respective plane. Five soft capillary tubes connect the five apertures with their respective

numbered tube connections. A circular solid flange provides possibilities for assembling with the object to be tested, a circular turntable dial with divisions from 0 to 360 degrees is incorporated into the flange. An arresting device enables the dial to be locked on the shaft of the pressure tube, a sighting device (two red dots marked on the top of the tube) can be adjusted to bring the spherical head in coincidence with the zero position of the dial.

3.2.2 PRESSURE AND TEMPERATURE MEASURING INSTRUMENTS

A set of circumferentially distributed static pressure tappings were drilled in the casing wall of the compressor ahead of and behind the rotor and stator rows. Four total pressure rakes were installed orthogonally, each supporting nine shrouded pitot tubes. Two 36 manometer banks registered all the downstream total pressures and the static pressure along the compressor casing, the banks were inclined to 30 degree for convenient reading, and provided an accuracy of ± 0.005 psi. The ambient pressure was indicated by a barometer in inches of mercury, and the ambient temperature was indicated by a thermometer in $^{\circ}$ Celsius.

3.3 HIGH RESPONSE INSTRUMENTATIONS AND PERIPHERAL EQUIPMENTS

3.3.1 SINE WAVE DISTORTION SCREEN

The sine wave distortion screen plate(2) was designed according to the small perturbation theory; the screen superimposes a generated distortion upon undistorted potential

flow of the developed annulus. A circumferential sine wave velocity distortion in the flow, resulting from a pressure disturbance convected along the stream lines, led to a design of a screen whose porosity varied both in the circumferential and meridional planes. The screen resistance coefficient " K " is shown in fig(2). It was suggested by Bruce Ref.(82) that,

$$K = \Delta P / \frac{1}{2} \rho V_{ref}^2 \quad \text{where;}$$

K = Resistance coefficient

ρ = Fluid Density

V_{ref} . = The uniform axial velocity at a point far upstream.

And

$$K = C / (1 - S)^2 \quad \text{where;}$$

C = Screen loss coefficient

(C = 0.8 for Reynolds numbers R < 4000 , based on wire diameter).

S = Solidity, the ratio of blocked area to total area.

$$S = 2 \left(\frac{d}{m} - \left(\frac{d}{m} \right)^2 \right) \quad \text{where;}$$

d = wire diameter

m = spacing between centres of wires.

The pressure distribution ahead of the rotor in blade mid height is shown in fig(3). This distribution was a result of mounting the screen onto the bell mouth intake of the compressor.

3.3.2 3-HOLE BUILT-IN TRANSDUCER PROBE

A cylindrical 3-hole probe of 4mm diameter, containing three Kulite miniature Silicon bonded pressure transducers (XCQ-080-1G) was specially designed for this investigation. Each hole of the probe was individually connected to a transducer, the measuring range of which was 7×10^5 Pa and the natural frequency response was 100 KHz. The length of the tube connecting each hole to the corresponding transducer was kept to a minimum (the maximum length being 33mm, giving a cavity resonance frequency of about 2.5 KHz).

3.3.3 LAY OUT OF THE HOT-WIRE SYSTEM

A single wire probe and a crossed wire probe were mounted in a mutually orthogonal framework in which the single wire probe was aligned radially, while the crossed wire probe was aligned with one wire tangentially and the other axially (plate 3,4). The probes used were of the miniature type wire probe (DISA 55P13). The single wire was "L" shaped and the sensor was parallel to the probe axis. The wire length is 1.25 mm with a diameter of 5 μ m and the wire prong support was 30 mm long had a diameter of 2 mm. The cross wire probe, referred to as the X-array probe, (DISA 55p62) had its sensor plane perpendicular to the probe axis. The wire prong support was 33 mm long and its diameter was 2.5 mm, and the sensors dimensions were similar to those of the single wire.

The probes were mounted with a gap of 3 mm between the

single wire and the cross wire centres. Because of the finite distance between the probes there was a time lag between the output signals of the two probes. This varied with the compressor speed and the radial locations of the measuring points. A blade strobe unit (which is described in sec 3.4.13) was specially designed to take into account this problem. Two shorting probes (DISA 55H30 and 55H31) were used for the two wire probes. The short circuit resistance was less than 0.01 ohms for these probes. Two Disa probe supports (DISA 55H21 and 55H25) were used for the probes and their lengths were enough to cover all the span wise measurement locations.

3.3.4 HOT WIRE MOUNTING SYSTEM

A specially designed mounting system was used to hold the hot wire system in the desired position behind the rotor . The mounting had the facility of traversing the wire accurately along the radial and axial directions. The mounting was designed rigid enough to prevent the probe from vibrating. The same mounting was used for holding the spherical pressure tube in the desired position along the compressor casing.

3.3.5 HOT WIRE CALIBRATION EQUIPMENT

The importance of the precise calibration of the hot wire system used, and the need for precisely judging the response of the hot wire to any slight changes in the velocity vector, and the turbulence level led to the need for a precise calibration rig . The rig was used in this investigation was a DISA 55D90 calibration rig(plate 5), which had the following facilities,

-Four different areas nozzles to control the flow velocity over a wide range 0.5 to 60 m/sec ,a pressure control valve which allowed a velocity change of .2 m/sec.

-The probe mounting arrangement . The rig was designed to allow for the flow direction relative to the probe to be altered on two calibrated axes at right angles to one another, the horizontal axis was connected to a multiturn potentiometer which delivered the signal that was used when recording directional characteristics. There were three banana jacks for connecting a voltage source and for taking the signal from the potentiometer. This mounting arrangement can be swung away from the nozzle so that a nozzle can be changed without removing the probe.

-The rig had a built-in set of filters to collect any dust particles in the flow. The calibration rig was used along with the data logger system which will be described shortly. The peripheral equipment which was used for the static calibration is shown in plate (6) . A computer program which gave a tabulated output for the velocity in m/sec against the pressure meter reading mm of water , for a wide range of ambient pressure and temperature conditions , was written. The effective nozzle area (which was a result of the parabolic velocity distribution in the boundary layer) was taken into consideration. The output tables were kept with the calibration rig as a permanent feature. Fig (4) and plate (7) show the peripheral equipment which was used for the dynamic calibration of the hot wires . The equipment consisted of

- a shaker
- a power supply with a built-in amplifier
- a charge amplifier
- an accelerometer
- a r.m.s voltmeter

3.4 MAIN EXPERIMENTAL DATA PROCESSING SYSTEM

3.4.1 LAY OUT OF THE PERIPHERAL EQUIPMENTS

3.4.1.2 GENERAL

The layout of the peripheral equipment is shown in fig. (5) and plate (8) . The output signals from the three hot wires were fed into the three DISA 55M01 anemometers and then into the high speed data logger micro-computer. The signals were fed through three cut-off voltage units, the function of which was to subtract a constant steady value from each signal to improve the resolution inside the ADC cards. Along with these signals another two signals were fed into the data logger from the blade strobe unit. The general operation of the blade strobe unit was as follows

1) Two signals were fed to the blade strobe unit from the photo cell unit, which was mounted on the shaft of the compressor. One of these signals represented every degree rotation of the compressor, while the other represented the position of the probe relative to a specific blade.

2) These signals were then used in The blade strobe unit to regenerate two groups of pulses with a time lag, each containing 50 pulses representing the distance between the centres of two consecutive blade passages in time. As mentioned earlier, this time lag was produced to account for the finite distance between the probes. These two groups of pulses were used in the data logger as external triggers to digitise the hot wire input signals for each revolution of the compressor.

3.4.1.3. BLADE STROBE UNIT:

The circuit operation of the blade strobe unit (Fig 6) was as follows

A 6" diameter disc with 360 slots(.020" wide) was bolted on to the compressor drive shaft and a slotted opto-switch was used to obtain a pulse for each degree of rotation of the shaft. These pulses were amplified by TR1 and fed to a Schmidt switch IC1a to obtain sharp pulses.

As shown in (fig 7) . the output of IC1a was taken to IC4 which was connected so as to divide the incoming pulses by 6, giving an output of 60 pulses per revolution. These pulses were then fed to a timer/counter IC6 which counted the pulses for one second periods and displayed the count on a 4 digit display, giving a readout directly in R.P.M.

The output of IC1a was also fed to the input of IC3, which was a phase lock loop operating as a frequency multiplier in conjunction with a decade divider IC2 and a DIL switch 1. This switch was set so that the circuit multiplied the input

frequency by 5, and the output was a train of pulses, each pulse representing a 0.2 degree of shaft rotation. By closing the appropriate switch on DIL switch 1, any multiple of frequency could be obtained from $x1(1\text{degree})$ to $x10(0.1\text{ degree})$. The output from IC3 was fed to a monostable circuit IC5a, the output of which was a constant width pulse and it was used as a data sampling pulse.

The data sampling pulse was also fed to another phase lock loop multiplier IC7, IC8 and DIL switch 2. This circuit was set to multiply the input frequency by 5 by the setting of DIL switch 2 and the output from IC8 was fed to monostable IC5b to produce a constant width pulse to be used as a shift register clock.

A narrow strip of reflecting foil was placed on the shaft of the compressor at a predetermined position and a reflective opto-switch was used to obtain a once per revolution signal. If this signal was of sufficient amplitude, it was fed directly to the Schmidt switch IC6 to obtain a sharp pulse.

When power was first applied to the circuit fig. (8), the two bistable circuits IC13a and IC13b were set to the 'off' state by a pulse generated by IC16a, IC16b and IC16c. The output from IC13a and IC13b were applied to the inputs of a gate IC14b. The 0.2 degree pulses were also fed to gate IC14b, but since the bistables were in the 'off' state, no output was obtained from the gate.

The once per revolution pulse was fed to the input of bistable IC13a which caused it to change to the 'on' state. Once output of IC13a was fed to decade counters IC10 and IC11 and they started counting the 0.2 degree pulses. When a count of 51

was reached detected by IC9a and IC9b, IC13a changed back to 'off' state, and awaited the next once per revolution pulse. The other output from IC13b was in the 'off' state, so there would be no output from the gate.

When the sample data switch SW4 was operated, IC17a, IC17b changed state and caused IC13b to change to the 'on' state. Once the output from IC13b was fed to the decade counters IC12 and IC15, IC18 started counting the once per rev). pulses until a count of 101 was reached (detected by IC9c and IC9d). IC13b changed back to the 'off' state, and awaited operation of the sample data switch again. The other output from IC13b raised the input to gate IC14a, and there would now be an output of pulses from the gate, each time IC13a changed to the 'on' state. It could be seen that the output from IC14b comprised of a series of 50 pulses at 0.2 degree intervals for a period of 100 revolutions, this is shown diagrammatically in figs (9,10). The 50 pulses were fed to a monostable IC19a, the output of which were negative pulses to form the main trigger. The pulses were also fed to a series of shift registers IC20-IC24 fig. (11), where the pulses were shifted along by the clock pulses and hence the delay was selected by the probe position switch SW3, and fed to monostable IC19b to give negative delayed trigger pulses.

3.4.1.4 DATA LOGGER

The high speed general purpose data logger consisted of the following components

- a) North Star Horizon microcomputer which contained
 - i) 48K bytes of random access memory
 - ii) Z80 microprocessor
 - iii) Dual floppy discs with total capacity of 320K bytes
- b) Two general purpose high speed ADC cards , each contained
 - i) 1 ADC
 - ii) 16 channel multiplexer
 - iii) 1 DAC channel

The memory map for the system is shown in fig (12) . The components of the data logging system are shown in fig (13) . Both the ADC cards were identical in all respects except that they occupied different port numbers. Each ADC card contained the following functional components:

- a) A high speed ADC
- b) A 16 channel multiplexer
- c) A 1MHz clock
- d) 8K of memory
- e) A DAC channel
- f) An external trigger for the ADC
- g) A flag which might be set by an external source
- h) A multiplexer status flag
- i) A scan status flag

The system diagram is shown in fig. (14) . The ADC's can be accessed directly from programs written in Basic2 which is the most efficient way of accessing them in terms of the computer memory that is used.

A program was written in Basic2 listed in Appendix (4) was used to control and collect the digitised signals and dump the data to the floppy discs. The digitising process was carried out using the external flag triggering facility through the blade strobe unit. Because there were three signals, we used only two channels on each ADC card and that enabled the recording of 4K of data on each channel at a time. This amount of aerodynamic wake data represented approximately 80 successive rotations of a specific blade at each recording run.

The data disc files were then accessed from programs written for any compiler which runs under CP/M. Because of the need of graphical output and larger memory, the data disc files were dumped onto a Vax/11-780 mainframe computer through the Data logger system and analysed with fortran 77 programs.

The experimental programme phases and the associated experimental analysis techniques and the error associated are all described in the next chapter.

CHAPTER 4 : EXPERIMENTAL PHASES ,
TECHNIQUES AND METHODS OF ANALYSIS AND ERROR ESTIMATION.

4.1 EXPERIMENTAL PHASES

The experimental programme was composed of several phases, all the phases were chosen such that a complete picture of the flow downstream of the rotor blade trailing edge could be obtained. The following sections of this chapter contain a description of each phase of the experimentation with the associated measurements and calibration techniques. Error estimation and correction procedures are quoted in the last section of this chapter. The experimental results and discussions are presented in the following chapters.

4.1.1 PHASE I

This phase involved the measurements which were made using the conventional (low response) instrumentation and it consisted of:

a- Compressor characteristics map

The compressor characteristics were obtained in the customary way by measuring the total pressure upstream and downstream of the single stage compressor. The mass flow rate was calculated from the static pressure tapping readings along the hub and annulus wall. The characteristics map of the loaded compressor was also obtained when the compressor was running under the effect of inlet circumferential sine wave pressure distortions.

b- spherical pressure tube experiments

The five hole probe was used to measure the flow velocity components in a three dimensional frame work downstream of the rotor blades, the objectives of this experiment were

1- To study the radial distribution of the circumferentially averaged flow parameters in the rotor wake region at several radii and flow conditions. This information about the flow was of crucial importance for the calibration technique of the hot wire setting used for the main experiments.

2- To indicate the effect of the circumferentially sine wave pressure distortion on the flow region behind the rotor, and in particular the effect on the three dimensionality of the flow and velocity level.

3- To obtain input data in both the clean and distorted flow for the rotor wake width/decay characteristics mathematical model. The radial gradients of the circumferentially averaged flow velocity components are of great importance as will be shown later.

Because of the particular nature of the 5-hole probe configuration, the probe was not used in the tip region. The measurements locations and conditions were as follows;

-Five heights: $\tilde{R} = .54, .6, .7, .8, .9$ (These values represent the radial distance from the hub nondimensionalised by the total radius).

-Three compressor speeds 1000 , 1250 , 1500 R.P.M

Seven throttle positions , which represent seven flow coefficients at each speed.

In the distorted flow experiment, the measurements were restricted to a position exactly downstream of the middle section of the screen ,for all the above mentioned conditions. The flow was measured in a location of 180 degree shift from the middle section of the screen to study the extent of the sine wave pressure distortion effect .

In order to get the velocity components ,the radial and the tangential flow angles were determined by the following procedure.

1- First , the flow coefficient K_{1234} was calculated by applying the formula :

$$K_{1234} = \frac{h_3 - h_1}{h_2 - h_4} \quad \dots (4.1)$$

From the diagram and the calibration chart fig(15),the radial angle of the flow for each coefficient within the range (45° to -45°) could be read off.

The tangential angle was already known from the dial reading on the probe itself.

2- The velocity of the flow can be calculated using the formula

$$v = \sqrt{\frac{h_2 - h_4}{\frac{1}{2} K_{24} \gamma / g}} \quad \text{m/sec} \quad \dots (4.2)$$

The coefficient K_{24} is referred to the angle α and is determined from the chart fig(15) by inserting the respective values for h_2, h_4 .

The above mentioned procedure had the disadvantage of having to adjust the probe to face the flow direction in the horizontal plane (nulling procedure). This was very tedious especially over a long period of time. To overcome this, a program based on a potential flow analysis has been developed. This program allows the use of the probe in a non-nulling mode. A comparison of the results with that obtained using the nulling system was made. The error was in the range of 4%, which was reasonably acceptable within the objective of the experiment. The program is listed in appendix(5)

4.1.2 PHASE II

This phase involved all the measurements which was made using high response instrumentations

4.1.2.1 SINGLE HOT WIRE PROBE EXPERIMENTS

An "L" shape single hot wire probe was used in the region behind the rotor blade trailing edge to measure ,

-The overall disturbance level.

-Turbulence level

-unsteadiness level

This experiment was made at The following locations and flow conditions,

-Six heights $\tilde{R}$ = .503 , .6 , .7 , .8 , .9 , 1.0

-Three speeds 1000 , 1250 , 1500 R.P.M

- Five throttle positions

In all the above conditions , the probe was installed downstream of the roter at $Z/C = 0.651$ (at B.M.H).

The mathematical process was applied for a successive 25 cycle of rotations of the shaft of the compressor. The signals were digitized every five degree rotation, which gave 72 points covering the circumferential perimeter.

The experiment was repeated with the flow again subjected to inlet sine wave pressure distortion and with the probe facing the middle section of the distortion screen.

The procedure which was followed to obtain the above mentioned information is best explained by the qualitative picture shown in fig.(16).

The output signals from the hot wire were first converted from voltage to effective cooling velocity signals through the calibration law of the wire. these velocity signals were then statistically averaged as shown in fig(16) to get the three turbulence parameters.

The overall disturbance was calculated as the amount of scatter around the overall average value of the velocity over the circumferential direction i.e.

$$T_{O.D.} \mid_J = \left\{ \sqrt{\frac{1}{N} \sum_{i=1}^N (Q_i - \bar{Q})^2} / \bar{Q} \right\} \times 100 \quad J=1, L \dots (4.3)$$

where

$$\bar{Q} = \left\{ \sum_{i=1}^M Q_i \right\} / M \quad M = L \cdot N$$

The same equation can be written on time based analysis in the form

$$T_{O.D.} \mid_J = \frac{1}{\bar{Q}} \left[\frac{1}{2T} \int_{-T}^T \left\{ Q(t) - \bar{Q} \right\}^2 dt \right]^{\frac{1}{2}} \dots (4.4)$$

which effectivelly gives the same result for continuous signals . (This is known as the Ergodic hypothesis).

The free stream turbulence level was represented by the amount of scatter around the "local" average value, where

$$T_{f.s.} \mid_J \% = \left\{ \sum_{i=1}^N \sqrt{(Q_i - \bar{Q})^2 / N} / \bar{Q} \right\} \times 100 \quad J=1, 2, \dots \quad (4.5)$$

where,

$$\bar{Q} = \left(\sum_{i=1}^N Q_i \right) / N$$

The unsteadiness which is mainly a result of the rotor wake shedding can be expressed by the equation,

$$T_{u.s.} \mid_J = \bar{Q}_J - \bar{Q} \quad \dots \quad (4.6)$$

The entire process has been programmed . The computer used was the ICL 1900 , as it was the only facility which had an access to the data cartridge contents. The program is listed in Appendix (6).

The single wire experiment was made using a data acquisition system different from that used for our main rotor wake experiment. The reason for this was simply because our system was still under development. A brief description of this system is given here:

The output signals from the single wire were recorded on the Motorola 6800 micro-computer . As mentioned earlier, there were 72 data points to be digitized every cycle of the rotor blades. Two programs were permanently stored :

a) The MIKBUG internal monitoring program.

b) The cartridge drive loader and handling program.

The first program was designing to store 25 cycles of data and generate a 26th cycle containing the ensemble average of all the cycles. The second program was to transfer the data stored in the microprocessor to the cartridge record unit for permanent storing. The final reduction of the data was achieved by transfererring the data on cartridge to a magnetic tape on an ICL 1903T main frame computer.

Although the use of this system was time consuming ,the experiment was undertaken for the following reasons:

- The experiment provided an average picture of the turbulence levels behind the rotor and especially in the span wise direction

- The experiment gave a good background basis on which an optimum selection of the instrumentation could be made for the rotor wake measurements.

- It gave an understanding of the mechanism by which the loading affecting the overall disturbance level and the unsteadiness level.

- The experiment helped to decide which flow parameter should be taken into consideration when conducting the main rotor wake experiment.

- The experiment helped to discern the effect of the random fluctuations from that of the unsteadiness periodicity due to wake shedding.

A visco-filter was used to prevent dust particles from entering the compressor. The filter was mounted on a grid on the bell mouth intake of the compressor. An experiment was conducted using the single hot wire probe to study the effect of the grid and the filter on the free stream turbulence level ahead and downstream the compressor rotor. The same experiment was made to study the effect of the distortion screen on the free stream turbulence level ahead of the rotor at mid-height.

4.1.2.2 THREE HOLE PRESSURE TRANSDUCER'S PROBE EXPERIMENT

In order to check the pressure distortion screen performance and to obtain the circumferentially distorted pressure distribution at the inlet of the compressor, we used the three hole pressure transducer probe prescribed in chapter 3. The experiment was conducted at the following locations and flow conditions:

- Three axial locations, ahead and downstream the rotor, and behind the stator at one chord length, half chord length and one chord length respectively.

- at one speed 1500 R.P.M

- at twenty circumferential positions. The locations were not regular in order to increase the accuracy in the region behind the screen. The different locations of the probe were obtained by rotating the pressure distortion screen circumferentially rather than by rotating the probe. This made the experiment simpler to manage.

The signals from the pressure transducer were passed through an amplifier and low pass filters and were recorded in the data logger (NORTH STAR) micro-computer . The calibration of the probe was given in the form of the coefficients A,B and C against the flow angle α (fig 17), where P_1 , P_2 and P_3 are the readings corresponding to the measuring holes 1,2 and 3. Using these calibration curves as computer input data , the flow angles, the static pressure P_s and the total pressure P_t in a plane perpendicular to the probe axis could be obtained. Although the radial component was not included in the measurements, the error introduced to the pressure distribution according to this effect could be neglected as indicated by the five hole probe measurements. The calibration of the probe was carried out in a low turbulence wind tunnel over a wide range of velocity (Reynolds number based on probe diameter was varied from 0.2×10^5 to 1.0×10^5).

The experimental results emerging from this experiment were used as basic parameters to understand the behaviour of the rotor wake (e.g. the incidence variations due to the distortion of the nondimensional total pressure distribution at the inlet of the compressor). The results added to the understanding of the overall effect of inlet pressure distortion on the compressor rotor.

4.1.3 PHASE III

4.1.3.1 GENERAL

This phase contains the main bulk of experimentaion ,and it consists of three parts:

I- PART ONE;

-Calibration of the hot wire setting (statically and dynamically)

-Preparation of the Microprocessor:

The preparation of the microprocessor included several experiments to check the digitising process and the phase lag of the signals and the change of both with the speed and the radial location of the probe. The experiments were made by feeding a D-C voltage signals (either constant or sinusoidal). Also the microprocessor ADC card was calibrated to check the resolution over different amplification gains. The signals were also checked for the relative position of the blade trailing edge to the probe.

II- PART TWO;

Rotor wake measurements in clean flow:

The measurements were conducted in the following locations and flow conditions

-six radial positions

- seven axial positions downstream the rotor
- one speed 1500 R.P.M
- three flow coefficients (or throttle positions)

The location dimensions are shown in fig.(18). The choice of the above locations and conditions was based on the following:

- the previous preliminary experimental observations
- the rotor wake measured at the axial position 7 (see fig.(18)). There the speed of rotation was varied 1000,1250 and 1500 R.P.M and the throttle position was varied five times.

The results of these experiments are fully presented and discussed in chapter 5 .

III- PART THREE;

Rotor wake measurements in distorted flow ;

The rotor wake was measured while the compressor was subjected to an inlet circumferential pressure distortion and the measurements were conducted at the following measuring stations and flow conditions :

- blade mid height.
- speed of rotation 1500 r.p.m.
- Eight circumferential positions

The flow coefficient was varied to three different values.

However only the results behind the middle section of the screen were obtained .

4.1.3.2 TECHNIQUE OF MEASUREMENTS AND METHOD OF ANALYSIS

A - CALIBRATION TECHNIQUES

A.1 Static calibration

Different forms of King's law have been used in earlier studies to establish the basic response properties of the hot wire systems. A general form of the law can be written as

$$E_i^2 = E_{oi}^2 + B_i (f_i) \quad i = 1, 2, 3 \quad \dots (4.7)$$

where

$$f = f_i (v, \alpha_i, \theta_i)$$

θ_i , α_i and V are the yaw, pitch angles and the flow velocity respectively. Because of the different slope of the calibration curve at speeds lower than 10 m/sec, a separate group of calibration constants should be used for this region.

The calibration rig described in chapter (3) was used for the calibration of the hot wires; the wires were calibrated separately with the velocity vector perpendicular to the sensor in the sensor-prongs plane. King's law was used in the form

$$E^2 = E_o^2 + B Q^n \quad \dots (4.8)$$

The power 'n' was varied from $n=0.3$ to 0.79 , and the correlation coefficient and the standard error in both E_o and B were compared. As mentioned earlier two sets of calibration constants were used.

The wires should also be calibrated to account for the effect of yaw and pitch variations as they have a non-linear response for these effects as shown in fig (52) . For this purpose there is a number of different techniques (Refs 85 to 99) available. Amongst these techniques, the one proposed by Jorgenson (Ref 99) seems to be quite good, except for the following limitations-

a) The wires were assumed to be affected by the full component of the velocity in the wire-prongs plane, i.e. $K_i = 1.0$ which was not true in practice.

b) The cross-coupling effects of the yaw and pitch (being applied simultaneously) on the wires response were not taken into account.

In order to overcome these disadvantages, the wires were calibrated as a setting (collectively) , over a wide range of velocities and angles. This same setting of the wires was then used for the actual experiments. The directional sensitivity matrix $[K]_{4 \times 4}$ was deduced using a general least square analysis. A general description of the analysis is presented in appendix(7) and the computer program used is listed in appendix(8). The error found in using this technique was very small (2.77%). The reasons for this are as follows:

- In the individual wire calibration (King's law) the signals from the wire were recorded in the data logger at each velocity step change , and the digitised data was averaged (over 2048 samples).

- the same procedure was followed in the directional

sensitivity matrix determination experiment. The use of the DISA 55190 calibration rig to facilitate the changing the wire pitch and yaw angles, enabled very precise movements to be made.

A very important observation at this stage of the calibration was made ;that is that although the wires were supposed to respond in the same manner to variations which simulate a change in the the directions of the radial angle of the flow (upward or downward) ,it was found that the wires gave a different response as a group or setting This was because of the different exposed area of the prongs to the flow as the pitch angle changes . This different area exposure causes a slight change in the heat transfer characteristics of the wires and hence the wire setting was sensitive to a change of as small as two degrees in the pitch angle.

Since the hot wire setting was calibrated in a flow with less than 1% turbulence (calibration rig nozzle flow), an experiment was needed to study the validity of these results for a flow having a considerable turbulence level such as the rotor wake. This led to the necessity of dynamically checking the wires response.

A.2 Dynamic calibration

To study the effect of turbulence on the wire response, the hot wire system was dynamically calibrated. Although the dynamic calibration procedure followed here was not designed to have a straight foward application (a parameters to be taken as constants in the main hot wire response equations). We merely

used the results as a tool to check the accuracy of the static calibration technique. Different techniques were used for dynamically checking the hot-wires (Refs.(100103)).

In this investigation , dynamic calibration of the hot wires was made using the system shown in fig (4) ,plate 9 The calibration was made by vibrating the wires with a predetermined frequency and amplitude in a stream of constant air velocity. An accelerometer was used to measure the acceleration of the sinusoidal motion and hence the velocity. The data from this experiment was recorded using the data logger with internal triggering. The soft ware used for the recording of the signals is listed in appendix (9). This experiment enabled a check to be made on the effect of turbulence during the static calibration on its results. Comparison of the measured dynamic calibration coefficient $\partial E / \partial U$ with that obtained from static calibration gave an estimate of the error in determining the turbulence intensity by using only data from static calibration.

The relation between the voltage fluctuations and the velocity fluctuations can be obtained by considering King's law in the form,

$$E^2 = E_0^2 + B U^n \quad \dots (4.9)$$

Differentiating , we obtain

$$2E dE = 0 + B n U^{n-1} dU$$

Deviding by 2E , we obtain,

$$\begin{aligned}
\frac{dE}{E} &= \frac{Bn}{2E^2} U^{n-1} dU & 70 \\
&= \frac{Bn U^n}{2E^2} \frac{dU}{U} \\
&= \frac{n}{2E^2} (E^2 - E_o^2) \frac{dU}{U}
\end{aligned}$$

And from (4.9)

$$\frac{\sqrt{e'^2}}{E} = \frac{n}{2} \left(1 - \left(\frac{E_o}{E} \right)^2 \right) \frac{\sqrt{u'^2}}{U} \quad \dots (4.10)$$

B-METHOD OF ANALYSIS OF HOT WIRE OUTPUT SIGNALS

B.1 THE HOT-WIRE RESPONSE EQUATIONS

The arrangement of the hot-wire setting being parallel to the physical turbomachinery axes simplified the response equations and the derivation of the results. The response of the three wires to a three dimensional flow can be expressed as-

$$(Q_J + q_j) = \sum_{i=1}^3 K_{Ji} (X_i + x_i)^2 \quad J=1, 2, 3 \quad \dots (4.11)$$

where $(Q_J + q_j)$ represents the effective cooling velocity for each wire. This is given by the following equation;

$$E_i^2 = E_{o_i}^2 + B_i (Q_i + q_i)^{n_i} \quad i = 1, 2, 3 \quad \dots (4.12)$$

which is known as the King's Law. Here the constants E , B and n were all obtained by calibration as described earlier.

$(X_i + x_i)$ are the flow mean and turbulent velocity components. Equation (4.11) represents a set of three linear equations in three instantaneous velocities. In order to derive the mean velocity components and the six stress tensor components, this equation can be dealt with in two different

ways-

- i) The linear method
- ii) The non-linear method

B.1.1 The linear method

Equation (1) can be solved linearly with the knowledge of the directional sensitivity matrix $\{ K \}_{4 \times 3}$. The result gives the three INSTANTANEOUS values of the velocity components, i.e. mean velocities plus a superimposed fluctuating part. The reproduced INSTANTANEOUS velocity SIGNALS can be processed by ensemble averaging to obtain the mean velocity components and all the six stress tensor components .

The averaging procedure of the velocity signals was carried out by the following method,

Consider any component of velocity (q_n), the average value of which is

$$\bar{Q}_i = \left[\sum_{n=1}^N Q_{in} \right] / N \quad i = 1, 2, 3 \quad \dots (4.13)$$

This value represents the velocity components in the direction (i). The turbulence intensity component in that direction is,

$$T_i = \sqrt{\sum_{n=1}^N (Q_{ni} - \bar{Q}_i)^2 / N} / \bar{Q}_i \quad i = 1, 2, 3 \quad \dots (4.14)$$

The value T_i was nondimensionalised by the local value of the mean velocity component across the wake.

In order to obtain the Reynolds stress components, the averaging procedure was carried out for the fluctuating components product, i.e.

$$q_i q_j \text{ where } i = 1, 2, j = 2, 3 \dots (4.15)$$

This gives,

$$\overline{q_i q_j} = \left[\sum_{n=1}^N q_{in} q_{jn} \right] / N$$

The shear stresses were nondimensionalised by the dynamic pressure value in the outside region of the wake (free stream value).

All three velocity components and the six stress tensor components were obtained in the following frames of reference;

- relative turbomachinary frame of reference
- relative stream wise frame of reference

The conversion between the two coordinate systems was made by resolving the turbomachinary velocity components with the relative outlet flow angle β where

$$\beta = \tan^{-1} \left((2 \pi \Omega r - V_t) / V_{ax} \right) \dots (4.16)$$

Velocity signals were reproduced by the following relations

$$V_{st} = V_{ax} \cos \beta + V_t \sin \beta \dots (4.17)$$

$$V_n = V_{ax} \sin \beta - V_t \cos \beta \dots (4.18)$$

The reproduced signals were reprocessed in the same manner

as before to obtain the velocity and stress components in the new frame of reference.

A computer program was written to perform this method by using the data from the recorded disc files on the vax/11-782 computer. The list of the program is given in appendix (10) . Because there were 47 points inside the examined section behind the rotor blade trailing edge the program gave the choice to analysing any particular number of points in the outside region of the wake .However in the wake location the points were all processed and the output of this program was coded (see section 4.2). The program also gives a graphic output of the different mean and turbulent components of the flow.

B.1.2 The non-linear method

In the non-linear method instead of solving equation (4.11) (instantaneously) and then averaging the results, the averaging process was carried out first for the effective cooling velocities themselves in the micro-computer. This led to nine values of Q_i , $\overline{q_i^2}$ and $\overline{q_i q_j}$; They represent the known input terms in the nine non-linear equations derived by expanding equation (4.11) as shown in Appendix (11).

In the appendix (11) only a brief outline of the mathematical derivation is presented. This is because the output equation were very long(number of terms of the equations were 15,15,15,79,79,79,141,141 and 79 respectively). The nine non-linear equations with nine unknowns (three mean velocities and six stress tensor components) were solved by a general Newton-Raphson iterative technique. The program based on this

method had the facility of switching the iterations to Modified Newton-Raphson at a chosen number of iterations in order to accelerate the solution; it had also convergence parameters to accelerate the convergence of the roots, as well as a linear segment to create a starting set of roots. The program discussion and list are presented in appendix(12), it was designed again to leave the choice of any point inside the wake to be analysed by the user.

B.1.3 COMPARISON OF THE TWO METHODS

Because of the non-linear nature of the second method, it was virtually impossible to express the solution in explicit form, so unlike the linear method (B.1.1) it was difficult to estimate the statistical error associated with it.

A comparison between the two methods can be done from the point of view of applicability as follows:

In the linear method, all the recorded data disc files on the floppy discs had to be transferred onto the Vax main frame computer, through the data logger. Although we had improved the port speed of the data logger, twenty four minutes was required to transfer one set of wake data. One set of data only represented just a single flow condition.

In the non-linear method application, the disc files were processed inside the micro-processor. The output of this process was a set of nine values. These nine values were the only data required to represent a single flow condition.

Although it might be obvious that the non-linear method

saves time, this time was lost in processing these nine values. The iteration algorithm was a very time consuming process. This time was much more expensive compared to the first method because it was a calculation time.

The Second method was also not so good since, the iteration procedure was liable to result in an ill condition matrix. This singularity can easily cause a divergence of the equation roots. Although the program was designed to have a control over the different ratios of the output set of roots, a divergence of the roots was still present in 20% of the examined cases.

Thus , although the non-linear method was believed to contain a relatively smaller statistical error, we preferred to use the linear method for our long experimental programme for the above mentioned reasons.

In Figs(19,20) a comparison of two different cases is presented. The agreement was "surprisingly" good. The non-linear method tends to give a lower value for the radial flow. In these two particular cases the convergence of the roots was very fast. In some other cases the program was always diverging ,even when we used the linear method output as an input data.

4.2 CODING SYSTEM

In order to facilitate the access to the output results, a data bank of these results was stored in the Vax/11-782 main frame computer. Nearly 80,000 pieces of information were stored. This data represents the rotor wake in both the clean

and distorted flow. The data was stored in a separate files under the name

NPL.***

Where "N" is represents the blade span wise location

-----"P" is represents the throttle position(loads)

-----"L" is represents the axial position behind the rotor blade trailing edge

-----"***" these asterisks could be either "RS" for nondimensional results in both the stream wise or turbomachinery frame of references, or "TUR" for dimensional results in the turbomachinery frame. Or "STR" for the stream wise frame.

By creating a file into the computer which contains a directory of the required files , a program- listed in appendix(13)- could use this created file to collect the required data and arrange them in proper format for use in any of the programs in the rotor wake analysis package.

4.3 ERROR SOURCES, ESTIMATION AND CORRECTIONS

The error associated with the measurement techniques and the use of hot wire probes in general are presented in this section:

1- First, in recording the output signals from the hot wires onto the ADC cards of the data logger, the ADC cards were calibrated by digitising a constant DC voltage at several gains. The digitised data was fitted to a straight line. The correlation coefficient was around the value .999 . The error in the recorded data was less than .05%. The gain setting of

all the measurements was taken as 64. This represents an amplitude of 2 Volts ,which means that the resolution inside the ADC card was 7.84 mv.

2-The error associated with the use of the hot wire as a mean of measurements is very much connected to the different parameters affecting their response. Apart from the foregoing discussion in section(4.1.3.2) of the wire response ,the following effects should be taken into consideration.

A- Effect of pressure

The fluid density is directly proportional to the absolute pressure and therefore a 1% change in pressure produces a 1% change in density,which would from King's law(equation 4.12) be equivalent to 1% change in velocity. The maximum change in pressure in the actual experiments was less than 0.8%. This value indicates that the pressure variation effect corresponds to an error of 0.8% in the measured velocity.

B- Effect of temperature

The effect of temperature has two different phases . The first was during the calibration of the hot wires and the second during the actual experiment.

B.1 Correction of temperature effect during the hot wire calibration stage

King's law can be used to describe the two dimensional heat transfer from a cylinder placed in an incompressible flow,

$$H = K L \left(1 + \sqrt{\frac{2 \pi \rho C_p d U}{K}} \right) (T - T_0)$$

and in this idealised expression, the important temperature parameter governing heat transfer is the temperature difference between the sensor and the fluid. For a typical wire probe in air $(T-T_0)$ is about 200°C , and 1°C change in fluid temperature therefore represents a 0.5% change in $(T-T_0)$. If we consider the exponent n in (4.12) as equal to 0.5, this would give a change of 1% in fluid velocity. Thus, if errors due to temperature variations are to be avoided it is very important to keep $(T-T_0)$ constant. If a slow variation in temperature occurs due to power dissipation in the calibration test rig, it is sufficient to check the probe cold resistance from time to time and to adjust the operating resistance so as to maintain a constant over heat ratio "a".

$$a = (R_t - R_0) / R_0 \quad \dots (4.19)$$

$$a = R_0 \eta (T - T_0) / R_0 \quad \dots (4.20)$$

B.2 Correction of temperature effect during the actual experiments

From Hinze Ref.(78) the equation of the hot wire response may be written as

$$\frac{I^2 R_w}{R_w - R_g} = A + B U^n \quad \dots (4.21)$$

Where R_w is the total electric resistance of the wire. R_g denotes the electric resistance of the wire at the fluid

temperature θ_g . A and B are constants which can be rewritten in the form

$$A = \frac{\pi \ell K_f}{b R_o} f_1 \left(P_{rf} \right)$$

$$B = \frac{\pi \ell K_f}{b R_o} \left(\frac{e_f d}{\mu_f} \right)^n f_2 \left(P_{rf} \right)$$

Where P_{rf} is the Prandtl number,

$$P_r = \frac{C_p \mu_g}{K_g}$$

The specific heat is practically independent of temperature but the heat conductivity, the viscosity and the density are all dependent upon it.

Since the heat conductivity and the viscosity vary approximately linearly within a rather large range of temperature, the Prandtl group is practically independent of temperature. For an exponent "n" around the value of 0.5, The group $K_f (e_f d / \mu_f)$ is only slightly dependent on the temperature. In fact - practically speaking - we can consider only the factor K_f as sensitive to temperature change. To approximate the dependence of this factor K_f on temperature, we can write

$$K_f = a + a_1 \theta_f$$

$$\text{where } \theta_f = \frac{\theta_w - \theta_g}{2} = \theta_g + \frac{\Delta \theta_w}{2}$$

$$\text{and } \Delta \theta_w = (\theta_w - \theta_g) / 2$$

From Ref.(78) for Air,

$$a_1 = 0.005 \text{ Watt/m}^0\text{C}$$

$$a_2 = 0.00007 \text{ Watt/m } ^0\text{C}^2$$

Introducing these, we can write

$$A_c = C_1 (1 + \alpha \theta_g) (\theta_w - \theta_{g_c})$$

$$B = C_1(\theta_w - \theta_g)$$

where $\alpha = a^{1/2} (a + a^{1/2} \theta_w)$ is constant for a constant temperature hot wire anemometer. Hence,

$$A_{Exp.} = A_c \frac{(1 + \alpha \theta_{g_e}) (\theta_w - \theta_{g_e})}{(1 + \alpha \theta_{g_c}) (\theta_w - \theta_{g_c})}$$

In the same way

$$B_{Exp.} = B_c \frac{(\theta_w - \theta_{g_c})}{(\theta_w - \theta_{g_c})}$$

The above two corrections were incorporated into the analysis.

C- Directional sensitivity of the hot wires

This source of error was fully taken into consideration as explained earlier in section 4.1.3.2. The overall error due to this was 5% in the measured velocity components. The uncertainty in the radial flow direction was about 7.5%. The direction in the horizontal plane (pitch wise) direction was of no great concern (from physical evidence).

D- Geometry of the probe body and prongs

This error is related to the inviscid effect of the probe body on the flow. This obstruction of the flow can cause a deviation of the flow velocity vector. This deviation depends to a great extent on the probe-prong length and the diameter. According to reference (78) for a prong of 7-8 mm length, the deviation in the velocity vector is very small and

it can be neglected. The lengths of the prongs of the hot wires used for this investigation were 7.5 and 8.5 mm. As for the effect of the combination of prongs-sensors on the heat transfer characteristics ,it was fully taken into account with the collective calibration followed and explained in section 4.1.3.2.

E- Spatial resolution of the probe

The spatial resolution of the probe can be a large source of error, especially in non-uniform flow measurements. The physical dimension between the probe sensors could result in a serious phase shift. This phase shift in the signals can completely distort the measured flow picture. This distortion is further increased if the data has to be treated in a statistical manner. For this reason a great deal of attention was given to this particular effect by designing the blade strobe unit explained in section (3.4.1.2) chapter 3 .

F- Spatial resolution of the wires

The spatial resolution of the hot wire sensor is a description of several errors connected with the sensing element of the probe. These errors are:

1-Errors resulting from the heat transfer parallel to the wire axis

2-Error due to cold length effect.

3-Error due to spatial resolution in turbulence data.

4-Error due to measurement in non-uniform flow .

5-Error due to the thermal inertia of the wire.

All of these errors are explained in some details in Ref.(83). Error 1 was minimised by calibrating the probe against this effect as indicated by the values of the directional sensitivity matrix $\{ K \}_{i \times j}$. Error 2 is eliminated by leaving the anemometers circuits to be stabilised for a long

time (2 hours according to DISA specifications). Error 3 and 4 are mainly due to a non-uniform velocity distribution over the entire length of the wire. Ref.(78) provide a correction factor for this effect as,

$$\overline{e^2} = B \quad (\overline{e^2})_{\text{measured}} \quad \dots (4.22)$$

Where

$$B \cong \left(1 - \frac{\ell^2}{6 \lambda_g^2} \right) \quad \text{for } \ell / \lambda_g < 1 \quad \dots (4.23)$$

λ_g as defined by Ref.(78) is a measure of the smallest eddies presented in the turbulent flow field. In order to estimate a value of λ_g , the output raw signals from the single hot wire and one of the cross wire array were processed, λ_g was calculated by the relation given in Ref.(84)

$$\lambda_g^2 = \frac{1 - r^2}{R^2} \quad \dots (4.24)$$

where

$$R = \frac{\overline{u'_1 u'_2}}{\overline{u'^2_1}} \quad \dots (4.25)$$

The signals were converted to velocity by King's law. This was made for blade mid height, at two locations $Z/C = 0.3$ and 0.65 . Although this is a rough estimation, it gives an idea about the maximum error incorporated in the turbulence measurements. The value of λ_g was found to be 1.8753 and 2.567, as compared to the wire length which is 1.25mm. This will give an error of around 4.7% in the turbulence measurements.

G- Probe contamination

Dust in the fluid stream is probably the most irritating problem encountered by hot wire users. Apart from the possibilities of breaking of the wire by particles moving with the stream at high velocity, there is the possibility of these particles forming deposits on the surface of the sensor, which may change its heat transfer characteristics. The dust accumulation could change the probe calibration even without any change occurring in the cold resistance of the probe. Dust may also cause a downward drift in probe sensitivity due to the thermal insulation effect of the dust layer. At the same time if the contamination is too much, it causes the wire diameter to grow, which in turn increases wire sensitivity, and causes a reduction in the frequency response. This has a serious effect on turbulence measurements. Although a fine air filter had been used in both the main and the calibration experiments, the minimization of the contamination effect was made by :

1- retaining a small time of exposure of the sensors to the flow.

2- Making a regular check on the wire frequency response. The readjustment was made through the built-in square wave test in the anemometers.

H- Probe body vibrations

The vibration of the probe body being subjected to a stream of air can also have a serious effect on the turbulence measured by the sensors. Because we had used two probes, the vibration of

the probes was calculated for each of the probes separately. The two probes were not welded together but were mounted attached to each other. Therefore any danger of resonance should occur because of the natural frequency of either of them and not from the probes as a one structure. From Ref.(106) the natural frequency of a cantilever beam is calculated by

$$W_n = B^2 \sqrt{\frac{E I}{W}} \quad \dots (4.26)$$

Where B is a constant given in Ref.(106) as $B_1 = 3.52$ for the first mode, E and I are the Young's modulus and area moment for the probe material and cross section respectively.

The natural frequency of the single probe (the lowest) was .106 KHz (** calculated in the foot note), The other modes will be a multiple of this frequency as indicated by the values of the constant "B" for the successive modes. The spectrum of the signals was examined at the particular natural frequencies and no spurious frequencies (spikes) were observed.

I- Error due to finite number of sampling

In any averaging process there is a statistical error involved, due to the fact that the ensemble averaging is made for a finite number of samples . The standard deviation error in the averaging process can not be estimated exactly because of the unknown quantity $\tilde{Q}$, where

 ** The calculation of the natural frequency was based on: Weight of the probe per unit length = $0.5 \times 28.3495 \times 100 / 24 / 1000 = .0591$ Kg/m
 Young's modulus for mild steel = $.2068435 \times 10^{11}$ n/m. The constant B for first mode = $3.52 / 17 / 17 \times 10000 = 121.7993$.
 Moment of Area = $\pi I / 64 (R_o - R_i) = 8.5901125 \times 10^{-12}$ m⁴
 $F_n = 121.7993 / 2 / \pi \times \sqrt{.2068 \times 8.59 / .059} = .106$ KHz

$$\tilde{Q} = \lim_{i \rightarrow \infty} \bar{Q}_i$$

The quantity $\tilde{Q}$ is used to defined the standerd deviation as,

$$\eta^2 = \frac{1}{N^2} \sum_{i=1}^n E \left[\frac{(Q_i - \tilde{Q})^2}{\tilde{Q}^2} \right] \quad \dots (4.27)$$

In order to overcome this problem , one can assume a Gaussian distribution for the signal samples and define a relative standard deviation as,

$$\eta^2 = \frac{1}{N^2} \sum_{i=1}^n E \left[\frac{(Q_i - \bar{Q})^2}{\bar{Q}^2} \right] \quad \dots (4.28)$$

where from the Gaussian distribution the quantity $E((Q_i - \bar{Q})^2 / \bar{Q})$ can be taken as 2. Hence, the relative standard deviation of the measurements can be found as,

$$\eta = \sqrt{\frac{2}{N}}$$

For a number of signals of (160) , the error in the measurements will be 11%.

4. STATISTICAL ERROR

The statistical error involved in the linear method analysis is easier to be estimated than that of the non-linear analysis method . The reason for this - as mentioned earlier - is the impossiblilty of obtaining the solution of the non linear hot wire response equations in explicit form.

For the linear analysis the error estimation can be obtained by considering the following equation:

$$\begin{Bmatrix} u_i^2 \\ v_i^2 \\ w_i^2 \end{Bmatrix} = [A]^{-1} \begin{Bmatrix} Q_{i,1}^2 \\ Q_{i,2}^2 \\ Q_{i,3}^2 \end{Bmatrix} \quad i = 1, N \quad \dots (4.30)$$

where U_i, V_i and W_i are the velocity components, $[A]$ is the directional sensitivity matrix and $Q_{i,j}$ are the components of the effective cooling velocity.

The error in the different components of velocity can be written as

$$\begin{Bmatrix} \Delta u_i \\ \Delta v_i \\ \Delta w_i \end{Bmatrix} = \begin{Bmatrix} u_i \\ v_i \\ w_i \end{Bmatrix}_{\text{calculated}} - \begin{Bmatrix} u_i \\ v_i \\ w_i \end{Bmatrix}_{\text{measured}} \quad \dots (4.31)$$

$$\begin{Bmatrix} (\Delta u_i)^2 \\ (\Delta v_i)^2 \\ (\Delta w_i)^2 \end{Bmatrix} = [A]^{-1} \begin{Bmatrix} Q_{i,1}^2 \\ Q_{i,2}^2 \\ Q_{i,3}^2 \end{Bmatrix}_{\text{measured}} - \begin{Bmatrix} u_i^2 \\ v_i^2 \\ w_i^2 \end{Bmatrix} \quad \dots (4.32)$$

The standard deviation in these errors can be written as:

$$\Delta U_{s.d.} = \sqrt{\sum_{i=1}^N (\Delta U_i)^2 / (N-1)} = 2.01 \% \quad \dots (4.33)$$

$$\Delta V_{s.d.} = \sqrt{\sum_{i=1}^N (\Delta V_i)^2 / (N-1)} = 3.02 \% \quad \dots (4.34)$$

$$\Delta W_{s.d.} = \sqrt{\sum_{i=1}^N (\Delta W_i)^2 / (N-1)} = 3.522 \% \quad \dots (4.35)$$

The above three errors in the velocity components are due to the assumed nature of the hot wire response equations. These errors are not a direct results of the finite number of samples, although they are affected by this number. Also, these errors represent the errors in the mean velocity components; hence we shall rename them as,

$$(e_{\bar{u}}, e_{\bar{v}}, \text{ and } e_{\bar{w}})$$

In order to proceed further to obtain the errors in the turbulence and reynolds stresses, we shall assume that the errors in the local (or instantaneous) velocity components are:

$$e_{u_i}, e_{v_i} \text{ and } e_{w_i}$$

These three errors are different than those of the mean flow components. The errors in the measured stresses are a result of both.

Consider the turbulence intensity in the axial direction

$$\frac{\overline{u'^2}}{\bar{U}} = \frac{\sqrt{\sum_{i=1}^N (u_i + e_{\bar{u}}\bar{U} - e_{\bar{u}})^2 / N}}{\bar{U} + e_{\bar{u}}} \quad \dots (4.36)$$

$$= \frac{\sqrt{\sum_{i=1}^N (u_i - \bar{u})^2 / N}}{\bar{U}} \left(1 + \frac{1/2 \sum_{i=1}^N (e_{u_i} - e_{\bar{u}})^2}{\sum_{i=1}^N (u_i - \bar{u})^2} + \epsilon(o) \right)$$

Hence, the relative error in the turbulence measurements is therefore

$$R.E._T = \sum_{i=1}^N \left(\frac{e_{u_i}}{u_i - \bar{u}} \right)^2 + \sum_{i=1}^N \left(\frac{e_{\bar{u}}}{u_i - \bar{u}} \right)^2 + \epsilon(o) \quad \dots (4.37)$$

Although the second part is known as a result of the calibration stage , the first part of the error is still unknown. By assuming a normal (Gaussian) distribution for the random error of the fluctuated velocity component, an estimation of the first part can be made according to the value of $e\bar{u}$ as the mean of the distribution Ref(107). The same procedure can be applied for the other two components of turbulence intensities.

Also for the shear correlation measurements , consider any components say, $\overline{u'v'}$. One can proceed as follows:

$$\overline{u'v'} = \sum_{i=1}^N \frac{(u_i - \bar{u})}{N} / \bar{u} \sum_{i=1}^N \frac{(v_i - \bar{v})}{N} / \bar{v}$$

$$= \sum_{i=1}^N \left[(e_{u_i} - e_{\bar{u}}) (v_i - \bar{v}) + (e_{v_i} - e_{\bar{v}}) (u_i - \bar{u}) \right] \dots (4.38)$$

$$R. E. \frac{\overline{u'v'}}{u'v'} = \sum_{i=1}^N \frac{(e_{u_i} - e_{\bar{u}})}{(u_i - \bar{u})} * \sum_{i=1}^N \frac{(e_{v_i} - e_{\bar{v}})}{(v_i - \bar{v})} + \epsilon(\phi) \dots (4.39)$$

And the same can be applied for the other two components.

By this method the average errors in the mean velocity components, the turbulence components and the Reynolds stress components were 2.7 , 10.1 and 13.7% respectively.

The overall error in the measurements can be obtained by simply adding the squares of the different errors and then taking the square root of the results. This gives a total error

of 4.75 , 14.5 and 19.76 % for the velocity , turbulence and shear stresses respectively.

CHAPTER 5 : CLEAN AND DISTORTED FLOW ROTOR WAKE
EXPERIMENTAL RESULTS

5.0 EXPERIMENTAL RESULTS AND DISCUSSION

5.1 GENERAL

In this chapter the experimental results obtained are presented and discussed according to the order of the experimental programme phases described in chapter 4. Because of the limited size of the thesis, we were not able to include all the results obtained. Only a selection of the results will be shown. This selection was based on quoting a typical distribution for a group of parameters which simulate an overall trend. Also we have presented the interesting features or characteristics. However this is done only for the results of the set of preliminary experimental phases (I and II) . For the main rotor wake experiments in clean and distorted flow phase(III) ,the presentation of the results was based on a different format,this is because the experiments were mainly based on three compressor loadings. The results are presented globally in a single figure for each parameter (i.e. velocity or stress component). A master outline for the legend will be referred to later.

5.2 PRELIMINARY EXPERIMENTAL RESULTS PHASE I,II

5.2.1 COMPRESSOR CHARACTERISTICS MAP

The single stage lightly loaded compressor characteristics are shown in the series of figures(21,22,23 and 24). Figs (21 and 22) represent the performance of the compressor as the

relation between the pressure and the non-dimensional mass flow coefficient at various rotational speeds. This is for normal entry pressure and temperature fig.(21) and for both normal and distorted entry pressure in fig.(22).

Figs(23 and 24) show the characteristics of the compressor as the relation between the stage loading and the flow coefficient . This is also for normal entry pressure and temperature in fig.(23), and for both normal and distorted entry pressure in fig.(24). ideally, the figs(23 and 24) are straight lines for an ideal compressor stage. The pressure distortion imposed on the compressor was a sine wave distribution over a circumferential sector of 90 degrees as explained in chapter (3),section (3.3.1). From the four figures we can observe that the loading of the compressor is very small (maximum pressure ratio is 1.05). The effect of the pressure distortion was to decrease the pressure ratio in the negative slope part of the rotational speed lines. This effect indicates the seriousness of pressure distortion, which can easily lead to instability by approaching the surge line. Also from the figure we notice that the effect of this particular distortion was to increase the pressure ratio in the positive slope side of the characteristic lines. This eventually causes (together with the previous effect) the well known hysteresis loop of distortion Ref.(104). Also shown in fig(21) are the three loading points where the investigation was conducted.

5.2.2 SPHERICAL PRESSURE TUBE EXPERIMENTAL RESULTS

This experiment was carried out with the probe positioned behind the compressor rotor at the measuring locations and with conditions prescribed in chapter (4), section(4.1.1). Figs (25,26,27,28 and 29) represent a complete averaged velocity vector at a height of ($H=0.4$), for three rotational speeds 1000 , 1250 and 1500 r.p.m. All the velocity components were non-dimensionalised by the total velocity. This height was chosen because it represents the general trend of variation of the velocity vector. As expected from the velocity triangle studies the tangential velocity increased with increased loading whilst the axial component of velocity decreased. Also ,the flow was found to be three-dimensional with a radial angle of the range -2 to $+2$ degrees. The migration of flow radially changed its direction from inward to outward with increased loading.

Figs(30,31,32,33 and 34) show the velocity vector (averaged) at the same height (0.4) but with the flow subjected to the circumferential sine wave pressure distortion. Although the trends of variation have not changed from that of the clean flow , the effect on the three-dimensionality of the flow is very obvious. As shown in fig(34) the variation in the radial angle is in the range of -12 to $+12$ degrees , as compared to -2 to $+2$ degrees in the clean flow. Not only were there variations in the magnitude of the angle but also in the way that the change took place with decreased loading. The screen appears to have smoothed the gradient of the radial angle more than that of

the clean flow shown in fig(29).

The five hole probe in this experiment was facing the middle part of the distortion screen, and it was of interest to investigate the extent of the distortion screen effect on the flow, as was mentioned earlier the distortion screen was covering a sector of 90 degrees. The experiment was repeated with the probe having a 180 degree shift from its previous position. The reason for this was that in the theoretical modelling of pressure distortion effects on compressor performance such as those in Refs(104 and 105), the main criterion was to use the parallel compressor theory, where the compressor is treated as two (or more) compressors operating with different flow conditions. Figs(35,36,37,38 and 39) show the averaged velocity vector components in this opposite position, and it can be seen that the radial flow distribution has returned to the original distribution of the clean flow. The only difference is that the flow keeps inward over the best part of the constant rotational speed lines. This result supports the credibility of the parallel compressor theory as a basic assumption for modelling the pressure distortion effect. The experimental results for the different locations were used as a basis for the selection of the velocity ranges and angles over which the hot wire system was calibrated

5.2.3 SINGLE HOT WIRE EXPERIMENTAL RESULTS

As mentioned in section (4.1.2.1) of chapter (4), the single wire probe used for this experiment was of the "L" shape, and it

was positioned axially at $Z/C=0.600$ (at B.M.H.) for all the measurements taken.

All the results presented here should be treated with caution , the reasons for this are as follows:

1- The output signals from the hot wire were digitised every 5 degrees of rotation of the compressor shaft over 25 cycles. It was not possible to sample all the points inside the wake region (which covers 2to3 degrees). Hence,the output signals were an average of both free stream and wake points.

2-The flow was assumed to be two-dimensional, this means that the velocity signals given by the wire were not the true three-dimensional ones indicated by the previous experiment.

Although the previous two reasons represent an inaccuracy in the result , the results still give a very good qualitative description.

Fig(40) shows the distribution of the overall disturbance level,the flow coefficient was based on the tip rotational speed. The overall disturbance level can be considered to consist of a random turbulent component and a periodical wake defect component. Because the position of the probe was $Z/C = .600$, the value of the measured quantities can be considered to represent the free stream averaged ; the wake in this axial position is very weak (this will be shown later in more detail). In fig(40),the overall disturbance level is not affected by the change in loading (decreasing the flow coefficient) except at a position very near to the surge or stall region. The value of the overall disturbance level was increased from less than 5% to over 45% in the stall region.

In fig.(41) , the distribution of the free stream turbulence is shown, the figure shows a behaviour very similar to that of the overall disturbance . This indicates that most of the overall disturbance was due to the existence of a random turbulence component rather than a wake defect. In fig(42) the unsteadiness distribution is shown. The reason for the low value of unsteadiness is again due to the axial position of the probe. which was in the far wake region. In this region the main feature is the low defect value of the velocity. This small defect was indicated by the unsteadiness level, and this was almost constant over most of the loadings except in the stall region. In the stall region the unsteadiness was interpreted to be due to the existence of the rotating stall cells rather than a rotor wake defect.

The behaviour of the flow was almost the same for all the examined span-wise locations except for that of the tip region , where a rather interesting feature of the compressor flow is shown : figs(43,44 and 45). In fig(43), the overall disturbance level is around 20% at the fully open throttle position, and this decreases to around 7-8% and suddenly grows to nearly 40%. This sudden rise in the overall disturbance level occurred at a time when the compressor stage was not in surge or stall regimes. Although the compressor was running normally, there was an indication of a rotating stall cell in the tip region. The same behaviour was noticed in both the free stream turbulence and the unsteadiness distributions : figs(44 and 45). A clear indication of one of the rotating stall cells can be seen in fig.(46) , the reason for the large extent of the cell

over the circumferential direction was that the cell was expected to move slightly over 25 cycles of rotation (it is normally held that the speed of rotation of a rotating stall cell is around one third of the compressor speed).

The experiment was conducted with the compressor subjected to the sine wave pressure distortion. The overall effect was to increase the measured parameters by approximately 6%. Fig(47) shows the free stream turbulence level for the clean flow and for the distorted flow. The probe was positioned at the blade mid-height downstream of the middle of the distortion screen.

5.2.3.1 Effect of dust filter arrangement and distortion screen on turbulence measurements

Because the Visco dust filter was mounted on a wire mesh screen, which was in turn mounted on the intake of the compressor, it was necessary to check the effect of the filter on the turbulence level upstream of the rotor, as it was believed that the upstream turbulence level would affect the rotor wake behaviour. Also, it was of interest to study the effect of the pressure distortion screen on the turbulence level ahead of the rotor. With the probe mounted as prescribed in

chapter (4) the results are shown in the following table;

=====				
I	T U R B U L E N C E L E V E L			I
=====				
I	in front of the rotor		behind the rotor	I
=====				
I	clean flow	1.2053 %	5.434 %	I
I	with filter	1.0966 %	4.979 %	I
I	with dist. screen	5.68198%	6.9794 %	I
=====				

From this table , the following were noticed

1- The filter has decreased the turbulence level in front of the rotor. This result might be surprising , especially with the knowledge that the filter was mounted on a wire mesh. But the reason for decreased turbulence is that the filter has smoothed and redistributed the flow entering the compressor . The flow was carrying the " wake " of the DC motor balancing arm. The motor was used for driving the compressor (the balancing arm of the motor was at a distance of nearly $1D$ from the bell mouth intake).

2- The distortion screen having changeable porosity ,has greatly increased the turbulence level ahead of the rotor by nearly five times its original value.

3- Also, from the above table it was noticed that the turbulence level downstream of the rotor has not been affected very much by the turbulence level ahead of the rotor. This suggests that the amplification of turbulence decreased by increasing the turbulence level ahead of the rotor.

Another effect of the dust filter on the screen is its influence on the isotropic characteristics of the turbulence. This effect has not been studied at this stage because the single wire was not able to produce a three-dimensional picture of the flow. The effect will be referred to in section (5.6.2.2).

5.3 EXPERIMENTAL RESULTS FOR PHASE THREE

5.3.1 HOT WIRE CALIBRATION RESULTS

5.3.1.1 STATIC CALIBRATION RESULTS

A typical example of the static calibration results is presented here for one of the three hot wires used for the main rotor wake experiments. Fig (48) shows the static calibration curve for the wire (non-linearised) in the velocity range of 1-10 m/sec , and for the velocity range 10-50 m/sec in fig.(49). The non-linearised output curves in both the figures are the pure wire response voltages to changes in velocity and it represents the relation E^2 vs Q^n . The linearised output was obtained by selecting an "n" value in King's law which gives the best correlation coefficient. This coefficient was around the value of 0.999 for the three wires. The linearised output represents the relation $E^2 = E$ vs Q^n . Because of the increased non-linearity in the wire response at low speeds , the linearised output in fig.(48) is not as straight as that in fig.(49).

The following table shows the results of the King's law calibration constants for the three wires.

=====					
I	Constant	Wire 1	Wire 2	Wire 3	I
=====					
I	n	0.4199999	0.4599998	0.5499997	I
I	Eo	2.9421654	2.1660075	1.6515918	I
I	B	2.1324380	2.2187609	3.4253060	I
=====					

5.3.1.2 Directional sensitivity characteristics

Fig (50) shows the response of the hot wire to a change in the yaw flow angle. The wire has a non-linear response to the variation in the flow angle, also it can be seen from the figure that this behaviour was not dependent on the magnitude of velocity. In fig(51) the response of the wire to a pitch flow angle variation is shown. The response is absolutely linear and again it is not affected by the magnitude of the velocity.

In the previous two figures the wire was exposed to the various yaw and pitch flow angles separately; the study of the wire response to the effects of angle variation applied simultaneously was very important as it is the case in real flow measurements. Fig.(52) shows the wire response to both yaw and pitch angle variations at four selected flow velocities. The pitch angle was varied in this particular figure from 5 to 20 degrees while the yaw angle was varied from 5 to 85 degrees. The combined effect of both the pitch and yaw variation was to affect slightly the pitch characteristics (being not so linear as it was), while the response to the yaw variation remained unchanged. Studying the heat transfer characteristics over a cylinder would verify this result, as the heat transfer characteristics of the cylinder would not change for a flow with different pitch angles. In the case of a hot wire the only variation in this characteristic is due to different prong area exposure to the flow at different pitch angles. As explained in chapter (4), the directional sensitivity characteristics of the hot wire assembly were studied using a least square analysis, and

the coefficients of the directional sensitivity matrix were deduced. The coefficients are listed below,

	1	2	3
1	.9948617	-9.6208945E-02	22.48575
2	.1593557	1.103778	1.807491
3	.9642125	.8389063	5.351976

5.3.1.3 DYNAMIC CALIBRATION RESULTS

The dynamic calibration experiment was carried out mainly to check the effect of a turbulence field on the wire response. It was also of interest to check the usefulness of the microprocessor as a main unit in carrying out the calibration experiment. It is customary to use a DC voltmeter to read the wire response to a certain velocity. This reading is affected by the turbulence field, and it is very difficult to read off the correct value. Fig(53) shows the results of a static calibration which was made in a very low turbulence field (less than 1%), and the calibration for a flow having different imposed turbulence levels up to 30%. The two curves coincide and the reason for this is because the signal output from the hot wire was digitised and recorded by the microprocessor. The signals were then averaged over a large number of samples. From this experiment we can conclude that the calibration rigs for hot wires do not necessarily have to have a very small turbulence level as many texts indicate, provided suitable measuring equipment is used. Figs(54 and 55) show the effect of

using a static calibration result for measuring turbulent quantities. The figures indicate an error in the turbulence intensity measurement of 11% . This is expected for a flow with >25% turbulence level. This error decreases with decreased turbulence, and it gave a 4.5% reading for a flow having 4% turbulence. This result is very important because most of the measurements made hitherto (Refs(17 to 49) on turbulent fields) did not take this fact into account.

5.4 PREPARATION OF THE MICRO-PROCESSOR EXPERIMENTATION RESULTS

A series of experiments was conducted to check the performance of the blade strobe unit as well as the microprocessor hot wire system. Table 2 gives the calibration results of the micro-processor ADC card channels. The equation shown in table 2 was used to correct the digitised voltage readings. It was found that there were different calibration curves for different channels. Also the signal to noise ratio was calculated by digitising a constant DC voltage signal. The signal to noise ratio was defined as

$$S_n = \frac{\sigma}{x} \quad \%$$

Where x is the arithmetical mean of the voltage and σ is the standard deviation as defined by

$$\sigma = \sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 / (N - 1)}$$

It was found that the signal to noise ratio was less than

1%. It was difficult to estimate this ratio in an actual experiment, because the separation of the noise source would have been impossible. Fig(56) shows a sample of a sine wave input voltage digitisation. This was used for checking the digitizing frequency at different speeds and heights of the hot wire probe assembly. Fig(57) shows a typical example of the three hot wire sensors output response in the rotor wake region. The different shape of the response was due to the different wire exposures to the flow. Fig (58) shows a sample of a series of figures used to adjust the relative position of the probe to the rotor blade trailing edge.

5.5 MAIN ROTOR WAKE EXPERIMENT RESULTS

Before conducting the main rotor wake experiment, a deciding experiment was performed; the objective of which, as mentioned in chapter (4), was to decide on the selection of the stations and flow conditions in which the main rotor wake experimentation should be made. A typical example of this experiment is shown in figs(59,60 and 61). These three figures represent the distribution of the mean velocity components inside the wake at the height number 3 ($\tilde{R}=0.7$) and at three rotor speeds 1000, 1250 and 1500 r.p.m respectively. The figures are presented as three-dimensional drawings between the mass flow coefficient ($W/\sqrt{T}/P$) (Throttle position variations) and the pitch-wise direction. The probe in all the experiments was positioned in the axial location number (7) ($Z/C = 0.651$ at

b.m.h). The figures show that the the effect of changing the rotational speed does not alter the behaviour of the wake. i.e. the wake behaviour on changing compressor loadings was almost the same for the three examined rotor speeds. This suggests that the important characteristics of the rotor wake such as decay and width variation, are not noticeably affected by the change in speed (it is important to note here that the speed variation was not to be associated with loading variations ,see fig 23 . This conclusion was verified later by Ref.(47). The level of the different velocity components has been affected by the increased rotational speed. The radial velocity has been decreased slightly at the speed of 1500 r.p.m (note that the radial velocity is presented as $(1-V_{rad}/V_{tot})$). The reason for the decreased three-dimensionality of the flow at this speed was because this was the designed speed of this free vortex design based compressor.

Figs(62,63,64 and 65) represent the distribution of the three velocity components and the six stress tensor components . Three turbulence intensities plus three Reynolds stresses . All the figures are valid with the probe positioned at $R=.7$ and $Z/C=.651$, and at three speeds 1000,1250 and 1500 in figs(62,63 and 64) respectively at fully open throttle position. Fig(65) was at a speed of 1500 r.p.m and a throttle position near the surge line (high loading). By comparing the four figures ,it was noticed that when the loading was varied the wake width was affected not only at this radius but also at all the examined radii from the hub to the tip. Also the turbulence characteristics which had seemed unaffected by speed variations

were affected by the loading variations (compare fig.(64) with fig.(65)). The turbulence profile has started to shape up increasing towards the centre of the wake. The shear stress profiles have also experienced the same effect. The magnitude of the stresses is more sensitive to loading variation than to rotor speed variations.

Studying this set of figures along with other results at different radial locations (not presented), has led to the choice of flow conditions upon which we based our detailed rotor wake study . The main choice was three loadings which seemed to give satisfactory results to clarify the loading effect. The details of the conditions and locations have been presented in chapter 4 section 4.1.3.

5.6 ROTOR WAKE CLEAN FLOW RESULTS

As a result of the vast amount of data obtained in the main rotor wake experiments ,it was decided to present these results collectively and not separately. The velocity and stress components are presented each on a single graph including all the locations and measuring conditions prescribed in chapter (4) section (4.1.3 part II). The flow quantities are presented as they "naturally occurred" behind the rotor blade trailing edge. The master legend by which all the presented results can be identified is shown in fig.(66). This method of presentation has the advantage of providing a global insight into the region behind the rotor , as well as aiding the extraction of the conclusions. This was made easier by discerning the various

effects of loading on the different span-wise locations.

5.6.1 MEAN VELOCITY PROFILES

Fig(67) shows the distribution of the stream-wise velocity at the measuring locations and conditions defined in fig(66) . From this figure we observe certain features which are of interest. The free stream velocity is higher at the the suction surface than it is at the pressure surface due to the different boundary layer growth at the suction and the pressure surface . The profile shows increasing asymmetry towards the blade trailing edge ,and the asymmetry in the profile is increasing with increased loading.

When dealing with the decay rate of the velocity defect one should be cautious because of the different decays at various loadings. The decay rate was completely arrested in the tip region, and the increased loading seems to have activated the decay in this region . The same conclusion was drawn in Ref.(37).

At the hub region the decay rate started more slowly than at the mid-heights ,but surprisingly the wake started to grow rather than decay at a stage of $Z/C=.23$ and the increased loading increases the defect in this region. We believe this behaviour was due either to secondary flow effect and persistence vortices or to pressure gradient effects which could have the same influence: Ref.(13).

An interesting feature can be seen from the graph in

fig(67), in which the effect of blade loading was completely reversed from hub to tip . It increases the velocity defect at the hub while it decreases the defect at the tip, and the change-over in this effect was constant along the radial direction for all the axial positions.

The wake at the tip region was much broader than at the hub region. At the tip , near the trailing edge of the blade, the wake almost occupied 80% of the distance between mid passage to mid passage ; this was the distance covered by the measured points. At the hub the wake is much thinner, this may be due to the mass and energy transfer between the hub and the tip.

Fig(68) shows the normal to stream-wise velocity profiles. The profiles shown are at the same locations as the stream-wise velocity profiles; these components of velocity were calculated by resolving the axial and tangential velocity to the stream-wise and normal to stream-wise through the average relative air angle distribution across the wake. The relative tangential velocity profiles in the turbomachinery frame of reference , fig.(71), were all of the "jet" type i.e. The velocity at the centre of the wake was higher than it was at the free stream. Here ,fig.(68), the relative normal to stream-wise velocity distribution is shown to be changeable between the wake type near the trailing edge and the jet type far downstream. The existence of these profiles indicates the effect of wake shedding on the distribution of the relative air angle across the wake. The loading effect was not predominant as it was on the stream-wise velocity profiles , however the reverse effect was still present but in the opposite direction. The profiles

show a large asymmetry near the blade trailing edge and the hub. The decay rate of the defect was higher in general than the stream-wise velocity defect decay and this was due to the increasing mixing effect of the relatively higher magnitude of turbulence measured in this direction.

Fig(69) shows the distribution of the radial velocity as non-dimensionalised by the maximum free stream velocity. At all the measurement locations the radial velocity profiles show an outward component in both the suction and the pressure sides across the wake. The asymmetry near the blade trailing edge is much weaker than that of the stream-wise velocity profiles. We believe this was due to the relatively high speed (1500 r.p.m.) for this lightly loaded compressor stage. A similar behaviour of the radial velocity profiles being of the "wake" type and a slight asymmetry was found at nearly the same sort of speed in Ref.(46).

A general comment that ought to be made here is that with all the data obtained and presented here the effect of loading is changeable with axial and radial locations. But at regions just after the blade trailing edge regions ($Z/C=0.13$ at b.m.h.) the effect of loading and span wise locations on the velocity profiles was minimal. Some of the literature reported an unexpected behaviour in this region: in Ref.(29), as soon as the wake "recovered" from the trailing edge zone a redistribution of energy took place and the response of the wake to any external change was increasing. This was strongly observed in the distribution of the absolute air outlet angle. The change in this angle was very small at $Z/C > 0.3$ and the decay of the

differential across the wake was very rapid. The loading appeared to disturb the distribution only at the tip and the trailing edge region.

Figs(70,71 and 72)show the distribution of the three velocity components in the turbomachinery frame of reference. The conclusions regarding the loading effect are much the same as those explained for the stream-wise components. The decay however is much slower than that of the stream-wise components. The relative tangential component ,fig(71), is of the jet type and the decay of this component is the slowest. The radial velocity component ,of course , is the same as that in the stream-wise frame of reference except that it is non-dimensionalised by the total velocity component rather than the maximum stream-wise velocity in the outer edge of the wake.

The air flow angle distribution is shown in fig.(73). As can be seen from the figure the flow angle increased across the wake and the decay of this increase is very slow. The flow angle in general decreased downstream of the trailing edge and in the near wake the profile exhibited a large assymetry especially near at the higher loadings.

The radial angle distribution is shown in fig.(74). The hot wire measurements reveal a very high radial angle across the wake . An average angle of about 18 degrees can be found near the tip region. The radial angle of the flow decreases to about 11 degrees in the far wake . Also , the radial angle is lower in the hub region. The redistribution of the flow in the far wake region causes the radial angle to remain unchanged across the wake , especially in the mid-heights.

In the design of the stator stages , it is very important to estimate the variation of the stator incidence angle. The absolute outlet angle from the rotor gave this incidence distribution. This absolute angle is shown in fig.(75). In the design of the stator stages the variation of this angle across the wake should be taken into account. As can be seen from the figure ,at nearly $Z/C = 0.6$ the variation of this angle is diminished in the mid-heights. As a conclusion, it can be said that the variation in the stator incidence angle across the wake of the preceeding rotor can be neglected , if the stator is at a distance greater than 0.6. Also, if the distance is less than 0.6, the designer should at least consider this variation in the hub and the tip regions.

The deviation angle of the rotor flow is shown in fig.(76). This angle is defined as the angle between the average exit flow direction and the line tangent to the camber line. The axial flow compressor designers use this angle in the loss predictions. Information about the deviation angle is obtained from the blade section profile characteristics. These characteristics are mainly dependent upon two-dimensional cascade. As shown in fig.(76), the angle is around 5 to 6 degrees , and it increases across the wake. Also the deviation angle decreases towards the tip region. The cascade prediction for the C4 based profile shape ,Ref.(108) seems to have over-estimated this angle.

5.6.2 NORMAL STRESS PROFILES

Fig.(77 and 78) show the stream-wise and the axial turbulence intensity profiles. The profiles are in the stream-wise and in the turbomachinery frame of reference respectively. The turbulence profiles were non-dimensionalised by the local velocity components(as it is the case for turbulence intensities being local properties). From both figures the following was noticed. The profiles exhibit clear asymmetry near the blade trailing edge and near the hub region. This asymmetry disappeared further downstream and towards the annulus wall. The asymmetry is known to be due to the different developments of turbulence field on both the suction and the pressure side of the blade.

The turbulence on the suction side of the wake is slightly larger than that on the pressure side. This was noticed on the profiles of low loading (symbolised by $\Delta---$ Δ) more than the ones of high loading (symbolised by $+---$ $+$). Also further downstream and near the tip, both sides have nearly the same value of turbulence. The reason for the slightly larger value of turbulence on the suction side is the history effect (turbulence over the suction side of the blade is affected by the separation point of the boundary layer). The flow further downstream tends to "forget" its original state and a redistribution of energy takes place. This redistribution of energy affects the turbulence level on both sides of the wake.

The turbulence value at the centre of the wake in the trailing edge and in the near wake, is very small (1 to 2 %).

This was expected as the turbulence on the trailing edge of the blade is zero. Again in the further downstream regions, this "defect" recovers, and the turbulence in the wake centre tends to become higher especially for high loadings (around 5% in the mid-heights).

The turbulence profiles show very high values near the tip (an average value of about 30%). It is believed that these high values would be a natural result in this region where the flow is very complicated. This complex flow is due to annulus boundary layer, tip leakage and scraping vortices. The scraping vortex was represented by the reverse of the profile shape in the second axial location at the tip. This can be seen in both distributions.

In the hub region the turbulence is slightly higher than it is in the middle heights. This indicates the influence of the hub boundary layer and secondary flow effects.

The decay of the turbulence in the middle heights (excluding the hub and the tip zones) is very fast at the first stages up to $Z/C = .305$ and then it tends to be very slow. The decay in the tip region was much slower. The slowest decay was in the hub region and the turbulence tends to increase slightly further downstream. This behaviour is similar to that of the velocity seen before in fig(67).

It was concurrently concluded in an independent investigation (Refs(30,47)) that the loading would generally increase the turbulence level. It is believed here that the loading does not have a straight-forward effect on the turbulence level. It affects the turbulence in the same

manner as it affects the velocity defect (discussed earlier). The effect of loading depends strongly on the span-wise location. For example, it decreases the turbulence level in the tip region. Also it decreases the turbulence level in the near wake in the hub region, then again it increases the turbulence elsewhere. So in general, we conclude that the loading would increase the stream-wise and the axial turbulence intensity inside the wake region in the near and far wake regions except at the tip region $\tilde{R} > .95$ and near hub region $\tilde{R} < .55$ and $Z/C < .305$ where it decreases the turbulence.

Figs(79 and 80) show the distribution of the normal stresses in the tangential direction in both the turbomachinery and the stream-wise frame of reference. The figure which is of interest is the one in the turbomachinery frame of reference. The profiles in the direction normal to stream-wise should be treated with caution. The reason for this is because, as mentioned earlier, all the turbulence profiles are non-dimensionalised by the local velocity component in the related coordinates. In the direction normal to stream-wise the local velocity components were more or less representing the scatter in the stream-wise flow angle.

The tangential turbulence profile (fig(80)) shows a large asymmetry in the near wake region. This asymmetry persists for a distance far downstream ($Z/C = 0.5$). The asymmetry of the profiles tends to disappear towards the tip region. The loading amplifies the profiles asymmetry. The turbulence on the suction side is slightly higher than it is on the pressure side in a

manner similar to that of the axial turbulence profiles, and it is believed that it is due to the same reasoning.

The level of the tangential turbulence in the tip region is much different to that of the axial or the stream wise turbulence. The level is much smaller in the tip region. This reflects the anisotropic nature of the rotor wake turbulence in this region.

The decay of the tangential turbulence is much slower than that of the axial or the stream-wise, and the decay is slow even in the near wake region. This indicates that the redistribution of energy in this direction is not as fast as it is in the stream-wise or axial directions.

The loading seems to have increased the tangential turbulence level in the hub region and in the lower radii. The effect becomes much weaker towards the tip region. This indicates that the loading has different effects on different turbulence components.

In fig(79) where the turbulence is shown in the direction normal to stream-wise the profiles exhibit a very slow decay rate in all the axial stations. Also the turbulence in the centre of the wake shows a higher value than any of the other components. These profiles indicate the important conclusion that the redistribution of energy and the structure of turbulence are directional properties and that in the modelling of turbulence it is not correct to assume the same structure distribution for all the turbulence components.

Fig(81) shows the distribution of the radial turbulence

intensity. As seen in the figure there is a considerable change in the profile from one location to another and from one loading to another. These characteristics are a typical of the radial turbulence distribution. The level of radial turbulence is very high in general (40% on average in the near wake). The higher values were concentrated in the hub and the tip (near wake). The high radial turbulence persisted in the tip region even in the far wake, whilst it retained a high level in the hub up to $Z/C = .305$. The radial turbulence is a result of Coriolis** forces and rotation. The profiles show asymmetry in the near wake region, and the decay of radial turbulence is faster than both the axial and the tangential turbulence. This characteristic seems to be attached to the lightly loaded compressor. Ref.(33) indicated a reverse effect for a moderately loaded compressor. A slower decay existed at $Z/C \searrow .305$.

=====
 **"The Coriolis force represents an attempt to maintain constant angular momentum, so that a particle must move out or in on a radius according as its (true) angular velocity decreases or increases. Since the wake spreading is associated with mean velocities in the (θ) direction, the radial mean component is thus produced. Because the Coriolis force cannot do work, there should be no change in energy. However, it can change the radial velocity profile and hence the turbulent energy production."
 =====

The loading effect on the radial turbulence is dependent on the different locations as was the case for the other turbulence components. In the tip and in the hub, , the loading decreases the turbulence . In the middle heights , the loading increases the turbulence and this effect increases further downstream.

The following table summarised the effect of loading on turbulence component level;

=====				
I With increased loading I		Near wake	I	far wake I
=====				
I		I Axial tur.I	Decreased	I DecreasedI
I	T I P	I Tang. Tur.I	Sl. Inc.	I Sl. Inc. I
I		I Rad. Tur.I	Decreased	I DecreasedI
=====				
I		I Axial tur.I	Increased	I IncreasedI
I	MID-HIGH.	I Tang. Tur.I	Sl. Inc.	I Sl. Inc. I
I		I Rad. tur.I	Increased	I IncreasedI
=====				
I		I Axial tur.I	Decreased	I IncreasedI
I	H U B	I Tang. Tur.I	Increased	I IncreasedI
I		I Rad. Tur. I	Decreased	I DecreasedI
=====				

5.6.2.1 DISTRIBUTION OF MAXIMUM TURBULENCE INTENSITIES

Figs(82 and 83) show an isometric and a contour plot of the distribution of the maximum turbulence intensities inside the wake. The figures show the axial ,the tangential and the radial turbulence at the three examined loadings. The coordinates represent the axial distance behind the rotor blade trailing edge and the span wise locations from hub to tip. The figures show the locations where the turbulence is more predominant and they also reveal the effect of loading on the maximum turbulence intensities inside the rotor wake. In the distribution of the maximum axial turbulence it can be seen that the highest value is at the tip and that the loading, when increased, decreases the maximum axial turbulence value at the tip. The maximum tangential turbulence values are concentrated in the hub region and lower radii. The effect of increased loading was to decrease the value of the maximum tangential turbulence near the hub and to slightly increase it near the tip. This effect is obviously opposite to that on the maximum axial turbulence values. The distribution of the maximum radial turbulence intensities clearly shows a very high value at the tip and the hub in the near and far wake regions. Also it shows high values in the near wake of the middle heights. The effect of increased loading was to substantially decrease the maximum radial turbulence in the tip and in the near wake. It also slightly increases the turbulence values in the hub.

5.6.2.2 ISOTROPIC CHARACTERISTICS OF ROTOR WAKE TURBULENCE

One of the most important characteristics of any turbulence field is whether the turbulence is isotropic or anisotropic. The isotropic turbulence is defined by "The invariance under rotation of the coordinate system and under reflection with respect to the coordinate planes of the statistically averaged properties of turbulence", Hinze (Ref. 78). In all the rotor wake studies (if not turbulence fields studies), the isotropic characteristics of the turbulence field were judged by the relative magnitude of turbulence components. It is tedious to compare the different magnitude of turbulence components over the whole field points. In this investigation, we are suggesting a coefficient to represent the isotropic characteristics of the rotor wake turbulence field, or indeed any other 3-D turbulence field. The coefficient is defined as;

$$C_{it} = \sqrt{\sum_{i=1}^3 (T_i - T_j)^2 / 3 T_1^2} \quad \text{Where } j=2,3, i \neq j$$

This coefficient would give an accurate measure of the relative deviation of the three turbulent components. The smaller the value of this coefficient (towards zero), the more isotropic the turbulence field is. Figs(84,85 and 86) show a three-dimensional plot for the isotropy coefficient at the three examined loadings. The variation of the coefficient was made with the axial distance downstream of the rotor blade trailing edge and the span wise location from the hub to the tip. An average value for the three turbulent components over the middle portion of the wake was used. The figures show that the rotor

wake turbulence field is generally anisotropic and that this anisotropic nature is retained even in the far wake region, especially at the hub. They also show that the flow tends to be highly anisotropic in the middle heights of the near wake, more than it does near the hub or the tip. This result would be difficult to derive if we had not used the abovementioned coefficient. The effect of loading as shown in figs(85 and 86) was to reduce (in general) the level of anisotropicality in the turbulence field, however it slightly increases the turbulence component deviations in the tip region.

The anisotropic characteristic of the rotor wake turbulence field was believed to have been introduced by the presence of the blade , pressure gradients and rotation.

5.6.2.3 DISTRIBUTION OF TOTAL ENERGY OF TURBULENCE

In the series of figures(87,88,89,90,91 and 92) the turbulent kinetic energy is presented. For the data of the stream-wise frame of reference ,the turbulent kinetic enegy is defined by the expression,

$$K. T.E = \sqrt{\overline{u_s^2} + \overline{u_n^2} + \overline{u_r^2}} / 2 U_{swo}$$

For the data obtained from the turbomachinery frame of reference ,we used

$$K. T.E = \sqrt{\overline{u^2} + \overline{v^2} + \overline{w^2}} / 2 v_{tot.}$$

The kinetic turbulence energy has arisen from the diffusion

along the mean velocity gradients. In all the figures shown, the turbulent total energy increases towards the tip region and the blade trailing edge and it decreases everywhere else. Because the production of turbulent energy represents losses, one can expect the greater losses in the tip and the trailing edge regions. These losses are due to the complex mixing flow regime where the tip leakage and scraping vortices have their maximum effects. These figures also indicate that a loss due to turbulence field would be greater in the tip and in the trailing edge region than it would be in the hub. The production of turbulent energy in the hub region is nearly the same along the axial distance downstream from the rotor trailing edge.

The effect of increased loading on the production of total turbulent energy was to decrease the production in the tip region. Also, the increased loading slightly increased the production of turbulence in the middle heights and in the hub region.

5.6.2.4 AXIAL AND SPAN WISE DISTRIBUTION OF FREE-STREAM TURBULENCE AT THE WAKE OUTER EDGE

The distribution of the free-stream turbulence is shown for the three loadings in figs(93,94 and 95). Fig.(93) shows that the free-stream turbulence decreases with increased distance downstream of the rotor trailing edge in the middle heights. In the tip region the free-stream turbulence retained very high values even in the far region. In the hub region the free

stream turbulence is nearly constant and it has a value of around 12% of its value at the tip.

The loading as shown in the successive figures(94 and 95) seemed to have slightly increased the free-stream turbulence level in the tip region and decreased it everywhere else. This result indicates that the general conclusion is that as the loading increases the turbulence increases ,and that this is a property of the free-stream turbulence inside the rotor passage, and not across the wake .

5.6.3 TURBULENT SHEAR (Reynolds) STRESS PROFILES

The production of the shear stress tensor components is brought about by the mean velocity gradients and the normal stress gradients across the wake. Because of the opposite gradients in these profiles around the wake centre line , negative and positive values of these stresses can be found. The turbulent shear stresses are presented here with their components in both the turbomachinery and the stream-wise frame of references. Although the Reynolds stress components in the stream-wise frame of reference are the ones of practical interest as they represent a good basis for turbulence modelling, the Reynolds stresses are also presented in the turbomachinery frame of reference to discern the effect of different gradients of mean velocity on their distributions. The shear stresses are shown in figs(96 to 101) in both frames of reference. The stresses were non-dimensionalised by the

local dynamic pressure : $\rho \frac{V_{\infty}^2}{2}$ for the turbomachinery frame of reference and $\rho \frac{U^2}{2}$ for stream-wise frame of reference .

The distribution $\frac{\overline{u_s' u_n'}}{\rho \frac{U^2}{2}}$ is shown in fig(96). It is obvious that the stresses are larger in the trailing edge region from the hub to the tip. This value of around (.01) tends to decrease to around 0.002 in $Z/C > .3$ and to .0002 at $Z/C > 0.6$. This indicates that the shear stresses are nearly zero in the far wake region. The stress profiles have a slight asymmetry in the near wake region and the loading has a very small effect on their levels. The loading slightly decreases the stresses almost everywhere except in the near wake region towards the tip. The shear stresses in the tangential direction and in the radial direction are shown in figs(97 and 98). In fig (97) the correlation $\frac{\overline{u_s' u_r'}}{\rho \frac{U^2}{2}}$ is shown to be decaying faster than the stream-wise stresses. Also its values are almost of the same order as those of the stream-wise stresses. The radial components of the stresses are much lower than the other two components and their decay is much faster. Also it was noticed that the shear stress components have higher values in the near tip region.

When looking at the shear stresses from the turbomachinery frame of reference, they seem to behave in quite a different manner. This was mainly due to the fact that the shear stresses are a primary function of the mean velocity component gradients across the wake. The relative tangential velocity component being of the "jet" type was the main reason for this "variation". The axial shear stress component fig(99) shows not only different values but also different decay characteristics.

This is somewhat problematic in the context of modelling the stresses through its transport equation. The coordinate system used in the analysis is of extreme importance in deciding the nature of the stresses. The axial component of the stresses has a much slower decay rate than that of the stream-wise component. Also they have negative values where the stream-wise stresses have almost positive ones. The effect of loading was also different, it has distinct effect of increasing the profile asymmetry and further decreasing the stresses (or more accurately drifting from the zero value).

The tangential shear stresses ($\overline{u'w'}$) are shown in fig.(100). It has positive values almost every where except near the hub region where the values of the component are amplified in a similar manner to that of the tangential turbulence component. The radial component of the shear stresses in the turbomachinery frame of reference is shown in fig(101). The profile shape is much different to that of the same component if viewed in the stream-wise frame of reference : fig(98). Also they have nearly the same value but of opposite sign. In addition the decay of this component is again slower than the related one. In general we can conclude that the shear stresses would give faster decay characteristics and that the loading effect would be less important if viewed from the stream-wise frame of reference.

5.6.3.1 CONTOURS OF MAXIMUM SHEAR STRESSES

Fig(102) shows the distribution of the absolute maximum shear stress components across the rotor wake. The reason for taking the maximum absolute values rather than the maximum values is that the production of shear stresses can be of either sign and the losses which accompany this production are higher with higher drifting from the zero values. The condensed stress lines represent the higher values of shear stress, and as can be seen from the figures these higher values are in the "near" hub region. The stresses almost disappear in the far wake region. The effect of loading can be deduced from the graph. When the loading increases the stresses are redistributed in such a way that they would decrease in the "near" hub region, and slightly increase in the "far" tip region.

5.6.3.2 DISTRIBUTION OF THE "G" PARAMETER ACROSS THE WAKE

The "G" parameter represents the ratio of the total Reynolds stress to the total turbulent energy. This ratio was taken as constant in the modelling of the three dimensional wake flows Ref.(109). In fig(103) the ratio is presented across the wake at all the examined locations and conditions. The value of the parameter "G" is nearly constant in the far wake region, however in the trailing edge region and the "near" tip region the value changes across the wake by as much as 50%. Also, the parameter increases its value at the higher radii.

5.7 DISTORTED FLOW RESULTS

The circumferential distortion screen was installed at the compressor bell mouth intake at a location 5 chord lengths upstream of the rotor. Before discussing the effect of circumferentially distorted pressure on the rotor wake behaviour, we shall quote the effect of this distortion on the mean flow properties in three locations upstream and downstream of the compressor stage as well as between the rotor and the stator. Although the distortion at the compressor inlet is assumed to arise only from pressure distortion with a uniform total temperature, the circumferential difference in work addition by the rotor should create a temperature distortion. No measurements were made to study this temperature distortion, also the measurements reported here were carried out with the three transducer probe and it was of two-dimensional nature. The location and condition where these measurements were carried out is described in chapter 4 section (4.1.2.2).

The effect of inlet distortion on the three above-mentioned zones is shown in the series of figures(3 and 104 to 109). Fig (3) shows the distorted total and static pressure distribution upstream of the rotor at blade mid-height. The measurements were taken at one chord length in front of the rotor. The pressures were non-dimensionalised by the related values at clean flow conditions. As shown in the figure, the inlet total pressure distortion is of the sine wave shape . This loss in the inlet is distributed in a static pressure defect as well as kinetic energy loss . The kinetic energy loss is presented by

the total velocity defect shown in fig(104). Because of the static pressure defect the flow has an inclination towards this zone , this causes an important change in the incidence angle to the rotor blades. This incidence distribution is shown in fig(105) , and it is clear that the angle becomes much higher than its steady value. The increased incidence angle is one of the very important features of the pressure distortion. The blade boundary layer dynamic behaviour is altered by this changed incidence and should in turn alter the turbulence characteristics of the rotor wake as will be seen later. The pressure distribution downstream of the rotor is shown in fig(106). The figure indicates that the pressure distortion persists behind the rotor . A slight decrease in the defect was observed, however the rotor row had not succeeded in redistributing the flow. The gradient of the incidence angle in the circumferential direction is well presented in the total pressure distribution and in the velocity distribution fig(107), especially in the middle part of the screen where the gradient is zero. In the distribution of the pressures and velocities downstream of the stator (figs(108 and 109)) further attenuation was observed in the total pressure and velocity defect, the static pressure had become nearly constant in this station.

The following table gives the maximum defect of the flow pressure and velocities in the three stages.


```
=====
I      PERCENTAGE OF MAXIMUM DEFECT      I
=====
I      I  UPSTREAM  I  MIDDLE  I  DOWNSTREAM I
=====
I  TOTAL P.  I  0.25 %    I  0.197 % I  0.1449 %  I
=====
I  STATIC P.  I  0.0889 %  I  0.0471 % I  0.02 %    I
=====
I  VELOCITY   I  22.9 %    I  12.2 %  I  3.66 %    I
=====
```


5.7.1 DISTORTED FLOW ROTOR WAKE RESULTS

5.7.1.1 MEAN VELOCITY DISTRIBUTIONS

The results of the compressor rotor wake in the distorted flow regime are presented in the series of figs(111 to 118). All the figures have the master legend shown in fig.(110), unless otherwise stated on the figure itself. The results are presented in both the turbomachinery and stream-wise frames of reference. As seen in the previous table the maximum average total velocity defect in the free-stream downstream of the rotor row is around 12%. This value is nearly in the middle section behind the distortion screen. This velocity defect seemed to have had a very small effect on the velocity component levels across the wake. This can be seen in figs(111 and 112), where the velocity components are presented by their real values in m/sec. As shown in both figures the level of the velocity components across the wake has not been affected by this defect in the free stream velocity. In the successive figures(113 to 117), the components of velocity are presented in their non-dimensionalised form in the same manner as that used for the clean flow results. In the stream-wise and axial velocity distribution, the wake nature is similar to that of the tip region of the clean flow (note that all the distortion measurements were carried out in the blade mid-height), This nature is characterised by the existence of symmetry even in the near wake, large wake width, large velocity defect and slow decay with downstream distance. Also it was noticed that the

velocity defect in the region behind the distortion screen ((2,1,8 and 7) - (Indicated in fig.(3) and fig.(110)) is larger than the defect in the other circumferential locations. The radial velocity profiles, fig(117) , show a large asymmetry in the near wake region as well as a large defect towards the middle of the screen. The characteristics of larger width and defect toward the middle part of the screen are exhibited in all the velocity profiles including the tangential and the normal to stream-wise profiles as seen in figs (115 and 116).

The air flow angle distribution across the wake is shown in fig(118). The angle generally decreases over the circumferential direction towards the distortion screen in the near wake. This behaviour is less dominant in the far wake where the flow had more time to redistribute over the circumferential.

5.7.1.2 NORMAL AND SHEAR STRESS DISTRIBUTIONS

Fig(119) shows the distribution of the stream-wise turbulence intensity . The profiles show asymmetry in the near wake region but yet again the level of turbulence ,though in general higher than that of the clean flow, was not affected by the circumferential position behind the distortion screen. Furthermore the profiles have no definite decay characteristics over the axial distance downstream of the rotor blades. This behaviour indicates a complex turbulent flow field; the "ups and downs" in the stream-wise turbulence along the axial distance can be due to a complex trailing edge vortex system.

These vortices could have arisen from the unsteady boundary layer on the rotor blades where the separation points change from blade to blade. These changes follow the change of the incidence angle due to the pressure distortion reported earlier. The same phenomena was noticed in all the turbulence profiles figs(120 to 123), especially in the radial turbulence profiles. In these profiles "dead" and "active" zones of turbulence were spread randomly over the circumferential and the axial distance behind the rotor blade.

The shear stress component distribution in both frames of reference is shown in figs(124 to 129). In general, the Reynolds stresses are of comparable magnitudes to those of the clean flow. In the near wake the stresses are not affected by the circumferential location behind the distortion screen, however the profiles exhibit the same phenomena as that of the turbulence profiles. The sudden increase (or decrease) in the stresses is predominant in the tangential and radial distributions in both frames of reference. Because the shear stresses are mainly dependent on the turbulence gradients, this behaviour was expected but the main reason is still vague. These measurements have not been obtained hitherto and a verification of these results is needed.

5.7.1.3 DISTRIBUTION OF FLOW QUANTITIES DOWNSTREAM THE MIDDLE OF THE SCREEN AT DIFFERENT LOADING

The distribution is shown in figs(130 and 131) for the turbomachinery and stream-wise frames of reference respectively.

These measurements were undertaken to discern the effect of loading on the wake, while the compressor undergoes pressure distortion. It can be seen from both figures that the effect of loading is still seen as a factor for increasing the mean velocity profile asymmetry. The loading however has a secondary effect on the stress profiles. This means that the changes occurring in the stress are not due to loading variations as much as to the distortion. This can be explained because the loading effectively is represented by an overall change in the incidence angle which is already altered by the pressure distortion.

5.7.1.4 COMPARISON BETWEEN THE ROTOR B.M.H. WAKE IN CLEAN AND DISTORTED FLOW

The distribution of the mean and turbulent flow quantities is presented in the series of figures(132 to 137). The distributions are presented in the stream-wise frame of reference in figs(132,133 and 134) at the three loadings. Fig(132) shows that the distortion had slowed the decay of the mean velocity components. In fact, the wake centre line velocity downstream of the middle of the distortion screen was slightly decreased in the far wake region, as will be seen in chapter 6. Also, the three-dimensionality of the flow was increased by the distortion. This result was reported earlier for the free stream flow when examined by the five hole conventional probe. It was also noticed that the distortion had decreased the asymmetry of the stream-wise and the normal to

stream-wise profiles, especially in the higher loading where the clean flow results show an increased asymmetry in the trailing edge region: figs(133 and 134).

The turbulence levels were in general increased by the distortion, and the decay characteristics of both the normal and shear stresses were completely altered as explained earlier. The effect of distortion on the flow quantities in the turbomachinery frame of reference was very much the same as that in the stream-wise frame of reference as seen in figs(135,136 and 137). A quantitative study of these effects will be discussed in the next chapter.

CHAPTER 6 : CORRELATIONS AND COMPARISON WITH THEORY

6.1 SELF SIMILARITY OF THE WAKE VELOCITY PROFILES

As a result of the importance of the self-similarity criterion in analytical modelling of the width and decay characteristics of the rotor wake, a careful study of the wake profile similarity was made. The similarity was examined for all velocity components, at all span-wise locations and at different loadings. This examination was made both for the data with the stream-wise frame of reference and with the turbomachinery frame of reference. Before we discuss the similarity profiles obtained, we would like to point out the technique followed in taking the measurements. The aim of the technique was to ensure that the output signal from each hot wire sensor was coming from the exact space point in the rotor passage. This was obtained by using the blade strobe unit, described earlier in chapter 3, which provides an accurate phase lag between the signals. By this technique the wakes were "captured" and they were not allowed to spread over into the pitch-wise direction as would have been the case if we had used a triple sensor probe without correction for its spatial resolution.

The similarity profiles for each velocity component in both the frames of reference are shown in figs(138,139 and 140). The profiles show the effect of the three different loadings on the similarity characteristics. The vertical axis represents the local defect non-dimensionalised by the maximum defect. The horizontal axis represents the pitch-wise distance non-dimensionalised by the distance over which the wake

recovered half its defect in both the suction and pressure sides separately . These coordinate parameters were followed in all the literature.

Some features of the cuspy profiles obtained are explained in the following discussion.

The space taken by the wake to recover half its velocity defect in the tangential direction (i.e pitch-wise direction) was much smaller than that needed to recover the other half.

Although the method of treating the data was designed to provide a similar shape over the two sides of the wake , because of the inclusion of the trailing edge and the near wake data in the similarity profiles, the similarity profiles had asymmetry in the suction and the pressure sides of the wake. The rate of change of the non-dimensionalised defect is reversed at the wake centre line from the pressure side to the suction side.

In most of Lakshminarayana's work (27-36) the similarity law was given by

$$Y = \text{Exp}(-\ln 2) X^2 \quad \text{-----} (6.1)$$

The constant $(\ln 2)$ was taken as universal for all the velocity and turbulence component profiles. In ref.(31) it was suggested that this Gaussian distribution acceptably fitted the data , however it tended to over-predict the profile on the suction side and under- predicted it on the pressure side.

From our data we found that the above mentioned distribution (Gaussian) would not fit well with the profile obtained, and the equation

$$Y = \text{Exp}(-K \text{ abs}(X)) \text{ -----(6.2)}$$

would give the best fit; the variable (X) instead of (X^2) was used in Ref.(27) . We also found that the constant "k" has two values ,one for each side of the wake. By taking separate values for the constant k, the asymmetry which resulted from the inclusion of the trailing edge data was well represented by the similarity profile. Furthermore, the constant "k" was varied for each span-wise location and for each loading.

In the figures shown(138 , 139 and 140), the solid line represents equation (6.2) with different values for the constant "k" for both sides of the wake. The program written to perform the self similarity characteristics of the rotor wake was designed to select the value of "k" which gives the minimum deviation from the experimental data. The deviation was taken in the form,

$$\text{Div} = (\text{SQRT}(\sum_{i=1}^N (e_i^2 - \bar{e}^2)) / N-1$$

The program is listed in Appendix(14). In order to obtain a generalised form of an equation which can be used for the constant "k" in the theoretical analysis, we used the incidence angle(in radians) and the non-dimensional radius as the two independent variables. In figures(141 to 164) the fitted surfaces which were obtained by least square analysis are shown. The surfaces provide the value of "K" at any chosen incidence or height for both sides of the wake.

This method is very useful in giving an accurate representation of the similarity profiles especially for

components such as total relative velocity where the profiles had extreme asymmetry . The results of this analysis were used as input data to the analytical model of wake width/decay characteristics as will be shown later.

The same procedure was repeated for the velocity profiles under the distortion mode and the same conclusion was drawn. The figure (165) provides the similarity profiles of the different velocity components in the distortion regime. The fitted surfaces of the constant "K" are also shown in figs(166 to 189). The two independent variable used were the incidence and the circumferential position in radians.

In general it was noticed that the scatter in the data of the distortion mode was larger than that of the clean flow. It is believed that this was not due to the flow being under distortion but because the experiments involving the distorted flow were made in the blade mid-height. This height was the one which exhibited a high scatter of the similarity profiles data points in the clean flow mode as shown in the figures(138 to 140). The reason for the larger scatter or the poor similarity at the blade mid-height, rather than at the tip or the hub ,is that the velocity profiles in the near wake of this height tended to be more assymetrical than those of the near wake near the tip or the hub(see: figs 67 to 72).

The constants in the set of equations shown in Appendix(15) give the value "k" for the velocity components for both the pressure and the suction side of the rotor wake.

6.2 SELF PRESERVATION OF TURBULENCE COMPONENTS OF ROTOR WAKE

The expression " self preservation " is used to indicate that the turbulence quantities maintain its main structure in the downstream direction of the flow field. It is usually difficult to mathematically describe a self preserved rotor wake turbulence field. This is because the turbulence profiles usually have a dip in the wake centre . This dip causes a scatter in the data when trying to collapse them to a single curve. Another reason is that the turbulence profiles sometimes reverse their shape from wake like to "jet" like shape . For these reasons ,in the literature, the rotor wake turbulent self preservation characteristics were usually made for the outer sides of the wake only, or else for the whole wake section but with extrapolation in the wake centre. Because of the need to describe the rotor wake turbulent field in the pitch-wise co-ordinates (as it is necessary for the theoretical analysis) we tried to obtain self preserved profiles for the rotor wake turbulent field. The program used was designed to overcome the above mentioned difficulties and we obtained the distribution of the constant "k" in the same manner as that for the velocity components. An example of these results is shown in the figs(190 to 201). Because of the nature of the rotor wake turbulent field in the pressure distortion regime (as described earlier in chapter 5) no attempt was made to assess self preservation characteristics for the turbulence profiles of this regime. The wake turbulent structure in the distortion mode failed to retain or preserve itself both with the

downstream distance and with the circumferential direction.

The results of self preservation constant "k" equations for the turbulent field of the rotor wake in the clean flow are shown in appendix (16)

6.3 ROTOR WAKE DECAY CHARACTERISTICS

Figs(202 , 203 and 204) show the decay characteristics of the velocity, turbulence and Reynolds stress components in the stream-wise frame of reference. The figures represent the three examined loadings. At each of these figures the data represented all the stations from the hub to the tip. The horizontal axis represents the stream-wise distance non-dimensionalised by the chord length. The vertical axis represents the maximum defect or gain in the particular component across the wake , non-dimensionalised by the maximum value of the component in the free stream (outside the wake). This parameter is given in the figures. In the case of the Reynolds stress decay, it was more realistic to take the absolute value of the maximum drift around the value zero as an indication of the decay of these stresses. All the decay curves were in agreement with the relation

$$Ud/U = A_1(X-X_0)^{M_1} + A_2(X-X_0)^{M_2} \text{ -----(6.3)}$$

Represented in the figures by the solid lines, this relation was originally proposed by Lieblein and Roudebush Ref.(8) for cascade wake correlations, and from then on followed in all the available literature.

In some of the early work, such as Raj et al. Ref(26) the following relation was suggested:

$$U_d = e^{-\frac{\pi^2}{R_s}(S/s + S_0/s)} \text{-----}(6.4)$$

Raj used this relation to describe the decay of all velocity and stress component . He specified different constants for each components. In most of the work published after Ref.(26), the authors preferred to use relation (6.3) to describe the decay of the different flow components. In our work, we found that the relation (6.3) gave a better description for the decay characteristics. In equation (6.3) the constants M1, M2 have negative values(-0.5 and -1.0 respectively), and X₀ is the virtual origin for each component. The decay rate of all components seemed to be in fair agreement with the above mentioned relationship. The constants "A1" and "A2" were calculated by a least square fitting for all the components. The program used is listed in Appendix(18). The analysis used in the determination of the constants is in Appendix(17). For the velocity components in the hub region , the constants of equation(6.3) M1, M2 were changed from(-.5 and -1.0) to (.5 and 0.0). The reason for this was because the behaviour of the velocity component in this region was growing rather than decaying after $z/c > .305$. The use of negative power for the hub region will not correlate with the decay characteristics of the velocity components in the hub region. This is very clear in figure(205) where the decay characteristics are shown for the velocity components in the turbomachinery frame of reference. The relation (6.3) with negative powers is still valid for all

the decay curves of the different stress components as shown in figs(206 and 207); here the decay of the turbulence and Reynolds stresses components are shown in the turbomachinery frame of reference . In these figures the horizontal axis represents the axial distance downstream from the rotor blade trailing edge which is non-dimensionalised by the chord length. The decay characteristics of the different flow components in the distortion regime were compared to those of the clean flow. Figs(208 and 209) show the decay of the flow component in the blade mid-height and the solid lines represent the different circumferential stations . The squared points represent the decay of the particular component in the clean flow mode. The figures indicate a very slow decay rate for the distorted flow components. This was concluded before from the original results of chapter (4). Figs(208 and 209) show the velocity decay as the difference between the maximum and the minimum value inside and outside the wake. This means that these figures do not necessarily represent the wake centre line velocity . When the centre line velocity was drawn , it was found that at some points this velocity slightly decreased instead of increasing. This will be referred to in the comparison of the results with the proposed theory. Figs(208 and 209) should be viewed cautiously, as the turbulence and Reynolds stress components of the distorted mode cannot be described as "decaying" (as mentioned in chapter 4). This figure was derived merely to compare with the clean flow result. In appendix (19) a table is given for the constants of relation (6.3) for all the flow components.

In most of the work which was published during this investigation (Refs(32 to 36)) the authors followed relation(6.3) for the decay of the different flow components of rotor wake. In these references a suggestion was made that a correlation with the section drag coefficients raised to a certain power would collapse the defect decay curves along the radial direction to a single curve. Contrary to this, Dring et al. Ref.(31) stated that any correlation with the drag coefficient will not collapse the data to a single curve. To examine this we proceeded as follows;

The constants A1 and A2 for a certain flow component at the three examined loadings were fitted separately with the radial location. A straight line fit gave a reasonable correlation coefficient. The slopes of the two different lines for each constant (A1 and A2) were then compared. If the slopes of the two lines were of the same order (difference < .01) , the relation (6.3) can then be written as

$$Q_d = (B_0 + B_1 * R) ((X-X_0)^{M_1} + S_1 (X-X_0)^{M_2}) \text{---(6.5)}$$

where S1 is the average slope and B0 and B1 are the new fitting constants. In this way equation (6.5) would stand for the decay of a particular flow component over all the radial locations (excluding the hub region for the velocity components).

The next step was to try to correlate the section drag coefficient by following the same procedure , aiming to end up with a relation of the sort

$$Qd/Cd^K = K1((X-Xo)^{M_1} + S1 (X-Xo)^{M_2})----(6.6)$$

Fig(210) shows the distribution of the cross section drag coefficient with the radial direction , the figure shows the distribution at three different flow coefficients and it shows the drag coefficient raised to three different powers. This distribution was calculated according to the original characteristics of the C4 profile compressor blade cross section Ref.(108) along with the available incidence variations. The figure indicates a nearly constant value of the drag coefficient in the radial direction when raised to a power .5 or 1.5. The drag coefficient itself(i.e raised to power 1) gives a positive slope with the increased radii towards the tip. The increase in the value of the drag coefficient towards the tip region was due to the increased losses in this region as indicated earlier in several locations. The important characteristic of this distribution is the positive slope. The relation (6.5) ,which was calculated for all flow components show that the data of the decay characteristics are able to be collapsed onto a single curve, however this collapsing of the data would correlate to a property which has a negative slope in the radial direction . The drag coefficient being of a positive slope would not correlate with the rotor wake decay characteristics.

6.4 WAKE WIDTH VARIATION CHARACTERISTICS

The semi-wake width is usually represented by the distance over which the velocity defect is halved. Because of the large

difference in the space taken by the wake to recover the first half of its defect than to recover the second half as shown by the self-similarity curves figs(138,139 and 140), we present the full width beside the semi-width. we defined the full width as the distance over which the wake recovered 95% of the maximum defect . This definition was originally used by Lieblein and Roudebush Ref(8) for cascade wake.

Figs(211 , 212 and 213) show the full and semi width at the three loadings. It is clear that the wake full width increases with the axial distance at all the measured radii, except at the hub and tip where the width behaviour deviates. At the first loading($\text{inc.} = -8^\circ$ At b.m.h)the width at the tip fluctuates but in an increasing manner , whilst at the hub it increased then decreased. In the other two loadings the width at these two radii retained almost the same behaviour. The reason for this behaviour is probably the same as was mentioned earlier when describing the stream-wise velocity distribution . Fig(214) shows the distribution of the wake semi-width in the radial direction . The slight increase in the width shown near the hub is believed to be due to the increase in the asymmetry of the velocity profile in this region.

The width is a minimum at the mid-heights and grows again near the tip. This was noticed in the stream-wise velocity distribution where the wake covers most of the blade passage . This increase was due to the outward migration of mass and energy.

In fig(215) the distribution of the semi and full wake width is presented for the rotor wake in the pressure distortion

regime. The figure also shows the width in the relevant location in the clean flow mode(the square points). It can be seen from the figure that the distortion effect was to increase the wake width in the near wake region. It also retains this width almost constantly further downstream. This result in turn indicates the slower decay of the velocity components in this regime.

6.5 COMPARISON OF THE RESULTS WITH THE THEORETICAL PREDICTIONS

The application of the theoretical model program described in chapter "2" is very much dependent upon the preparation of the input data . The more accurate the input data , the more realistic the results would be. Because the program was initially designed to be expansible , it offers several choices for different parameters . For example, all the turbulence and the pressure terms can be neglected or taken into account. Also, in applying for the Reynold stresses the program gives the choice between using approximate values for them or applying the simple eddy viscosity model . Some of the important features are discussed here.

Because there were no measurements for the static pressure distribution inside the rotor wake , and this information was important for the pressure terms of the momentum equations, an estimation of the static pressure rise inside the rotor wake was made based on the measuements taken by Reynolds et al. Ref. (28) for a single stage lightly loaded compressor. The static

pressure is said to increase by as much as 25% inside the wake from its value in the free stream. The value of the static pressure in the free stream was obtained from the five hole probe measurements reported earlier.

Although we used the free stream input data from the measurements made with the conventional five hole probe, the program can be used with data calculated by any three-dimensional inviscid numerical scheme which gives an information on the mean flow

The radial gradient of the different flow parameters was obtained using the Lagrangian slope in the form

$$Y(R) = \sum_i^n \mathcal{L}_i^n(R) Y_i$$

$$\mathcal{L}_i^n(R) = \prod_{\substack{r=1 \\ r \neq i}}^n \frac{(R)_k - R_r}{R_i - R_r}$$

$$\left(\frac{dY}{dR} \right)_{R=R_k} = \sum_{i=1}^n \left(\sum_{\substack{j=1 \\ j \neq i}}^n \frac{1}{R_i - R_j} \prod_{\substack{r=1 \\ r \neq j}}^n \frac{(R)_k - R_r}{R_i - R_r} \right) Y_i$$

The program used to obtain the local radial gradient of the flow parameters is listed in Appendix(20) .

Fig (216) shows the distribution of the wake centre line velocity with the axial direction downstream of the blade trailing edge. The figure shows the distribution for the three

velocity components , and for the three examined loadings. The velocity components are shown for the radial locations from the hub to the tip. The solid lines represent the theoretical prediction, whilst the symbol points represent the experimental data. One must bear in mind that the distribution is drawn for the wake centre line velocity which means an increasing value for a decaying wake and a decreased value for a decaying "jet" , which is the case represents the relative tangential flow velocity. In the figure shown , we used all the turbulence components in the solution as well as the estimated static pressure value. In fact, we found that when the program was used neglecting the turbulence terms the velocity components were over-estimated by more than 30%. Also, running the program using the eddy viscosity model gave nearly the same results as those obtained by using our experimental values for the Reynolds correlations.

The theoretical program is listed in Appendix (2), where there is a complete set of data and its results. Also in Appendix (21), a complete set of the results for the clean and distorted flow case are presented.

As it can be seen from fig(216) that the program gives a fair agreement with the axial and the radial velocity. For the relative tangential velocity, the theoretical model tends to over-estimate the relative tangential wake centre line velocity in the near wake region. It also under-estimated in the far wake region. The width variation is shown in fig(217). The width in this figure is defined as :

$$\delta = r (\theta_o - \theta_c)$$

The agreement with the width variation is better than that for the velocity components. The values of the powers m_1 to m_8 in equation(2-15) of chapter 2 was used as 0.5 , 0.0 , -0.5 , -1.0 , 0.5 , 0.0 , 1.0 and 0.0 respectively.

The program was used to predict the decay of the wake centre line velocity at b.m.h with the compressor subjected to inlet flow distortion. We used a different power for the decay equations to obtain a linear output. The results are shown in fig.(218) and the same conclusion was drawn for the relative tangential velocity prediction.

In both the clean and the distorted flow analyses , the equations for the self similarity were used to identify the wake in the pitch-wise direction.

Although the agreement of the theoretical prediction with the experimental data for the hub and the tip region was poor , we believe that a better turbulence modelling and pressure gradients should greatly improve the results.

6.6 WAKE CENTRE LINE CURVATURE

Figs(219 , 220 and 221) show a qualitative view of the wake centre line curvature as defined by the relative air outlet angle at the wake centre(the wake centre is defined as the position of maximum defect in stream-wise velocity). The figures also show the curvatures at three loadings. The straight lines represent the blade stagger angle at different locations from the hub to the tip. It can be seen that at the mid-heights ,with all three loadings, the radius of curvature is

small at the near wake . This curvature is in the direction of the blade camber line . Downstream from this region the flow tends to follow the blade stagger line, again in both the hub and tip region the behaviour is different. At the tip the divergence from the stagger is amplified, while at the hub the curvature has an opposite shape to that of all the other radii. Because the curvature of the wake centre line is dependent on the preceeding blade section, the interaction between the hub and blade boundary layer tends to define another shape of the blade section at the hub. Refs(28 and 29) show a tendency for the curvature to behave in similar manner, however only two radii were shown.

The curvature at blade mid-height in the distortion mode is shown in fig(222). The square points represent the curvature in the blade mid-height for the clean flow mode. For the flow region far away from the pressure distortion screen sector, the curvature of the distortion is almost as that of the clean flow.

But for the flow downstream of the distortion screen the flow curvature is smaller in the near wake region. However the flow tends to diverge from the stagger line.

6.7 WAKE THICKNESS DISTRIBUTION

In the same manner as that used in boundary layer studies, the wake displacement, momentum and energy thickness and the shape factor (ratio of m/δ) were obtained . Fig(223) represents a global picture of the changes of these factors; each individual section represents the distribution with the incidence (high loadings towards the origin) for all the radii , while the figure

as a whole shows the distribution along the axial distance.

The wake thickness distribution was obtained by integrating the non-dimensional stream-wise velocity across the wake. The equations of the different thicknesses are:

$$\text{Displacement thickness } \delta = \frac{1}{S} \int_{\theta_c}^{\theta_o} (1-u/U) r d\theta$$

$$\text{Momentum thickness } M = \frac{1}{S} \int_{\theta_c}^{\theta_o} u/U (1-u/U) r d\theta$$

$$\text{Energy thickness } E = \frac{1}{S} \int_{\theta_c}^{\theta_o} u/U (1-(u/U)) r d\theta$$

$$\text{Shape factor } H = \delta / M$$

The process of integration was programmed and the program is listed in Appendix(22).

In general the thicknesses decreased with increasing distance downstream of the trailing edge and they were nearly asymptotic in the far region. Also they tended to increase with the higher loading except for those at the tip where the thicknesses decreased with increased loading. This again proves that the loading has different effects at different radii. Also from the figure it can be seen that all the thicknesses tend to increase with an increase in the height where the effect of outward flow is more predominant.

The different behaviour in the tip region was also reported by Lakshminarayana Ref.(36). Near the blade trailing edge (the L.H.S. of the graph) all the thicknesses show higher values which indicates the large variation of velocity gradients and increased losses.

The shape factor has a value of around 1.1 at the far

downstream and this value is slightly higher for the hub and the tip zones. This value of 1.1 was reported by both Kool Ref.(53) and Lakshminarayana Ref(36). The behaviour of the momentum thickness in the different flow thicknesses are shown in fig(224) for the distortion mode. The horizontal lines represent the thicknesses in the clean flow mode. The figure shows that the distortion has lowered the value of the thicknesses in the near wake region. In the far wake region the thicknesses have almost the same value as those of the clean flow. It is believed that the reason for the lower values in the near wake region is that the velocity profiles with the distortion were less asymmetrical than those of the clean flow.

6.8 COMPRESSOR ROTOR WAKE AS A NOISE GENERATION SOURCE

The unsteady components from the wake shedding over the blades induce a fluctuating force on the next row of blades which causes noise. This fluctuating force is mainly caused by a variation of flow angle across the wake(see fig.(75)). Also the turbulence has an effect on the noise generated inside the compressor . Most of the acousticians believe that the effect of velocity defect is the most important factor in noise generation. Analysis of the velocity defect into Fourier components is necessary in order to obtain the propagation of the different harmonics with the downstream location behind the rotor trailing edge. Ref.(33)used a finite Fourier series to analyse the rotor wake using the recursive technique (Ref.(110)). Ref(33) indicated the importance of all harmonics at the near wake and only the first two in the far wake .In our

analysis we could not find any important harmonics apart from the first , even in the trailing edge region. This is shown in fig(225),where the coefficients A's are shown up to A6 with the downstream distance from hub to tip for all loadings. The sine coefficients are shown in fig(226). These coefficients reflect the asymmetry of the rotor wake near the blade trailing edge at the lower radii,the profiles return to symmetry at the tip and in the far wake.

CHAPTER 7 : CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK.

7.0 CONCLUSIONS

The main conclusions derived from the present investigation are presented below.

1- Introduction of a phase lag in the output signals from a group of hot wire sensors used for rotating turbomachinery measurements is essential. The spatial resolution of the probe used could cause a serious phase shift. This phase shift could distort the measured flow characteristics, especially when the output signals are to be treated statistically.

2- The rotor flow wake is highly three-dimensional and its turbulence structure is anisotropic.

3- The effect of loading on the rotor wake characteristics is a function of the radii locations. It is also different for different velocity components. It was found that the loading has a reverse effect on the velocity defect from the hub to the tip, as explained in sec(5.6) of chapter 5. Also, it was found that the loading increases the asymmetry of the wake in the trailing edge region.

4- The decay of the defect was completely arrested in the tip region, whilst at the hub the rotor wake started to grow rather than decay at a position of $Z/C > 0.23$

5- At a position just after the rotor trailing edge region, the response of the wake to any external effect such as loading was very slow. Also the velocity profiles seemed to have an identical shape over the radial direction.

6- The similarity of the velocity profiles was found to follow the relation (6.2) where the constant "K" varied for

different loadings and heights. Also when applying different values of K for the suction and the pressure surfaces, the increased asymmetry of the profiles at the trailing edge region could be well represented by equation (6.2).

7- The use of the section drag coefficient as the main parameter to correlate the decay of the different velocity defects to a single curve was unsuccessful. This conclusion is a verification of that drawn in Ref(32). The rotor wake defect data would correlate with a variable which has a negative slope over the radial direction.

8- The turbulence level is very high at the tip region. A turbulence of $\approx 90\%$ intensity can be found in the centre of the wake, in the near tip region. The radial turbulence intensity component is the highest. The axial, the stream-wise and the tangential are of the same order of magnitude.

9- The turbulence level maintains its high value far downstream in the tip region. However it decays very fast in the mid-heights. The stream-wise intensity component has the fastest decay characteristics.

10- The rotor wake turbulence field is anisotropic. The anisotropic level increases in the trailing edge region in the mid heights.

11- The maximum production of the turbulent energy is concentrated in the near-tip region.

12- The shear stress component decays very fast and it reaches the zero value at $Z/C > .55$.

13- The circumferential pressure distortion at the inlet of the compressor has several effects on the rotor wake. These

effects can be summarised as follows,

a- When the distortion is applied on the compressor , it becomes the prime factor controlling the wake behaviour. i.e. the changing of the operating point of the compressor in terms of changing the loading would have little effect on this behaviour.

b- The behaviour of the rotor wake under distortion in the blade mid-height can be simulated by the behaviour of the rotor wake in the tip region in clean flow.

This behaviour is characterised by very slow decay , symmetrical profile in the near wake , and large width and defect.

c- The turbulence intensity across the wake in the distortion mode is higher than that of the related clean flow.

d- The pressure distortion seems to have created randomly distributed turbulence zones of different intensities , it also affects the shear stresses in the same way.

e- Although the distortion screen was covering a 90 degree sector , the distortion effect on the wake was extended to the opposite sector. This result was not seen when the free stream zone was examined by the five hole probe in this opposite sector.

f- The wake centre line velocity behind the middle of the distortion screen has decreased slightly in the far wake region . This characteristic is completely opposite to that of the clean flow.

14- The integral momentum technique was used to predict the wake width and decay characteristics. The assumption used in

the analysis included the radial flow in the outer wake edge. It gave a good agreement for the mid-height locations of the region behind the rotor trailing edge. (The method over-predicts the wake centre line tangential velocity.) The omission of the pressure and turbulence terms has altered the results and the predictions tend to over-estimate the velocity in the whole region.

15- The technique was applied for the rotor wake under the effect of distortion regime . The circumferential location behind the screen was used along with the incidence angle to describe the wake in the pitch-wise direction. Equation (6.3) was used to describe the decay characteristics with different powers. A straight line equation gave the best results of the axial and radial velocity .

7.1 RECOMMENDATION FOR FUTURE WORK

Although an effort has been made to study the axial flow compressor rotor wake in clean and distorted flow , the subject is far from complete. The experimental and theoretical techniques which have been developed are recommended to be used for the following;

- To measure the rotor wake in several radial locations downstream of the distortion screen . (This investigation was confined to the blade mid-height).
- To measure the rotor wake with different forms of distortion (square wave or triangle).
- Detailed measurements using this experimental technique

should be made in the hub and tip regions. These measurements will help in the understanding of the complex phenomena which are responsible for the high losses.

- A small (size) pressure transducer probe , capable of measuring the total and static pressure gradients inside the rotor wake , is crucial to the interpretation of some of the wake characteristics , especially at the hub and the tip. It is also important to model the pressure gradients terms in the theoretical model.

- The experimental data should be added to that already stored in the computer to form a complete data bank. This data would be very useful in developing a numerical scheme to predict the local profile shape of the different flow components.

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FIGURES

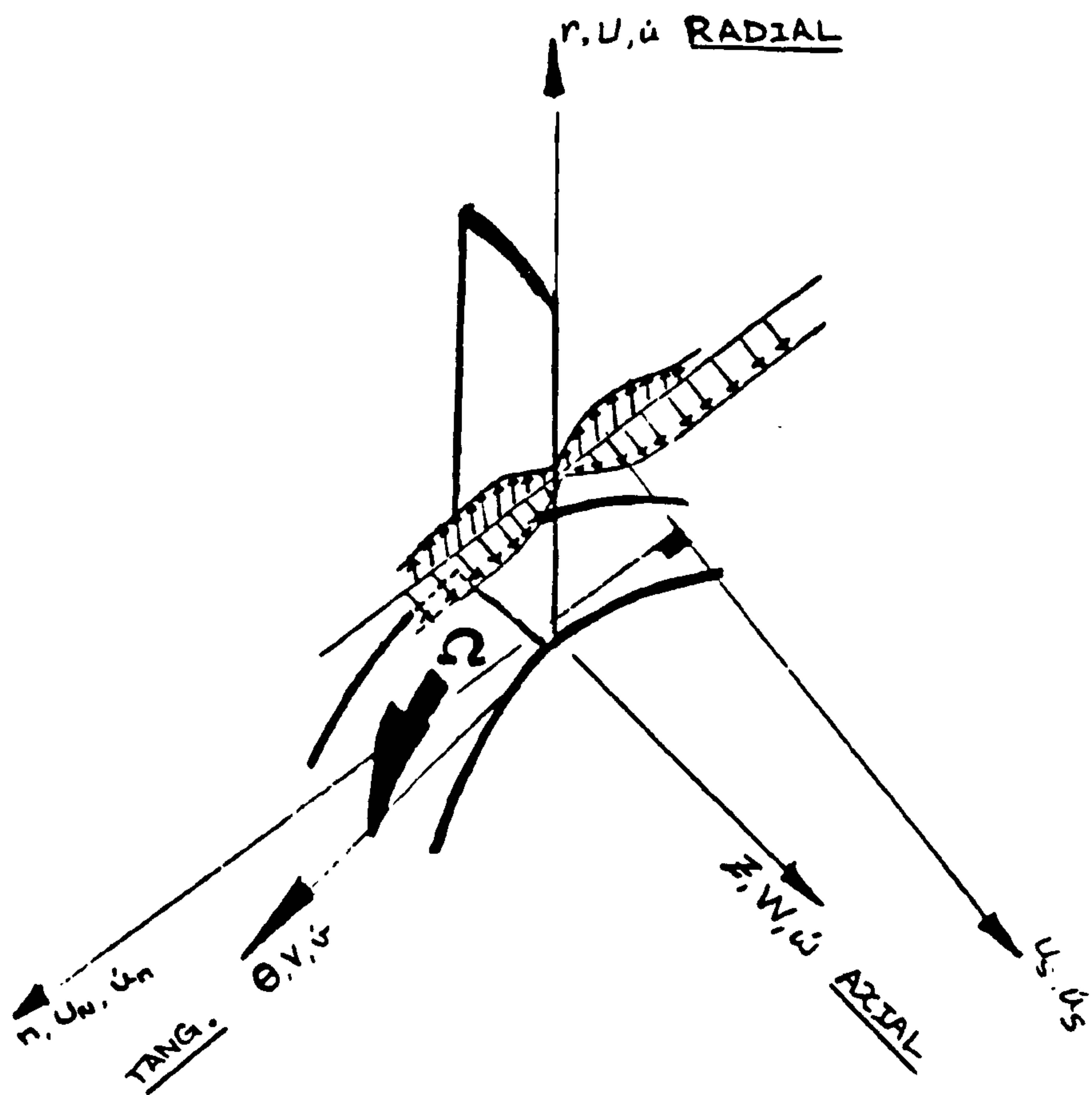


FIG. 1 ROTOR WAKE CO-ORDINATE SYSTEM.

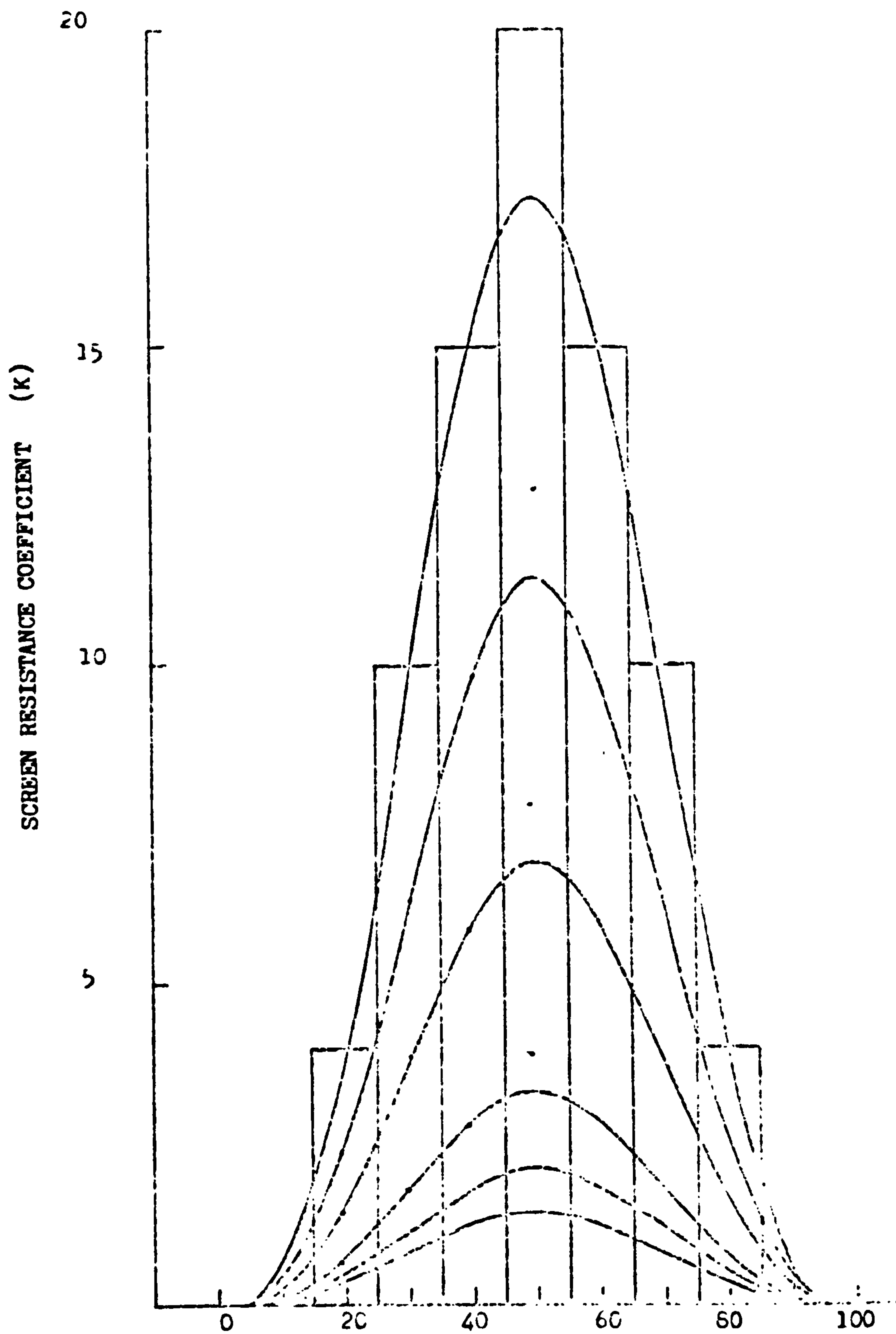


FIG. 2 Distortion screen resistance coefficient (K).

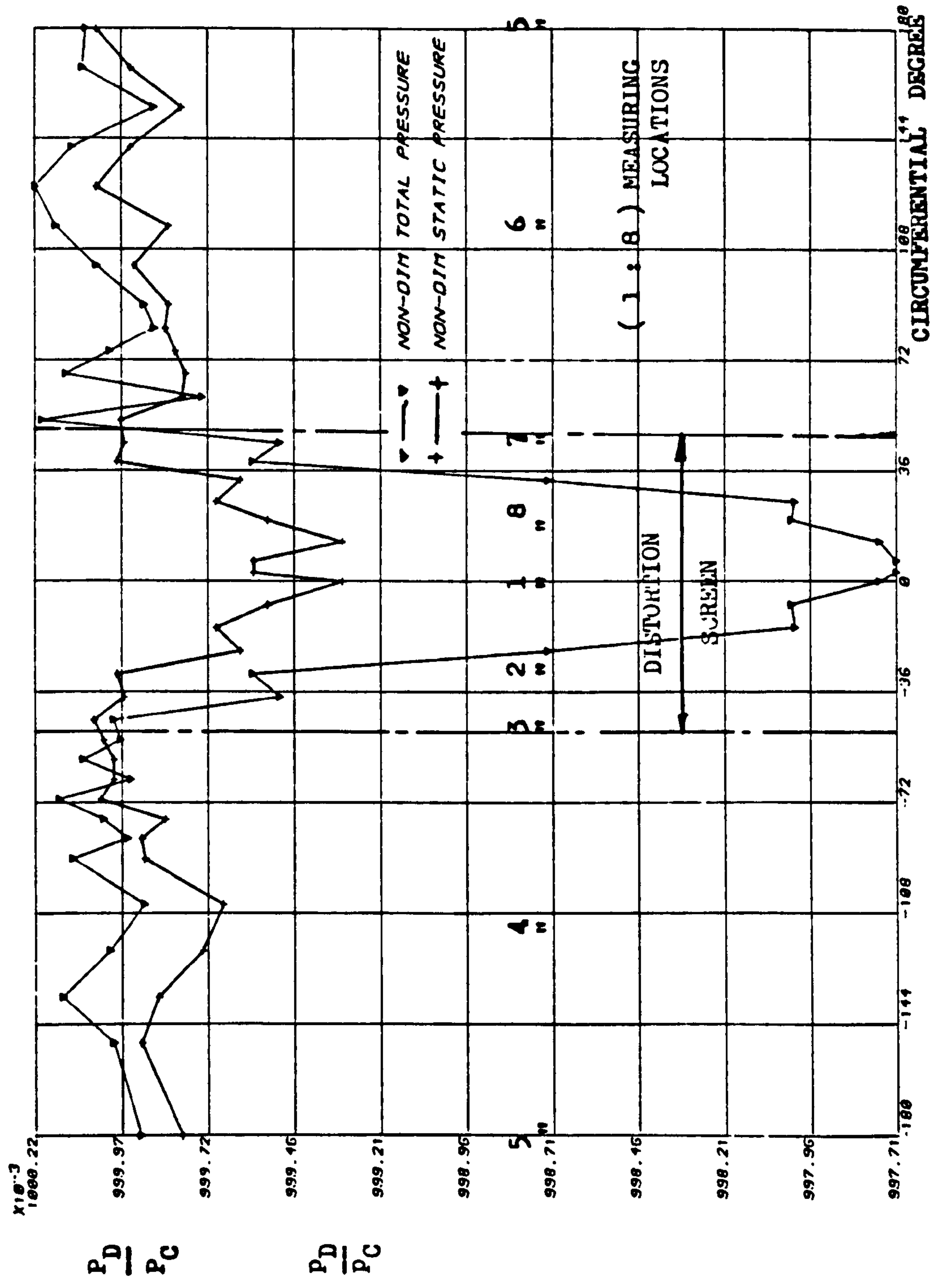


FIG. 3 DISTRIBUTION OF FLOW PARAMETERS DOWNSTREAM OF THE SINEWAVE DISTORTION SCREEN
UPSTREAM OF THE ROTOR

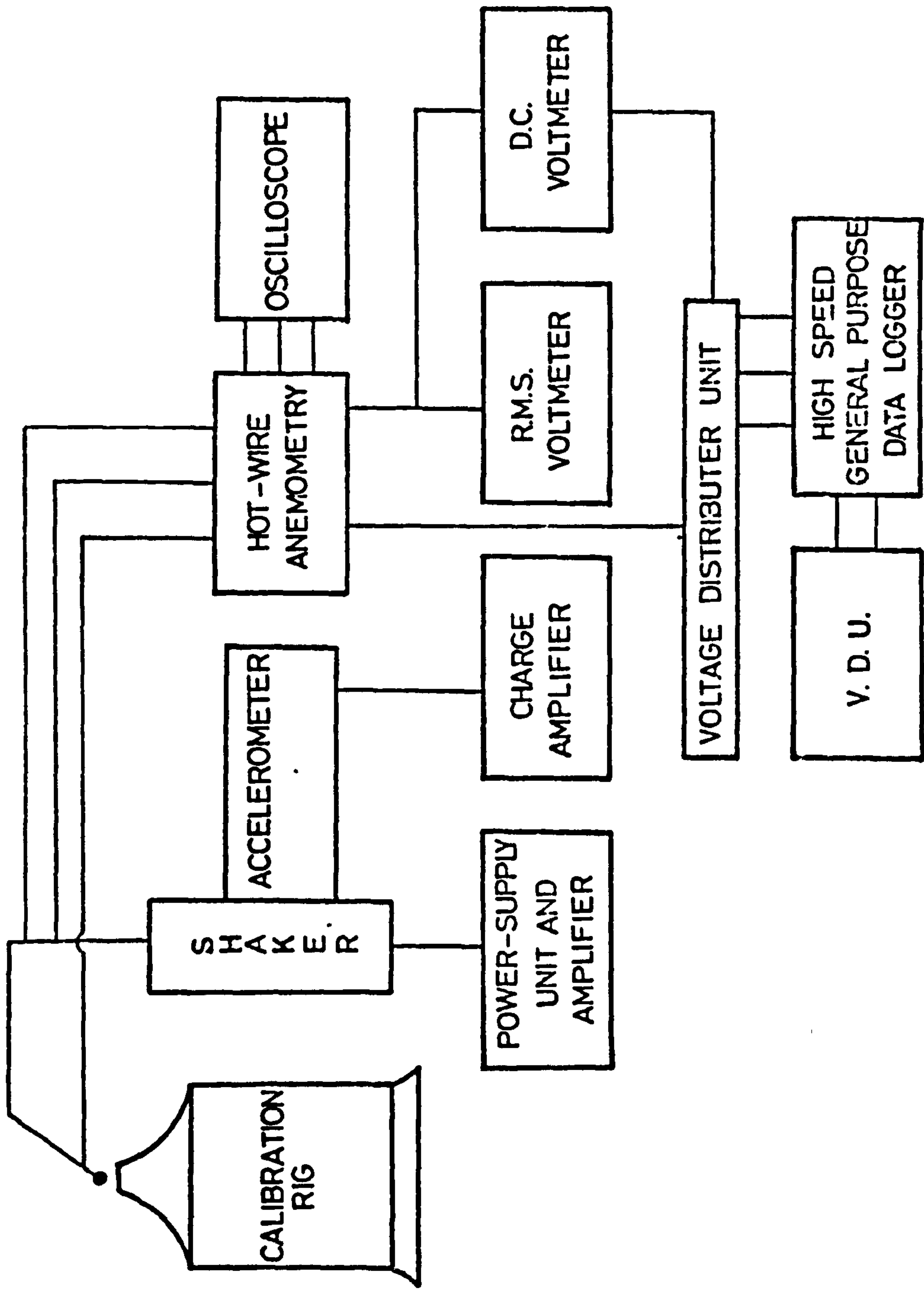


FIG. 4 Dynamic calibration peripheral equipment.

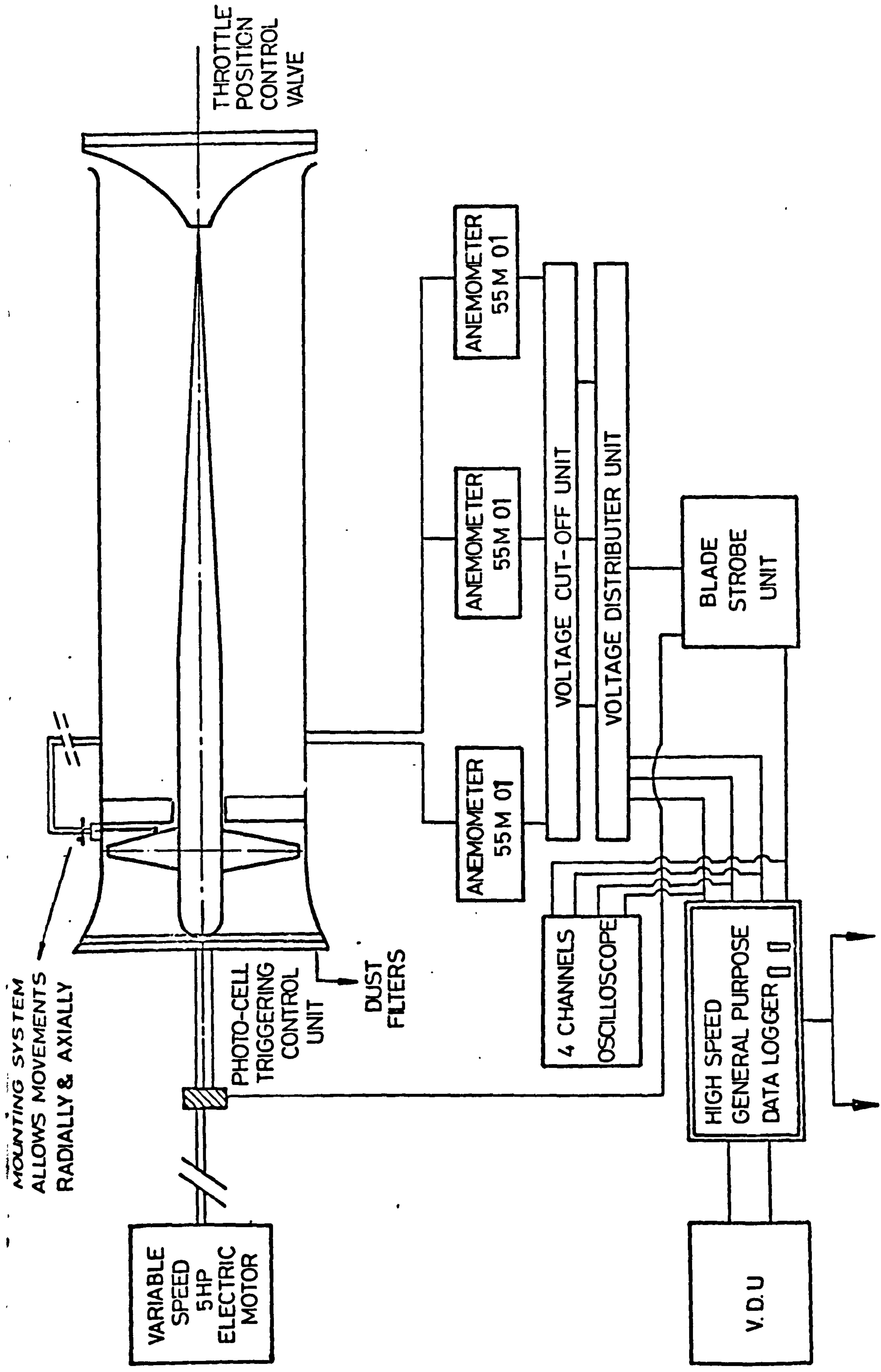


FIG. 5 Layout of the compressor peripheral equipment

VAX 11/780
COMPUTER

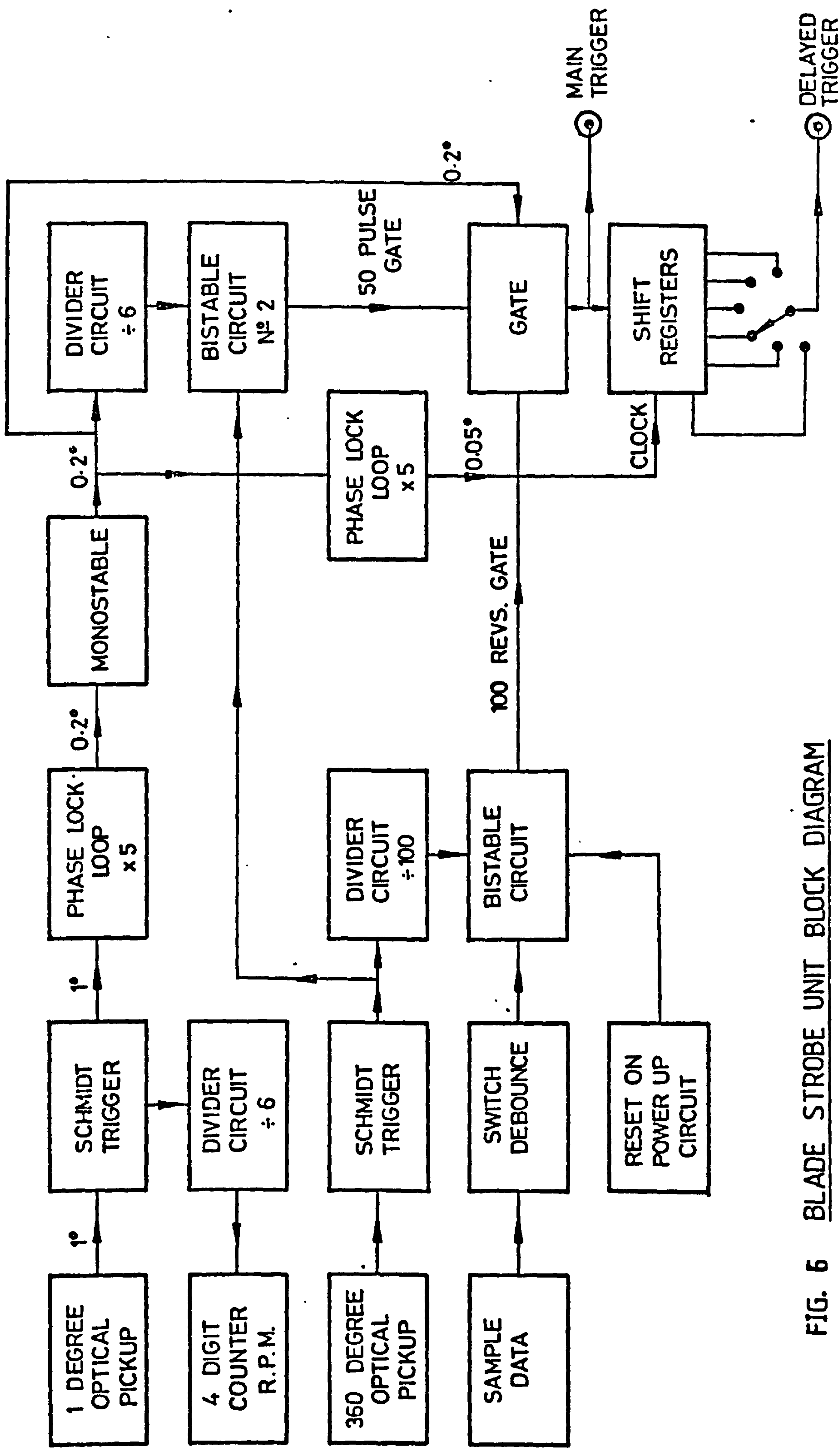


FIG. 6 BLADE STROBE UNIT BLOCK DIAGRAM

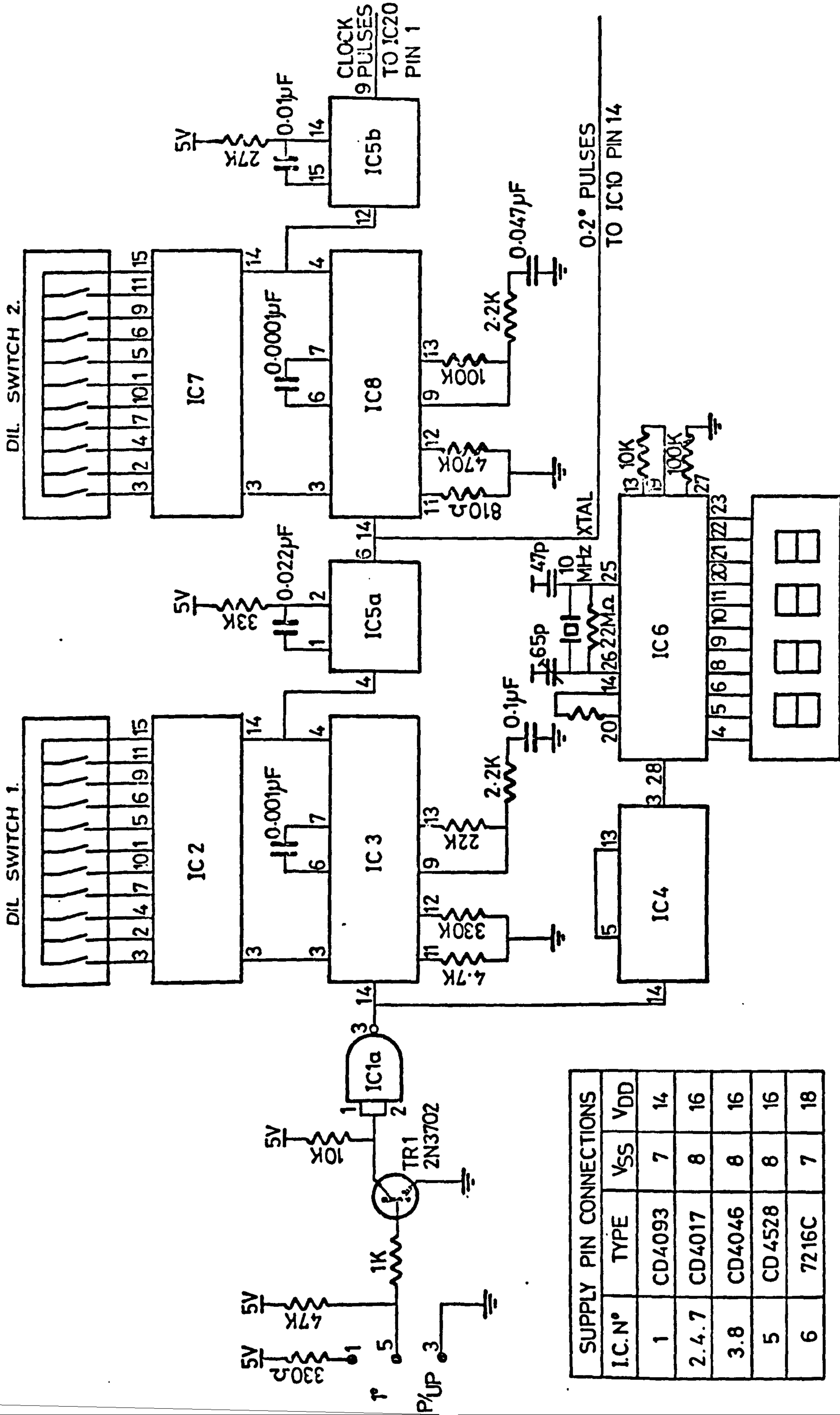


FIG 7 PHASE LOCK LOOP MULTIPLIERS AND SPEED COUNTER CIRCUITS

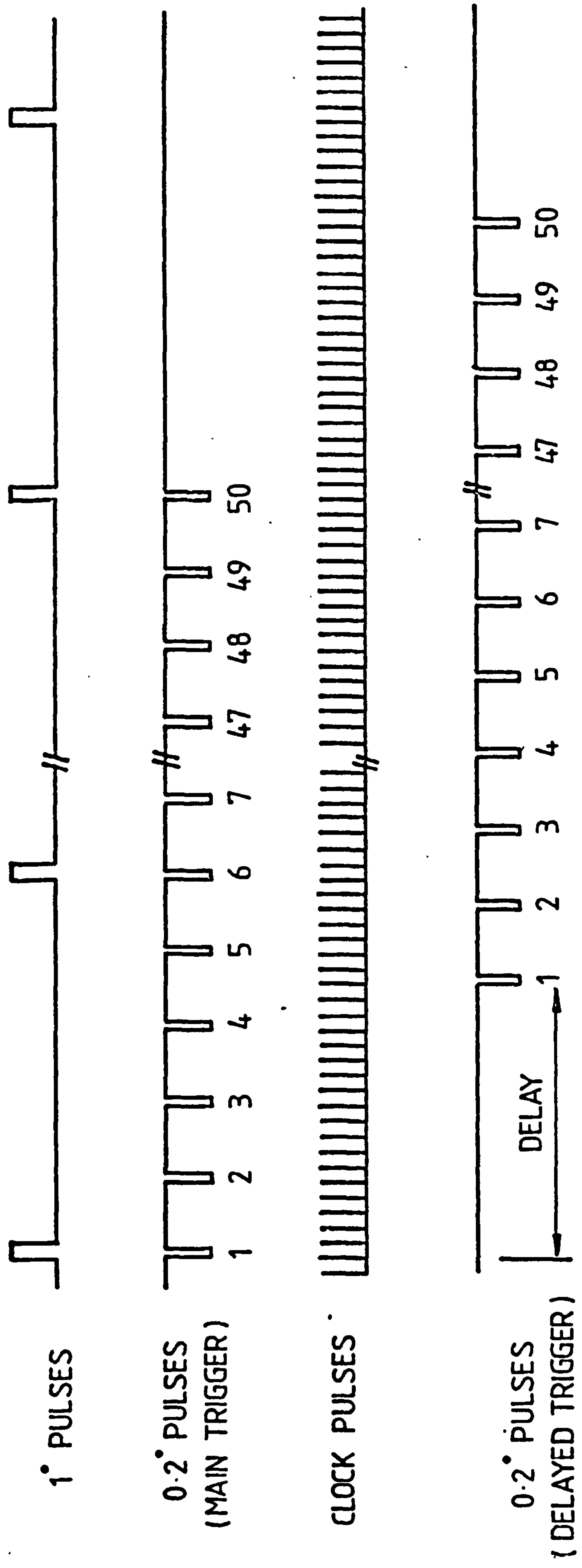


FIG. 9 DIAGRAMATIC REPRESENTATION OF MAIN AND DELAYED TRIGGER PULSES

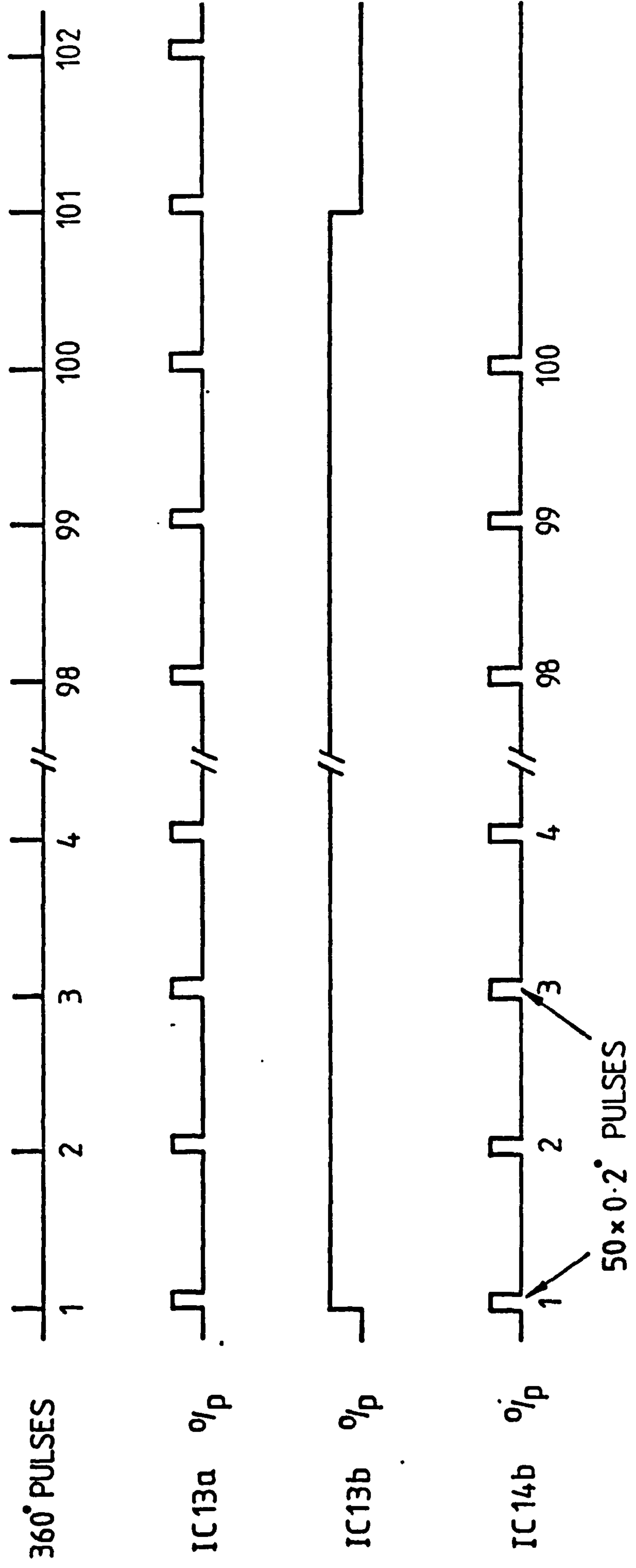


FIG. 10 DIAGRAMATIC REPRESENTATION OF GATING AND TIMING WAVEFORMS

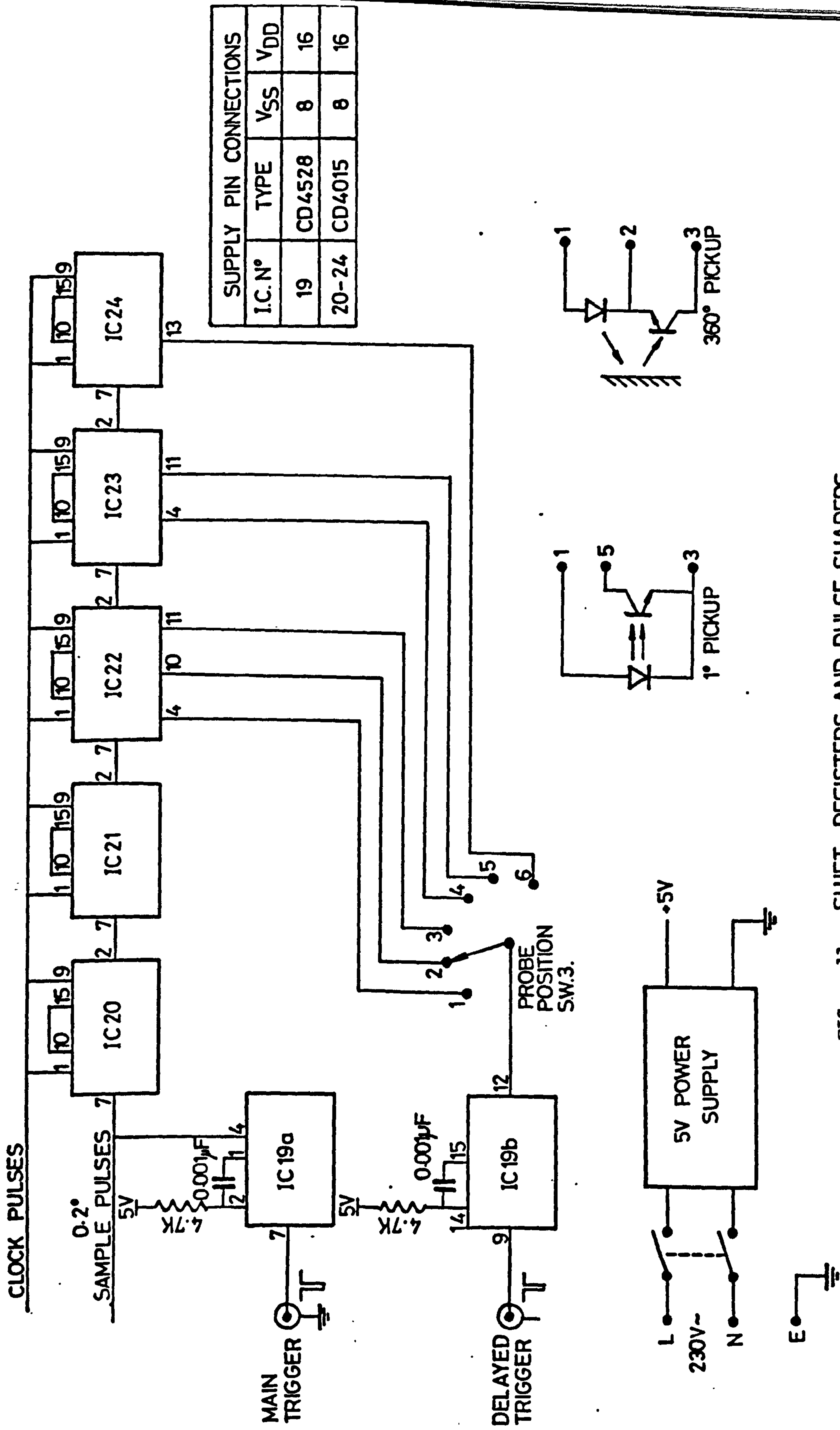


FIG. 11 SHIFT REGISTERS AND PULSE SHAPERS

MEMORY MAP

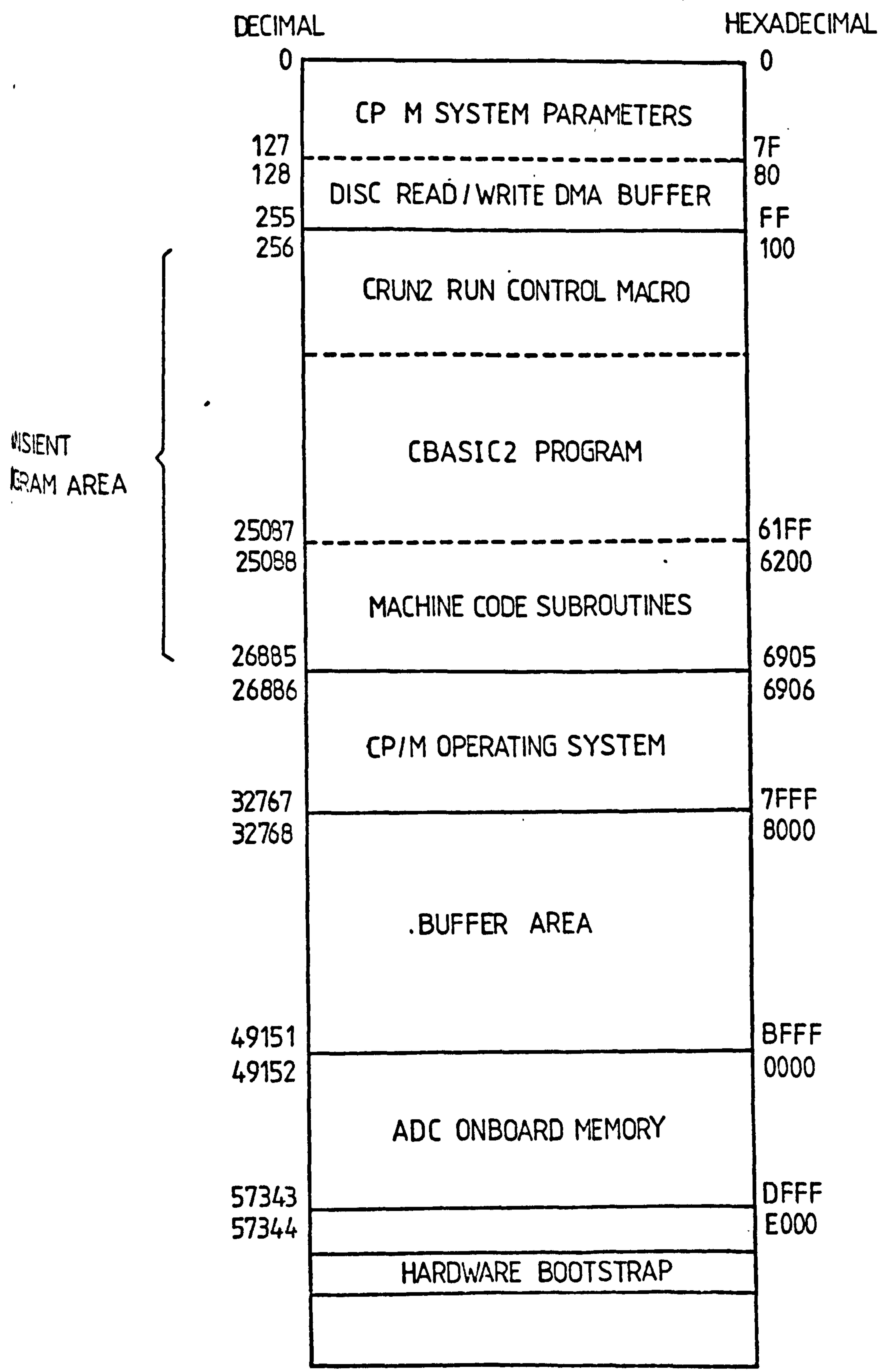


FIG. 12 MEMORY MAP.

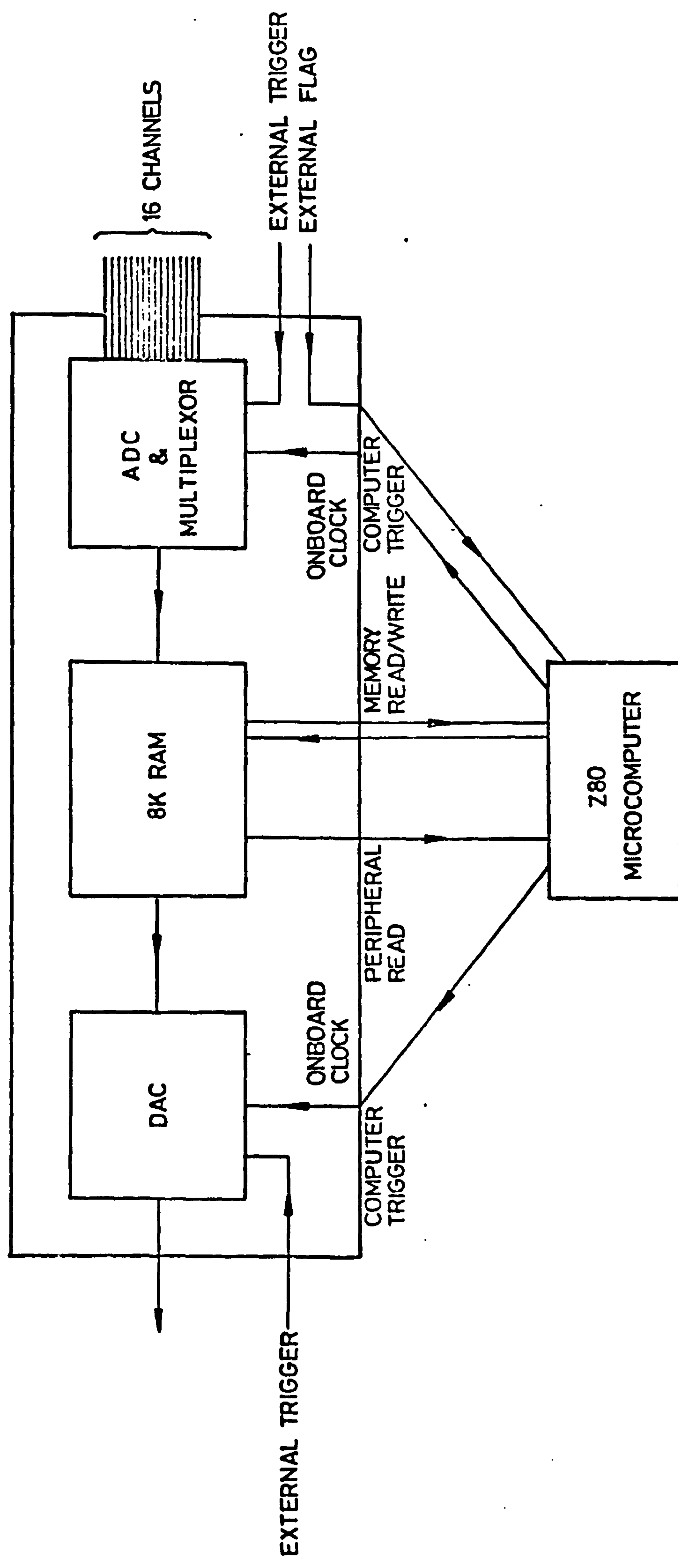


FIG. 13 ADC SYSTEM

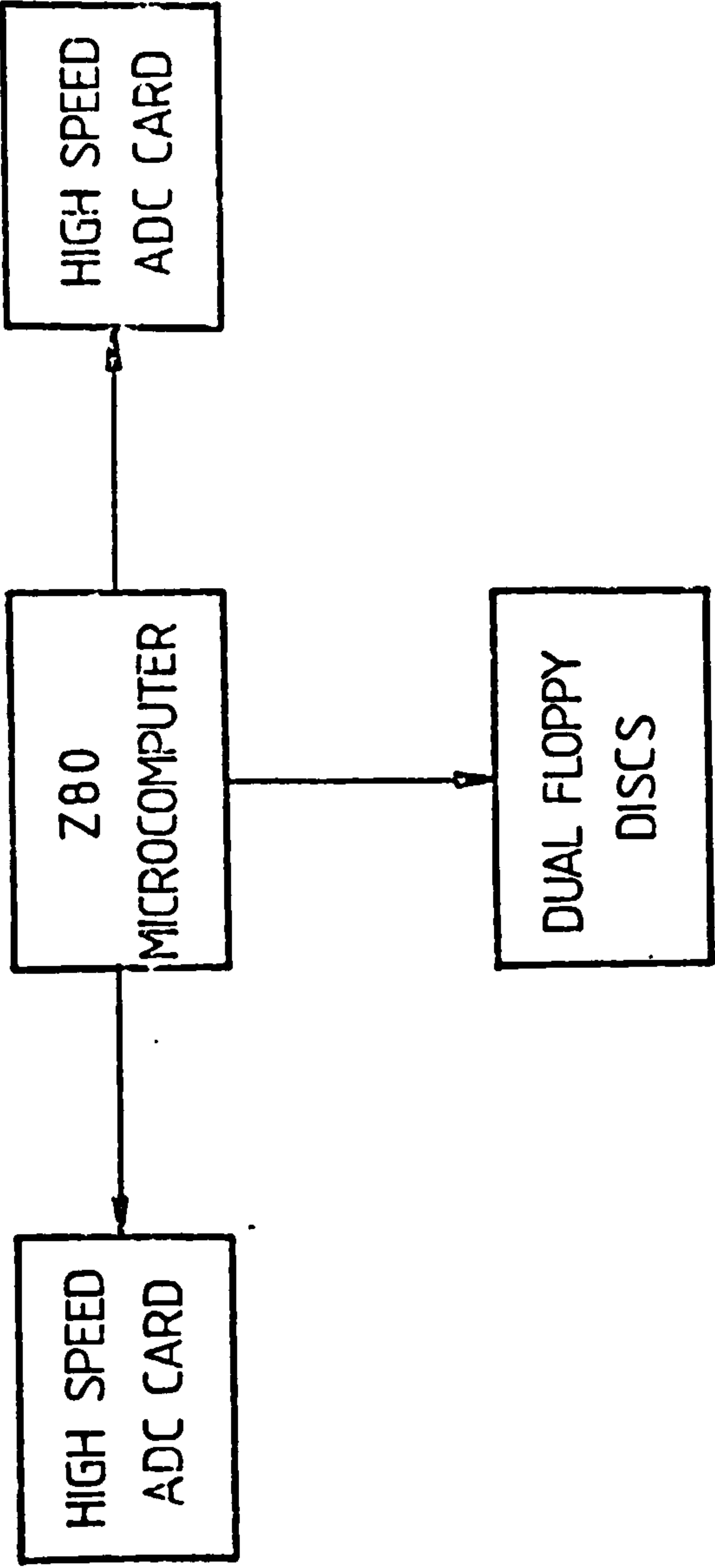


FIG. 14 SYSTEM DIAGRAM.

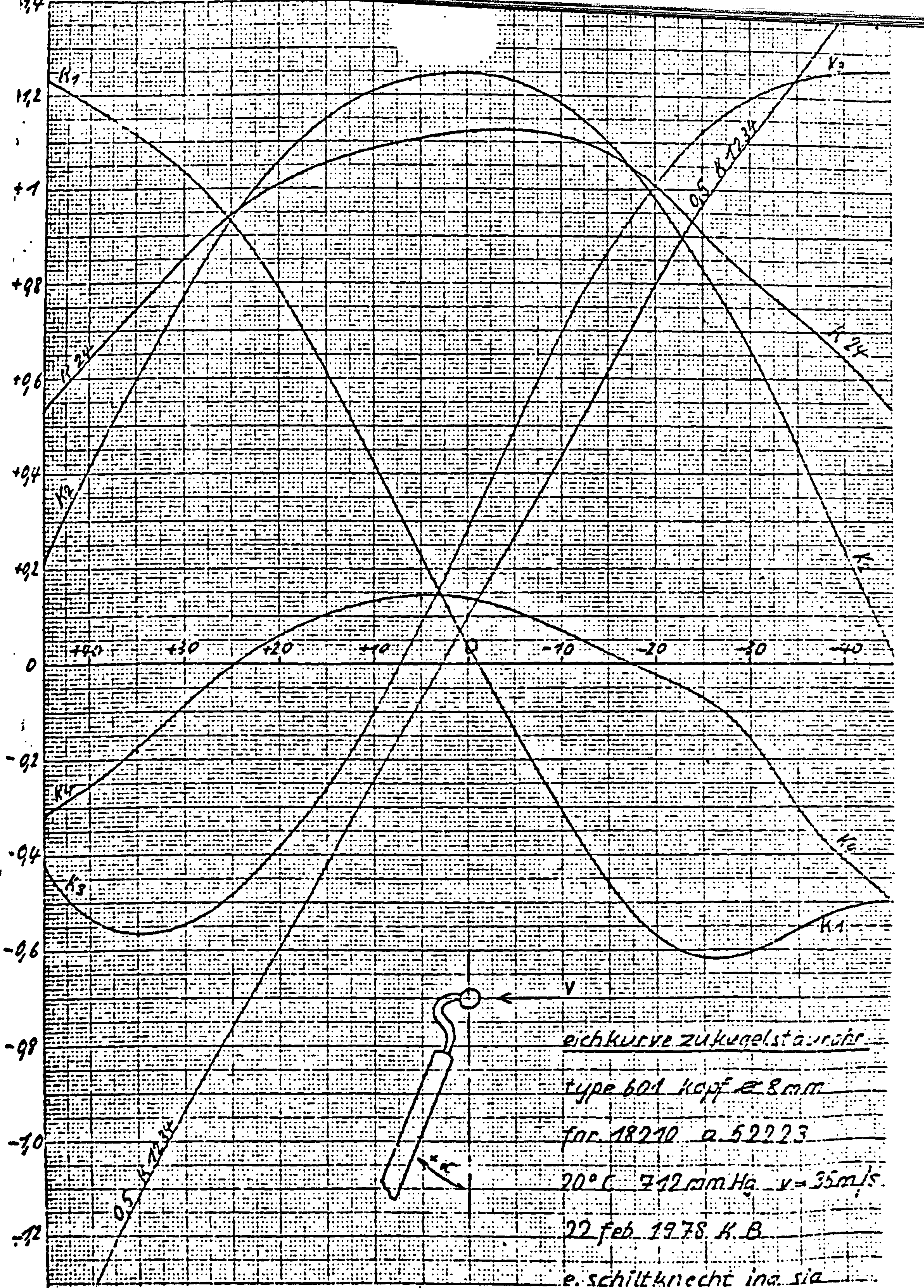
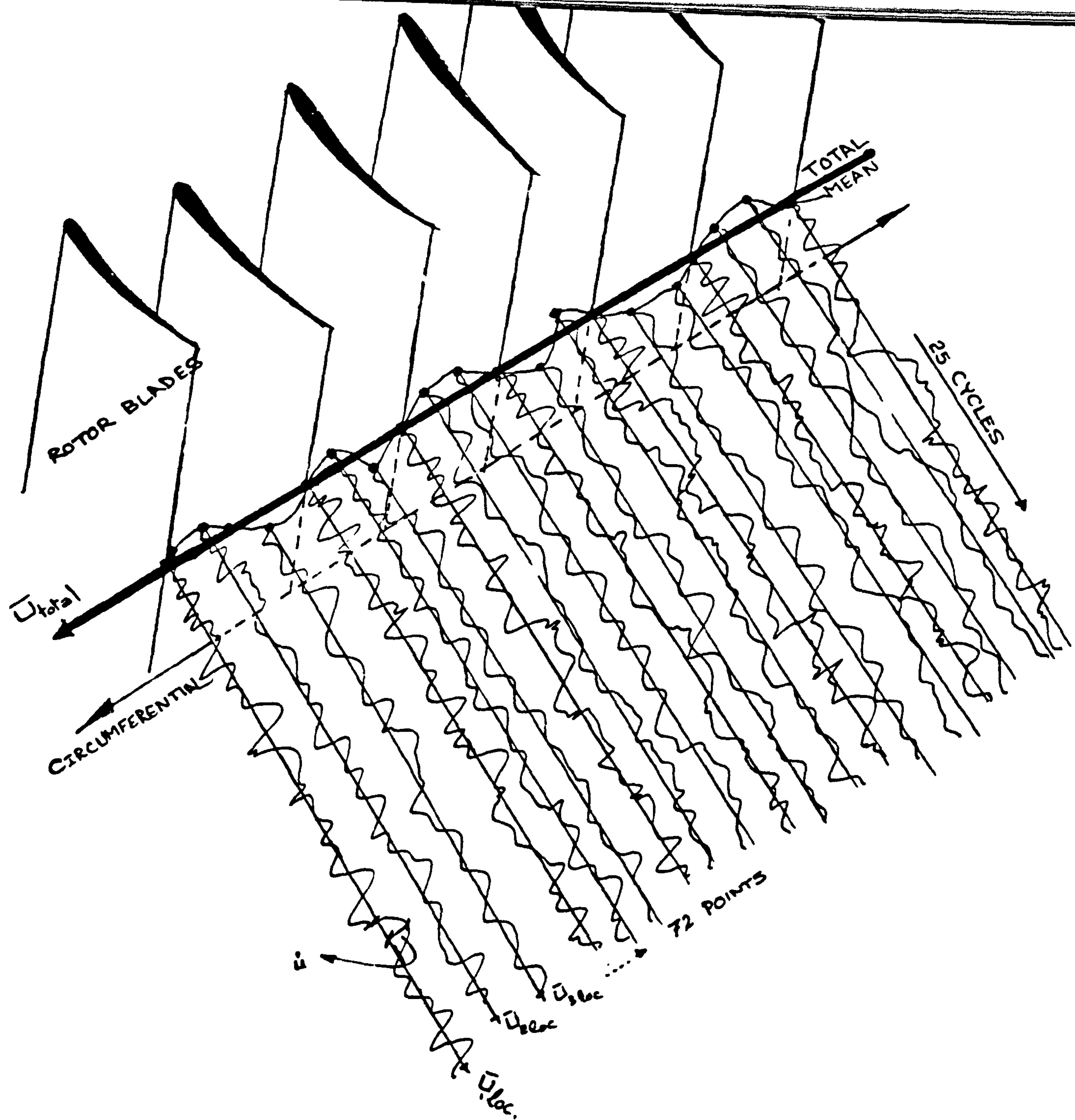


Fig 15 Calibration chart of the spherical pressure tube.



$$\dot{u}_{loc} \cdot \bar{U}_{tot} \xrightarrow{\text{GIVE}}$$

OVERALL DISTURBANCE LEVEL

$$\dot{u}_{loc} \cdot \bar{U}_{loc} \xrightarrow{\text{GIVE}}$$

LOCAL TURBULENCE (FREE STREAM TURBULENCE)

$$\bar{U}_{tot} \cdot \bar{U}_{loc} \xrightarrow{\text{GIVE}}$$

UNSTEADINESS LEVEL

FIG 16 EXPLANATION OF THE SINGLE HOT WIRE EXPERIMENT.

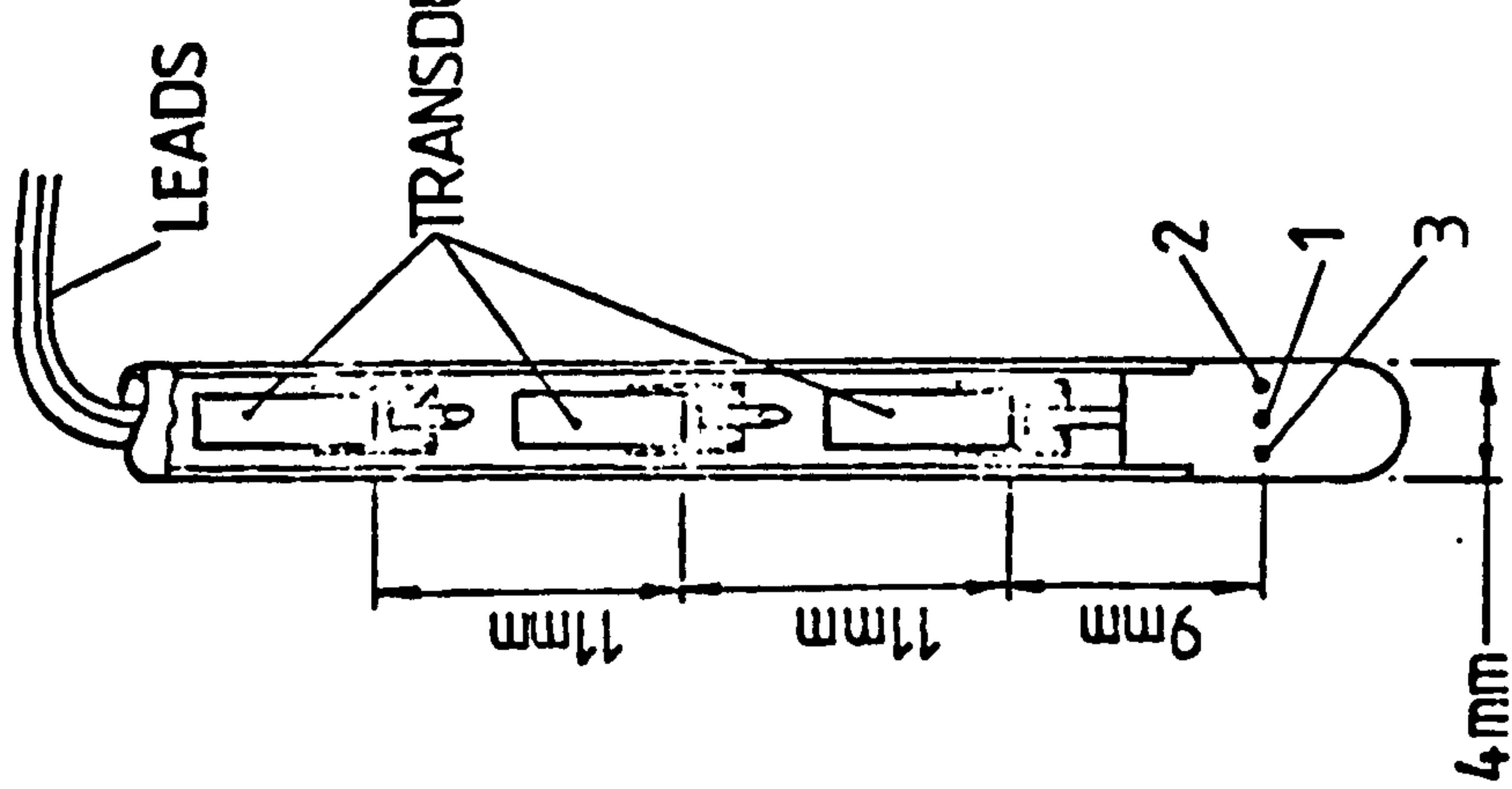
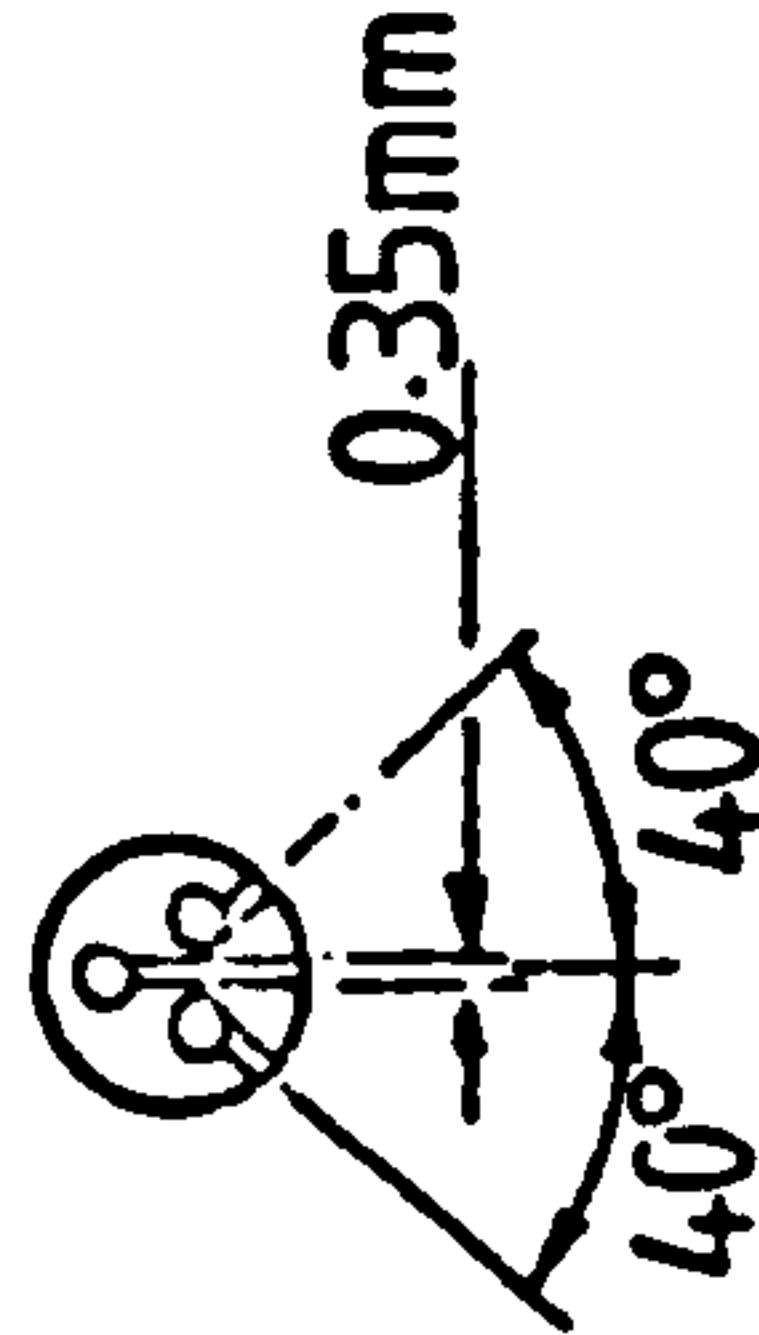
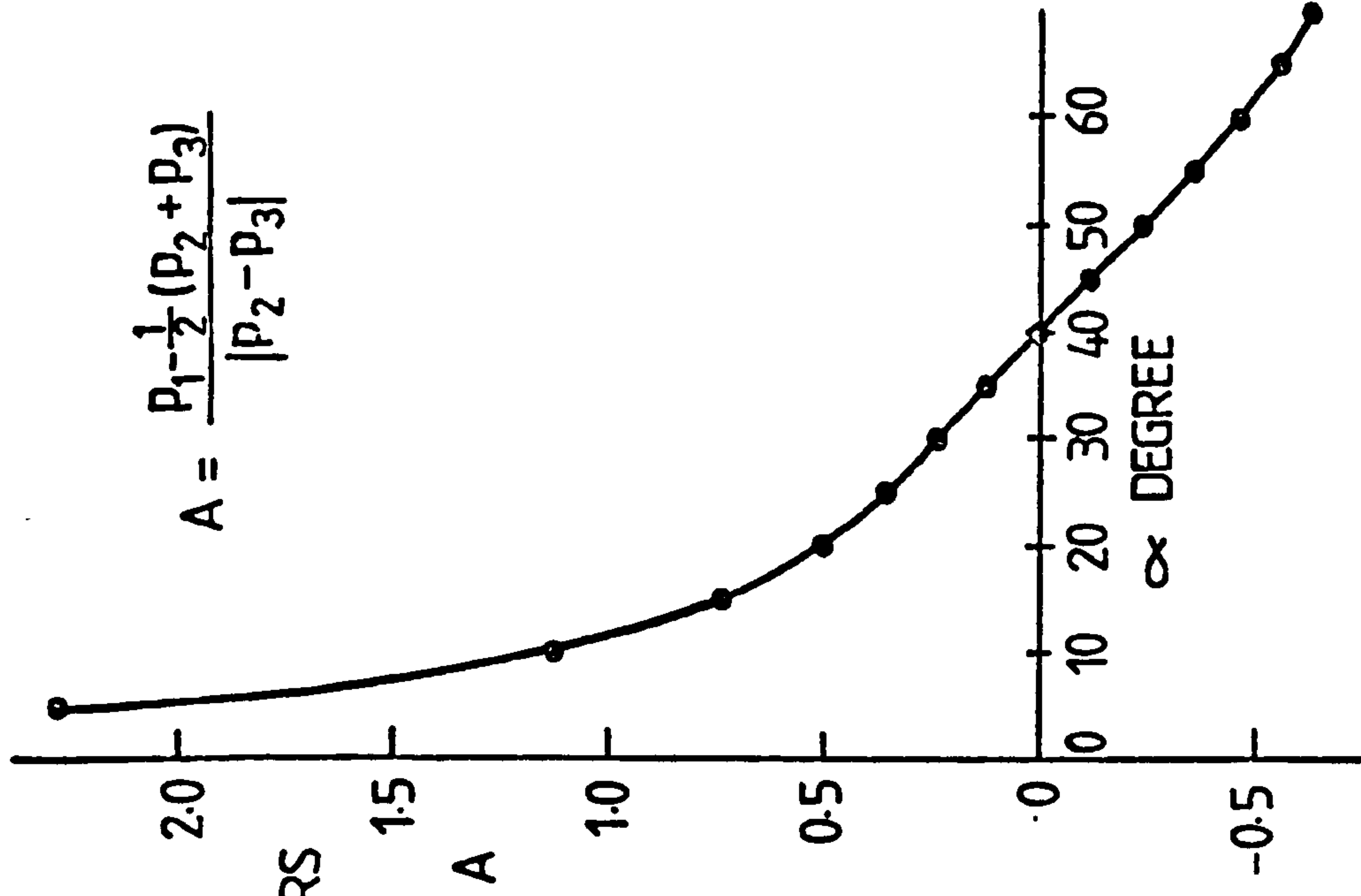
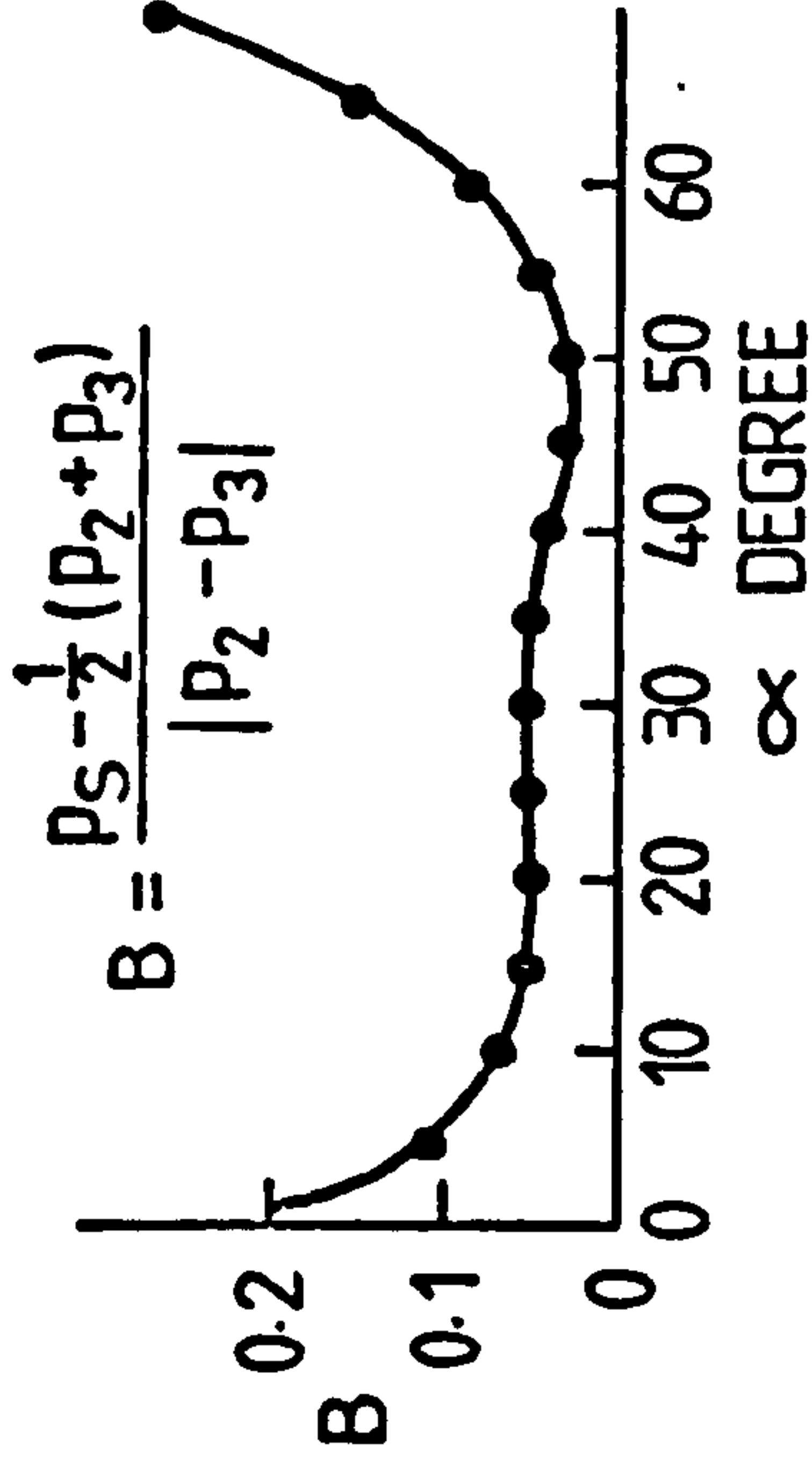
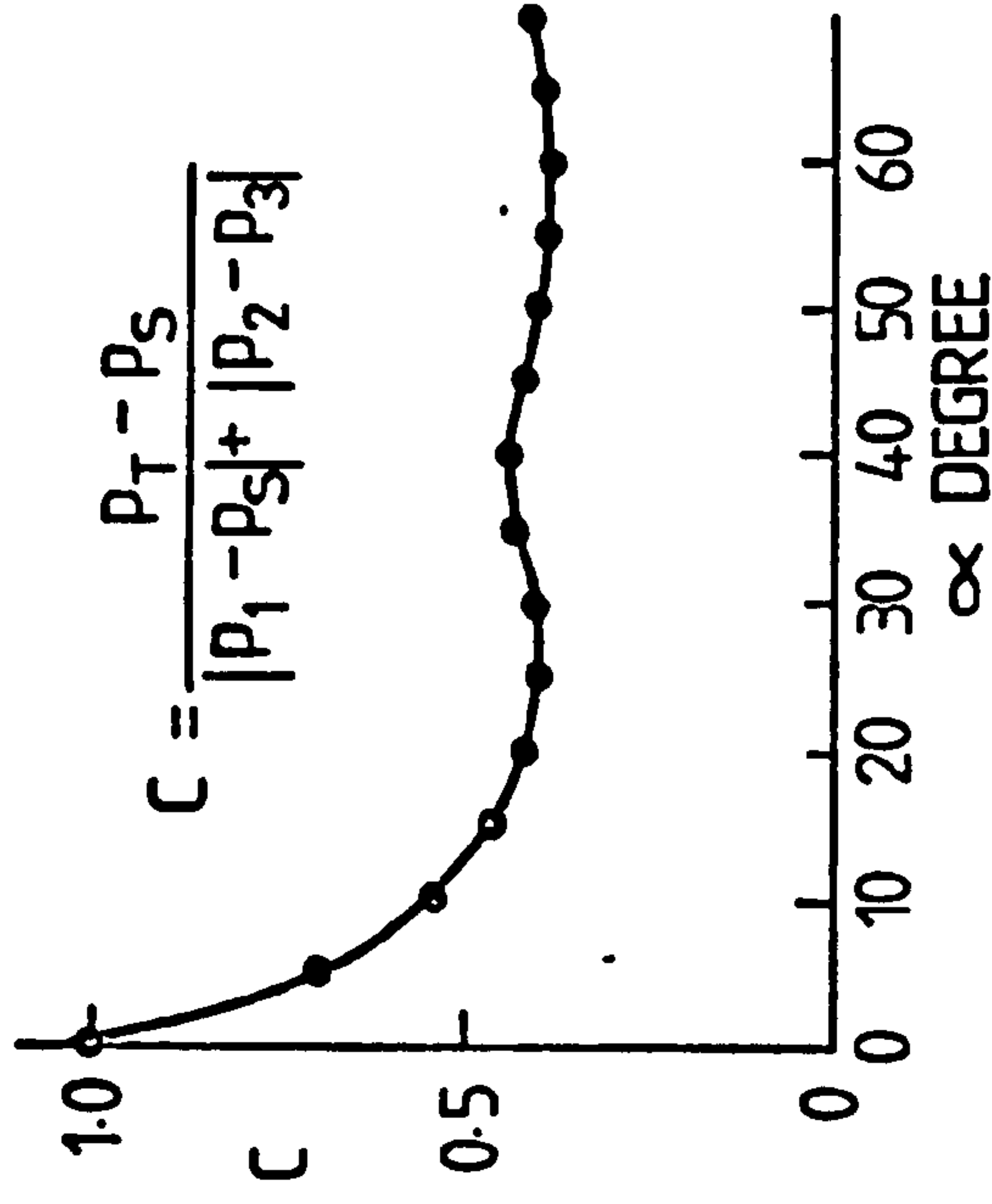


FIG. 17 CALIBRATION CURVES OF THE THREE HOLE TRANSDUCER PROBE.

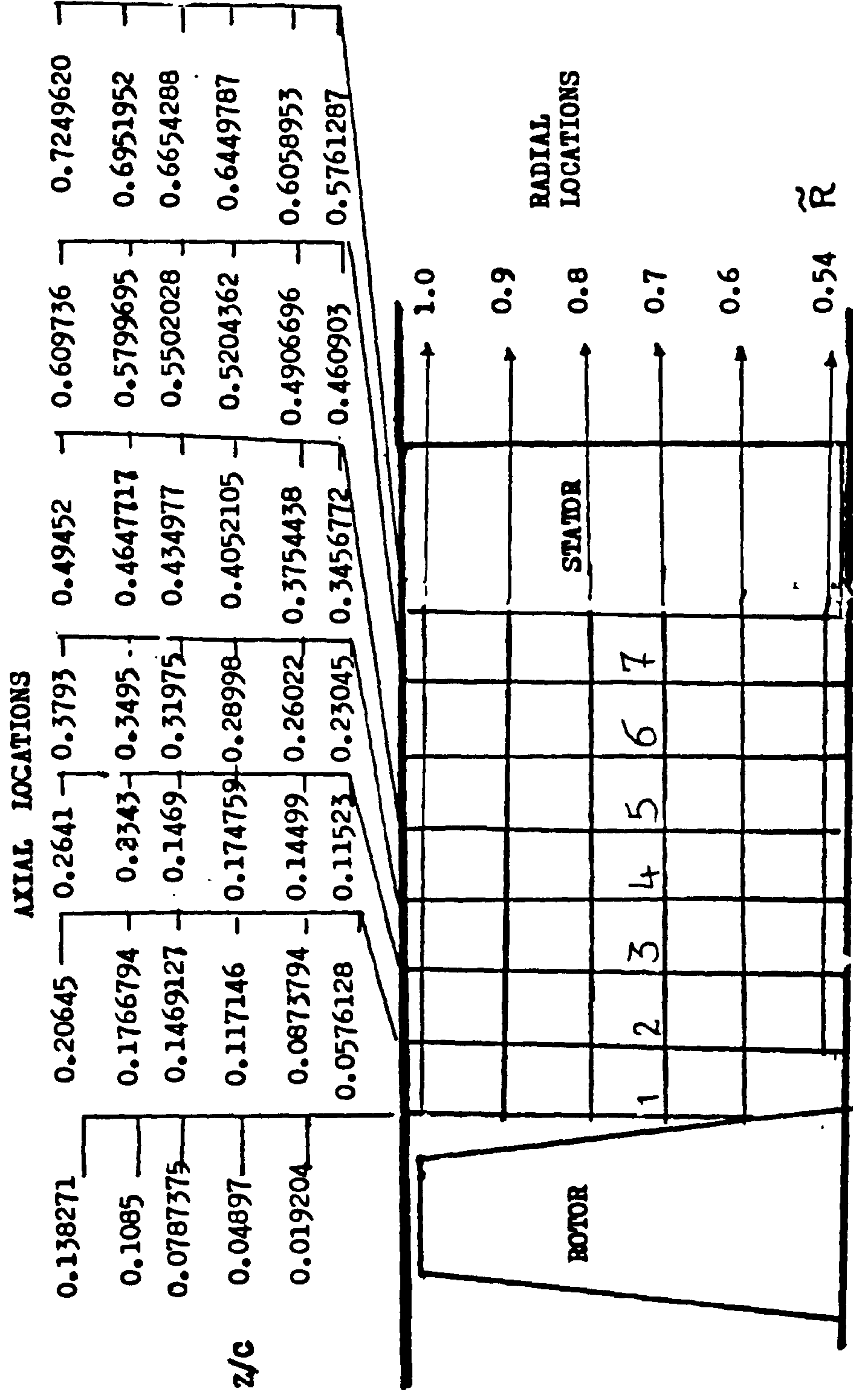


FIG. 18 MEASUREMENT LOCATIONS.

Axial

Tangential

Radial

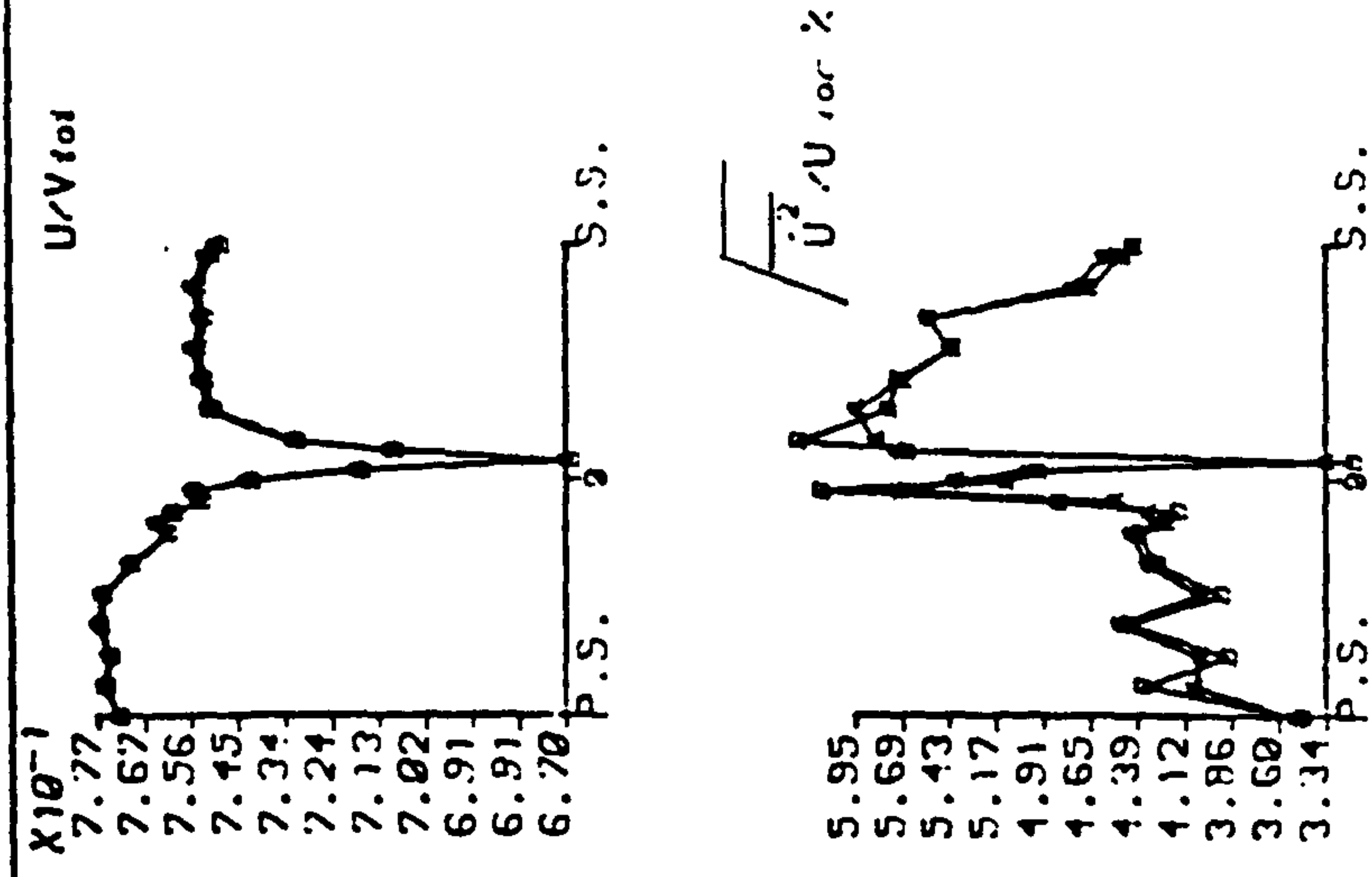
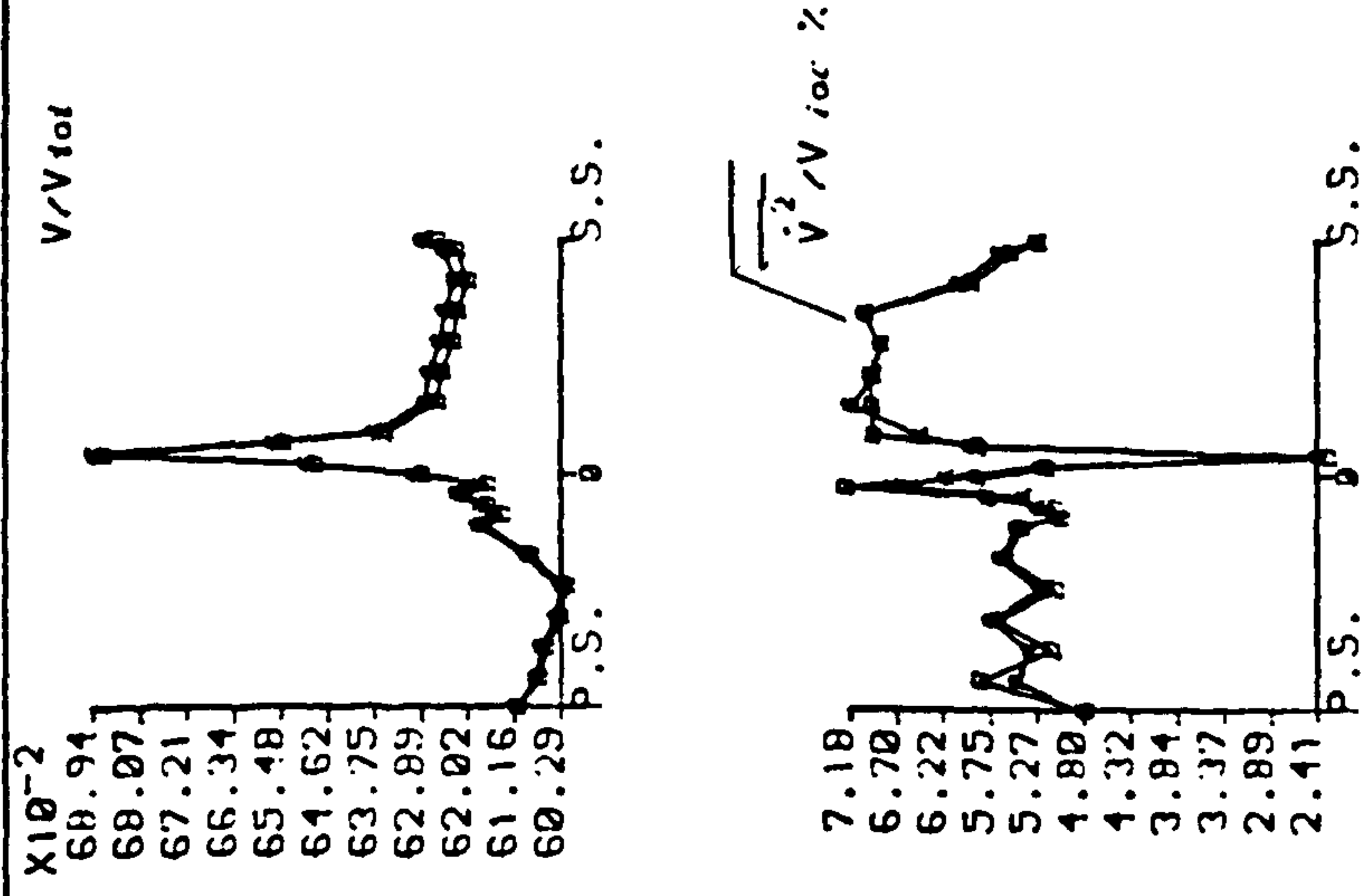
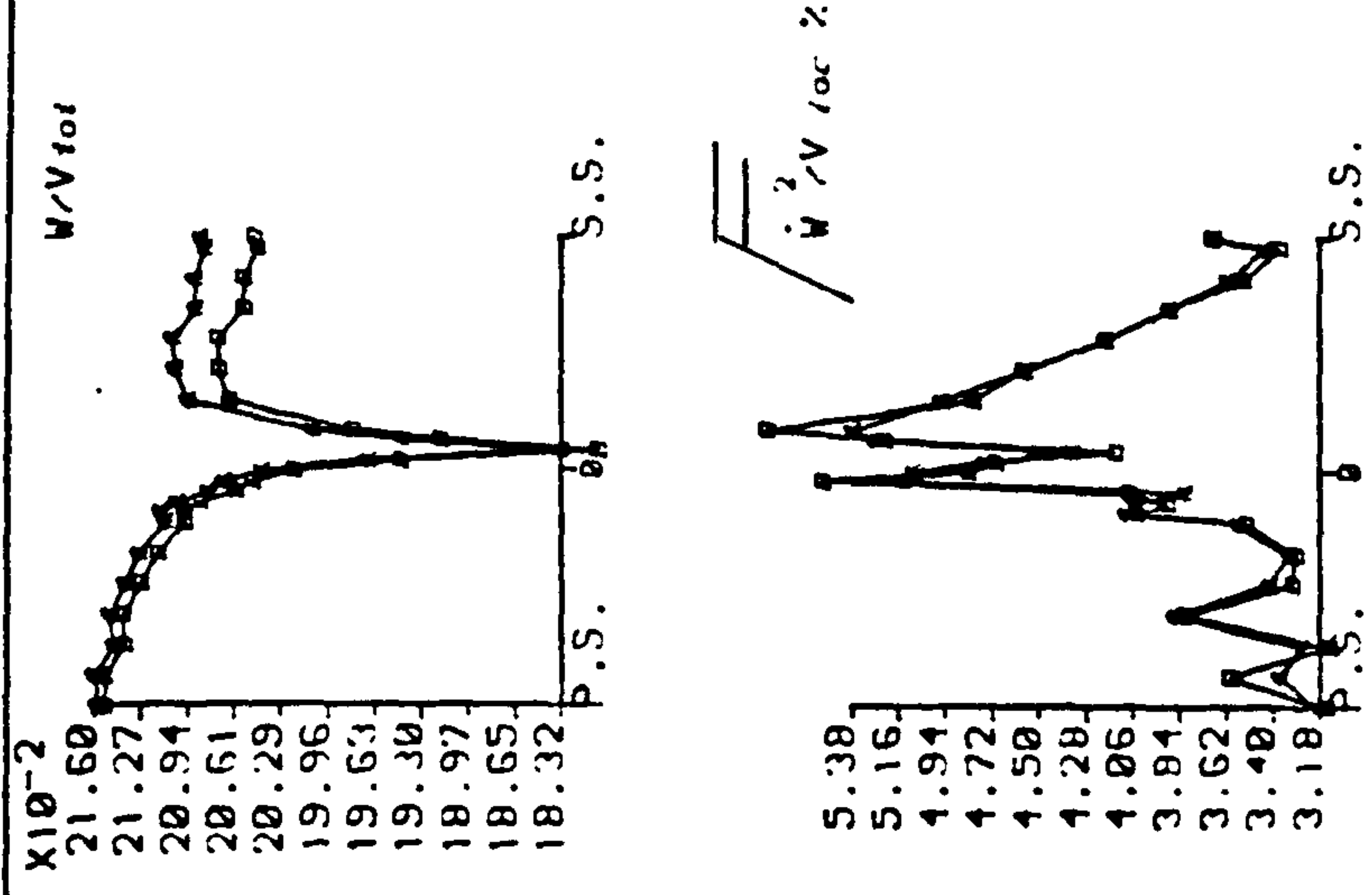
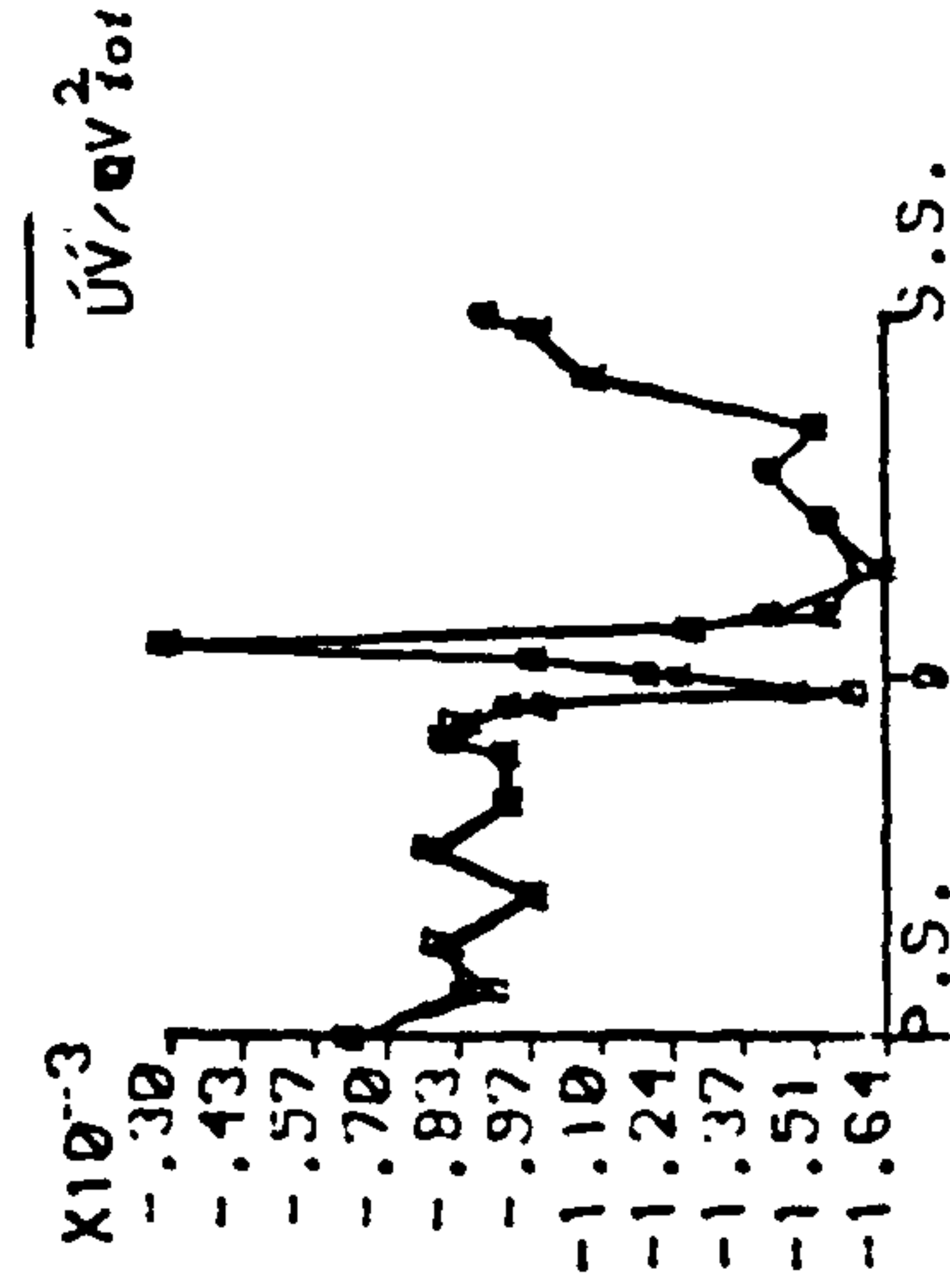
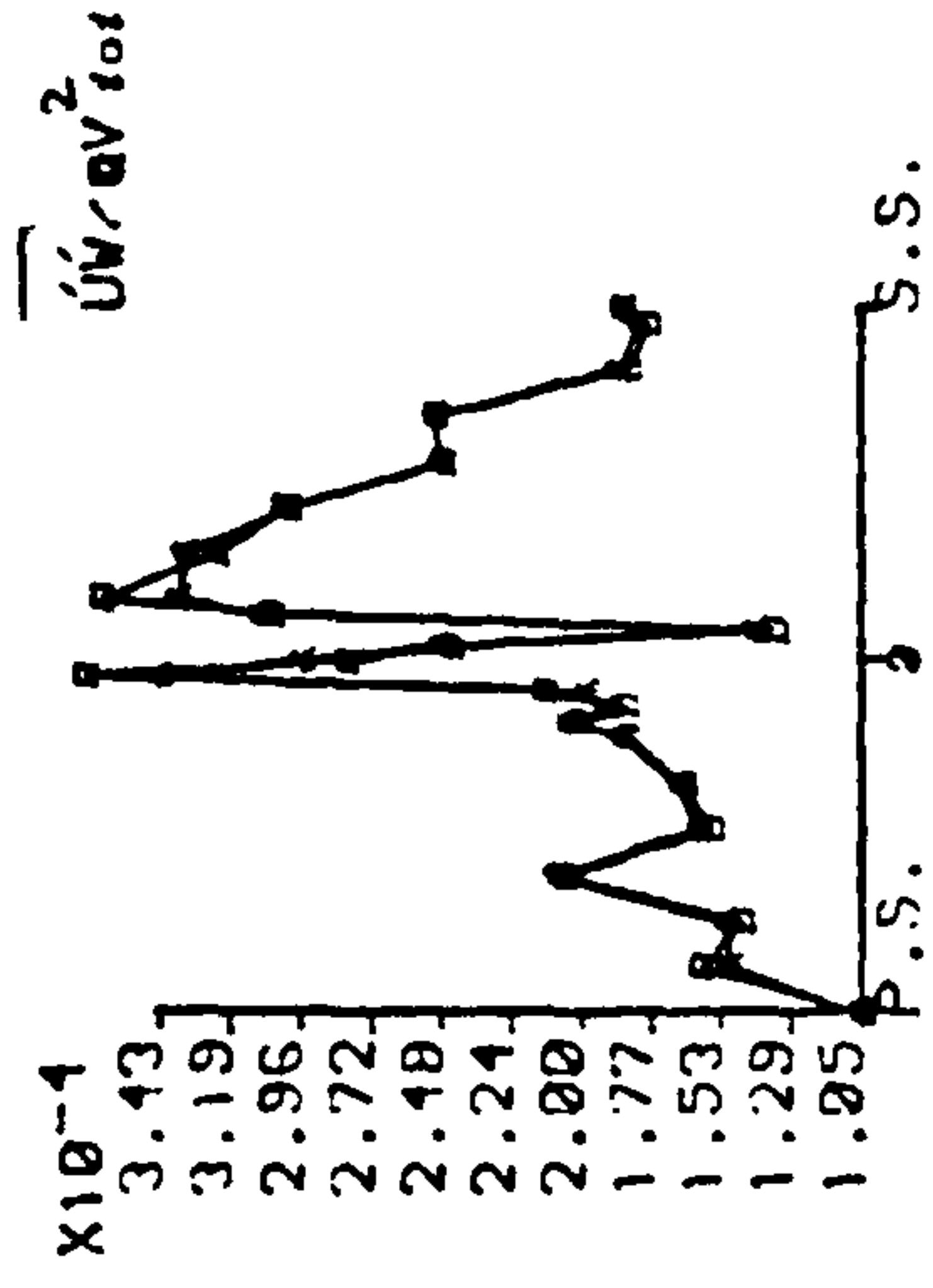
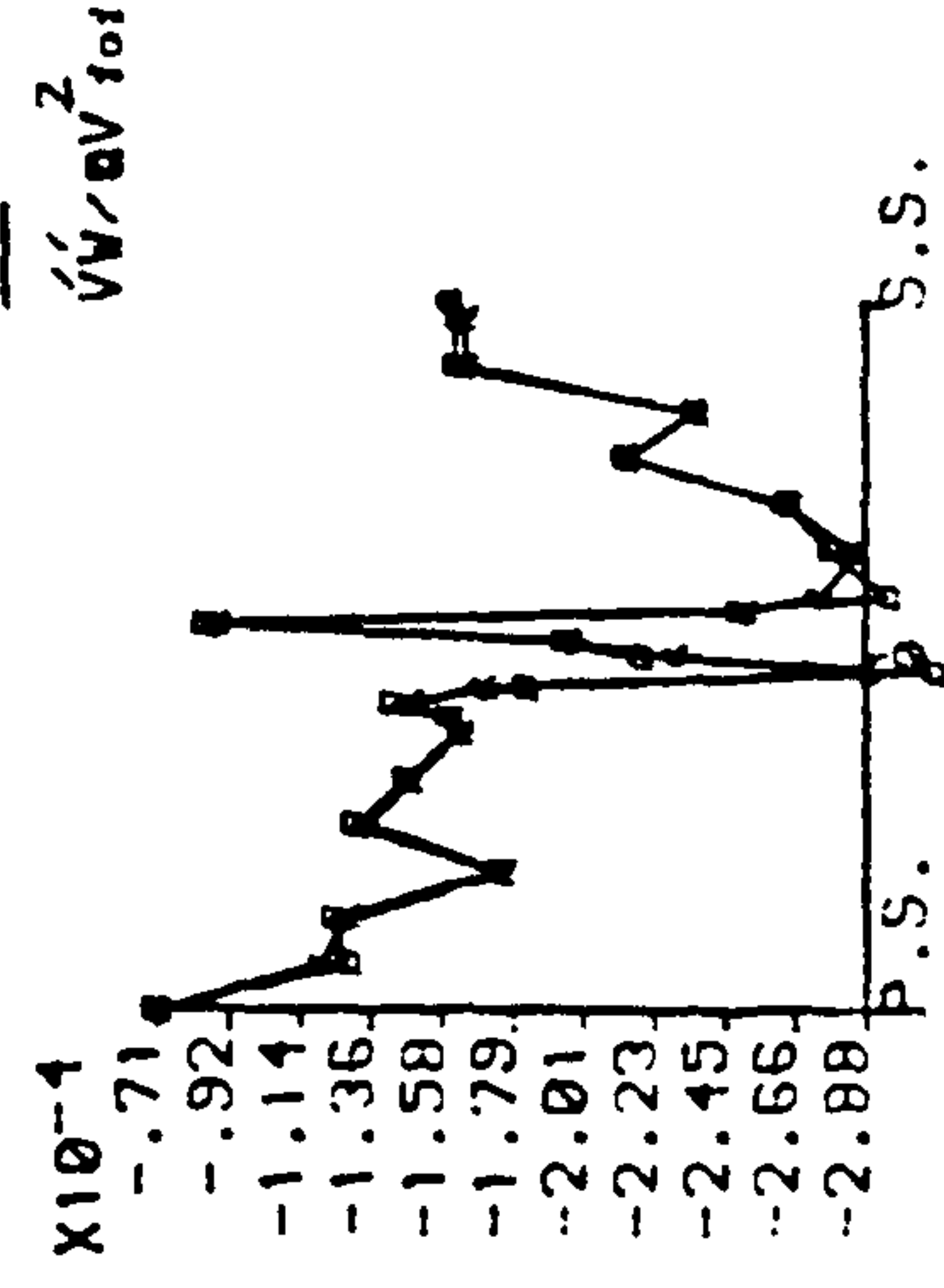


Fig 19 Flow field quantities at the relative turbomachinery frame of reference

..... LINEAR NON-LINEAR

Z/C = 0.22 INC. = -1.0 DEGREE

Angular

Radial

Radial

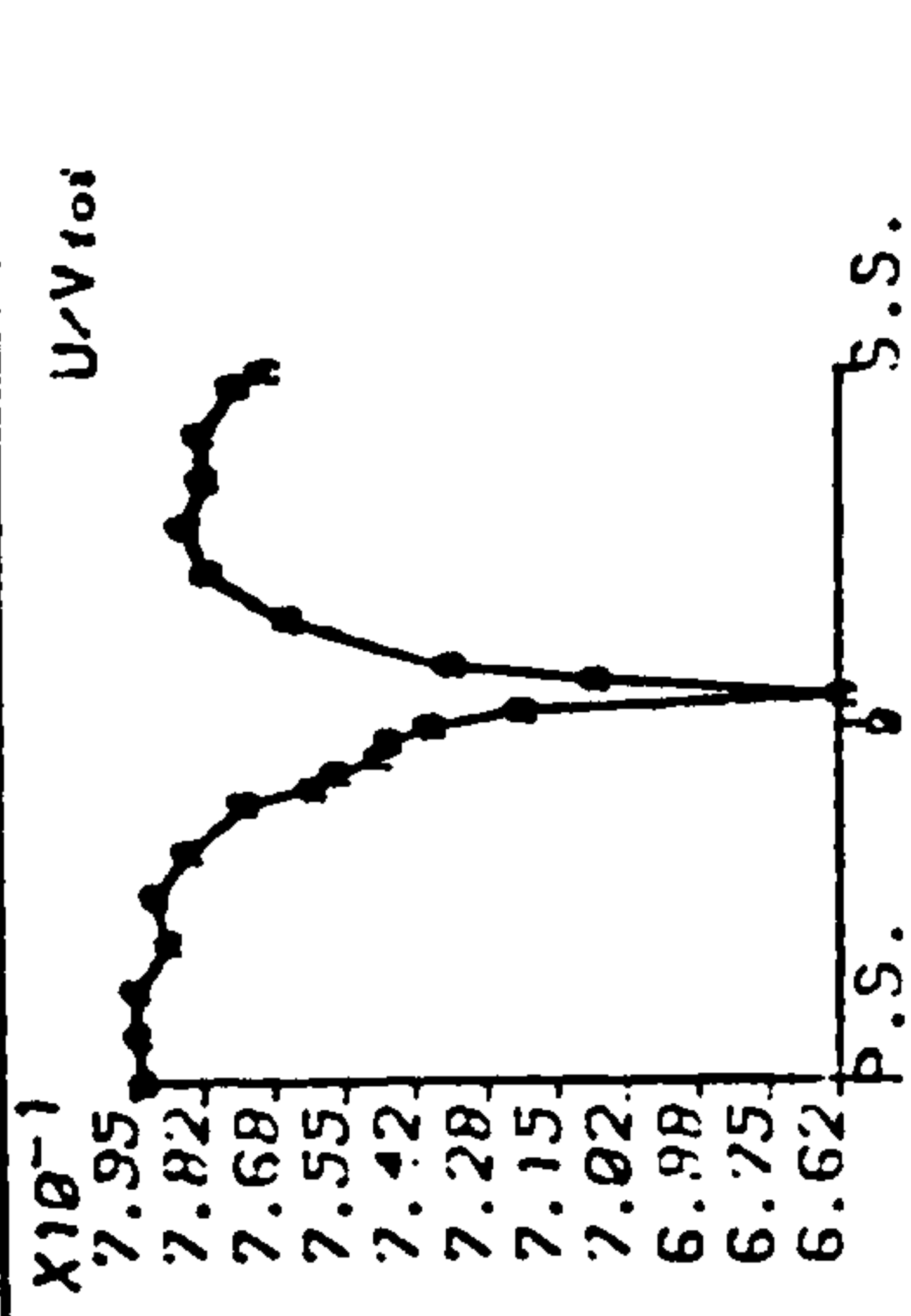
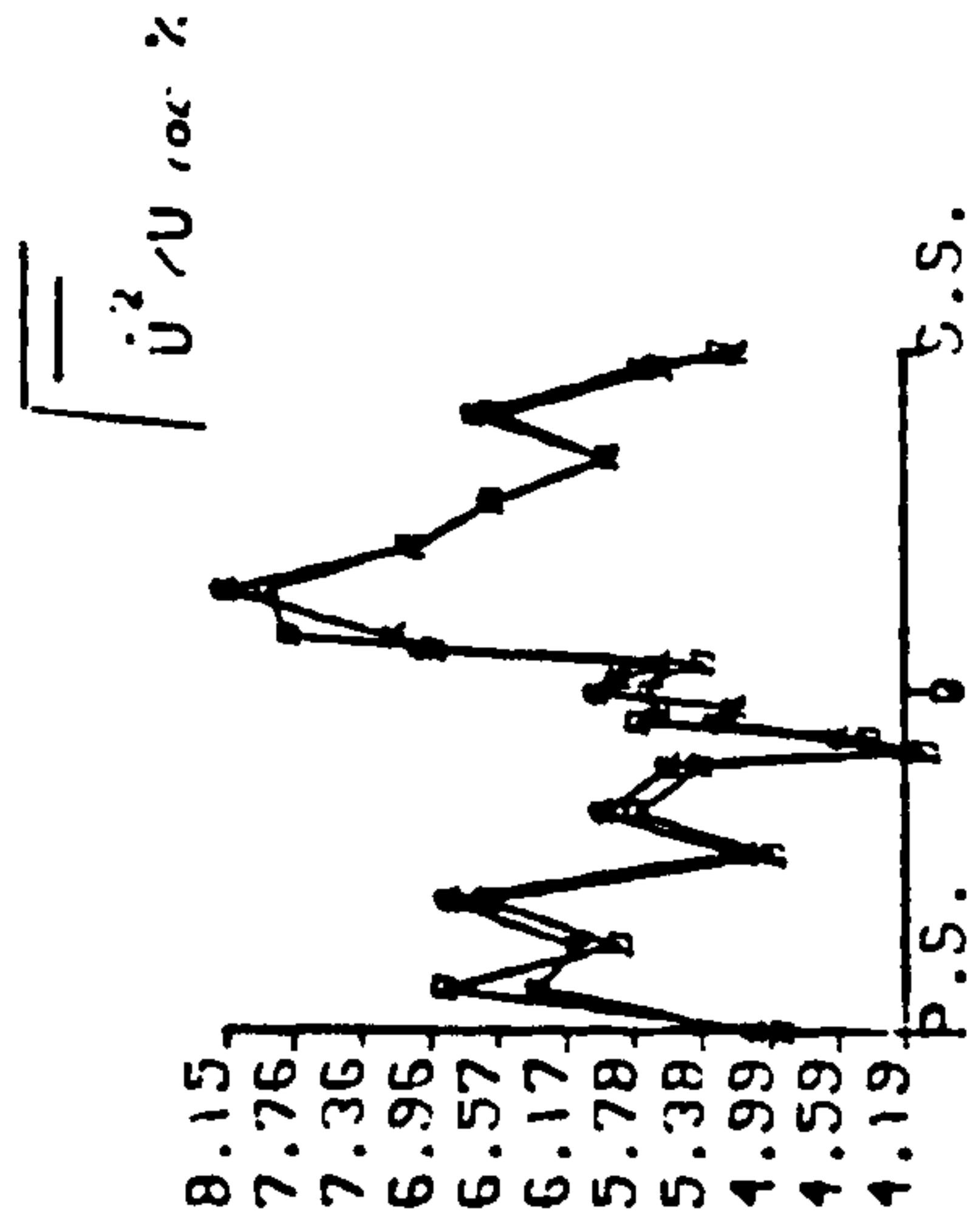
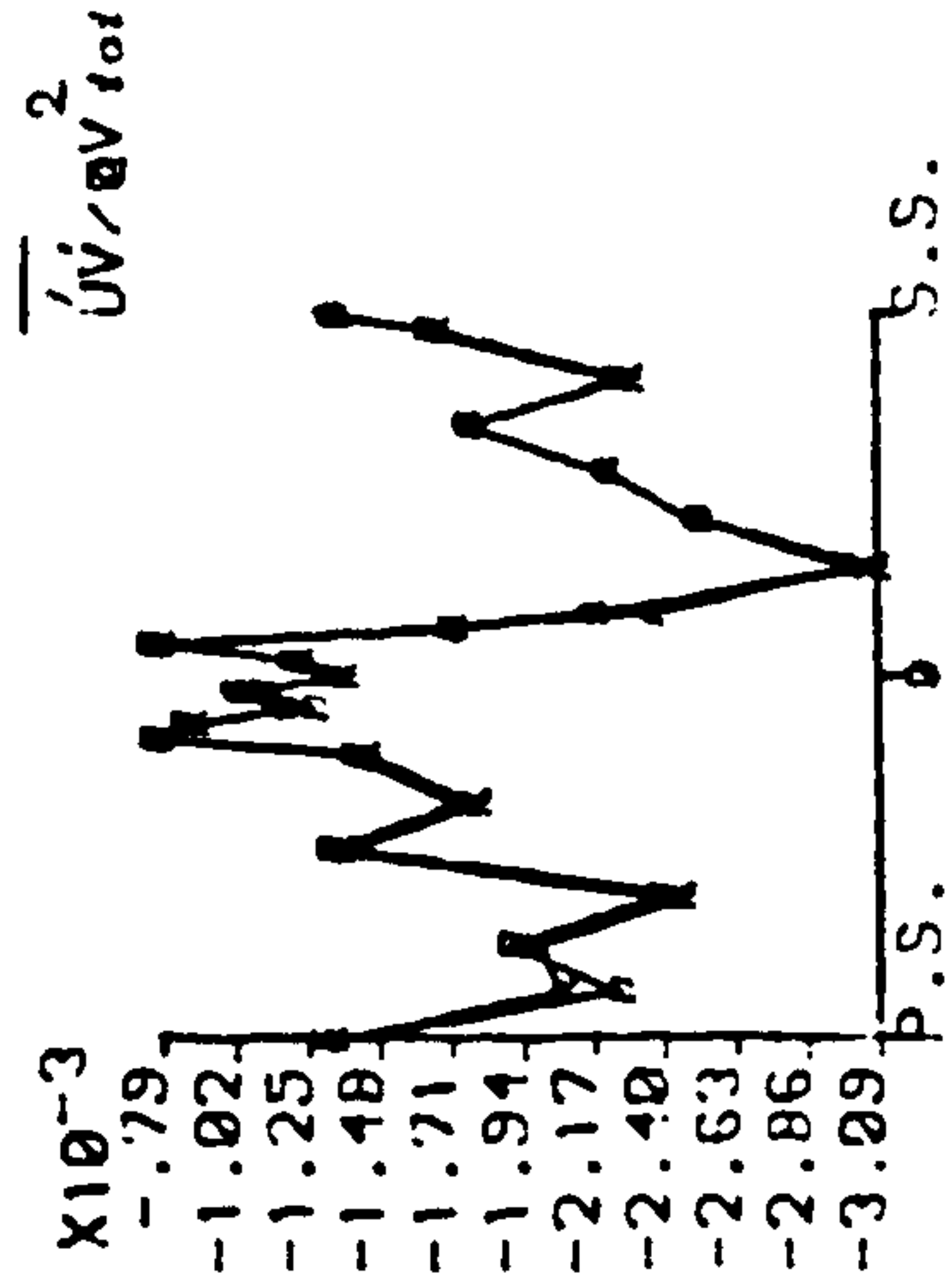
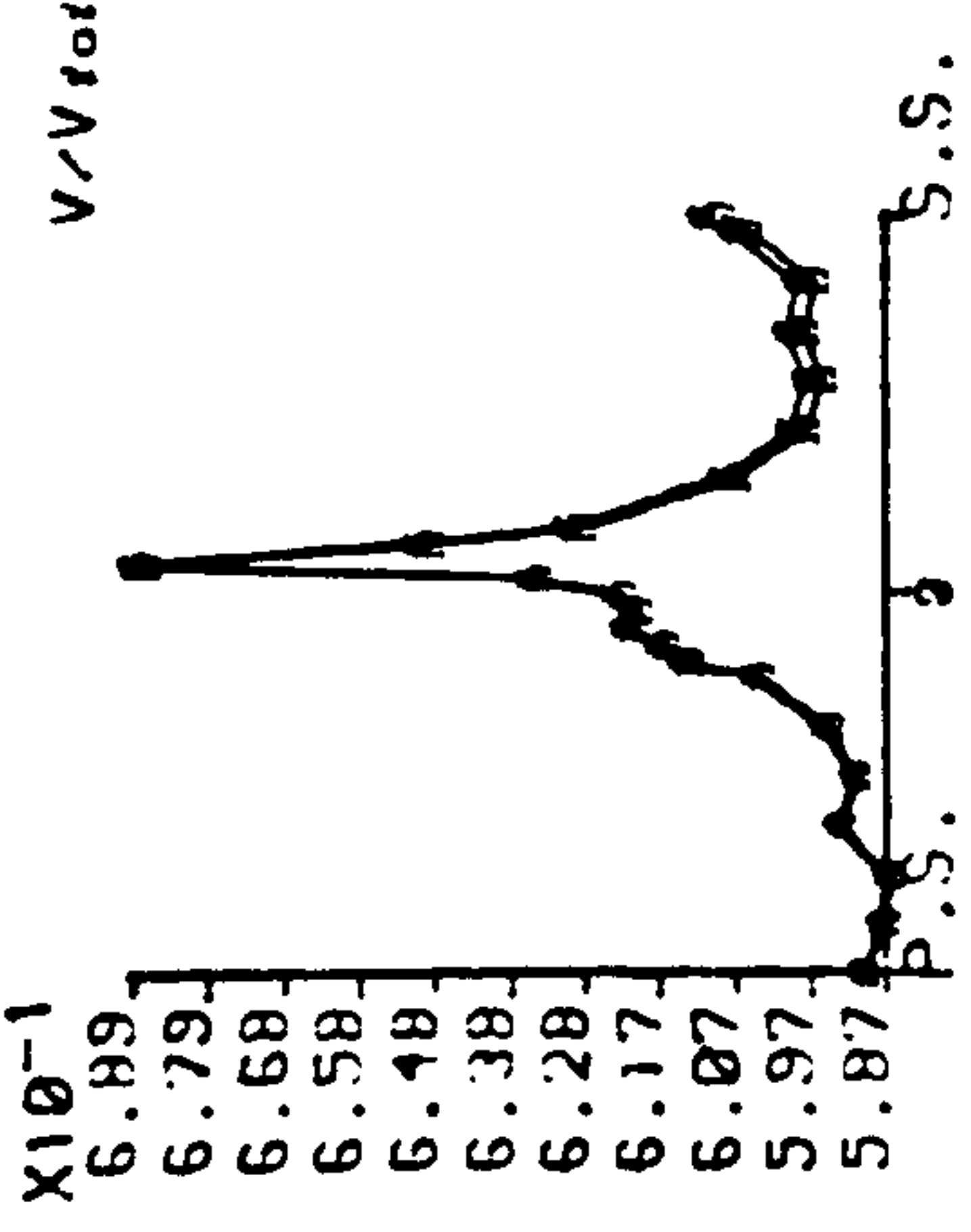
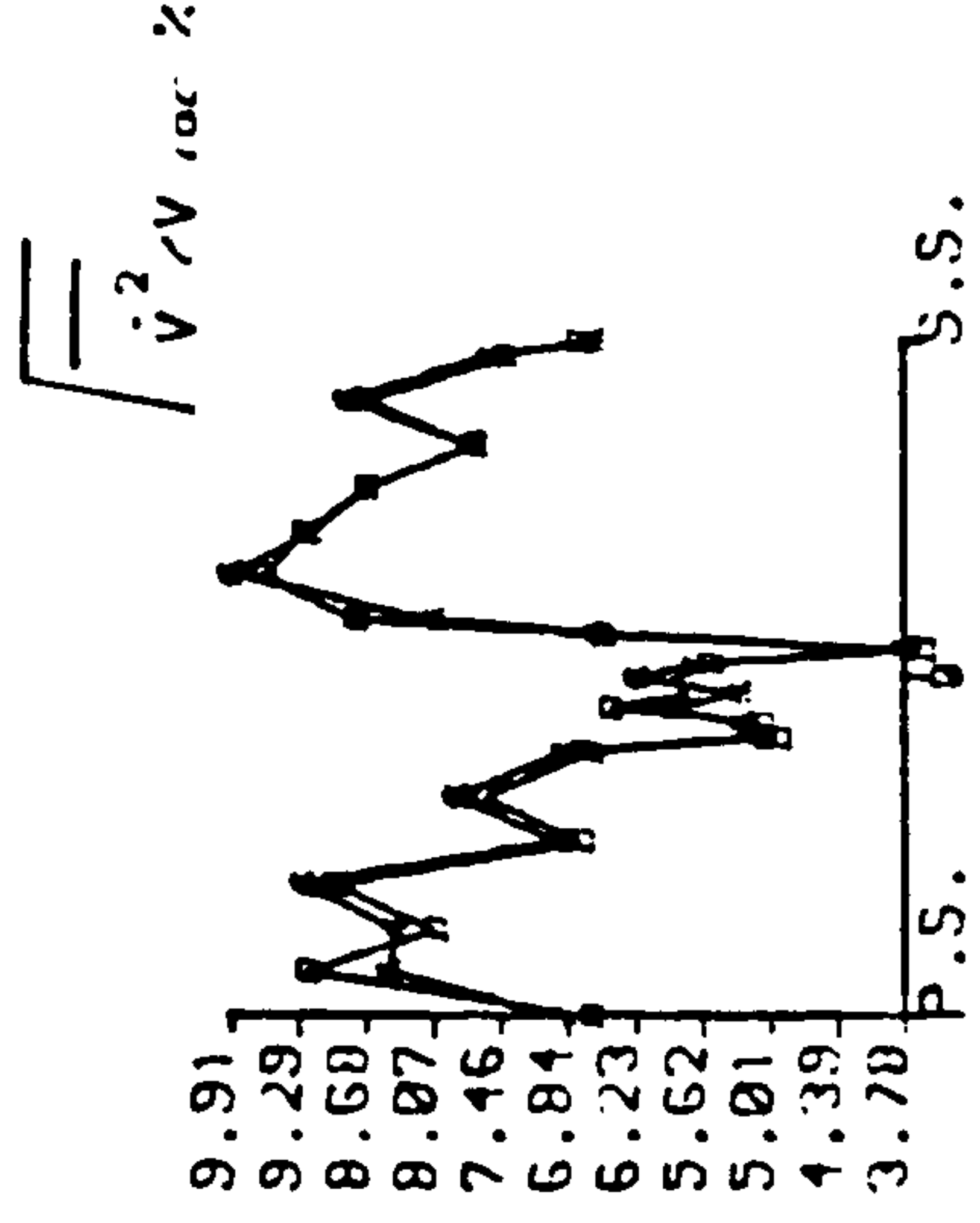
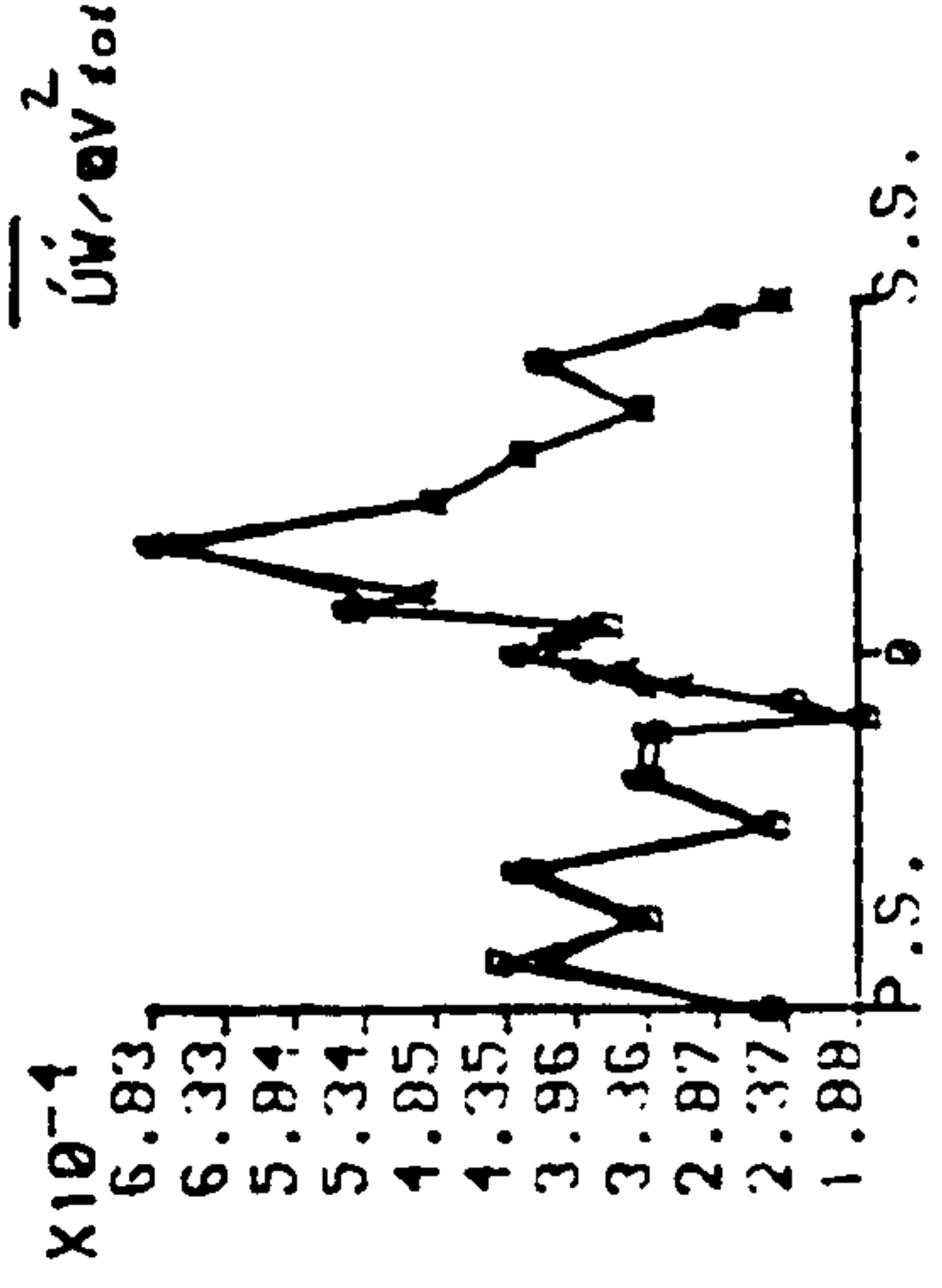
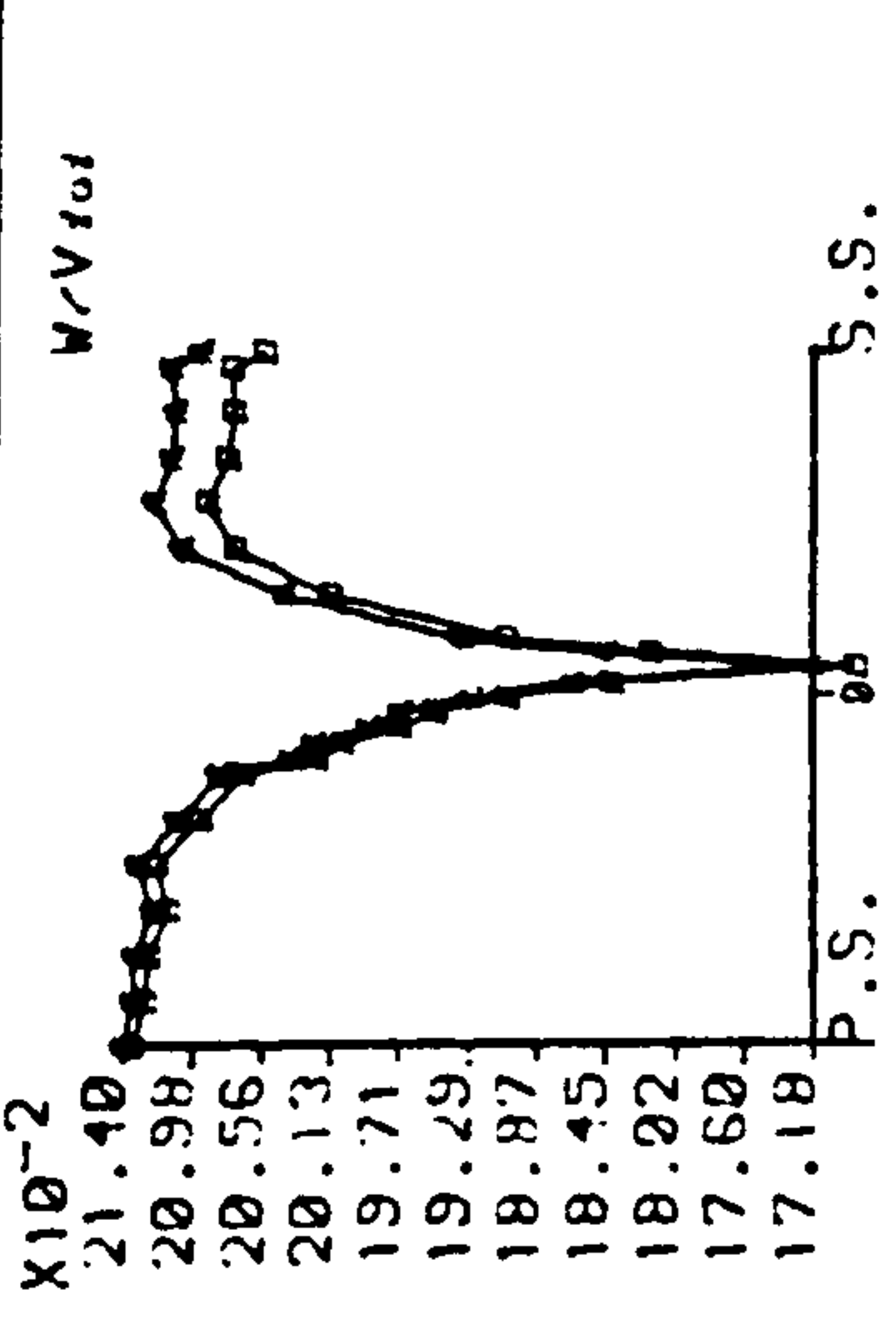
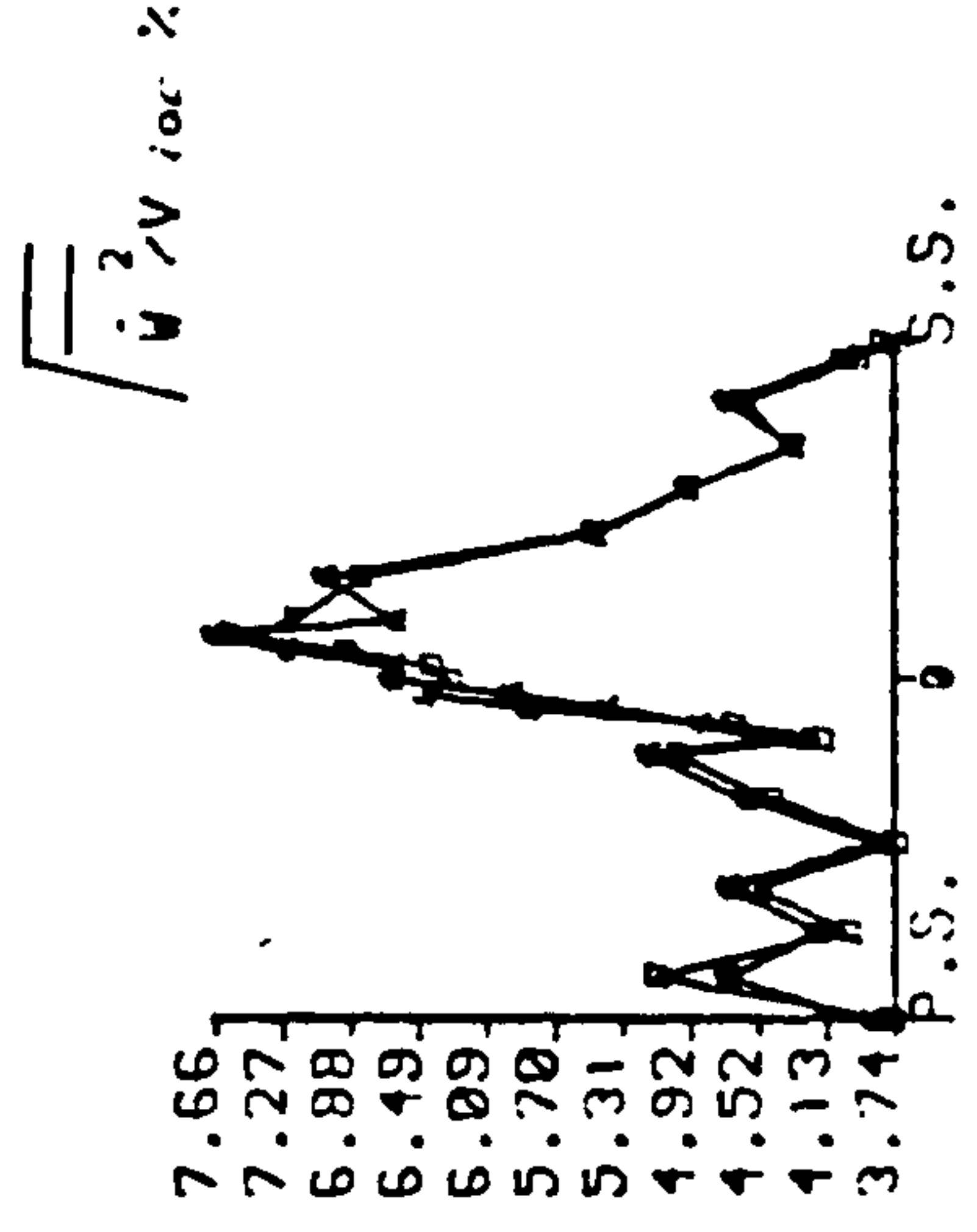
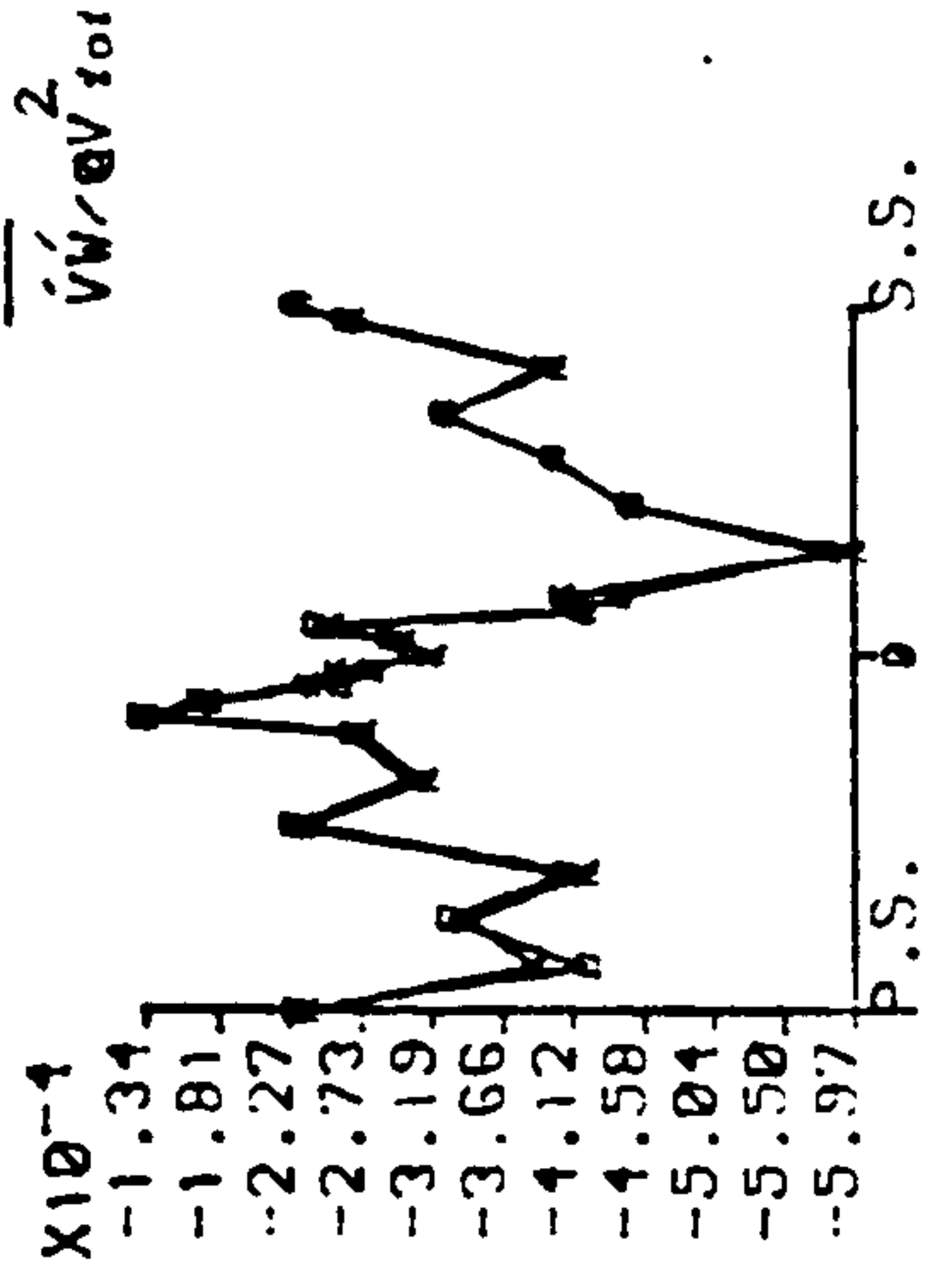


Fig20 Flow field quantities at the relative turbomachinery frame of reference

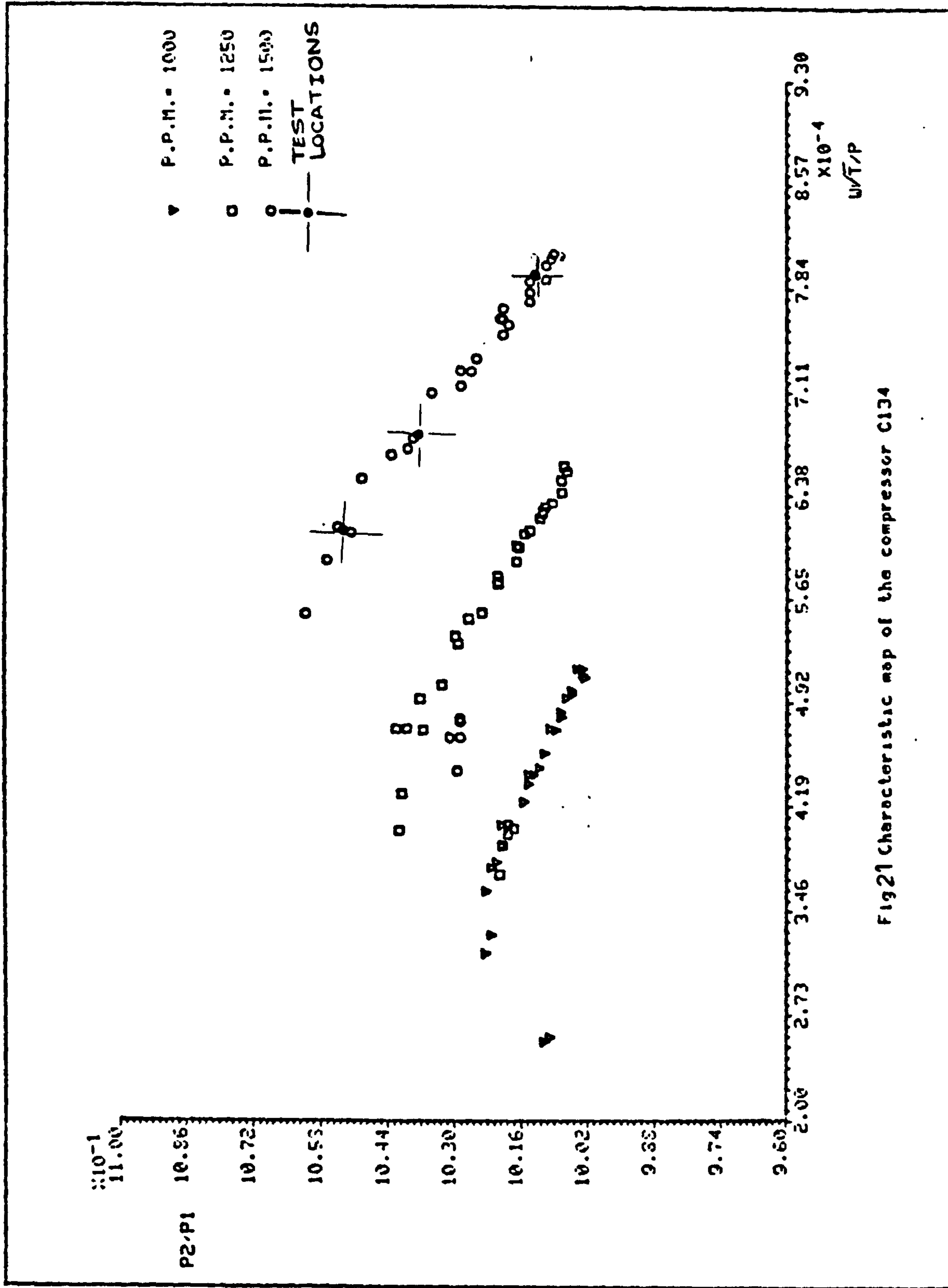


Fig21 Characteristic map of the compressor C134

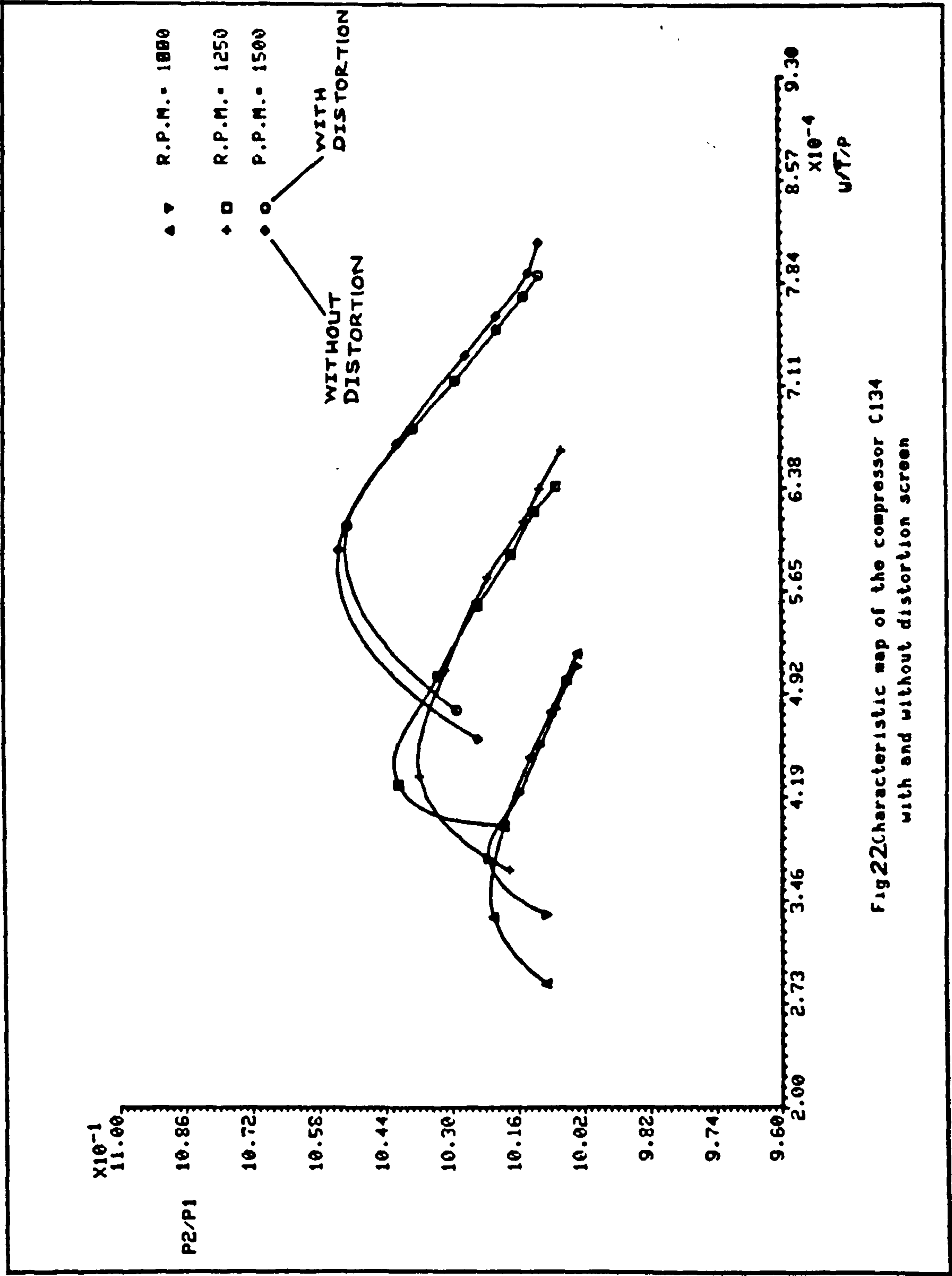


Fig22Characteristic map of the compressor C134
with and without distortion screen

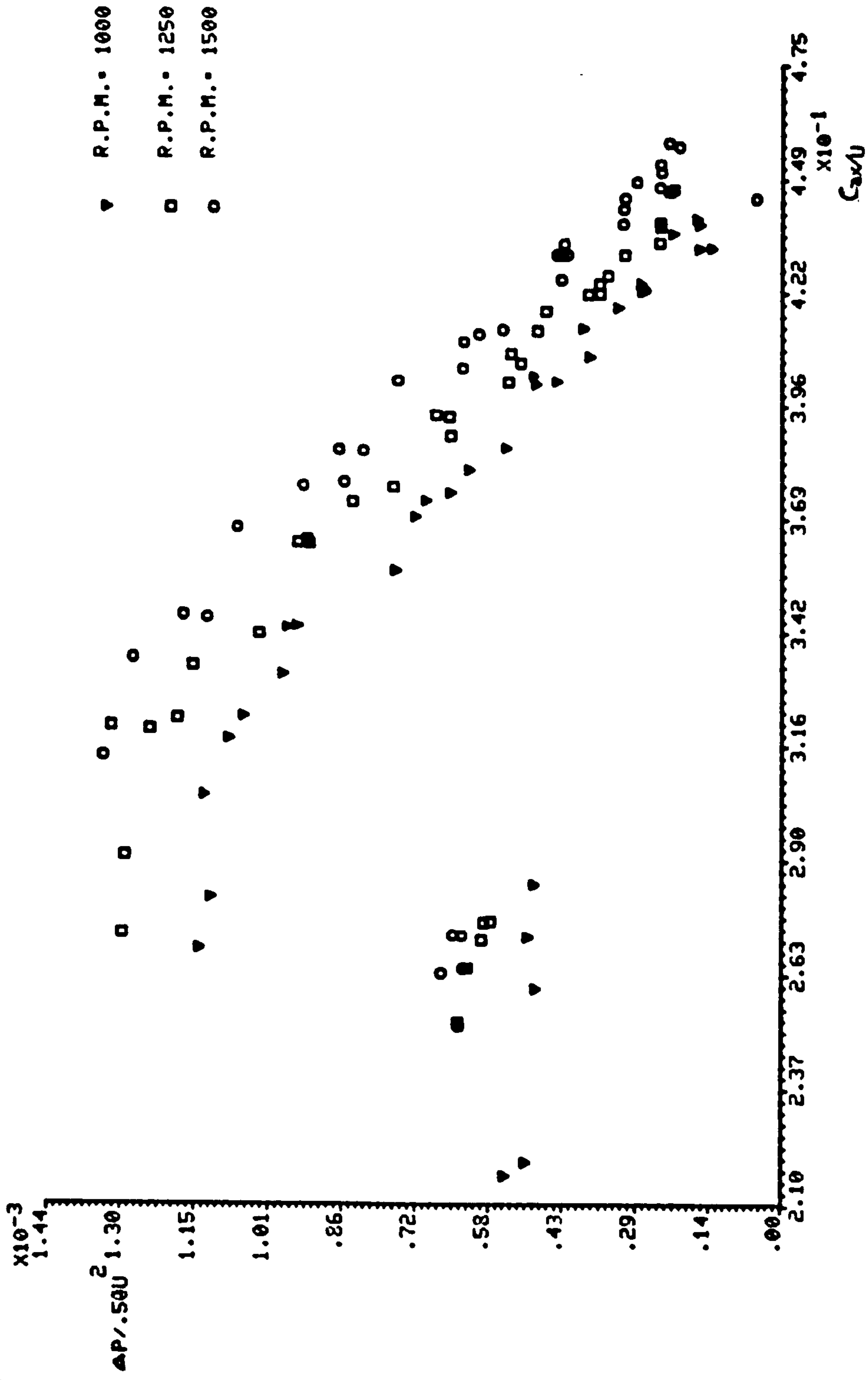


Fig23 Characteristic map of compressor C134

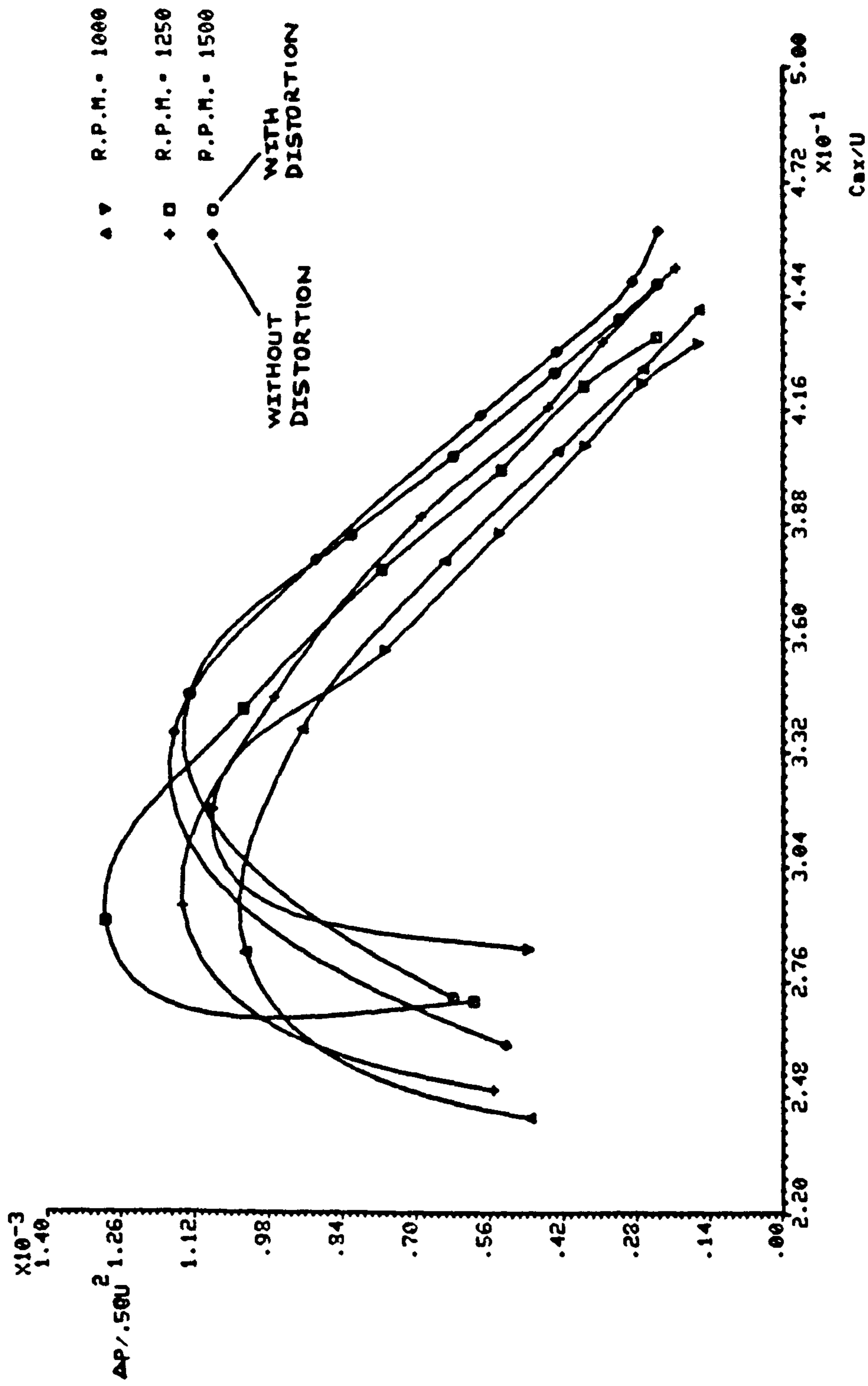


Fig24 Characteristic map of the compressor C134
with and without distortion screen

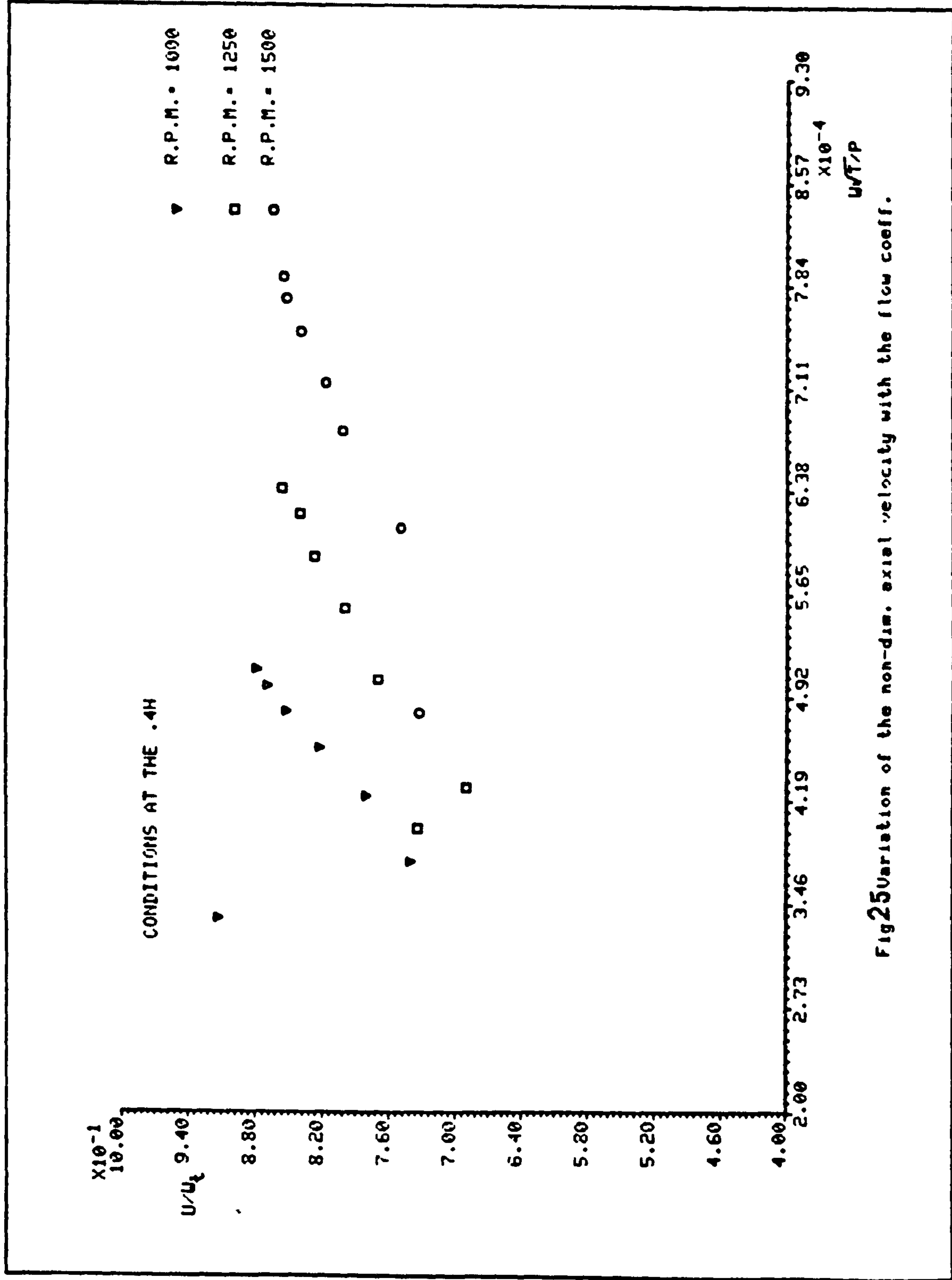


Fig 25 Variation of the non-dim. axial velocity with the flow coeff.

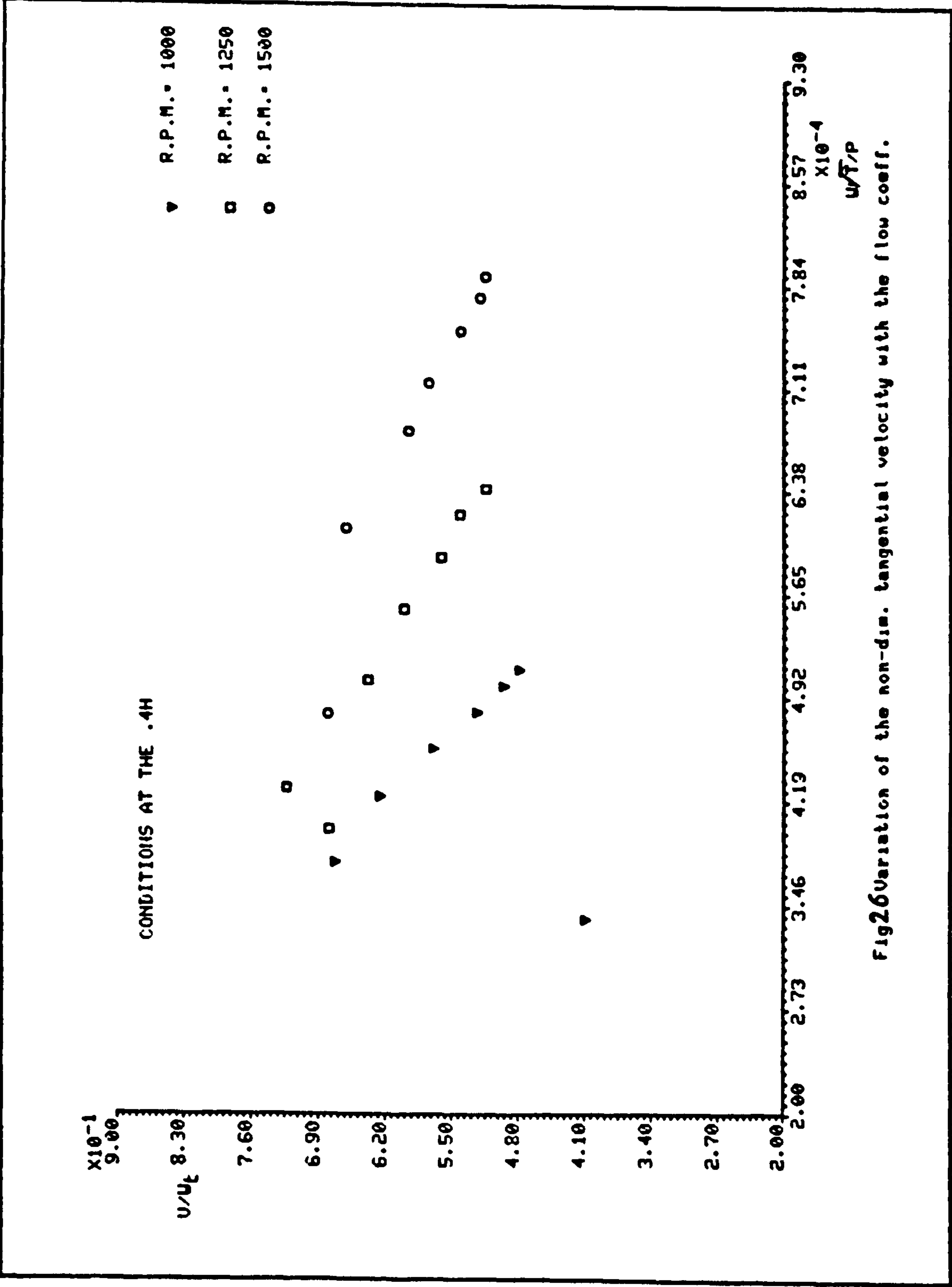


Fig26 Variation of the non-dim. tangential velocity with the flow coeff.

CONDITIONS AT THE .4H

▼ R.P.M. = 1000
 □ R.P.M. = 1250
 ○ R.P.M. = 1500

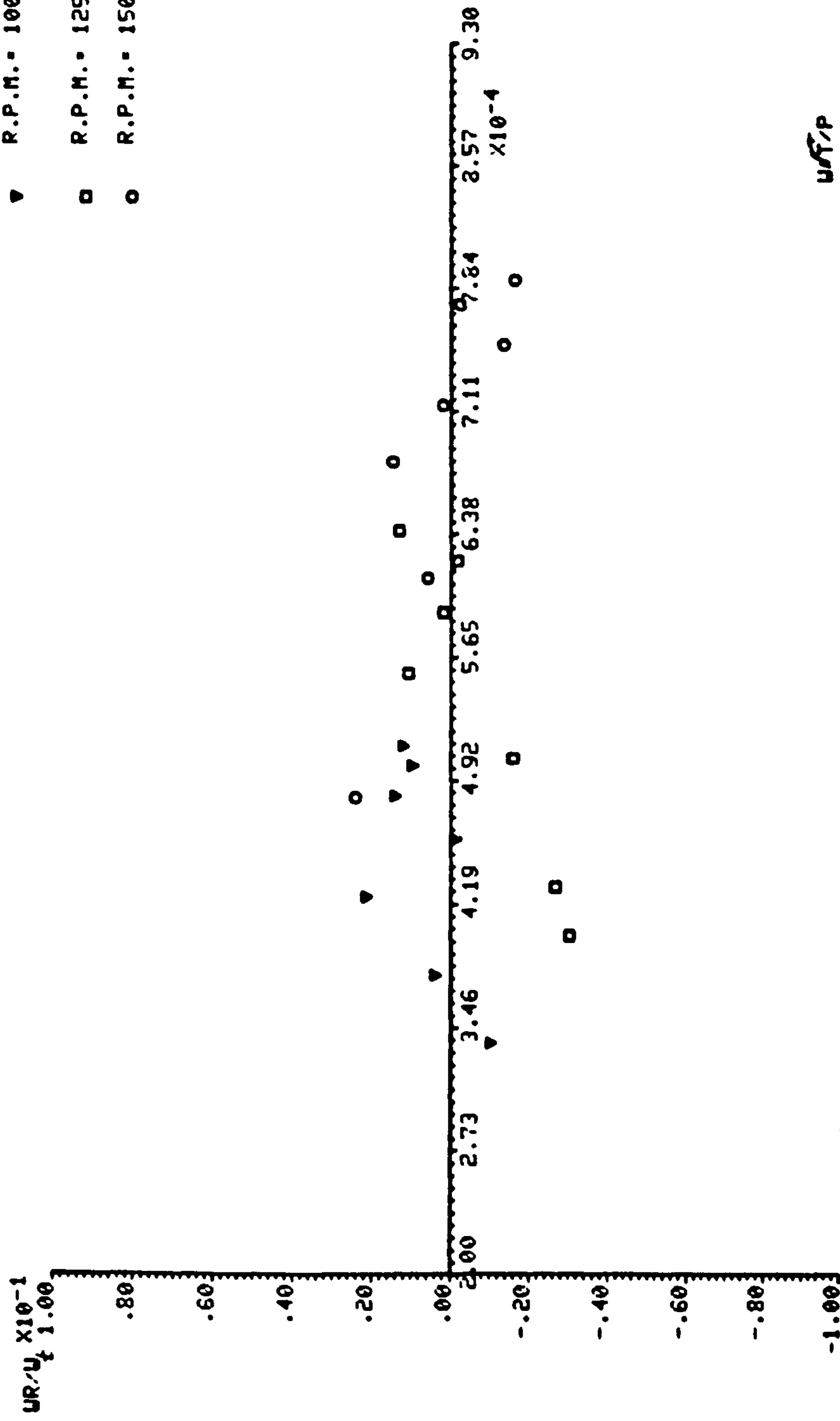


Fig27 Variation of the non-dim. radial velocity with the flow coeff. Uf/P

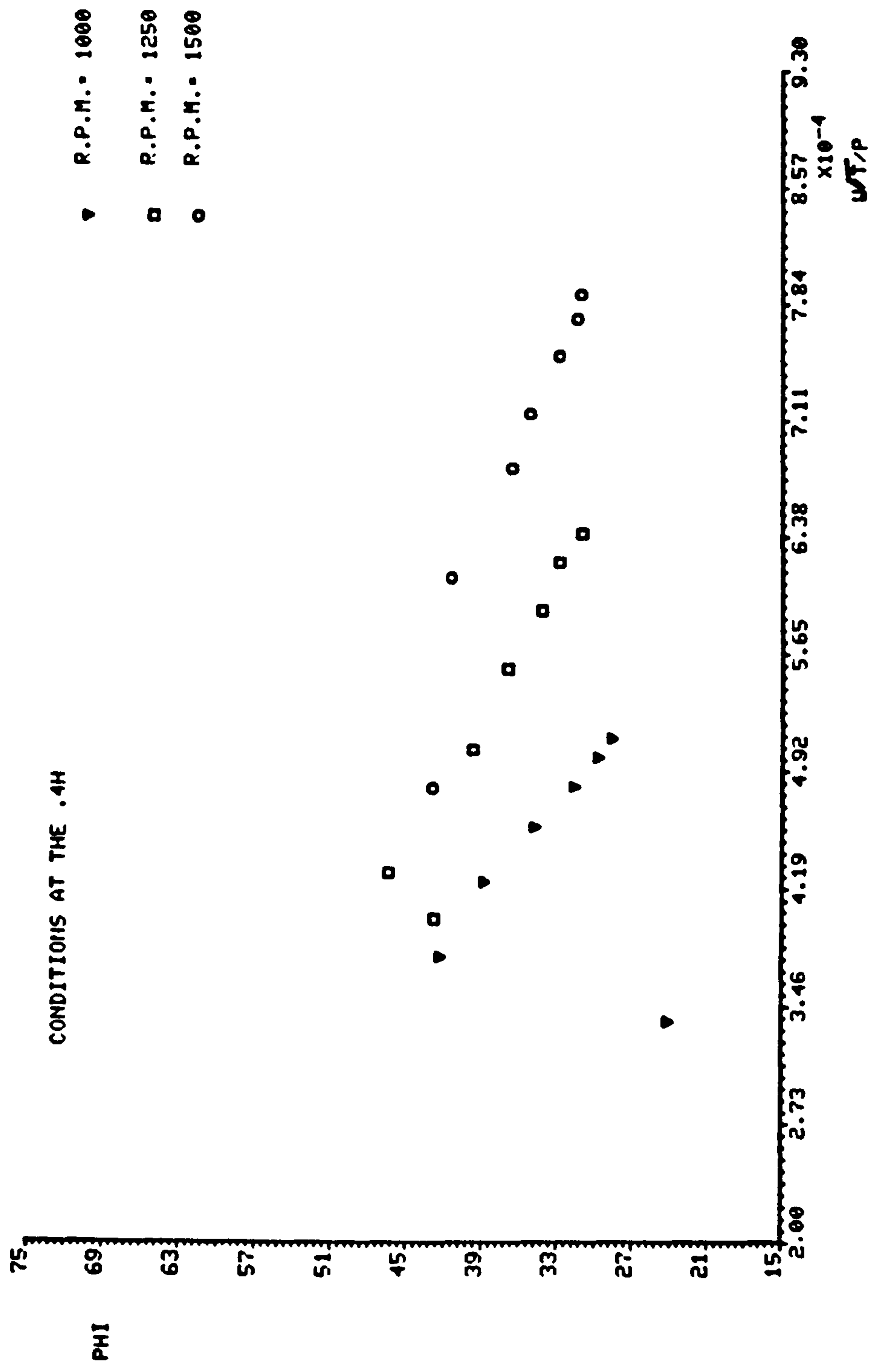


Fig28 Variation of the flow yaw angle with the non-dim. flow coeff.

CONDITIONS AT THE .4H

▼ R.P.M. = 1000
 □ R.P.M. = 1250
 ○ R.P.M. = 1500

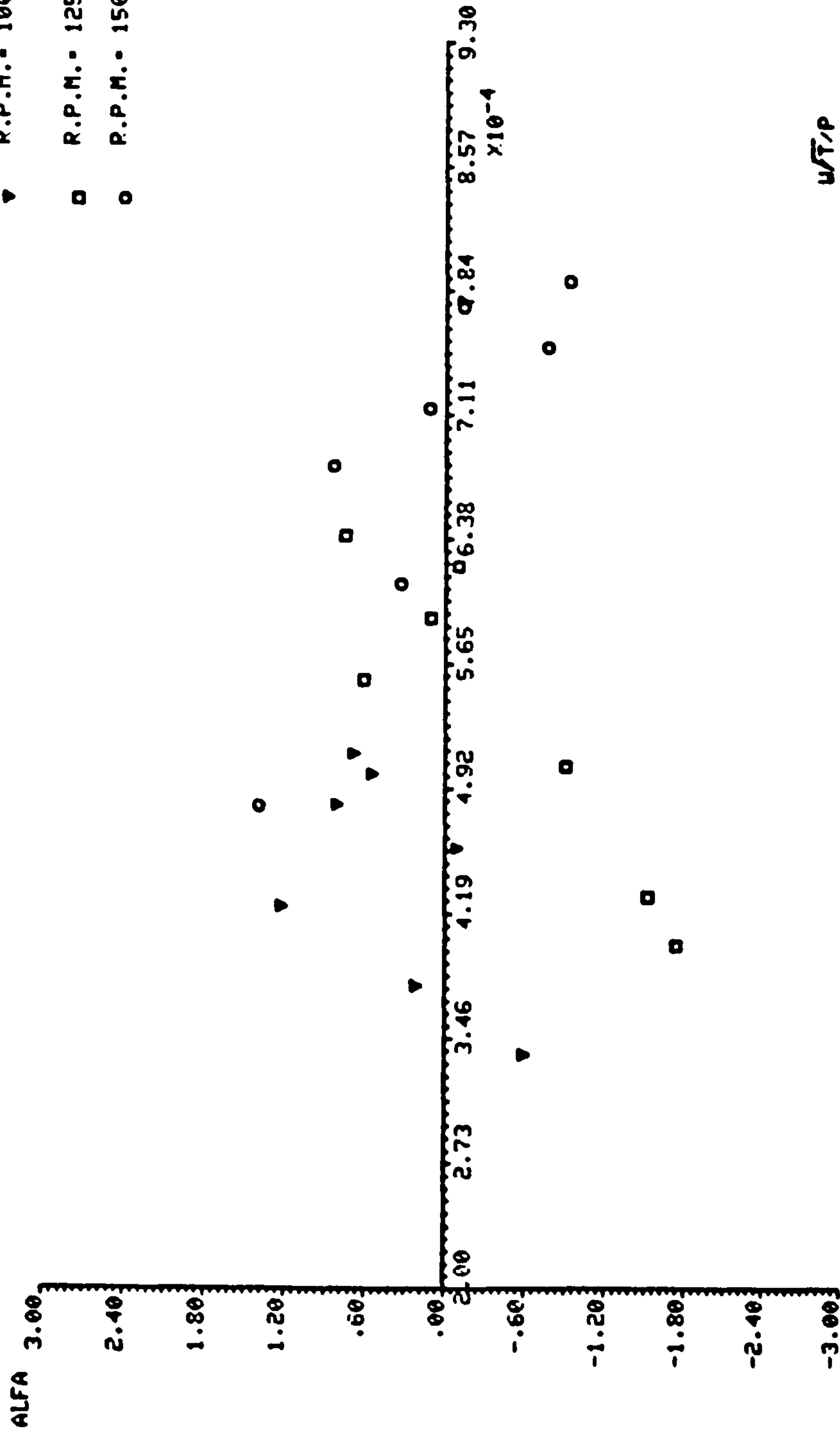


Fig29 Variation of the radial angle with the non-dim. flow coeff.

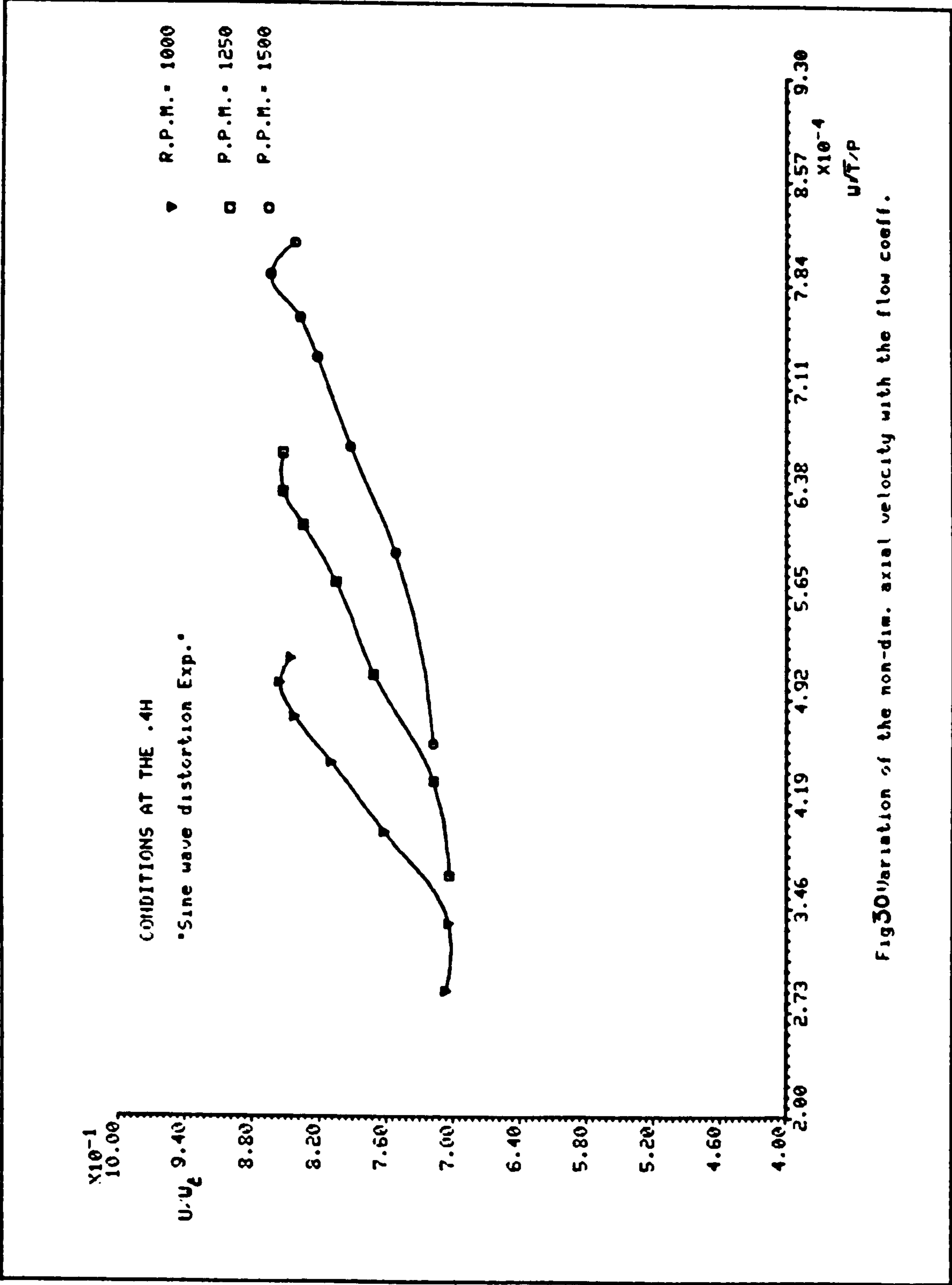


Fig 30 Variation of the non-dim. axial velocity with the flow coeff.

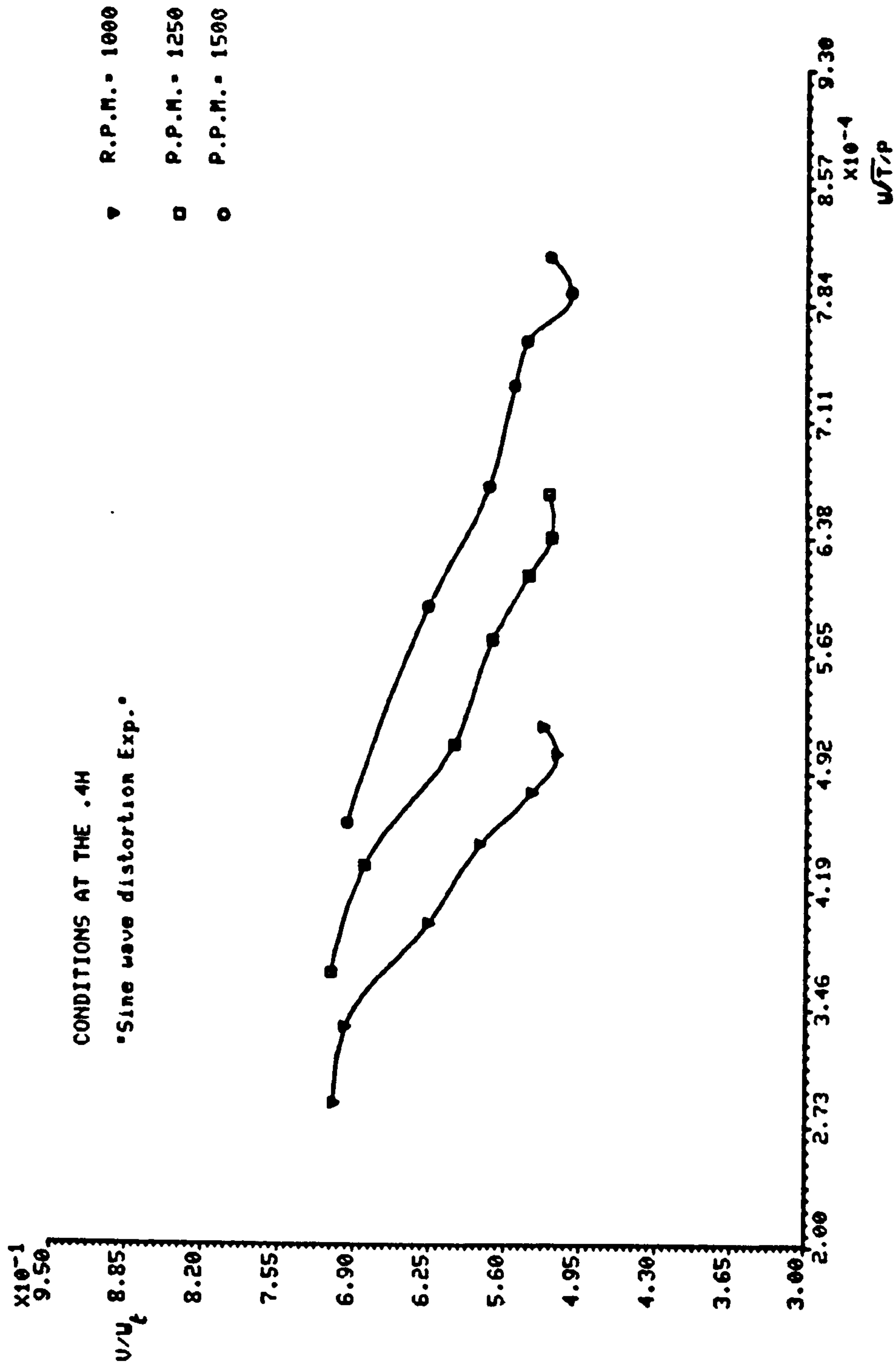


Fig 31 Variation of the non-dim. tangential velocity with the flow coeff.

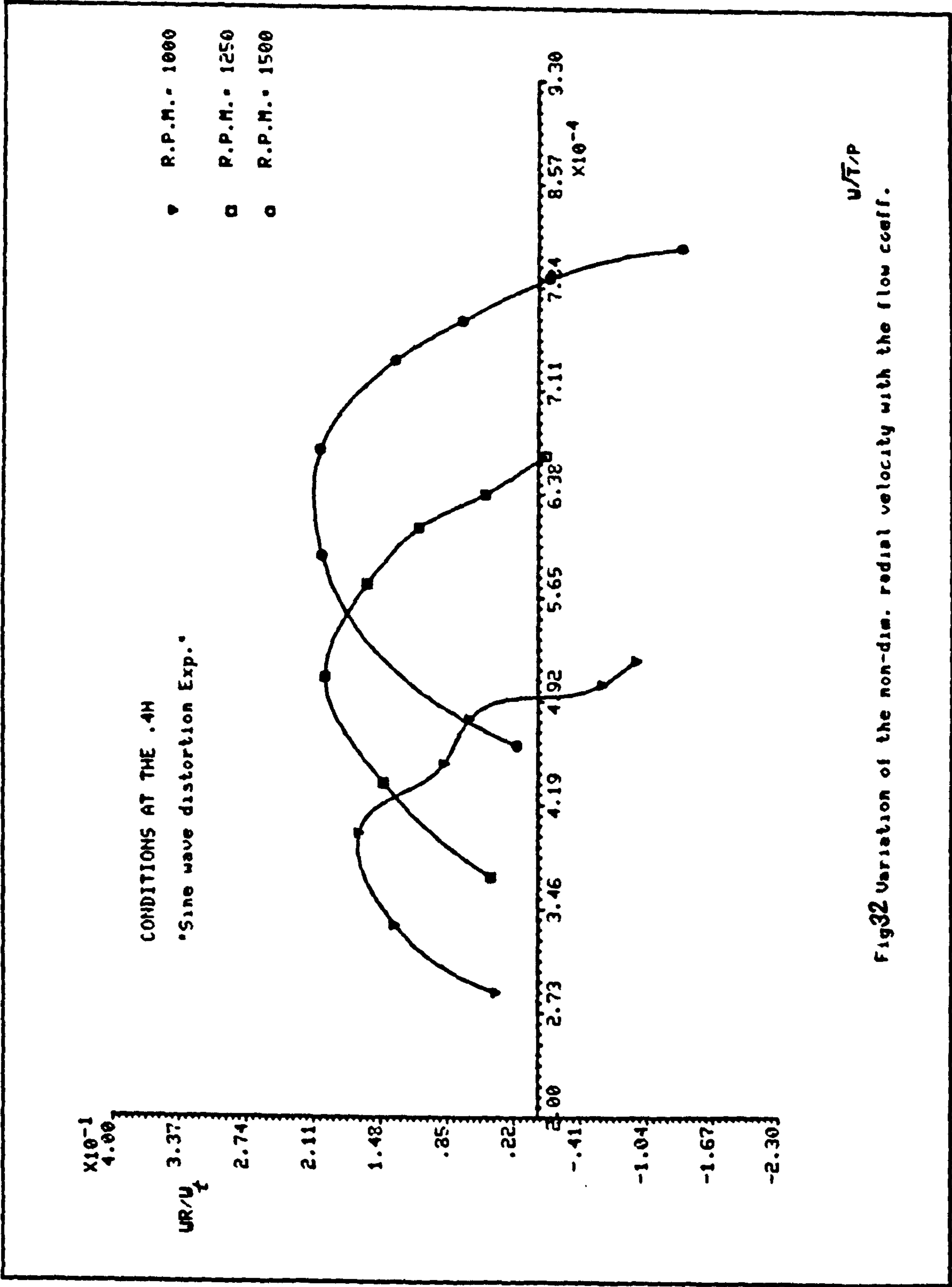


Fig32 Variation of the non-dim. radial velocity with the flow coeff. $U/\sqrt{P}$

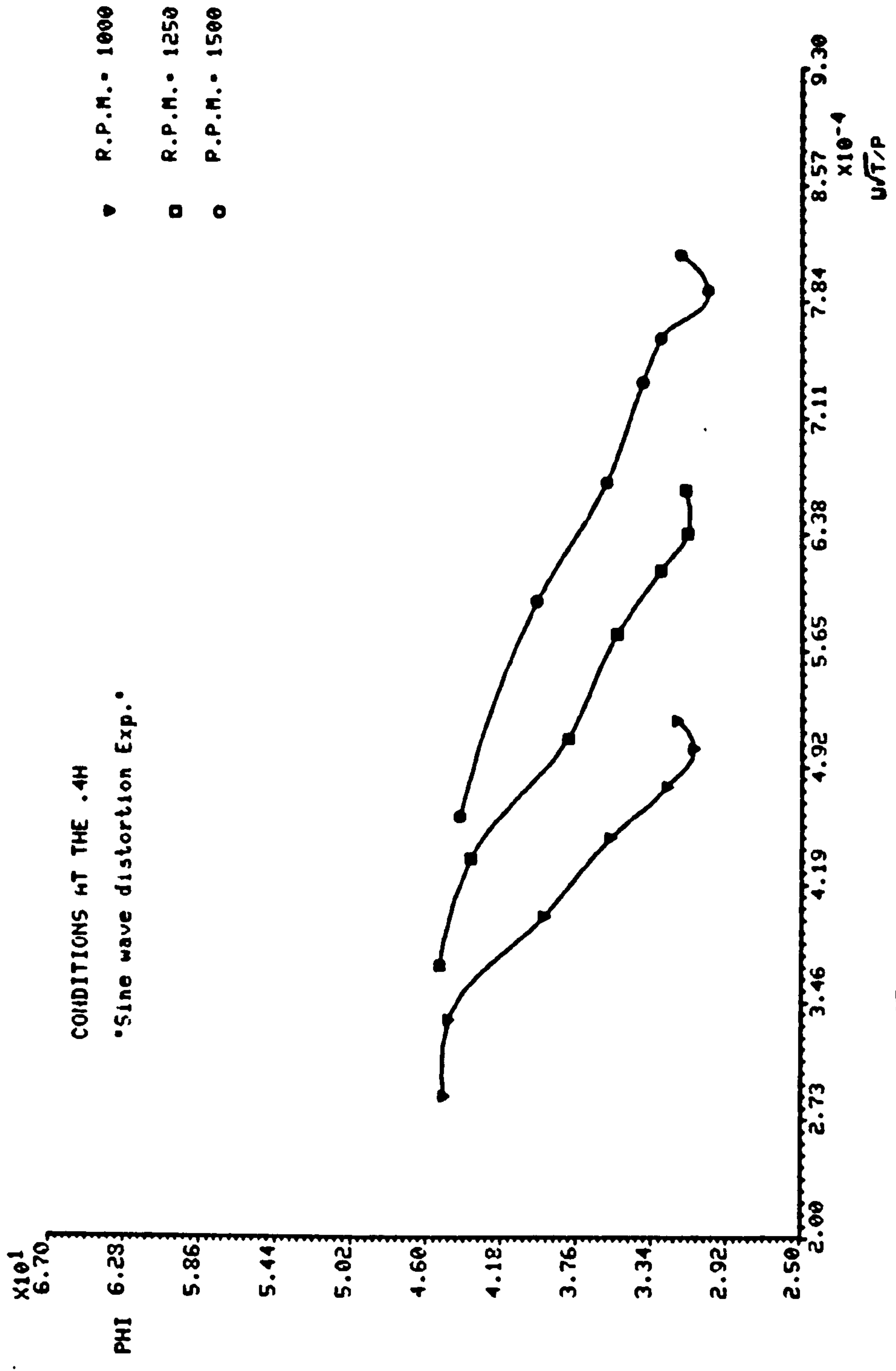
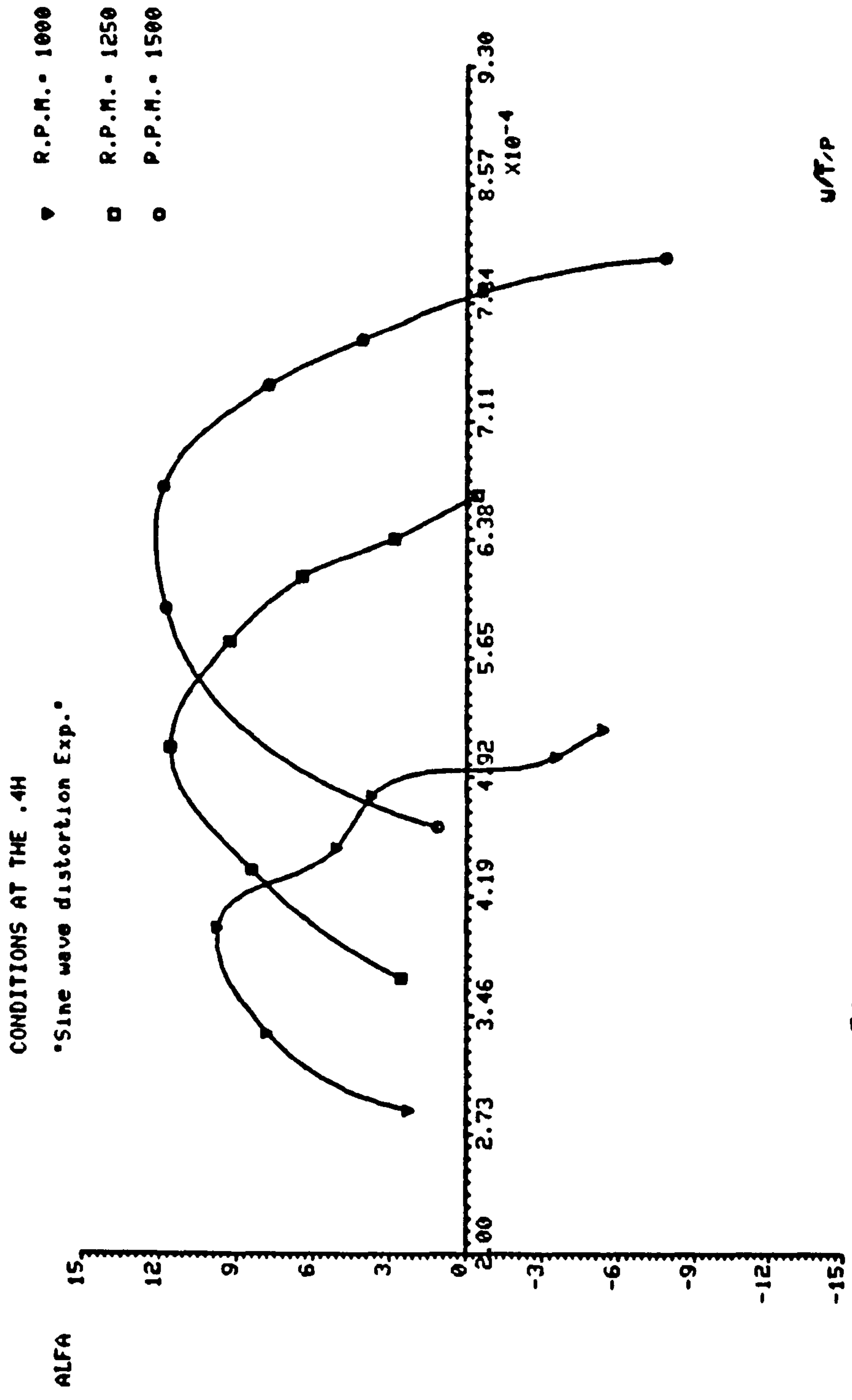


Fig33 Variation of the flow yaw angle with the non-dim. flow coeff.



u/P

Fig 34 Variation of the radial angle with the non-dim. flow coeff.

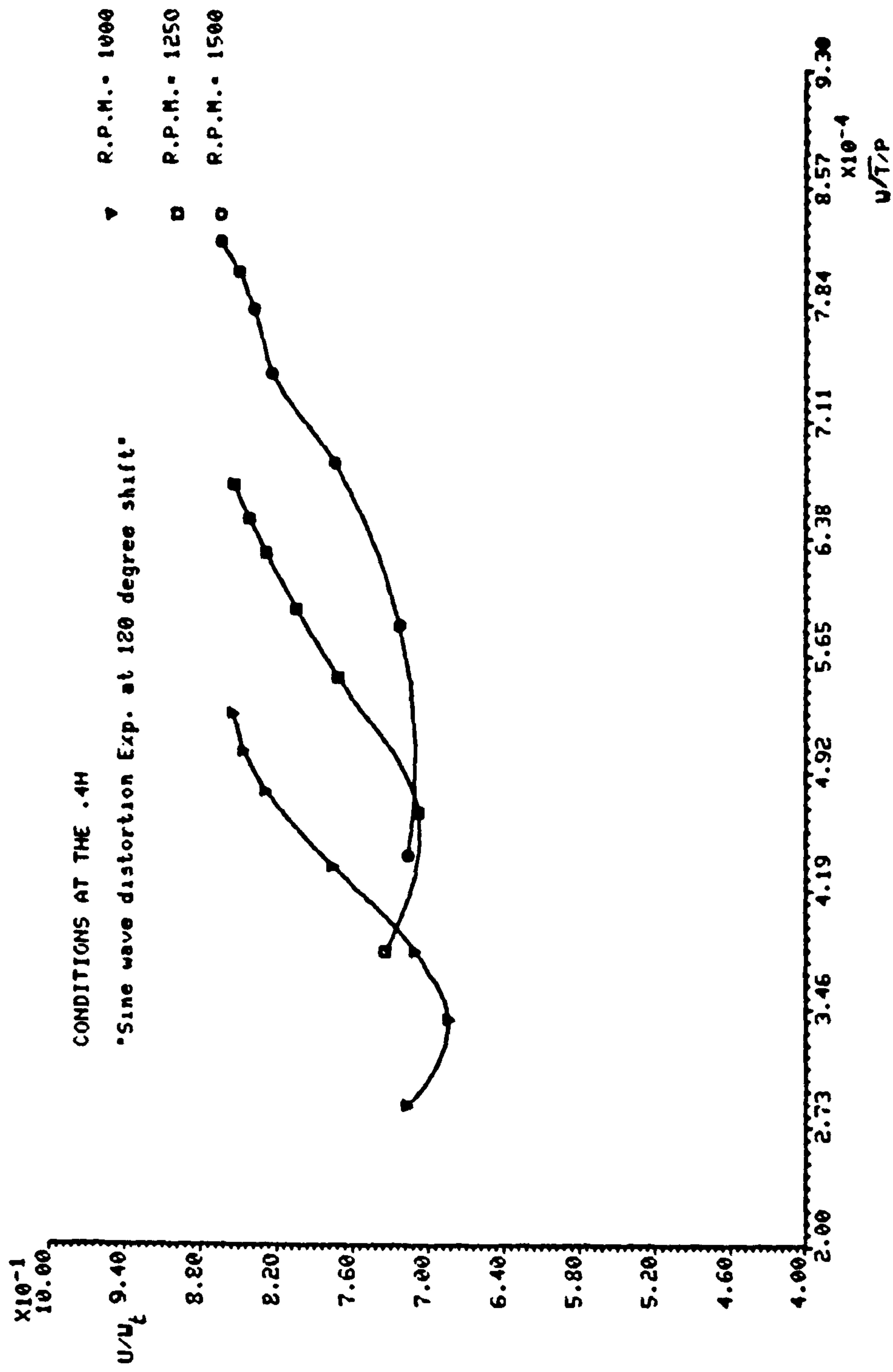


Fig 55 Variation of the non-dim. axial velocity with the flow coeff.

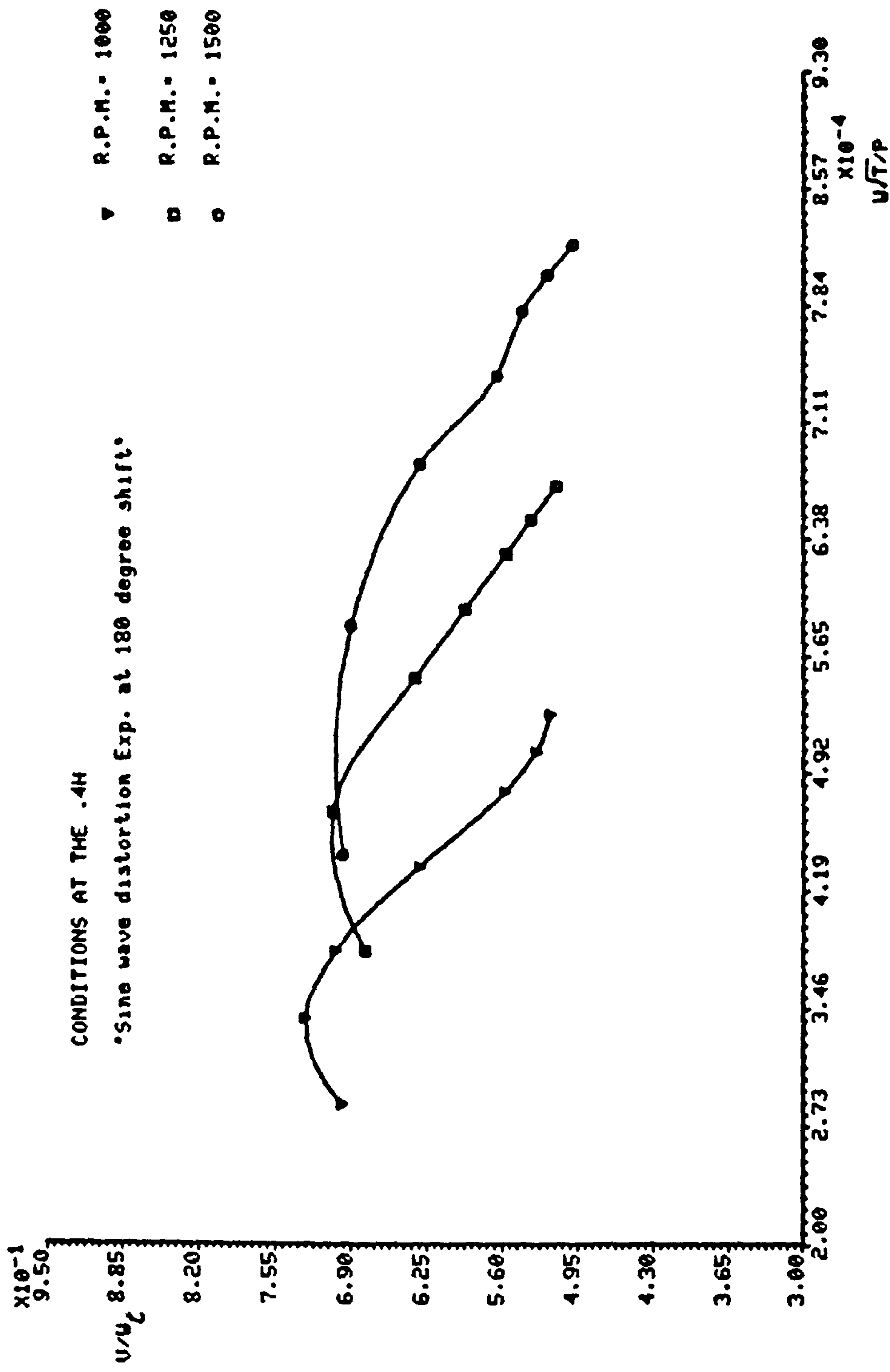


Fig 56 Variation of the non-dis. tangential velocity with the flow coeff.

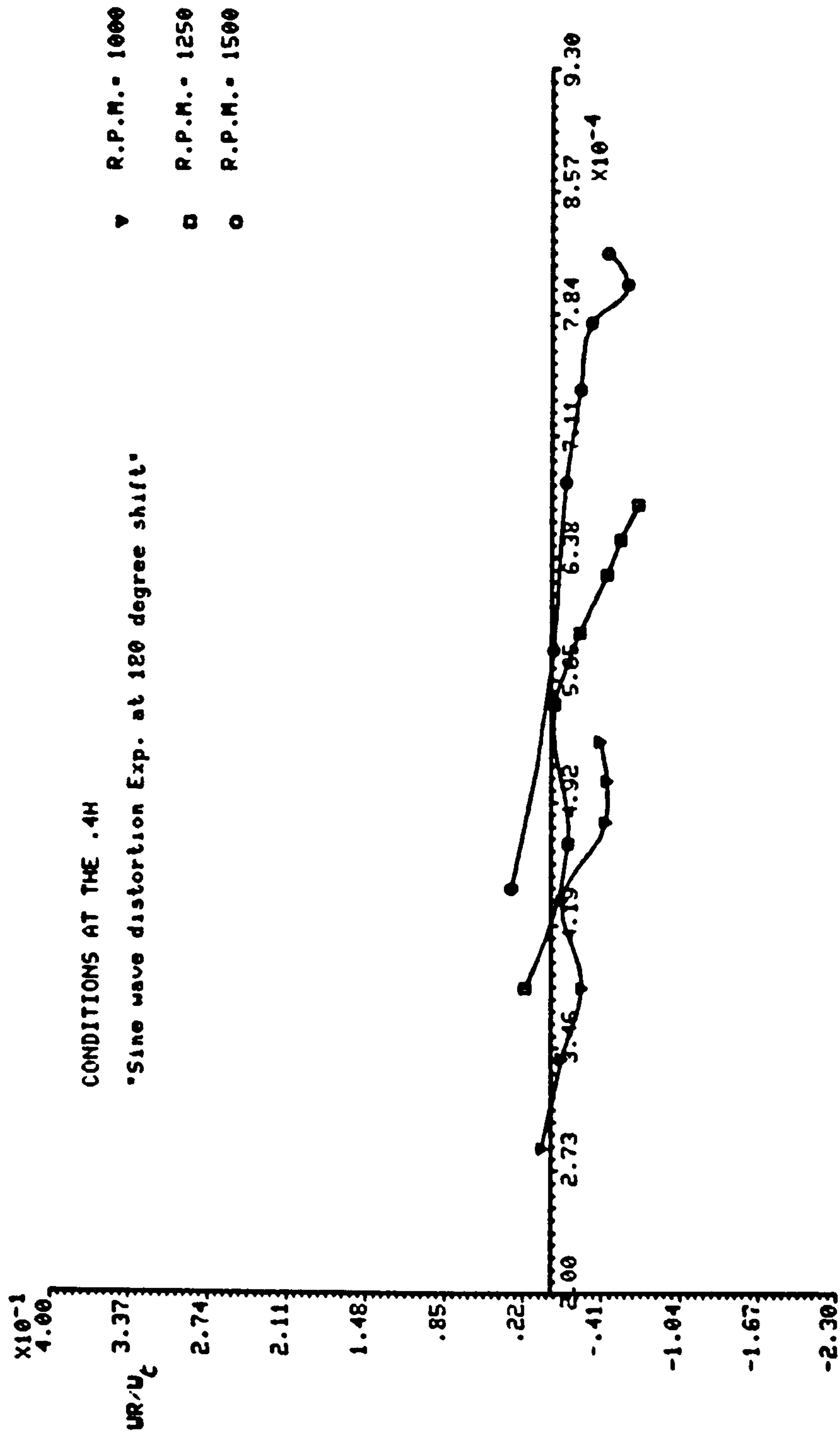


Fig 37 Variation of the non-dim. radial velocity with the flow coeff.

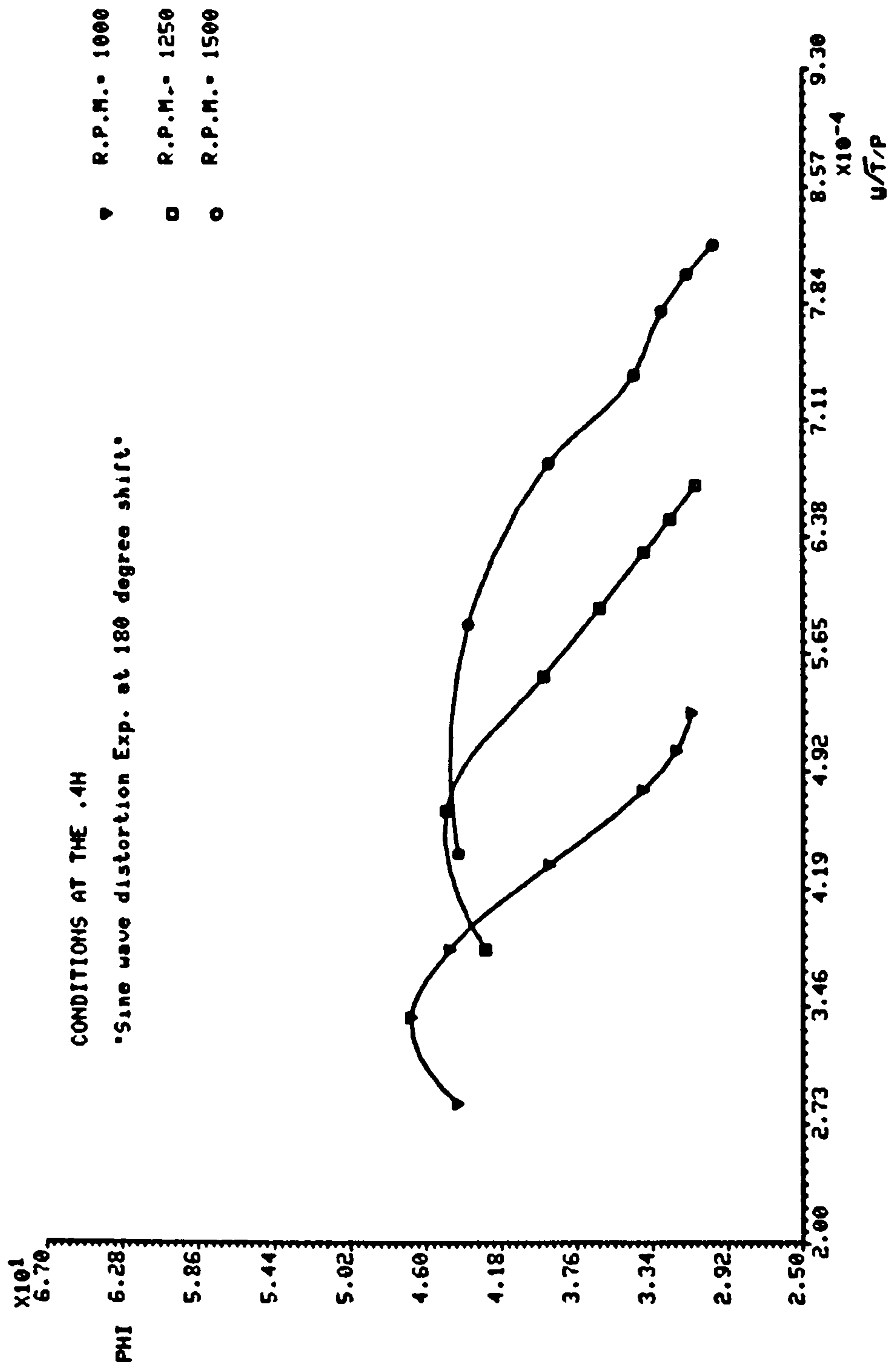


Fig 38 Variation of the flow yaw angle with the non-dim. flow coeff.

CONDITIONS AT THE .4H

"Sine wave distortion Exp. at 180 degree shift"

▼ R.P.M.= 1000

▣ R.P.M.= 1250

○ R.P.M.= 1500

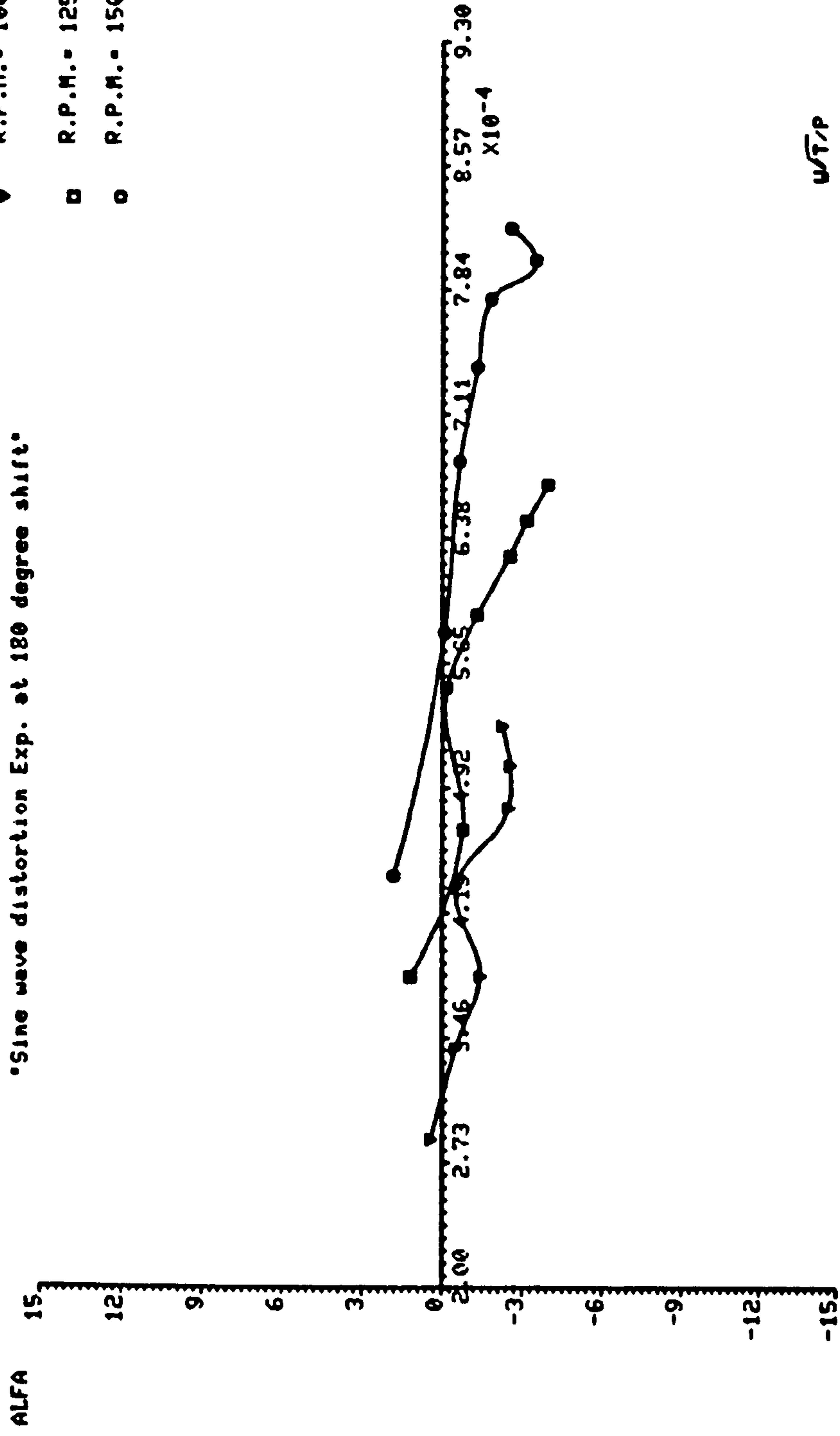


Fig 39 Variation of the radial angle with the non-dim. flow coeff.

Condition at 1500 R.P.M.
At blade mid height

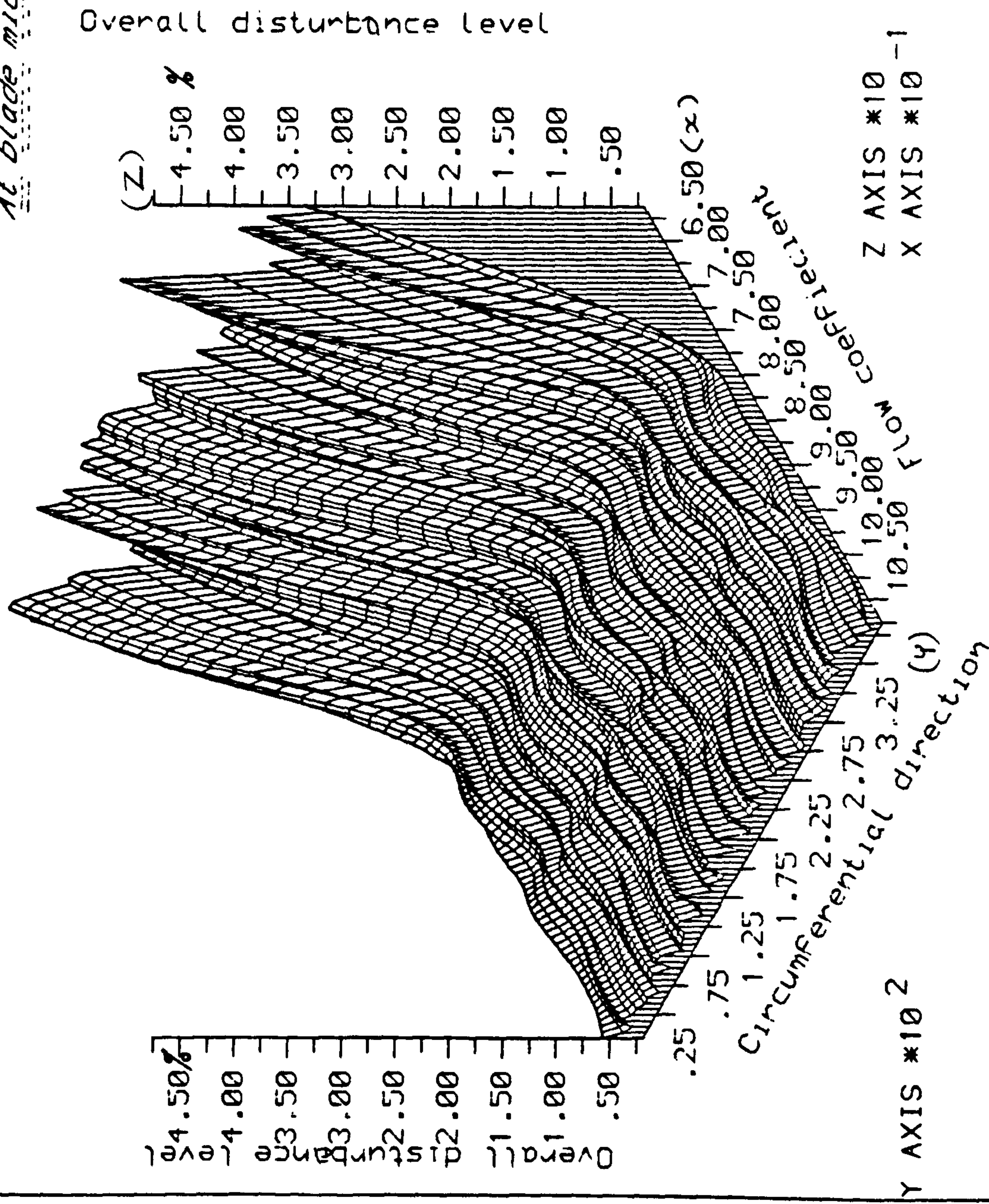


Fig40 Dist. of overall disturbance level.

Condition at 1500 R.P.M.
At blade mid height

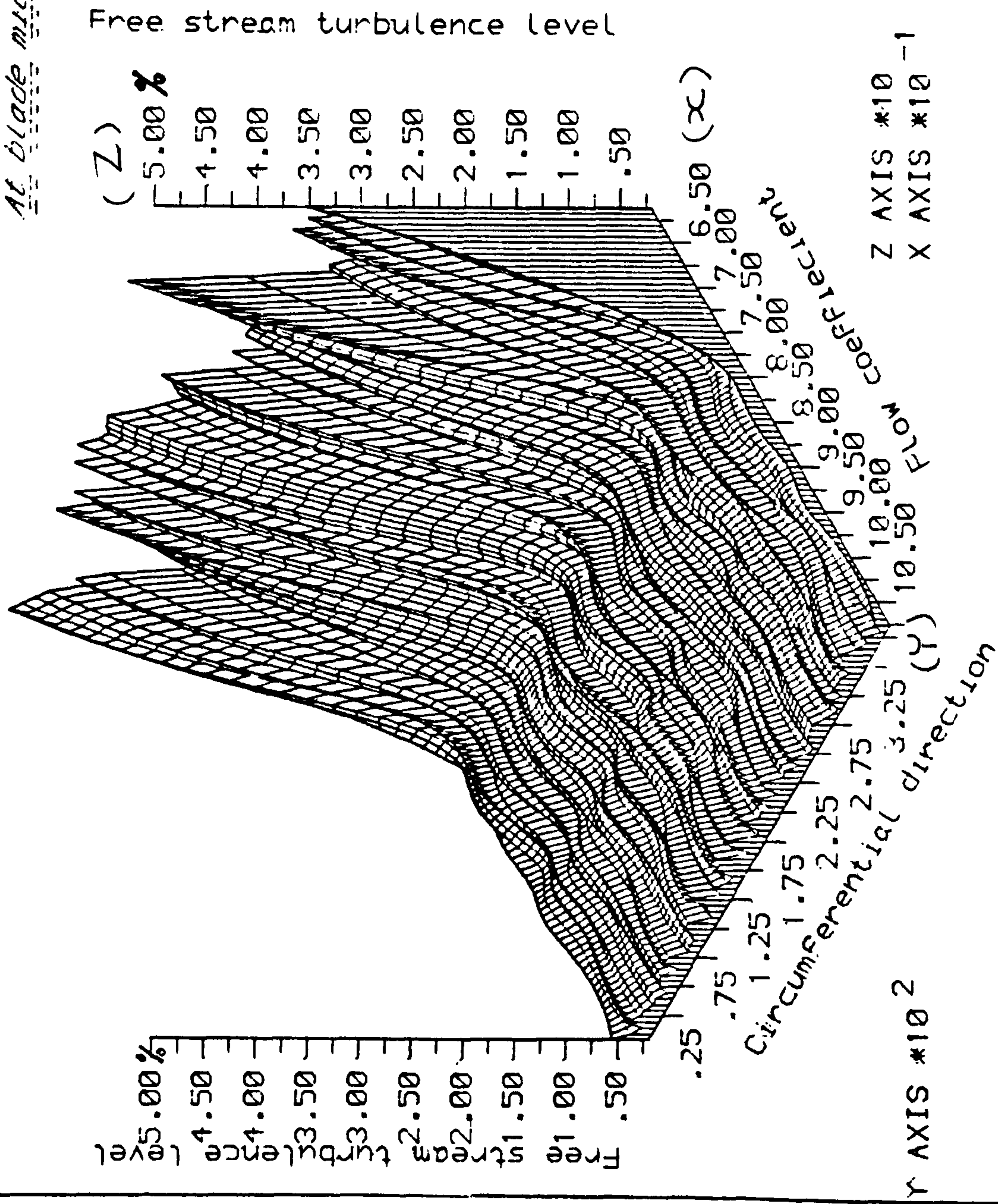


Fig 41 Dist. of Free stream turbulence level

Condition at 15:0 R.P.M.
At blade mid height

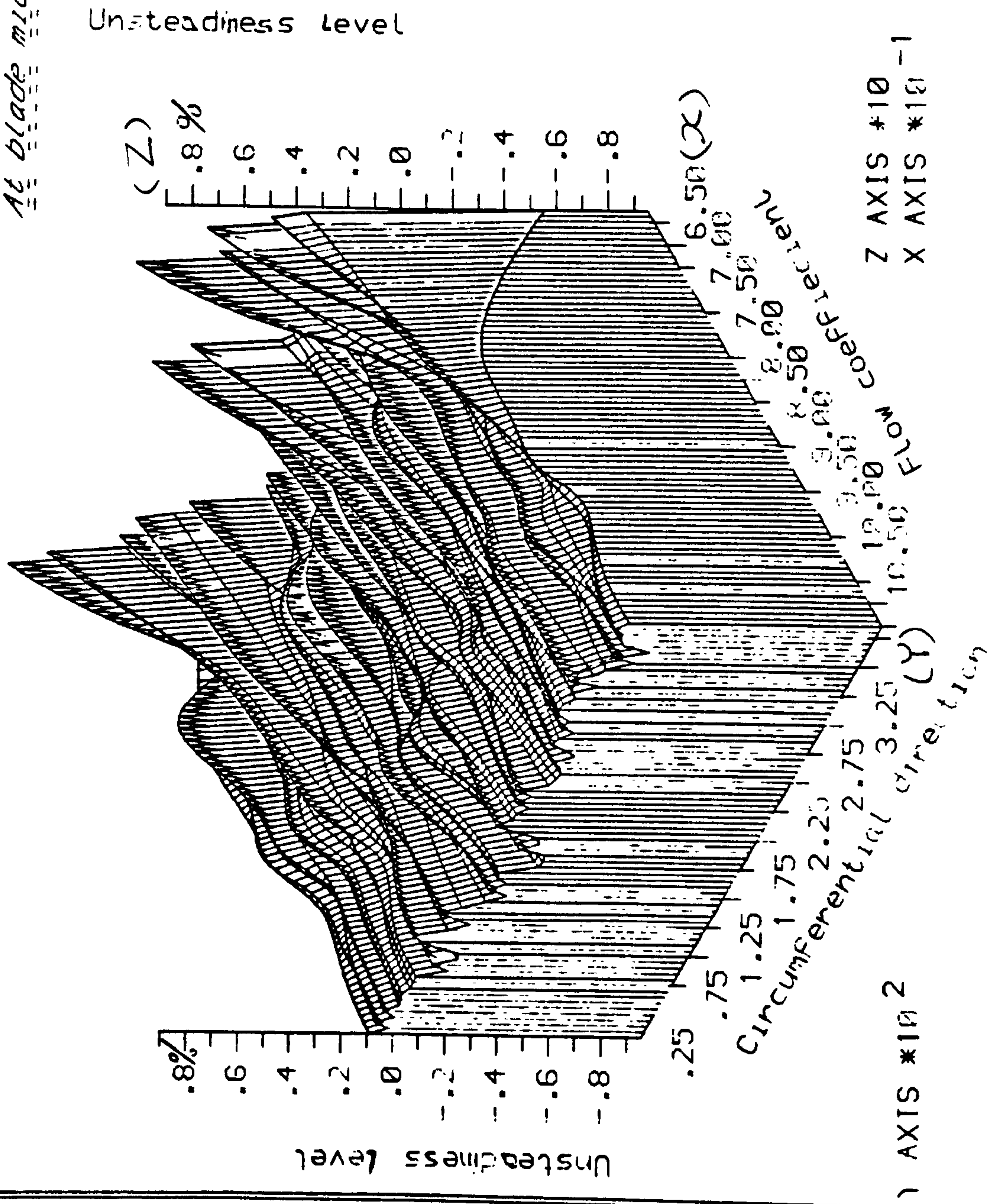


Fig 42 Dist. of unsteadiness level

Condition at 1500 R.P.M.
At height H "TIP REGION"

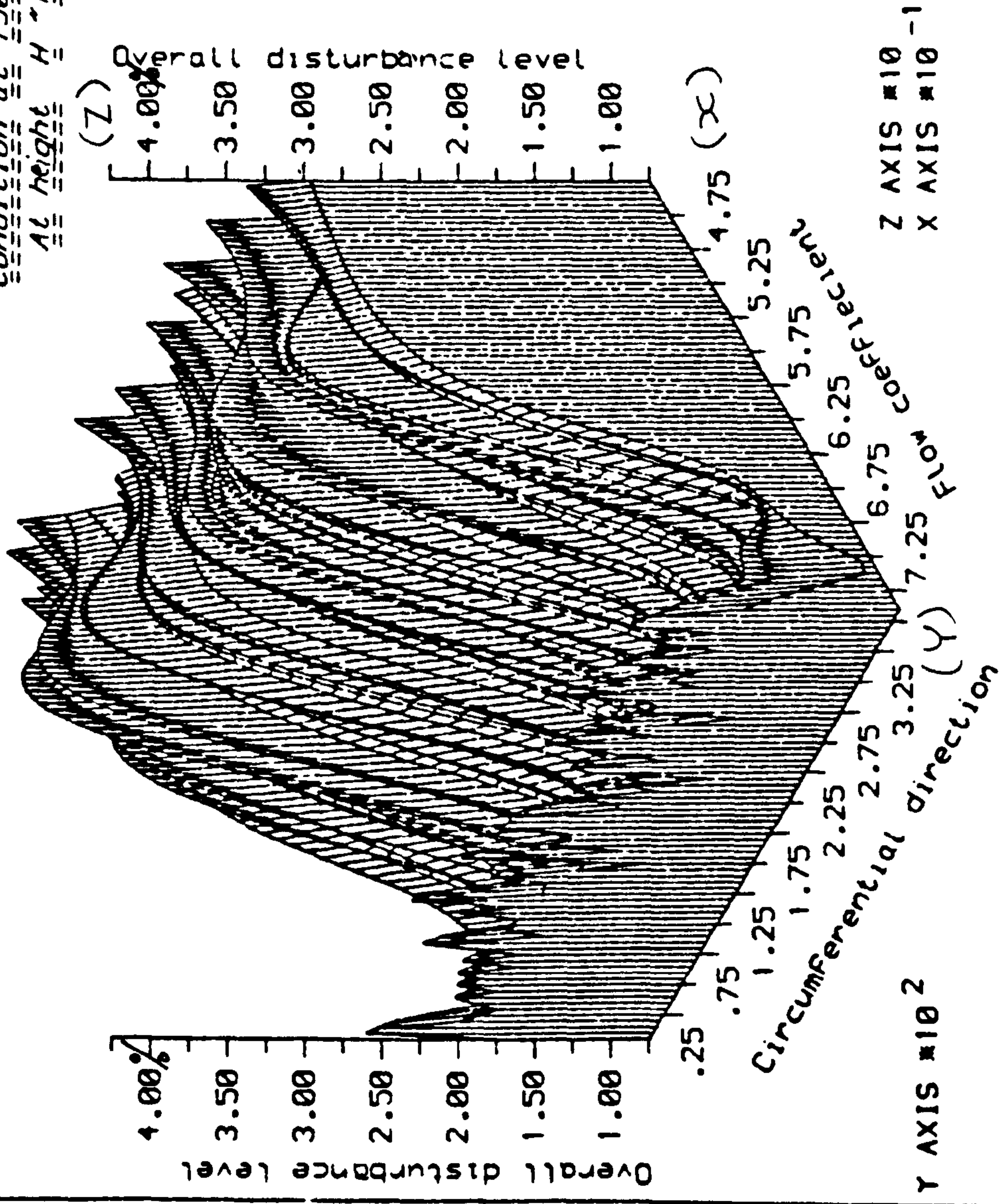


Fig 43 Dist. of overall disturbance level

Condition at 1500 R.P.M.
At height H "TIP REGION"

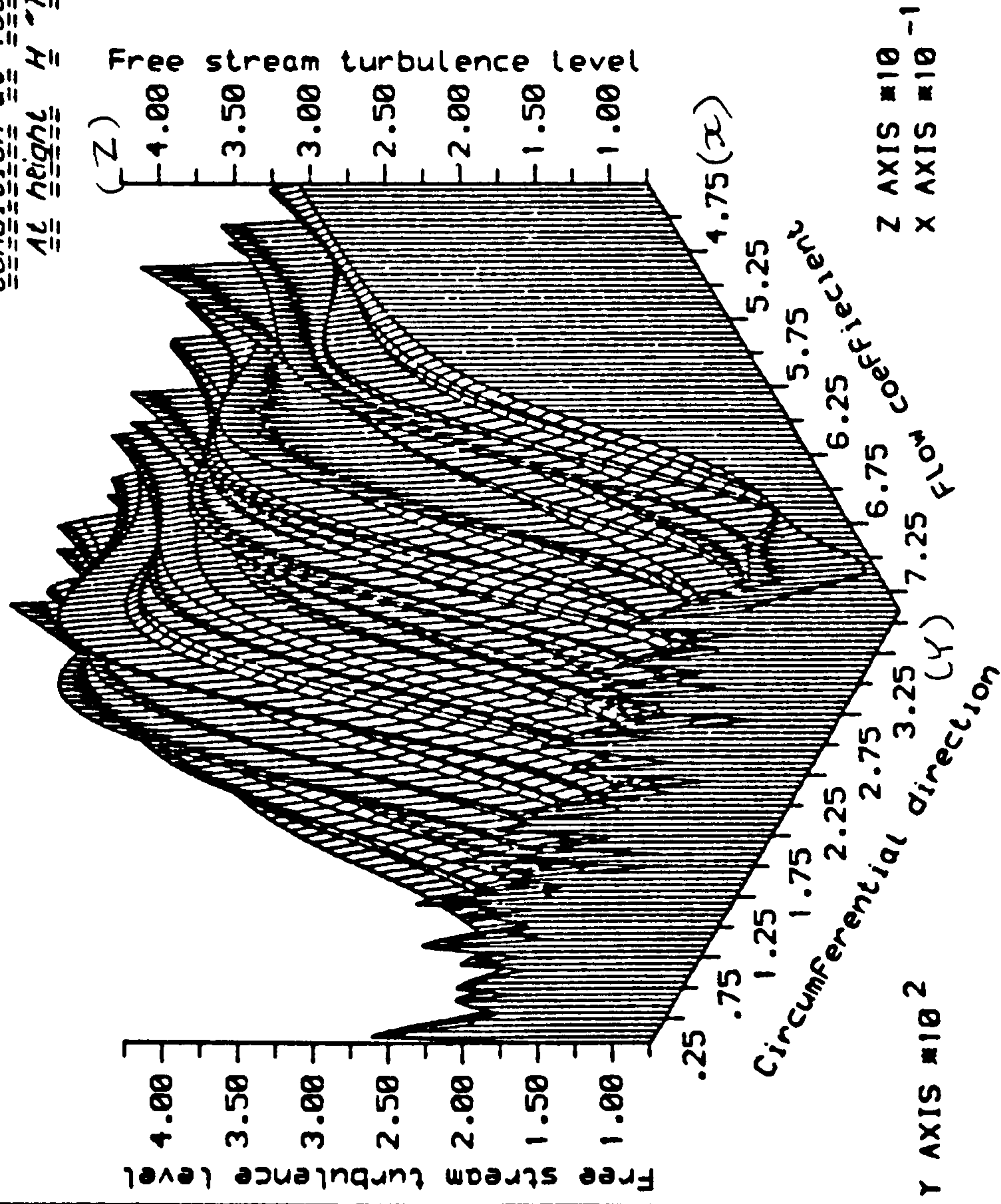


Fig 4-4 Dist. of free stream turbulence level

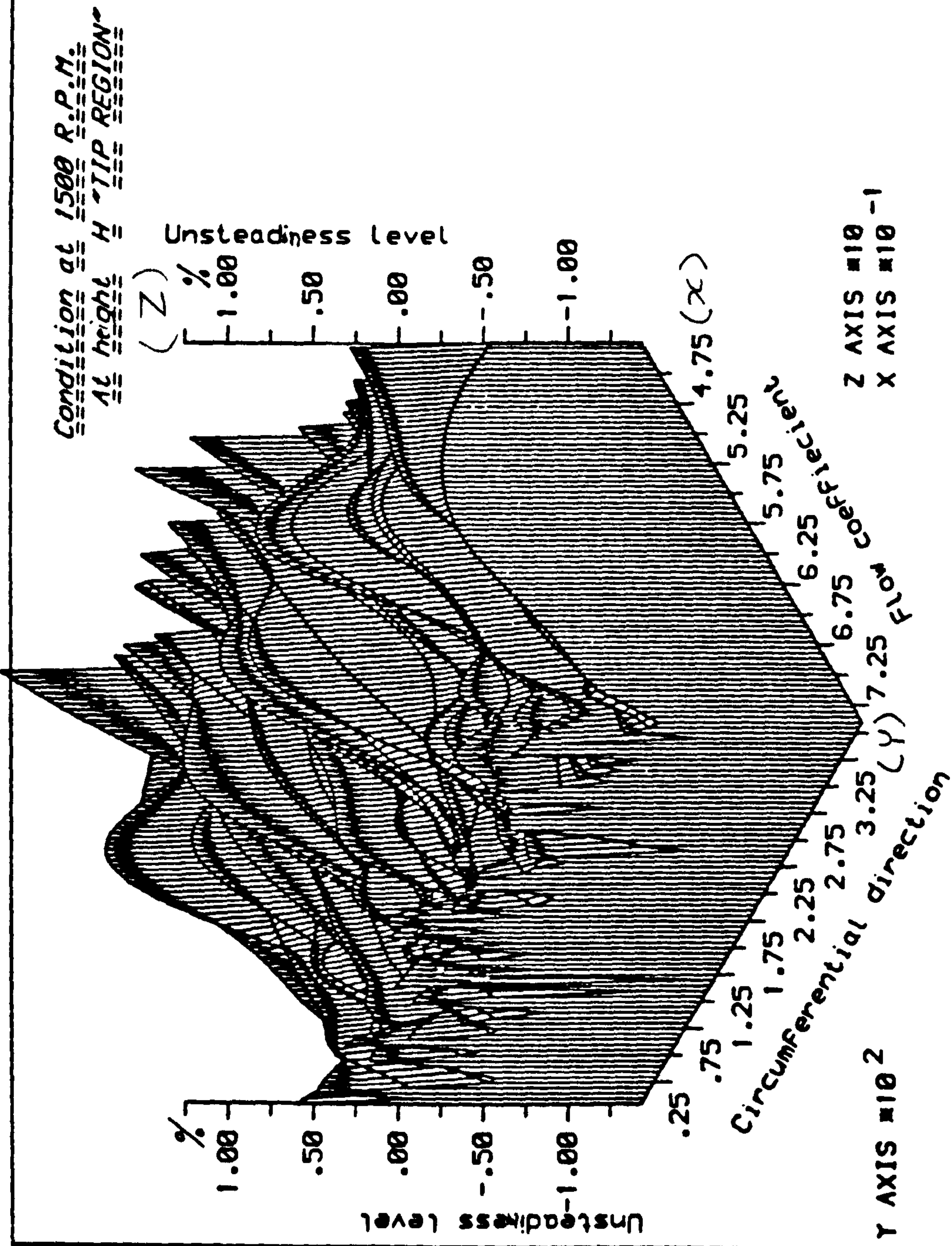


Fig 45 Dist. of unsteadiness level

Condition at 1250 R.P.M.
At height .8H

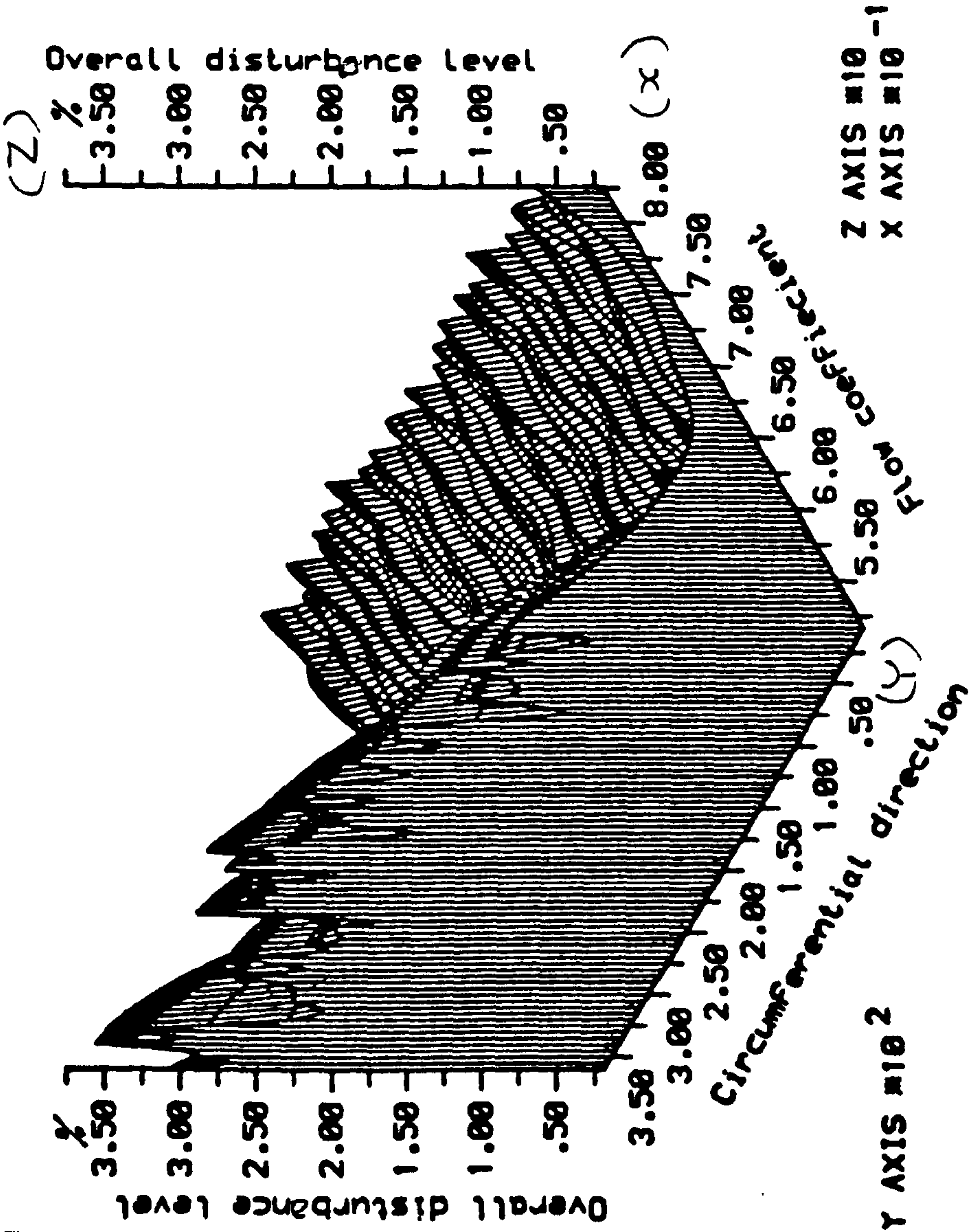


Fig 4-6 Dist. of overall disturbance level

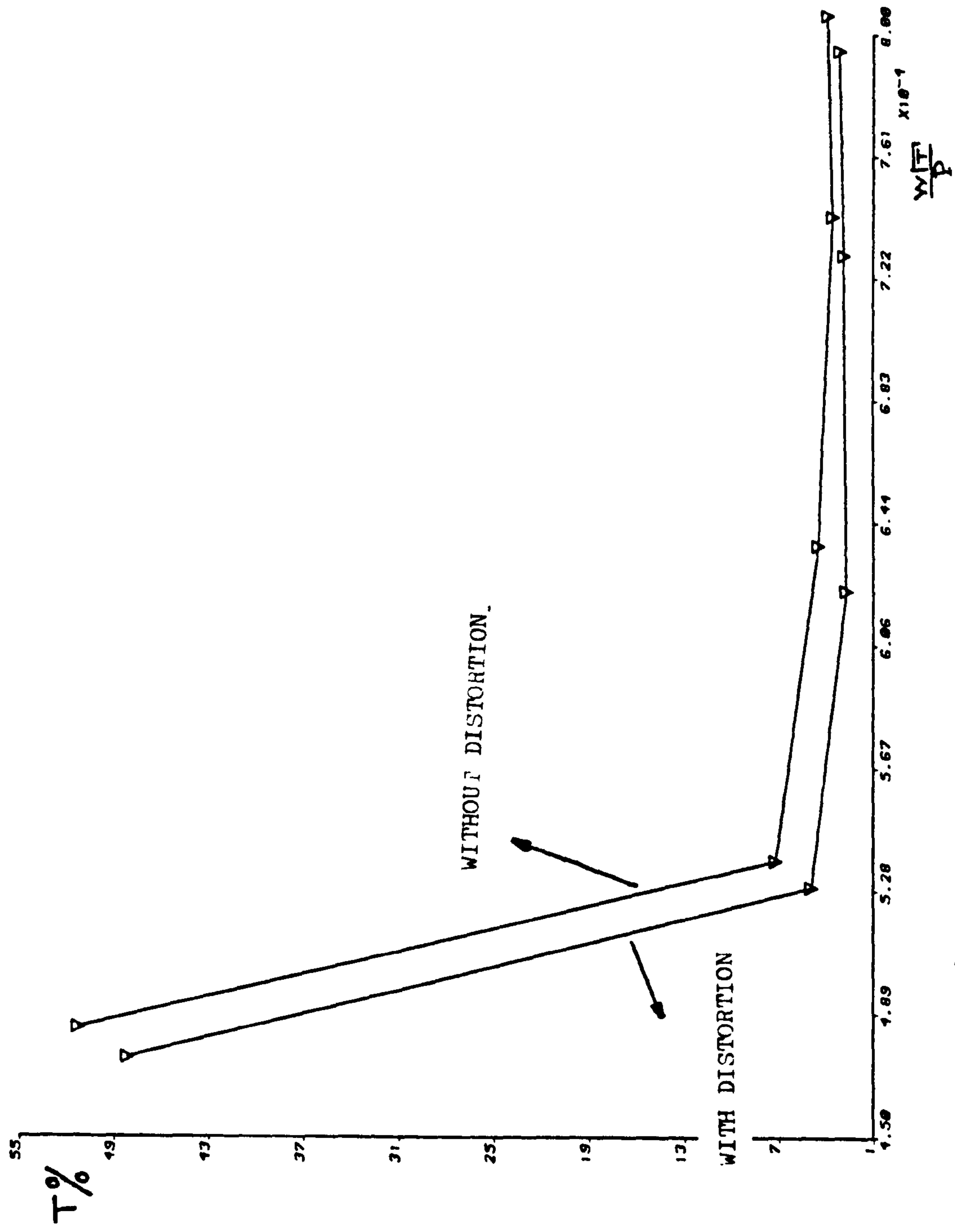


FIG. 4. VARIATION OF TURBULENCE LEVEL WITH FLOW COEFF. WITHOUT DISTORTION.

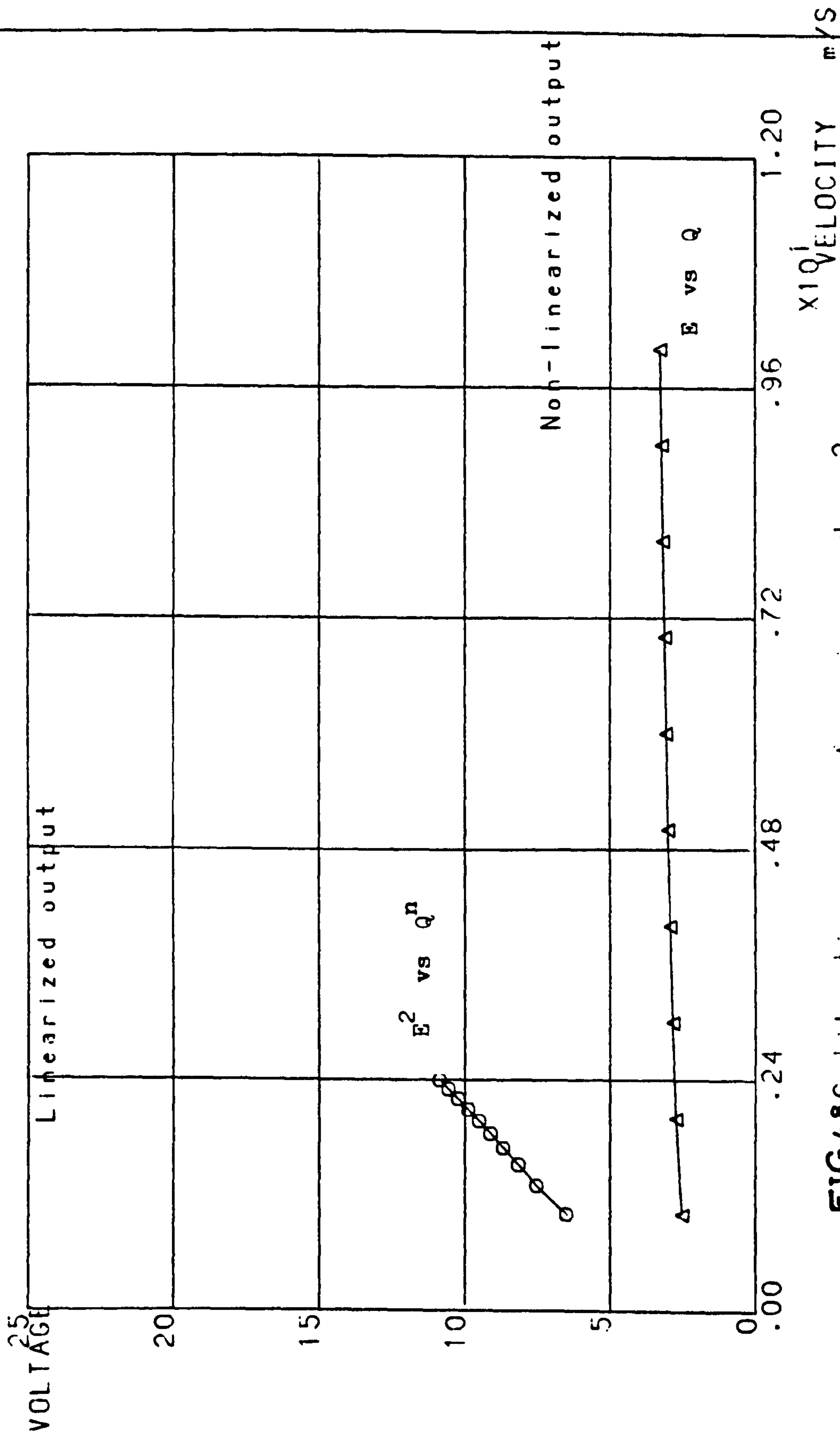


FIG 48 Calibration curve for wire number 2.

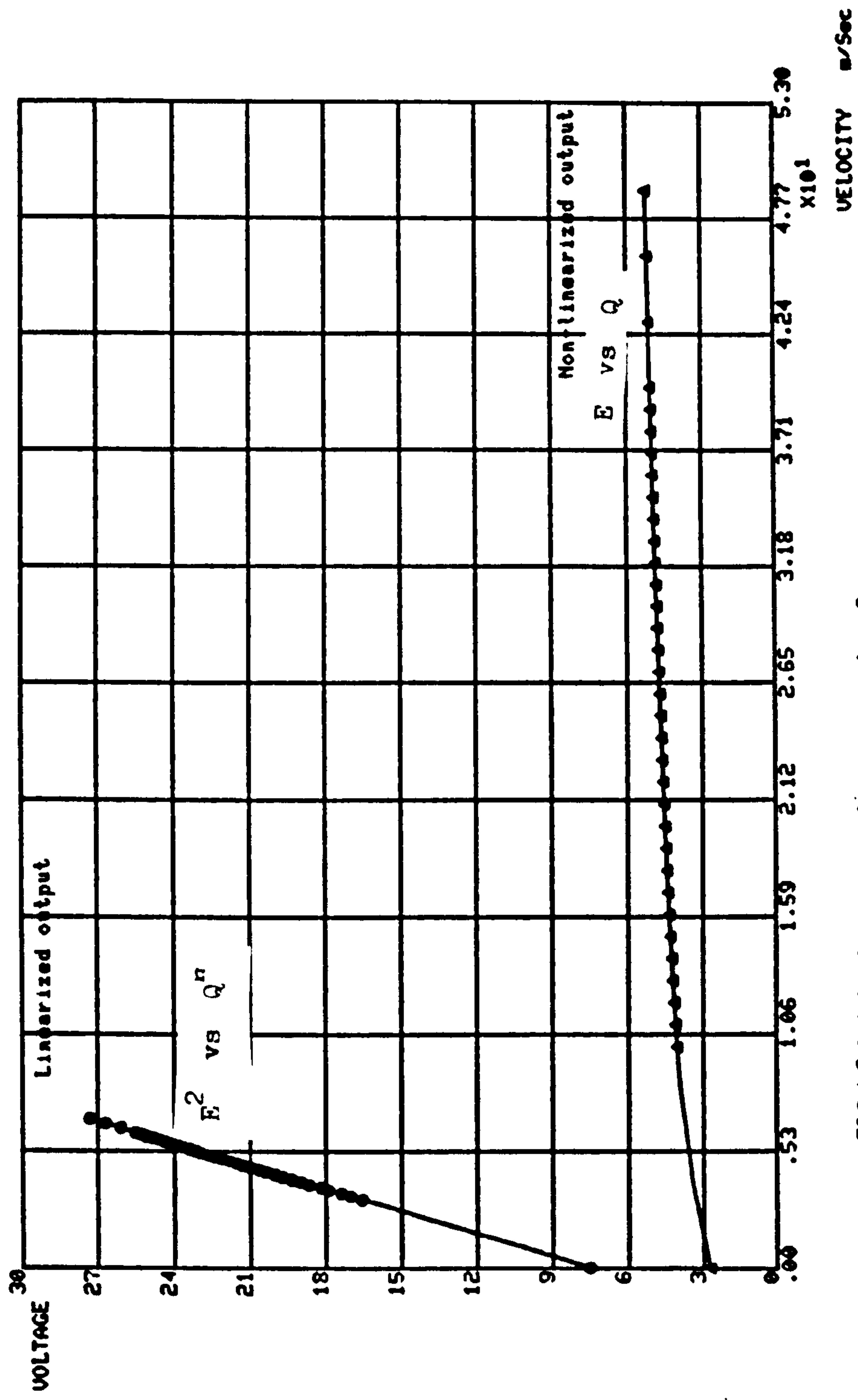


FIG 49 Calibration curve for wire number 2..

WIRE NO 2

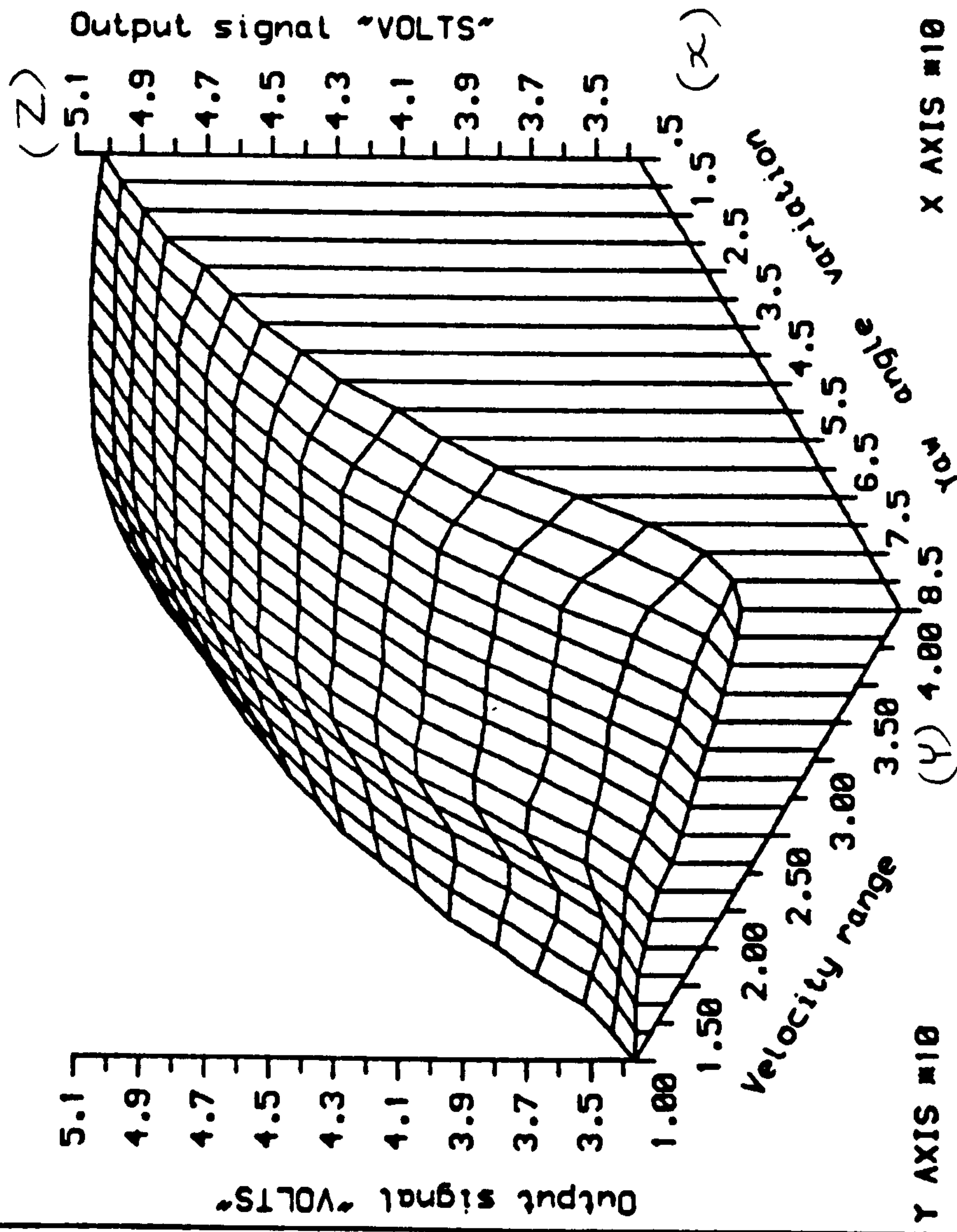


Fig 50 Hot-wire yaw/velocity variation characteristics

WIRE NO 2

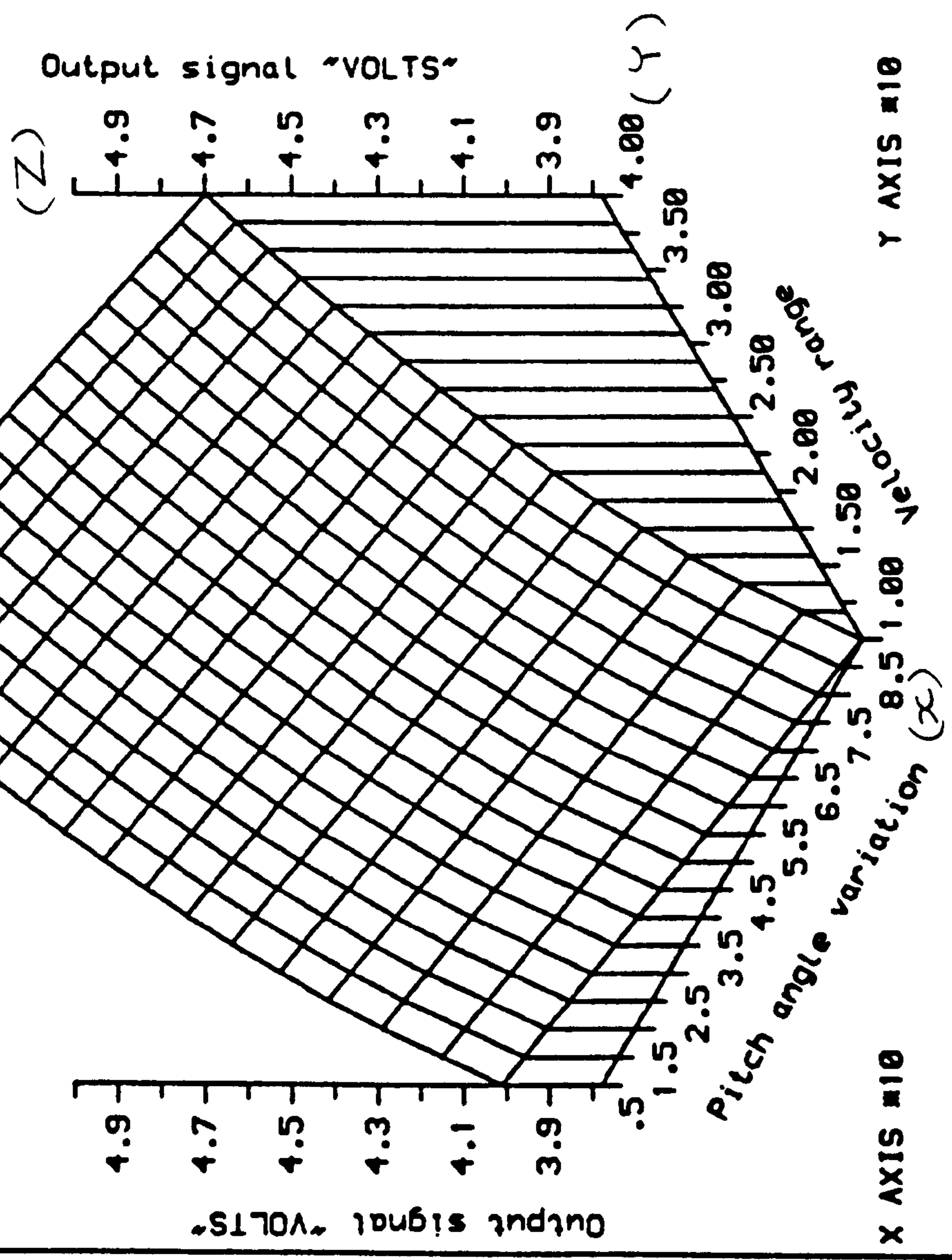
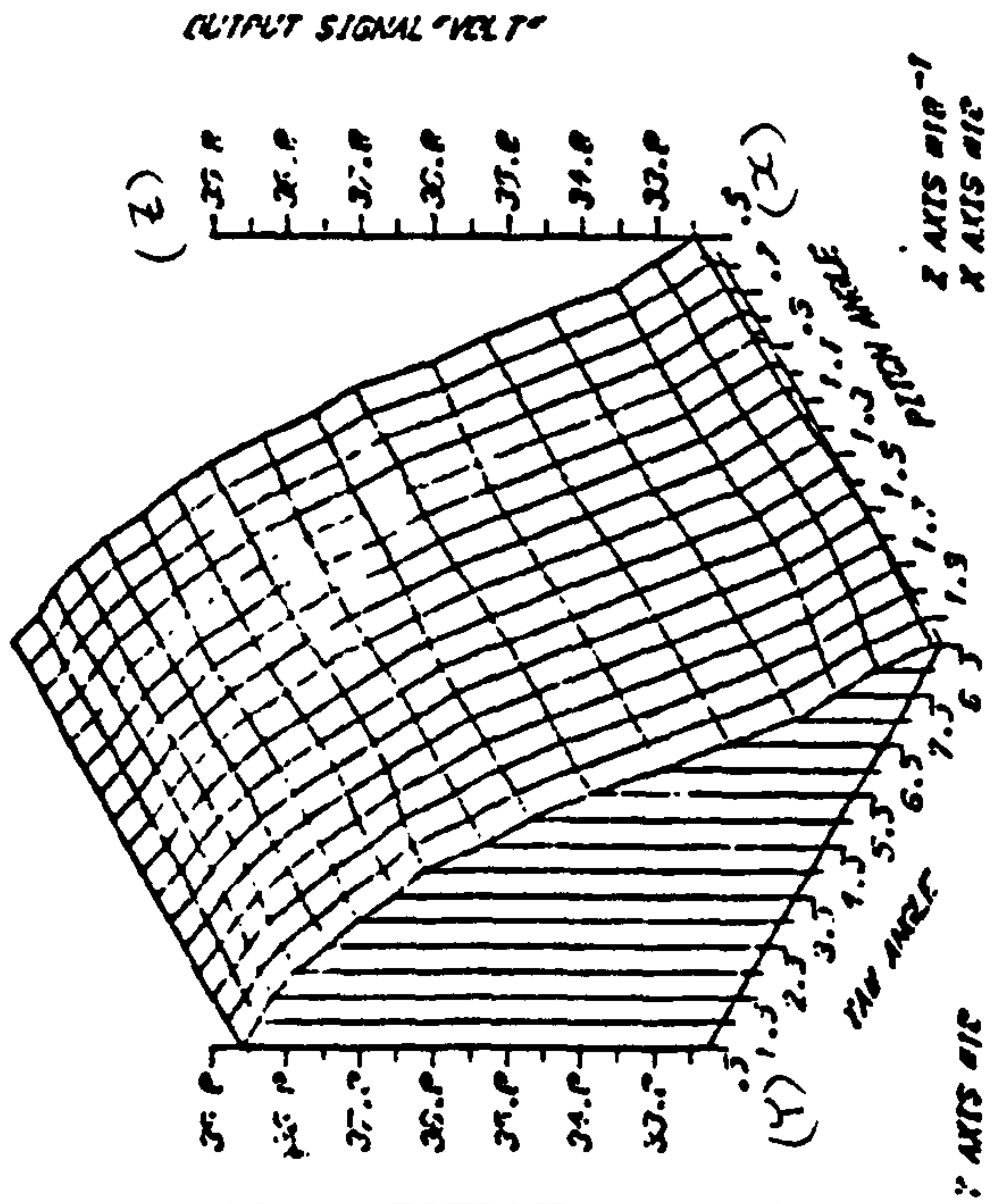


Fig51 Hot-wire pitch/velocity variation characteristics



WIRE NO 2

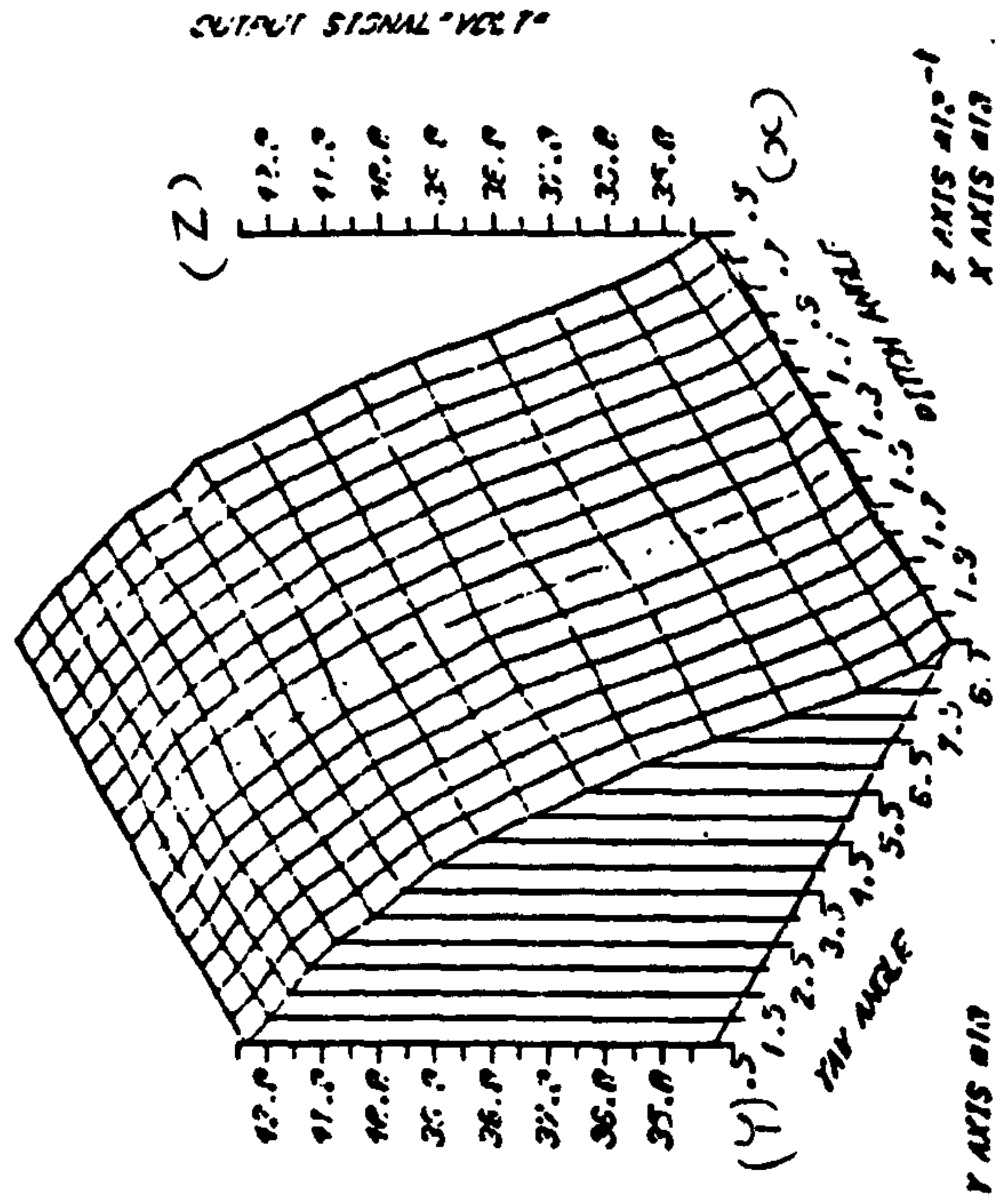
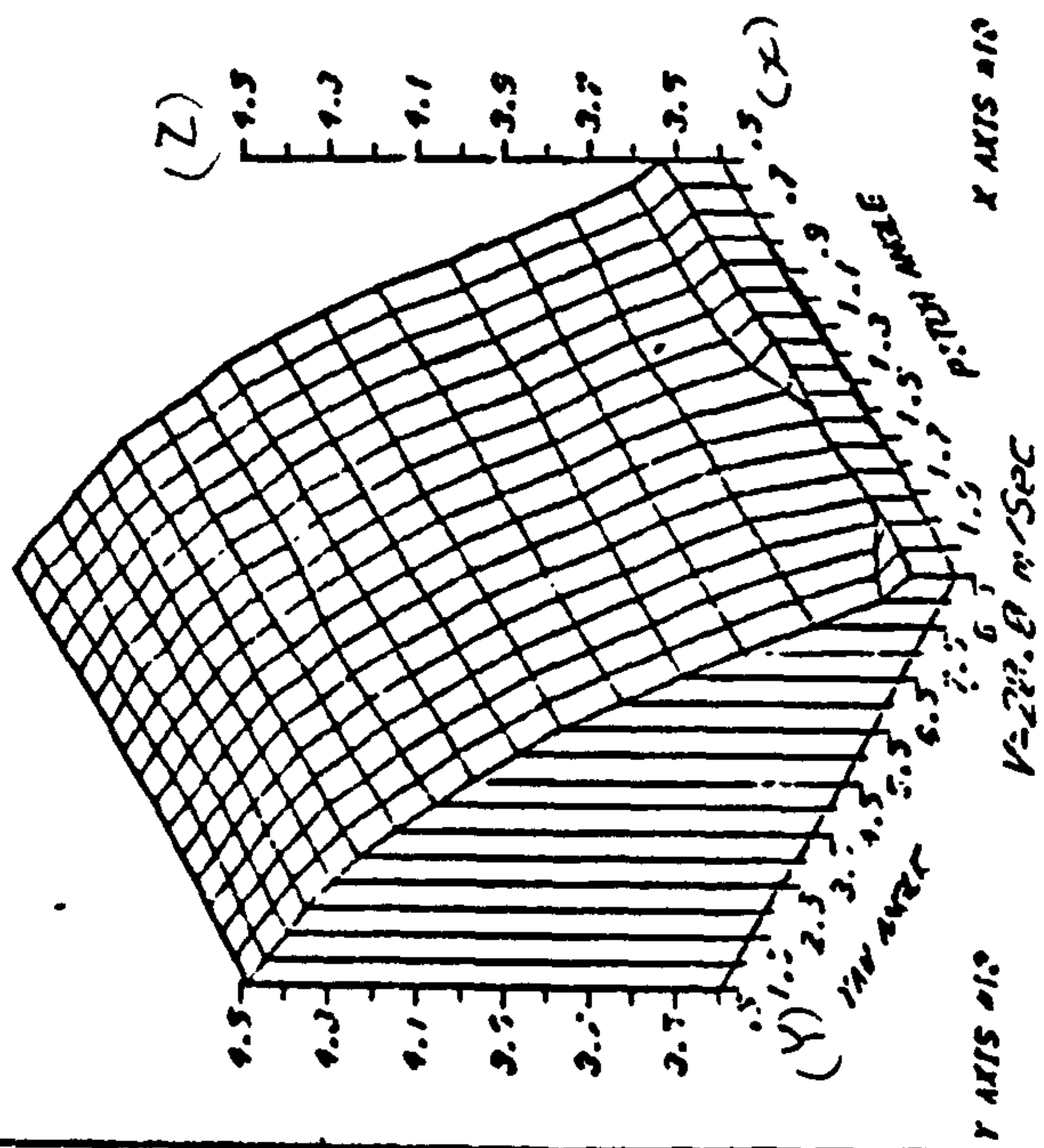
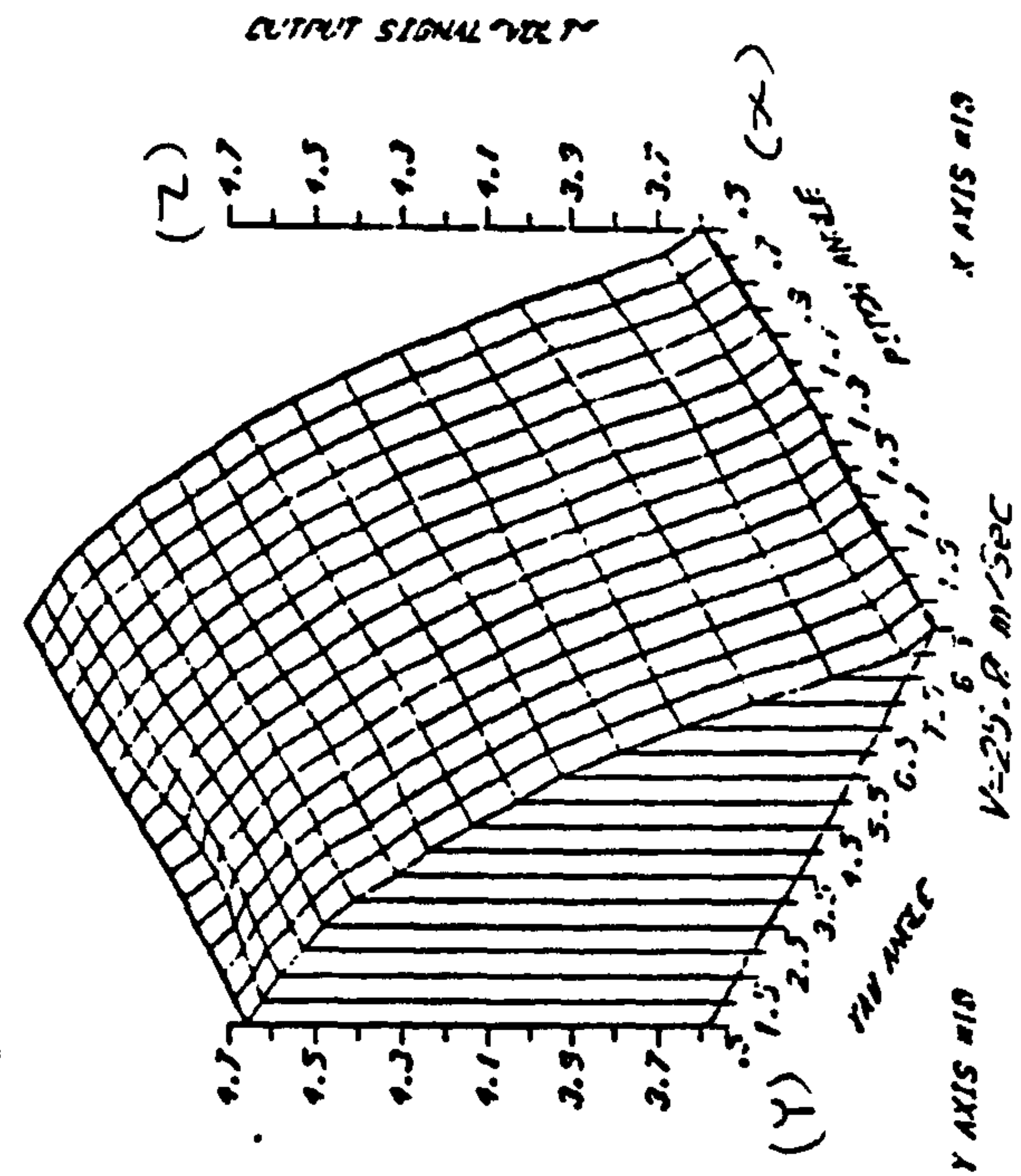


FIG 52 RESPONSE OF THE HOT WIRE TO THE EFFECT OF YAW AND PITCH VARIATIONS.

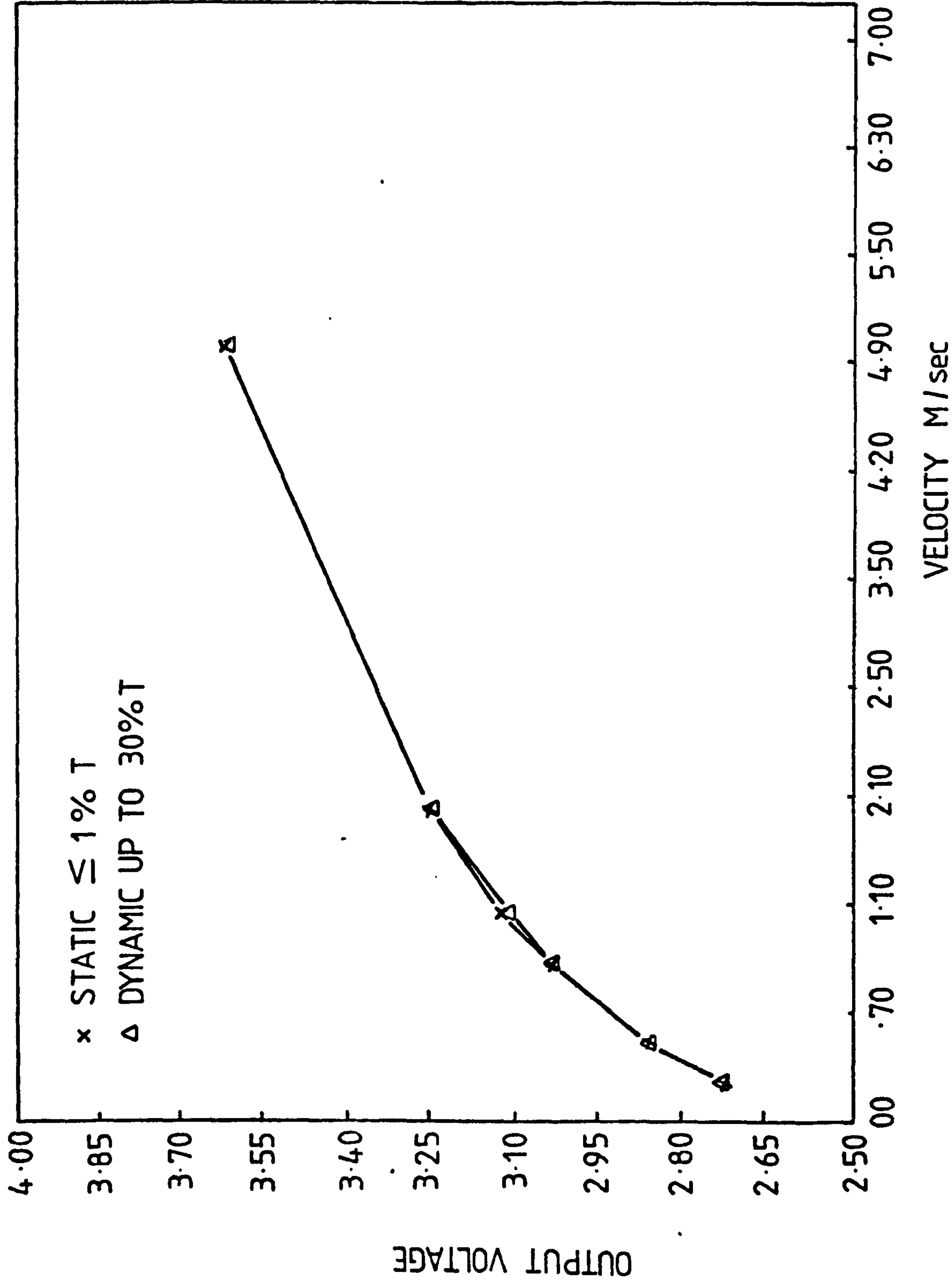


FIG 53 CLIBRATION CURVES FOR STATIC AND DYNAMIC RESPONSE OF THE HOT WIRE

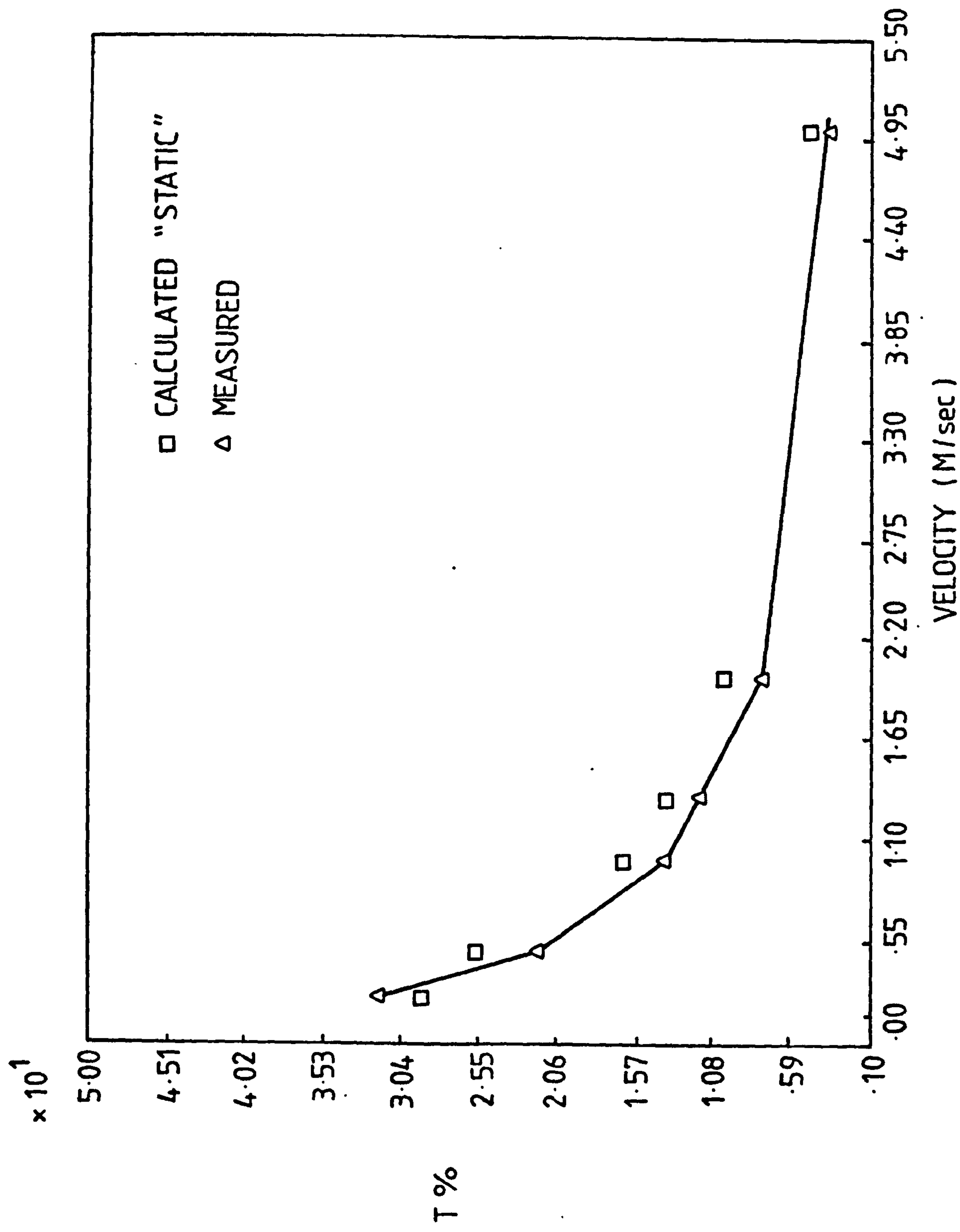


FIG 54 MEASURED AND CALCULATED TURBULENCE INTENSITY
(FROM STATIC CALIBRATION)

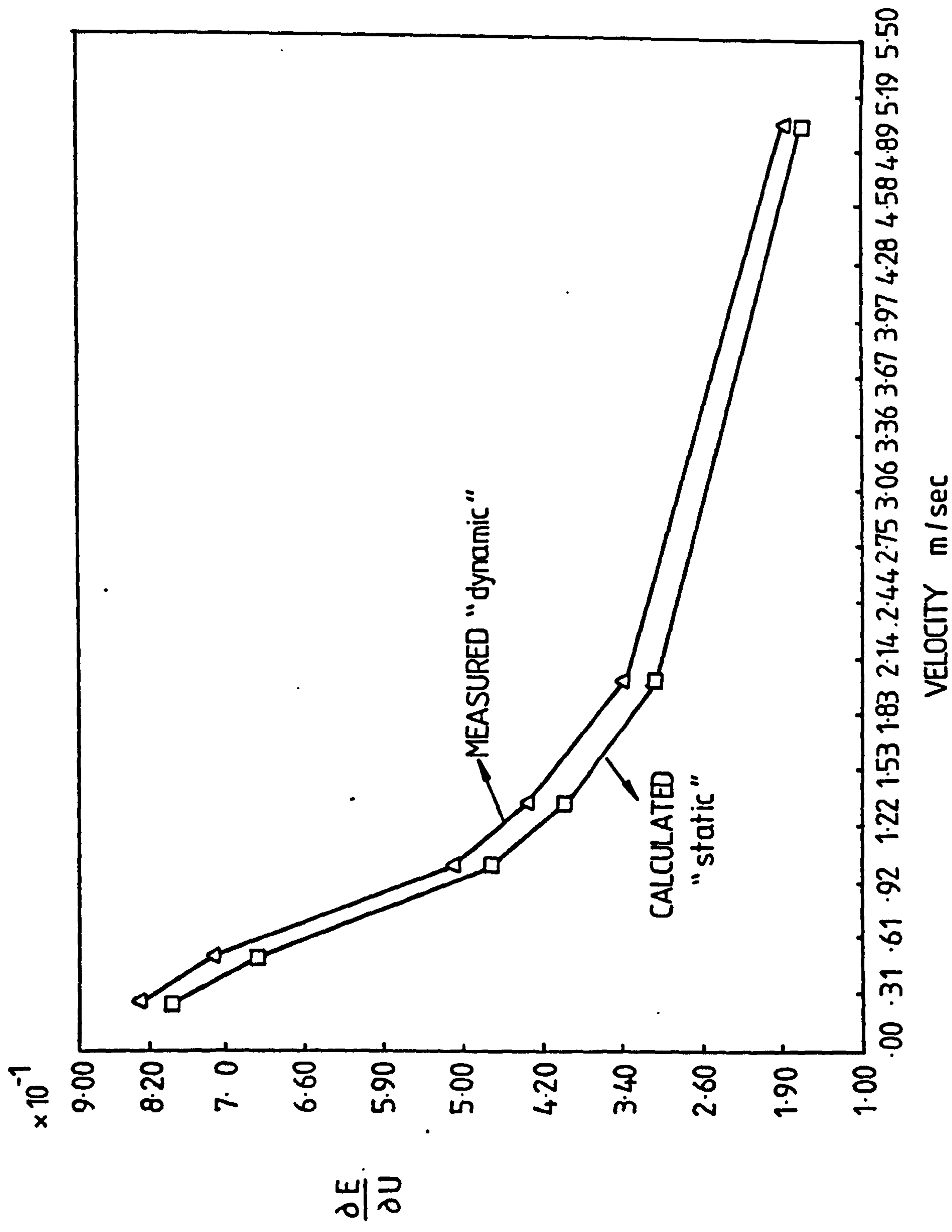


FIG 55 $\frac{\partial E}{\partial U}$ MEASURED AND CALCULATED FROM KING'S LAW

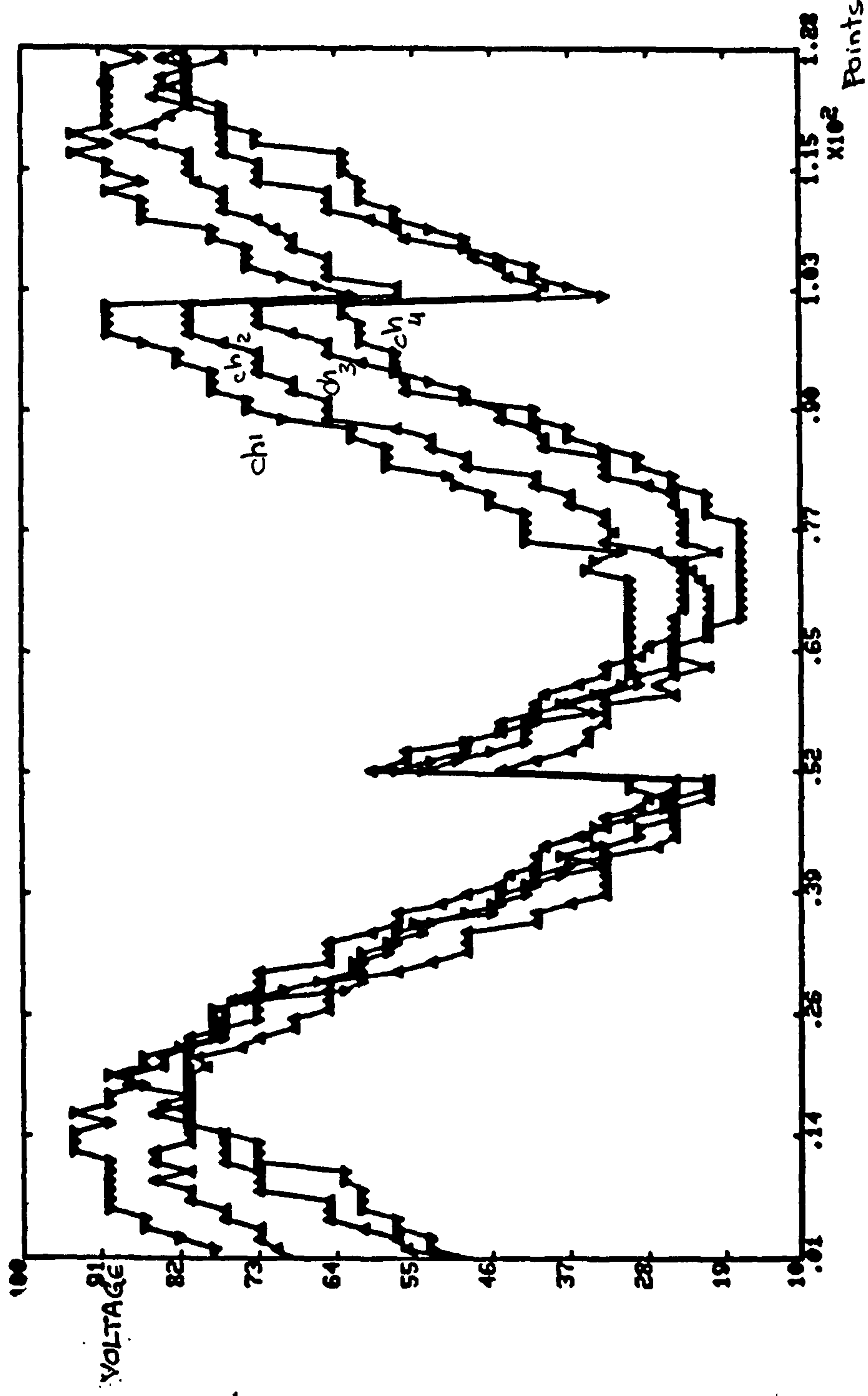


FIG56 OUTPUT DIGITIZING SIGNAL FROM THE FOUR CHANNELS

1000 R.P.M. VOLTAGE

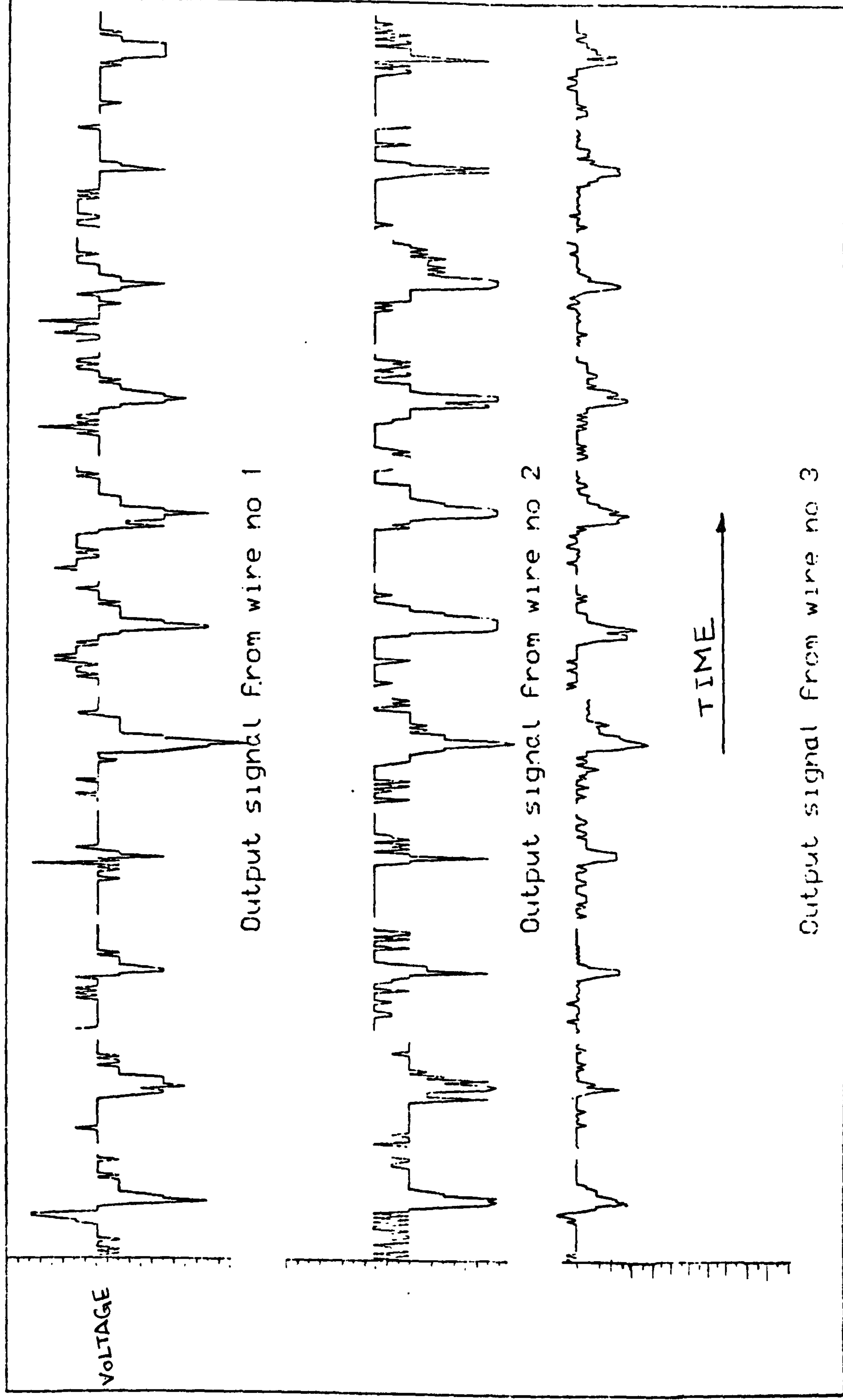


FIG 57 OUTPUT SIGNALS FROM THE THREE HOT WIRES.

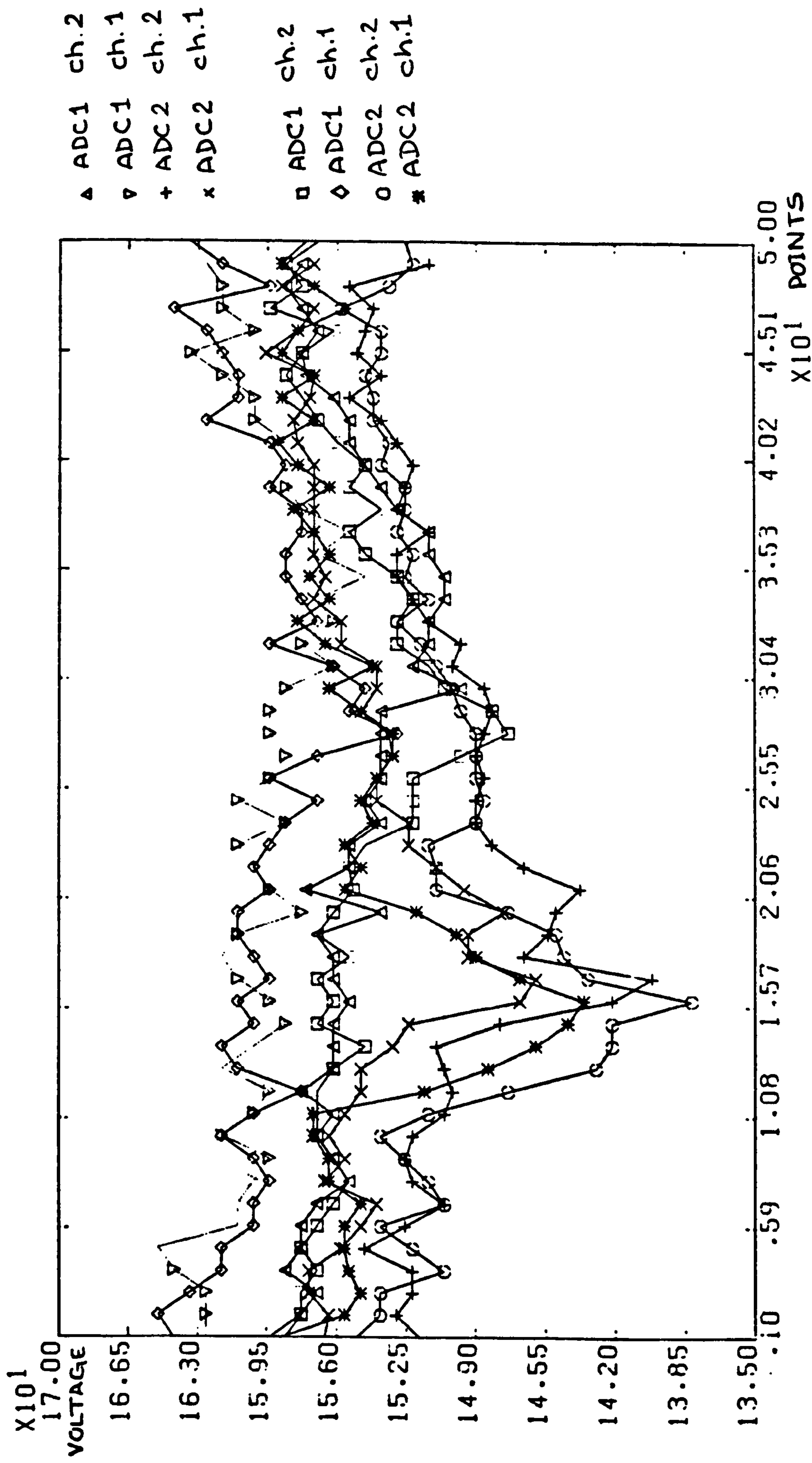


Fig 58 ADJUSTMENT OF THE ROTOR WAKE SIGNALS LOCATION WITH RESPECT TO THE HOT WIRE ASSEMBLY LOCATION.

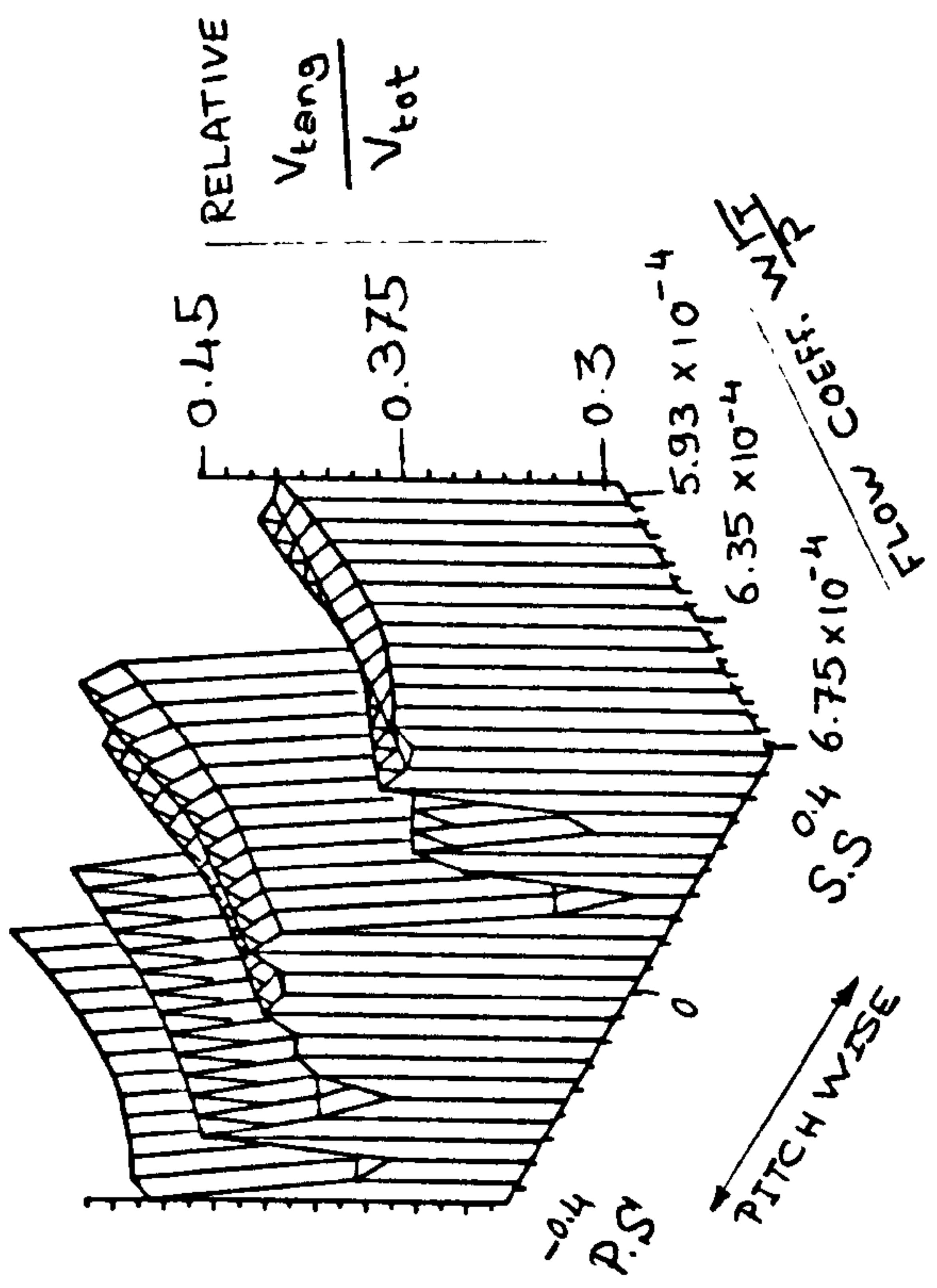
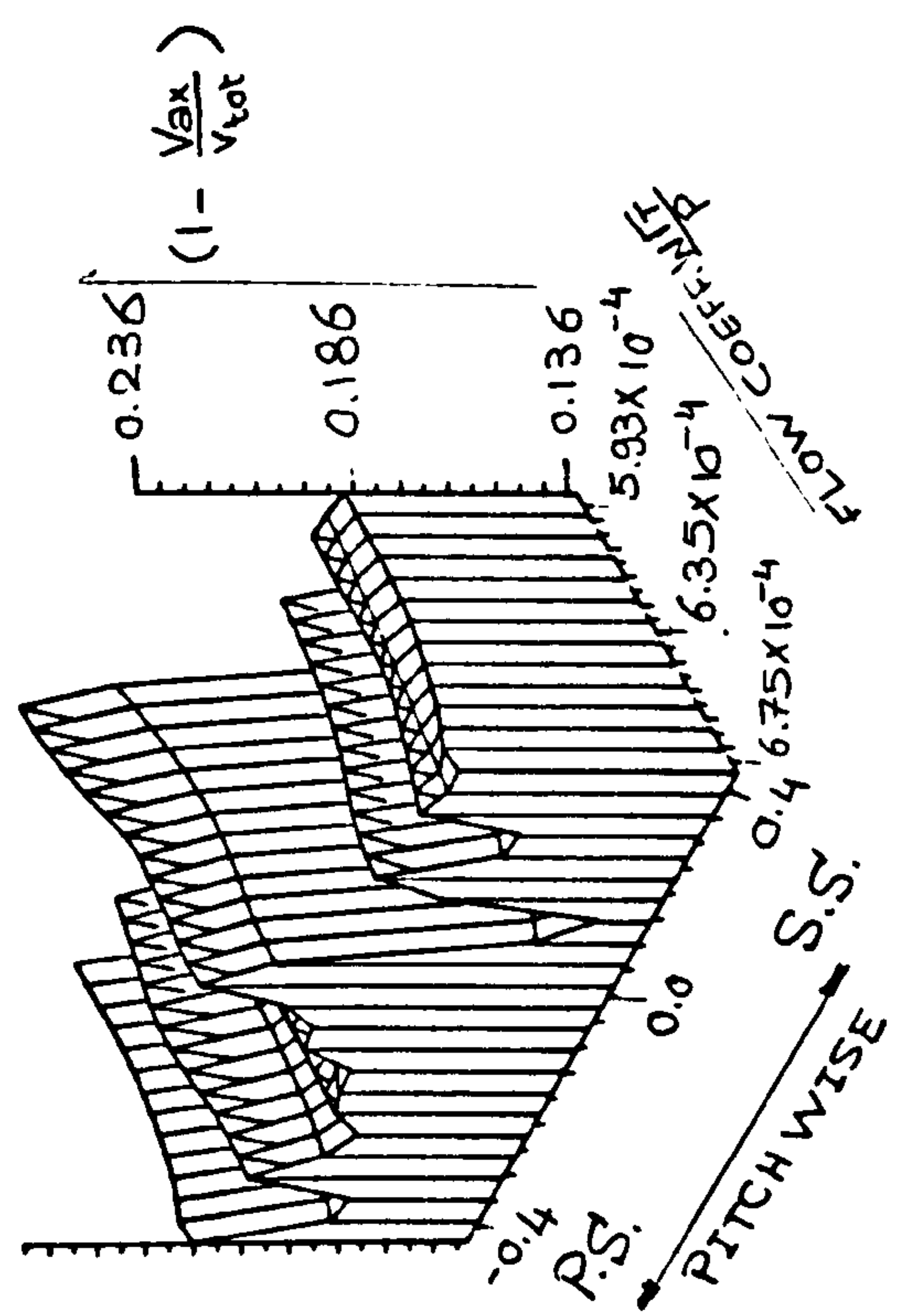
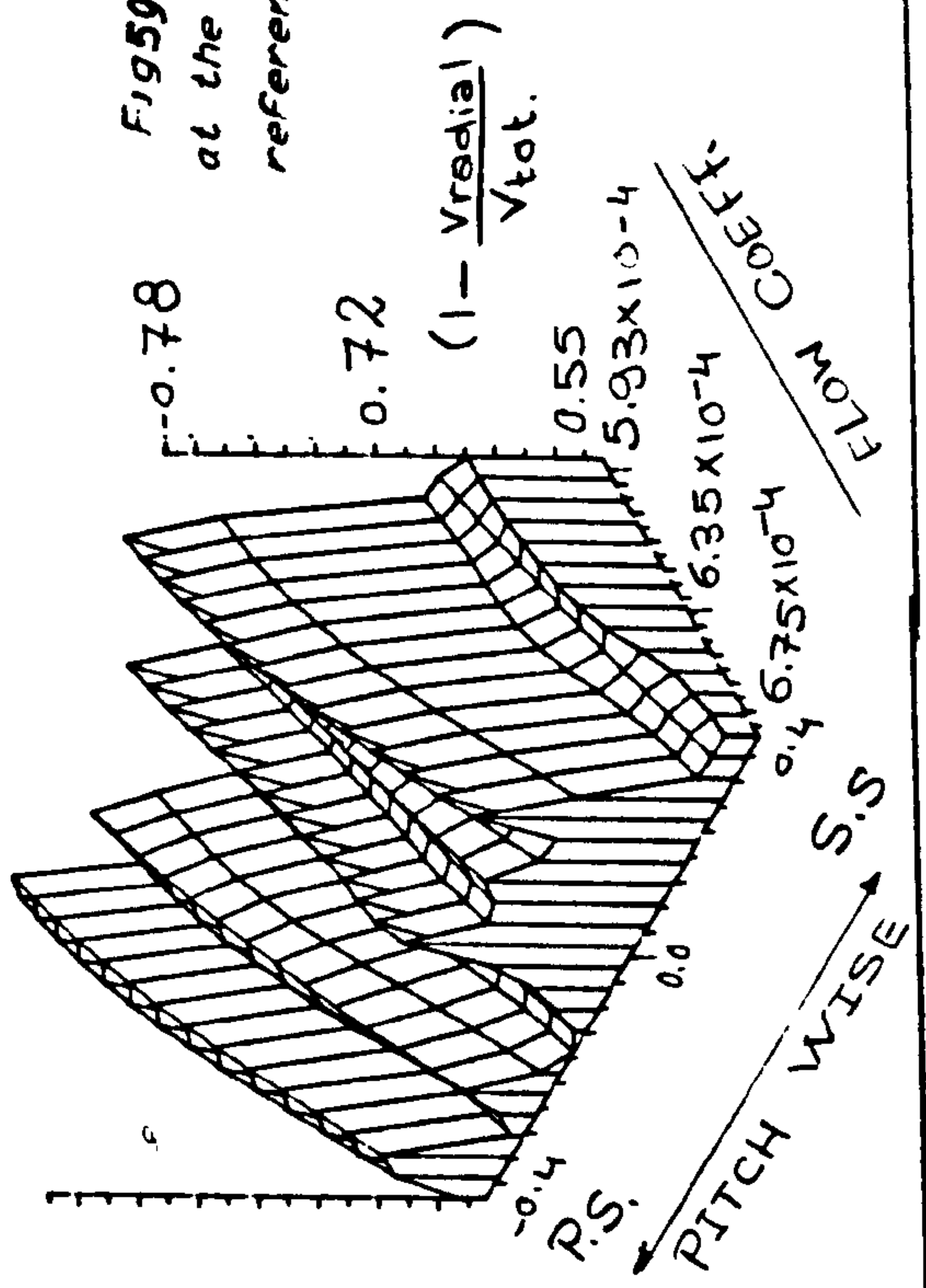


Fig 59 Distribution of 3-D velocities at the turbomachinery relative frame of reference at: R.P.M - 1000
HEIGHT = 3

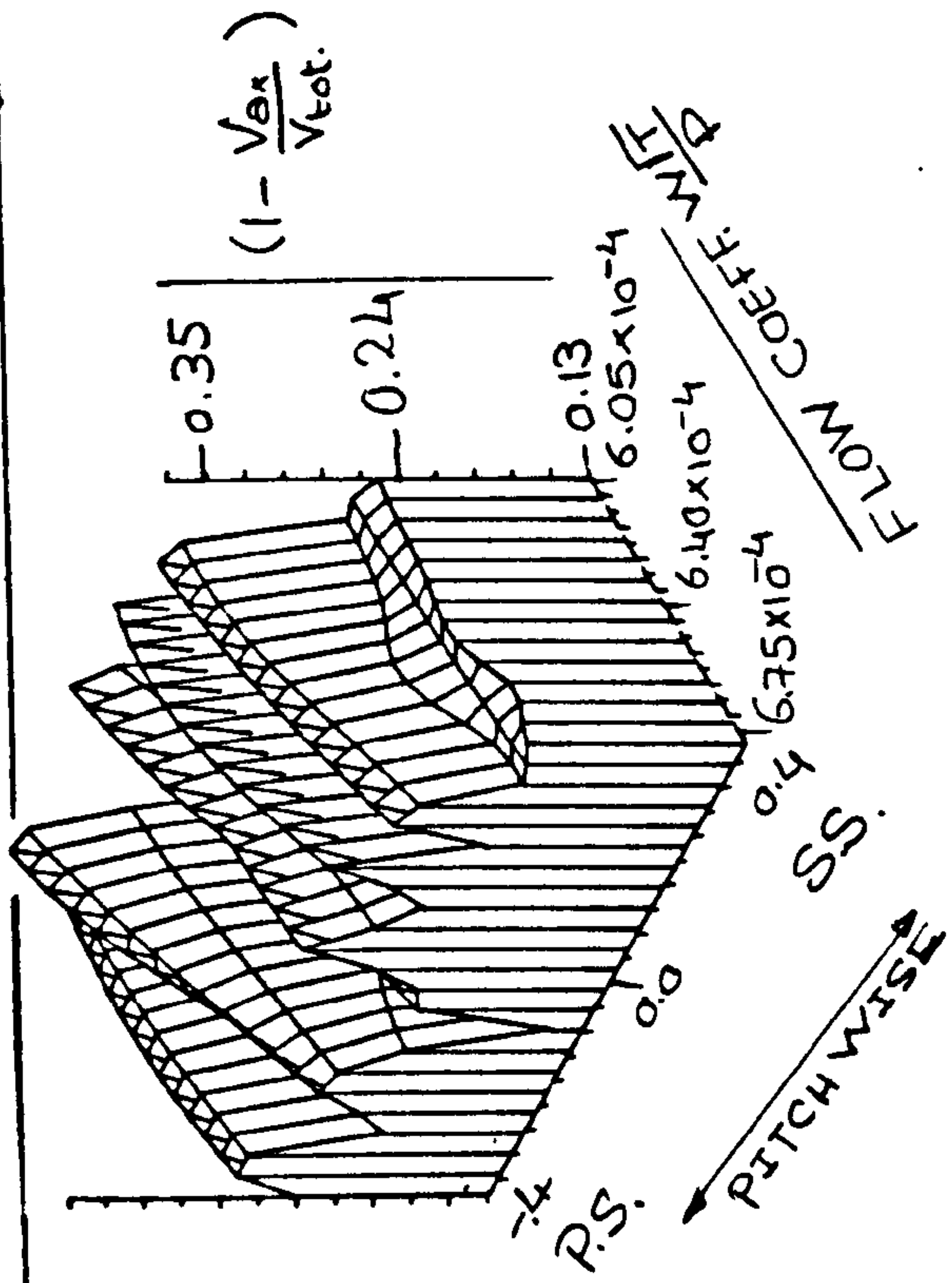
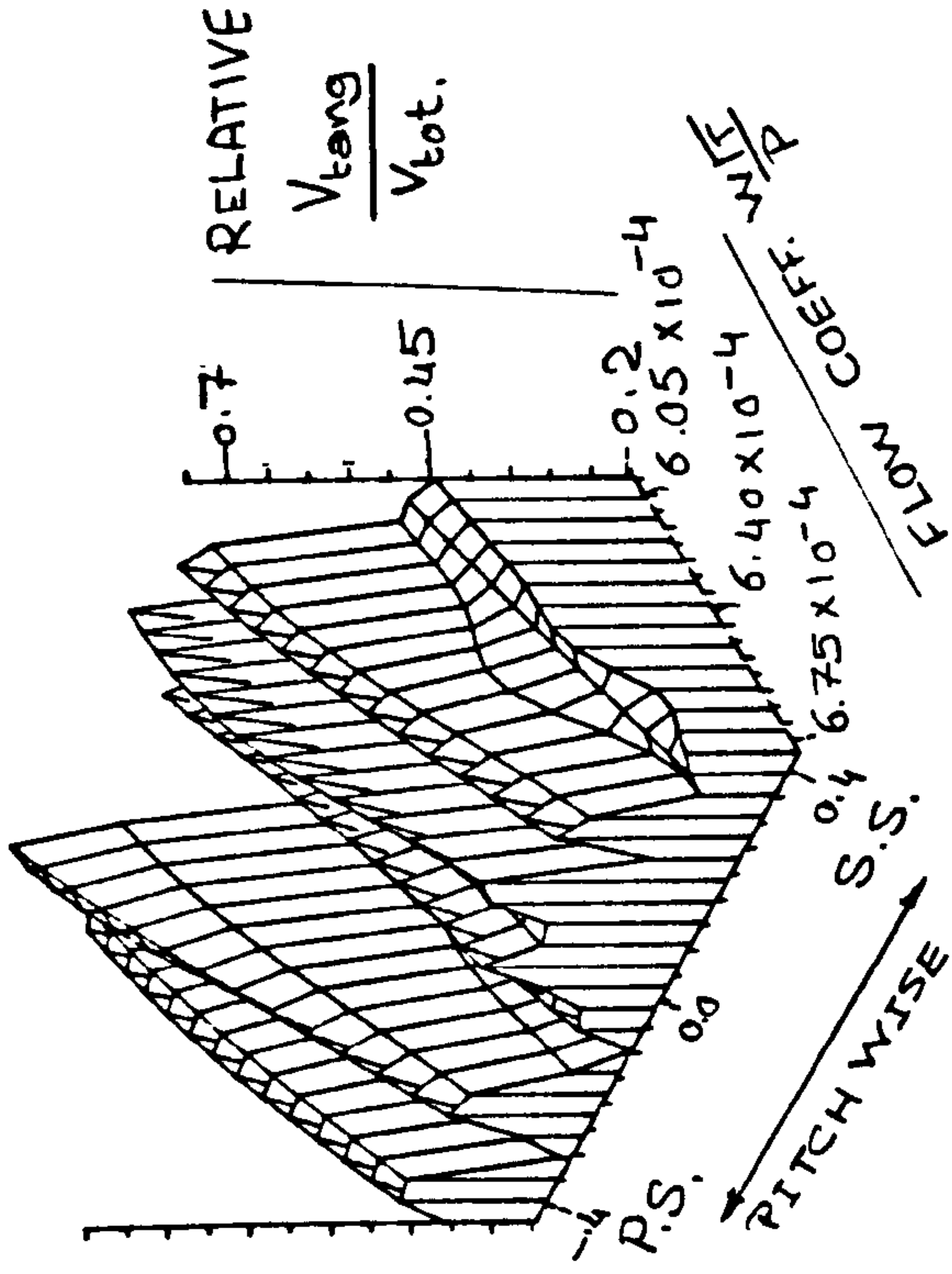
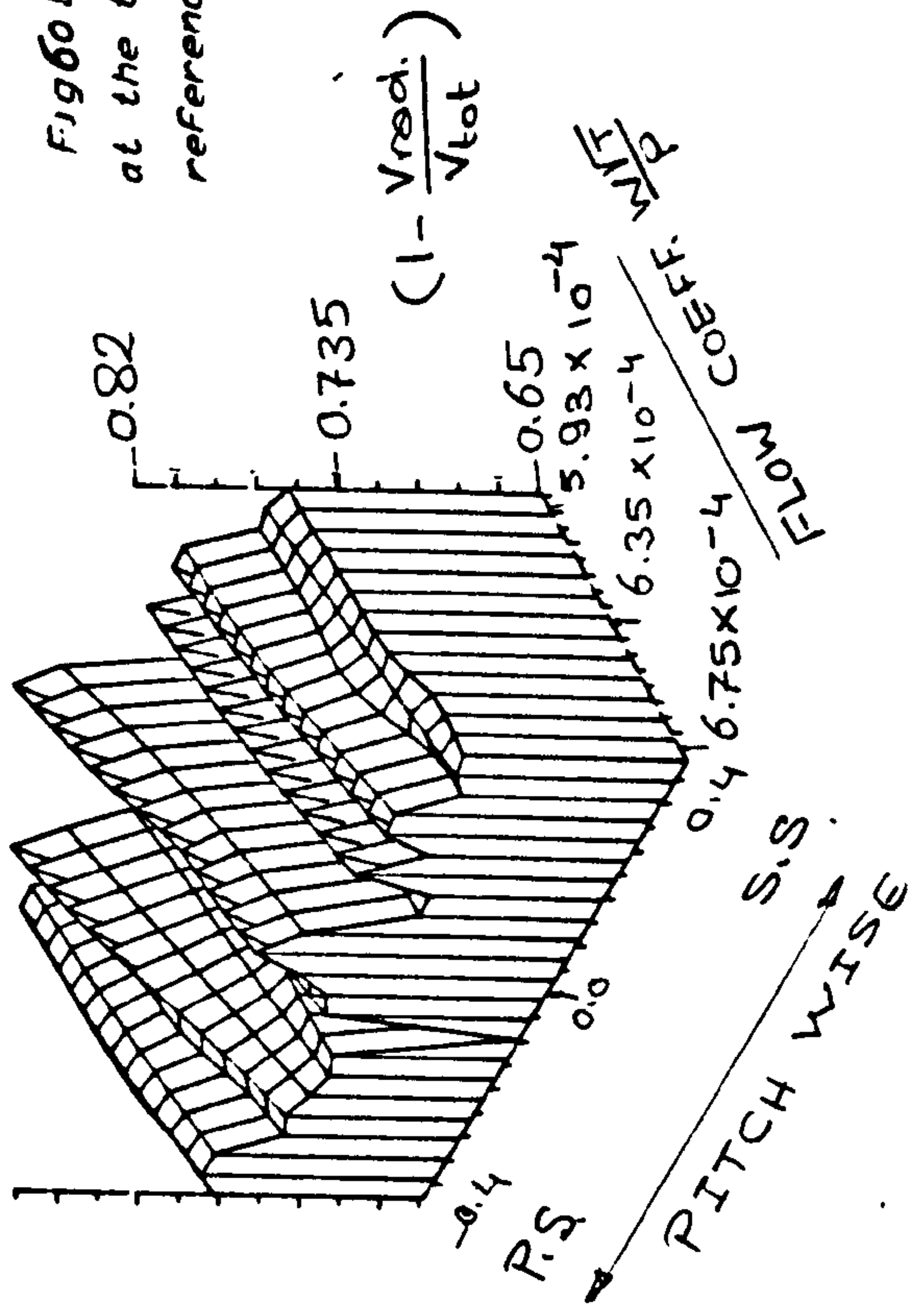


Fig 60 Distribution of 3-D velocities at the turbomachinery relative frame of reference at: R.P.M. = 1250 HEIGHT = 3

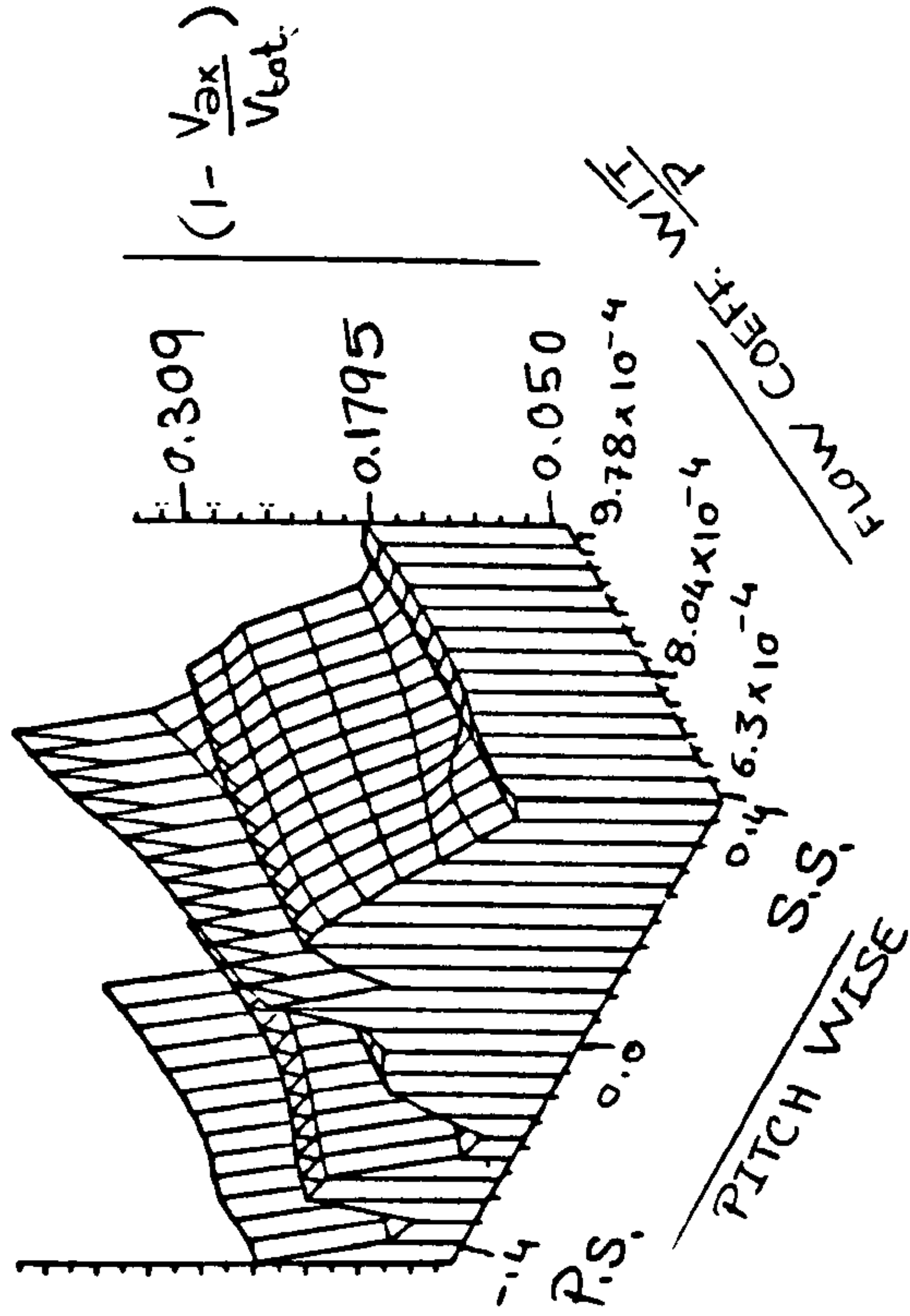
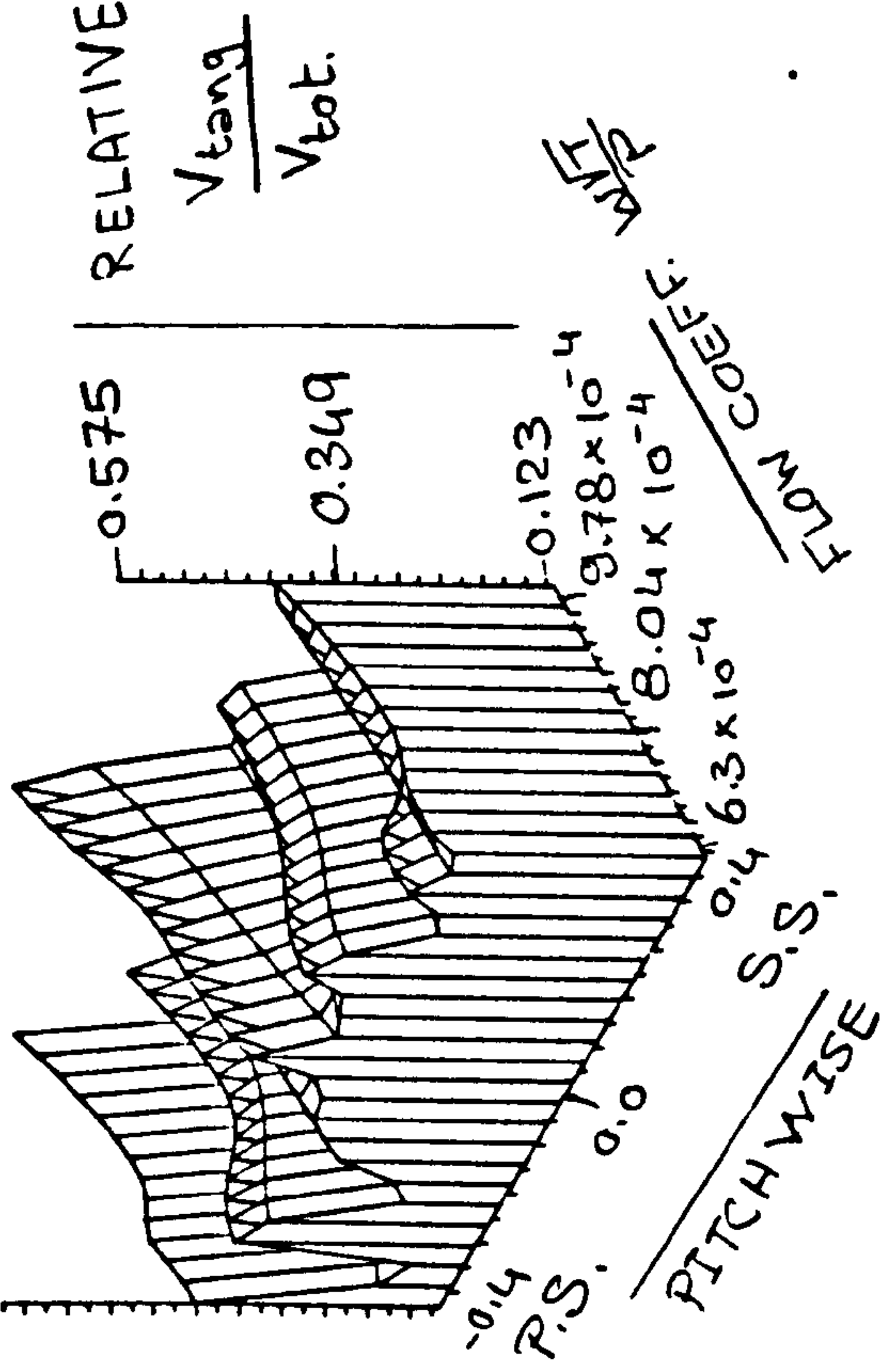
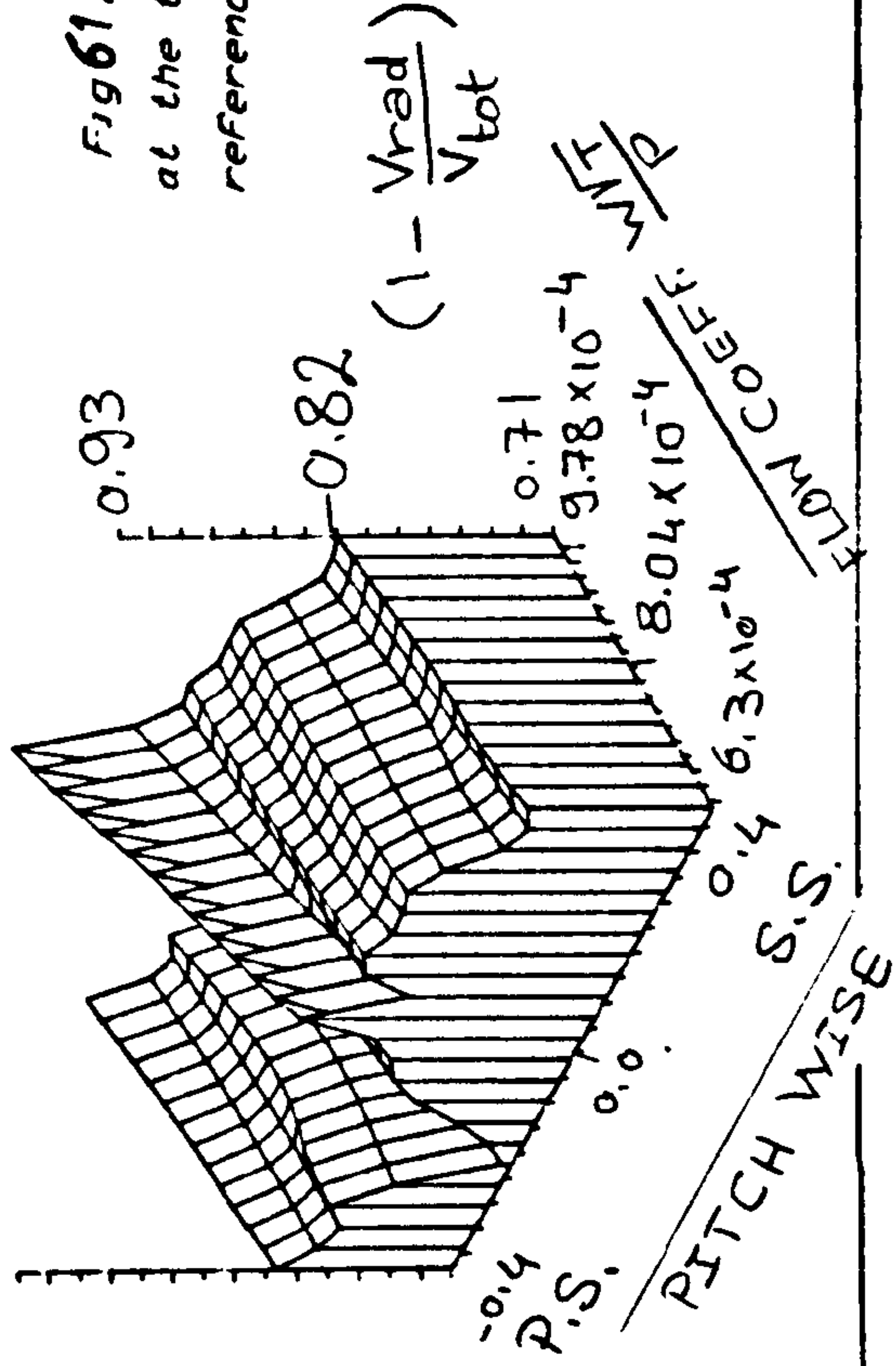


Fig 61 Distribution of 3-D velocities at the turbomachinery relative frame of reference at: R.P.M. = 1500
HEIGHT = 3

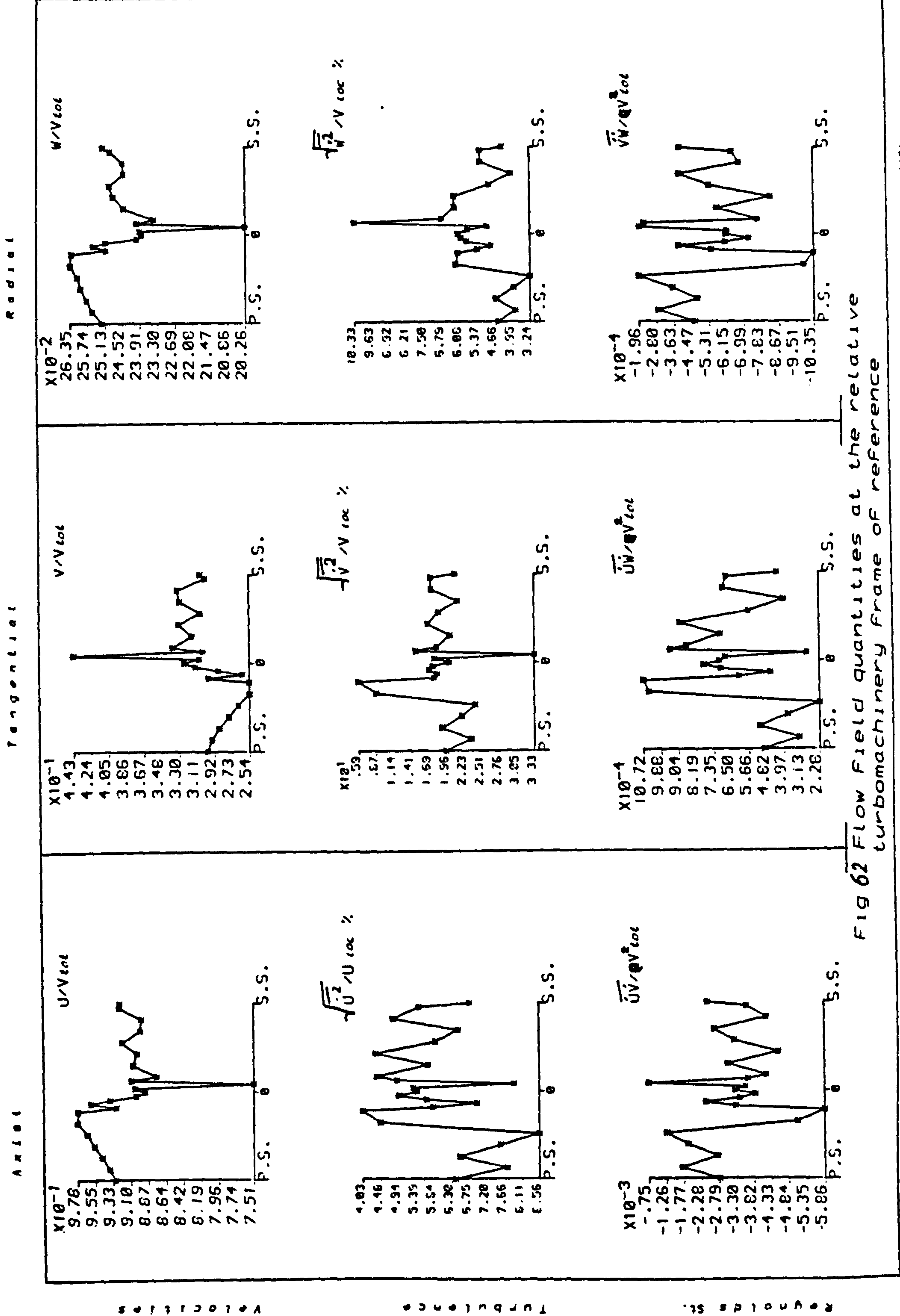


Fig 62 Flow field quantities at the relative turbomachinery frame of reference

Axial

Tangential

Radial

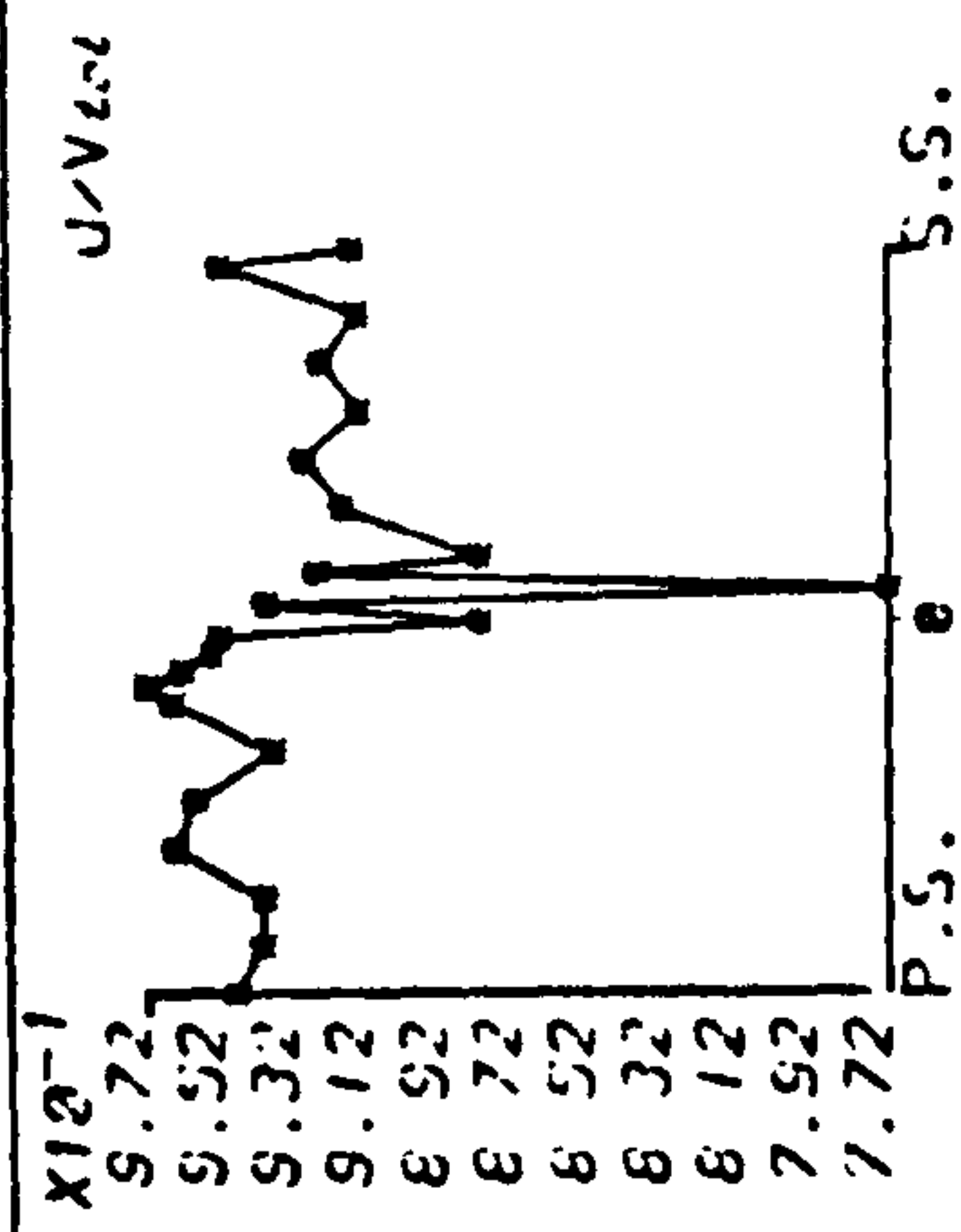
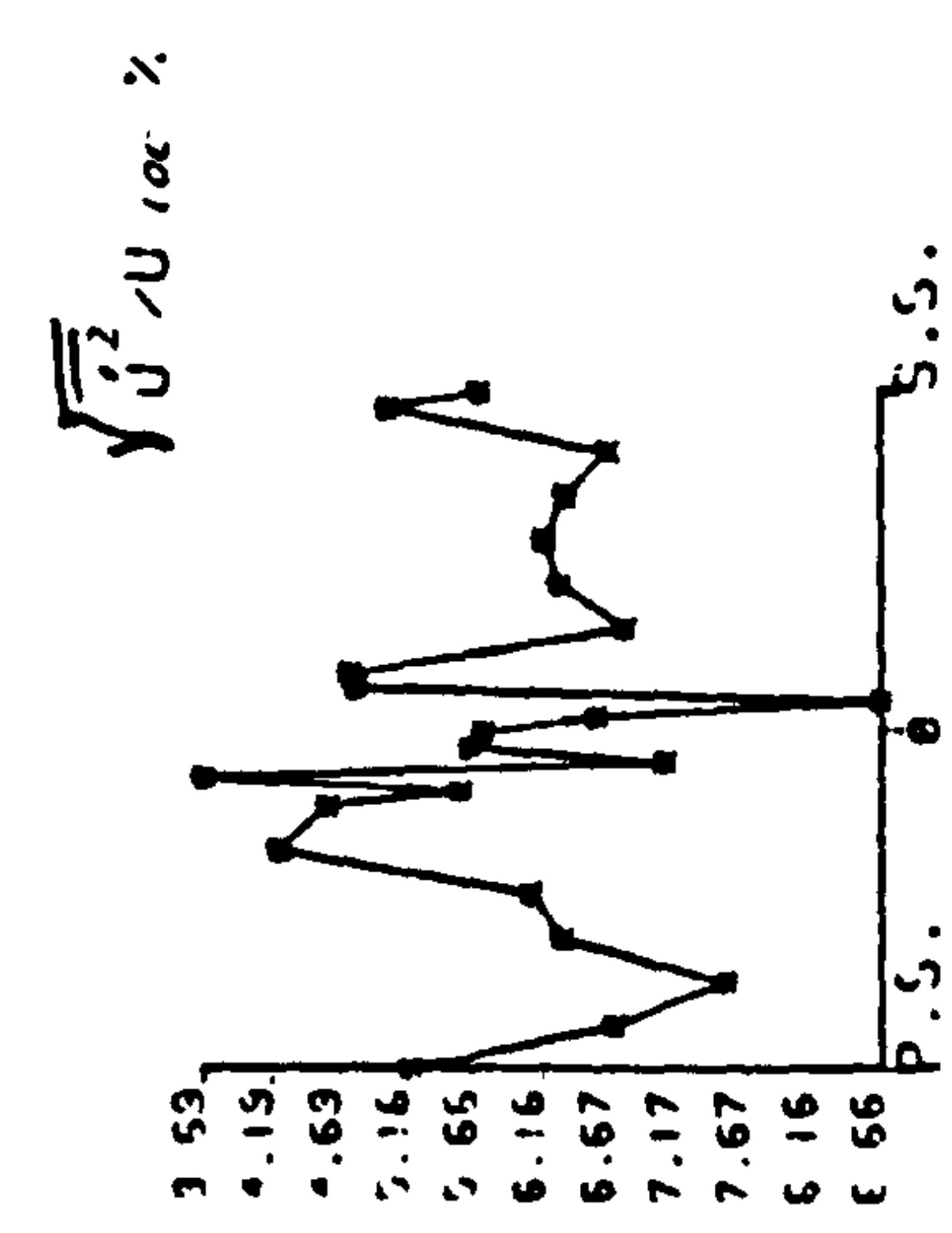
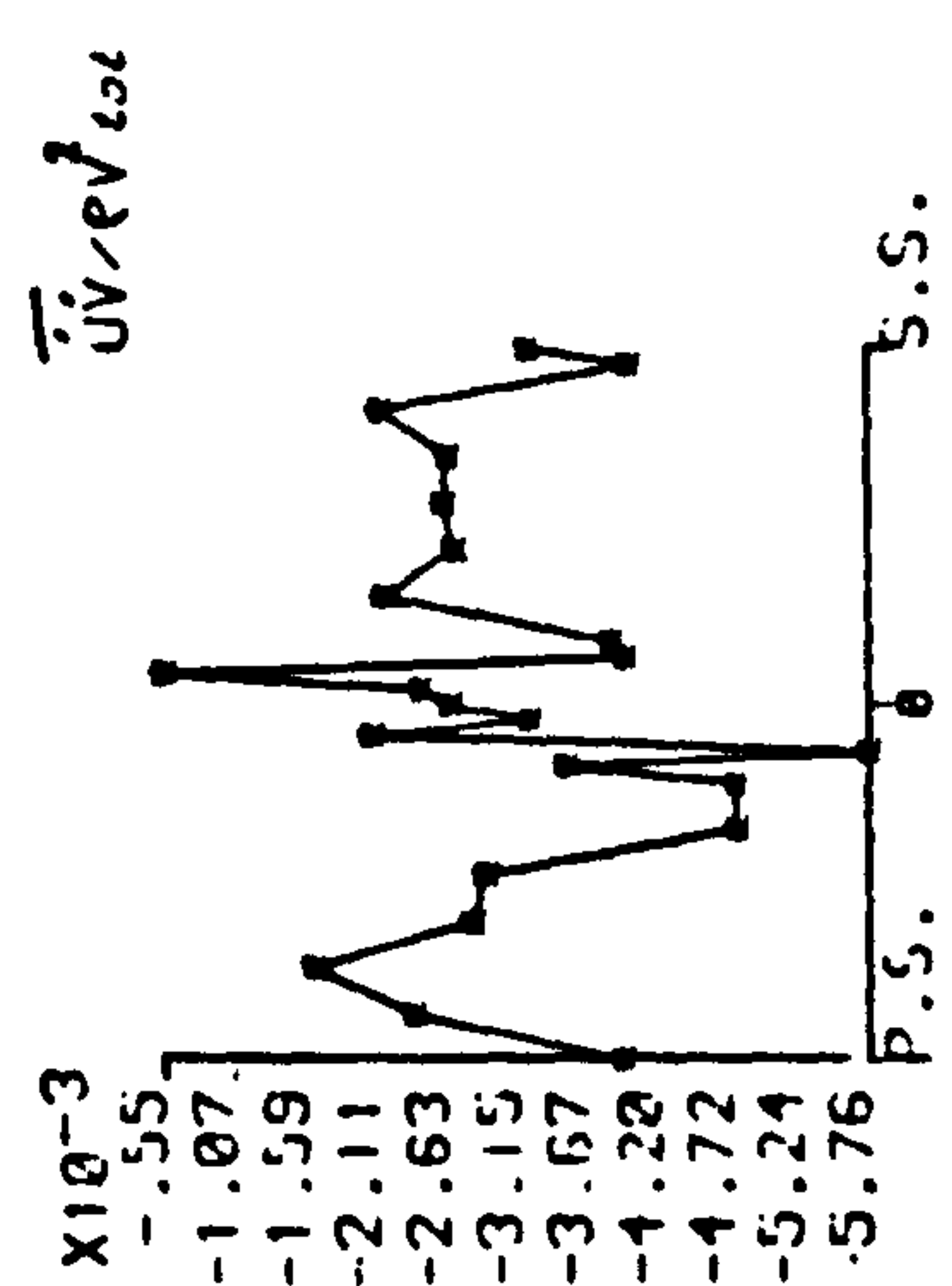
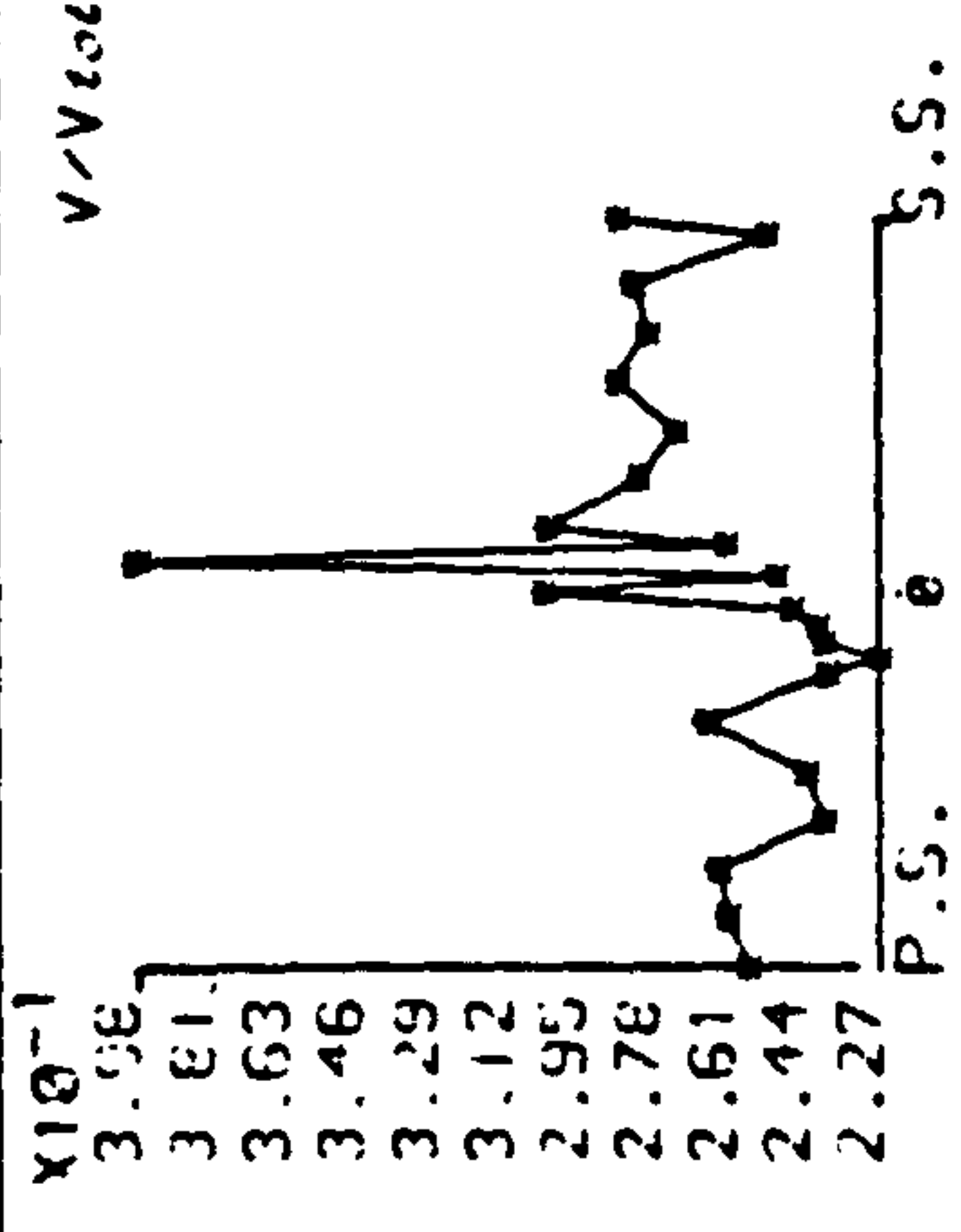
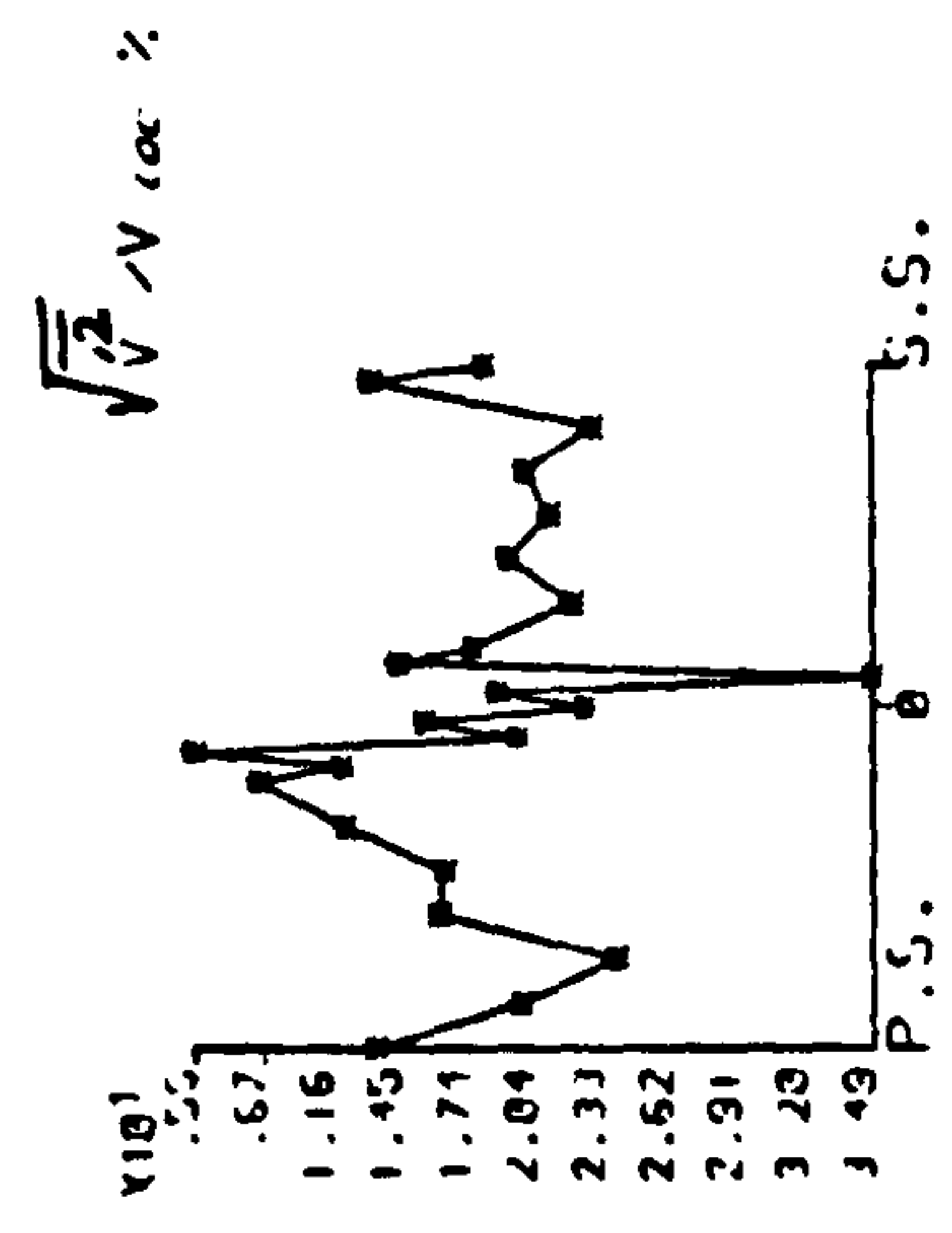
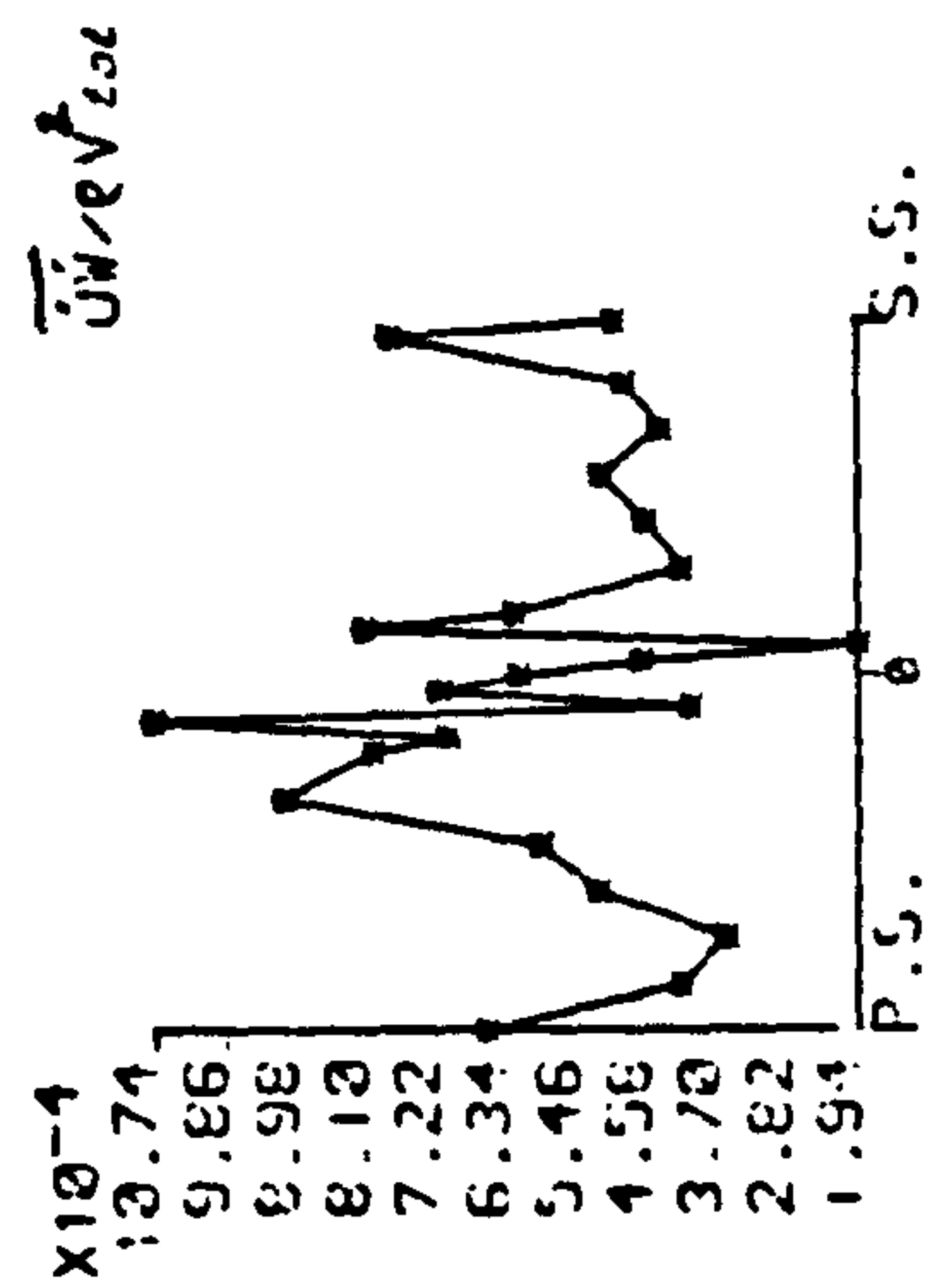
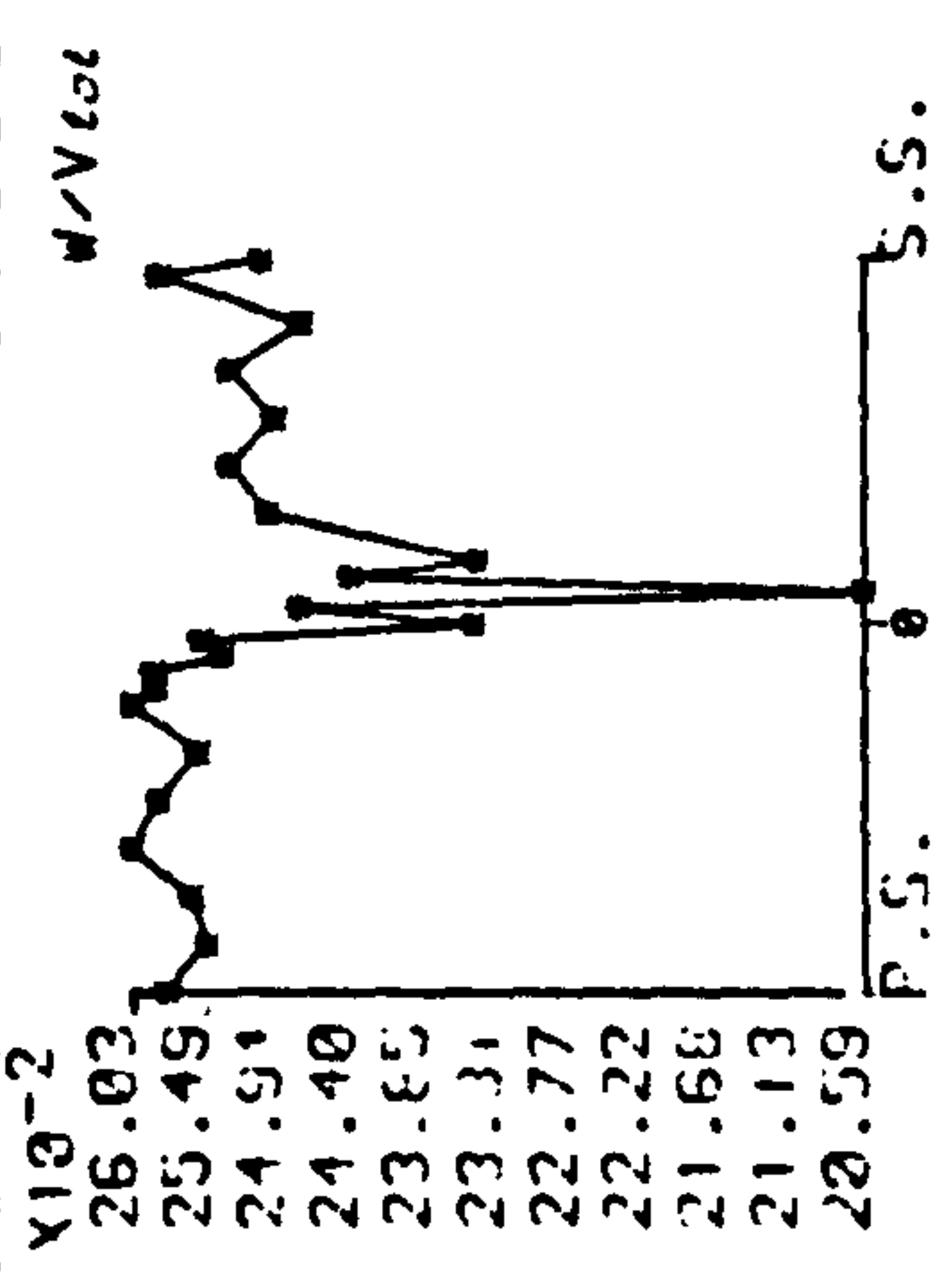
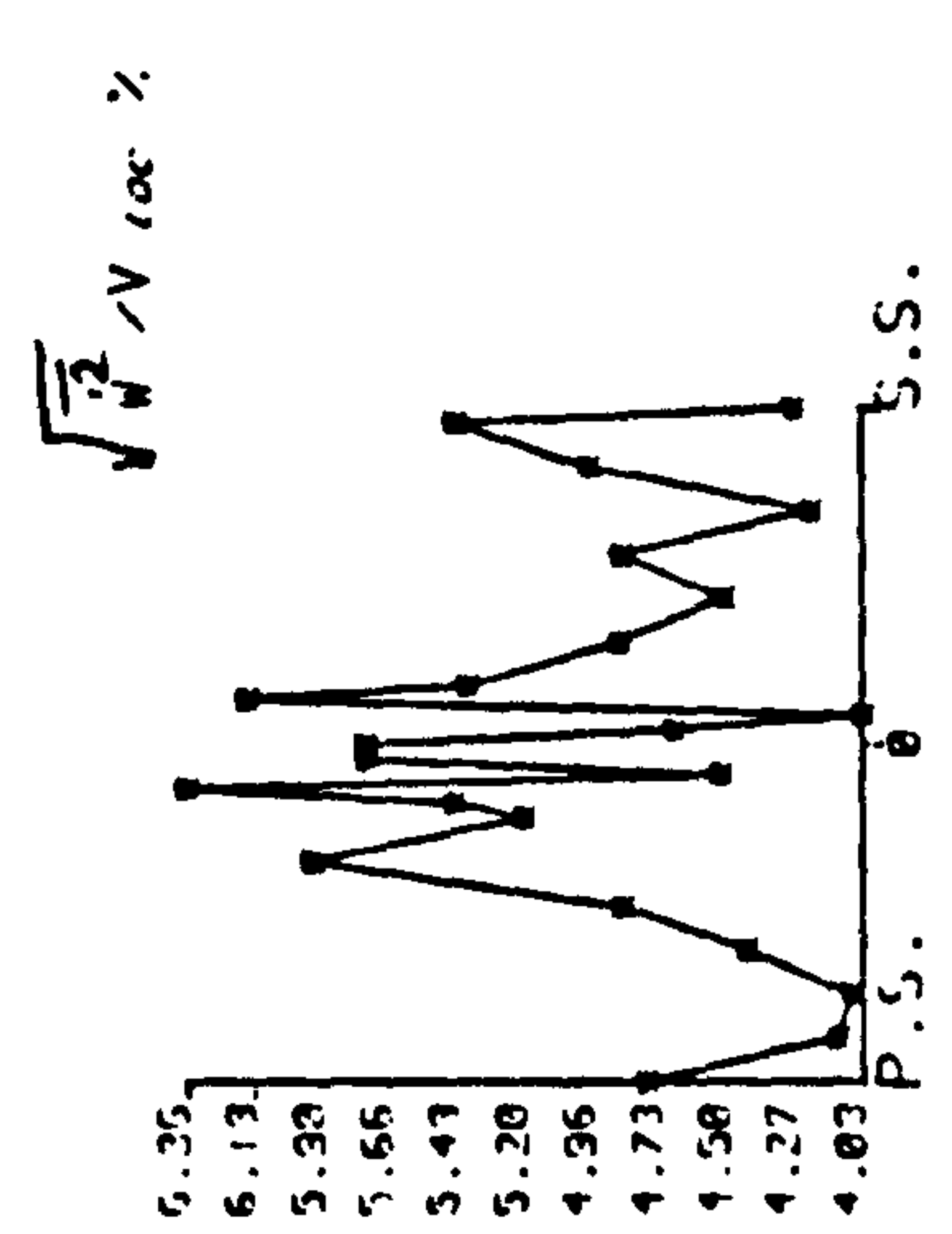
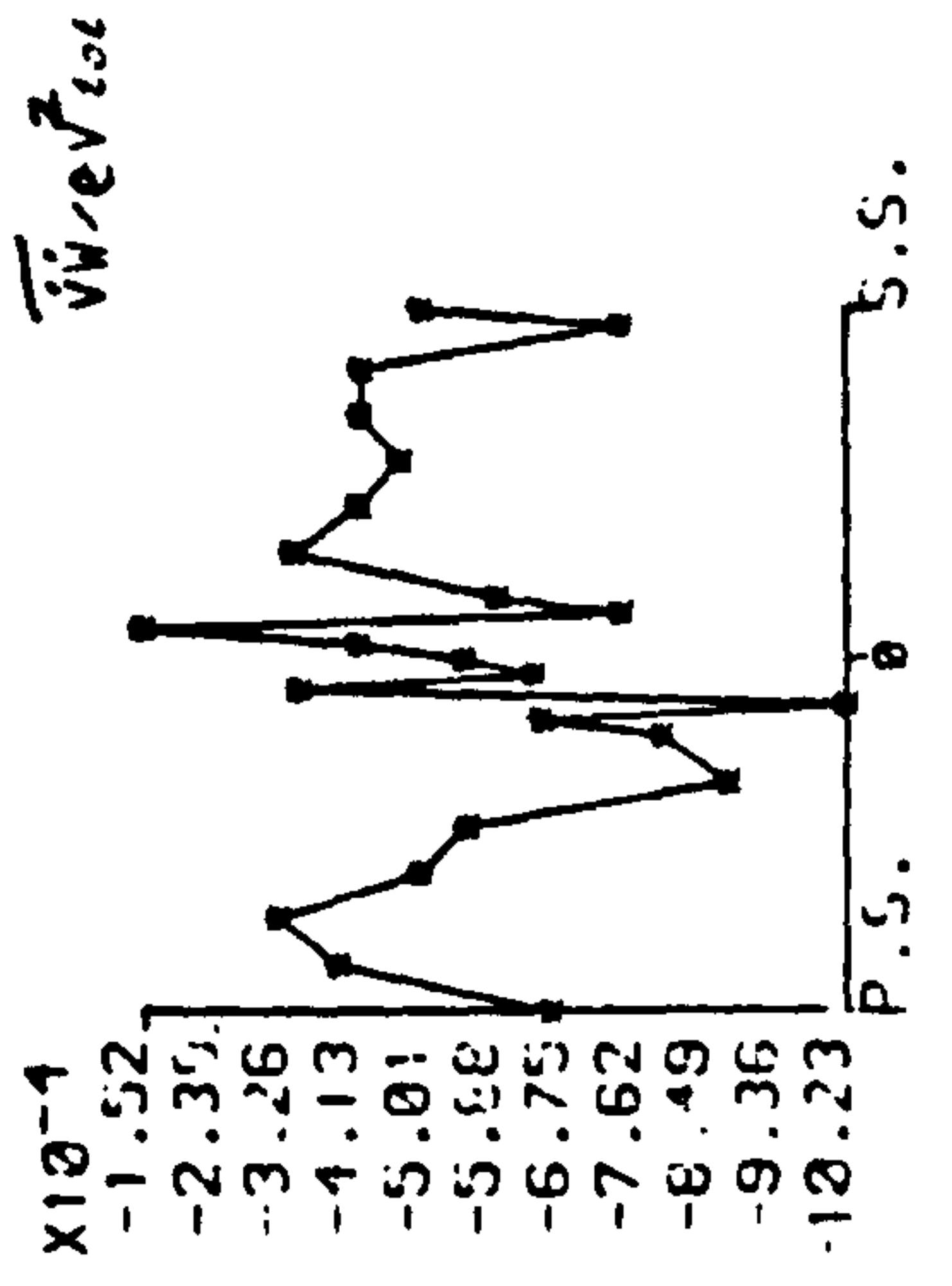


Fig 63 Flow Field quantities at the relative turbomachinery frame of reference

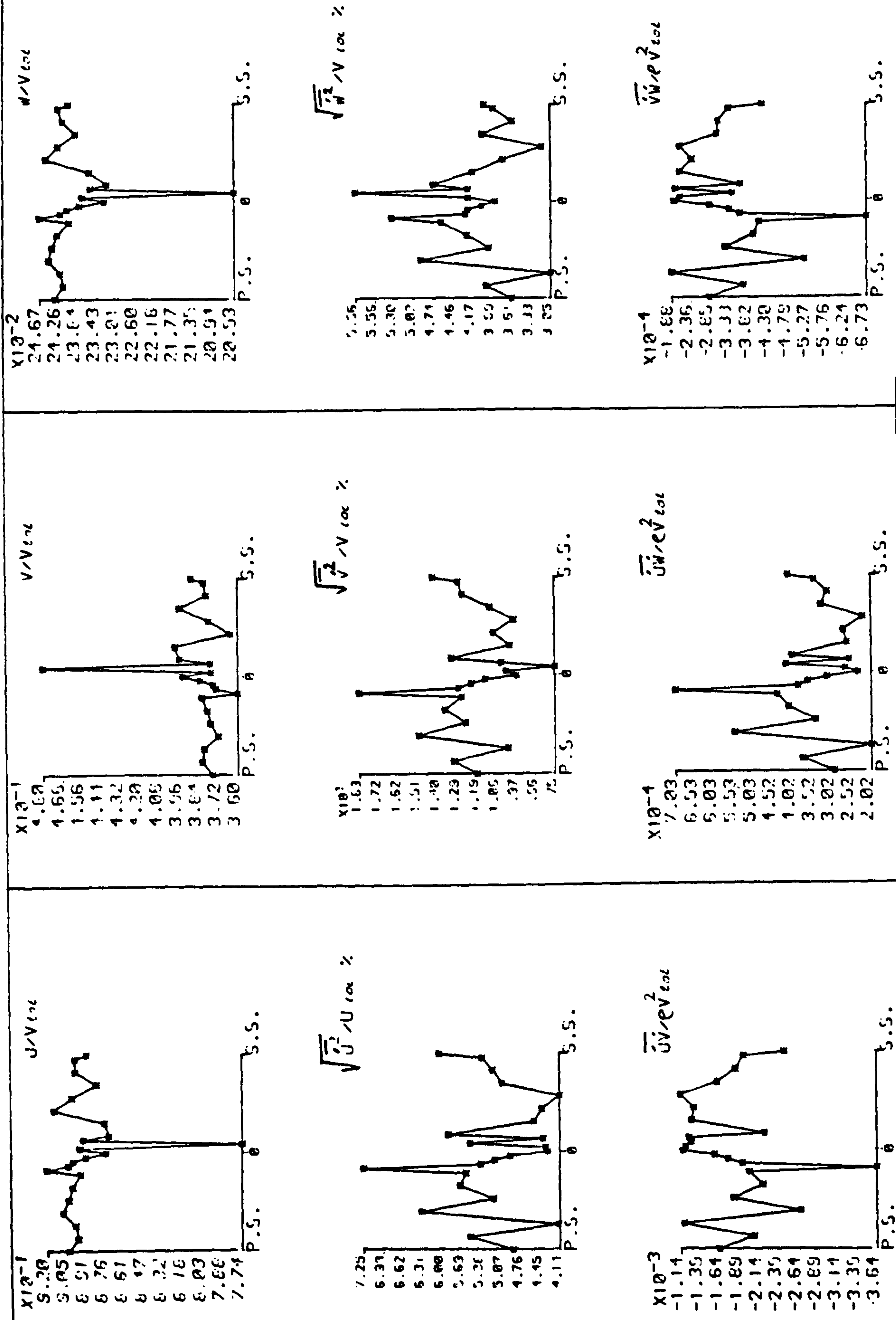


Fig 64 Flow field quantities at the relative turbomachinery frame of reference

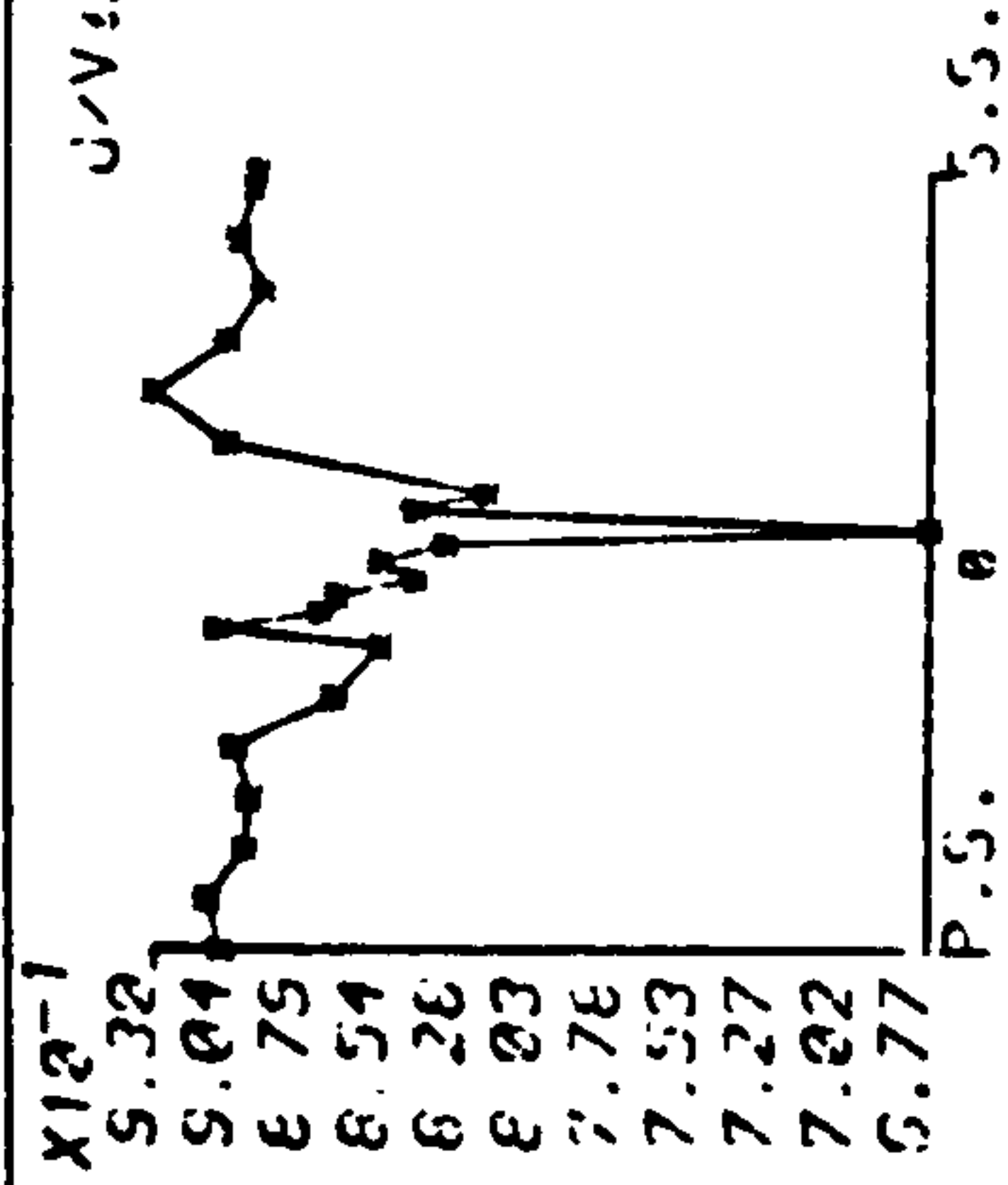
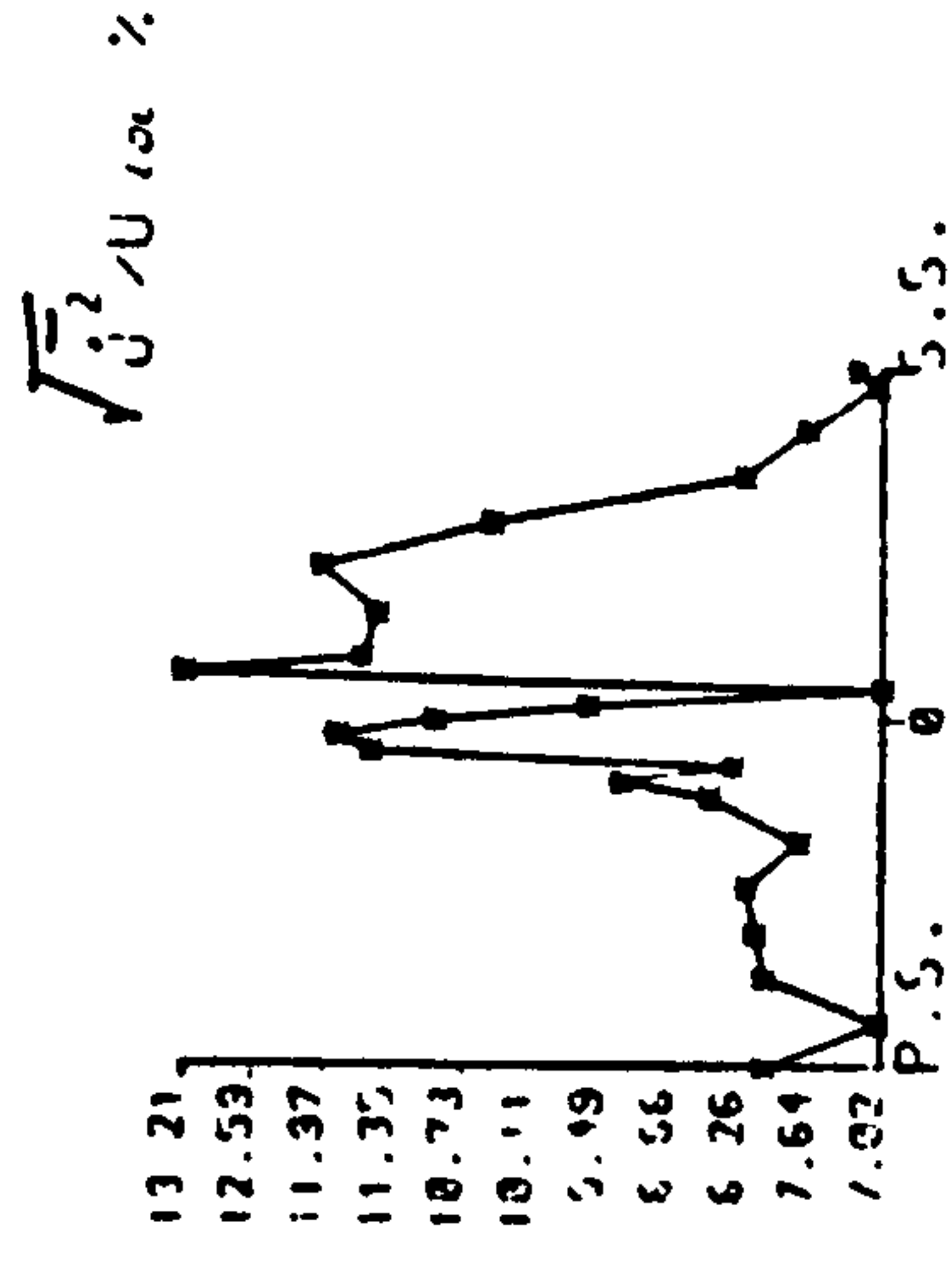
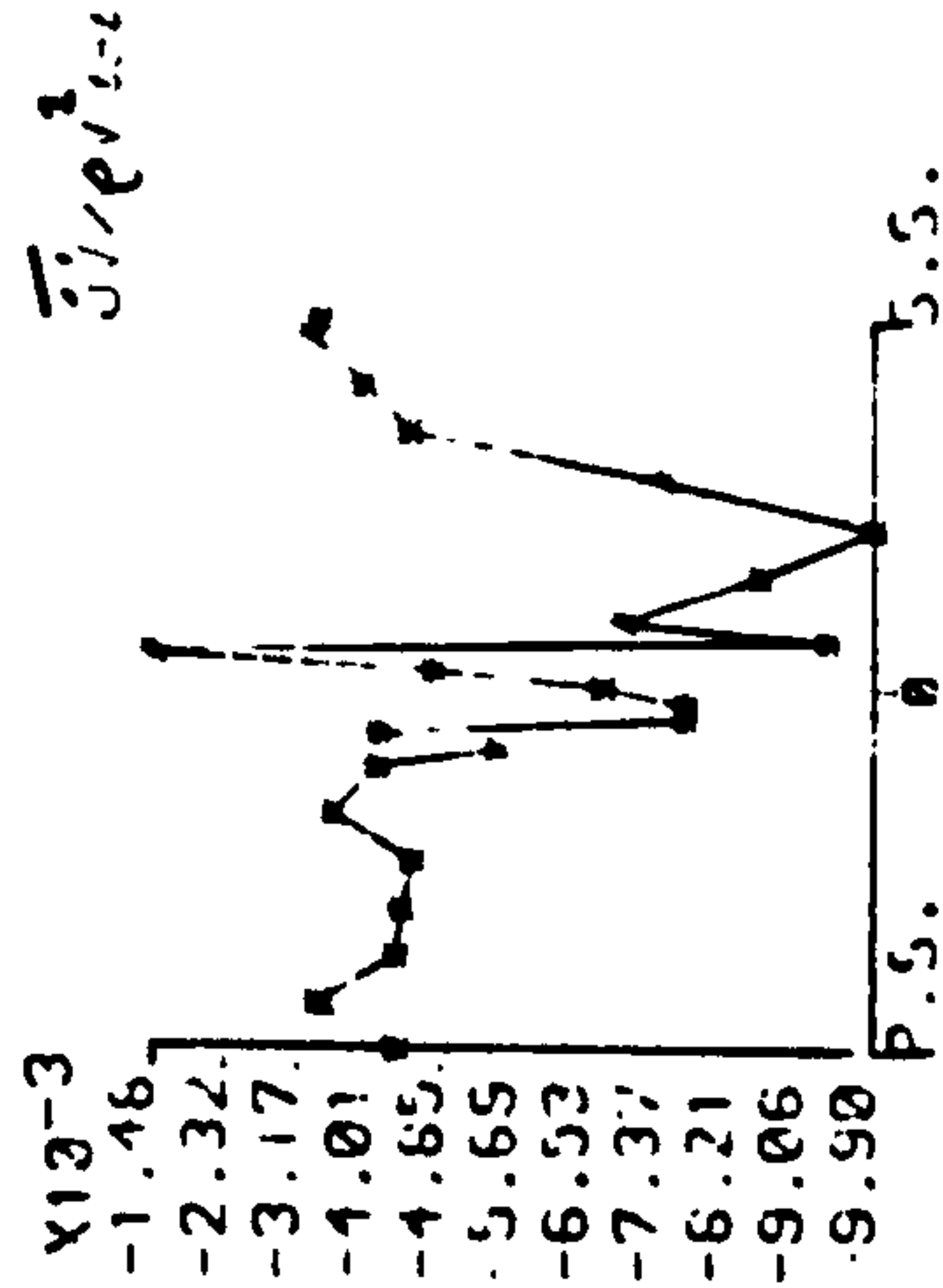
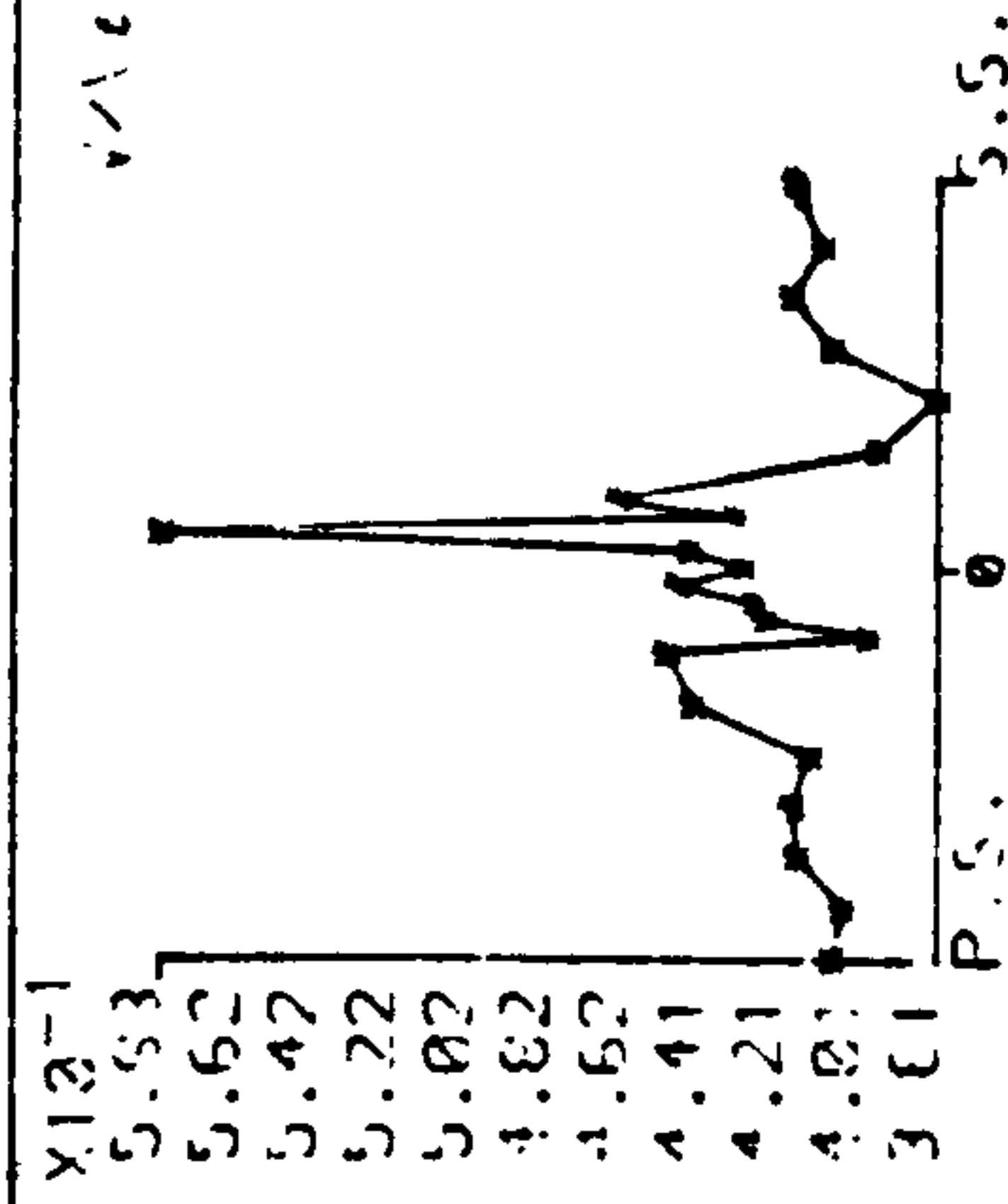
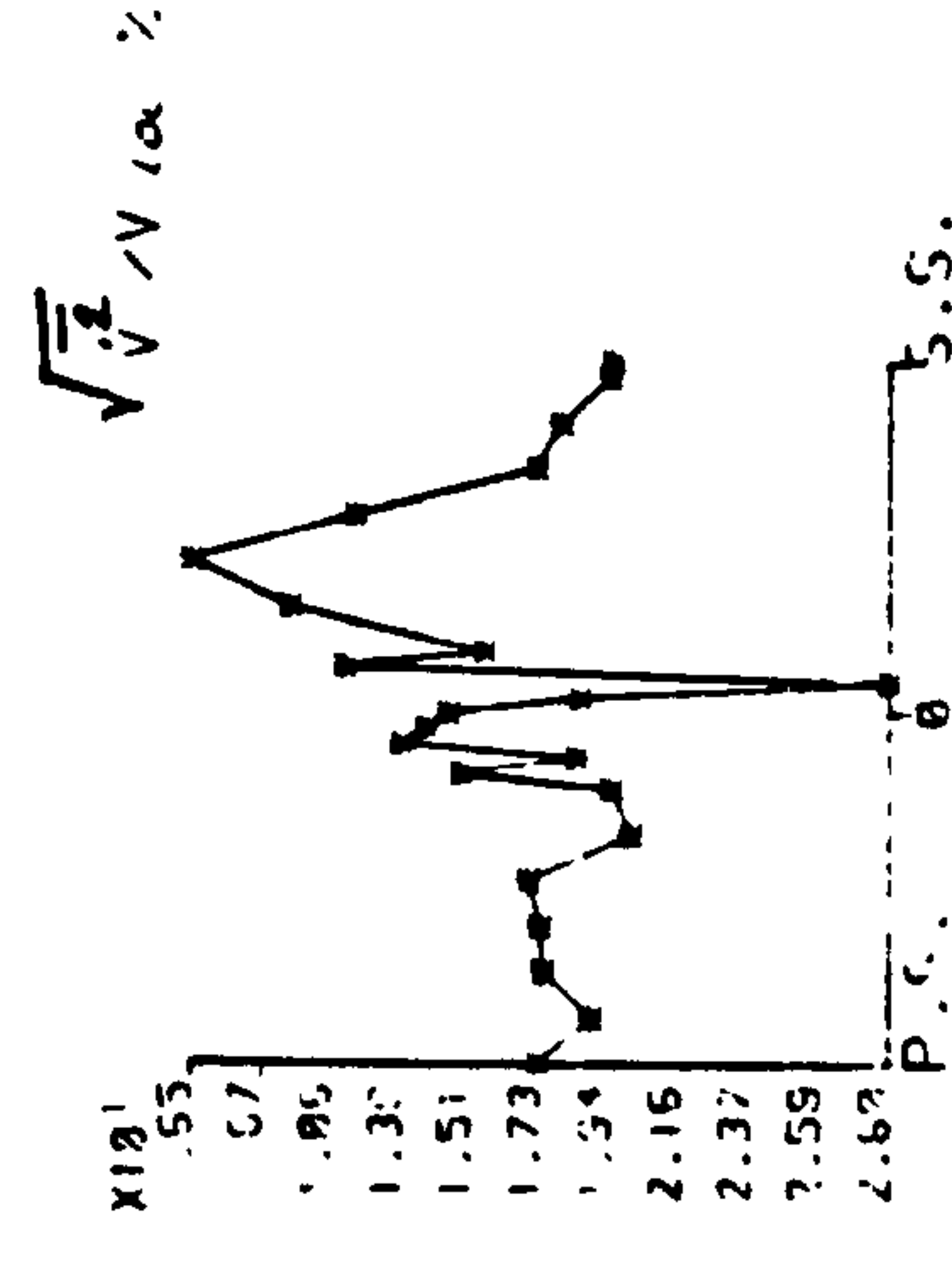
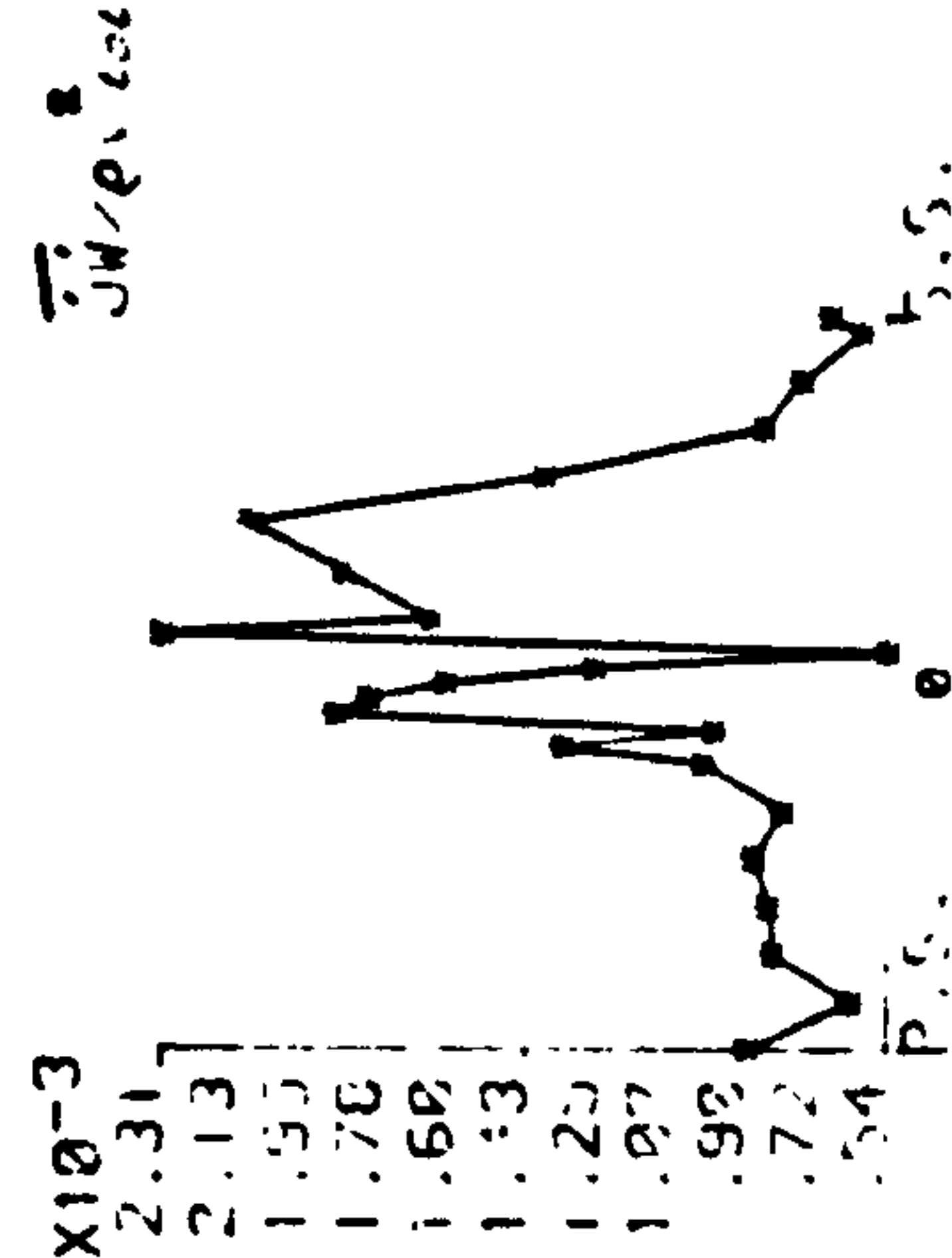
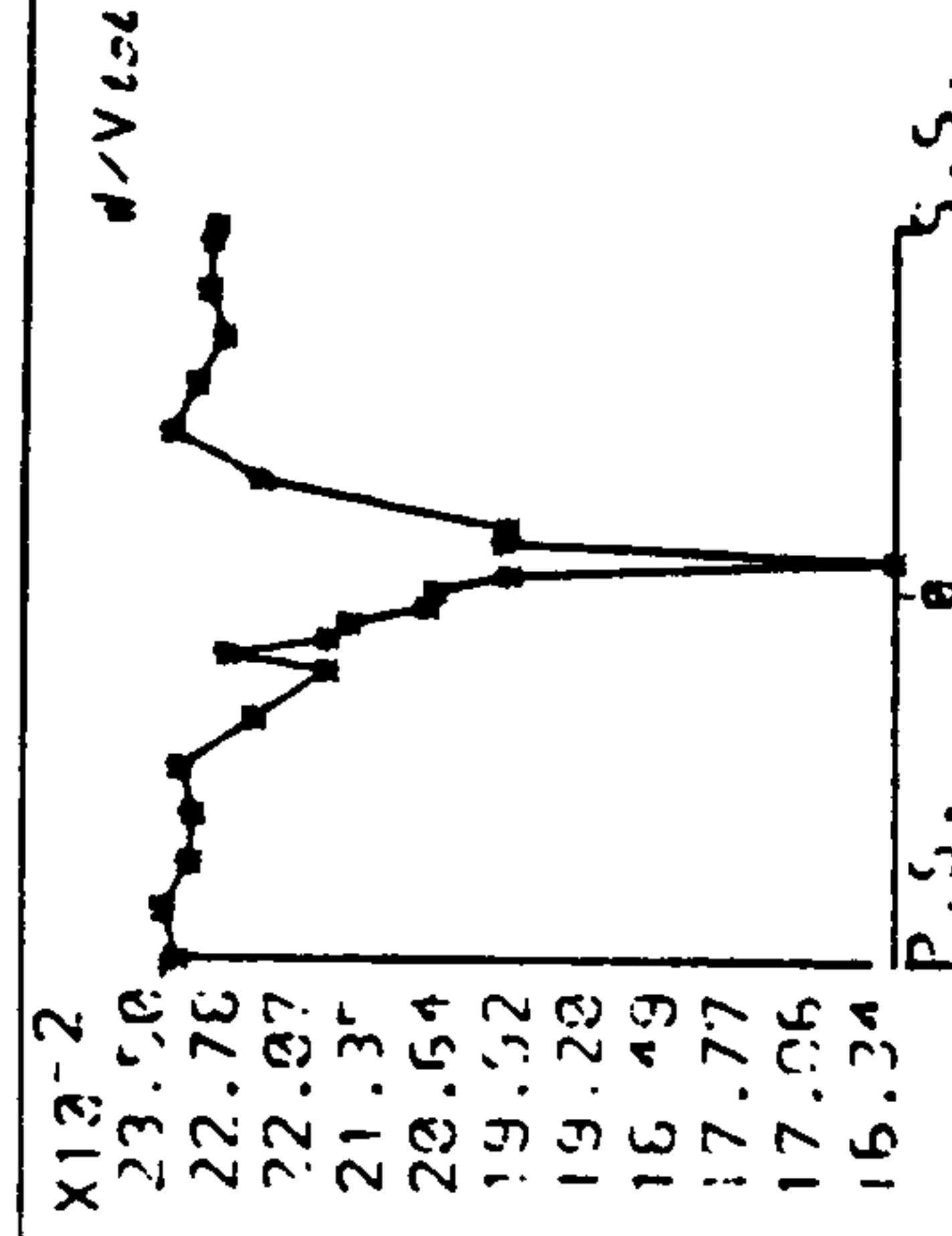
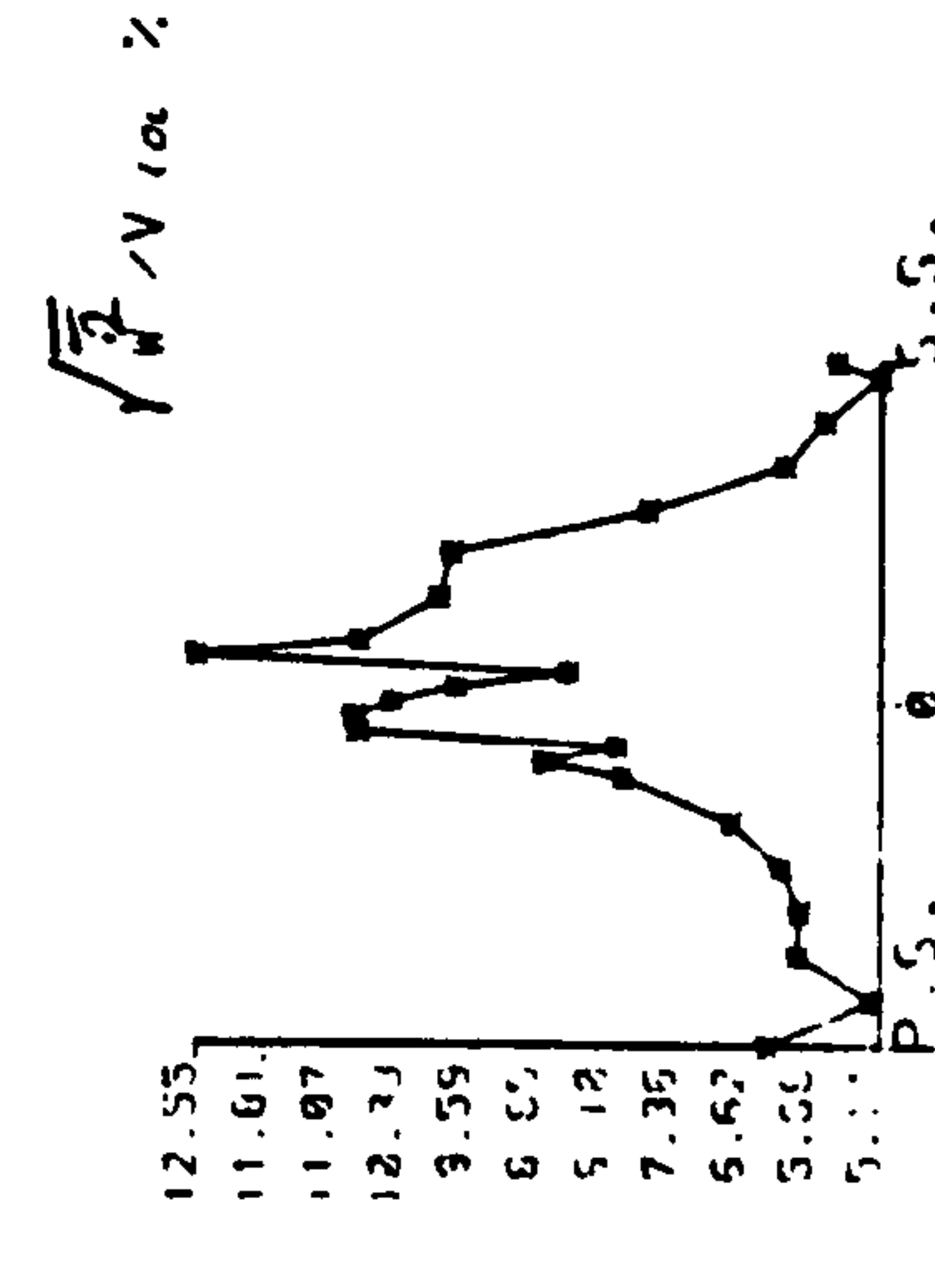
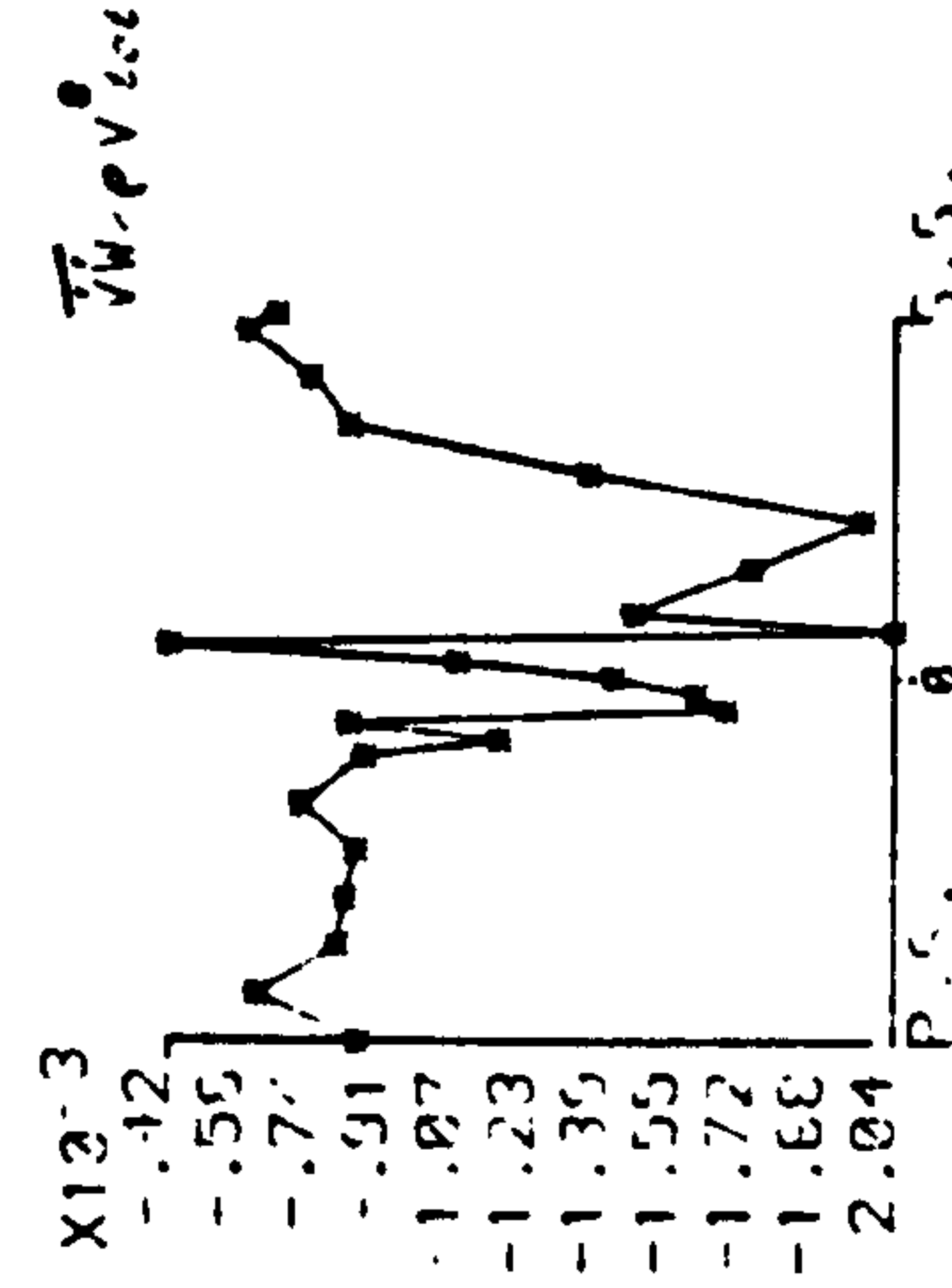


Fig 65 Flow field quantities at the relative turbomachinery frame of reference

TOWARDS THE BLADE TRAILING EDGE

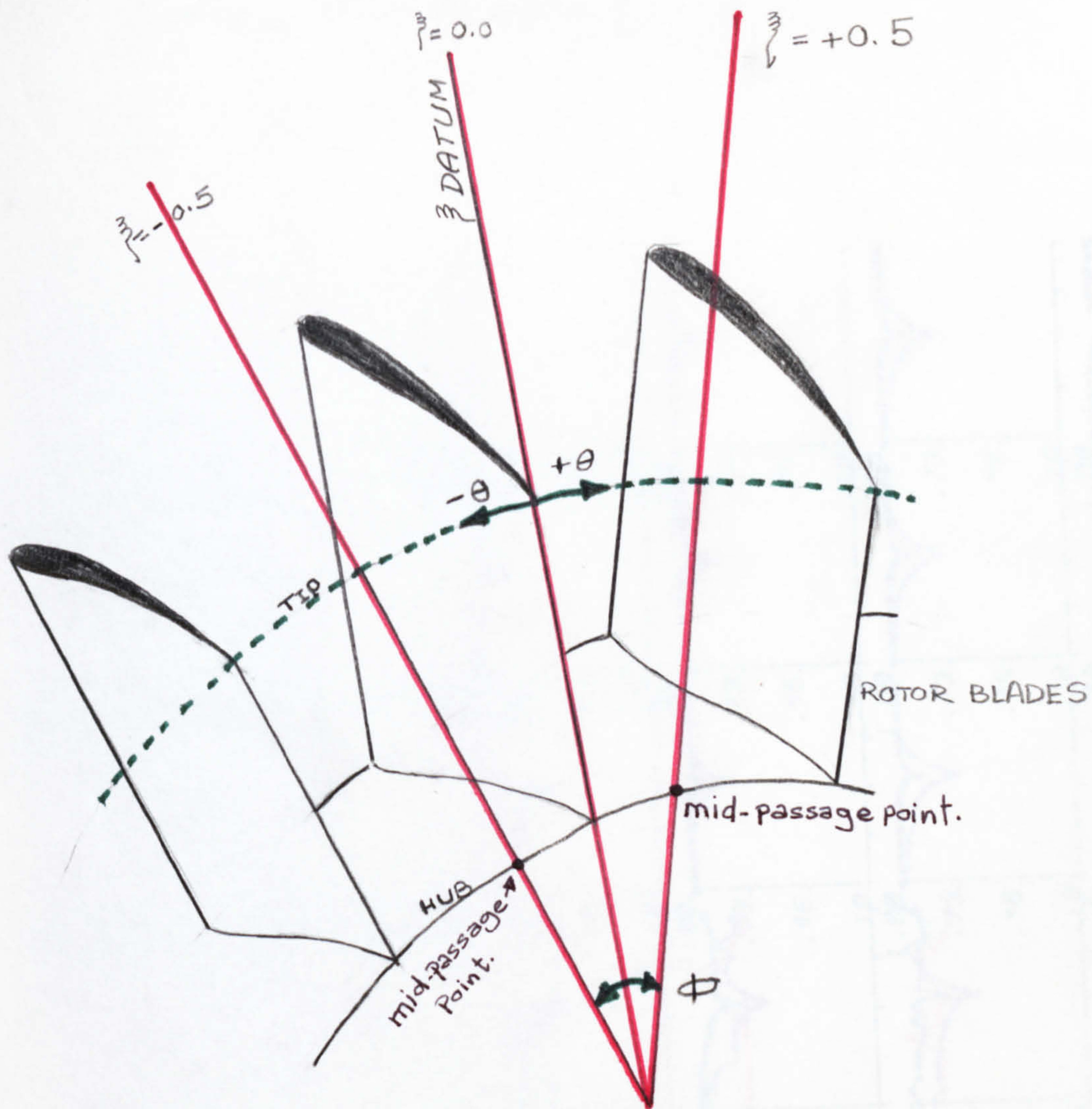
TIP	REYNOLDS No.	INC. ANG.	R̄	AXIAL DIRECTION									
				Z/C	Z/C	Z/C	Z/C	Z/C	Z/C	Z/C	Z/C	Z/C	Z/C
LOAD I	0.1229027 x 10 ⁶	-8.0	1.0	.1383	0.20645	0.2641	0.3793	0.49452	0.609736	0.724962			
LOAD II	0.1116814 x 10 ⁶	-5.0											
LOAD III	9.9020571E-02x10 ⁶	-2.0											
LOAD I	0.1234865 x 10 ⁶	-9.0	0.9	0.1085	0.1766794	0.2343	0.3495	0.4647717	0.5799695	0.6951952			
LOAD II	0.1116362 x 10 ⁶	-6.0											
LOAD III	9.5319390E-02x10 ⁶	-2.0											
LOAD I	0.1237315 x 10 ⁶	-10.0	0.8	.0787375	0.1469127	0.1469	0.31975	0.434977	0.5502028	0.6654288			
LOAD II	0.1106836 x 10 ⁶	-6.0											
LOAD III	9.4601803E-02x10 ⁶	-2.0											
LOAD I	0.1237009 x 10 ⁶	-6.0	0.7	.04897	0.117146	0.174759	0.28998	0.4052105	0.5204362	0.6449787			
LOAD II	0.112324 x 10 ⁶	-4.0											
LOAD III	9.6973114E-02x10 ⁶	0.0											
LOAD I	0.1239761 x 10 ⁶	-7.0	0.6	.019204	0.0873794	0.14499	0.26022	0.3754438	0.4906696	0.6058953			
LOAD II	0.1124471 x 10 ⁶	-4.0											
LOAD III	9.8752588E-02x10 ⁶	0.0											
LOAD I	0.1238539 x 10 ⁶	-7.0	0.54	*****	0.0576128	0.11523	0.23045	0.3456772	0.460903	0.5761287			
LOAD II	0.1112285 x 10 ⁶	-4.0											
LOAD III	9.595274E-02 x10 ⁶	0.0											

Pressure side 0 Suction side
-4 +4
4.7 POINTS } See Next page

FIG 66 MASTER LEGEND

RADIAL DIRECTION

HUB



$$\phi = \frac{2\pi}{\text{no. of Blades}}$$

$\bar{z}$ = Non-Dimensional Tangential distance

$$\bar{z} = \frac{\theta}{\phi}$$

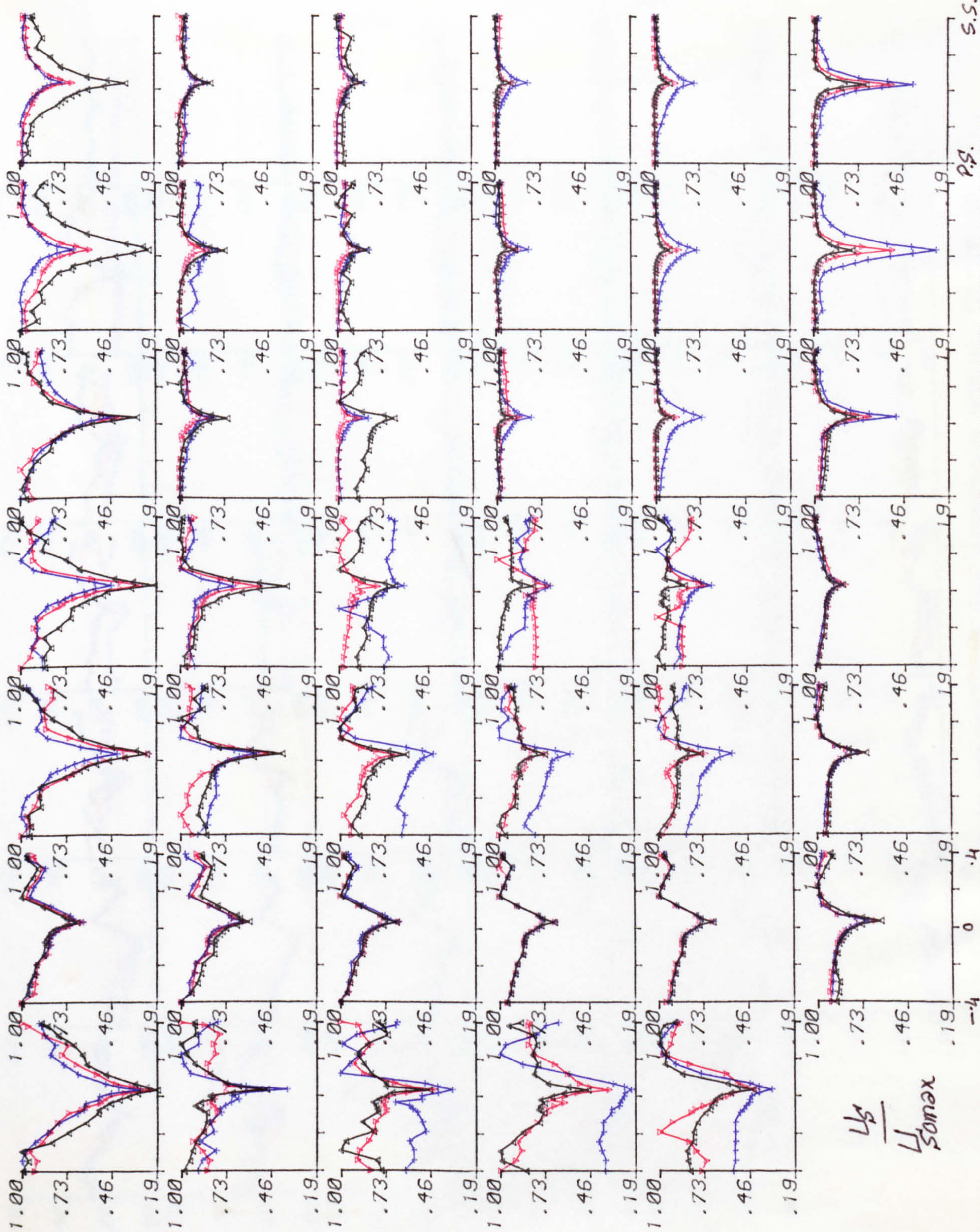


FIG 67 DISTRIBUTION OF FLOW VELOCITY COMPONENT IN THE STREAM WISE DIRECTION.

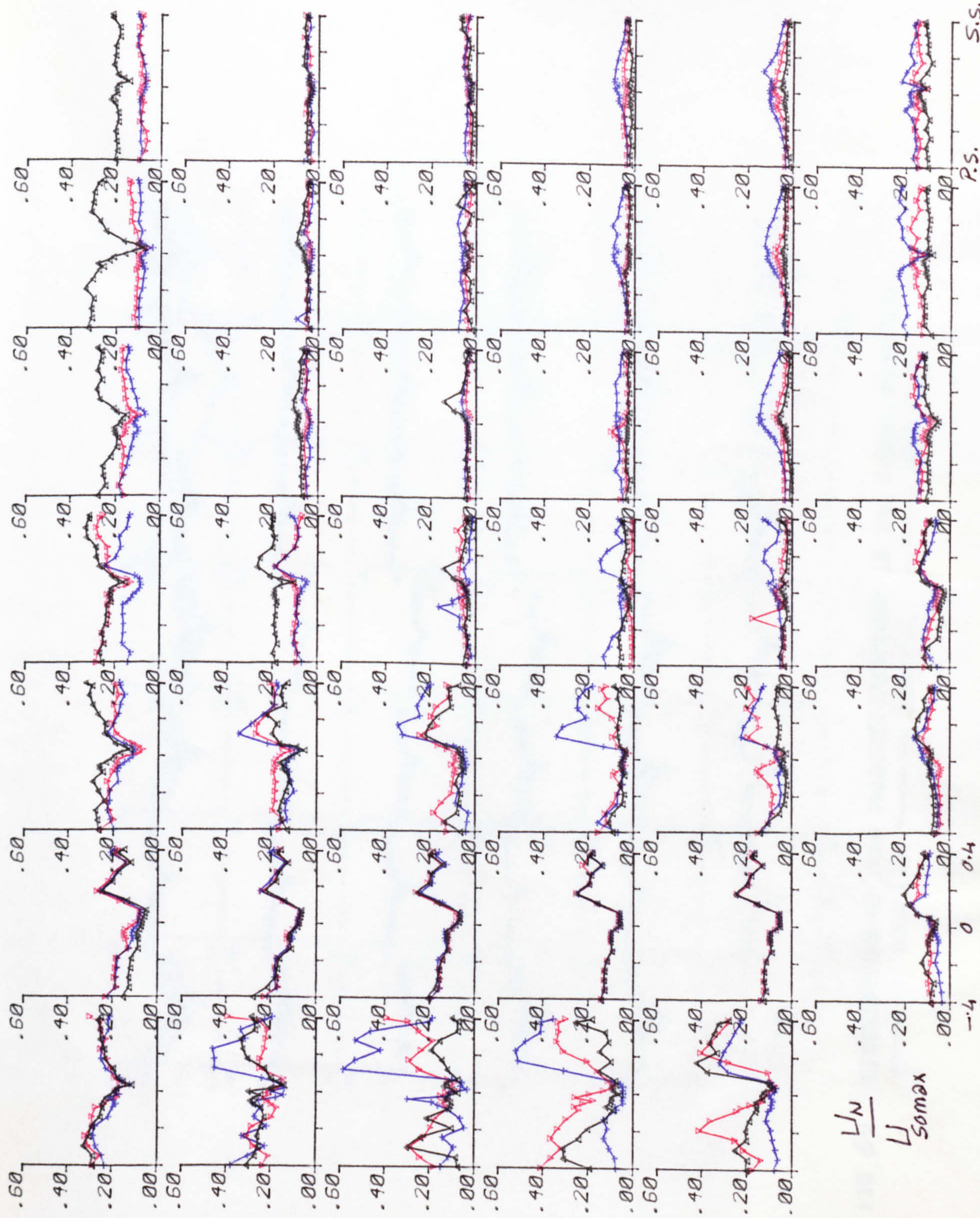


FIG 68 DISTRIBUTION OF FLOW VELOCITY IN THE DIRECTION NORMAL TO STREAM WISE.

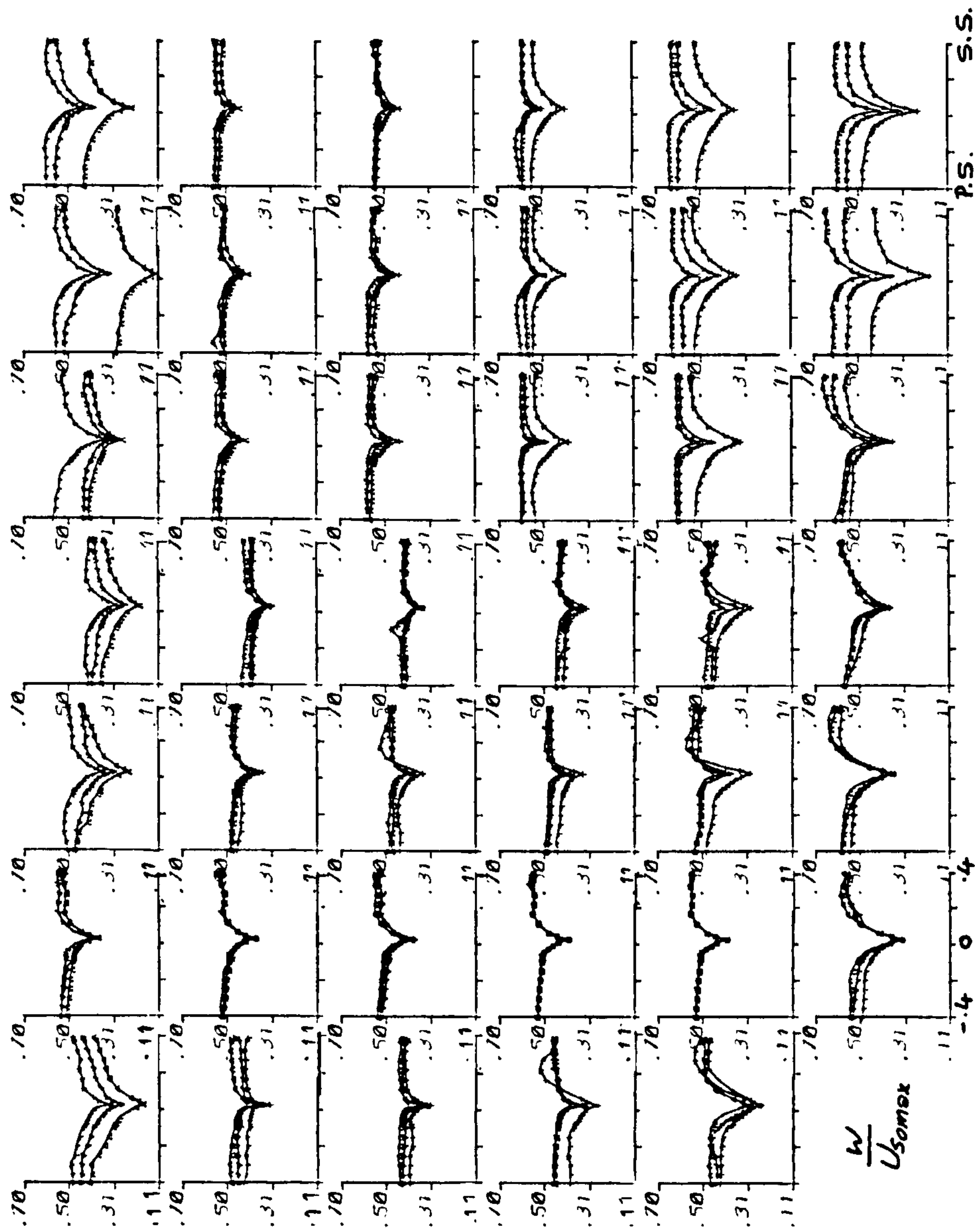


FIG 69 DISTRIBUTION OF FLOW VELOCITY COMPONENT IN THE RADIAL DIRECTION.
 ▲-----▲ LOAD (I) ▼-----▼ LOAD (II) +-----+ LOAD (III)

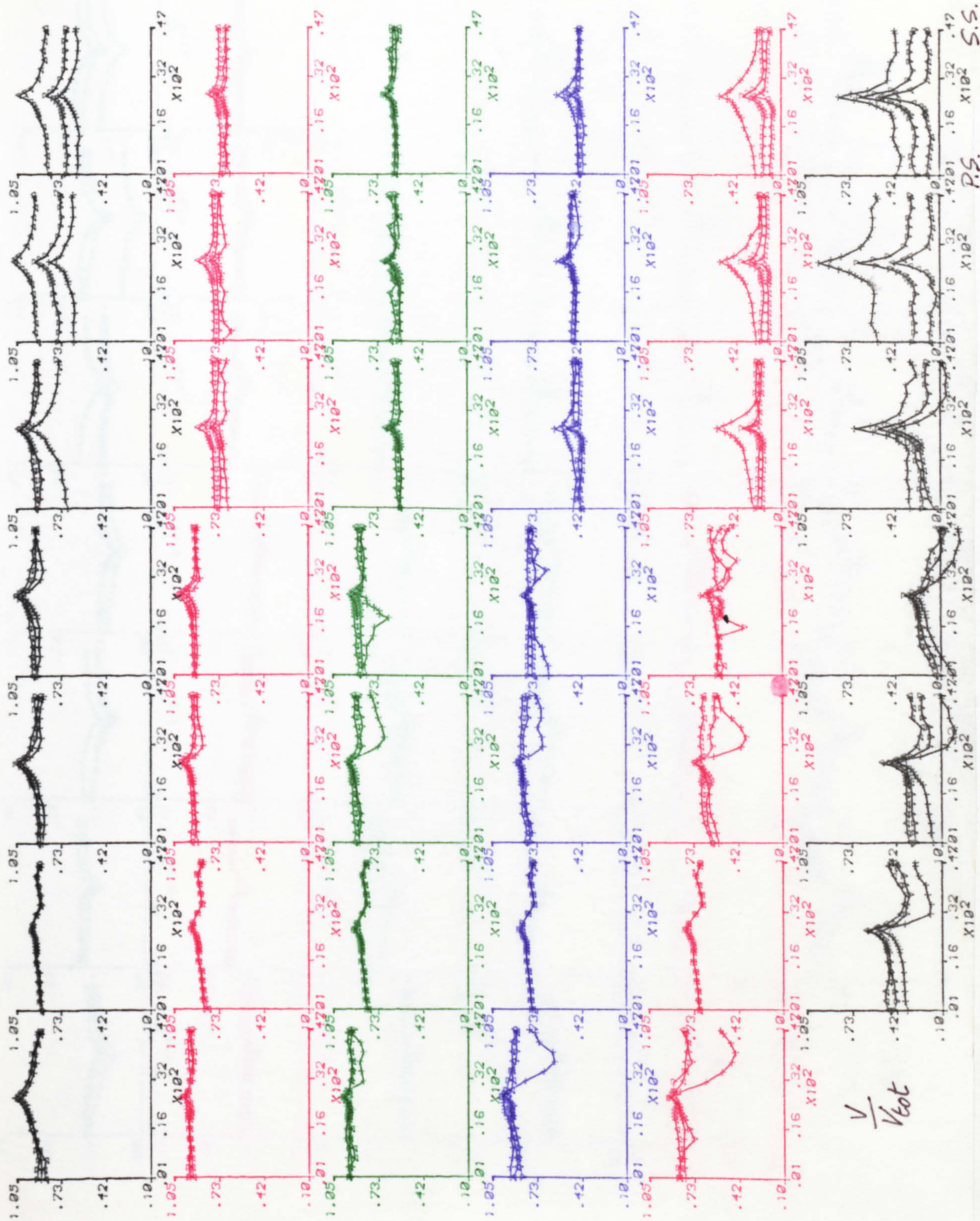


FIG 71 DISTRIBUTION OF FLOW VELOCITY COMPONENT IN THE RELATIVE TANGENTIAL DIRECTION.

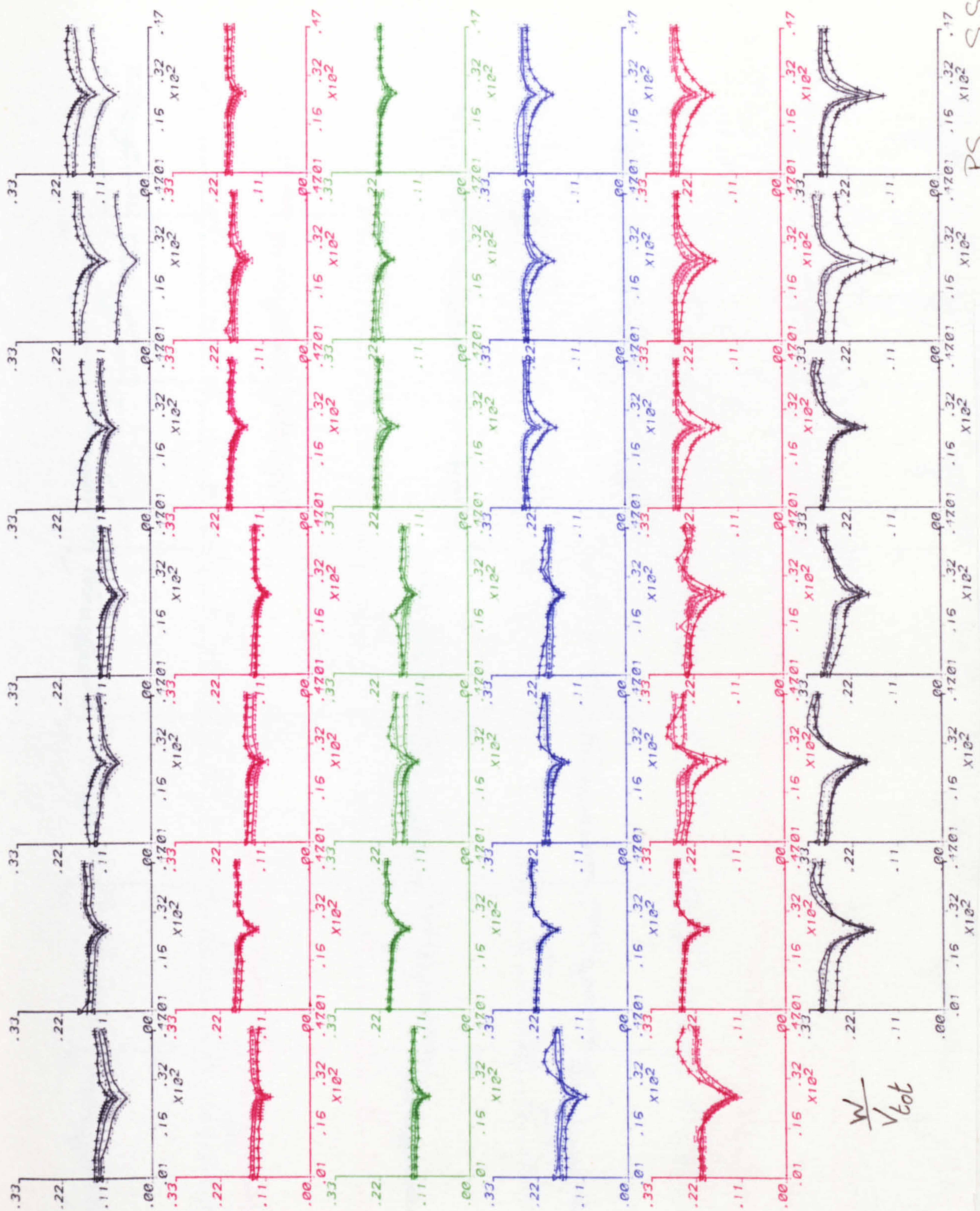
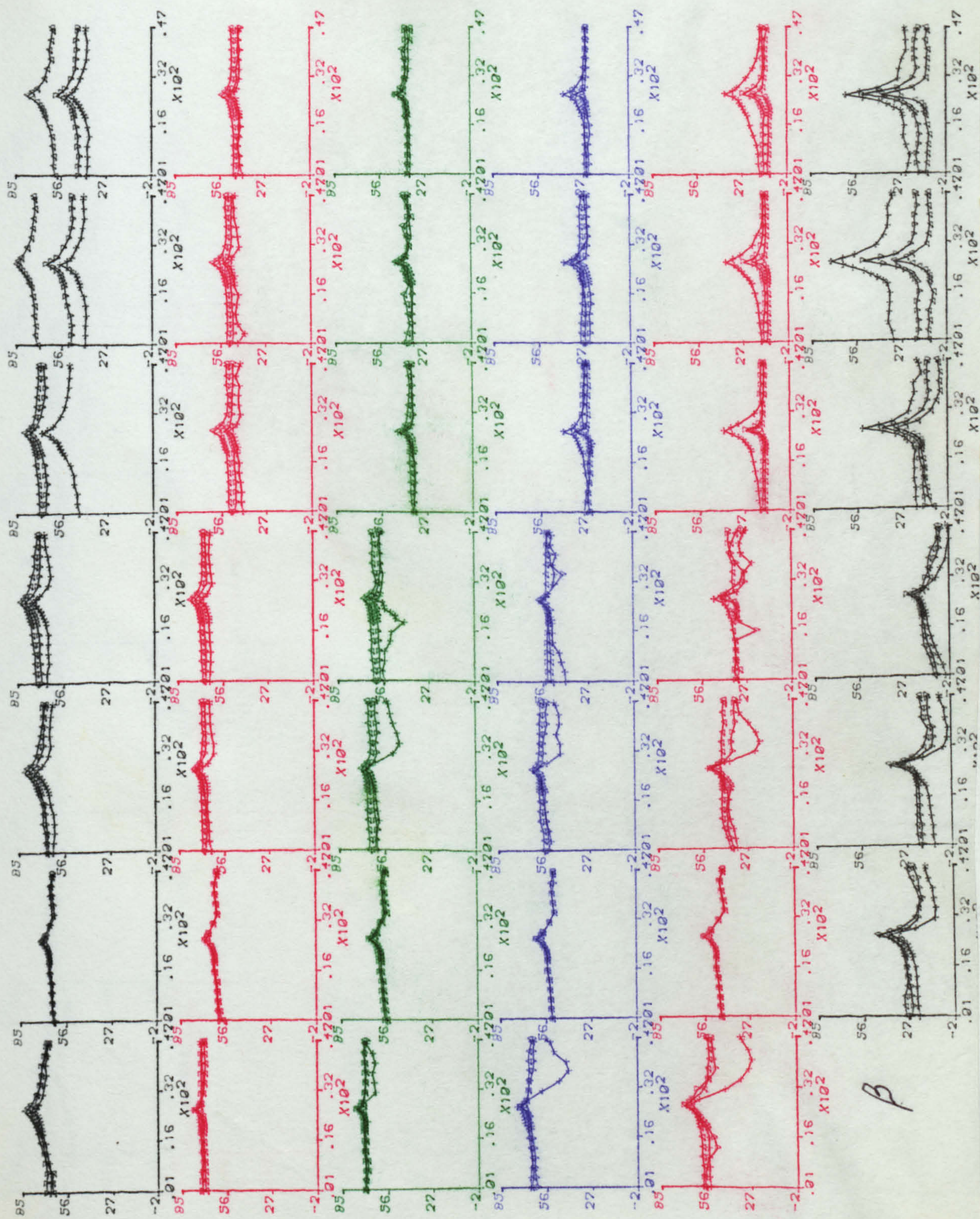


FIG 72 DISTRIBUTION OF VELOCITY COMPONENT IN THE RADIAL DIRECTION.

Δ-----Δ LOAD (I) ▽-----▽ LOAD (II) †-----† LOAD (III).



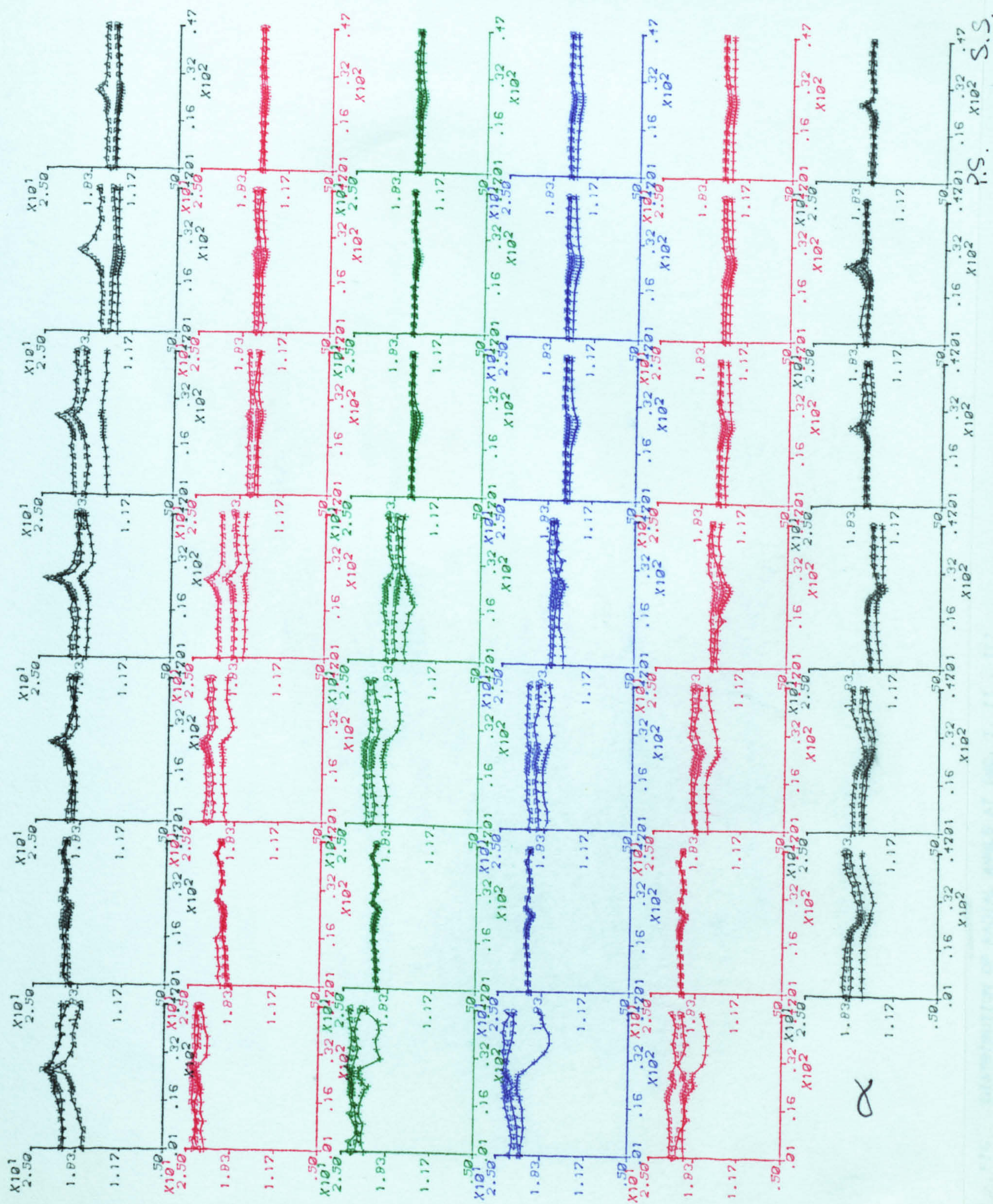


FIG 74 DISTRIBUTION OF RADIAL FLOW ANGLE Δ ----- ∇ LOAD (I) ∇ ----- ∇ LOAD (II) +-----+ LOAD (III)

AXIAL DIR

TO BLADE TRAILING EDGE ----- TO STATOR

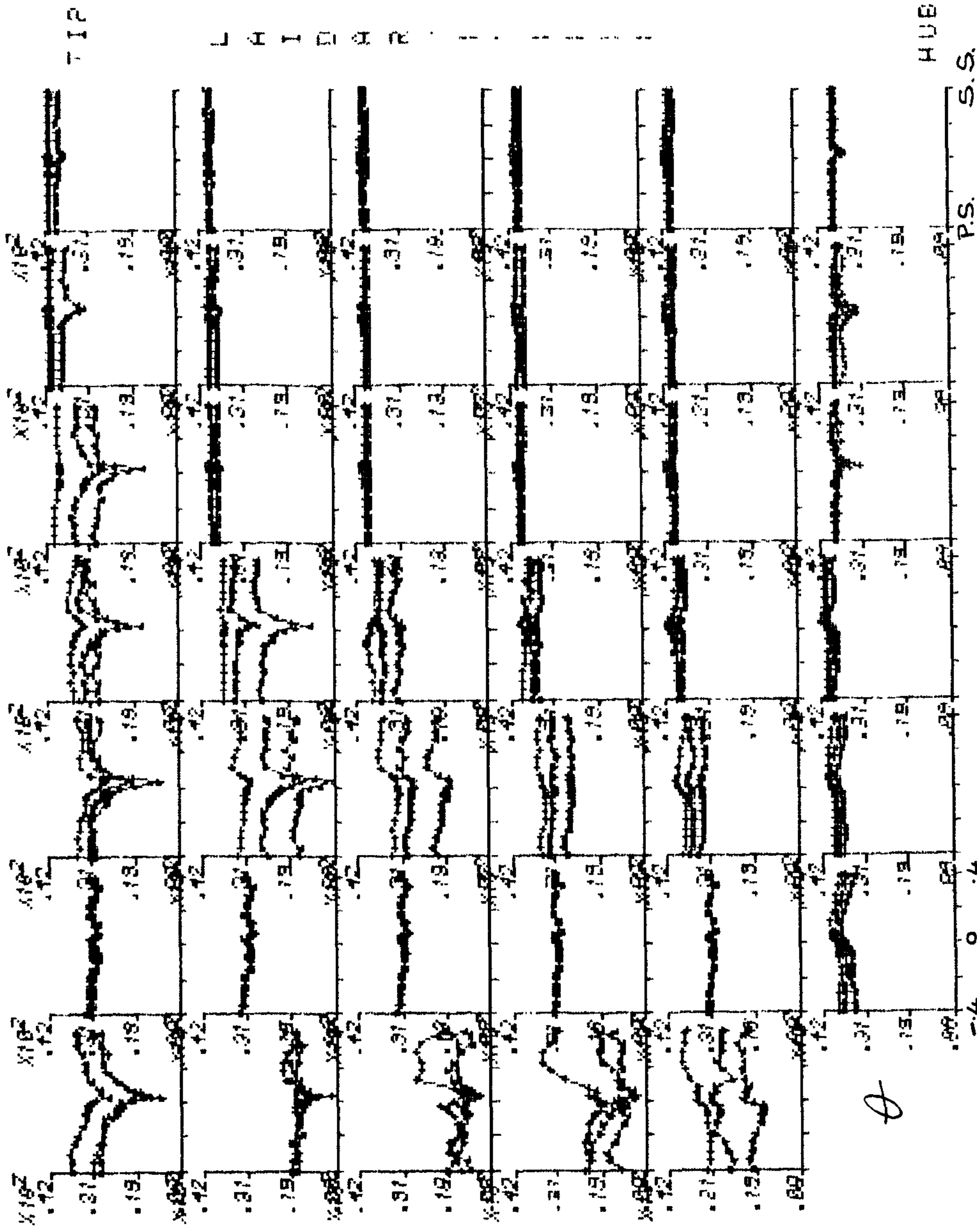


FIG 75 DISTRIBUTION OF ABSOLUTE AIR ANGLE.

AXIAL DIR. TO BLADE TRAILING EDGE TO STATOR

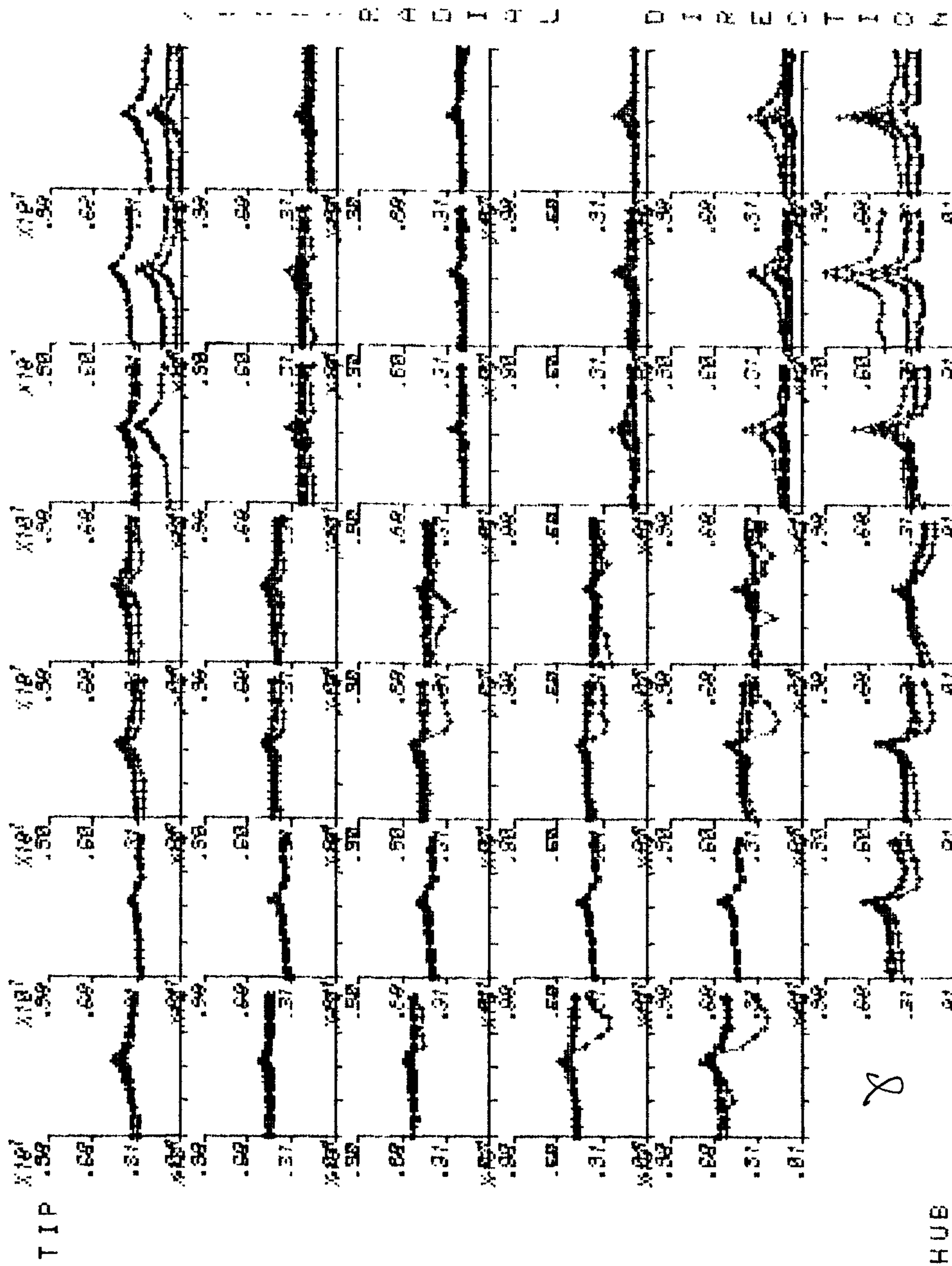


FIG 76 DISTRIBUTION OF THE DEVIATION ANGLE

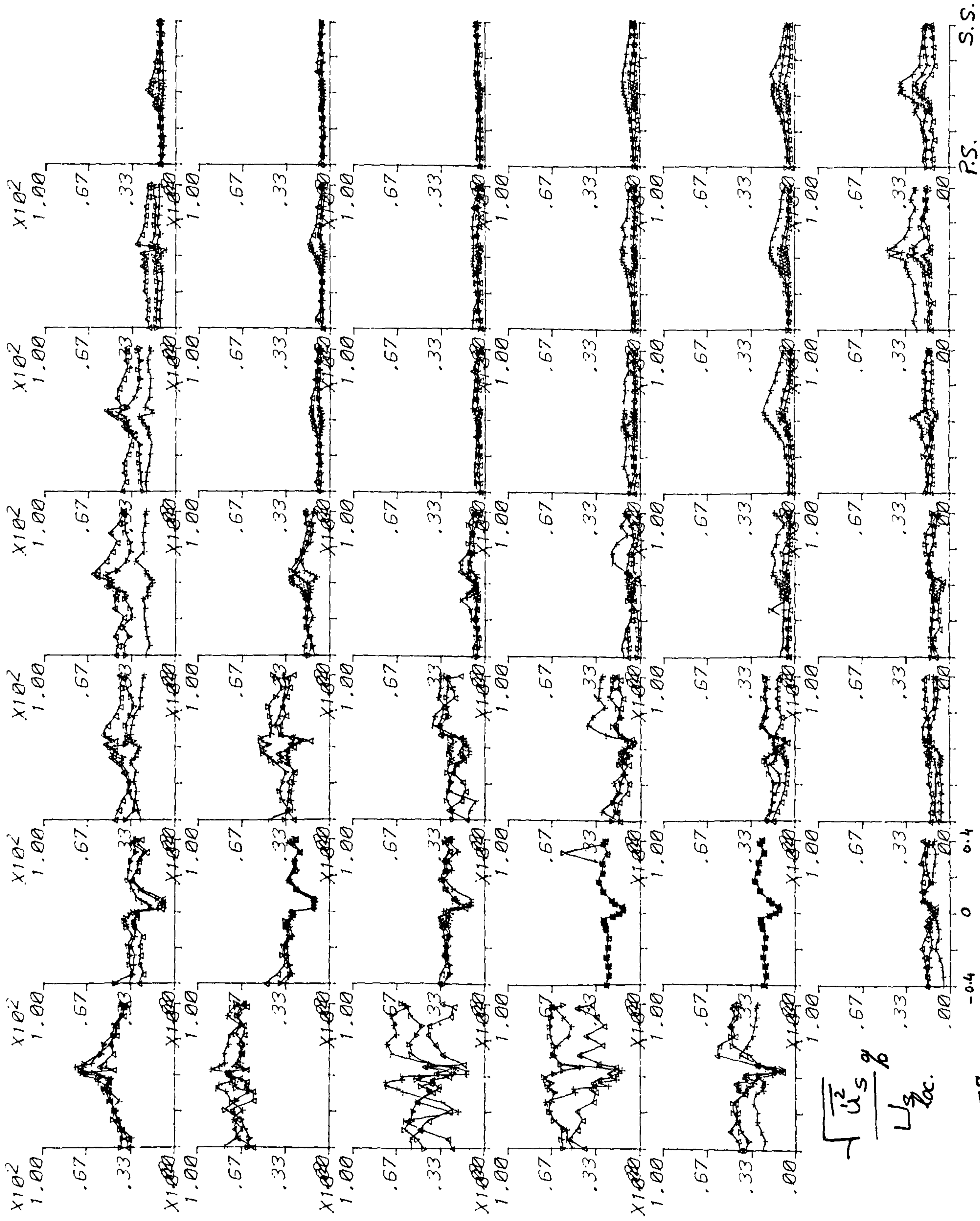


FIG 77 DISTRIBUTION OF STREAM WISE TURBULENCE INTENSITY.

Δ LOAD(I) $\circ$ LOAD(II) $\times$ LOAD(III)

P.S. S.S.

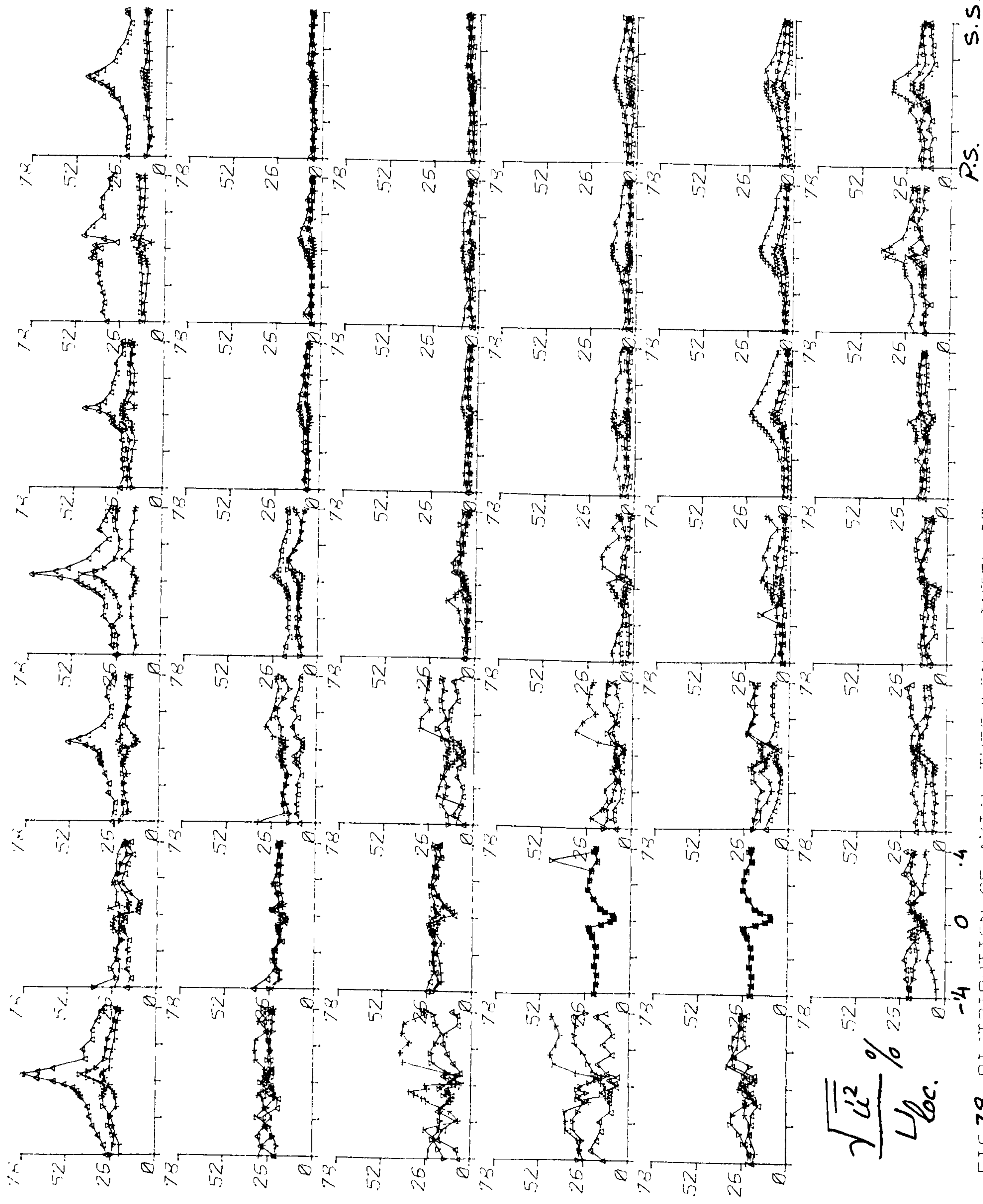
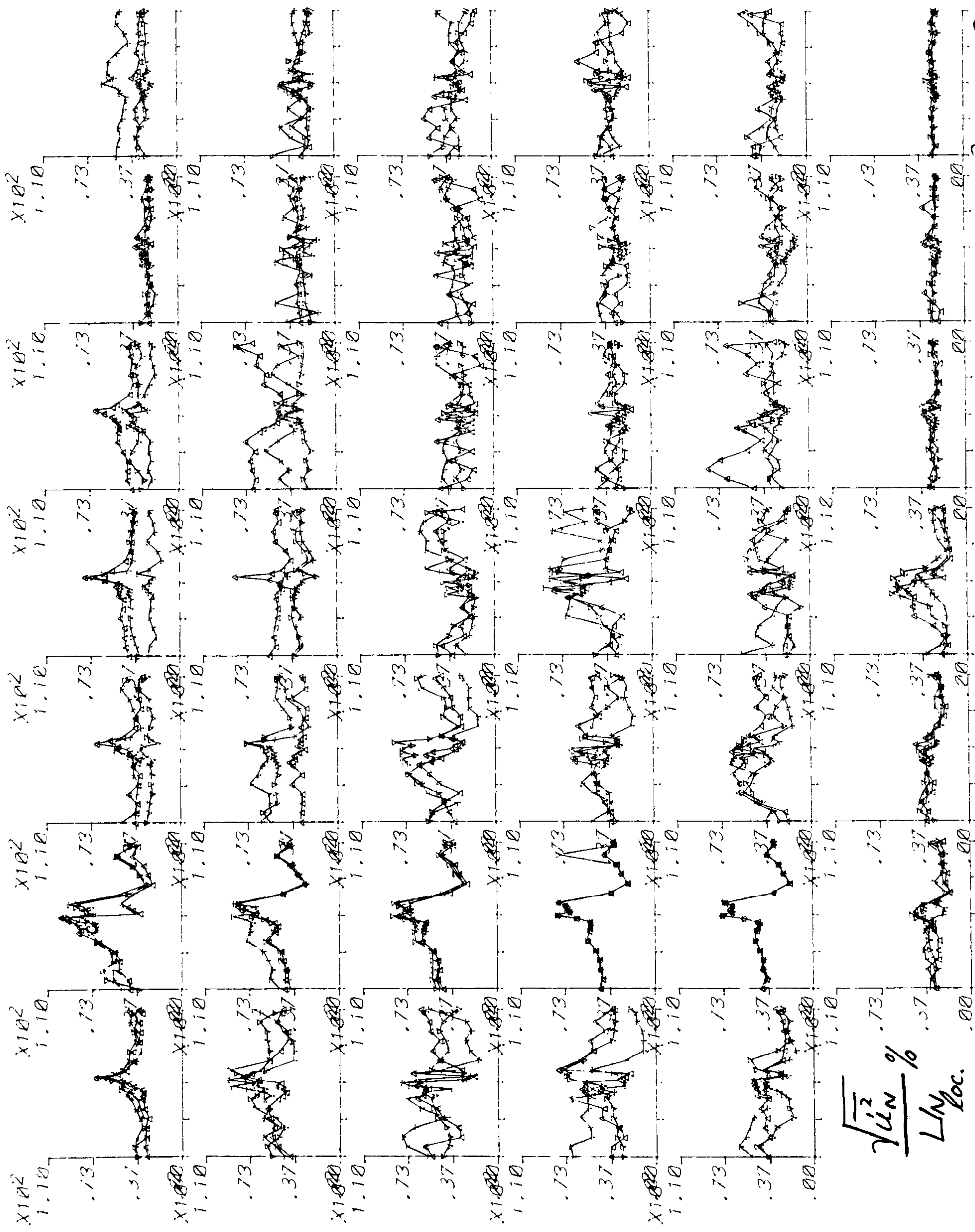


FIG 78 DISTRIBUTION OF AXIAL TURBULENCE INTENSITY.
 Δ LOAD(I) $\longrightarrow$ LOAD(II) + LOAD(III) P.S. S.S.



$$\frac{\sqrt{u^2}}{L_{loc}} \%$$

FIG 19 DISTRIBUTION OF TURBULENCE INTENSITY IN THE DIRECTION NORMAL TO THE STREAM WISE.

Δ — LOAD (I) ∇ — LOAD (II) $+$ — LOAD (III)

P.S. S.S.

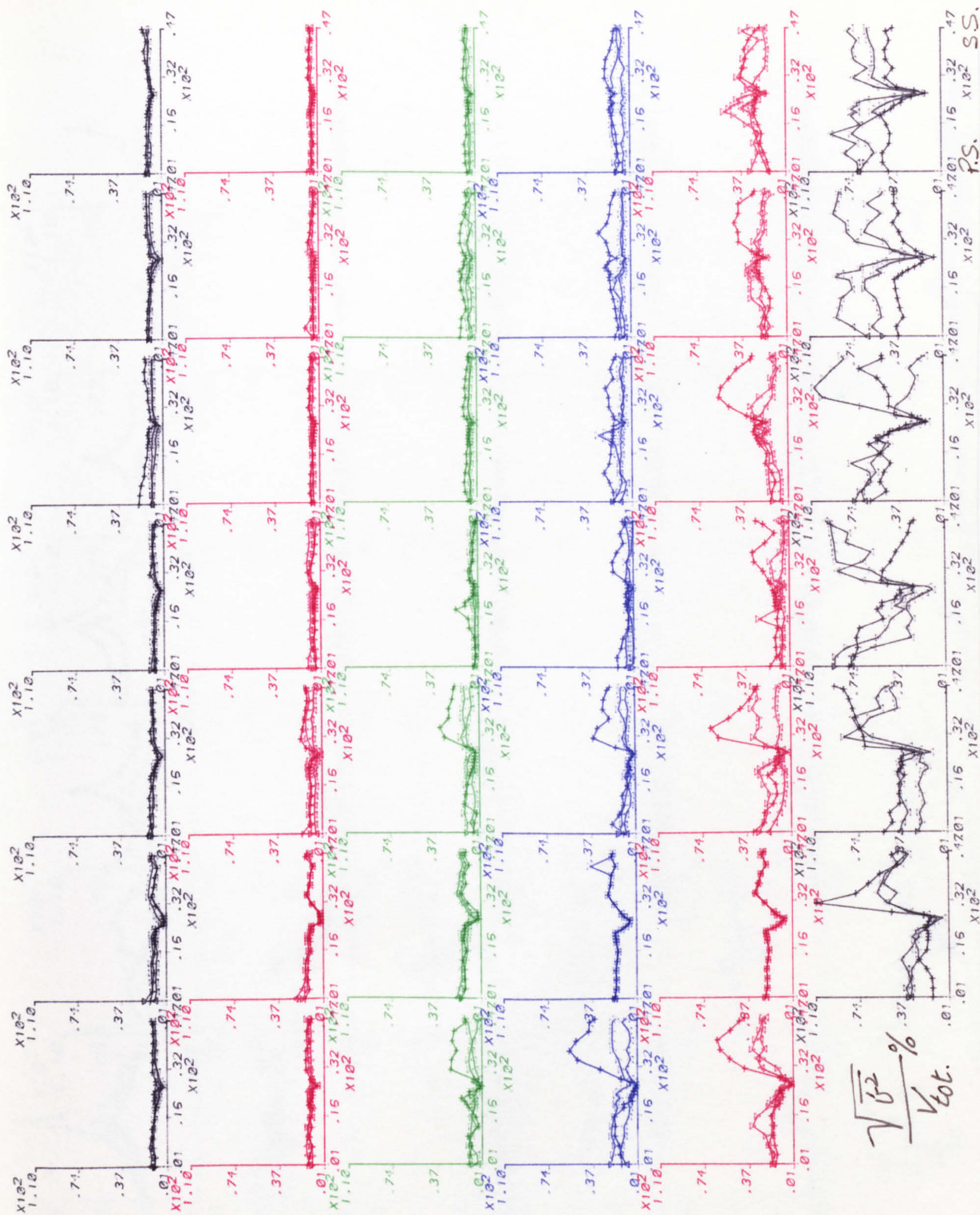


FIG 80 DISTRIBUTION OF TURBULENCE INTENSITY COMPONENT IN THE TANGENTIAL DIRECTION.

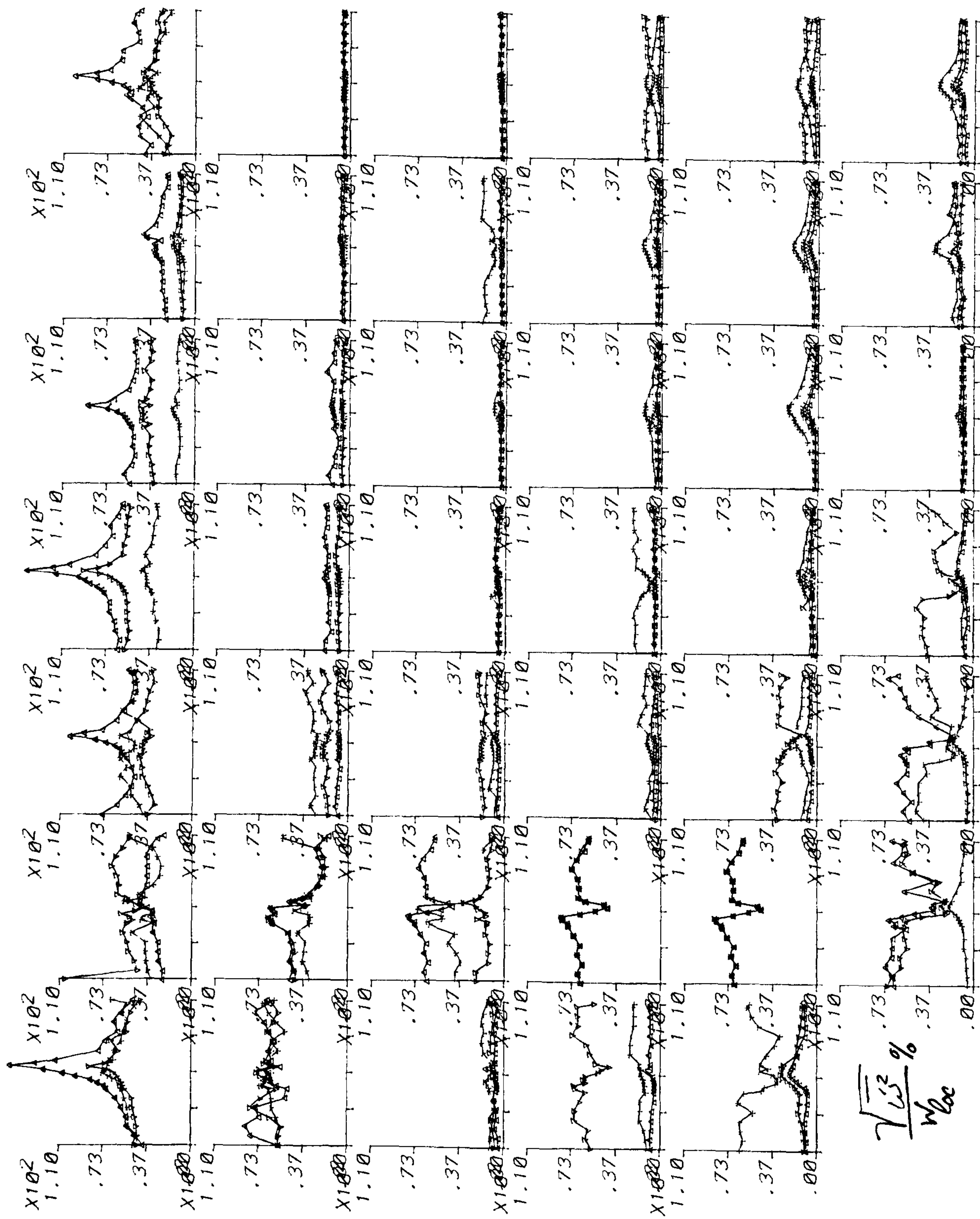


FIG 81 DISTRIBUTION OF RADIAL TURBULENCE INTENSITY.

INC. (III)

INC. (II)

INC. (I)

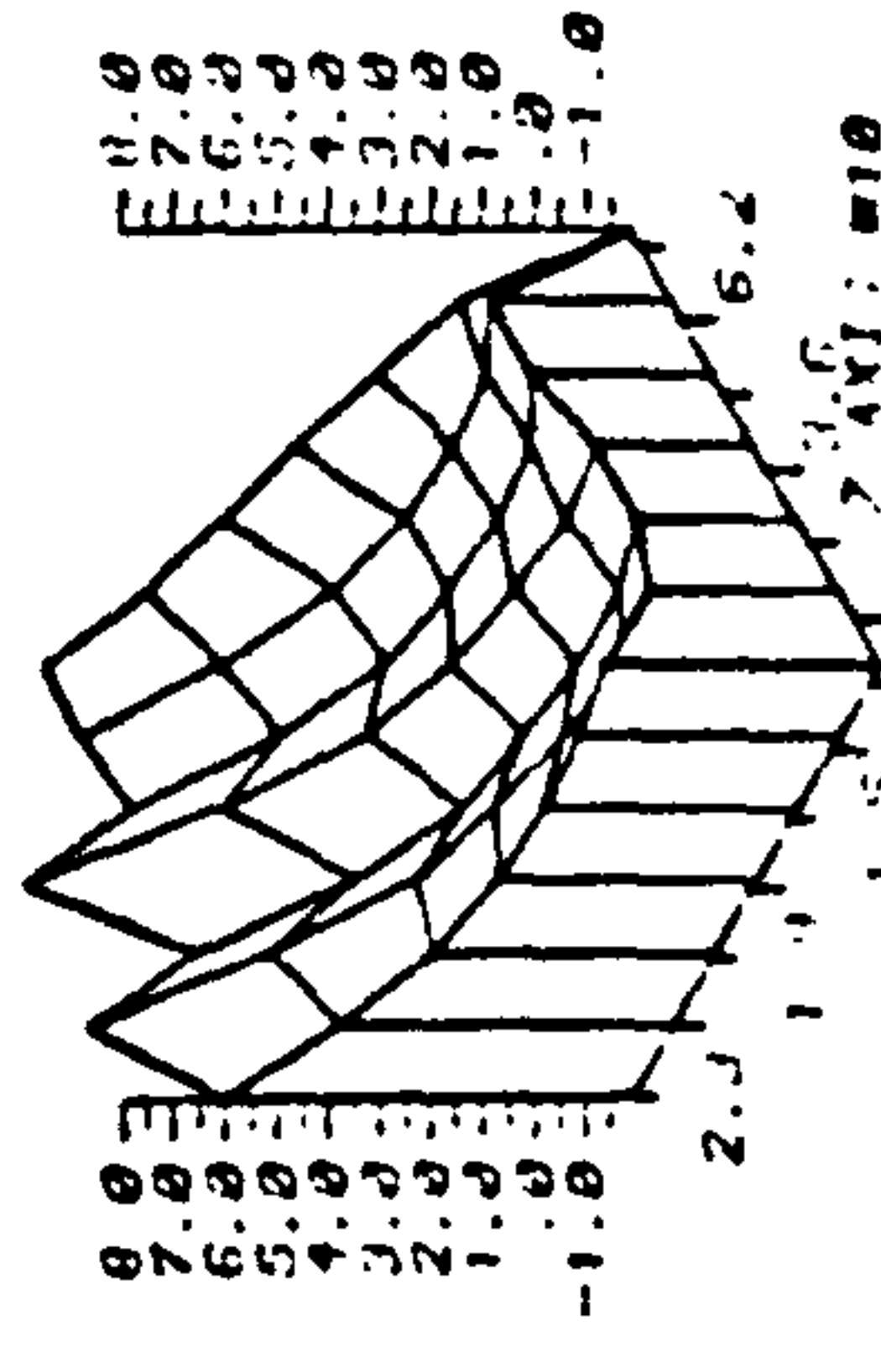
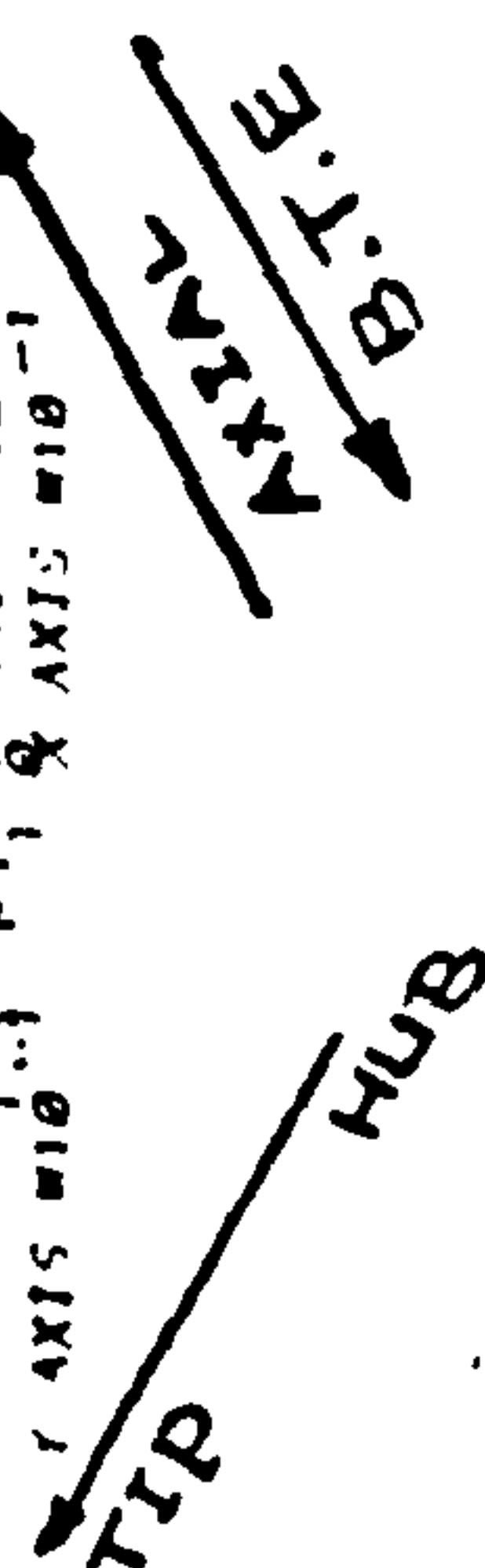
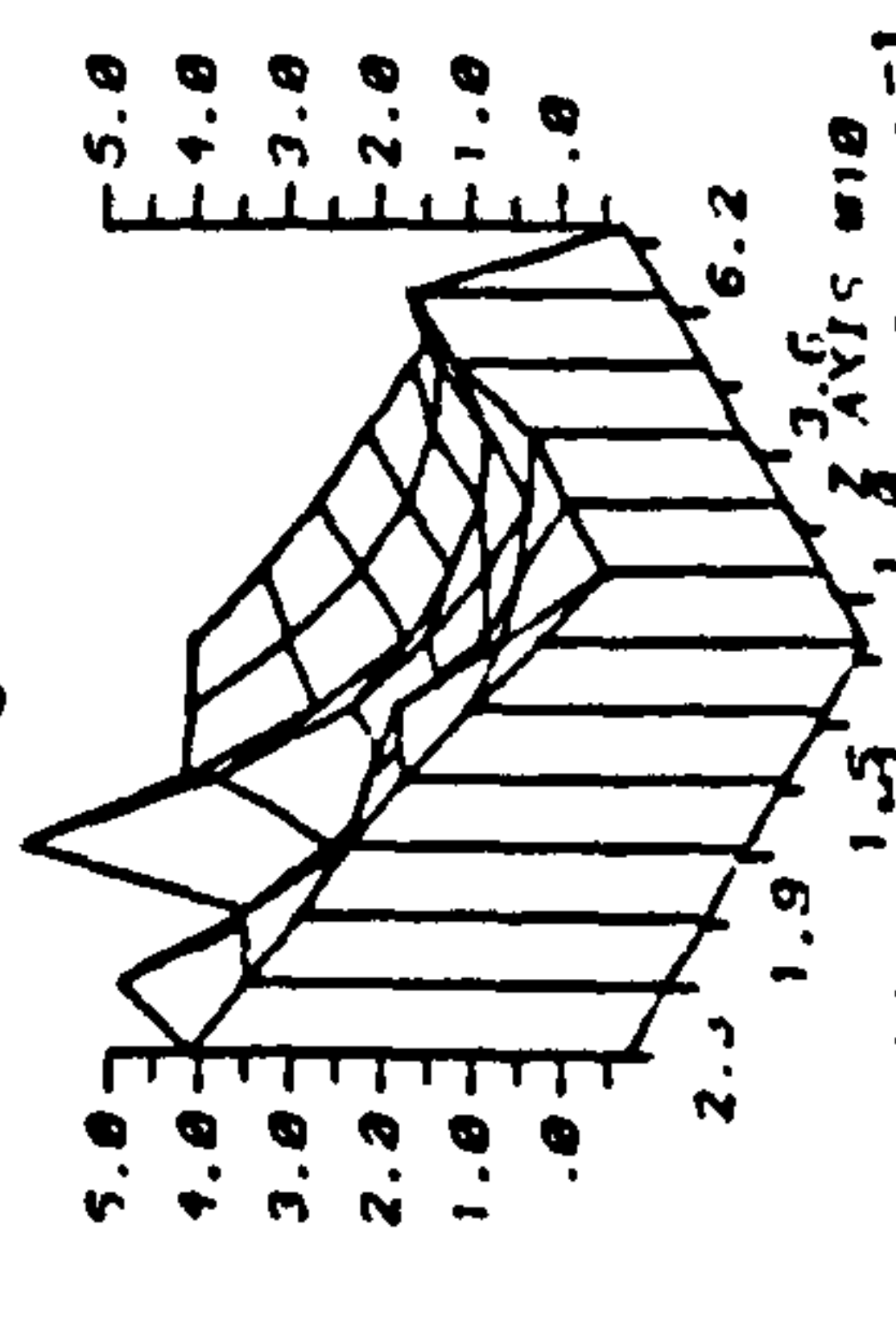
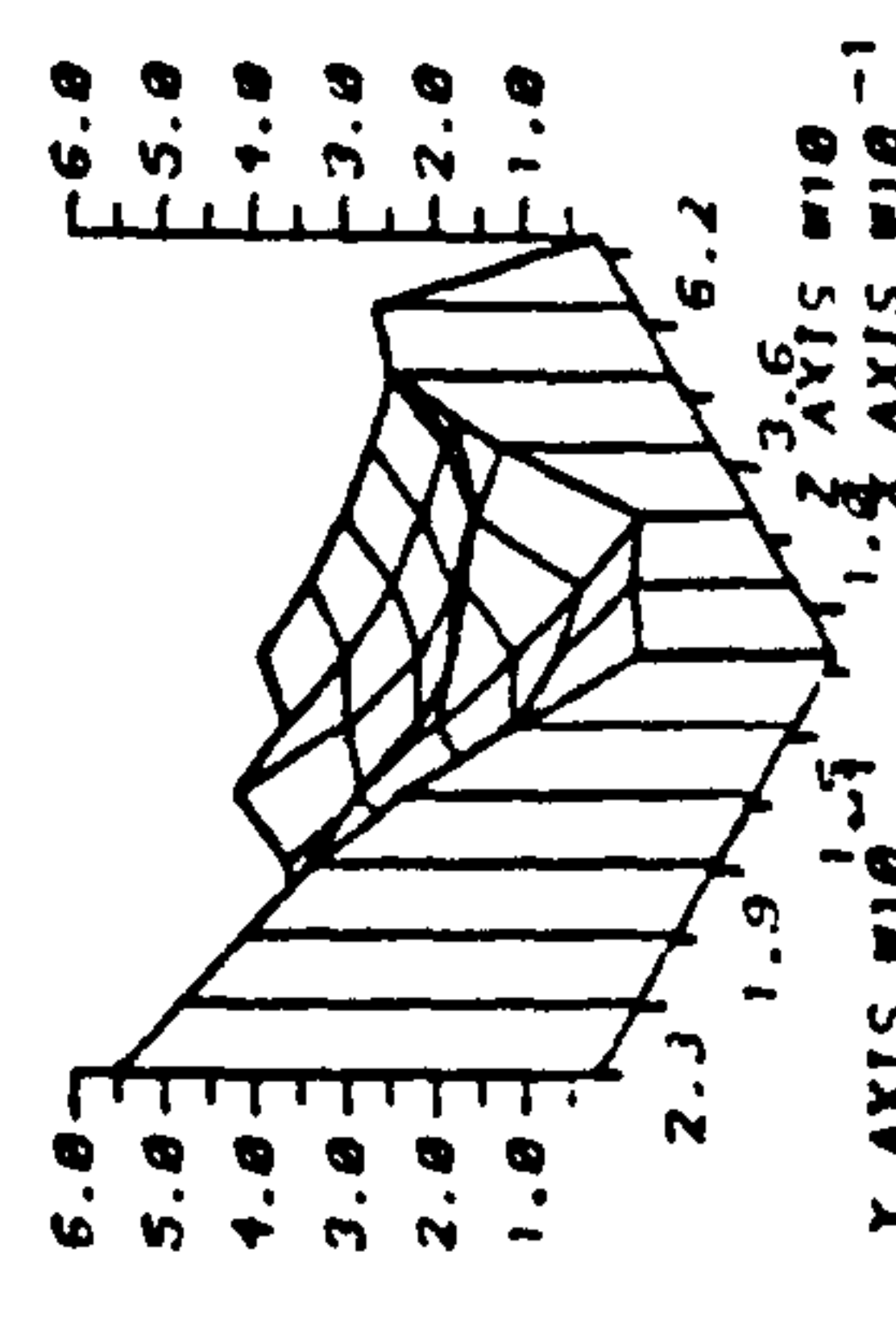
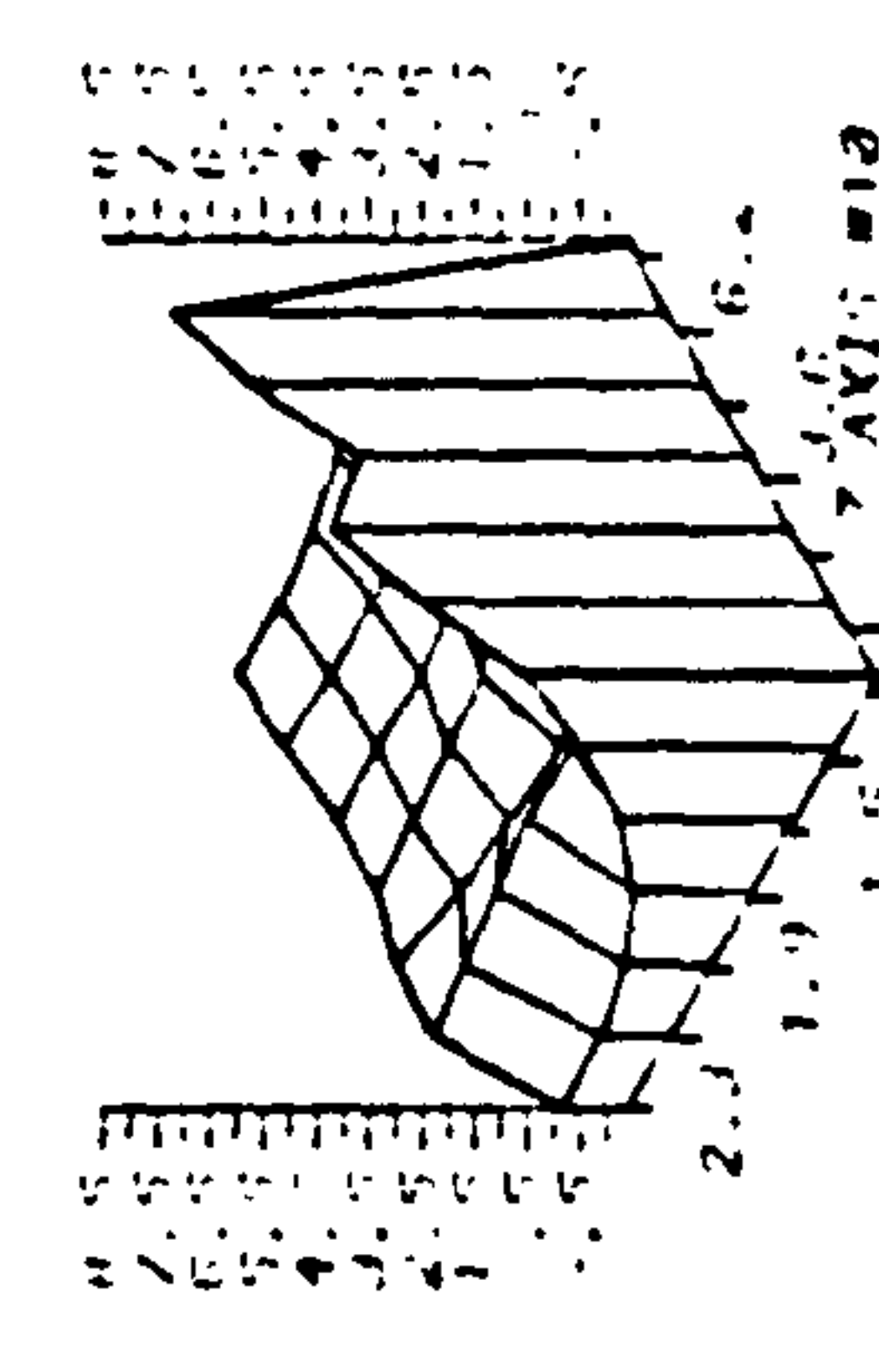
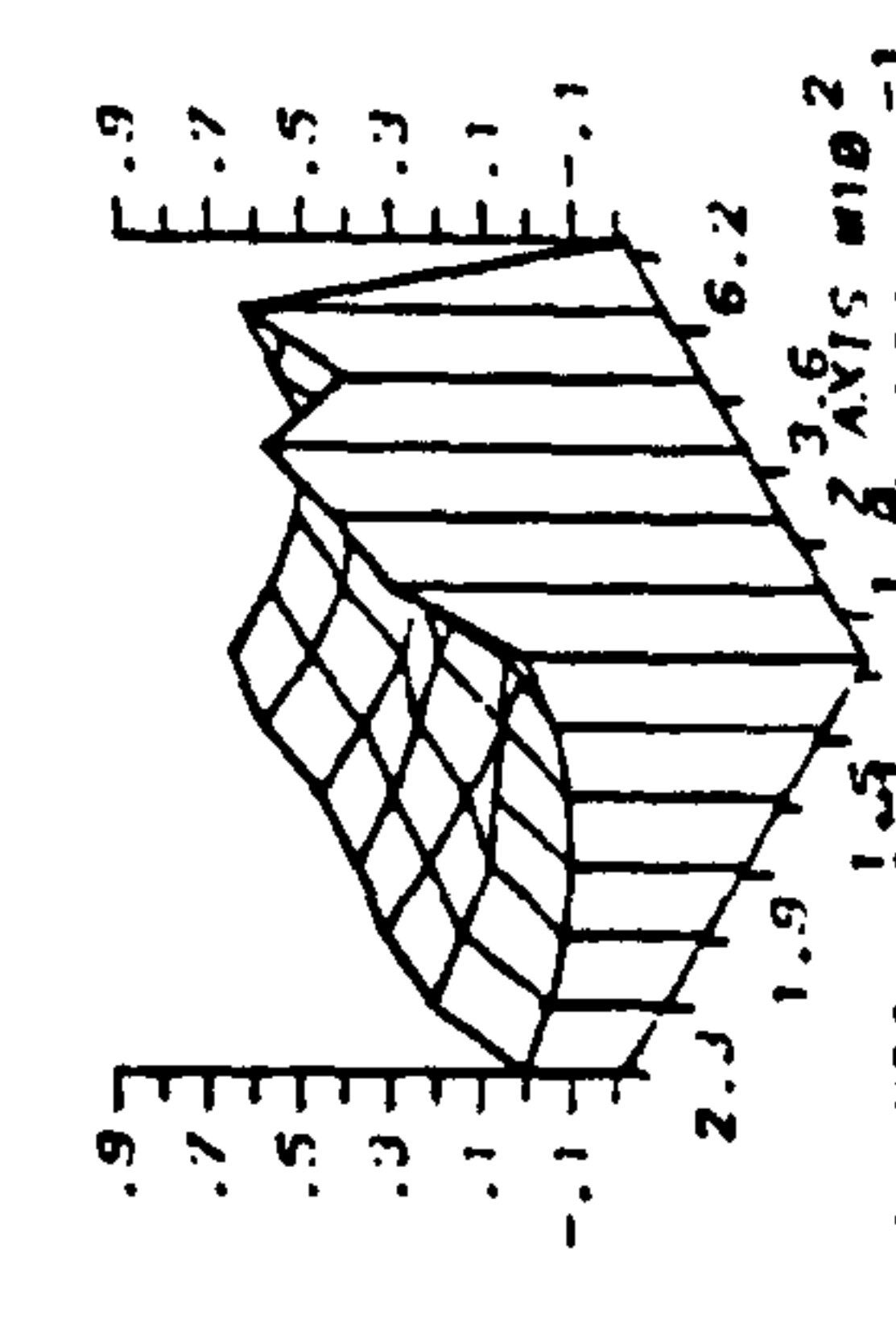
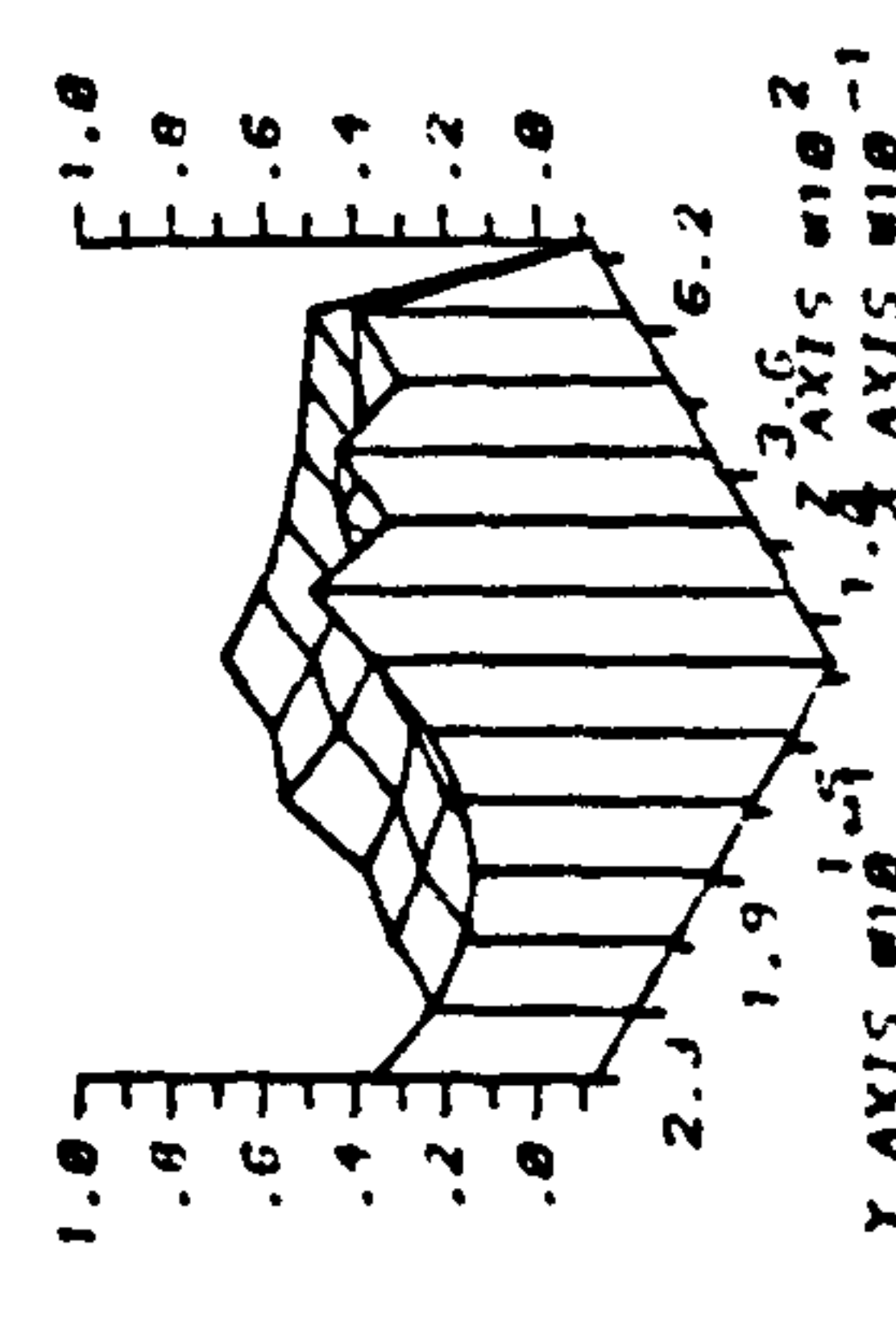


Fig 02 VALUES OF MAX. TURBULENCE INT. VS
RADIAL AND AXIAL DIRECTIONS

Axial

Tangential

Radial

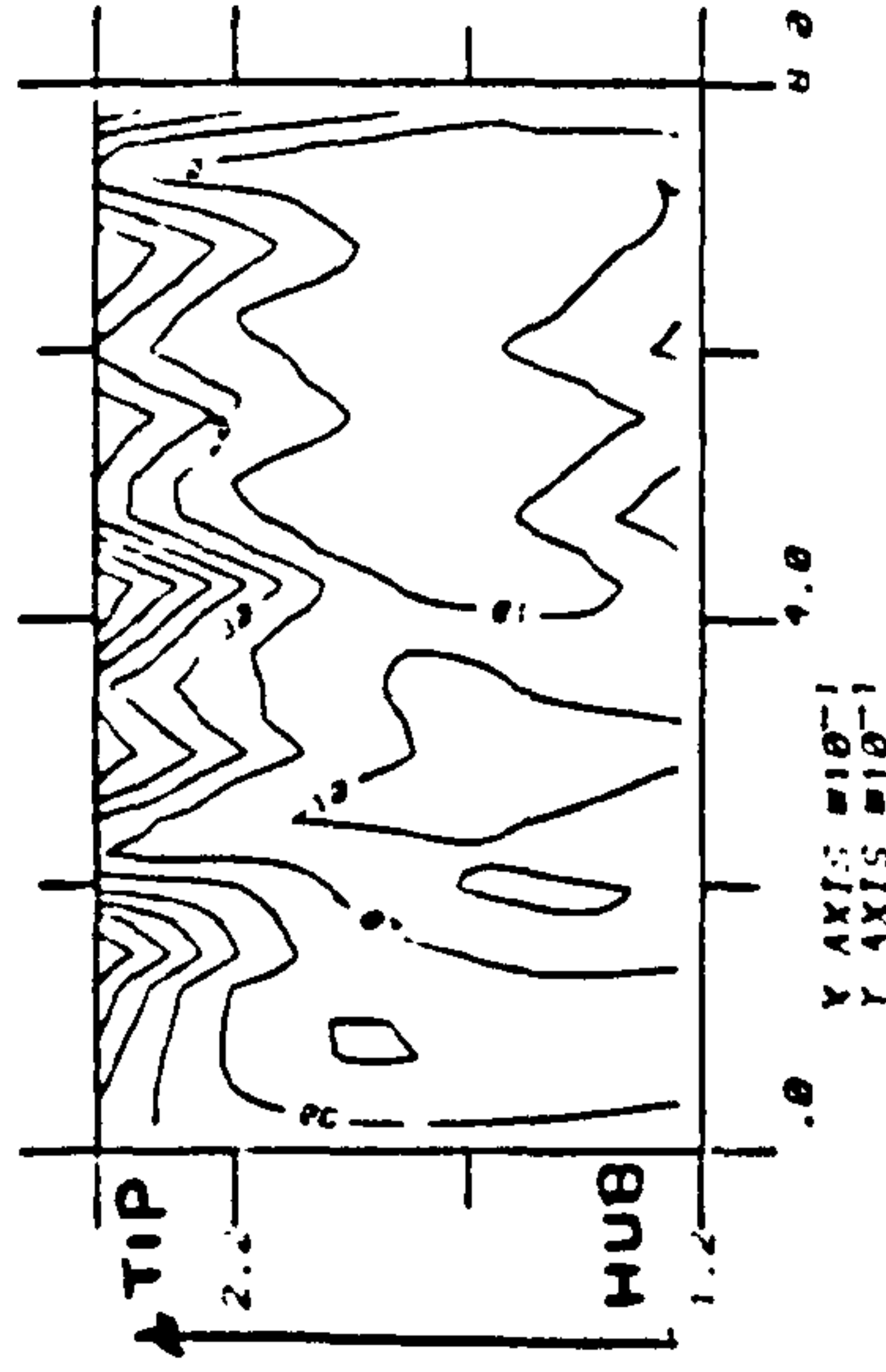
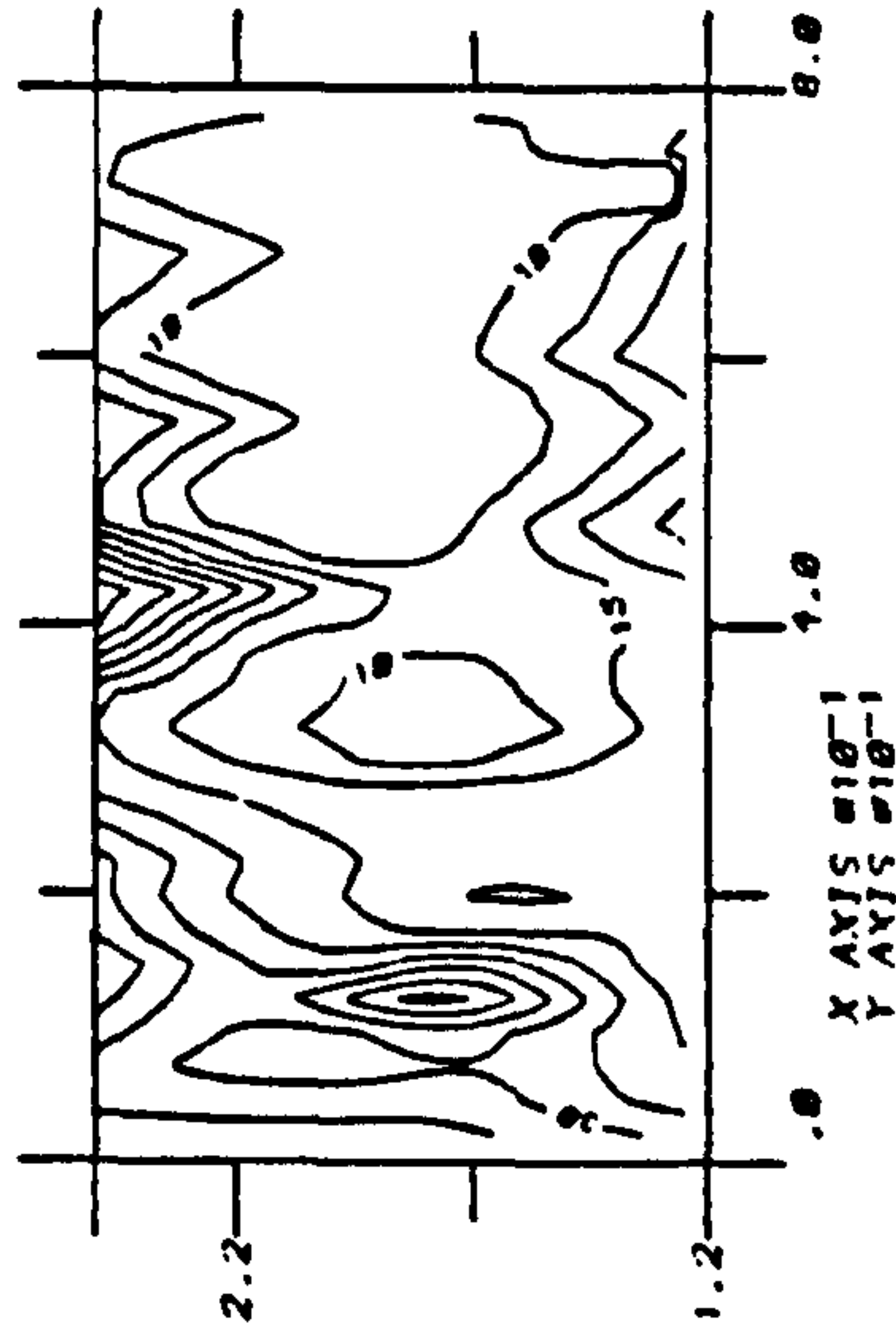
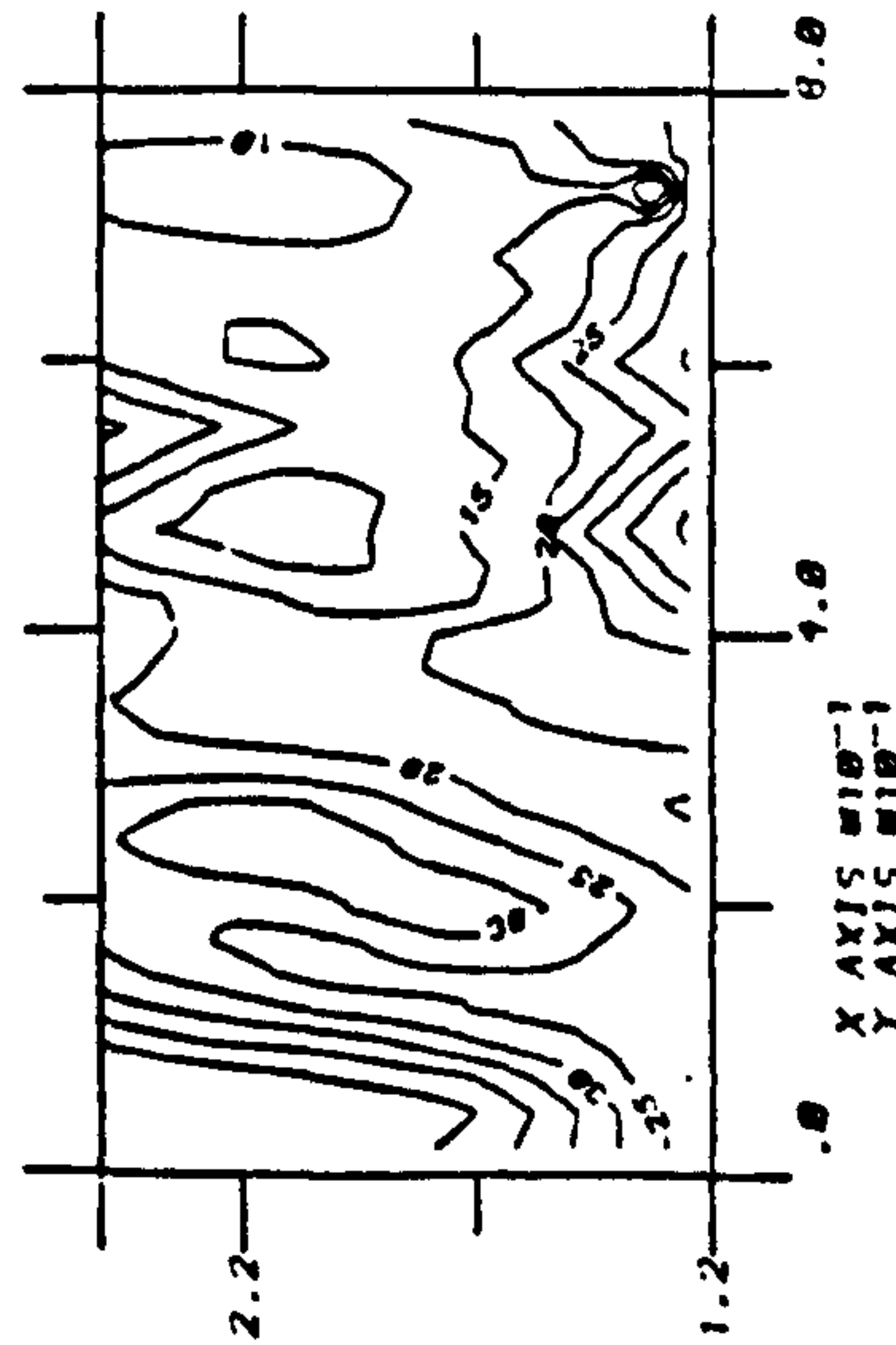
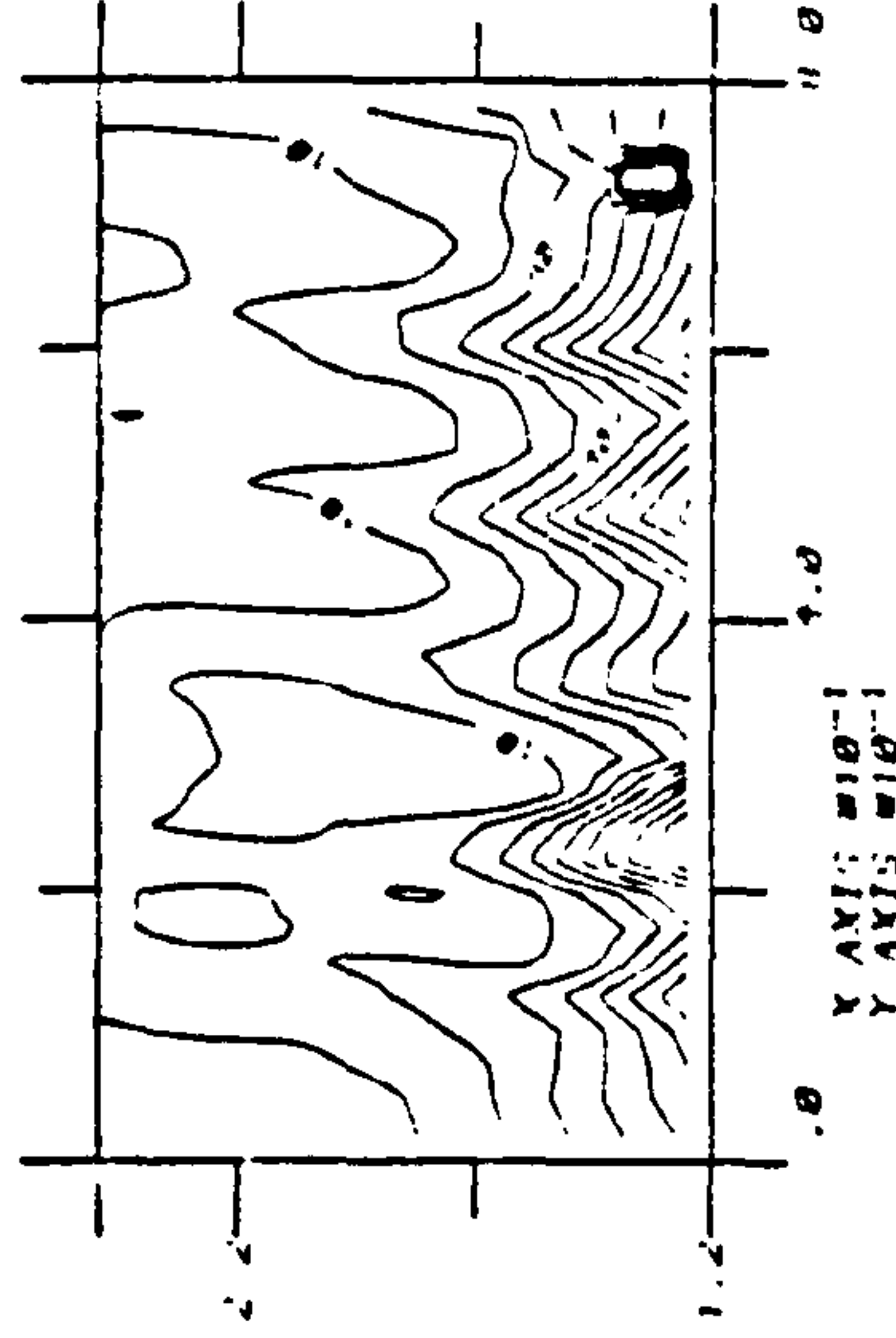
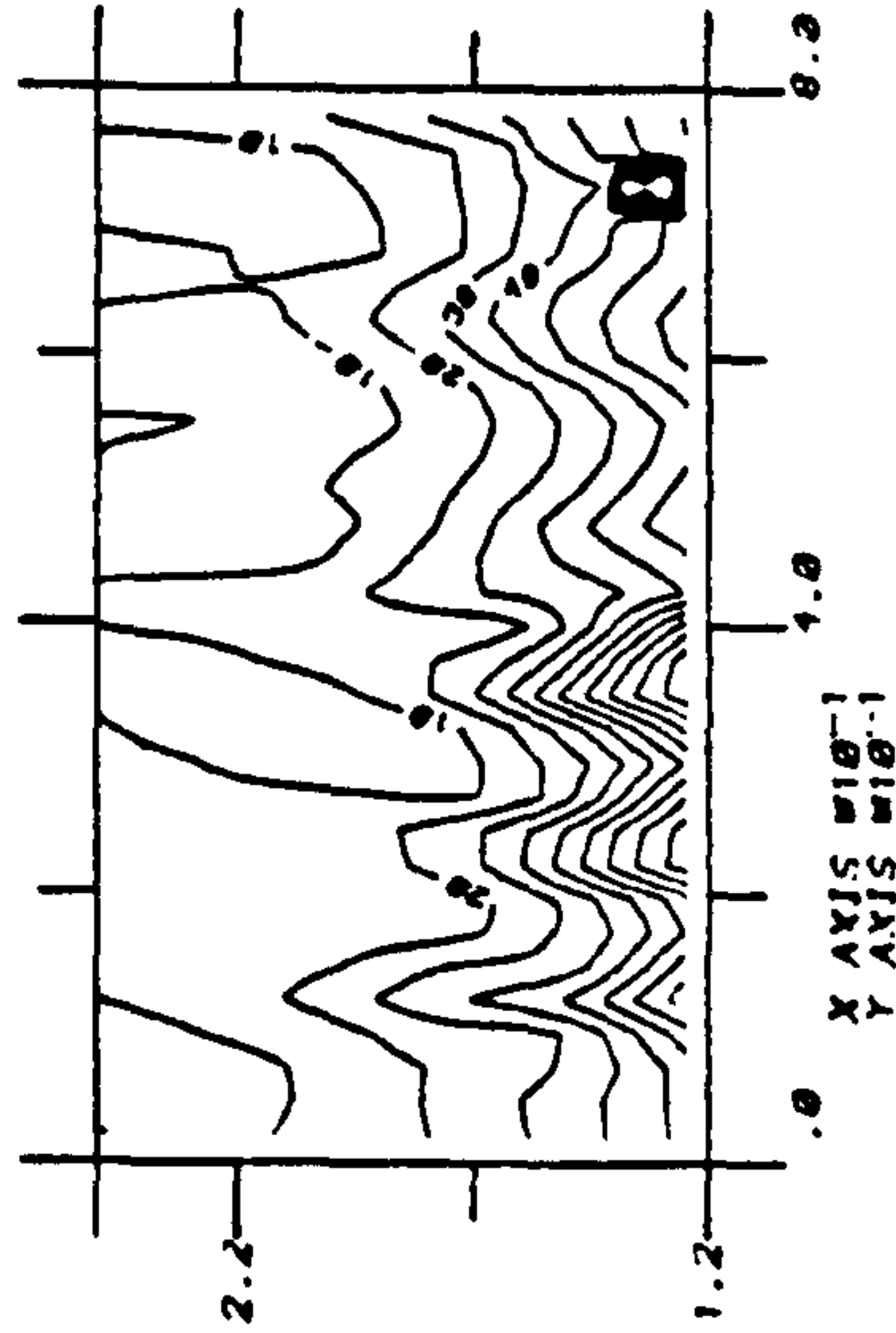
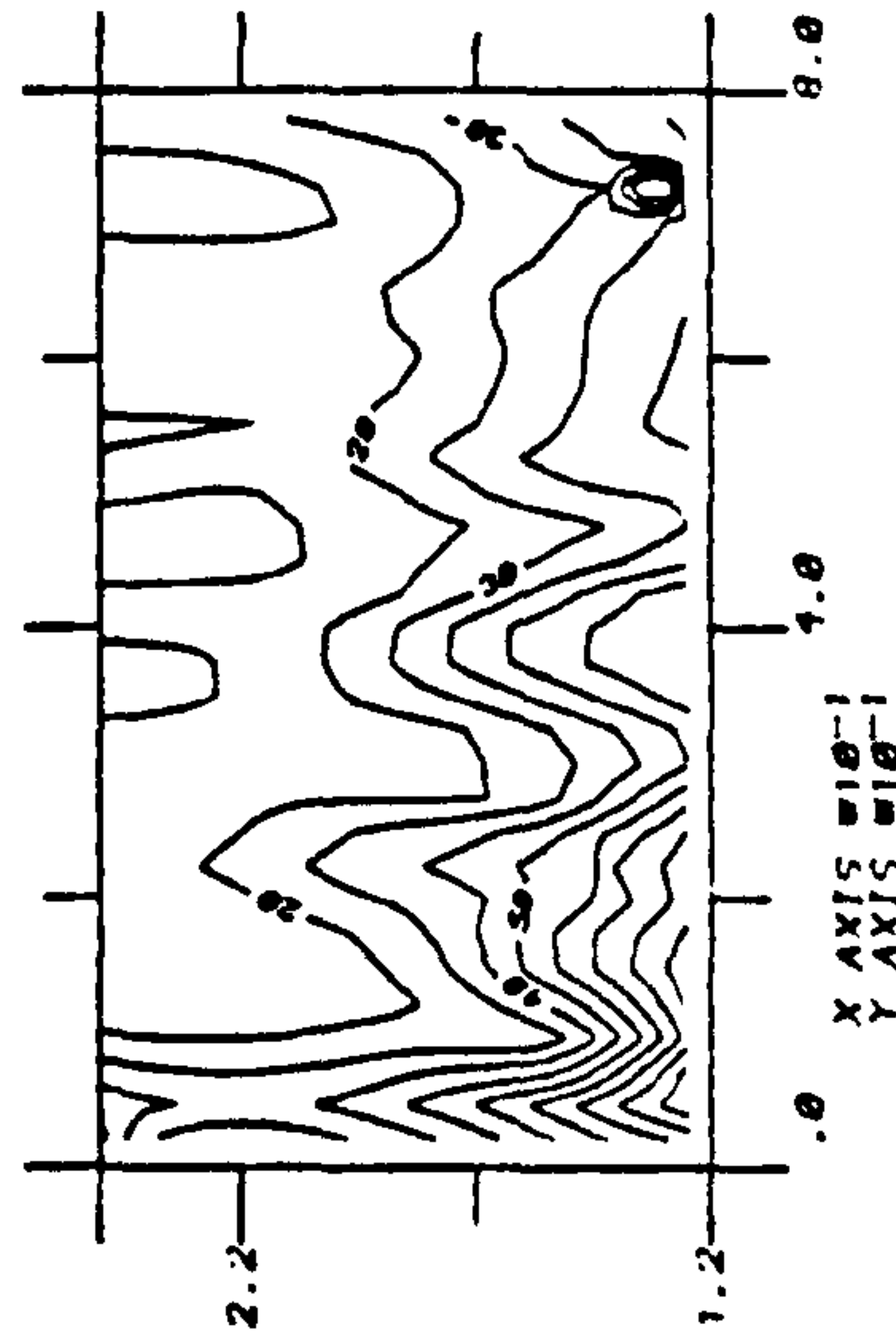
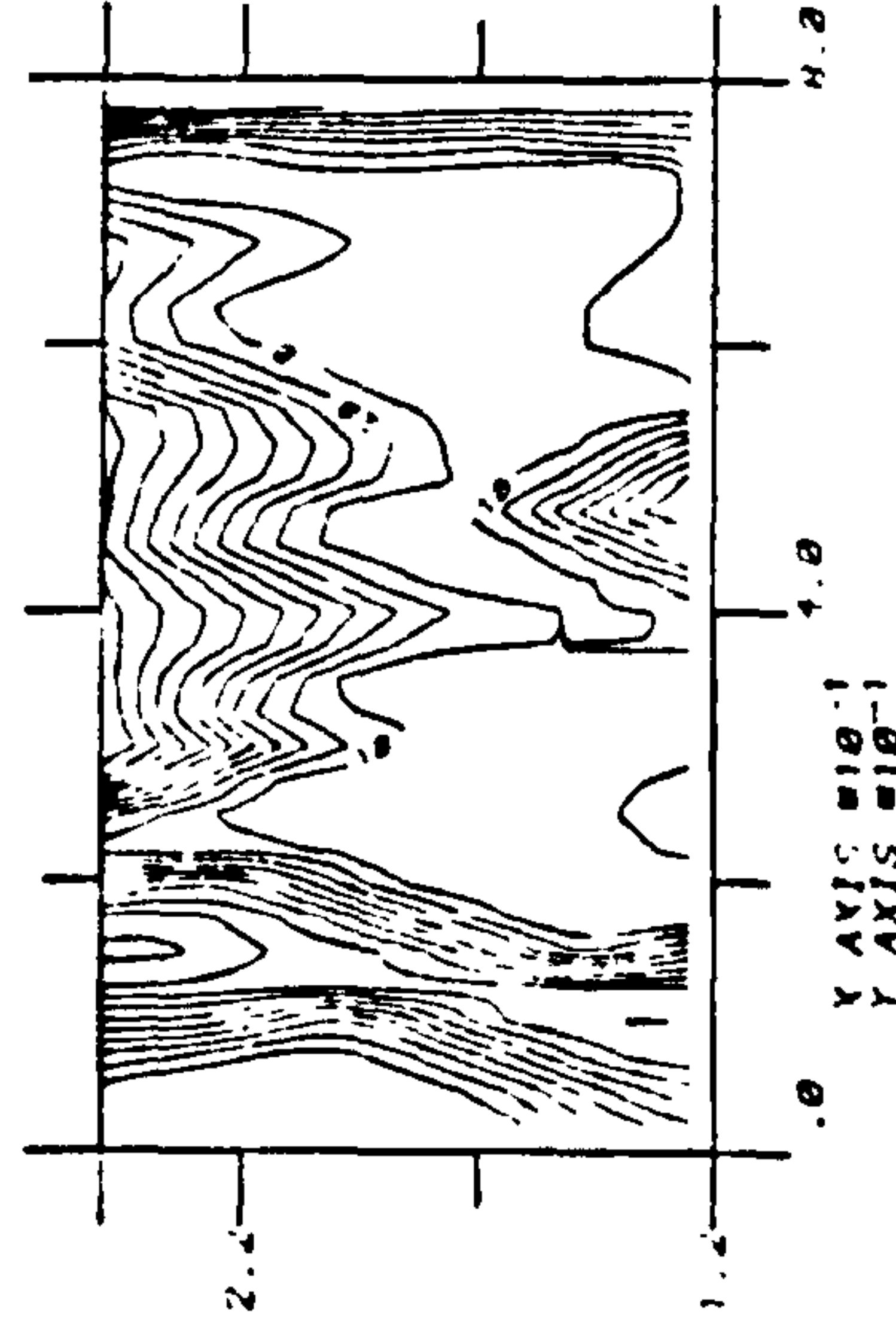
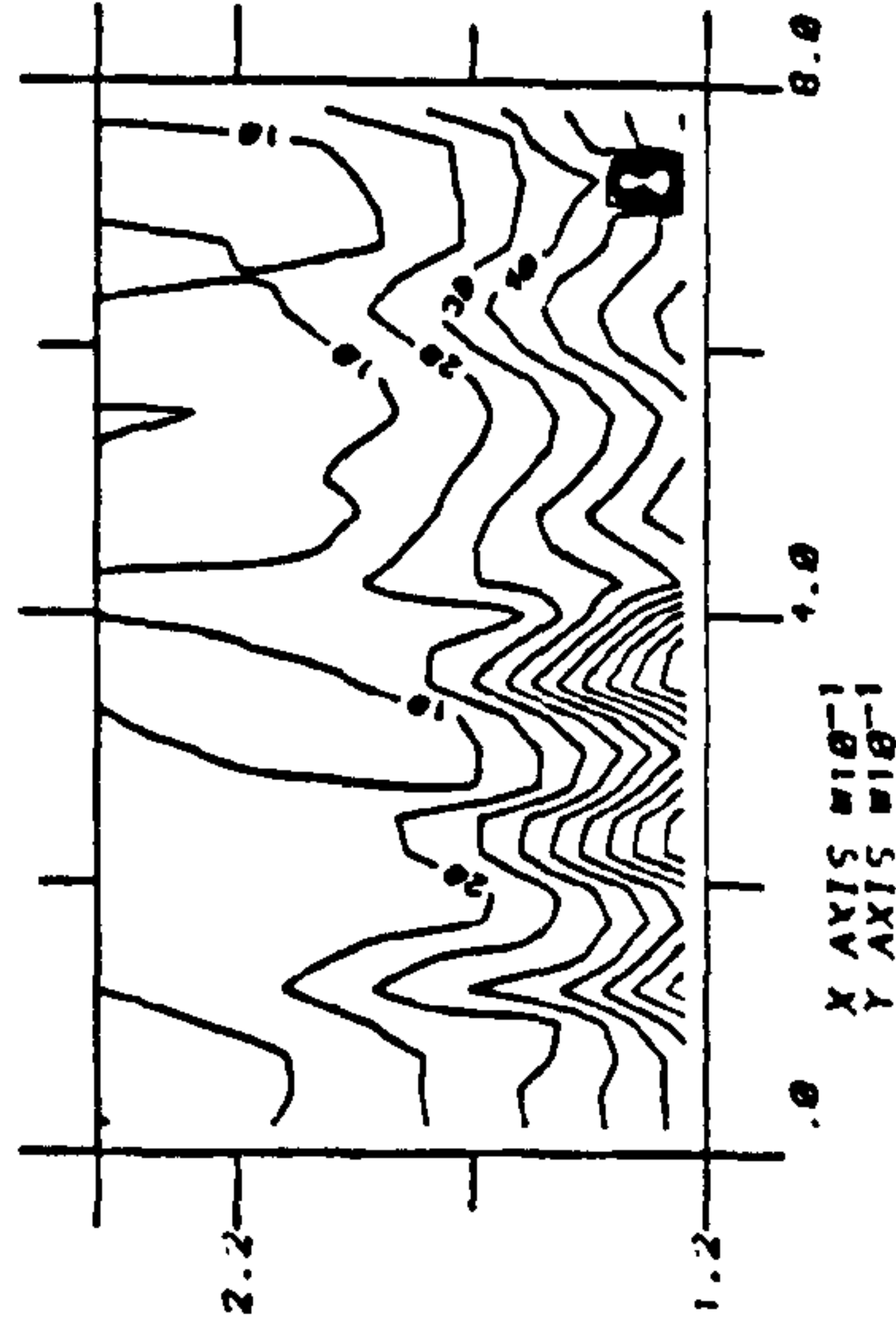
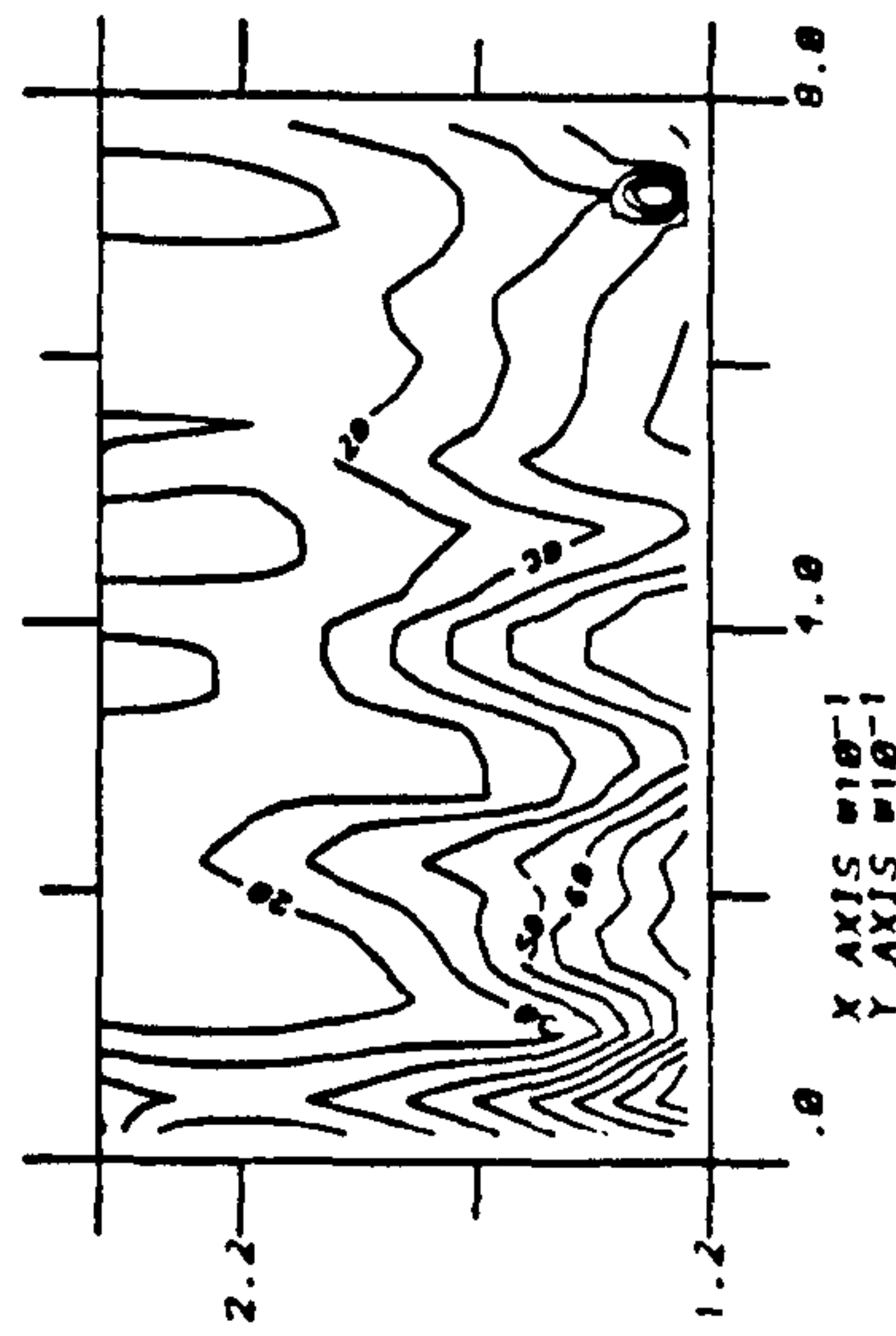


Fig 83 CONTOUR VALUES OF MAX. TURBULENCE INT. VS
RADIAL AND AXIAL DIRECTIONS

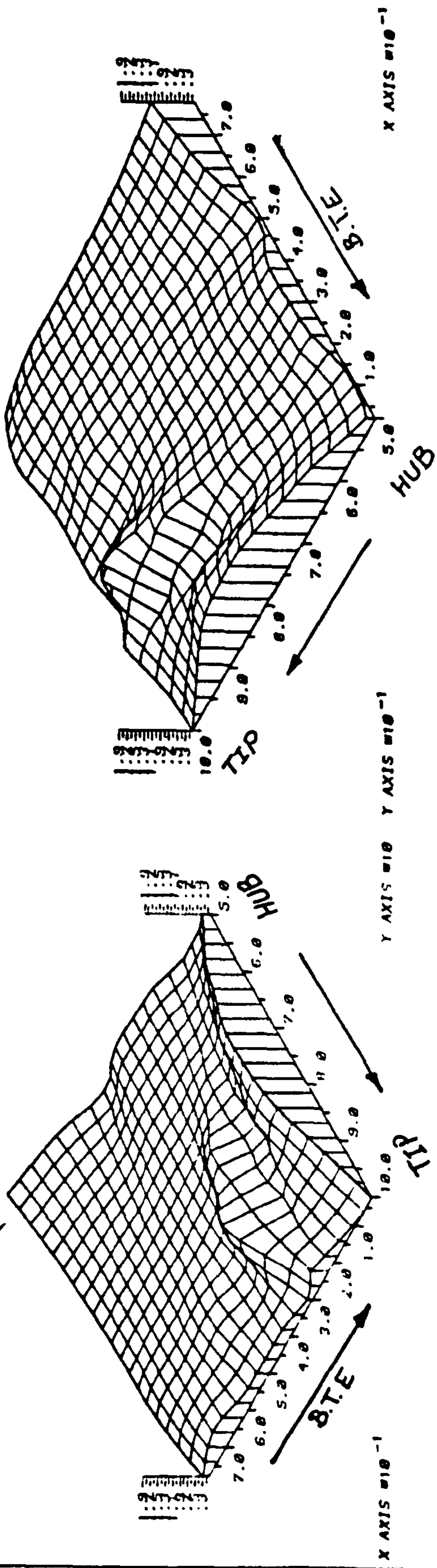
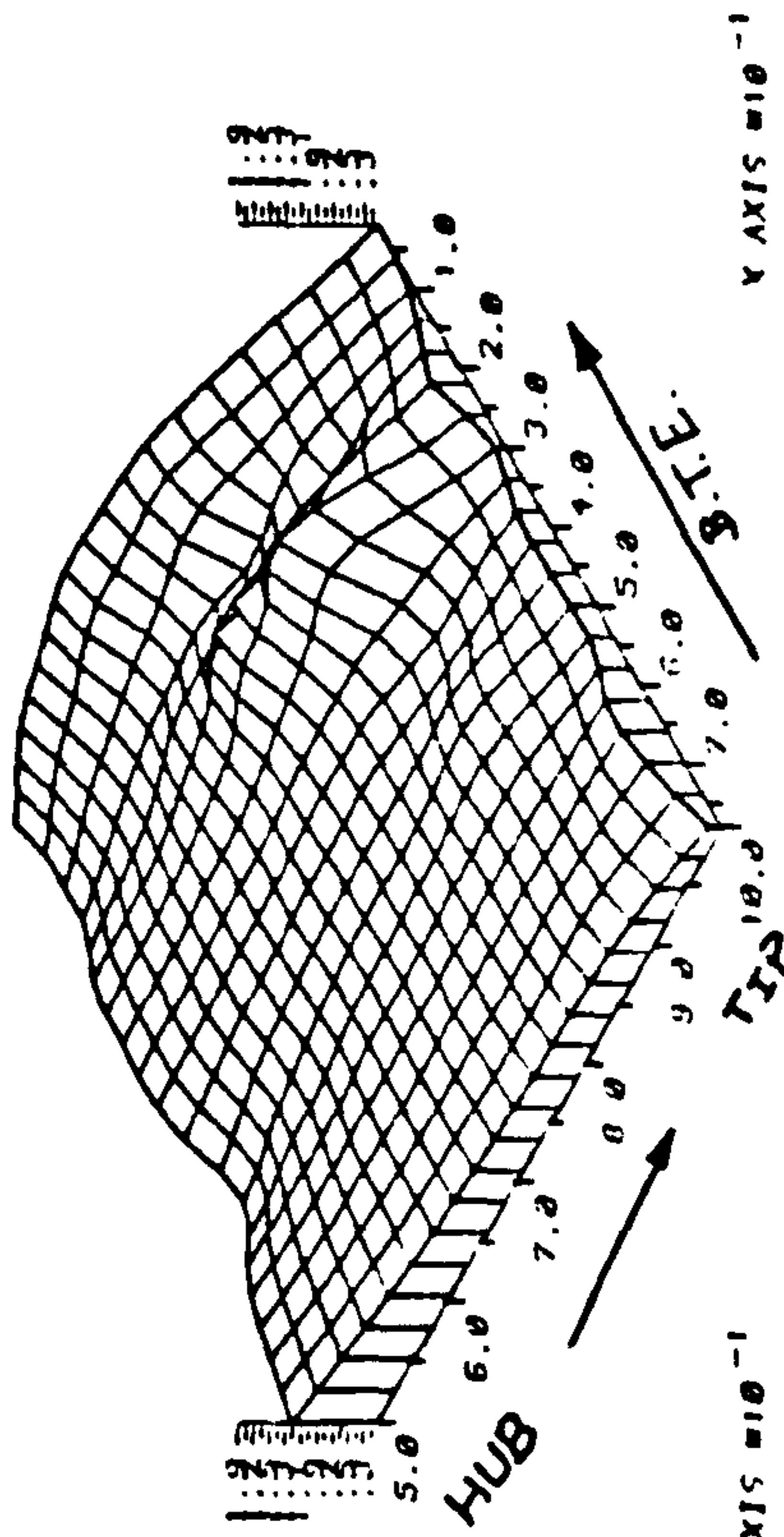
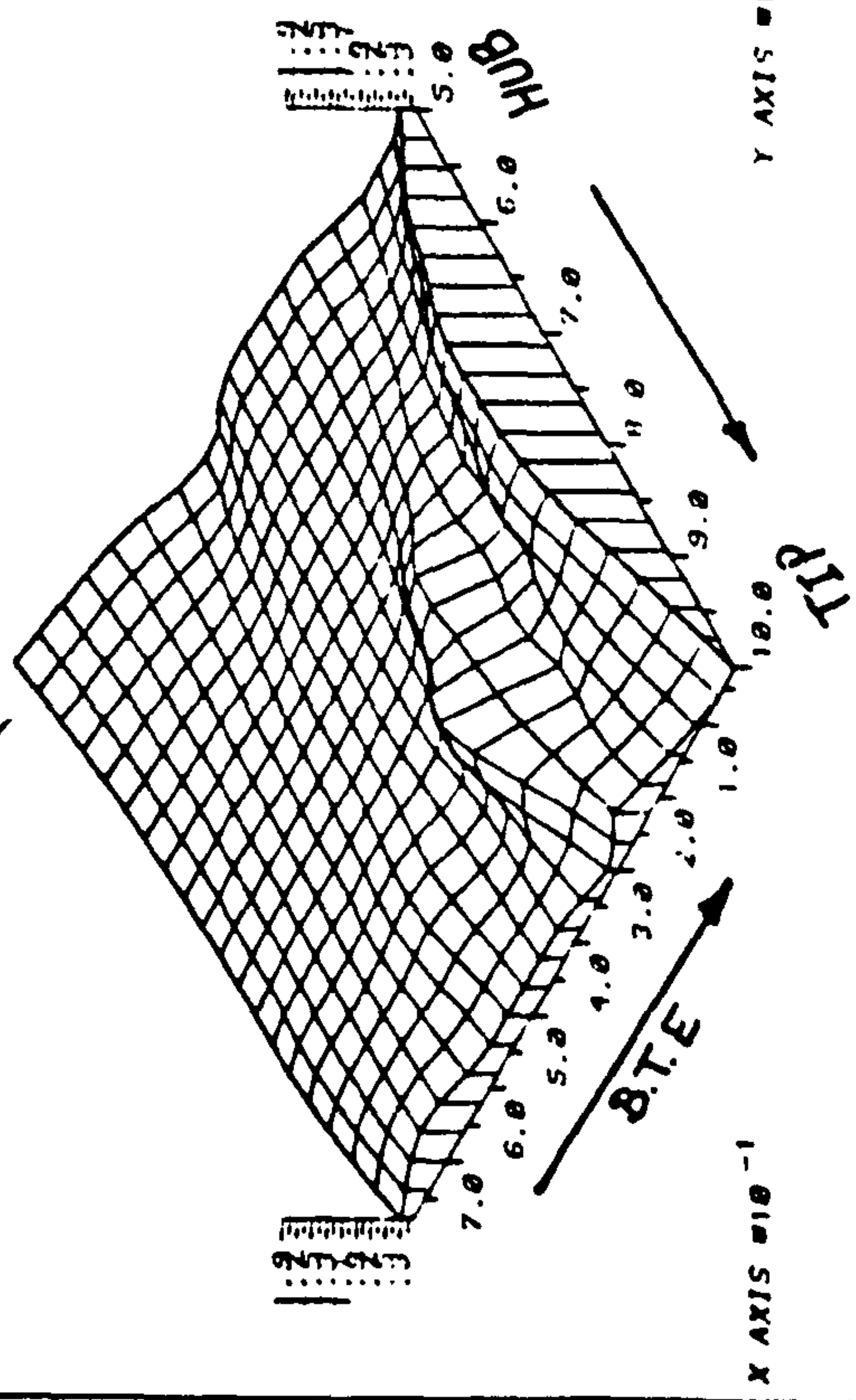
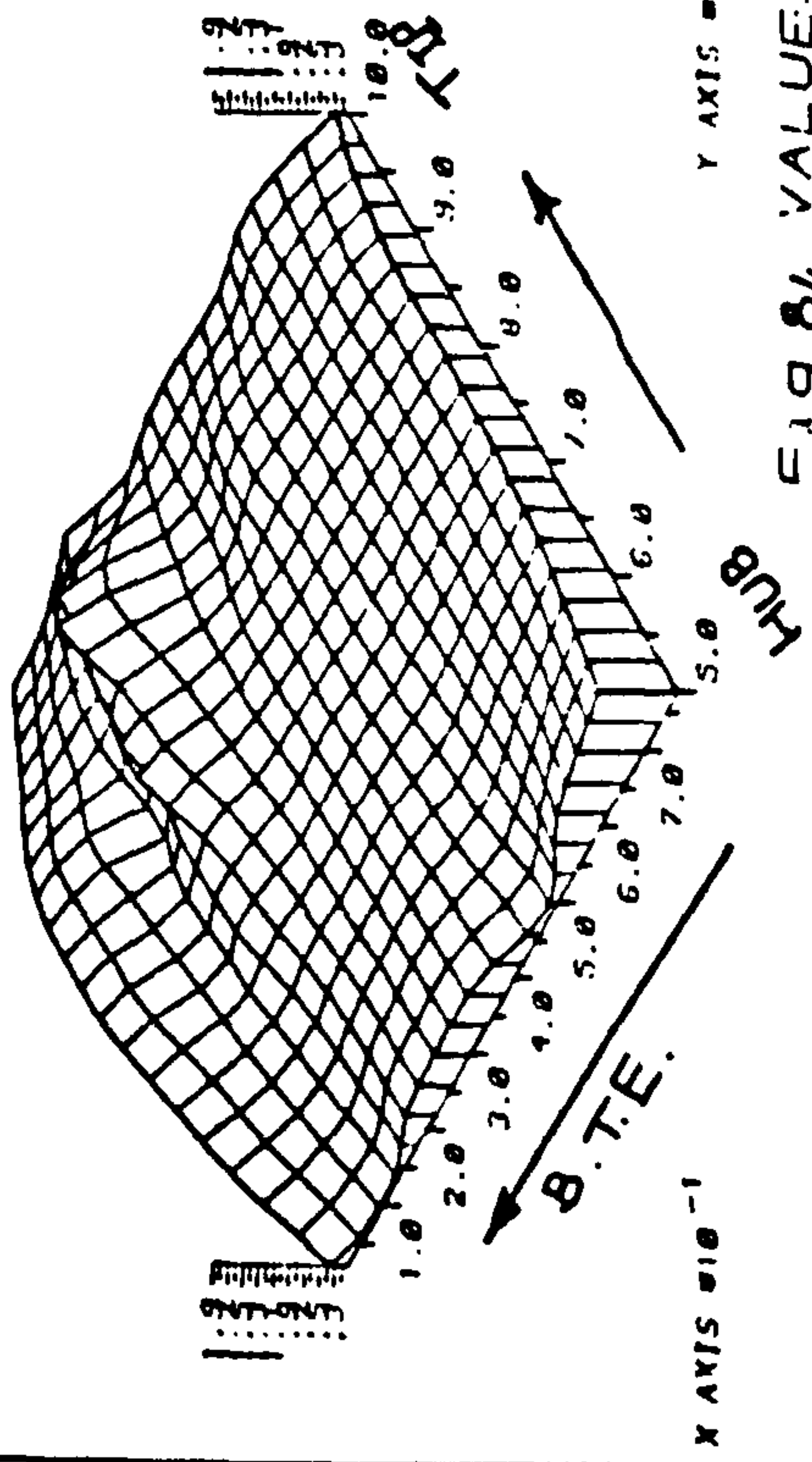


FIG 84 VALUES OF THE ISOTROPY COEFFICIENT

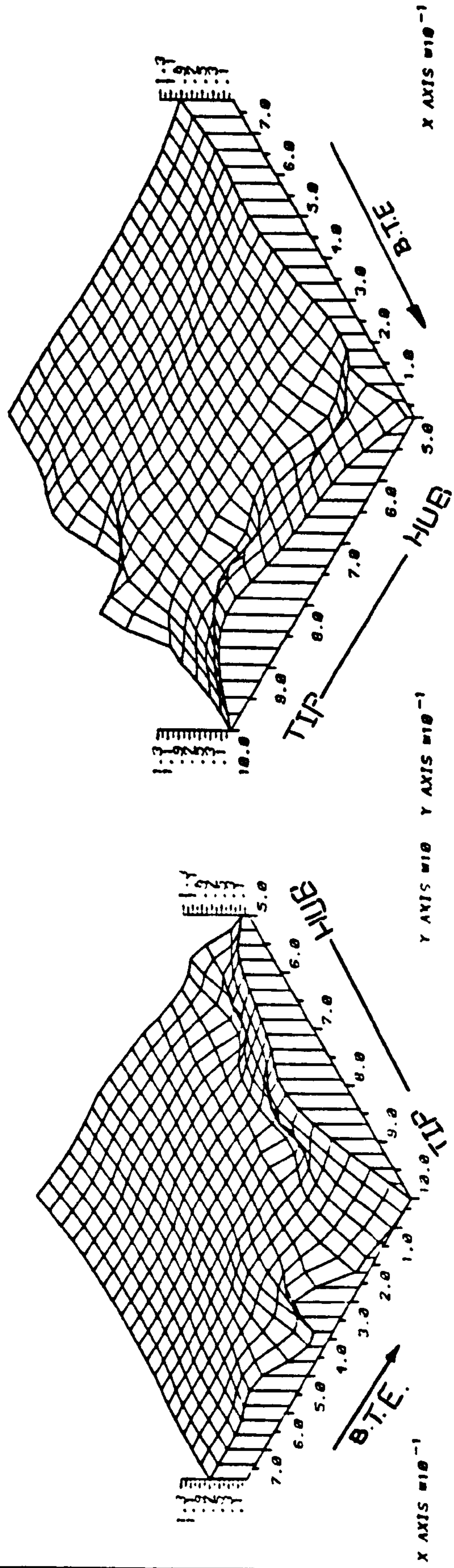
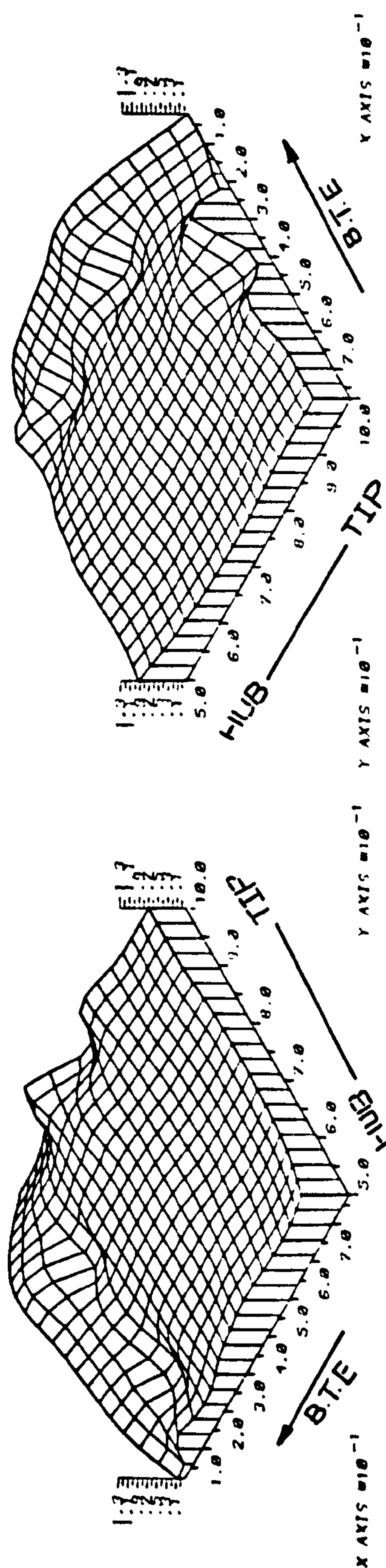


Fig 85 VALUES OF THE ISOTROPY COEFFICIENT

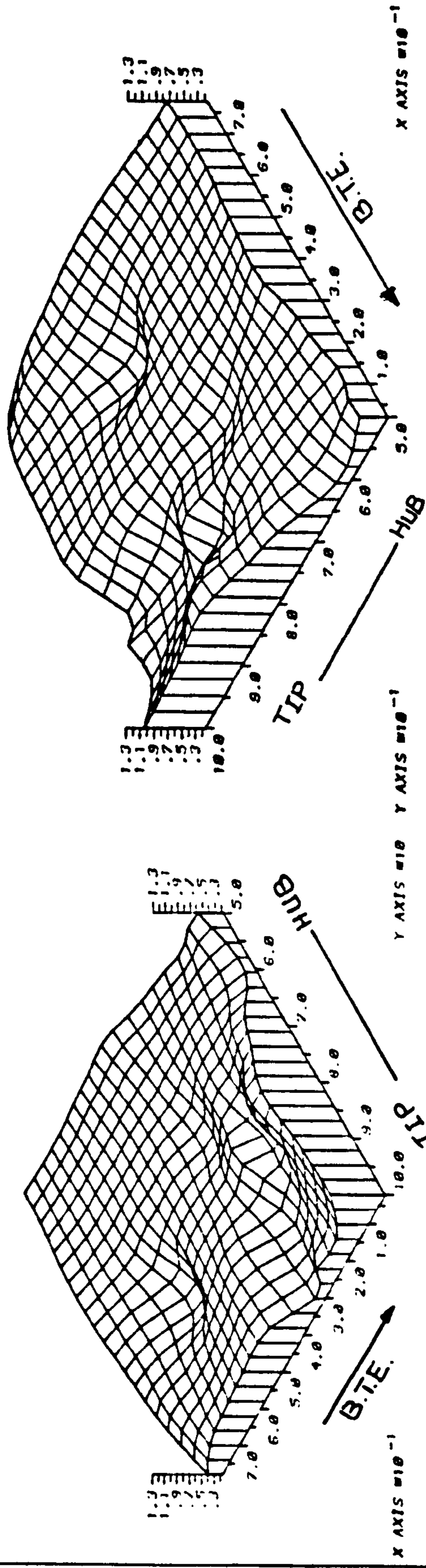
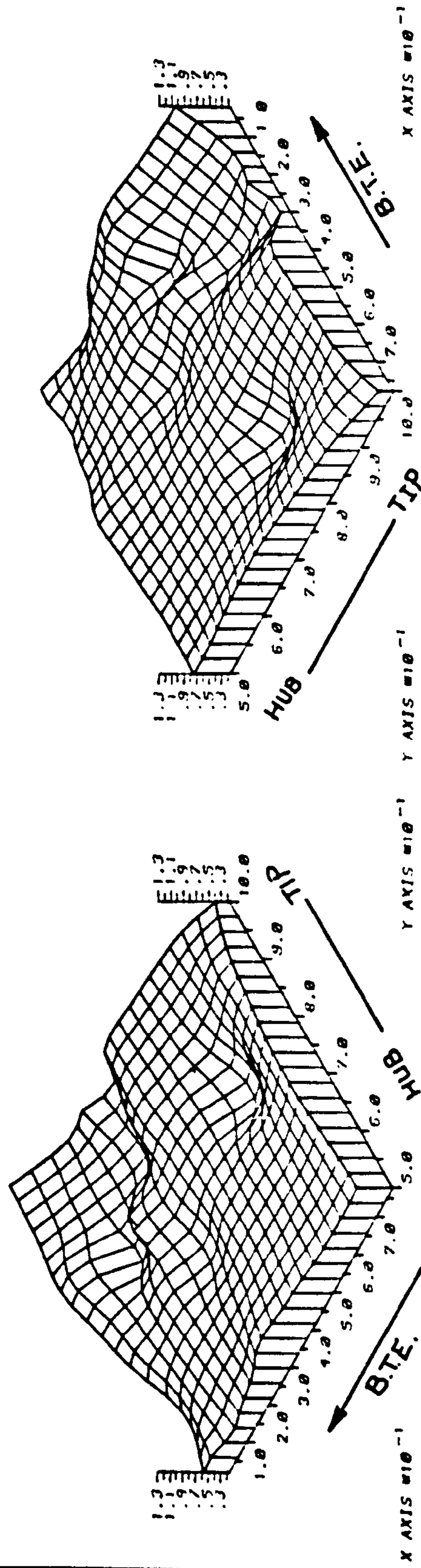


Fig 86 VALUES OF THE ISOTROPY COEFFICIENT

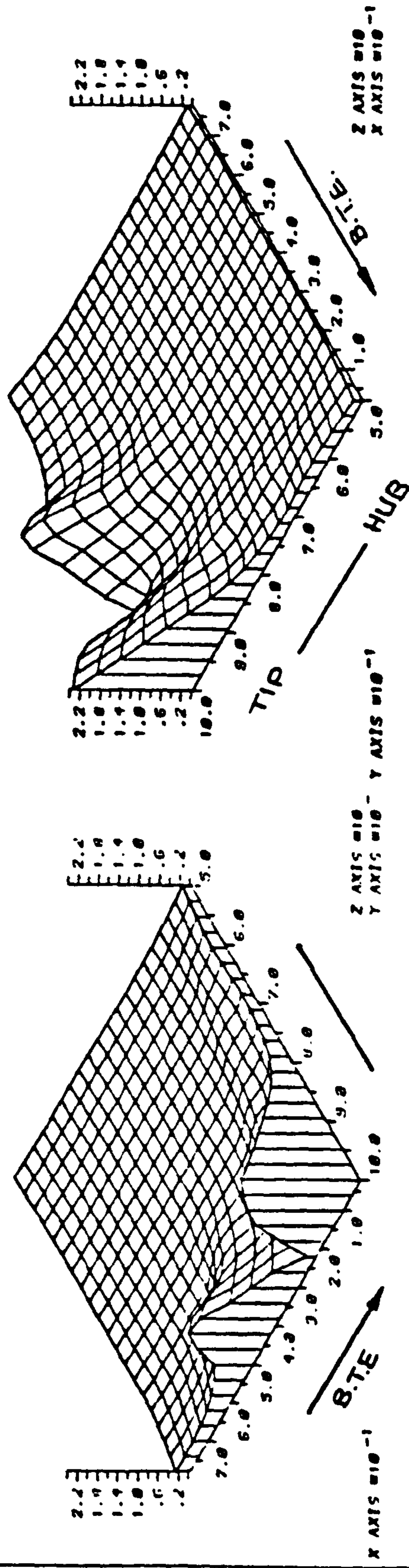
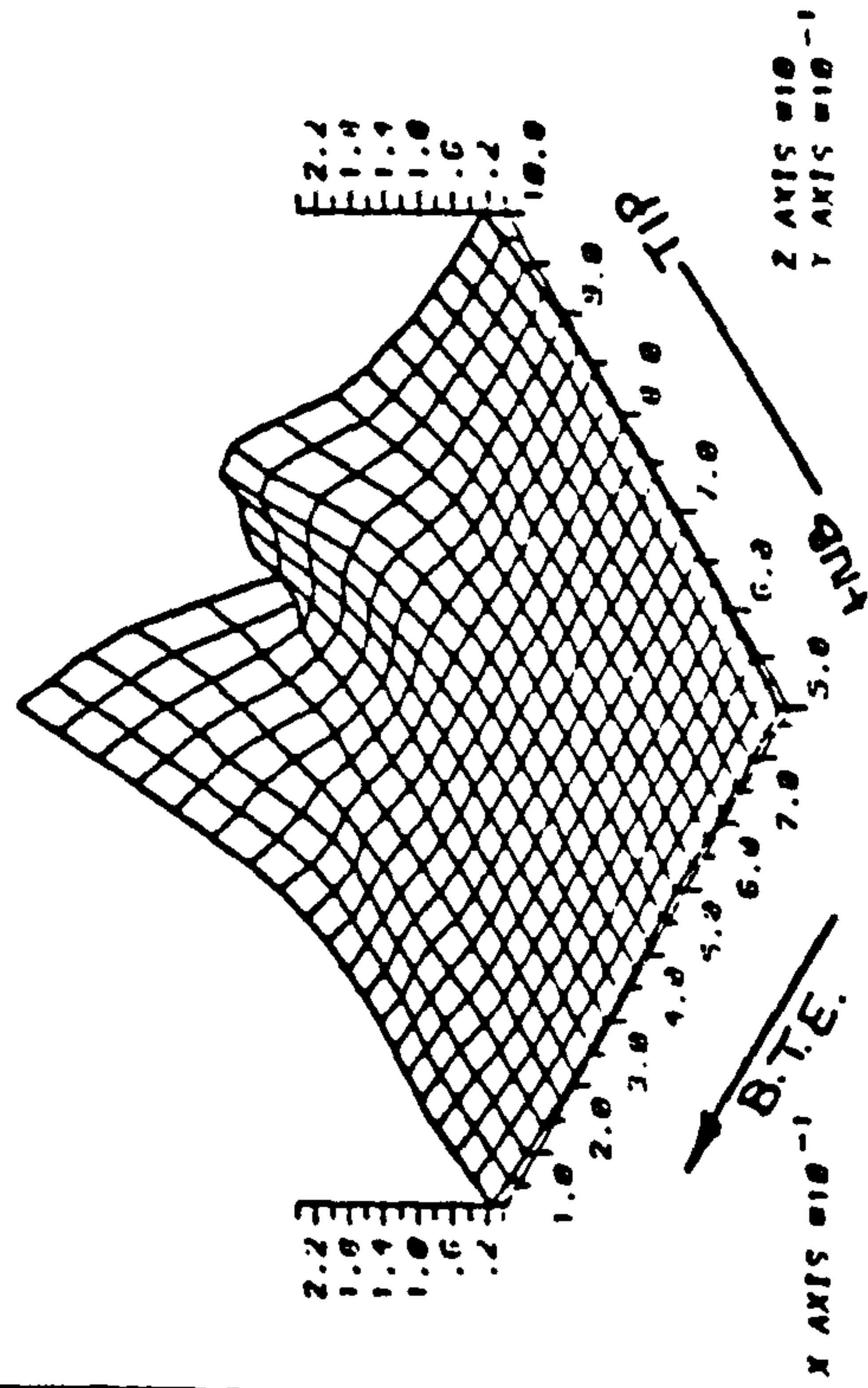
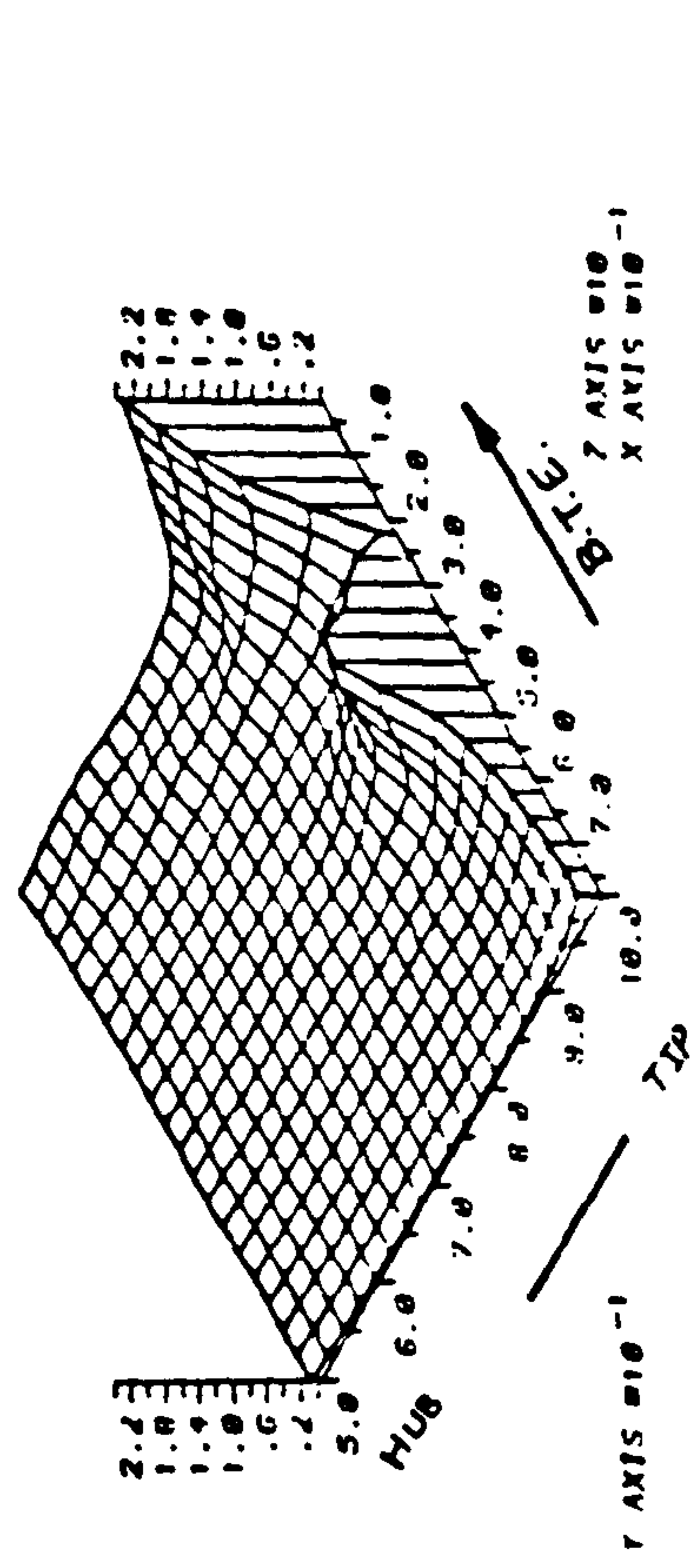


Fig 87 DISTRIBUTION OF THE TOTAL ENERGY OF TURBULENCE

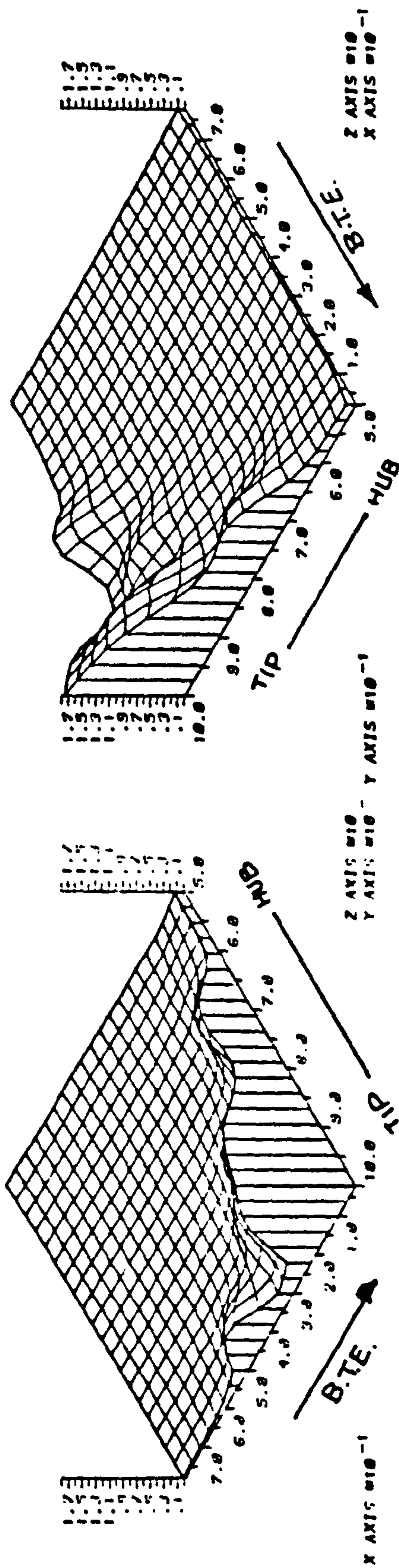
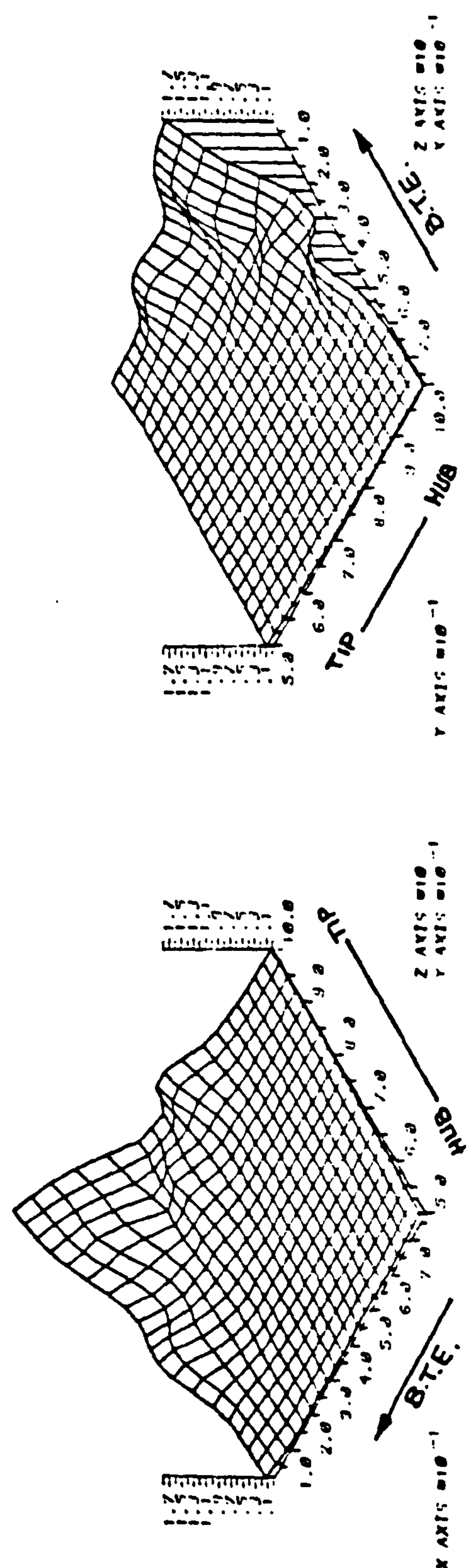


Fig 86 DISTRIBUTION OF THE TOTAL ENERGY OF TURBULENCE

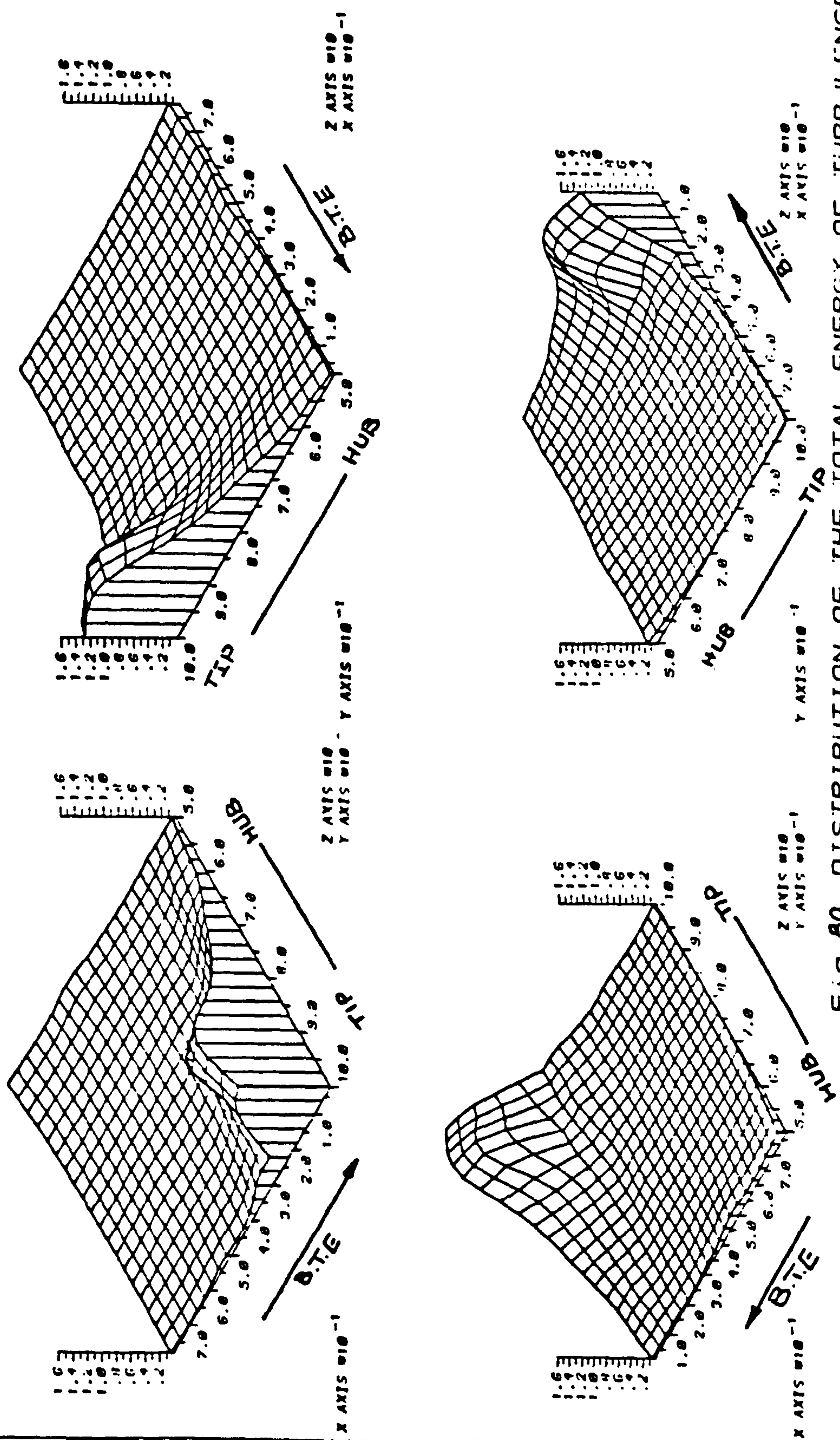


Fig 89 DISTRIBUTION OF THE TOTAL ENERGY OF TURBULENCE

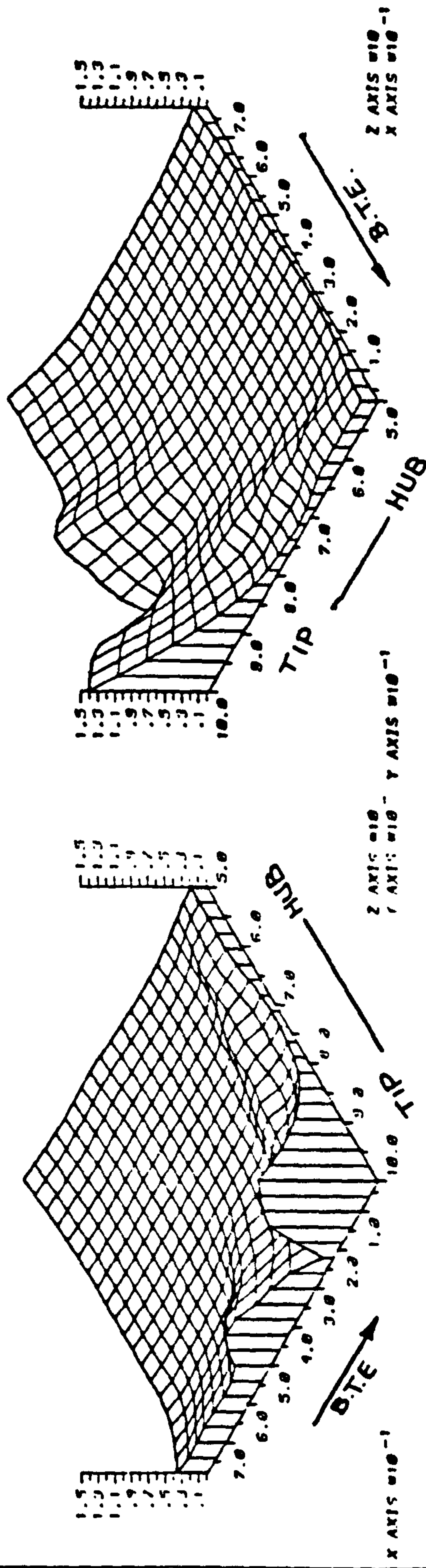
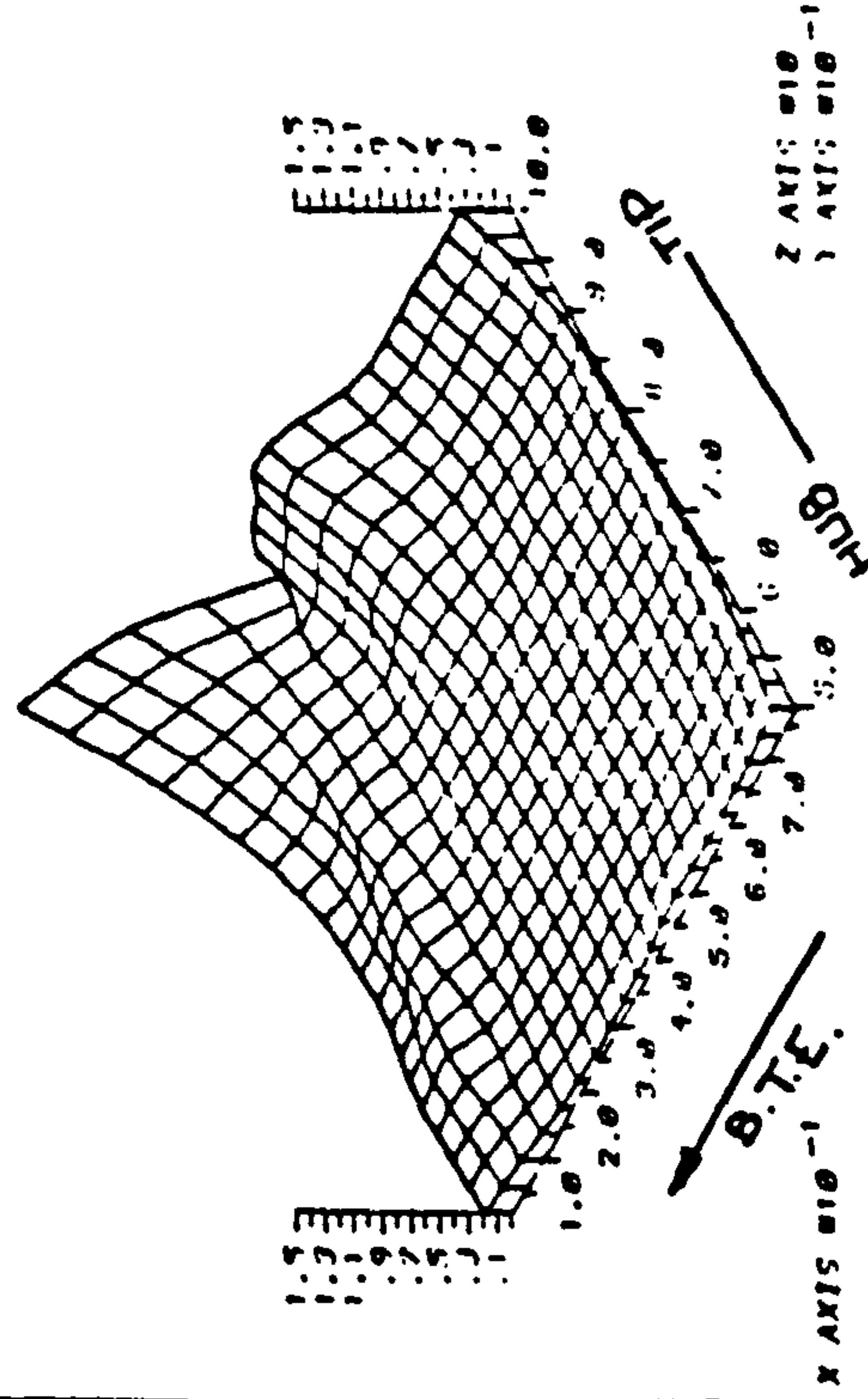
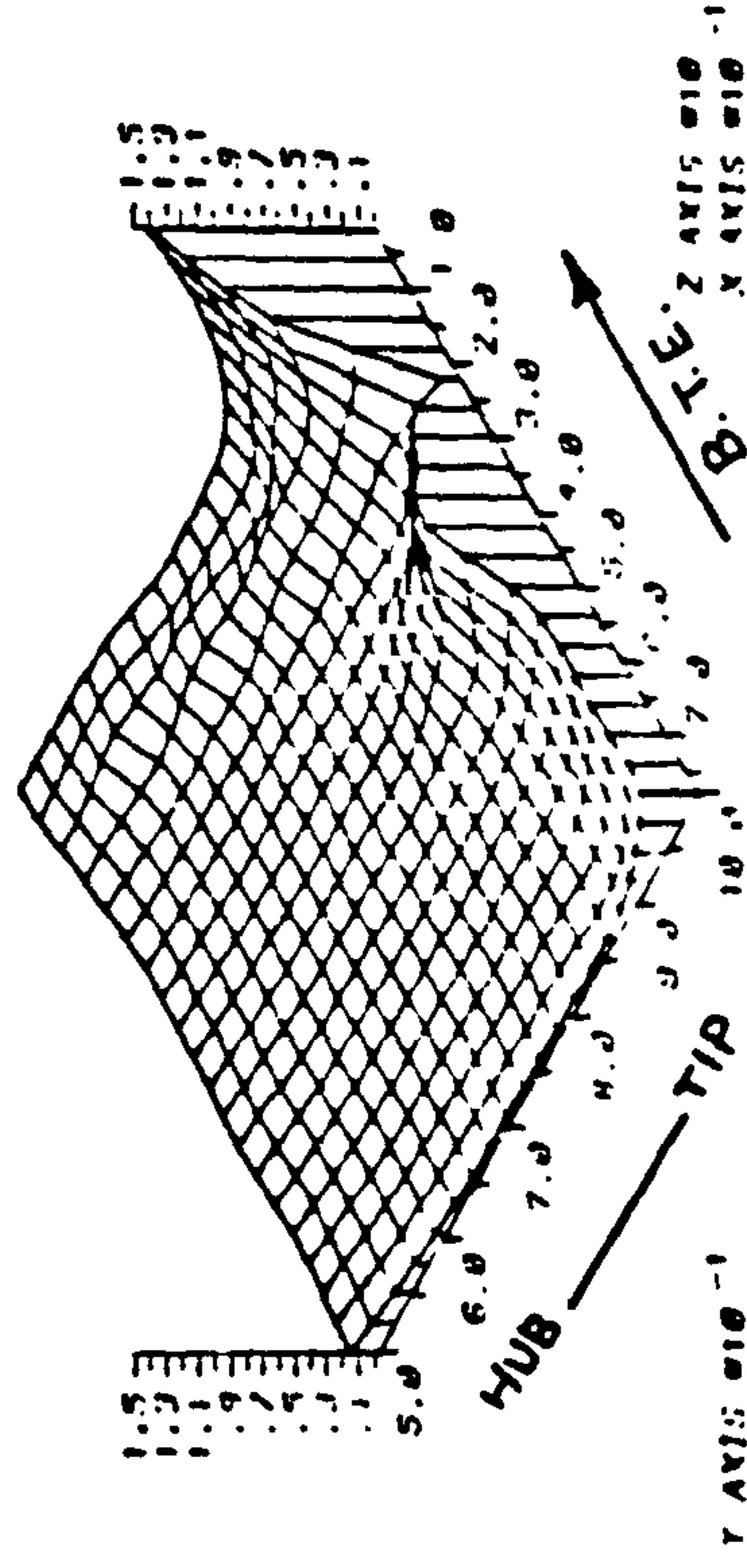


Fig 90 DISTRIBUTION OF THE TOTAL ENERGY OF TURBULENCE

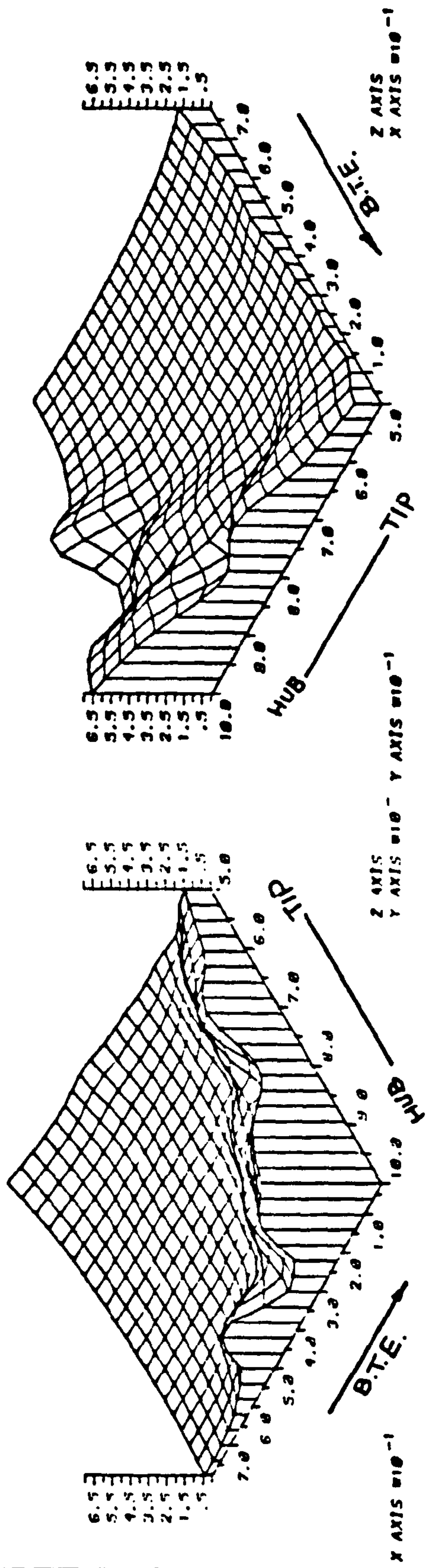
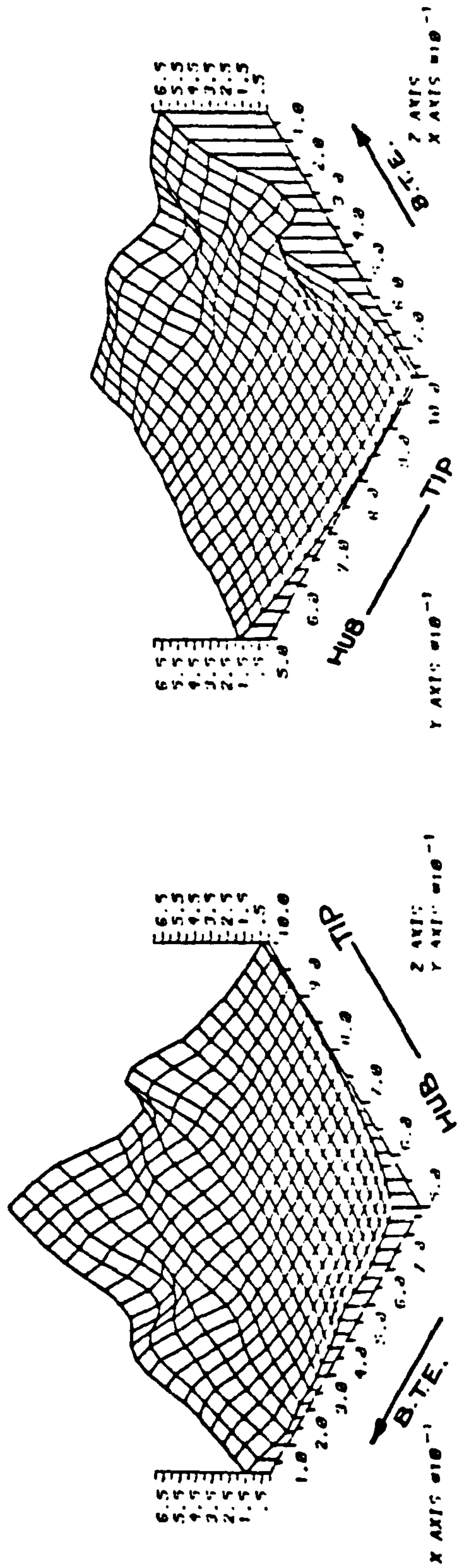


Fig 91 DISTRIBUTION OF THE TOTAL ENERGY OF TURBULENCE

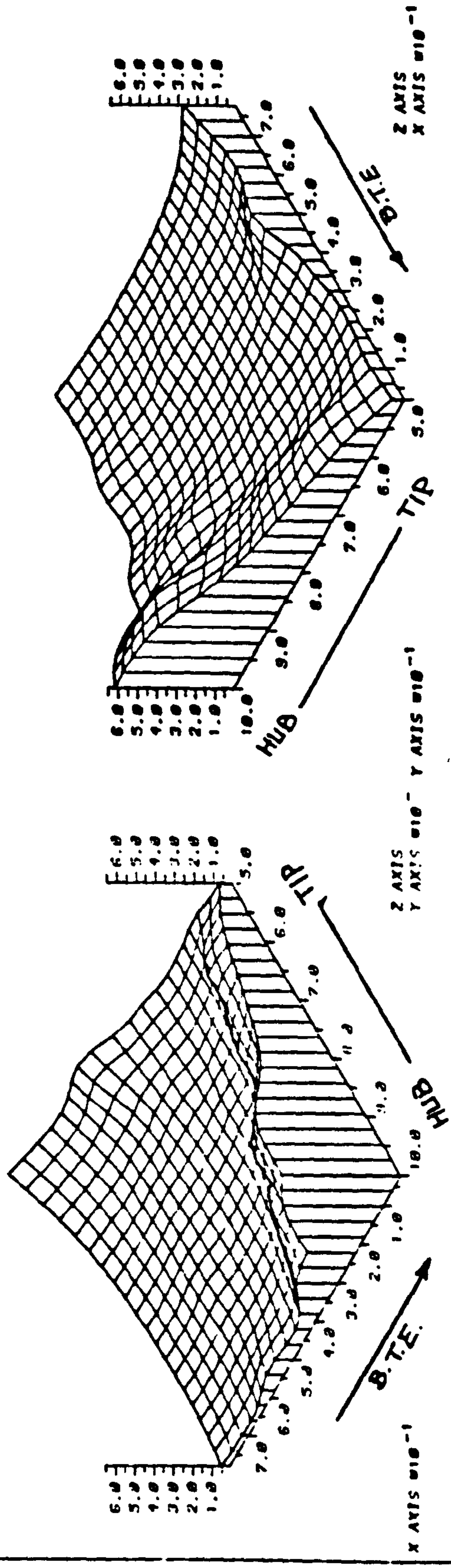
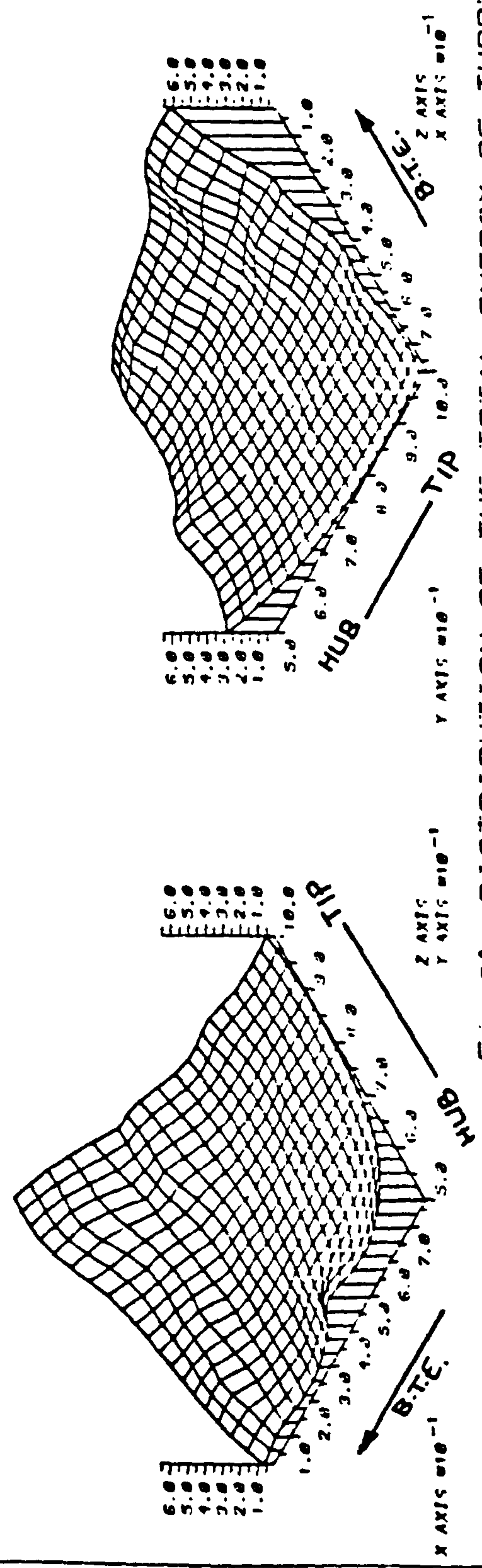


FIG 92 DISTRIBUTION OF THE TOTAL ENERGY OF TURBULENCE

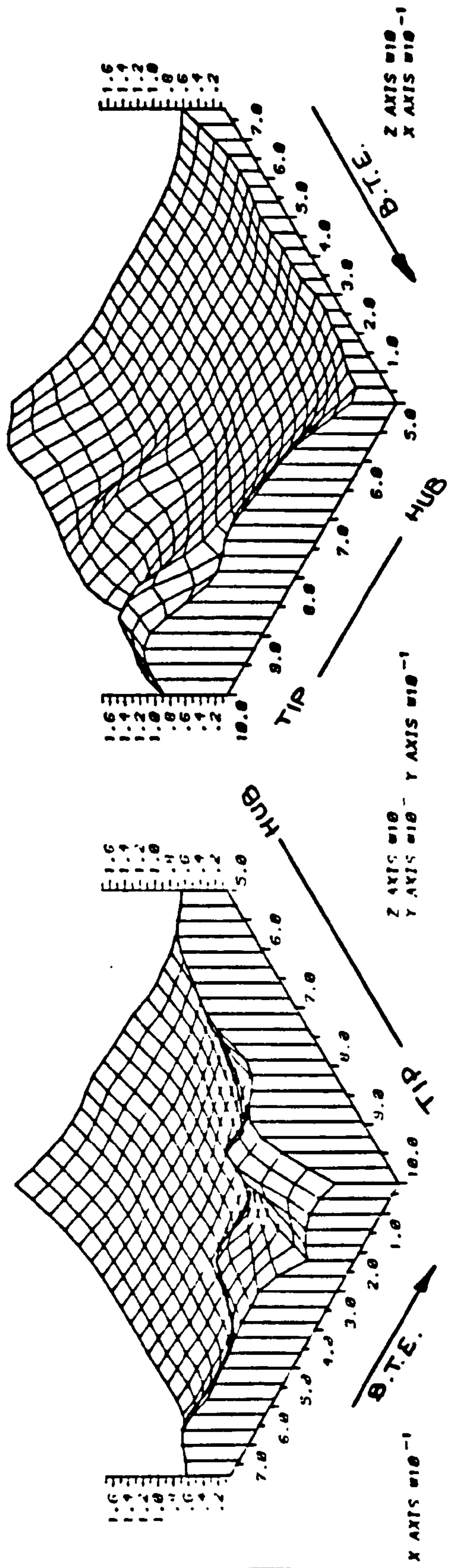
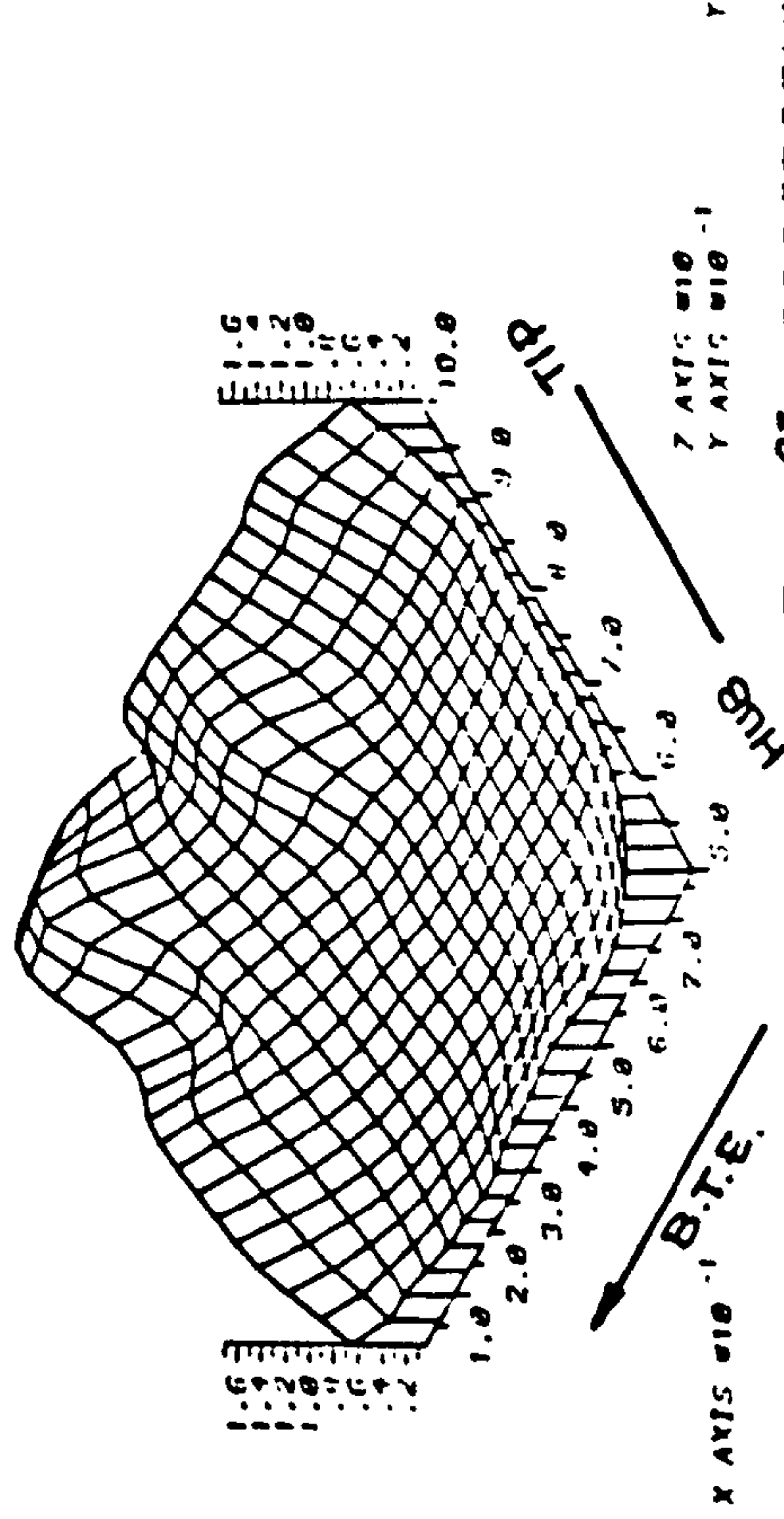
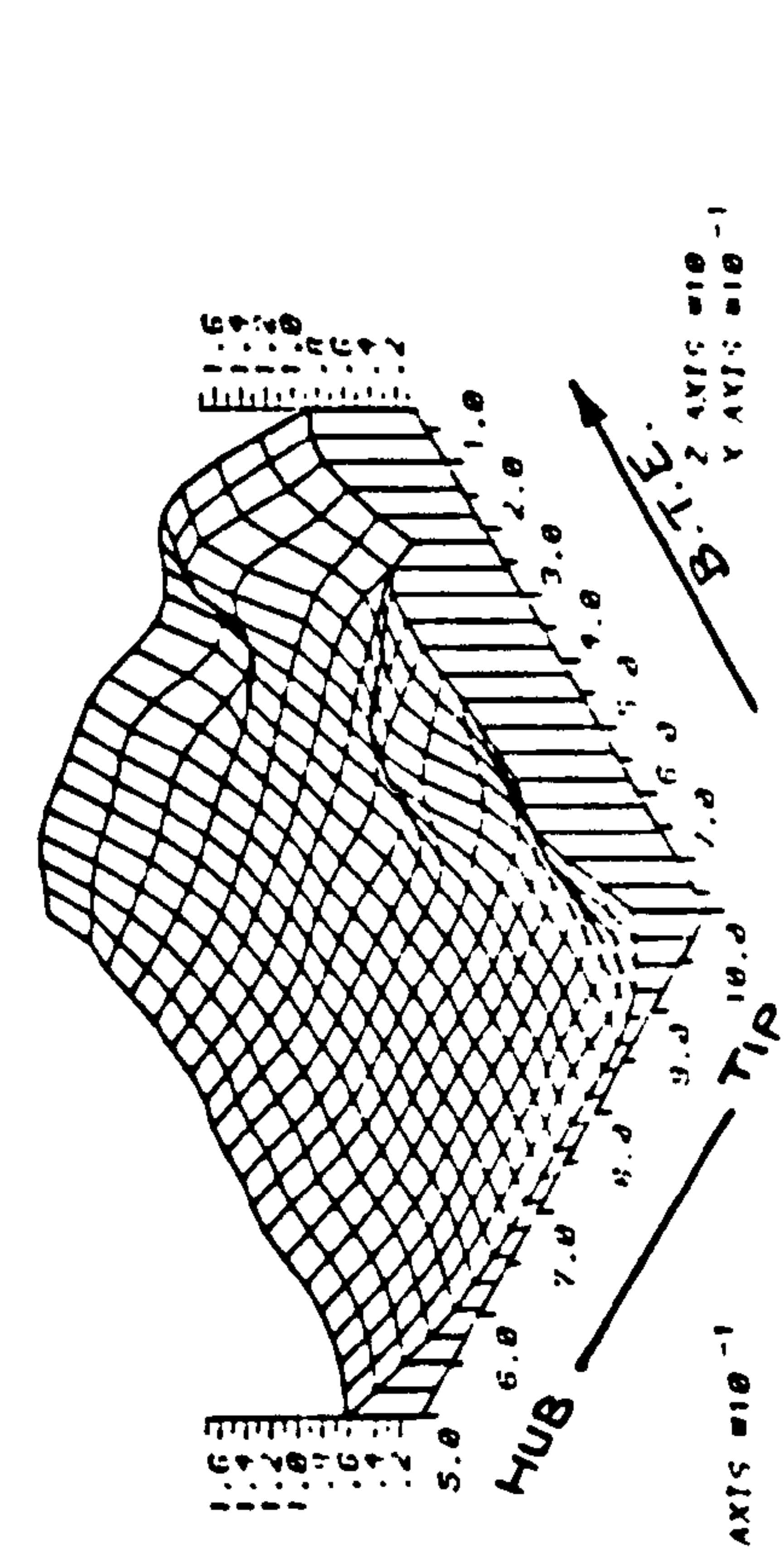


Fig 93 DISTRIBUTION OF THE FREE STREAM TURBULENCE

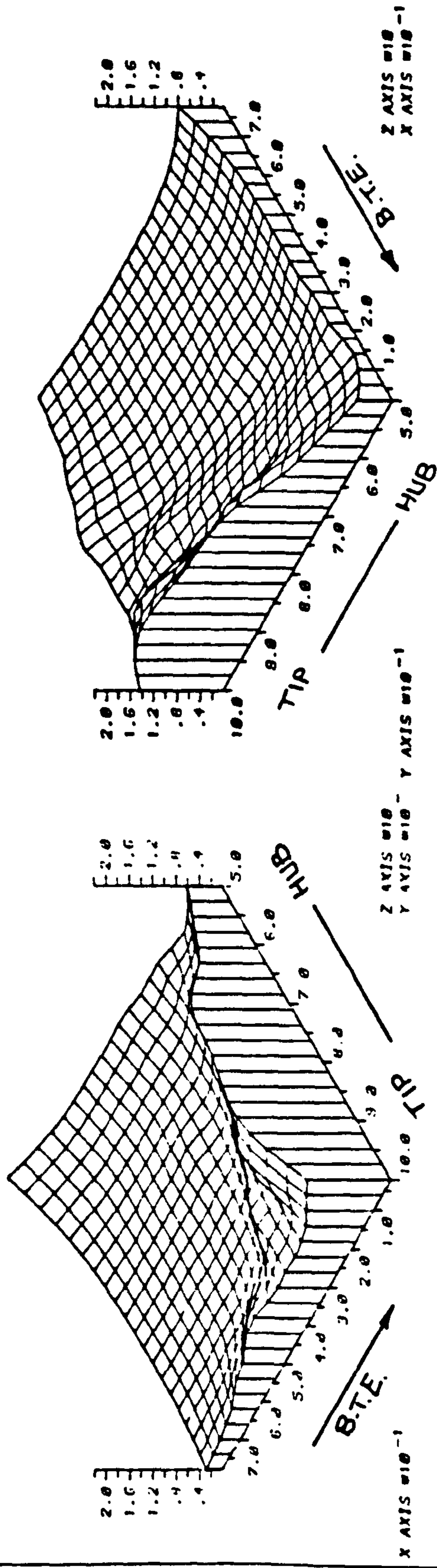
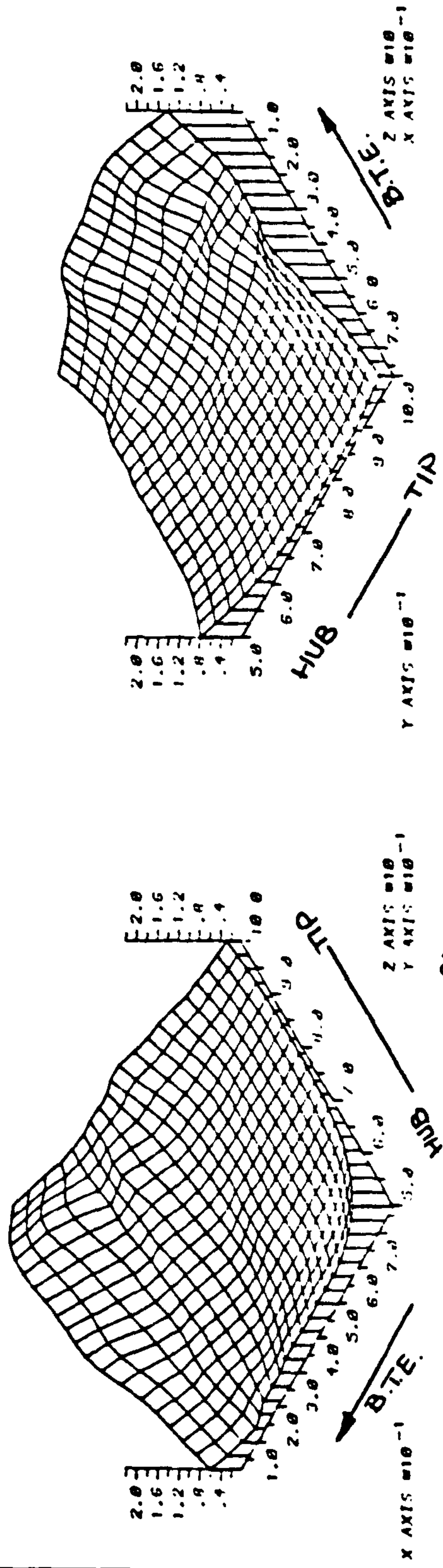


Fig 94 DISTRIBUTION OF THE FREE STREAM TURBULENCE

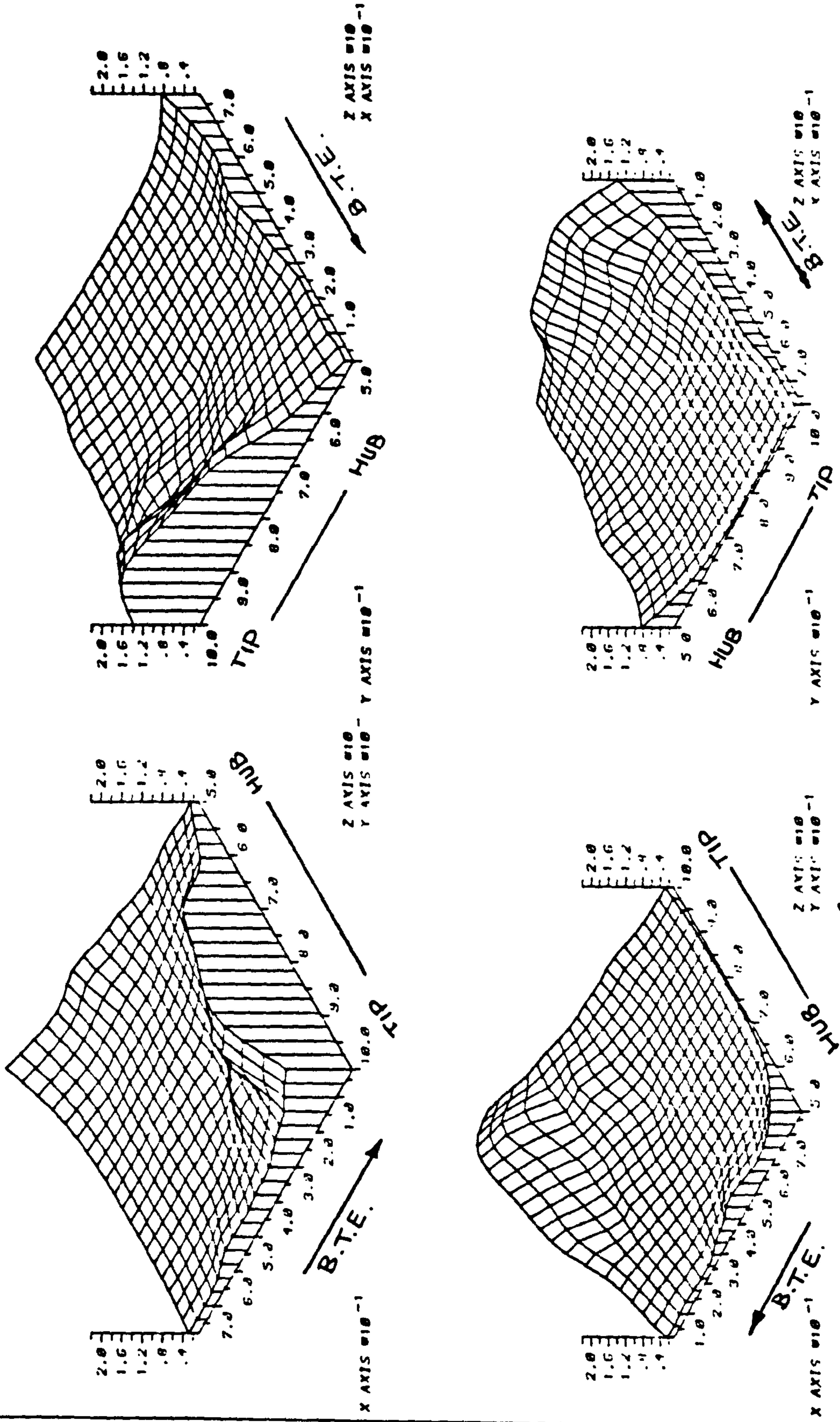


Fig 95 DISTRIBUTION OF THE FREE STREAM TURBULENCE

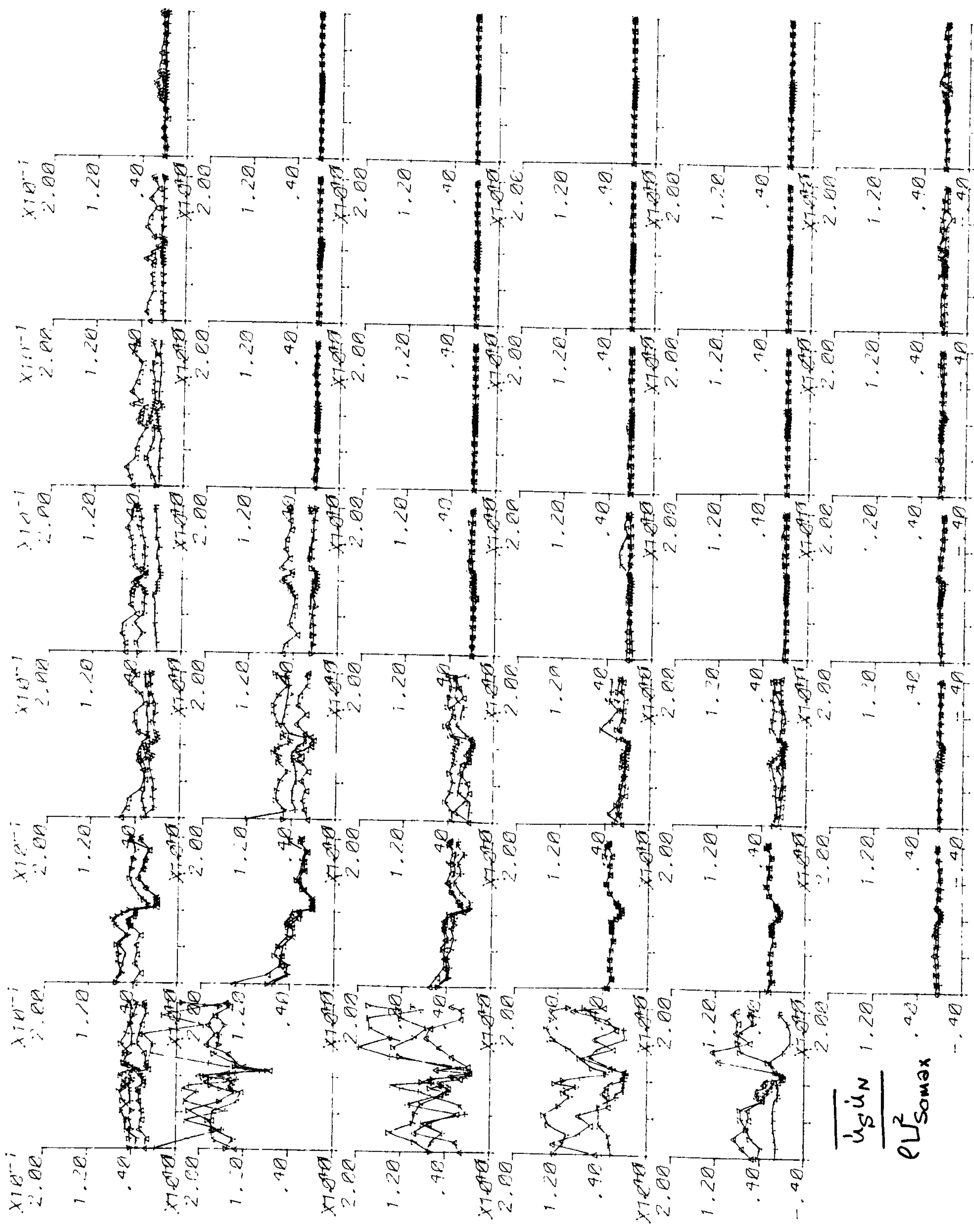


FIG 96 DISTRIBUTION OF STREAM WISE COMPONENT OF REYNOLDS STRESSES.

Δ LOAD(I) ∇ LOAD(II) $\times$ LOAD(III) $\square$ LOAD(IV)

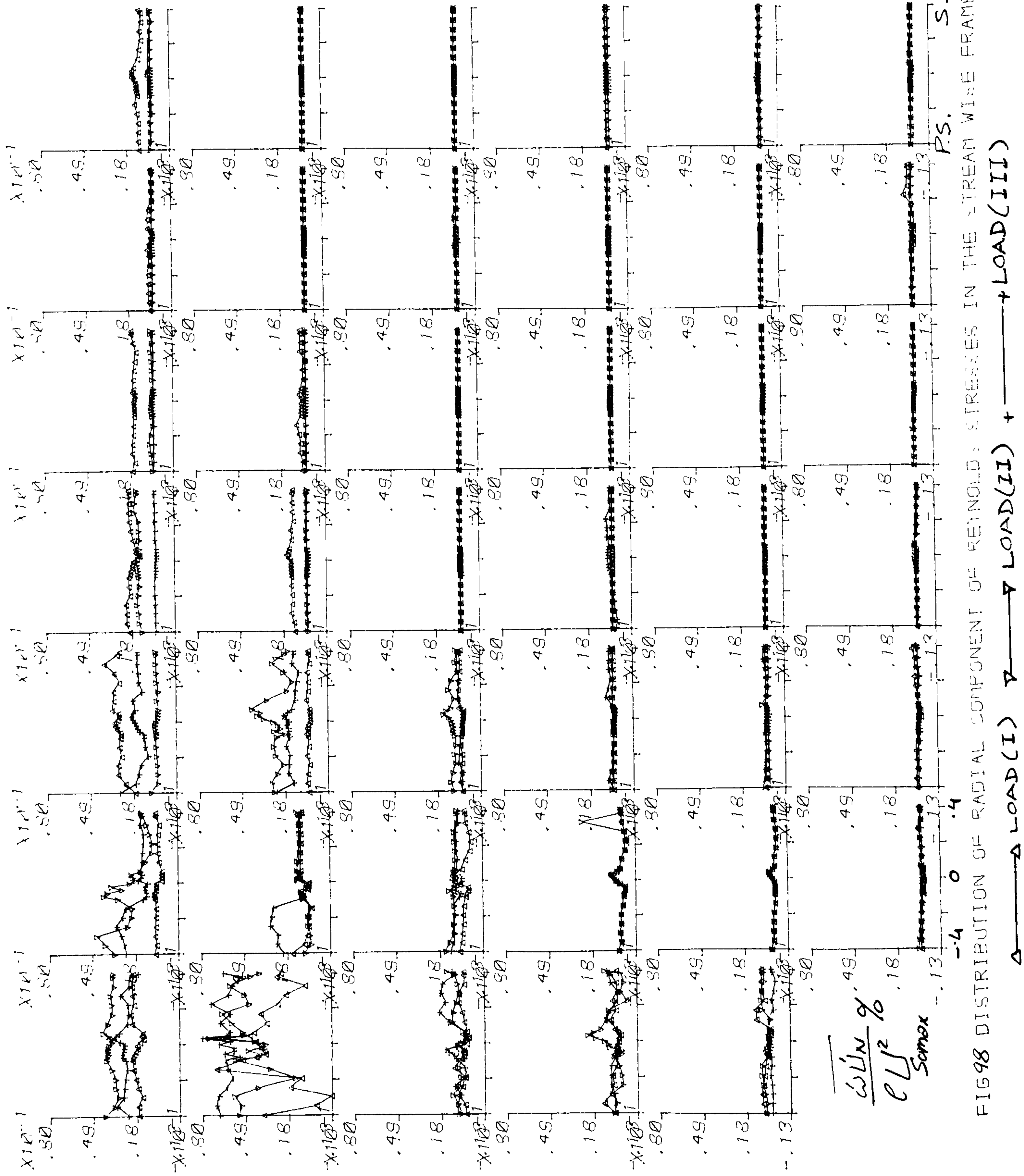


FIG98 DISTRIBUTION OF RADIAL COMPONENT OF REYNOLDS STRESSES IN THE STREAM WISE FRAME OF REFERENCE.

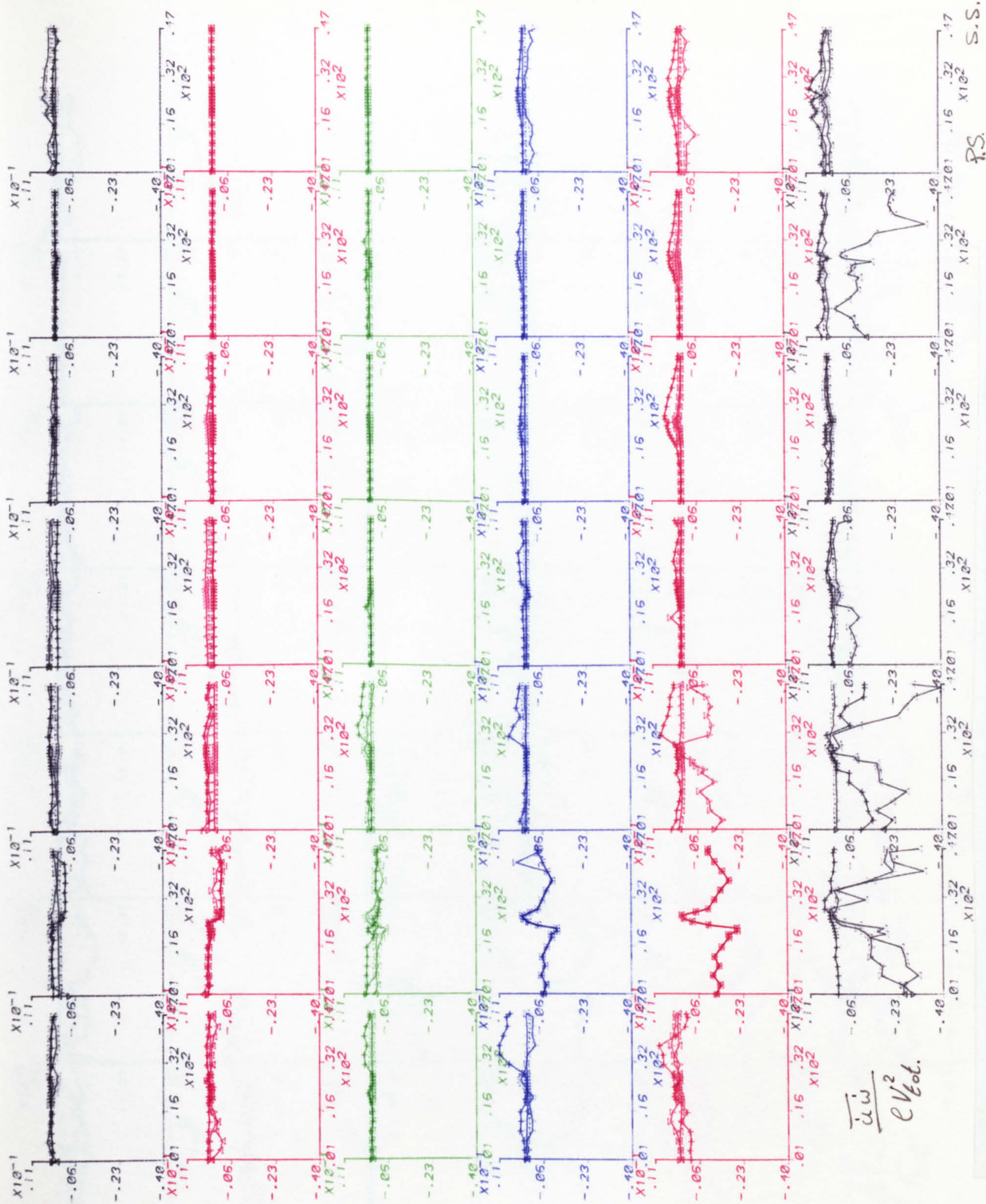


FIG 100 DISTRIBUTION OF TANGENTIAL COMPONENTS OF REYNOLDS STRESSES.

Δ ----- Δ LOAD (I) ∇ ----- ∇ LOAD (II) $+$ ----- $+$ LOAD (III).

AXIAL

TANGENTIAL

RADIAL

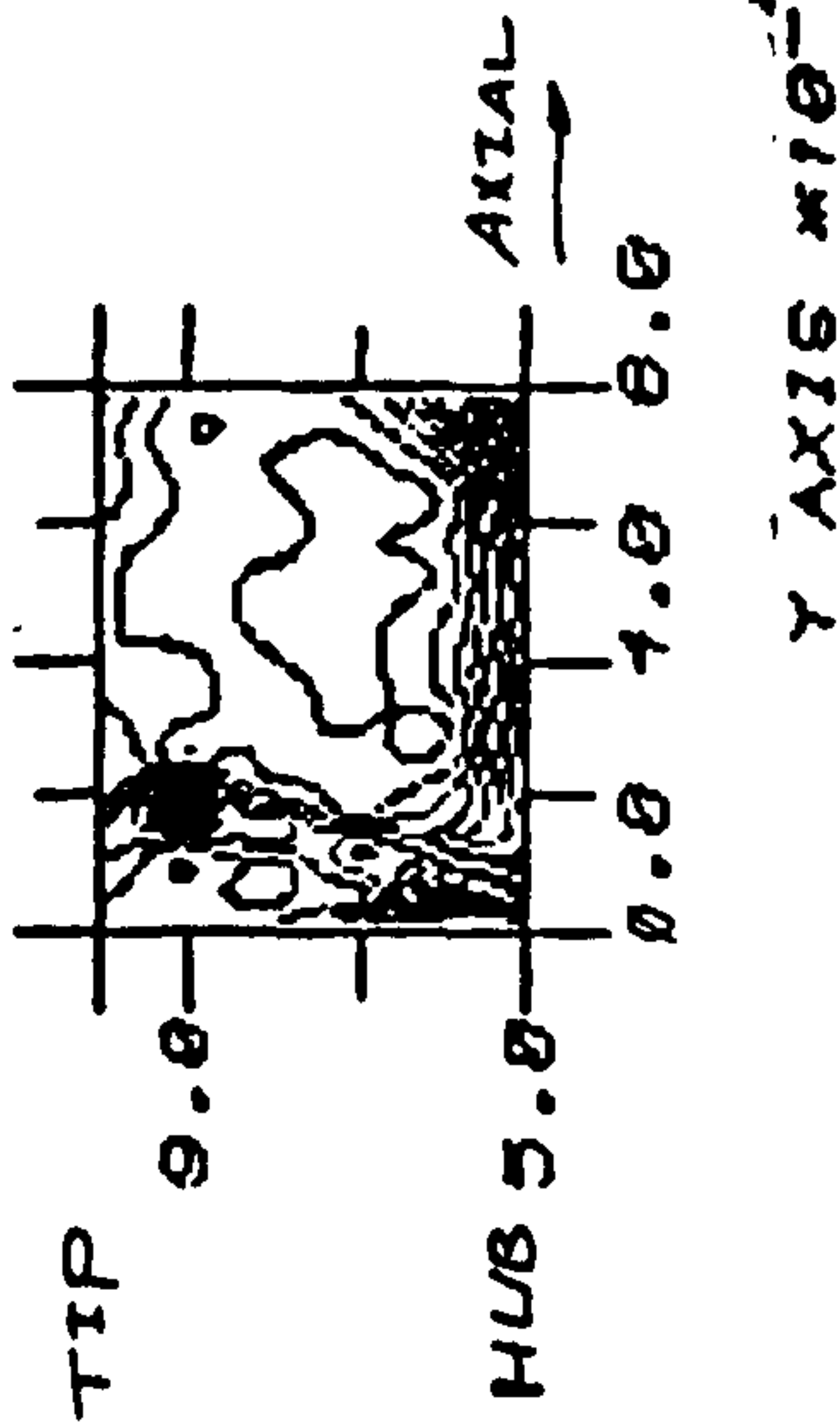
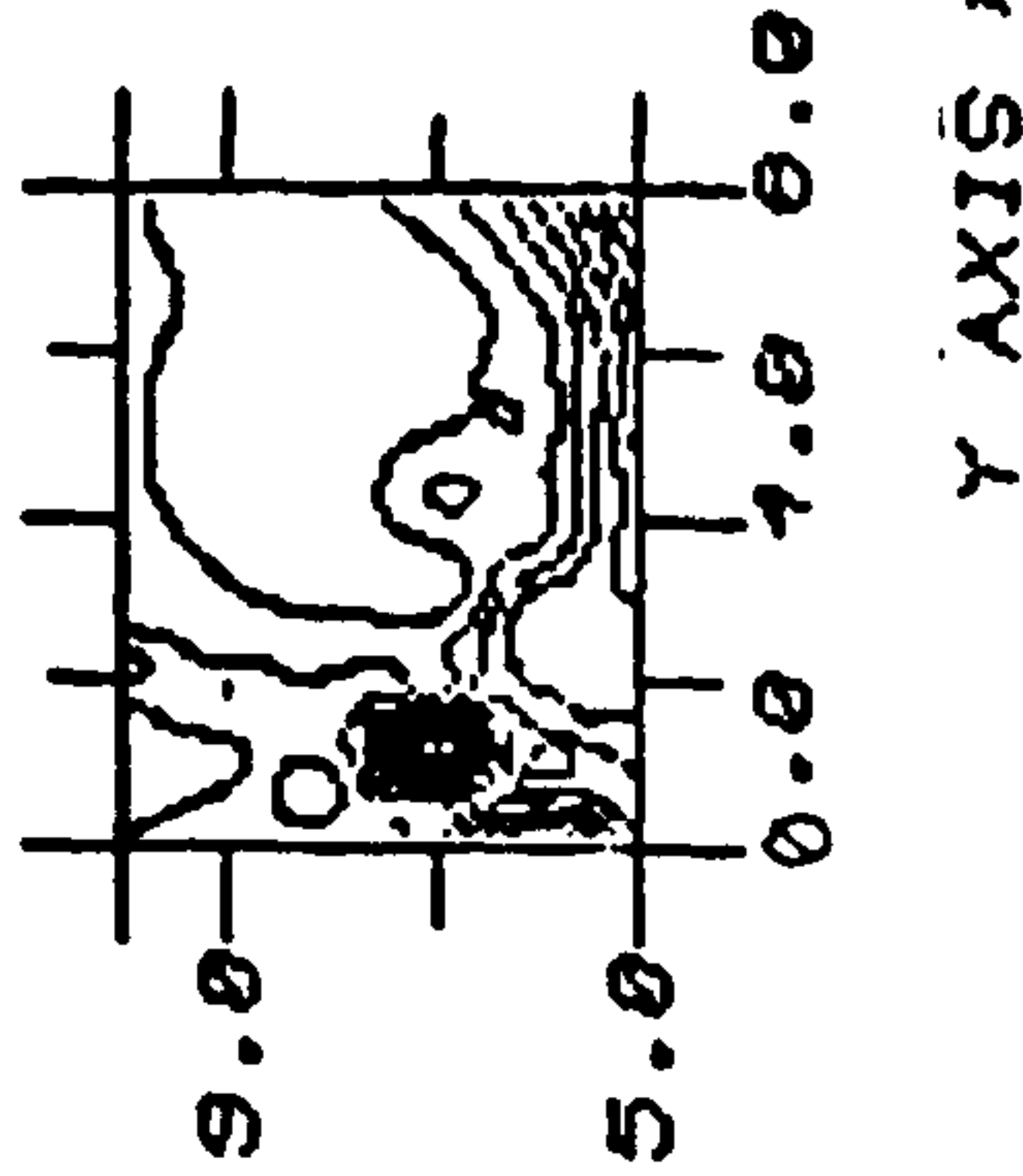
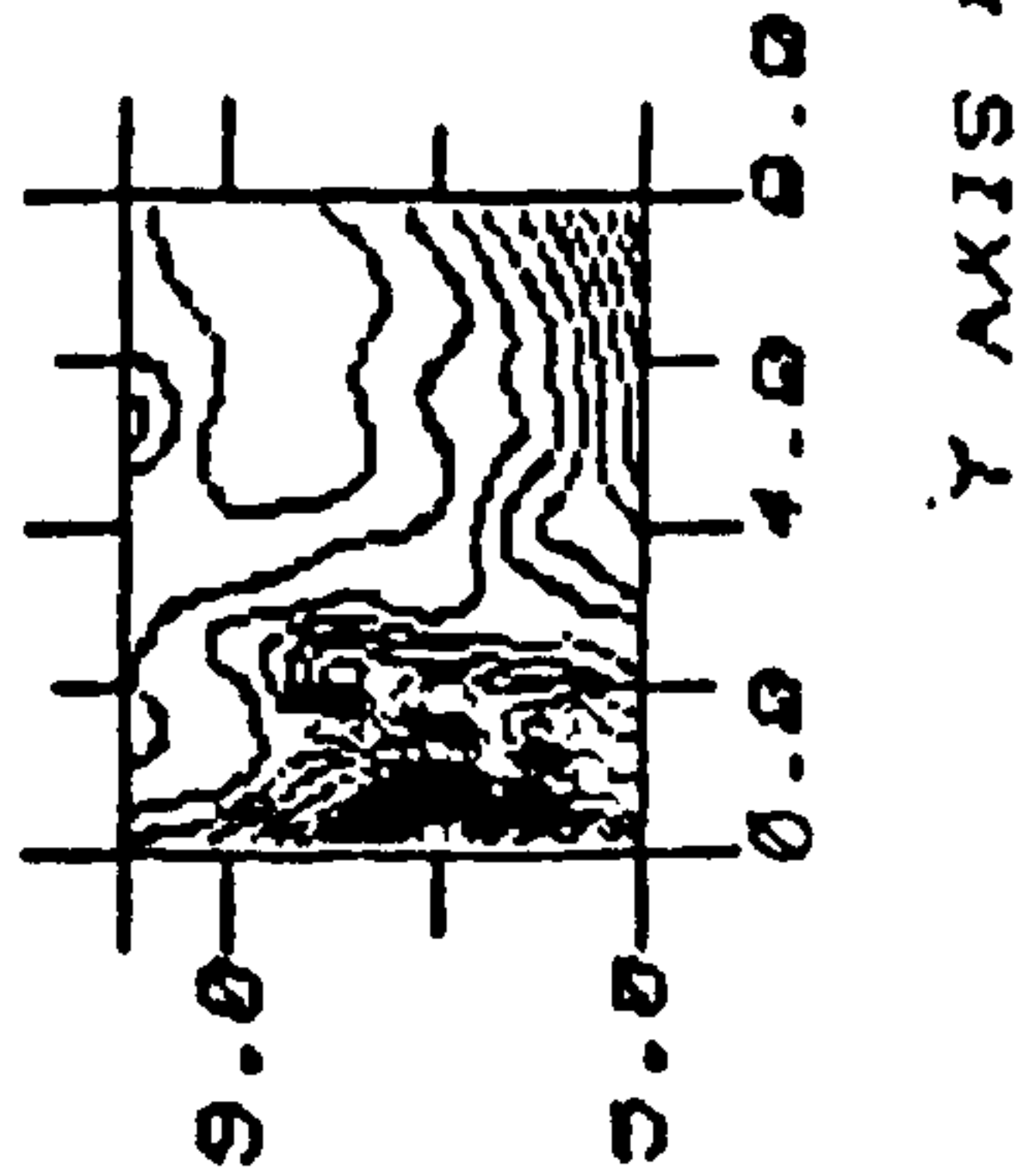
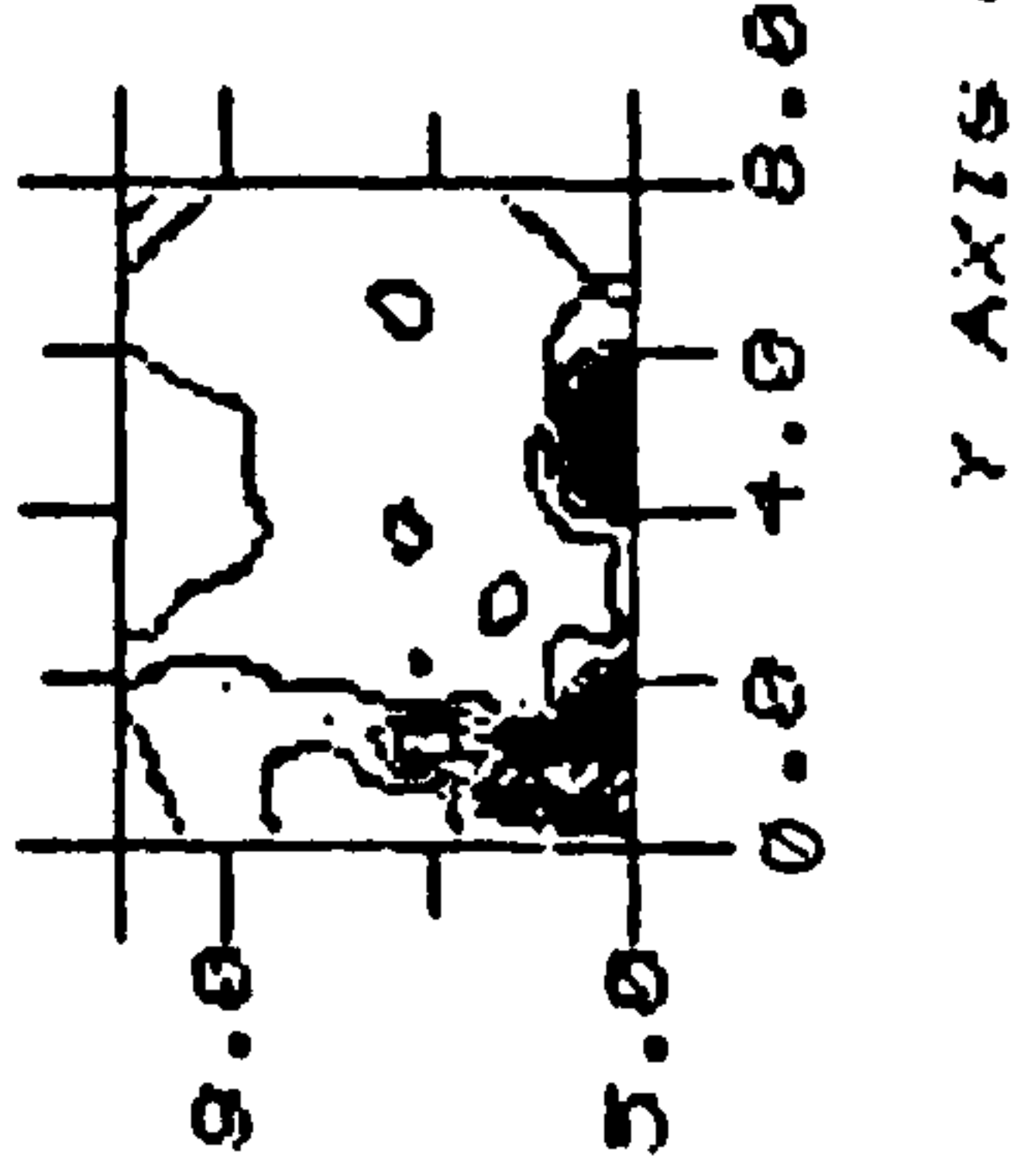
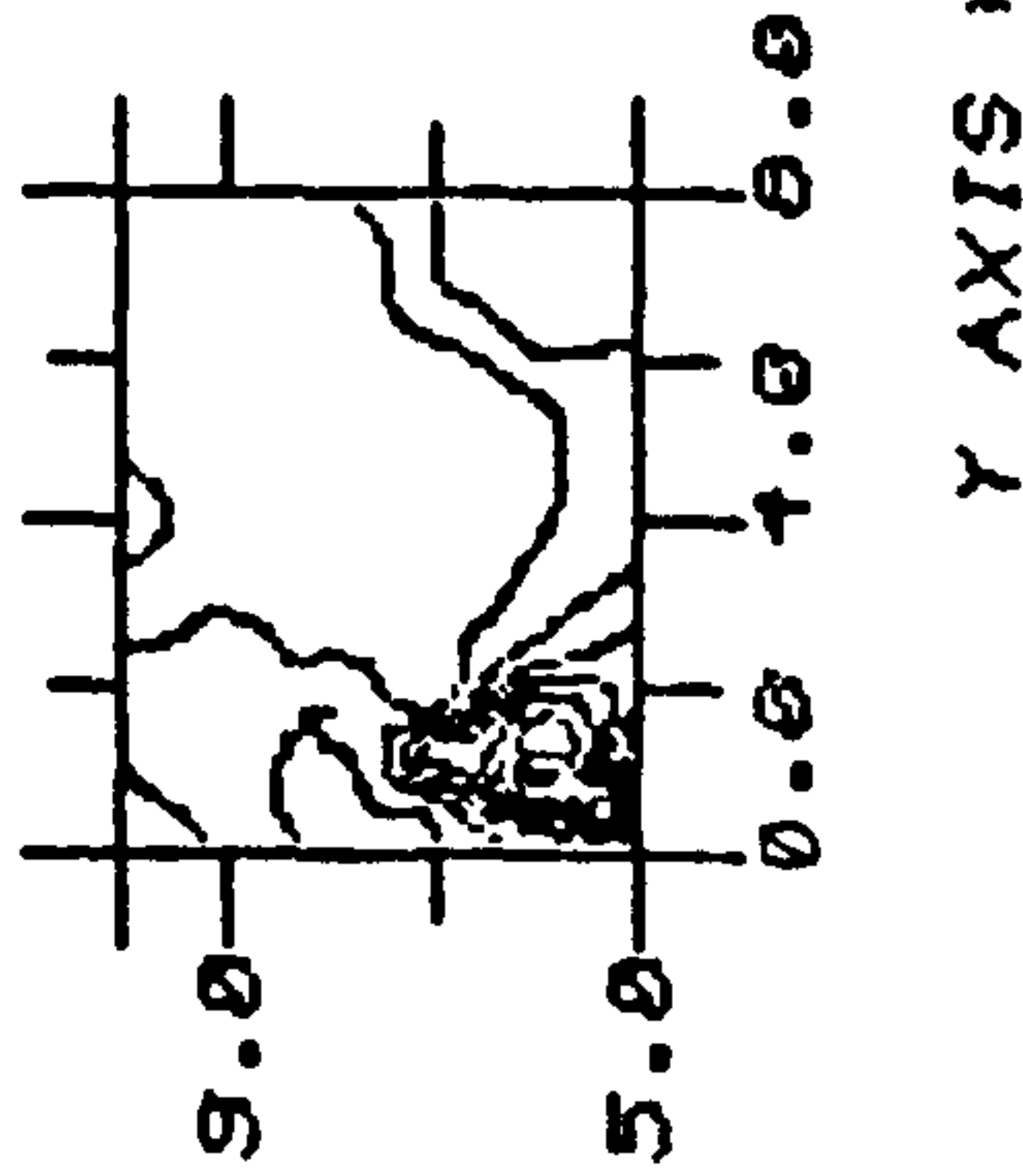
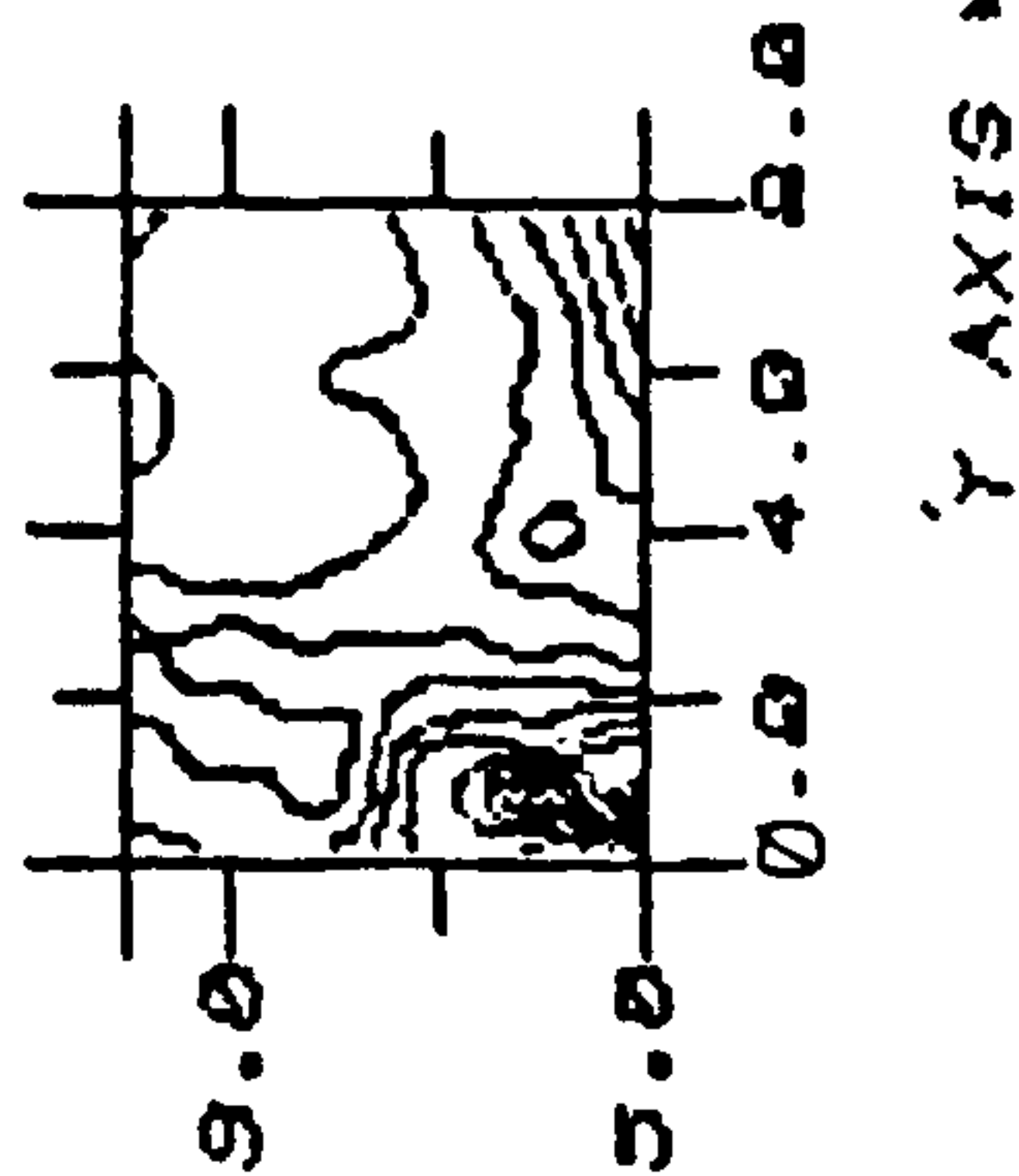
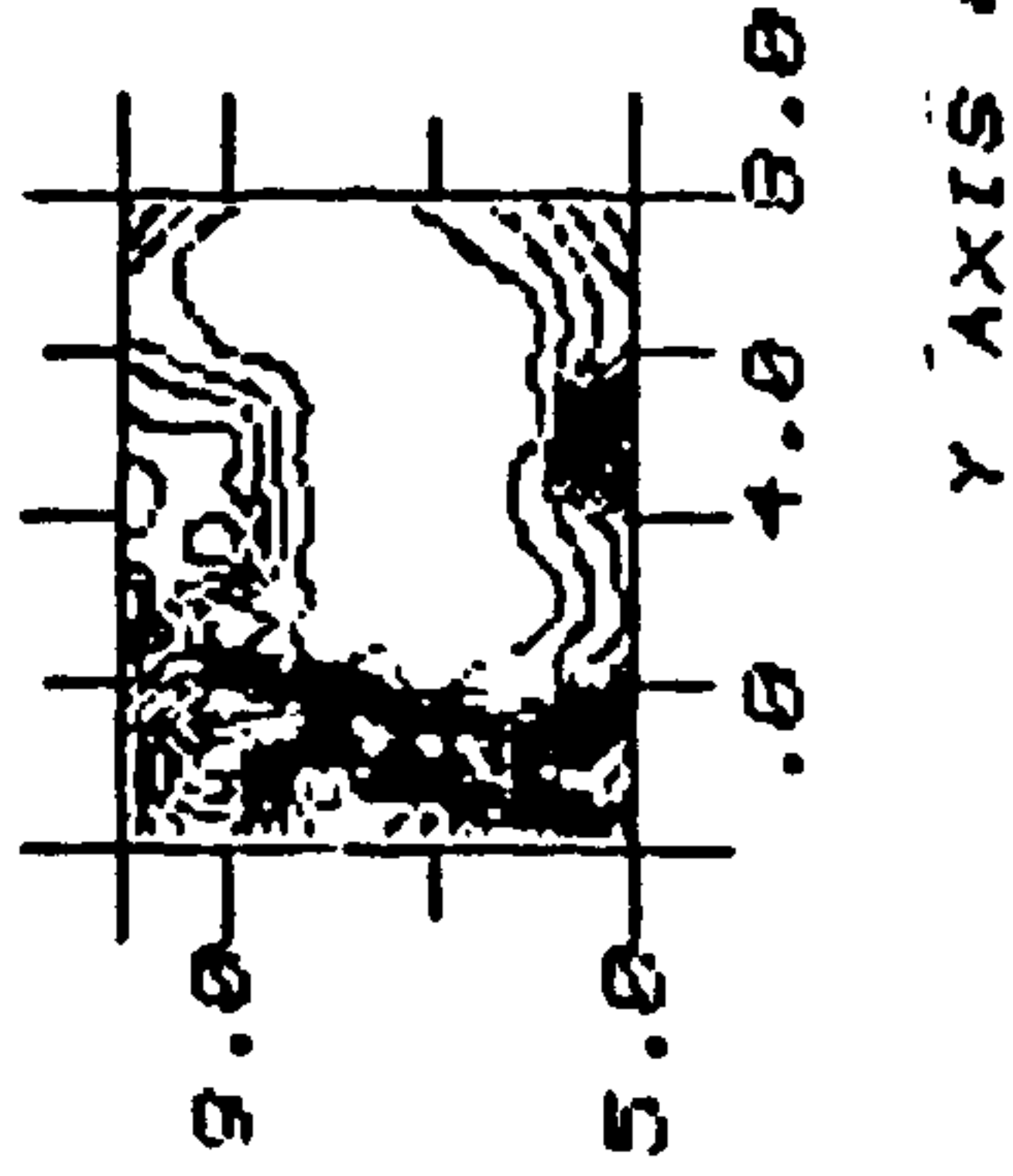
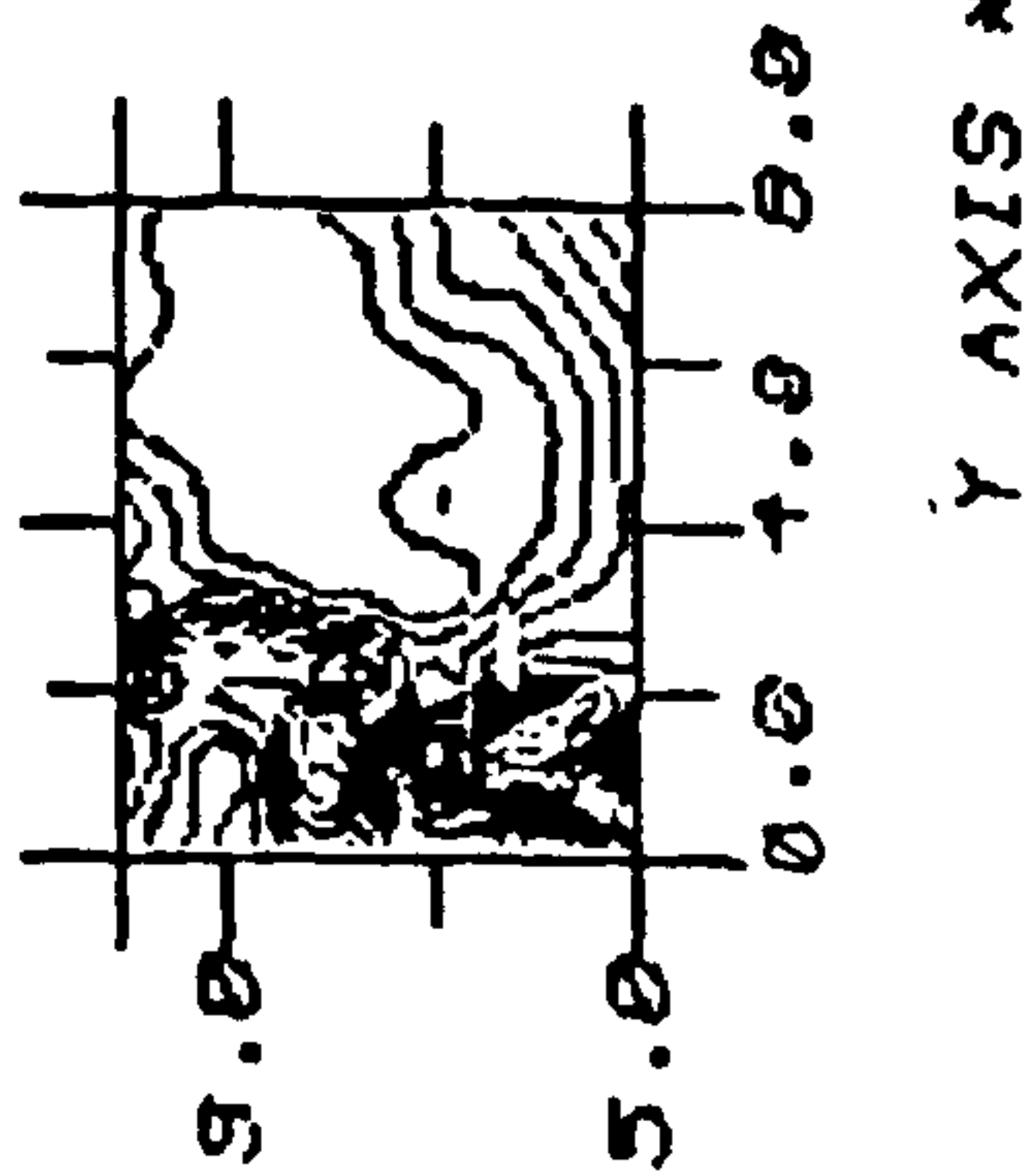
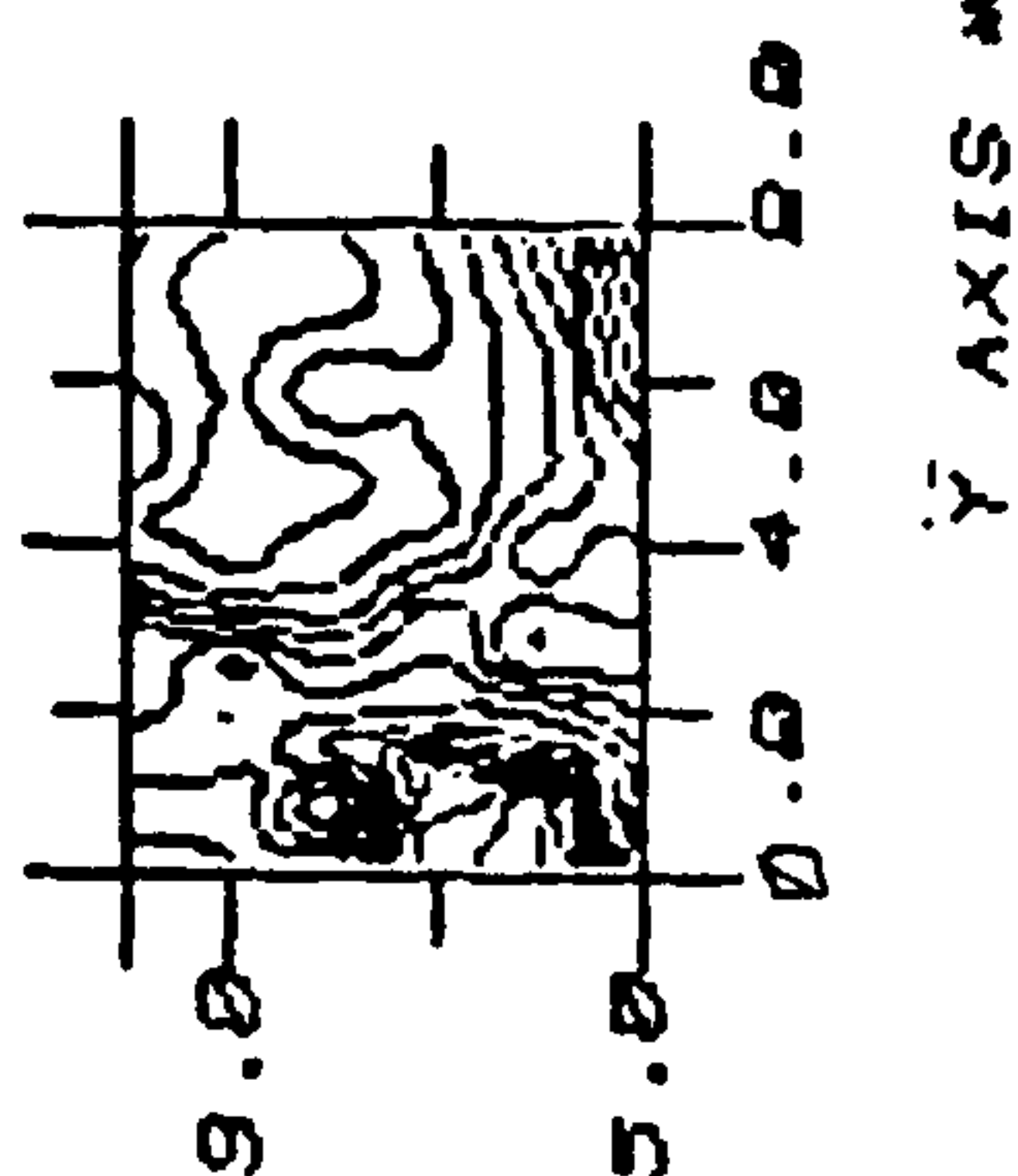


FIG 102 CONTOUR VALUES OF ABSOLUTE MAX. REYNOLDS STRESSES
RADIAL AND AXIAL DIRECTIONS

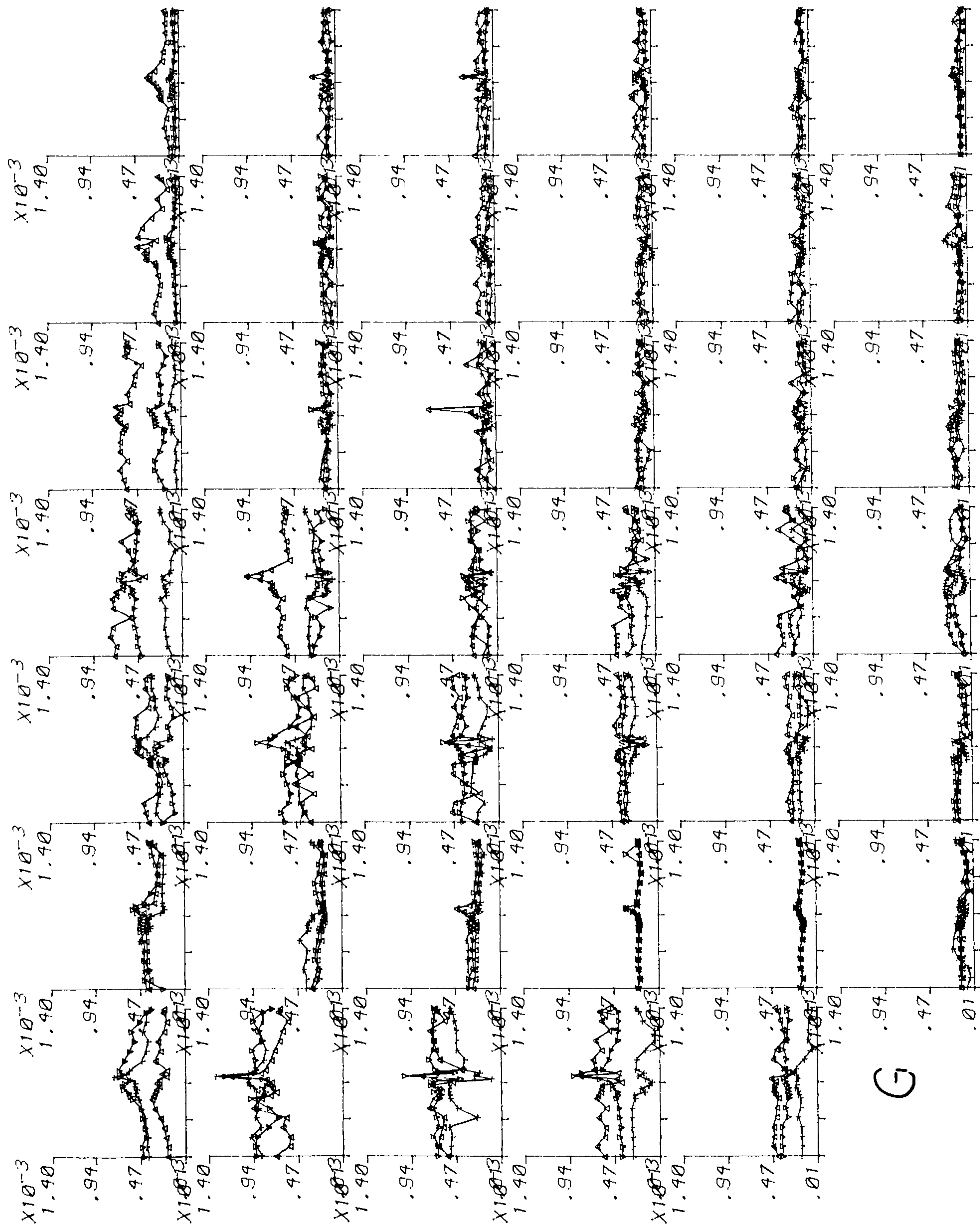


FIG 103 DISTRIBUTION OF THE PARAMETER "G" ACROSS THE ROTOR WAKE.

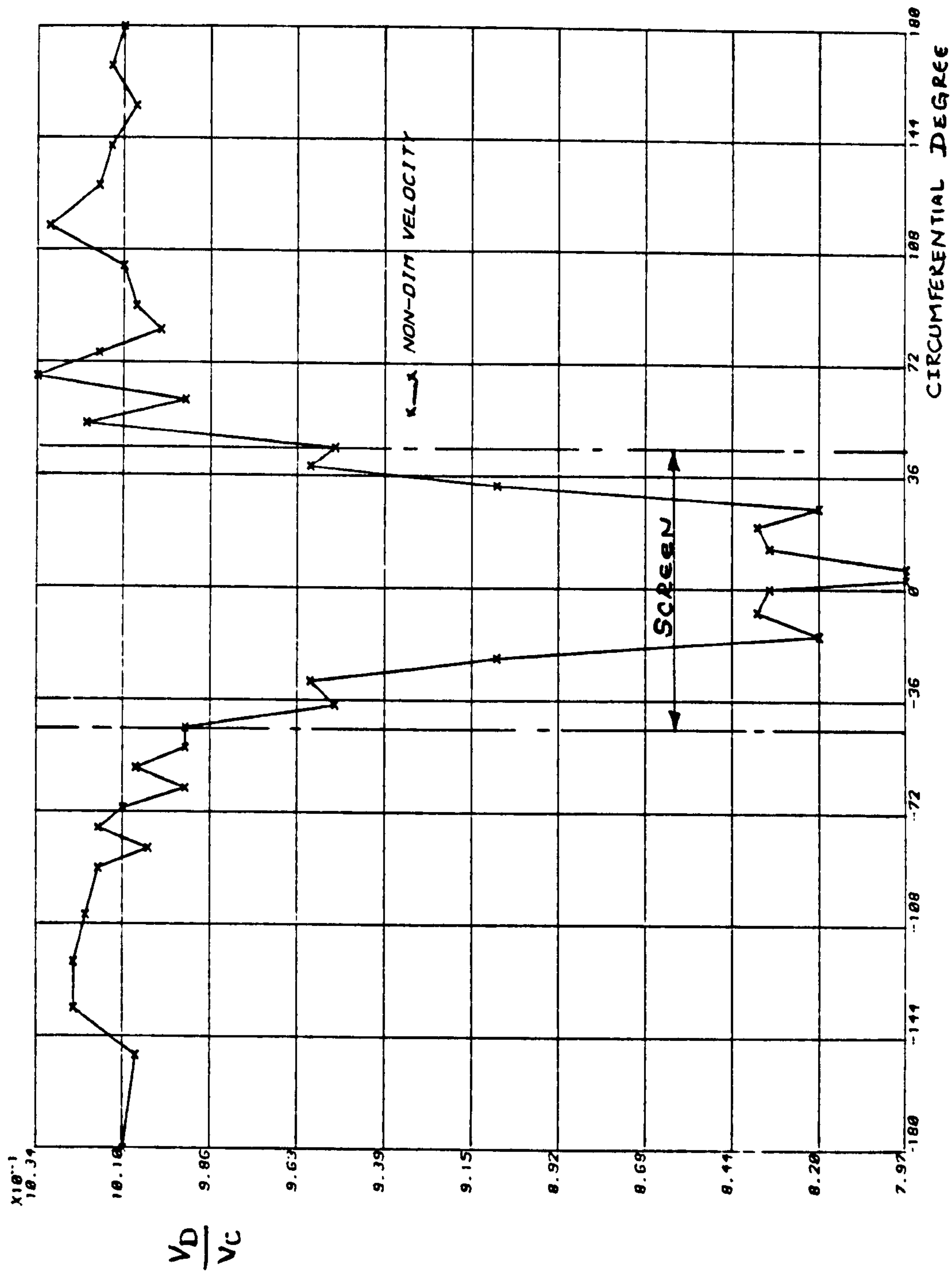


FIG 10 DISTRIBUTION OF FLOW VELOCITY DOWNSTREAM OF THE SINEWAVE DISTORTION SCREEN
UPSTREAM OF THE ROTOR

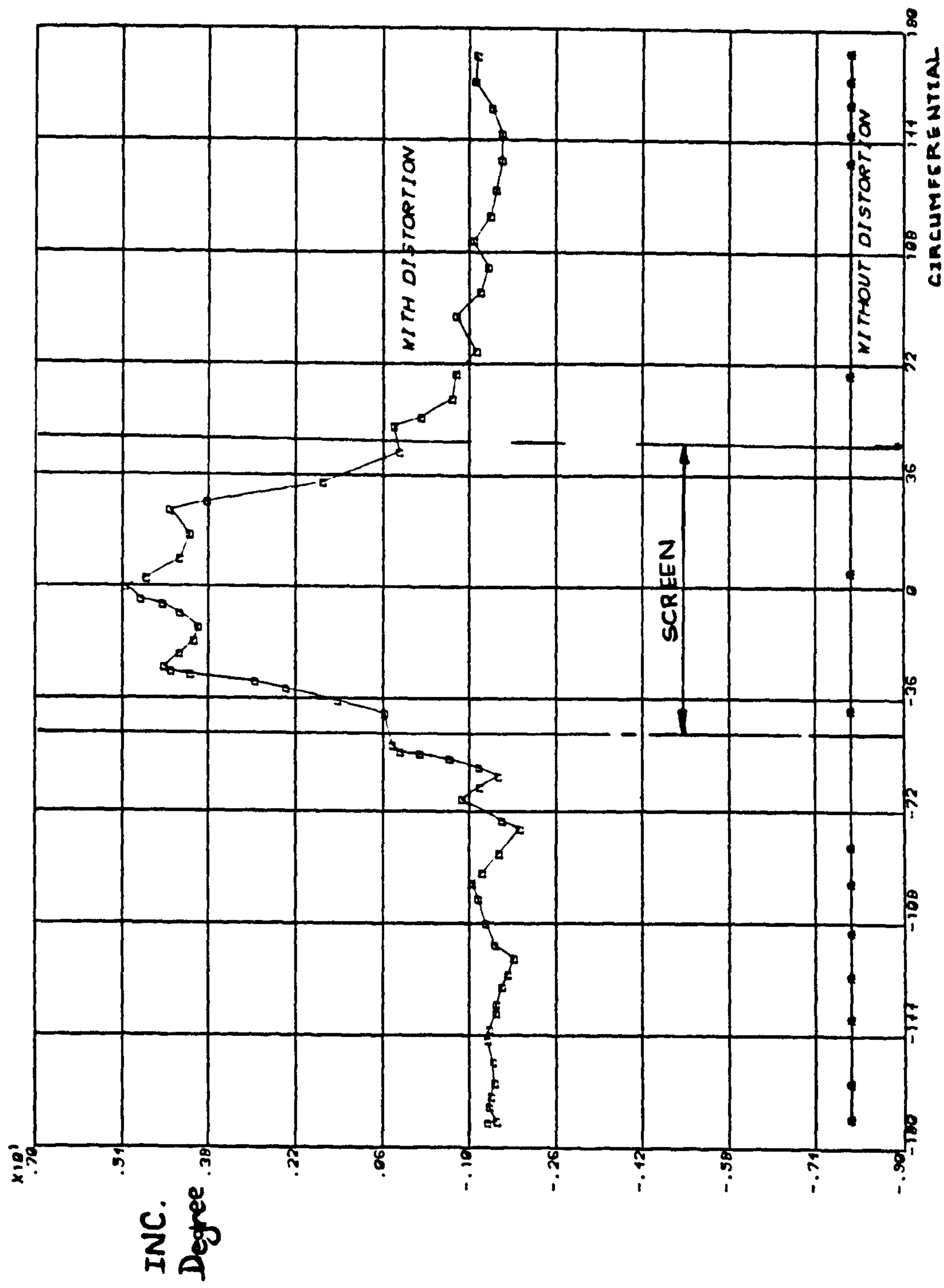


Fig 105 DISTRIBUTION OF FLOW INCIDENCE DOWNSTREAM OF THE SINEWAVE DISTORTION SCREEN

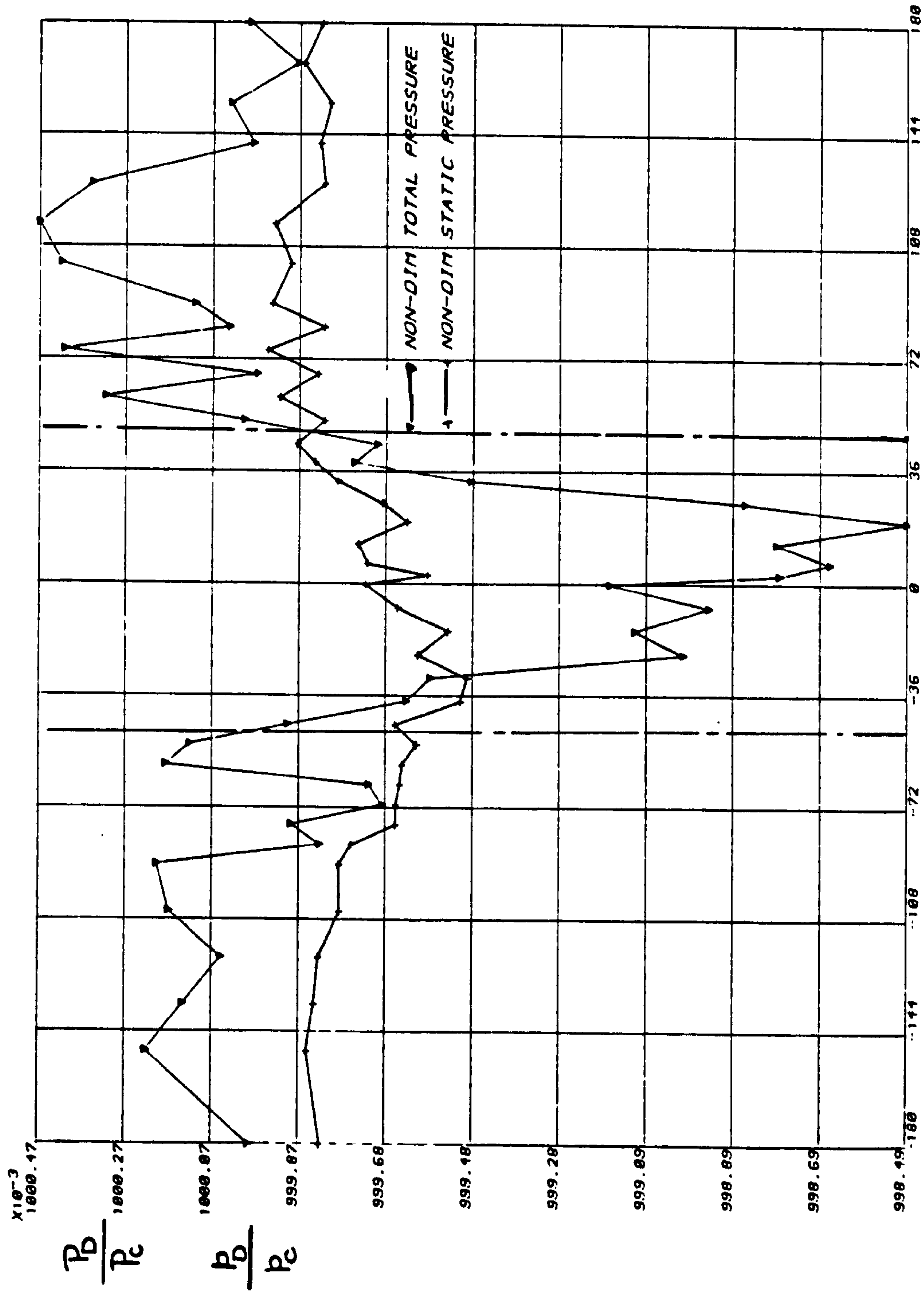


FIGURE 10 DISTRIBUTION OF FLOW PARAMETERS DOWNSTREAM OF THE SINEWAVE DISTORTION SCREEN
DOWNSTREAM OF THE ROTOR

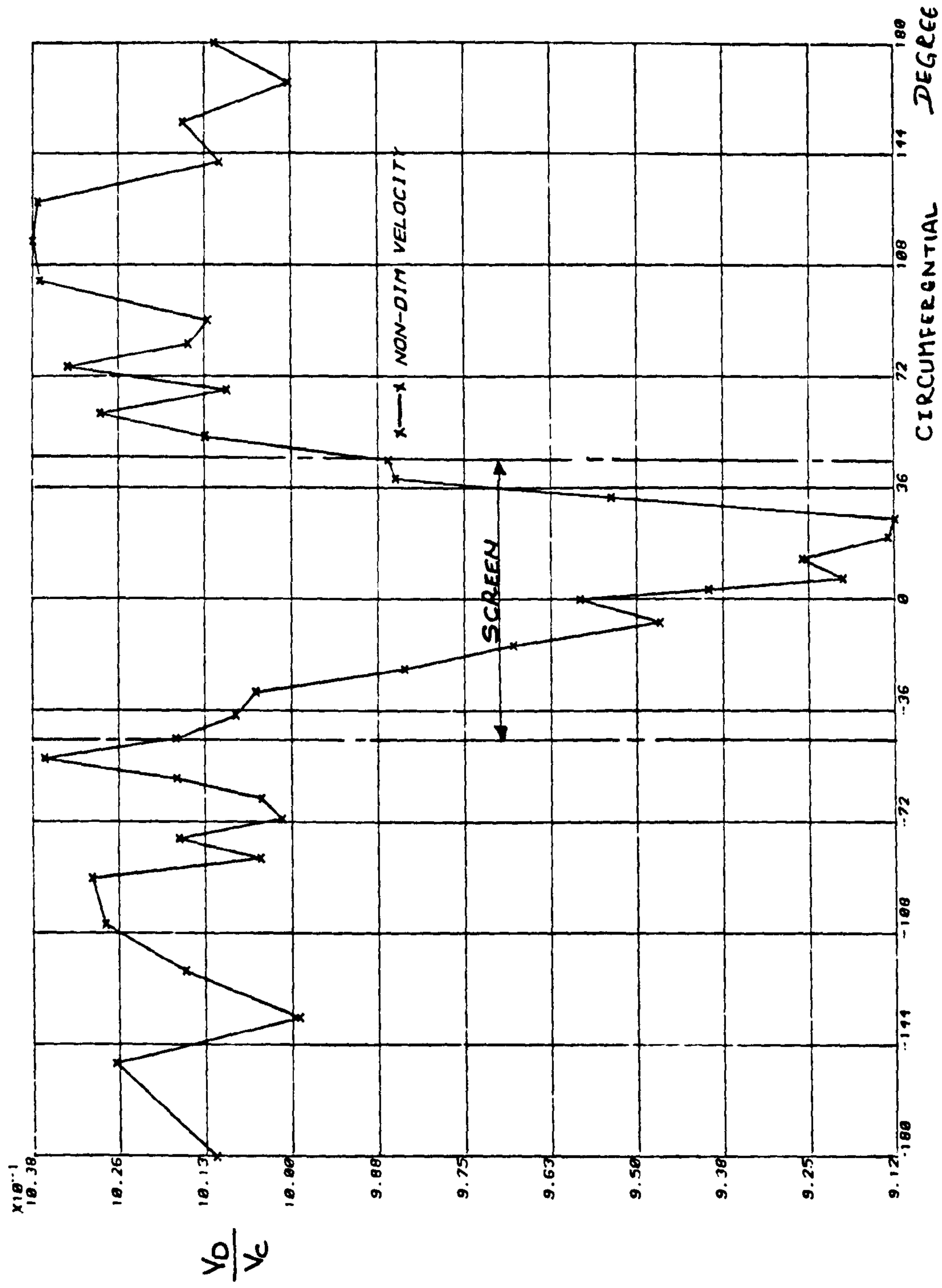


Fig 9107 DISTRIBUTION OF FLOW VELOCITY DOWNSTREAM OF THE SINEWAVE DISTORTION SCREEN
DOWNSTREAM OF THE ROTOR

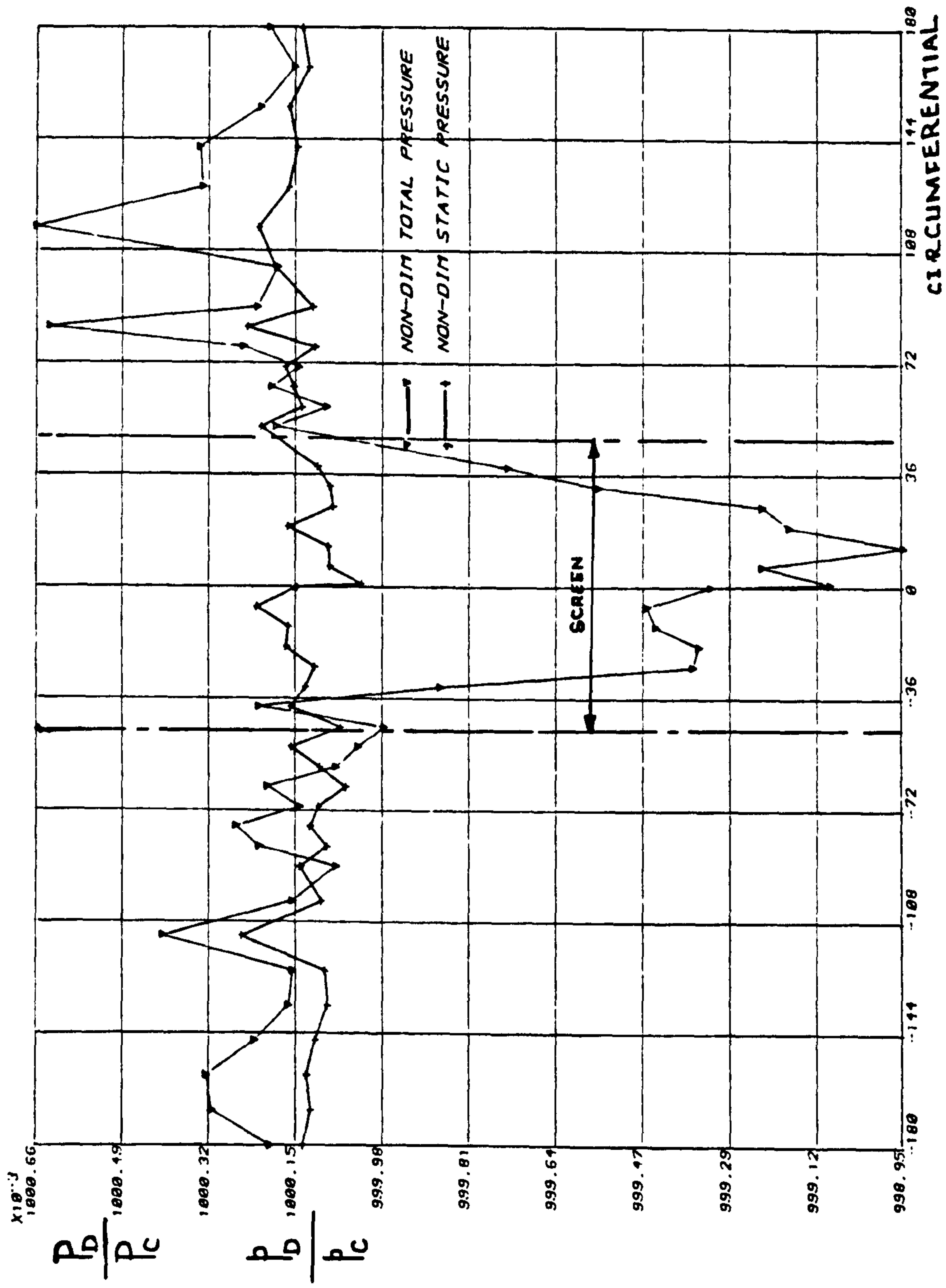


Fig 108 DISTRIBUTION OF FLOW PARAMETERS DOWNSTREAM OF THE SINEWAVE DISTORTION SCREEN
DOWNSTREAM OF THE STATOR

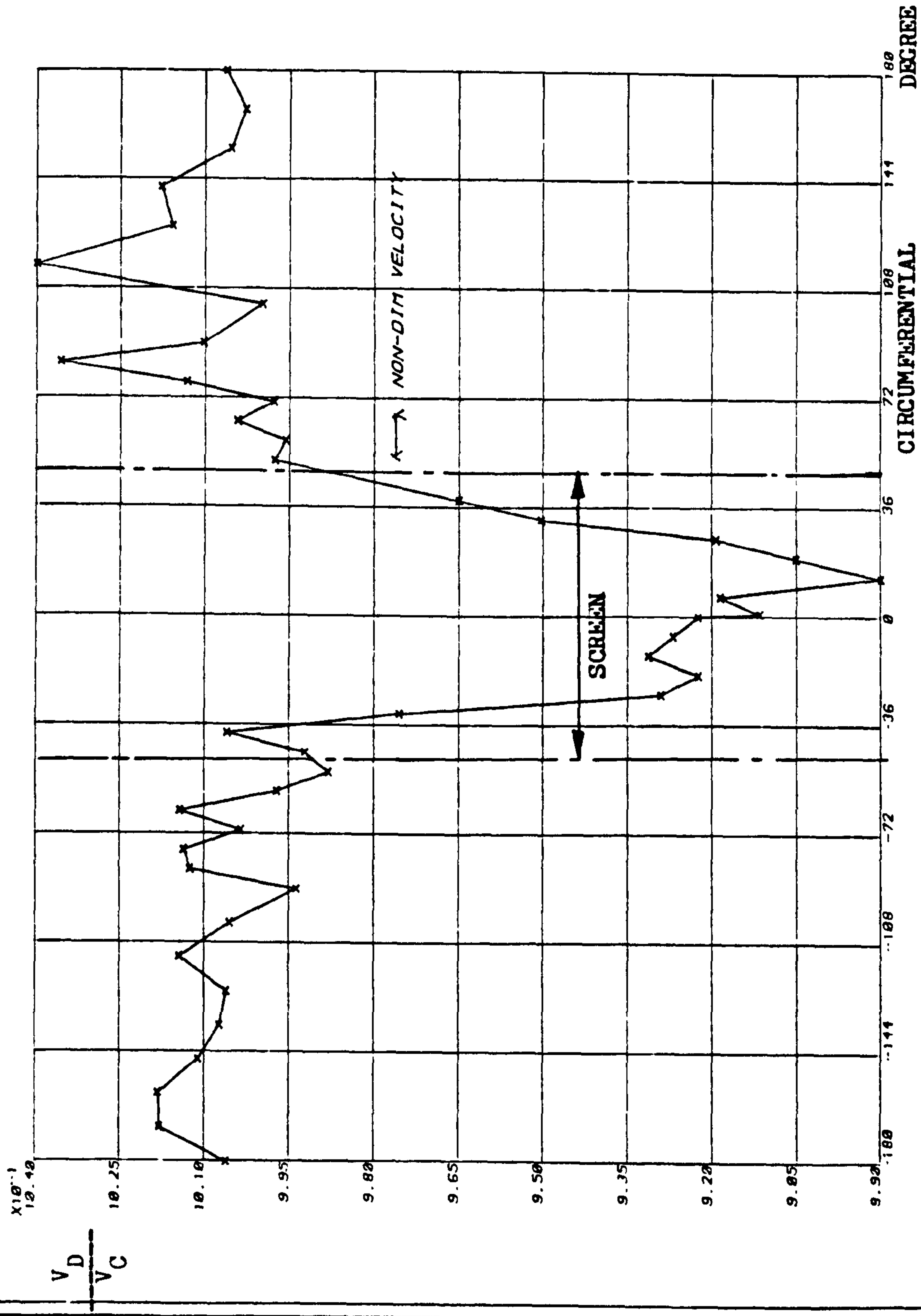


Fig 109 DISTRIBUTION OF FLOW VELOCITY DOWNSTREAM OF THE SINEWAVE DISTORTION SCREEN
DOWNSTREAM OF THE STATOR

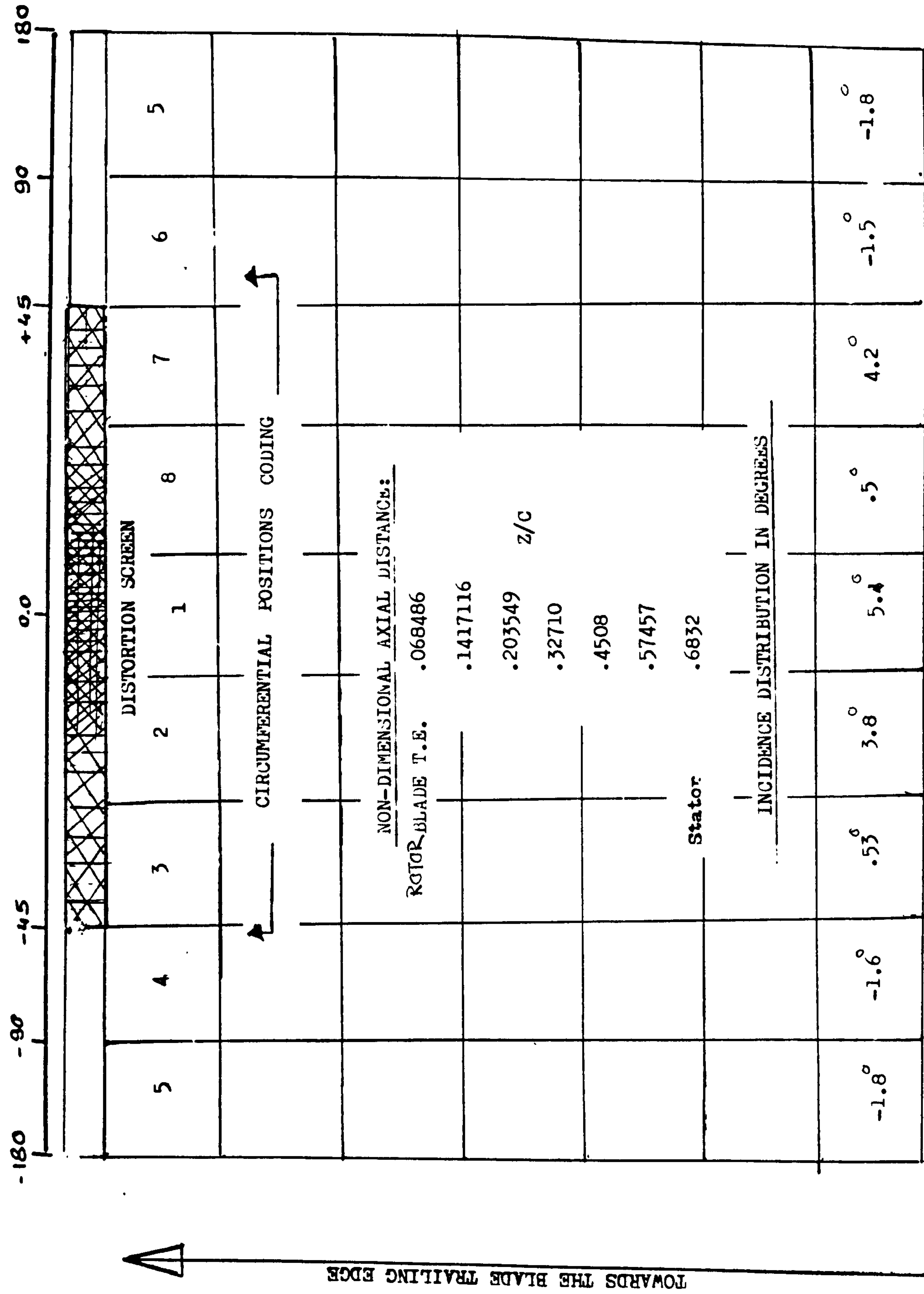


FIG 110 MASTER LEGEND FOR DISTORTION FLOW RESULTS.

B.T.E

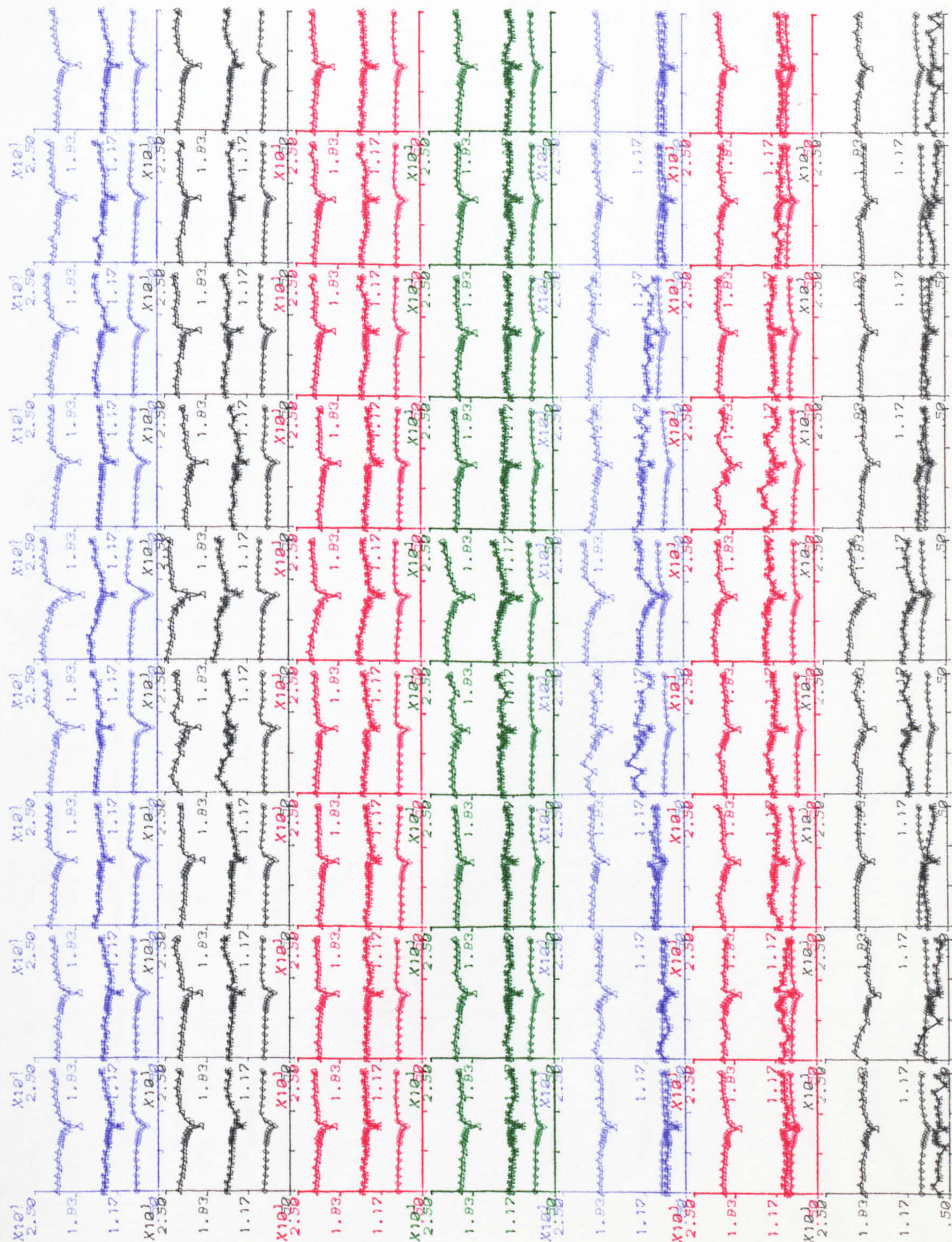


FIG 111 DISTRIBUTION OF VELOCITY COMPONENTS IN THE DISTORTION REGIME IN THE TURBOMACHINERY FRAME OF REFERENCE.

Δ---Δ AXIAL VEL. *---* TANG. VEL. ◇---◇ RADIAL VEL.

B.T.E

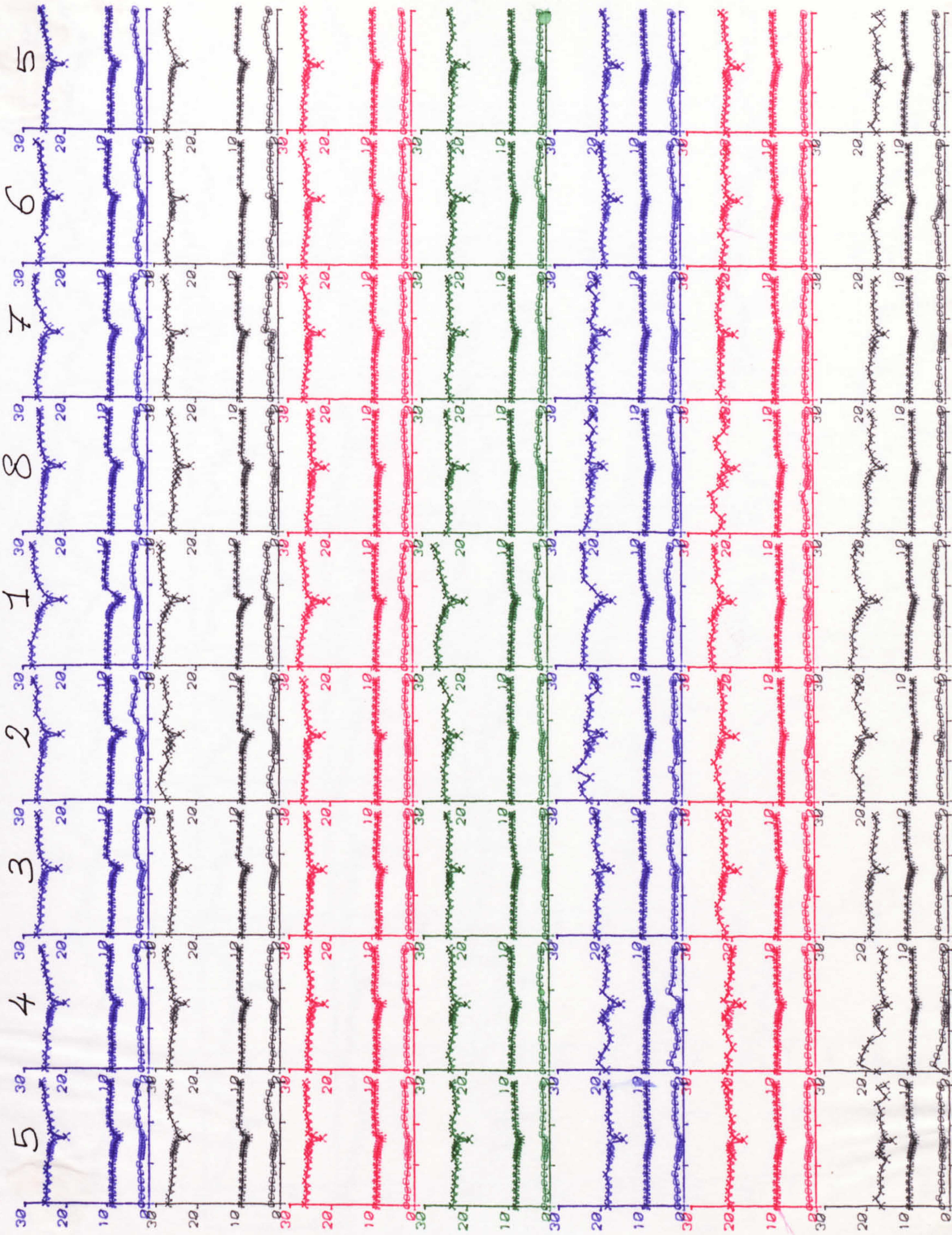


FIG 112 DISTRIBUTION OF VELOCITY COMPONENTS IN THE DISTORTION REGIME IN THE STREAM WISE FRAME OF REFERENCE.
 x---x STREAM WISE VELOCITY
 o---o NORMAL TO ST. W. VELOCITY *---* RADIAL VELOCITY

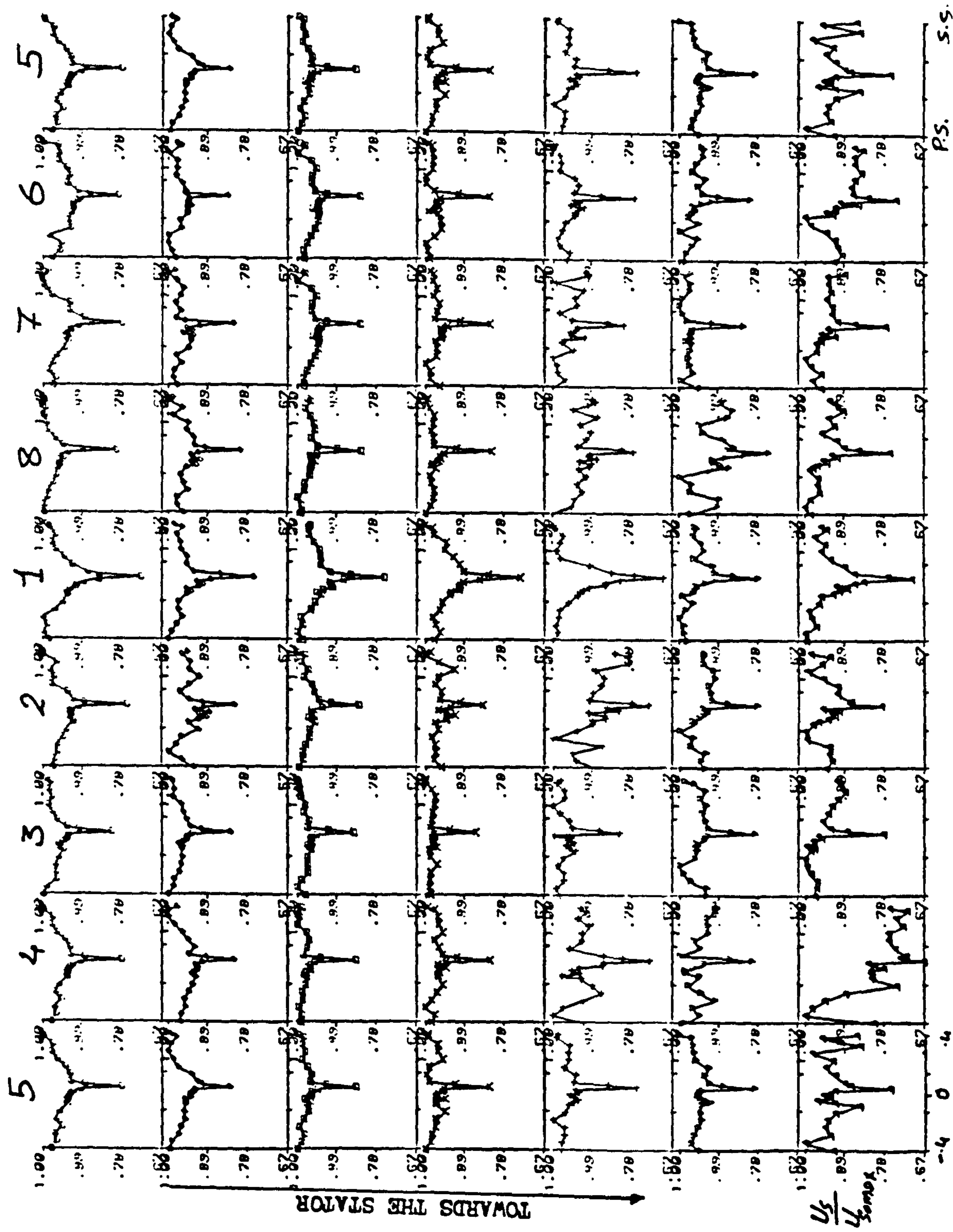


FIG 113 DISTRIBUTION OF VELOCITY COMPONENT IN THE STREAM WISE DIRECTION.

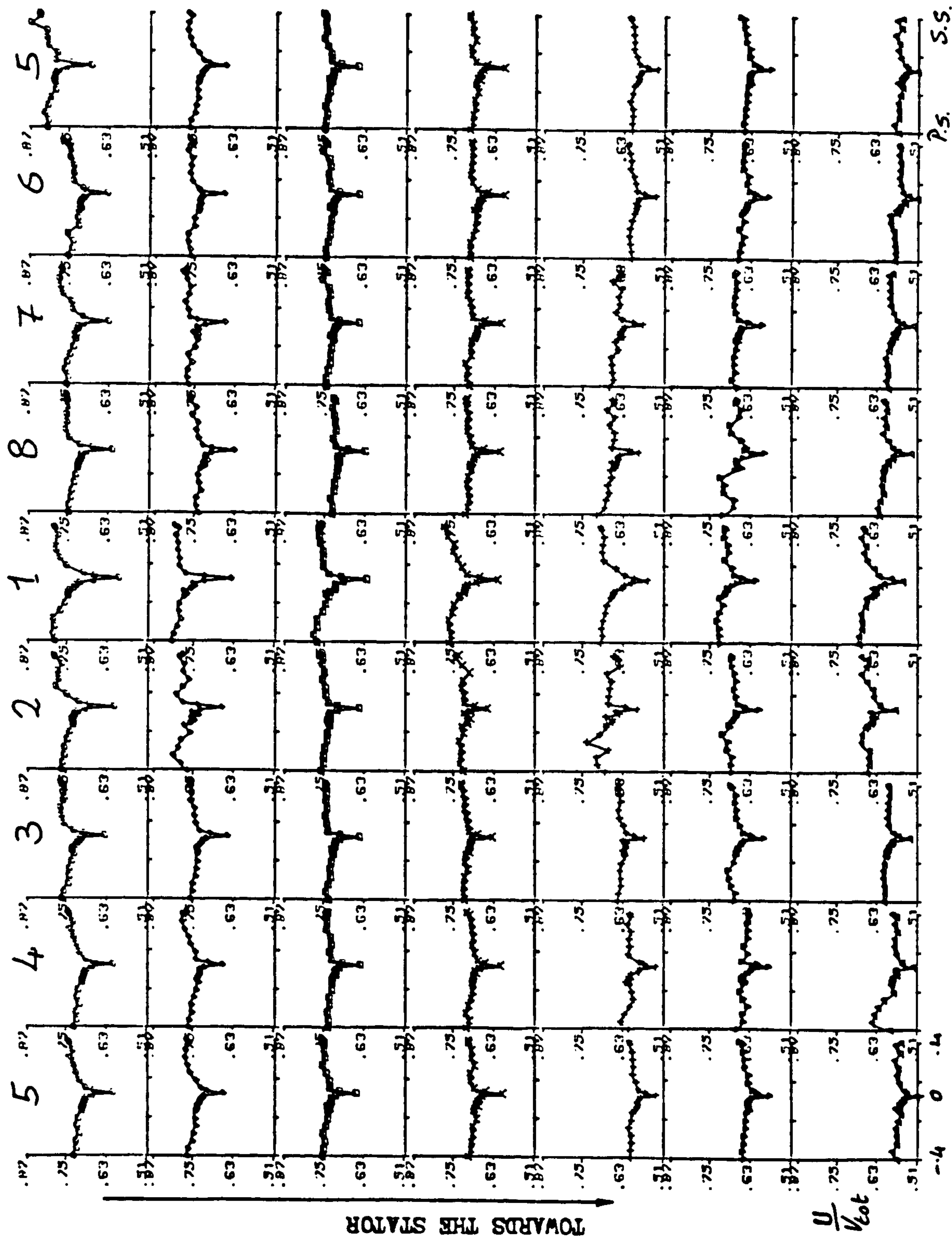


FIG 114 DISTRIBUTION OF AXIAL VELOCITY COMPONENT.

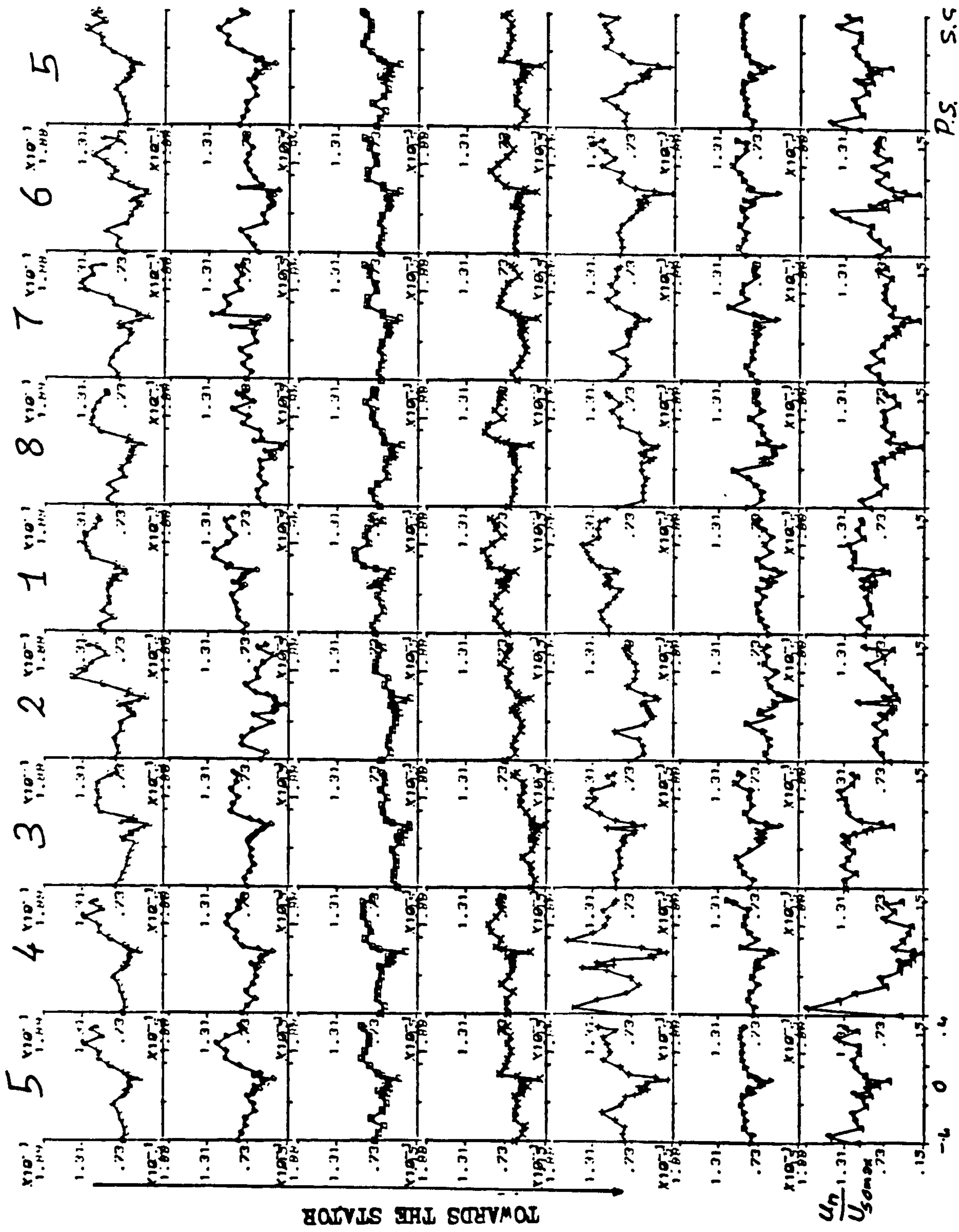


FIG 115 DISTRIBUTION OF VELOCITY COMPONENT IN THE DIRECTION NORMAL TO THE STREAMWISE DIRECTION.

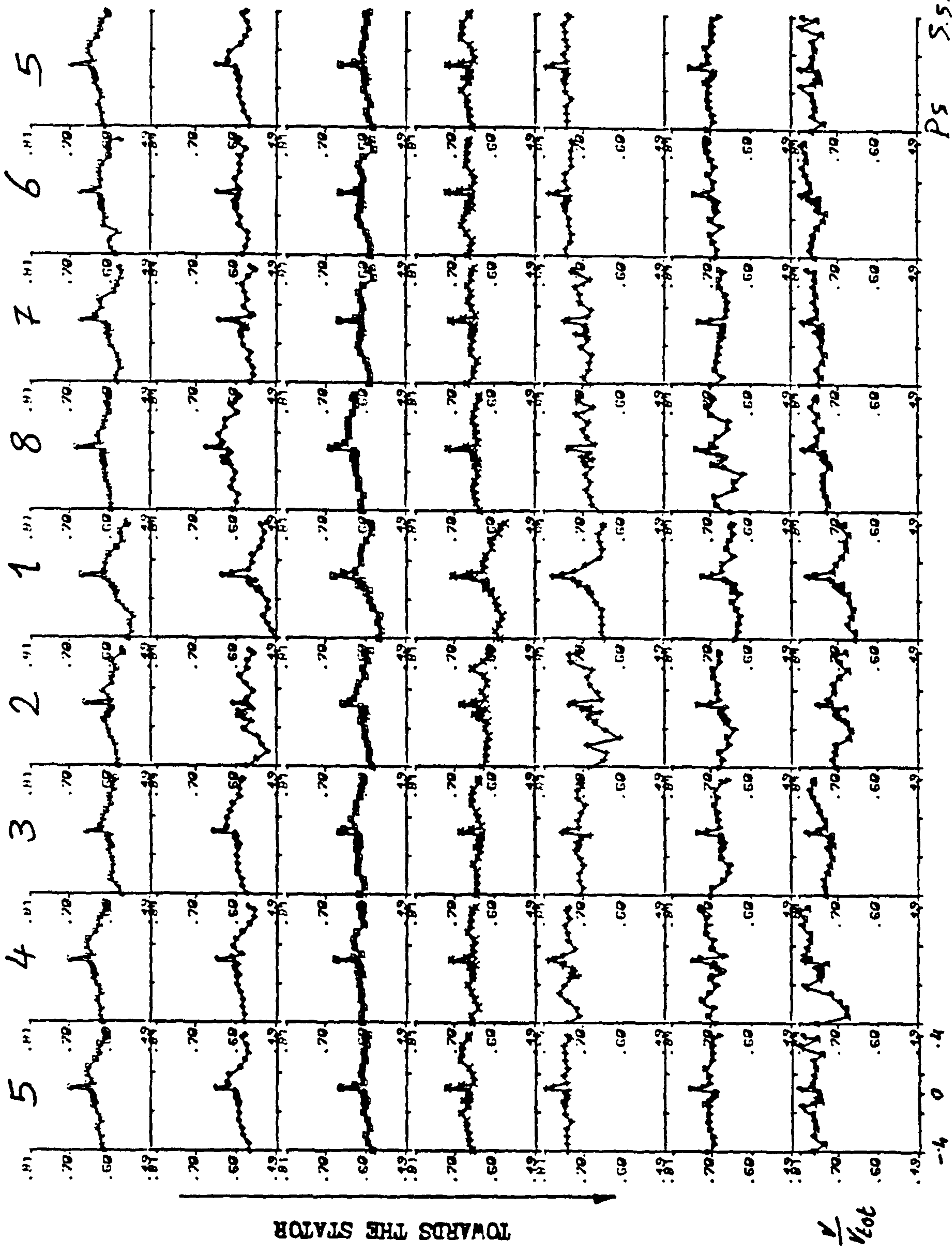


FIG 116 DISTRIBUTION OF RELATIVE TANGENTIAL VELOCITY COMPONENT

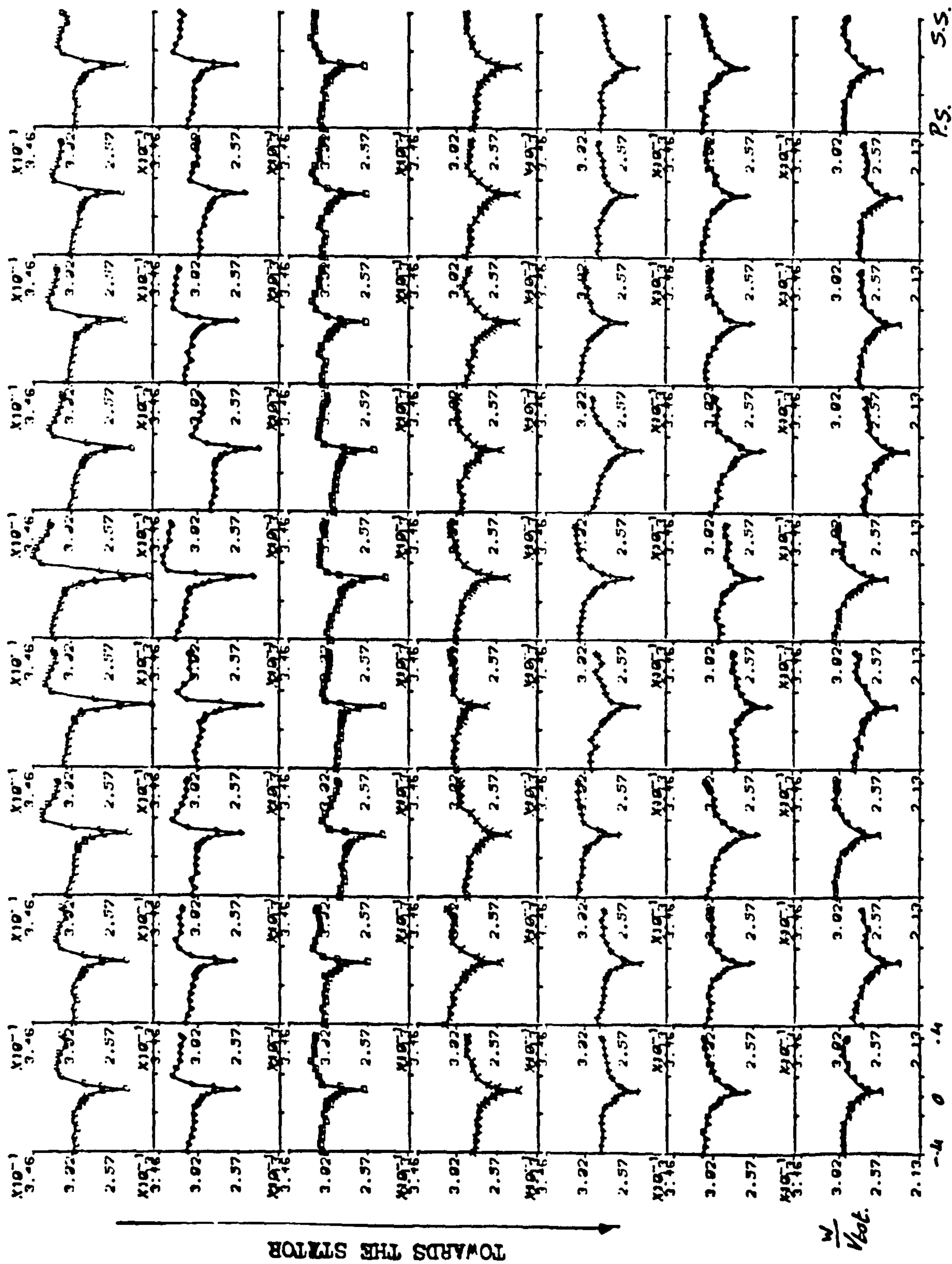


FIG 117 DISTRIBUTION OF RADIAL VELOCITY COMPONENT.

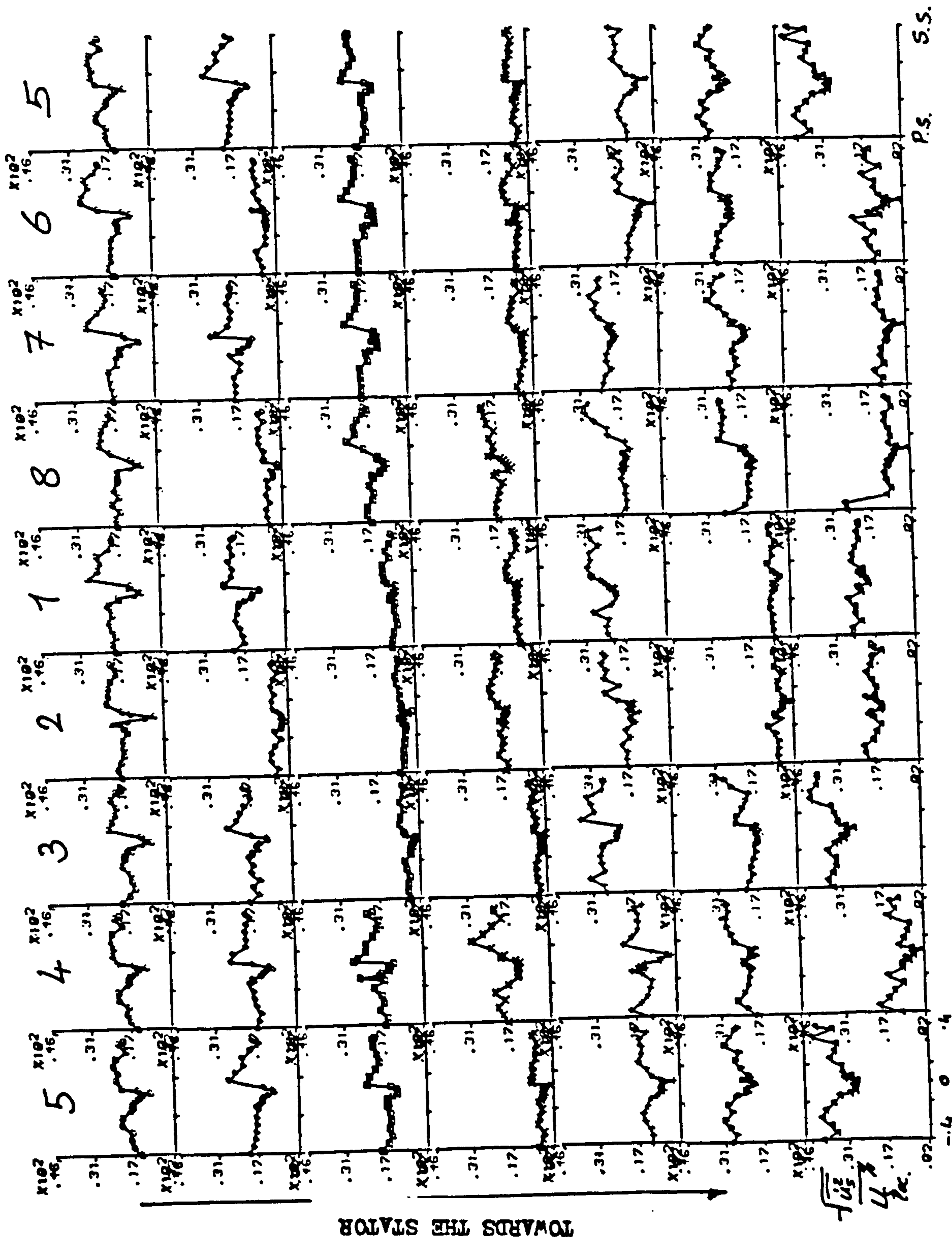


FIG 119 DISTRIBUTION OF TURBULENCE COMPONENT IN THE STREAM WISE DIRECTION.

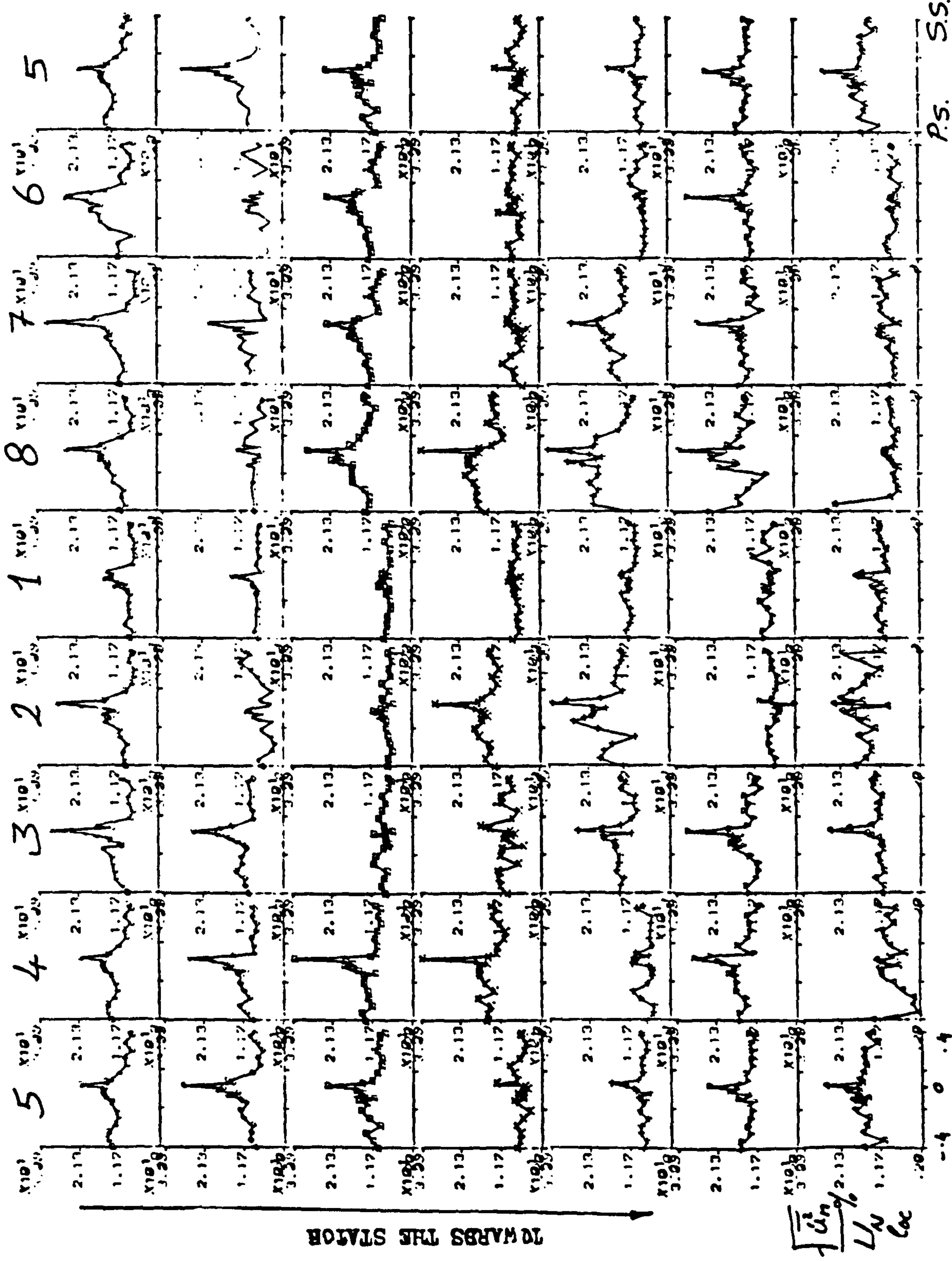


FIG 120 DISTRIBUTION OF TURBULENCE INTENSITY COMPONENT IN THE DIRECTION NORMAL TO THE STREAM WISE DIRECTION.

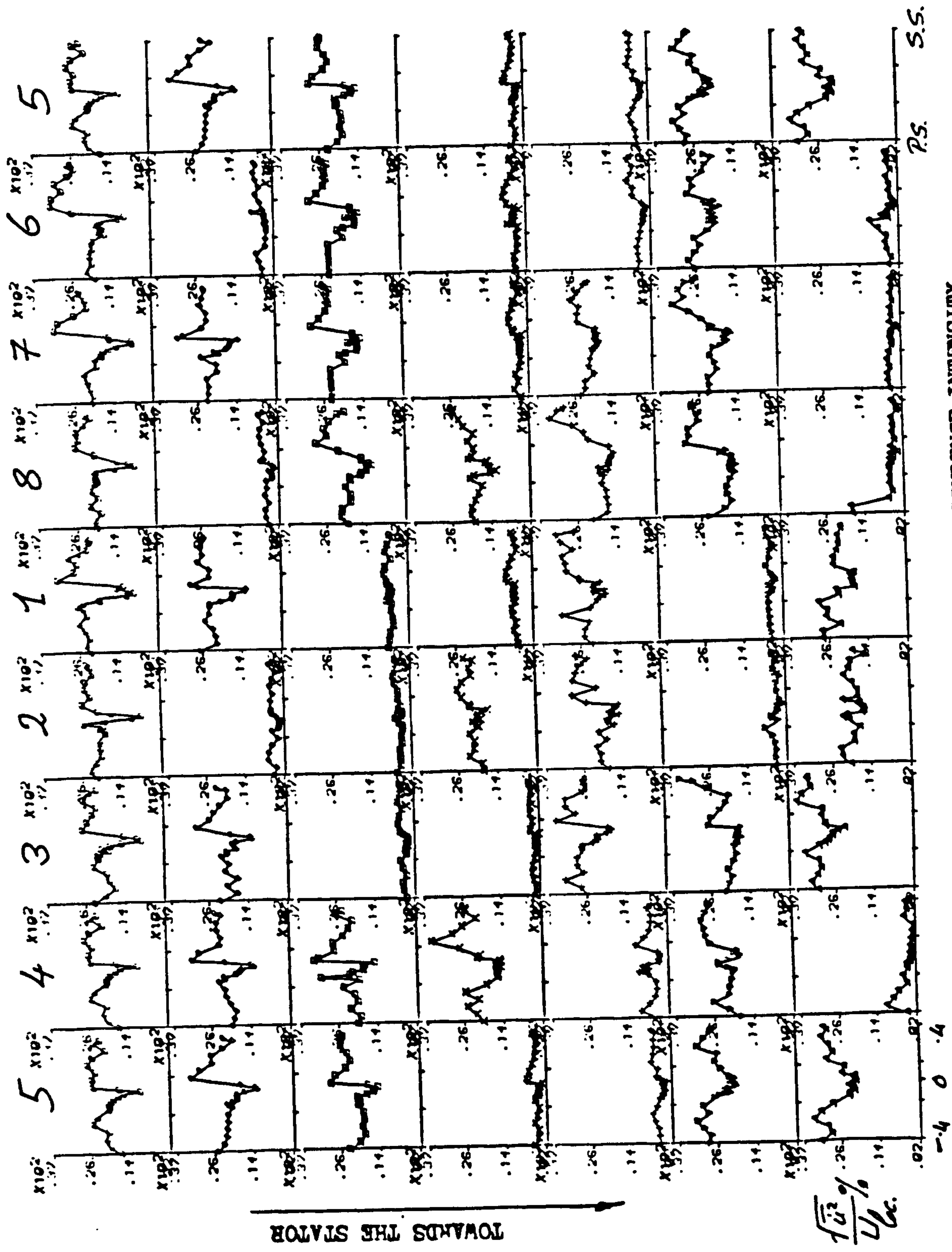


FIG 121 DISTRIBUTION OF AXIAL COMPONENT OF TURBULENCE INTENSITY.

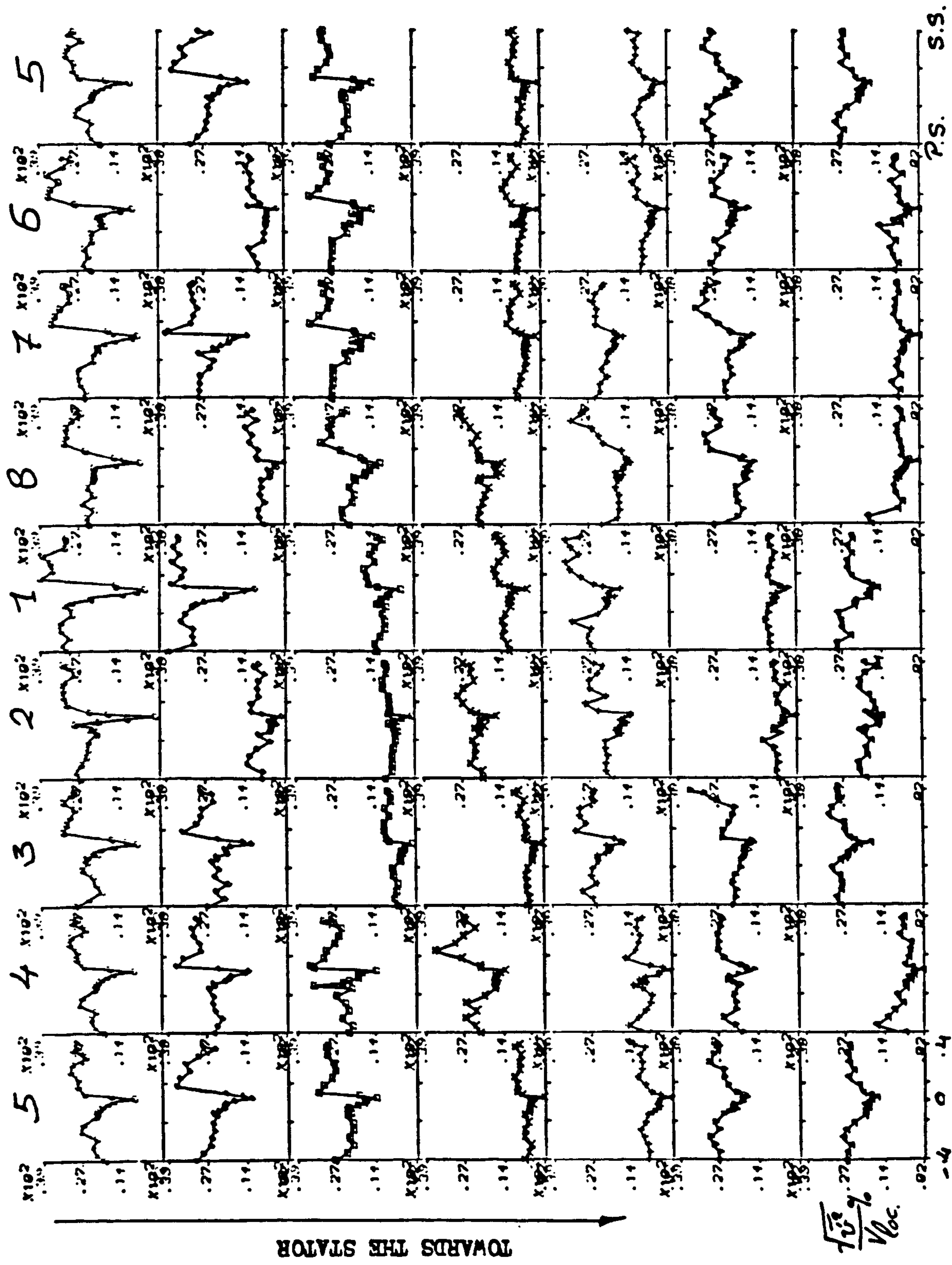


FIG 122 DISTRIBUTION OF TANGENTIAL COMPONENT OF TURBULENCE INTENSITY.

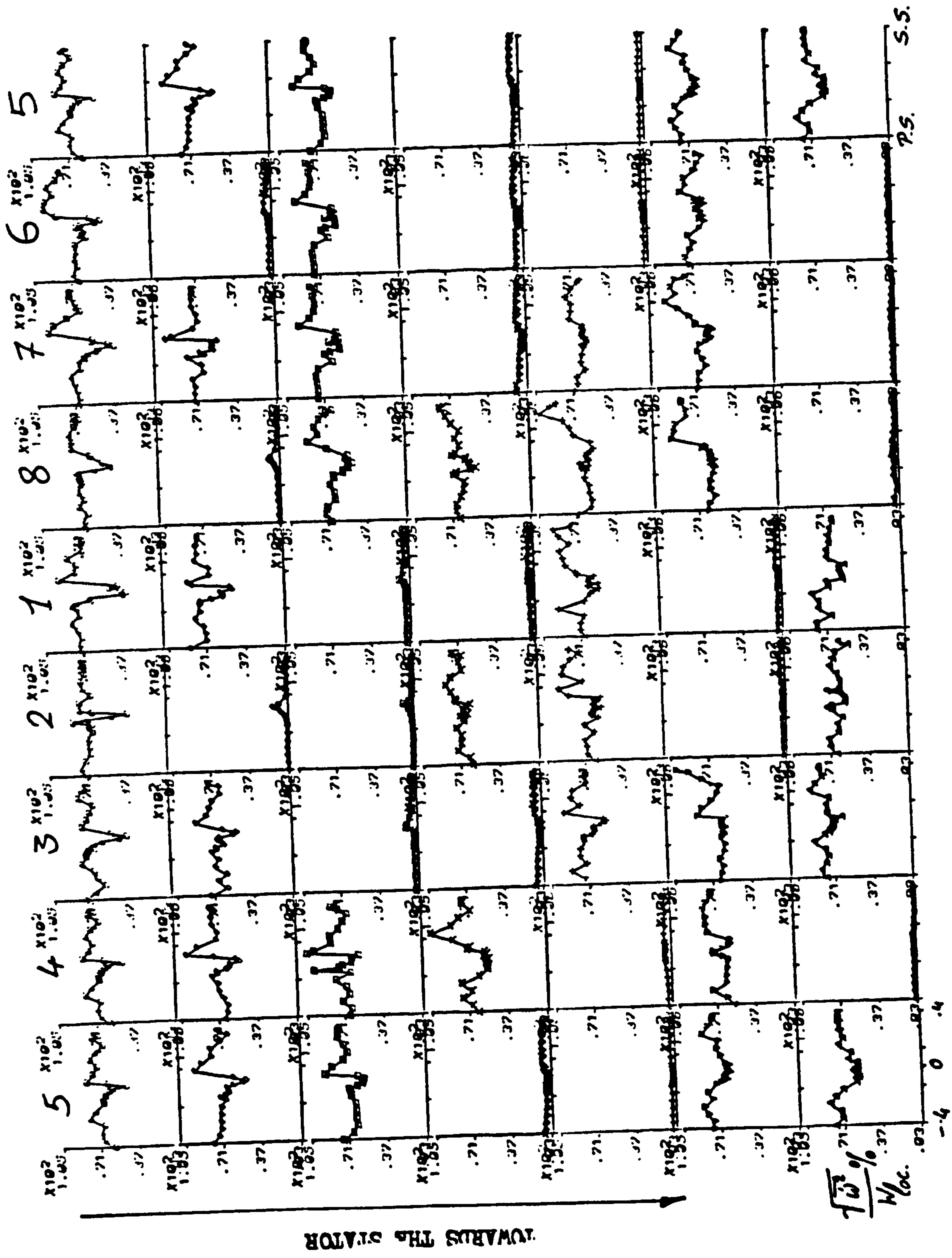


FIG 123 DISTRIBUTION OF RADIAL TURBULENCE INTENSITY.

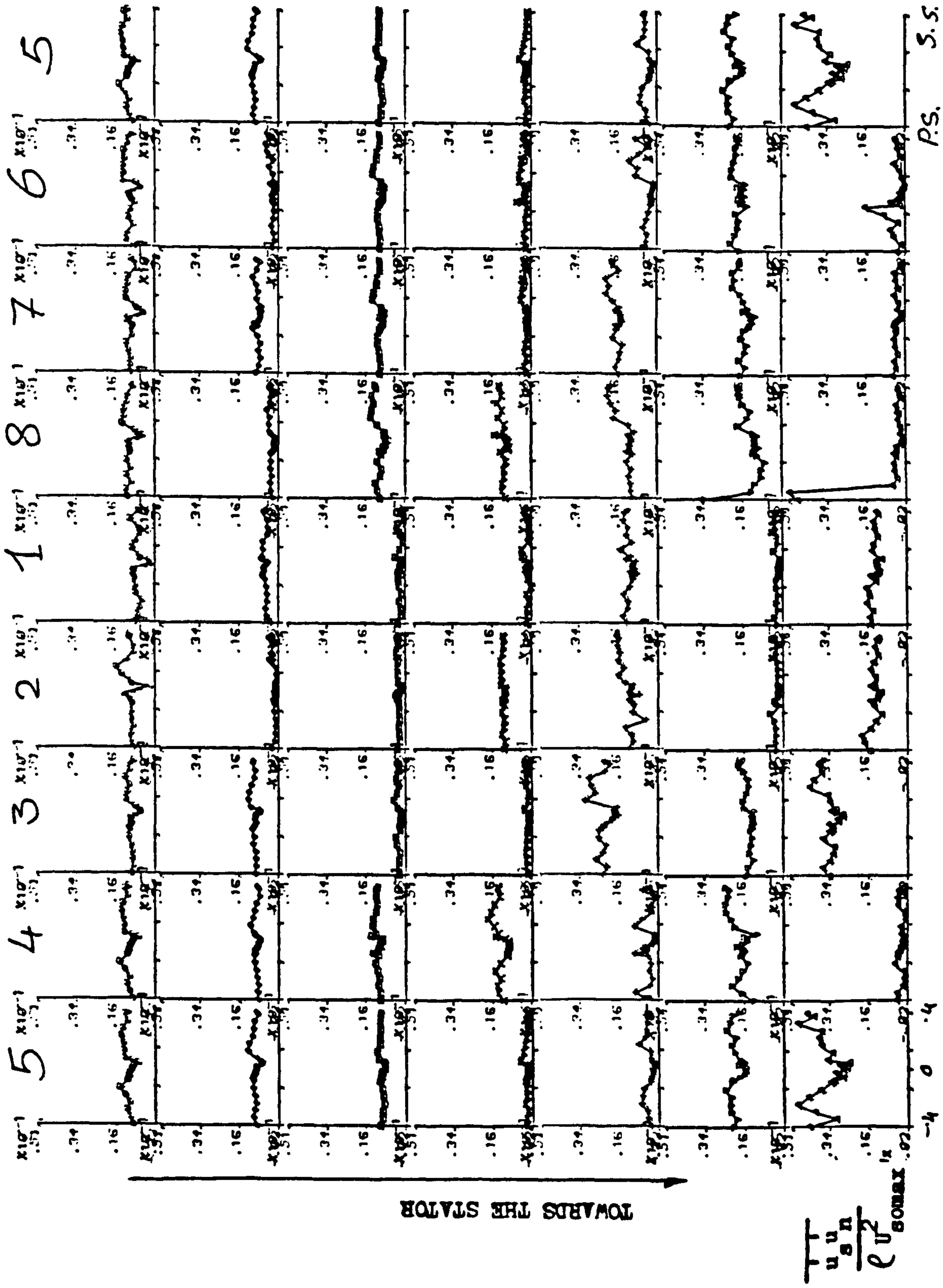


FIG 124 DISTRIBUTION OF STREAM WISE COMPONENT OF REYNOLDS STRESSES

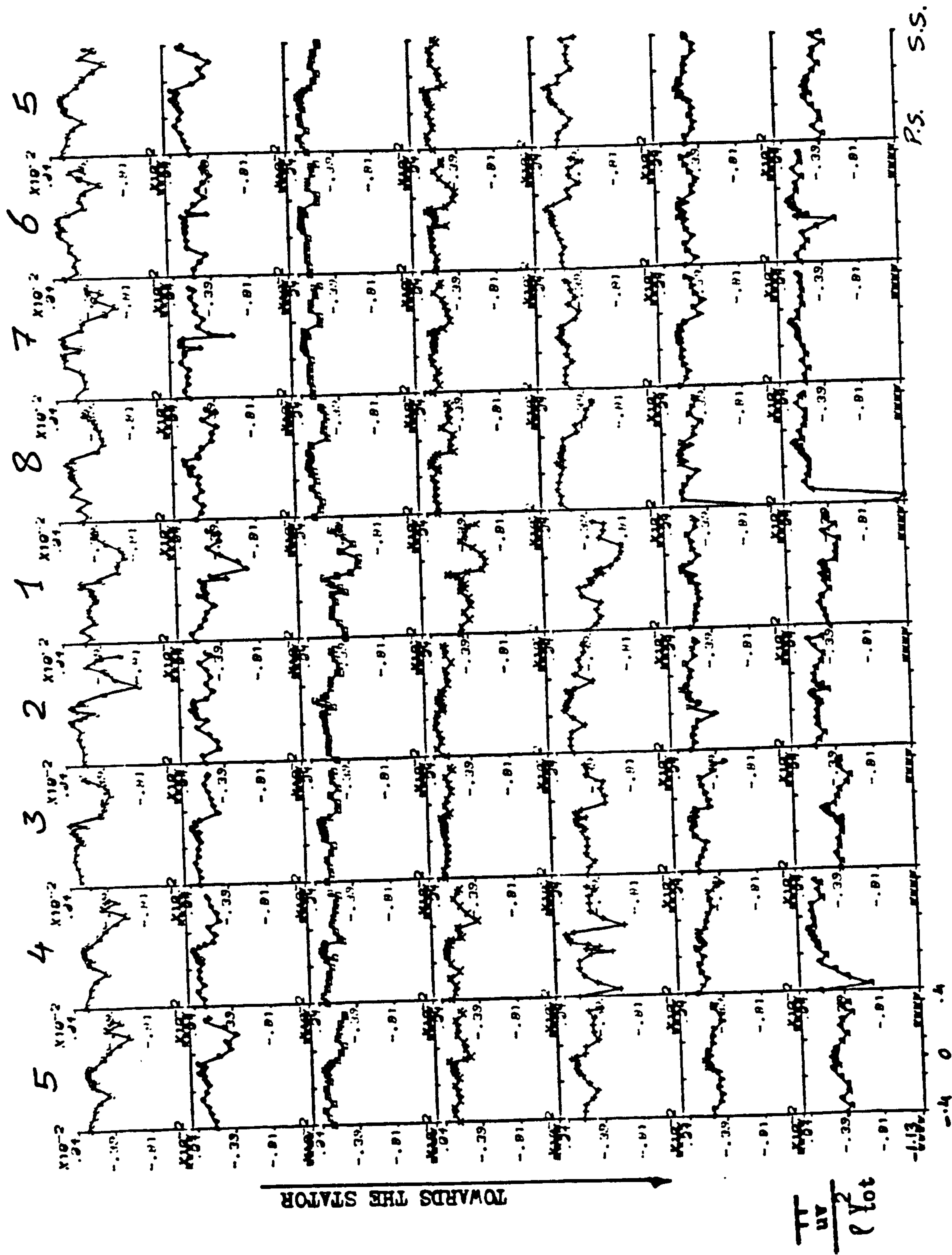
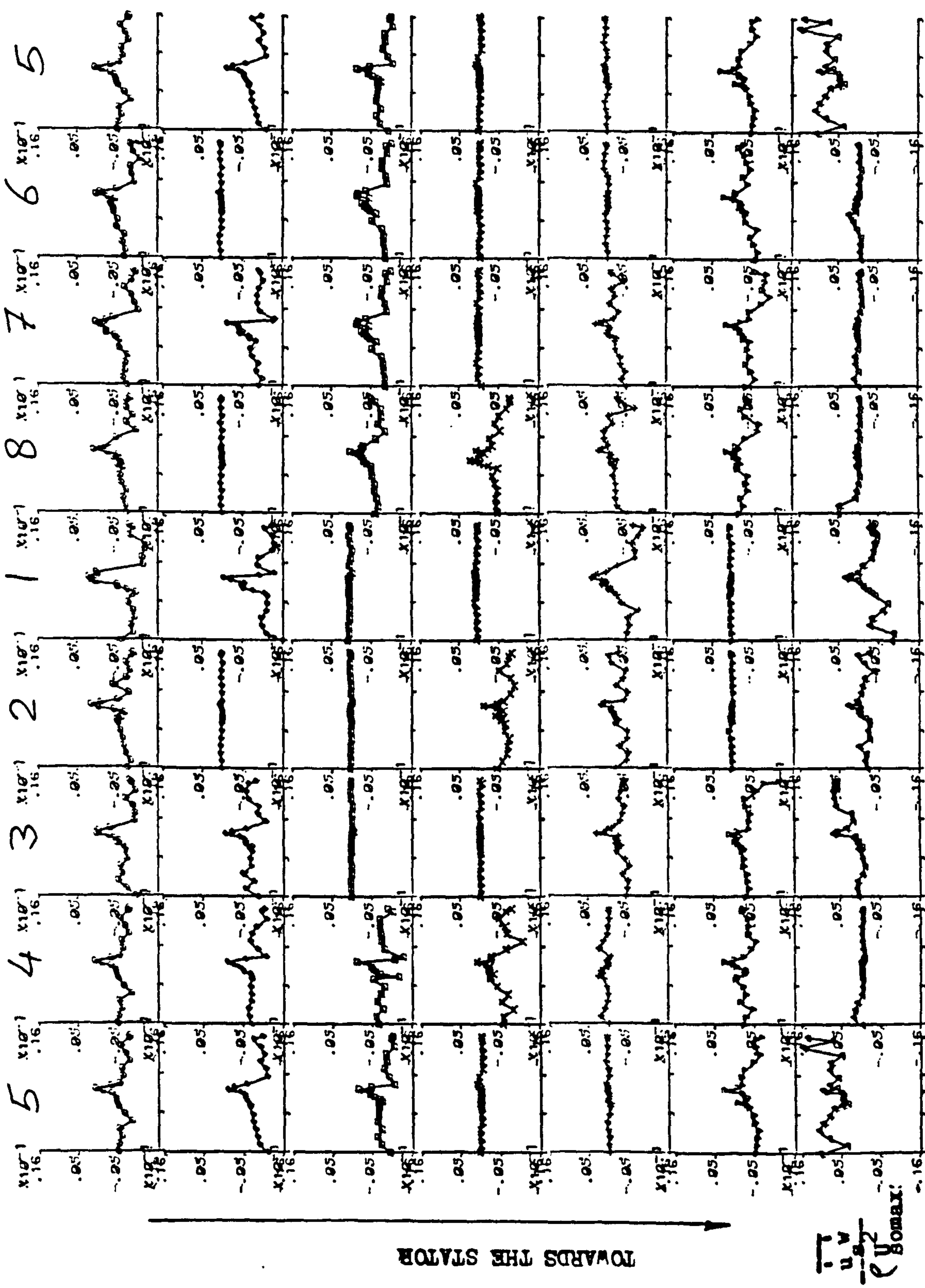


FIG 125 DISTRIBUTION OF AXIAL COMPONENT OF REYNOLDS STRESSES



P.5 S.5.

FIG 126 DISTRIBUTION OF REYNOLDS STRESS COMPONENT IN THE DIRECTION NORMAL TO THE STREAM WISE

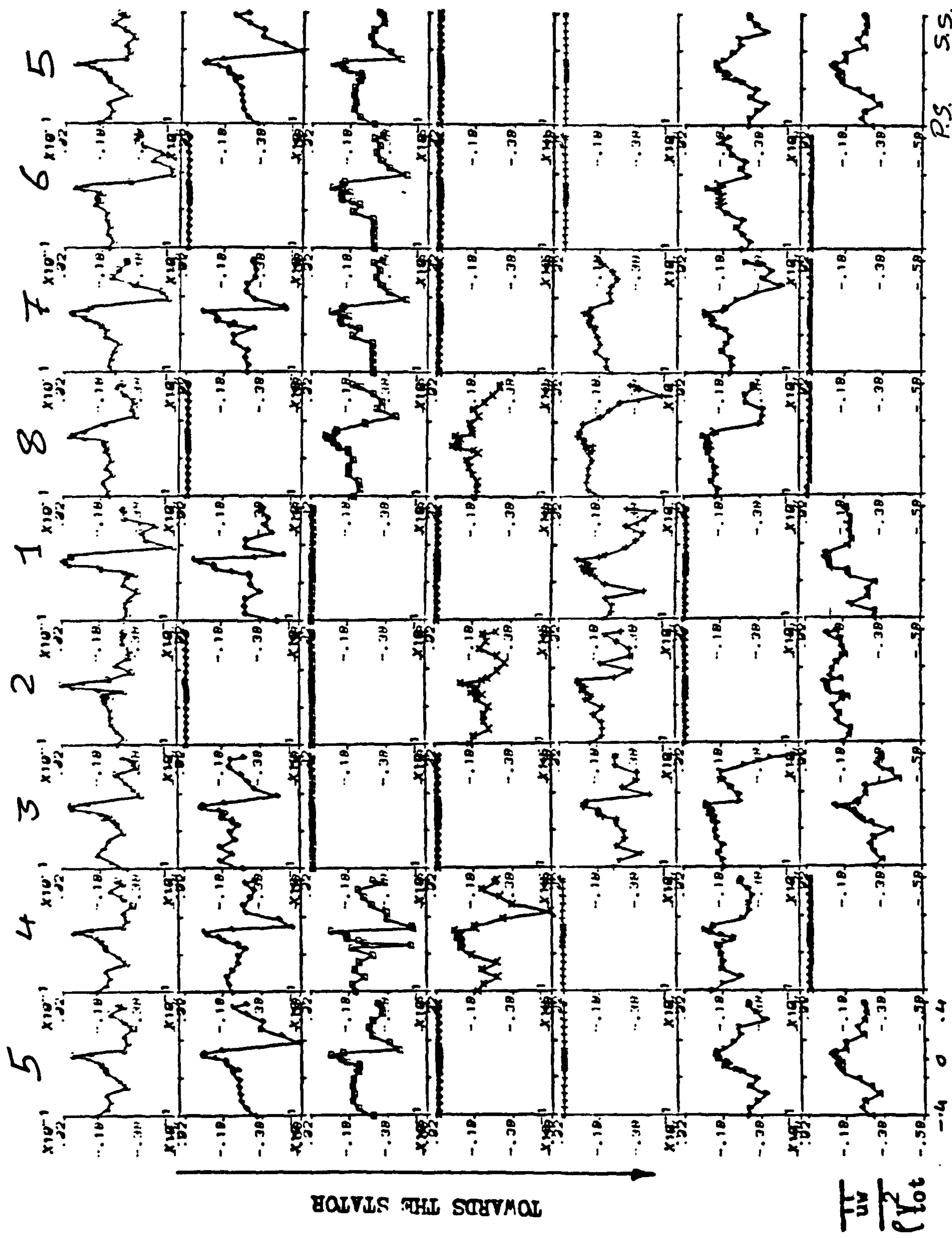


FIG 127 DISTRIBUTION OF TANGENTIAL COMPONENT OF REYNOLDS STRESSES

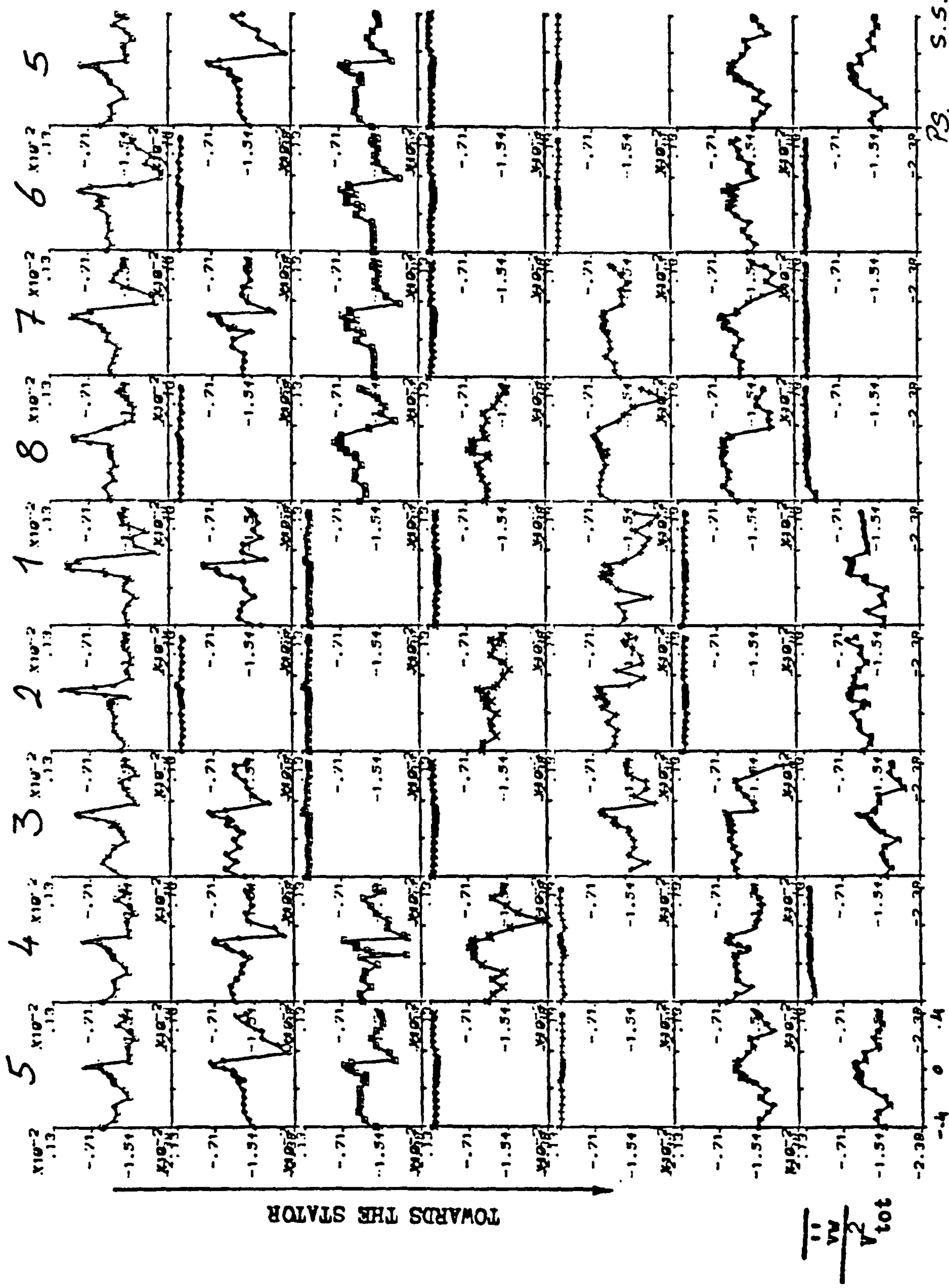


FIG 128 DISTRIBUTION OF RADIAL COMPONENT OF REYNOLDS STRESSES

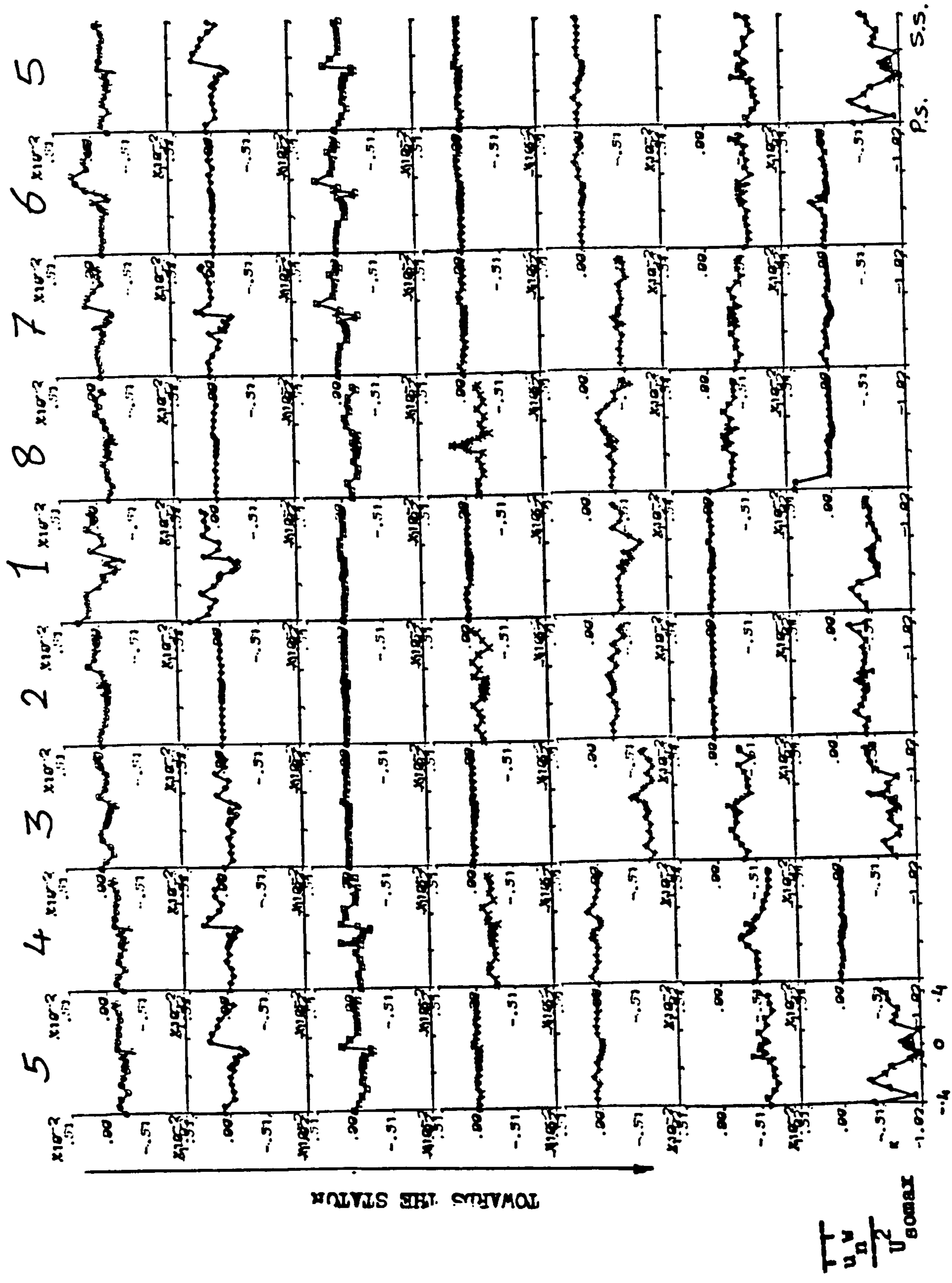


FIG 129 DISTRIBUTION OF RADIAL COMPONENT OF REYNOLDS STRESSES

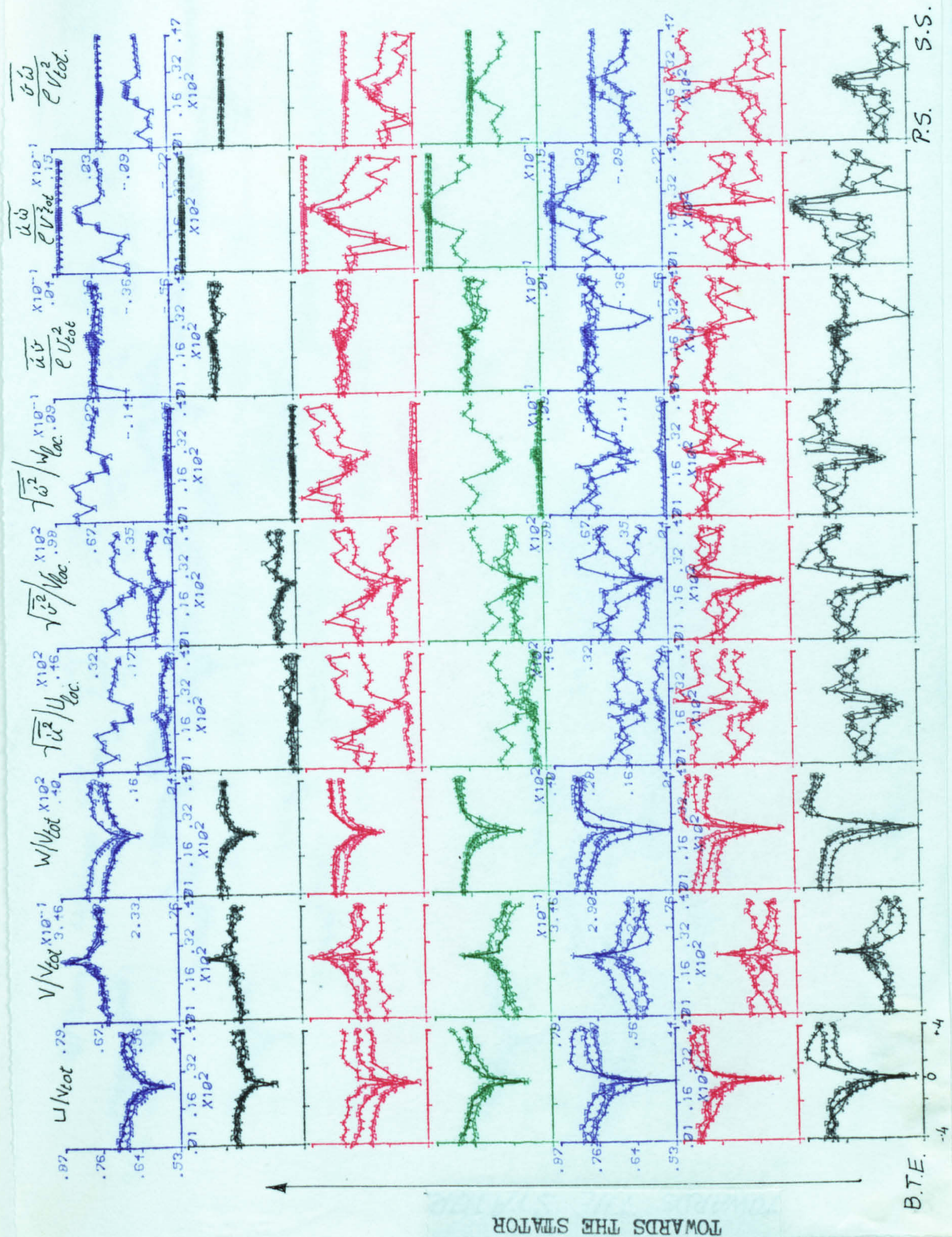


FIG 130 DISTRIBUTION OF FLOW QUANTITIES IN THE TURBOMACHINERY FRAME

OF REFERENCE
 Δ ---LOAD (I) ∇ ---LOAD (II) + ---LOAD (III)

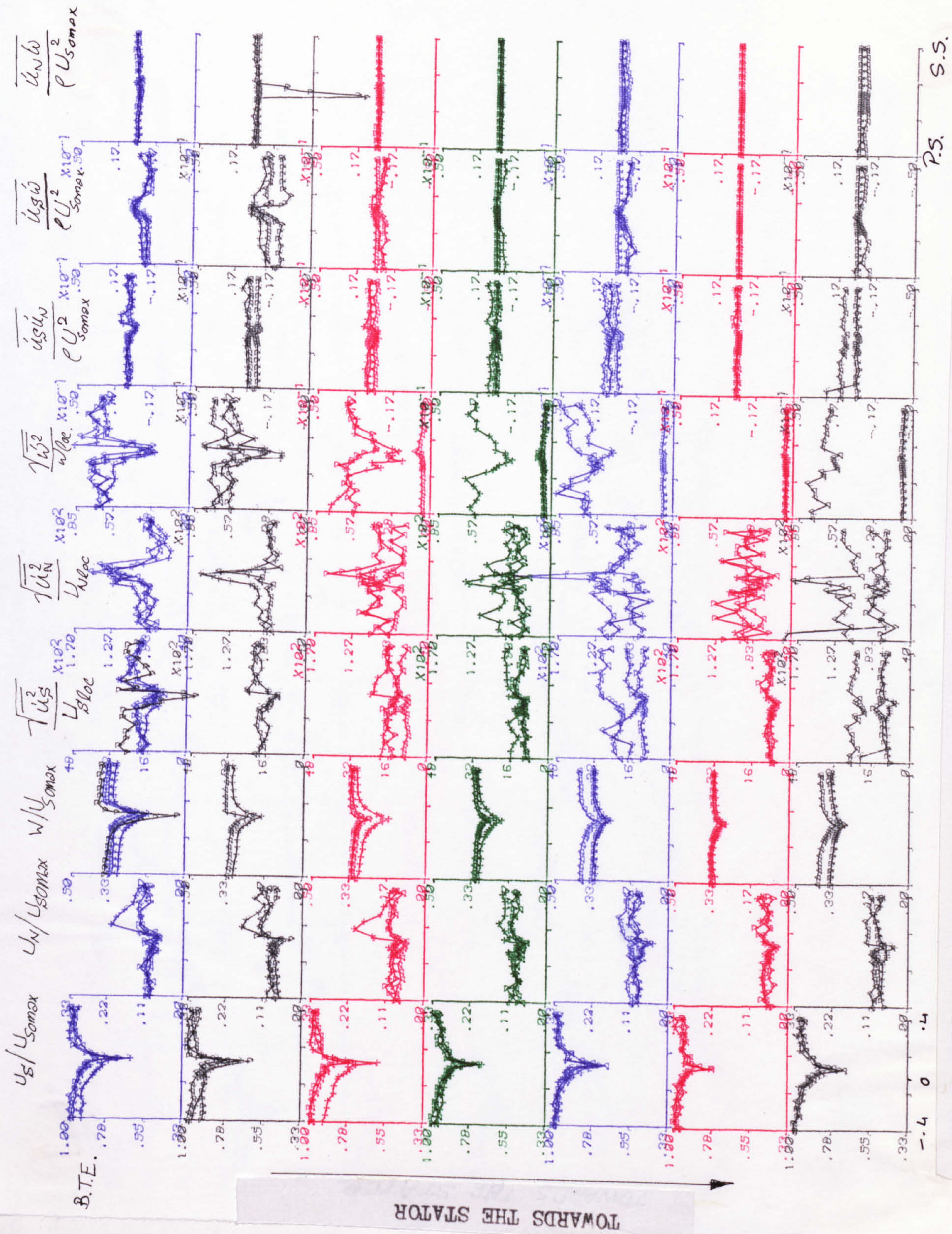


FIG 131 DISTRIBUTION OF FLOW QUANTITIES IN THE STREAM WISE FRAME OF REFERENCE.

Δ -----LOAD (I) ∇ -----LOAD (II) +-----LOAD (III)

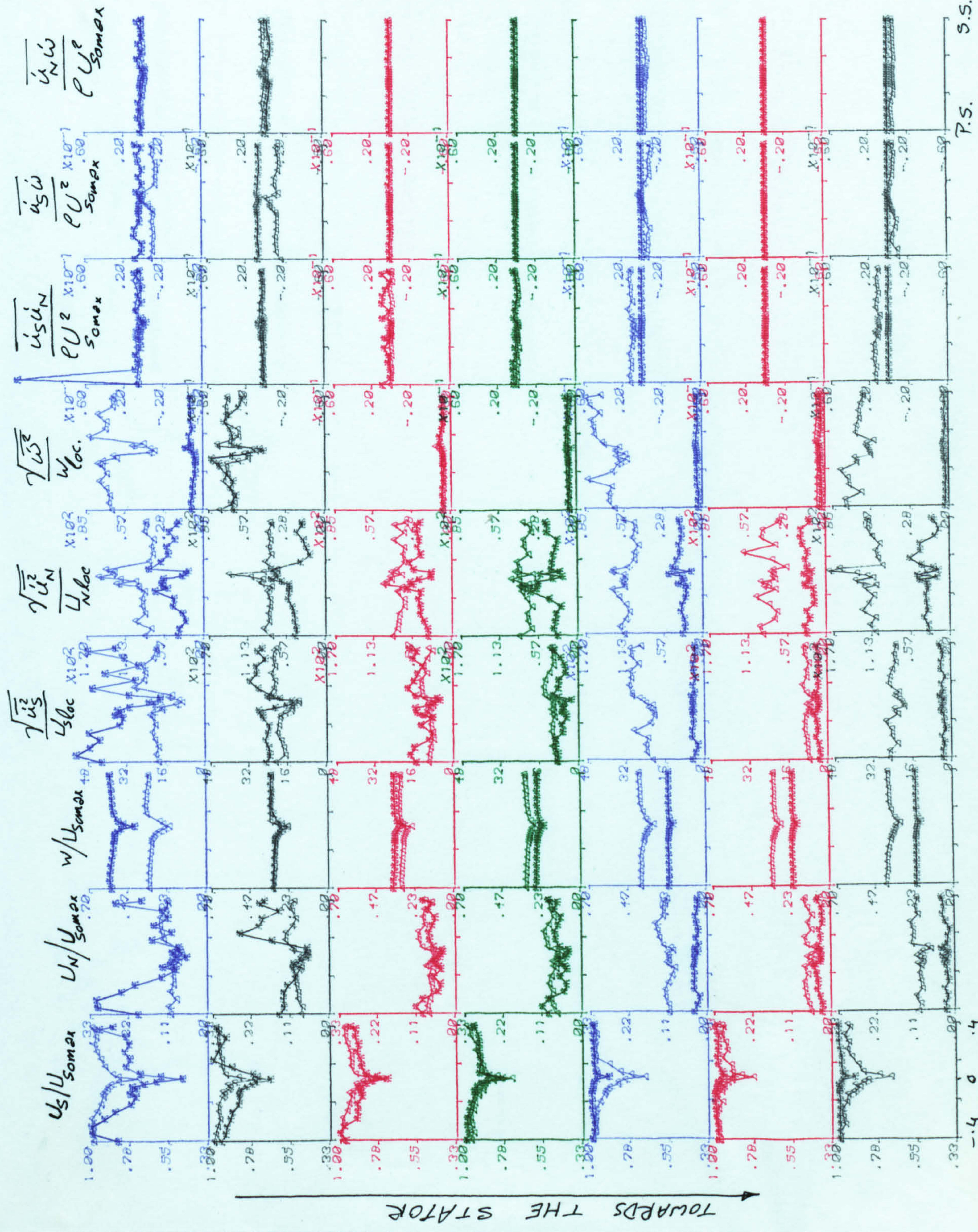


FIG 132 DIST. OF FLOW QUANTITIES WITHOUT DISTORTION (LOAD 1). *—* CLEAN FLOW Δ—Δ DISTORTED FLOW

TOWARDS THE STATOR

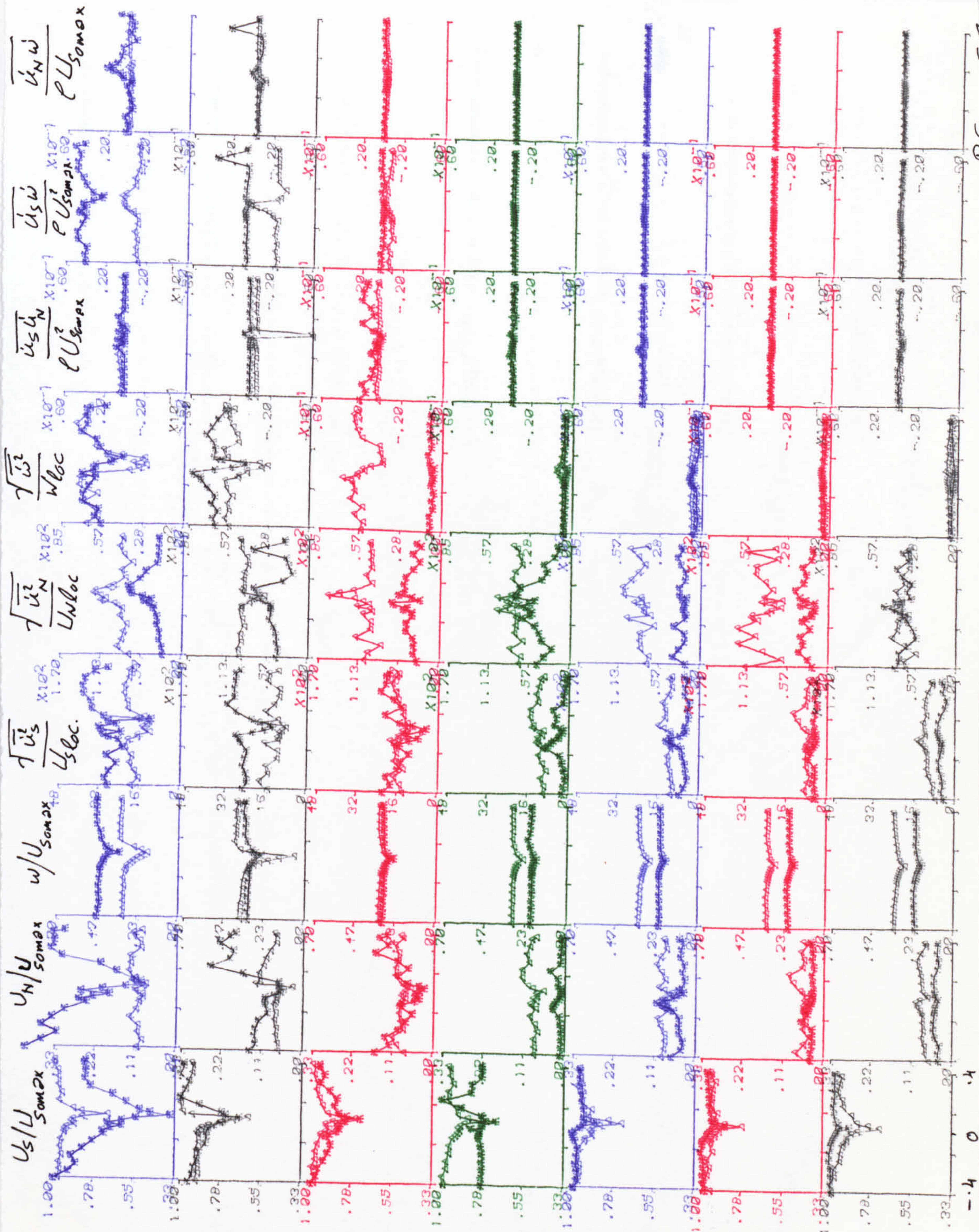


FIG 133 DISTRIBUTION OF FLOW QUANTITIES WITH AND WITHOUT DISTORTION.
IN THE STREAM WISE FRAME OF REFERENCE. LOAD (II)

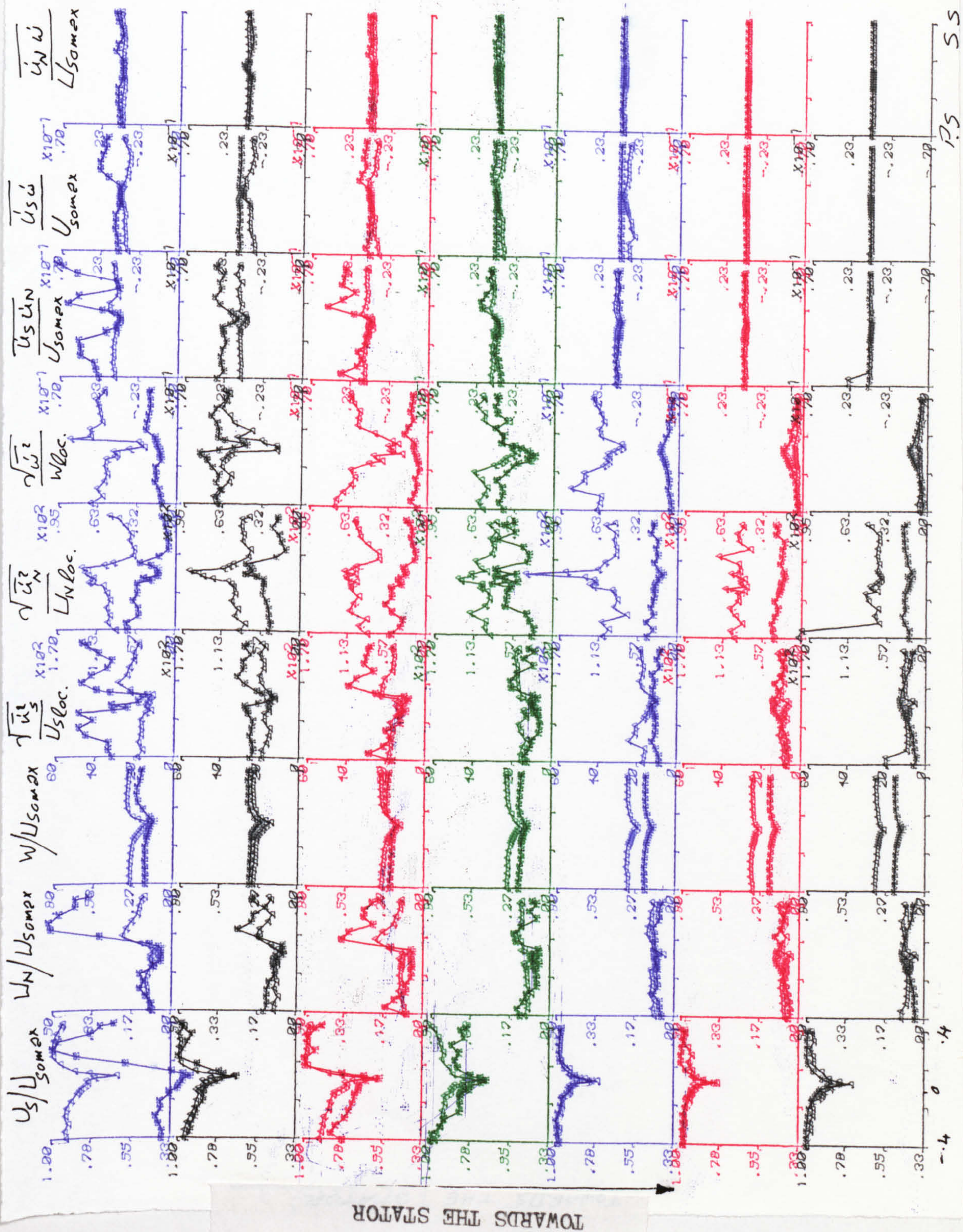


FIG 134 DISTRIBUTION OF FLOW QUANTITIES WITH AND WITHOUT DISTORTION.
IN THE STREAM WISE FRAME OF REFERENCE. LOAD (III)

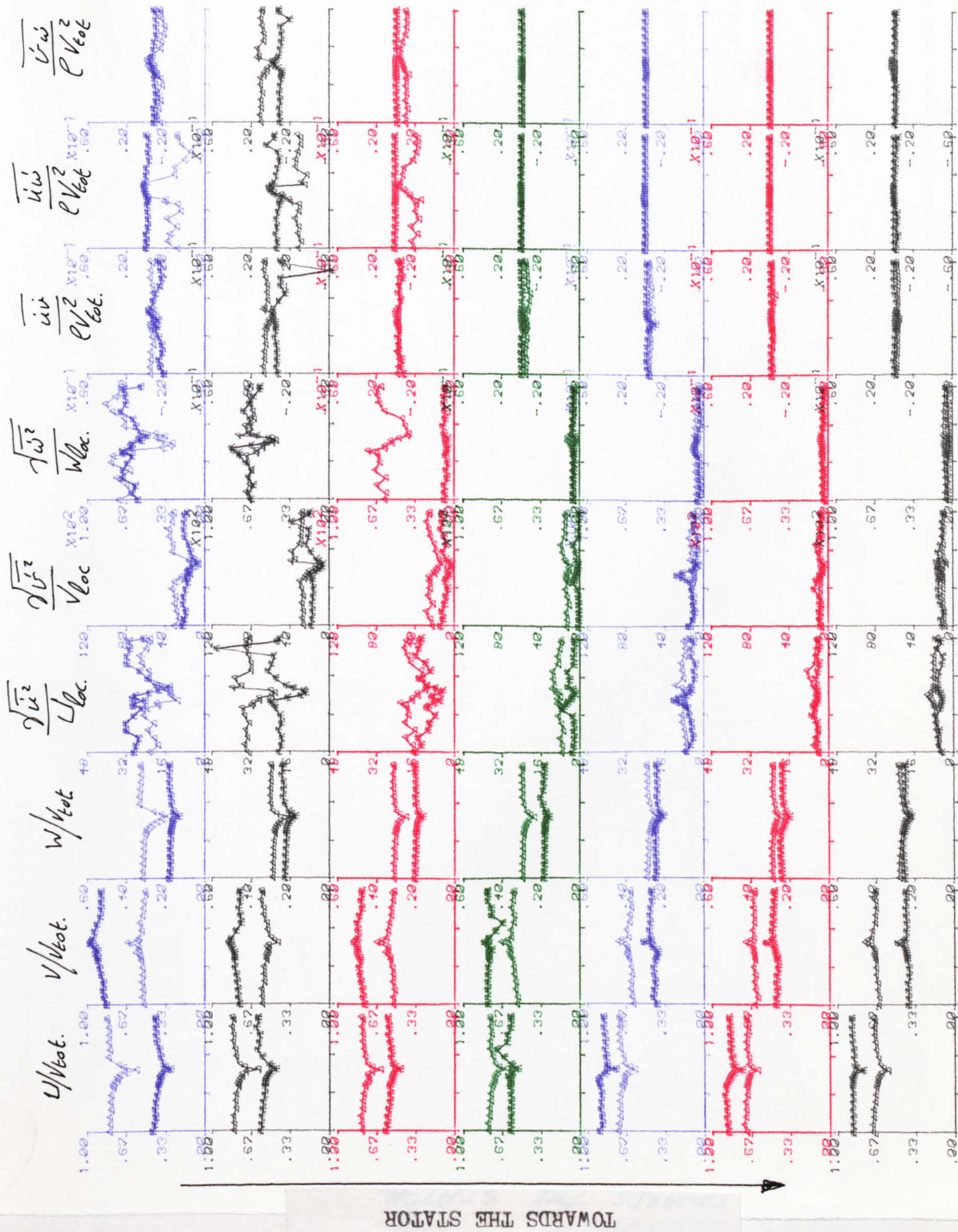


FIG 1-36 DISTRIBUTION OF FLOW QUANTITIES WITH AND WITHOUT DISTORTION
 IN THE TURBOMACHINERY FRAME OF REFERENCE. LOAD (II)

→ TOWARDS THE STATOR

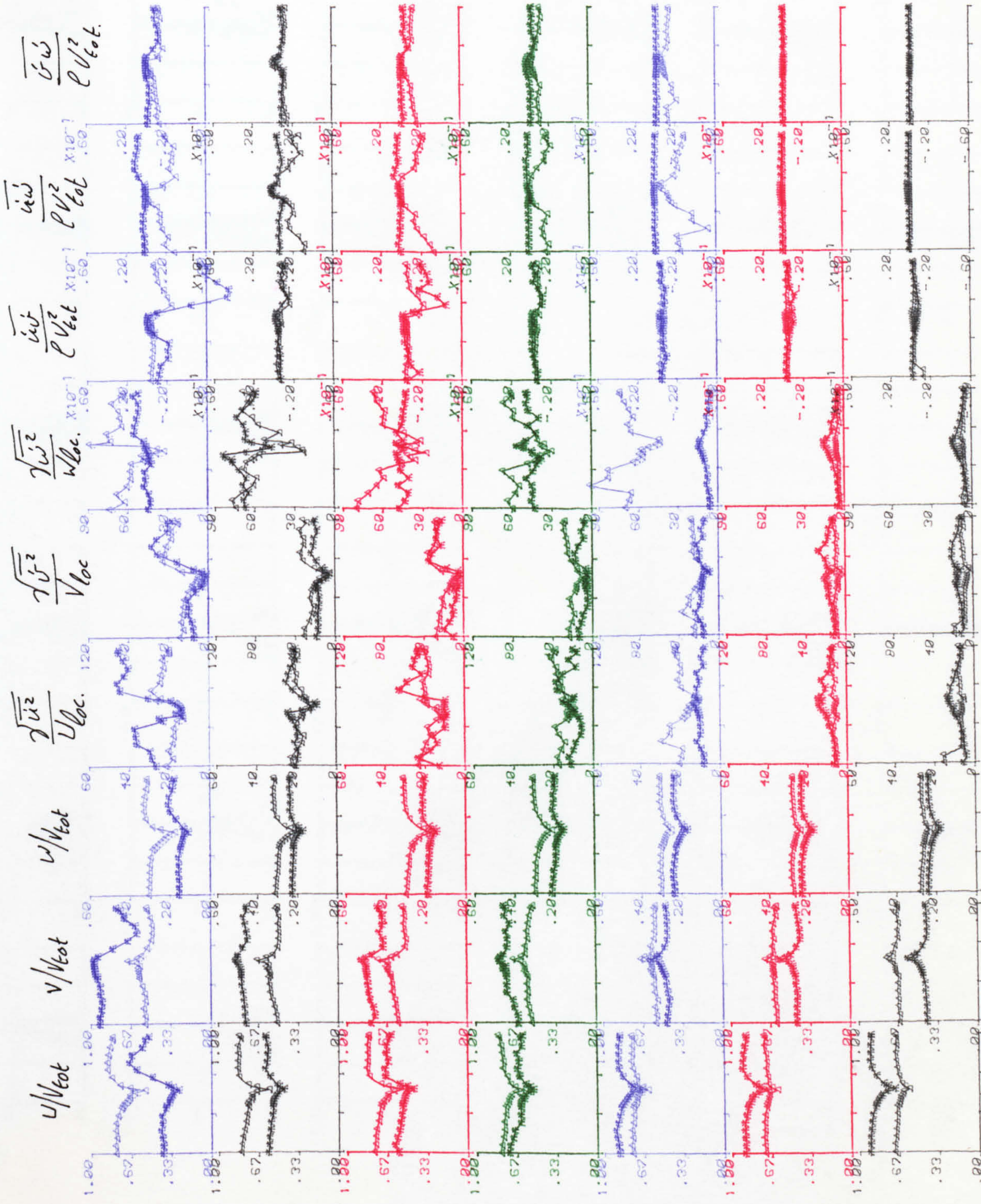
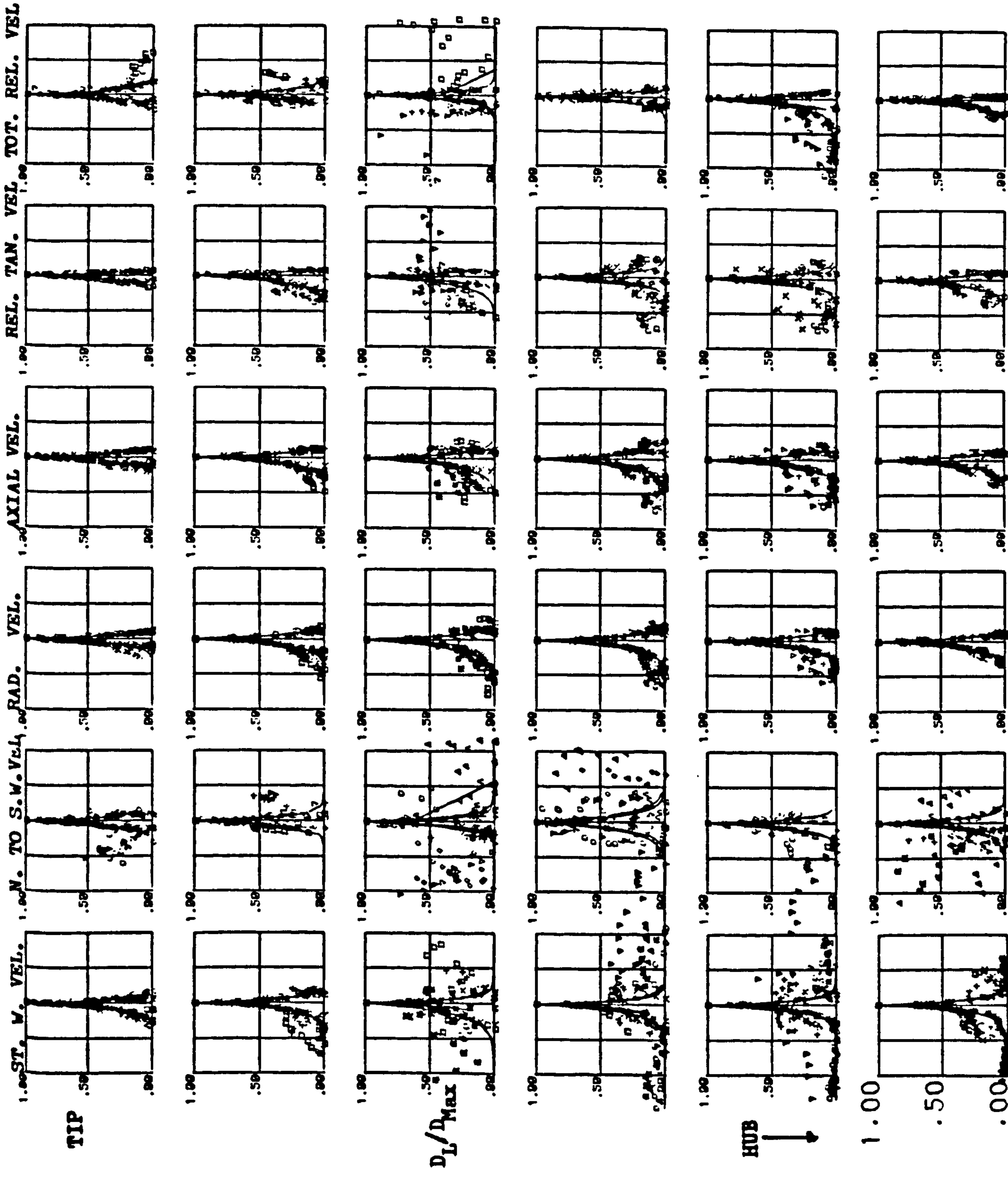
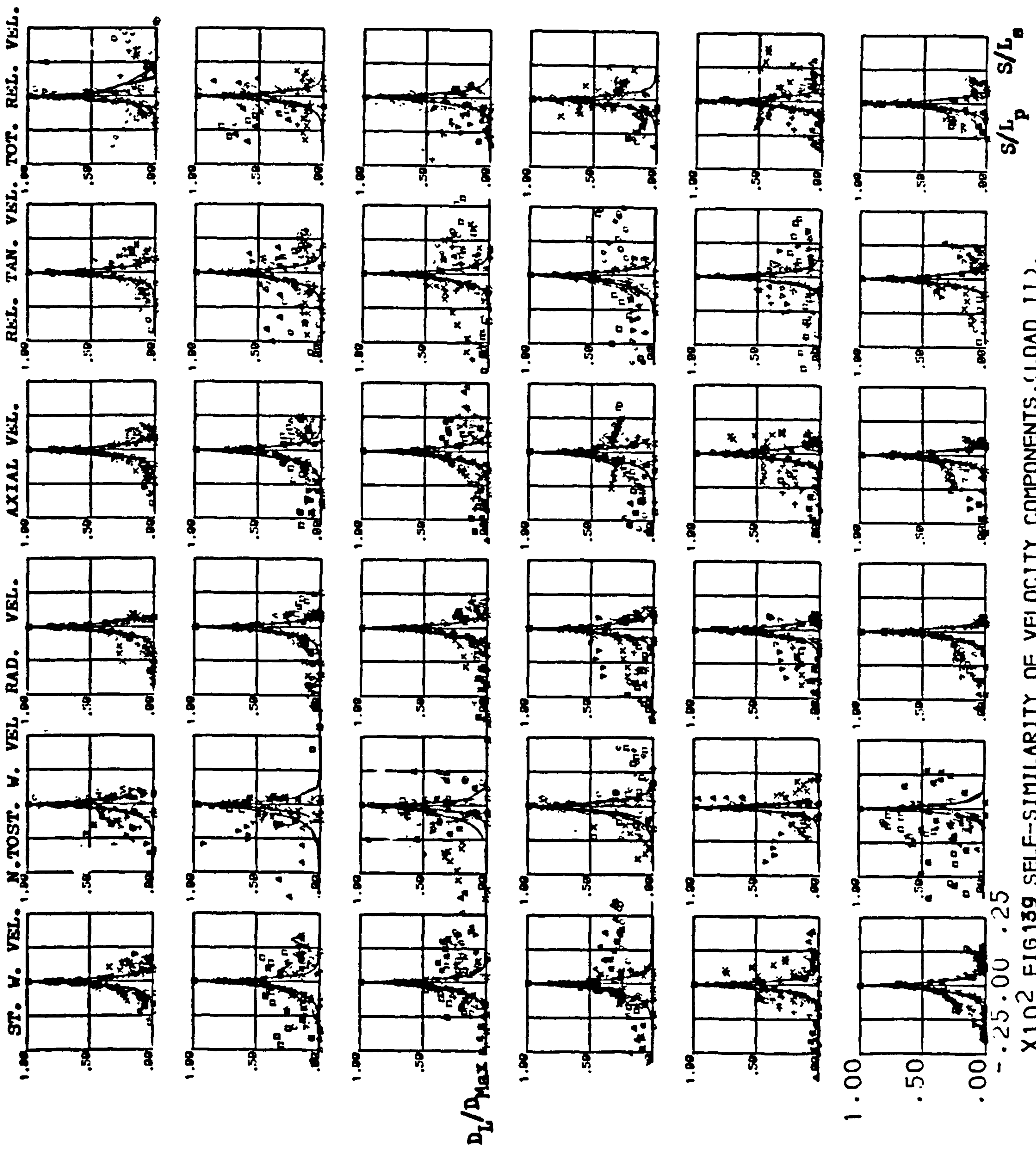


FIG 137 DIST. OF FLOW QUANTITIES WITHOUT DISTORTION AT LOAD (III). TUR. * — CLEAN FLOW P.S. S.S. Δ — DISTORTED

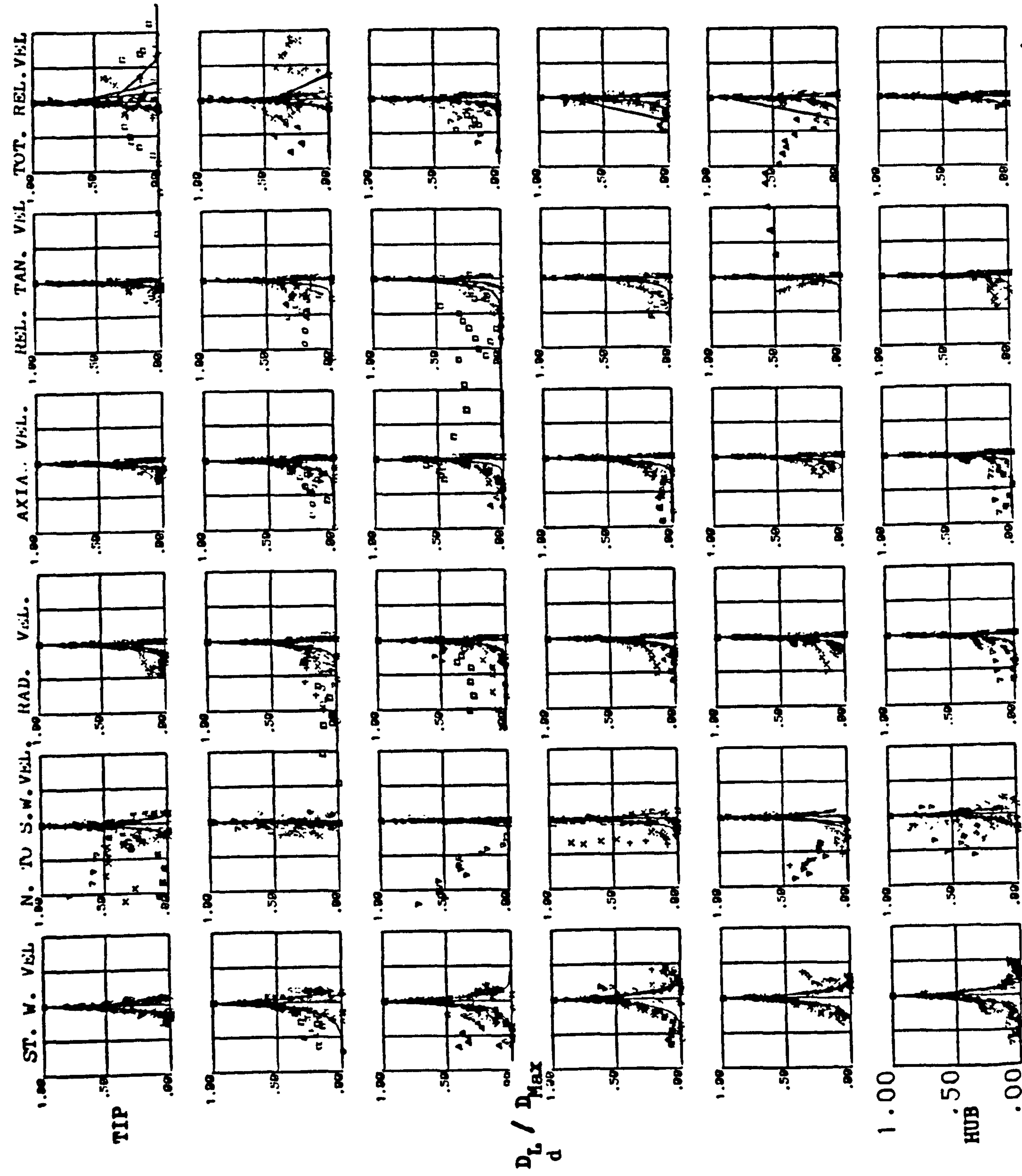


- .25 .00 .25
 X102 FIG 138 SELF-SIMILARITY OF VELOCITY COMPONENTS (LOAD 1). S/L_p S/L_B

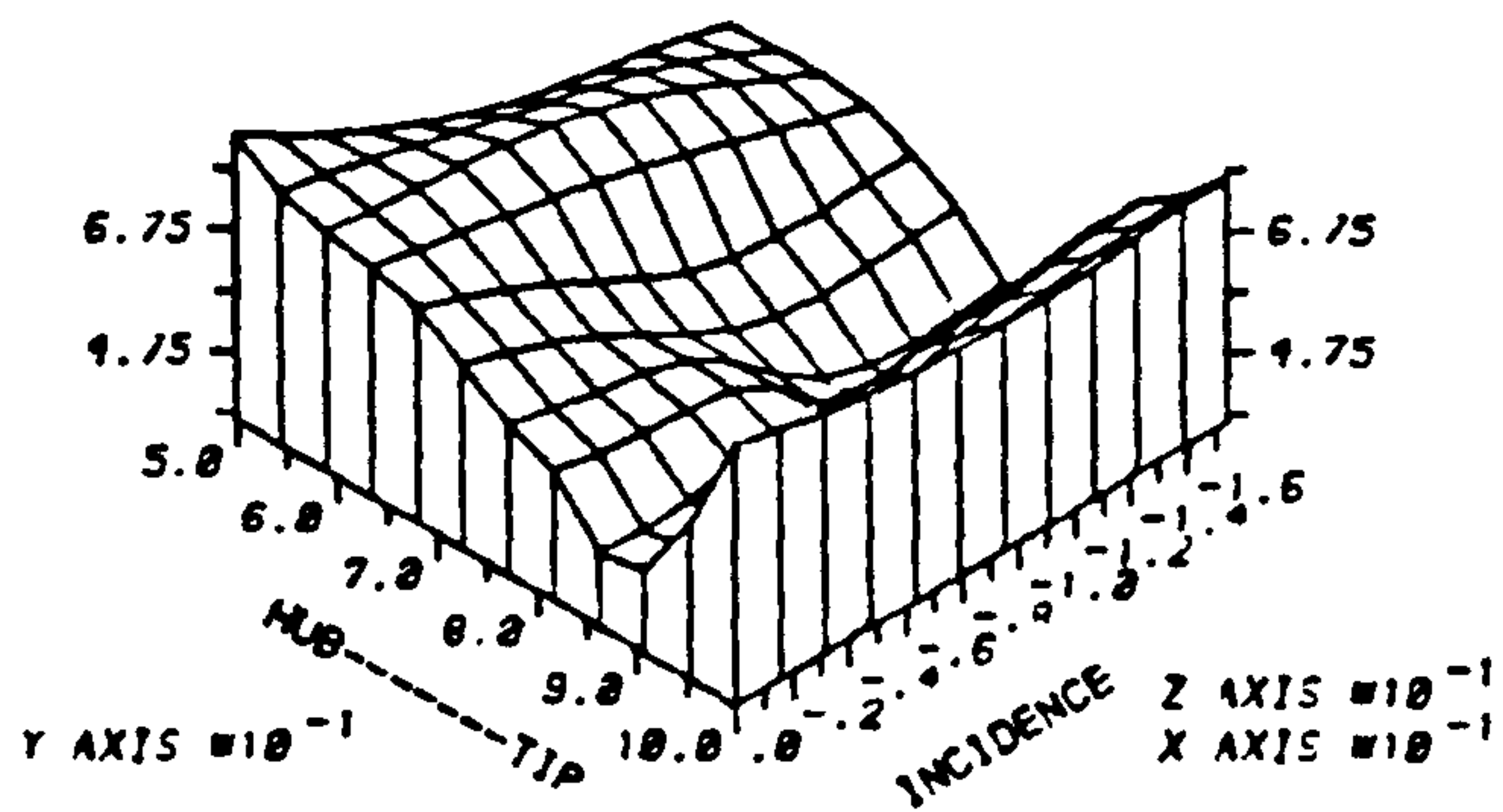


- .25 .00 .25

X102 FIG139 SELF-SIMILARITY OF VELOCITY COMPONENTS.(LOAD 11).



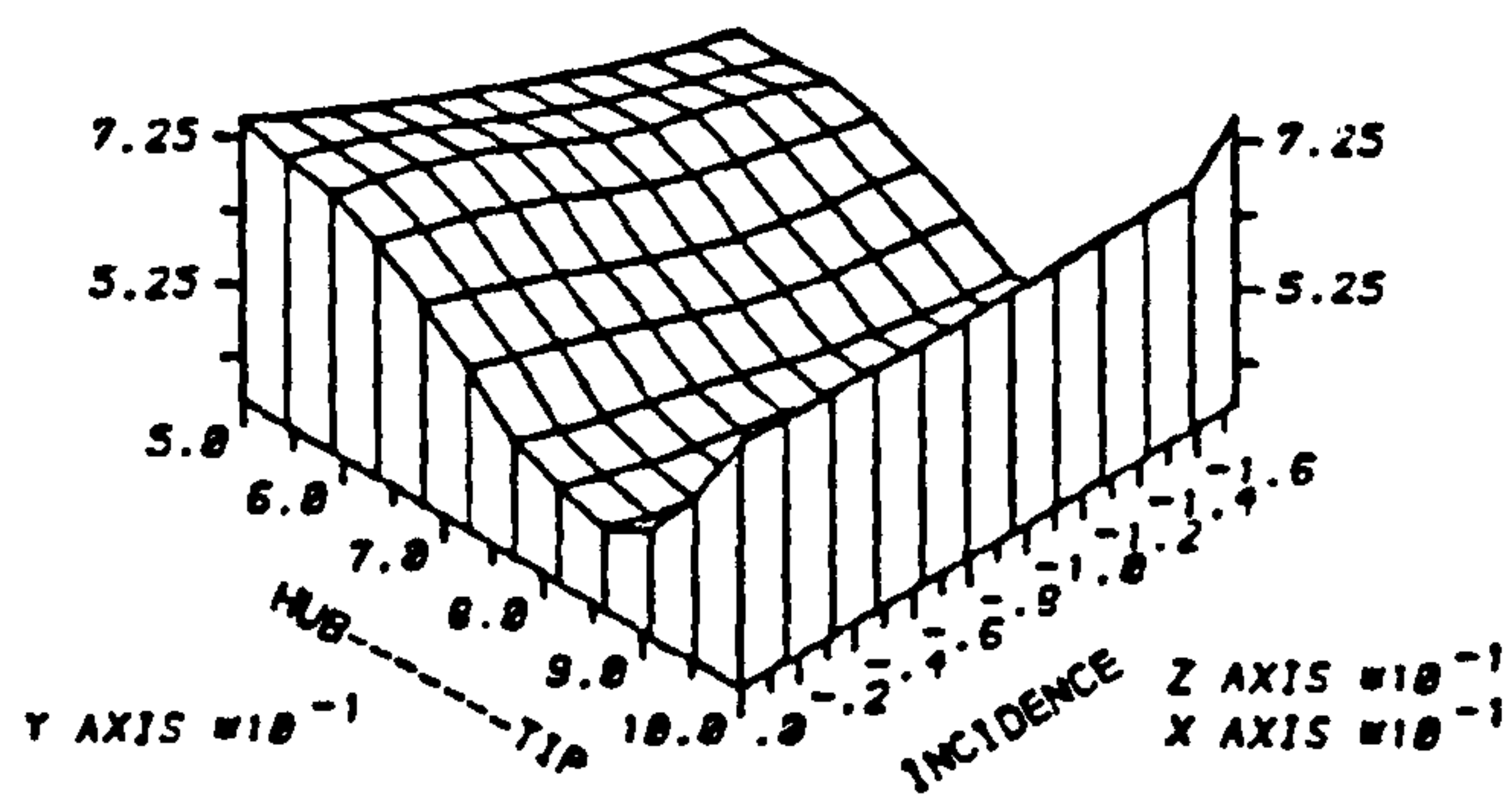
X102 FIG 140 SELF-SIMILARITY OF VELOCITY COMPONENTS.(LOAD III).



STREAM WISE VELOCITY (P.S.)

Fig 11 VALUES OF THE SIMILARITY COEFF.

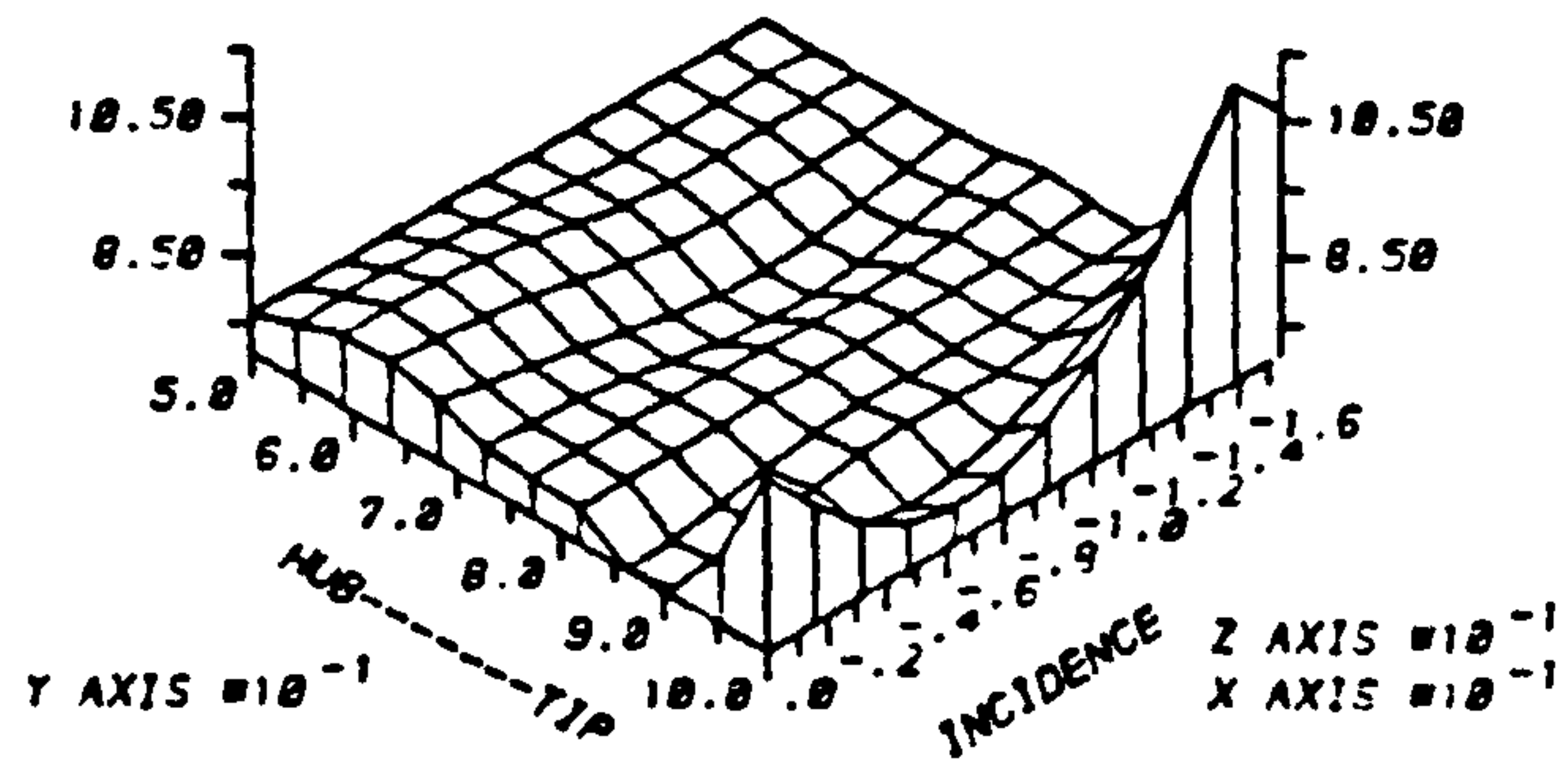
REAL



STREAM WISE VELOCITY (P.S.)

Fig 12 VALUES OF THE SIMILARITY COEFF.

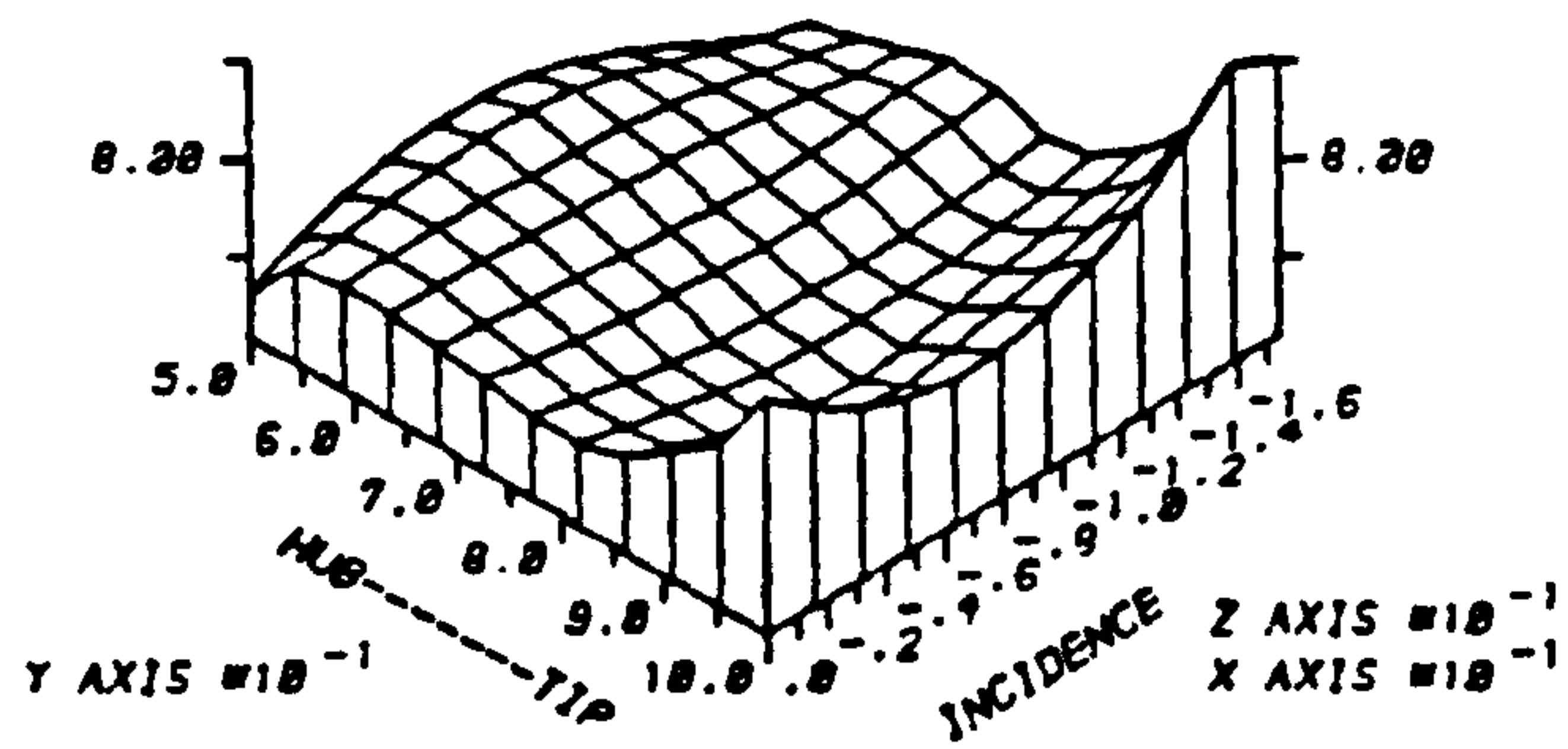
FITTING



STREAM WISE VELOCITY (S.S.)

Fig 43 VALUES OF THE SIMILARITY COEFF.

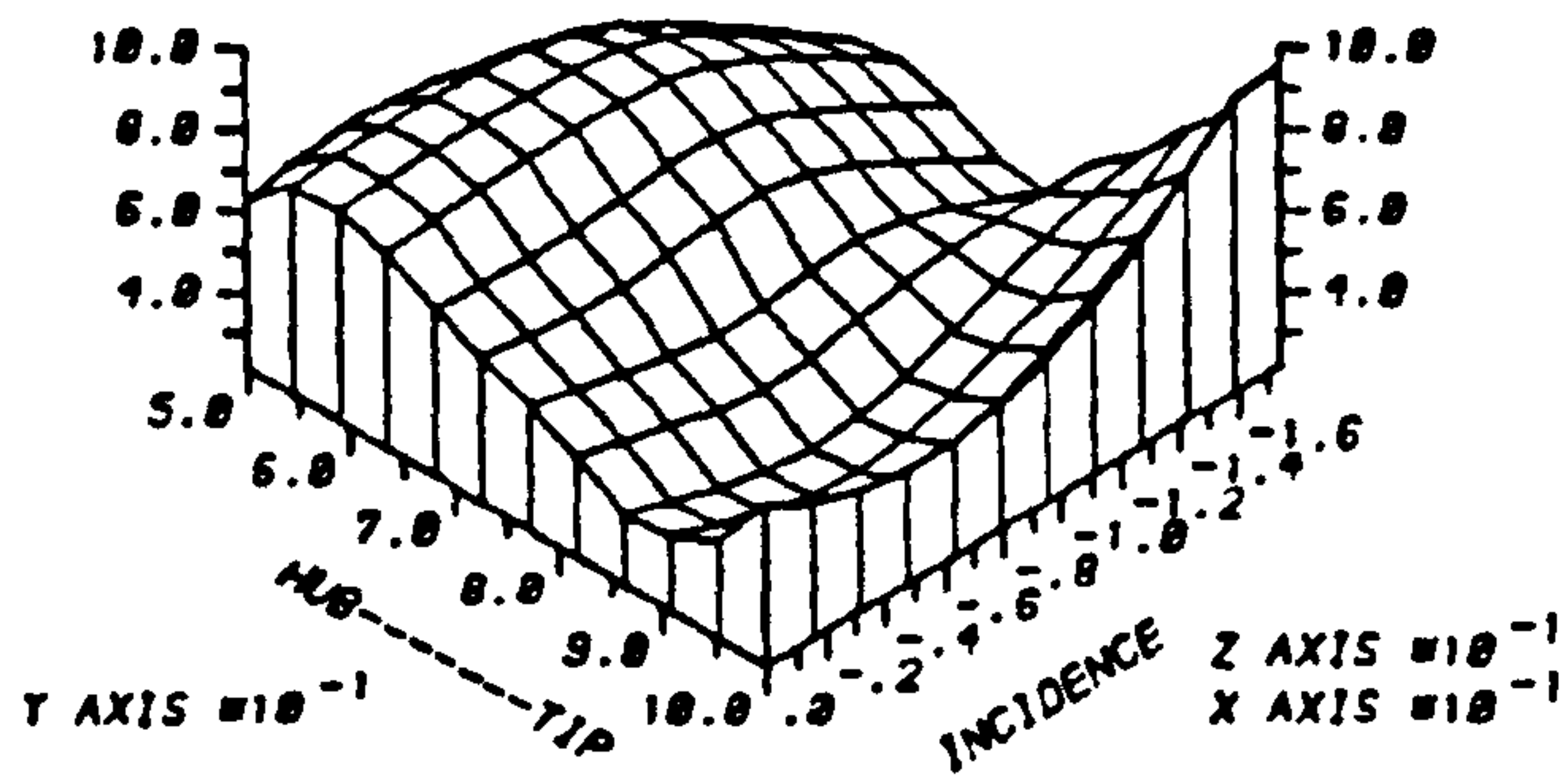
REAL



STREAM WISE VELOCITY (S.S.)

Fig 44 VALUES OF THE SIMILARITY COEFF.

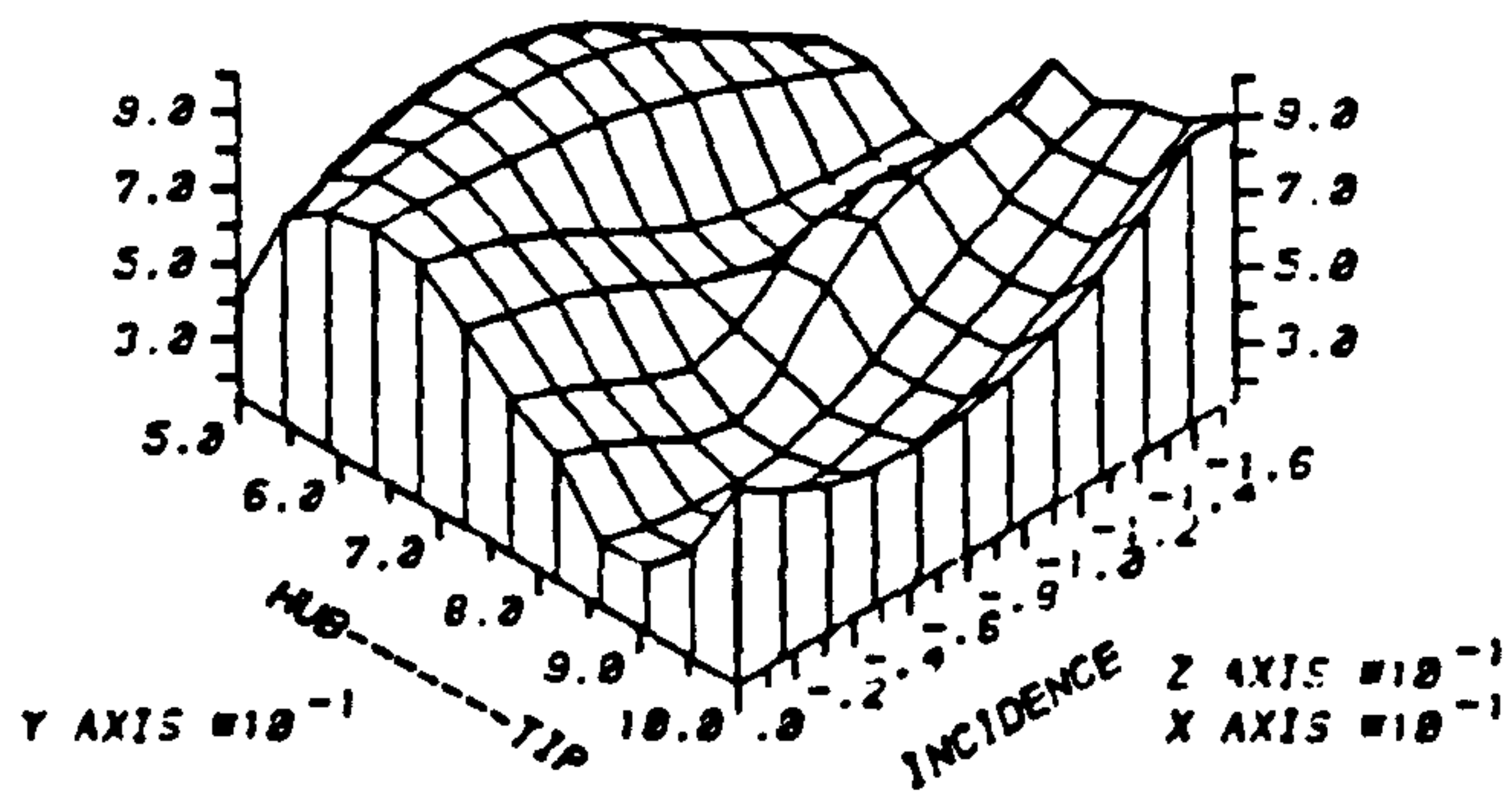
FITTING



NORMAL TO STREAM WISE VEL. (P.S.)

Fig 145 VALUES OF THE SIMILARITY COEFF.

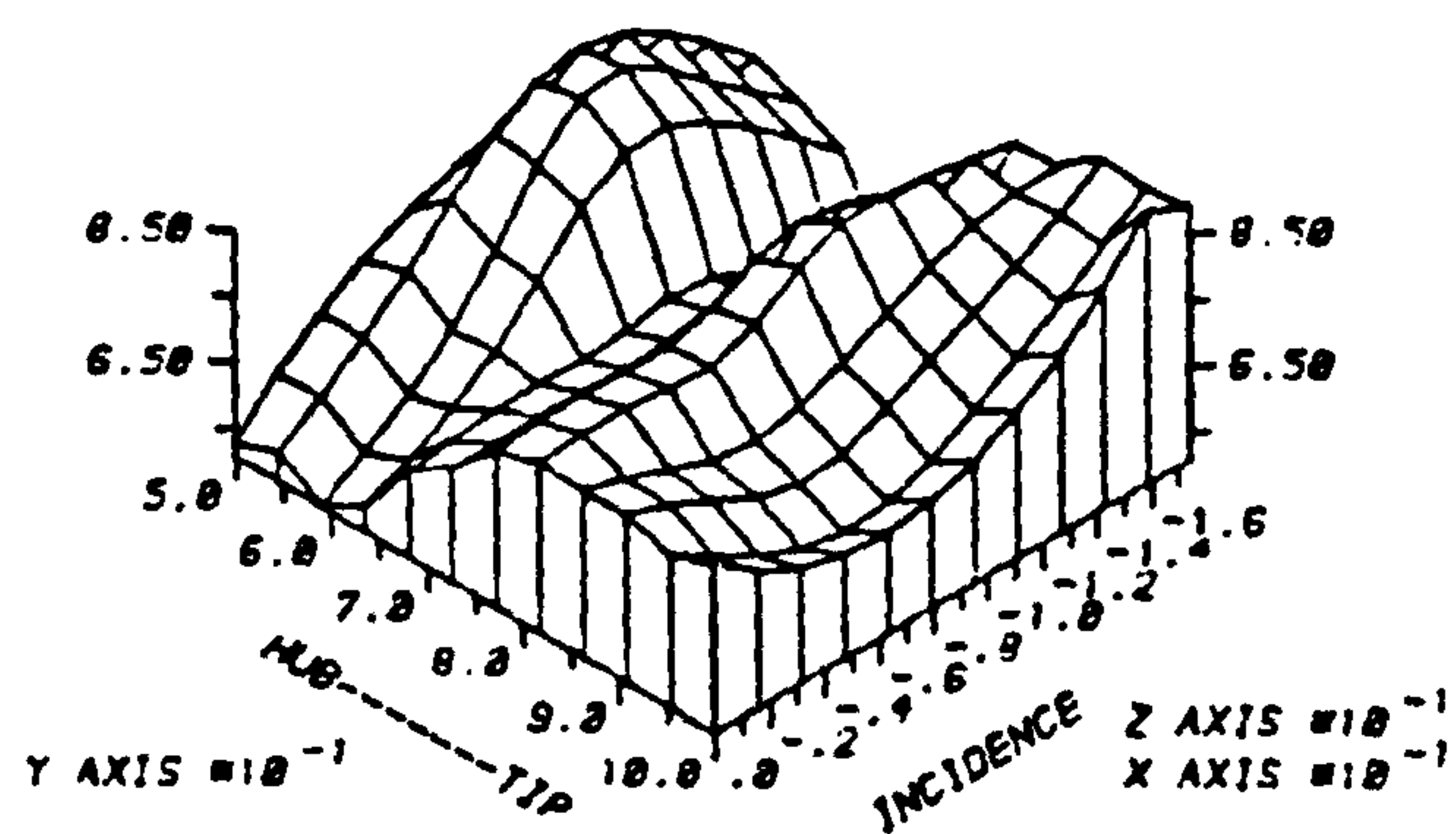
FITTING



NORMAL TO STREAM WISE VEL. (P.S.)

Fig 146 VALUES OF THE SIMILARITY COEFF.

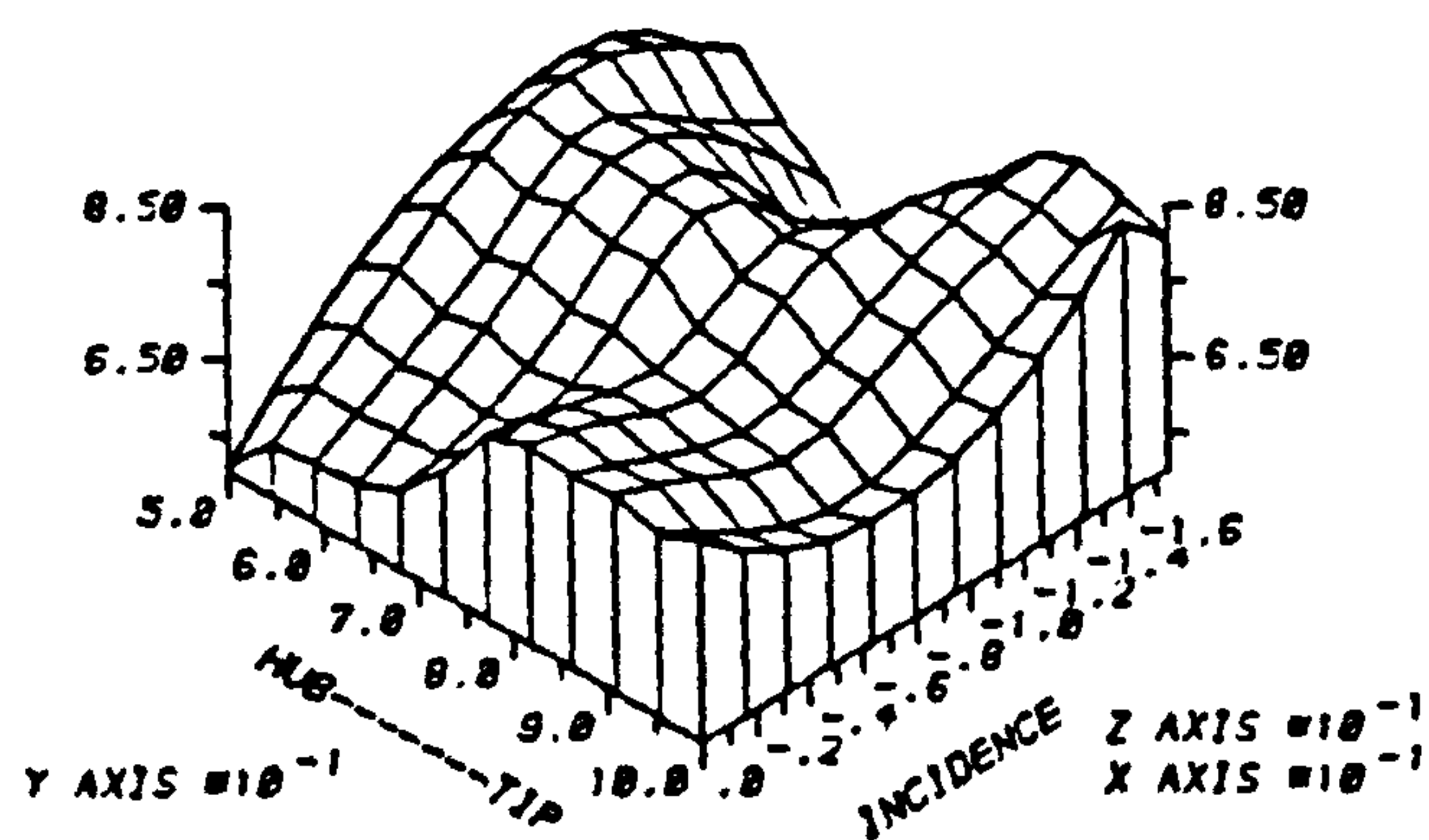
REAL



NORMAL TO STREAM WISE VEL. (S.S.)

Fig 147 VALUES OF THE SIMILARITY COEFF.

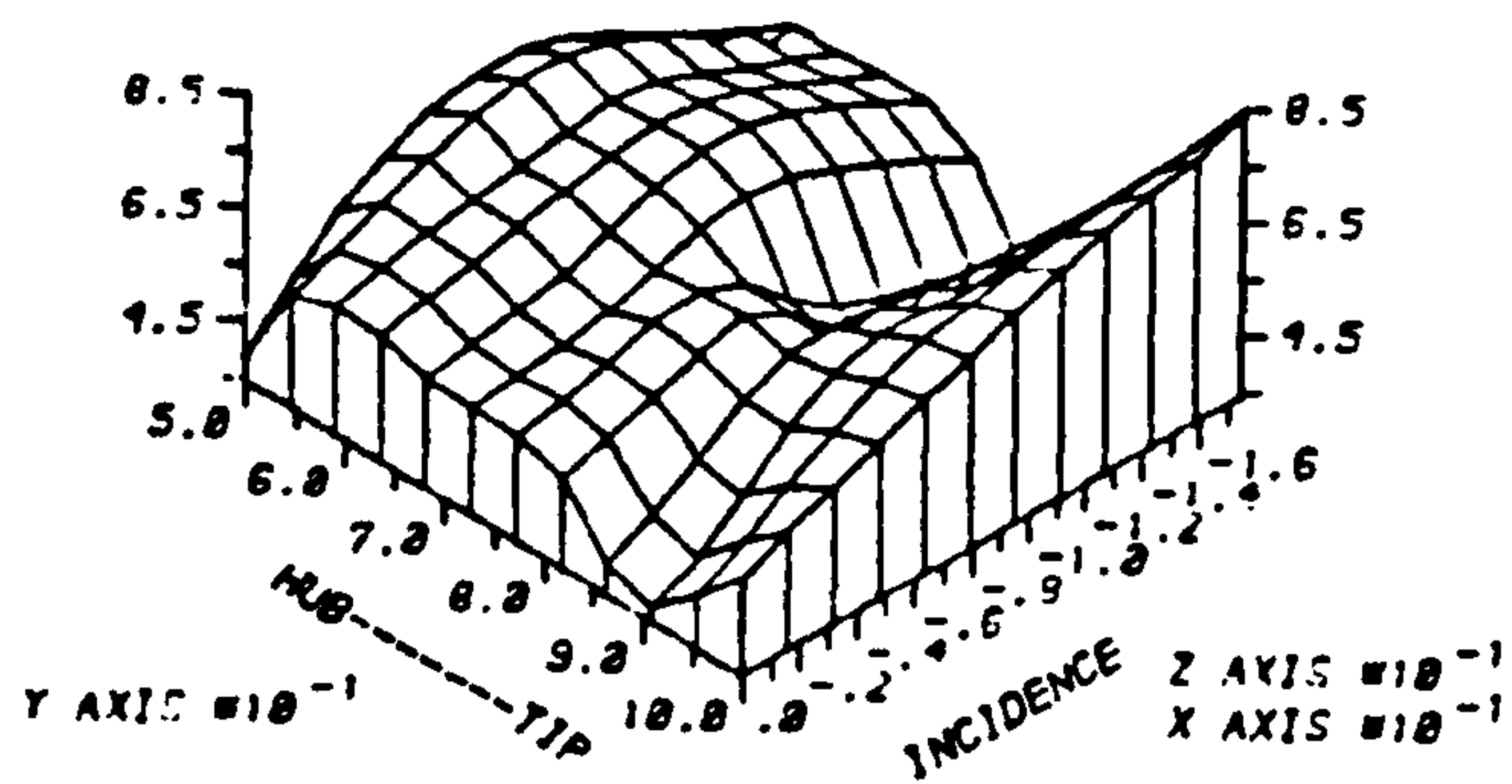
REAL



NORMAL TO STREAM WISE VEL. (S.S.)

Fig 148 VALUES OF THE SIMILARITY COEFF.

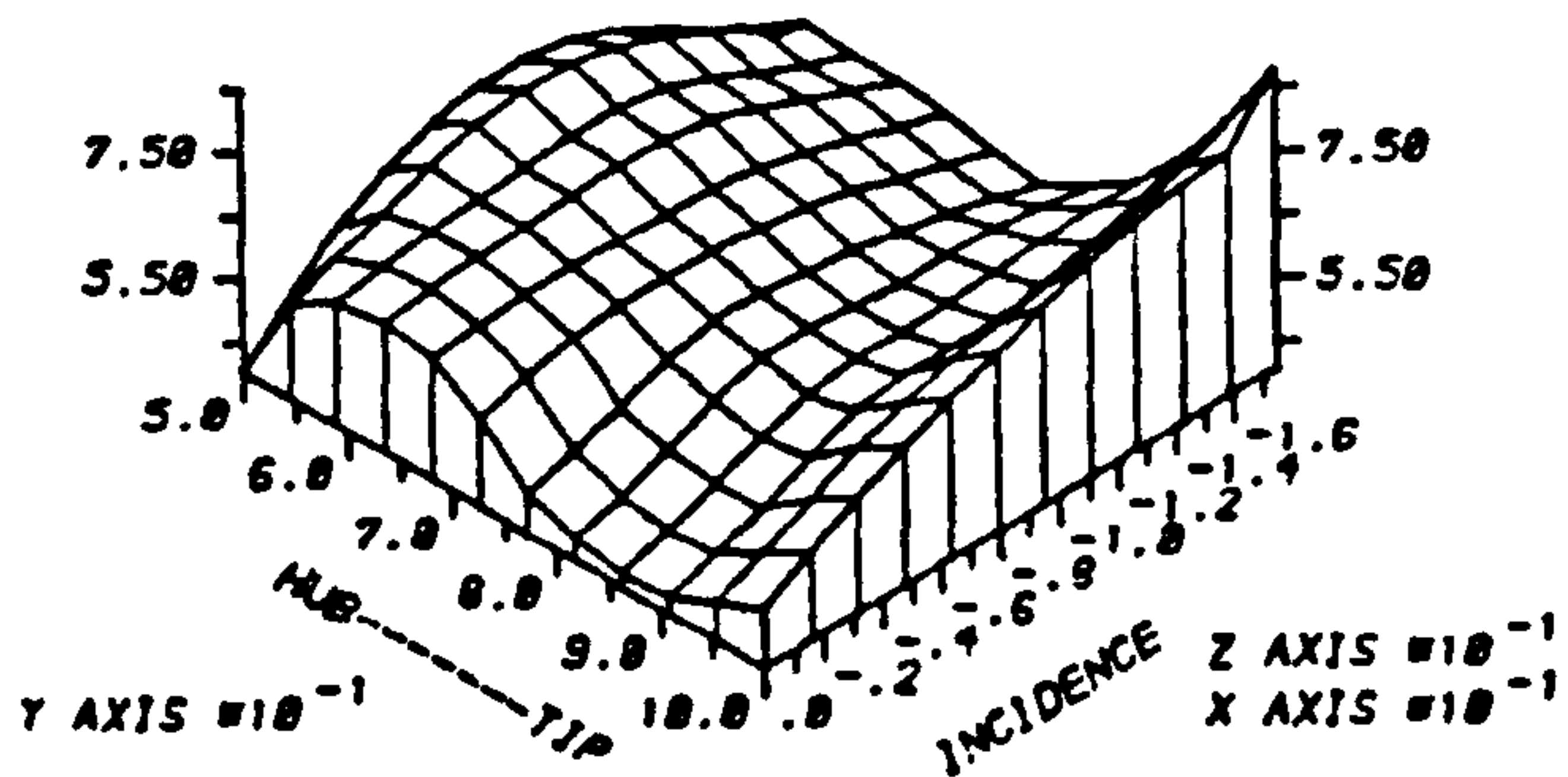
FITTING



RADIAL VELOCITY (P.S.)

Fig 14 VALUES OF THE SIMILARITY COEFF.

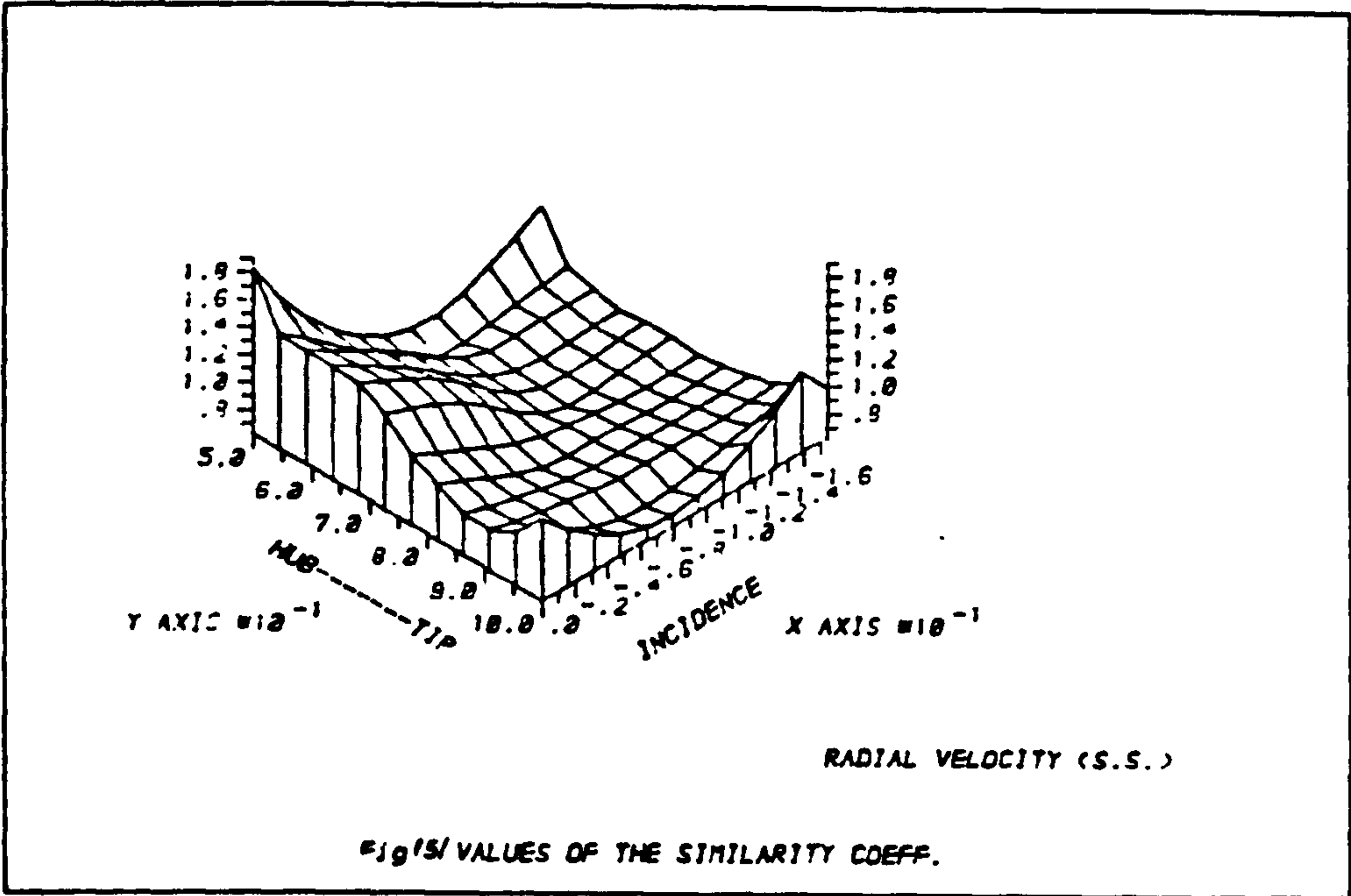
REAL



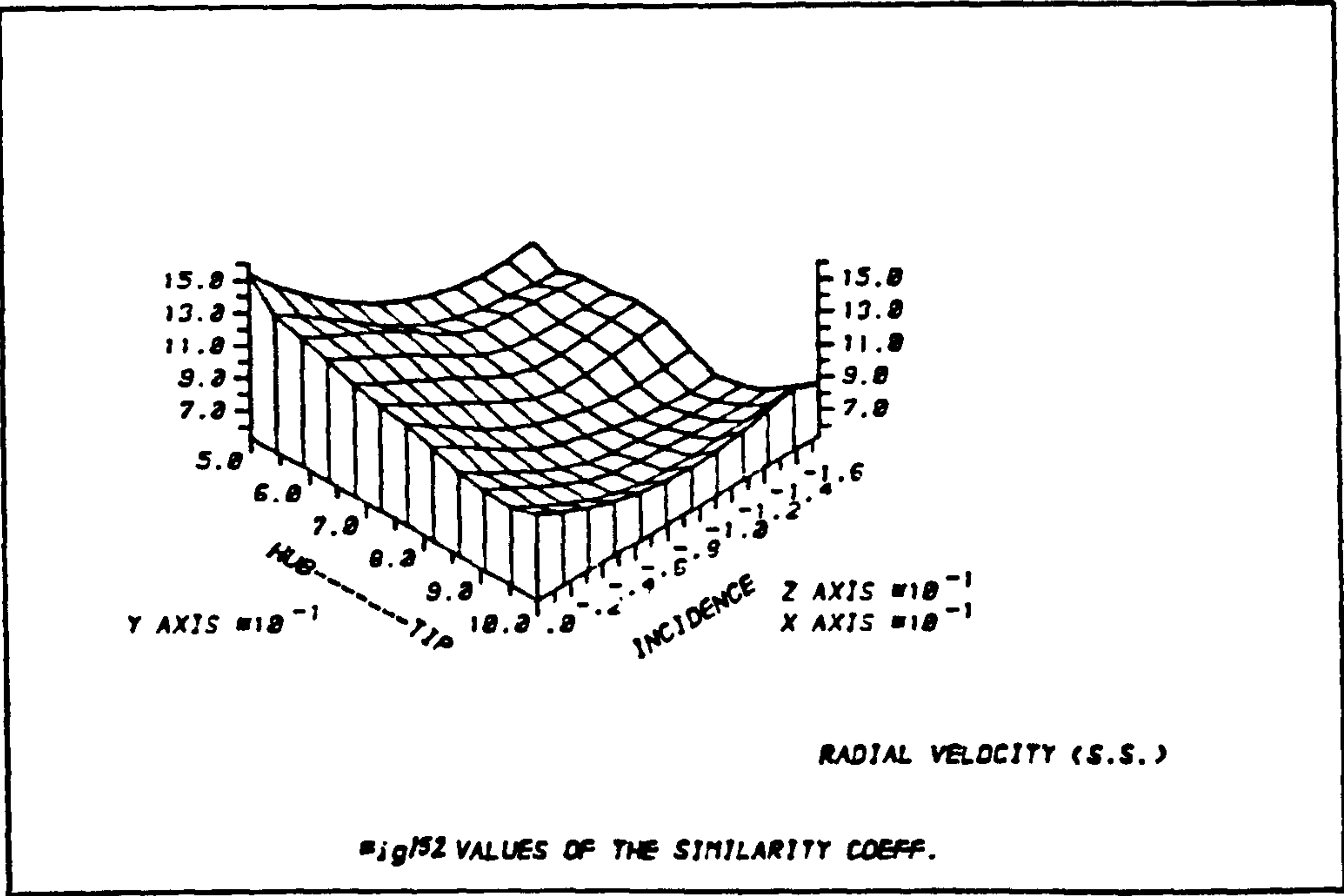
RADIAL VELOCITY (P.S.)

Fig 15 VALUES OF THE SIMILARITY COEFF.

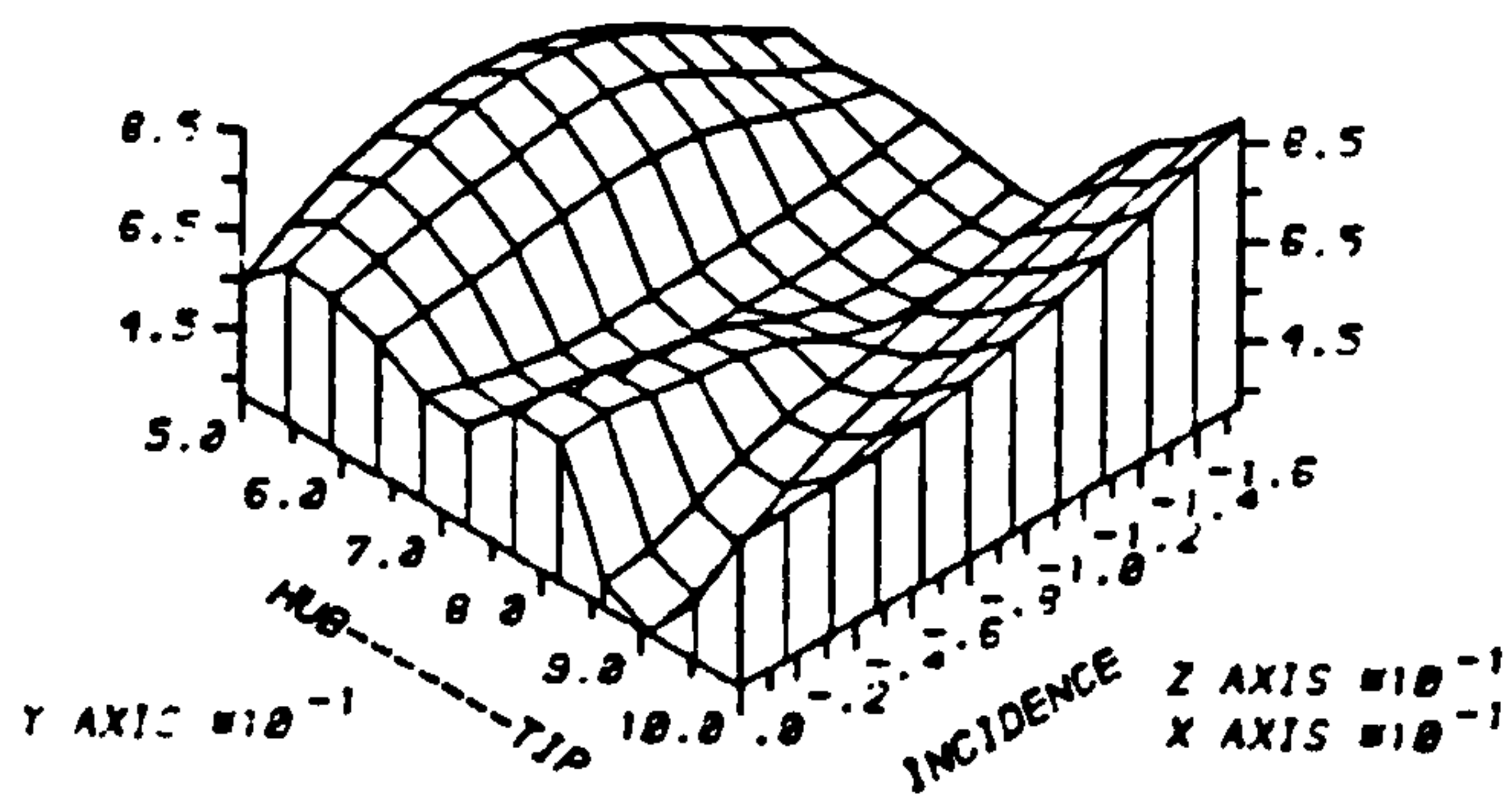
FITTING



REAL



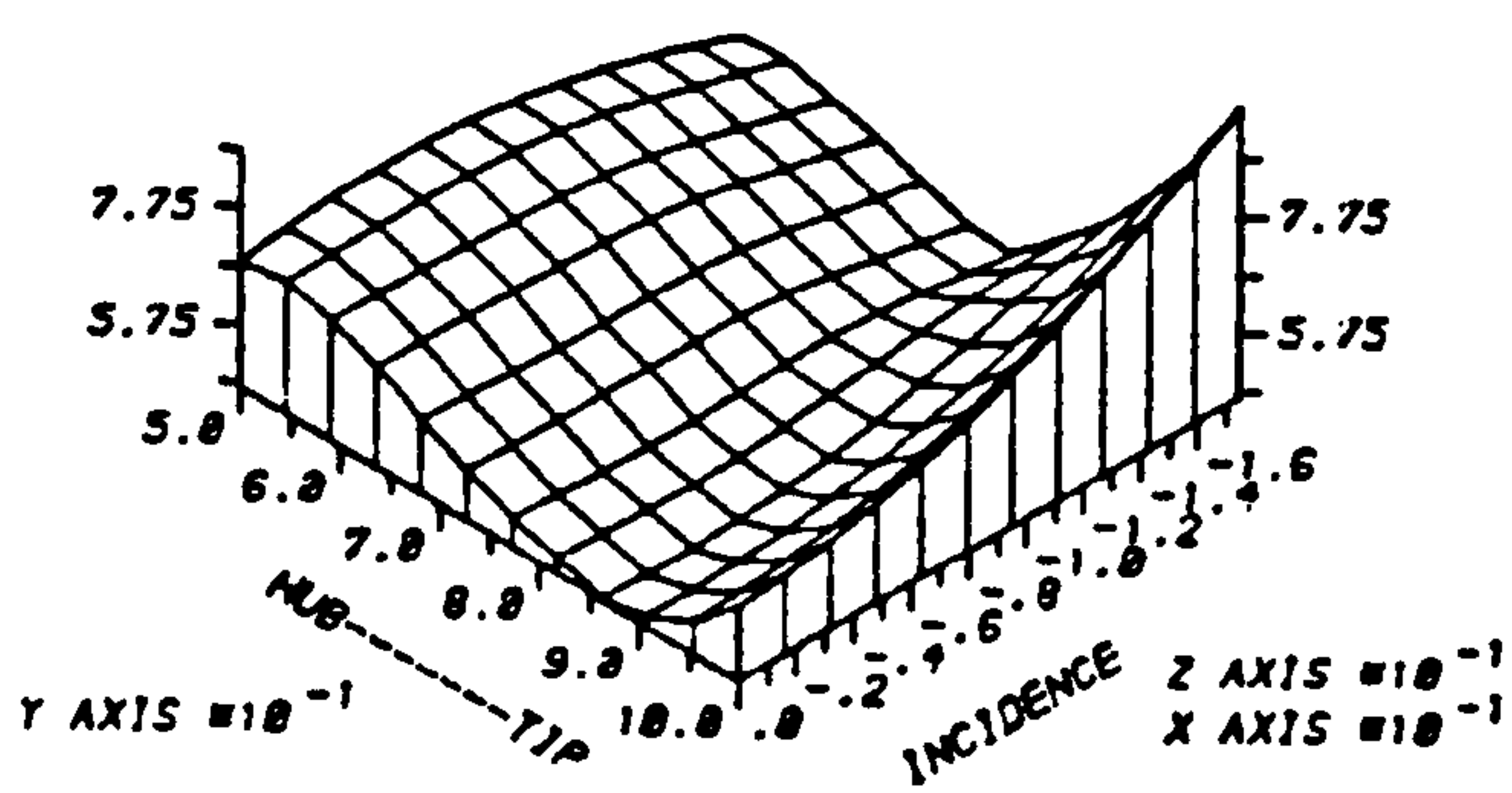
FITTING



AXIAL VELOCITY (P.S.)

Fig 153 VALUES OF THE SIMILARITY COEFF.

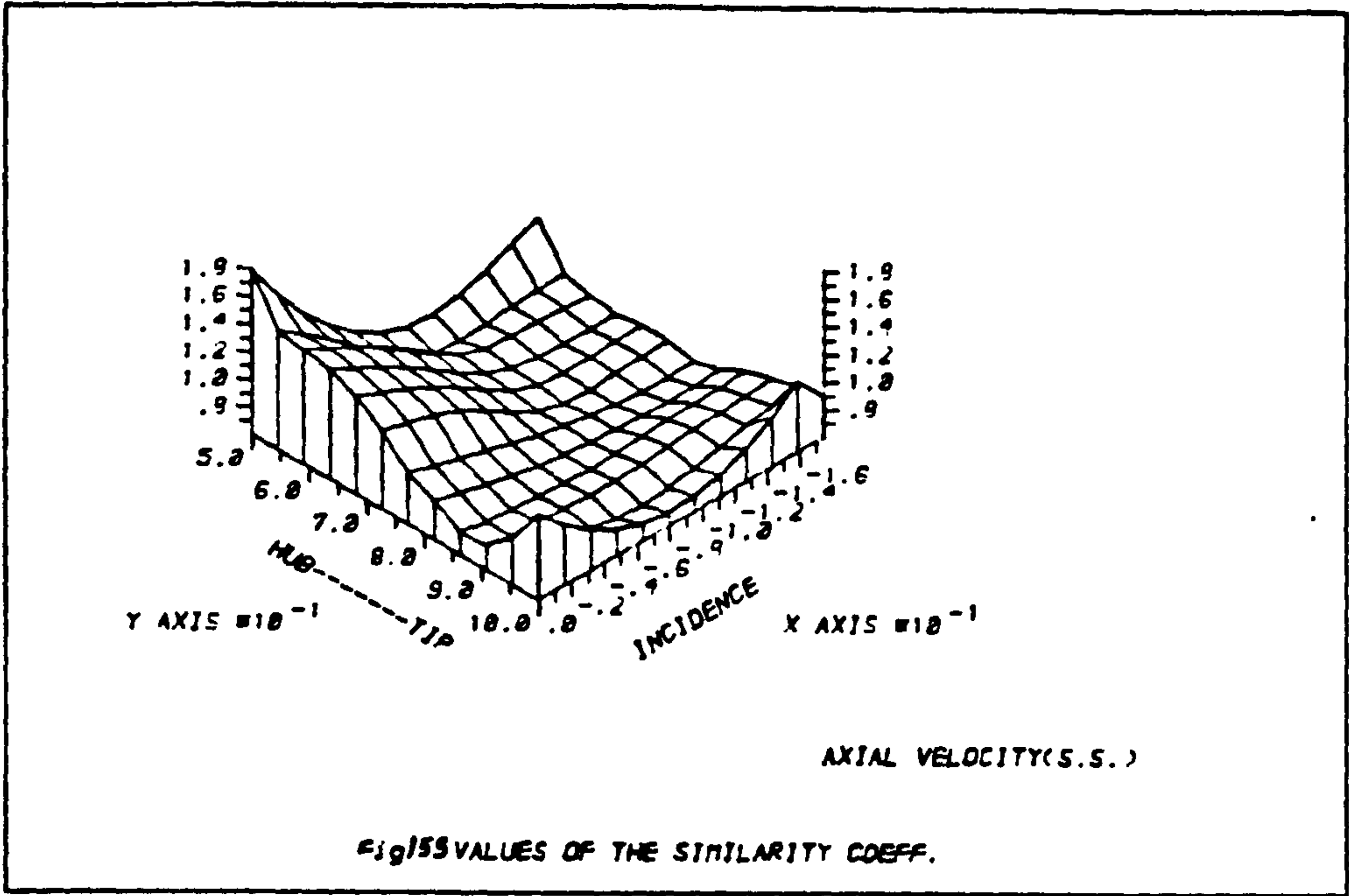
REAL



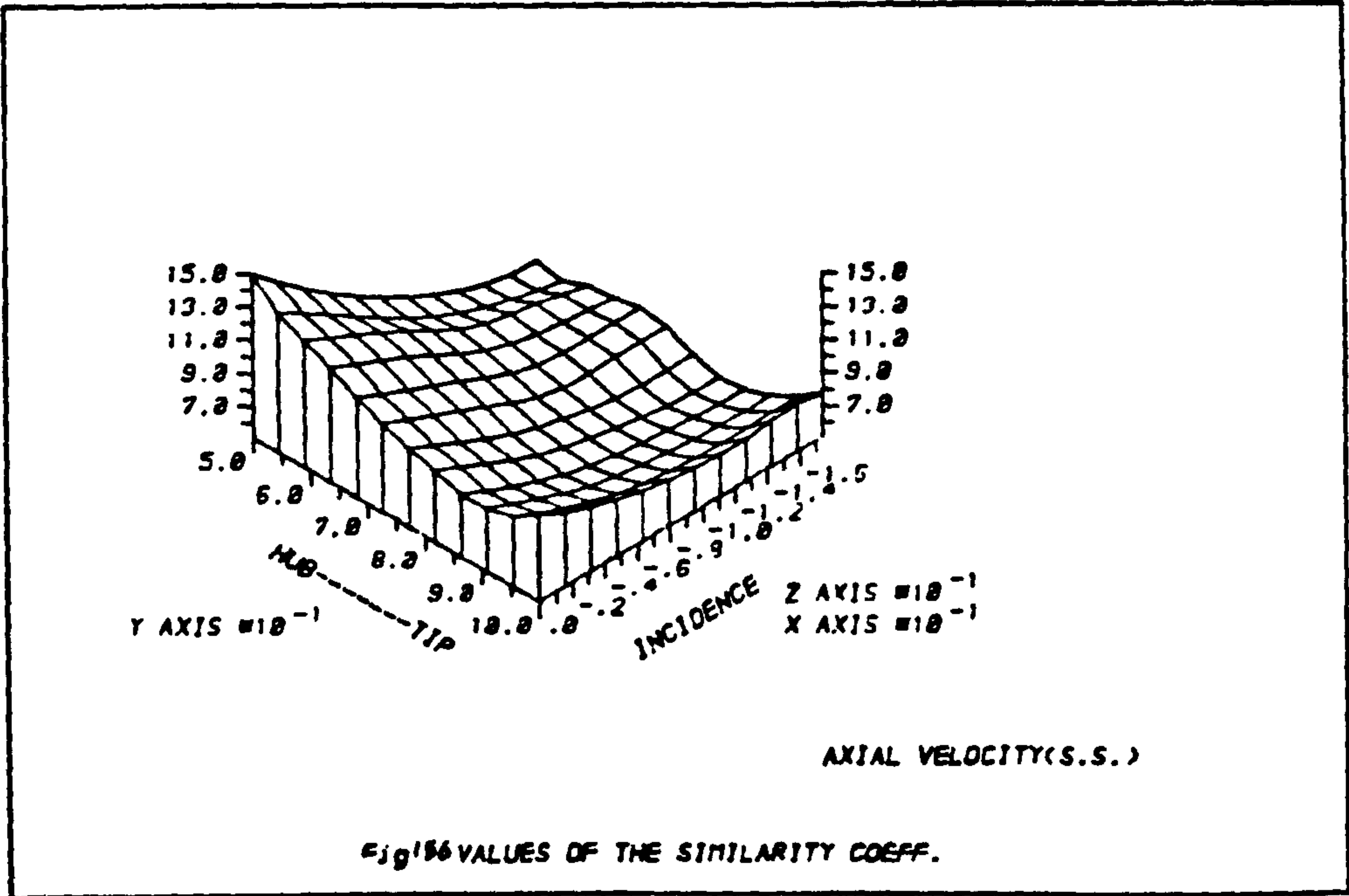
AXIAL VELOCITY (P.S.)

Fig 154 VALUES OF THE SIMILARITY COEFF.

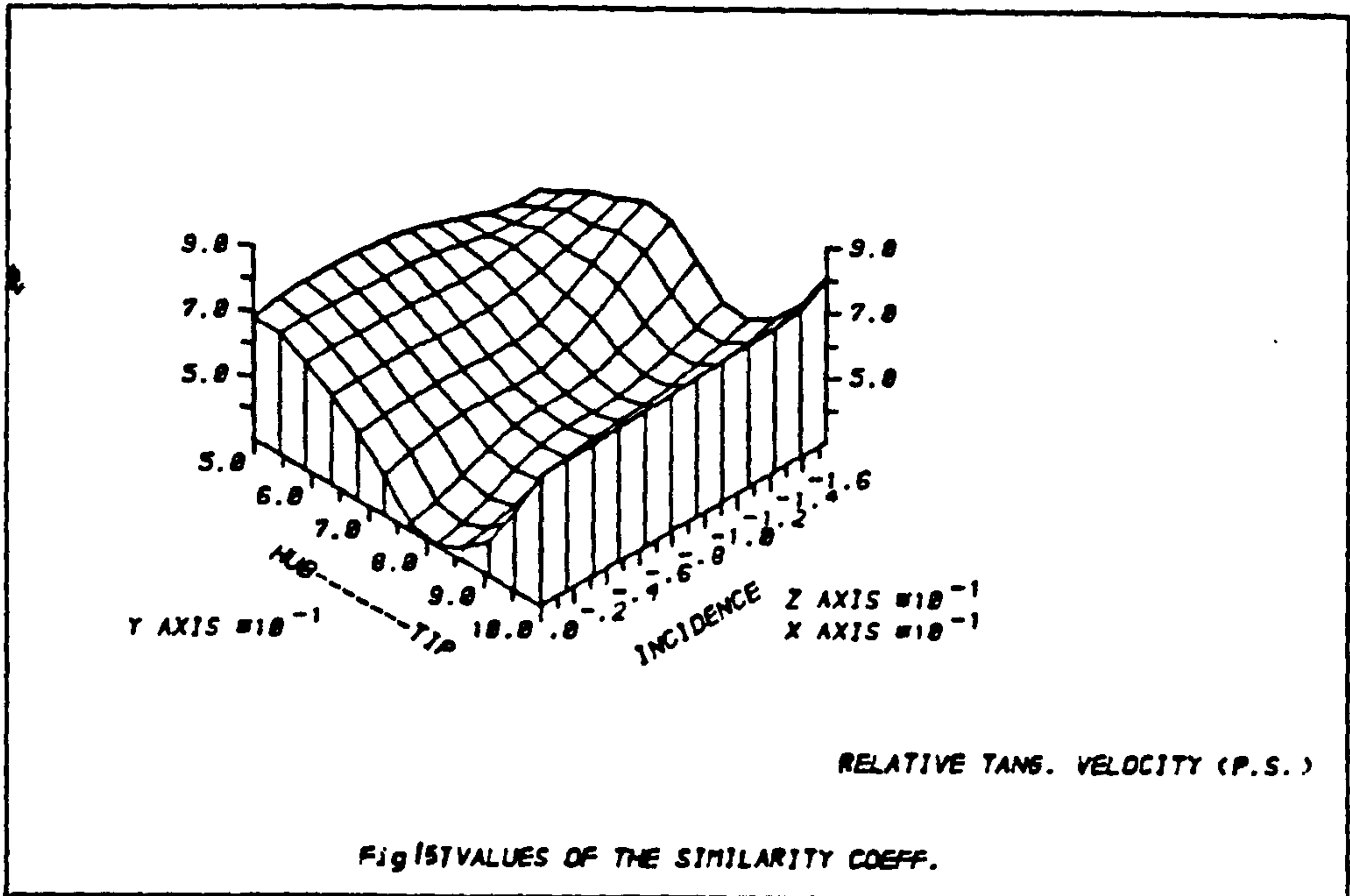
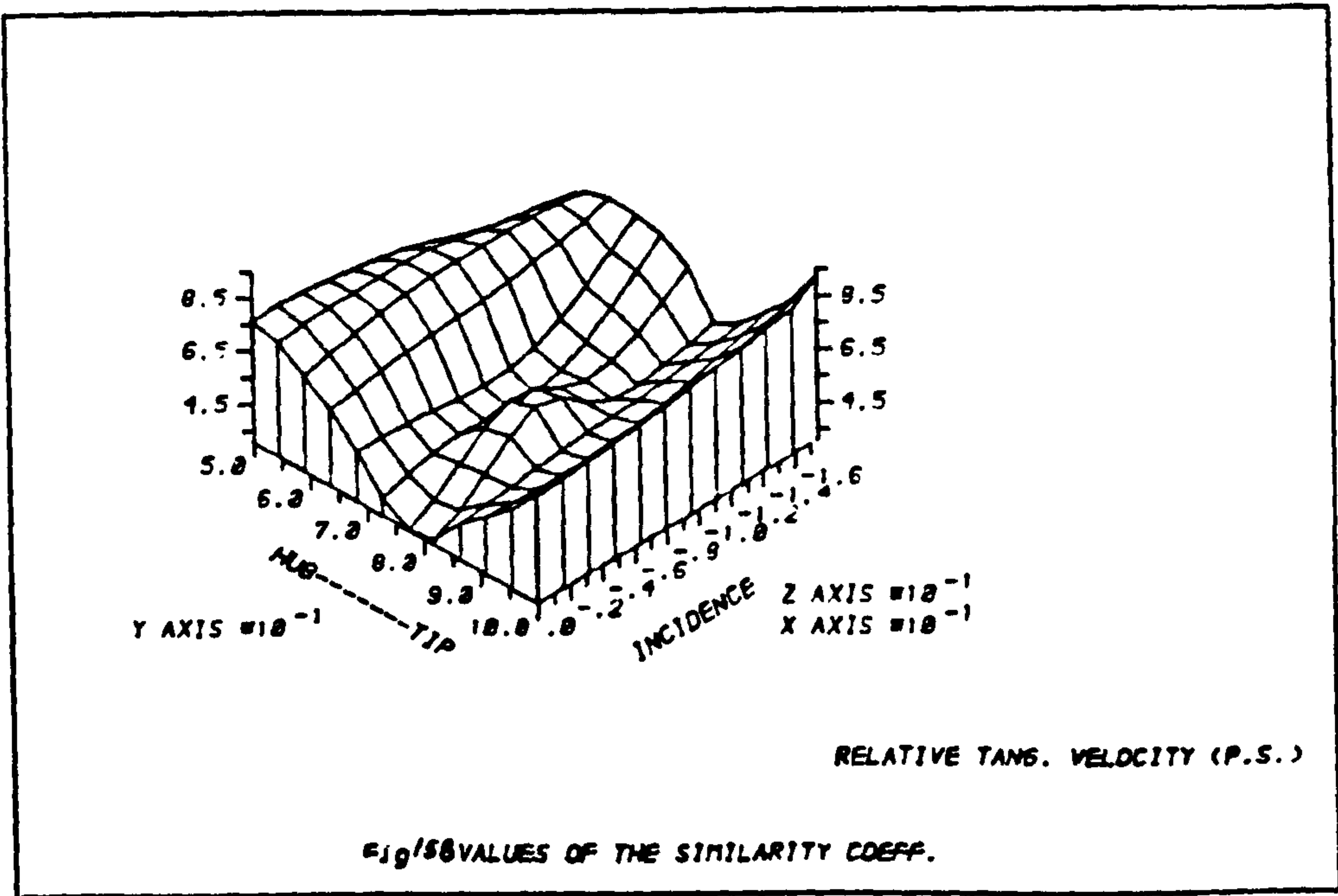
FITTING

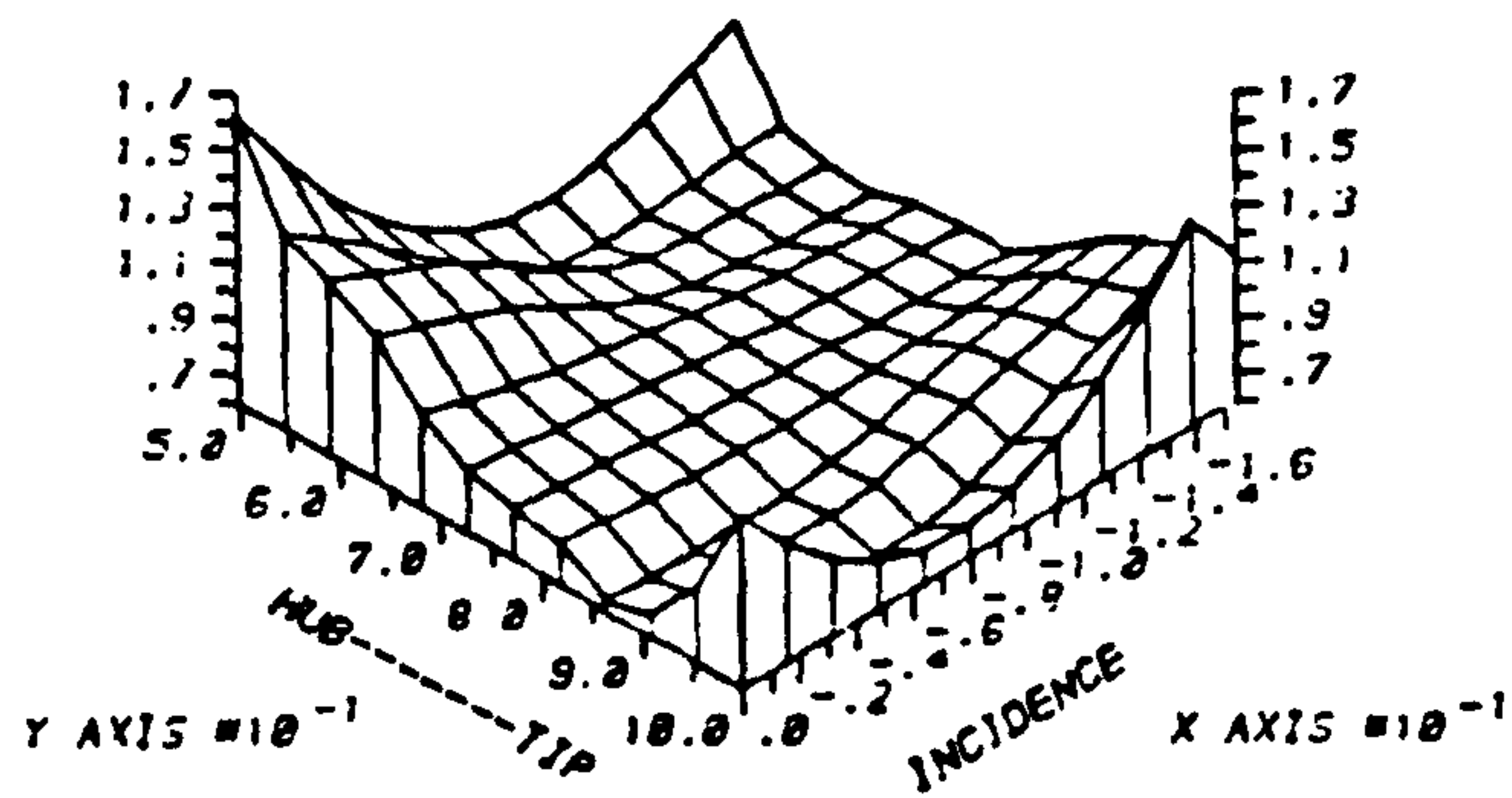


REAL



FITTING

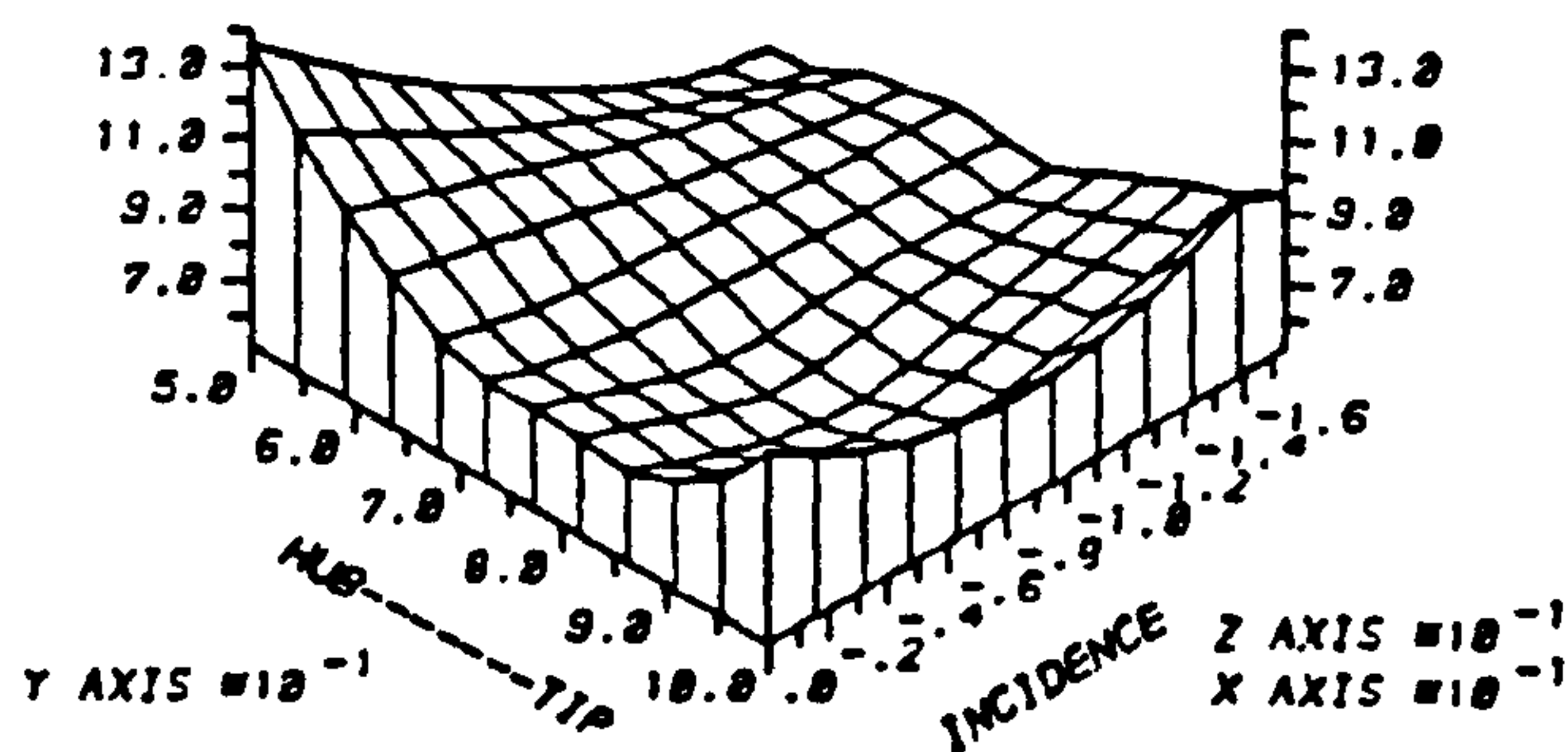




RELATIVE TANG. VELOCITY (S.S.)

Fig 159 VALUES OF THE SIMILARITY COEFF.

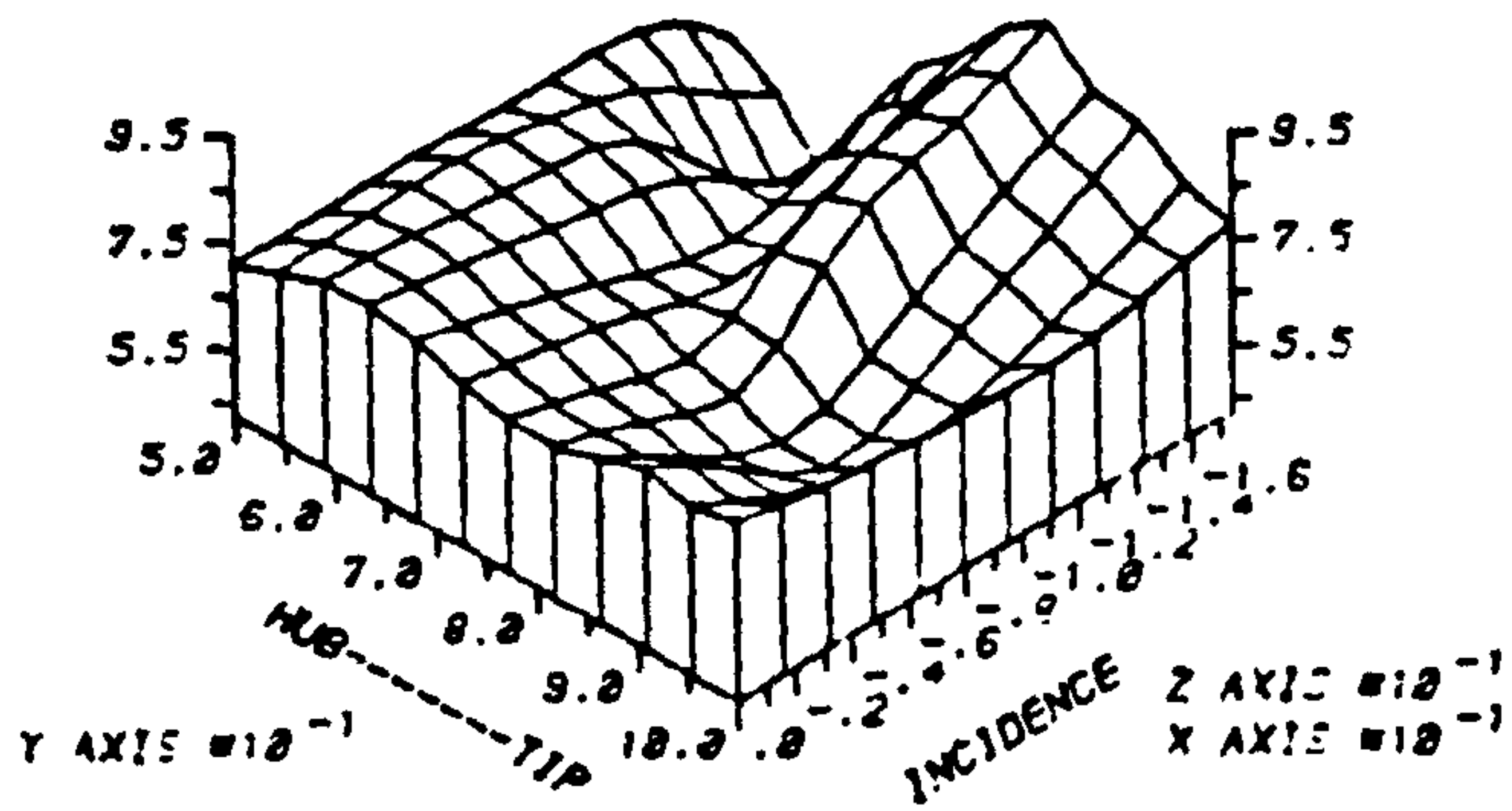
REAL



RELATIVE TANG. VELOCITY (S.S.)

Fig 160 VALUES OF THE SIMILARITY COEFF.

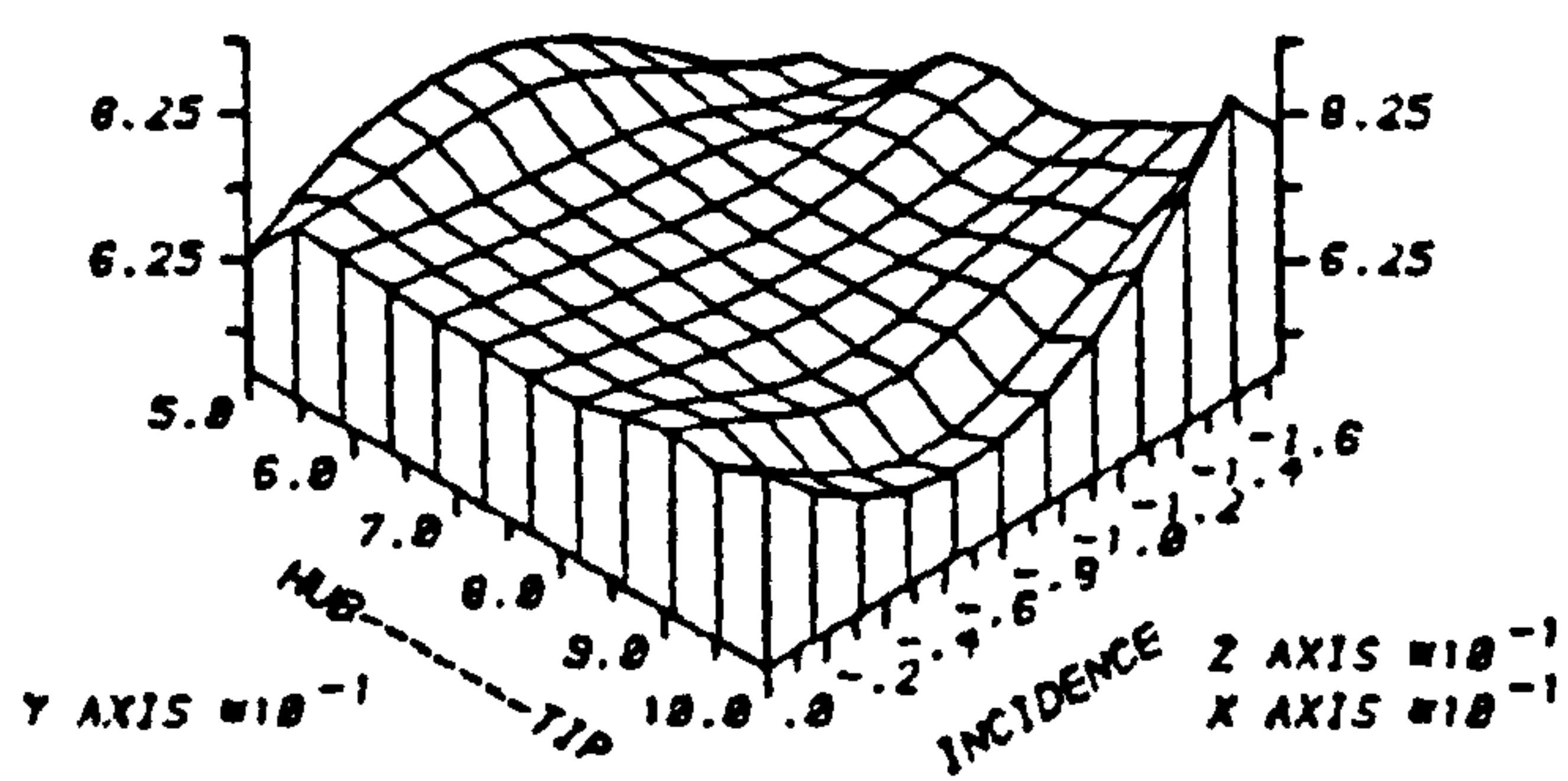
FITTING



TOTAL RELATIVE VELOCITY (P.S.)

Fig 61 VALUES OF THE SIMILARITY COEFF.

REAL



TOTAL RELATIVE VELOCITY (P.S.)

Fig 62 VALUES OF THE SIMILARITY COEFF.

FITTING

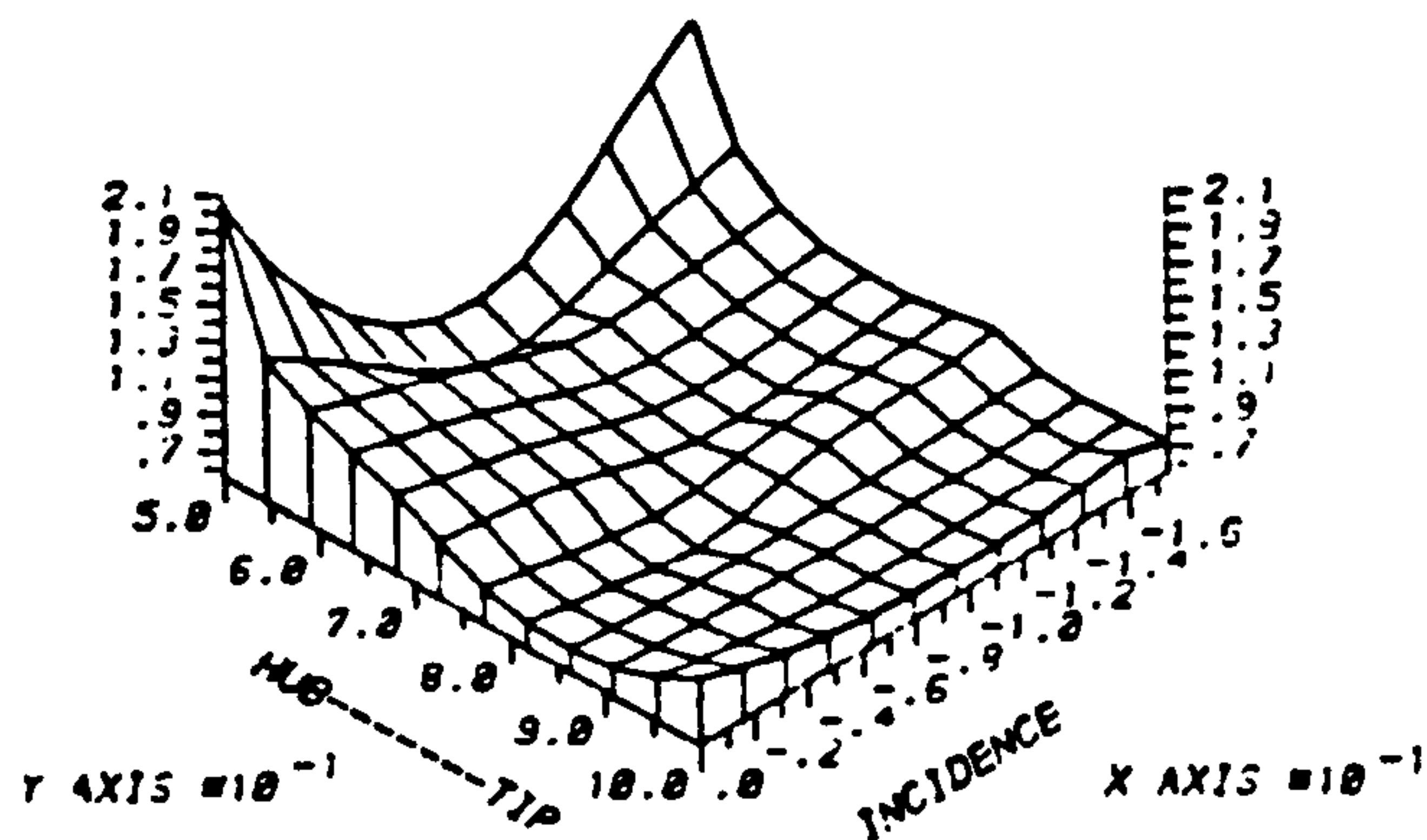


Fig 163 VALUES OF THE SIMILARITY COEFF.

REAL

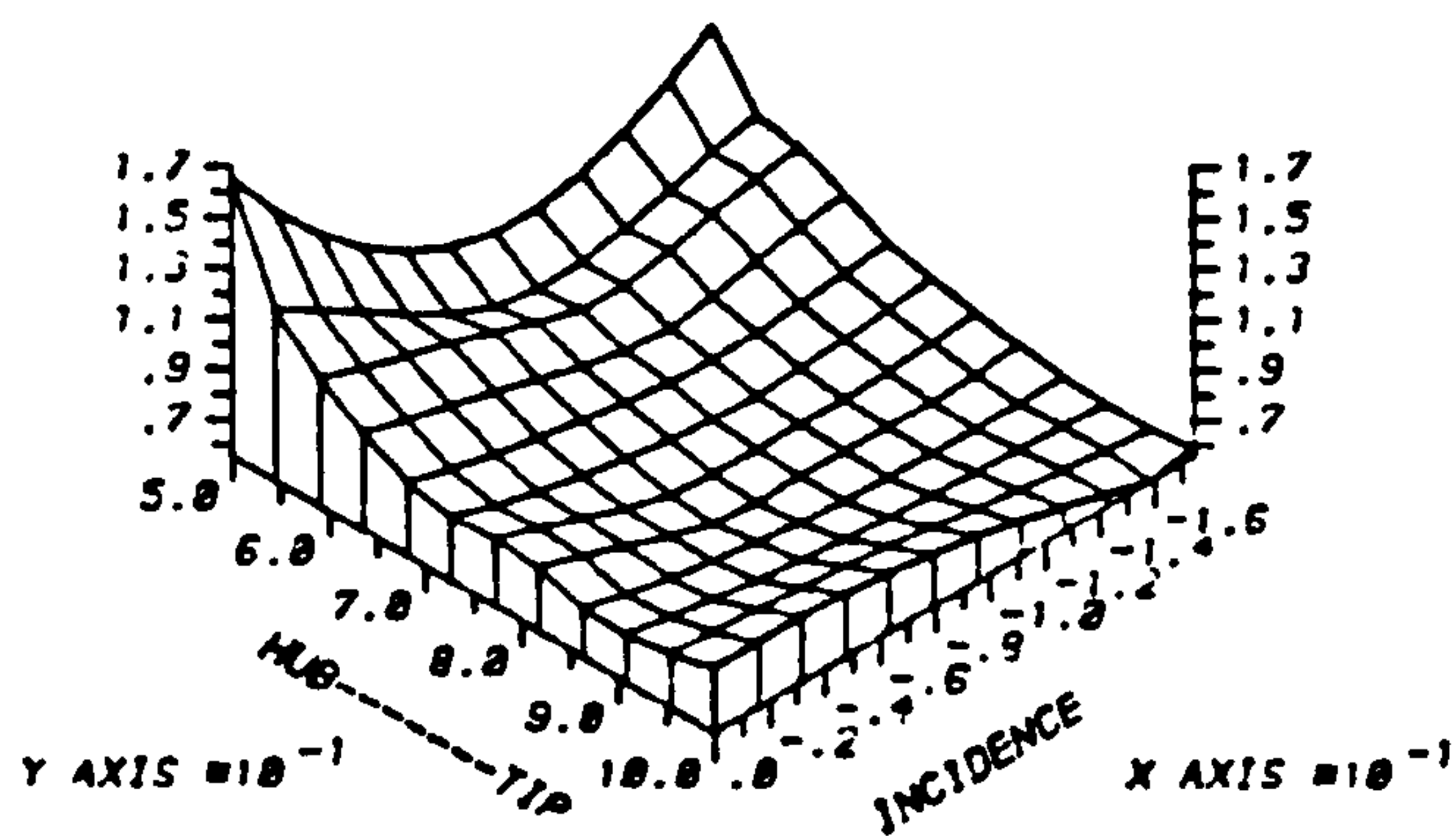
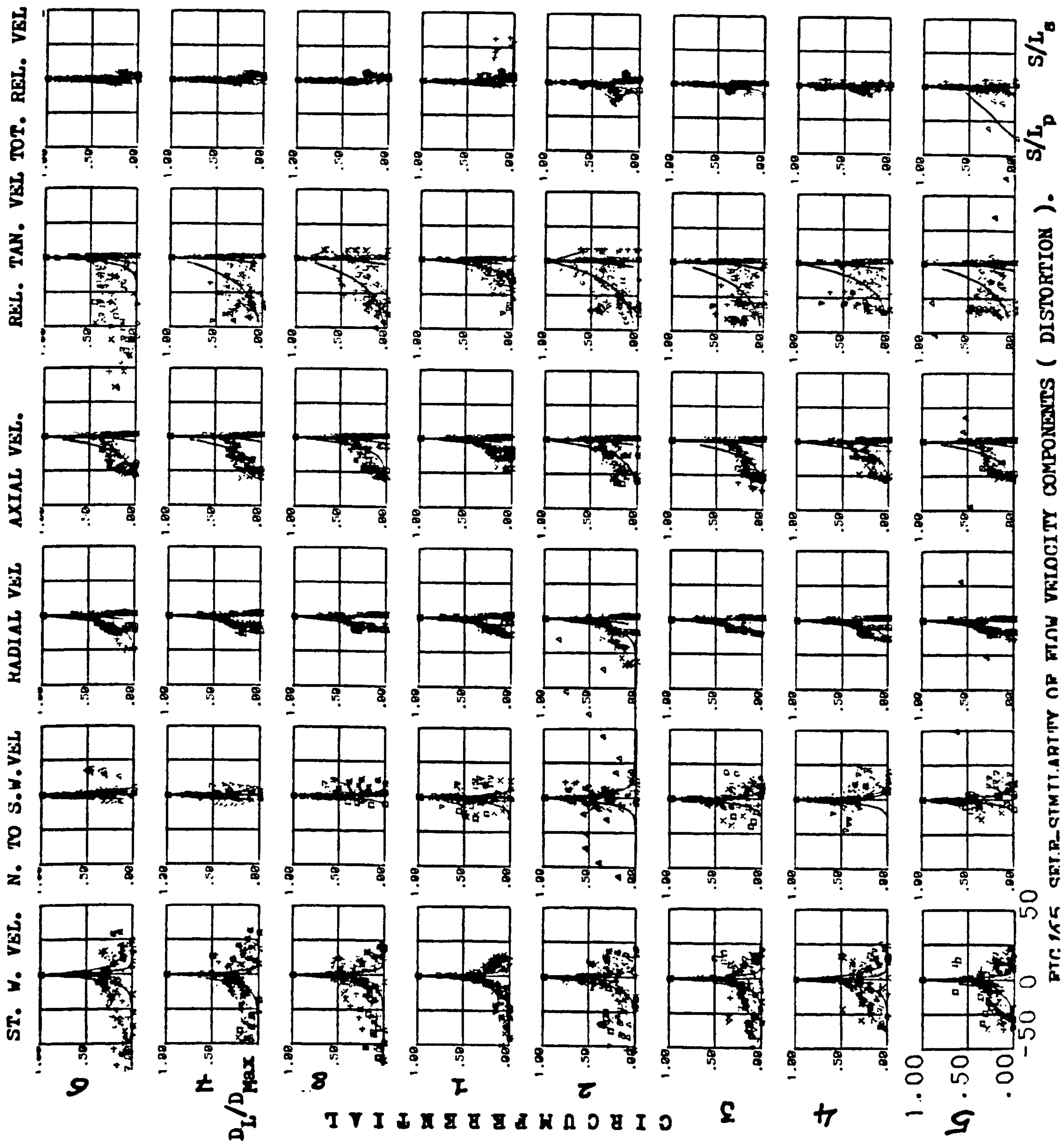
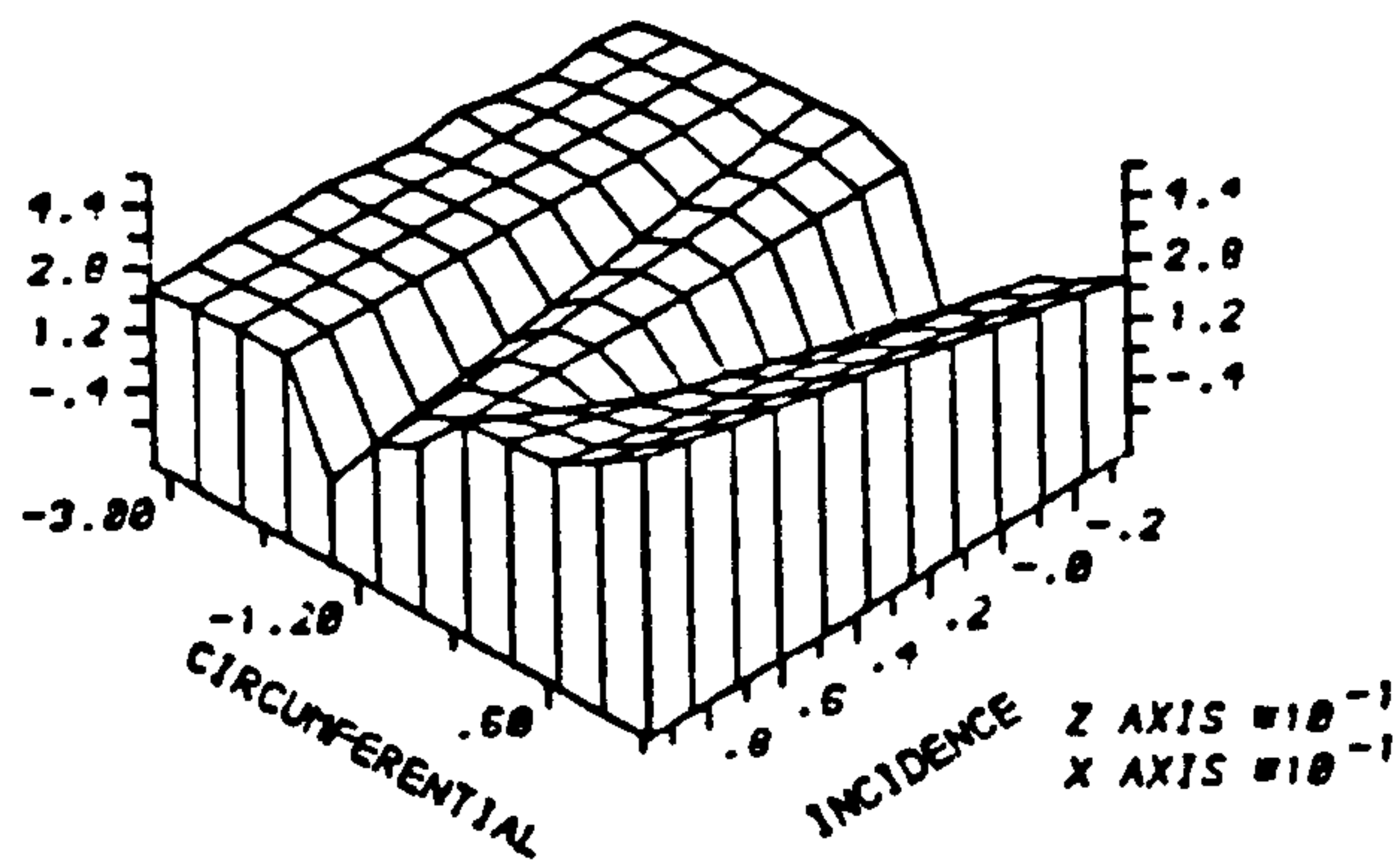


Fig 164 VALUES OF THE SIMILARITY COEFF.

FITTING

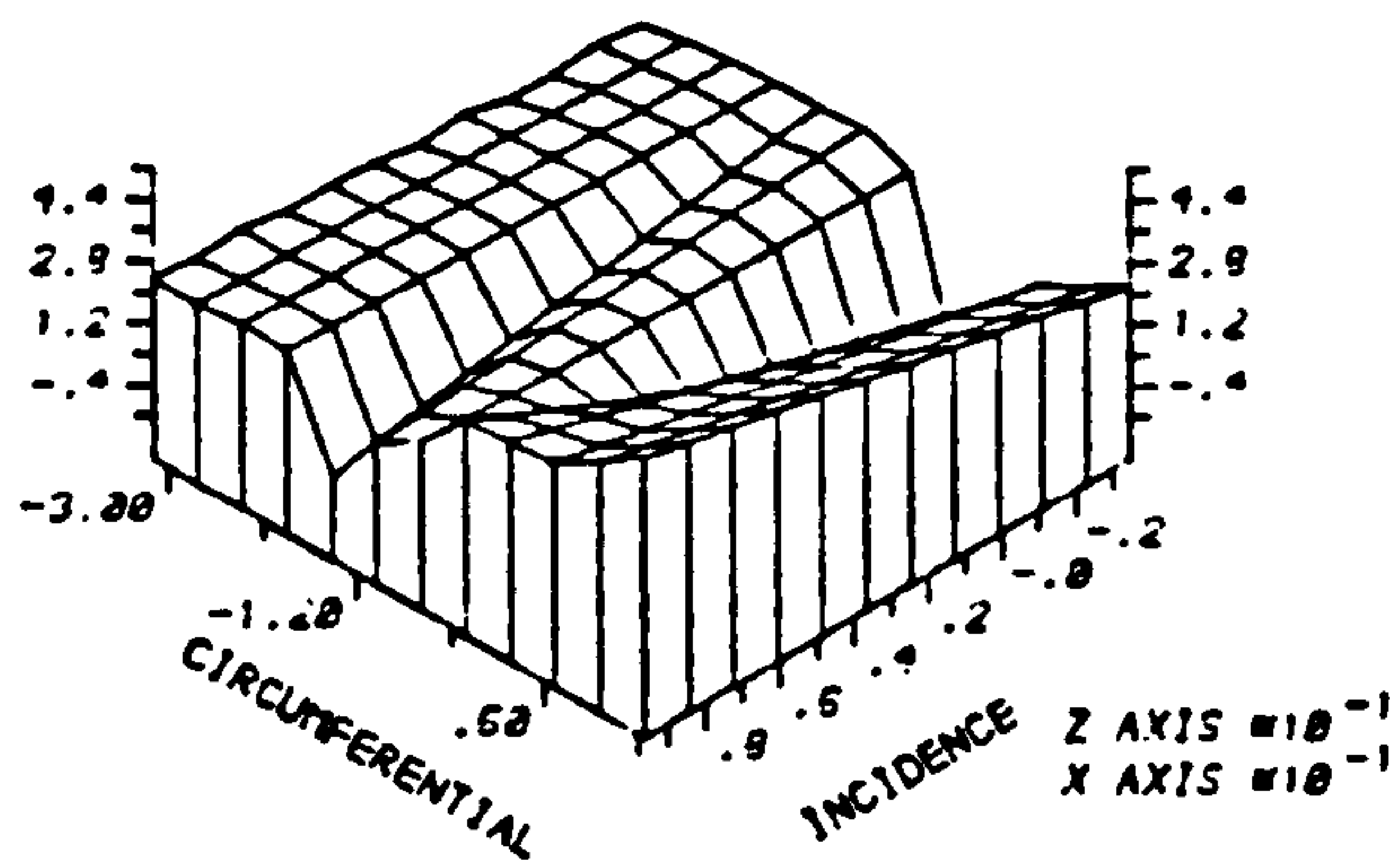




STREAM WISE VELOCITY (P.S.)

Fig 166 VALUES OF THE SIMILARITY COEFF.

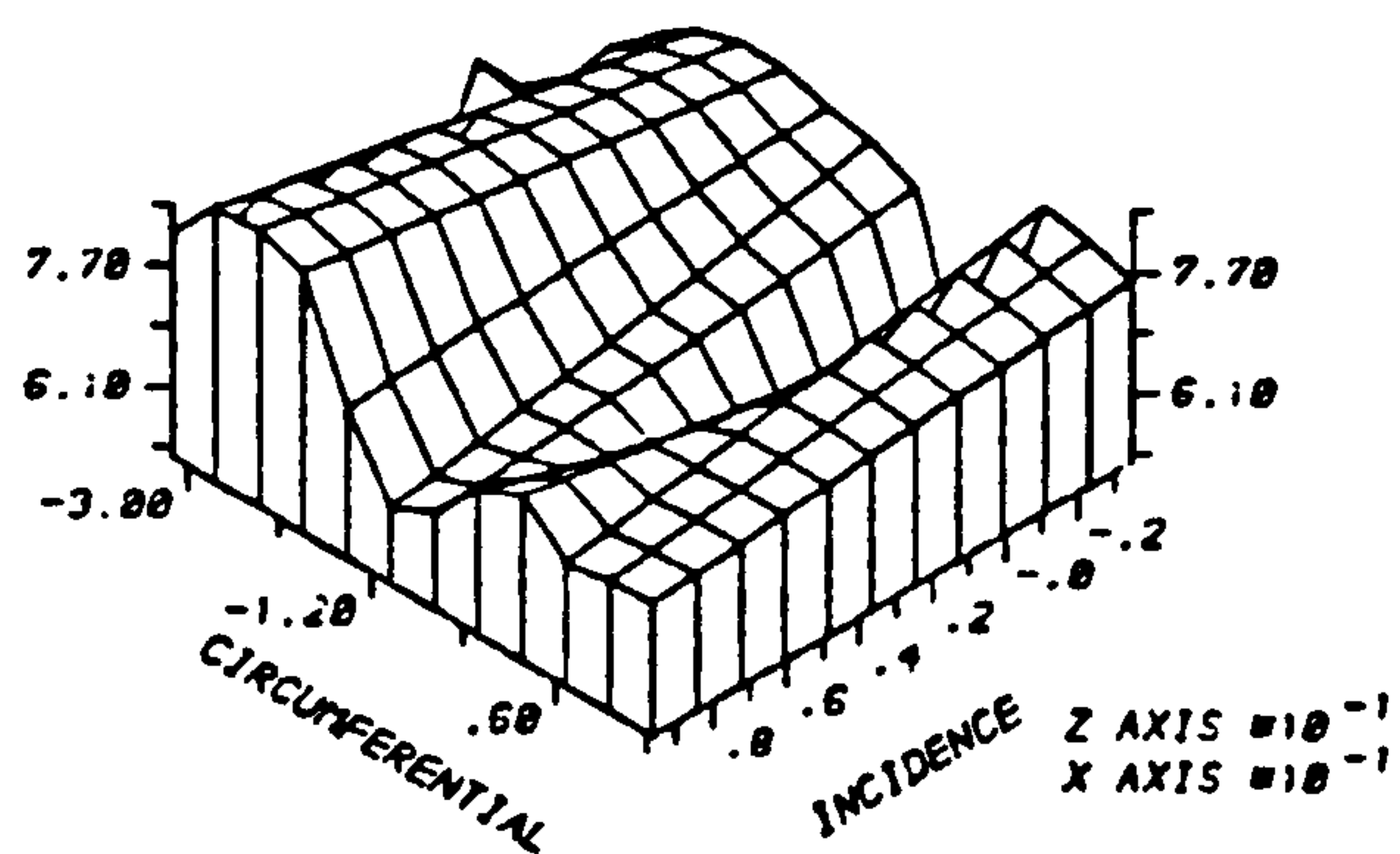
REAL-DIST.



STREAM WISE VELOCITY (P.S.)

Fig 167 VALUES OF THE SIMILARITY COEFF.

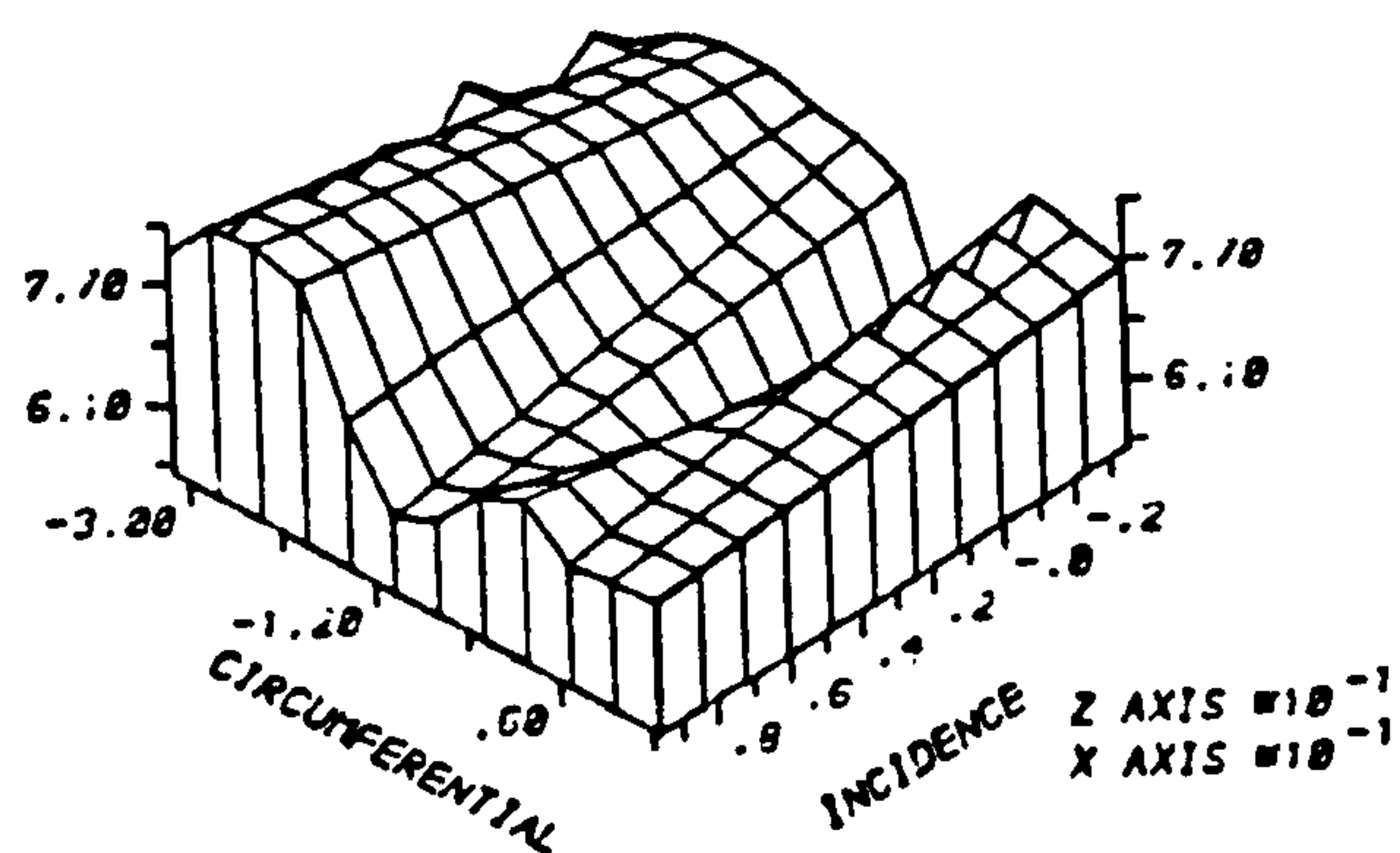
FITTING-DIST.



STREAM WISE VELOCITY (S.S.)

Fig 168 VALUES OF THE SIMILARITY COEFF.

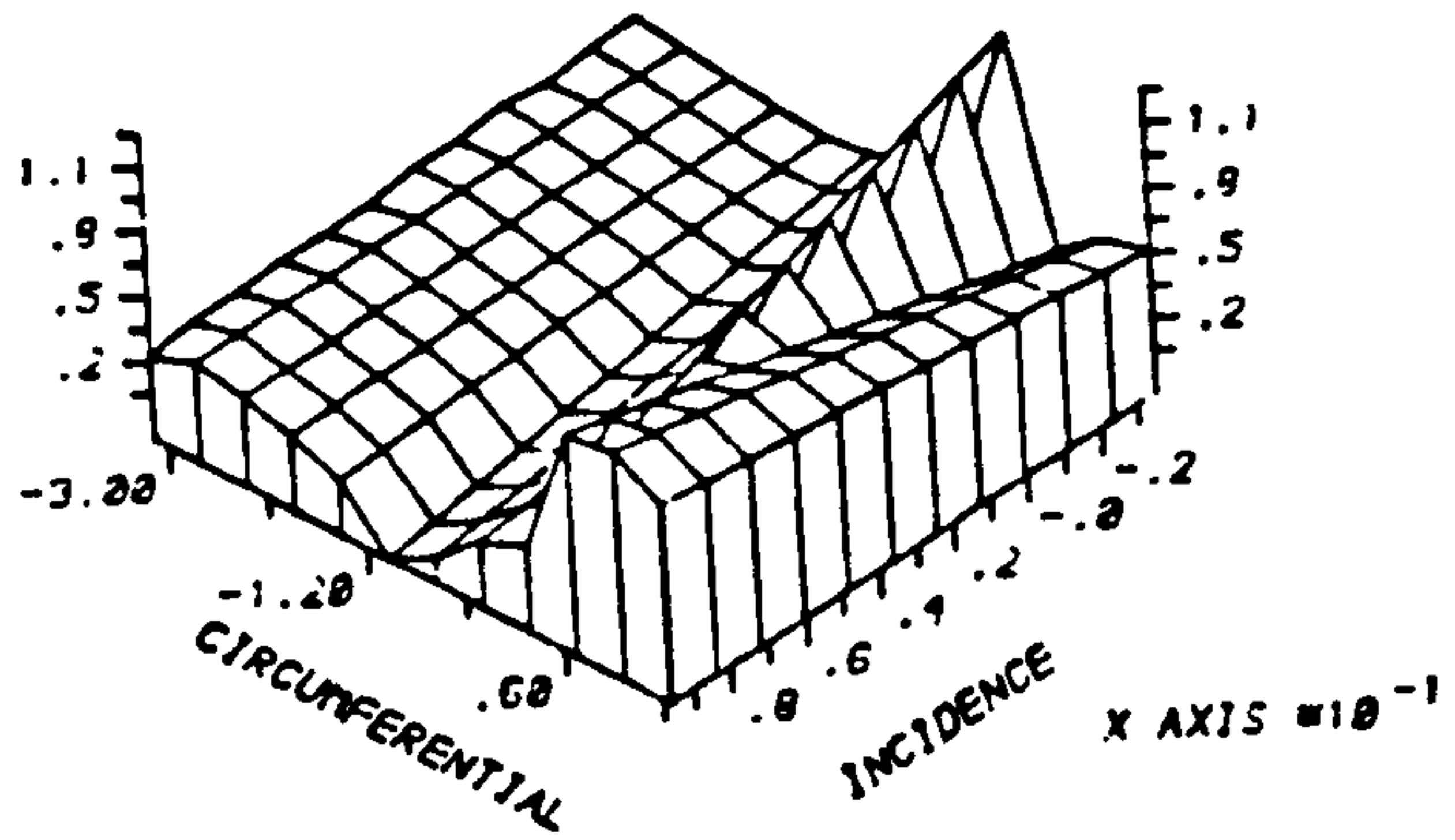
REAL-DIST.



STREAM WISE VELOCITY (S.S.)

Fig 169 VALUES OF THE SIMILARITY COEFF.

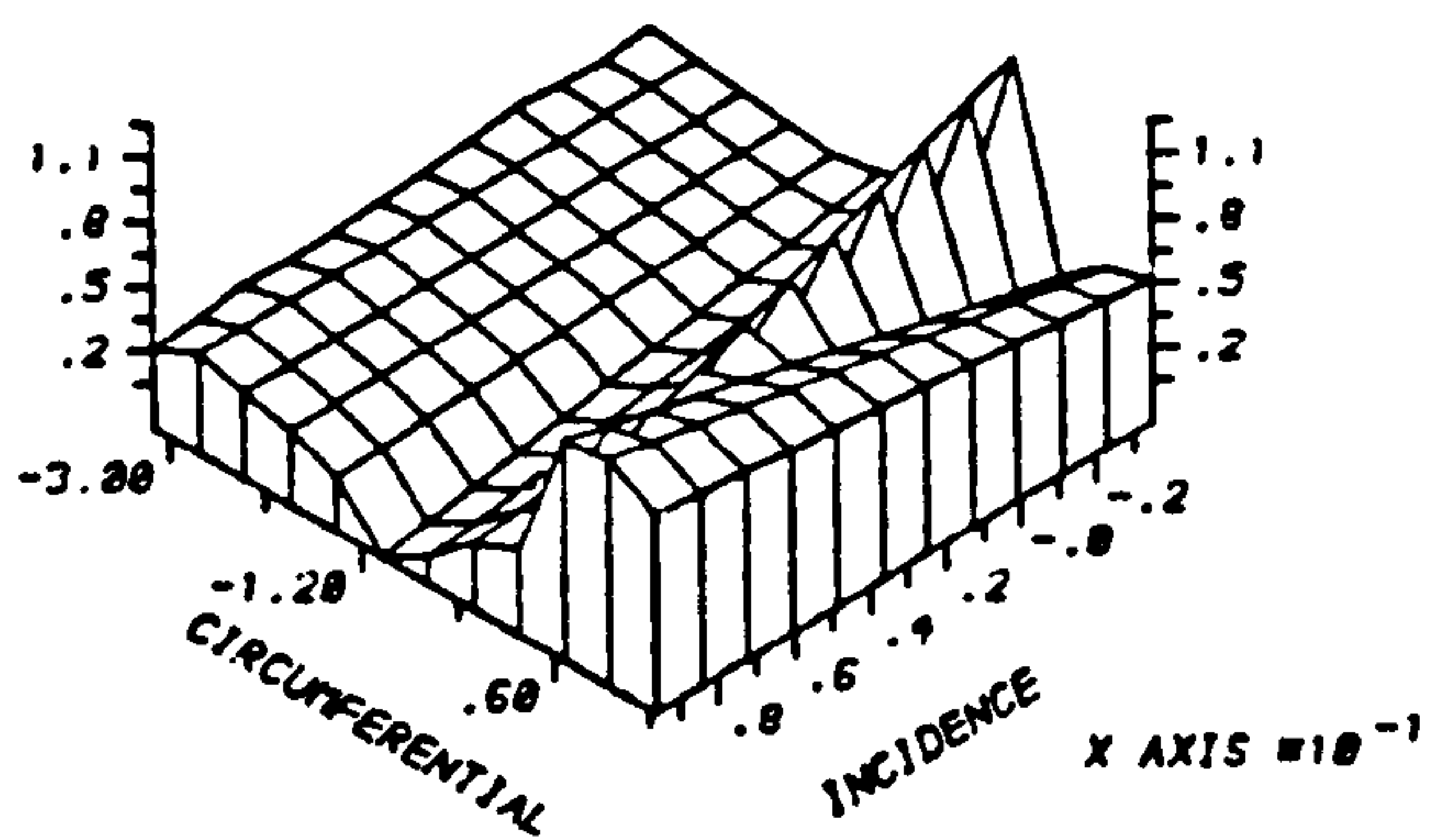
FITTING-DIST.



NORMAL TO STREAM WISE VEL. (P.S.)

Fig 170 VALUES OF THE SIMILARITY COEFF.

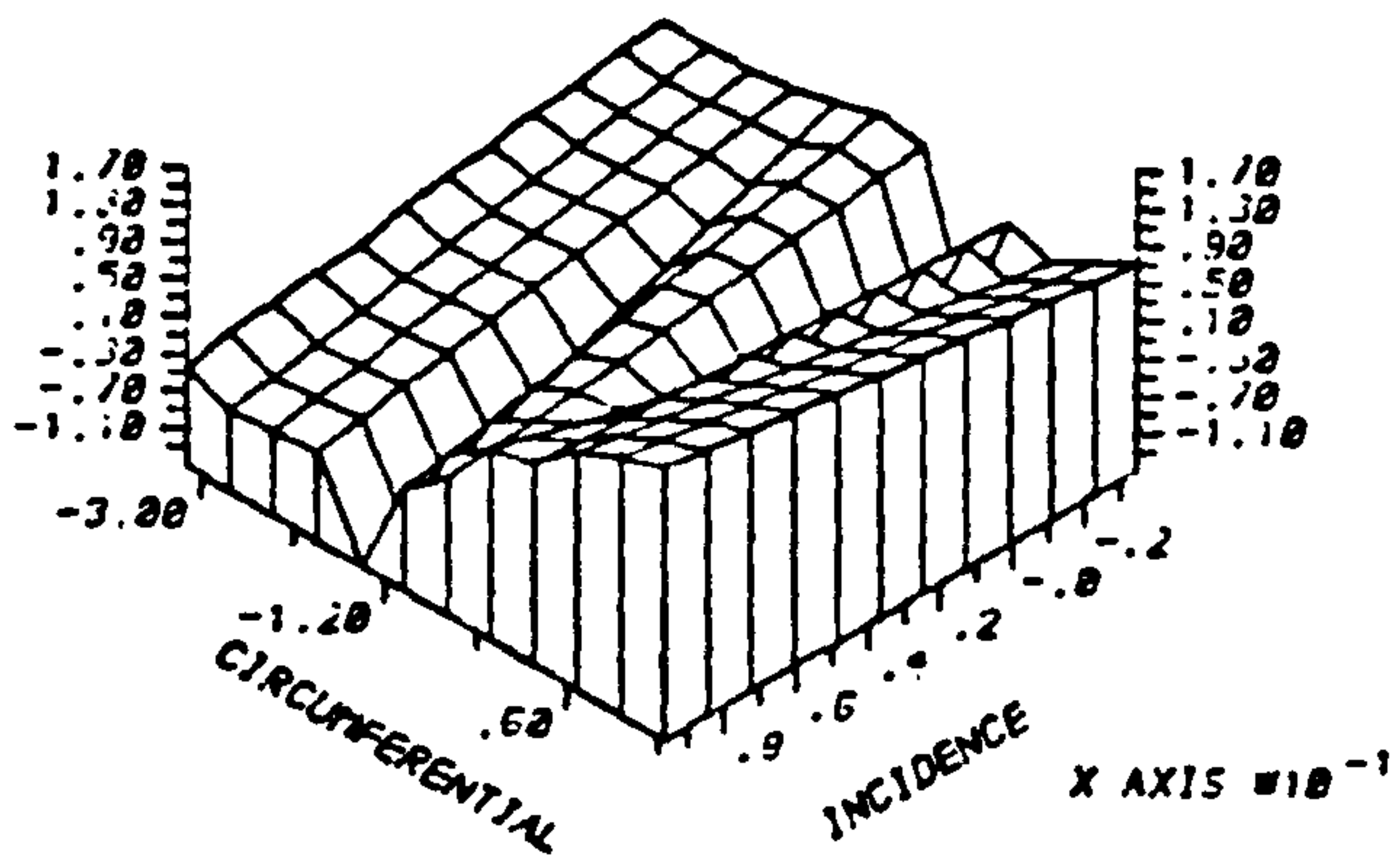
FITTING-DIST.



NORMAL TO STREAM WISE VEL. (P.S.)

Fig 171 VALUES OF THE SIMILARITY COEFF.

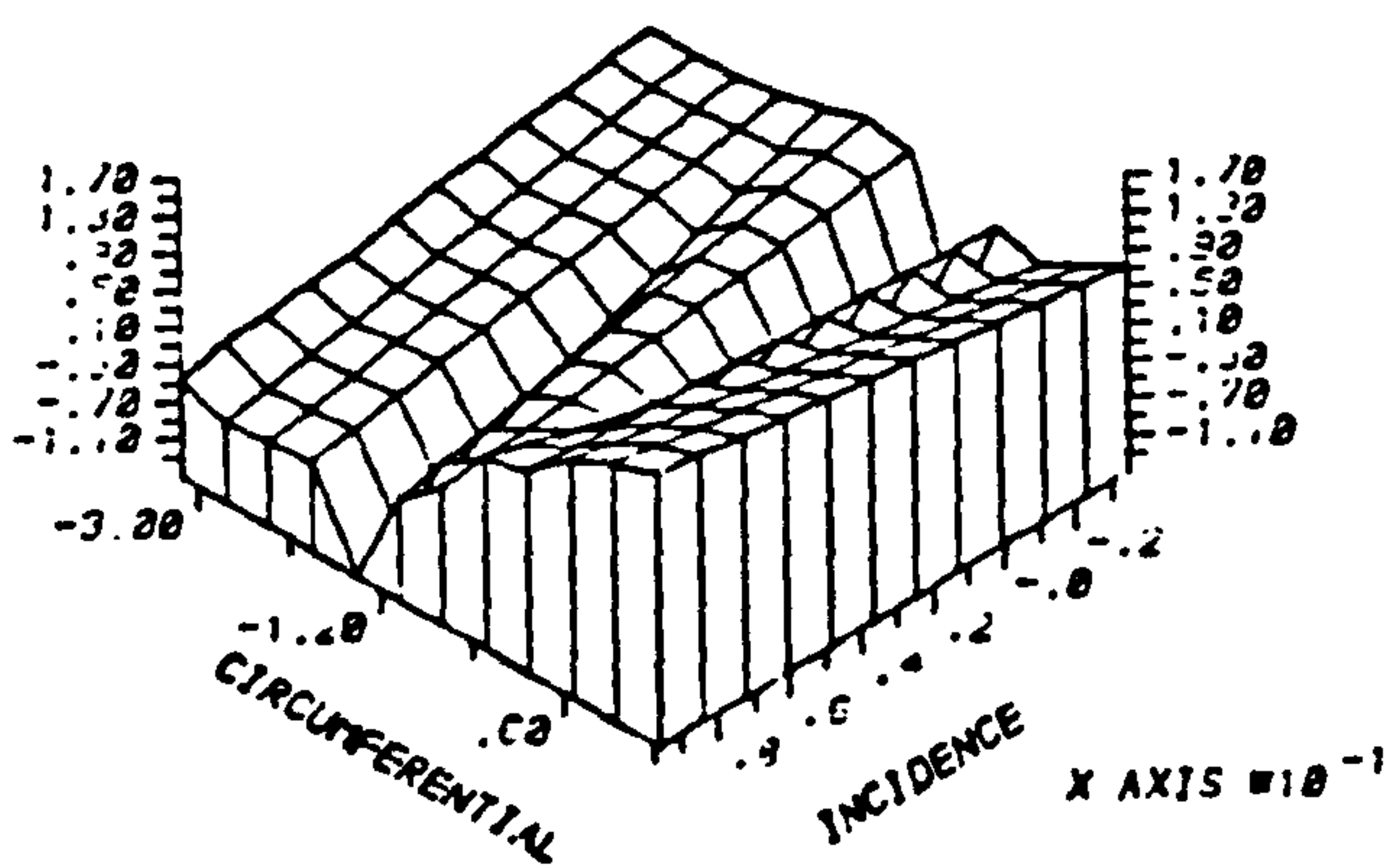
REAL-DIST.



NORMAL TO STREAM WISE VEL.(S.S.)

Fig 172 VALUES OF THE SIMILARITY COEFF.

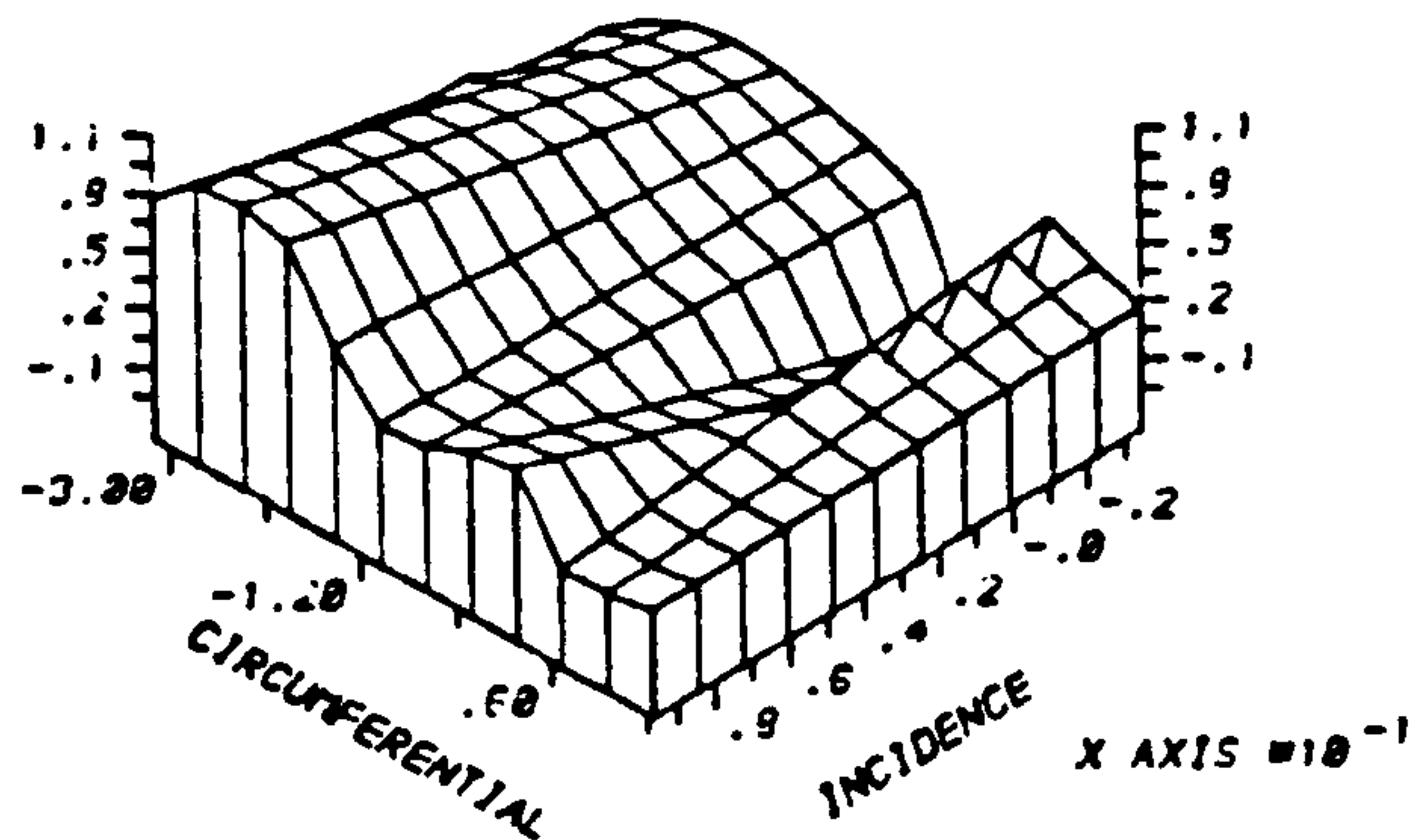
REAL-DIST.



NORMAL TO STREAM WISE VEL.(S.S.)

Fig 173 VALUES OF THE SIMILARITY COEFF.

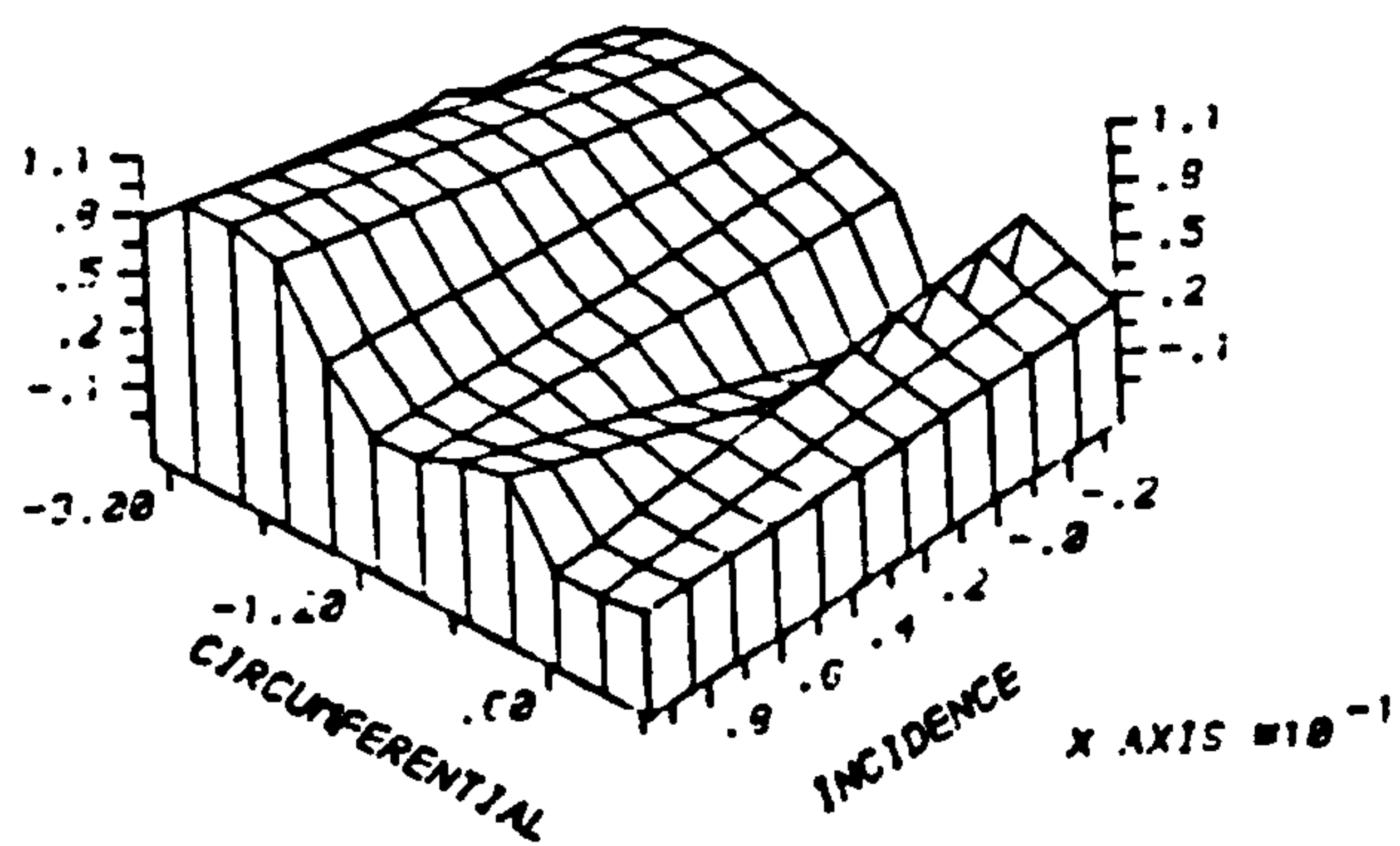
FITTING-DIST.



RADIAL VELOCITY (P.S.)

Fig 174 VALUES OF THE SIMILARITY COEFF.

REAL-DIST.



RADIAL VELOCITY (P.S.)

Fig 175 VALUES OF THE SIMILARITY COEFF.

FITTING-DIST.

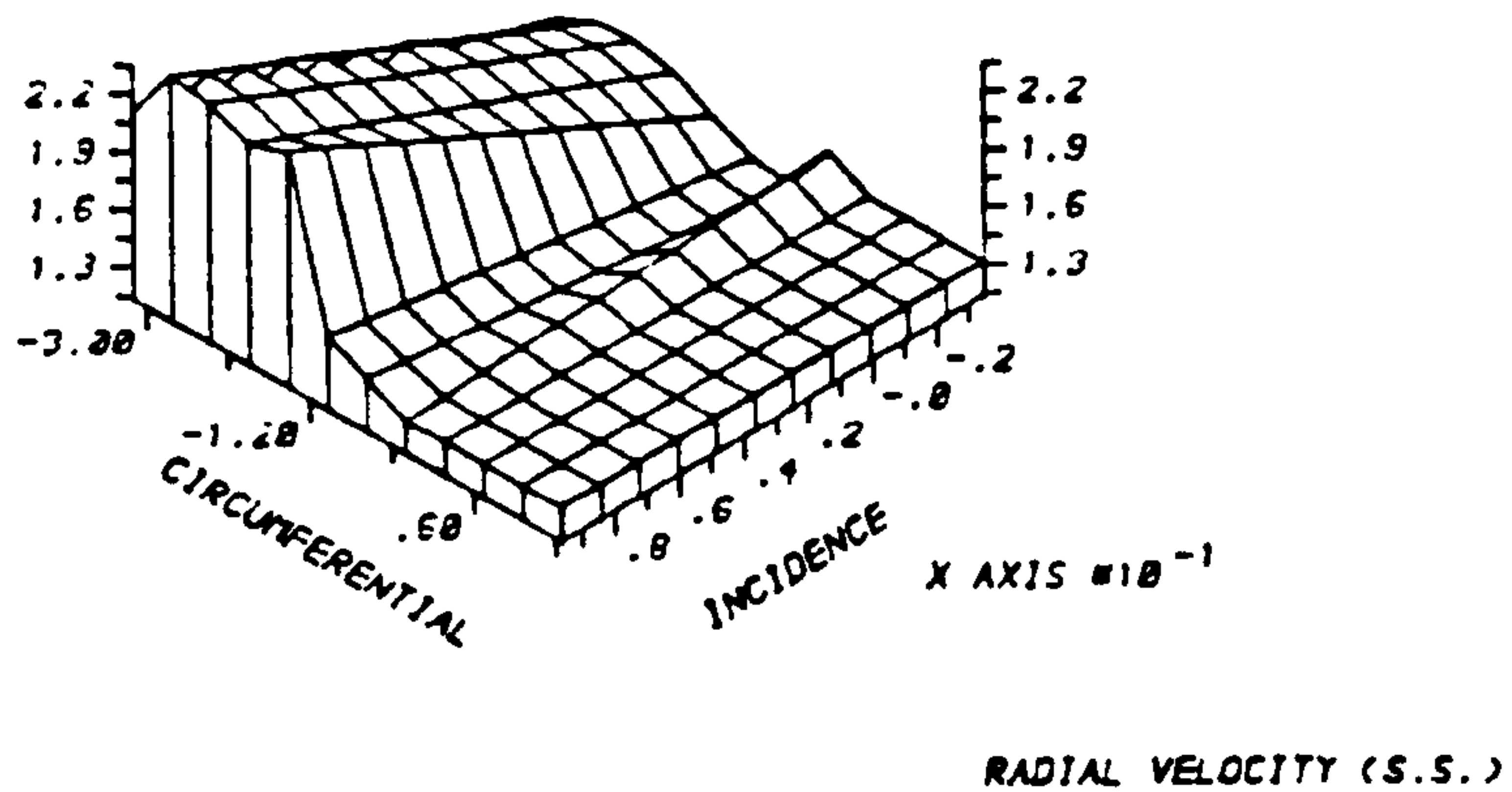


Fig 176 VALUES OF THE SIMILARITY COEFF.

REAL-DIST.

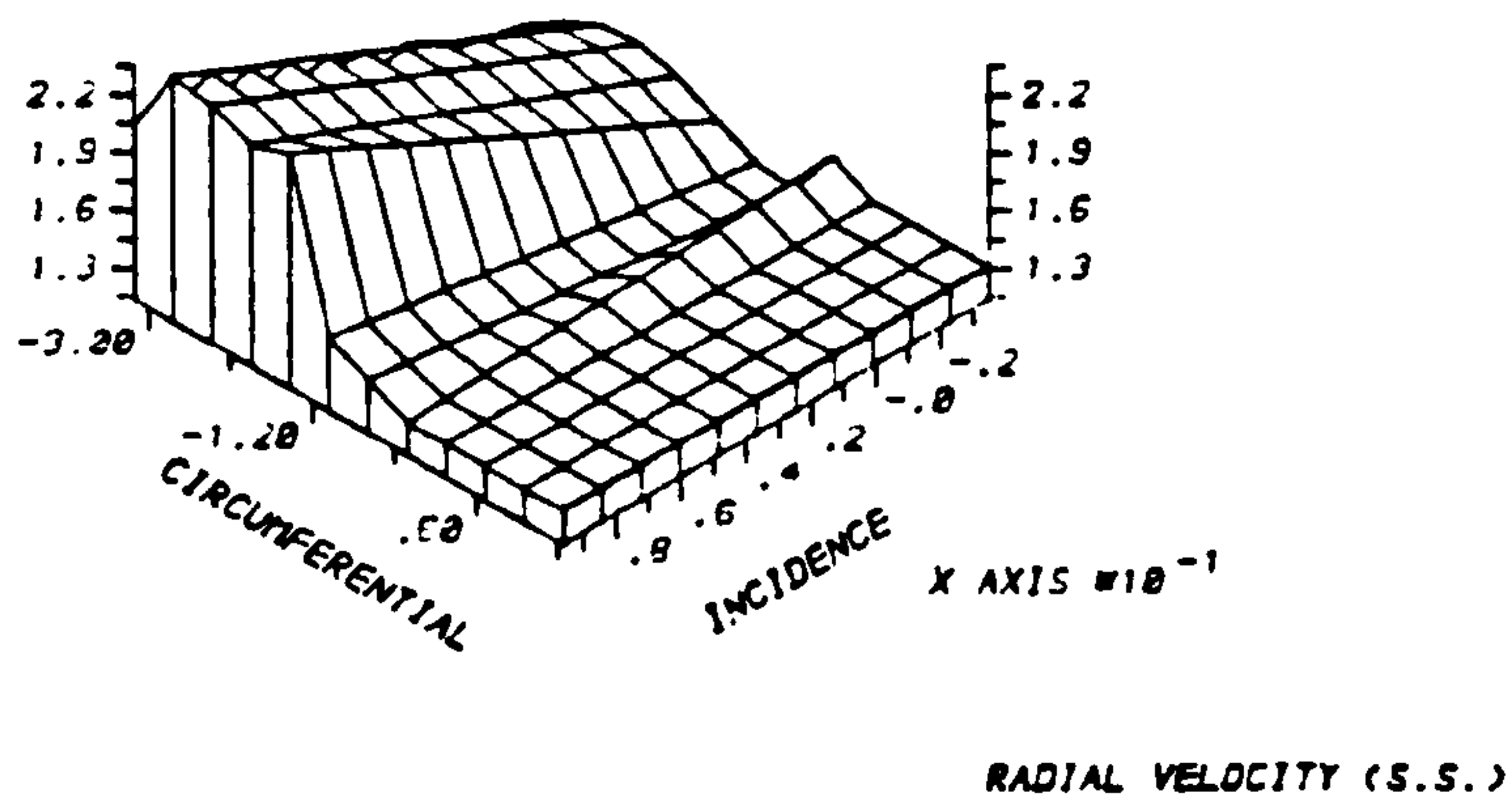
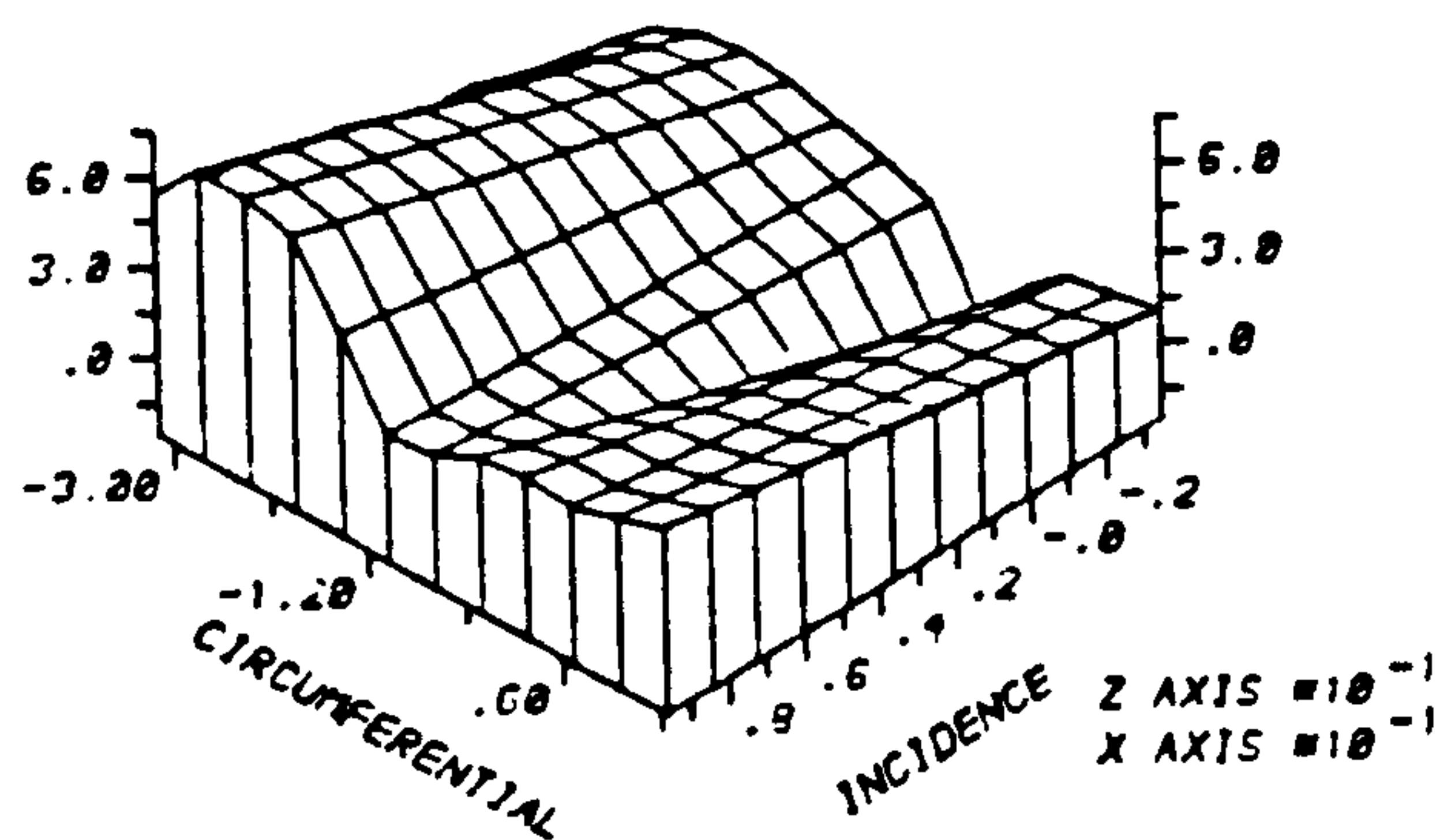


Fig 177 VALUES OF THE SIMILARITY COEFF.

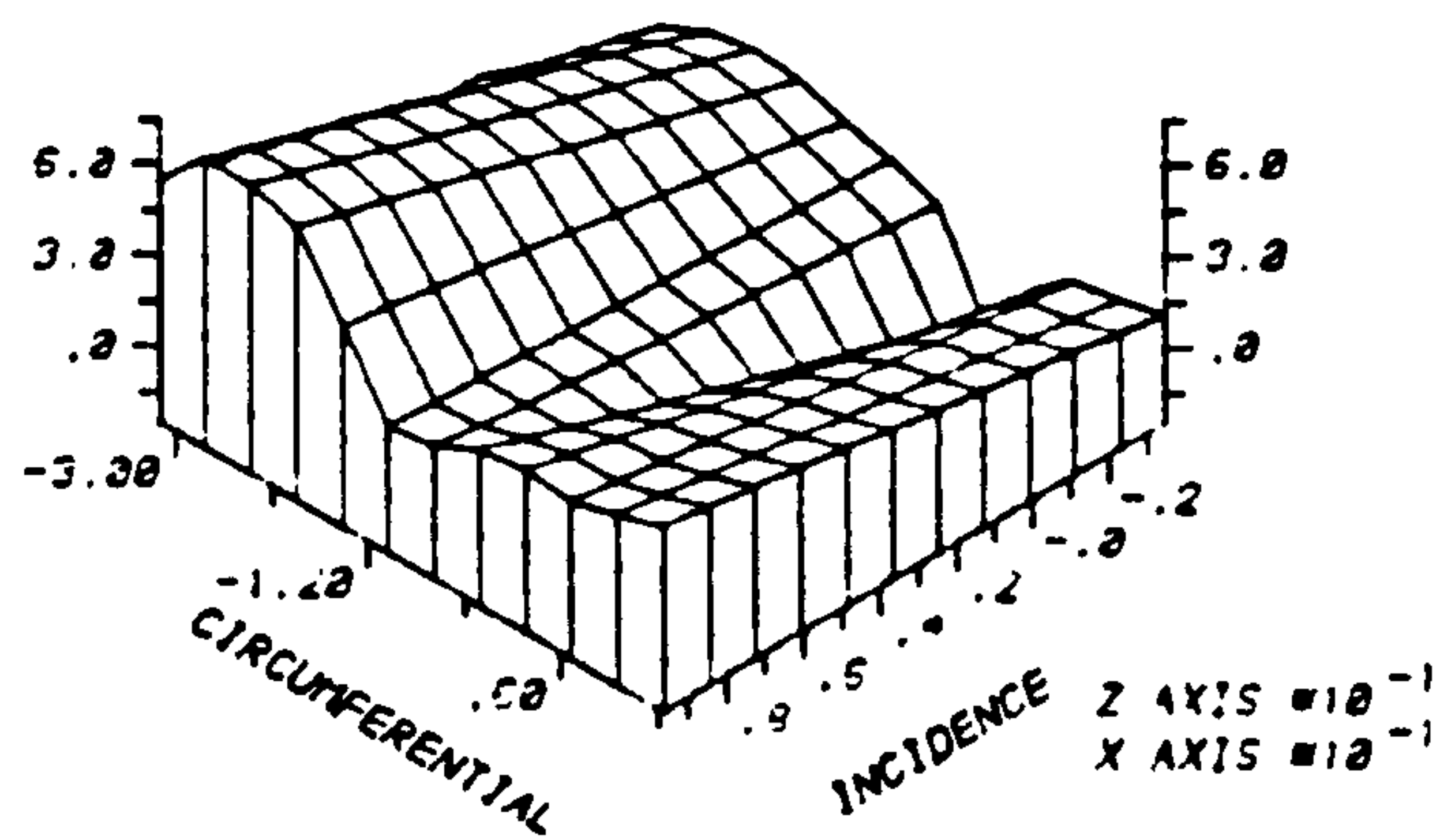
FITTING-DIST.



AXIAL VELOCITY (P.S.)

Fig 178 VALUES OF THE SIMILARITY COEFF.

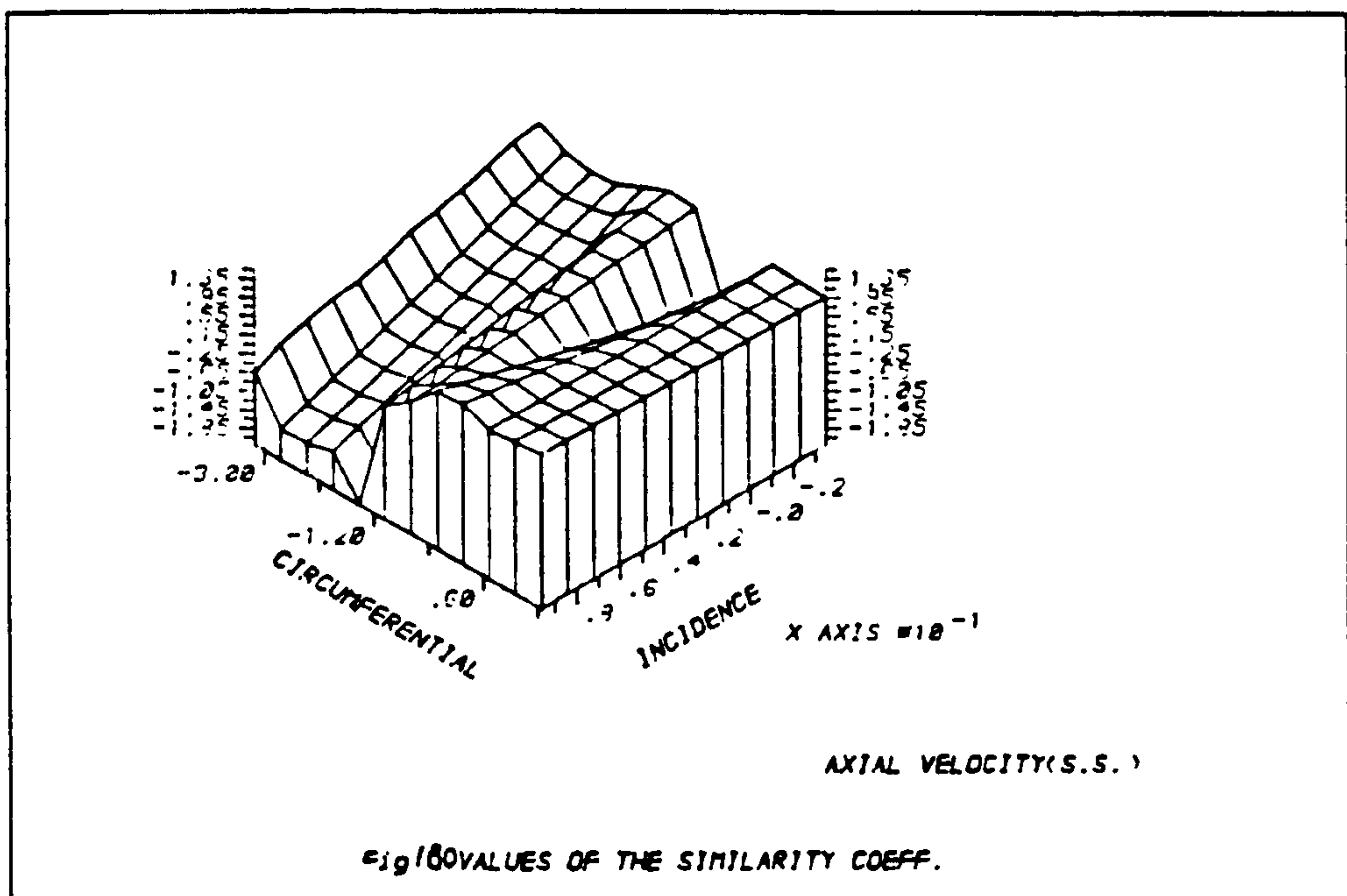
REAL-DIST.



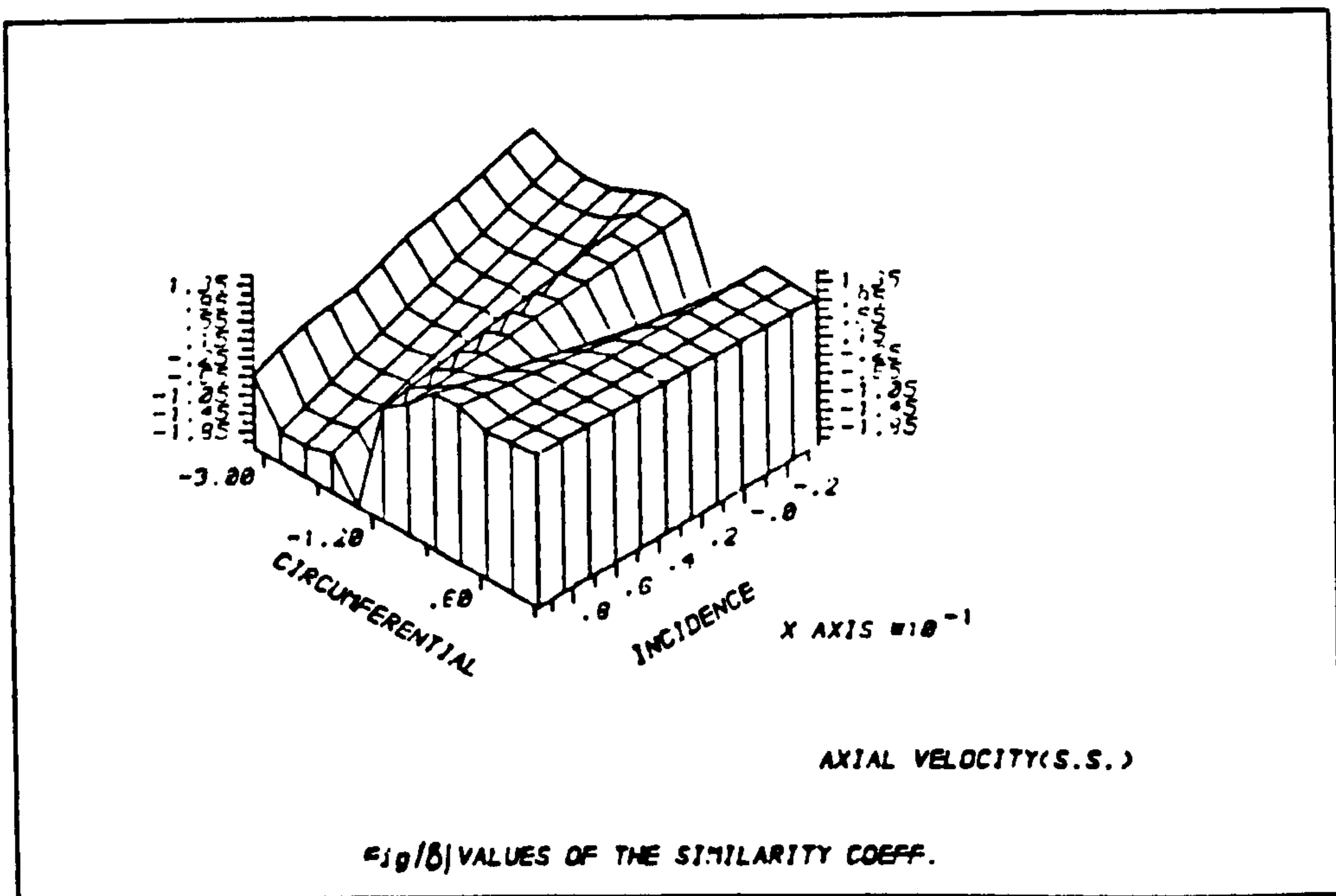
AXIAL VELOCITY (P.S.)

Fig 179 VALUES OF THE SIMILARITY COEFF.

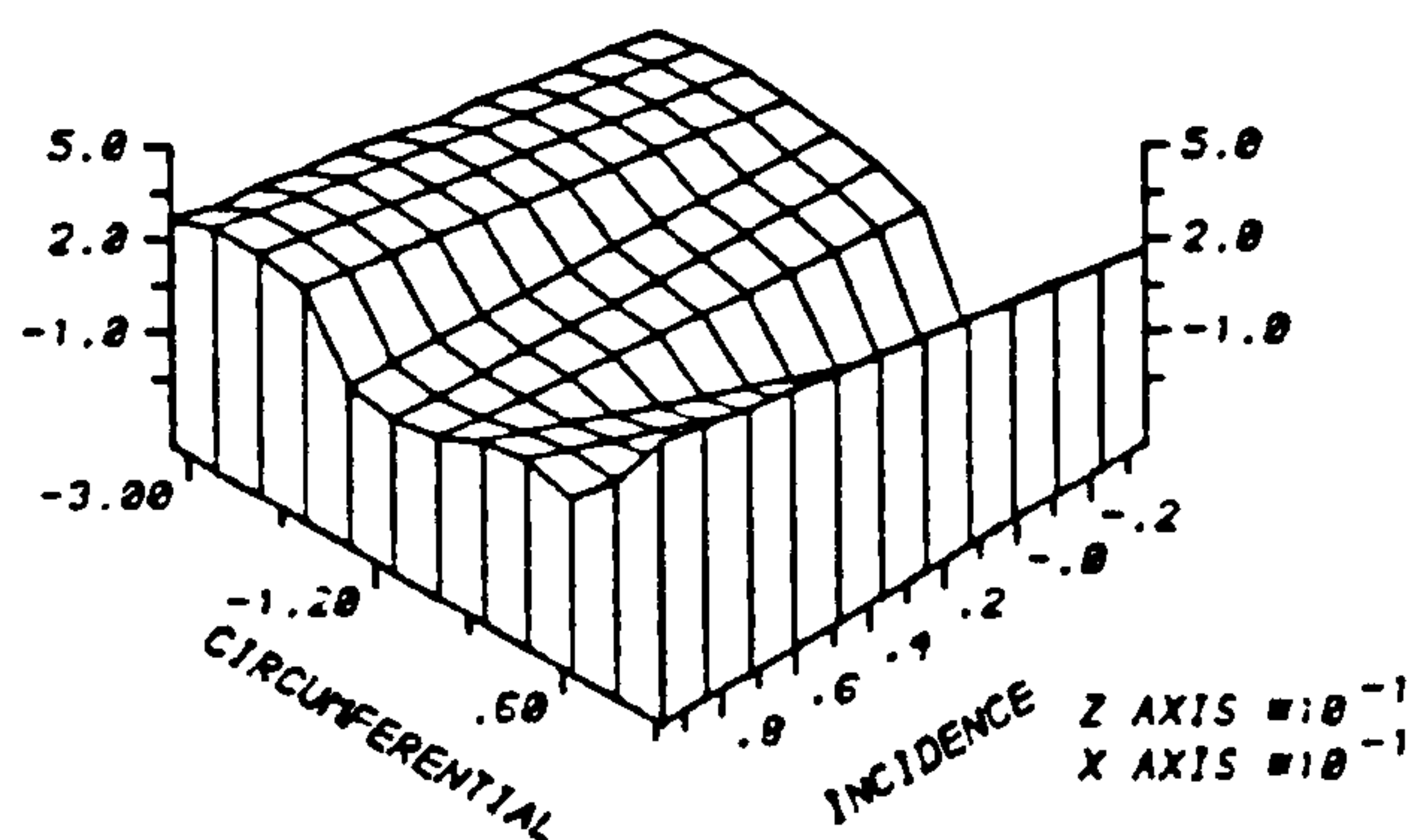
FITTING-DIST.



FITTING-DIST.



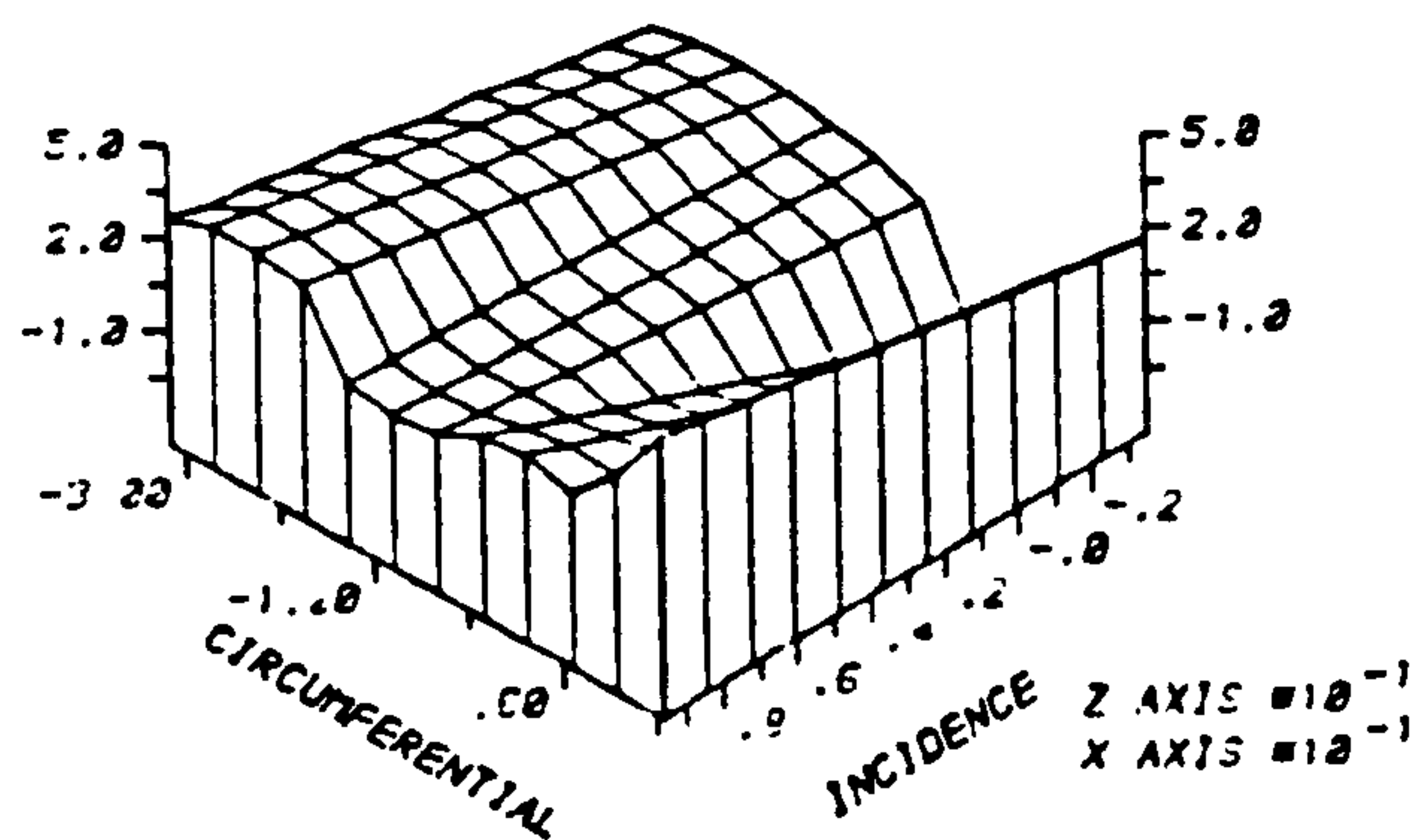
REAL-DIST.



RELATIVE TANG. VELOCITY (P.S.)

Fig 182 VALUES OF THE SIMILARITY COEFF.

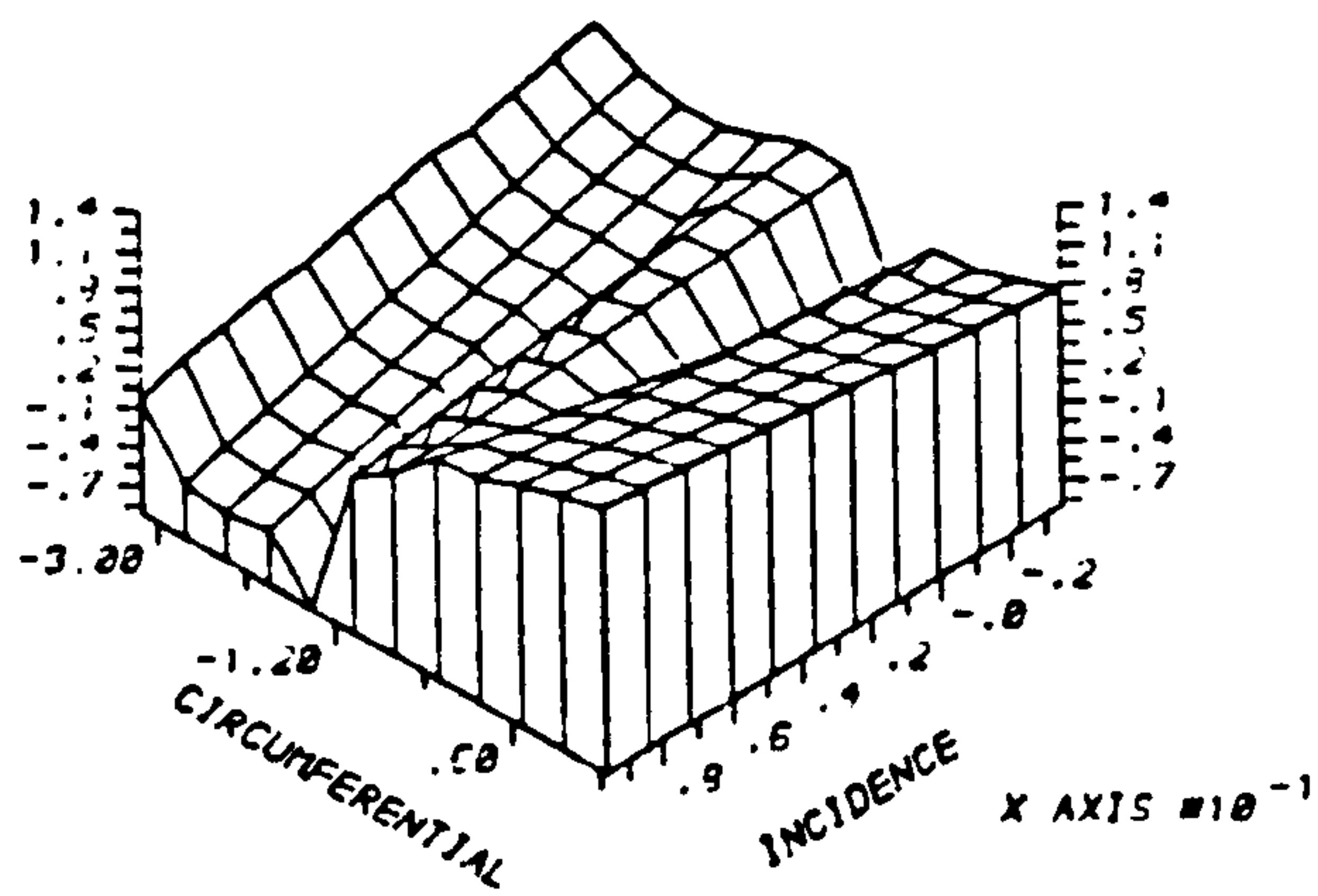
REAL-DIST.



RELATIVE TANG. VELOCITY (P.S.)

Fig 183 VALUES OF THE SIMILARITY COEFF.

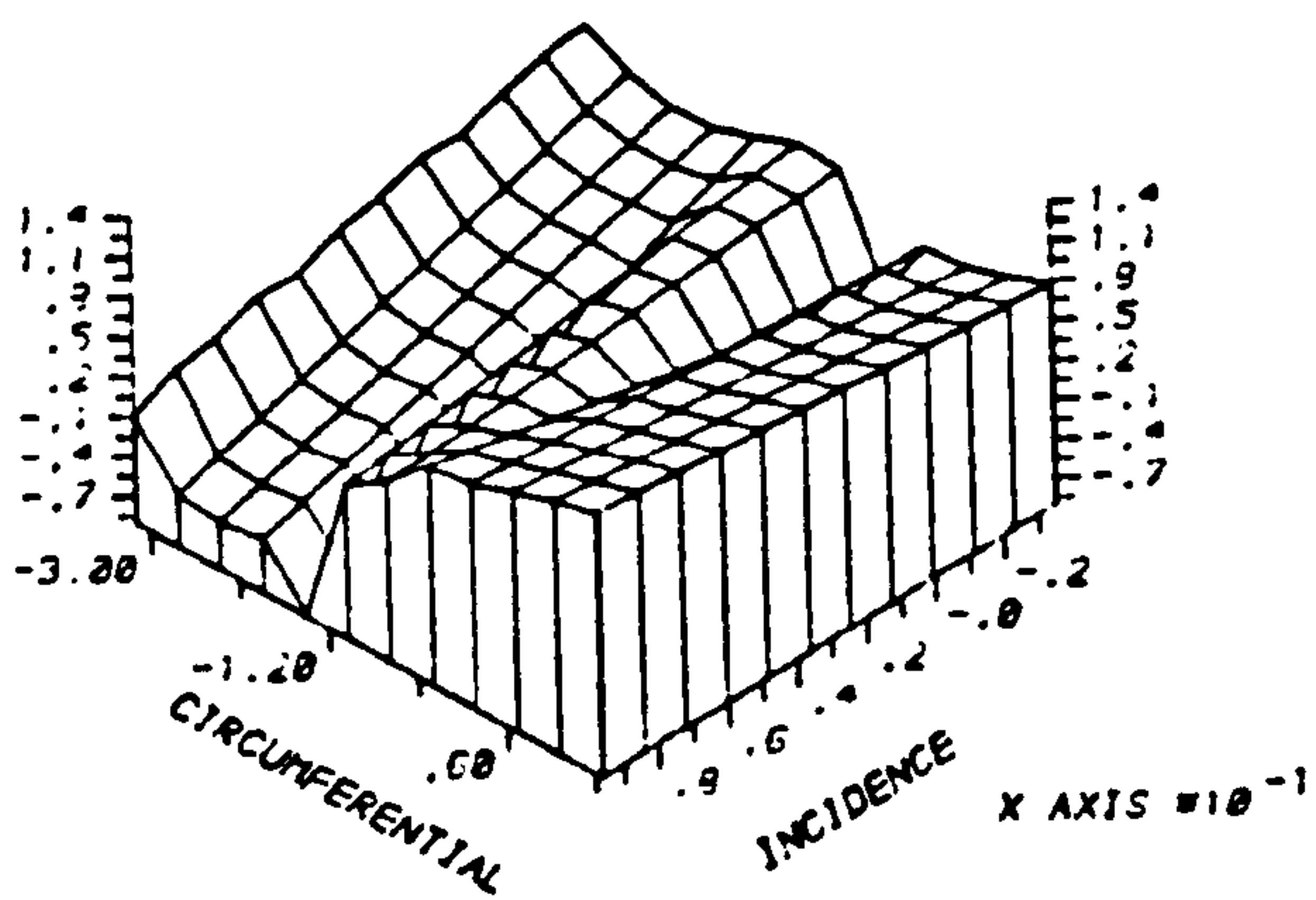
FITTING-DIST.



RELATIVE TANG. VELOCITY (S.S.)

Fig 184 VALUES OF THE SIMILARITY COEFF.

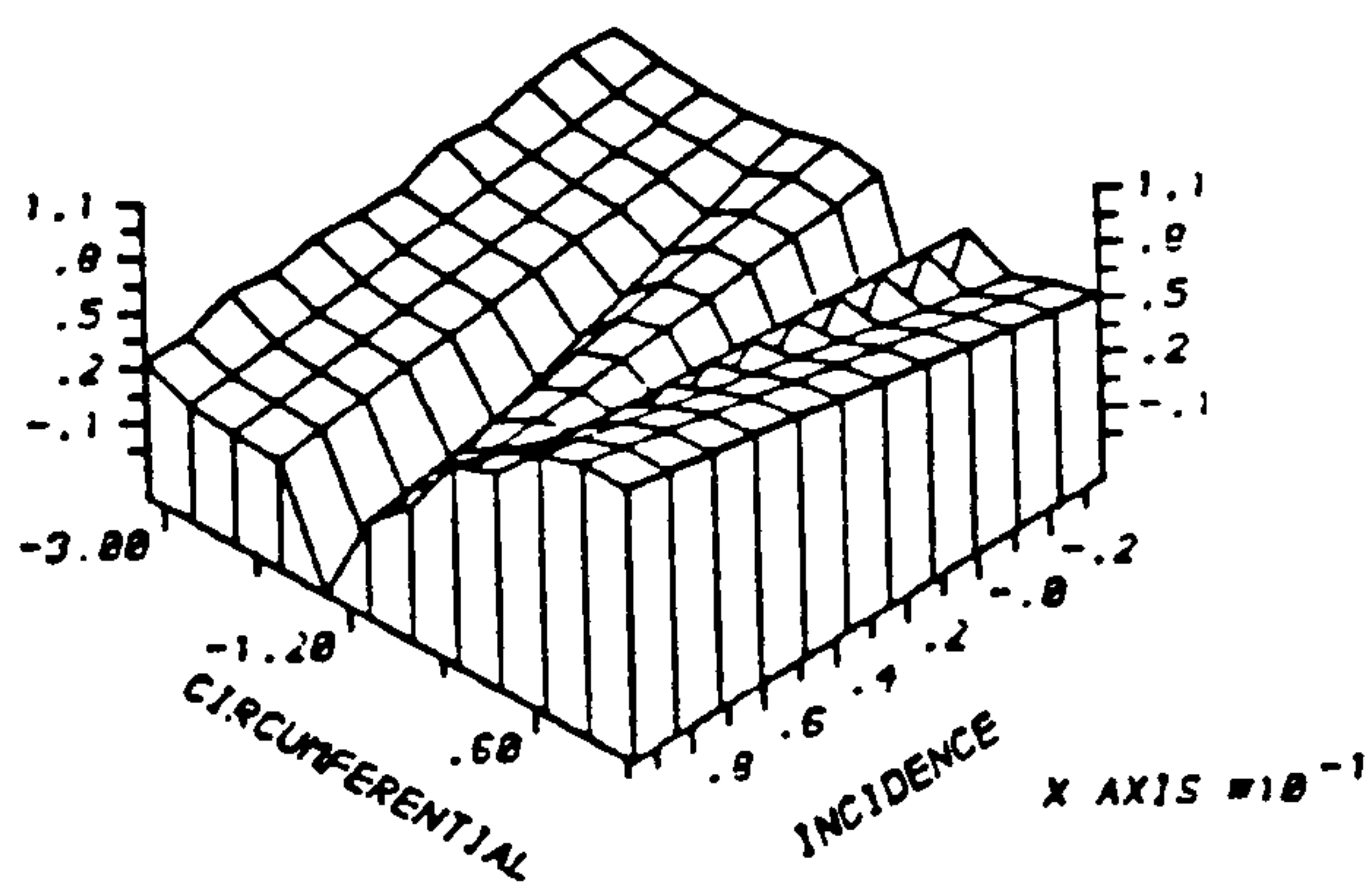
FITTING-DIST.



RELATIVE TANG. VELOCITY (S.S.)

Fig 185 VALUES OF THE SIMILARITY COEFF.

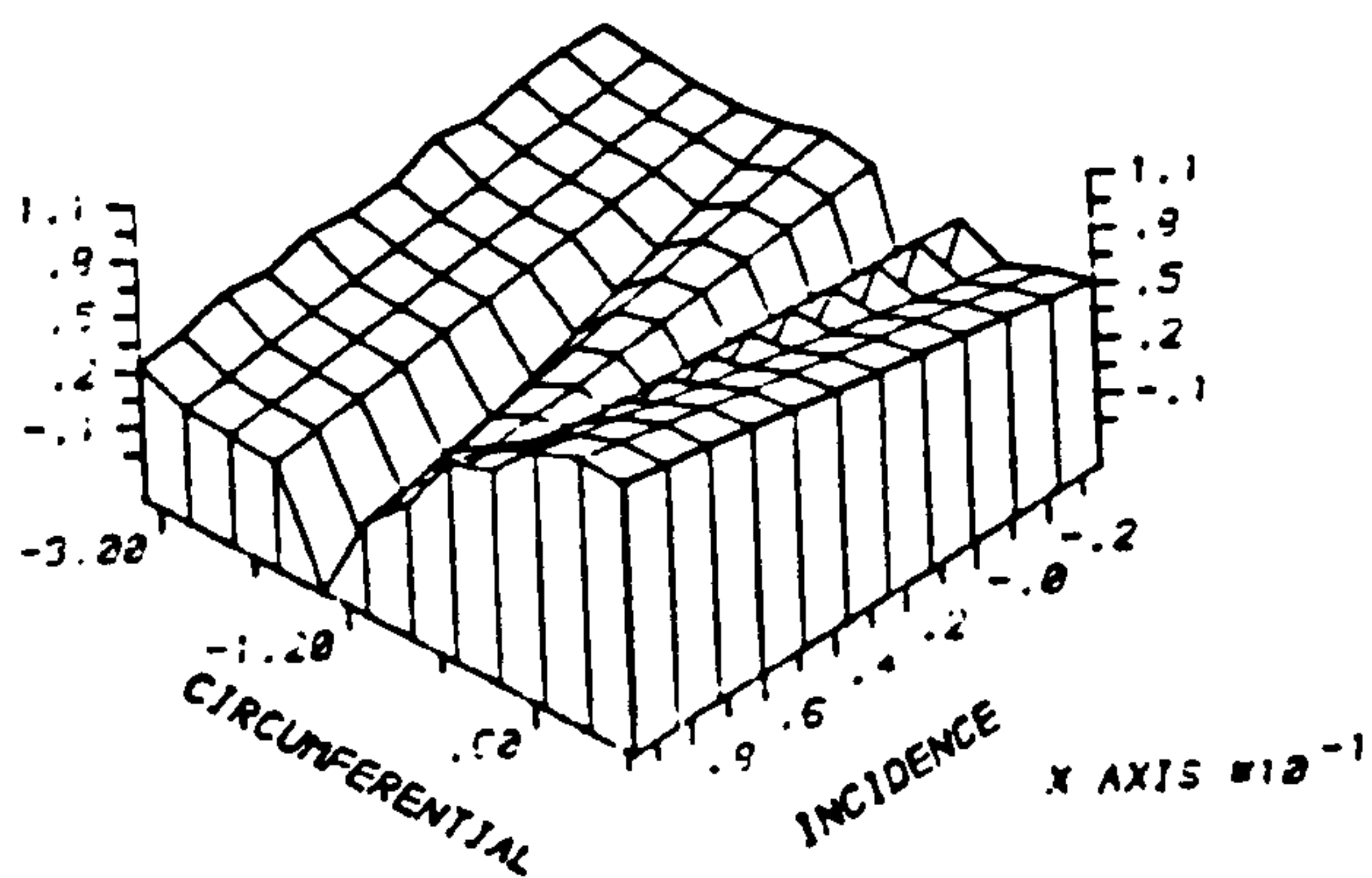
REAL-DIST.



TOTAL RELATIVE VELOCITY (P.S.)

Fig 186 VALUES OF THE SIMILARITY COEFF.

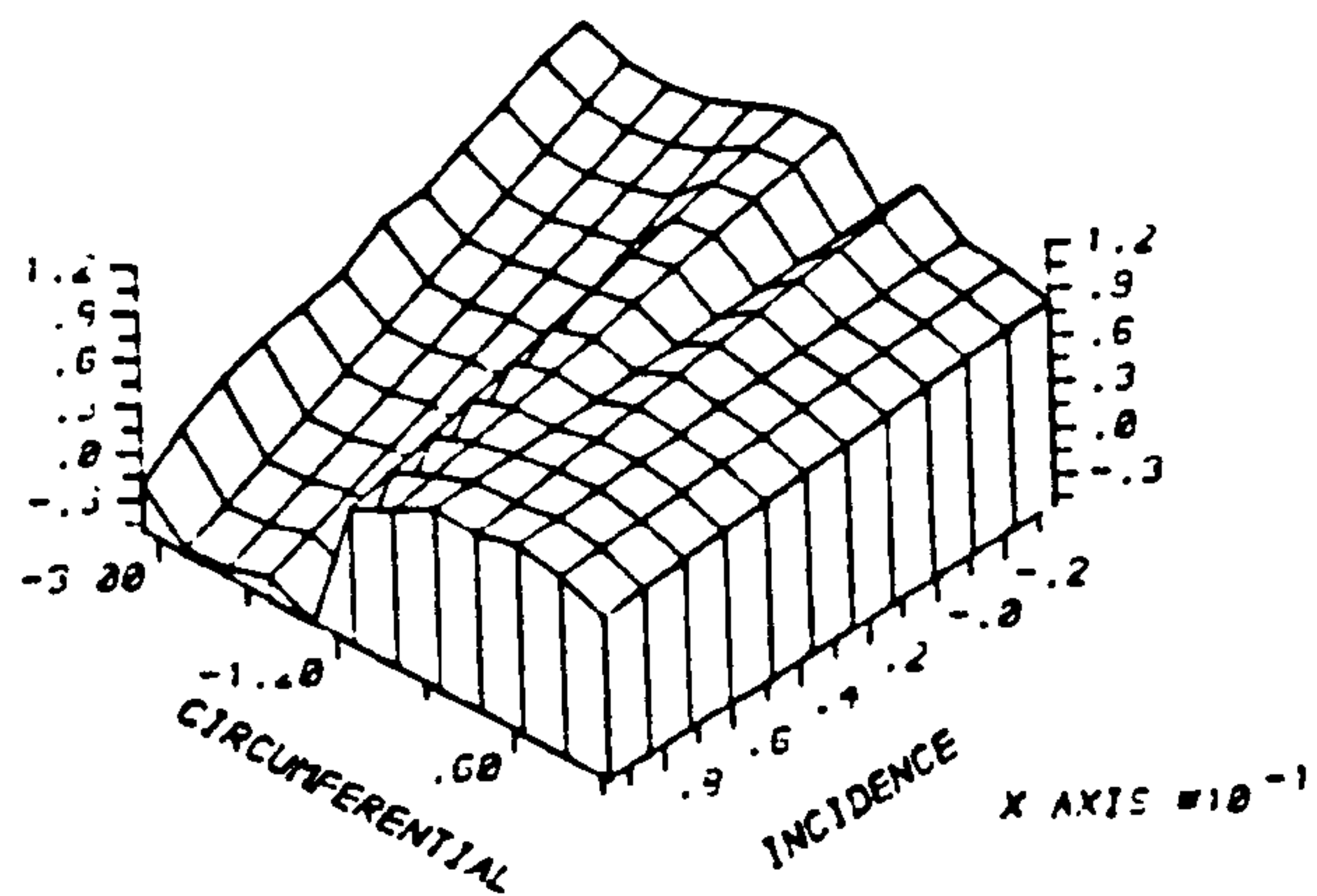
REAL-DIST.



TOTAL RELATIVE VELOCITY (P.S.)

Fig 187 VALUES OF THE SIMILARITY COEFF.

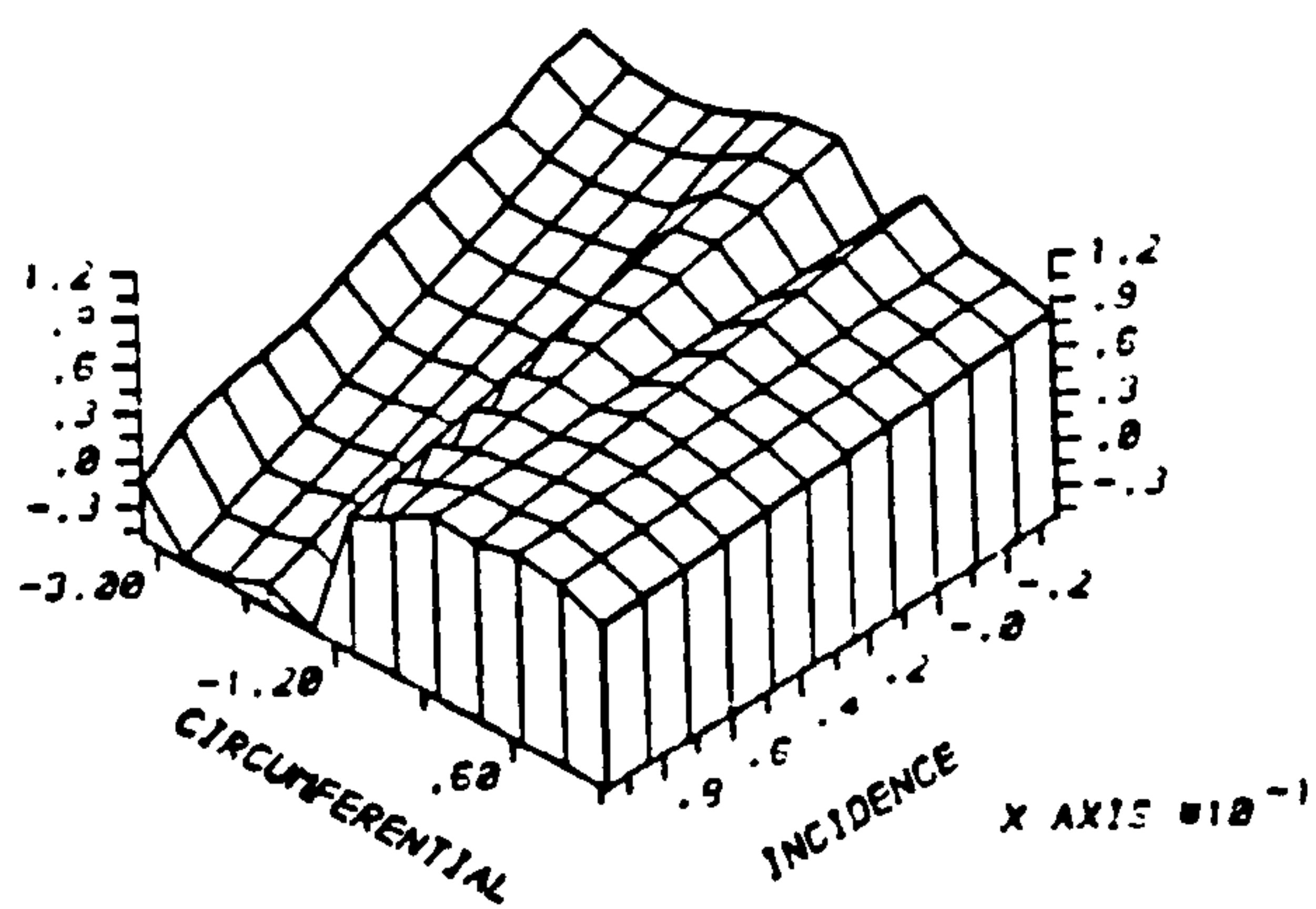
FITTING-DIST.



TOTAL RELATIVE VELOCITY (S.S.)

Fig 18 VALUES OF THE SIMILARITY COEFF.

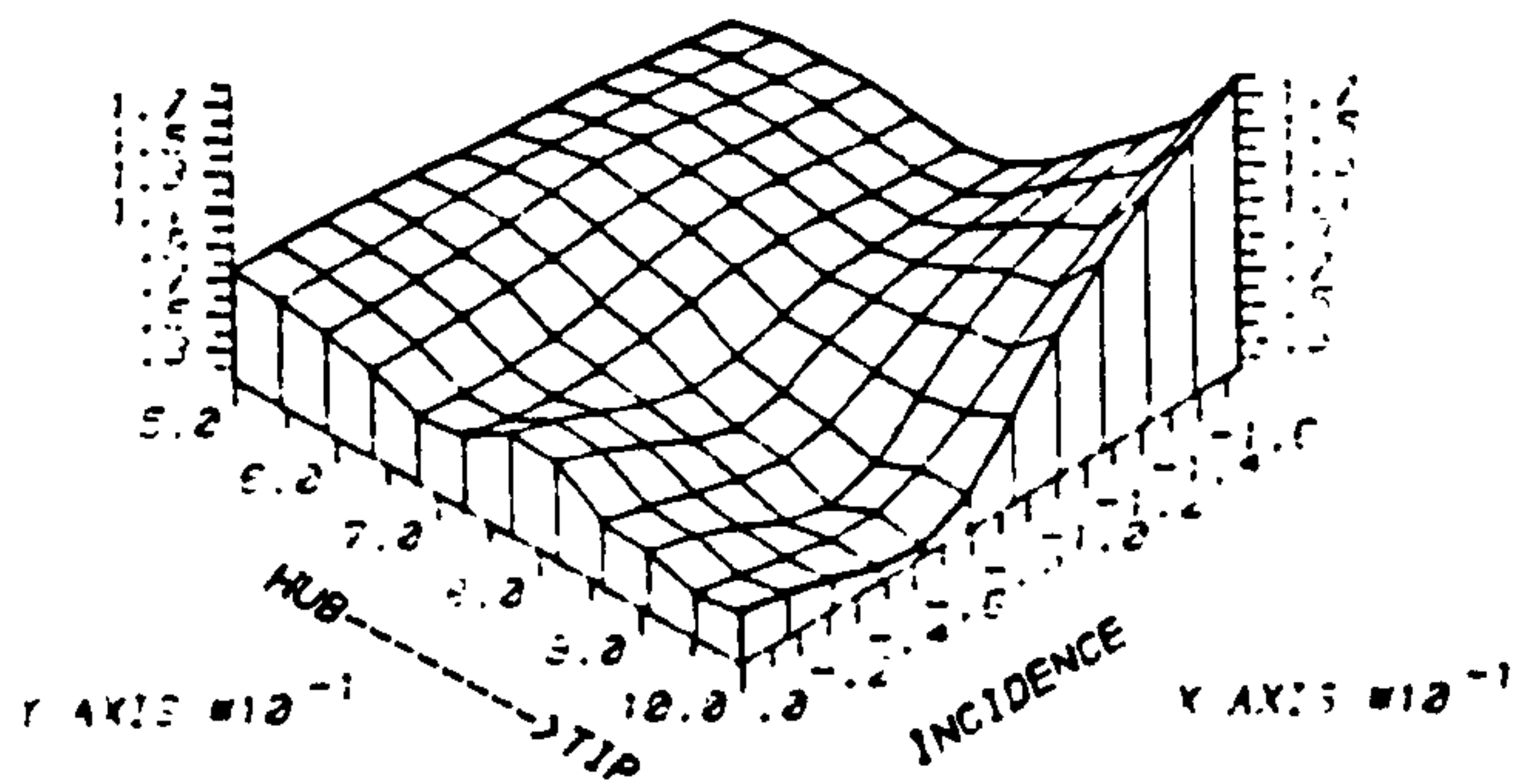
REAL-DIST.



TOTAL RELATIVE VELOCITY (S.S.)

Fig 18 VALUES OF THE SIMILARITY COEFF.

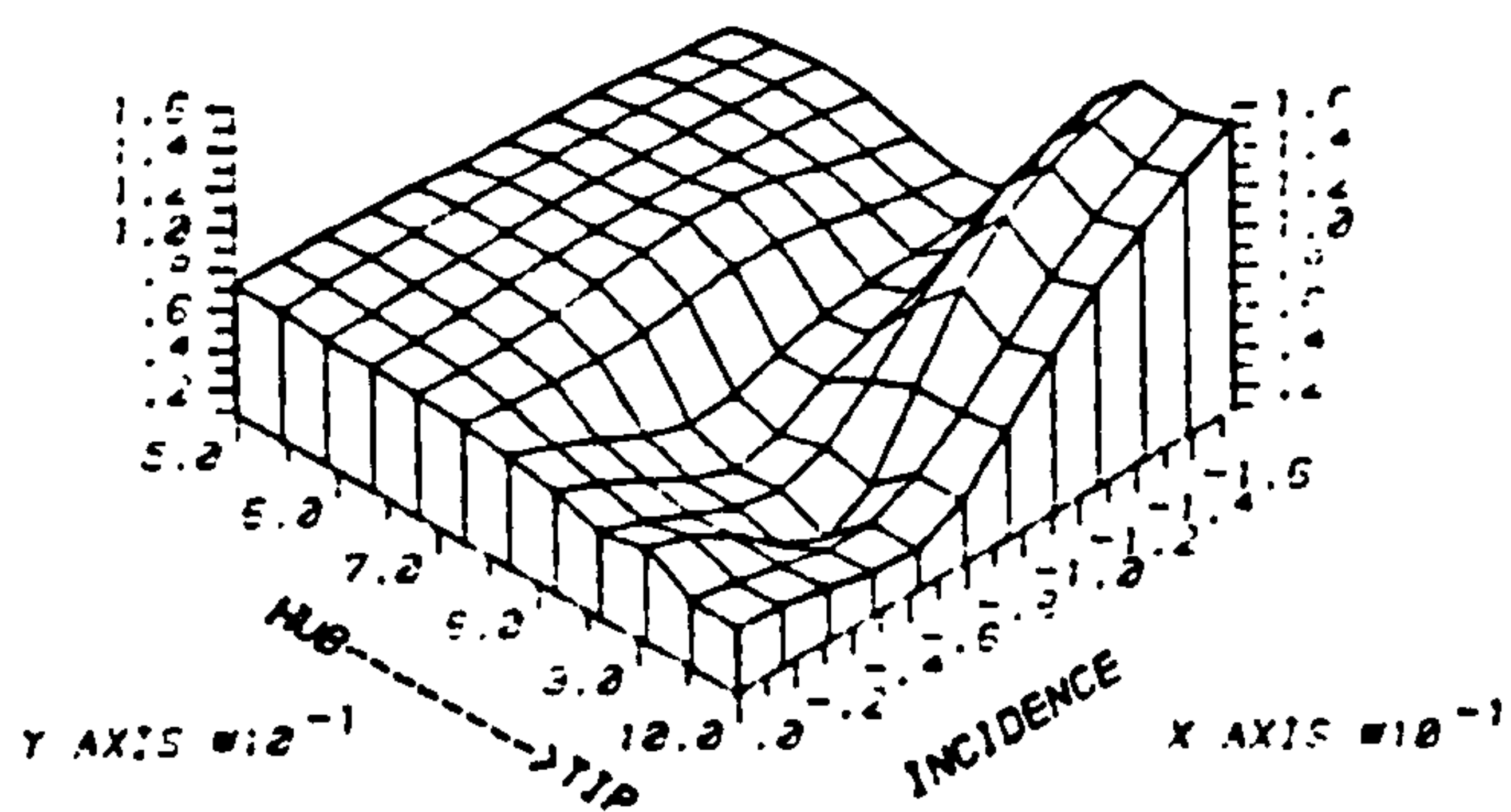
FITTING-DIST.



AXIAL TURBULENCE (P.S.)

Fig 190 VALUES OF THE SELF PRESERVATION COEFFS

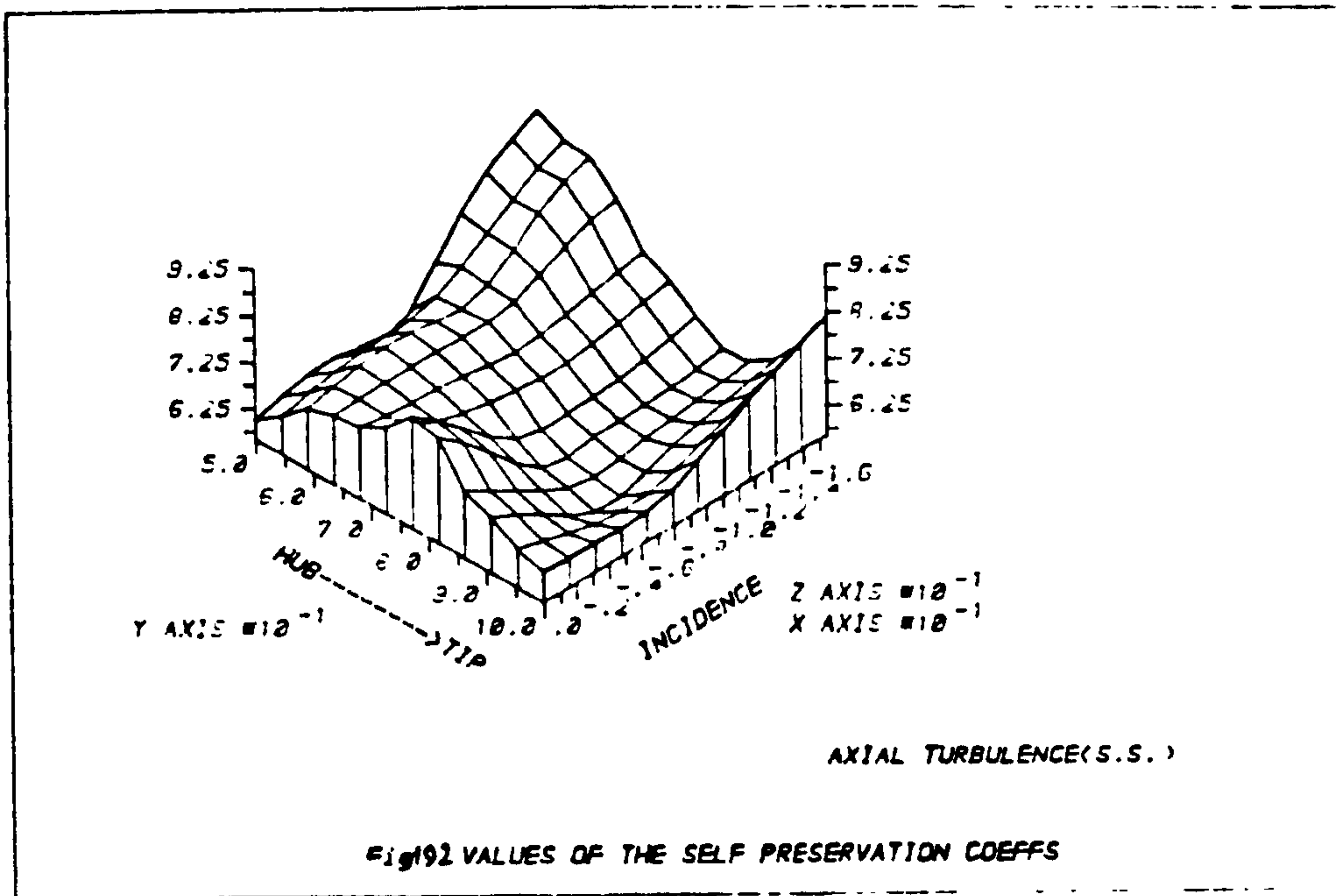
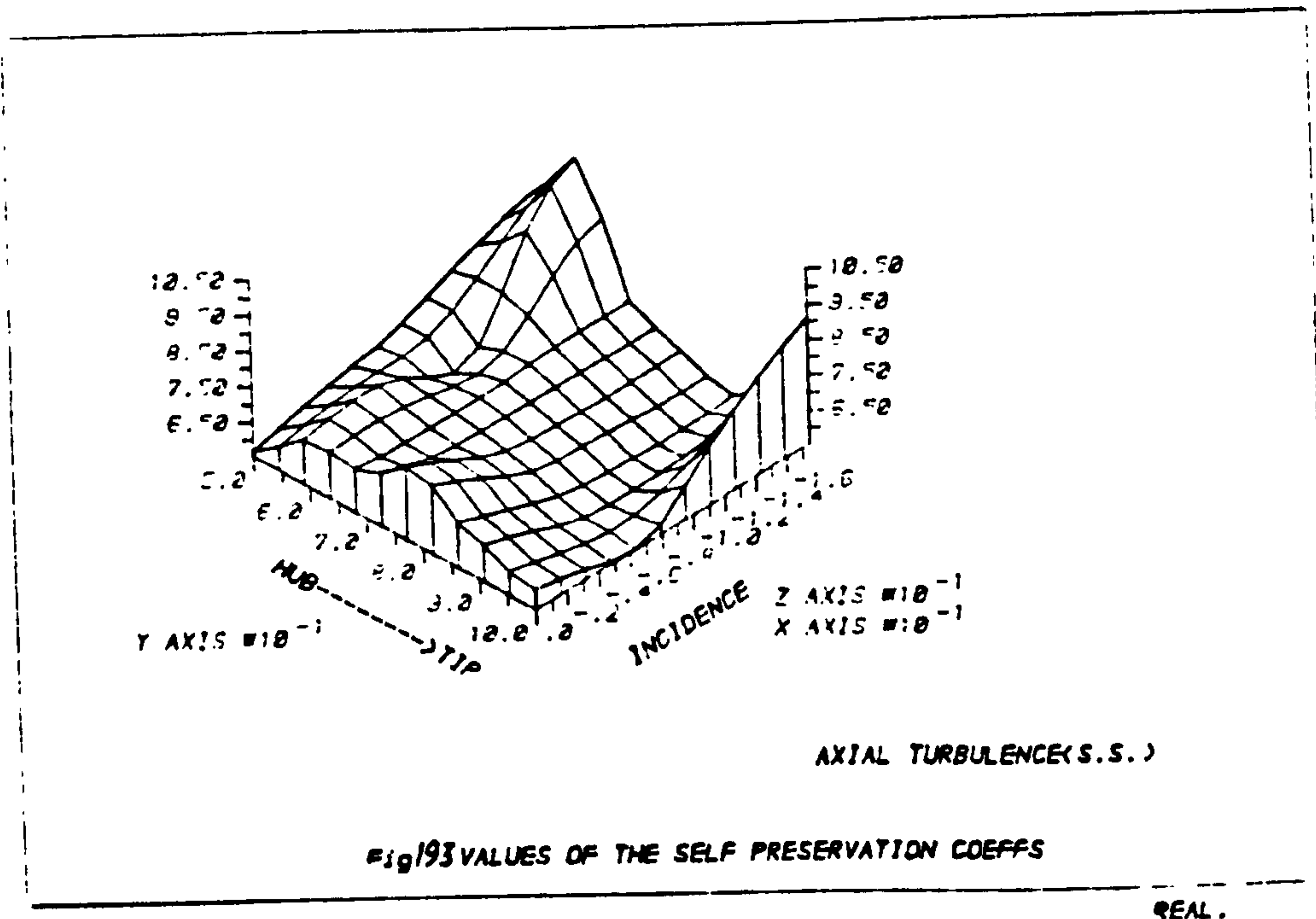
FITTING.

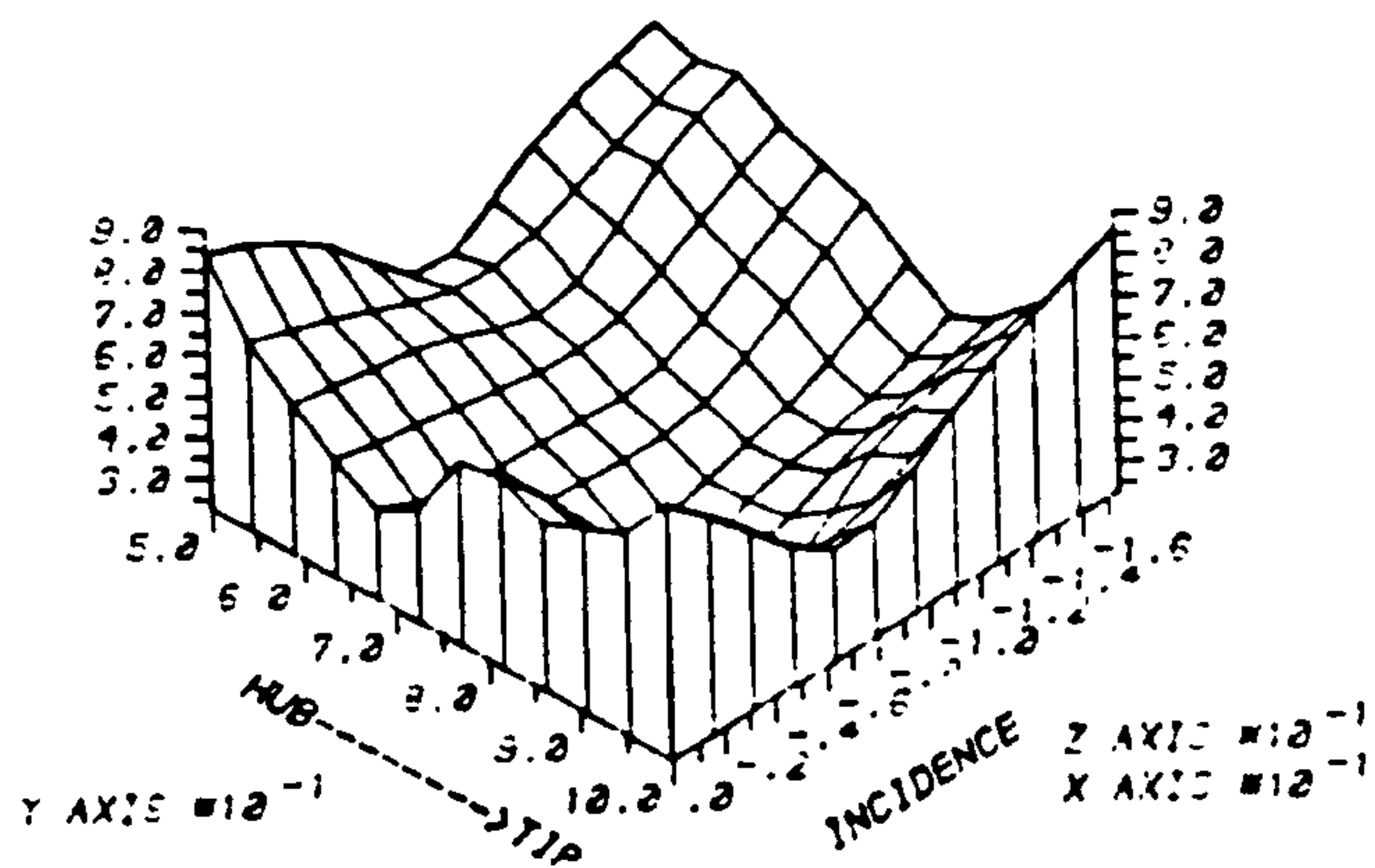


AXIAL TURBULENCE (P.S.)

Fig 191 VALUES OF THE SELF PRESERVATION COEFFS

REAL.

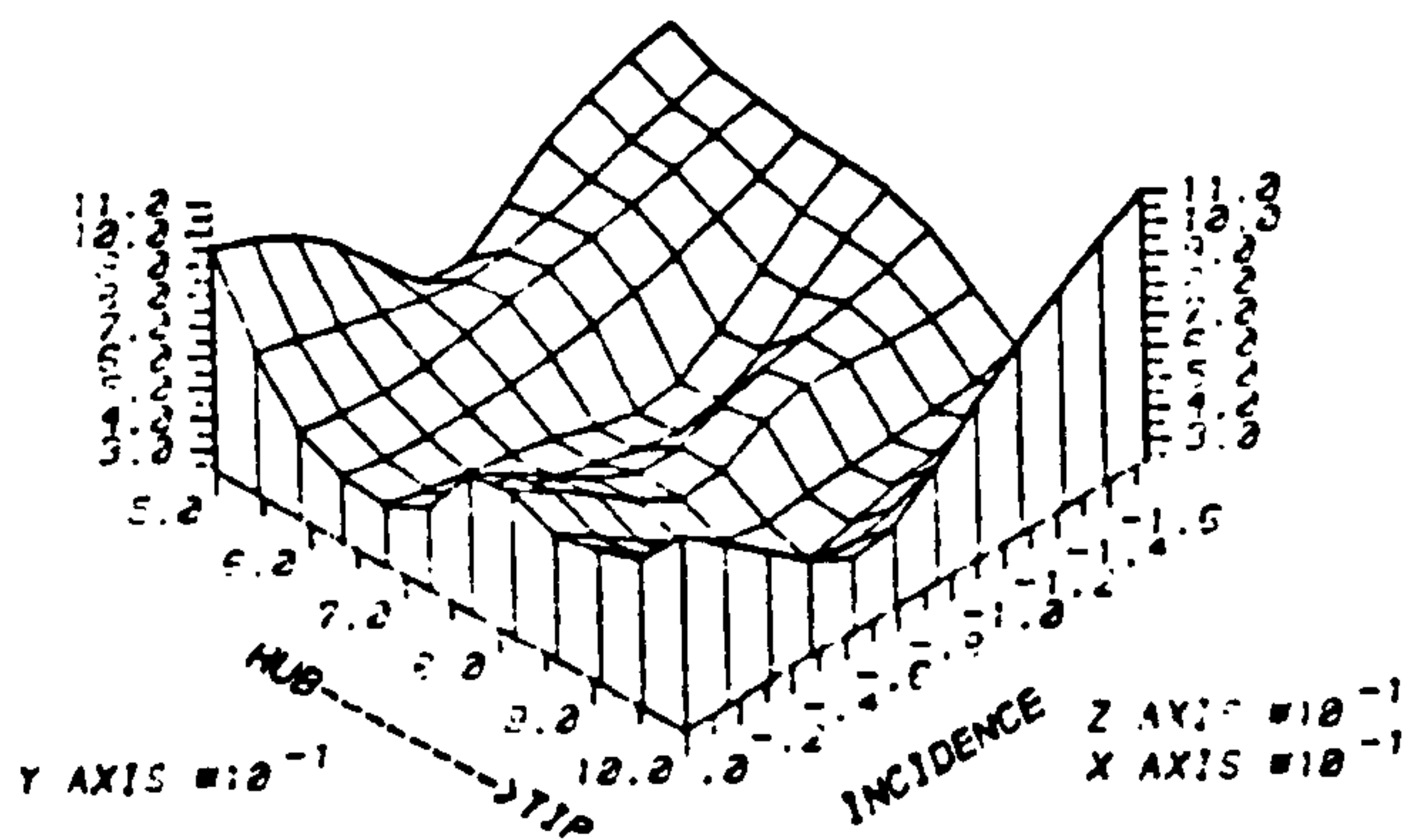




TANGENTIAL TURBULENCE (P.S.)

Fig 194 VALUES OF THE SELF PRESERVATION COEFFS

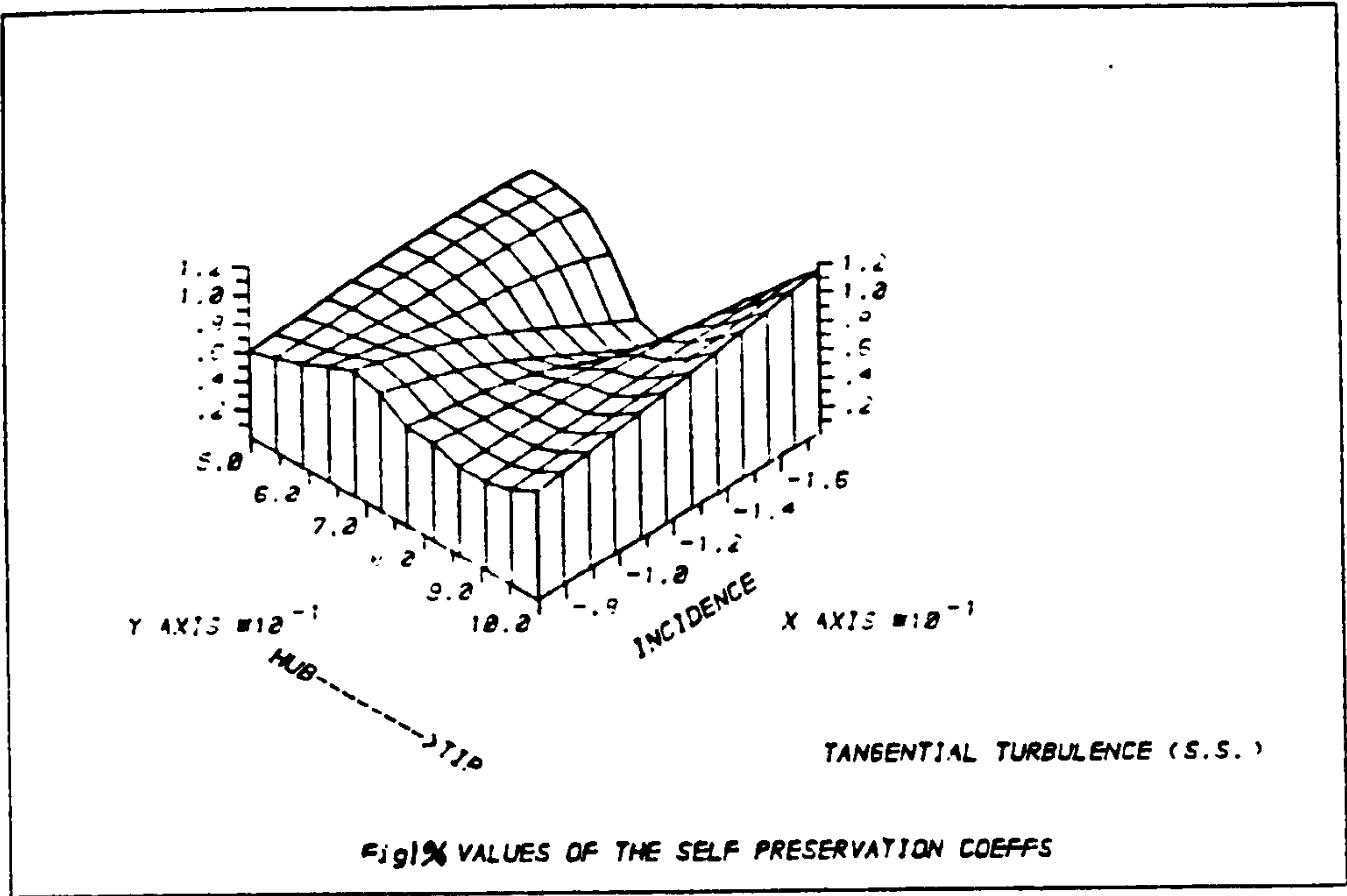
FITTING.



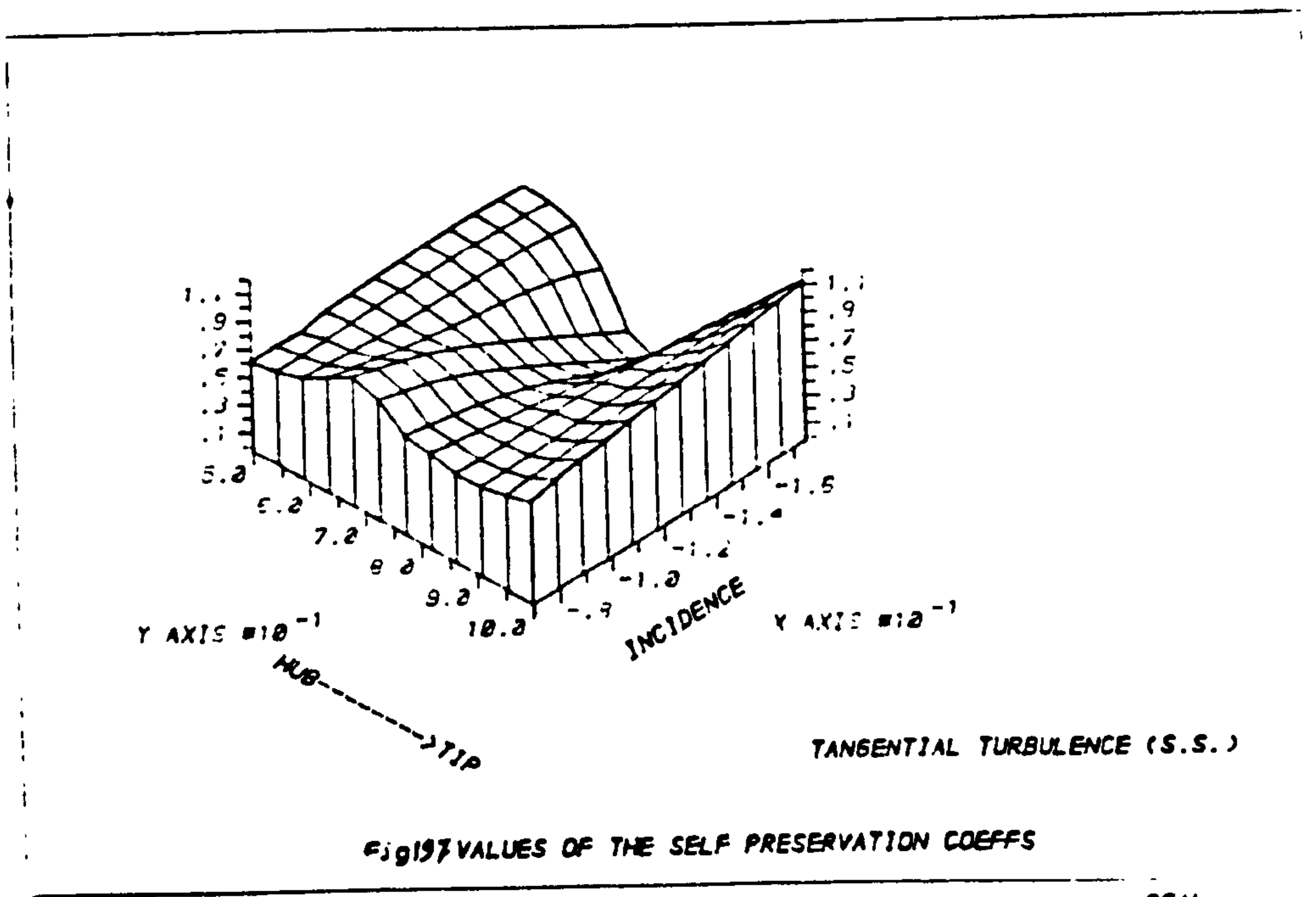
TANGENTIAL TURBULENCE (P.S.)

Fig 195 VALUES OF THE SELF PRESERVATION COEFFS

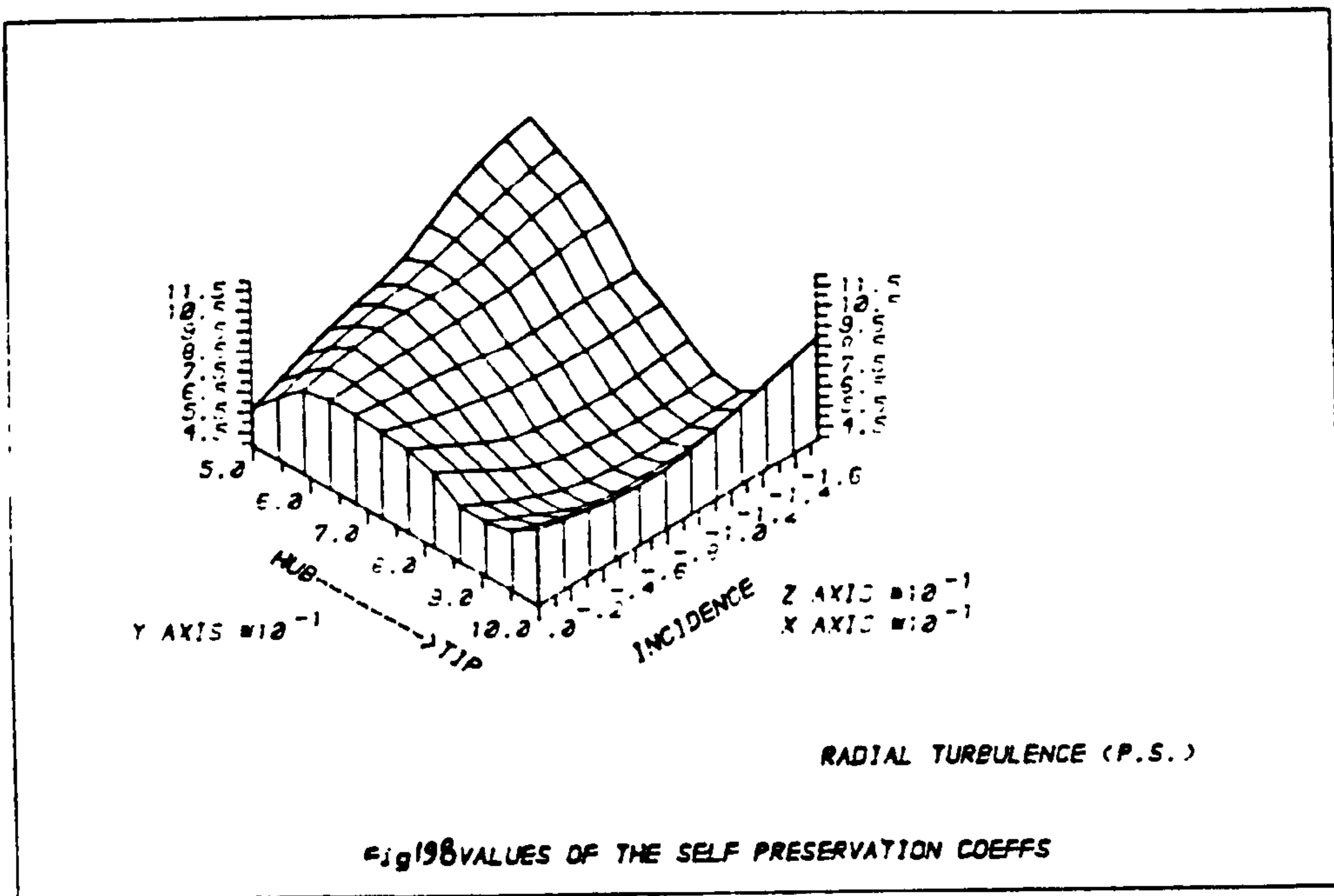
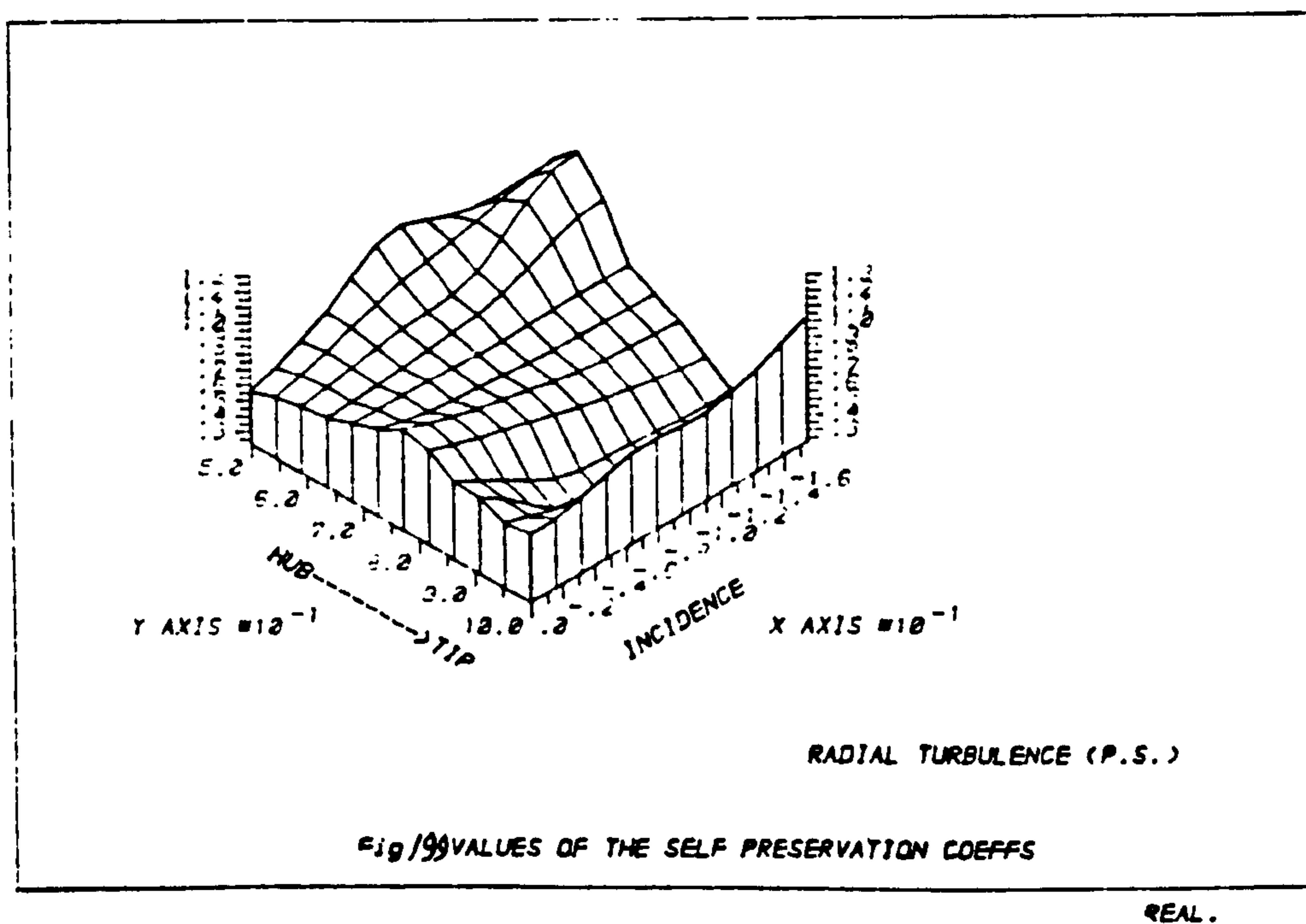
REAL.

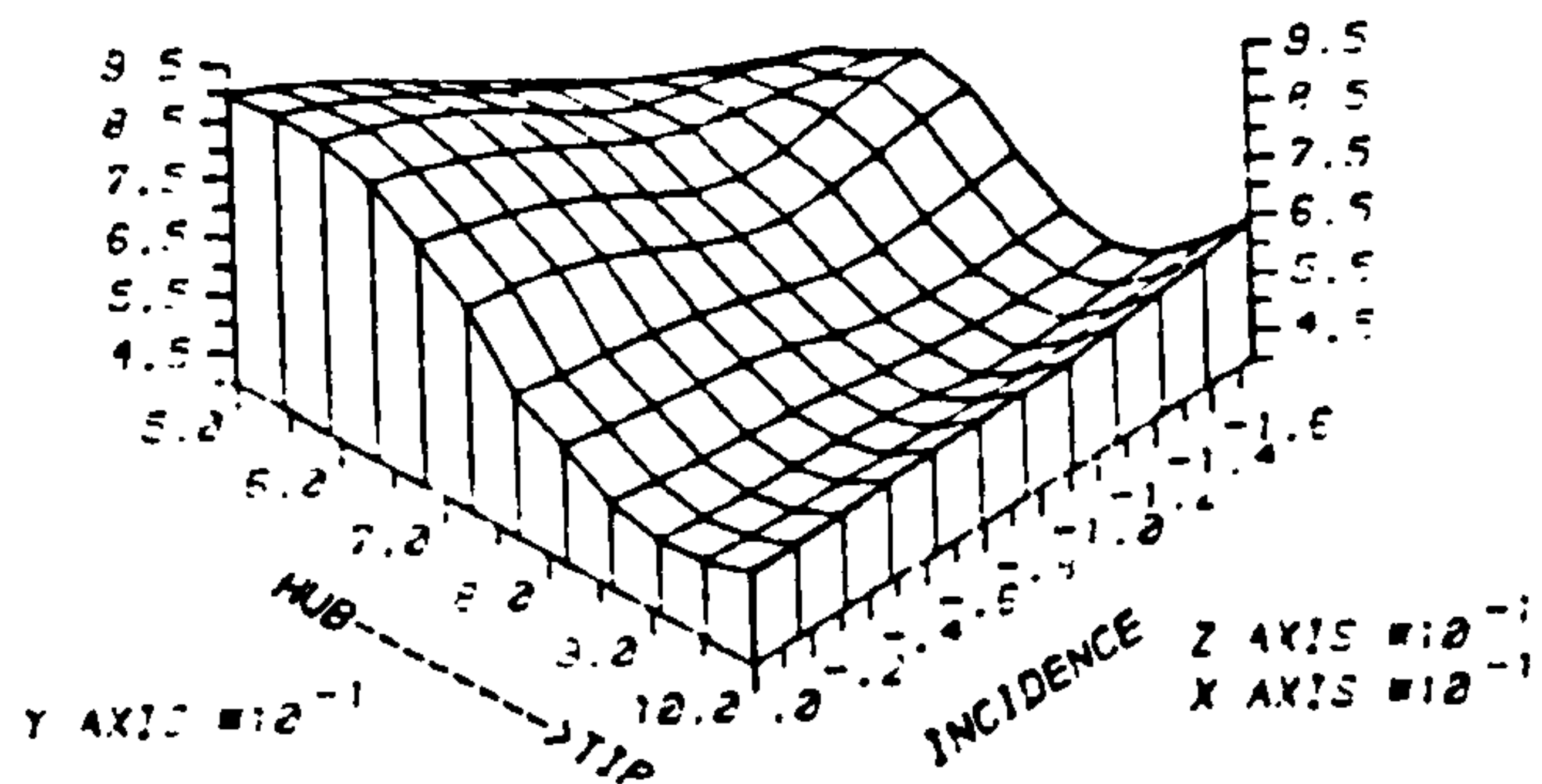


FITTING



REAL

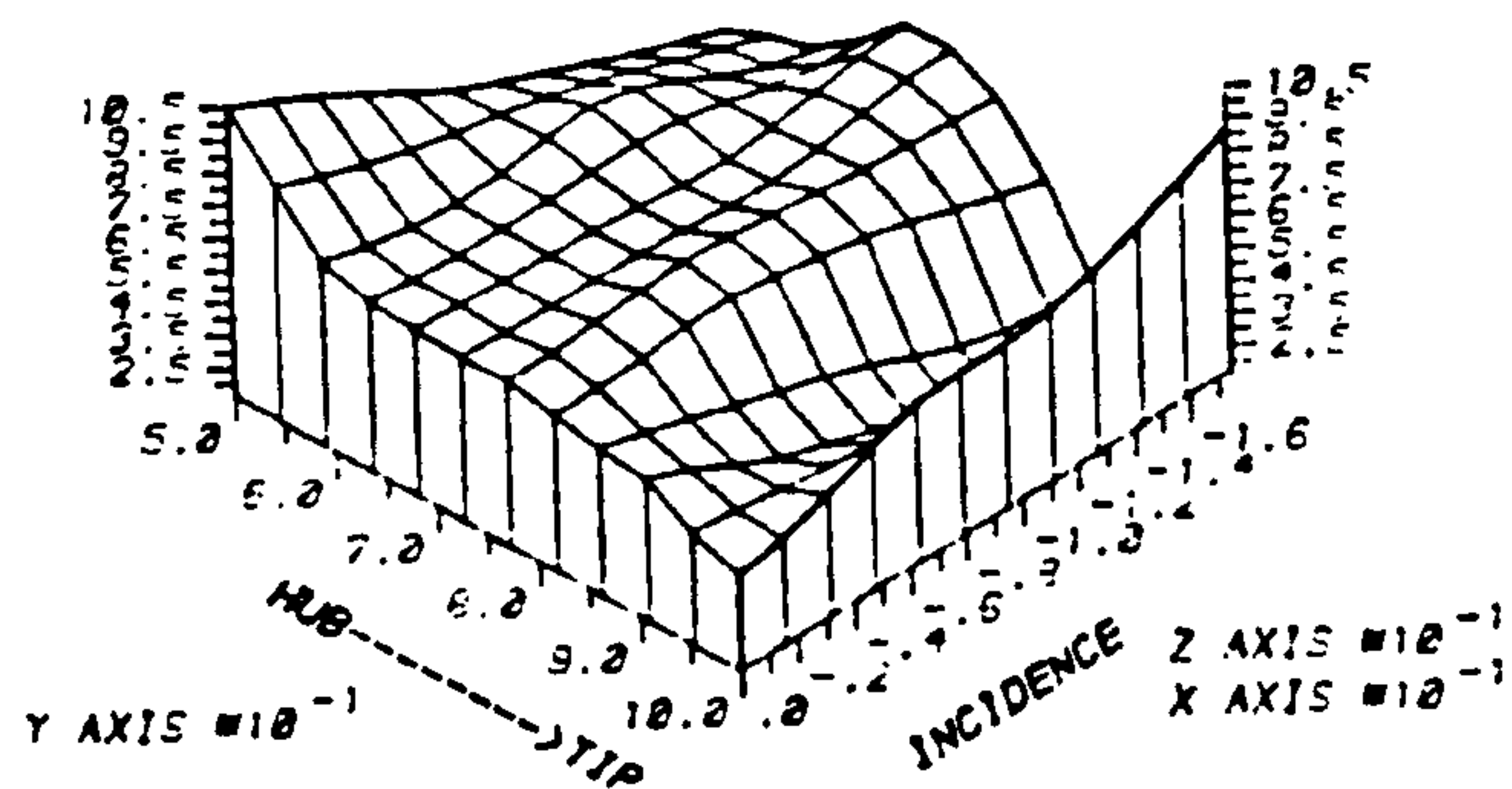




RADIAL TURBULENCE (S.S.)

Fig 200 VALUES OF THE SELF PRESERVATION COEFFS

FITTING.



RADIAL TURBULENCE (S.S.)

Fig 201 VALUES OF THE SELF PRESERVATION COEFFS

REAL.

SYMBOLS REPRESENT RADIAL LOCATIONS $\tilde{R} = 0.54 \rightarrow 0.64 \rightarrow 0.74 \rightarrow 0.84 \rightarrow 0.94 \rightarrow 1.0$

HUB

r/p

V_{Dmax}
 V_{SOMAX}

INC. (I)

INC. (II)

INC. (III)

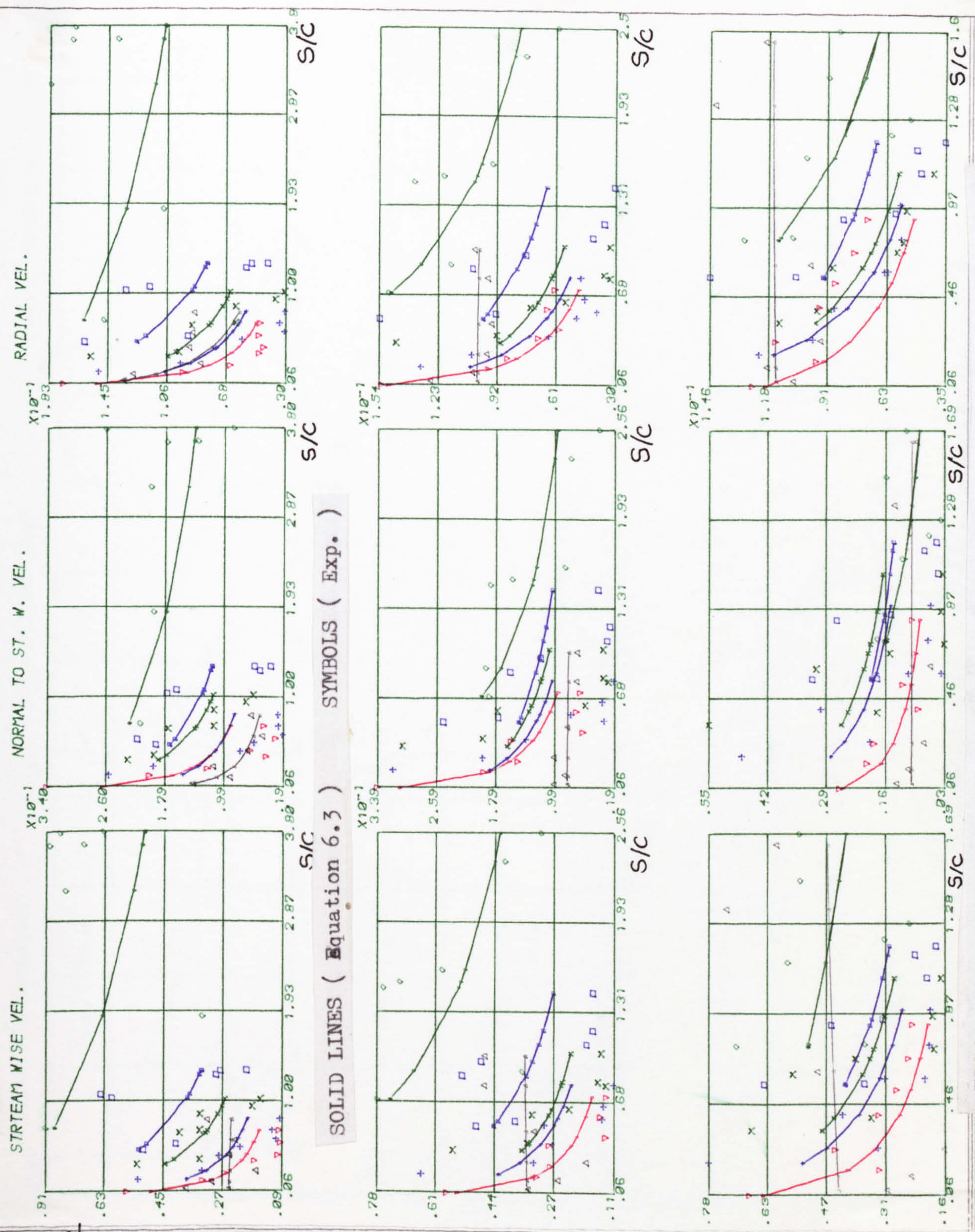


FIG 202 DECAY CHARACTERISTICS OF DIFFERENT VELOCITY COMPONENTS IN THE
 STREAM WISE FRAME OF REFERENCE.

HUB

SYMBOLS REPRESENT RADIAL LOCATIONS

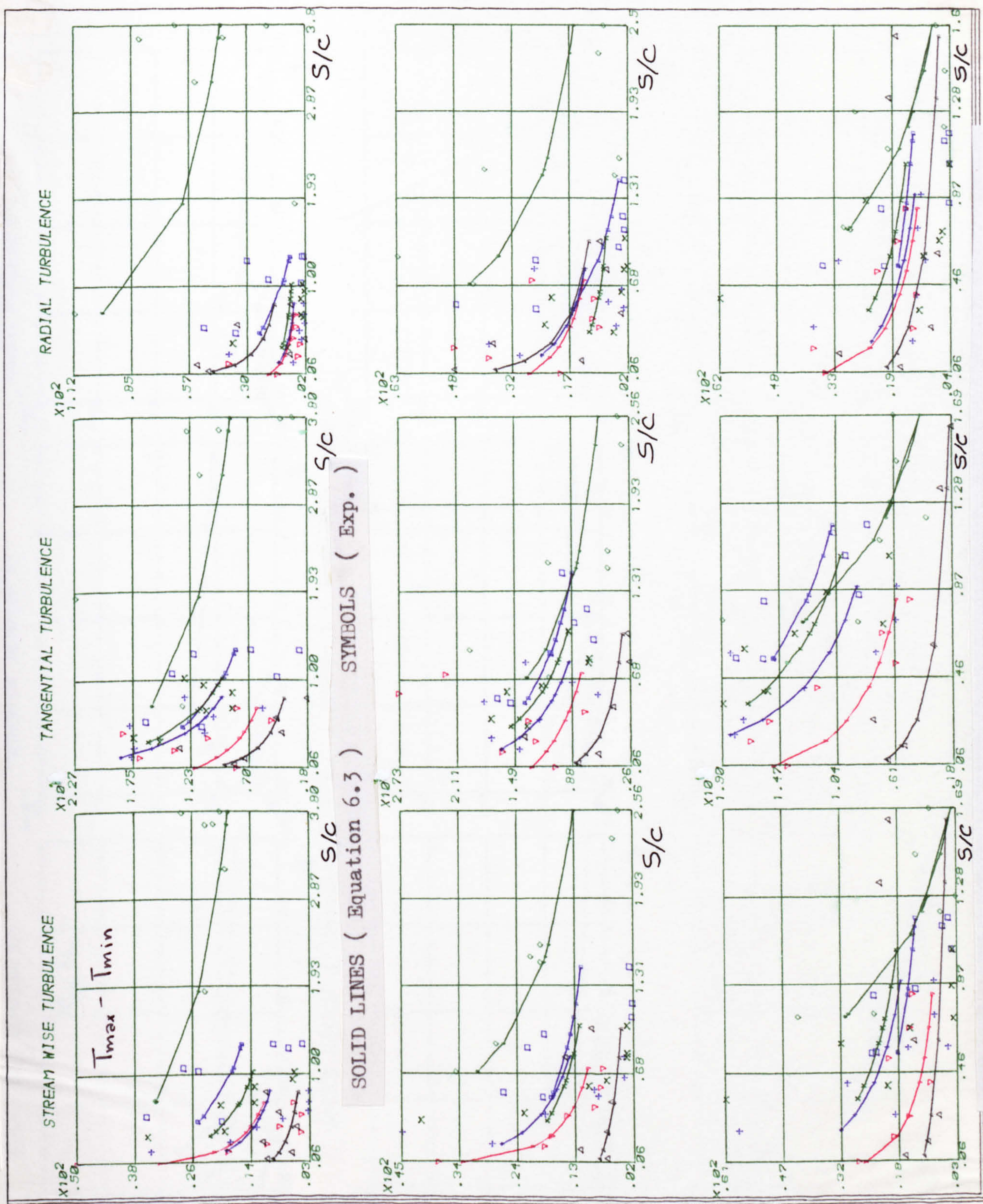


FIG 203 DECAY CHARACTERISTICS OF DIFFERENT TURBULENCE INTENSITY COMPONENTS

IN THE STREAM WISE FRAME OF REFERENCE.

SYMBOLS REPRESENT RADIAL LOCATIONS $\bar{R}=0.54 \Delta 0.6 + 0.7 \times - 0.8 \square - 0.9 \diamond 1.0$

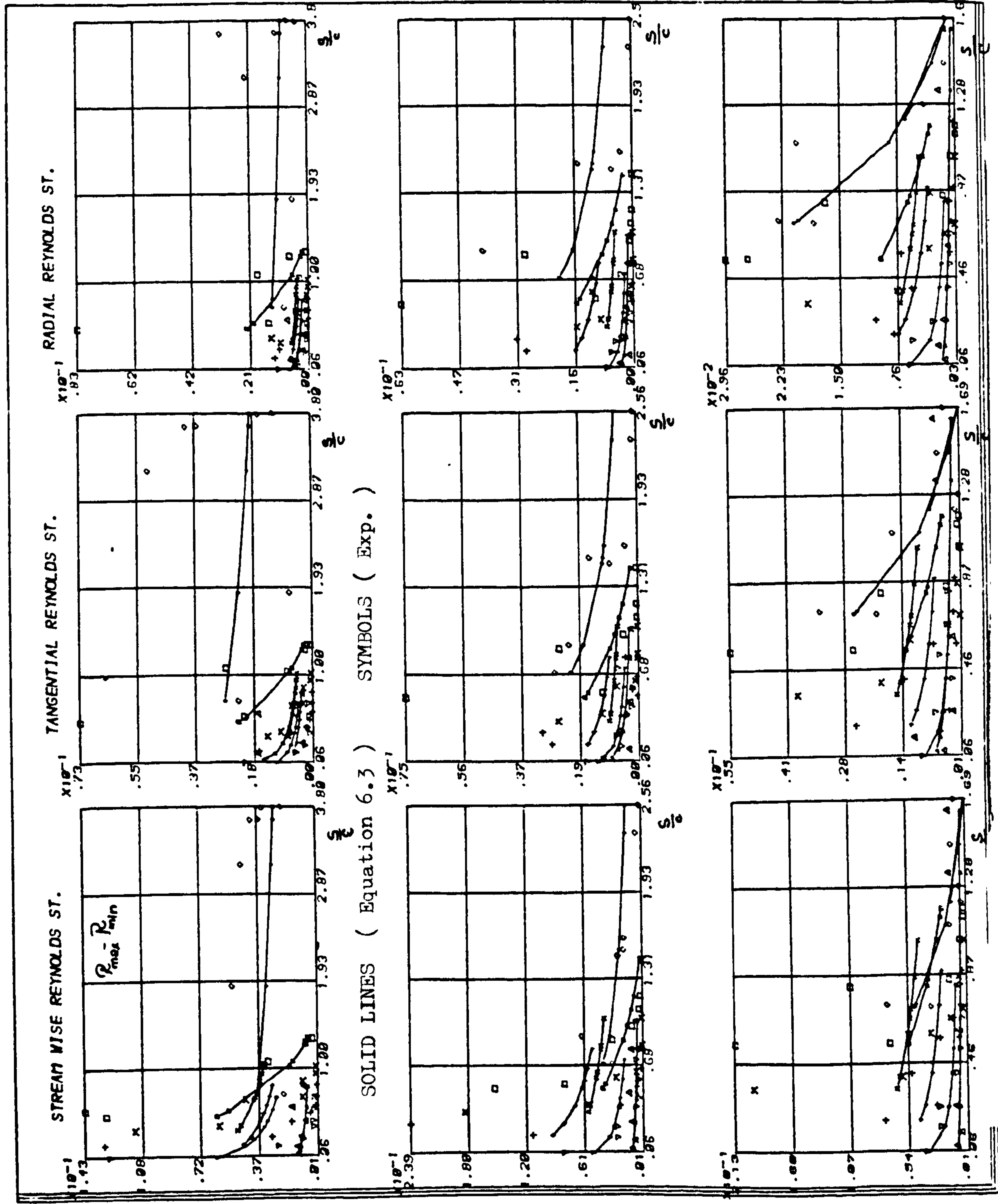


FIG 204 DECAY CHARACTERISTICS OF DIFFERENT REYNOLDS STRESS COMPONENTS IN THE STREAM WISE FRAME OF REFERENCE.

SYMBOLS REPRESENT RADIAL LOCATIONS $R=0.54 \times 0.61 \times 0.7 \times 0.8 \times 0.9 \times 1.0$

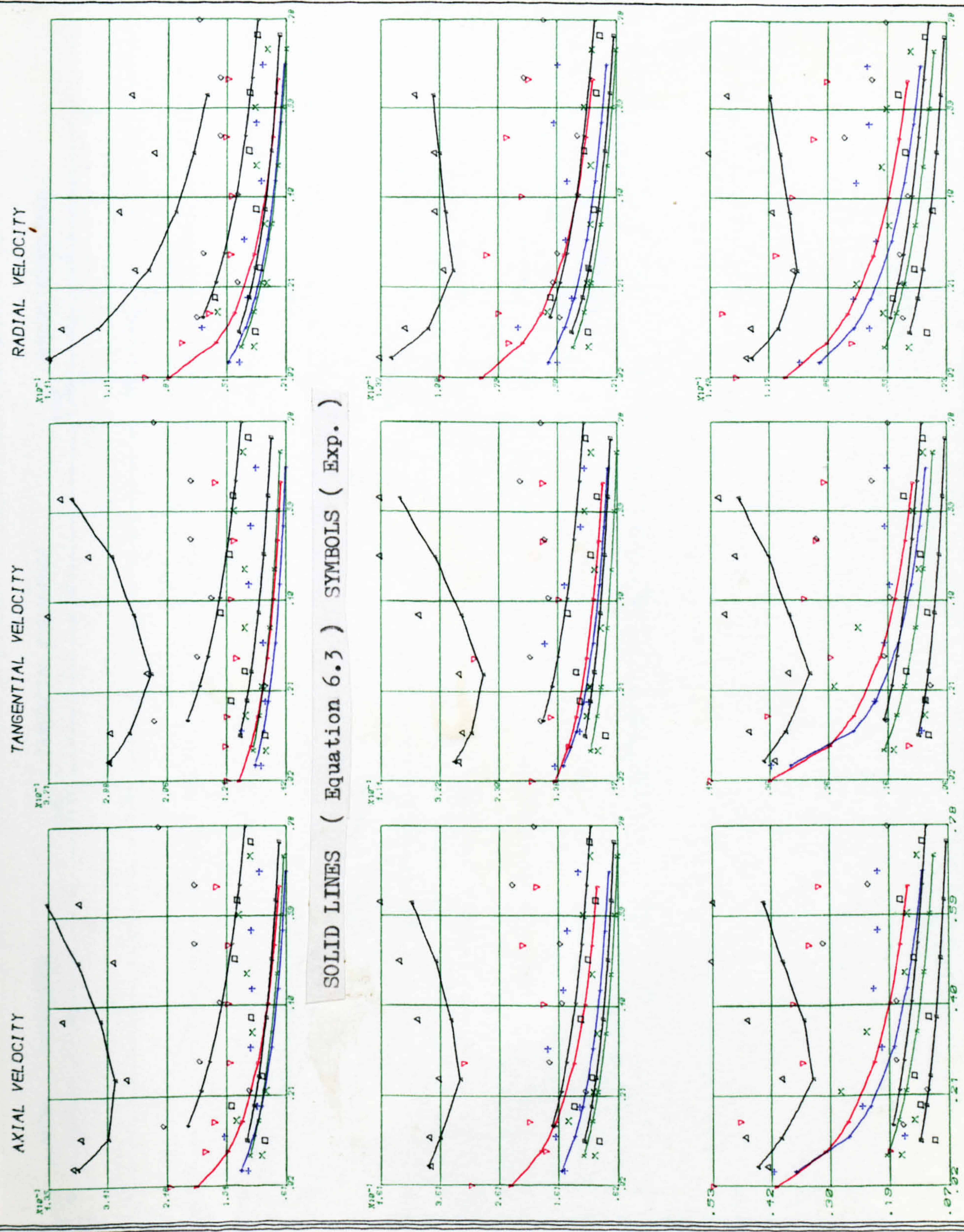
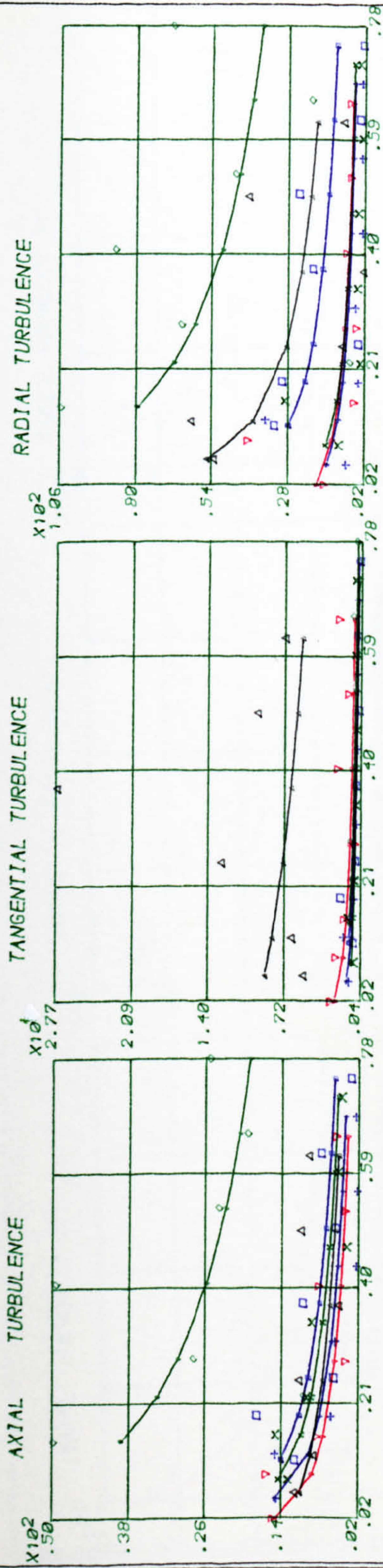


FIG 205 DECAY CHARACTERISTICS OF DIFFERENT VELOCITY COMPONENTS IN THE TURBOMACHINERY FRAME OF REFERENCE.

SYMBOLS REPRESENT RADIAL LOCATIONS $\tilde{R} = \Delta 0.54 \nabla 0.6 + \cdot 0.7 \times - \times 0.8 \square 0.9 \diamond 1.0$



SOLID LINES (Equation 6.3) SYMBOLS (Exp.)

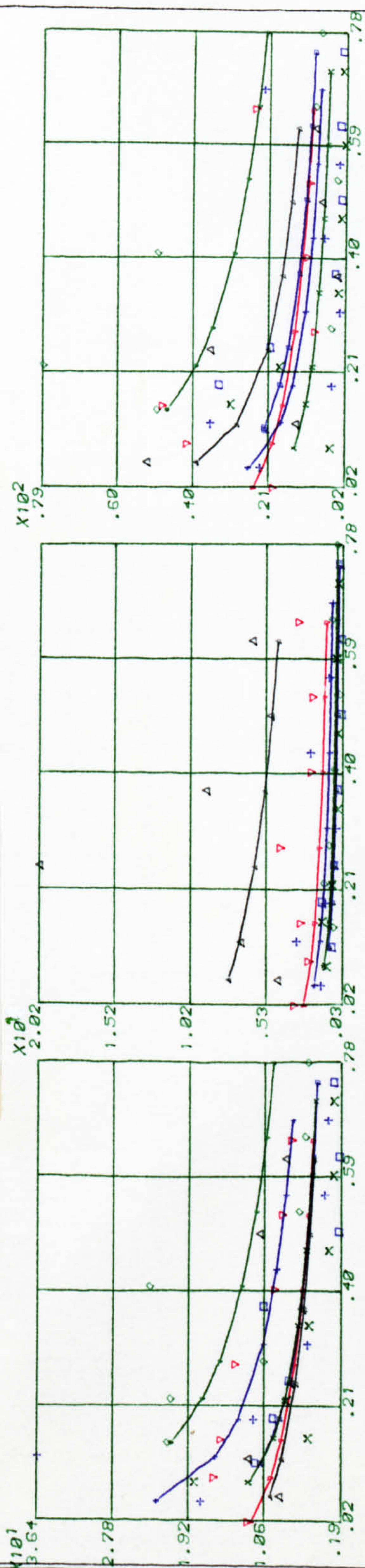
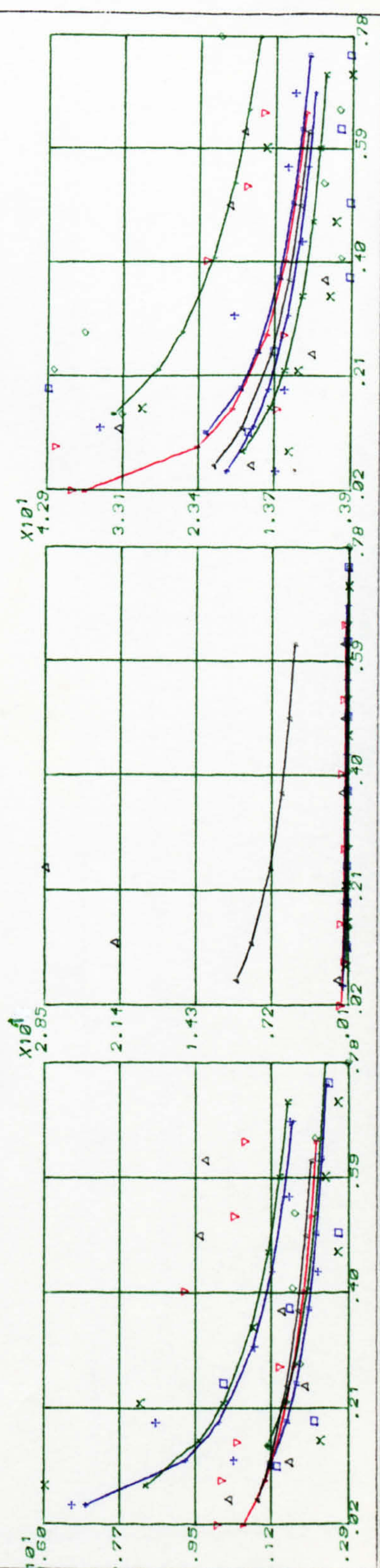


FIG 206 DECAY CHARACTERISTICS OF DIFFERENT COMPONENTS OF TURBULENCE INTENSITY IN THE TURBOMACHINERY FRAME OF REFERENCE.

SYMBOLS REPRESENT RADIAL LOCATIONS $R = 0.54, 0.6, 0.7, 0.8, 0.9, 1.0$

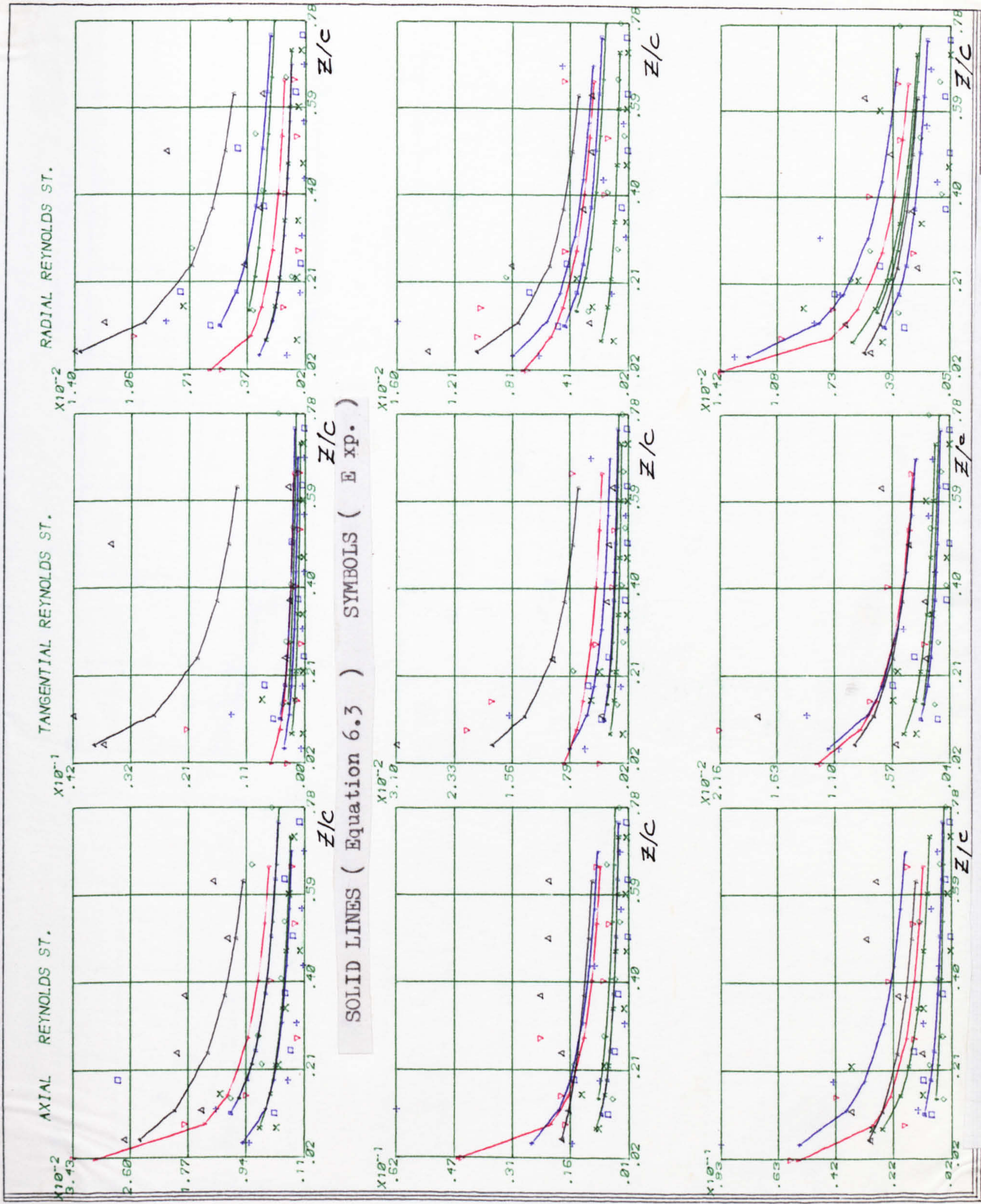


FIG 207 DECAY CHARACTERISTICS OF DIFFERENT COMPONENTS OF REYNOLDS STRESSES IN THE TURBOMACHINERY FRAME OF REFERENCE.

SYMBOLS REPRESENT CIRCUMFERENTIAL LOCATIONS 1 x x 2 + + 3 v - v 4 Δ Δ 5 * * 6 ◇ ◇ 7 ○ ○ 8

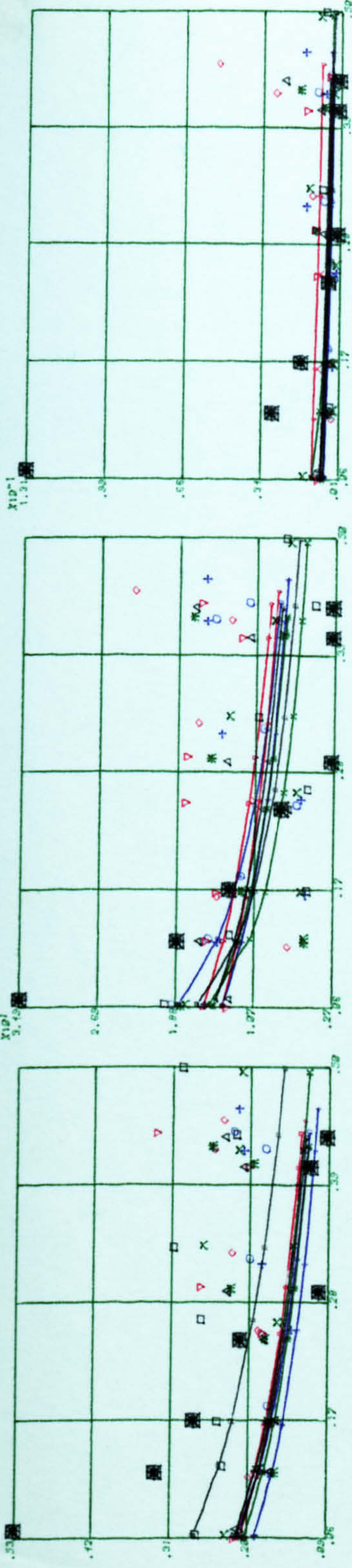
CLEAN FLOW

" See Fig. 1110 "

VELOCITIES (ST. W.)

TURBULENCE (ST. W.)

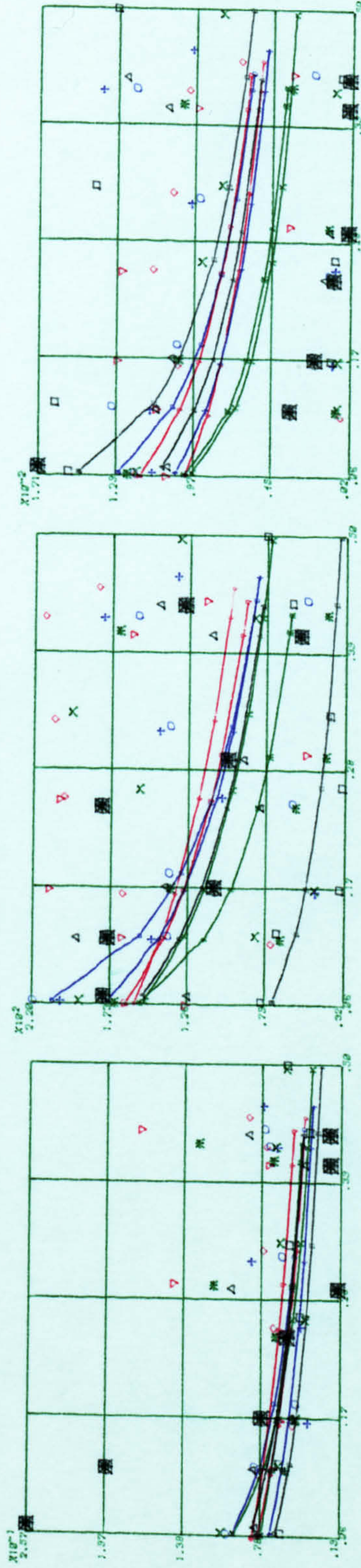
REYNOLDS STRESSES



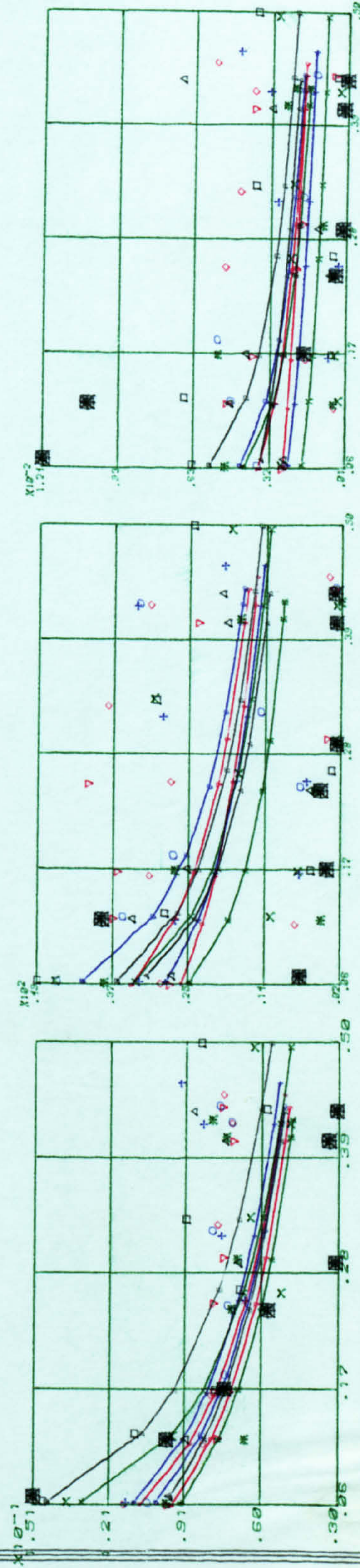
AXIAL

SOLID LINES (Equation 6.3)

SYMBOLS (Exp.)



TANGENTIAL



RADIAL

FIG 208 DECAY CHARACTERISTICS OF FLOW PARAMETERS IN THE STREAM WISE FRAME OF REFERENCE
IN THE DISTORTION REGIME.

SYMBOLS REPRESENT CIRCUMFERENTIAL POSITIONS 0 1 2 3 4 5 6 7 8

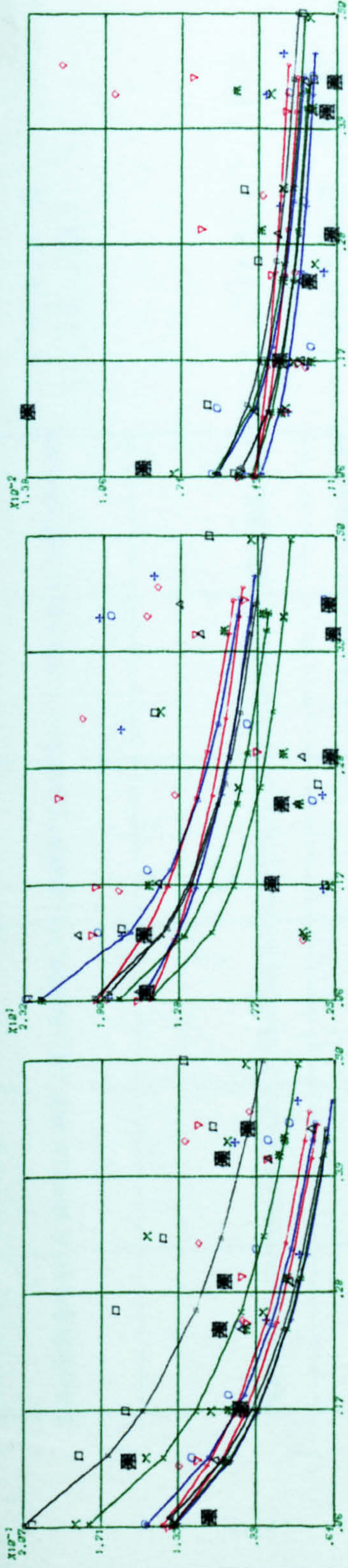
See fig. 110

CLEAN FLOW

VELOCITIES (TURBOMACHINERY)

TURBULENCE (TURBOMACHINERY)

REYNOLDS STRESSES (TUR.)



SOLID LINES (Equation 6.3) SYMBOLS (Exp.)

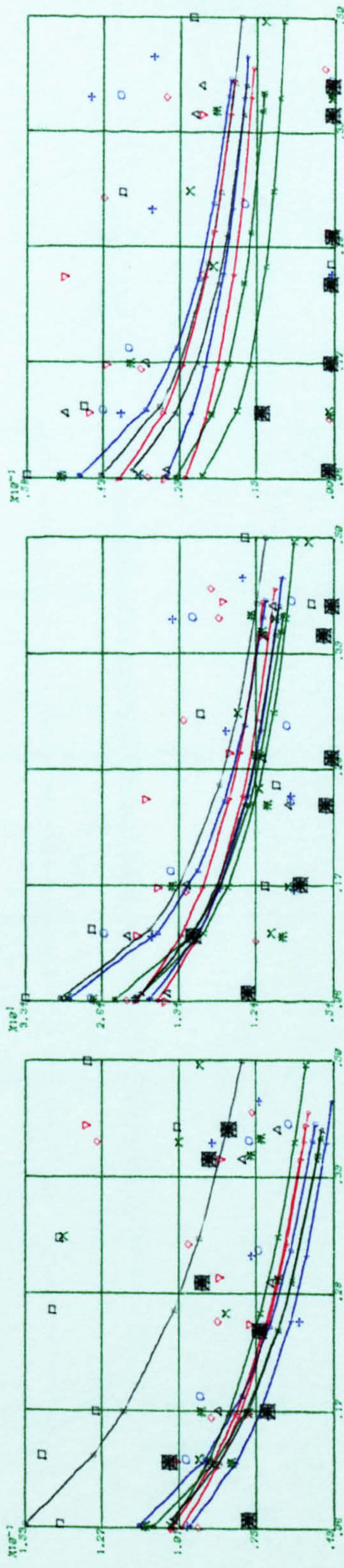
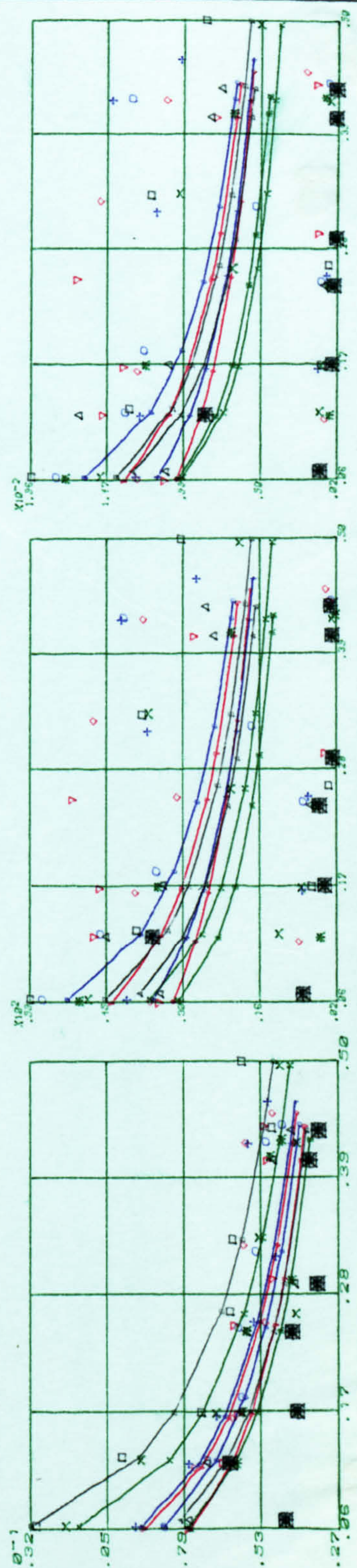


FIG 209 DECAY CHARACTERISTICS OF FLOW PARAMETERS IN THE TURBOMACHINERY FRAME OF REFERENCE IN THE DISTORTION REGIME.

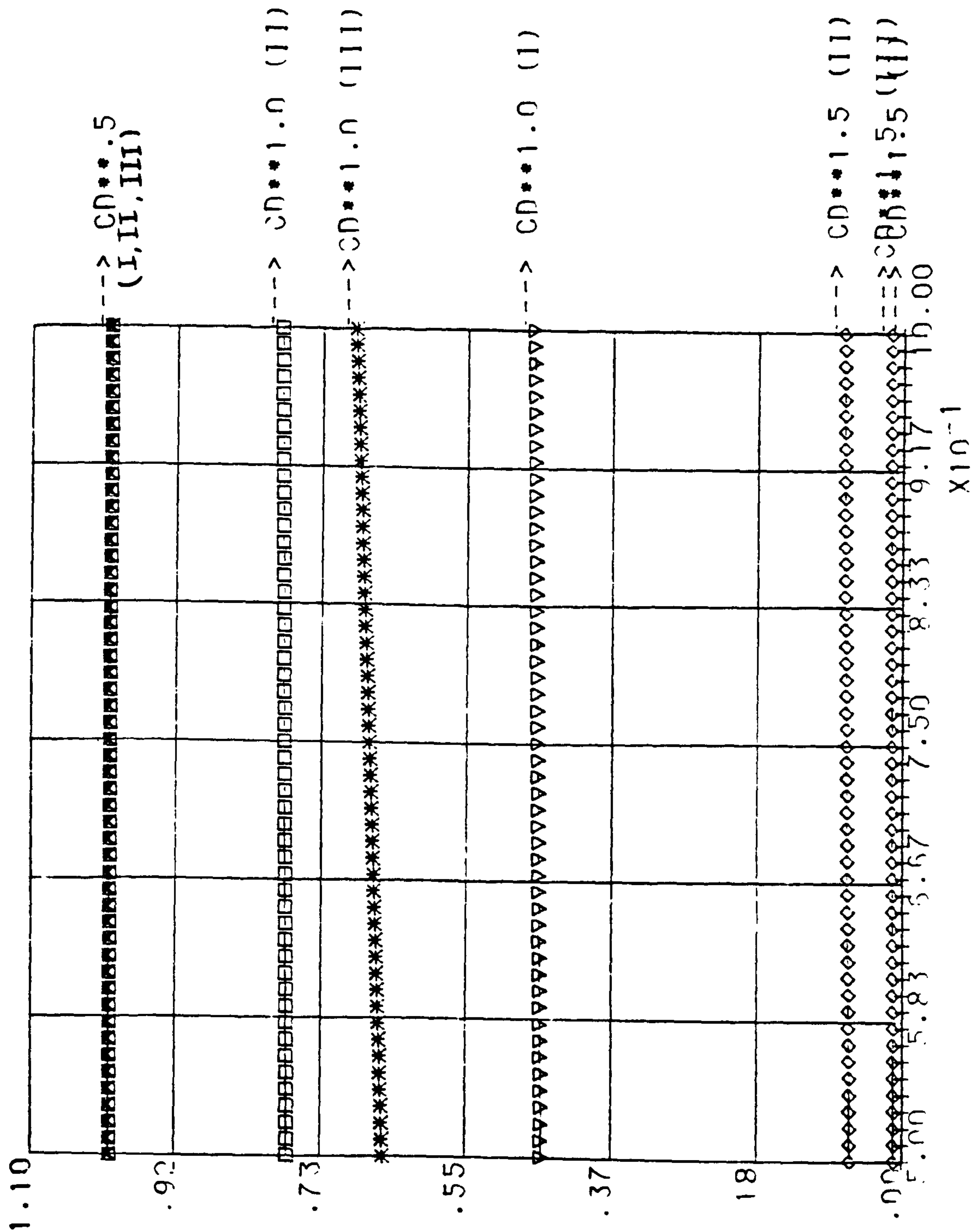


FIG 210 CROSS SECTION DRAG COEFFICIENT DIST. WITH THE RADIAL DIR.

SYMBOLS REPRESENT RADIAL LOCATIONS FROM THE HUB TO THE TIP.

HUB Δ 0.54 ∇ 0.6 $+$ 0.7 $\times$ 0.8 $\square$ 0.9 $\diamond$ 1.0 TIP

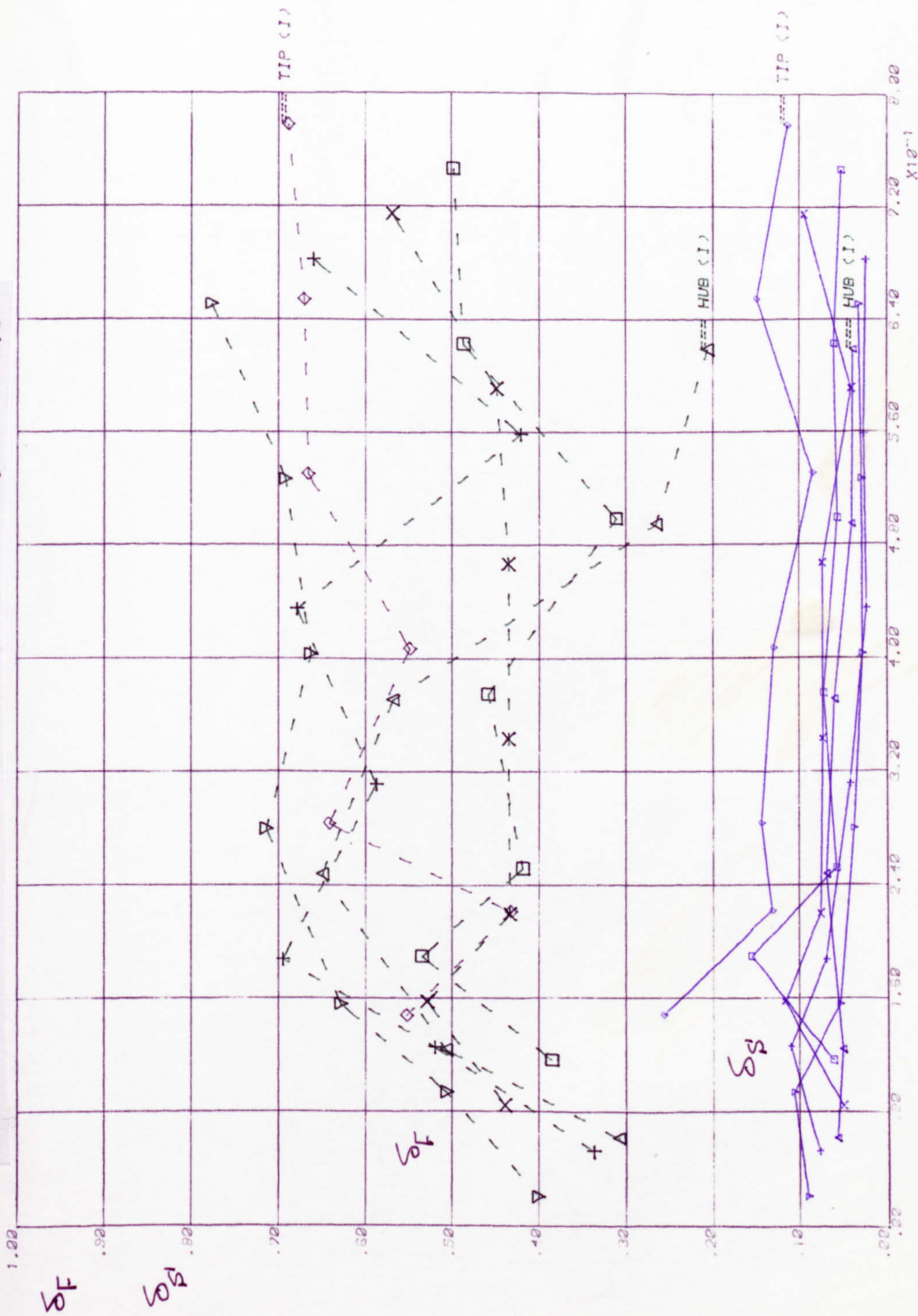


Fig 211 DISTRIBUTION OF SEMI WAKE WIDTH AND FULL WAKE WIDTH AT LOAD (I)

SYMBOLS REPRESENT RADIAL LOCATION FROM THE HUB TO THE TIP

$\tilde{R} = \Delta \rightarrow 0.54 \nabla \rightarrow 0.6 + \rightarrow 0.7 \times \rightarrow 0.8 \square \rightarrow 0.9 \diamond \rightarrow 1.0$

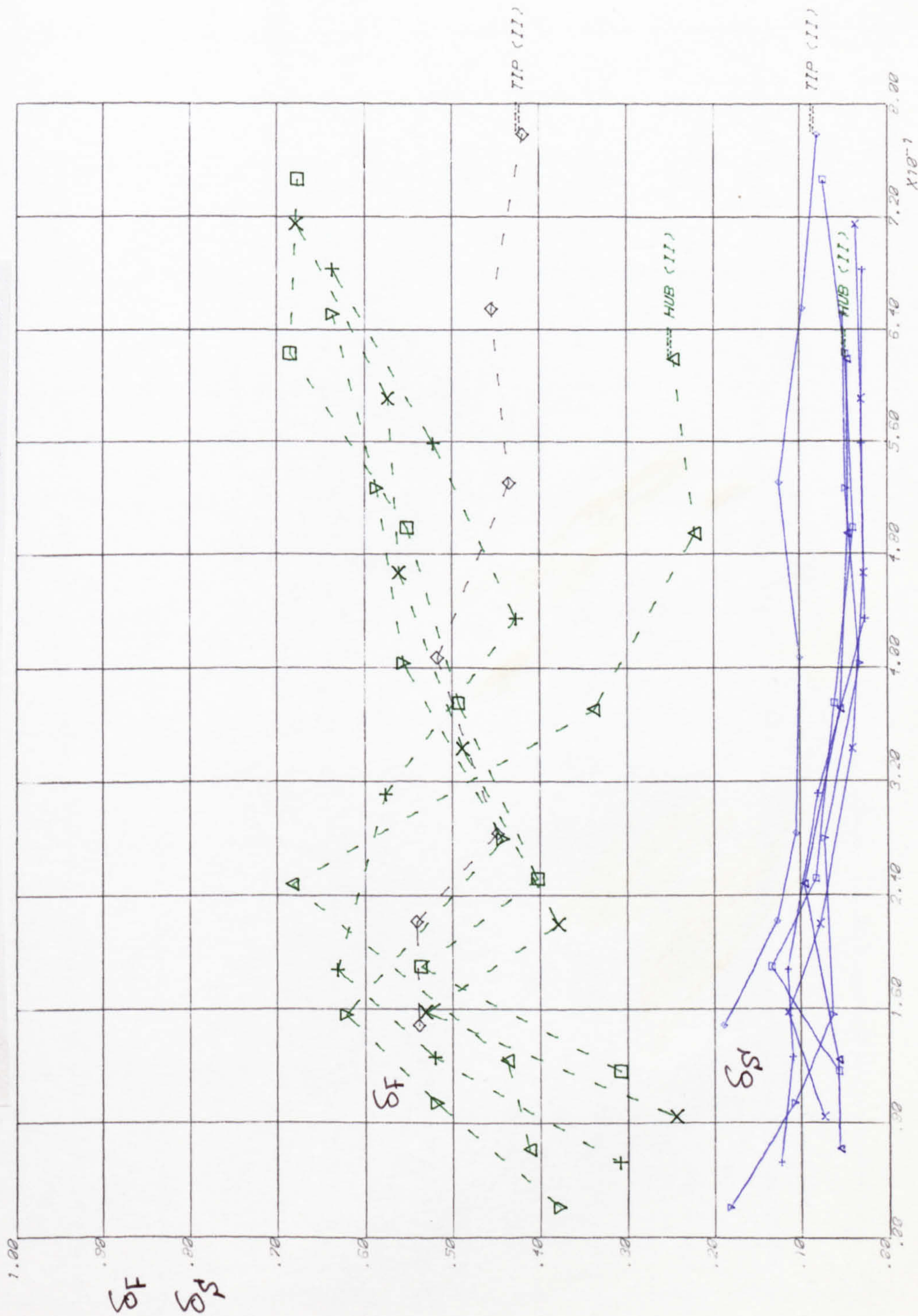


Fig 212 DISTRIBUTION OF SEMI WAKE WIDTH AND FULL WAKE WIDTH AT LOADS

SYMBOLS REPRESENT RADIAL LOCATIONS FROM THE HUB TO THE TIP

$\tilde{R} = 0.54$ $\square$ 0.6 $+$ 0.7 $\times$ 0.8 $\square$ 0.9 $\diamond$ 1.0

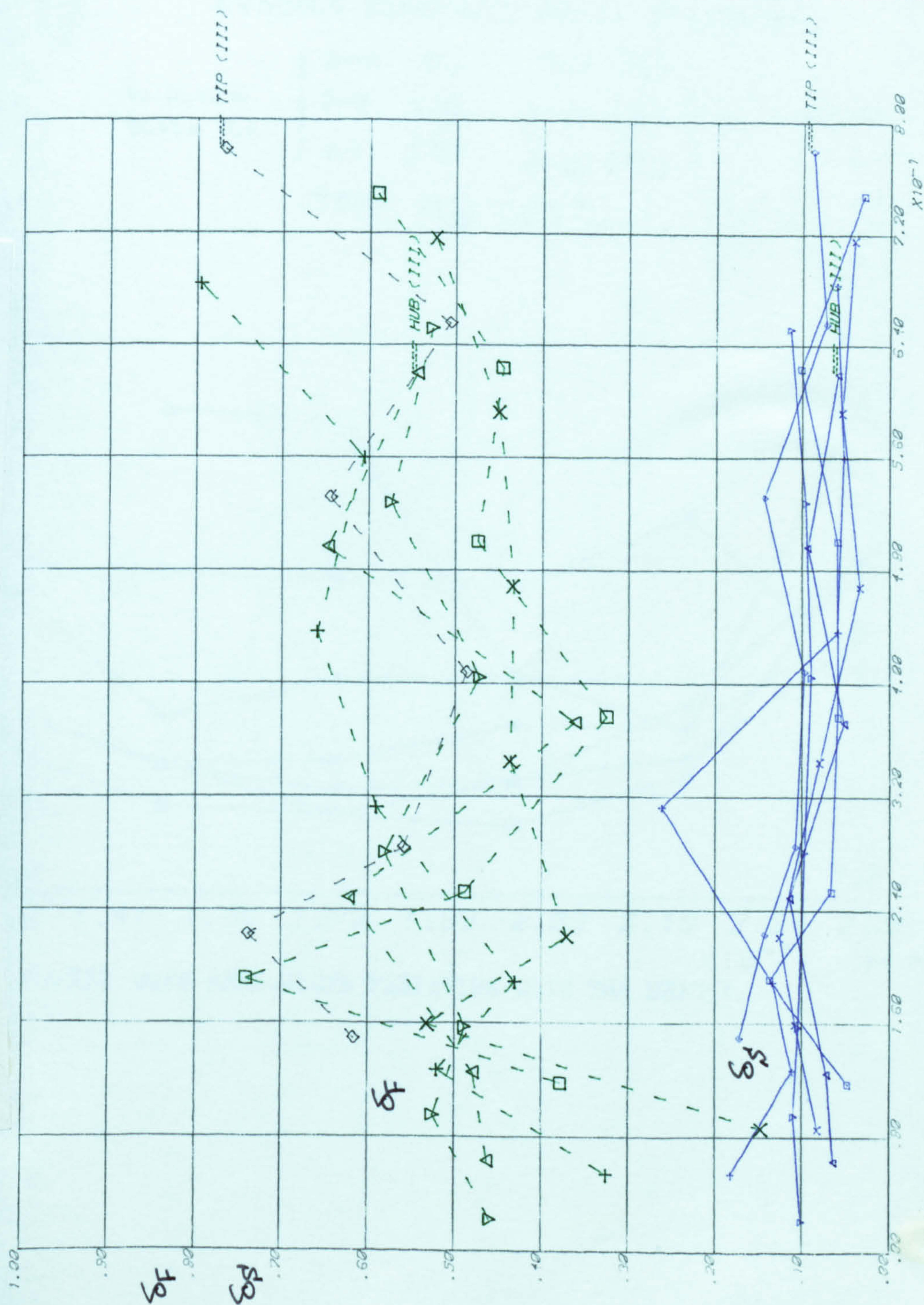


Fig 213 DISTRIBUTION OF SEMI WAKE WIDTH AND FULL WAKE WIDTH AT LOAD III

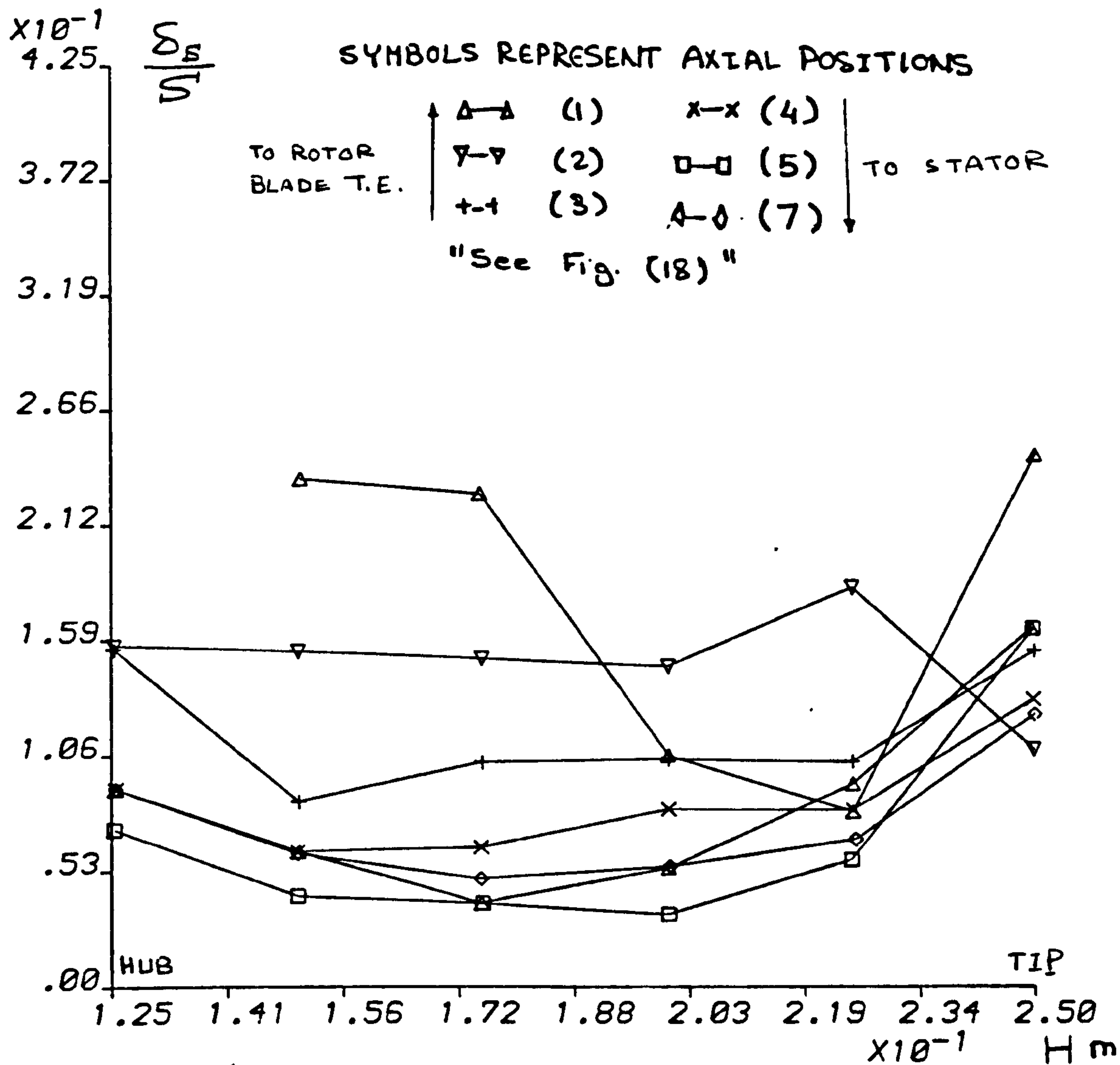


FIG 214 WAKE SEMI-WIDTH VARIATION WITH THE HEIGHT.

SYMBOLS REPRESENT CIRCUMFERENTIAL POSITIONS D-1 * 2 + - 3 ▽ - 4 Δ - 5 * - 6 ◇ - 7 ○ - 8
 ■ CLEAN FLOW
 " See Fig 110 "

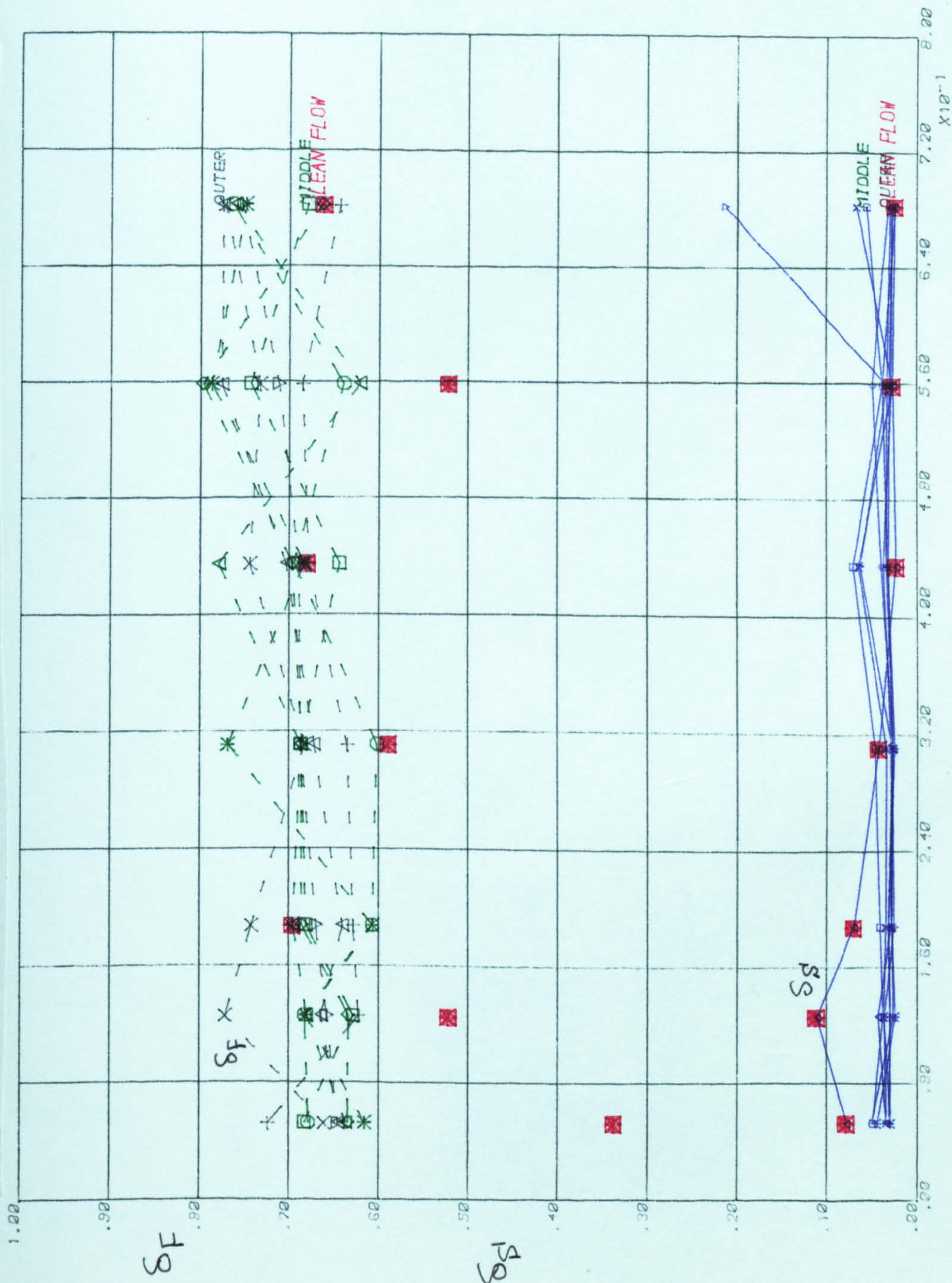
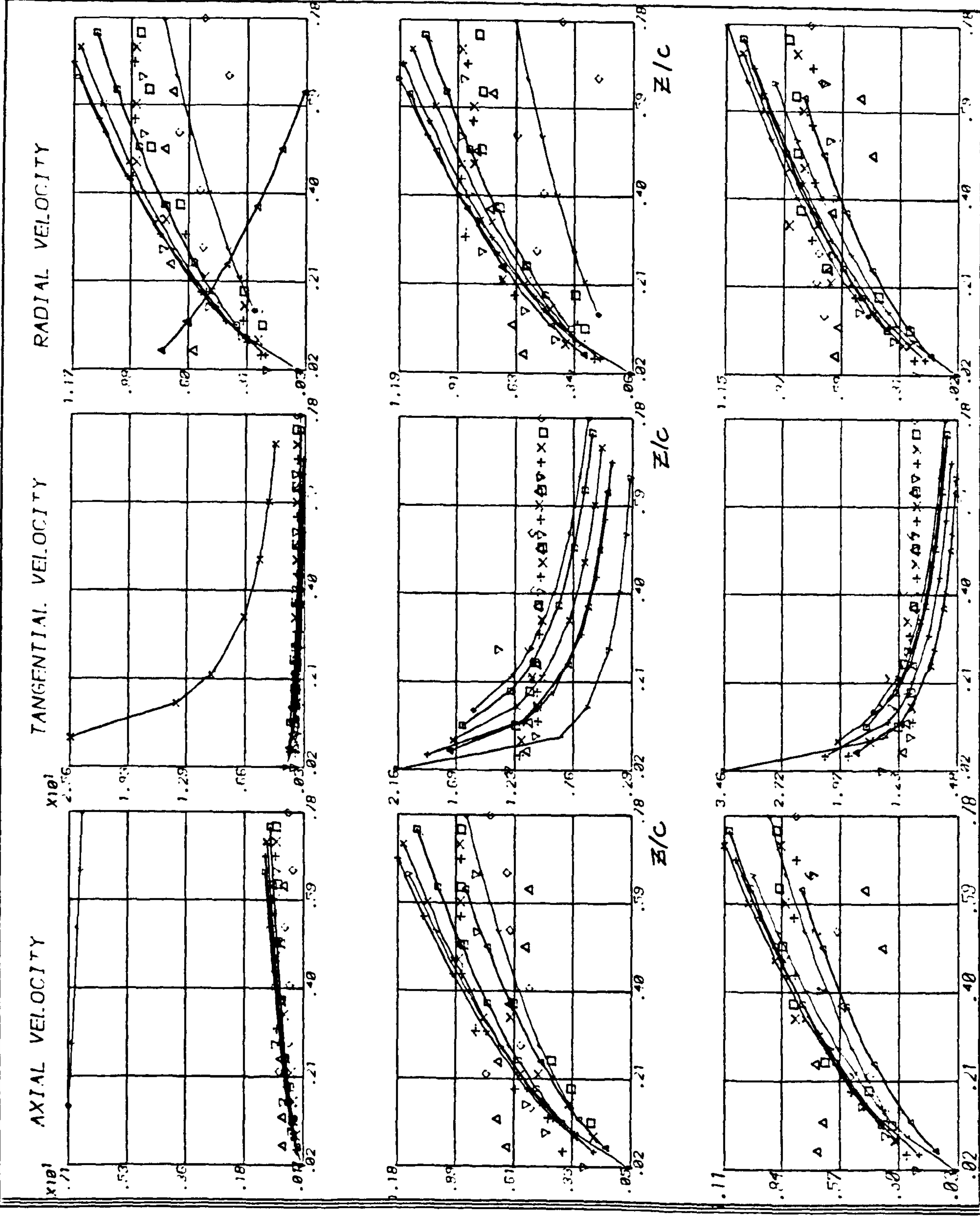


Fig 25 DISTRIBUTION OF SEMI WAKE WIDTH AND FULL WAKE WIDTH IN THE CLEAN AND DISTORTED FLOW

$\tilde{R} = \Delta \rightarrow 0.54 \quad \nabla \rightarrow 0.6 \quad + \rightarrow 0.7 \quad \times \rightarrow 0.8 \quad \square \rightarrow 0.9 \quad \circ \rightarrow 1.0$

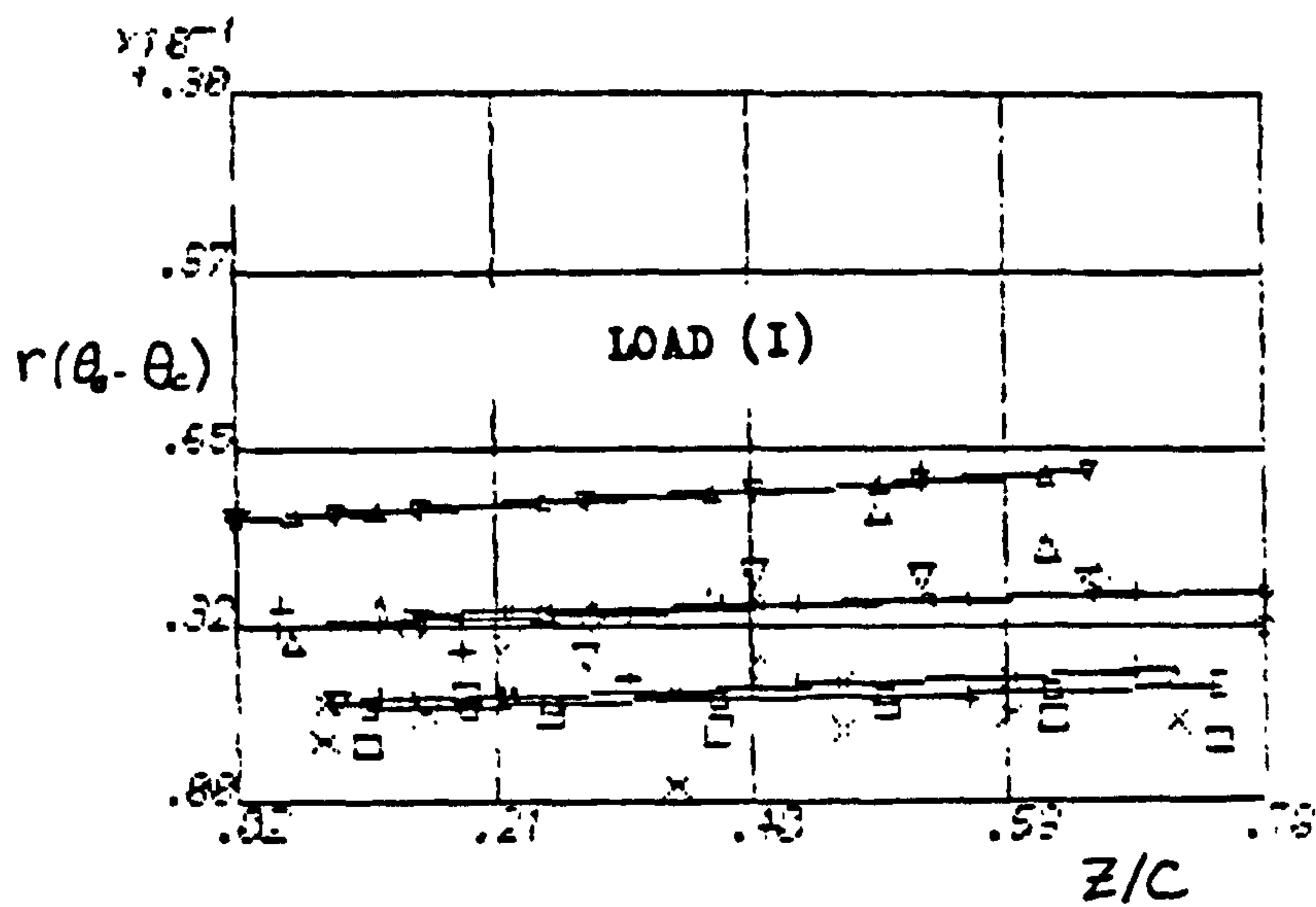
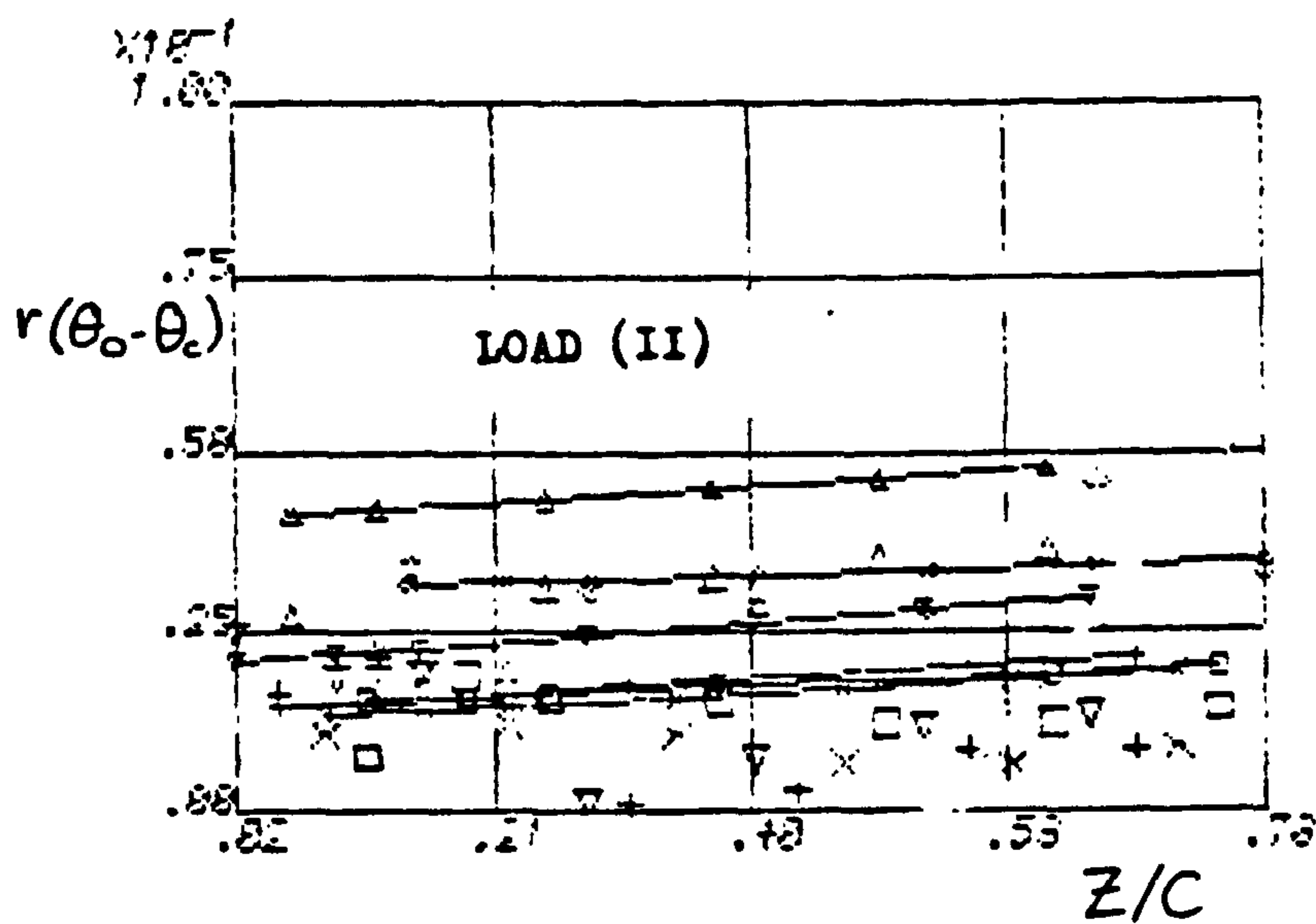


INC (I)

INC (II)

INC (III)

FIG 216 DISTRIBUTION OF THEORETICAL AND EXPERIMENTAL ROTOR WAKE CENTRE LINE VELOCITY.



$\tilde{R} = \Delta - \Delta$ 0.54 HUB
 $\nabla - \nabla$ 0.6
 $+ - +$ 0.7
 $x - x$ 0.8
 $\square - \square$ 0.9
 $\diamond - \diamond$ ~ 1.0 TIP

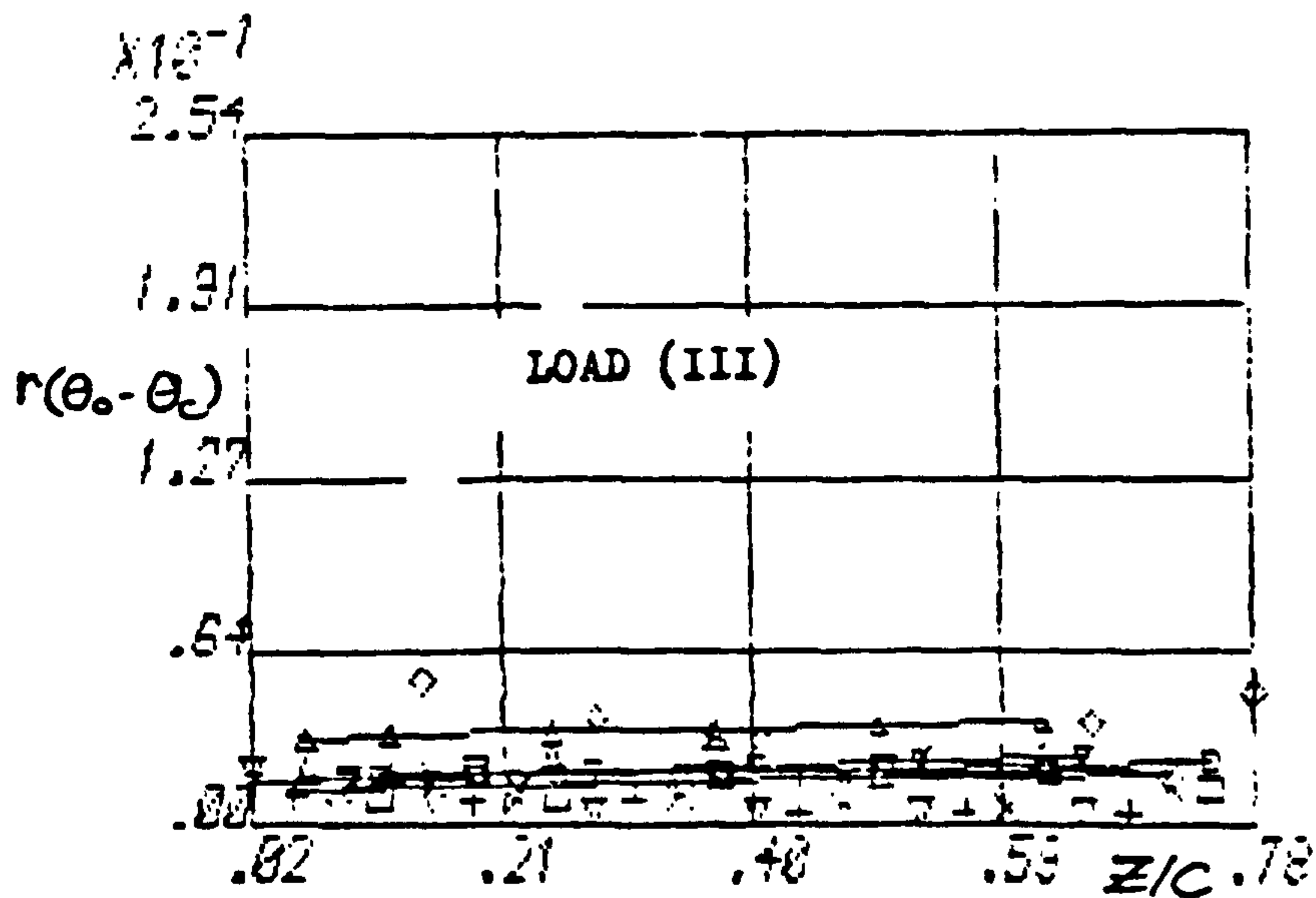


FIG 217 DISTRIBUTION OF THE THEORETICAL AND EXPERIMENTAL HALF WAKE WIDTH DEFINED AS $r(\theta_0 - \theta_c)$. SOLID LINES (THEORY) SYMBOLS (EXP.)

" SYMBOLS REPRESENT CIRCUMFERENTIAL POSITIONS 0-1 x-2 +-3 v-4 d-5 *-6 d-7 o-8"
 (See Fig. 110)

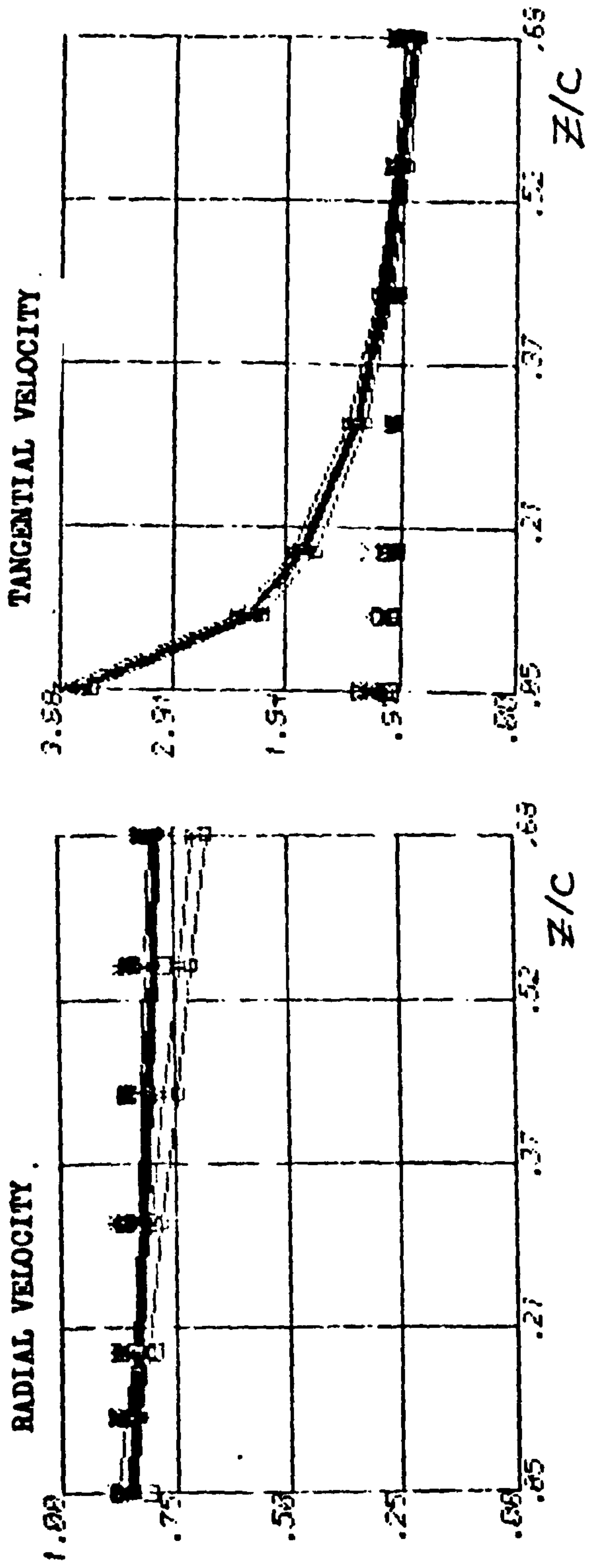
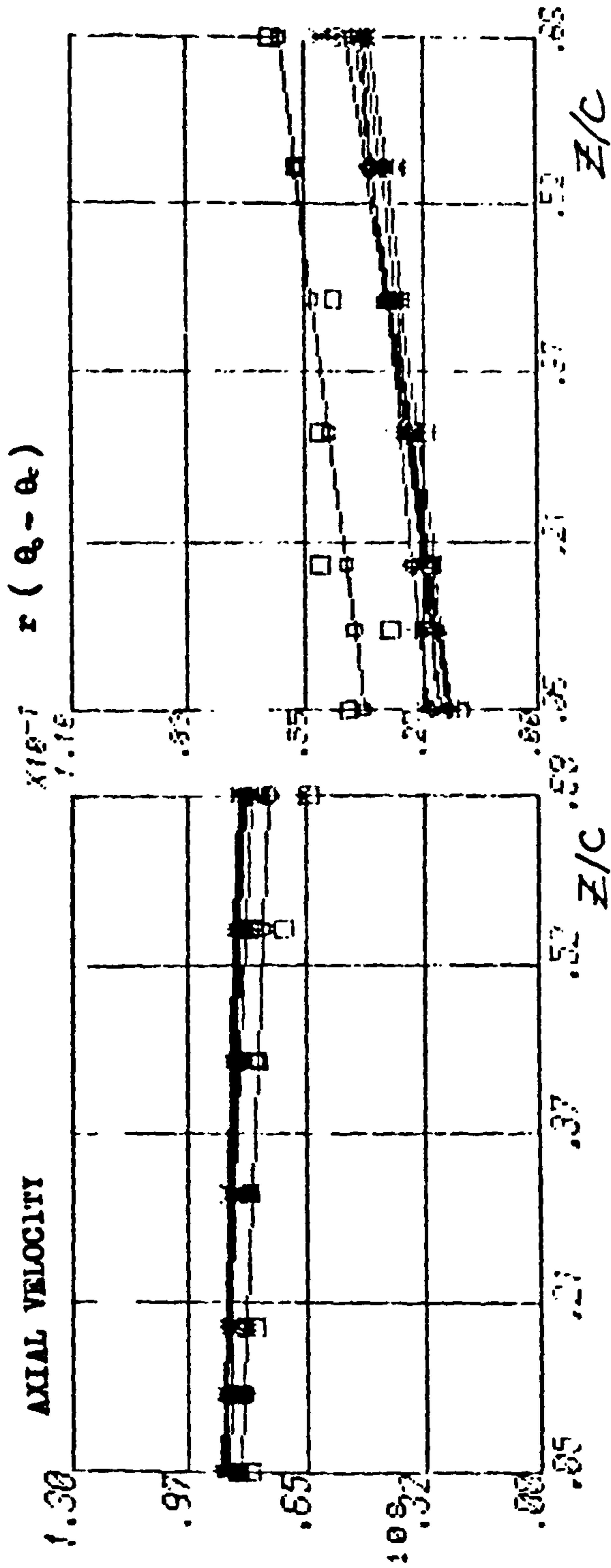


FIG 218 DISTRIBUTION OF DIFFERENT COMPONENTS OF ROTOR WAKE CENTRE LINE VELOCITY AND WAKE WIDTH (DEFINED AS $r (\theta_0 - \theta_c)$) IN THE DISTORTION REGIME.
 SOLID LINES (THEORY) SYMBOLS (EXP.)

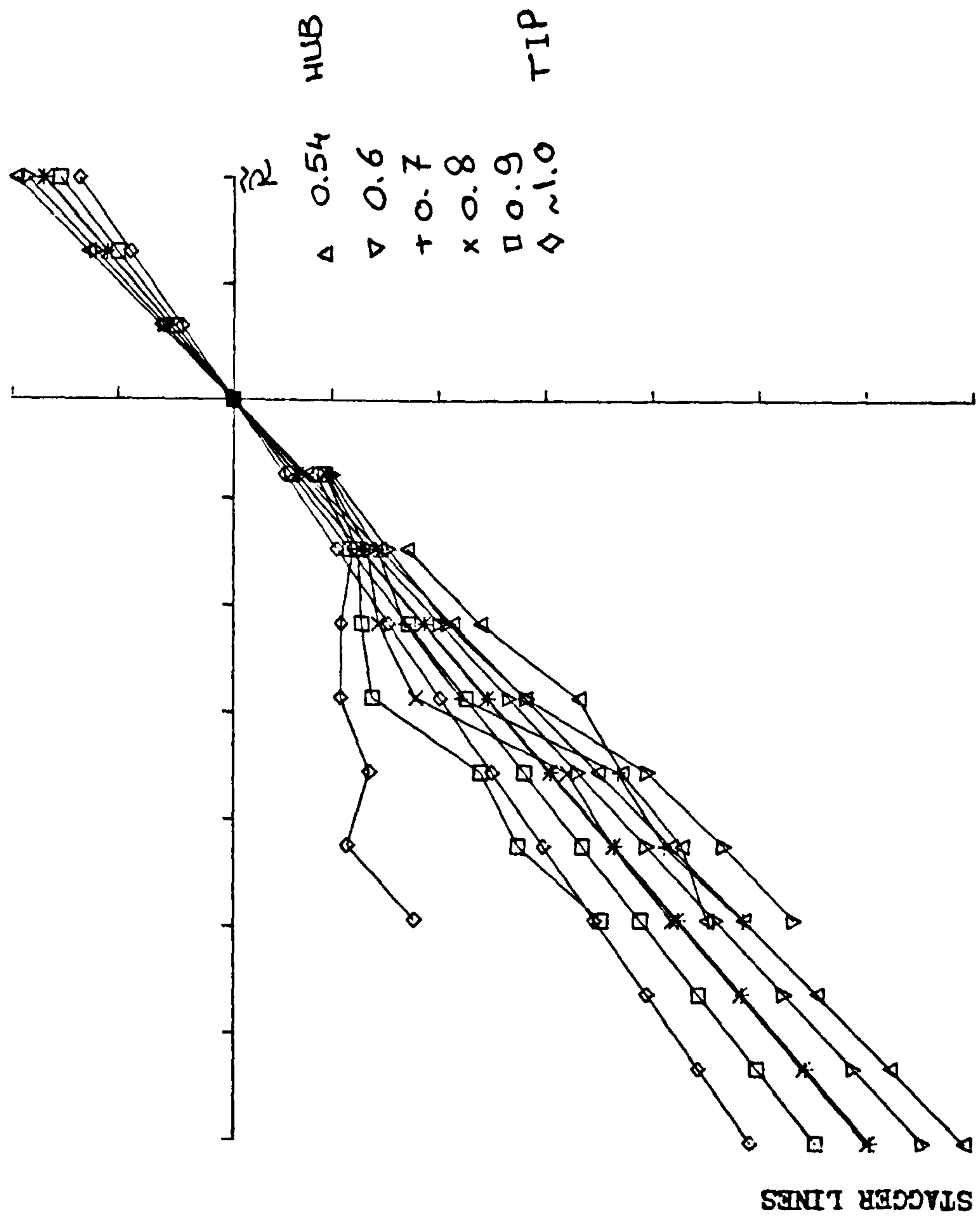


FIG 219 CURVATURE OF THE WAKE CENTRE LINE AT LOADING (I).

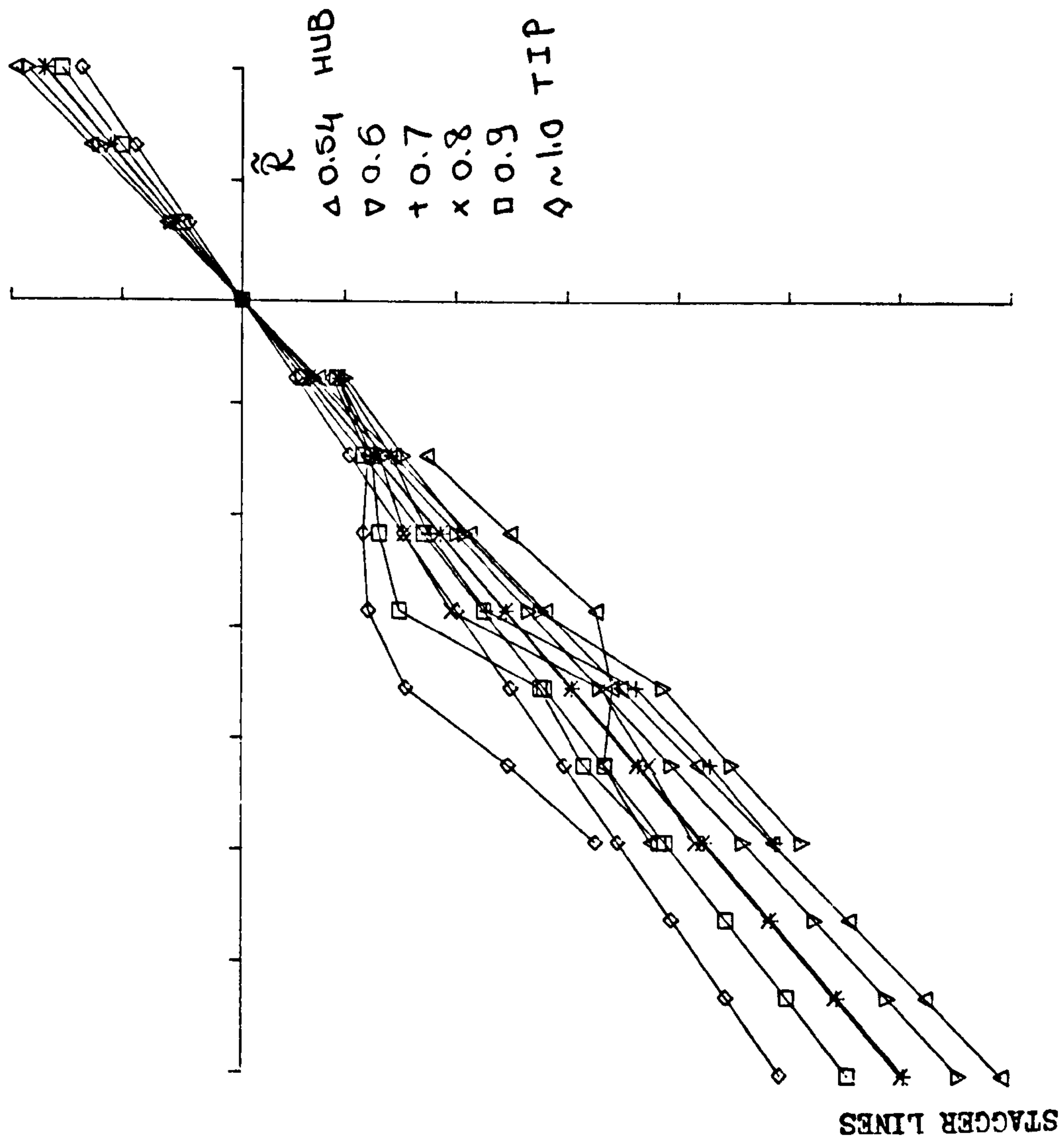


FIG 220 CURVATURE OF WAKE CENTRE LINE AT LOADING (II).

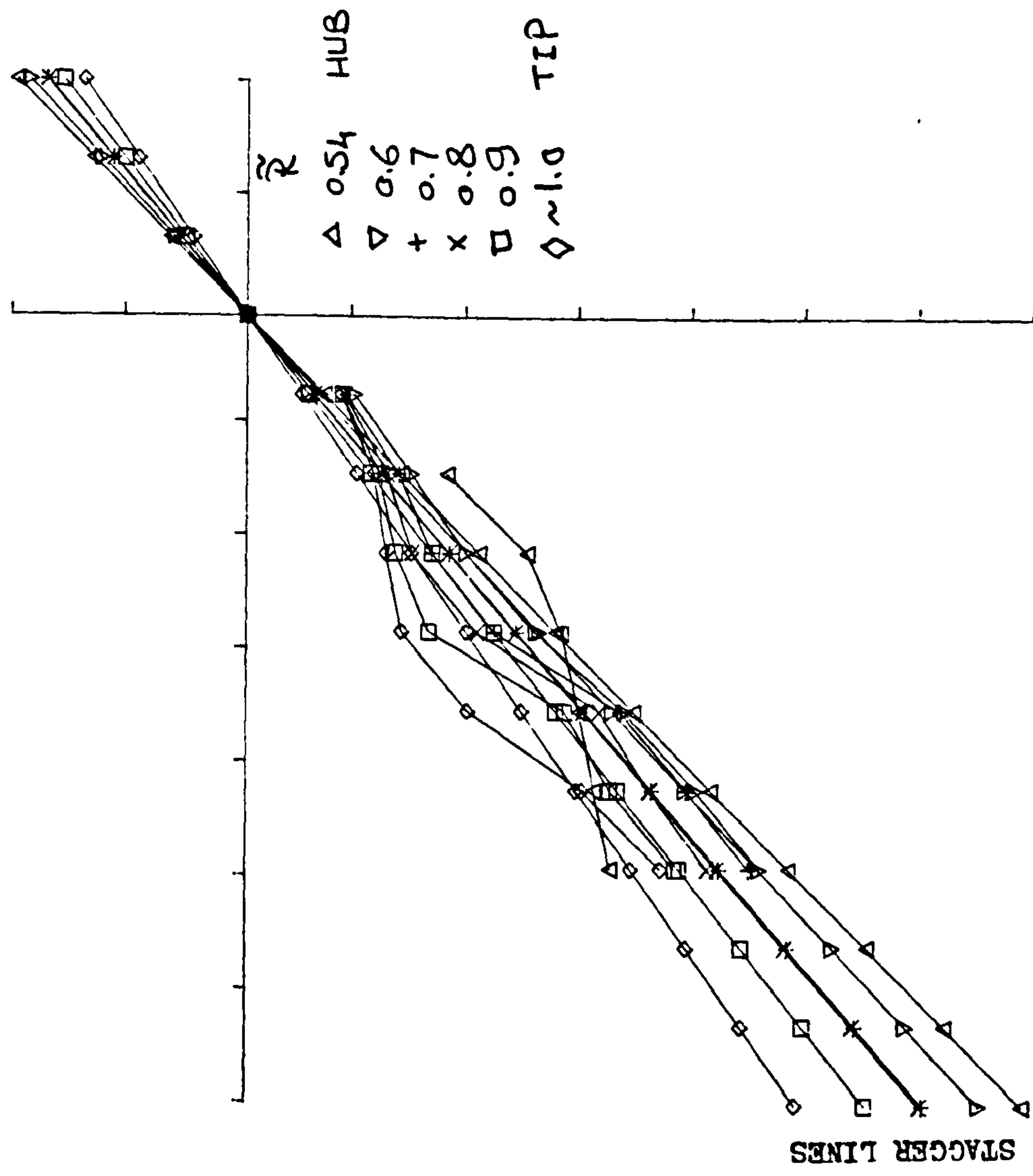
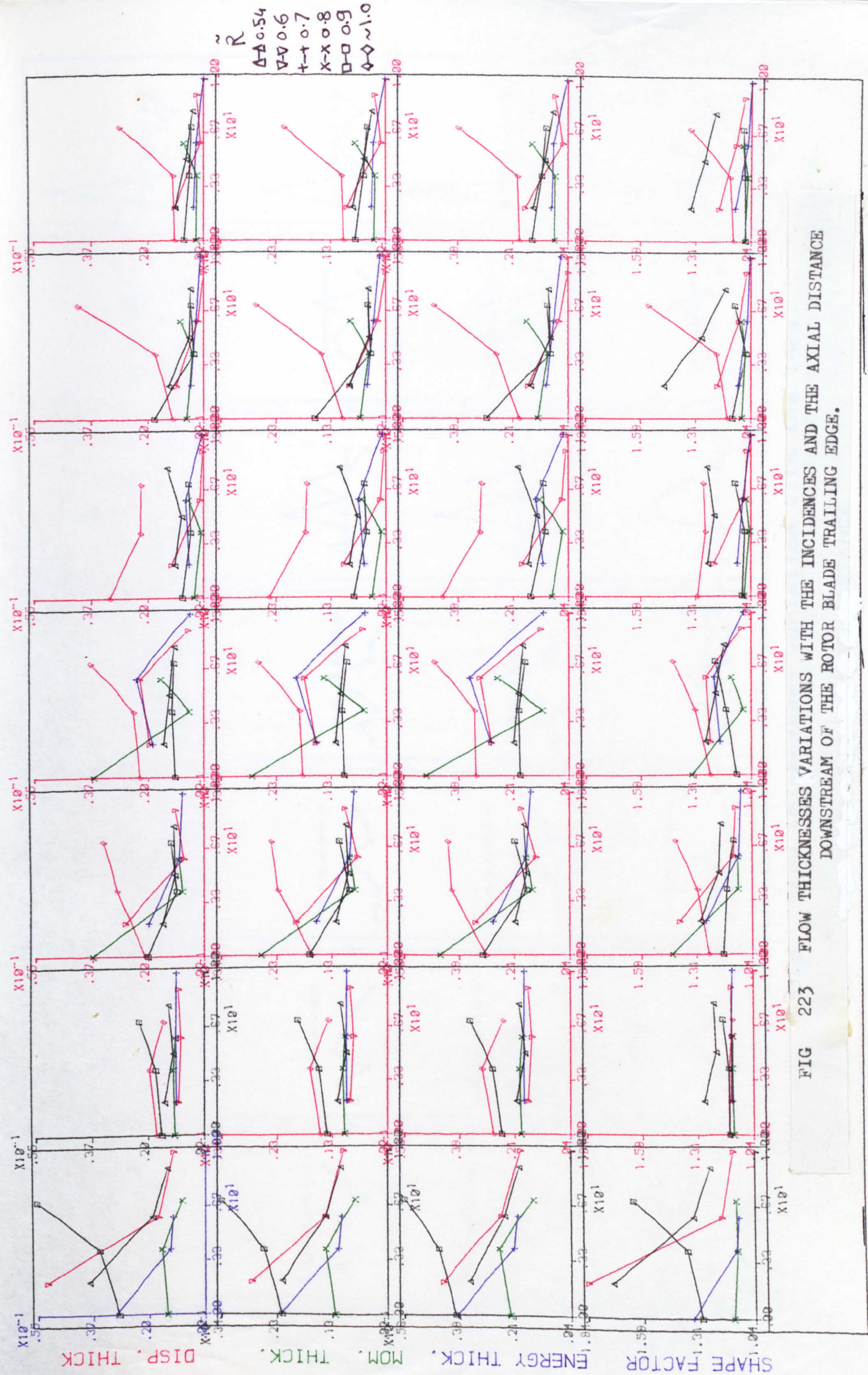


FIG 221 CURVATURE OF WAKE CENTRE LINE AT LOADING(III).



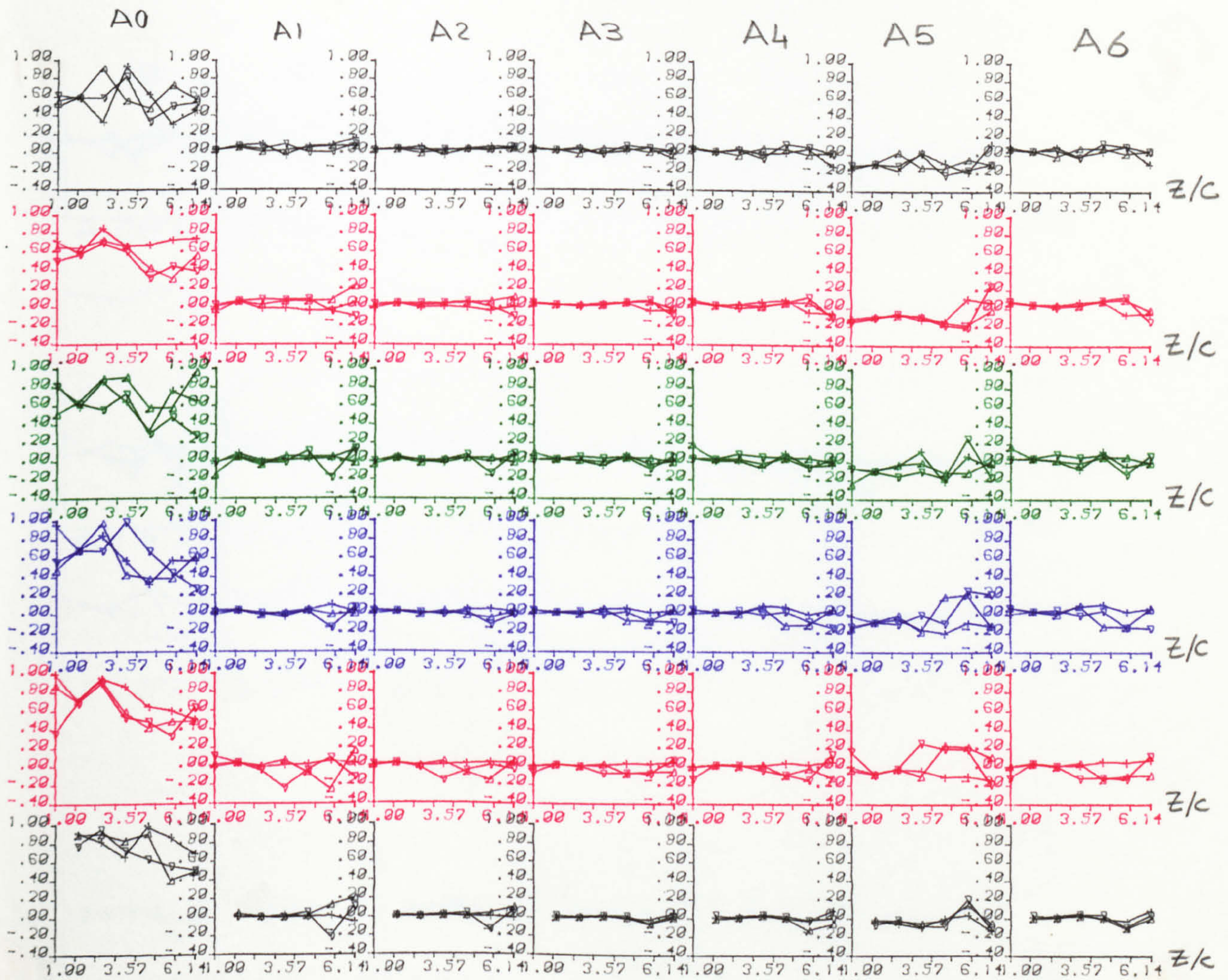


FIG 225 DISTRIBUTION OF A'S COEFFICIENTS OF WAKE FOURIERS' HARMONICS AT ALL THREE LOADINGS.

△△ LOAD (I)

○○ LOAD (II)

+--+ LOAD (III)

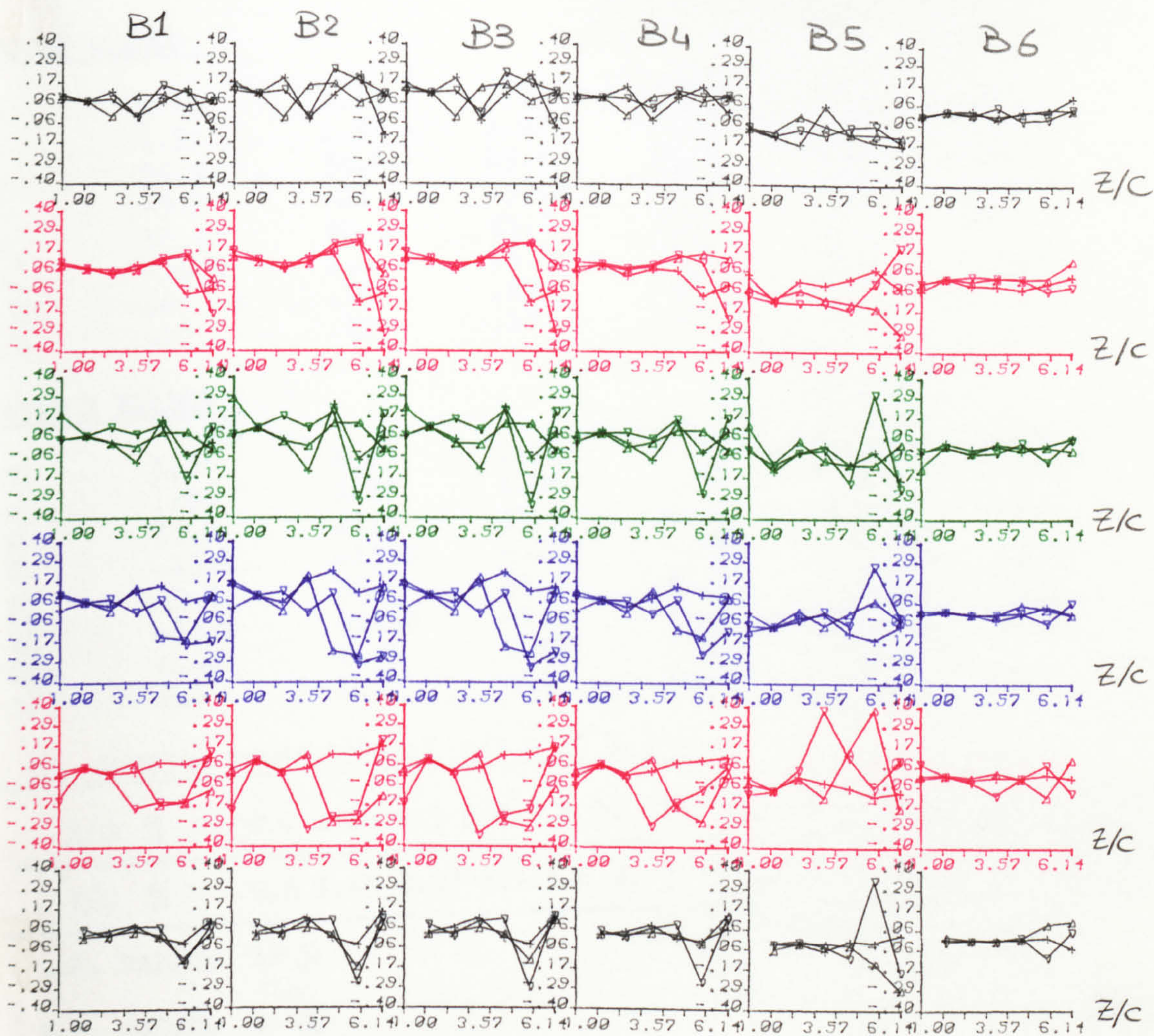


FIG 226 DISTRIBUTION OF B'S COEFFICIENTS OF WAKE FOURIERS CONTENTS AT ALL THREE LOADINGS.

TABLE (1)

DETAILS OF COMPRESSOR BLADING

Rotor blades 27 blades
 Stator blades 28 blades

ROTOR BLADES

R	5.10	6.23	7.35	7.5	8.53	9.7
c	1.91	1.91	1.91	1.91	1.91	1.91
θ	52.4	38.6	29.6	28.6	23.3	17.0
γ	-9.2	-21.6	-30.9	-31.3	-38.3	-45.0
B ₁	35.4	40.9	45.7	46.1	49.9	53.5
B ₂	-16.9	2.2	16.2	17.5	26.6	36.5
S/C	.63	.76	.89	.92	1.04	1.18
t/c	.12	.12	.12	.12	.12	.12

STATOR BLADES

R	5.1	6.23	7.35	7.5	8.53	9.7
c	1.86	1.86	1.86	1.86	1.86	1.86
θ	53.2	47.6	43.0	42.4	39.4	36.0
γ	-13.6	-13.0	-11.9	-11.7	-10.5	-9.0
B ₃	40.2	36.8	33.4	32.9	30.2	27.0
B ₄	-13.0	-10.8	-9.5	-9.5	-9.2	-9.0
S/C	0.62	0.75	0.89	0.905	1.03	1.17
t/c	0.1	0.1	0.1	0.1	0.1	0.1

CA SECTION COORDINATES (t/c = 10 %)

X/C %	0.0	1.25	2.5	5.0	7.5	10.	15.	20.	30.	40.	50.	60.	70.	80.	90.	95.	100.
Y/C %	0.0	1.65	2.27	3.1	3.6	4.	4.55	4.8	5.	4.9	4.6	4.1	3.4	2.54	1.6	1.06	0.0

L.E. RADIUS 12 %

T.E. RADIUS 6 %

TABLE (2)

GAIN 64 :

CALIBERATION RESULTS FOR ADC UNIT NO 1 CHANNEL 1

=====

NUMBER OF POINTS IS = 10

Y= 0.10000000	X= 24.029301
Y= 0.20100001	X= 48.712951
Y= 0.30050001	X= 72.860352
Y= 0.40095999	X= 98.730469
Y= 0.50300002	X= 129.53320
Y= 0.60000002	X= 152.75980
Y= 0.69995999	X= 177.13480
Y= 0.80000001	X= 202.53909
Y= 0.89995998	X= 232.68159
Y= 1.00000000	X= 252.91500

Equation is

	Y= 0.12053735E-01+0.38715384E-02*X
Corr. Coeff.	S.E. A S.E. B
0.99573863	0.21299121E-04 0.49326569E-02

CALIBERATION RESULTS FOR ADC UNIT 2 CHANNEL 1

NUMBER OF POINTS IS = 10

Y= 0.10000000	X= 16.095599
Y= 0.20100001	X= 43.175781
Y= 0.30050001	X= 69.207021
Y= 0.40095999	X= 95.495117
Y= 0.50300002	X= 123.71090
Y= 0.60000002	X= 148.84470
Y= 0.69995999	X= 174.41550
Y= 0.80000001	X= 202.63480
Y= 0.89995998	X= 227.46629
Y= 1.00000000	X= 251.45700

Equation is

	Y= 0.36604047E-01+0.37999621E-02*X
Corr. Coeff.	S.E. A S.E. B
0.99591876	0.17121733E-04 0.26521806E-02

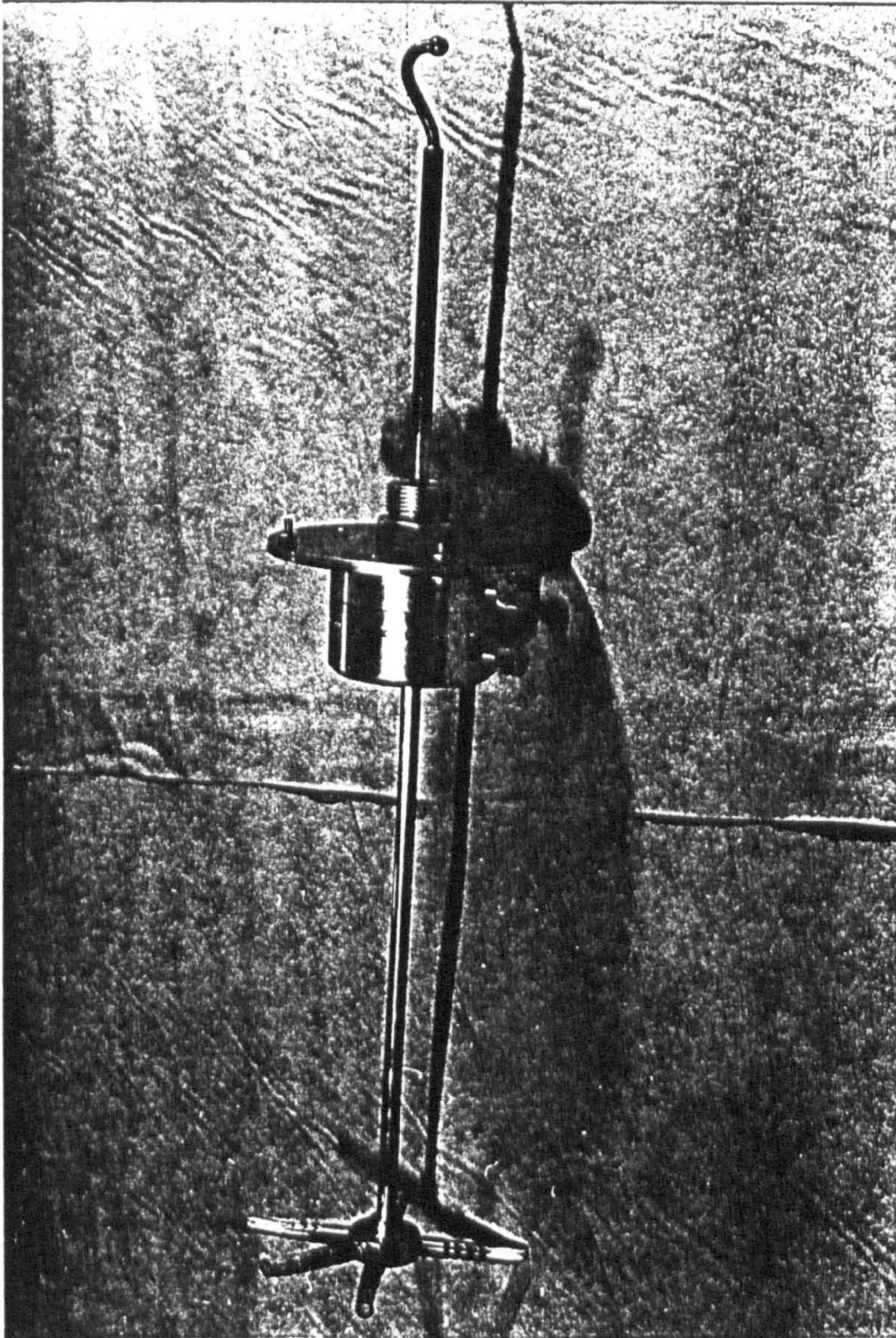


PLATE 1 : 5 - HOLES SPHERICAL PRESSURE TUBE

PLATE 1 : 5 - HOLES SPHERICAL PRESSURE TUBE

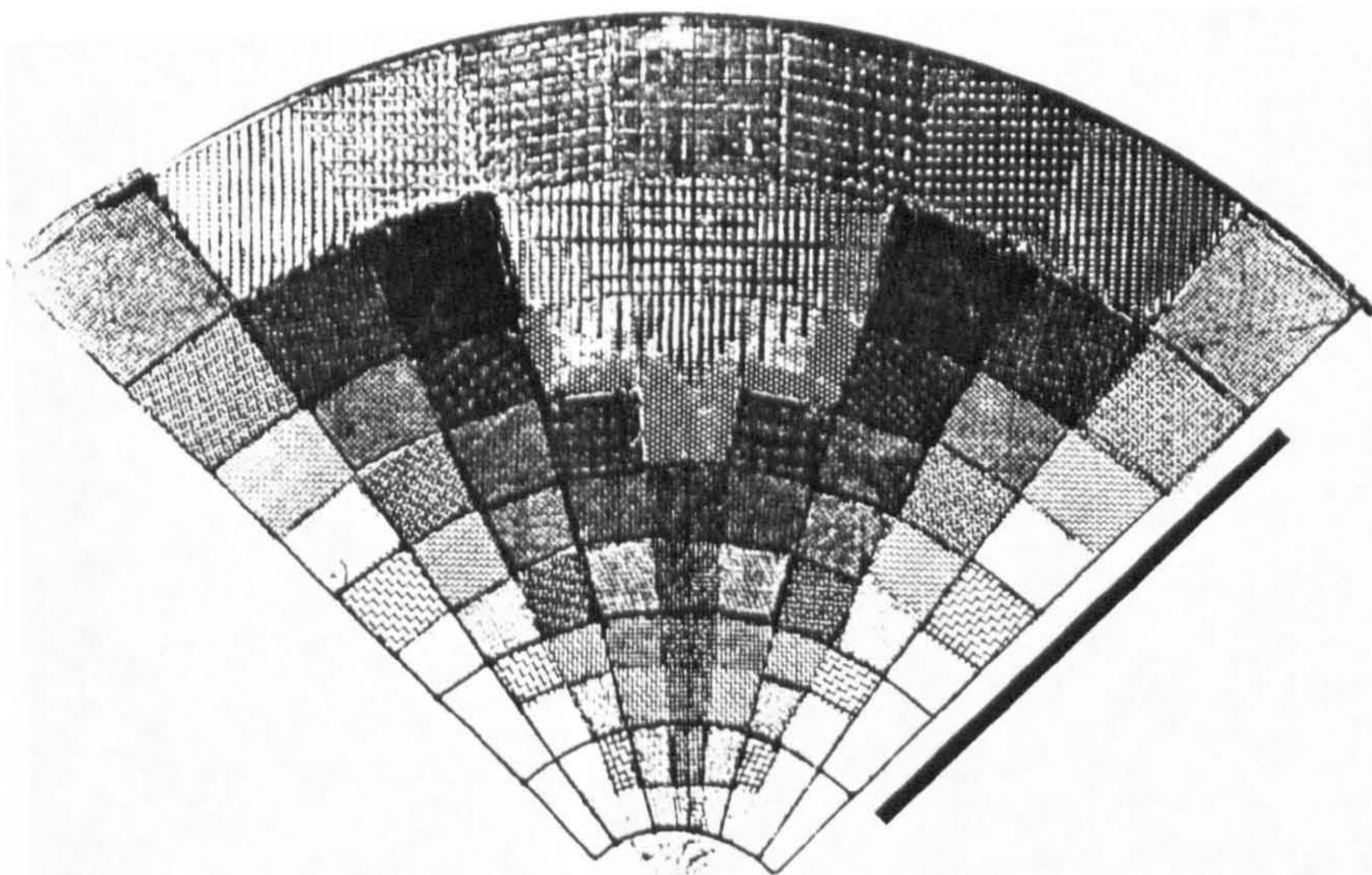


PLATE 2 SINE WAVE DISTORTION SCREEN

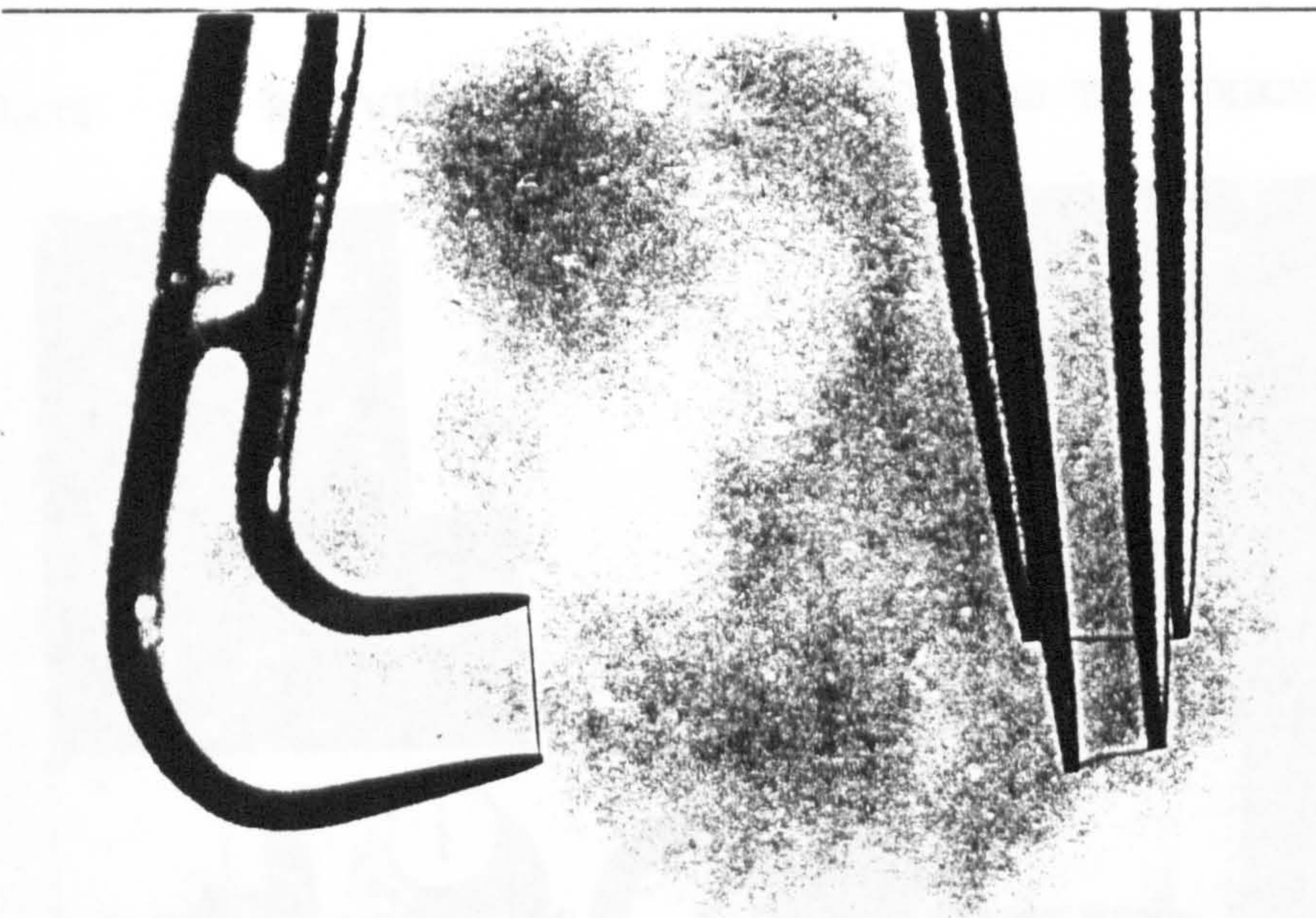


PLATE 3 HOT WIRE SETTING

PLATE 3 HOT WIRE CALIBRATION RIG.

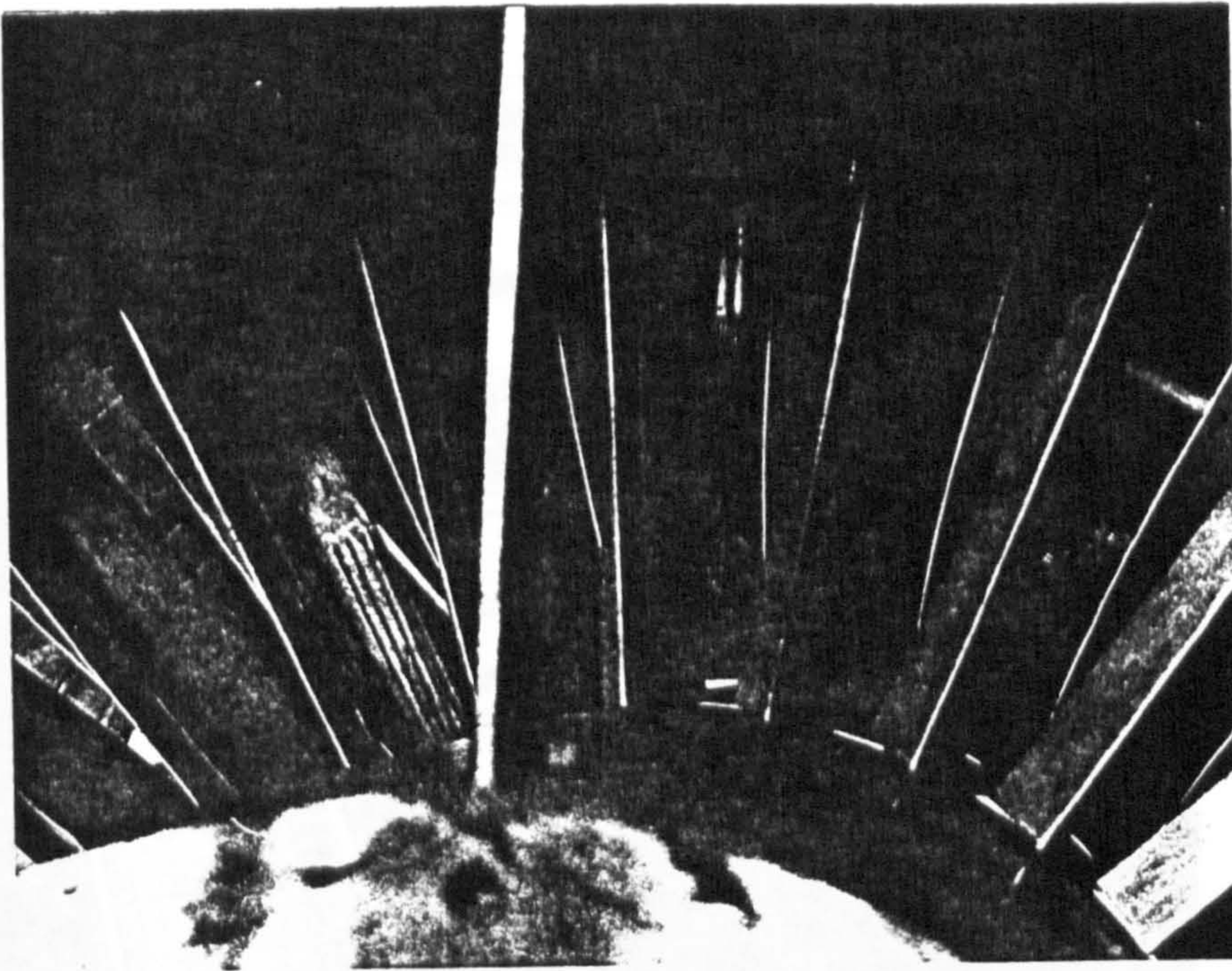


PLATE 4 HOT WIRE PROBES INSTALLED INSIDE THE TURBOMACHINERY.

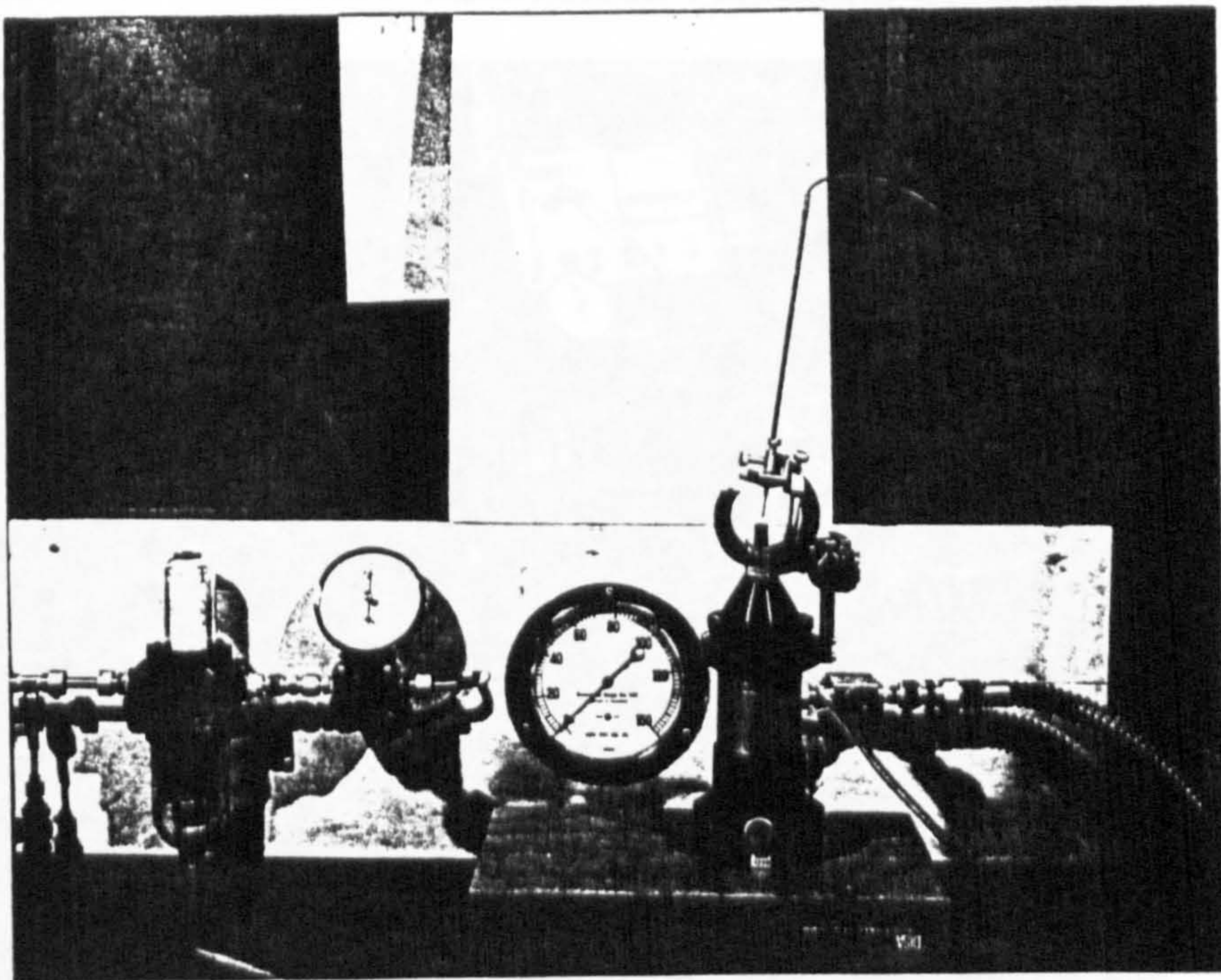


PLATE 5 HOT WIRE CALIBRATION RIG.

PLATE 7 DYNAMIC CALIBRATION PRINCIPAL EQUIPMENT

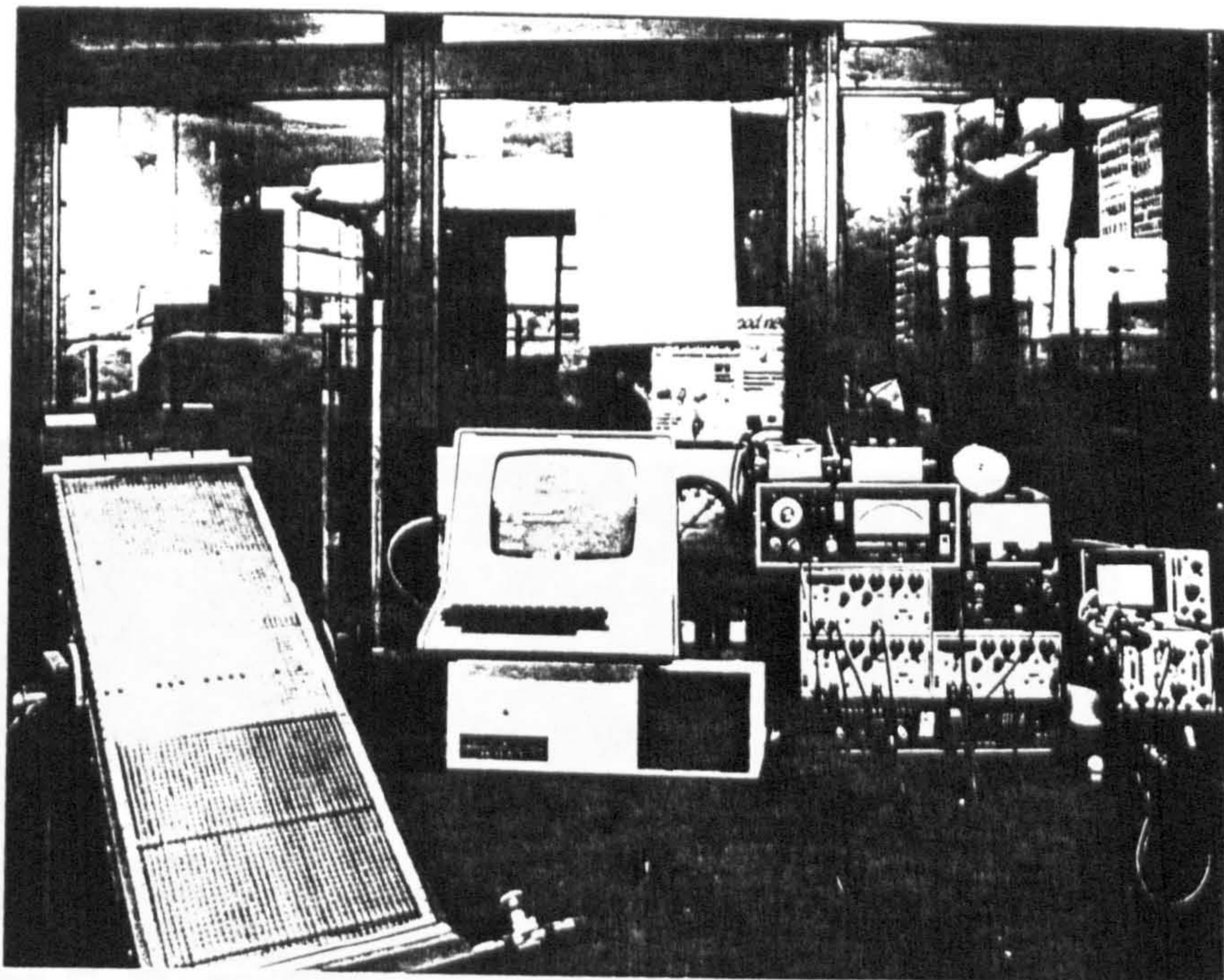


PLATE 6 STATIC CALIBRATION PRIPHERAL EQUIPMENT.

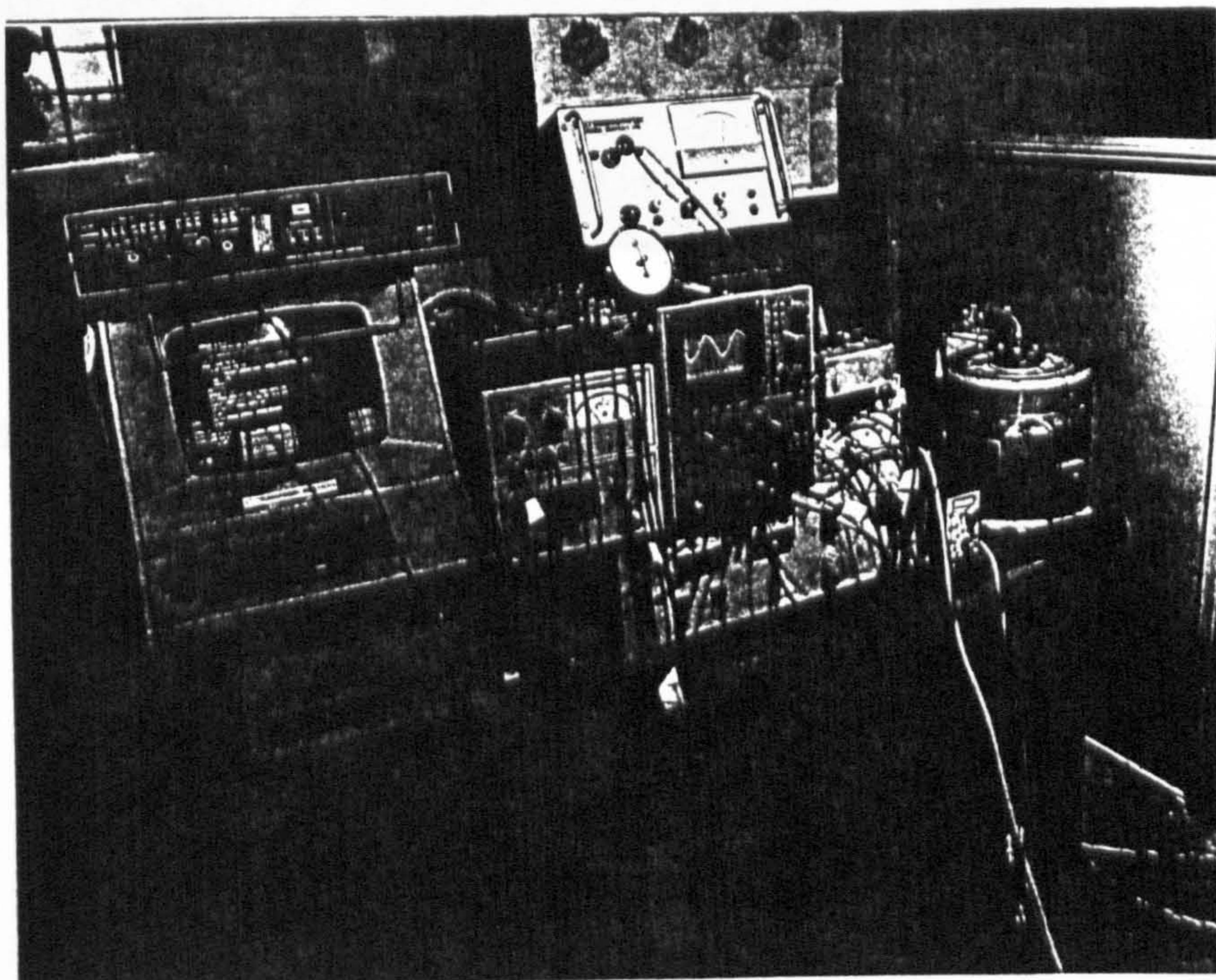


PLATE 7 DYNAMIC CALIBRATION PRIPHERAL EQUIPMENT

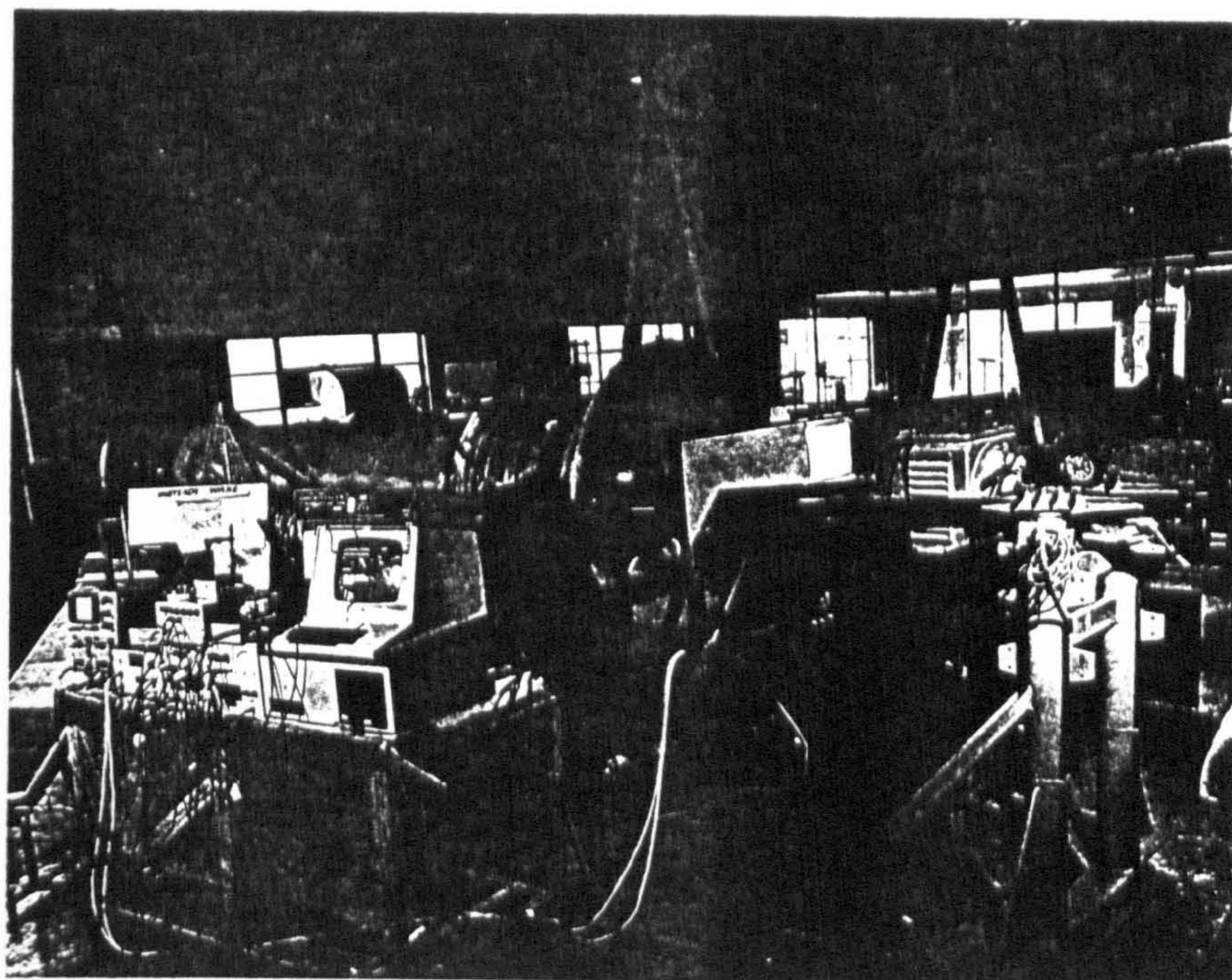


PLATE 8 ROTOR WAKE MAIN PRIPHERAL INSTRUMENTS.

APPENDICES

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APPENDIX (1)THE RUNDON RABISON METHOD FOR THE SOLUTION OF NON LINEAR
ALGEBRAIC EQUATIONS.

Given a system of n simultaneous non linear equations in the form:

$$y_1(x_1, x_2, x_3, \dots, x_n) = 0$$

$$y_2(x_1, x_2, x_3, \dots, x_n) = 0$$

.....

$$y_n(x_1, x_2, x_3, \dots, x_n) = 0$$

it is required to get $(x_1, x_2, x_3, \dots, x_n)$ satisfying these equations.

Assume an approximate solution;

$$x_{01}, x_{02}, x_{03}, \dots, x_{0n}$$

Let the exact solution be in the form:

$$(x_{01} + \delta x_1), (x_{02} + \delta x_2), \dots, (x_{0n} + \delta x_n).$$

whence,

$$0 = y_1(x_{01} + \delta x_1, x_{02} + \delta x_2, \dots, x_{0n} + \delta x_n)$$

$$0 = y_2(x_{01} + \delta x_1, x_{02} + \delta x_2, \dots, x_{0n} + \delta x_n)$$

.....

$$0 = y_n(x_{01} + \delta x_1, x_{02} + \delta x_2, \dots, x_{0n} + \delta x_n).$$

The above equations can be expanded using Taylor's series.

$$0 = y_{01} + \left(\frac{\partial y_1}{\partial x_1}\right)_0 \delta x_1 + \left(\frac{\partial y_1}{\partial x_2}\right)_0 \delta x_2 + \dots + \left(\frac{\partial y_1}{\partial x_n}\right)_0 \delta x_n + H.O.T.$$

$$0 = y_{02} + \left(\frac{\partial y_2}{\partial x_1} \right)_0 \delta x_1 + \left(\frac{\partial y_2}{\partial x_2} \right)_0 \delta x_2 + \dots + \left(\frac{\partial y_2}{\partial x_n} \right)_0 \delta x_n + \text{H.O.T.}$$

$$0 = y_{0n} + \left(\frac{\partial y_n}{\partial x_1} \right)_0 \delta x_1 + \left(\frac{\partial y_n}{\partial x_2} \right)_0 \delta x_2 + \dots + \left(\frac{\partial y_n}{\partial x_n} \right)_0 \delta x_n + \text{H.O.T.}$$

Neglecting the H.O.T. and putting the above set of equations in matrix form we get,

$$0 = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} + \begin{bmatrix} \frac{\partial y_1}{\partial x_1} & \frac{\partial y_1}{\partial x_2} & \dots & \frac{\partial y_1}{\partial x_n} \\ \frac{\partial y_2}{\partial x_1} & \frac{\partial y_2}{\partial x_2} & \dots & \frac{\partial y_2}{\partial x_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial y_n}{\partial x_1} & \frac{\partial y_n}{\partial x_2} & \dots & \frac{\partial y_n}{\partial x_n} \end{bmatrix} \begin{bmatrix} \delta x_1 \\ \delta x_2 \\ \vdots \\ \delta x_n \end{bmatrix}$$

which can be re-written as,

$$\begin{bmatrix} \frac{\partial y_1}{\partial x_1} & \frac{\partial y_1}{\partial x_2} & \dots & \frac{\partial y_1}{\partial x_n} \\ \frac{\partial y_2}{\partial x_1} & \frac{\partial y_2}{\partial x_2} & \dots & \frac{\partial y_2}{\partial x_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial y_n}{\partial x_1} & \frac{\partial y_n}{\partial x_2} & \dots & \frac{\partial y_n}{\partial x_n} \end{bmatrix} \begin{bmatrix} \delta x_1 \\ \delta x_2 \\ \vdots \\ \delta x_n \end{bmatrix} = - \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}$$

or simply ,

$$\left[\frac{\partial y_i}{\partial x_t} \right]_0 \{ \delta x_t \} = - \{ y_i \}_0$$

In tensor notation,

$$\frac{\partial y_i}{\partial x_t} \delta x_t = - y_{i0}$$

which has the following solution,

$$\left\{ \delta x_t \right\}_1 = - \left[\frac{\partial y_i}{\partial x_t} \right]_0^{-1} \left\{ y_i \right\}_0$$

and the new value of x ,

$$\left\{ x_t \right\}_1 = \left\{ x_t \right\}_0 + \left\{ \delta x_t \right\}_1$$

because of neglecting the high order term the above equation does not give the exact answer and we must check the values of the functions y :

$$(y_1)_1, (y_2)_1, (y_3)_1, \dots, (y_n)_1$$

For the iterative procedure,

$$\left\{ y_i \right\}_{n \text{ trial}} = (y_i(x_{1n}, x_{2n}, x_{3n}, \dots, x_{nn}))$$

$$\left\{ \delta x_t \right\}_{n \text{ trial}} = - \left[\frac{\partial y_i}{\partial x_t} \right]_n^{-1} \left\{ y_i \right\}_n$$

$$\left\{ x_t \right\}_{n+1} = \left\{ x_t \right\}_n + \left\{ \delta x_t \right\}_n$$

Iterations are made up to,

$$i. \text{ maximum } \left\{ \delta x_t \right\}_i \leq \text{a certain permissible error.}$$

$$ii. \text{ maximum } \left\{ y_i \right\}_n \leq \text{a certain permissible error.}$$

Unfortunately in some few cases if the matrix $\left[\frac{\partial y_i}{\partial x_t} \right]_n$ is ill-conditioned or singular, the Newton-Raphson iteration diverges.

APPENDIX (2)

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```

PROGRAM WAKE MATHEMATICAL MODEL
INTEGER P(8,8,100)
CHARACTER*4 CONT
COMMON DET,I CONT
DOUBLE PRECISION DF(9,9)
DIMENSION NC(8),C(8,100),F(8),X(8),DX(8)
PRINT *, 'GROUP ??'
READ *, GROUP
PRINT *, 'ERROR??'
WRITE(*,*) 'DATA LIST', GROUP, GROUP
WRITE(*,30271)
error=10e-05
nmax=1000
icont=10
WRITE(*,*) 'MAX NUMBER OF ITTERATIONS IS ',NMAX
WRITE(*,30271)
WRITE(*,*) 'NUMBER OF ITTERATIONS AFTER WHICH MODIFIED NEWTON-'
WRITE(*,*) 'RAPHSON IS APPLIED IS ',I CONT
WRITE(*,30271)
WRITE(*,*) 'MAX. PERMISSABLE ERROR IS ',ERROR
WRITE(*,30271)
CALL EQCOEFF(C,NC,IHM,RB,UO,VO,WO)
WRITE(*,*) 'IHM AFTER CALLING =',IHM
DO 200 I=1,8
  READ(IHM,*)NC(I)
  WRITE(*,*) 'NC(' ,I ,')=' ,NC(I)
  DO 200 R=1,NC(I)
200   READ(IHM,*) (P(I,J,R),J=1,8)
  READ(1,*)X
  WRITE(*,*) 'THE STARTING ROOTS ARE'
  WRITE(*,*) (X(I),I=1,8)
  WRITE(*,30271)
30271  FORMAT(2X,68(1H ))
  IF(IHM.EQ.5)MNHF=48
  IF(IHM.EQ.6)MNHF=78
  IF(IHM.EQ.7)MNHF=78
  CALL NEWTON(8,MNHF,NC,C,P,F,DF,X,DX,NMAX,ERROR,CONV,IT,EMAX)
  CALL OUTPUT(X,CONV,IT,EMAX,RB,UO,VO,WO,GROUP)
  STOP
END
SUBROUTINE OUTPUT(X,CONV,IT,EMAX,RB,UO,VO,WO,GROUP)
DIMENSION X(8)
LOGICAL CONV
IF(RB.EQ..125)AA=.03
IF(RB.EQ..15)AA=.034
IF(RB.EQ..175)AA=.047
IF(RB.EQ..1875)AA=.0475

```



```

IF(RB.EQ..2)AA=.048
IF(RB.EQ..225)AA=.053
IF(RB.EQ..25)AA=.059
WRITE(2,9076)
9076  FORMAT(2X,/,66(1H ))
      WRITE(2,*) 'RESULTS OF RADIUS =      ',RB
      WRITE(2,*) '                                GROUP',GROUP
      WRITE(2,*) ' '
      WRITE(2,*) ' T R I A L      N U M B E R      ',IT
      WRITE(2,*) ' '
      AA=.0475
12     WRITE(2,12)CONV
      FORMAT(20X,' C O N V E R G E N C E      =      ',L3)
      X(1)=X(1)/UO
      X(2)=X(2)/UO
      X(3)=X(3)/VO
      X(4)=X(4)/VO
      X(5)=X(5)/WO
      X(6)=X(6)/WO
      X(7)=X(7)/AA
      X(8)=X(8)/AA
      WRITE(2,9076)
      WRITE(2,*)(X(I),I=1,8)
      RETURN
      END
      SUBROUTINE EQCOEFF(C,NC,IHM,RB,UO,VO,WO)
      REAL OM,I,J,K,M1,M2,M3,M4,M5,M6,M7,M8,M371,NEWT
1      ,INC,I1,I2,I3,I4,I5,I6,I7,I8,I9,I10,K1,K2,K3,K4,K5,K6,K7,K8
1      ,K9,K10,J1,J2,J3,J4,J5,J6,J7,J8,J9,J10
1,I,P,IS,KP,KS,JP,JS,IS1,IS2,IS3,IS4,IS5,IS6,IS7,IS8,IS9,IS10
1,JS1,JS2,JS3,JS4,JS5,JS6,JS7,JS8,JS9,JS10
1,KS1,KS2,KS3,KS4,KS5,KS6,KS7,KS8,KS9,KS10
      DIMENSION C(8,100),NC(8)
      PRINT *, 'ARE YOU GOING TO NEGLECT ALL THE TURBULENCE TERMS'
      PRINT *, 'AND THE PRESSURE TERMS IN THE MOMENTUM EQUATIONS ????'
25     READ(*,25)CONT
      FORMAT(A4)
      IF (CONT.EQ. 'YES') THEN
      IHM=5
      ELSE
      IHM=6
      END IF
      WRITE(*,*)IHM
      om=175.08
      xl=.2
      x2=.75
      ch=.045
      read(1,*)rb,m1,m2,m3,m4,m5,m6,m7,m8,inc,CIR
      RBB=RB/.25
      WRITE(*,*) '                                RBB ',RBB
      WRITE(*,*) '                                CIR ',CIR
      inc=inc*3.141526954/180.0
      CIR=CIR*3.141526954/180.0
      READ(1,*)DISPTH
      WRITE(*,5620)

```



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WRITE(*,*) ' DISPLACMENT THICKNESS X CONST. =',DISPTH
NEWT=DISPTH*.0168
READ(1,*)DUODR,DVODR,DWODR,UO,VO,WO,UDASHC2,VDASHC2
1 ,WDASHC2,UDASHO2,VDASHO2,WDASHO2
READ(1,*)I1,I2,I3,I4,I5,I6,I7,I8,I9,I10
WRITE(*,*) 'I1—I10',I1,I2,I3,I4,I5,I6,I7,I8,I9,I10
READ(1,*)J1,J2,J3,J4,J5,J6,J7,J8,J9,J10
READ(1,*)K1,K2,K3,K4,K5,K6,K7,K8,K9,K10
READ(1,*)G1,G2,G3,G4,G5,G6,G7,G8,G9,G10
READ(1,*)H1,H2,H3,H4,H5,H6,H7,H8,H9,H10
READ(1,*)F1,F2,F3,F4,F5,F6,F7,F8,F9,F10
WRITE(*,*) 'F1—F10',F1,F2,F3,F4,F5,F6,F7,F8,F9,F10
IP=I1+I2*INC+I3*RBB+I4*INC*RBB+I5*INC**2+I6*RBB**2+I7*INC**2*RBB+
1 I8*INC*RBB**2+I9*INC**3+I10*RBB**3
JP=J1+J2*INC+J3*RBB+J4*INC*RBB+J5*INC**2+J6*RBB**2+J7*INC**2*RBB+
1 J8*INC*RBB**2+J9*INC**3+J10*RBB**3
HP=H1+H2*INC+H3*CI R+H4*INC*CI R+H5*INC**2+H6*CI R**2+H7*INC**2*CI R+
1 H8*INC*CI R**2+H9*INC**3+H10*CI R**3
FP=F1+F2*INC+F3*CI R+F4*INC*CI R+F5*INC**2+F6*CI R**2+F7*INC**2*CI R+
1 F8*INC*CI R**2+F9*INC**3+F10*CI R**3
KP=K1+K2*INC+K3*RBB+K4*INC*RBB+K5*INC**2+K6*RBB**2+K7*INC**2*RBB+
1 K8*INC*RBB**2+K9*INC**3+K10*RBB**3
GP=G1+G2*INC+G3*CI R+G4*INC*CI R+G5*INC**2+G6*CI R**2+G7*INC**2*CI R+
1 G8*INC*CI R**2+G9*INC**3+G10*CI R**3
WRITE(*,*) 'IP JP KP HP GP FP',IP,JP,KP,HP,GP,FP
READ(1,*)IS1,IS2,IS3,IS4,IS5,IS6,IS7,IS8,IS9,IS10
WRITE(*,*) 'IS1—IS10',IS1,IS2,IS3,IS4,IS5,IS6,IS7,IS8,IS9,IS10
READ(1,*)JS1,JS2,JS3,JS4,JS5,JS6,JS7,JS8,JS9,JS10
READ(1,*)KS1,KS2,KS3,KS4,KS5,KS6,KS7,KS8,KS9,KS10
READ(1,*)GS1,GS2,GS3,GS4,GS5,GS6,GS7,GS8,GS9,GS10
READ(1,*)HS1,HS2,HS3,HS4,HS5,HS6,HS7,HS8,HS9,HS10
READ(1,*)FS1,FS2,FS3,FS4,FS5,FS6,FS7,FS8,FS9,FS10
T=RBB
P=CI R
IS=IS1+IS2*INC+IS3*T+IS4*INC*T+IS5*INC**2+IS6*T**2+IS7*INC**2*T+
1 IS8*INC*T**2+IS9*INC**3+IS10*T**3
WRITE(*,*) ' IS',IS
IS=IS1+IS2*INC+IS3*T+IS4*INC*T+IS5*INC**2+IS6*T**2+IS7*IN
1C**2*T+IS8*INC*T**2+IS9*INC**3+IS10*T**3
WRITE(*,*) ' NEW IS ',IS
JS=JS1+JS2*INC+JS3*T+JS4*INC*T+JS5*INC**2+JS6*T**2+JS7*INC**2*T+
1 JS8*INC*T**2+JS9*INC**3+JS10*T**3
HS=HS1+HS2*INC+HS3*P+HS4*INC*P+HS5*INC**2+HS6*P**2+HS7*INC**2*P+
1 HS8*INC*P**2+HS9*INC**3+HS10*P**3
FS=FS1+FS2*INC+FS3*P+FS4*INC*P+FS5*INC**2+FS6*P**2+FS7*INC**2*P+
1 FS8*INC*P**2+FS9*INC**3+FS10*P**3
KS=KS1+KS2*INC+KS3*T+KS4*INC*T+KS5*INC**2+KS6*T**2+KS7*INC**2*T+
1 KS8*INC*T**2+KS9*INC**3+KS10*T**3
GS=GS1+GS2*INC+GS3*P+GS4*INC*P+GS5*INC**2+GS6*P**2+GS7*INC**2*P+
1 GS8*INC*P**2+GS9*INC**3+GS10*P**3
WRITE(*,*) 'IP JP KP GP HP FP ',IP,JP,KP,GP,HP,FP
WRITE(*,*) 'IS JS KS GS HS FS',IS,JS,KS,GS,HS,FS
I=(1/IP - (EXP(-IP*30.0))/IP)+(1/IS-(EXP(-IS*30.0))/IS)
J=(1/JP - (EXP(-JP*30.0))/JP)+(1/JS-(EXP(-JS*30.0))/JS)
K=(1/KP - (EXP(-KP*30.0))/KP)+(1/KS-(EXP(-KS*30.0))/KS)

```



```

F=(1/FP - (EXP(-FP*30.0))/FP)+(1/FS-(EXP(-FS*30.0))/FS)
G=(1/GP - (EXP(-GP*30.0))/GP)+(1/GS-(EXP(-GS*30.0))/GS)
H=(1/HP - (EXP(-HP*30.0))/HP)+(1/HS-(EXP(-HS*30.0))/HS)
WRITE(*,*) ' FINAL CALCULATIONS '
WRITE(*,*) 'I J K G H F ',I,J,K,G,H,F
WRITE(*,5620)
5620 FORMAT(2X,60(1H$),/,2X,60(1H=))
WRITE(*,*) 'RB=',RB,' OM= ',OM,' X1= ',X1,' X2= ',X2
WRITE(*,5620)
WRITE(*,*) ' CH= ',CH,' NEWT ',NEWT,' RHO= ',RHO
WRITE(*,5620)
WRITE(*,*) ' I= ',I
WRITE(*,*) 'N E W T ',NEWT
WRITE(*,5620)
WRITE(*,*) 'UO,VO,WO =',UO,' ',VO,' ',WO
WRITE(*,5620)
WRITE(*,*) 'DUO/DR-DVO/DR-DWO/DR',DUODR,' ',DVODR,' ',DWODR
WRITE(*,5620)
WRITE(*,*) 'U"C2 - V"C2 - W"C2 ',UDASHC2,' ',VDASHC2,' ',WDASHC2
WRITE(*,5620)
WRITE(*,*) 'U"O2 - V"O2 - W"O2 ',UDASHO2,' ',VDASHO2,'
',WDASHO2
WRITE(*,5620)
PE=1.00165*101325-.5*RHO*(SQRT(UO**2+VO**2+WO**2))
PC=1.22*PE
WRITE(*,*) ' PE= ',PE,' PC= ',PC
WRITE(*,5620)
IF ( (M1+M3+1).EQ.0.0) THEN
C(1,1)=-(CH*VO/RB*(LOG(X2)-LOG(X1)))
GO TO 33
END IF
33 C(1,1)=-(CH*VO*(X2**(M1+M3+1)-X1**(M1+M3+1)))/RB/(M1+M3+1)
C(1,2)=-(CH*VO*(X2**(M4+M1+1)-X1**(M4+M1+1)))/RB/(M4+M1+1)
IF ( (M1+M7+1).EQ.0.0) THEN
C(1,3)=(CH*UO*DUODR/RB*(LOG(X2)-LOG(X1)))
GO TO 35
END IF
35 C(1,3)=(CH*UO*DUODR*(X2**(M1+M7+1)-X1**(M1+M7+1)))/RB/(M1+M7+1)
C(1,4)=(CH*UO*DUODR*(X2**(M8+M1+1)-X1**(M8+M1+1)))/RB/(M8+M1+1)
IF ( (M1+M7+1).EQ.0.0) THEN
C(1,5)=-(CH*H*UO*DUODR/RB*(LOG(X2)-LOG(X1)))
GO TO 36
END IF
1 C(1,5)=-(CH*H*UO*DUODR*(X2**(M1+M7+1)-X1**(M1+M7+1)))/RB/(M7+M1
36 1 +1)
C(1,6)=(CH*H*DUODR*(X2**(M7+2*M1+1)-X1**(M7+2*M1+1)))/RB/(M7+2*
1 M1+1)
C(1,7)=(CH*H*DUODR*(X2**(M7+M2+M1+1)-X1**(M7+M2+M1+1)))/RB/(M7
1 +M2+M1+1)
C(1,8)=-(CH*H*UO*DUODR*(X2**(M8+M1+1)-X1**(M8+M1+1)))/RB/(M8+M1
1 +1)
C(1,9)=(CH*H*DUODR*(X2**(M8+2*M1+1)-X1**(M8+2*M1+1)))/RB/(M8+2*
1 M1+1)
C(1,10)=(CH*H*DUODR*(X2**(M8+M2+M1+1)-X1**(M8+M2+M1+1)))/RB/(M8
1 +M2+M1+1)

```


93

```

C(1,11)=- (WO*H*UO*M7* (X2** (M7+M1) -X1** (M7+M1) ) ) /RB/ (M7+M1)
C(1,12)= (WO*H* (M7+M1) * (X2** (M7+ 2*M1) -X1** (M7+ 2*M1) ) ) /RB/ (M7+ 2*
1 M1)
C(1,13)= (WO*H* (M7+M2) * (X2** (M7+M2+M1) -X1** (M7+M2+M1) ) ) /RB/ (M7+M2
1 +M1)
C(1,14)=- (WO*H*UO*M8* (X2** (M8+M1) -X1** (M8+M1) ) ) /RB/ (M8+M1)
C(1,15)= (WO*H* (M8+M1) * (X2** (M8+ 2*M1) -X1** (M8+ 2*M1) ) ) /RB/ (M8* 2+ M
1 1)
C(1,16)= (WO*H* (M8+M2) * (X2** (M8+M2+M1) -X1** (M8+M2+M1) ) ) /RB/ (M8+M
1 2+M1)
IF (M1.EQ.-.5) THEN
C(1,17)= (VO*CH/RB* (LOG (X2) -LOG (X1) ) )
GO TO 93
END IF
C(1,17)= (VO*CH* (X2** (2*M1+ 1) -X1** (2*M1+ 1) ) ) /RB/ (2*M1+ 1)
C(1,18)= (VO*CH* (X2** (M2+M1+ 1) -X1** (M2+M1+ 1) ) ) /RB/ (M2+M1+ 1)
C(1,19)=- (CH* (X2** (2*M1+M3+ 1) -X1** (2*M1+M3+ 1) ) ) /RB/ (2*M1+M3+ 1)
C(1,20)= (CH* (X2** (2*M1+M4+ 1) -X1** (2*M1+M4+ 1) ) ) /RB/ (2*M1+M4+ 1)
C(1,21)=- (CH* (X2** (M1+M2+M3+ 1) -X1** (M1+M2+M3+ 1) ) ) /RB/ (M1+M2+M3
1 +1)
C(1,22)=- (CH* (X2** (M1+M2+M4+ 1) -X1** (M1+M2+M4+ 1) ) ) /RB/ (M1+M2+M4
1 +1)
C(1,23)=- (CH* (X2** (2*M1+M3+M5+ 1) -X1** (2*M1+M3+M5+ 1) ) ) /RB/WO/ (
1 2*M1+M3+M5+ 1)
C(1,24)=- (CH* (X2** (2*M1+M4+M5+ 1) -X1** (2*M1+M4+M5+ 1) ) ) /RB/WO/ (
1 2*M1+M4+M5+ 1)
C(1,25)=- (CH* (X2** (M2+M3+M5+M1+ 1) -X1** (M2+M3+M5+M1+ 1) ) ) /RB/W
1 O/ (M2+M3+M5+M1+ 1)
C(1,26)=- (CH* (X2** (M1+M2+M4+M5+ 1) -X1** (M1+M2+M4+M5+ 1) ) ) /RB/WO/
1 (M1+M2+M4+M5+ 1)
C(1,27)=- (CH* (X2** (2*M1+M3+M6+ 1) -X1** (2*M1+M3+M6+ 1) ) ) /RB/WO/
1 (2*M1+M3+M6+ 1)
C(1,28)=- (CH* (X2** (2*M1+M4+M6+ 1) -X1** (2*M1+M4+M6+ 1) ) ) /RB/WO/
1 (2*M1+M4+M6+ 1)
C(1,29)=- (CH* (X2** (M1+M2+M3+M6+ 1) -X1** (M1+M2+M3+M6+ 1) ) ) /RB/WO/
1 (M1+M2+M3+M6+ 1)
C(1,30)=- (CH* (X2** (M1+M2+M4+M6+ 1) -X1** (M1+M2+M4+M6+ 1) ) ) /RB/WO/
1 (M1+M2+M4+M6+ 1)
IF ( (M1+M7+ 1) .EQ.0.0) THEN
C(1,31)=- (VO**2*CH/RB**2/ (LOG (X2) -LOG (X1) ) )
C(1,32)=- (2*VO**2*CH*G/RB**2* (LOG (X2) -LOG (X1) ) )
C(1,33)=- (CH*OM**2* (LOG (X2) -LOG (X1) ) )
C(1,34)=- (CH*2*OM*VO/RB* (LOG (X2) -LOG (X1) ) )
C(1,35)=- (2*OM*CH*VO*G/RB* (LOG (X2) -LOG (X1) ) )
GO TO 37
END IF
C(1,31)=- ( (VO**2) *CH* (X2** (M1+M7+ 1) -X1** (M1+M7+ 1) ) ) /RB**2/ (M7+
1 +M1+ 1)
C(1,32)=- (2* (VO**2) *CH*G* (X2** (M1+M7+ 1) -X1** (M1+M7+ 1) ) ) / (RB**2)
1 / (M1+M7+ 1)
C(1,33)=- (CH* (OM**2) * (X2** (M1+M7+ 1) -X1** (M1+M7+ 1) ) ) / (M1+M7+ 1)
C(1,34)=- (CH*2*OM*VO* (X2** (M1+M7+ 1) -X1** (M1+M7+ 1) ) ) /RB/ (M7+M1+
1 1)
C(1,35)=- (2*OM*CH*VO*G* (X2** (M1+M7+ 1) -X1** (M1+M7+ 1) ) ) /RB/ (M7+M1
1 +1)

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37      C(1,36)=- (CH*VO**2* (X2** (M8+M1+1) -X1** (M8+M1+1) ) ) /RB**2/ (M8+M1+
1      1)
      C(1,37)= (2*G*CH* (VO**2) * (X2** (M8+M1+1) -X1** (M8+M1+1) ) ) /RB**2/ (
1      M8+M1+1)
      C(1,38)=- (OM**2*CH* (X2** (M8+M1+1) -X1** (M8+M1+1) ) ) / (M8+M1+1)
      C(1,39)=- (2*OM*CH*VO* (X2** (M8+M1+1) -X1** (M8+M1+1) ) ) /RB/ (M8+M1
1      +1)
      C(1,40)=- (2*OM*CH*VO*G* (X2** (M8+M1+1) -X1** (M8+M1+1) ) ) /RB/ (M8+M1
1      +1)
      C(1,41)=- (2*VO*CH*G* (X2** (M1+M3+M7+1) -X1** (M1+M7+M3+1) ) ) /RB**2/
1      (M1+M7+M3+1)
      C(1,42)=- (2*VO*CH*G* (X2** (M1+M7+M4+1) -X1** (M1+M7+M4+1) ) ) /RB**2/
1      (M1+M7+M4+1)
      C(1,43)=- (2*VO*CH*G* (X2** (M3+M8+M1+1) -X1** (M8+M3+M1+1) ) ) /RB**2/
1      (M3+M8+M1+1)
      C(1,44)=- (2*VO*CH*G* (X2** (M4+M8+M1+1) -X1** (M4+M8+M1+1) ) ) /RB**2/
1      (M4+M8+M1+1)
      C(1,45)=- (2*OM*CH*G* (X2** (M7+M3+M1+1) -X1** (M7+M3+M1+1) ) ) /RB/ (M7
1      +M3+M1+1)
      C(1,46)=- (2*OM*CH*G* (X2** (M7+M4+M1+1) -X1** (M7+M4+M1+1) ) ) /RB/ (M
1      7+M4+M1+1)
      C(1,47)=- (2*OM*CH*G* (X2** (M8+M3+M1+1) -X1** (M8+M3+M1+1) ) ) /RB/ (
1      M8+M3+M1+1)
      C(1,48)=- (2*OM*CH*G* (X2** (M8+M4+M1+1) -X1** (M8+M4+M1+1) ) ) /RB/ (M8
1      +M4+M1+1)
      IF ( (M1+M7+1) .EQ.0.0) THEN
      C(1,49)= (I*CH*UDASHC2*UO/RB**2* (LOG (X2) -LOG (X1) ) )
      GO TO 38
      END IF
      C(1,49)= (I*CH*UDASHC2*UO* (X2** (M1+M7+1) -X1** (M1+M7+1) ) ) /RB**2/ (M
1      7+M1+1)
38      C(1,50)= (I*CH*UDASHC2*UO* (X2** (M8+M1+1) -X1** (M8+M1+1) ) ) /RB**2/ (M
1      8+M1+1)
      IF ( (M1+M7+1) .EQ.0.0) THEN
      C(1,51)= - (J*CH*VDASHC2*VO/RB**2* (LOG (X2) -LOG (X1) ) )
      GO TO 39
      END IF
      C(1,51)= - (J*CH*VDASHC2*VO* (X2** (M1+M7+1) -X1** (M1+M7+1) ) ) /RB**2/ (
1      M7+M1+1)
39      C(1,52)= - (J*CH*VDASHC2*VO* (X2** (M8+M1+1) -X1** (M8+M1+1) ) ) /RB**2/ (
1      M8+M1+1)
      C(1,53)= - (NEWI*WO*H*VO*M7* (M7-1) * (X2** (M1+M7-1) -X1** (M1+M7-1) ) ) /RB
1      /CH/ (M1+M7-1)
      C(1,54)= - (NEWI*WO*H*UO*M8* (M8-1) * (X2** (M8+M1-1) -X1** (M8+M1-1) ) ) /RB
1      /CH/ (M8+M1-1)
      C(1,55)= (NEWI*WO*H* (M1+M7) * (M1+M7-1) * (X2** (2*M1+M7-1) -X1** (2*M1+M
1      7-1) ) ) /CH/RB/ (2*M1+M7-1)
      C(1,56)= (NEWI*WO*H* (M1+M8) * (M1+M8-1) * (X2** (M8+2*M1-1) -X1** (2*M1+M8
1      -1) ) ) /RB/CH/ (M8+2*M1-1)
      C(1,57)= (NEWI*WO*H* (M2+M7) * (M2+M7-1) * (X2** (M1+M2+M7-1) -X1** (M1+M2
1      +M7-1) ) ) /RB/CH/ (M1+M2+M7-1)
      C(1,58)= (NEWI*WO* (M8+M2) * (M8+M2-1) * (X2** (M8+M2+M1-1) -X1** (M8+M2+M1
1      -1) ) ) /RB/CH/ (M8+M2+M1-1)
      C(1,59)= (NEWI*WO*VO*M1* (X2** (2*M1) -X1** (2*M1) ) ) /RB/VO/ (2*M1)
      C(1,60)= - (NEWI*WO* (M1+M3) * (X2** (2*M1+M3) -X1** (2*M1+M3) ) ) /RB/VO/

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1  (2*M1+M3)
  C(1,61)=- (NEWT*WO* (M4+M1) * (X2** (2*M1+M4) -X1** (2*M1+M4) ) ) /RB/CH/WO
1  / (2*M1+M4)
  C(1,62)=- (NEWT*WO*VO* (M5+M1) * (X2** (2*M1+M5) -X1** (2*M1+M5) ) ) /RB/W
1  O**2/ (2*M1+M5)
  C(1,63)=- (NEWT*WO*VO* (M1+M6) * (X2** (2*M1+M6) -X1** (2*M1+M6) ) ) /RB/W
1  O**2/ (2*M1+M6)
  C(1,64)= (NEWT*WO*VO*M2* (X2** (M1+M2) -X1** (M1+M2) ) ) /RB/WO/ (M1+M2)
  C(1,65)=- (NEWT*WO* (M1+M3) * (X2** (M1+M2+M3) -X1** (M1+M2+M3) ) ) /RB/WO
1  / (M1+M2+M3)
  C(1,66)=- (NEWT*WO* (M2+M4) * (X2** (M1+M2+M4) -X1** (M1+M2+M4) ) ) /RB/WO
1  / (M1+M2+M4)
  C(1,67)=- (NEWT*WO*VO* (M5+M2) * (X2** (M5+M2+M1) -X1** (M5+M2+M1) ) ) /RB/W
1  O**2/ (M5+M2+M1)
  C(1,68)=- (NEWT*WO*VO* (M6+M2) * (X2** (M1+M6+M2) -X1** (M1+M6+M2) ) ) /RB/W
1  O**2/ (M1+M6+M2)
  C(1,69)=- (NEWT*WO*M7*DWO DR* (X2** (M1+M7) -X1** (M1+M7) ) ) /RB/ (M1+M2)
  C(1,70)=- (NEWT*WO*M8*DWO DR* (X2** (M1+M8) -X1** (M1+M8) ) ) /RB/ (M1+M8)
  IF (IHM.EQ.5) GO TO 13
  PRINT *, 'ARE YOU APPLYING A CONDITION FOR UV OR NOT'
  PRINT *, '                1  FOR YES-----2  FOR NO '
  READ *, KCOND
  IF (KCOND.EQ.1) GO TO 14
  IF (KCOND.EQ.2) THEN
  PRINT *, 'PLEASE ENTER THE APPROXIMATE VALUES FOR UVO AND'
  PRINT *, '                UVC                '
  READ (3,*) UDASHVDO, UDASHVDC
  WRITE (*,5620)
  WRITE (*,*) '  U"V"O                U"V"C      ', UDASHVDO, '  ', UDASHVDC
  END IF
  IF (M1.EQ.-1) GO TO 12
  C(1,71)= (CH* (UDASHVDO-UDASHVDC) * (X2** (M1+1) -X1** (M1+1) ) ) /RB/
1  (M1+1) /RHO/SQRT (UO**2+VO**2+WO**2)
  IHM=6
  GO TO 13
12  C(1,71)=CH* (UDASHVDO-UDASHVDC) /RB* (LOG (X2)-LOG (X1) ) /RHO/SQRT (WO
1  **2+UO**2+VO**2)
  IHM=6
  GO TO 13
14  IHM=7
  IF ( (M1+M7+1) .EQ.0.0) THEN
  C(1,71)= (NEWT*WO*CH*G*VO/RB**3* (LOG (X2)-LOG (X1) ) )
  GO TO 43
  END IF
  C(1,71)= (NEWT*WO*CH*G*VO* (X2** (M1+M7+1) -X1** (M1+M7+1) ) ) /RB**3/
1  (M1+M7+1)
43  C(1,72)=- (NEWT*WO*CH*G* (X2** (M7+M3+M1+1) -X1** (M7+M3+M1+1) ) ) /RB**3
1  / (M7+M3+M1+1)
  C(1,73)=- (NEWT*WO*CH*G* (X2** (M7+M4+M1+1) -X1** (M7+M4+M1+1) ) ) /RB**3
1  / (M7+M4+M1+1)
  C(1,74)= (NEWT*WO*CH*G*VO* (X2** (M8+M1+1) -X1** (M8+M1+1) ) ) /RB**3/ (M8+
1  M1+1)
  C(1,75)=- (NEWT*WO*CH*G* (X2** (M3+M8+M1+1) -X1** (M3+M8+M1+1) ) ) /RB**3
1  / (M8+M3+M1+1)
  C(1,76)=- (NEWT*WO*CH*G* (X2** (M8+M4+M1+1) -X1** (M8+M4+M1+1) ) ) /RB**3

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1 / (M8+M4+M1+1)
C*****
C*****
C
C=====
13 C(2,1)=- (CH*VO* (X2** (M3+M2+1) -X1** (M3+M2+1) ) ) /RB/ (M3+M2+1)
C(2,2)=- (CH*VO* (X2** (M4+M2+1) -X1** (M4+M2+1) ) ) /RB/ (M4+M2+1)
C(2,3)= (CH*UO*DUODR* (X2** (M7+M2+1) -X1** (M7+M2+1) ) ) /RB/ (M7+M2+1)
C(2,4)= (CH*UO*DUODR* (X2** (M8+M2+1) -X1** (M8+M2+1) ) ) /RB/ (M8+M2+1)
C(2,5)=- (CH*H*UO*DUODR* (X2** (M7+M2+1) -X1** (M7+M2+1) ) ) /RB/ (M7+M2
1 +1)
C(2,6)= (CH*H*DUODR* (X2** (M7+M1+M2+1) -X1** (M7+M1+M2+1) ) ) /RB/ (M7+
1 M1+M2+1)
C(2,7)= (CH*H*DUODR* (X2** (M7+M2+M2+1) -X1** (M7+M2+M2+1) ) ) /RB/ (M7
1 +M2+M2+1)
C(2,8)=- (CH*H*UO*DUODR* (X2** (M8+M2+1) -X1** (M8+M2+1) ) ) /RB/ (M8+M2
1 +1)
C(2,9)= (CH*H*DUODR* (X2** (M8+M1+M2+1) -X1** (M8+M1+M2+1) ) ) /RB/ (M8+
1 M1+M2+1)
C(2,10)= (CH*H*DUODR* (X2** (M8+M2+M2+1) -X1** (M8+M2+M2+1) ) ) /RB/ (M8
1 +M2+M2+1)
C(2,11)=- (WO*H*UO*M7* (X2** (M7+M2) -X1** (M7+M2) ) ) /RB/ (M7+M2)
C(2,12)= (WO*H* (M7+M1) * (X2** (M7+M1+M2) -X1** (M7+M1+M2) ) ) /RB/ (M7+
1 M1+M2)
C(2,13)= (WO*H* (M7+M2) * (X2** (M7+M2+M2) -X1** (M7+M2+M2) ) ) /RB/ (M7+M2
1 +M2)
C(2,14)=- (WO*H*UO*M8* (X2** (M8+M2) -X1** (M8+M2) ) ) /RB/ (M8+M2)
C(2,15)= (WO*H* (M8+M1) * (X2** (M8+M2+M1) -X1** (M8+M2+M1) ) ) /RB/ (M8+M
1 2+M1)
C(2,16)= (WO*H* (M8+M2) * (X2** (M8+M2+M2) -X1** (M8+M2+M2) ) ) /RB/ (M8+M
1 2+M2)
C(2,17)= (VO*CH* (X2** (M2+M1+1) -X1** (M2+M1+1) ) ) /RB/ (M2+M1+1)
C(2,18)= (VO*CH* (X2** (M2+M2+1) -X1** (M2+M2+1) ) ) /RB/ (M2+M2+1)
C(2,19)=- (CH* (X2** (M2+M1+M3+1) -X1** (M2+M1+M3+1) ) ) /RB/ (M2+M1+M3+
1 1)
C(2,20)= (CH* (X2** (M2+M1+M4+1) -X1** (M2+M1+M4+1) ) ) /RB/ (M2+M1+M4+1)
C(2,21)=- (CH* (X2** (M2+M2+M3+1) -X1** (M2+M2+M3+1) ) ) /RB/ (M2+M2+M3
1 +1)
C(2,22)=- (CH* (X2** (M2+M2+M4+1) -X1** (M2+M2+M4+1) ) ) /RB/ (M2+M2+M4
1 +1)
C(2,23)=- (CH* (X2** (M2+M1+M3+M5+1) -X1** (M2+M1+M3+M5+1) ) ) /RB/WO/ (
1 M2+M1+M3+M5+1)
C(2,24)=- (CH* (X2** (M2+M1+M4+M5+1) -X1** (M2+M1+M4+M5+1) ) ) /RB/WO/ (
1 M2+M1+M4+M5+1)
C(2,25)=- (CH* (X2** (M2+M3+M5+M2+1) -X1** (M2+M3+M5+M2+1) ) ) /RB/W
1 O/ (M2+M3+M5+M2+1)
C(2,26)=- (CH* (X2** (M2+M2+M4+M5+1) -X1** (M2+M2+M4+M5+1) ) ) /RB/WO/
1 (M2+M2+M4+M5+1)
C(2,27)=- (CH* (X2** (M2+M1+M3+M6+1) -X1** (M2+M1+M3+M6+1) ) ) /RB/WO/
1 (M2+M1+M3+M6+1)
C(2,28)=- (CH* (X2** (M2+M1+M4+M6+1) -X1** (M2+M1+M4+M6+1) ) ) /RB/WO/
1 (M2+M1+M4+M6+1)
C(2,29)=- (CH* (X2** (M2+M2+M3+M6+1) -X1** (M2+M2+M3+M6+1) ) ) /RB/WO/
1 (M2+M2+M3+M6+1)
C(2,30)=- (CH* (X2** (M2+M2+M4+M6+1) -X1** (M2+M2+M4+M6+1) ) ) /RB/WO/

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1 (M2+M2+M4+M6+1)
C(2,31)=-((VO**2)*CH*(X2** (M7+M2+1)-X1** (M7+M2+1)))/RB**2/(M7+
1 +M2+1)
C(2,32)=- (2*(VO**2)*CH*G*(X2** (M7+M2+1)-X1** (M7+M2+1)))/(RB**2)
1 /(M7+M2+1)
C(2,33)=- (CH*(OM**2)*(X2** (M7+M2+1)-X1** (M7+M2+1)))/(M7+M2+1)
C(2,34)=- (CH*2*OM*VO*(X2** (M7+M2+1)-X1** (M7+M2+1)))/RB/(M7+M2+
1 1)
C(2,35)=- (2*OM*CH*VO*G*(X2** (M7+M2+1)-X1** (M7+M2+1)))/RB/(M7+M2
1 +1)
C(2,36)=- (CH*VO**2*(X2** (M8+M2+1)-X1** (M8+M2+1)))/RB**2/(M8+M2+
1 1)
C(2,37)= (2*G*CH*(VO**2)*(X2** (M8+M2+1)-X1** (M8+M2+1)))/RB**2/(
1 M8+M2+1)
C(2,38)=- (OM**2*CH*(X2** (M8+M2+1)-X1** (M8+M2+1)))/(M8+M2+1)
C(2,39)=- (2*OM*CH*VO*(X2** (M8+M2+1)-X1** (M8+M2+1)))/RB/(M8+M2
1 +1)
C(2,40)=- (2*OM*CH*VO*G*(X2** (M8+M2+1)-X1** (M8+M2+1)))/RB/(M8+M2
1 +1)
C(2,41)=- (2*VO*CH*G*(X2** (M2+M3+M7+1)-X1** (M2+M7+M3+1)))/RB**2/
1 (M2+M7+M3+1)
C(2,42)=- (2*VO*CH*G*(X2** (M2+M7+M4+1)-X1** (M2+M7+M4+1)))/RB**2/
1 (M2+M7+M4+1)
C(2,43)=- (2*VO*CH*G*(X2** (M3+M8+M2+1)-X1** (M8+M3+M2+1)))/RB**2/
1 (M3+M8+M2+1)
C(2,44)=- (2*VO*CH*G*(X2** (M4+M8+M2+1)-X1** (M4+M8+M2+1)))/RB**2/
1 (M4+M8+M2+1)
C(2,45)=- (2*OM*CH*G*(X2** (M7+M3+M2+1)-X1** (M7+M3+M2+1)))/RB/(M7
1 +M3+M2+1)
C(2,46)=- (2*OM*CH*G*(X2** (M7+M4+M2+1)-X1** (M7+M4+M2+1)))/RB/(M
1 7+M4+M2+1)
C(2,47)=- (2*OM*CH*G*(X2** (M8+M3+M2+1)-X1** (M8+M3+M2+1)))/RB/(
1 M8+M3+M2+1)
C(2,48)=- (2*OM*CH*G*(X2** (M8+M4+M2+1)-X1** (M8+M4+M2+1)))/RB/(M8
1 +M4+M2+1)
C(2,49)= (I*CH*UDASHC2*UO*(X2** (M7+M2+1)-X1** (M7+M2+1)))/RB**2/(M
1 7+M2+1)
C(2,50)= (I*CH*UDASHC2*UO*(X2** (M8+M2+1)-X1** (M8+M2+1)))/RB**2/(M
1 8+M2+1)
C(2,51)=- (J*CH*VDASHC2*VO*(X2** (M7+M2+1)-X1** (M7+M2+1)))/RB**2/(
1 M7+M2+1)
C(2,52)=- (J*CH*VDASHC2*VO*(X2** (M8+M2+1)-X1** (M8+M2+1)))/RB**2/(
1 M8+M2+1)
C(2,53)=- (NEWT*WO*H*VO*M7*(M7-1)*(X2** (M2+M7-1)-X1** (M2+M7-1)))/RB
1 /CH/(M2+M7-1)
IF (M8.EQ.0.0) THEN
C(2,54)=0.0
GO TO 949
END IF
C(2,54)=- (NEWT*WO*H*UO*M8*(M8-1)*(X2** (M8+M2-1)-X1** (M8+M2-1)))/RB
1 /CH/(M8+M2-1)
949 C(2,55)= (NEWT*WO*H*(M1+M7)*(M1+M7-1)*(X2** (M1+M2+M7-1)-X1** (M1+M2
1 +M7-1)))/CH/RB/(M1+M2+M7-1)
C(2,56)= (NEWT*WO*H*(M1+M8)*(M1+M8-1)*(X2** (M8+M1+M2-1)-X1** (M1+M2+
1 M8-1)))/RB/CH/(M8+M1+M2-1)

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C(2,57)=(NEWT*WO*H*(M2+M7)*(M2+M7-1)*(X2**(M2+M2+M7-1)-X1**(M2+M2
1 +M7-1)))/RB/CH/(M2+M2+M7-1)
C(2,58)=(NEWT*WO*(M8+M2)*(M8+M2-1)*(X2**(M8+M2+M2-1)-X1**(M8+M2+M2
1 -1)))/RB/CH/(M8+M2+M2-1)
C(2,59)=(NEWT*WO*VO*M1*(X2**(M1+M2)-X1**(M1+M2)))/RB/VO/(M1+M2)
C(2,60)=- (NEWT*WO*(M1+M3)*(X2**(M1+M2+M3)-X1**(M1+M2+M3)))/RB/VO/
1 (M1+M2+M3)
C(2,61)=- (NEWT*WO*(M4+M1)*(X2**(M1+M2+M4)-X1**(M1+M2+M4)))/RB/CH/VO
1 /(M1+M2+M4)
C(2,62)=- (NEWT*WO*VO*(M5+M1)*(X2**(M1+M2+M5)-X1**(M1+M2+M5)))/RB/W
1 O**2/(M1+M2+M5)
C(2,63)=- (NEWT*WO*VO*(M1+M6)*(X2**(M1+M2+M6)-X1**(M1+M2+M6)))/RB/W
1 O**2/(M1+M2+M6)
C(2,64)=(NEWT*WO*VO*M2*(X2**(M2+M2)-X1**(M2+M2)))/RB/VO/(M2+M2)
C(2,65)=- (NEWT*WO*(M2+M3)*(X2**(M2+M2+M3)-X1**(M2+M2+M3)))/RB/VO
1 /(M2+M2+M3)
C(2,66)=- (NEWT*WO*(M2+M4)*(X2**(M2+M2+M4)-X1**(M2+M2+M4)))/RB/VO
1 /(M2+M2+M4)
C(2,67)=- (NEWT*WO*VO*(M5+M2)*(X2**(M5+M2+M2)-X1**(M5+M2+M2)))/RB/W
1 O**2/(M5+M2+M2)
C(2,68)=- (NEWT*WO*VO*(M6+M2)*(X2**(M2+M6+M2)-X1**(M2+M6+M2)))/RB/W
1 O**2/(M2+M6+M2)
C(2,69)=- (NEWT*WO*M7*DWODR*(X2**(M2+M7)-X1**(M2+M7)))/RB/(M2+M7)
C(2,70)=- (NEWT*WO*M8*DWODR*(X2**(M2+M8)-X1**(M2+M8)))/RB/(M2+M8)
IF(IHM.EQ.5)GO TO 130
PRINT *, 'ARE YOU APPLYING A CONDITION FOR UV OR NOT??'
PRINT *, '1 FOR YES-----2 FOR NO '
READ *,KCOND
IF (KCOND.EQ.1)GO TO 140
IF (KCOND.EQ.2)THEN
PRINT *, 'PLEASE ENTER THE APPROXIMATE VALUES FOR UVO AND'
PRINT *, 'UVC '
READ (3,*)UDASHVDO,UDASHVDC
WRITE (2,5620)
END IF
IF(M2.EQ.-1)GO TO 120
C(2,71)=(CH*(UDASHVDO-UDASHVDC)*(X2**(M2+1)-X1**(M2+1)))/RB/
1 (M2+1)/RHO/(VO**2+UO**2+WO**2)
IHM=6
GO TO 130
120 C(2,71)=CH*(UDASHVDO-UDASHVDC)/RB*(LOG(X2)-LOG(X1))/(VO**2+UO**2
1 +WO**2)/RHO
IHM=6
GO TO 130
140 IHM=7
C(2,71)=(NEWT*WO*CH*G*VO*(X2**(M7+M2+1)-X1**(M7+M2+1)))/RB**3/
1 (M7+M2+1)
C(2,72)=- (NEWT*WO*CH*G*(X2**(M7+M3+M2+1)-X1**(M7+M3+M2+1)))/RB**3
1 /(M7+M3+M2+1)
C(2,73)=- (NEWT*WO*CH*G*(X2**(M7+M4+M2+1)-X1**(M7+M4+M2+1)))/RB**3
1 /(M7+M4+M2+1)
C(2,74)=(NEWT*WO*CH*G*VO*(X2**(M8+M2+1)-X1**(M8+M2+1)))/RB**3/(M8+
1 M2+1)
C(2,75)=- (NEWT*WO*CH*G*(X2**(M3+M8+M2+1)-X1**(M3+M8+M2+1)))/RB**3
1 /(M8+M3+M2+1)

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C(2,76)=- (NEWI*WO*CH*G*(X2** (M8+M4+M2+ 1)-X1** (M8+M4+M2+ 1)))/RB**3
1 / (M8+M4+M2+ 1)
*****
*****
C
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
130 IF(M3.EQ.-.5) THEN
      C(3,1)=(CH*VO/RB*(LOG(X2)-LOG(X1)))
      GO TO 96
      END IF
      C(3,1)=(CH*VO*(X2**(2*M3+ 1)-X1**(2*M3+ 1))/RB/(2*M3+ 1)
96    C(3,2)=(CH*VO*(X2**(M4+M3+ 1)-X1**(M4+M3+ 1))/RB/(M4+M3+ 1)
      M371=M3+M7+ 1
      IF(M371.EQ.0.0) THEN
      C(3,3)=(CH*UO*DVODR/RB*(LOG(X2)-LOG(X1)))
      GO TO 63
      END IF
      C(3,3)=(CH*UO*DVODR*(X2**(M3+M7+ 1)-X1**(M3+M7+ 1))/RB/(M3+M7+ 1)
63    C(3,4)=(UO*CH*DVODR*(X2**(M3+M8+ 1)-X1**(M3+M8+ 1))/RB/(M8+M3+ 1)
      IF(M371.EQ.0.0) THEN
      C(3,5)=-(H*CH*DVODR/RB*(LOG(X2)-LOG(X1)))
      GO TO 64
      END IF
      C(3,5)=-(H*CH*DVODR*(X2**(M3+M7+ 1)-X1**(M3+M7+ 1))/RB/(M3+M7+ 1)
64    C(3,6)=-(H*CH*DVODR*VO*(X2**(M8+M3+ 1)-X1**(M8+M3+ 1))/RB/(M8+M3
1     + 1)
1     C(3,7)=(H*CH*DVODR*(X2**(M1+M3+M7+ 1)-X1**(M1+M3+M7+ 1))/RB/(M1
1     +M3+M7+ 1)
      C(3,8)=(H*CH*DVODR*(X2**(M1+M3+M8+ 1)-X1**(M1+M3+M8+ 1))/RB/(M8
1     +M3+M1+ 1)
1     C(3,9)=(H*CH*DVODR*(X2**(M2+M3+M7+ 1)-X1**(M2+M3+M7+ 1))/RB/(M2
1     +M3+M7+ 1)
1     C(3,10)=(H*CH*DVODR*(X2**(M2+M3+M8+ 1)-X1**(M2+M3+M8+ 1))/RB/(M2
1     +M8+M3+ 1)
      C(3,11)=-(WO*G*M7*VO*(X2**(M3+M7)-X1**(M3+M7))/RB/(M3+M7)
      C(3,12)=-(VO*WO*G*(X2**(M3+M8)-X1**(M3+M8))/RB/(M3+M8)
      IF(2*M3+M7.EQ.0.0) THEN
      C(3,13)=0.0
      GO TO 6132
      END IF
      C(3,13)=(WO*G*(M3+M7)*(X2**(2*M3+M7)-X1**(2*M3+M7))/RB/(2*M3+
1     M7)
6132 C(3,14)=(WO*G*(M8+M3)*(X2**(2*M3+M8)-X1**(2*M3+M8))/RB/(2*M3+
1     M8)
1     C(3,15)=(WO*G*(M7+M4)*(X2**(M4+M3+M7)-X1**(M4+M3+M7))/RB/(M4
1     +M3+M7)
1     C(3,16)=(WO*G*(M8+M4)*(X2**(M3+M8+M4)-X1**(M3+M8+M4))/RB/(M3
1     +M8+M4)
      IF(M3.EQ.-.5) THEN
      C(3,17)=-(CH*V/RB*(LOG(X2)-LOG(X1)))
      GO TO 98
      END IF
      C(3,17)=-(CH*VO*(X2**(2*M3+ 1)-X1**(2*M3+ 1))/RB/(2*M3+ 1)
98    C(3,18)=(CH*(X2**(3*M3+ 1)-X1**(3*M3+ 1))/WO/(3*M3+ 1)
      C(3,19)=(CH*(X2**(2*M3+M4+ 1)-X1**(2*M3+M4+ 1))/WO/(2*M3+M4+ 1)

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1 C(3,20)=(CH*VO*(X2**(2*M3+M5+1)-X1**(2*M3+M5+1)))/WO**2/(2*M3
1 +M5+1)
1 C(3,21)=(CH*VO*(X2**(2*M3+M6+1)-X1**(2*M3+M6+1)))/WO**2/(2*M3
1 +M6+1)
1 C(3,22)=-(VO*CH*(X2**(M4+M3+1)-X1**(M4+M3+1)))/WO/(M4+M3+1)
1 C(3,23)=(CH*(X2**(2*M3+M4+1)-X1**(2*M3+M4+1)))/WO/(2*M3+M4+1)
1 C(3,24)=(CH*(X2**(2*M4+M3+1)-X1**(2*M4+M3+1)))/WO/(2*M4+M3+1)
1 C(3,25)=(VO*CH*(X2**(M4+M5+M3+1)-X1**(M4+M3+M5+1)))/WO**2/(M
1 4+M3+M5+1)
1 IF(M371.EQ.0.0) THEN
1 C(3,26)=(UO*VO*CH/RB**2*(LOG(X2)-LOG(X1)))
1 GO TO 65
1 END IF
1 C(3,26)=(UO*VO*CH*(X2**(M3+M7+1)-X1**(M3+M7+1)))/RB**2/(M7+M3
1 +1)
65 C(3,27)=(UO*VO*CH*(X2**(M8+M3+1)-X1**(M8+M3+1)))/RB**2/(M8+M3
1 +1)
1 IF(M371.EQ.0.0) THEN
1 C(3,28)=-(H*CH*VO*UO/RB**2*(LOG(X2)-LOG(X1)))
1 GO TO 66
1 END IF
1 C(3,28)=-(H*CH*VO*UO*(X2**(M3+M7+1)-X1**(M3+M7+1)))/RB**2/(M7+M3
1 +1)
66 C(3,29)=-(H*CH*VO*UO*(X2**(M8+M3+1)-X1**(M8+M3+1)))/RB**2/(M8+M3
1 +1)
1 C(3,30)=-(H*VO*CH*(X2**(M1+M3+M7+1)-X1**(M1+M3+M7+1)))/RB**2/(M
1 1+M3+M7+1)
1 C(3,31)=(H*VO*CH*(X2**(M3+M2+M7+1)-X1**(M3+M7+M2+1)))/RB**2/(M3
1 +M2+M7+1)
1 C(3,32)=(H*VO*CH*(X2**(M1+M3+M8+1)-X1**(M1+M3+M8+1)))/RB**2/(M1
1 +M3+M8+1)
1 C(3,33)=(H*VO*CH*(X2**(M2+M8+M3+1)-X1**(M2+M3+M8+1)))/RB**2/(M2
1 +M8+M3+1)
1 IF(M371.EQ.0.0) THEN
1 C(3,34)=-(UO*VO*CH*G/RB**2*(LOG(X2)-LOG(X1)))
1 GO TO 67
1 END IF
1 C(3,34)=-(UO*VO*CH*G*(X2**(M3+M7+1)-X1**(M3+M7+1)))/RB**2/(M7+M
1 3+1)
67 C(3,35)=-(UO*VO*CH*G*(X2**(M8+M3+1)-X1**(M8+M3+1)))/RB**2/(M8+M
1 3+1)
1 C(3,36)=(UO*G*(X2**(2*M3+M7+1)-X1**(2*M3+M7+1)))/RB**2/(2*M3+M7
1 +1)
1 C(3,37)=(UO*CH*G*(X2**(M4+M7+M3+1)-X1**(M4+M7+M3+1)))/RB**2/(M4
1 +M7+M3+1)
1 IF(M8+2*M3.EQ.-1) THEN
1 C(3,38)=UO*G*CH/RB**2*(LOG(X2)-LOG(X1))
1 GO TO 2095
1 END IF
1 C(3,38)=(UO*G*CH*(X2**(M8+2*M3+1)-X1**(M8+2*M3+1)))/RB**2/(M8+2
1 *M3+1)
2095 C(3,39)=(UO*G*CH*(X2**(M3+M4+M8+1)-X1**(M3+M8+M4+1)))/RB**2/(M3
1 +M4+M8+1)
1 IF(M371.EQ.0.0) THEN
1 C(3,40)=(2*OM*CH*UO/RB*(LOG(X2)-LOG(X1)))

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GO TO 68
END IF
C(3,40)=(2*OM*CH*UO*(X2**(M3+M7+1)-X1**(M3+M7+1)))/RB/(M3+M7+1)
68 C(3,41)=(2*OM*UO*CH*(X2**(M3+M8+1)-X1**(M3+M8+1)))/RB/(M3+M8+1)
IF (M371.EQ.0.0) THEN
C(3,42)=-(2*OM*UO*CH*H/RB*(LOG(X2)-LOG(X1)))
GO TO 73
END IF
C(3,42)=-(2*H*OM*UO*CH*(X2**(M3+M7+1)-X1**(M3+M7+1)))/RB/(M3+M
1 7+1)
73 C(3,43)=-(2*H*OM*CH*UO*(X2**(M8+M3+1)-X1**(M8+M3+1)))/RB/(M8+M3
1 +1)
C(3,44)=(2*OM*H*CH*(X2**(M7+M1+M3+1)-X1**(M7+M3+M1+1)))/RB/(M7+
1 M1+M3+1)
C(3,45)=(2*OM*H*CH*(X2**(M2+M8+M3+1)-X1**(M2+M3+M8+1)))/RB/(M2+
1 M8+M3+1)
C(3,46)=(2*OM*CH*H*(X2**(M2+M7*M3+1)-X1**(M2+M3+M7+1)))/RB/(M2+
1 M7+M3+1)
C(3,47)=(2*OM*H*CH*(X2**(M8+M3+M1+1)-X1**(M8+M3+M1+1)))/RB/(M8+
1 M3+M1+1)
IF (M3.EQ.-1) GO TO 1
C(3,48)=(CH*(PE-PC)*(X2**(M3+1)-X1**(M3+1)))/RHO/RB/(M3+1)
C(3,49)=(CH*VO*(VDASHO2-VDASHC2)*(X2**(M3+1)-X1**(M3+1)))/RB/(M3+1
1 )
GO TO 2
1 C(3,48)=CH*(PE-PC)/RHO/RB*(LOG(X2)-LOG(X1))
C(3,49)=CH*VO*(VDASHO2-VDASHC2)/RB*(LOG(X2)-LOG(X1))
2 C(3,50)=(NEWI*WO*(X2**(M5+M3)-X1**(M5+M3)))/RB/(M5+M3)
C(3,51)=(NEWI*WO*M6*(X2**(M3+M6)-X1**(M3+M6)))/RB/(M3+M6)
C(3,52)=-(G*VO*M7*(M7-1)*(X2**(M3+M7-1)-X1**(M3+M7-1)))/CH/RB/
1 (M3+M7-1)
C(3,53)=-(G*VO*M8*(M8-1)*(X2**(M3+M8-1)-X1**(M3+M8-1)))/CH/RB/
1 (M3+M8-1)
C(3,54)=(G*(M7+M3)*(M7+M3-1)*(X2**(M7+2*M3-1)-X1**(M7+2*M3-1)))/
1 /RB/CH/(M7+2*M3-1)
C(3,55)=(G*(M7+M4)*(M7+M4-1)*(X2**(M7+M4+M3-1)-X1**(M7+M3+M4-1)
1 ))/RB/CH/(M7+M4+M3-1)
C(3,56)=(G*(M3+M8)*(M3+M8-1)*(X2**(2*M3+M8-1)-X1**(2*M3+M8-1)))/
1 /RB/CH/(2*M3+M8-1)
C(3,57)=(G*(M3+M4)*(M3+M4-1)*(X2**(2*M3+M4-1)-X1**(2*M3+M4-1)))/
1 /RB/CH/(2*M3+M4-1)
C(3,58)=(VO*M3*(X2**(2*M3)-X1**(2*M3)))/WO/RB/(2*M3)
C(3,59)=(VO*M4*(X2**(M3+M4)-X1**(M3+M4)))/RB/WO/(M3+M4)
C(3,60)=-(2*M3*(X2**(3*M3)-X1**(3*M3)))/RB/WO/(3*M3)
C(3,61)=-(2*M4*(X2**(M3+2*M4)-X1**(M3+2*M4)))/RB/WO/(M3+2*M4)
C(3,62)=-(M3+M4)*(X2**(2*M3+M4)-X1**(2*M3+M4))/RB/WO/(M4+2
1 *M3)
C(3,63)=-(VO*(M3+M5)*(X2**(2*M3+M5)-X1**(2*M3+M5)))/RB/WO**2/(
1 2*M3+M5)
C(3,64)=-(VO*(M4+M5)*(X2**(M3+M4+M5)-X1**(M3+M4+M5)))/RB/WO**2
1 /(M3+M4+M5)
IF (2*M3+M6.EQ.0.0) THEN
C(3,65)=-(VO*(M3+M6)/RB/WO**2*(LOG(X2)-LOG(X1)))
GO TO 2614
END IF

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      C(3,65)=- (VO* (M3+M6) * (X2** (2*M3+M6) -X1** (2*M3+M6) ) ) /RB/VO**2/ (2
1      *M3+M6)
2614      C(3,66)=- (VO* (M4+M6) * (X2** (M3+M4+M6) -X1** (M3+M4+M6) ) ) /RB/VO**2/
1      (M3+M4+M6)
      IF (M371.EQ.0.0) THEN
      C(3,67) = (NEWI*VO**2*CH*DVODR/RB**2* (LOG (X2) -LOG (X1) ) )
      GO TO 74
      END IF
      C(3,67) = (NEWI*VO**2*CH*DVODR* (X2** (M3+M7+1) -X1** (M3+M7+1) ) ) /RB**2/(
1      M7+M3+1)
74      C(3,68) = (NEWI*VO**2*CH*DVODR* (X2** (M8+M3+1) -X1** (M8+M3+1) ) ) /RB**2/(
1      M8+M3+1)
      IF ( (M1+M3+1) .EQ.0.0) THEN
      C(3,69) = (NEWI*VO**2*CH/RB**3* (LOG (X2) -LOG (X1) ) )
      GO TO 34
      END IF
      C(3,69) = (NEWI*VO**2*CH* (X2** (M1+M3+1) -X1** (M1+M3+1) ) ) /RB**3/(M1+M3+
1      1)
34      C(3,70) = (NEWI*VO**2*CH* (X2** (M2+M3+1) -X1** (M2+M3+1) ) ) /RB**2/(M2+M3+
1      1)
      IF (M371.EQ.0.0) THEN
      C(3,71)=- (NEWI*VO**2*CH*VO/RB**3* (LOG (X2) -LOG (X1) ) )
      GO TO 75
      END IF
      C(3,71)=- (NEWI*VO**2*CH*VO* (X2** (M3+M7+1) -X1** (M3+M7+1) ) ) /RB**3/(M7
1      +M3+1)
75      C(3,72)=- (2*NEWI*VO**2*CH* (X2** (M8+M3+1) -X1** (M8+M3-1) ) ) /RB**3/(M8+M3
1      +1)
      IF (M371.EQ.0.0) THEN
      C(3,73) = (NEWI*VO**2*G*CH/RB**3* (LOG (X2) -LOG (X1) ) )
      GO TO 77
      END IF
      C(3,73) = (NEWI*VO**2*G*CH* (X2** (M3+M7+1) -X1** (M3+M7+1) ) ) /RB**3/
1      (M3+M7+1)
77      C(3,74) = (NEWI*VO**2*CH*G*VO* (X2** (M8+M3+1) -X1** (M8+M3+1) ) ) /RB**3/(M
1      8+M3+1)
      C(3,75)=- (NEWI*VO**2*CH*G* (X2** (2*M3+M7+1) -X1** (2*M3+M7+1) ) ) /RB**3/
1      (2*M3+M7+1)
      C(3,76)=- (NEWI*VO**2*CH*G* (X2** (M3+M4+M8+1) -X1** (M3+M4+M8+1) ) ) /RB**
1      3/(M3+M4+M8+1)
      C(3,77)=- (2*NEWI*VO**2*G*CH* (X2** (M3+M4+M7+1) -X1** (M3+M7+M4+1) ) ) /RB**
1      3/(M4+M7+M3+1)
      IF (M8+ 2*M3.EQ.-1.0) THEN

      C(3,78)=- (2*NEWI*VO**2*CH*G/RB**3* (LOG (X2) -LOG (X1) ) )
      GO TO 7302
      END IF
      C(3,78)=- (2*NEWI*VO**2*CH*G* (X2** (M8+ 2*M3+1) -X1** (M8+ 2*M3+1) ) ) /RB**3/
1      (M8+ 2*M3+1)
C*****
C*****
C
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
7302      C(4,1) = (CH*VO* (X2** (M3+M4+1) -X1** (M3+M4+1) ) ) /RB/(M3+M4+1)
      C(4,2) = (CH*VO* (X2** (M4+M4+1) -X1** (M4+M4+1) ) ) /RB/(M4+M4+1)

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C(4,3)=(CH*UO*DVODR*(X2**(M7+M4+1)-X1**(M7+M4+1)))/RB/(M7+M4+1)
IF(M4+M8+1.EQ.0.0)THEN
C(4,4)=UO*CH*DVODR/RB*(LOG(X2)-LOG(X1))
GO TO 6410
END IF
6410 C(4,4)=(UO*CH*DVODR*(X2**(M4+M8+1)-X1**(M4+M8+1)))/RB/(M8+M4+1)
C(4,5)=-(H*CH*DVODR*(X2**(M7+M4+1)-X1**(M7+M4+1)))/RB/(M7+M4+1)
IF(M8+M4+1.EQ.0.0)THEN
C(4,6)=-(H*CH*DVODR*VO/RB*(LOG(X2)-LOG(X1)))
GO TO 5207
END IF
C(4,6)=-(H*CH*DVODR*VO*(X2**(M8+M4+1)-X1**(M8+M4+1)))/RB/(M8+M4
1 +1)
5207 C(4,7)=(H*CH*DVODR*(X2**(M1+M4+M7+1)-X1**(M1+M4+M7+1)))/RB/(M1
1 +M4+M7+1)
C(4,8)=(H*CH*DVODR*(X2**(M1+M4+M8+1)-X1**(M1+M4+M8+1)))/RB/(M8
1 +M4+M1+1)
C(4,9)=(H*CH*DVODR*(X2**(M2+M4+M7+1)-X1**(M2+M4+M7+1)))/RB/(M2
1 +M4+M7+1)
C(4,10)=(H*CH*DVODR*(X2**(M2+M4+M8+1)-X1**(M2+M4+M8+1)))/RB/(M2
1 +M8+M4+1)
IF(M4+M7.EQ.0.0)THEN
C(4,11)=-(WO*G*M7*VO/RB*(LOG(X2)-LOG(X1)))
GO TO 7650
END IF
7650 C(4,11)=-(WO*G*M7*VO*(X2**(M4+M7)-X1**(M4+M7)))/RB/(M4+M7)
C(4,12)=-(VO*WO*G*(X2**(M4+M8)-X1**(M4+M8)))/RB/(M4+M8)
C(4,13)=(WO*G*(M3+M7)*(X2**(M3+M4+M7)-X1**(M3+M4+M7)))/RB/(M3+M4+
1 M7)
C(4,14)=(WO*G*(M8+M3)*(X2**(M3+M4+M8)-X1**(M3+M4+M8)))/RB/(M3+M4+
1 M8)
C(4,15)=(WO*G*(M7+M4)*(X2**(M4+M4+M7)-X1**(M4+M4+M7)))/RB/(M4
1 +M4+M7)
C(4,16)=(WO*G*(M8+M4)*(X2**(M4+M8+M4)-X1**(M4+M8+M4)))/RB/(M4
1 +M8+M4)
C(4,17)=-(CH*VO*(X2**(M3+M4+1)-X1**(M3+M4+1)))/RB/(M3+M4+1)
C(4,18)=(CH*(X2**(2*M3+M4+1)-X1**(2*M3+M4+1)))/WO/(2*M3+M4+1)
C(4,19)=(CH*(X2**(M3+M4+M4+1)-X1**(M3+M4+M4+1)))/WO/(M3+M4+M4+1)
C(4,20)=(CH*VO*(X2**(M3+M4+M5+1)-X1**(M3+M4+M5+1)))/WO**2/(M3+M4
1 +M5+1)
C(4,21)=(CH*VO*(X2**(M3+M4+M6+1)-X1**(M3+M4+M6+1)))/WO**2/(M3+M4
1 +M6+1)
C(4,22)=-(VO*CH*(X2**(M4+M4+1)-X1**(M4+M4+1)))/WO/(M4+M4+1)
C(4,23)=(CH*(X2**(M3+M4+M4+1)-X1**(M3+M4+M4+1)))/WO/(M3+M4+M4+1)
C(4,24)=(CH*(X2**(M4+M4+M4+1)-X1**(M4+M4+M4+1)))/WO/(M4+M4+M4+1)
C(4,25)=(VO*CH*(X2**(M4+M5+M4+1)-X1**(M4+M4+M5+1)))/WO**2/(M
1 4+M4+M5+1)
C(4,26)=(UO*VO*CH*(X2**(M7+M4+1)-X1**(M7+M4+1)))/RB**2/(M7+M4
1 +1)
IF(M8+M4+1.EQ.0.0)THEN
C(4,27)=UO*VO*CH/RB**2*(LOG(X2)-LOG(X1))
GO TO 8201
END IF
C(4,27)=(UO*VO*CH*(X2**(M8+M4+1)-X1**(M8+M4+1)))/RB**2/(M8+M4
1 +1)

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8201  C(4,28)=- (H*CH*VO*UO* (X2** (M7+M4+ 1) -X1** (M4+M7+ 1) ) ) /RB**2/ (M7+M4
1  +1)
      IF (M8+M4+1.EQ.0.0) THEN
      C(4,29)=- (H*CH*VO*UO/RB**2* (LOG (X2) -LOG (X1) ) )
      GO TO 30921
      END IF
      C(4,29)=- (H*CH*VO*UO* (X2** (M8+M4+ 1) -X1** (M8+M4+ 1) ) ) /RB**2/ (M8+M4
1  +1)
30921 C(4,30)=- (H*VO*CH* (X2** (M1+M4+M7+ 1) -X1** (M1+M4+M7+ 1) ) ) /RB**2/ (M
1  1+M4+M7+ 1)
      C(4,31)= (H*VO*CH* (X2** (M4+M2+M7+ 1) -X1** (M4+M7+M2+ 1) ) ) /RB**2/ (M4
1  +M2+M7+ 1)
      C(4,32)= (H*VO*CH* (X2** (M1+M4+M8+ 1) -X1** (M1+M4+M8+ 1) ) ) /RB**2/ (M1
1  +M4+M8+ 1)
      C(4,33)= (H*VO*CH* (X2** (M2+M8+M4+ 1) -X1** (M2+M4+M8+ 1) ) ) /RB**2/ (M2
1  +M8+M4+ 1)
      C(4,34)=- (UO*VO*CH*G* (X2** (M4+M7+ 1) -X1** (M7+M4+ 1) ) ) /RB**2/ (M7+M
1  4+ 1)
      IF (M8+M4+1.EQ.0.0) THEN
      C(4,35)=- (UO*VO*CH*G/RB**2* (LOG (X2) -LOG (X1) ) )
      GO TO 1919
      END IF
      C(4,35)=- (UO*VO*CH*G* (X2** (M8+M4+ 1) -X1** (M8+M4+ 1) ) ) /RB**2/ (M8+M
1  4+ 1)
1919  C(4,36)= (UO*G* (X2** (M3+M4+M7+ 1) -X1** (M3+M4+M7+ 1) ) ) /RB**2/ (M3+M4+M7
1  +1)
      IF (2*M4+M7+1.EQ.0.0) THEN
      C(4,37)=UO*CH*G/RB**2* (LOG (X2) -LOG (X1) )
      GO TO 96713
      END IF
      C(4,37)= (UO*CH*G* (X2** (M4+M7+M4+ 1) -X1** (M4+M7+M4+ 1) ) ) /RB**2/ (M4
1  +M7+M4+ 1)
96713 C(4,38)= (UO*G*CH* (X2** (M8+M3+M4+ 1) -X1** (M8+M3+M4+ 1) ) ) /RB**2/ (M8+ 2
1  *M4+ 1)
      C(4,39)= (UO*G*CH* (X2** (M4+M4+M8+ 1) -X1** (M4+M8+M4+ 1) ) ) /RB**2/ (M4
1  +M4+M8+ 1)
      C(4,40)= (2*OM*CH*UO* (X2** (M4+M7+ 1) -X1** (M4+M7+ 1) ) ) /RB/ (M4+M7+ 1)
      IF (M4+M8+1.EQ.0.0) THEN
      C(4,41)=2*OM*UO*CH/RB* (LOG (X2) -LOG (X1) )
      GO TO 6529
      END IF
      C(4,41)= (2*OM*UO*CH* (X2** (M4+M8+ 1) -X1** (M4+M8+ 1) ) ) /RB/ (M4+M8+ 1)
6529  C(4,42)=- (2*H*OM*UO*CH* (X2** (M4+M7+ 1) -X1** (M4+M7+ 1) ) ) /RB/ (M4+M
1  7+ 1)
      IF (M8+M4+1.EQ.0.0) THEN
      C(4,43)=- (2*H*OM*CH*UO/RB* (LOG (X2) -LOG (X1) ) )
      GO TO 84104
      END IF
      C(4,43)=- (2*H*OM*CH*UO* (X2** (M8+M4+ 1) -X1** (M8+M4+ 1) ) ) /RB/ (M8+M4
1  +1)
84104 C(4,44)= (2*OM*H*CH* (X2** (M7+M1+M4+ 1) -X1** (M7+M4+M1+ 1) ) ) /RB/ (M7+
1  M1+M4+ 1)
      C(4,45)= (2*OM*H*CH* (X2** (M2+M8+M4+ 1) -X1** (M2+M4+M8+ 1) ) ) /RB/ (M2+
1  M8+M4+ 1)
      C(4,46)= (2*OM*CH*H* (X2** (M2+M7*M4+ 1) -X1** (M2+M4+M7+ 1) ) ) /RB/ (M2+

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1 M7+M4+1)
  C(4,47)=(2*OM*H*CH*(X2**(M8+M4+M1+1)-X1**(M8+M4+M1+1)))/RB/(M8+
1 M4+M1+1)
  IF(M4.EQ.-1)GO TO 101
  C(4,48)=(CH*(PE-PC)*(X2**(M4+1)-X1**(M4+1)))/RHO/RB/(M4+1)
  C(4,49)=(CH*VO*(VDASHO2-VDASHC2)*(X2**(M4+1)-X1**(M4+1)))/RB/(M4+1)
1 )
  GO TO 202
101 C(4,48)=CH*(PE-PC)/RHO/RB*(LOG(X2)-LOG(X1))
  C(4,49)=CH*VO*(VDASHO2-VDASHC2)/RB*(LOG(X2)-LOG(X1))
202 C(4,50)=(NEWT*WO*(X2**(M5+M4)-X1**(M5+M4)))/RB/(M5+M4)
  IF(M4+M6.EQ.0.0)THEN
  C(4,51)=NEWT*WO*M6/RB*(LOG(X2)-LOG(X1))
  GO TO 3916
  END IF
  C(4,51)=(NEWT*WO*M6*(X2**(M4+M6)-X1**(M4+M6)))/RB/(M4+M6)
3916 C(4,52)=- (G*VO*M7*(M7-1)*(X2**(M4+M7-1)-X1**(M4+M7-1)))/CH/RB/
1 (M4+M7-1)
  C(4,53)=- (G*VO*M8*(M8-1)*(X2**(M4+M8-1)-X1**(M4+M8-1)))/CH/RB/
1 (M4+M8-1)
  C(4,54)=(G*(M7+M3)*(M7+M3-1)*(X2**(M7+M3+M4-1)-X1**(M7+M3+M4-1)))/
1 /RB/CH/(M7+M3+M4-1)
  C(4,55)=(G*(M7+M4)*(M7+M4-1)*(X2**(M7+M4+M4-1)-X1**(M7+M4+M4-1)
1 ))/RB/CH/(M7+M4+M4-1)
  C(4,56)=(G*(M3+M8)*(M3+M8-1)*(X2**(M3+M4+M8-1)-X1**(M3+M4+M8-1)))/
1 /RB/CH/(M3+M4+M8-1)
  C(4,57)=(G*(M3+M4)*(M3+M4-1)*(X2**(M3+M4+M4-1)-X1**(M3+M4+M4-1)))/
1 /RB/CH/(M3+M4+M4-1)
  C(4,58)=(VO*M3*(X2**(M3+M4)-X1**(M3+M4)))/WO/RB/(M3+M4)
  C(4,59)=(VO*M4*(X2**(M4+M4)-X1**(M4+M4)))/RB/WO/(M4+M4)
  C(4,60)=- (2*M3*(X2**(2*M3+M4)-X1**(2*M3+M4)))/RB/WO/(2*M3+M4)
  C(4,61)=- (2*M4*(X2**(M4+2*M4)-X1**(M4+2*M4)))/RB/WO/(M4+2*M4)
  C(4,62)=- ((M3+M4)*(X*(M3+M4+M4)-X1**(M3+M4+M4)))/RB/WO/(M3+2
1 *M4)
  C(4,63)=- (VO*(M3+M5)*(X2**(M3+M4+M5)-X1**(M3+M4+M5)))/RB/WO**2/(
1 M3+M4+M5)
  IF(2*M4+M5.EQ.0.0)THEN
  C(4,64)=- (VO*(M4+M5)/RB/WO**2*(LOG(X2)-LOG(X1)))/
  GO TO 4137
  END IF
  C(4,64)=- (VO*(M4+M5)*(X2**(M4+M4+M5)-X1**(M4+M4+M5)))/RB/WO**2
1 /(M4+M4+M5)
4137 C(4,65)=- (VO*(M3+M6)*(X2**(M3+M4+M6)-X1**(M3+M4+M6)))/RB/WO**2/
1 (M3+M4+M6)
  C(4,66)=- (VO*(M4+M6)*(X2**(M4+M4+M6)-X1**(M4+M4+M6)))/RB/WO**2/
1 (M4+M4+M6)
  C(4,67)=(NEWT*WO*2*CH*DVODR*(X2**(M7+M4+1)-X1**(M7+M4+1)))/RB**2/(
1 M7+M4+1)
  IF(M8+M4+1.EQ.0.0)THEN
  C(4,68)=NEWT*WO*2*CH*DVODR/RB**2*(LOG(X2)-LOG(X1))
  GO TO 7103
  END IF
  C(4,68)=(NEWT*WO*2*CH*DVODR*(X2**(M8+M4+1)-X1**(M8+M4+1)))/RB**2/(
1 M8+M4+1)
7103 C(4,69)=(NEWT*WO*2*CH*(X2**(M1+M4+1)-X1**(M1+M4+1)))/RB**3/(M1+M4+

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1      1)
      C(4,70)=(NEWI*WO*2*CH*(X2**(M2+M4+1)-X1**(M2+M4+1)))/RB**2/(M2+M4+
1      1)
      C(4,71)=-(NEWI*WO*2*CH*VO*(X2**(M7+M4+1)-X1**(M7+M4+1)))/RB**3/(M7
1      +M4+1)
      IF(M8+M4+1.EQ.0.0) THEN
      C(4,72)=-(2*NEWI*WO*CH/RB**3*(LOG(X2)-LOG(X1)))
      GO TO 87132
      END IF
      C(4,72)=-(2*NEWI*WO*CH*(X2**(M8+M4+1)-X1**(M8+M4-1)))/RB**3/(M8+M4
1      +1)
87132   C(4,73)=(NEWI*WO*VO**2*G*CH*(X2**(M7+M4+1)-X1**(M7+M4+1)))/RB**3/
1      (M7+M4+1)
      IF(M8+M4+1.EQ.0.0) THEN
      C(4,74)=NEWI*WO*2*CH*G*VO/RB**3*(LOG(X2)-LOG(X1))
      GO TO 1847
      END IF
      C(4,74)=(NEWI*WO*2*CH*G*VO*(X2**(M8+M4+1)-X1**(M8+M4+1)))/RB**3/(M
1      8+M4+1)
1847    C(4,75)=-(NEWI*WO*2*CH*G*(X2**(M3+M4+M7+1)-X1**(M3+M4+M7+1)))/
1      RB**3/
1      (M3+M4+M7+1)
      C(4,76)=-(NEWI*WO*2*CH*G*(X2**(M4+M4+M8+1)-X1**(M4+M4+M8+1)))/RB**
1      3/(M4+M4+M8+1)
      IF(2*M4+M7+1.EQ.0.0) THEN
      C(4,77)=-(2*NEWI*WO*G*CH/RB**2*(LOG(X2)-LOG(X1)))
      GO TO 89071
      END IF
      C(4,77)=-(2*NEWI*WO*G*CH*(X2**(M4+M4+M7+1)-X1**(M4+M7+M4+1)))/RB**
1      3/(M4+M7+M4+1)
89071   C(4,78)=-(2*NEWI*WO*CH*G*(X2**(M8+M3+M4+1)-X1**(M8+M3+M4+1)))/RB**3/
1      (M8+M3+M4+1)
C*****
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C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
      IF(M5.EQ.-0.5) THEN
      C(5,1)=(VO*CH/RB*(LOG(X2)-LOG(X1)))
      GO TO 142
      END IF
      C(5,1)=(VO*CH*(X2**(2*M5+1)-X1**(2*M5+1)))/RB/(2*M5+1)
142     C(5,2)=(VO*CH*(X2**(M6+M5+1)-X1**(M6+M5+1)))/RB/(M6+M5+1)
      IF((M5+M7+1).EQ.0.0) THEN
      C(5,3)=(UO*CH*DWODR/RB*(LOG(X2)-LOG(X1)))
      GO TO 83
      END IF
      C(5,3)=(UO*CH*DWODR*(X2**(M5+M7+1)-X1**(M5+M7+1)))/RB/(M7+M5
1      +1)
83      C(5,4)=(UO*CH*DWODR*(X2**(M8+M5+1)-X1**(M8+M5+1)))/RB/(M8+M5
1      +1)
      IF((M5+M7+1).EQ.0.0) THEN
      C(5,5)=-(H*CH*UO*DWODR/RB*(LOG(X2)-LOG(X1)))
      GO TO 9542
      END IF
      C(5,5)=-(H*CH*UO*DWODR*(X2**(M5+M7+1)-X1**(M5+M7+1)))/RB/(M5

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1 +M7+1)
9542 C(5,6)=- (DWODR*H*CH*UO* (X2** (M8+M5+1) -X1** (M8+M5+1) ) ) /RB/ (M8
1 +M5+1)
C(5,7)= (H*CH*DVODR* (X2** (M7+M1+M5+1) -X1** (M7+M1+M5+1) ) ) /RB/ (M7
1 +M1+M5+1)
C(5,8)= (DWODR*H*CH* (X2** (M7+M2+M5+1) -X1** (M7+M2+M5+1) ) ) /RB/ (M7
1 +M2+M5+1)
C(5,9)=- (H*CH*DWODR* (X2** (M1+M8+M5+1) -X1** (M8+M1+M5+1) ) ) /RB/ (M8
1 +M1+M5+1)
C(5,10)=- (DWODR*H*CH* (X2** (M8+M2+M5+1) -X1** (M8+M2+M5+1) ) ) /RB/ (M
1 8+M2+M5+1)
C(5,11)=- (WO*G*M7*VO* (X2** (M5+M7) -X1** (M5+M7) ) ) /RB/ (M5+M7)
C(5,12)=- (WO*G*VO*M8* (X2** (M8+M5) -X1** (M8+M5) ) ) /RB/ (M8+M5)
C(5,13)= (WO*G* (M7+M3) * (X2** (M7+M3+M5) -X1** (M7+M3+M5) ) ) /RB/ (M7+M
1 3+M5)
C(5,14)= (WO*G* (M7+M4) * (X2** (M5+M7+M4) -X1** (M5+M7+M4) ) ) /RB/ (M5
1 +M7+M4)
C(5,15)= (WO*G* (M8+M3) * (X2** (M5+M8+M3) -X1** (M5+M3+M8) ) ) /RB/ (M5
1 +M8+M3)
C(5,16)= (WO*G* (M4+M8) * (X2** (M5+M4+M8) -X1** (M5+M4+M8) ) ) /RB/ (M5
1 +M4+M8)
IF ( (M3+M5+1) .EQ.0.0) THEN
C(5,17)= (VO*CH/RB* (LOG (X2) -LOG (X1) ) )
GO TO 44
END IF
C(5,17)= (VO*CH* (X2** (M3+M5+1) -X1** (M3+M5+1) ) ) /RB/ (M3+M5+1)
44 C(5,18)=- (CH* (X2** (2*M3+M5+1) -X1** (2*M3+M5+1) ) ) /RB/ (2*M3+M5+1)
C(5,19)=- (CH* (X2** (M5+M3+M4+1) -X1** (M5+M3+M4+1) ) ) /RB/ (M5+M3+M4
1 +1)
C(5,20)=- (VO*CH* (X2** (2*M5+M3+1) -X1** (2*M5+M3+1) ) ) /RB/VO/ (2*M5
1 +M3+1)
C(5,21)=- (VO*CH* (X2** (M3+M6+M5+1) -X1** (M3+M6+M5+1) ) ) /RB/VO/ (M3
1 +M6+M5+1)
C(5,22)= (VO*CH* (X2** (M4+M5+1) -X1** (M4+M5+1) ) ) /RB/ (M5+M4+1)
C(5,23)=- (CH* (X2** (M3+M4+M5+1) -X1** (M3+M4+M5+1) ) ) /RB/ (M3+M4+M5
1 +1)
C(5,24)=- (CH* (X2** (2*M4+M5+1) -X1** (2*M4+M5+1) ) ) /RB/ (2*M4+M5+1)
C(5,25)=- (VO*CH* (X2** (2*M5+M4+1) -X1** (2*M5+M4+1) ) ) /RB/VO/ (2*M5
1 +M4+1)
C(5,26)=- (VO*CH* (X2** (M6+M4+M5+1) -X1** (M6+M5+M4+1) ) ) /RB/VO/ (M6
1 +M4+M5+1)
C(5,27)=- (M7*PBAR* (X2** (M5+M7) -X1** (M5+M7) ) ) /RHO/ (M7+M5)
C(5,28)= (PBAR*M8* (X2** (M8+M5) -X1** (M8+M5) ) ) /RB/ (M8+M5)
IF (M5.EQ.-1) GO TO 5
C(5,29)=- (PC*VO*CH* (X2** (M5+1) -X1** (M5+1) ) ) /RB/VO/ (M5+1)
GO TO 6
5 C(5,29)=-PC*VO*CH/RB/VO* (LOG (X2) -LOG (X1) )
6 IF ( (M3+M5+1) .EQ.0.0) THEN
C(5,30)=- (PC*CH/RB* (LOG (X2) -LOG (X1) ) )
GO TO 45
END IF
C(5,30)=- (PC*CH* (X2** (M3+M5+1) -X1** (M3+M5+1) ) ) /RB/ (M3+M5+1)
45 C(5,31)=- (PC*CH* (X2** (M5+M4+1) -X1** (M5+M4+1) ) ) /RB/VO/ (M5+M4+1)
IF (M5.EQ.-0.5) THEN
C(5,32)=- (PC*VO*CH/RB/VO**2* (LOG (X2) -LOG (X1) ) )

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GO TO 176
END IF
C(5,32) = -(PC*VO*CH*(X2**(2*M5+1)-X1**(2*M5+1)))/RB/VO**2/(2*M5
1 +1)
176 IF (M3+M5+1).EQ.0.0) THEN
C(5,33) = -(PE*CH/RB/VO*(LOG(X2)-LOG(X1)))
GO TO 47
END IF
C(5,33) = -(PE*CH*(X2**(M3+M5+1)-X1**(M3+M5+1)))/RB/VO/(M3+M5+1)
47 C(5,34) = (PE*CH*(X2**(M4+M5+1)-X1**(M4+M5+1)))/RB/VO/(M5+M4+1)
IF(M5.EQ.-.5) THEN
C(5,35) = (PE*VO*CH/RB/VO*(LOG(X2)-LOG(X1)))
GO TO 387
END IF
C(5,35) = (PE*VO*CH*(X2**(2*M5+1)-X1**(2*M5+1)))/RB/VO**2/(2*M5
1 +1)
387 C(5,36) = (PE*VO*CH*(X2**(M5+M6+1)-X1**(M6+M5+1)))/RB/VO**2/(M5+M
1 6+1)
C(5,37) = -(PE*M7*CH*(X2**(M5+M7)-X1**(M5+M7)))/RB/(M5+M7)
C(5,38) = -(PE*M8*CH*(X2**(M5+M8)-X1**(M5+M8)))/RB/(M5+M8)
C(5,39) = (K*M7*WDASHC2*VO*(X2**(M5+M7)-X1**(M5+M7)))/RB/(M5+M7)
C(5,40) = (K*WDASHC2*VO*M8*(X2**(M5+M8)-X1**(M5+M8)))/RB/(M5+M8)
IF(M5.EQ.-1) GO TO 7
C(5,41) = -(WDASHC2*VO*CH*VO*(X2**(M5+1)-X1**(M5+1)))/RB/VO/(M5+1)
GO TO 8
7 C(5,41) = -(WDASHC2*VO*CH*VO/RB/VO*(LOG(X2)-LOG(X1)))
8 IF (M3+M5+1).EQ.0.0) THEN
C(5,42) = (WDASHC2*VO*CH/RB/VO*(LOG(X2)-LOG(X1)))
GO TO 48
END IF
C(5,42) = (WDASHC2*VO*CH*(X2**(M3+M5+1)-X1**(M3+M5+1)))/RB/VO/(M3+M5
1 +1)
48 C(5,43) = (WDASHC2*VO*CH*(X2**(M4+M5+1)-X1**(M4+M5+1)))/RB/VO/(M4+M5
1 +1)
IF(M5.EQ.-0.5) THEN
C(5,44) = (WDASHC2*VO*CH*VO/RB/VO**2*(LOG(X2)-LOG(X1)))
GO TO 546
END IF
C(5,44) = (WDASHC2*VO*CH*VO*(X2**(2*M5+1)-X1**(2*M5+1)))/RB/VO**2/(2
1 *M5+1)
546 C(5,45) = (WDASHC2*VO*CH*VO*(X2**(M6+M5+1)-X1**(M6+M5+1)))/RB/VO**2
1 /(M6+M5+1)
C(5,46) = -(NEWT*VO*H*UO*M7*(M7-1)*(X2**(M5+M7-1)-X1**(M5+M7-1)))/RB
1 **2/CH/(M5+M7-1)
C(5,47) = -(NEWT*VO*H*UO*M8*(M8-1)*(X2**(M5+M8-1)-X1**(M5+M8-1)))/RB
1 **2/CH/(M5+M8-1)
C(5,48) = (NEWT*VO*VO*M1*(X2**(M5+M1)-X1**(M5+M1)))/RB**2/VO/(M5+M1)
C(5,49) = (NEWT*VO*VO*M2*(X2**(M2+M5)-X1**(M2+M5)))/RB**2/VO/(M5+M2)
C(5,50) = -(NEWT*VO*(M1+M3)*(X2**(M1+M3+M5)-X1**(M3+M1+M5)))/RB**2/
1 CH/VO/(M1+M3+M5)
C(5,51) = -(NEWT*VO*(M3+M2)*(X2**(M2+M3+M5)-X1**(M2+M3+M5)))/RB**2/W
1 O/(M2+M3+M5)
C(5,52) = -(NEWT*VO*(M1+M4)*(X2**(M1+M4+M5)-X1**(M1+M4+M5)))/RB**2/
1 VO/(M1+M4+M5)
C(5,53) = -(NEWT*VO*(M2+M4)*(X2**(M2+M5+M4)-X1**(M2+M5+M4)))/RB**2/

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C(6,24)=- (CH/RB* (LOG (X2) -LOG (X1) ) )
GO TO 96831
END IF
C(6,24)=- (CH* (X2** (2*M4+M6+1) -X1** (2*M4+M6+1) ) ) /RB/ (2*M4+M6+1)
96831 C(6,25)=- (VO*CH* (X2** (M5+M6+M4+1) -X1** (M5+M6+M4+1) ) ) /RB/WO/ (M5+M6
1 +M4+1)
C(6,26)=- (VO*CH* (X2** (M6+M4+M6+1) -X1** (M6+M6+M4+1) ) ) /RB/WO/ (M6
1 +M4+M6+1)
C(6,27)=- (M7*PBAR* (X2** (M6+M7) -X1** (M6+M7) ) ) /RHO/ (M7+M6)
C(6,28)= (PBAR*M8* (X2** (M8+M6) -X1** (M8+M6) ) ) /RB/ (M8+M6)
IF (M6.EQ.-1) GO TO 505
C(6,29)=- (PC*VO*CH* (X2** (M6+1) -X1** (M6+1) ) ) /RB/WO/ (M6+1)
GO TO 606
505 C(6,29)=-PC*VO*CH/RB/WO* (LOG (X2) -LOG (X1) )
606 C(6,30)=- (PC*CH* (X2** (M6+M3+1) -X1** (M6+M3+1) ) ) /RB/ (M6+M3+1)
C(6,31)=- (PC*CH* (X2** (M6+M4+1) -X1** (M6+M4+1) ) ) /RB/WO/ (M6+M4+1)
C(6,32)=- (PC*VO*CH* (X2** (M5+M6+1) -X1** (M5+M6+1) ) ) /RB/WO**2/ (M5+M6
1 +1)
C(6,33)=- (PE*CH* (X2** (M3+M6+1) -X1** (M3+M6+1) ) ) /RB/WO/ (M6+M3+1)
C(6,34)= (PE*CH* (X2** (M4+M6+1) -X1** (M4+M6+1) ) ) /RB/WO/ (M6+M4+1)
C(6,35)= (PE*VO*CH* (X2** (M5+M6+1) -X1** (M5+M6+1) ) ) /RB/WO**2/ (M5+M6
1 +1)
C(6,36)= (PE*VO*CH* (X2** (M6+M6+1) -X1** (M6+M6+1) ) ) /RB/WO**2/ (M6+M
1 6+1)
C(6,37)=- (PE*M7*CH* (X2** (M6+M7) -X1** (M6+M7) ) ) /RB/ (M6+M7)
C(6,38)=- (PE*M8*CH* (X2** (M6+M8) -X1** (M6+M8) ) ) /RB/ (M6+M8)
C(6,39)= (K*M7*WDASHC2*WO* (X2** (M6+M7) -X1** (M6+M7) ) ) /RB/ (M6+M7)
C(6,40)= (K*WDASHC2*WO*M8* (X2** (M6+M8) -X1** (M6+M8) ) ) /RB/ (M6+M8)
IF (M6.EQ.-1) GO TO 707
C(6,41)=- (WDASHC2*WO*CH*VO* (X2** (M6+1) -X1** (M6+1) ) ) /RB/WO/ (M6+1)
GO TO 808
707 C(6,41)=- (WDASHC2*WO*CH*VO/RB/WO* (LOG (X2) -LOG (X1) ) )
808 C(6,42)= (WDASHC2*WO*CH* (X2** (M3+M6+1) -X1** (M3+M6+1) ) ) /RB/WO/ (M3+M6
1 +1)
C(6,43)= (WDASHC2*WO*CH* (X2** (M4+M6+1) -X1** (M4+M6+1) ) ) /RB/WO/ (M4+M6
1 +1)
C(6,44)= (WDASHC2*WO*CH*VO* (X2** (M5+M6+1) -X1** (M5+M6+1) ) ) /RB/WO**2/ (2
1 *M6+1)
C(6,45)= (WDASHC2*WO*CH*VO* (X2** (M6+M6+1) -X1** (M6+M6+1) ) ) /RB/WO**2
1 / (M6+M6+1)
C(6,46)=- (NEWT*WO*H*UO*M7* (M7-1) * (X2** (M6+M7-1) -X1** (M6+M7-1) ) ) /RB
1 **2/CH/ (M6+M7-1)
IF (M8.EQ.0.0) THEN
C(6,47)=0.0
GO TO 50412
END IF
C(6,47)=- (NEWT*WO*H*UO*M8* (M8-1) * (X2** (M6+M8-1) -X1** (M6+M8-1) ) ) /RB
1 **2/CH/ (M6+M8-1)
50412 C(6,48)= (NEWT*WO*VO*M1* (X2** (M6+M1) -X1** (M6+M1) ) ) /RB**2/WO/ (M6+M1)
C(6,49)= (NEWT*WO*VO*M2* (X2** (M2+M6) -X1** (M2+M6) ) ) /RB**2/WO/ (M6+M2)
C(6,50)=- (NEWT*WO* (M1+M3) * (X2** (M1+M3+M6) -X1** (M3+M1+M6) ) ) /RB**2/
1 CH/WO/ (M1+M3+M6)
C(6,51)=- (NEWT*WO* (M3+M2) * (X2** (M2+M3+M6) -X1** (M2+M3+M6) ) ) /RB**2/W
1 O/ (M2+M3+M6)
C(6,52)=- (NEWT*WO* (M1+M4) * (X2** (M1+M4+M6) -X1** (M1+M4+M6) ) ) /RB**2/

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1 WO/(M1+M4+M6)
C(6,53)=-(NEWI*WO*(M2+M4)*(X2**(M2+M6+M4)-X1**(M2+M6+M4)))/RB**2/
1 WO/(M2+M4+M6)
C(6,54)=-(NEWI*WO*VO*M6*(X2**(M5+M6)-X1**(M5+M6)))/RB**2/VO**2/(2*M
1 5)
C(6,55)=-(NEWI*WO*UO*M6*(X2**(M6+M6)-X1**(M6+M6)))/RB**2/VO**2/(M
1 6+M6)
C(6,56)=(NEWI*WO*DWO DR*M7*(X2**(M6+M7)-X1**(M6+M7)))/RB**2/(M6+M7)
C(6,57)=(NEWI*WO*DWO DR*M8*(X2**(M8+M6)-X1**(M8+M6)))/RB**2/(M8+M6)
C*****
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C
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
IF(M371.EQ.0.0)THEN
C(7,1)=-(CH/RB*(LOG(X2)-LOG(X1)))
GO TO 78
END IF
78 C(7,1)=-(CH*(X2**(M3+M7+1)-X1**(M3+M7+1))/RB/(M3+M7+1)
C(7,2)=-(CH*(X2**(M4+M7+1)-X1**(M4+M7+1))/RB/(M4+M7+1)
C(7,3)=-(F*WO*M7*(X2**(2*M7)-X1**(2*M7))/RB/(2*M7)
C(7,4)=-(F*WO*M8*(X2**(M7+M8)-X1**(M7+M8))/RB/(M7+M8)
C(7,5)=(F*WO*(M5+M7)*(X2**(M5+2*M7)-X1**(M5+2*M7))/RB**2/(M5
1 +2*M7)
C(7,6)=(F*(M7+M6)*(X2**(2*M7+M6)-X1**(2*M7+M6))/RB/(2*M7+M6)
C(7,7)=(F*(M5+M8)*(X2**(M7+M5+M8)-X1**(M7+M8+M5))/RB/(M7+M8+M5
1 )
C(7,8)=(F*(M6+M8)*(X2**(M7+M6+M8)-X1**(M7+M8+M6))/RB/(M8+M7+M6
1 )
IF((M5+M7+1).EQ.0.0)THEN
C(7,9)=(VO*CH/RB/VO*(LOG(X2)-LOG(X1)))
GO TO 3098
END IF
3098 C(7,9)=(VO*CH*(X2**(M5+M7+1)-X1**(M5+M7+1))/RB/VO/(M5+M7+1)
C(7,10)=(VO*CH*(X2**(M6+M7+1)-X1**(M6+M7+1))/RB/VO/(M6+M7+1)
C(7,11)=(-CH*(X2**(M3+M5+M7+1)-X1**(M3+M5+M7+1))/RB/VO/(M3+M
1 5+M7+1)
C(7,12)=-(CH*(X2**(M3+M6+M7+1)-X1**(M3+M6+M7+1))/RB/VO/(M3+M6
1 M7+1)
C(7,13)=-(CH*(X2**(M4+M5+M7+1)-X1**(M4+M5+M7+1))/RB/VO/(M4+M5
1 +M7+1)
C(7,14)=-(CH*(X2**(M4+M6+M7+1)-X1**(M4+M6+M7+1))/RB/VO/(M4+M6
1 +M7+1)
C(7,15)=-(VO*CH*(X2**(2*M5+M7+1)-X1**(2*M5+M7+1))/VO**2/RB/(2*
1 M5+M7+1)
C(7,16)=-(VO*CH*(X2**(2*M6+M7+1)-X1**(2*M6+M7+1))/VO**2/RB/(2*
1 M6+M7+1)
C(7,17)=-(2*VO*CH*(X2**(M5+M6+M7+1)-X1**(M5+M6+M7+1))/RB/VO**2
1 /(M5+M6+M7+1)
IF(M7.EQ.-0.5)THEN
C(7,18)=-(CH*DUODR/RB*(LOG(X2)-LOG(X1)))
GO TO 932
END IF
932 C(7,18)=-(CH*DUODR*(X2**(2*M7+1)-X1**(2*M7+1))/RB/(2*M7+1)
C(7,19)=-(CH*DUODR*(X2**(M8+M7+1)-X1**(M8+M7+1))/RB/(M8+M7+1)
IF(M7.EQ.-0.5)THEN

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C(7,20)=- (CH*H*UO/RB**2*(LOG(X2)-LOG(X1))) )
GO TO 943
END IF
C(7,20)=- (CH*H*UO*(X2**(2*M7+1)-X1**(2*M7+1)))/RB**2/(2*M7+1)
943 C(7,21)=- (H*CH*UO*(X2**(M8+M7+1)-X1**(M7+M8+1)))/RB/(M8+M7+1)
C(7,22)= (H*CH*(X2**(2*M7+M1+1)-X1**(2*M7+M1+1)))/RB**2/(2*M7
1 +M1+1)
C(7,23)= (H*CH*(X2**(2*M7+M2+1)-X1**(2*M7+M2+1)))/RB**2/(2*M7
1 +M2+1)
C(7,24)= (H*CH*(X2**(M8+M1+M7+1)-X1**(M8+M1+M7+1)))/RB**2/(M8
1 +M1+M7+1)
C(7,25)= (H*CH*(X2**(M8+M1+M7+1)-X1**(M8+M7+M1+1)))/RB**2/(M8+M7
1 +M1+1)
C*****
C*****
C
C$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C(8,1)=- (CH*(X2**(M3+M8+1)-X1**(M3+M8+1)))/RB/(M3+M8+1)
IF(M4+M8+1.EQ.0.0) THEN
C(8,2)=- (CH/RB*(LOG(X2)-LOG(X1))) )
GO TO 1942
END IF
C(8,2)=- (CH*(X2**(M4+M8+1)-X1**(M4+M8+1)))/RB/(M4+M8+1)
1942 C(8,3)=- (F*WO*M7*(X2**(M7+M8)-X1**(M7+M8)))/RB/(M7+M8)
IF(M8.EQ.0.0) THEN
C(8,3)=0.0
GO TO 87410
END IF
C(8,4)=- (F*WO*M8*(X2**(M8+M8)-X1**(M8+M8)))/RB/(M8+M8)
87410 C(8,5)= (F*WO*(M5+M7)*(X2**(M5+M7+M8)-X1**(M5+M7+M8)))/RB**2/(M5
1 +M7+M8)
C(8,6)= (F*(M7+M6)*(X2**(M7+M8+M6)-X1**(M7+M8+M6)))/RB/(M7+M8+M6)
C(8,7)= (F*(M5+M8)*(X2**(M8+M5+M8)-X1**(M8+M8+M5)))/RB/(M8+M8+M5
1 )
C(8,8)= (F*(M6+M8)*(X2**(M8+M6+M8)-X1**(M8+M8+M6)))/RB/(M8+M8+M6
1 )
C(8,9)= (VO*CH*(X2**(M5+M8+1)-X1**(M5+M8+1)))/RB/VO/(M5+M8+1)
C(8,10)= (VO*CH*(X2**(M6+M8+1)-X1**(M6+M8+1)))/RB/VO/(M6+M8+1)
C(8,11)= (-CH*(X2**(M3+M5+M8+1)-X1**(M3+M5+M8+1)))/RB/VO/(M3+M
1 5+M8+1)
C(8,12)=- (CH*(X2**(M3+M6+M8+1)-X1**(M3+M6+M8+1)))/RB/VO/(M3+M6
1 M8+1)
C(8,13)=- (CH*(X2**(M4+M5+M8+1)-X1**(M4+M5+M8+1)))/RB/VO/(M4+M5
1 +M8+1)
C(8,14)=- (CH*(X2**(M4+M6+M8+1)-X1**(M4+M6+M8+1)))/RB/VO/(M4+M6
1 +M8+1)
C(8,15)=- (VO*CH*(X2**(2*M5+M8+1)-X1**(2*M5+M8+1)))/WO**2/RB/(2*
1 M5+M8+1)
C(8,16)=- (VO*CH*(X2**(2*M6+M8+1)-X1**(2*M6+M8+1)))/WO**2/RB/(2*
1 M6+M8+1)
C(8,17)=- (2*VO*CH*(X2**(M5+M6+M8+1)-X1**(M5+M6+M8+1)))/RB/VO**2
1 /(M5+M6+M8+1)
C(8,18)=- (CH*DUODR*(X2**(M7+M8+1)-X1**(M7+M8+1)))/RB/(M7+M8+1)
C(8,19)=- (CH*DUODR*(X2**(M8+M8+1)-X1**(M8+M8+1)))/RB/(M8+M8+1)
C(8,20)=- (CH*H*UO*(X2**(M7+M8+1)-X1**(M7+M8+1)))/RB**2/(M7+M8+1)

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C(8,21) = -(H*CH*UO*(X2** (M8+M8+1) -X1** (M8+M8+1) ) ) /RB/ (M8+M8+1)
C(8,22) = (H*CH*(X2** (M7+M8+M1+1) -X1** (M7+M8+M1+1) ) ) /RB**2/ (M7+M8
1 +M1+1)
C(8,23) = (H*CH*(X2** (M7+M8+M2+1) -X1** (M7+M8+M2+1) ) ) /RB**2/ (M7+M8
1 +M2+1)
C(8,24) = (H*CH*(X2** (M8+M1+M8+1) -X1** (M8+M1+M8+1) ) ) /RB**2/ (M8
1 +M1+M8+1)
C(8,25) = (H*CH*(X2** (M8+M1+M8+1) -X1** (M8+M8+M1+1) ) ) /RB**2/ (M8+M8
1 +M1+1)
RETURN
END
SUBROUTINE NEWTON(N,M,NT,C,P,F,DF,X,DX,NMAX,
X ERROR,CONV,IT,EMAX)
02 LOGICAL CONV
03 DOUBLE PRECISION DF(N,N)
COMMON DET,ICONT
INTEGER P(N,N,M)
DIMENSION NT(N),C(N,M),F(N),X(N),DX(N)
CONV=.TRUE.
06 EO=1.0E38
07 IT=0
08
10 IT=IT+1
WRITE(*,12)IT
12 FORMAT(/1X,60(2H**))//10X,'TRIAL NO',I3)
EMAX=0.0
10 CALL FUN(N,M,NT,C,P,X,F)
IF(IT.GT.ICONT)GO TO 16
CALL DFUN(N,M,NT,C,P,X,DF)
WRITE(*,15)F
WRITE(*,15)DF
15 FORMAT(3X,9G13.5)
CALL INV(N,N,DF)
WRITE(*,15)DET
16 DO 30 I=1,N
14 DX(I)=0.0
15 DO 20 J=1,N
16
20 DX(I)=DX(I)-DF(I,J)*F(J)
17 IF (ABS(DX(I)).GT.EMAX)EMAX=ABS(DX(I))
18
30 X(I)=X(I)+DX(I)
19 WRITE(*,15)X
IF (EMAX.LT.ERROR)RETURN
20 IF (IT.EQ.NMAX)GO TO 50

```



```

EO=EMAX
22
GO TO 10
23
50 CONV=.FALSE.
24
RETURN
25
END
26
C---
27
SUBROUTINE IFUN(X,S,IIT)
C THIS SUBROUTINE WAS MADE TO IMPROVE THE CONVERGENCEY OF THE
C PROGRAM BY USING TWO CRITERIA
C 1- SCALING FACTORS
C 2- CONVERGENCE ACCELERATORS
C A DEVELOPED CONTROL SYMPO (NFR) HAS BEEN CREATED IN ORDER TO
C FIX FREQUENCY OF INTRUPTION BY WHICH WE MODIFY THE ITERATIONS
C ANOTHER CONTROL SYMPO HAS BEEN DEVELOPED (IIT) BY WHICH WE CAN
C DECIDE WHICH CRITERION WILL BE USED (SCALING OR CONVERGENCE ACC. A/OR
C BOTH..
DIMENSION X(9),S(9)
DO 1100 I=1,9
IF(IIT.EQ.1)GO TO 20
A=1.0
N=0
Z=ABS(X(I))
IF(Z.EQ.0.0.OR.Z.EQ.1.0)GO TO 10
IF(Z.GT.1.0)GO TO 33
2 N=N-1
Z=Z*10
IF(Z.LT.1)GO TO 2
GO TO 15
33 N=N+1
Z=Z/10
IF(Z.GT.1)GO TO 33
15 M=0
IF(I.GT.2.AND.I.LT.5)M=-1
IF(I.GT.5)M=-2
A=10**(M-N)
10 IF(I.LT.6.AND.I.NE.3)A=A*SIGN(1.0,X(I))
X(I)=A*X(I)
20 S(I)=1.0
IF(IIT.NE.2.AND.X(I).NE.0.0)S(I)=1/X(I)
1100 CONTINUE
RETURN
END

SUBROUTINE FUN(N,M,NT,C,P,X,F)
INTEGER P(N,N,M),R,S
DIMENSION NT(N),F(N),X(N),C(N,M)
DO 100 I=1,N
31
F(I)=0.0

```

NRNE

NRNE

NRNE

NRNE

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NRNE

NRNE

NRNE

32	DO 100 R=1,NT(I)	NRNE
33	Q=C(I,R)	NRNE
34	DO 20 S=1,N	NRNE
35	20 Q=Q*DI F(0,P(I,S,R),X(S))	NRNE
36	100 F(I)=F(I)+Q	NRNE
37	RETURN	NRNE
38	END	NRNE
39		
C——		NRNE
40	SUBROUTINE DFUN(N,M,NT,C,P,X,DF)	
	INTEGER P(N,N,M),R,S,T	
	DOUBLE PRECISION DF(N,N)	
	DIMENSION NT(N),X(N),C(N,M)	
	DO 100 I=1,N	NRNE
44	DO 100 T=1,N	NRNE
45	DF(I,T)=0.0	NRNE
46	DO 100 R=1,NT(I)	NRNE
47	Q=C(I,R)	NRNE
48	DO 20 S=1,N	NRNE
50	L=0	NRNE
49	IF(S.EQ.T)L=1	NRNE
51	20 Q=Q*DI F(L,P(I,S,R),X(S))	NRNE
52	100 DF(I,T)=DF(I,T)+Q	NRNE
53	RETURN	NRNE
54	END	NRNE
C++		NRNE
56		
C	S2-2.1.5 DI F	S2DF
18		
C	————	S2DF
19	FUNCTION DI F(I,N,X)	S2DF
20	DI F=0.0	S2DF
21	IF(N.LT.1) RETURN	S2DF


```

22      T=1.0                                     S2DF
23      IF (I.EQ.0) GO TO 20                      S2DF
24      DO 10 K=1,I                             S2DF
25      10 T=T* (N-K+ 1)                         S2DF
26      20 DIF=T
          IF (X.EQ.0.0.AND. (N-I) .EQ.0) RETURN
          DIF=T*X** (N-I)
          RETURN                                     S2DF
28      END                                       S2DF
29
C++                                             S2PD
C      S0-1.0.21  INV  PARTIAL PIVOTING
C      -----
          SUBROUTINE INV (N,NA,AA)
          DIMENSION II (15)
          DOUBLE PRECISION AA (NA,NA) ,A (15,15)
          COMMON DET,ICONT
          DET=1
          DO 10 I=1,N
              II (I) =I
              DO 10 J=1,N
10      A (I ,J) =AA (I ,J)
              DO 60 K=1,N
                  P=1.0E-10
                  IP=0
                  DO 20 I=K,N
                      IA=II (I)
                      IF (ABS (A (IA,K) ) .LE.P) GO TO 20
                      IP=I
                      P=ABS (A (IA,K) )
20      CONTINUE
                  IF (IP.EQ.0) STOP 'SINGULAR MATRI X'
                  KP=II (IP)
                  II (IP) =II (K)
                  II (K) =KP
                  P=A (KP ,K)
                  DET=DET*P
                  DO 30 J=1,N
30      A (KP ,J) =A (KP ,J) /P
                  DO 50 IA=1,N
                      I=II (IA)
                      IF (I.EQ.KP) GO TO 50
                      Q=-A (I ,K)
                      A (I ,K) =Q/P
                      DO 40 J=1,N
                          IF (J.EQ.K) GO TO 40
                          A (I ,J) =A (I ,J) +Q*A (KP ,J)
40      CONTINUE

```



```
50 CONTINUE
60 A(KP,K)=1.0/P
   DO 100 I=1,N
   DO 100 J=1,N
100 AA(I,II(J))=A(II(I),J)
   RETURN
   E N D
   SUBROUTINE SOLV(N,NA,L,W,X)
   DOUBLE PRECISION L(NA,NA)
   DIMENSION W(NA),X(NA)
   CALL INV(N,NA,L)
   DO 10 I=1,N
   X(I)=0
   DO 10 J=1,N
10  X(I)=X(I)+L(I,J)*W(J)
   RETURN
   END
```


DUO/DR-DVO/DR-DWO/DR			-3.481232	-21.24337	-21.37885
\$					
=====					
U"C2 - V"C2 - W"C2	301.6017	307.9633	205.6959		
\$					
=====					
U"O2 - V"O2 - W"O2	319.0432	476.6570	294.3857		
\$					
=====					
PE=	101480.9	PC=	123806.7		
\$					
=====					

ARE YOU APPLYING A CONDITION FOR UV OR NOT
1 FOR YES-----2 FOR NO
ARE YOU APPLYING A CONDITION FOR UV OR NOT??
1 FOR YES-----2 FOR NO

IHM AFTER CALLING =	7
NC(1)=	76
NC(2)=	76
NC(3)=	78
NC(4)=	78
NC(5)=	57
NC(6)=	57
NC(7)=	25
NC(8)=	25

```
THE STARTING ROOTS ARE
0.6015000      -0.2530000      1.1100000E-04      1.3411000E-02      0.1100600
-9.7921997E-02  7.4805998E-06      4.5400002E-06
```

TRIAL NO	1							
-1.0596	-1.5966	-2830.2	-4466.0	-6442.4	-9489.3	-0.24397E-02	-0.48556E-02	
0.53743	0.76754	0.13417E-01	0.20329E-01	0.87838E-02	0.13421E-01	0.14517E-04		
0.27681E-04	0.75760							
1.1192	0.85304E-02	0.14556E-01	0.67505E-04	0.11694E-03	0.16829E-04			
0.32595E-04	-0.18510E-01	-0.26081E-01						
-2.6921	-9.4166	-14338.	-21835.	-0.73600E-01	-0.16724	-1.5944	0.11057	
-14.461								
-26.543	-212.66	-335.58	-0.10983	-0.26386	-0.89587E-04	-0.12905E-03		
0.49495E-02	0.31795E-01							
-44.615	-58.578	0.27781E-01	0.55276E-01	-0.10057E-03	-0.21074E-03	0.17209E-01		
0.31089E-01	351.55							
517.84	0.35304E-01	0.74341E-01	-3859.3	-5469.5	-3438.6	-5332.6	43820.	
64550.								
-38.208	59.186	-4682.5	-7050.8	-7322.4	-11940.	66.851	96.564	
-1.4701								
-3.1139								
-0.69734E+09								
700.26	-77.815	-0.28329E-01	4.7736	12.022	4.8979	0.13812E-02		
-0.48317E-01								

TRIAL NO	2							
-0.94041E+06	-0.87524E+06	-0.26025E+06	-0.79037E+06	-0.17702E+08	-0.30014E+08			
853.55	1634.5							
-213.53	-186.98	-197.68	-301.24	-2538.2	-4301.6	-0.79725	-1.5882	


```

-70.225
-55.355 -300.32 -471.88 2271.3 3852.5 -0.79299 -1.5791 3224.3
5057.9
-1015.8 -1919.5 -14359. -21788. -1.2225 -1.5931 6590.8 1714.6
-24831.
-48189. -0.37154E+06 -0.62985E+06 -1.0656 -2.4655 1053.3 1687.1 17.368
30.676
-48.146 -63.955 2.2512 4.0513 1686.4 -3736.8 61.253 110.66
346.17
509.35 -0.88296 -1.9216 -0.10769E+06 -0.23205E+06 -0.11433E+07 -0.30989E+07
65312. 0.11124E+06
36026. 71621. 0.25752E+07 0.19642E+07 0.56924E+06 0.16682E+07 -71511.
-0.11434E+06 -921.23
-1734.5
0.11722E+29
469.08 -51.769 -0.59263E-01 3.1744 6.7869 2.9092 0.67732E-03
-0.16319E-01
.....

```

```

TRIAL NO 3
-0.18730E+06 -0.18962E+06 -56904. -0.17459E+06 -0.52459E+07 -0.88944E+07 201.27
384.60
-71.353 -61.765 -66.443 -101.28 -1122.3 -1902.2 -0.26732 -0.53285
-28.071
-19.123 -100.84 -158.13 1012.6 1717.3 -0.26523 -0.52840 1310.7
2060.1
-250.14 -484.99 -14351. -21845. -0.74416 -0.98839 3086.4 917.25
-7974.4
-15496. -0.16573E+06 -0.28094E+06 -0.66005 -1.5323 457.10 732.98 11.401
20.146
-46.942 -62.123 1.2753 2.3797 732.56 -1674.2 40.731 73.584
348.01
512.24 -0.52312 -1.1559 -64497. -0.14414E+06 -0.75696E+06 -0.20566E+07
57903. 95308.
20027. 39849. 0.17234E+07 0.13134E+07 0.38737E+06 0.11219E+07 -47184.
-75399. -598.92
-1136.2
0.35491E+26
315.44 -34.524 -0.57100E-01 2.0980 3.1875 1.5777 0.38614E-03
-0.55670E-02
.....

```

```

TRIAL NO 4
-35031. -40603. -13088. -39734. -0.15547E+07 -0.26359E+07 46.981 89.362
-22.198 -17.724 -22.429 -34.212 -494.50 -838.12 -0.89764E-01 -0.17918
-9.9840
-4.3266 -33.963 -53.027 450.31 763.66 -0.88571E-01 -0.17664 502.32
791.96
-29.087 -67.671 -14345. -21854. -0.42060 -0.57660 1481.6 509.08
-2462.6
-4797.4 -74457. -0.12620E+06 -0.38380 -0.89703 197.62 317.31 7.4693
13.208
-46.144 -60.907 0.86436 1.6552 317.04 -746.98 26.920 48.633
349.22
514.16 -0.27390 -0.62146 -37382. -88086. -0.50201E+06 -0.13677E+07 53046.
84771.
8996.7 17942. 0.11574E+07 0.88077E+06 0.25579E+06 0.73956E+06 -31047.

```


-49609. -399.29
-768.48
-0.94383E+23
214.48 -23.460 -0.56993E-01 1.3454 0.95690 0.71936 0.26251E-03
-0.19470E-02
.....

TRIAL NO 5
-5870.7 -8660.0 -3965.0 -10700. -0.46010E+06 -0.78004E+06 8.9897 16.820
-5.7185 -3.0711 -7.6473 -11.683 -215.43 -365.13 -0.30217E-01
-0.60529E-01 -2.6720
0.93484 -11.518 -17.790 196.41 333.07 -0.29405E-01 -0.58804E-01 188.17
297.75
19.875 27.369 -14342. -21851. -0.21515 -0.31772 766.10 317.72
-715.43
-1400.4 -34523. -58496. -0.21018 -0.49750 85.150 136.79 4.7148
8.3465
-45.585 -60.056 0.70147 1.3650 136.60 -327.97 17.262 31.185
350.07
515.51 -0.10889 -0.26636 -26229. -61133. -0.34205E+06 -0.93085E+06 50070.
78001.
2152.5 4354.0 0.78565E+06 0.59660E+06 0.12777E+06 0.41387E+06 -20634.
-32886. -308.94
-607.02
-0.17114E+21
140.15 -17.111 -0.61904E-01 0.83407 -0.36189E-01 0.12605 0.73606E-04
-0.82059E-03
.....

TRIAL NO 6
-1141.2 -2266.9 -1810.8 -3876.9 -0.13507E+06 -0.22897E+06 2.6637 4.9810
-1.3840 0.27973 -3.2723 -4.9938 -97.398 -165.07 -0.13077E-01
-0.26132E-01 -0.44387
1.5842 -4.9563 -7.7131 79.564 134.92 -0.12850E-01 -0.25648E-01 90.660
142.42
18.593 27.098 -14340. -21846. -0.92205E-01 -0.17892 447.73 231.32
-248.06
-487.58 -16567. -28056. -0.11743 -0.28248 44.096 70.049 2.8253
5.0120
-45.202 -59.474 0.19509 0.37100 69.891 -136.01 10.701 19.332
350.66
516.42 -0.17907E-01 -0.68550E-01 -62856. -0.10730E+06 -0.27468E+06 -0.71509E+06
49325. 75166.
-1000.0 -1876.1 0.51230E+06 0.38809E+06 -56546. 40278. -16077. -25191.
-522.69
-1040.3
0.10895E+19
201.72 -22.293 -0.55936E-01 -0.59425 5.0533 0.87952 0.75447E-03
0.31350E-03
.....

TRIAL NO 7
-4628.2 -4042.7 -7747.3 -15399. 0.18630E+06 0.31579E+06 115.63 231.81
5.0438 6.3742 2.4306 3.5963 90.327 153.12 0.12221E-01
0.23103E-01 6.6286
7.5523 4.0948 7.5666 -81.742 -138.58 0.14552E-01 0.28060E-01 354.08
554.78
-11.880 -24.232 -14339. -21842. -0.38140 -0.63533 995.15 678.08

..... CONTINUE

TRIAL	NO	88					
	5.6415	17.003	-0.85939E-01	-0.33548	-2.7272	-1.6286	
0.34463E-04		0.25849E-03					
.....							
TRIAL	NO	89					
	5.6419	17.003	-0.85939E-01	-0.33550	-2.7271	-1.6286	
0.34466E-04		0.25849E-03					
.....							
TRIAL	NO	90					
	5.6416	17.003	-0.85939E-01	-0.33550	-2.7272	-1.6286	
0.34465E-04		0.25849E-03					
.....							
TRIAL	NO	91					
	5.6416	17.003	-0.85939E-01	-0.33550	-2.7272	-1.6286	
0.34465E-04		0.25849E-03					
.....							
TRIAL	NO	92					
	5.6414	17.003	-0.85939E-01	-0.33549	-2.7272	-1.6286	
0.34463E-04		0.25849E-03					
.....							
TRIAL	NO	93					
	5.6418	17.003	-0.85939E-01	-0.33550	-2.7271	-1.6286	
0.34466E-04		0.25849E-03					
.....							
TRIAL	NO	94					
	5.6415	17.003	-0.85939E-01	-0.33549	-2.7272	-1.6286	
0.34464E-04		0.25849E-03					
.....							
TRIAL	NO	95					
	5.6415	17.003	-0.85939E-01	-0.33549	-2.7272	-1.6286	
0.34463E-04		0.25849E-03					
.....							
TRIAL	NO	96					
	5.6420	17.003	-0.85939E-01	-0.33551	-2.7271	-1.6286	
0.34468E-04		0.25849E-03					
.....							
TRIAL	NO	97					
	5.6417	17.003	-0.85939E-01	-0.33551	-2.7271	-1.6286	
0.34468E-04		0.25849E-03					
.....							
TRIAL	NO	98					
	5.6411	17.003	-0.85939E-01	-0.33548	-2.7272	-1.6286	
0.34462E-04		0.25850E-03					
.....							
TRIAL	NO	99					
	5.6418	17.003	-0.85939E-01	-0.33551	-2.7271	-1.6286	
0.34468E-04		0.25849E-03					
.....							
TRIAL	NO	100					
	5.6414	17.003	-0.85939E-01	-0.33550	-2.7271	-1.6286	
0.34466E-04		0.25850E-03					
.....							
TRIAL	NO	101					
	5.6415	17.003	-0.85939E-01	-0.33550	-2.7271	-1.6286	
0.34465E-04		0.25849E-03					


```

.....
TRIAL  NO102
      5.6418  17.003  -0.85939E-01  -0.33551  -2.7271  -1.6286
0.34468E-04  0.25849E-03
.....
TRIAL  NO103
      5.6412  17.003  -0.85939E-01  -0.33549  -2.7272  -1.6286
0.34464E-04  0.25850E-03
.....
TRIAL  NO104
      5.6417  17.003  -0.85939E-01  -0.33550  -2.7271  -1.6286
0.34466E-04  0.25849E-03
.....
TRIAL  NO105
      5.6414  17.003  -0.85939E-01  -0.33549  -2.7272  -1.6286
0.34464E-04  0.25849E-03
.....
TRIAL  NO106
      5.6416  17.003  -0.85939E-01  -0.33549  -2.7272  -1.6286
0.34465E-04  0.25849E-03
.....
TRIAL  NO107
      5.6416  17.003  -0.85939E-01  -0.33549  -2.7272  -1.6286
0.34465E-04  0.25849E-03
.....
TRIAL  NO108
      5.6416  17.003  -0.85939E-01  -0.33549  -2.7272  -1.6286
0.34465E-04  0.25849E-03
.....
TRIAL  NO109
      5.6417  17.003  -0.85939E-01  -0.33550  -2.7271  -1.6286
0.34466E-04  0.25849E-03
.....
TRIAL  NO110
      5.6415  17.003  -0.85939E-01  -0.33549  -2.7272  -1.6286
0.34464E-04  0.25849E-03
.....
TRIAL  NO111
      5.6418  17.003  -0.85939E-01  -0.33550  -2.7271  -1.6286
0.34466E-04  0.25849E-03
.....
TRIAL  NO112
      5.6414  17.003  -0.85939E-01  -0.33549  -2.7272  -1.6286
0.34463E-04  0.25849E-03
.....
TRIAL  NO113
      5.6420  17.003  -0.85939E-01  -0.33551  -2.7271  -1.6286
0.34469E-04  0.25849E-03
.....
TRIAL  NO114
      5.6413  17.003  -0.85939E-01  -0.33549  -2.7271  -1.6286
0.34465E-04  0.25850E-03
.....
TRIAL  NO115
      5.6415  17.003  -0.85939E-01  -0.33550  -2.7271  -1.6286

```


0.34466E-04 0.25849E-03
.....

TRIAL	NO116					
	5.6414	17.003	-0.85939E-01	-0.33549	-2.7272	-1.6286
0.34464E-04	0.25849E-03					
.....						

In this Appendix , the final set of equations is presented. This set of equations is to be solved by Newton-Raphson iteration.

In the following set of equations we used these definitions:

$$x = z/c - z_0/c \quad , \quad d/dz = \frac{1}{c} d/dx$$

And

$$z^{m_i} = x_2^{m_i} - x_1^{m_i}$$

The pressure terms in the equations were left as integrations. In the final solutions these terms were substituted for from a similar set of measurements as was explained in chapter 6.

Integration of $\int_{x_1}^{x_2} \Phi_i R C dx$

$$\begin{aligned}
 & - \frac{C V_0}{r} \frac{r^{m_3+m_1+1}}{(m_3+m_1+1)} - \frac{V_0 C}{r} A_4 \frac{r^{m_4+m_1+1}}{m_4+m_1+1} + \frac{C U_0}{r} \frac{dU_0}{dr} A_7 \frac{r^{m_7+m_1+1}}{m_7+m_1+1} + \frac{C U_0}{r} \frac{dU_0}{dr} A_8 \frac{r^{m_8+m_1+1}}{m_8+m_1+1} - \frac{C H}{r} \frac{dU_0}{dr} \\
 & A_7 \frac{r^{m_7+m_1+1}}{m_7+m_1+1} + \frac{C H}{r} \frac{dU_0}{dr} A_7 A_1 \frac{r^{m_7+2m_1+1}}{m_7+2m_1+1} + \frac{C H}{r} \frac{dU_0}{dr} A_7 A_2 \frac{r^{m_7+m_2+m_1+1}}{m_7+m_2+m_1+1} - \frac{C H}{r} \frac{dU_0}{dr} \\
 & U_0 A_8 \frac{r^{m_8+m_1+1}}{m_8+m_1+1} + \frac{C H}{r} \frac{dU_0}{dr} A_8 A_1 \frac{r^{m_8+2m_1+1}}{m_8+2m_1+1} + \frac{C H}{r} \frac{dU_0}{dr} A_8 A_2 \frac{r^{m_8+m_2+m_1+1}}{m_8+m_2+m_1+1} - \frac{W_0 H}{r} A_7 U_0 \\
 & \frac{r^{m_7+m_1}}{m_7+m_1} + \frac{W_0}{r} H A_7 A_1 (m_7+m_1) \frac{r^{m_7+2m_1}}{m_7+2m_1} + \frac{W_0}{r} H A_7 A_2 (m_7+m_2) \frac{r^{m_7+m_2+m_1}}{m_7+m_2+m_1} \\
 & - \frac{W_0}{r} H A_8 U_0 \frac{r^{m_8+m_1}}{m_8+m_1} + \frac{W_0 H}{r} A_8 A_1 (m_8+m_1) \frac{r^{m_8+2m_1}}{m_8+2m_1} + \frac{W_0}{r} H A_8 A_2 (m_8+m_2) \frac{r^{m_8+m_2+m_1}}{m_8+m_2+m_1} \\
 & + \frac{V_0 C}{r} A_1 \frac{r^{2m_1+1}}{2m_1+1} + \frac{V_0 C}{r} A_2 \frac{r^{m_2+m_1+1}}{m_2+m_1+1} - \frac{C}{r} A_1 A_3 \frac{r^{2m_1+m_3+1}}{2m_1+m_3+1} - \frac{C}{r} A_1 A_4 \frac{r^{2m_1+m_4+1}}{2m_1+m_4+1} \\
 & - \frac{C}{r} A_2 A_3 \frac{r^{m_1+m_2+m_3+1}}{m_1+m_2+m_3+1} - \frac{C}{r} A_2 A_4 \frac{r^{m_1+m_2+m_4+1}}{m_1+m_2+m_4+1} - \frac{C}{r W_0} A_1 A_3 A_5 \frac{r^{2m_1+m_3+m_5+1}}{2m_1+m_3+m_5+1} \\
 & - \frac{C}{r W_0} A_1 A_4 A_5 \frac{r^{2m_1+m_4+m_5+1}}{2m_1+m_4+m_5+1} - \frac{C}{r W_0} A_2 A_3 A_5 \frac{r^{m_2+m_3+m_5+m_1+1}}{m_2+m_3+m_5+m_1+1} - \frac{C}{r W_0} A_2 A_4 A_5 \frac{r^{m_1+m_2+m_4+m_5+1}}{m_1+m_2+m_4+m_5+1} \\
 & - \frac{C}{r W_0} A_1 A_3 A_6 \frac{r^{2m_1+m_3+m_6+1}}{2m_1+m_3+m_6+1} - \frac{C}{r W_0} A_1 A_4 A_6 \frac{r^{2m_1+m_4+m_6+1}}{2m_1+m_4+m_6+1} - \frac{C}{r W_0} A_2 A_3 A_6 \frac{r^{m_1+m_2+m_3+m_6+1}}{m_1+m_2+m_3+m_6+1} \\
 & - \frac{C}{r W_0} A_2 A_4 A_6 \frac{r^{m_1+m_2+m_4+m_6+1}}{m_1+m_2+m_4+m_6+1} - \frac{V_0^2 C}{r^2} A_7 \frac{r^{m_7+m_1+1}}{m_7+m_1+1} + \frac{2 V_0^2 C}{r^2} G A_7 \frac{r^{m_7+m_1+1}}{m_7+m_1+1} - C A_7 \Omega^2 \frac{r^{m_7+m_1+1}}{m_7+m_1+1} \\
 & - \frac{2 C \Omega}{r} V_0 A_7 \frac{r^{m_7+m_1+1}}{m_7+m_1+1} - 2 \Omega \frac{C V_0}{r} G A_7 \frac{r^{m_7+m_1+1}}{m_7+m_1+1} - \frac{V_0^2 C}{r^2} A_8 \frac{r^{m_8+m_1+1}}{m_8+m_1+1} + \frac{2 V_0^2 C}{r^2} G A_8 \frac{r^{m_8+m_1+1}}{m_8+m_1+1} \\
 & - \Omega^2 A_8 C \frac{r^{m_8+m_1+1}}{m_8+m_1+1} - 2 \Omega \frac{C V_0}{r} A_8 \frac{r^{m_8+m_1+1}}{m_8+m_1+1} - 2 \Omega \frac{C V_0}{r} G A_8 \frac{r^{m_8+m_1+1}}{m_8+m_1+1} - \frac{2 V_0 C}{r^2} G A_7 A_3 \\
 & \frac{r^{m_1+m_3+m_7+1}}{m_1+m_3+m_7+1} - \frac{2 V_0 C}{r^2} G A_7 A_4 \frac{r^{m_1+m_3+m_4+1}}{m_1+m_3+m_4+1} - 2 \frac{V_0 C}{r^2} G A_8 A_3 \frac{r^{m_3+m_8+m_1+1}}{m_3+m_8+m_1+1} - \frac{2 V_0 C}{r^2} G A_8 A_4 \\
 & \frac{r^{m_4+m_8+m_1+1}}{m_4+m_8+m_1+1} - \frac{2 \Omega}{r} C G A_7 A_3 \frac{r^{m_7+m_3+m_1+1}}{m_7+m_3+m_1+1} - \frac{2 \Omega}{r} C G A_7 A_4 \frac{r^{m_7+m_4+m_1+1}}{m_7+m_4+m_1+1} - \frac{2 \Omega}{r} C G A_8 A_3 \\
 & \frac{r^{m_8+m_3+m_1+1}}{m_8+m_3+m_1+1} - \frac{2 \Omega}{r} C G A_8 A_4 \frac{r^{m_8+m_4+m_1+1}}{m_8+m_4+m_1+1} - \frac{1}{r} \int_{x_1}^{x_2} x^m \frac{\partial}{\partial r} (B/r (A_7 x^{m_7} A_8 x^{m_8})) C dx \\
 & + \frac{C}{r} (P_c - P_e) \frac{\partial \theta_c}{\partial r} \frac{r^{m_1+1}}{m_1+1} \left\{ \text{if } m_1 = -1.0, \text{ the last term will read } \frac{C}{r} (P_c - P_e) \frac{\partial \theta_c}{\partial r} \right. \\
 & \left. [\lg x_2 - \lg x_1] \right\} + \frac{P_e}{r^2} C \left\{ A_7 \frac{r^{m_7+m_1+1}}{m_7+m_1+1} + A_8 \frac{r^{m_8+m_1+1}}{m_8+m_1+1} \right\} + \frac{I_0}{r^2} \bar{u}_c' A_7 \frac{r^{m_7+m_1+1}}{m_7+m_1+1} + \frac{I_0}{r^2} \bar{u}_c' \\
 & A_8 \frac{r^{m_8+m_1+1}}{m_8+m_1+1} - \frac{J_0}{r^2} \bar{u}_c' A_7 \frac{r^{m_7+m_1+1}}{m_7+m_1+1} - \frac{J_0}{r^2} C \bar{u}_c' A_8 \frac{r^{m_8+m_1+1}}{m_8+m_1+1} + \text{either } \left\{ \frac{C}{r} (\bar{u}_v' |_0 - \bar{u}_v' |_c) \right. \\
 & \left. \frac{r^{m_1+1}}{m_1+1} \right\} \text{ or } \left\{ \frac{2 \epsilon C}{r^3} G A_7 V_0 \frac{r^{m_7+m_1+1}}{m_7+m_1+1} - \frac{2 \epsilon C}{r^3} G A_7 A_3 \frac{r^{m_7+m_3+m_1+1}}{m_7+m_3+m_1+1} - \frac{2 \epsilon C}{r^3} G A_7 A_4 \right. \\
 & \left. \frac{r^{m_7+m_4+m_1+1}}{m_7+m_4+m_1+1} + \frac{2 \epsilon C}{r^3} G V_0 A_8 \frac{r^{m_8+m_1+1}}{m_8+m_1+1} - \frac{2 \epsilon C}{r^3} G A_8 A_3 \frac{r^{m_3+m_8+m_1+1}}{m_3+m_8+m_1+1} - \frac{2 \epsilon C}{r^3} \right. \\
 & \left. G A_8 A_4 \frac{r^{m_8+m_4+m_1+1}}{m_8+m_4+m_1+1} - \frac{2 \epsilon H}{r C} V_0 A_7 m_7 (m_7-1) \frac{r^{m_7+m_1+1}}{m_7+m_1+1} - \frac{2 \epsilon H}{r C} U_0 A_8 m_8 (m_8-1) \right. \\
 & \left. \frac{r^{m_8+m_1+1}}{m_8+m_1+1} + \frac{2 \epsilon H}{r C} A_1 A_7 (m_1+m_7)(m_1+m_7-1) \frac{r^{2m_1+m_7-1}}{2m_1+m_7-1} + \frac{2 \epsilon H}{r C} A_1 A_8 (m_1+m_8) \right. \\
 & \left. (m_8+m_1-1) \frac{r^{m_8+m_1-1}}{m_8+m_1-1} + \frac{2 \epsilon H}{r C^2} H_2 A_7 (m_2+m_7)(m_2+m_7-1) \frac{r^{m_1+m_2+m_7-1}}{m_1+m_2+m_7-1} + \frac{2 \epsilon H}{r C} A_2 A_8 \right. \\
 & \left. (m_8+m_2)(m_8+m_2-1) \frac{r^{m_8+m_2+m_1-1}}{m_8+m_2+m_1-1} + \frac{2 \epsilon}{r} A_1 \frac{V_0}{W_0} m_1 \frac{r^{2m_1}}{2m_1} - \frac{2 \epsilon}{r} \frac{A_1 A_3}{W_0} (m_1+m_3) \frac{r^{2m_1+m_3}}{2m_1+m_3} \right\}
 \end{aligned}$$

$$\begin{aligned}
& - \frac{\mathcal{E}}{rc} \frac{A_1 A_4}{W_0} (m_4 + m_1) \frac{r^{m_4 + 2m_1}}{m_4 + 2m_1} - \frac{\mathcal{E}}{r} \frac{A_1 V_0}{W_0^2} A_5 (m_5 + m_1) \frac{r^{m_5 + 2m_1}}{m_5 + 2m_1} - \frac{\mathcal{E}}{r} \frac{V_0}{W_0^2} A_1 A_6 (m_1 + m_6) \\
& \frac{r^{2m_1 + m_6}}{2m_1 + m_6} + \frac{\mathcal{E}}{r} \frac{A_2 V_0}{W_0} m_2 \frac{r^{m_1 + m_2}}{m_1 + m_2} - \frac{\mathcal{E}}{r W_0} A_2 A_3 (m_2 + m_3) \frac{r^{m_1 + m_2 + m_3}}{m_1 + m_2 + m_3} - \frac{\mathcal{E}}{r} \frac{A_2 A_4}{W_0} \\
& (m_2 + m_4) \frac{r^{m_1 + m_2 + m_4}}{m_1 + m_2 + m_4} - \frac{\mathcal{E}}{r} \frac{A_2 V_0}{W_0^2} A_5 (m_5 + m_2) \frac{r^{m_5 + m_2 + m_1}}{m_5 + m_2 + m_1} - \frac{\mathcal{E}}{r} \frac{V_0}{W_0^2} A_2 A_6 (m_6 + m_2) \\
& \frac{r^{m_1 + m_6 + m_2}}{m_1 + m_6 + m_2} - \frac{\mathcal{E}}{r} \frac{dW_0}{dr} A_7 m_7 \frac{r^{m_1 + m_7}}{m_1 + m_7} - \frac{\mathcal{E}}{r} \frac{dW_0}{dr} A_8 m_8 \frac{r^{m_1 + m_8}}{m_1 + m_8}
\end{aligned}$$

Integration of $\int_{x_1}^{x_2} \Phi_2 R_1 C dx$

$$\begin{aligned}
& - \frac{V_0 C}{r} A_3 \frac{r^{m_3 + m_2 + 1}}{m_3 + m_2 + 1} - \frac{V_0 C}{r} A_4 \frac{r^{m_4 + m_2 + 1}}{m_4 + m_2 + 1} + \frac{U_0 C}{r} \frac{dW_0}{dr} A_7 \frac{r^{m_7 + m_2 + 1}}{m_7 + m_2 + 1} + \frac{U_0 C}{r} \frac{dU_0}{dr} A_8 \frac{r^{m_8 + m_2 + 1}}{m_8 + m_2 + 1} \\
& - \frac{H C}{r} \frac{dU_0}{dr} U_0 A_7 \frac{r^{m_7 + m_2 + 1}}{m_7 + m_2 + 1} + \frac{H C}{r} \frac{dU_0}{dr} A_7 A_1 \frac{r^{m_7 + m_2 + 1}}{m_7 + m_2 + 1} + \frac{H C}{r} \frac{dU_0}{dr} A_7 A_2 \frac{r^{2m_2 + m_7 + 1}}{2m_2 + m_7 + 1} \\
& - \frac{H C}{r} \frac{dU_0}{dr} U_0 A_8 \frac{r^{m_8 + m_2 + 1}}{m_8 + m_2 + 1} + \frac{H C}{r} \frac{dU_0}{dr} A_8 A_1 \frac{r^{m_8 + m_2 + 1}}{m_8 + m_2 + 1} + \frac{H C}{r} \frac{dU_0}{dr} A_8 A_2 \frac{r^{m_8 + 2m_2 + 1}}{m_8 + 2m_2 + 1} \\
& - \frac{W_0}{r} H A_7 U_0 m_7 \frac{r^{m_7 + m_2}}{m_7 + m_2} + \frac{W_0}{r} H A_7 A_1 (m_7 + m_1) \frac{r^{m_7 + m_2}}{m_7 + m_2} + \frac{W_0}{r} H A_7 A_2 (m_7 + m_2) \frac{r^{m_7 + 2m_2}}{m_7 + 2m_2} \\
& - \frac{W_0 H}{r} A_8 U_0 m_8 \frac{r^{m_8 + m_2}}{m_8 + m_2} + \frac{W_0}{r} H A_8 A_1 (m_8 + m_1) \frac{r^{m_8 + m_2}}{m_8 + m_2} + \frac{W_0}{r} H A_8 A_2 (m_8 + m_2) \frac{r^{m_8 + 2m_2}}{m_8 + 2m_2} \\
& + \frac{C V_0}{r} A_1 \frac{r^{m_1 + m_2 + 1}}{m_1 + m_2 + 1} + \frac{V_0 C}{r} A_2 \frac{r^{2m_2 + 1}}{2m_2 + 1} - \frac{C}{r} A_1 A_3 \frac{r^{m_1 + m_2 + m_3 + 1}}{m_1 + m_2 + m_3 + 1} - \frac{C}{r} A_1 A_4 \frac{r^{m_1 + m_2 + m_4}}{m_1 + m_2 + m_4} \\
& - \frac{C}{r} A_2 A_3 \frac{r^{2m_2 + m_3 + 1}}{2m_2 + m_3 + 1} - \frac{C}{r} A_2 A_4 \frac{r^{2m_2 + m_4 + 1}}{2m_2 + m_4 + 1} - \frac{C}{r W_0} A_1 A_3 A_5 \frac{r^{m_1 + m_2 + m_3 + m_5 + 1}}{m_1 + m_2 + m_3 + m_5 + 1} - \frac{C}{r W_0} \\
& A_1 A_4 A_5 \frac{r^{m_1 + m_2 + m_4 + m_5 + 1}}{m_1 + m_2 + m_4 + m_5 + 1} - \frac{C}{r W_0} A_2 A_3 A_5 \frac{r^{2m_2 + m_3 + m_5 + 1}}{2m_2 + m_3 + m_5 + 1} - \frac{C}{r W_0} A_2 A_4 A_5 \frac{r^{2m_2 + m_4 + m_5 + 1}}{2m_2 + m_4 + m_5 + 1} \\
& - \frac{C}{r W_0} A_1 A_3 A_6 \frac{r^{m_1 + m_2 + m_3 + m_6 + 1}}{m_1 + m_2 + m_3 + m_6 + 1} - \frac{C}{r W_0} A_1 A_4 A_6 \frac{r^{m_1 + m_2 + m_4 + m_6 + 1}}{m_1 + m_2 + m_4 + m_6 + 1} - \frac{C}{r W_0} A_1 A_3 A_6 \\
& \frac{r^{2m_2 + m_3 + m_6 + 1}}{2m_2 + m_3 + m_6 + 1} - \frac{C}{r W_0} A_2 A_4 A_6 \frac{r^{2m_2 + m_4 + m_6 + 1}}{2m_2 + m_4 + m_6 + 1} - \frac{V_0^2 C}{r^2} A_7 \frac{r^{m_7 + m_2 + 1}}{m_7 + m_2 + 1} + \frac{2V_0^2 C}{r^2} G A_7 \\
& \frac{r^{m_7 + m_2 + 1}}{m_7 + m_2 + 1} - A_7 \Omega^2 C \frac{r^{m_7 + m_2 + 1}}{m_7 + m_2 + 1} - 2 \frac{\Omega}{r} V_0 A_7 \frac{r^{2m_2 + m_7 + 1}}{2m_2 + m_7 + 1} - 2 \frac{\Omega}{r} C V_0 G A_7 \frac{r^{m_7 + m_2 + 1}}{m_7 + m_2 + 1} \\
& - \frac{V_0^2}{r^2} C A_8 \frac{r^{m_8 + m_2 + 1}}{m_8 + m_2 + 1} + \frac{2V_0^2}{r^2} C G A_8 \frac{r^{m_8 + m_2 + 1}}{m_8 + m_2 + 1} - \Omega^2 A_8 C \frac{r^{m_8 + m_2 + 1}}{m_8 + m_2 + 1} - \frac{2\Omega}{r} C V_0 A_8 \\
& \frac{r^{m_8 + m_2 + 1}}{m_8 + m_2 + 1} - 2 \frac{\Omega}{r} C V_0 G A_8 \frac{r^{m_8 + m_2 + 1}}{m_8 + m_2 + 1} - 2 \frac{V_0 C}{r^2} \Omega A_7 A_3 \frac{r^{m_3 + m_2 + m_7 + 1}}{m_3 + m_2 + m_7 + 1} - \frac{2V_0 C}{r^2} G \\
& A_7 A_4 \frac{r^{m_2 + m_7 + m_4 + 1}}{m_2 + m_7 + m_4 + 1} - \frac{2V_0 C}{r^2} G A_8 A_3 \frac{r^{m_2 + m_8 + m_3 + 1}}{m_2 + m_8 + m_3 + 1} - \frac{2V_0}{r^2} G A_8 A_4 \frac{r^{m_8 + m_4 + m_2 + 1}}{m_8 + m_4 + m_2 + 1} \\
& - \frac{2\Omega}{r} G A_7 A_3 \frac{r^{m_7 + m_3 + m_2 + 1}}{m_7 + m_3 + m_2 + 1} - 2 \frac{\Omega}{r} C G A_4 A_7 \frac{r^{m_7 + m_4 + m_2 + 1}}{m_7 + m_4 + m_2 + 1} - 2 \frac{\Omega}{r} C G A_8 A_3 \\
& \frac{r^{m_8 + m_3 + m_2 + 1}}{m_8 + m_3 + m_2 + 1} - 2 \frac{\Omega}{r} G A_8 A_4 \frac{r^{m_8 + m_4 + m_2 + 1}}{m_8 + m_4 + m_2 + 1} - \int_{x_1}^{x_2} \frac{1}{r} C x^{m_2} \left[\left(\frac{\partial}{\partial r} (P/r (A_7 x^7 + A_8 x^8)) \right) \right] dx \\
& + \frac{C}{r} (P - P_e) \frac{r^{m_2 + 1}}{m_2 + 1} + \frac{C}{r} (P - P_e) \frac{\partial \theta_c}{\partial r} \frac{r^{m_2 + 1}}{m_2 + 1} + \frac{C}{r} P \frac{1}{r^2} A_7 \frac{r^{m_2 + m_7 + 1}}{m_2 + m_7 + 1} + \frac{C}{r} P \frac{1}{r^2} A_8 \frac{r^{m_2 + m_8 + 1}}{m_2 + m_8 + 1}
\end{aligned}$$

$$\begin{aligned}
& + \frac{IC}{r^2} \bar{U}_c^2 A_7 \frac{\gamma^{\frac{m_7+m_2+1}{2}}}{\gamma^{\frac{m_7+m_2+1}{2}}} + \frac{IC}{r^2} \bar{U}_c^2 A_8 \frac{\gamma^{\frac{m_8+m_2+1}{2}}}{\gamma^{\frac{m_8+m_2+1}{2}}} - \frac{JC}{r^2} \bar{U}_c^2 A_7 \frac{\gamma^{\frac{m_7+m_2+1}{2}}}{\gamma^{\frac{m_7+m_2+1}{2}}} - \frac{JC}{r^2} \bar{U}_c^2 A_8 \frac{\gamma^{\frac{m_8+m_2+1}{2}}}{\gamma^{\frac{m_8+m_2+1}{2}}} \\
& + \text{either } \left\{ \frac{C}{r} (\bar{U}_c^2|_0 - \bar{U}_c^2|_c) \frac{\gamma^{\frac{m_2+m_1}{2}}}{\gamma^{\frac{m_2+m_1}{2}}} \right\} \text{ or } \left\{ \frac{2\epsilon C}{r^3} G A_7 U_0 \frac{\gamma^{\frac{m_7+m_2+1}{2}}}{\gamma^{\frac{m_7+m_2+1}{2}}} \right. \\
& - \frac{2\epsilon C}{r^2} G A_7 A_3 \frac{\gamma^{\frac{m_7+m_3+m_2+1}{2}}}{\gamma^{\frac{m_7+m_3+m_2+1}{2}}} - \frac{2\epsilon C}{r^3} G C A_7 A_4 \frac{\gamma^{\frac{m_2+m_3+m_4+1}{2}}}{\gamma^{\frac{m_2+m_3+m_4+1}{2}}} + \frac{2\epsilon C}{r^3} G V_0 A_8 \\
& \left. \frac{\gamma^{\frac{m_8+m_2+1}{2}}}{\gamma^{\frac{m_8+m_2+1}{2}}} - \frac{2\epsilon C}{r^3} G A_8 A_3 \frac{\gamma^{\frac{m_3+m_8+1}{2}}}{\gamma^{\frac{m_3+m_8+1}{2}}} - \frac{2\epsilon C}{r^3} G A_8 A_4 \frac{\gamma^{\frac{m_8+m_4+m_2+1}{2}}}{\gamma^{\frac{m_8+m_4+m_2+1}{2}}} \right\} - \frac{2\epsilon H}{rc} \\
& V_0 A_7 m_7 (m_7-1) \frac{\gamma^{\frac{m_7+m_7-1}{2}}}{\gamma^{\frac{m_7+m_7-1}{2}}} - \frac{2\epsilon H}{rc} U_0 A_8 m_8 (m_8-1) \frac{\gamma^{\frac{m_8+m_8-1}{2}}}{\gamma^{\frac{m_8+m_8-1}{2}}} + \frac{2\epsilon H}{rc} A_1 A_7 (m_1+m_7) \\
& (m_1+m_7-1) \frac{\gamma^{\frac{m_1+m_7+m_7-1}{2}}}{\gamma^{\frac{m_1+m_7+m_7-1}{2}}} + \frac{2\epsilon H}{rc} A_1 A_8 (m_8+m_1) (m_8+m_1-1) \frac{\gamma^{\frac{m_8+m_2+m_1-1}{2}}}{\gamma^{\frac{m_8+m_2+m_1-1}{2}}} + \frac{2\epsilon H}{rc} A_1 A_7 \\
& (m_2+m_7) (m_2+m_7-1) \frac{\gamma^{\frac{2m_2+m_7-1}{2}}}{\gamma^{\frac{2m_2+m_7-1}{2}}} + \frac{2\epsilon H}{rc} A_1 A_8 (m_8+m_2) (m_8+m_2-1) \frac{\gamma^{\frac{2m_2+m_2-1}{2}}}{\gamma^{\frac{2m_2+m_2-1}{2}}} \\
& + \frac{2\epsilon}{r} A_1 \frac{V_0}{W_0} m_1 \frac{\gamma^{\frac{m_2+m_1}{2}}}{\gamma^{\frac{m_2+m_1}{2}}} - \frac{2\epsilon}{r} \frac{A_1 A_3}{W_0} (m_1+m_3) \frac{\gamma^{\frac{m_1+m_2+m_3}{2}}}{\gamma^{\frac{m_1+m_2+m_3}{2}}} - \frac{2\epsilon}{r} \frac{A_1 A_4}{W_0} (m_4+m_2) \\
& \frac{\gamma^{\frac{m_4+m_2+m_1}{2}}}{\gamma^{\frac{m_4+m_2+m_1}{2}}} - \frac{2\epsilon A_1 V_0}{W_0^2} A_5 (m_5+m_1) \frac{\gamma^{\frac{m_5+m_1}{2}}}{\gamma^{\frac{m_5+m_1}{2}}} - \frac{2\epsilon}{r W_0} A_1 A_6 (m_1+m_6) \frac{\gamma^{\frac{m_1+m_2+m_6}{2}}}{\gamma^{\frac{m_1+m_2+m_6}{2}}} + \frac{2\epsilon}{r} \\
& A_2 \frac{V_0}{W_0} m_2 \frac{\gamma^{\frac{2m_2}{2}}}{\gamma^{\frac{2m_2}{2}}} - \frac{2\epsilon}{r W_0} A_2 A_3 (m_2+m_3) \frac{\gamma^{\frac{m_2+m_3}{2}}}{\gamma^{\frac{m_2+m_3}{2}}} - \frac{2\epsilon}{r} \frac{A_2 A_4}{W_0} (m_2+m_4) \frac{\gamma^{\frac{2m_2+m_4}{2}}}{\gamma^{\frac{2m_2+m_4}{2}}} \\
& - \frac{2\epsilon}{r} \frac{A_2 V_0}{W_0^2} A_5 (m_5+m_2) \frac{\gamma^{\frac{m_5+2m_2}{2}}}{\gamma^{\frac{m_5+2m_2}{2}}} - \frac{2\epsilon}{r} \frac{V_0}{W_0^2} A_2 A_6 (m_6+m_2) \frac{\gamma^{\frac{m_6+2m_2}{2}}}{\gamma^{\frac{m_6+2m_2}{2}}} - \frac{2\epsilon}{r} \frac{dW_0}{dr} \\
& A_7 \frac{\gamma^{\frac{m_7+m_7}{2}}}{\gamma^{\frac{m_7+m_7}{2}}} - \frac{2\epsilon}{r} \frac{dW_0}{dr} A_8 m_8 \frac{\gamma^{\frac{m_2+m_8}{2}}}{\gamma^{\frac{m_2+m_8}{2}}}
\end{aligned}$$

Integration of $\int_{x_1}^{x_2} \Phi_3 R_2 C dx$

$$\begin{aligned}
& \frac{CV_0}{r} A_3 \frac{\gamma^{\frac{2m_3+1}{2}}}{\gamma^{\frac{2m_3+1}{2}}} + A_4 \frac{V_0 C}{r} \frac{\gamma^{\frac{m_3+m_4+1}{2}}}{\gamma^{\frac{m_3+m_4+1}{2}}} + \frac{U_0 C}{r} \frac{dU_0}{dr} A_7 \frac{\gamma^{\frac{m_7+m_3+1}{2}}}{\gamma^{\frac{m_7+m_3+1}{2}}} + \frac{U_0 C}{r} \frac{dV_0}{dr} A_8 \frac{\gamma^{\frac{m_8+m_3+1}{2}}}{\gamma^{\frac{m_8+m_3+1}{2}}} \\
& - \frac{HC}{r} \frac{dV_0}{dr} U_0 A_7 \frac{\gamma^{\frac{m_7+m_3+1}{2}}}{\gamma^{\frac{m_7+m_3+1}{2}}} - \frac{HC}{r} \frac{dV_0}{dr} V_0 A_8 \frac{\gamma^{\frac{m_8+m_3+1}{2}}}{\gamma^{\frac{m_8+m_3+1}{2}}} + \frac{HC}{r} \frac{dV_0}{dr} A_1 A_7 \frac{\gamma^{\frac{m_1+m_3+m_7+1}{2}}}{\gamma^{\frac{m_1+m_3+m_7+1}{2}}} + A_1 A_8 \\
& \frac{HC}{r} \frac{dV_0}{dr} \frac{\gamma^{\frac{m_1+m_3+m_8+1}{2}}}{\gamma^{\frac{m_1+m_3+m_8+1}{2}}} + \frac{HC}{r} \frac{dV_0}{dr} A_2 A_7 \frac{\gamma^{\frac{m_2+m_3+m_7+1}{2}}}{\gamma^{\frac{m_2+m_3+m_7+1}{2}}} + \frac{HC}{r} \frac{dV_0}{dr} A_1 A_8 \frac{\gamma^{\frac{m_1+m_2+m_8+1}{2}}}{\gamma^{\frac{m_1+m_2+m_8+1}{2}}} \\
& - \frac{W_0 G}{r} V_0 A_7 m_7 \frac{\gamma^{\frac{m_3+m_7}{2}}}{\gamma^{\frac{m_3+m_7}{2}}} - \frac{V_0 W_0}{r} G A_8 m_8 \frac{\gamma^{\frac{m_3+m_8}{2}}}{\gamma^{\frac{m_3+m_8}{2}}} + \frac{W_0 G}{r} A_7 A_3 (m_5+m_7) \frac{\gamma^{\frac{2m_3+m_7}{2}}}{\gamma^{\frac{2m_3+m_7}{2}}} \\
& + \frac{W_0 G}{r} A_3 A_8 (m_3+m_8) \frac{\gamma^{\frac{2m_3+m_8}{2}}}{\gamma^{\frac{2m_3+m_8}{2}}} + \frac{W_0 G}{r} A_4 A_2 (m_7+m_4) \frac{\gamma^{\frac{m_4+m_3+m_7}{2}}}{\gamma^{\frac{m_4+m_3+m_7}{2}}} + \frac{W_0 G}{r} (m_8+m_4) A_8 A_4 \\
& \frac{\gamma^{\frac{m_3+m_8+m_4}{2}}}{\gamma^{\frac{m_3+m_8+m_4}{2}}} - A_3 \frac{V_0}{W_0} C \frac{\gamma^{\frac{2m_3+1}{2}}}{\gamma^{\frac{2m_3+1}{2}}} + A_3^2 \frac{C}{W_0} \frac{\gamma^{\frac{3m_3+1}{2}}}{\gamma^{\frac{3m_3+1}{2}}} + \frac{A_3 A_4}{W_0} C \frac{\gamma^{\frac{2m_3+m_4+1}{2}}}{\gamma^{\frac{2m_3+m_4+1}{2}}} + A_3 \frac{V_0 C}{W_0^2} \\
& A_5 \frac{\gamma^{\frac{m_3+m_5+1}{2}}}{\gamma^{\frac{m_3+m_5+1}{2}}} + \frac{A_3 V_0 C}{W_0^2} A_6 \frac{\gamma^{\frac{m_6+2m_3+1}{2}}}{\gamma^{\frac{m_6+2m_3+1}{2}}} - A_4 \frac{V_0}{W_0} C \frac{\gamma^{\frac{m_4+m_3+1}{2}}}{\gamma^{\frac{m_4+m_3+1}{2}}} + \frac{A_4 C}{W_0} A_3 \frac{\gamma^{\frac{2m_3+m_4+1}{2}}}{\gamma^{\frac{2m_3+m_4+1}{2}}} \\
& + \frac{A_4^2}{W_0} C \frac{\gamma^{\frac{2m_4+m_3+1}{2}}}{\gamma^{\frac{2m_4+m_3+1}{2}}} + \frac{V_0 C}{W_0^2} A_4 A_5 \frac{\gamma^{\frac{m_5+m_4+m_3+1}{2}}}{\gamma^{\frac{m_5+m_4+m_3+1}{2}}} + \frac{U_0 V_0}{r^2} C A_7 \frac{\gamma^{\frac{m_7+m_3+1}{2}}}{\gamma^{\frac{m_7+m_3+1}{2}}} + \frac{U_0 V_0}{r^2} C A_8 \\
& \frac{\gamma^{\frac{m_8+m_3+1}{2}}}{\gamma^{\frac{m_8+m_3+1}{2}}} - \frac{HC}{r^2} V_0 A_7 U_0 \frac{\gamma^{\frac{m_7+m_3+1}{2}}}{\gamma^{\frac{m_7+m_3+1}{2}}} - \frac{HC}{r^2} V_0 U_0 A_8 \frac{\gamma^{\frac{m_8+m_3+1}{2}}}{\gamma^{\frac{m_8+m_3+1}{2}}} + \frac{HV_0}{r^2} C A_7 A_1 \frac{\gamma^{\frac{m_1+m_7+m_3+1}{2}}}{\gamma^{\frac{m_1+m_7+m_3+1}{2}}}
\end{aligned}$$

$$\begin{aligned}
& + \frac{HV_0}{r^2} C A_7 A_2 \frac{\gamma^{m_3+m_2+m_7+1}}{\gamma^{m_3+m_2+m_7+1}} + \frac{HV_0}{r^2} C A_8 A_1 \frac{\gamma^{m_1+m_3+m_8+1}}{\gamma^{m_1+m_3+m_8+1}} + \frac{HV_0}{r^2} C A_8 A_2 \frac{\gamma^{m_2+m_8+m_3+1}}{\gamma^{m_2+m_8+m_3+1}} \\
& - \frac{U_0 V_0}{r^2} C G A_7 \frac{\gamma^{m_7+m_3+1}}{\gamma^{m_7+m_3+1}} - \frac{U_0 V_0}{r^2} C G A_8 \frac{\gamma^{m_8+m_3+1}}{\gamma^{m_8+m_3+1}} + \frac{U_0}{r^2} G A_7 A_3 \frac{\gamma^{2m_3+m_7+1}}{\gamma^{2m_3+m_7+1}} \\
& + \frac{U_0 G}{r^2} C A_7 A_4 \frac{\gamma^{m_4+m_7+m_3+1}}{\gamma^{m_4+m_7+m_3+1}} + \frac{U_0}{r^2} G C A_8 A_3 \frac{\gamma^{m_8+2m_3+1}}{\gamma^{m_8+2m_3+1}} + \frac{U_0 G}{r^2} C A_4 A_8 \\
& \frac{\gamma^{m_3+m_4+m_8+1}}{\gamma^{m_3+m_4+m_8+1}} + 2 \frac{\Omega}{r} C U_0 A_7 \frac{\gamma^{m_7+m_3+1}}{\gamma^{m_7+m_3+1}} + 2 \frac{\Omega U_0}{r} C A_8 \frac{\gamma^{m_3+m_8+1}}{\gamma^{m_3+m_8+1}} - 2 \frac{H \Omega}{r} C \\
& U_0 A_7 \frac{\gamma^{m_3+m_7+1}}{\gamma^{m_3+m_7+1}} - 2 \frac{H \Omega}{r} C U_0 A_8 \frac{\gamma^{m_8+m_3+1}}{\gamma^{m_8+m_3+1}} + 2 \frac{\Omega H C}{r} A_7 A_1 \frac{\gamma^{m_7+m_1+m_3+1}}{\gamma^{m_7+m_1+m_3+1}} \\
& + 2 \frac{\Omega H C}{r} A_8 A_2 \frac{\gamma^{m_2+m_8+m_3+1}}{\gamma^{m_2+m_8+m_3+1}} + 2 \frac{\Omega}{r} C H A_7 A_2 \frac{\gamma^{m_2+m_7+m_3+1}}{\gamma^{m_2+m_7+m_3+1}} + 2 \frac{\Omega H}{r} \\
& C A_8 A_1 \frac{\gamma^{m_8+m_1+m_3+1}}{\gamma^{m_8+m_1+m_3+1}} + \frac{1}{\rho} \frac{C}{r} (P_e - P_c) \frac{\gamma^{m_3+1}}{\gamma^{m_3+1}} + \text{either } \left\{ \frac{1}{r} C (\bar{V}_0 - \bar{V}_c^2) \frac{\gamma^{m_3+1}}{\gamma^{m_3+1}} \right\} \\
& \text{or } \left\{ \frac{C}{r} (\bar{V}_0 - \bar{V}_c^2) (\log x_2 - \log x_1) \right\} + 2 \frac{\rho_c}{r^2} \frac{dV_0}{dr} A_7 \frac{\gamma^{m_7+m_3+1}}{\gamma^{m_7+m_3+1}} + 2 \frac{\rho_c}{r^2} C \frac{dV_0}{dr} \\
& A_8 \frac{\gamma^{m_8+m_3+1}}{\gamma^{m_8+m_3+1}} + 2 \frac{\rho_c}{r^3} C A_1 \frac{\gamma^{m_1+m_3}}{\gamma^{m_1+m_3}} + 2 \frac{\rho_c}{r^2} C A_2 \frac{\gamma^{m_2+m_3+1}}{\gamma^{m_2+m_3+1}} - 2 \frac{\rho_c}{r^3} C V_0 A_7 \\
& \frac{\gamma^{m_7+m_3+1}}{\gamma^{m_7+m_3+1}} - 2 \frac{\rho_c}{r^3} C A_8 \frac{\gamma^{m_8+m_3+1}}{\gamma^{m_8+m_3+1}} + 2 V_0^2 \frac{\rho_c}{r^3} G A_7 C \frac{\gamma^{m_7+m_3+1}}{\gamma^{m_7+m_3+1}} + 2 \frac{\rho_c}{r^3} C A_8 \\
& G V_0 \frac{\gamma^{m_8+1}}{\gamma^{m_8+1}} - 2 \frac{\rho_c}{r^3} C G A_7 A_3 \frac{\gamma^{2m_3+m_7+1}}{\gamma^{2m_3+m_7+1}} - 2 \frac{\rho_c}{r^3} C G A_8 A_4 \frac{\gamma^{m_3+m_4+m_8+1}}{\gamma^{m_3+m_4+m_8+1}} \\
& - 2 \frac{G \rho_c}{r^3} C A_7 A_4 \frac{\gamma^{m_3+m_4+m_7+1}}{\gamma^{m_3+m_4+m_7+1}} - 2 \frac{\rho_c}{r^3} C G A_8 A_3 \frac{\gamma^{m_8+2m_3+1}}{\gamma^{m_8+2m_3+1}} + \frac{\rho_c}{r} A_5 m_5 \\
& \frac{\gamma^{m_5+m_3}}{\gamma^{m_5+m_3}} + \frac{\rho_c}{r} A_6 m_6 \frac{\gamma^{m_3+m_6}}{\gamma^{m_3+m_6}} - \frac{G}{C} \frac{V_0}{r} A_7 m_7 (m_7-1) \frac{\gamma^{m_3+m_7-1}}{\gamma^{m_3+m_7-1}} - \frac{G}{C} \frac{V_0}{r} \\
& A_8 m_8 (m_8-1) \frac{\gamma^{m_8+m_3+1}}{\gamma^{m_8+m_3+1}} + \frac{G}{r C} A_3 A_7 (m_7+m_3)(m_3+m_7-1) \frac{\gamma^{m_7+2m_3+1}}{\gamma^{m_7+2m_3+1}} + \frac{G}{r C} \\
& A_7 A_4 (m_7+m_4)(m_7+m_4-1) \frac{\gamma^{m_7+m_4+m_3-1}}{\gamma^{m_7+m_4+m_3-1}} + \frac{G}{r C} A_8 A_3 (m_3+m_8)(m_3+m_8-1) \\
& \frac{\gamma^{2m_3+m_8-1}}{\gamma^{2m_3+m_8-1}} + \frac{G}{r C} A_4 A_8 (m_3+m_4)(m_3+m_4-1) \frac{\gamma^{2m_3+m_4-1}}{\gamma^{2m_3+m_4-1}} + \frac{1}{r} \frac{V_0}{\omega_0} A_3 m_3 \frac{\gamma^{2m_3}}{\gamma^{2m_3}} + \frac{V_0}{r} \\
& \frac{A_4}{\omega_0} m_4 \frac{\gamma^{m_3+m_4}}{\gamma^{m_3+m_4}} - \frac{V_0}{r} A_3^2 (2m_3) \frac{\gamma^{2m_3}}{\gamma^{2m_3}} - \frac{1}{r \omega_0} A_4^2 (2m_4) \frac{\gamma^{2m_4}}{\gamma^{2m_4}} - \frac{2 A_3 A_4}{r \omega_0} \\
& (m_3+m_4) \frac{\gamma^{2m_3+m_4}}{\gamma^{2m_3+m_4}} - \frac{V_0}{r \omega_0^2} A_3 A_5 (m_3+m_5) \frac{\gamma^{2m_3+m_5}}{\gamma^{2m_3+m_5}} - \frac{V_0}{r \omega_0^2} A_4 A_5 (m_4+m_5) \\
& \frac{\gamma^{m_3+m_4+m_5}}{\gamma^{m_3+m_4+m_5}} - \frac{V_0}{r \omega_0^2} A_3 A_6 (m_3+m_6) \frac{\gamma^{2m_3+m_6}}{\gamma^{2m_3+m_6}} - \frac{V_0}{r \omega_0^2} A_4 A_6 (m_4+m_6) \frac{\gamma^{m_3+m_4+m_6}}{\gamma^{m_3+m_4+m_6}}
\end{aligned}$$

Integration of $\int_{x_1}^{x_2} \Phi_4 R_2 C dx$

$$\begin{aligned}
& \frac{V_0}{r} C A_3 \frac{\gamma^{m_3+m_4+1}}{\gamma^{m_3+m_4+1}} + \frac{V_0 C}{r} A_4 \frac{\gamma^{2m_4+1}}{\gamma^{2m_4+1}} + \frac{V_0 C}{r} \frac{dV_0}{dr} A_7 \frac{\gamma^{m_7+m_4+1}}{\gamma^{m_7+m_4+1}} + \frac{U_0}{r} \frac{dV_0}{dr} A_8 C \frac{\gamma^{m_8+m_4+1}}{\gamma^{m_8+m_4+1}} \\
& - \frac{H C}{r} \frac{dV_0}{dr} A_7 A_1 \frac{\gamma^{m_1+m_7+m_4+1}}{\gamma^{m_1+m_7+m_4+1}} + A_1 A_8 \frac{H C}{r} \frac{dV_0}{dr} \frac{\gamma^{m_8+m_4+m_1+1}}{\gamma^{m_8+m_4+m_1+1}} + \frac{H}{r} \frac{dV_0}{dr} A_2 A_7 \frac{\gamma^{m_1+m_7+m_4+1}}{\gamma^{m_1+m_7+m_4+1}}
\end{aligned}$$

$$\begin{aligned}
& + \frac{Hc}{r} \frac{dV_0}{dn} A_2 A_8 \frac{\tau^{m_2+m_8+1}}{m_2+m_8+1} - \frac{W_0 G}{r} V_0 A_7 m_7 \frac{\tau^{m_4+m_7}}{m_4+m_7} - \frac{V_0 W_0 G}{r} A_8 m_8 \frac{\tau^{m_8}}{m_8} + \frac{W_0 G}{r} A_7 A_3 \\
& (m_3+m_7) \frac{\tau^{m_4+m_3+m_7}}{m_4+m_3+m_7} + \frac{W_0 G}{r} A_3 A_8 (m_8+m_3) \frac{\tau^{m_8+m_3+m_4}}{m_8+m_3+m_4} + \frac{W_0 G}{r} A_4 A_7 (m_7+m_4) \frac{\tau^{2m_4+m_7}}{2m_4+m_7} \\
& + \frac{W_0 G}{r} (m_8+m_4) A_8 A_4 \frac{\tau^{m_8+m_4}}{m_8+m_4} - A_3 \frac{V_0}{W_0} C \frac{\tau^{m_3+m_4+1}}{m_3+m_4+1} + A_3^2 C \frac{1}{W_0} \frac{\tau^{2m_3+m_4+1}}{2m_3+m_4+1} \\
& + \frac{A_3 A_4}{W_0} \frac{\tau^{m_3+2m_4+1}}{m_3+2m_4+1} + \frac{A_3 V_0}{W_0^2} A_5 C \frac{\tau^{m_3+m_5+m_4+1}}{m_3+m_5+m_4+1} + A_3 V_0 / W_0^2 C A_6 \frac{\tau^{m_6+m_3+m_4+1}}{m_6+m_3+m_4+1} \\
& - A_4 \frac{V_0}{W_0} C \frac{\tau^{2m_4+1}}{2m_4+1} + \frac{A_4}{W_0} C A_4 \frac{\tau^{m_3+2m_4}}{m_3+2m_4} + \frac{A_4^2 C}{W_0} \frac{\tau^{3m_4+1}}{3m_4+1} + \frac{V_0 C}{W_0^2} A_4 A_5 \\
& \frac{\tau^{2m_4+m_5+1}}{2m_4+m_5+1} + \frac{U_0 V_0}{r^2} C A_7 \frac{\tau^{m_7+m_4+1}}{m_7+m_4+1} + \frac{U_0 V_0}{r^2} A_8 C \frac{\tau^{m_8+m_4+1}}{m_8+m_4+1} - \frac{H C}{r^2} V_0 A_7 U_0 \\
& \frac{\tau^{m_7+m_4+1}}{m_7+m_4+1} - \frac{H V_0}{r^2} C U_0 A_8 \frac{\tau^{m_8+m_4+1}}{m_8+m_4+1} - \frac{H V_0}{r^2} C A_7 A_1 \frac{\tau^{m_1+m_7+m_4+1}}{m_1+m_7+m_4+1} \\
& + \frac{H V_0}{r^2} C A_7 A_2 \frac{\tau^{m_2+m_7+m_4+1}}{m_2+m_7+m_4+1} + \frac{C H V_0}{r^2} A_8 A_1 \frac{\tau^{m_1+m_8+m_4+1}}{m_1+m_8+m_4+1} + \frac{H V_0}{r^2} C G A_8 t_2 \\
& \frac{\tau^{m_8+m_4+m_1+1}}{m_8+m_4+m_1+1} - \frac{U_0 V_0}{r^2} C G A_7 \frac{\tau^{m_7+m_4+1}}{m_7+m_4+1} - \frac{U_0 V_0}{r^2} G C A_8 \frac{\tau^{m_8+m_4+1}}{m_8+m_4+1} \\
& + \frac{U_0}{r^2} C G A_7 A_3 \frac{\tau^{m_3+m_7+m_4+1}}{m_3+m_7+m_4+1} + \frac{U_0 G}{r^2} A_7 A_4 C \frac{\tau^{2m_4+m_7+1}}{2m_4+m_7+1} + \frac{U_0 G C}{r^2} A_8 A_3 \\
& \frac{\tau^{m_3+m_8+m_4+1}}{m_3+m_8+m_4+1} + \frac{U_0}{r^2} G C A_4 A_8 \frac{\tau^{2m_4+m_8+1}}{2m_4+m_8+1} + 2 \frac{Q}{r} U_0 A_7 \frac{\tau^{m_7+m_4+1}}{m_7+m_4+1} \\
& + 2 \frac{Q}{r} \frac{U_0}{r} A_8 C \frac{\tau^{m_8+m_4+1}}{m_8+m_4+1} - 2 \frac{H Q}{r} U_0 A_7 C \frac{\tau^{m_7+m_4+1}}{m_7+m_4+1} - 2 \frac{H Q U_0}{r} \\
& A_8 C \frac{\tau^{m_8+m_4+1}}{m_8+m_4+1} + 2 \frac{Q}{r} C H A_7 A_1 \frac{\tau^{m_7+m_4+m_1+1}}{m_7+m_4+m_1+1} + 2 \frac{Q}{r} H C A_8 A_2 \frac{\tau^{m_2+m_8+m_4+1}}{m_2+m_8+m_4+1} \\
& + 2 \frac{Q}{r} C H A_7 A_2 \frac{\tau^{m_2+m_7+m_4+1}}{m_2+m_7+m_4+1} + 2 \frac{Q}{r} \frac{H C}{r} A_8 A_1 \frac{\tau^{m_8+m_1+m_4+1}}{m_8+m_1+m_4+1} - \frac{1}{r} \frac{C}{r} (P \cdot P_c) \\
& \frac{\tau^{m_4+1}}{m_4+1} + \frac{C}{r} (\vec{V}_0 - \vec{V}_c) \frac{\tau^{m_4+1}}{m_4+1} + 2 \frac{\gamma_t}{r^2} C \frac{dV_0}{dn} A_7 \frac{\tau^{m_8+m_1+m_4+1}}{m_8+m_1+m_4+1} + 2 \frac{\gamma_t}{r^2} \\
& \frac{dV_0}{dn} C A_8 \frac{\tau^{m_8+m_4+1}}{m_8+m_4+1} + 2 \frac{\gamma_t}{r^3} C A_1 \frac{\tau^{m_1+m_4+1}}{m_1+m_4+1} + 2 \frac{\gamma_t}{r^2} C A_2 \frac{\tau^{m_2+m_4+1}}{m_2+m_4+1} - 2 \\
& \frac{\gamma_t}{r^3} C V_0 A_7 \frac{\tau^{m_7+m_4+1}}{m_7+m_4+1} - 2 \frac{\gamma_t}{r^3} C A_8 \frac{\tau^{m_8+m_4+1}}{m_8+m_4+1} + 2 \frac{\gamma_t C}{r^3} G V_0 A_7 \frac{\tau^{m_7+m_4+1}}{m_7+m_4+1} \\
& - 2 \frac{\gamma_t}{r^3} G C A_8 A_4 \frac{\tau^{2m_4+m_8+1}}{2m_4+m_8+1} - 2 \frac{G \gamma_t}{r^3} C A_4 A_7 \frac{\tau^{2m_4+m_7+1}}{2m_4+m_7+1} - 2 \frac{\gamma_t}{r^3} A_8 \\
& A_3 G C \frac{\tau^{m_3+m_8+m_4+1}}{m_3+m_8+m_4+1} + \frac{\gamma_t}{r} A_5 m_5 \frac{\tau^{m_5+m_4}}{m_5+m_4} + \frac{\gamma_t}{r} A_6 m_6 \frac{\tau^{m_6+m_4}}{m_6+m_4} - \frac{G}{r} \frac{V_0}{r} A_7 m_7 \\
& (m_7-1) \frac{\tau^{m_7+m_4-1}}{m_7+m_4-1} - \frac{G V_0}{r} A_8 (m_8-1) m_8 \frac{\tau^{m_8+m_4-1}}{m_8+m_4-1} + \frac{G}{r} A_7 (m_7+m_3) A_3 (m_3+m_7-1) \\
& \frac{\tau^{m_7+m_3+m_4-1}}{m_7+m_3+m_4-1} + \frac{G}{r C} A_7 A_4 (m_7+m_4-1) \frac{\tau^{m_7+2m_4-1}}{m_7+2m_4-1} + \frac{G}{r C} A_8 A_3 (m_3+m_8)(m_3+m_8-1) \\
& \frac{\tau^{m_4+m_3+m_8-1}}{m_4+m_3+m_8-1} + \frac{G}{r C} A_4 A_8 (m_3+m_4)(m_3+m_4-1) \frac{\tau^{m_3+2m_4-1}}{m_3+2m_4-1} + \frac{1}{r} \frac{V_0}{W_0} A_3 m_3 \\
& \frac{\tau^{m_4+m_3}}{m_4+m_3} - \frac{1}{r} \frac{V_0}{W_0} A_4 m_4 \frac{\tau^{2m_4}}{2m_4} - \frac{2 m_3}{r W_0} A_3^2 \frac{\tau^{2m_3+m_4}}{2m_3+m_4} - \frac{2}{r W_0} A_4^2 m_4 \frac{\tau^{3m_4}}{3m_4} - \frac{2}{r W_0} \\
& C A_3 A_4 (m_3+m_4) \frac{\tau^{m_3+2m_4}}{m_3+2m_4} - \frac{V_0}{r W_0^2} A_3 A_5 (m_3+m_5) \frac{\tau^{m_3+m_5+m_4}}{m_3+m_5+m_4} - \frac{V_0}{r W_0^2} A_4 A_5
\end{aligned}$$

$$(m_4+m_5) \frac{z^{2m_4+m_5}}{2m_4+m_5} - \frac{V_0}{r\omega_0^2} A_3 A_6 (m_3+m_6) \frac{z^{m_3+m_6+m_4}}{m_3+m_6+m_4} - \frac{V_0}{r\omega_0^2} A_4 A_6 (m_4+m_6) \frac{z^{2m_4+m_6}}{2m_4+m_6}$$

Integration of $\int_{x_1}^{x_2} \Phi_5 R_3 C dx$

$$\begin{aligned} & \frac{V_0}{r} C A_5 \frac{z^{2m_5+1}}{2m_5+1} + \frac{V_0}{r} C A_6 \frac{z^{m_6+m_5+1}}{m_6+m_5+1} + \frac{U_0 C}{r} \frac{d\omega_0}{dr} A_7 \frac{z^{m_7+m_5+1}}{m_7+m_5+1} + \frac{U_0 C}{r} \frac{d\omega_0}{dr} \\ & A_8 \frac{z^{m_5+m_8+1}}{m_5+m_8+1} - \frac{H C}{r} U_0 A_7 \frac{d\omega_0}{dr} \frac{z^{m_5+m_7+1}}{m_5+m_7+1} - \frac{d\omega_0}{dr} \frac{H C}{r} U_0 A_8 \frac{z^{m_8+m_5+1}}{m_8+m_5+1} \\ & + \frac{d\omega_0}{dr} \frac{H C}{r} A_7 A_1 \frac{z^{m_7+m_5+m_1+1}}{m_7+m_5+m_1+1} + A_2 A_7 \frac{d\omega_0}{dr} \frac{H C}{r} \frac{z^{m_7+m_5+m_2+1}}{m_7+m_5+m_2+1} - A_8 A_1 \frac{H C}{r} \frac{d\omega_0}{dr} \\ & \frac{z^{m_8+m_5+m_1+1}}{m_8+m_5+m_1+1} - A_8 A_2 \frac{d\omega_0}{dr} \frac{H C}{r} \frac{z^{m_8+m_5+m_2+1}}{m_8+m_5+m_2+1} - \frac{\omega_0}{r} G V_0 A_7 m_7 \frac{z^{m_7+m_5}}{m_7+m_5} - \frac{\omega_0 G}{r} \\ & V_0 m_8 A_8 \frac{z^{m_8+m_5}}{m_8+m_5} + \frac{\omega_0 G}{r} A_7 A_3 (m_7+m_3) \frac{z^{m_5+m_7+3}}{m_5+m_7+3} + \frac{\omega_0 G}{r} A_7 A_4 (m_7+m_4) \\ & \frac{z^{m_5+m_7+m_4}}{m_5+m_7+m_4} + \frac{\omega_0 G}{r} A_8 A_3 (m_8+m_3) \frac{z^{m_5+m_8+3}}{m_5+m_8+3} + \frac{\omega_0 G}{r} A_8 A_4 (m_8+m_4) \frac{z^{m_4+m_5+m_8}}{m_4+m_5+m_8} \\ & + \frac{V_0}{r} C A_3 \frac{z^{m_5+m_3+1}}{m_5+m_3+1} - \frac{1}{r} A_3^2 C \frac{z^{2m_3+m_5+1}}{2m_3+m_5+1} - \frac{C}{r} A_3 A_4 \frac{z^{m_5+m_4+3+1}}{m_5+m_4+3+1} - \frac{V_0}{r\omega_0} \\ & C A_5 A_3 \frac{z^{2m_5+m_3+1}}{2m_5+m_3+1} - \frac{V_0 C}{r\omega_0} A_3 A_6 \frac{z^{m_3+m_5+m_6+1}}{m_3+m_5+m_6+1} + \frac{V_0}{r} C A_4 \frac{z^{m_4+m_5+1}}{m_4+m_5+1} - \frac{1}{r} A_3 \\ & A_4 C \frac{z^{m_3+m_4+1}}{m_3+m_4+1} - \frac{C}{r} A_4^2 \frac{z^{2m_4+m_5+1}}{2m_4+m_5+1} - \frac{V_0 C}{r\omega_0} A_4 A_5 \frac{z^{2m_5+m_4+1}}{2m_5+m_4+1} - \frac{V_0 C}{r\omega_0} A_6 A_4 \\ & \frac{z^{m_6+m_4+m_5+1}}{m_6+m_4+m_5+1} - \frac{1}{r} \left\{ \frac{F}{r} A_7 m_7 \frac{z^{m_7+m_5}}{m_7+m_5} + \frac{F}{r} A_8 m_8 \frac{z^{m_8+m_5}}{m_8+m_5} + \frac{F}{r} \frac{V_0}{\omega_0} C \right. \\ & \frac{z^{m_5+1}}{m_5+1} - \frac{F}{\omega_0} \frac{C}{r} A_3 \frac{z^{m_5+m_3+1}}{m_5+m_3+1} - \frac{F}{r\omega_0} C A_4 \frac{z^{m_5+m_4+1}}{m_5+m_4+1} - \frac{F}{r} \frac{V_0 C}{\omega_0^2} A_5 \frac{z^{2m_5+1}}{2m_5+1} \\ & - \frac{F}{r} \frac{V_0}{\omega_0^2} C A_6 \frac{z^{m_6+m_5+1}}{m_6+m_5+1} - \frac{F}{r} \frac{V_0}{\omega_0} C \frac{z^{m_5+1}}{m_5+1} + \frac{F}{r\omega_0} C A_3 \frac{z^{m_3+m_5+1}}{m_3+m_5+1} + \frac{F C}{r\omega_0} \\ & A_4 \frac{z^{m_5+m_4+1}}{m_5+m_4+1} + \frac{F}{r} \frac{V_0 C}{\omega_0^2} A_5 \frac{z^{2m_5+1}}{2m_5+1} + \frac{F}{r} \frac{V_0}{\omega_0} C A_6 \frac{z^{m_5+m_6+1}}{m_5+m_6+1} - \frac{F}{r} \\ & A_7 m_7 C \frac{z^{m_5+m_7}}{m_5+m_7} - \frac{F}{r} A_8 m_8 C \frac{z^{m_5+m_8}}{m_5+m_8} + \frac{K}{r} \frac{r\omega_0^2}{\omega_0^2} A_7 m_7 - \frac{z^{m_5+m_7}}{m_5+m_7} + \frac{K}{r} \\ & \frac{1}{\omega_0^2} A_8 m_8 \frac{z^{m_5+m_8}}{m_5+m_8} - \frac{1}{r\omega_0^2} C V_0 \frac{z^{m_5+1}}{m_5+1} + \frac{1}{r\omega_0^2} C A_3 \frac{z^{m_3+m_5+1}}{m_3+m_5+1} + \frac{1}{r\omega_0^2} C A_4 \frac{z^{m_4+m_5+1}}{m_4+m_5+1} \\ & + \frac{C}{r} \frac{1}{\omega_0^2} \frac{1}{\omega_0^2} V_0 A_5 \frac{z^{2m_5+1}}{2m_5+1} + \frac{1}{r\omega_0^2} C V_0 A_6 \frac{z^{m_6+m_5+1}}{m_6+m_5+1} - \frac{2\epsilon H}{r^2 C} U_0 A_7 m_7 (m_7-1) \\ & \frac{z^{m_5+m_7-1}}{m_5+m_7-1} - \frac{2\epsilon H}{r^2 C} U_0 A_8 m_8 (m_8-1) \frac{z^{m_5+m_8-1}}{m_5+m_8-1} + \frac{2\epsilon}{r^2} \frac{V_0}{\omega_0} A_1 m_1 \frac{z^{m_5+m_1}}{m_5+m_1} + \frac{2\epsilon}{r^2} \\ & \frac{V_0}{\omega_0} A_2 m_2 \frac{z^{m_5+m_2}}{m_5+m_2} - \frac{2\epsilon}{C r^2 \omega_0} A_1 A_3 (m_1+m_3) \frac{z^{m_1+m_3+m_5}}{m_1+m_3+m_5} - \frac{2\epsilon}{r^2 \omega_0} A_2 A_3 \\ & (m_2+m_3) \frac{z^{m_2+m_3+m_5}}{m_2+m_3+m_5} - \frac{2\epsilon}{r^2 \omega_0} A_1 A_4 (m_1+m_4) \frac{z^{m_1+m_4+m_5}}{m_1+m_4+m_5} - \frac{2\epsilon}{r^2 \omega_0} A_2 A_3 (m_2+m_3) \frac{z^{m_2+m_3+m_5}}{m_2+m_3+m_5} - \frac{2\epsilon}{r^2 \omega_0} A_1 A_4 \\ & (m_1+m_4) \frac{z^{m_1+m_4+m_5}}{m_1+m_4+m_5} - \frac{2\epsilon}{r^2 \omega_0} A_2 A_4 (m_2+m_4) \frac{z^{m_2+m_4+m_5}}{m_2+m_4+m_5} - \frac{2\epsilon}{r^2 \omega_0^2} \frac{V_0}{\omega_0^2} A_5 \frac{z^{2m_5}}{2m_5} \end{aligned}$$

$$- \frac{\gamma_t}{r^2 \omega_0^2} U_0 A_6 m_6 \frac{r^{m_5+m_6}}{m_5+m_6} + \frac{\gamma_t}{r^2} \frac{d\omega_0}{dr} A_7 m_7 \frac{r^{m_6+m_7}}{m_6+m_7} + \frac{\gamma_t}{r^2} \frac{d\omega_0}{dr} A_8 m_8 \frac{r^{m_7+m_8}}{m_7+m_8}$$

Integration of $\int_{x_1}^{x_2} \Phi_6 R_3 C dx$

$$\begin{aligned} & \frac{V_0}{r} A_5 C \frac{r^{m_5+m_6+1}}{m_5+m_6+1} + \frac{V_0}{r} C A_6 \frac{r^{2m_6+1}}{2m_6+1} + \frac{U_0 C}{r} \frac{d\omega_0}{dr} A_7 \frac{r^{m_7+m_6+1}}{m_7+m_6+1} + \frac{U_0}{r} C \frac{d\omega_0}{dr} \\ & A_8 \frac{r^{m_8+m_6+1}}{m_8+m_6+1} - \frac{d\omega_0}{dr} \frac{H C}{r} U_0 A_7 \frac{r^{m_7+m_6+1}}{m_7+m_6+1} - \frac{d\omega_0}{dr} \frac{H C}{r} U_0 A_8 \frac{r^{m_6+m_8+1}}{m_6+m_8+1} + \frac{H C}{r} \\ & \frac{d\omega_0}{dr} A_7 A_1 \frac{r^{m_6+m_7+m_1+1}}{m_6+m_7+m_1+1} + A_7 A_2 \frac{d\omega_0}{dr} \frac{H C}{r} \frac{r^{m_7+m_2+m_6+1}}{m_7+m_2+m_6+1} - A_8 A_1 \frac{H C}{r} \frac{d\omega_0}{dr} \\ & \frac{r^{m_6+m_8+m_1+1}}{m_6+m_8+m_1+1} - A_8 A_2 \frac{d\omega_0}{dr} \frac{H C}{r} \frac{r^{m_8+m_6+m_2+1}}{m_8+m_6+m_2+1} + \frac{\omega_0}{r} G V_0 A_7 m_7 \frac{r^{m_7+m_6}}{m_7+m_6} \\ & - \frac{\omega_0 G}{r} V_0 A_8 m_8 \frac{r^{m_6+m_8}}{m_6+m_8} + \omega_0 A_7 A_3 \frac{G}{r} (m_7+m_3) \frac{r^{m_6+m_7+m_3}}{m_6+m_7+m_3} + \frac{\omega_0 G}{r} A_7 A_4 (m_7+m_4) \\ & \frac{r^{m_6+m_7+m_4}}{m_6+m_7+m_4} + \frac{\omega_0 G}{r} A_8 A_3 (m_8+m_3) \frac{r^{m_6+m_8+m_3}}{m_6+m_8+m_3} + \frac{\omega_0 G}{r} A_8 A_4 (m_8+m_4) \frac{r^{m_6+m_8+m_4}}{m_6+m_8+m_4} \\ & + \frac{V_0}{r} A_3 C \frac{r^{m_6+m_3+1}}{m_6+m_3+1} - \frac{1}{r} C A_3^2 \frac{r^{2m_3+m_6+1}}{2m_3+m_6+1} - \frac{1}{r} A_3 A_4 C \frac{r^{m_6+m_3+m_4+1}}{m_6+m_3+m_4+1} - \frac{V_0}{r \omega_0} C A_5 A_3 \\ & \frac{r^{m_6+m_5+m_3+1}}{m_6+m_5+m_3+1} - \frac{V_0}{r \omega_0} C A_3 A_6 \frac{r^{2m_6+m_3+1}}{2m_6+m_3+1} + \frac{V_0}{r} C A_4 \frac{r^{m_4+m_6+1}}{m_4+m_6+1} - \frac{1}{r} A_3 A_4 C \frac{r^{m_3+m_4+m_6+1}}{m_3+m_4+m_6+1} \\ & - \frac{1}{r} A_4^2 C \frac{r^{2m_4+m_6+1}}{2m_4+m_6+1} - \frac{V_0 C}{r \omega_0} A_4 A_5 \frac{r^{m_6+m_5+m_4+1}}{m_6+m_5+m_4+1} - \frac{V_0}{r \omega_0} C A_5 A_4 \frac{r^{2m_6+m_4}}{2m_6+m_4} - \frac{1}{r} \left\{ \right. \\ & \frac{P}{r} A_7 m_7 \frac{r^{m_6+m_7}}{m_6+m_7} + \frac{P}{r} A_8 m_8 \frac{r^{m_6+m_8}}{m_6+m_8} + \frac{P V_0}{r \omega_0} C \frac{r^{m_6+1}}{m_6+1} - \frac{P}{\omega_0} C A_3 \frac{r^{m_3+m_6+1}}{m_3+m_6+1} - \frac{P}{r \omega_0} \\ & A_4 C \frac{r^{m_4+m_6+1}}{m_4+m_6+1} - \frac{P}{r \omega_0^2} V_0 A_5 \frac{r^{m_5+m_6+1}}{m_5+m_6+1} - \frac{P}{r} \frac{V_0 C}{\omega_0^2} A_6 \frac{r^{2m_6+1}}{2m_6+1} - \frac{P}{r} \frac{V_0}{\omega_0} \frac{r^{m_6+1}}{m_6+1} \\ & + \frac{P}{r \omega_0} C A_3 \frac{r^{m_3+m_6+1}}{m_3+m_6+1} + \frac{P}{r \omega_0} A_4 C \frac{r^{m_4+m_6+1}}{m_4+m_6+1} + \frac{P}{r} \frac{V_0}{\omega_0^2} C A_5 \frac{r^{m_5+m_6+1}}{m_5+m_6+1} + \frac{P}{r} \frac{V_0}{\omega_0^2} A_6 \frac{r^{2m_6+1}}{2m_6+1} \\ & - \frac{P}{r} A_7 m_7 C \frac{r^{m_6+m_7}}{m_6+m_7} + \frac{P}{r C} A_8 m_8 \frac{r^{m_8+m_6}}{m_8+m_6} + \frac{K}{r} \frac{\omega_0^2}{\omega_0^2} A_7 m_7 \frac{r^{m_6+m_7}}{m_6+m_7} + \frac{K}{r} \\ & \frac{\omega_0^2}{\omega_0^2} A_8 m_8 \frac{r^{m_6+m_8}}{m_6+m_8} - \frac{\omega_0^2}{r} \frac{V_0}{\omega_0} \frac{r^{m_6+1}}{m_6+1} + \frac{\omega_0^2}{r \omega_0} C A_3 \frac{r^{m_3+m_6+1}}{m_3+m_6+1} + \frac{\omega_0^2}{r \omega_0} \\ & A_4 C \frac{r^{m_4+m_6+1}}{m_4+m_6+1} + \frac{\omega_0^2}{r \omega_0^2} C V_0 A_5 \frac{r^{m_6+m_5+1}}{m_6+m_5+1} + \frac{\omega_0^2}{r \omega_0^2} C V_0 A_6 \frac{r^{2m_6+1}}{2m_6+1} - \frac{\gamma_t H}{r^2 C} \\ & V_0 A_7 m_7 (m_7-1) \frac{r^{m_6+m_7-1}}{m_6+m_7-1} - \frac{\gamma_t H}{r^2 C} U_0 A_8 m_8 (m_8-1) \frac{r^{m_6+m_8-1}}{m_6+m_8-1} + \frac{\gamma_t}{r^2} \frac{V_0}{\omega_0} A_1 m_1 \\ & \frac{r^{m_6+m_1}}{m_6+m_1} + \frac{\gamma_t}{r^2} \frac{V_0}{\omega_0} A_2 m_2 \frac{r^{m_6+m_2}}{m_6+m_2} - \frac{\gamma_t}{r^2 \omega_0} A_1 A_3 (m_1+m_3) \frac{r^{m_1+m_3+m_6}}{m_1+m_3+m_6} - \frac{\gamma_t}{r^2 \omega_0} A_2 A_3 \\ & (m_2+m_3) \frac{r^{m_6+m_2+m_3}}{m_6+m_2+m_3} - \frac{\gamma_t}{r^2 \omega_0} A_1 A_4 (m_1+m_4) \frac{r^{m_1+m_4+m_6}}{m_1+m_4+m_6} - \frac{\gamma_t}{r^2 \omega_0} A_2 A_4 (m_2+m_4) \frac{r^{m_2+m_4+m_6}}{m_2+m_4+m_6} \\ & - \frac{\gamma_t V_0}{r^2 \omega_0^2} A_5 m_5 \frac{r^{m_5+m_6}}{m_5+m_6} - \frac{\gamma_t}{r^2 \omega_0^2} V_0 A_6 m_6 \frac{r^{2m_6}}{2m_6} - \frac{\gamma_t}{r^2} \frac{d\omega_0}{dr} A_7 m_7 \frac{r^{m_7+m_6}}{m_7+m_6} + \frac{\gamma_t}{r^2} \frac{d\omega_0}{dr} A_8 m_8 \frac{r^{m_8+m_6}}{m_8+m_6} \end{aligned}$$

Integration of $\int_{x_1}^{x_2} \Phi_7 R_4 C dx$

$$\begin{aligned}
 & -\frac{C}{r} A_3 \frac{\gamma^{m_3+m_7+1}}{\gamma^{m_7+m_8}} - \frac{A_4}{r} C \frac{\gamma^{m_4+m_7+1}}{\gamma^{m_4+m_7+1}} - \frac{FW_0}{r} A_7 m_7 \frac{\gamma^{2m_7}}{2m_7} - \frac{FW_0}{r} A_8 m_8 \frac{\gamma^{m_8}}{m_8} \\
 & + \frac{FW_0}{r^2} A_5 A_7 (m_5+m_7) \frac{\gamma^{m_5+2m_7}}{\gamma^{m_5+2m_7}} + \frac{F}{r} A_7 A_6 (m_7+m_6) \frac{\gamma^{m_6+2m_7}}{\gamma^{m_6+2m_7}} \\
 & + \frac{F}{r} A_8 A_5 (m_5+m_8) \frac{\gamma^{m_7+m_5+m_8}}{\gamma^{m_7+m_5+m_8}} + \frac{F}{r} A_8 A_6 (m_6+m_8) \frac{\gamma^{m_7+m_6+m_8}}{\gamma^{m_7+m_6+m_8}} + \frac{V_0}{rW_0} A_5 C \\
 & \frac{\gamma^{m_5+m_7+1}}{\gamma^{m_5+m_7+1}} + \frac{A_6 V_0}{rW_0} C \frac{\gamma^{m_6+m_7+1}}{\gamma^{m_6+m_7+1}} - \frac{1}{rW_0} C A_3 A_5 \frac{\gamma^{m_5+m_3+m_7+1}}{\gamma^{m_5+m_3+m_7+1}} - \frac{1}{rW_0} C A_3 A_6 \\
 & \frac{\gamma^{m_3+m_6+m_7+1}}{\gamma^{m_3+m_6+m_7+1}} + \frac{1}{rW_0} C A_4 A_5 \frac{\gamma^{m_5+m_4+m_7+1}}{\gamma^{m_5+m_4+m_7+1}} - \frac{1}{rW_0} C A_4 A_6 \frac{\gamma^{m_4+m_6+m_7+1}}{\gamma^{m_4+m_6+m_7+1}} \\
 & - \frac{V_0}{W_0^2} \frac{C}{r} A_5^2 \frac{\gamma^{2m_5+m_7+1}}{2m_5+m_7+1} - \frac{V_0}{W_0^2} \frac{C}{r} A_6^2 \frac{\gamma^{2m_6+m_7+1}}{2m_6+m_7+1} - \frac{2V_0 C}{W_0^2 r} A_5 A_6 \\
 & \frac{\gamma^{m_5+m_6+m_7+1}}{\gamma^{m_5+m_6+m_7+1}} - \frac{C}{r} \frac{dU_0}{dr} A_7 \frac{\gamma^{2m_7-1}}{2m_7-1} + \frac{C}{r} \frac{dU_0}{dr} A_8 \frac{\gamma^{m_8+m_7+1}}{\gamma^{m_8+m_7+1}} - \frac{HC}{r^2} \\
 & U_0 A_7 \frac{\gamma^{2m_7+1}}{2m_7+1} - \frac{HC}{r} U_0 A_8 \frac{\gamma^{m_8+m_7+1}}{\gamma^{m_8+m_7+1}} + \frac{HC}{r^2} A_7 A_1 \frac{\gamma^{2m_7+m_1+1}}{2m_7+m_1+1} \\
 & + \frac{HC}{r^2} A_7 A_2 \frac{\gamma^{2m_7+m_2+1}}{2m_7+m_2+1} + \frac{HC}{r^2} A_8 A_1 \frac{\gamma^{m_8+m_1+m_7+1}}{\gamma^{m_8+m_1+m_7+1}} + \frac{HC}{r^2} A_2 A_8 \\
 & \frac{\gamma^{m_8+m_2+m_7+1}}{\gamma^{m_8+m_2+m_7+1}}
 \end{aligned}$$

Integration of $\int_{x_1}^{x_2} \Phi_8 R_4 C dx$

$$\begin{aligned}
 & -\frac{C}{r} A_3 \frac{\gamma^{m_3+m_8+1}}{\gamma^{m_3+m_8+1}} - \frac{A_4 C}{r} \frac{\gamma^{m_4+m_8+1}}{\gamma^{m_4+m_8+1}} - \frac{FW_0}{r} A_7 m_7 \frac{\gamma^{m_8+m_7}}{\gamma^{m_8+m_7}} - \frac{FW_0}{r} A_8 m_8 \frac{\gamma^{2m_8}}{2m_8} \\
 & - \frac{F}{r} \frac{W_0}{r} A_5 A_7 (m_5+m_7) \frac{\gamma^{m_5+m_7+m_8}}{\gamma^{m_5+m_7+m_8}} + \frac{F}{r} A_7 A_6 (m_7+m_6) \frac{\gamma^{m_7+m_8+m_6}}{\gamma^{m_7+m_8+m_6}} + \frac{F}{r} A_8 A_5 (m_5+m_8) \\
 & \frac{\gamma^{m_5+2m_8}}{\gamma^{m_5+2m_8}} + \frac{F}{r} A_8 A_6 (m_6+m_8) \frac{\gamma^{m_6+2m_8}}{\gamma^{m_6+2m_8}} + \frac{V_0}{rW_0} C A_5 \frac{\gamma^{m_5+m_8+1}}{\gamma^{m_5+m_8+1}} + \frac{A_6 V_0 C}{rW_0} \\
 & \frac{\gamma^{m_6+m_8+1}}{\gamma^{m_6+m_8+1}} - \frac{1}{rW_0} C A_3 A_5 \frac{\gamma^{m_3+m_5+m_8+1}}{\gamma^{m_3+m_5+m_8+1}} - \frac{1}{rW_0} A_3 A_6 C \frac{\gamma^{m_3+m_6+m_8+1}}{\gamma^{m_3+m_6+m_8+1}} - \frac{1}{rW_0} C A_4 A_5 \frac{\gamma^{m_4+m_5+m_8+1}}{\gamma^{m_4+m_5+m_8+1}} \\
 & - \frac{1}{rW_0} A_4 A_8 C \frac{\gamma^{m_4+m_8+m_8+1}}{\gamma^{m_4+m_8+m_8+1}} - \frac{V_0}{W_0^2} \frac{C}{r} A_5^2 \frac{\gamma^{2m_5+m_8+1}}{2m_5+m_8+1} - \frac{V_0 C}{W_0^2 r} A_6^2 \frac{\gamma^{2m_6+m_8+1}}{2m_6+m_8+1} - \frac{2V_0}{rW_0^2} \\
 & C A_5 A_6 \frac{\gamma^{m_5+m_6+m_8+1}}{\gamma^{m_5+m_6+m_8+1}} - \frac{1}{r} \frac{dU_0}{dr} C A_7 \frac{\gamma^{m_7+m_8+1}}{\gamma^{m_7+m_8+1}} - \frac{1}{r} \frac{dU_0}{dr} C A_8 \frac{\gamma^{2m_8+1}}{2m_8+1} - \frac{HC}{r^2} U_0 \\
 & A_7 \frac{\gamma^{m_7+m_8+1}}{\gamma^{m_7+m_8+1}} - \frac{H}{r^2} C U_0 A_8 \frac{\gamma^{2m_8+1}}{2m_8+1} - \frac{HC}{r^2} A_7 A_1 \frac{\gamma^{m_7+m_1+m_8+1}}{\gamma^{m_7+m_1+m_8+1}} + \frac{HC}{r^2} A_7 A_2 \\
 & \frac{\gamma^{m_7+m_2+m_8+1}}{\gamma^{m_7+m_2+m_8+1}} + \frac{H}{r^2} C A_8 A_1 \frac{\gamma^{2m_8+m_1+1}}{2m_8+m_1+1} + \frac{H}{r^2} C A_8 A_2 \frac{\gamma^{2m_8+m_2+1}}{2m_8+m_2+1}
 \end{aligned}$$

APPENDIX (4)

10

```

SAVEMEM 1542,"ASMLIB.COM"
GOSUB 0.400
GOSUB 0.500
PRINT
PRINT "EXTERNAL TRIGG. WAKE PICKUP PROGRAM"
PRINT "-----"
PRINT
PRINT
GOSUB 0.110
DISC.DRIVE%=1
GOSUB 0.120
INPUT"FILENAME";DISC.FN$
INPUT"RECORDS ";DISC.COUNT%
GOSUB 0.290
IF PROG.ERROR% NE 0 THEN GOTO 100
GOSUB 0.200
IF PROG.ERROR% NE 0 THEN GOTO 100
DISC.AREA=49152
DISC.RECORD%=0
PRINT
INPUT"ADC1 GAIN";ADC1.GAIN%
INPUT"ADC2 GAIN";ADC2.GAIN%
INPUT"ADC1 CHAN";ADC1.CHANNELS%
INPUT"ADC2 CHAN";ADC2.CHANNELS%
INPUT"PULSE DELAY";PULSE%
INPUT"GAP DELAY";GAP%
ADC1.PRIME%=64+32+16+2
ADC2.PRIME%=64+32+16+2
GOSUB 0.600
GOSUB 0.610
PRINT
PRINT
PRINT"ADC CARDS PRIMED"
PRINT"SYSTEM READY"
PRINT
OUT 0,255
FOR I%=1 TO 100
FOR J%=1 TO 50
OUT 0,0
OUT 0,255
IF(INP(ADC1.PORT%+6) AND 128) NE 0 THEN 20
IF(INP(ADC2.PORT%+6) AND 128) EQ 0 THEN 30
FOR K%=1 TO PULSE%
NEXT K%
NEXT J%
FOR K%=1 TO GAP%
NEXT K%
NEXT I%
PRINT"FINISHED"
OUT ADC1.PORT%,128
GOSUB 0.410
IF PROG.ERROR% NE 0 THEN GOTO 100
FOR I%=0 TO 9
FOR J%=0 TO 15

```

20

30


```

PRINT USING"      ";PEEK(49152+I%'16+J%);
NEXT J%
PRINT
NEXT I%
OUT ADC1.PORT%,64
OUT ADC2.PORT%,128
GOSUB 0.410
IF PROG.ERROR% NE 0 THEN 100
PRINT"SAMPLE OUTPUT - ADC2"
PRINT
FOR I%=0 TO 9
FOR J%=0 TO 15
PRINT USING"      ";PEEK(49152+I%'16+J%);
NEXT J%
PRINT
NEXT I%
GOSUB 0.140
IF PROG.ERROR% NE 0 THEN GOTO 100
INPUT"CONTINUE? (Y)ES OR (N)O";C$
IF C$="Y" THEN GOTO 10
STOP
100 PRINT"PROG.ERROR";PROG.ERROR%
STOP
%NOLIST
%INCLUDE DISCS
%INCLUDE ADCS
STOP

```


APPENDIX (5)

```

PROGRAM HOLE
1234 READ(1,*)PATP,PATM,T
      IF(PATP.EQ.-200.)GO TO 3333
10    READ(1,*)P51,P52,P21,P22,P41,P42,P11,P12,P31,P32,PST,PTC
      IF(P51.LT.0.0)GO TO 100
      P5=(P51+P52)/2
      P4=(P41+P42)/2
      P3=(P31+P32)/2
      P2=(P21+P22)/2
      P1=(P11+P12)/2
      RHO=PATP*14.5038*6895/287.06/(T+273)
      VIN=SQRT(8*9.81*(PST-PATM)/RHO)
      P21=((P21-P22)/2)+PATM/PATM
      WT=RHO*VIN*.1472621*SQRT(T+273)/(PATP*14.5038*6895)
      WRITE(2,14)VIN,P21,WT
14    FORMAT(5X,'0(1H)',/,5X,'THE INLET VELOCITY IS ',G14.8,/,5X,'THE
1    PRESSURE RATIO IS ',G14.8,/,5X,'THE NON-DIMENSIONAL FACTOR ((W/T
2/P)) IS ',G14.8)
      WRITE(2,99)P5,P2,P4,P1,P3
99    FORMAT(5X,'P1=',G14.8,3X,'P2=',G14.8,3X,'P3=',G14.8,3X,'P4='
1,G14.8,3X,'P5=',G14.8)
      D=ATAN((P4-P5)/(P3-P1))
      D=D*180./3.1415926
      IF(P3.GE.P1)GO TO 1
      IF(D.GE.0.0)GO TO 2
      D=D+180.0
      GO TO 1
2    D=D-180.0
1    WRITE(2,3))
3    FORMAT(5X,'THE ANGLE DELTA IS',G14.8)
      D=D*3.1415926/180.
      IF(D.GE.0.0)GO TO 5
      PHI=ATAN((-SQRT((1-2*((P2-P5)/(P4-P5)))**2+1)+(1-2*((P2-P5)/
1(P4-P5))))/SIN(D))
      PHI=PHI*180./3.1415926
      GO TO 5
5    PHI=ATAN((SQRT((1+2*((P2-P4)/(P4-P5)))**2+1)-(1+2*((P2-P4)/(P4
1-P5))))/SIN(D))
      PHI=PHI*180./3.1415926
6    WRITE(2,7)PHI
7    FORMAT(5X,'THE ANGLE PHI IS',G14.8)
      PHI=PHI*3.1415926/180.
      ALFA=ATAN(TAN(PHI)*SIN(D))
      BETA=ATAN(TAN(PHI)*COS(D))
      W=SQRT(800./9.*(P4-P5)/RHO*9.81/(SIN(D)*SIN(2*PHI)))
      ALFA=ALFA*180./3.1415926
      BETA=BETA*180./3.1415926
      WRITE(2,8)ALFA,BETA,W
8    FORMAT(5X,'THE ANGLE ALFA IS ',G14.8,/,5X,'THE ANGLE BETA IS '
1,G14.8,/,5X,'THE VELOCITY IS ',G14.8)
      ALFA=ALFA*3.1415926/180.
      BETA=BETA*3.1415926/180.
      X1=COS(ALFA)*COS(BETA)
      X2=COS(ALFA)*SIN(BETA)

```



```

      X3=SIN(ALFA)
      WRITE(2,53)X1,X2,X3
53   FORMAT(5X,'U/W= ',G14.8,5X,'V/W= ',G14.8,5X,'WP/W= ',
      1G14.8)
      IF(X3.LT.0.0)GO TO 44
      IF(X3.GT.0.0)GO TO 45
      WRITE(2,58)

98   FORMAT(40X,20(1H*),/,39X,1H*,/,39X,1H*, 'THE FLOW IS 2-DIM.
      1,1H*,/,39X,1H*,20X,1H*,/,39X,20(1H*))
      GO TO 123

44   WRITE(2,581)
881  FORMAT(39X,20(1H*),/,39X,1H*,28X,1H*,/,39X,1H*, 'THE FLOW IS
      1 3-DIM. INWOPD ',1H*,/,39X,1H*,29X,1H*,/,39X,29(1H*))
      GO TO 133

45   WRITE(2,582)
882  FORMAT(39X,20(1H*),/,39X,1H*,28X,1H*,/,39X,1H*, 'THE FLOW IS 3-
      1DIM. OUTWOPD ',1H*,/,39X,1H*,29X,1H*,/,39X,29(1H*))
123  WRITE(2,13)
13   FORMAT(1X,50(1H*))
      GO TO 10

100  WRITE(2,1399)
1398 FORMAT(3X,50(1H*))
      GO TO 1234

3333 STOP 'END OF ALL GIVEN DATA'
      END

```


APPENDIX (6)

```

LIBRARY(SUBGROUPSURF)
LIBRARY(SUBGROUPGINO)
PROGRAM(OSKA)
INPUT 3=MTD/(SCRATCHTAPE)/724
OUTPUT 2=LPO
COMPRESS INTEGER AND LOGICAL
EXTENDED
END
MASTER OSKA
INTEGER V
DIMENSION V(72,10),S(72,25),F(72),VD2(72,25),KREAD(32),KK(72,10)
1,VD(72,25),F1(72),F2(72),F3(72),F4(72),LC(100)
2,Q1(360),Q3(360),Q4(360)
CALL CC936N
CALL DEVSP(4800)
CALL UNITS(.667)
CALL DEVPAP(360.,270.,0)
DO 12035 KLMN=1,16
READ(3)(KREAD(I),I=1,32)
READ(3)KREAD(1)
DO 11 K=1,25
11 READ(3)((V(J,I),I=1,10),J=1,72)
READ(3)((KK(J,I),I=1,10),J=1,72)
12035 CONTINUE
DO 200 M=1,20
MM=M-((M-1)/5)*5
READ(3)(KREAD(I),I=1,32)
READ(3)KREAD(1)
DO 13 K=1,25
READ(3)((V(J,I),I=1,10),J=1,72)
DO 13 L=1,72
IF(M.LT.15)B131=5.119
IF(M.GT.15.AND.M.LE.30)B131=5.114
IF(M.GT.30)B131=5.063
S(L,K)=-V(L,1)/100.+B131
IF(S(L,K).GT.6.0)S(L,K)=3.98
IF(S(L,K).LT.0.0)S(L,K)=3.98
13 CONTINUE
READ(3)((KK(J,I),I=1,10),J=1,72)
L=25
N=72
DO 119 J=1,L
LC(J)=1
DO 120 I=1,N
IF(S(I,J)**2.GT.9.4504757)GO TO 130
LC(J)=0
WRITE(2,3)M,J
3 FORMAT(5X,////,5X,'THERE IS MISTAKE IN TRACK 1 SUBFILE NO ',I3,

```



```

      1//,5X,'      IN CYCLE NO      ',I3,5X,'I WILL MOVE TO THE NEXT ')
      GO TO 119
130    S(I,J)=((S(I,J)**2-9.4504757)/4.0349741)**(1./(0.45009986))
120    CONTINUE
      119    CONTINUE
           IC=0
           DO 7000 K=1,L
           IF(LC(K).EQ.0) GO TO 7000
           IC=1
           GO TO 8000
7000    CONTINUE
8000    IF(IC.EQ.0)GO TO 9000
           MAX=1
           DO 2000 J=1,L
           IF(LC(J).EQ.0)GO TO 1500
           MAX=J
           GO TO 2000
1500    IF(J.EQ.L)GO TO 4000
           JK=J+1
           DO 3000 K=JK,L
           IF(LC(K).EQ.0)GO TO 3000
           MAX=K
           GO TO 4000
3000    CONTINUE
4000    DO 6000 K=1,N
6000    S(K,J)=S(K,MAX)
2000    CONTINUE
           DO 5 J=1,L
           DO 5 I=1,N
           5    Q=Q+S(I,J)
           UBAR=Q/(L*N)
           DO 10 J=1,L
           DO 10 I=1,N
           10  VD(I,J)=S(I,J)-UBAR
C+++++SEGMENT FOR CALCULATING THE DISTRIBUTION OF THE OVERALL
C++++DISTURBNCE LEVEL OVER THE SIRCUMFERENTIAL
C-----
           WRITE(2,308)M
308    FORMAT(2X,'THE CIRCUMFERINTIAL DIST. OF OVER A.DISTURBNCE',I3)
           DO 301 I=1,N
           DO 302 J=1,L
           302  F1(I)=F1(I)+(VD(I,J)**2)
           301  F1(I)=SQRT(F1(I)/L)/UBAR*100.
           DO 1212 I=1,72
1212    Q1(72*(MM-1)+I)=F1(I)
           WRITE(2,303)(F1(I),I=1,N)
           303  FORMAT(3X,G14.8,2X,G14.8,2X,G14.8,2X,G14.8,2X,G14.8)
           WRITE(2,305)

```



```

305     FORMAT(2X,68(1H*))
      DO 401 J=1,L
      DO 401 I=1,N
        VD2(I,J)=VD(I,J)**2
401     VDK=VDK+VD2(I,J)
        VDKB=VDK/(L*N)
        VDKBG=SQRT(VDKB)
        TUD=VDKBG/UBAR*100.
C+++++
C-----SEGMENT FOR CALCULATING THE DIST. OF THE F.S.TURBULENCE
      DO 49 I=1,N
        DO 15 J=1,L
15     F(I)=F(I)+S(I,J)
49     F(I)=F(I)/L
      DO 201 I=1,N
        VDAS=0.0
      DO 202 J=1,L
202     VDAS=VDAS+((S(I,J)-F(I))**2)
        F2(I)=SQRT(VDAS/L)/F(I)*100.
201     F3(I)=SQRT(VDAS/L)/UBAR*100.
      WRITE(2,742)M
742     FORMAT(2X,'THE CIRCUM. DIST. OF THE F.S.TURBULENCE BASED ON ',
1/,3X,'THE LOCAL ENSAMBLE AVERAGE AS NON-DIMENSIONALIZED FACTOR',
2,2X,I4)
      WRITE(2,303)(F2(I),I=1,N)
      WRITE(2,305)
      WRITE(2,751)M
751     FORMAT(3X,'THE CIRCUMFERENTIAL DIST. OF F.S.TURBULENCE',
1',3X,
1' BASED ON THE TOTAL MEAN VALUE OF THE VELOCITY AS NON-DIM.',
2,3X,' FACTOR', I4)
      DO 1213 I=1,72
1213     Q3(72*(MM-1)+I)=F3(I)
      WRITE(2,303)(F3(I),I=1,N)
      WRITE(2,305)
      DO 203 I=1,N
        TUT=TUT+F2(I)
203     TUE=TUE+F3(I)
        TUT=TUT/N
        TUE=TUE/N
      WRITE(2,305)
      WRITE(2,851)M
851     FORMAT(2X,'THE DISTRIBUTION OF THE UNSTEADNESS LEVEL OVER',
1',3X,
1' THE SIRCUMFERENTIAL ',I4)
C+++++
C+++++ SEGMENT FOR CALCULATION OR THE UNSTEADNESS LEVEL DIST.
C+++++ OVER THE SIRCUMFERENTIAL DIRECTION
      DO 443 I=1,N
443     F4(I)=(F(I)-UBAR)/UBAR*100.

```


[illegible]


```

SUBROUTINE MAINPLOT(M,G1,Q3,Q4)
  DIMENSION Q1(360),Q3(360),Q4(360),Y(360),YC(5,3),YMAX(3),YMIN(3)
  1,YY(360)
  DATA
  1 YC/1.231313,1.1647053,1.0879552,.39328831,.65236521,1.2308810,
  *1.1596704,1.0759087,.87524315,.67795825,1.2349081,1.1760687,1.0161
  *,.88330704,.67900372/,YMAX/1.231313,1.2308810,1.2349081/,YMIN/.652
  *36521,.67795825,.67900372/
  IF(M.LT.11)RETURN
  IG=(M-1)/5+1
  I=0
  DO 1 K=1,5
    DO 1 J=1,72
      I=I+1
      YY(I)=5*J
      Y(I)=YC(K,IG)
      CALL BPLLOT(Q1,Y,YMIN(IG),YMAX(IG),YY,IG)
      CALL PLOT1(Q1,Y,YMIN(IG),YMAX(IG),YY,IG)
      CALL BPLLOT(Q3,Y,YMIN(IG),YMAX(IG),YY,IG)
      CALL PLOT1(Q3,Y,YMIN(IG),YMAX(IG),YY,IG)
      CALL EPLLOT(Q4,Y,YMIN(IG),YMAX(IG),YY,IG)
      CALL PLOT2(Q4,Y,YMIN(IG),YMAX(IG),YY,IG)
      RETURN
    END
  SUBROUTINE EPLOT(ZZ,XX,XL,XH,YY,IG)
    DIMENSION ZARR(72,72),XX(360),YY(360),ZZ(360),ITI(7),WW(17000)
    1,WXL(4),WXH(4),WYL(4),WYH(4)
    DATA M/72/,N/72/,NW/13000/,IFR/3/,XIU/0.0/,YIU/0.0/,ZIU/0.0/,IV/1
    1/,IP/360/,WXL(1)/0.0/,WXH(1)/360./,WYL(1)/0.0/,WYH(1)/250./
    DATA YL/5.0/,YH/360.0/
    DO 354 I=2,4
      WXL(I)=0.0
      WXH(I)=0.0
      WYL(I)=0.0
      WYH(I)=0.0
    WRITE(2,1675)
    1675 FORMAT(4X,60(1H&))
    CALL PICCLE
    CALL MOVTO2(1.,1.)
    CALL LINBY2(355.,0.)
    CALL LINBY2(0.,260.)
    CALL LINBY2(-355.,0.)
    CALL LINBY2(0.0,-260.)
    CALL CIRPTS(84)
    CALL RANGRD(NP,XX,YY,ZZ,M,XL,XH,N,YL,YH,ZARR,NW,WW)
    CALL ISOFRA(3)
    CALL MOVTO2(70.,70.)

```



```
CALL HEIRAT(1.)  
CALL ISOSCA(XIU,YIU,ZIU)  
CALL CHASIZ(4.,4.)  
CALL PENSEL(1,0.0,0)  
DO 200 I=1,1  
CALL WINDOW(WXL(I),WXH(I),WYL(I),WYH(I))  
200 CALL ISOPRJ(M,XL,XH,N,YL,YH,Z-EP,IV,NW,WV)  
CALL CHAANG(30.)  
CALL MOVTO(15.,4.)  
CALL CHAHOL(29HF*LIRCUMFERENTIAL DIRECTION*. )  
CALL CHAANG(-3.)  
CALL MOVTO2(33.,75.)  
CALL CHAHOL(20HF*LLOW COEFFICIENT*. )  
C$$$  
RETURN  
ENTRY PLOT1(ZZ,XX,XL,XH,YY,IG)  
CALL CHAANG(-9.)  
CALL MOVTO2(248.,217)  
CALL CHAHOL(27HOVERALL DISTURBENCE LEVEL*. )  
CALL CHAANG(90.)  
CALL MOVTO(13.,105.)  
CALL CHAHOL(27HOVERALL DISTURBENCE LEVEL*. )  
CALL CHAANG(0.)  
CALL ITALIC(25.)  
CALL MOVTO2(175.,15.)  
CALL CHAHOL(49HF*LIG *UD*LIST OF OVERALL DISTURBENCE LEVEL*. )  
CALL MOVTO2(200.,240.)  
CALL ITALIC(40.)  
GO TO 300  
ENTRY PLOT2(ZZ,XX,XL,XH,YY,IG)  
CALL CHAANG(-9.)  
CALL MOVTO2(248.,217)  
CALL CHAHOL(32HF*LREE STREAM TURPULENCE LEVEL*. )  
CALL CHAANG(90.)  
CALL MOVTO(13.,105.)  
CALL CHAHOL(32HF*LREE STREAM TURPULENCE LEVEL*. )  
CALL CHAANG(0.)  
CALL ITALIC(25.)  
CALL MOVTO2(167.,15.)  
CALL CHAHOL(52HF*LIG *UD*LIST OF FREE STREAM TURPULENCE LEVEL*. )  
1.)  
CALL MOVTO2(200.,240.)  
CALL ITALIC(40.)  
GO TO 300  
ENTRY PLOT3(ZZ,XX,XL,XH,YY,IG)  
CALL CHAANG(-90.)  
CALL MOVTO2(248.,217)  
CALL CHAHOL(21HU*LNSTEADNESS LEVEL*. )
```


APPENDIX (7)

It is required to obtain $f(x, y, \dots)$

$$F = a_1 \phi_1(x, y, \dots) + a_2 \phi_2(x, y, \dots) + \dots + a_n \phi_n(x, y, \dots)$$

where $a_1, a_2, \dots, a_n$ are arbitrary constants to be determined.

$\phi_1(x, y, \dots)$ are sets of basic functions.

These sets are preferred to be orthogonal function and for polynomial approximation, it is preferred to take a small number of terms, as large term numbers cause inaccuracy.

The orthogonal functions is defined as :

$$\phi_i(x), \phi_j(x) \text{ are orthogonal}$$

$$\text{if } \int_a^b \phi_i(x) \phi_j(x) dx \begin{cases} \neq 0 & \text{for } i=j \\ = 0 & \text{for } i \neq j \end{cases}$$

hence,

$$F_i = \sum_{i=1}^N a_i \phi_i(x, y, \dots)$$

* If the number of given points "m" equal "n", the problem will be an Interpolation problem solved by using the Lagrangian determinate :-

$$\left| \begin{array}{cccc} \phi_1(x, y, \dots) & \phi_2(x, y, \dots) & \dots & \phi_n(x, y, \dots) - F_1 \\ \phi_1(x_1, y_1, \dots) & \phi_2(x_1, y_1, \dots) & \dots & \phi_n(x_1, y_1, \dots) - F_1 \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ \phi_1(x_n, y_n, \dots) & \phi_2(x_n, y_n, \dots) & \dots & \phi_n(x_n, y_n, \dots) - F_n \end{array} \right| = 0$$

* If the number of given points "m" is greater than "n" this will be "a least square problem". a_1 is chosen so that

$$\sum e_r^2 = \text{Min}$$

$$e_J = \sum_{i=1}^n a_i \phi_i(x_1, y_1, \dots) - F_J$$

$$e_J^2 = \left[\sum_{i=1}^n a_i \phi_i(x_1, y_1, \dots) - F_J \right]^2$$

$$\sum_{J=1}^m e_J^2 = [\text{Minimum}]$$

$$\frac{\partial}{\partial a_x} \sum_{J=1}^m e_J^2 = 0 \quad x = 1, 2, \dots, n$$

$$\sum_{J=1}^m \frac{\partial}{\partial a_x} e_J^2 = 0 \sum_{J=1}^m e_J \frac{\partial e_J}{\partial a_x} = 0$$

hence,

$$\sum_{J=1}^m \left[\sum_{i=1}^n a_i \phi_i(x_i, y_i) \phi_x(x_J, y_J, \dots) \right]$$

$$= \sum_{i=1}^m F_J \phi_x(x_J, y_J, \dots)$$

i.e.
$$[c] [a] = Y$$

where

$$C_{i,J} = \sum_{r=1}^m \phi_i(x_r, y_r, \dots) \phi_J(x_r, y_r, \dots)$$

$$Y_i = \sum_{r=1}^m F_r \phi_i(x_r, y_r, \dots)$$

$$a = [c]^{-1} Y \quad \text{which is the required solution.}$$

For one particular case

$$a_1 x + a_2 y + a_3 z = F_1$$

$$b_1 x + b_2 y + b_3 z = F_2$$

$$c_1 x + c_2 y + c_3 z = F_3$$

to determine a_1, a_2, a_3

$$\text{Error} = F_1 \text{ analytical} - F_1 \text{ measured}$$

$$= (a_1 x + a_2 y + a_3 z) - F_1$$

$$\sum_{k=1}^n E^2 = \text{minimum}$$

$$\sum_{k=1}^n \left[(a_1 x + a_2 y + a_3 z) - F_1 \right]^2 = \min$$

$$\frac{\partial}{\partial a_i} \left\{ \sum_{k=1}^n \left[(a_1 x + a_2 y + a_3 z) - F_1 \right]^2 \right\} = 0$$

$$i = 1, 2, 3$$

$$\sum_{k=1}^n \frac{\partial}{\partial a_i} \left[(a_1 x_k + a_2 y_k + a_3 z_k) - F_{1k} \right]^2 = 0$$

$$\sum_{k=1}^n 2 \left[(a_1 x_k + a_2 y_k + a_3 z_k) - F_{1k} \right] x_k = 0$$

$$\begin{aligned} a_1 \left(\sum_{k=1}^n x_k^2 \right) + a_2 \sum_{k=1}^n (x_k y_k) + a_3 \sum_{k=1}^n (x_k z_k) \\ = \sum_{k=1}^n (x_k F_{1k}) \quad \dots (1) \end{aligned}$$

$$\begin{aligned} a_1 \left(\sum_{k=1}^n x_k y_k \right) + a_2 \sum_{k=1}^n (y_k)^2 + a_3 \sum_{k=1}^n (y_k z_k) \\ = \sum_{k=1}^n (y_k F_{1k}) \quad \dots (2) \end{aligned}$$

$$a_1 \sum_{k=1}^n (x_k z_k) + a_2 \sum_{k=1}^n (z_k y_k)$$

$$+ a_3 \sum_{k=1}^n (z_k^2)$$

$$= \sum_{k=1}^n (z_k F_{1k})$$

... (3)

From (1) and (3)

$$D_{11} = \sum_{k=1}^n x_k^2 \quad D_{12} = \sum_{k=1}^n x_k y_k$$

$$D_{13} = \sum_{k=1}^n x_k z_k \quad D_{22} = \sum_{k=1}^n y_k^2$$

$$D_{23} = \sum_{k=1}^n y_k z_k \quad D_{33} = \sum_{k=1}^n z_k^2$$

$$D_{21} = D_{12} \quad , \quad D_{31} = D_{13} \quad , \quad D_{32} = D_{23}$$

$$\begin{bmatrix} D_{11} & D_{12} & D_{13} \\ D_{21} & D_{22} & D_{23} \\ D_{31} & D_{32} & D_{33} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix} = \begin{bmatrix} \sum x_k F_{1k} \\ \sum y_k F_{1k} \\ \sum z_k F_{1k} \end{bmatrix} \quad \dots (11)$$

$$\begin{bmatrix} D \\ D \\ D \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} \sum x_k F_{2k} \\ \sum y_k F_{2k} \\ \sum z_k F_{2k} \end{bmatrix} \quad \dots (22)$$

$$\begin{bmatrix} D \\ D \\ D \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} = \begin{bmatrix} \sum x_k F_{3k} \\ \sum y_k F_{3k} \\ \sum z_k F_{3k} \end{bmatrix} \quad \dots (33)$$

APPENDIX (8) =====

```

PROGRAM LINEAR
DOUBLE PRECISION QL(3,3)
DIMENSION X(100),Y(100),Z(100),F1(100),F2(100),F3(100),
1 D(3),A(3),B(3),C(3),U(3),V(3),W(3),ERR(3)
DO 10 I=1,3
DO 10 J=1,3
10  QL(I,J)=0.0
DO 30 K=1,3
U(K)=0.0
V(K)=0.0
30  W(K)=0.0
PRINT *, 'INPUT NO OF SAMPLES'
READ *,M
DO 60 K=1,M
60  READ(1,*)F1(K),F2(K),F3(K),X(K),Y(K),Z(K)
DO 654 K=1,M
F1(K)=-.26928902+.31223321E-01*F1(K)
F2(K)=.11801386+.30768463E-01*F2(K)
654  F3(K)=.50813198E-01+.30955680E-01*F3(K)
DO 902 K=1,M
F1(K)=((F1(K)**2-4.5475292)/2.4421654)**(1/.4199999)**2
F2(K)=((F2(K)**2-4.9229002)/2.1660075)**(1/.45999986)**2
902  F3(K)=((F3(K)**2-11.732722)/1.6515918)**(1/.54999977)**2
DO 20 K=1,M
QL(1,1)=QL(1,1)+X(K)**2
QL(1,2)=QL(1,2)+X(K)*Y(K)
QL(1,3)=QL(1,3)+X(K)*Z(K)
QL(2,2)=QL(2,2)+Y(K)**2
QL(2,3)=QL(2,3)+Y(K)*Z(K)
QL(3,3)=QL(3,3)+Z(K)**2
W(1)=W(1)+X(K)*F1(K)
W(2)=W(2)+Y(K)*F1(K)
W(3)=W(3)+Z(K)*F1(K)
U(1)=U(1)+X(K)*F2(K)
U(2)=U(2)+Y(K)*F2(K)
U(3)=U(3)+Z(K)*F2(K)
V(1)=V(1)+X(K)*F3(K)
V(2)=V(2)+Y(K)*F3(K)
20  V(3)=V(3)+Z(K)*F3(K)
QL(2,1)=QL(1,2)
QL(3,1)=QL(1,3)
QL(3,2)=QL(2,3)
CALL INV(3,3,QL)
CALL SOLV(3,3,QL,W,A)
CALL SOLV(3,3,QL,U,B)
CALL SOLV(3,3,QL,V,C)
WRITE(2,*) 'A', (A(I),I=1,3)
WRITE(2,*) 'B', (B(I),I=1,3)

```



```

WRITE(2,*) 'C', (C(I), I=1,3)
A(3)=20.0
DO 100 I=1,3
DO 100 J=1,3
100  QL(I,J)=0.0
DO 120 I=1,3
    QL(1,I)=A(I)
    QL(2,I)=B(I)
120  QL(3,I)=C(I)
WRITE(2,*) ((QL(I,J), J=1,3), I=1,3)
CALL INV(3,3,QL)
DO 130 I=1,M
    W(1)=F1(I)
    W(2)=F2(I)
    W(3)=F3(I)
    CALL SOLV(3,3,QL,W,D)
    WRITE(2,*) (D(J), J=1,3)
    IF(D(1).LT.0.0) D(1)=-D(1)
    IF(D(2).LT.0.0) D(2)=-D(2)
    IF(D(3).LT.0.0) D(3)=-D(3)
    WRITE(2,*) (D(JK), JK=1,3)
    WRITE(2,*) '*****'
    WRITE(2,*) X(I), Y(I), Z(I)
    WRITE(2,*) '*****'
    ERR(1)=(D(1)-X(I))/D(1)*100
    ERR(2)=(D(2)-Y(I))/D(2)*100
    ERR(3)=(D(3)-Z(I))/D(3)*100
    WRITE(2,*) 'ERR%', (ERR(I2), I2=1,3)
    V11=V11+ERR(1)
    V12=V12+ERR(2)
    V13=V13+ERR(3)
    DO 150 I2=1,3
150  ERR(I2)=0.0
130  CONTINUE
    V11=V11/M
    V12=V12/M
    V13=V13/M
    WRITE(2,*) V11, V12, V13
    STOP
END
SUBROUTINE SOLV(N,NA,L,W,X)
DOUBLE PRECISION L(NA,NA)
DIMENSION W(NA), X(NA)
DO 10 I=1,N
    X(I)=0
    DO 10 J=1,N
10  X(I)=X(I)+L(I,J)*W(J)
RETURN
END
SUBROUTINE INV(N,NA,AA)
DIMENSION II(15)
DOUBLE PRECISION AA(NA,NA), A(15,15)
COMMON Z(9), DET
DET=1
DO 10 I=1,N

```



```

      II (I) = I
      DO 10 J=1,N
10    A(I,J) = AA(I,J)
      DO 60 K=1,N
      P=1.0E-10
      IP=0
      DO 20 I=K,N
      IA=II (I)
      IF (ABS (A (IA,K) ) .LE.P) GO TO 20
      IP=I
      P=ABS (A (IA,K) )
20    CONTINUE
      IF (IP.EQ.0) STOP 'SINGULAR MATRIX'
      KP=II (IP)
      II (IP) = II (K)
      II (K) = KP
      P=A (KP,K)
      DET=DET*P
      DO 30 J=1,N
30    A (KP,J) = A (KP,J) / P
      DO 50 IA=1,N
      I=II (IA)
      IF (I.EQ.KP) GO TO 50
      Q=-A (I,K)
      A (I,K) = Q/P
      DO 40 J=1,N
      IF (J.EQ.K) GO TO 40
      A (I,J) = A (I,J) + Q*A (KP,J)
40    CONTINUE
50    CONTINUE
60    A (KP,K) = 1.0/P
      DO 100 I=1,N
      DO 100 J=1,N
100   AA (I,II (J) ) = A (II (I) ,J)
      RETURN
      E N D

```


APPENDIX (9)

```

SAVEMEM 1542,"ASMLIB.COM"
GOSUB 0.400
GOSUB 0.500
10 PRINT
PRINT "PROGRAM OF INT. TRIGG. OF H.S.ADC CARDS"
PRINT "/////////////////////////////////////"
PRINT
PRINT
GOSUB 0.110
DISC.DRIVE%=1
GOSUB 0.120
INPUT"FILENAME";DISC.FN$
INPUT"RECORDS ";DISC.COUNT%
GOSUB 0.290
IF PROG.ERROR% NE 0 THEN GOTO 100
GOSUB 0.200
IF PROG.ERROR% NE 0 THEN GOTO 100
DISC.AREA=49152
DISC.RECORD%=0
PRINT
INPUT"ADC1 GAIN";ADC1.GAIN%
INPUT"ADC2 GAIN";ADC2.GAIN%
INPUT"ADC1 CHAN";ADC1.CHANNELS%
INPUT"ADC2 CHAN";ADC2.CHANNELS%
ADC1.PRIME%=64+32+16+2
ADC2.PRIME%=64+32+16+2
GOSUB 0.600
GOSUB 0.610
PRINT
PRINT
PRINT"ADC CARDS PRIMED"
PRINT"SYSTEM READY"
PRINT
20 IF(INP(ADC1.PORT%+6) AND 128) NE 0 THEN 20
30 IF(INP(ADC2.PORT%+6) AND 128) NE 0 THEN 30
PRINT"FINISHED"
OUT ADC1.PORT%,128
GOSUB 0.410
IF PROG.ERROR% NE 0 THEN GOTO 100
FOR I%=0 TO 9
FOR J%=0 TO 15
PRINT USING"      ";PEEK(49152+I%*16+J%);
NEXT J%
PRINT
NEXT I%
OUT ADC1.PORT%,64
OUT ADC2.PORT%,128
GOSUB 0.410
IF PROG.ERROR% NE 0 THEN 100
PRINT"SAMPLE OUTPUT - ADC2"
PRINT
FOR I%=0 TO 9
FOR J%=0 TO 15
PRINT USING"      ";PEEK(49152+I%*16+J%);

```



```
NEXT J%  
PRINT  
NEXT I%  
GOSUB 0.140  
IF PROG.ERROR% NE 0 THEN GOTO 100  
INPUT"CONTINUE? (Y)ES OR (N)O";C$  
IF C$="Y" THEN GOTO 10  
STOP  
100 PRINT"PROG.ERROR";PROG.ERROR%  
STOP
```

```
%NOLIST  
%INCLUDE DISCS  
%INCLUDE ADCS  
STOP
```


APPENDIX (10)

=====

```

PROGRAM SIGNALS ANALYSIS
CHARACTER*2 CONT
REAL N(3),K(2,3)
INTEGER RAKM(6)
DIMENSION EO(3),B(3),E(80,3),Q(3,3),NC(9),Q1(80,3),XX(80,3)
1,SS(80,3),BB(80,3),FF(9,60),X(3),TT(9,60),WW(9,60),P1(60)
1,BC(60),A1A(3),B1B(3),C1C(3),QTA(20)
PRINT *, 'Enter no of the case'
READ (*, '(6A1)') RAKM
PRINT *, 'Enter the r.p.s....'
READ *, GG
PRINT *, 'Enter the hight..'
READ *, RR
WRITE(2,2)
2   FORMAT(5X, ' P1(I1) ', ' U1 ', ' V1 ', ' W1 ', ' BC(P1(I1))
1', '/', 5X, (65(1H*)) )
WRITE(2,3)
3   FORMAT(5X, ' U2 ', ' V2 ', ' W2 ', '/', 5X, 65(1H*), '/', ' FF(7, NCA
1SE) ', ' FF(8, NCASE) ', ' FF(9, NCASE) ' )
WRITE(3,6)
6   FORMAT(5X, ' FF(1, NCASE) ', ' FF(2, NCASE) ', ' FF(3, NCASE) '
1, '/', 5X, 65(1H*), '/', ' U2 ', ' V2 ', ' W2 ', '/', 5X, 65(1H*), '/', ' FF(7
1, NCASE) ', ' FF(8, NCASE) ', ' FF(9, NCASE) ' )
PRINT *, 'Enter step of calculation'
READ *, INTER
OK=INTER
I1=1
II=1
CALL CDATA (NA,EO,B,N,K,NCASE,MIN,A1A,B1B,C1C,FAC)
10 CALL VDATA (NA,E,NCASE,MIN)
CALL QCALC (EO,B,N,NA,E,Q1)
CALL LINEAR(K,Q1,XX,NA,A1A,B1B,C1C,FAC)
CALL SOLU(XX,NA,SS,I1,P1,BC,GG,RR)
CALL STREAMTURBO(XX,NA,TT,NCASE,1.0)
CALL STREAMTURBO(SS,NA,WW,NCASE,0.0)
PRINT *, 'POINT NO =', NCASE
P1(I1)=NCASE
I1=I1+1
NCASE=NCASE+INTER
IF (NCASE.GE.18) INTER=1
IF (NCASE.GE.28) INTER=OK
IF (NCASE.LT.MIN) GO TO 10
IF (NCASE.GE.MIN.AND.II.EQ.1) THEN
NCASE=MIN
II=II+1
GO TO 10
END IF
I1=I1-1

```



```

CALL NONDIM(TT,MIN,P1,I1,1.0)
CALL NONDIM(WW,MIN,P1,I1,2.0)
CALL CCL051
CALL DEVSPE(4800)
CALL DEVPAP(360.,270.,0)
CALL NIDRA(TT,MIN,P1,I1,1.0,RAKM)
CALL NIDRA(WW,MIN,P1,I1,2.0,RAKM)
CALL DEVEND
STOP
END
C***** THIS SUBROUTINE CALCULATE THE DIRECTIONAL SENSITIVITY FACTORS
C***** FOR THE THREE HOT WIRES AND IT CORRECTS THE KING'S LAW CONSTANT
C***** FOR THE TEMPRATURE VARIATIONS
SUBROUTINE CDATA(NA,EO,B,N,K,NCASE,MIN,A1A,B1B,C1C,FAC)
REAL EO(3),B(3),N(3),K(2,3),A1A(3),B1B(3),C1C(3)
NCASE=1
PRINT *, 'Enter the number of ensamples at each signal please...'
READ *, NA
PRINT *, 'NO OF ENSAMPLES= ',NA
PRINT *, 'Enter the number of data points inside the wake '
READ *, MIN
READ(1,*)N,B,EO
PRINT *, 'Are you going to use groups of 3 or 2 factors??'
READ *, FAC
IF(FAC.EQ.3)GO TO 10
PRINT *, 'Enter the yaw angle and the pitch angle bywhitch we
1 can estimate the sensitivity factors ... '
READ *, YY
READ *, PP
YY=YY*3.141592654/180.
PP=PP*3.141592654/180.
K(1,1)=.3846387-.1650606*YY
K(2,1)=1.509583-.4194605*PP
K(1,2)=.6156235-.3047967*YY
K(2,2)=.3144946+.2963247*PP
K(1,3)=.6239951-.2611685*YY
K(2,3)=1.396839-.2700438*PP
DO 2137 J=1,3
DO 2137 I=1,2
IF(K(I,J).LT.0.0)THEN
564 WRITE(*,564)I,J,K(I,J)
1 FORMAT(5X,'The factor K('',I3,'','',I3,'') is negative and its value'
'is ',F9.6)
PRINT *, 'Please enter the constant value of this factor..'
READ *, K(I,J)
END IF
2137 CONTINUE
DO 5482 J=1,3
DO 5482 I=1,2
5482 K(I,J)=SQRT(K(I,J))
GO TO 14
10 READ(1,*) (A1A(I),I=1,3)
READ(1,*) (B1B(I),I=1,3)
READ(1,*) (C1C(I),I=1,3)
14 READ(1,*)TE,TC,TW

```



```

        DO 6 I=1,3
        EO(I)=(EO(I)**2*(1+(1.75E-07+1.225E-09*TW)*TE)*(TW-TE)/
1  1+(1.75E-07+1.225E-09*TC))/(TW-TC)**0.5
6  B(I)=B(I)*(TW-TE)/(TW-TC)
    RETURN
    END
C***** THIS SUBROUTINE GETS THE REQUIRED VOLTAGE DATA AT A PARTICULAR
C***** POINT INSIDE THE WAKE AS WELL AS DRAWING THE RAW SIGNALS FROM
C***** THE HOT WIRES
    SUBROUTINE VDATA (NA,E,NCASE,MIN)
    DIMENSION E(80,3)
    IF(NCASE.EQ.100) CALL SIGNALPLOT(MIN)
    CALL WAKESELECT(NCASE,NA,E)
    RETURN
    END
C***** THIS SUBROUTINE CALCULATE THE INSTANTENOUS VELOCITES IN THE
C***** REFERENCE SYSTEM OF THE THREE WIRES
C+++
S2PD

    SUBROUTINE LINEAR (K,Q1,XX,NA,ALA,B1B,C1C,FAC)
    REAL K,L11,L12,L13,L21,L22,L23,L31,L32,L33
    DIMENSION K(2,3),W(6),F(3),XX(80,3),Q1(80,3),X(3),ALA(3),B1B(3)
1  ,C1C(3)
    IF(FAC.EQ.3) GO TO 10
    L11=1.0
    L12=K(2,1)**2
    L13=K(1,1)**2
    L21=K(2,2)**2
    L22=K(1,2)**2
    L23=1.0
    L31=K(1,3)**2
    L32=K(2,3)**2
    L33=1.0
    GO TO 20
10  L11=ALA(1)
    L12=ALA(2)
    L13=ALA(3)
    L21=B1B(1)
    L22=B1B(2)
    L23=B1B(3)
    L31=C1C(1)
    L32=C1C(2)
    L33=C1C(3)
20  CT=L11*(L22*L33-L23*L32)+L12*(L23*L31-L21*L33)+L13*(L21*L32
1-L22*L31)
    DO 40 A=1,NA
    W(1)=Q1(A,1)**2
    W(2)=Q1(A,2)**2
    W(3)=Q1(A,3)**2
    X(1)=(W(1)*(L22*L33-L23*L32)+W(2)*(L13*L32-L12*L33)+W(3)*(L12*L
1  23-L13*L22))/CT
    X(2)=(W(1)*(L21*L33-L23*L31)+W(2)*(L13*L31-L11*L33)+W(3)
1  *(L11*L23-L13*L21))/CT
    X(3)=(W(1)*(L21*L32-L22*L31)+W(2)*(L12*L31-L11*L32)+W(3)
1  *(L11*L22-L12*L21))/CT

```



```

DO 1111 I=1,3
IF(X(I)) 555,1111,1111
555    X(I)=-X(I)
1111  CONTINUE
      IF(W(1).LE.150.0)THEN
      XX(A,1)=SQRT((1.0*X(1)))
      ELSE
      XX(A,1)=SQRT(X(1))
      END IF
      XX(A,2)=SQRT(X(2))
      IF(W(1).LE.150.0)THEN
      XX(A,3)=SQRT((1.0*X(3)))
      ELSE
      XX(A,3)=SQRT(X(3))
      END IF
40    CONTINUE
      RETURN
      END

C***** THIS SUBROUTINE GETS THE VOLTAGE SIGNALS FOR THE THREE WIRES
C***** AT ANY POINT INSIDE THE BLADE PASSAGE
      SUBROUTINE WAKESELECT(IPOINT,NA,E)
      DIMENSION E(80,3),REC(47)
      DATA IOPEN/-1/
      IOPEN=IOPEN+1
      IF(IOPEN.EQ.0.0)OPEN(10,STATUS='OLD',ERR=200)
      IF(IOPEN.GT.0)REWIND(10)
      DO 100 I=1,3
      DO 100 J=1,NA
      READ(10,*,ERR=300)(REC(K),K=1,47)
      E(J,I)=REC(IPOINT)
100    CONTINUE
      RETURN
200    STOP'FILE FOR010 NOT FOUND !!!!!'
300    STOP'READ ERROR IN FILE FOR010'
      END

C***** THIS SUBROUTINE DRAW THE RAW SIGNALS FROM THE THREE WIRES AT
C***** AT EACH SINGLE RUNNING CONDITION
      SUBROUTINE SIGNALPLOT(MIN)
      CHARACTER*2 NONA
      DIMENSION YAO(3),YT(60,80),X(60),Y(60)
      DATA NPLT/11/,NIN/23/,PX,PY/300.0,210./,XO,YO/25.
5,40./,XAL,YAL/18.5,40/,GAP/2.0/,XAO/24./,YAO/110.,60.,10./,XL,YL
2/250.,150./
      CALL WINDOW(2)
      CALL PICCLE
10    PRINT *, 'Enter the increment and the number of ensamples tog.'
      READ(*,*,ERR=10)INC,MIN1
      CALL MOVTO2(XO+10.,YO-10.)
      CALL CHASIZ(4.0,4.0)
      CALL CHAHOL(41HF*LIG      *USIGNALS FROM THE HOT WIRE AT*.)
      CALL CHASIZ(3.,3.)
      CALL SHIFT2(XO,YO)
      CALL MOVTO2(0.0,0.0)
      CALL LINBY2(XL,0.0)
      CALL LINBY2(0.0,YL)

```



```

CALL LINBY2(-XL,0.0)
CALL LINBY2(0.0,-YL)
CALL MOVTO2(83.0,105.)
CALL CHAHOL(32HO*LUTPUT SIGNAL FROM WIRE NO 1*.)
CALL MOVTO2(83.0,55.0)
CALL CHAHOL(32HO*LUTPUT SIGNAL FROM WIRE NO 2*.)
CALL MOVTO2(83.0,5.0)
CALL CHAHOL(32HO*LUTPUT SIGNAL FROM WIRE NO 3*.)
DO 20 I=1,MIN
20  X(I)=I
    XMIN=1
    XMAX=MIN
    DO 100 IW=1,3
        XAO=24.
        DO 40 J=1,MIN1
40  READ(30,*,ERR=200) (YT(I,J),I=1,MIN)
        IC=0
        J=NIN-INC
        XAO=XAO-XAL-GAP
50  IC=IC+1
        J=J+INC
        IF(IC.GT.NPLOT) GO TO 100
        IF(J.GT.MIN) J=J-MIN
        DO 60 I=1,MIN
60  Y(I)=YT(I,J)
        YMAX=FMAX(Y,MIN)
        YMIN=FMIN(Y,MIN)
        CALL PENSEL(IW,0.0,0)
        XAO=XAO+XAL+GAP
        CALL AXIPOS(1,XAO,YAO(IW),XAL,1)
        CALL AXISCA(3,2,XMIN,XMAX,1)
        CALL AXIPOS(1,XAO,YAO(IW),YAL,2)
        CALL AXISCA(3,10,YMIN,YMAX,2)
        IF(IC.EQ.1) CALL AXIDRA(-2,0,2)
        CALL GRAPOL(X,Y,MIN)
        GO TO 50
100  CONTINUE
    RETURN
200  STOP 'FILE FOR030 READ ERROR'
    END
C***** THIS SUBROUTINE CALCULATES THE INSTANTENOUS EFFECTIVE COOLING
C***** VELOCITIES FOR THE THREE WIRES
SUBROUTINE QCALC(E0,B,N,NA,E,Q1)
REAL N(3)
INTEGER A
DIMENSION E(80,3),Q1(80,3),EO(3),B(3)
DO 10 A=1,NA
    LMDJ=0
    IF(E(A,1).LT.EO(1)) THEN
        Q1(A,1)=(E(A,1)**2-2.43741)/4.3603299)**(1.0/.329999983)
        LMDJ=1
    ELSE
        Q1(A,1)=(E(A,1)**2-EO(1)**2)/B(1))**(1/N(1))
    END IF
    IF(E(A,2).LT.EO(2)) THEN

```



```

Q1(A,2)=( (E(A,2)**2-3.475695)/3.010558786)**(1.0/.37999994)
LMDJ=1
ELSE
Q1(A,2)=( (E(A,2)**2-EO(2)**2)/B(2))**(1/N(2))
END IF
IF (E(A,3).LT.EO(3)) THEN
Q1(A,3)=( (E(A,3)**2-7.4409204)/2.743496545)**(1.0/.5199998)
LMDJ=1
ELSE
Q1(A,3)=( (E(A,3)**2-EO(3)**2)/B(3))**(1/N(3))
END IF
VTOT=SQRT(Q1(A,1)**2+Q1(A,2)**2+Q1(A,3)**2)
IF (LMDJ.EQ.0.AND.VTOT.LT.10) THEN
Q1(A,1)=( ( (4.50877508+2.8922041*Q1(A,1)**.4199999)-2.43741001)/
14.3603299)**(1.0/.329999983)
Q1(A,2)=( ( (4.880947164+2.12922624*Q1(A,2)**.45999986)-3.475695)/
13.010558786)**(1.0/.37999994)
Q1(A,3)=( ( (11.6327355+1.623545901*Q1(A,3)**.5499997)-7.4409204)/
12.743496545)**(1.0/.5199998)
END IF
10    CONTINUE
    RETURN
    END
C***** THIS SUBROUTINE CALCULATES THE INSTANTENOUS VELOCITIES IN
C***** THE RELATIVE FRAME OF REFERENCE IN TWO DIFFERENT COORDINATE
C***** SYSTEMS; 1-TURBOMACHINERY AXES
C***** 2-STEAMWISE AND NORMAL TO THE STREAM WISE DIRECTIONS
C***** AND IT CALCULATES THE INSTANTENOUS OUTLET FLOW ANGLE
    SUBROUTINE SOLU (XX,NA,SS,I1,P1,BC,GG,RR)
    INTEGER P1
    DIMENSION XX(80,3),SS(80,3),P1(60),BC(60)
    U1=0.0
    V1=0.0
    W1=0.0
    DO 10 A=1,NA
    U1=U1+XX(A,1)
    V1=V1+XX(A,2)
    W1=W1+XX(A,3)
10    U1=U1/NA
    V1=V1/NA
    W1=W1/NA
    BC(P1(I1))=ATAN((2*3.141529654*GG*RR-V1)/U1)
    DO 20 A=1,NA
    SS(A,1)=XX(A,1)*COS(BC(P1(I1)))+XX(A,2)*SIN(BC(P1(I1)))
    SS(A,2)=ABS(-XX(A,1)*SIN(BC(P1(I1)))+(2*3.141529654*GG*RR-
1    XX(A,2))*COS(BC(P1(I1))))
    SS(A,3)=XX(A,3)
20    XX(A,2)=2*3.141529654*GG*RR-XX(A,2)
    BC(P1(I1))=BC(P1(I1))*180/3.141529654
    WRITE(2,*)P1(I1),U1,V1,W1,BC(P1(I1))
    RETURN
    END
C***** THIS SUBROUTINE CALCULATES THE VELOCITIES,TURBULENCE
C***** INTENSITIES AND REYNOLDS STRESSES IN BOTH COORDINATES
    SUBROUTINE STREAMTURBO (BB,NA,FF,NCASE,WR)

```



```

1  DIMENSION XX(80,3),SS(80,3),BB(80,3),FF(9,60),TT(9,60)
    ,WW(9,60)
    U1=0.0
    V1=0.0
    W1=0.0
    U2=0.0
    V2=0.0
    W2=0.0
    U3=0.0
    V3=0.0
    W3=0.0
    DO 10 A=1,NA
      U1=U1+BB(A,1)
      V1=V1+BB(A,2)
10   W1=W1+BB(A,3)
      FF(1,NCASE)=U1/NA
      FF(2,NCASE)=V1/NA
      FF(3,NCASE)=W1/NA
      IF(WR.EQ.0.0) THEN
        WRITE(3,*) FF(1,NCASE),FF(2,NCASE),FF(3,NCASE)
      END IF
      DO 20 A=1,NA
        U2=U2+(BB(A,1)-FF(1,NCASE))**2
        V2=V2+(BB(A,2)-FF(2,NCASE))**2
20   W2=W2+(BB(A,3)-FF(3,NCASE))**2
      IF(WR.EQ.1.0) THEN
        WRITE(2,*) U2,V2,W2
      ELSE
        WRITE(3,*) U2,V2,W2
      END IF
      FF(4,NCASE)=(SQRT(U2/NA)/FF(1,NCASE))*100
      FF(5,NCASE)=(SQRT(V2/NA)/FF(2,NCASE))*100
      FF(6,NCASE)=(SQRT(W2/NA)/FF(3,NCASE))*100
      DO 30 A=1,NA
        U3=U3+(BB(A,1)-FF(1,NCASE))*(BB(A,2)-FF(2,NCASE))
        V3=V3+(BB(A,1)-FF(1,NCASE))*(BB(A,3)-FF(3,NCASE))
30   W3=W3+(BB(A,2)-FF(2,NCASE))*(BB(A,3)-FF(3,NCASE))
      FF(7,NCASE)=U3/NA
      FF(8,NCASE)=V3/NA
      FF(9,NCASE)=W3/NA
      IF(WR.EQ.1.0) THEN
        WRITE(2,*) FF(7,NCASE),FF(8,NCASE),FF(9,NCASE)
      ELSE
        WRITE(3,*) FF(7,NCASE),FF(8,NCASE),FF(9,NCASE)
      END IF
      RETURN
    END
C***** THIS IS A GENERAL FUNCTION TO GET A MAX. VALUE FOR AN ARRAY
    FUNCTION FMAX(B1,MIN)
    DIMENSION B1(60)
    FMAX=-1.0E20
    DO 10 NCASE=1,MIN
      IF(FMAX.LT.B1(NCASE)) FMAX=B1(NCASE)
10   CONTINUE
    RETURN

```



```

      END
C***** THIS IS A GENERAL FUNCTION TO GET A MIN. VALUE OF AN ARRAY
      FUNCTION FMIN(B1,MIN)
      DIMENSION B1(60)
      FMIN=1.0E20
      DO 10 NCASE=1,MIN
      IF (FMIN.GT.B1 (NCASE) ) FMIN=B1 (NCASE)
10    CONTINUE
      RETURN
      END
C***** THIS SUBROUTINE PRODUCES A 2-D DRAWING FOR ALL THE NONDIMENSION-
C***** LIZED NINE VALUES OF VELOCITY,TURBULENCE INTENISITY AND REYNOLDS
C***** STRESSES IN BOTH COORDINATES
      SUBROUTINE NIDRA (FF,MIN,P1,I1,CD,RAKM)
      DIMENSION FF(9,60),WW(9,60),TT(9,60),B1(60),B2(60),X1(9),Y1(9)
1    ,P1(60),QTA(20)
      CALL WINDOW(2)
      CALL WINDO2(0.0,360.,0.0,270.)
      CALL PICCLE
      CALL PENSEL(1,0.0,0)
      CALL MOVTO2(20.,20.)
      CALL LINBY2(255.,0.0)
      CALL LINBY2(0.0,170.)
      CALL LINBY2(-255.,0.0)
      CALL LINBY2(0.0,-170.)
      CALL MOVTO2(105.,30.)
      CALL LINBY2(0.0,160.0)
      CALL MOVTO2(190.,30.0)
      CALL LINBY2(0.0,160.)
      CALL MOVTO2(100.,30.)
      CALL LINBY2(10.,0.0)
      CALL MOVTO2(185.,30.)
      CALL LINBY2(10.0,0.0)
      CALL CHASWI(1)
      CALL CHASIZ(1.5,1.5)
      CALL MOVTO2(240.,16.)
      CALL CHAA1(RAKM,6)
      CALL CHASWI(0)
      CALL CHASWI(1)
      CALL CHASIZ(2,1.5)
      CALL ITALIC(9.0)
      CALL MOVTO2(41.25,195.)
      CALL CHAHOL(13HA*L X I A L*.)
      CALL MOVTO2(126.25,195.)
      CALL CHAHOL(23HT*L A N G E N T I A L*.)
      CALL MOVTO2(211.25,195.)
      CALL CHAHOL(15HR*L A D I A L*.)
      CALL CHAANG(90.0)
      CALL MOVTO2(15.0,147.45)
      CALL PENSEL(2,0.0,0)
      CALL CHAHOL(23HV*L E L O C I T I E S*.)
      CALL MOVTO2(15.0,90.833332)
      CALL PENSEL(4,0.0,0)
      CALL CHAHOL(23HT*L U R B U L E N C E*.)
      CALL MOVTO2(15.0,34.166666)

```



```

CALL PENSEL(3,0.0,0)
CALL CHAHOL(28HR*L E Y N O L D S *US*LT*.)
CALL CHAANG(0.0)
CALL CHASWI(0)
CALL CHASWI(1)
CALL CHASIZ(3.0,2.0)
CALL ITALIC(12.0)
CALL MOVTO2(87.0,26.5)
CALL PENSEL(1,0.0,0)
CALL CHAHOL(51HF*LIG *UF*LOW FIELD QUANTITIES AT THE RELATI
IVE*.)
CALL MOVTO2(95.0,22.5)
IF(CD.EQ.1.0)THEN
CALL CHAHOL(40H*L TURBOMACHINERY FRAME OF REFERENCE*.)
END IF
IF(CD.EQ.2)THEN
CALL CHAHOL(36H*L STREAMWISE FRAME OF REFERENCE*.)
END IF
CALL CHASWI(0)
DO 50 I=1,I1
50 B2(I)=P1(I)
DO 30 KK=1,9
IF(KK.LT.4)CALL PENSEL(2,0.0,0)
IF(KK.GT.3.AND.KK.LT.7)CALL PENSEL(4,0.0,0)
IF(KK.GT.6)CALL PENSEL(3,0.0,0)
DO 40 NCASE=1,I1
40 B1(NCASE)=FF(KK,P1(NCASE))
B1MAX=FMAX(B1,I1)
B1MIN=FMIN(B1,I1)
DO 60 K1K=1,3
X1(3*K1K-2)=40.
X1(3*K1K-1)=125.
X1(3*K1K)=210.
Y1(K1K)=148.333
Y1(K1K+3)=91.666
60 Y1(K1K+6)=35.0
CALL CHASIZ(2.,2.)
CALL AXIPOS(1,X1(KK),Y1(KK),35.,1)
CALL AXIPOS(1,X1(KK),Y1(KK),35.,2)
CALL AXISCA(3,2,1.0,REAL(MIN),1)
CALL AXISCA(3,10,B1MIN,B1MAX,2)
CALL AXIDRA(+1,0,1)
IF(KK.LT.4.OR.KK.GT.6)THEN
CALL AXIDRA(-1,-1,2)
END IF
WRITE(4,*)'*****'
WRITE(4,*)'KK= ',KK
WRITE(4,*)'CD= ',CD
IF(CD.EQ.1.0)WRITE(4,*)'TURBOMACHINERY RESULTS'
IF(CD.EQ.2.0)WRITE(4,*)'STREAMWISE RESULTS'
WRITE(4,*)(B2(LDT),B1(LDT),LDT=1,I1)

CALL GRAPOL(B2,B1,I1)
CALL CHASWI(1)
CALL CHASIZ(1.5,1.5)

```



```

CALL GRASYM(B2,B1,I1,8,0)
CALL CHASWI (0)
CALL ITALIC (0.0)
RR1=REAL (MIN) /2
RR2=- ( (B1MAX-B1MIN) /12.0)+B1MIN
CALL GRAMOV (RR1,RR2)
CALL CHAHOL (3H0*.)
CALL GRAMOV (1.0,RR2)
CALL CHASWI (1)
CALL CHASI Z (2.1,2.1)
CALL CHAHOL (6HP.S*.)
CALL GRAMOV (REAL (MIN) ,RR2)
CALL CHAHOL (6HS.S*.)
CALL CHASWI (0)
CALL CHASWI (1)
CALL CHASI Z (2.,2.)
IF (KK.EQ.1.AND.CD.EQ.1.0) THEN
RR3= (B1MAX-B1MIN) /20.0+B1MAX
CALL GRAMOV (REAL (MIN) ,RR3)
CALL CHAHOL (10HU/V*L *.)
CALL GRAMOV (REAL (MIN) ,RR3)
CALL ITALIC (25.0)
CALL CHASWI (1)
CALL CHASI Z (1.5,1.5)
CALL CHAHOL (13H *LTOT *.)
CALL CHASWI (0)
CALL ITALIC (0.0)
END IF
IF (KK.EQ.2.AND.CD.EQ.1.0) THEN
RR3= (B1MAX-B1MIN) /20.0+B1MAX
CALL GRAMOV (REAL (MIN) ,RR3)
CALL CHAHOL (10HV/V*L *.)
CALL GRAMOV (REAL (MIN) ,RR3)
CALL ITALIC (25.0)
CALL CHASWI (1)
CALL CHASI Z (1.5,1.5)
CALL CHAHOL (13H *LTOT *.)
CALL CHASWI (0)
CALL ITALIC (0.0)
END IF
IF (KK.EQ.3.AND.CD.EQ.1.0) THEN
RR3= (B1MAX-B1MIN) /20.0+B1MAX
CALL GRAMOV (REAL (MIN) ,RR3)
CALL CHAHOL (10HW/V*L *.)
CALL GRAMOV (REAL (MIN) ,RR3)
CALL ITALIC (25.0)
CALL CHASI Z (1.5,1.5)
CALL CHAHOL (13H *LTOT *.)
CALL CHASWI (0)
CALL ITALIC (0.0)
END IF
IF (KK.EQ.4.AND.CD.EQ.1.0) THEN
RR3= (B1MAX-B1MIN) /20.0
RR4=RR3+B1MAX
RR5=RR4+RR3

```



```

RR6=RR5+RR3/2.0
CALL GRAMOV (REAL (MIN) ,RR4)
CALL CHAHOL (13HU /U*L      8*.)
CALL ITALIC (25.0)
CALL CHASWI (1)
CALL CHASIZ (1.5,1.5)
CALL GRAMOV (REAL (MIN) ,RR4)
CALL CHAHOL (16H      *LLOC  *.)
CALL ITALIC (0.0)
RR7=REAL (MIN)+RR3*2.0
CALL GRAMOV (RR7,RR5)
CALL CHAHOL (3H'*. )
RR8=RR7+RR3*2.0
CALL GRAMOV (RR8,RR6)
CALL CHAHOL (4H 2*.)
END IF
IF (KK.EQ.5.AND.CD.EQ.1.0) THEN
RR3= (B1MAX-B1MIN)/20.0
RR4=RR3+B1MAX
RR5=RR4+RR3
RR6=RR5+RR3/2.0
CALL GRAMOV (REAL (MIN) ,RR4)
CALL CHAHOL (13HV /V*L      8*.)
CALL ITALIC (25.0)
CALL CHASWI (1)
CALL CHASIZ (1.5,1.5)
CALL GRAMOV (REAL (MIN) ,RR4)
CALL CHAHOL (16H      *LLOC  *.)
CALL ITALIC (0.0)
RR7=REAL (MIN)+RR3*2.0
CALL GRAMOV (RR7,RR5)
CALL CHAHOL (3H'*. )
RR8=RR7+RR3*2.0
CALL GRAMOV (RR8,RR6)
CALL CHAHOL (4H 2*.)
END IF
IF (KK.EQ.6.AND.CD.EQ.1.0) THEN
RR3= (B1MAX-B1MIN)/20.0
RR4=RR3+B1MAX
RR5=RR4+RR3
RR6=RR3/2.0+RR5
CALL GRAMOV (REAL (MIN) ,RR4)
CALL CHAHOL (13HW /V*L      8*.)
CALL ITALIC (25.0)
CALL CHASWI (1)
CALL CHASIZ (1.5,1.5)
CALL GRAMOV (REAL (MIN) ,RR4)
CALL CHAHOL (16H      *LLOC  *.)
CALL ITALIC (0.0)
RR7=REAL (MIN)+RR3*2.0
CALL GRAMOV (RR7,RR5)
CALL CHAHOL (3H'*. )
RR8=RR7+RR3*2.0
CALL GRAMOV (RR8,RR6)
CALL CHAHOL (5H 2*.)

```



```

END IF
IF (KK.EQ.7.AND.CD.EQ.1.0) THEN
RR3= (B1MAX-B1MIN)/20.0+B1MAX
CALL GRAMOV (REAL (MIN),RR3)
CALL CHAHOL (12HUV/@V*L   *.)
CALL GRAMOV (REAL (MIN),RR3)
CALL ITALIC (25.0)
CALL CHASWI (1)
CALL CHASIZ (1.5,1.5)
CALL CHAHOL (17H          *LTOT   *.)
CALL CHASWI (0)
CALL ITALIC (0.0)
END IF
IF (KK.EQ.8.AND.CD.EQ.1.0) THEN
RR3= (B1MAX-B1MIN)/20.0+B1MAX
CALL GRAMOV (REAL (MIN),RR3)
CALL CHAHOL (12HUW/@V*L   *.)
CALL GRAMOV (REAL (MIN),RR3)
CALL ITALIC (25.0)
CALL CHASWI (1)
CALL CHASIZ (1.5,1.5)
CALL CHAHOL (17H          *LTOT   *.)
CALL CHASWI (0)
CALL ITALIC (0.0)
END IF
IF (KK.EQ.9.AND.CD.EQ.1.0) THEN
RR3= (B1MAX-B1MIN)/20.0+B1MAX
CALL GRAMOV (REAL (MIN),RR3)
CALL CHAHOL (12HVV/@V*L   *.)
CALL GRAMOV (REAL (MIN),RR3)
CALL ITALIC (25.0)
CALL CHASIZ (1.5,1.5)
CALL CHAHOL (17H          *LTOT   *.)
CALL CHASWI (0)
CALL ITALIC (0.0)
END IF
IF (KK.EQ.1.AND.CD.EQ.2.0) THEN
RR3= (B1MAX-B1MIN)/20.0+B1MAX
CALL GRAMOV (REAL (MIN),RR3)
CALL CHAHOL (11HUS/U*L   *.)
CALL GRAMOV (REAL (MIN),RR3)
CALL ITALIC (25.0)
CALL CHASWI (1)
CALL CHASIZ (1.5,1.5)
CALL CHAHOL (16H          *LSOMAX *.)
CALL CHASWI (0)
CALL ITALIC (0.0)
END IF
IF (KK.EQ.2.AND.CD.EQ.2.0) THEN
RR3= (B1MAX-B1MIN)/20.0+B1MAX
CALL GRAMOV (REAL (MIN),RR3)
CALL CHAHOL (11HUN/U*L   *.)
CALL GRAMOV (REAL (MIN),RR3)
CALL ITALIC (25.0)
CALL CHASWI (1)

```



```

CALL CHASIZ (1.5,1.5)
CALL CHAHOL (16H      *LSOMAX *.)
CALL CHASWI (0)
CALL ITALIC (0.0)
END IF
IF (KK.EQ.3.AND.CD.EQ.2.0) THEN
RR3= (B1MAX-B1MIN)/20.0+B1MAX
CALL GRAMOV (REAL (MIN),RR3)
CALL CHAHOL (10HW/U*L      *.)
CALL GRAMOV (REAL (MIN),RR3)
CALL ITALIC (25.0)
CALL CHASIZ (1.5,1.5)
CALL CHAHOL (16H      *LSOMAX *.)
CALL CHASWI (0)
CALL ITALIC (0.0)
END IF
IF (KK.EQ.4.AND.CD.EQ.2.0) THEN
RR3= (B1MAX-B1MIN)/20.0
RR4=RR3+B1MAX
RR5=RR4+RR3
RR6=RR5+RR3/2.0
CALL GRAMOV (REAL (MIN),RR4)
CALL CHAHOL (15HUS /US*L      8*.)
CALL ITALIC (25.0)
CALL CHASWI (1)
CALL CHASIZ (1.5,1.5)
CALL GRAMOV (REAL (MIN),RR4)
CALL CHAHOL (20H      *LLOC      *.)
CALL ITALIC (0.0)
RR7=REAL (MIN)+RR3*2.0
CALL GRAMOV (RR7,RR5)
CALL CHAHOL (3H'*. )
RR8=RR7+RR3*2.0
CALL GRAMOV (RR8,RR6)
CALL CHAHOL (5H  2*.)
END IF
IF (KK.EQ.5.AND.CD.EQ.2.0) THEN
RR3= (B1MAX-B1MIN)/20.0
RR4=RR3+B1MAX
RR5=RR4+RR3
RR6=RR5+RR3/2.0
CALL GRAMOV (REAL (MIN),RR4)
CALL CHAHOL (15HUN /UN*L      8*.)
CALL ITALIC (25.0)
CALL CHASWI (1)
CALL CHASIZ (1.5,1.5)
CALL GRAMOV (REAL (MIN),RR4)
CALL CHAHOL (20H      *LLOC      *.)
CALL ITALIC (0.0)
RR7=REAL (MIN)+RR3*2.0
CALL GRAMOV (RR7,RR5)
CALL CHAHOL (3H'*. )
RR8=RR7+RR3*2.0
CALL GRAMOV (RR8,RR6)
CALL CHAHOL (5H  2*.)

```



```

END IF
IF (KK.EQ.6.AND.CD.EQ.2.0) THEN
RR3= (B1MAX-B1MIN)/20.0
RR4=RR3+B1MAX
RR5=RR4+RR3
RR6=RR3/2.0+RR5
CALL GRAMOV (REAL (MIN),RR4)
CALL CHAHOL (13HW /W*L      8*.)
CALL ITALIC (25.0)
CALL CHASWI (1)
CALL CHASI Z (1.5,1.5)
CALL GRAMOV (REAL (MIN),RR4)
CALL CHAHOL (16H      *LSOMAX *.)
CALL ITALIC (0.0)
RR7=REAL (MIN)+RR3*2.0
CALL GRAMOV (RR7,RR5)
CALL CHAHOL (3H'*. )
RR8=RR7+RR3*2.0
CALL GRAMOV (RR8,RR6)
CALL CHAHOL (5H  2*.)
END IF
IF (KK.EQ.7.AND.CD.EQ.2.0) THEN
RR3= (B1MAX-B1MIN)/20.0+B1MAX
CALL GRAMOV (REAL (MIN),RR3)
CALL CHAHOL (14HUSUN/@U*L    *.)
CALL GRAMOV (REAL (MIN),RR3)
CALL ITALIC (25.0)
CALL CHASWI (1)
CALL CHASI Z (1.5,1.5)
CALL CHAHOL (20H      *LSOMAX *.)
CALL CHASWI (0)
CALL ITALIC (0.0)
END IF
IF (KK.EQ.8.AND.CD.EQ.2.0) THEN
RR3= (B1MAX-B1MIN)/20.0+B1MAX
CALL GRAMOV (REAL (MIN),RR3)
CALL CHAHOL (13HUSW/@U*L    *.)
CALL GRAMOV (REAL (MIN),RR3)
CALL ITALIC (25.0)
CALL CHASWI (1)
CALL CHASI Z (1.5,1.5)
CALL CHAHOL (20H      *LSOMAX *.)
CALL CHASWI (0)
CALL ITALIC (0.0)
END IF
IF (KK.EQ.9.AND.CD.EQ.2.0) THEN
RR3= (B1MAX-B1MIN)/20.0+B1MAX
CALL GRAMOV (REAL (MIN),RR3)
CALL CHAHOL (13HUNW/@U*L    *.)
CALL GRAMOV (REAL (MIN),RR3)
CALL ITALIC (25.0)
CALL CHASI Z (1.5,1.5)
CALL CHAHOL (20H      *LSOMAX *.)
CALL CHASWI (0)
CALL ITALIC (0.0)

```



```

END IF
IF (KK.GE.4.AND.KK.LE.6) GO TO 300
GO TO 30
300 CLMD=0.0
DO 320 IKL=1,I1
320 CLMD=CLMD+B1(IKL)
CLMD=CLMD/I1
DO 310 IJK4=7,16
310 QTA(IJK4-6)=ABS(B1(IJK4)-CLMD)
QQTA=FMAX(QTA,10)
DO 330 IIM=1,10
IF (QQTA.EQ.QTA(IIM)) ITAL=IIM
330 CONTINUE
CALL PENSEL(4,0.0,0)
IF (B1(ITAL+6)-CLMD).LT.0.0) THEN
CALL AXIPOS(1,X1(KK),Y1(KK),35.,2)
CALL AXISCA(3,10,B1MIN,B1MAX,2)
CALL AXIDRA(-1,-1,2)
ELSE
CALL AXIPOS(1,X1(KK),Y1(KK),35.,2)
CALL AXISCA(3,10,B1MIN,B1MAX,2)
CALL AXIDRA(-1,-1,2)
END IF
30 CONTINUE
RETURN
END
C***** THIS SUBROUTINE NONDIMENSIONALIZES THE VELOCITY AND THE REYNOLDS
C***** STRESS IN BOTH COORDINATES
SUBROUTINE NONDIM(CC,MIN,P1,I1,CD)
DIMENSION CC(9,60),TT(9,60),WW(9,60),CB(60),P1(60)
IF (CD.EQ.1.0) GO TO 60
DO 10 I=1,I1
10 CB(I)=CC(1,P1(I))
CCMAX=FMAX(CB,I1)
DO 20 I=1,3
DO 30 J=1,I1
30 CC(I,P1(J))=CC(I,P1(J))/CCMAX
20 CONTINUE
GO TO 70
60 TVV=0.0
DO 80 J=1,I1
80 TVV=TVV+SQRT(CC(1,P1(J))**2+CC(2,P1(J))**2+CC(3,P1(J))**2)
TVV=TVV/I1
DO 90 I=1,3
DO 100 J=1,I1
100 CC(I,P1(J))=CC(I,P1(J))/TVV
90 CONTINUE
70 RHO=1.2
IF (CD.EQ.2.0) CC1=(CCMAX**2)*RHO
IF (CD.EQ.1.0) CC1=(TVV**2)*RHO
DO 40 I=7,9
DO 50 J=1,I1
50 CC(I,P1(J))=CC(I,P1(J))/CC1
40 CONTINUE
RETURN
END

```


APPENDIX (11)

The main set of equations for the hot-wire response may be written as:

$$(Q_j + q_j)^2 = \sum_{i=1}^3 K_{ji}^2 (X_i + x_i)^2 \quad j = 1, 2, 3$$

or

$$(Q_j + q_j)^2 = \left(K_{j1}^2 (U + u)^2 + K_{j2}^2 (V + v)^2 + K_{j3}^2 (W + w)^2 \right)$$

For wire (1) the equation may be re-written as:

$$(Q + q_1)^2 = K_{11}^2 (U + u)^2 \left(1 + \frac{K_{12}^2 (V+v)^2}{K_{11}^2 (U+u)^2} + \frac{K_{13}^2 (W+w)^2}{K_{11}^2 (U+u)^2} \right) \quad \dots A1$$

$$\begin{aligned} (Q_1 + q_1) &= K_{11}^2 (U + u) (1 + \xi)^{\frac{1}{2}} \\ &= K_{11}^2 (U + u) (1 + \frac{1}{2}\xi - \frac{1}{8}\xi^2 + \dots \epsilon(o)) \end{aligned} \quad \dots A1.1$$

And considering

$$1/(X + x)^2 = 1/X^2 (1 - 2 \frac{x}{X} + \dots \epsilon(o)) \quad \dots A1.2$$

Equation (A1) can be expanded binomially using A1.1, A1.2 to give:

$$\begin{aligned} (Q_1/U + q_1/U) &= K_{11}^2 + \frac{1}{2} \frac{K_{12}^2}{K_{11}^2} \left(\frac{V}{U} \right)^2 + K_{21}^2 \left(\frac{V}{U} \right) \left(\frac{v}{u} \right) \\ &+ \dots - K_{13}^2 \left(\frac{W}{U} \right)^2 \left(\frac{u^2}{U^2} \right) - \frac{1}{2} K_{12}^2 \left(\frac{V}{U} \right)^4 \left(\frac{u}{U} \right) \\ &- \frac{1}{2} \frac{K_{12}^2 K_{13}^2}{K_{11}^2} \left(\frac{W}{U} \right)^2 \left(\frac{V}{U} \right)^2 \left(\frac{u}{U} \right) - \frac{1}{2} \frac{K_{13}^4}{K_{11}^2} \left(\frac{W}{U} \right)^4 \left(\frac{u}{U} \right) + \epsilon(o) \end{aligned} \quad \dots A2$$

Considering only time averaged conditions we obtain:

$$\begin{aligned} (Q_1/U) &= K_{11}^2 + \frac{1}{2} K_{12}^2 \left(\frac{V}{U} \right)^2 + \frac{1}{2} K_{12}^2 \frac{\overline{v^2}}{U^2} \\ &+ \dots + K_{12}^2 \left(\frac{V}{U} \right) \frac{\overline{uv}}{U^2} - K_{12}^2 \left(\frac{V}{U} \right) \left(\frac{\overline{u^2}}{U^2} \right) \\ &+ K_{13}^2 \left(\frac{W}{U} \right) \left(\frac{\overline{uw}}{U^2} \right) - K_{13}^2 \left(\frac{W}{U} \right) \left(\frac{\overline{u^2}}{U^2} \right) \end{aligned} \quad \dots A3$$

Similarly we can obtain another two equations for Q_2/U and Q_3/U . These three equations consist of 9 unknowns:

$1/U, V/U, W/U, \overline{u^2}/U^2, \overline{v^2}/U^2, \overline{w^2}/U^2, \overline{uv}/U^2, \overline{vw}/U^2$ and $\overline{uw}/U^2$

The solution of which calls for 6 further equations. By subtracting equation A3 from equation A2 we get:

$$\begin{aligned}
(q_1/U) &= K_{12}^2 \left(\frac{V}{U}\right) \left(\frac{v}{U}\right) - K_{12}^2 \left(\frac{V}{U}\right)^2 \left(\frac{u}{U}\right) + K_{13}^2 \left(\frac{W}{U}\right) \left(\frac{w}{U}\right) \\
&+ \dots + \frac{1}{2} K_{13}^2 \left(\frac{W}{U}\right)^2 \left(\frac{u}{U}\right) - \frac{K_{12}^4}{K_{11}^2} \left(\frac{V}{U}\right)^4 \left(\frac{u}{U}\right) \quad \dots A4 \\
&- \frac{1}{2} K_{12}^2 K_{13}^2 / K_{11}^2 \left(\frac{V}{U}\right)^2 \left(\frac{W}{U}\right)^2 \left(\frac{u}{U}\right) - \frac{K_{13}^4}{K_{11}^2} \left(\frac{W}{U}\right)^4 \left(\frac{u}{U}\right)
\end{aligned}$$

By squaring and taking time averages and neglecting higher order terms we get:

$$\begin{aligned}
(\overline{q_1^2}/U^2) &= K_{12}^4 \left(\frac{V}{U}\right)^2 \left(\frac{\overline{v^2}}{U^2}\right) - 2K_{12}^4 \left(\frac{V}{U}\right)^3 \left(\frac{\overline{uv}}{U^2}\right) \\
&+ \dots + \frac{1}{16} \frac{K_{12}^6 K_{13}^2}{K_{11}^4} \left(\frac{V}{U}\right)^6 \left(\frac{W}{U}\right)^2 \left(\frac{\overline{u^2}}{U^2}\right) \\
&+ \frac{1}{64} \frac{K_{13}^8}{K_{11}^4} \left(\frac{W}{U}\right)^8 \left(\frac{\overline{u^2}}{U^2}\right) \quad \dots A5
\end{aligned}$$

In the same way we get two further equations for $\overline{q_2^2}$, $\overline{q_3^2}$.

Equation (A4) can be obtained for q_2 and q_3 and multiplying these forms of equation A4 in the sequences $q_1 q_2$, $q_2 q_3$ and $q_1 q_3$, taking time average and neglecting higher order terms, three equations for $\overline{q_1 q_2}$, $\overline{q_2 q_3}$ and $\overline{q_1 q_3}$ are obtained.

The nine non-linear equations are solved by Newton-Raphson iteration to obtain the nine unknowns. In general the set of these equations can be written in the polynomial form as:

$$f_i(X_1, X_2, \dots, X_n) = \sum_{r=1}^{m_i} C_{i,r} \left(\prod_{s=1}^n X_s^{P_{i,s,r}} \right)$$

The differentiation of the above equation can be written as:

$$\frac{\partial f_i}{\partial X_t} = \sum_{r=1}^{m_i} C_{i,r} \left(\prod_{\substack{s=1 \\ s \neq t}}^n X_s^{P_{i,s,r}} \right) P_{i,t,r} X_t^{P_{i,t,r}-1}$$

The quantities Q_1 , Q_2 , Q_3 , $\overline{q_1^2}$, $\overline{q_2^2}$, $\overline{q_3^2}$, $\overline{q_1 q_2}$, $\overline{q_2 q_3}$ and $\overline{q_1 q_3}$ are obtained by the equations,

$$Q_i = \left((E_i^2 - E_{oi}^2) / B_i \right)^{1/n_i} \quad i = 1, 2, 3$$

$$\overline{q_i^2} = \left(2 E_i / n_i B_i Q_i^{n_i-1} \right) \overline{e_i^2} \quad i = 1, 2, 3$$

$$\overline{q_i q_j} = \left(4 E_i E_j / n_i n_j B_i B_j Q_i^{n_i-1} Q_j^{n_j-1} \right) \overline{e_i e_j} \quad i = 1, 2; j = 2, 3 \text{ and } i \neq j$$

APPENDIX (12)

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PROGRAM SIGNALS ANALYSIS
INTEGER P(9,9,141)
  CHARACTER*2 CONT
COMMON A(9),DET,ICONT,NFR,IIT
DOUBLE PRECISION DF(9,9)
REAL N(3),K(2,3)
DIMENSION EO(3),B(3),E(80,3),Q(3,3),NC(9),C(9,141),F(9),X(9),DX(9)
1,EE(3,3),D(3,3)
  READ(1,*)NFR,IIT,LIN,LZZ
  READ(1,*)NMAX,ICONT,ERROR,A
  CALL CDATA (NA,EO,B,N,K,P)
10 CALL VDATA (NA,E,NCASE)
  READ(1,*)TE,TC,TW
  DO 6 I=1,3
    EO(I)=(EO(I)**2*(1+(1.75E-07+1.225E-09*TW)*TE)*(TW-TE)/(1
1+ (1.75E-07+1.225E-09*TC)))/(TW-TC))**0.5
6  B(I)=B(I)*(TW-TE)/(TW-TC)
  CALL QCALC (EE,EO,B,N,NA,E,D,LZZ,Q)
20  PRINT*,'Enter either continue or stop please...'
  READ(*,25)CONT
25  FORMAT(A2)
  IF(CONT.EQ.'CO')GO TO 30
  IF(CONT.EQ.'ST')STOP
  GO TO 20
30  CONTINUE
  CALL DSFAC (K,Q,C,NC)
  IF(LIN.NE.0)CALL LINEAR(K,Q,X)
  IF(LIN.EQ.0)READ(1,*)X
  CALL NEWTON(9,141,NC,C,P,F,DF,X,DX,NMAX,ERROR,CONV,IT,EMAX)
  CALL OUTPUT(NCASE,X,CONV,IT,EMAX)
  GO TO 10
END
SUBROUTINE DSFAC(K,Q,C,NC)
C.....SEGMENT FOR CALCULATIONS OF CONSTANTS GENERATED FROM DIRECTIONAL
C.....SENSITIVITY FACTORS
REAL K12,K22,K13,K23,K122,K222,K132,K232
REAL K(2,3),K1LSQ,K2LSQ
DIMENSION Q(3,3),C(9,141),NC(9)
COMMON A(9)
DATA ICONT/0/
ICOUNT=ICOUNT+1
NC(1)=15
NC(2)=15
NC(3)=15
NC(4)=79
NC(5)=79
NC(6)=79
NC(7)=141
NC(8)=141
NC(9)=79
DO10J=1,3
DO10I=1,3
10 C(3*(J-1)+I,2)=-Q(I,J)

```



```

IF (ICOUNT.GT.1) RETURN
C(1,1)=1.0
C(1,3)=K(2,1)**2/2*(A(2)**2)
C(1,4)=K(2,1)**2/2*(A(5))
C(1,5)=(-(K(2,1)**2))*A(2)*A(5)
C(1,6)=K(1,1)**2/2*(A(3)**2)
C(1,7)=K(1,1)**2/2*(A(6))
C(1,8)=(-(K(1,1)**2))*(A(3))*(A(9))
C(1,9)=(-(K(2,1)**4))/8*(A(2)**4)
C(1,10)=(-(K(2,1)**2)*(K(1,1)**2))/4*(A(2)**2)*(A(3)**2)
C(1,11)=(-(K(1,1)**4))/8*(A(3)**4)
C(1,12)=(-(K(2,1)**2))*(A(2)**2)*(A(4))
C(1,13)=(-(K(2,1)**2))*(A(5))*(A(4))
C(1,14)=(-(K(1,1)**2))*(A(3)**2)*(A(4))
C(1,15)=(-(K(1,1)**2))*(A(6))*A(4)
DO 20 I=2,3
EX=K(I-1,I)**2/K(4-I,I)
C(I,1)=K(4-I,I)
C(I,3)=0.5*EX*(A(2)**2)
C(I,4)=0.5*EX*(A(5))
C(I,5)=-EX*(A(2))*(A(7))
C(I,6)=0.5*1/K(4-I,I)*(A(3)**2)
C(I,7)=0.5*1/K(4-I,I)*(A(6))
C(I,8)=-1/K(4-I,I)*(A(3))*(A(9))
C(I,9)=-1/8.0/(EX**2)/K(4-I,I)*(A(2)**4)
C(I,10)=-1/4./(EX)/K(4-I,I)**2*(A(2)**2)*(A(3)**2)
C(I,11)=-1/8./K(4-I,I)**3*(A(3)**4)
C(I,12)=-EX*(A(2)**2)*(A(4))
C(I,13)=-EX*(A(4))*(A(5))
C(I,14)=-1/K(4-I,I)*A(3)**2*A(4)
20 C(I,15)=-1/K(4-I,I)*A(4)*A(6)
C(4,1)=K(2,1)**4*(A(2)**2)*A(5)
C(4,3)=0.25*K(2,1)**4*(A(2)**4)*(A(4))
C(4,4)=0.25*K(2,1)**4*(A(5)**2)*(A(4))
C(4,5)=K(1,1)**4*A(3)**2*A(6)
C(4,6)=0.25*K(1,1)**4*A(3)**4*A(4)
C(4,7)=0.25*K(1,1)**4*A(6)**2*A(4)
C(4,8)=A(4)
C(4,9)=4.0*K(2,1)**4*(A(2)**2)*A(5)*(A(4)**2)
C(4,10)=4.0*K(1,1)**4*(A(3)**2)*A(6)*A(4)**2
C(4,11)=1/64.0*(K(2,1)**8)*(A(2)**8)*A(4)
C(4,12)=1/16.0*K(2,1)**4*K(1,1)**4*A(2)**4*A(3)**4*A(4)
C(4,13)=1/64.0*K(1,1)**8*A(3)**8*A(4)
C(4,14)=-K(2,1)**4*A(2)**3*A(7)
C(4,15)=-K(2,1)**4*A(2)*A(5)*A(7)
C(4,16)=2.0*K(2,1)**2*K(1,1)**2*A(2)*A(3)*A(8)
C(4,17)=-K(1,1)**2*K(2,1)**2*A(2)*A(3)**2*A(7)
C(4,18)=-K(1,1)**2*K(2,1)**2*A(2)*A(6)*A(7)
C(4,19)=2.0*K(2,1)**2*A(2)*A(7)
C(4,20)=-4.0*K(2,1)**4*A(2)**2*A(5)*A(4)
C(4,21)=-4.0*K(1,1)**2*K(2,1)**2*A(2)*A(3)*A(4)*A(8)
C(4,22)=-0.25*K(2,1)**6*A(2)**5*A(7)
C(4,23)=-0.50*K(2,1)**4*K(1,1)**2*A(2)**3*A(3)**2*A(7)
C(4,24)=-0.25*K(1,1)**4*K(2,1)**2*A(3)**4*A(2)*A(7)
C(4,25)=0.5*K(2,1)**4*A(2)**2*A(4)*A(5)

```


$C(4,26) = -(K(1,1)**2)*(K(2,1)**2)*A(2)**2*A(3)*A(9)$
 $C(4,27) = 0.5*K(1,1)**2*K(2,1)**2*A(2)**2*A(3)**2*A(4)$
 $C(4,28) = K(1,1)**2*K(2,1)**2*0.5*A(2)**2*A(4)*A(6)$
 $C(4,29) = -(K(2,1)**2)*A(2)**2*A(4)$
 $C(4,30) = 2.0*K(2,1)**4*A(2)**3*A(4)*A(7)$
 $C(4,31) = 2.0*K(1,1)**2*K(2,1)**2*A(2)**2*A(3)*A(4)*A(9)$
 $C(4,32) = 0.125*K(2,1)**6*A(2)**6*A(4)$
 $C(4,33) = 0.25*K(2,1)**4*K(1,1)**2*A(2)**4*A(3)**2*A(4)$
 $C(4,34) = 0.125*K(1,1)**4*K(2,1)**2*A(2)**2*A(3)**4*A(4)$
 $C(4,35) = -(K(1,1)**2)*K(2,1)**2*A(3)*A(5)*A(9)$
 $C(4,36) = 0.5*K(1,1)**2*K(2,1)**2*A(3)**2*A(5)*A(4)$
 $C(4,37) = 0.5*K(1,1)**2*K(2,1)**2*A(4)*A(5)*A(6)$
 $C(4,38) = -(K(2,1)**2)*A(4)*A(5)$
 $C(4,39) = 2.0*K(2,1)**4*A(2)*A(4)*A(5)*A(7)$
 $C(4,40) = 2.0*K(1,1)**2*K(2,1)**2*A(3)*A(4)*A(5)*A(9)$
 $C(4,41) = 0.125*K(2,1)**6*A(2)**4*A(4)*A(5)$
 $C(4,42) = 0.25*K(1,1)**2*K(2,1)**4*A(2)**2*A(3)**2*A(4)*A(5)$
 $C(4,43) = 0.125*K(1,1)**4*K(2,1)**2*A(3)**4*A(4)*A(5)$
 $C(4,44) = -(K(1,1)**4)*A(3)**3*A(9)$
 $C(4,45) = -(K(1,1)**4)*A(3)*A(6)*A(9)$
 $C(4,46) = 2.0*K(1,1)**2*A(3)*A(9)$
 $C(4,47) = -(4.0*K(1,1)**2*K(2,1)**2)*A(2)*A(3)*A(4)*A(8)$
 $C(4,48) = -4.0*(K(1,1)**4)*A(3)**2*A(4)*A(6)$
 $C(4,49) = -0.25*K(1,1)**2*K(2,1)**4*A(2)**4*A(3)*A(9)$
 $C(4,50) = -0.50*K(1,1)**4*K(2,1)**2*A(2)**2*A(3)**3*A(9)$
 $C(4,51) = -0.25*K(1,1)**6*A(3)**5*A(9)$
 $C(4,52) = 0.5*K(1,1)**4*A(3)**2*A(4)*A(6)$
 $C(4,53) = -(K(1,1)**2)*A(3)**2*A(4)$
 $C(4,54) = 2.0*K(1,1)**2*K(2,1)**2*A(2)*A(3)**2*A(4)*A(7)$
 $C(4,55) = 2.0*K(1,1)**4*A(3)**3*A(4)*A(9)$
 $C(4,56) = 0.125*K(1,1)**2*K(2,1)**4*A(2)**4*A(3)**2*A(4)$
 $C(4,57) = 0.25*K(1,1)**4*K(2,1)**2*A(2)**2*A(3)**4*A(4)$
 $C(4,58) = 0.125*K(1,1)**6*A(3)**6*A(4)$
 $C(4,59) = -(K(1,1)**2)*A(6)*A(4)$
 $C(4,60) = 2.0*K(1,1)**2*K(2,1)**2*A(2)*A(4)*A(6)*A(7)$
 $C(4,61) = 2.0*K(1,1)**4*A(3)*A(4)*A(9)*A(6)$
 $C(4,62) = 0.125*K(1,1)**2*K(2,1)**4*A(2)**4*A(4)*A(6)$
 $C(4,63) = 0.25*K(1,1)**4*K(2,1)**2*A(2)**2*A(3)**2*A(4)*A(6)$
 $C(4,64) = 0.125*K(1,1)**6*A(3)**4*A(4)*A(6)$
 $C(4,65) = -4.0*(K(2,1)**2)*A(2)*A(4)*A(7)$
 $C(4,66) = -4.0*(K(1,1)**2)*A(3)*A(4)*A(9)$
 $C(4,67) = -0.25*(K(2,1)**2)*A(2)**4*A(4)$
 $C(4,68) = -0.5*K(2,1)**2*K(1,1)**2*A(2)**2*A(3)**2*A(4)$
 $C(4,69) = -0.25*K(1,1)**4*A(3)**4*A(4)$
 $C(4,70) = 8.0*K(1,1)**2*K(2,1)**2*A(2)*A(3)*A(4)**2*A(8)$
 $C(4,71) = 0.5*K(2,1)**6*A(2)**5*A(4)*A(7)$
 $C(4,72) = K(2,1)**4*K(1,1)**2*A(2)**3*A(3)**2*A(4)*A(7)$
 $C(4,73) = 0.5*K(1,1)**4*K(2,1)**2*A(2)*A(3)**4*A(4)*A(7)$
 $C(4,74) = 0.5*K(1,1)**2*K(2,1)**4*A(2)**4*A(3)*A(4)*A(9)$
 $C(4,75) = K(1,1)**4*K(2,1)**2*A(2)**2*A(3)**3*A(4)*A(9)$
 $C(4,76) = 0.5*K(1,1)**6*A(3)**5*A(4)*A(9)$
 $C(4,77) = 1/16.*K(2,1)**6*K(1,1)**2*A(2)**6*A(3)**2*A(4)$
 $C(4,78) = 1/32.0*K(1,1)**4*K(2,1)**4*A(2)**4*A(3)**4*A(4)$
 $C(4,79) = 1/16.0*K(1,1)**6*K(2,1)**2*A(2)**2*A(3)**6*A(4)$
DO 30 I=2,3


```

EX1=K(4-I,I)**2
EX2=K(I-1,I)**2
EX3=EX2/EX1
EX4=EX3*EX2
EX5=EX3/EX1
C(I+3,1)=EX4*A(2)**2*A(5)
C(I+3,3)=0.25*EX4*A(2)**4*A(4)
C(I+3,4)=0.25*EX4*A(5)**2*A(4)
C(I+3,5)=1/EX1*A(3)**2*A(6)
C(I+3,6)=0.25/EX1*A(3)**4*A(4)
C(I+3,7)=0.25/EX1*A(6)**2*A(4)
C(I+3,8)=EX1*A(4)
C(I+3,9)=4.0*EX4*A(2)**2*A(5)*A(4)**2
C(I+3,10)=4.0/EX1*A(3)**2*A(6)*A(4)**2
C(I+3,11)=1/64.0*EX4**2/EX1*A(2)**8*A(4)
C(I+3,12)=1/16.0*EX4/EX1**2*A(3)**4*A(2)**4*A(4)
C(I+3,13)=1/64.0/EX1**3*A(3)**8*A(4)
C(I+3,14)=-EX4*A(2)**3*A(7)
C(I+3,15)=-EX4*A(2)*A(5)*A(7)
C(I+3,16)=-2.0*EX3*A(2)*A(3)*A(8)
C(I+3,17)=-EX3*A(2)*A(3)**2*A(7)
C(I+3,18)=-EX3*A(2)*A(6)*A(7)
C(I+3,19)=2.0*EX2*A(2)*A(7)
C(I+3,20)=-4.0*EX4*A(2)**2*A(5)*A(4)
C(I+3,21)=-4.0*EX3*A(2)*A(3)*A(4)*A(8)
C(I+3,22)=-1.0*EX4**2/EX2*A(2)**5*A(7)
C(I+3,23)=-0.5*EX3**2*A(2)**3*A(3)**2*A(7)
C(I+3,24)=-0.25*EX5*A(2)*A(3)**4*A(7)
C(I+3,25)=0.5*EX4*A(2)**2*A(5)*A(4)
C(I+3,26)=-EX3*A(2)**2*A(3)*A(9)
C(I+3,27)=0.5*EX3*A(2)**2*A(3)**2*A(4)
C(I+3,28)=0.5*EX3*A(2)**2*A(4)*A(6)
C(I+3,29)=-EX2*A(2)**2*A(4)
C(I+3,30)=2.0*EX4*A(2)**3*A(7)*A(4)
C(I+3,31)=2.0*EX3*A(2)**2*A(3)*A(9)*A(4)
C(I+3,32)=1/8.0*EX4*EX2*A(2)**6*A(4)
C(I+3,33)=1/8.0*EX3**2*A(2)**4*A(3)**2*A(4)
C(I+3,34)=1/8.0*EX5*A(2)**2*A(3)**4*A(4)
C(I+3,35)=-EX3*A(3)*A(5)*A(9)
C(I+3,36)=0.5*EX3*A(3)**2*A(5)*A(4)
C(I+3,37)=0.5*EX3*A(4)*A(5)*A(6)
C(I+3,38)=-EX2*A(5)*A(4)
C(I+3,39)=2.0*EX4*A(2)*A(5)*A(7)*A(4)
C(I+3,40)=2.0*EX3*A(3)*A(9)*A(5)*A(4)
C(I+3,41)=1/8.0*EX4/EX1*EX2*A(2)**4*A(5)*A(4)
C(I+3,42)=0.25*EX3**2*A(3)**2*A(2)**2*A(5)*A(4)
C(I+3,43)=1/8.0*EX5*A(3)**4*A(5)*A(4)
C(I+3,44)=-1.0/EX1**2*A(3)**3*A(9)
C(I+3,45)=-1.0/EX1**2*A(3)*A(9)*A(6)
C(I+3,46)=2.0*A(3)*A(9)
C(I+3,47)=-4.0*EX3*A(2)*A(3)*A(8)*A(4)
C(I+3,48)=-4.0/EX1*A(3)**2*A(6)*A(4)
C(I+3,49)=-0.25*EX3**2*A(2)**4*A(3)*A(9)
C(I+3,50)=-0.5*EX5*A(3)**2*A(2)**2*A(9)
C(I+3,51)=-0.25*1/EX1**2*A(3)**5*A(9)

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C(I+3,52)=0.5*1/EX1*A(3)**2*A(6)*A(4)
C(I+3,53)=-1.0*A(3)**2*A(4)
C(I+3,54)=2.0*EX3*A(2)*A(3)**2*A(7)*A(4)
C(I+3,55)=2.0/EX1*A(3)**3*A(9)*A(4)
C(I+3,56)=1/8.0*EX4/EX1*A(2)**4*A(3)**2*A(4)
C(I+3,57)=0.25*EX5*A(3)**4*A(2)**2*A(4)
C(I+3,58)=1/8.0*(1/EX1**2)*A(3)**6*A(4)
C(I+3,59)=-1.0*A(4)*A(6)
C(I+3,60)=2.0*EX3*A(2)*A(7)*A(6)*A(4)
C(I+3,61)=2.0/EX1*A(3)*A(9)*A(6)*A(4)
C(I+3,62)=1/8.0*EX3**2*A(2)**4*A(6)*A(4)
C(I+3,63)=EX5*A(2)**2*A(3)**2*A(6)*A(4)
C(I+3,64)=1/8.0*(1.0/EX1**2)*A(3)**4*A(6)*A(4)
C(I+3,65)=-4.0*EX2*A(2)*A(7)*A(4)
C(I+3,66)=-4.0*A(3)*A(9)*A(4)
C(I+3,67)=-0.25*EX4*A(2)**4*A(4)
C(I+3,68)=-0.5*EX3*A(3)**2*A(2)**2*A(4)
C(I+3,69)=-0.25/EX1*A(3)**4*A(4)
C(I+3,70)=8.0*EX3*A(2)*A(3)*A(8)*A(4)**2
C(I+3,71)=0.5*EX5*EX2**2*A(2)**5*A(7)*A(4)
C(I+3,72)=EX3**2*A(2)**3*A(3)**2*A(7)*A(4)
C(I+3,73)=0.5*EX5*A(2)*A(3)**4*A(7)*A(4)
C(I+3,74)=0.5*EX3**2*A(2)**4*A(3)*A(9)*A(4)
C(I+3,75)=EX5*A(3)**3*A(2)**2*A(9)*A(4)
C(I+3,76)=0.5/EX1**2*A(3)**5*A(9)*A(4)
C(I+3,77)=1/16.0*EX3**3*A(2)**6*A(3)**2*A(4)
C(I+3,78)=1/32.0*EX5**2*EX1*A(2)**4*A(3)**4*A(4)
30 C(I+3,79)=1/16.0*EX3/EX1**2*A(3)**6*A(2)**2*A(4)
K1LSQ=K(1,1)**2
K2LSQ=K(2,1)**2
DO 40 I=2,3
EX1=K(4-I,I)**2
EX2=K(I-1,I)**2
EX3=EX2/EX1
EX4=EX3*EX2
EX5=EX3/EX1
EX6=EX2/EX1**0.5
C(I+5,1)=EX6*K2LSQ*A(2)**2*A(5)
C(I+5,3)=-EX6*K2LSQ*A(2)**3*A(7)
C(I+5,4)=-EX6*K2LSQ*A(2)*A(5)*A(7)
C(I+5,5)=EX6/EX2*K2LSQ*A(3)*A(2)*A(8)
C(I+5,6)=-0.5*EX6/EX2*A(2)*A(3)**2*A(7)*K2LSQ
C(I+5,7)=-0.5*EX6/EX2*K2LSQ*A(2)*A(6)*A(7)
C(I+5,8)=EX1**0.5*K2LSQ*A(2)*A(7)
C(I+5,9)=-1.5*EX6*K2LSQ*A(2)**2*A(5)*A(4)
C(I+5,10)=-2.0/EX1**0.5*A(2)*K2LSQ*A(3)*A(8)*A(4)
C(I+5,11)=-1/8.*EX4/EX1**0.5*K2LSQ*A(2)**5*A(7)
C(I+5,12)=-0.25*EX3/EX1**0.5*K2LSQ*A(3)**2*A(2)**3*A(7)
C(I+5,13)=-1/8.0/EX1/EX1**0.5*K2LSQ*A(2)*A(3)**4*A(7)
C(I+5,14)=0.25*EX6*A(2)**4*A(4)
C(I+5,15)=-0.5*1.0/EX1**0.5*K2LSQ*A(2)**2*A(3)*A(9)
C(I+5,16)=0.25/EX1**0.5*K2LSQ*A(2)**2*A(3)**2*A(4)
C(I+5,17)=0.25/EX1**0.5*K2LSQ*A(2)**2*A(4)*A(6)
C(I+5,18)=-0.5*EX1**0.5*K2LSQ*A(2)**2*A(4)
C(I+5,19)=EX6*K2LSQ*A(2)**3*A(4)*A(7)

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$C(I+5,20)=1.0/EX1**0.5*K21SQ*A(2)**2*A(3)*A(9)*A(4)$
 $C(I+5,21)=1.0/16.0*EX4/EX1**0.5*K21SQ*A(2)**6*A(4)$
 $C(I+5,22)=1.0/8.0*EX3/EX1**0.5*K21SQ*A(2)**3*A(3)**2*A(4)$
 $C(I+5,23)=1/16.0/EX1/EX1**0.5*K21SQ*A(2)**2*A(3)**4*A(4)$
 $C(I+5,24)=0.25*EX6*K21SQ*A(5)**2*A(4)$
 $C(I+5,25)=-0.5/EX1**0.5*K21SQ*A(3)*A(5)*A(9)$
 $C(I+5,26)=0.25/EX1**0.5*K21SQ*A(3)**2*A(5)*A(4)$
 $C(I+5,27)=0.25/EX1**0.5*K21SQ*A(4)*A(5)*A(6)$
 $C(I+5,28)=-0.5/EX1**0.5*K21SQ*A(4)*A(5)$
 $C(I+5,29)=EX6*K21SQ*A(5)*A(2)*A(4)*A(7)$
 $C(I+5,30)=1.0/EX1**0.5*K21SQ*A(3)*A(4)*A(5)*A(9)$
 $C(I+5,31)=1/16.0/EX1**0.5*EX4*K21SQ*A(2)**4*A(4)*A(5)$
 $C(I+5,32)=1/8.0/EX1**0.5*EX3*K21SQ*A(2)**2*A(3)**2*A(4)*A(5)$
 $C(I+5,33)=1/16.0/EX1/EX1**0.5*K21SQ*A(3)**4*A(5)*A(4)$
 $C(I+5,34)=EX6*K11SQ*A(2)*A(3)*A(8)$
 $C(I+5,35)=-0.5*EX6*K11SQ*A(2)**2*A(3)*A(9)$
 $C(I+5,36)=-0.5*EX6*K11SQ*A(3)*A(5)*A(9)$
 $C(I+5,37)=1.0/EX1**0.5*K11SQ*A(3)**2*A(6)$
 $C(I+5,38)=-0.5/EX1**0.5*K11SQ*A(3)**3*A(9)$
 $C(I+5,39)=-0.5/EX1**0.5*K11SQ*A(3)*A(6)*A(9)$
 $C(I+5,40)=EX1**0.5*K11SQ*A(3)*A(9)$
 $C(I+5,41)=-2.0*EX6*K11SQ*A(2)*A(3)*A(8)*A(4)$
 $C(I+5,42)=-2.0/EX1**0.5*K11SQ*A(3)**2*A(6)*A(4)$
 $C(I+5,43)=-1/8.0*EX4/EX1**0.5*K11SQ*A(2)**4*A(3)*A(9)$
 $C(I+5,44)=-0.25*EX3/EX1**0.5*K11SQ*A(3)**3*A(2)**2*A(9)$
 $C(I+5,45)=-1/8.0/EX1/EX1**0.5*A(3)**5*A(9)$
 $C(I+5,46)=-0.5*EX6*K11SQ*A(2)*A(3)**2*A(7)$
 $C(I+5,47)=0.25*EX6*K11SQ*A(2)**2*A(3)**2*A(4)$
 $C(I+5,48)=0.25*EX6*K11SQ*A(3)**2*A(5)*A(4)$
 $C(I+5,49)=-0.5/EX1**0.5*K11SQ*A(3)**3*A(9)$
 $C(I+5,50)=0.25/EX1**0.5*K11SQ*A(3)**4*A(4)$
 $C(I+5,51)=0.25/EX1**0.5*K11SQ*A(3)**2*A(6)*A(4)$
 $C(I+5,52)=-0.5/EX1**0.5*K11SQ*A(3)**2*A(4)$
 $C(I+5,53)=EX6*K11SQ*A(2)*A(3)**2*A(7)*A(4)$
 $C(I+5,54)=1.0/EX1**0.5*K11SQ*A(3)**3*A(9)*A(4)$
 $C(I+5,55)=1/16.0/EX1**0.5*EX4*K11SQ*A(2)**4*A(3)**2*A(4)$
 $C(I+5,56)=1/8.0/EX1**0.5*EX3*K11SQ*A(3)**4*A(2)**2*A(4)$
 $C(I+5,57)=1/16.0/EX1**0.5/EX1*K11SQ*A(3)**6*A(4)$
 $C(I+5,58)=-0.5*EX6*K11SQ*A(2)*A(7)*A(6)$
 $C(I+5,59)=0.25*EX6*K11SQ*A(2)**2*A(6)*A(4)$
 $C(I+5,60)=0.25*EX6*K11SQ*A(4)*A(5)*A(6)$
 $C(I+5,61)=-0.5/EX1**0.5*K11SQ*A(3)*A(9)*A(6)$
 $C(I+5,62)=0.25/EX1**0.5*K11SQ*A(3)**2*A(6)*A(4)$
 $C(I+5,63)=0.25/EX1**0.5*K11SQ*A(6)**2*A(4)$
 $C(I+5,64)=-0.5*EX1**0.5*K11SQ*A(6)*A(4)$
 $C(I+5,65)=EX6*K11SQ*A(2)*A(7)*A(6)*A(4)$
 $C(I+5,66)=1.0/EX1**0.5*K11SQ*A(3)*A(9)*A(6)*A(4)$
 $C(I+5,67)=1/16.0*EX4/EX1**0.5*K11SQ*A(2)**4*A(6)*A(4)$
 $C(I+5,68)=0.125*EX3/EX1**0.5*K11SQ*A(2)**2*A(3)**2*A(6)*A(4)$
 $C(I+5,69)=1/16.0/EX1/EX1**0.5*K11SQ*A(3)**4*A(6)*A(4)$
 $C(I+5,70)=EX6*A(2)*A(7)$
 $C(I+5,71)=-0.5*EX6*A(2)**2*A(4)$
 $C(I+5,72)=-0.5*EX6*A(5)*A(4)$
 $C(I+5,73)=EX1**0.5*A(3)*A(9)*1/EX1$
 $C(I+5,74)=-0.5/EX1**0.5*A(3)**2*A(4)$

$C(I+5,75)=-0.5/EX1^{**0.5}*A(6)*A(4)$
 $C(I+5,76)=EX1^{**0.5}*A(4)$
 $C(I+5,77)=-2.0*EX6*A(2)*A(7)*A(4)$
 $C(I+5,78)=-2.0/EX1^{**0.5}*A(3)*A(9)*A(4)$
 $C(I+5,79)=-.125*EX4/EX1^{**0.5}*A(2)^{**4}*A(4)$
 $C(I+5,80)=-.25*EX3/EX1^{**0.5}*A(3)^{**2}*A(2)^{**2}*A(4)$
 $C(I+5,81)=-.125/EX1/EX1^{**0.5}*A(3)^{**4}*A(4)$
 $C(I+5,82)=-2.0*EX6*K2LSQ*A(2)^{**2}*A(5)*A(4)$
 $C(I+5,83)=EX6*K2LSQ*A(2)^{**3}*A(7)*A(4)$
 $C(I+5,84)=EX6*K2LSQ*A(2)*A(5)*A(7)*A(4)$
 $C(I+5,85)=-2.0/EX1^{**0.5}*K2LSQ*A(2)*A(3)*A(8)*A(4)$
 $C(I+5,86)=1.0/EX1^{**0.5}*K2LSQ*A(2)*A(3)^{**2}*A(7)*A(4)$
 $C(I+5,87)=1.0/EX1^{**0.5}*K2LSQ*A(2)*A(6)*A(7)*A(4)$
 $C(I+5,88)=-2.0*EX1^{**0.5}*K2LSQ*A(2)*A(7)*A(4)$
 $C(I+5,89)=4.0*EX6*K2LSQ*A(2)^{**2}*A(5)*A(4)^{**2}$
 $C(I+5,90)=4.0/EX1^{**0.5}*K2LSQ*A(2)*A(3)*A(8)*A(4)^{**2}$
 $C(I+5,91)=0.25*EX4/EX1^{**0.5}*A(2)^{**5}*A(7)*A(4)*K2LSQ$
 $C(I+5,92)=0.5*EX3/EX1^{**0.5}*K2LSQ*A(2)^{**3}*A(3)^{**2}*A(7)*A(4)$
 $C(I+5,93)=0.25/EX1/EX1^{**0.5}*K2LSQ*A(3)^{**4}*A(2)*A(7)*A(4)$
 $C(I+5,94)=-2.0*EX6*K1LSQ*A(3)*A(2)*A(8)*A(4)$
 $C(I+5,95)=EX6*K1LSQ*A(3)*A(2)^{**2}*A(9)*A(4)$
 $C(I+5,96)=EX6*K1LSQ*A(3)*A(5)*A(9)*A(4)$
 $C(I+5,97)=-2.0/EX1^{**0.5}*K1LSQ*A(3)^{**2}*A(6)*A(4)$
 $C(I+5,98)=1.0/EX1^{**0.5}*K1LSQ*A(3)^{**3}*A(9)*A(4)$
 $C(I+5,99)=1.0/EX1^{**0.5}*K1LSQ*A(3)*A(6)*A(9)*A(4)$
 $C(I+5,100)=-2.0*EX1^{**0.5}*K1LSQ*A(3)*A(9)*A(4)$
 $C(I+5,101)=4.0*EX6*K1LSQ*A(2)*A(3)*A(8)*A(4)^{**2}$
 $C(I+5,102)=4.0/EX1^{**0.5}*K1LSQ*A(3)^{**2}*A(6)*A(4)^{**2}$
 $C(I+5,103)=0.25*EX4/EX1^{**0.5}*K1LSQ*A(2)^{**4}*A(3)*A(9)*A(4)$
 $C(I+5,104)=0.5*EX3/EX1^{**0.5}*K1LSQ*A(3)^{**3}*A(2)^{**2}*A(9)*A(4)$
 $C(I+5,105)=0.25/EX1/EX1^{**0.5}*K1LSQ*A(3)^{**5}*A(9)*A(4)$
 $C(I+5,106)=-0.125*EX6*K2LSQ^{**2}*A(2)^{**5}*A(7)$
 $C(I+5,107)=1/16.0*EX6*K2LSQ^{**2}*A(2)^{**6}*A(4)$
 $C(I+5,108)=1/16.0*EX6*K2LSQ^{**2}*A(2)^{**4}*A(4)*A(5)$
 $C(I+5,109)=-.125/EX1^{**0.5}*K2LSQ^{**2}*A(2)^{**4}*A(3)*A(9)$
 $C(I+5,110)=1/16.0/EX1^{**0.5}*K2LSQ^{**2}*A(2)^{**4}*A(3)^{**2}*A(4)$
 $C(I+5,111)=1/16.0/EX1^{**0.5}*K2LSQ^{**2}*A(2)^{**4}*A(6)*A(4)$
 $C(I+5,112)=-0.125*EX1^{**0.5}*K2LSQ^{**2}*A(2)^{**4}*A(4)$
 $C(I+5,113)=0.25*EX6*K2LSQ^{**2}*A(2)^{**5}*A(7)*A(4)$
 $C(I+5,114)=0.25/EX1^{**0.5}*K2LSQ^{**2}*A(3)*A(2)^{**4}*A(9)*A(4)$
 $C(I+5,115)=1/64.0*EX4/EX1^{**0.5}*K2LSQ^{**2}*A(2)^{**8}*A(4)$
 $C(I+5,116)=1/32.0*EX3/EX1^{**0.5}*K2LSQ^{**2}*A(2)^{**6}*A(3)^{**2}*A(4)$
 $C(I+5,117)=1/64.0/EX1/EX1^{**0.5}*K2LSQ^{**2}*A(2)^{**4}*A(3)^{**4}*A(4)$
 $C(I+5,118)=-0.25*EX6*K1LSQ*K2LSQ*A(2)^{**3}*A(3)^{**2}*A(7)$
 $C(I+5,119)=0.125*EX6*K1LSQ*K2LSQ*A(2)^{**4}*A(3)^{**2}*A(4)$
 $C(I+5,120)=0.125*EX6*K1LSQ*K2LSQ*A(2)^{**2}*A(3)^{**2}*A(5)*A(4)$
 $C(I+5,121)=-.25/EX1^{**0.5}*K1LSQ*K2LSQ*A(2)^{**2}*A(3)^{**3}*A(9)$
 $C(I+5,122)=1/8.0/EX1^{**0.5}*K1LSQ*K2LSQ*A(2)^{**2}*A(3)^{**4}*A(4)$
 $C(I+5,123)=1/8.0/EX1^{**0.5}*K1LSQ*K2LSQ*A(2)^{**2}*A(3)^{**2}*A(6)*A(4)$
 $C(I+5,124)=-0.25*EX1^{**0.5}*K1LSQ*K2LSQ*A(2)^{**2}*A(3)^{**2}*A(4)$
 $C(I+5,125)=0.5*EX6*K1LSQ*K2LSQ*A(2)^{**3}*A(3)^{**2}*A(7)*A(4)$
 $C(I+5,126)=0.5/EX1^{**0.5}*K1LSQ*K2LSQ*A(2)^{**2}*A(3)^{**2}*A(9)*A(4)$
 $C(I+5,127)=1/32.0*EX4/EX1^{**0.5}*K1LSQ*K2LSQ*A(2)^{**6}*A(3)^{**2}*A(4)$
 $C(I+5,128)=1/16.0*EX3/EX1^{**0.5}*K1LSQ*K2LSQ*A(2)^{**4}*A(3)^{**4}*A(4)$
 $C(I+5,129)=1/32.0/EX1/EX1^{**0.5}*K1LSQ*K2LSQ*A(2)^{**2}*A(3)^{**6}*A(4)$

$C(I+5,130) = -.125 * EX6 * K11SQ^{**2} * A(2) * A(3)^{**4} * A(7)$
 $C(I+5,131) = 1/16. * EX6 * K11SQ^{**2} * A(2)^{**2} * A(3)^{**4} * A(4)$
 $C(I+5,132) = 1/16. * EX6 * K11SQ^{**2} * A(3)^{**4} * A(5) * A(4)$
 $C(I+5,133) = -1/8.0 / EX1^{**0.5} * K11SQ^{**2} * A(3)^{**5} * A(9)$
 $C(I+5,134) = 1/16.0 / EX1^{**0.5} * K11SQ^{**2} * A(3)^{**6} * A(4)$
 $C(I+5,135) = 1/16.0 / EX1^{**0.5} * K11SQ^{**2} * A(3)^{**4} * A(4) * A(6)$
 $C(I+5,136) = -1/8.0 * EX1^{**0.5} * K11SQ^{**2} * A(3)^{**4} * A(4)$
 $C(I+5,137) = 0.25 * EX6 * K11SQ^{**2} * A(3)^{**4} * A(2) * A(7) * A(4)$
 $C(I+5,138) = 0.25 / EX1^{**0.5} * K11SQ^{**2} * A(3)^{**5} * A(9) * A(4)$
 $C(I+5,139) = 1/64.0 / EX1^{**0.5} * EX4 * K11SQ^{**2} * A(3)^{**4} * A(2)^{**4} * A(4)$
 $C(I+5,140) = 1/32.0 * EX3 / EX1^{**0.5} * K11SQ^{**2} * A(3)^{**6} * A(2)^{**2} * A(4)$
40 $C(I+5,141) = 1/64.0 / EX1 / EX1^{**0.5} * K11SQ^{**2} * A(3)^{**8} * A(4)$
 $K12 = K(1,2)$
 $K22 = K(2,2)$
 $K13 = K(1,3)$
 $K23 = K(2,3)$
 $K122 = K(1,2)^{**2}$
 $K222 = K(2,2)^{**2}$
 $K132 = K(1,3)^{**2}$
 $K232 = K(2,3)^{**2}$
 $C(9,1) = K122 / K22 * K232 / K13 * A(2)^{**2} * A(5)$
 $C(9,3) = K122 * K232 / 4.0 / K22 / K13 * A(2)^{**4} * A(4)$
 $C(9,4) = K232 * K122 / 4.0 / K22 / K13 * A(5)^{**2} * A(4)$
 $C(9,5) = 1.0 / K22 / K13 * A(3)^{**2} * A(6)$
 $C(9,6) = 1.0 / 4.0 / K22 / K13 * A(3)^{**4} * A(4)$
 $C(9,7) = 1.0 / 4.0 / K13 / K22 * A(6)^{**2} * A(4)$
 $C(9,8) = K13 * K22 * A(4)$
 $C(9,9) = 4.0 / K13 / K22 * A(3)^{**2} * A(6) * A(4)^{**2}$
 $C(9,10) = 1/64.0 / K222 / K22 / K132 / K13 * A(3)^{**8} * A(4)$
 $C(9,11) = K232^{**2} * K122^{**2} / 64.0 / K222 / K22 / K132 / K13 * A(2)^{**8} * A(4)$
 $C(9,12) = K232 * K122 / 16.0 / K132 / K13 / K222 / K22 * A(2)^{**4} * A(3)^{**4} * A(4)$
 $C(9,13) = 4.0 * K232 * K122 / K13 / K22 * A(2) * A(5) * A(4)^{**2}$
 $C(9,14) = -K122 * K232 / K22 / K13 * A(2)^{**3} * A(7)$
 $C(9,15) = -K122 * K232 / K13 / K22 * A(2) * A(7) * A(5)$
 $C(9,16) = 1 / K22 / K13 * (K122 + K232) * A(2) * A(3) * A(8)$
 $C(9,17) = -.5 / K22 / K13 * (K232 + K122) * A(2) * A(3)^{**2} * A(7)$
 $C(9,18) = -0.5 / K22 / K13 * (K232 + K122) * A(2) * A(6) * A(7)$
 $C(9,19) = ((K22 * K232 / K13) + (K13 * K122 / K22)) * A(2) * A(7)$
 $C(9,20) = ((-2 * K232 / K22 / K13) - (2 * K122 / K13 / K22)) * A(2) * A(3) * A(8) * A(4)$
 $C(9,21) = ((-K122 / 8 / K13^{**3} / K22) - (K232 / 8 / K13 / K22^{**3})) * A(3)^{**4} * A(2) * A(17)$
 $C(9,22) = ((K232^{**2} * K122 / 8 / K13^{**3} / K22) - (K12^{**4} * K232 / 8 / K22^{**3} / K13)) * A(2)^{**5} * A(7)$
 $C(9,23) = ((-K232 * K122 / 4 / K13^{**3} * K22) - (K232 * K122 / 4 / K13 / K22^{**3})) * A(3) * 3^{**2} * A(2)^{**3} * A(7)$
 $C(9,24) = -4 * K232 * K122 / K22 / K13 * A(2)^{**2} * A(5) * A(4)$
 $C(9,25) = -K232 * K122 / 2 / K22 / K13 * A(2)^{**2} * A(5) * A(4)$
 $C(9,26) = ((-K122 / 2 / K22 / K13) - (K232 / 2 / K13 / K22)) * A(3) * A(2)^{**2} * A(9)$
 $C(9,27) = ((K122 / 4 / K22 / K13) + (K232 / 4 / K22 / K13)) * A(2)^{**2} * A(3)^{**2} * A(4)$
 $C(9,28) = ((K122 / 4 / K13 / K22) + (K232 / 4 / K13 / K22)) * A(2)^{**2} * A(6) * A(4)$
 $C(9,29) = ((-K13 * K122 / 2 / K22) - (K22 * K232 / 2 / K13)) * A(2)^{**2} * A(4)$
 $C(9,30) = ((K122 / K22 / K13) + (K232 / K13 / K22)) * A(4) * A(3) * A(2)^{**2} * A(9)$
 $C(9,31) = ((K122 / 16 / K13^{**3} / K22) + (K232 / 16 / K13 / K22^{**3})) * A(2)^{**2} * A(3)^{**4} * A(4)$
 $C(9,32) = ((K23^{**4} * K122 / 16 / K22 / K13^{**3}) + (K12^{**4} * K232 / 16 / K22^{**3} / K13)) * A$

$$5(2)**6*A(4)$$

$$C(9,33) = ((K122*K232/8/K13**3/K22) + (K122*K232/8/K13/K22**3)) * A(3) ** 62 * A(2) ** 4 * A(4)$$

$$C(9,34) = 2 * K122 * K232 / K13 / K22 * A(2) ** 3 * A(7) * A(4)$$

$$C(9,35) = ((-K122/2/K22/K13) - (K232/2/K22/K13)) * A(3) * A(5) * A(9)$$

$$C(9,36) = ((K122/4/K13/K22) + (K232/4/K13/K22)) * A(3) ** 2 * A(5) * A(4)$$

$$C(9,37) = ((K122/4/K22/K13) + (K232/4/K22/K13)) * A(4) * A(5) * A(6)$$

$$C(9,38) = ((-K13*K122/2/K22) - (K22*K232/2/K13)) * A(5) * A(4)$$

$$C(9,39) = ((K122/K13/K22) + (K232/K22/K13)) * A(3) * A(9) * A(4) * A(5)$$

$$C(9,40) = ((K122/16/K22/K13**2) + (K232/16/K22**3/K13)) * A(3) ** 4 * A(5) * A(7) * A(4)$$

$$C(9,41) = ((K23**4*K122/16/K13**3/K22) + (K12**4*K232/16/K22**3/K13)) * 8A(2) ** 4 * A(5) * A(4)$$

$$C(9,42) = ((K122*K232/8/K13**3/K22) + (K122*K232/8/K22**3/K13)) * A(2) ** 92 * A(4) * A(5) * A(3) ** 2$$

$$C(9,43) = ((2*K122*K232/K13/K22)) * A(2) * A(5) * A(7) * A(4)$$

$$C(9,44) = -1/K22/K13 * A(3) ** 3 * A(9)$$

$$C(9,45) = -1/K22/K13 * A(3) * A(6) * A(9)$$

$$C(9,46) = ((K13/K22) + (K22/K13)) * A(3) * A(9)$$

$$C(9,47) = -4/K13/K22 * A(3) * A(6) * A(4)$$

$$C(9,48) = ((-.125/K13**3/K22) - (.125/K22**3/K13)) * A(3) ** 5 * A(9)$$

$$C(9,49) = ((- (K23**4) / 8 / K13**3 / K22) - (K12**4 / 8 / K22**3 / K13)) * A(2) ** 4 * A(1) * A(3) * A(9)$$

$$C(9,50) = ((-K232/4/K13**3/K22) - (K122/4/K22**3/K13)) * A(3) ** 3 * A(2) ** 21 * A(9)$$

$$C(9,51) = ((-2*K232/K13/K22) - (2*K122/K22/K13)) * A(2) * A(3) * A(8) * A(4)$$

$$C(9,52) = .5/K22/K13 * A(3) ** 2 * A(6) * A(4)$$

$$C(9,53) = ((-K13/2/K22) - (K22/2/K13)) * A(3) ** 2 * A(4)$$

$$C(9,54) = 2/K22/K13 * A(3) ** 3 * A(9) * A(4)$$

$$C(9,55) = ((K22/K13**3) + (K13/K22**3)) * A(3) ** 6 * A(4) * 1/16.$$

$$C(9,56) = ((K23**4/16/K22/K13**3) + (K12**4/16/K22**3/K13)) * A(2) ** 4 * A(23) ** 2 * A(4)$$

$$C(9,57) = ((K23**2/8/K22/K13**3) + (K122/8/K22**3/K13)) * A(2) ** 2 * A(3) ** 34 * A(4)$$

$$C(9,58) = ((K232/K13/K22) + (K122/K22/K13)) * A(2) * A(3) ** 2 * A(7) * A(4)$$

$$C(9,59) = ((-K13/2/K22) - (K22/2/K13)) * A(6) * A(4)$$

$$C(9,60) = 2/K13/K22 * A(6) * A(3) * A(9) * A(4)$$

$$C(9,61) = ((K13**3/K22) + (K22**3/K13)) * 1/16 * A(3) ** 4 * A(6) * A(4)$$

$$C(9,62) = ((K23**4/16/K13**3/K22) + (K12**4/16/K13/K22**3)) * A(2) ** 4 * A(46) * A(4)$$

$$C(9,63) = ((K122/8/K22**3/K13) + (K232/8/K22/K13**3)) * A(2) ** 2 * A(3) ** 25 * A(6) * A(4)$$

$$C(9,64) = ((K232/K13/K22) + (K122/K13/K22)) * A(4) * A(2) * A(6) * A(7)$$

$$C(9,65) = ((-2*K22/K13) - (2*K13/K22)) * A(3) * A(9) * A(4)$$

$$C(9,66) = ((-K22/8/K13**3) - (K13/8/K22**3)) * A(3) ** 4 * A(4)$$

$$C(9,67) = ((-K22*K23**4/8/K13**3) - (K13*K12**4/8/K22**3)) * A(2) ** 4 * A(6)$$

$$C(9,68) = ((-K232*K22/4/K13**2) - (K122*K13/4/K22**3)) * A(3) ** 2 * A(2) ** 27 * A(4)$$

$$C(9,69) = ((-2*K232*K22/K13) - (2*K122*K13/K22)) * A(4) * A(7) * A(4)$$

$$C(9,70) = ((.25/K22/K13**3) + (.25/K22**3/K13)) * A(3) ** 5 * A(9) * A(4)$$

$$C(9,71) = ((K23**4/4/K13**3/K22) + (K12**4/4/K22**3/K13)) * A(2) ** 4 * A(1) * A(9)$$

$$C(9,72) = ((K232/2/K22/K13**3) + (K122/2/K13/K22**3)) * A(2) ** 2 * A(3) ** 32 * A(9) * A(4)$$

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```

READ *,NCASE
IF (NCASE.LE.0) STOP 'END OF DATA'
  CALL SIGNALPLOT
  CALL WAKESELECT (NCASE,NA,E)
RETURN
END
SUBROUTINE QCALC (EE,EO,B,N,NA,E,D,LZZ,Q)
REAL N(3)
COMMON Z(9)
INTEGER A
DIMENSION EE(3,3),EO(3),B(3),E(NA,3),Q(3,3),D(3,3)
DO10J=1,3
DO10I=1,3
10 EE(I,J)=0.0
DO20A=1,NA
  EE(1,1)=EE(1,1)+E(A,1)
  EE(2,1)=EE(2,1)+E(A,2)
20 EE(3,1)=EE(3,1)+E(A,3)
  DO 30 I=1,3
30 EE(I,1)=EE(I,1)/NA
  DO 40 A=1,NA
    EE(1,2)=EE(1,2)+(E(A,1)-EE(1,1))**2
    EE(2,2)=EE(2,2)+(E(A,2)-EE(2,1))**2
    EE(3,2)=EE(3,2)+(E(A,3)-EE(3,1))**2
    EE(1,3)=EE(1,3)+(E(A,1)-EE(1,1))*(E(A,2)-EE(2,1))
    EE(2,3)=EE(2,3)+(E(A,1)-EE(1,1))*(E(A,3)-EE(3,1))
40 EE(3,3)=EE(3,3)+(E(A,2)-EE(2,1))*(E(A,3)-EE(3,1))
    DO 50 J=2,3
    DO 50 I=1,3
50 EE(I,J)=EE(I,J)/NA
    IF (LZZ.EQ.0) GO TO 60
    READ(1,*)D
    DO 12 J=1,3
12 Q(I,J)=(D(1,J)+D(2,J)*EE(J,1)+D(3,J)*EE(J,1)**2)*Z(1)
    DO 14 J=1,3
14 Q(J,2)=(D(2,J)**2+4*D(3,J)**2*EE(J,1)**2+2*D(2,J)*D(3,J)
1*EE(J,1))*EE(J,2)+D(3,J)**2*EE(J,2)**2)*Z(1)**2
    DO 16 J=2,3
16 Q(J-1,3)=(D(2,1)*D(2,J)+2*D(3,1)*D(2,J)*EE(1,1)+2*D(2
2,1)*D(3,J)*EE(J,1)+4*D(3,1)*D(3,J)*EE(1,1)*EE(J,1))
3*EE(J-1,3)+D(3,1)*D(3,J)*EE(J-1,3))*Z(1)**2
    Q(3,3)=(D(2,2)*D(2,3)+2*D(3,2)*D(2,3)*EE(2,1)+2*D(2,2)
1*D(3,3)*EE(3,1)+4*D(3,3)*D(3,2)*EE(2,1)*EE(3,1))*EE(3,3)
2+D(3,2)*D(3,3)*EE(3,3)**2)*Z(1)**2
    GO TO 70
60 Q(1,1)=(EE(1,1)**2-EO(1)**2)/B(1)**(1/N(1))*Z(1)
  Q(2,1)=(EE(2,1)**2-EO(2)**2)/B(2)**(1/N(2))*Z(1)
  Q(3,1)=(EE(3,1)**2-EO(3)**2)/B(3)**(1/N(3))*Z(1)
  Q(1,2)=(2*EE(1,1)/N(1)/B(1)/(Q(1,1)/Z(1))**(N(1)-1))**2*EE(1,2)*Z(
11)**2
  Q(2,2)=(2*EE(2,1)/N(2)/B(2)/(Q(2,1)/Z(1))**(N(2)-1))**2*EE(2,2)*Z(
11)**2
  Q(3,2)=(2*EE(3,1)/N(3)/B(3)/(Q(3,1)/Z(1))**(N(3)-1))**2*EE(3,2)*Z(
11)**2
  Q(1,3)=4*EE(1,1)*EE(2,1)/N(1)/N(2)/B(1)/B(2)/((Q(1,1)/Z(1))**(N(1)

```



```

1-1)*(Q(2,1)/Z(1))**(N(2)-1))*EE(1,3)*Z(1)**2
  Q(2,3)=4*EE(1,1)*EE(3,1)/N(1)/N(3)/B(1)/B(3)/((Q(1,1)/Z(1))**(N(1)
1-1)*(Q(3,1)/Z(1))**(N(3)-1))*EE(2,3)*Z(1)**2
  Q(3,3)=4*EE(2,1)*EE(3,1)/N(2)/N(3)/B(2)/B(3)/((Q(2,1)/Z(1))**(N(2)
1-1)*(Q(3,1)/Z(1))**(N(3)-1))*EE(3,3)*Z(1)**2
70 WRITE(2,2)
  2 FORMAT (1H1)
  WRITE (2,4) ((I,J,EE(I,J),I=1,3),J=1,3)
  4 FORMAT (5X,3HEE(,I1,1H,,I1,2H)=,G15.8)
  WRITE (2,2)
  WRITE(2,6) ((I,J,Q(I,J),I=1,3),J=1,3)
  6 FORMAT(6X,2HQ(,I1,1H,,I1,2H)=,G15.8)
  RETURN
  END
  SUBROUTINE NEWTON(N,M,NT,C,P,F,DF,X,DX,NMAX,
X
      ERROR,CONV,IT,EMAX)
02
  LOGICAL CONV
03
  DOUBLE PRECISION DF(N,N)
  COMMON Z(9),DET,ICONF,NFR,IIT
  INTEGER P(N,N,M)
  DIMENSION NT(N),C(N,M),F(N),X(N),DX(N)
  CONV=.TRUE.
06
  EO=1.0E38
07
  IT=0
08
  10 IT=IT+1
  WRITE(2,12)IT
  12 FORMAT(/1X,60(2H**))//10X,'TRIAL NO',I3)
  EMAX=0.0
10
  CALL FUN(N,M,NT,C,P,X,F)
  IF(IT.GT.ICONF)GO TO 16
  CALL DFUN(N,M,NT,C,P,X,DF)
  WRITE(2,15)F
  WRITE(2,15)DF
  15 FORMAT(3X,9G13.5)
  CALL INV(N,N,DF)
  WRITE(2,15)DET
  16 DO 30 I=1,N
14
  DX(I)=0.0
15
  DO 20 J=1,N
16
  20 DX(I)=DX(I)-DF(I,J)*F(J)
17
  IF(ABS(DX(I)).GT.EMAX)EMAX=ABS(DX(I))
18
  30 X(I)=X(I)+DX(I)
19
  WRITE(2,15)X

```



```

IF (EMAX.LT.ERROR) RETURN
20 IF ( (IT/NFR) *NFR.EQ.IT.AND.IIT.NE.0) CALL IFUN(X,Z,IIT)
IF (IT.EQ.NMAX) GO TO 50
EO=EMAX
22 GO TO 10
23 50 CONV=.FALSE.
24 RETURN
25 END
26
C—
27
SUBROUTINE IFUN(X,S,IIT)
C THIS SUBROUTINE WAS MADE TO IMPROVE THE CONVERGENCEY OF THE
C PROGRAM BY USING TWO CRITERIA
C 1- SCALING FACTORS
C 2- CONVERGENCE ACCELERATORS
C A DEVELOPED CONTROL SYMPO (NFR) HAS BEEN CREATED IN ORDER TO
C FIX FREQUENCY OF INTRUPTION BY WHICH WE MODIFY THE ITERATIONS
C ANOTHER CONTROL SYMPO HAS BEEN DEVELOPED (IIT) BY WHICH WE CAN
C DECIDE WHICH CRITERION WILL BE USED (SCALING OR CONVERGENCE ACC. A/OR
C BOTH..
DIMENSION X(9),S(9)
DO 1100 I=1,9
IF (IIT.EQ.1) GO TO 20
A=1.0
N=0
Z=ABS(X(I))
IF (Z.EQ.0.0.OR.Z.EQ.1.0) GO TO 10
IF (Z.GT.1.0) GO TO 33
2 N=N-1
Z=Z*10
IF (Z.LT.1) GO TO 2
GO TO 15
33 N=N+1
Z=Z/10
IF (Z.GT.1) GO TO 33
15 M=0
IF (I.GT.2.AND.I.LT.5) M=-1
IF (I.GT.5) M=-2
A=10**(M-N)
10 IF (I.LT.6.AND.I.NE.3) A=A*SIGN(1.0,X(I))
X(I)=A*X(I)
20 S(I)=1.0
IF (IIT.NE.2.AND.X(I).NE.0.0) S(I)=1/X(I)
1100 CONTINUE
RETURN
END

SUBROUTINE FUN(N,M,NT,C,P,X,F)
INTEGER P(N,N,M),R,S

```



```

        DIMENSION NT(N),F(N),X(N),C(N,M)
        DO 100 I=1,N
31      F(I)=0.0
32      DO 100 R=1,NT(I)
33        Q=C(I,R)
34        DO 20 S=1,N
35          20 Q=Q*DIF(0,P(I,S,R),X(S))
36      100 F(I)=F(I)+Q
37      RETURN
38      END
39
C——
40      SUBROUTINE DFUN(N,M,NT,C,P,X,DF)
        INTEGER P(N,N,M),R,S,T
        DOUBLE PRECISION DF(N,N)
        DIMENSION NT(N),X(N),C(N,M)
        DO 100 I=1,N
44      DO 100 T=1,N
45      DF(I,T)=0.0
46      DO 100 R=1,NT(I)
47        Q=C(I,R)
48        DO 20 S=1,N
50          L=0
49          IF(S.EQ.T)L=1
51          20 Q=Q*DIF(L,P(I,S,R),X(S))
52      100 DF(I,T)=DF(I,T)+Q
53      RETURN
54      END
C+++
56
C      S2-2.1.5      DIF
18
C      —————
19
        FUNCTION DIF(I,N,X)

```



```

20      DIF=0.0
21      IF (N.LT.I) RETURN
22      T=1.0
23      IF (I.EQ.0) GO TO 20
24      DO 10 K=1,I
25 10    T=T* (N-K+1)
26      20 DIF=T
      IF (X.EQ.0.0.AND. (N-I) .EQ.0) RETURN
      DIF=T*X** (N-I)
      RETURN
28      END
29
C+++
C      S0-1.0.21    INV  PARTIAL PIVOTING
C      -----
      SUBROUTINE INV (N,NA,AA)
      DIMENSION II (15)
      DOUBLE PRECISION AA (NA,NA) ,A (15,15)
      COMMON Z (9) ,DET
      DET=1
      DO 10 I=1,N
      II (I)=I
      DO 10 J=1,N
10    A (I,J)=AA (I,J)
      DO 60 K=1,N
      P=1.0E-10
      IP=0
      DO 20 I=K,N
      IA=II (I)
      IF (ABS (A (IA,K)) .LE.P) GO TO 20
      IP=I
      P=ABS (A (IA,K) )
20    CONTINUE
      IF (IP.EQ.0) STOP 'SINGULAR MATRIX'
      KP=II (IP)
      II (IP)=II (K)
      II (K)=KP
      P=A (KP,K)
      DET=DET*P
      DO 30 J=1,N
30    A (KP,J)=A (KP,J) /P
      DO 50 IA=1,N
      I=II (IA)
      IF (I.EQ.KP) GO TO 50
      Q=-A (I,K)
      A (I,K)=Q/P

```



```

      DO 40 J=1,N
      IF (J.EQ.K) GO TO 40
      A(I,J)=A(I,J)+Q*A(KP,J)
40  CONTINUE
50  CONTINUE
60  A(KP,K)=1.0/P
      DO 100 I=1,N
      DO 100 J=1,N
100 AA(I,II(J))=A(II(I),J)
      RETURN
      E N D
      SUBROUTINE OUTPUT(NCASE,X,CONV,IT,EMAX)
      DIMENSION X(9)
      LOGICAL CONV
      COMMON A(9)
      DO 5 I=1,9
5    X(I)=X(I)/A(I)
      X(1)=1/X(1)
      X(2)=X(1)*X(2)
      X(3)=X(1)*X(3)
      DO 10 I=4,9
10   X(I)=X(1)**2*X(I)
      WRITE(2,12) NCASE,IT,CONV
12  FORMAT(1H1/20X,'RESULTS OF TEST CASE',I3/10X,14HTRIALS NUMBER=,I3
1/10X,14HCONVERGENCE =,L3)
      DO 15 I=1,9
15  WRITE(2,20) I,X(I)
20  FORMAT(10X,'X(',I1,')=',G14.8)
      C=SQRT(X(1)**2+X(2)**2+X(3)**2)
      DO 25 I=4,6
25  X(I)=SIGN(1.0,X(I))*SQRT(ABS(X(I)))
      DO 30 I=1,6
30  X(I)=X(I)/C
      DO 35 I=7,9
35  X(I)=X(I)/C**2
      ALFA=ASIN(X(3))
      THETA=ACOS(X(1)/COS(ALFA))
      ALFA=ALFA*180/3.141592654
      THETA=THETA*180/3.141592654
      WRITE(2,40)
      WRITE(2,45) X(1),X(2),X(3)
      WRITE(2,50)
      WRITE(2,45) X(4),X(5),X(6)
      WRITE(2,55)
      WRITE(2,45) X(7),X(8),X(9)
      WRITE(2,60) ALFA,THETA
40  FORMAT(/5X,'NONDIMENSIONAL ABSOLUTE MEAN VELOCITIES')
45  FORMAT(10X,G15.8)
50  FORMAT(/5X,'COMPONENTS OF TURBULENCE INTENSITY')
55  FORMAT(/5X,'COMPONENT OF REYNOLDS STRESSES')
60  FORMAT(/5X,6HALFA =,G15.8/5X,6HTHETA=,G15.8)
      RETURN
      END
      SUBROUTINE LINEAR (K,Q,X)
      CHARACTER*2 CONK

```



```

DOUBLE PRECISION L(6,6)
REAL K
REAL K11,K112,K21,K212,K214,K114,K12,K122,K22,K13,K132,K23
1,K232
DIMENSION K(2,3),W(6),F(3),X(9),Q(3,3)
L(1,1)=1.0
L(1,2)=K(2,1)**2
L(1,3)=K(1,1)**2
DO 4 I=2,3
L(I,1)=K(4-I,I)**2
L(I,2)=K(I-1,I)**2
4 L(I,3)=1.0
W(1)=Q(1,1)
W(2)=Q(2,1)
W(3)=Q(3,1)
WRITE(2,74) (I,W(I),I=1,3)
74 FORMAT(//,5X,'W(' ,I1,')=' ,G14.8)
WRITE(2,75) ((I,J,L(I,J),J=1,3),I=1,3)
75 FORMAT(/,5X,'L(' ,I1,',' ,I1,')=' ,G14.8)
CALL SOLV(3,6,L,W,X)
WRITE(2,76) (I,X(I),I=1,3)
76 FORMAT(/,5X,'X(' ,I1,')=' ,G14.8)
DO 1111 I=1,3
IF(X(I)) 555,1111,1111
555 WRITE(2,333)I
333 FORMAT(5X,2HX( ,I1,2H)=,'-VE')
X(I)=-X(I)
1111 CONTINUE
F1=1/X(1)**0.5
F2=(X(2)/X(1))**0.5
F3=(X(3)/X(1))**0.5
K11=K(1,1)
K112=K(1,1)**2
K21=K(2,1)
K212=K(2,1)**2
K214=K(2,1)**4
K114=K(1,1)**4
K12=K(1,2)
K122=K(1,2)**2
K22=K(2,2)
K13=K(1,3)
K132=K(1,3)**2
K23=K(2,3)
K232=K(2,3)**2
WRITE(2,5)F1,F2,F3
5 FORMAT(//,10X,'1/U =' ,G14.8,5X,'V/U =' ,G14.8,5X,'W/U =' ,G14.8)
WRITE(2,78)K11,K21,K12,K22,K13,K23
78 FORMAT(/,5X,'K11=' ,G14.8,10X,'K12=' ,G14.8
1,/,5X,'K12=' ,G14.8,10X,'K22=' ,G14.8,/,5X,'K'
2,'13=' ,G14.8,10X,'K23=' ,G14.8)
DO 6 I=1,3
6 W(I)=Q(I,2)*F1**2
DO 7 I=4,6
7 W(I)=Q(I-3,3)*F1**2
WRITE(2,89) (I,W(I),I=1,6)

```



```

89  FORMAT(/,5X,'W(' ,I1,')=' ,G14.8)
    L(1,1)=K214/4*F2**4+K114/4*F3**4+1.0+K112*K212/2*F2**2*F3**2-K1
212*F3**2-K212*F2**2
    L(1,2)=K214*F2**4
    L(1,3)=K114*F3**2
    L(1,4)=-K214*F2**3-K112*K212*F2*F3**2+2*K212*F2
    L(1,5)=2*K112*K212*F2*F3
    L(1,6)=2*K112*F3-K112*K212*F3*F2**2-K114*F3**3
    WRITE(2,92) (J,L(1,J),J=1,6)
92  FORMAT(/,5X,'L(1,' ,I1,')=' ,G14.8)
    DO 61 I=2,3
    L(I,1)=K(I-1,I)**4/4/K(4-I,I)**2*F2**4+0.25/K(4-I,I)**2*F3**4+K(4
3-I,I)**2+0.5*K(I-1,I)**2/K(4-I,I)**2*F3**2*F2**2-K(I-1,I)**2*F2**2
4-F3**2
    L(I,2)=K(I-1,I)**4/K(4-I,I)**2*F2**2
    L(I,3)=1/K(4-I,I)**2*F3**2
    L(I,4)=-K(I-1,I)**4/K(4-I,I)**2*F2**3-(K(I-1,I)**2/K(4-I,I)
5**2)*F2*F3**2+2*K(I-1,I)**2*F2
    L(I,5)=2*K(I-1,I)**2/K(4-I,I)**2*F2*F3
61  L(I,6)=2.0*F3-1/K(4-I,I)**2*F3**3-K(I-1,I)**2/K(4-I,I)**2*F2**2*F3
    WRITE(2,93) (I,J,L(I,J),J=1,6),I=2,3)
93  FORMAT(/,5X,'L(' ,I1,',',I1,')=' ,G14.8)
    DO 71 I=2,3
    L(I+2,1)=0.25*K212*K(I-1,I)**2/K(4-I,I)*F2**3+(0.25*K212/K(4-I,I)+
60.25*K112*K(I-1,I)**2/K(4-I,I))*F2**2*F3**2-0.5*(K212*K(4-I,I)+K(I
7-1,I)**2/K(4-I,I))*F2**2-0.5*(K112*K(4-I,I)+1/K(4-I,I)
9)*F3**2+0.25*K112/K(4-I,I)
8*F3**4+K(4-I,I)
    L(I+2,2)=K212*K(I-1,I)**2/K(4-I,I)*F2**2
    L(I+2,3)=K112/K(4-I,I)*F3**2
    L(I+2,4)=-K212*K(I-1,I)**2/K(4-I,I)*F2**3-0.5*(K212/K(4-I,I)
1+K112*K(I-1,I)**2/K(4-I,I))*F2*F3**2+(K212*K(4-I,I)+K(I-1,I)
2**2/K(4-I,I))*F2
    L(I+2,5)=1/K(4-I,I)*(K212+K112*K(I-1,I)**2)*F2*F3
71  L(I+2,6)=-0.5/K(4-I,I)*(K212+K112*K(I-1,I)**2)*F2**2*F3
2-K112/K(4-I,I)*F3**3
1+(K112*K(4-I,I)+1/K(4-I,I))*F3
    WRITE(2,94) (I,J,L(I,J),J=1,6),I=4,5)
94  FORMAT(/,5X,'L(' ,I1,',',I2,')=' ,G14.8)
    L(6,1)=-K232*K122/4/K22/K13)*F2**4+1/K22/K13*(K122+K232)
4*F2**2*F3**2-0.5*(K13*K122/K22+K22*K232/K13)*F2**2+0.25/K22/K13
3*F3**4*F4-0.5*(K13/K22+K22/K13)*F3**2+K13*K22
    L(6,2)=K122*K232/K22/K13*F2**2
    L(6,3)=1/K13/K22
    L(6,4)=-K122*K232/K22/K13*F3**3-0.5/K22/K13*(K122+K232)*F2
3*F3**2+(K13*K122/K22+K232*K22/K13)*F2
    L(6,5)=(K122/K13/K22+K232/K13/K22)*F2*F3
    L(6,6)=-0.5/K13/K22*(K122+K232)*F2**2*F3-1/K22/K13
4*F3**3+(K13/K22+K22/K13)*F3
    WRITE(2,95) (J,L(6,J),J=1,6)
95  FORMAT(/,5X,'L(6,' ,I1,')=' ,G14.8)
    CALL SOLV(6,6,L,W,X)
    DO 8 I=1,6
    J=7-I
8  X(J+3)=X(J)

```



```

X(1)=F1
X(2)=F2
X(3)=F3
WRITE(2,37)
37  FORMAT(1H1,31(1H ),'THE STARTING ROOTS ARE',31(1H ),/,31(1H*),
122(1H=),31(1H*),/)
WRITE(2,9) (I,X(I),I=1,9)
9  FORMAT(32X,'X(',I1,')= ',G14.8)
982  PRINT *,'Please enter either stop or continue..'
READ(*,251)CONK
251  FORMAT(A2)
IF(CONK.EQ.'CO')GO TO 857
IF(CONK.EQ.'ST')STOP
GO TO 982
857  RETURN
END
SUBROUTINE SOLV(N,NA,L,W,X)
DOUBLE PRECISION L(NA,NA)
DIMENSION W(NA),X(NA)
CALL INV(N,NA,L)
DO 10 I=1,N
X(I)=0
DO 10 J=1,N
10  X(I)=X(I)+L(I,J)*W(J)
RETURN
END
SUBROUTINE WAKESELECT(IPOINT,NA,E)
DIMENSION E(NA,3),REC(47)
DATA IOPEN/-1/
IOPEN=IOPEN+1
IF(IOPEN.EQ.0.0)OPEN(10,STATUS='OLD',ERR=200)
IF(IOPEN.GT.0)REWIND(10)
DO 100 I=1,3
DO 100 J=1,NA
READ(10,*,ERR=300)(REC(K),K=1,47)
E(J,I)=REC(IPOINT)
100 CONTINUE
RETURN
200 STOP'FILE FOR010 NOT FOUND !!!!'
300 STOP'READ ERROR IN FILE FOR010'
END
SUBROUTINE SIGNALPLOT
CHARACTER*2 NONA
DIMENSION YAO(3),YT(47,80),X(47),Y(47)
DATA NT/47/,NPLOT/11/,NIN/23/,PX,PY/300.0,210./,XO,YO/25.
5,40./,XAL,YAL/18.5,40/,GAP/2.0/,XAO/24./,YAO/110.,60.,10./,XL,YL
2/250.,150./
111 PRINT *,'Are you going to draw the signals or not?..ys for YES '
READ(*,225)NONA
225 FORMAT(A2)
IF(NONA.EQ.'YS')GO TO 900
IF(NONA.EQ.'NO')RETURN
GO TO 111
900 CALL CC936N
CALL DEVPAP(PX,PY,0)

```



```

CALL WINDOW(2)
CALL PICCLE
CALL MOVTO2(XO+10.,YO-10.)
CALL CHASIZ(4.0,4.0)
CALL CHAHOL(41HF*LIG      *USIGNALS FROM THE HOT WIRE AT*.)
CALL CHASIZ(3.,3.)
CALL SHIFT2(XO,YO)
CALL MOVTO2(0.0,0.0)
CALL LINBY2(XL,0.0)
CALL LINBY2(0.0,YL)
CALL LINBY2(-XL,0.0)
CALL LINBY2(0.0,-YL)
CALL MOVTO2(83.0,105.)
CALL CHAHOL(32HO*LUTPUT SIGNAL FROM WIRE NO 1*.)
CALL MOVTO2(83.0,55.0)
CALL CHAHOL(32HO*LUTPUT SIGNAL FROM WIRE NO 2*.)
CALL MOVTO2(83.0,5.0)
CALL CHAHOL(32HO*LUTPUT SIGNAL FROM WIRE NO 3*.)
10  PRINT *, 'Enter INC,MIN'
    READ(*,*,ERR=10)INC,MIN
    DO 20 I=1,47
20    X(I)=I
    XMIN=1
    XMAX=47
    DO 100 IW=1,3
    XAO=24.
30    PRINT *, 'Enter YMIN,YMAX Please .....'
    READ(*,*,ERR=30)YMIN,YMAX
    DO 40 J=1,MIN
40    READ(30,*,ERR=200) (YT(I,J),I=1,47)
    IC=0
    J=NIN-INC
    XAO=XAO-XAL-GAP
50    IC=IC+1
    J=J+INC
    IF(IC.GT.NPLOT) GO TO 100
    IF (J.GT.NT)J=J-NT
    DO 60 I=1,47
60    Y(I)=YT(I,J)
    CALL PENSEL(IW,0.0,0)
    XAO=XAO+XAL+GAP
    CALL AXIPOS(1,XAO,YAO(IW),XAL,1)
    CALL AXISCA(3,10,XMIN,XMAX,1)
    CALL AXIPOS(1,XAO,YAO(IW),YAL,2)
    CALL AXISCA(3,10,YMIN,YMAX,2)
    IF(IC.EQ.1)CALL AXIDRA(-2,0,2)
    CALL GRAPOL(X,Y,47)
    GO TO 50
100   CONTINUE
    CALL DEVEND
    RETURN
200   STOP 'FILE FOR030 READ ERROR'
    END

```


Master Signal Analysis :

- It makes the call for the different segments in the program. It reads the maximum number of trials, the number of trials after which the solution is switched from Newton-Raphson method to the modified Newton-Raphson method, the maximum permissible error in the sequence of the resulting roots, and the values of the 9 convergence parameters.

The master calls different subroutines, the discussion of each of which follows in the sequence in which they are called.

Subroutine CDATE :

This subroutine reads the number of voltages to be analysed from each wire, the values of voltage output from the anemometer at zero velocity for each wire, the values of the constants "B" and "n" of each wire and the directional sensitivity factors of the three wires, and the powers of the different unknowns in each term for the nine equations, for the programs which solve the nine equations simultaneously, but reads only the powers of the different unknowns in each term for the equations in question in general if less than nine.

Subroutine VDATA :

This subroutine reads the values of the voltages of the three wires ($E+e$), in sequence. The number of values is described in CDATE.

This subroutine also reads the number of cases which were terminated by a negative number.

Subroutine QCALC :

This subroutine evaluates the mean voltage, and the fluctuating values for each wire, expressed as,

$$E_1, E_2, E_3, \overline{e_1^2}, \overline{e_2^2}, \overline{e_3^2}, \overline{e_1 e_2}, \overline{e_1 e_3}, \text{ and } \overline{e_2 e_3},$$

as well as the mean effective cooling velocities, and their fluctuating values, as,

$$Q_1, Q_2, Q_3, \overline{q_1^2}, \overline{q_2^2}, \overline{q_3^2}, \overline{q_1 q_2}, \overline{q_1 q_3}, \text{ and } \overline{q_2 q_3}.$$

Subroutine DSFAC :

This subroutine evaluates the coefficients of each term in the whole nine equations as generated from the directional sensitivity factors.

This subroutine solves a system of n algebraic equations in the form,

$$F (i) = 0 ,$$

where $F (i)$ is given. The solution is based on the Newton Raphson solution, generalised for the functions of n variables .

The functions , and their derivatives are calculated by FUN and DFUN respectively.

Subroutine FUN :

This subroutine calculates the values of each function $F (1)$, $F (2)$, , to $F (N)$, from the given values of $X (1)$, $X (2)$, , to $X (N)$, based on the relation,

$$F (i) = \sum_{r=1}^{NT(i)} c_{i,r} \prod_{s=1}^n x(s)^{P_{i,s,r}}$$

Subroutine DFUN :

This subroutine DFUN calculates the partial derivative of the function with respect to the different variables based on the equation,

$$DF(i, T) = \sum_{n=1}^{NT(i)} c_{i,r} \prod_{\substack{s=1 \\ s \neq T}}^n x(s)^{P_{i,s,r}} \frac{\partial x_t^{P_{i,T,r}}}{\partial x_t}$$

$i = 1, 2, 3, \dots, n$ and $T = 1, 2, 3, \dots, n$.

Function DIF :

Called by FUN and DFUN to calculate,

$$DIF(i, n, X) = \frac{\partial^i X^n}{\partial x^{i_{th}}}$$

which is the i derivative of X^n with respect to X , and

when $i = 0$, $DIF = X^n$.

Subroutine INV :

This subroutine uses partial pivoting to perform the inversion of the derivative matrix.

Subroutines LINEAR and SOLVE :

These two subroutines perform the job of solving the remaining six equations in the programs using only three non linear equations. The input data for these six equations are the three terms , $1/U$, V/U , and W/U .

Subroutine OUTPUT :

This subroutine converts the roots of the equations,

$$\frac{1}{U}, \frac{V}{U}, \frac{W}{U}, \frac{\overline{u'^2}}{U^2}, \frac{\overline{v'^2}}{U^2}, \frac{\overline{w'^2}}{U^2}, \frac{\overline{u'v'}}{U^2}, \frac{\overline{v'w'}}{U^2}, \text{ and } \frac{\overline{w'u'}}{U^2},$$

to non dimensional mean velocities, U/C , V/C , W/C , and the components of turbulence intensity,

$$\frac{\sqrt{\overline{u'^2}}}{C}, \frac{\sqrt{\overline{v'^2}}}{C}, \text{ and } \frac{\sqrt{\overline{w'^2}}}{C},$$

and the components of Reynolds stresses, $\overline{u'v'}/C^2$, $\overline{v'w'}/C^2$, and $\overline{w'u'}/C^2$, besides the yaw and pitch angles of the flow expressed as θ and α .

APPENDIX (13) =====

```

CHARACTER*23 FILENAME
CHARACTER*80 RECORD
LOGICAL EOF
EOF=.FALSE.
KLA=1
DO WHILE (.NOT.EOF)
    READ (3,'(A)',IOSTAT=IER) FILENAME
    IF (IER.NE.0) THEN
        EOF=.TRUE.
    ELSE
        OPEN (FILE=FILENAME,STATUS='OLD',UNIT=1)
        CALL READ (KLA)
        KLA=KLA+1
        CLOSE (UNIT=1)
    END IF
END DO
STOP
END
SUBROUTINE READ (KLA)
DIMENSION B (23),W (23),A (50),BB (100,100)
IF (KLA.EQ.1) THEN
    PRINT *, 'ENTER WHICH SET OF RESULTS YOU NEED'
    PRINT *, 'FOR REAL VALUES----- (1) '
    PRINT *, 'FOR NON-DIMENSIONAL VALUES-- (2) '
    READ *,IRN
END IF
IF (IRN.EQ.1.AND.KLA.EQ.1) THEN
    PRINT *, 'ENTER IS,T STR(2) OR TUR(1) '
    READ *,ITTR
END IF
    IF (IRN.EQ.2.AND.KLA.EQ.1) THEN
        PRINT *, 'ENTER WHICH FRAME OF REFERENCE YOU NEED'
        PRINT *, 'TURBOMACHINERY----- (1) '
        PRINT *, 'STREAMWISE----- (2) '
        READ *,IREF
        PRINT *, 'ENTER COMPONENT,S NUMBER'
        PRINT *, 'AXIAL VELOCITY----- (1) '
        PRINT *, 'TANGENTIAL VELOCITY----- (2) '
        PRINT *, 'RADIAL VELOCITY----- (3) '
        PRINT *, 'AXIAL TURBULENCE----- (4) '
        PRINT *, 'TANGENTIAL TURBULENCE----- (5) '
        PRINT *, 'RADIAL TURBULENCE----- (6) '
        PRINT *, 'AXIAL REYNOLD STRESSES----- (7) '
        PRINT *, 'TANGENTIAL REYNOLDS STRESSES----- (8) '
        PRINT *, 'RADIAL RENOLD STRESSES----- (9) '
        READ *,KDEW
    
```



```

END IF
IF (IRN.EQ.1.AND.KLA.EQ.1) THEN
PRINT *, 'ENTER COMPONENTS NUMBER'
PRINT *, 'FOR AXIAL VELOCITY COMPONENT (2) '
PRINT *, '"    TANG.    "    "' (3) '
PRINT *, '"    RADIAL    "    "' (4) '
PRINT *, '"    FLOW ANGLE    ' (5) '
PRINT *, '"    AXIAL    TURBULENCE COMPONENT (6) '
PRINT *, '"    TANG.    "    "' (7) '
PRINT *, '"    RADIAL    "    "' (8) '
PRINT *, '"    AXIAL RENOLDS STRESS COMP. (9) '
PRINT *, '"    TANG.    "    "    "' (10) '
PRINT *, '"    RADIAL    "    "    "    "' (11) '
READ *, KDEW
END IF
IF (IRN.EQ.1) GO TO 200
DO IJT=1,9
    READ (1, ' (A4) ') L
    READ (1, ' (A4) ') M
    READ (1, ' (A4) ') N
    READ (1, ' (A4) ') O
    FORMAT (4 (2X,A4), I3)
    READ (1, *) (A(KK), B(KK), KK=1,23)
    IF (IREF.EQ.1.AND.IJT.EQ.KDEW) THEN
        DO IIKM=1,23
            WRITE (2, *) B (IIKM)
        END DO
    END IF
END DO
DO LLDE=1,9
    READ (1, ' (A4) ') L
    READ (1, ' (A4) ') M
    READ (1, ' (A4) ') N
    READ (1, ' (A4) ') O
    READ (1, *) (A(KK), B(KK), KK=1,23)
    IF (IREF.EQ.2.AND.LLDE.EQ.KDEW) THEN
        DO IHG=1,23
            WRITE (2, *) B (IHG)
        END DO
    END IF
END DO
GO TO 300
200 READ (1, ' (A4) ') M
    READ (1, ' (A4) ') N
    READ (1, ' (A4) ') L
    READ (1, ' (A4) ') O
    READ (1, ' (A4) ') K
    IF (ITTR.EQ.1) IH=11
    IF (ITTR.EQ.2) IH=9
    DO II=1,23
        READ (1, *) (BB (II, J), J=1, IH)
    END DO
    DO II=1,23
        WRITE (2, *) BB (II, KDEW)
    END DO

```


300 RETURN
END

appendix (14)

C
C

```

PROGRAM SELF
REAL LP,LS
INTEGER RAKM(150)
DIMENSION
Z1(900),U1(900),V1(900),W1(900),TA(900),TT(900),TR(90)
1 ,RR(900),RA(900),B1(900),B(900),BA(900),RT(900),BB(900),CV(900)
1 ,BB1(900),VC(900),B1B(900),VVC(900),BB11(900),B11B(900),AB(3)
1 ,PX(2),PXX(2)
PRINT ', 'UNITS?'
READ ',SO
N=23
READ(20,')(B(I),I=1,23)
CALL CC1012
CALL DEVSPE(4800)
CALL DEVPAP(360.,270.,0)
CALL UNITS(SO)
CALL PICCLE
CALL WINDOW(2)
DO IS=5,1,-1
DO JS=1,6
BX=((IS-5)-1)*(-57.6)+51.0
BXX=(JS-1)*43.2+15.0
CALL AXIPOS(1,BX,BXX,47.6,1)
CALL AXIPOS(1,BX,BXX,33.2,2)
SX=120.0
CALL AXISCA(3,4,-SX,SX,1)
CALL AXISCA(3,2,0.0,1.0,2)
IF(IS.EQ.5.AND.JS.EQ.1)THEN
CALL PENSEL(4,0.0,0.0)
CALL GRID(3,1,1)
ELSE
CALL GRID(3,0,1)
END IF
CALL CHASIZ(2.0,2.0)
IF(JS.EQ.1)KLJ=6
IF(JS.NE.1)KLJ=7
IF(JS.EQ.50)GO TO 49
GO TO 712
49 IF(JS.EQ.1)THEN
LQ=6
ELSE
LQ=7
END IF
DO KH=1,LQ
READ(1,')(U1(KJ),KJ=1,23)
END DO
CALL GRAMOV(-47.0,.6)
CALL CHASIZ(5.,5.)
CALL CHAHOL(11HNO S. PR.'.)
CALL CHASIZ(2.,2.)

```



```

GO TO 3187
712 DO 2000 III=1,KLJ
    READ(1,')(U1(KJ),KJ=1,23)
    CALL DIFFER(U1,LBC)
    IF(LBC.EQ.1)GO TO 9873
    YMIN=1.0E30
    YMAX=-1.0E30
    DO 401 I=1,N
    IF(YMAX.LT.U1(I))THEN
    MAX=I
    YMAX=U1(I)
    END IF
    IF(YMIN.GT.U1(I))THEN
    MIN=I
    YMIN=U1(I)
    END IF
401 CONTINUE
    V=(YMAX+YMIN)/2.0
    DO 501 I=MAX-1,1,-1
    IF(U1(I).LT.V)THEN
    XMU=((B(I+1)-B(I))/(U1(I+1)-U1(I)))'(V-U1(I+1))+B(I+1)
    LP=-B(MAX)+XMU
    GO TO 410
    ELSE
    1 IF(U1(I).EQ.V)THEN
    XMU=B(I)
    LP=-B(MAX)+XMU
    GO TO 410
    END IF
501 CONTINUE
    GO TO 2000
410 DO 601 I=MAX+1,N
    IF(U1(I).LT.V)THEN
    XPL=((B(I-1)-B(I))/(U1(I-1)-U1(I)))'(V-U1(I-1))+B(I-1)
    LS=XPL-B(MAX)
    GO TO 510
    ELSE
    1 IF(U1(I).EQ.V)THEN
    XPL=B(I)
    LS=XPL-B(MAX)
    GO TO 510
    END IF
601 CONTINUE
    GO TO 2000
510 DO 701 I=1,N
701 B1(I)=U1(I)
    YMIN=FMIN(B1,N)
    YMAX=FMAX(B1,N)
    DO 801 I=MAX-1,1,-1
    B1(I)=(B1(I)-YMIN)/(YMAX-YMIN)
801 B(I)=(B(MAX)-B(I))/LP
    DO 901 I=MAX+1,N
    B1(I)=(B1(I)-YMIN)/(YMAX-YMIN)
901 B(I)=(B(I)-B(MAX))/LS
    B(MAX)=0.0

```



```

      B1(MAX)=1.0
      CALL PENSEL(2,0.0,0.0)
      CALL CHASIZ(2.0,2.0)
      CALL GRASYM(B,B1,23,III,0)
      DO 1593 I=1,23
      BB1((III-1)'23+I)=B1(I)
      BB((III-1)'23+I)=B(I)
1593  CONTINUE
      GO TO 2000
9873  YMIN=1.0E30
      YMAX=-1.0E30
      DO 40 I=1,N
      IF(YMAX.LT.U1(I))THEN
      MAX=I
      YMAX=U1(I)
      END IF
      IF(YMIN.GT.U1(I))THEN
      MIN=I
      YMIN=U1(I)
      END IF
40    CONTINUE
      V=(YMAX+YMIN)/2.0
      DO 50 I=MIN-1,1,-1
      IF(U1(I).GT.V)THEN
      XMU=((B(I+1)-B(I))/(U1(I+1)-U1(I)))'(V-U1(I+1))+B(I+1)
      LP=-B(MIN)+XMU
      GO TO 400
      ELSE
1    IF(U1(I).EQ.V)THEN
      XMU=B(I)
      LP=-B(MIN)+XMU
      GO TO 400
      END IF
50    CONTINUE
      GO TO 2000
400  DO 60 I=MIN+1,N
      IF(U1(I).GT.V)THEN
      XPL=((B(I-1)-B(I))/(U1(I-1)-U1(I)))'(V-U1(I-1))+B(I-1)
      LS=XPL-B(MIN)
      GO TO 500
      ELSE
1    IF(U1(I).EQ.V)THEN
      XPL=B(I)
      LS=XPL-B(MIN)
      GO TO 500
      END IF
60    CONTINUE
      GO TO 2000
500  DO 70 I=1,N
70    B1(I)=U1(I)
      YMIN=FMIN(B1,N)
      YMAX=FMAX(B1,N)
      DO 80 I=MIN-1,1,-1
      B1(I)=(YMAX-B1(I))/(YMAX-YMIN)
80    B(I)=(B(MIN)-B(I))/LP

```



```

DO 90 I=MIN+1,N
B1(I)=(YMAX-B1(I))/(YMAX-YMIN)
90  B(I)=(B(I)-B(MIN))/LS
    B(MIN)=0.0
    B1(MIN)=1.0
912  FORMAT (2(5X,G14.8))
    CALL PENSEL(1,0.0,0)
    IF(III.LT.8)ILM=III
    IF(III.GE.8.AND.III.LT.15)ILM=III-7
    IF(III.GE.15.OR.III.LT.23)ILM=III-14
    IF(III.GE.23.OR.III.LT.31)ILM=III-22
    IF(III.GE.31.OR.III.LT.39)ILM=III-30
    IF(III.GE.39.OR.III.LT.46)ILM=III-38
    CALL CHASWI(1)
    CALL CHASIZ(2.0,2.0)
    CALL PENSEL(2,0.0,0.0)
    CALL GRASYM(B,B1,23,ILM,0)
    CALL CHASWI(0)
    DO 1539 I=1,23
    BB1((III-1)'23+I)=B1(I)
    BB((III-1)'23+I)=B(I)
1539 CONTINUE
2000 CONTINUE
    DO 903 IBL=1,2
    CALL BESF(BB1,BB,IBL,KLJ,C,DELTA)
    PX(IBL)=C
    PXX(IBL)=DELTA
903  CONTINUE
    WRITE(' ',')IS,JS,PXX(1),PXX(2)
    WRITE(' ',')PX(1)
    WRITE(' ',')PX(2)
    DO IBL=1,2
    DO 2750 IKLH=1,KLJ
    CALL PENSEL(1,0.0,0)
    IF(IBL.EQ.1)THEN
    LPK=1
    LPKK=12
    MMN=0
    ELSE
    LPK=12
    LPKK=23
    MMN=11
    END IF
    DO 3950 KK=LPK,LPKK
    CV(KK-MMN)=EXP(-PX(IBL)'ABS(BB((IKLH-1)'23+KK)))
    BB(KK-MMN)=BB((IKLH-1)'23+KK)
3950 CONTINUE
    CALL PENSEL(1,0.0,0.0)
    CALL GRAPOL(BB,CV,12)
2750 CONTINUE
    END DO
3187 END DO
    END DO
    CALL MOVTO2(100.0,1.0)
    CALL CHASIZ(3.5,3.5)

```



```

      PRINT ', 'ENTER THE TITLE'
      READ(', '(150A1)'),RAKM
      CALL PENSEL(1,0.0,0.0)
      CALL CHAA1(RAKM,150)
      CALL DEVEND
      STOP
      END
C'''''' THIS IS A GENERAL FUNCTION TO GET A MAX. VALUE FOR AN
ARRAY
      FUNCTION FMAX(B1,MIN)
      DIMENSION B1(120)
      FMAX=-1.0E20
      DO 10 NCASE=1,MIN
      IF(FMAX.LT.B1(NCASE))FMAX=B1(NCASE)
10      CONTINUE
      RETURN
      END
C'''''' THIS IS A GENERAL FUNCTION TO GET A MIN. VALUE OF AN
ARRAY
      FUNCTION FMIN(B1,MIN)
      DIMENSION B1(120)
      FMIN=1.0E20
      DO 10 NCASE=1,MIN
      IF(FMIN.GT.B1(NCASE))FMIN=B1(NCASE)
10      CONTINUE
      RETURN
      END
      SUBROUTINE INV(N,NA,AA)
      DIMENSION II(15)
      DOUBLE PRECISION AA(NA,NA),A(15,15)
      COMMON Z(9),DET
      DET=1
      DO 10 I=1,N
      II(I)=I
      DO 10 J=1,N
10      A(I,J)=AA(I,J)
      DO 60 K=1,N
      P=1.0E-10
      IP=0
      DO 20 I=K,N
      IA=II(I)
      IF(ABS(A(IA,K)).LE.P)GO TO 20
      IP=I
      P=ABS(A(IA,K))
20      CONTINUE
      IF(IP.EQ.0)STOP'SINGULAR MATRIX'
      KP=II(IP)
      II(IP)=II(K)
      II(K)=KP
      P=A(KP,K)
      DET=DET/P
      DO 30 J=1,N
30      A(KP,J)=A(KP,J)/P
      DO 50 IA=1,N
      I=II(IA)

```



```

      IF(I.EQ.KP)GO TO 50
      Q=-A(I,K)
      A(I,K)=Q/P
      DO 40 J=1,N
      IF(J.EQ.K)GO TO 40
      A(I,J)=A(I,J)+Q*A(KP,J)
40  CONTINUE
50  CONTINUE
60  A(KP,K)=1.0/P
      DO 100 I=1,N
      DO 100 J=1,N
100 AA(I,II(J))=A(II(I),J)
      RETURN
      END
      SUBROUTINE SOLV(N,NA,L,W,X)
      DOUBLE PRECISION L(NA,NA),W
      DIMENSION W(NA),X(NA)
      CALL INV(N,NA,L)
      DO 10 I=1,N
      X(I)=0
      DO 10 J=1,N
10  X(I)=X(I)+L(I,J)*W(J)
      RETURN
      END
      SUBROUTINE BESF(BB1,BB,IBL,KLJ,C,DELTA)
      DIMENSION BB1(900),BB(900)
      IF(IBL.EQ.1)THEN
      LPK=1
      LPKK=12
      MMN=0
      ELSE
      LPK=12
      LPKK=23
      MMN=11
      END IF
      DELTA=0.0
      C1=0.01
      CN=1.2
      DC=0.05
      DIVO=1.0E30
10  DO 100 C=C1,CN,DC
      DELTA=0.0
      DO 27500 IKLH=1,KLJ
      DO 39500 KK=LPK,LPKK
      IF(BB1((IKLH-1)'23+KK).EQ.0.0)GO TO 39500
      DELTA=DELTA+SQRT((EXP(-C*ABS(BB((IKLH-1)'23+KK)))-BB1((IKLH-1)
1'23+KK))'2)
39500 CONTINUE
27500 CONTINUE
      IF(DELTA.GE.DIVO)GO TO 205
      DIVO=DELTA
100 CONTINUE
      GO TO 305
205 IF(DC.LE.0.001)GO TO 100

```


305

```
C1=C-DC
DC=DC/10
CN=C
GO TO 10
RETURN
END
SUBROUTINE DIFFER(U1,LBC)
DIMENSION U1(900)
LBC=0
VB=0.0
DO I=1,23
  VB=VB+U1(I)
END DO
VB=VB/23.
YMIN=1.0E30
YMAX=-1.0E30
DO I=5,19
  IF(YMAX.LT.U1(I))THEN
    YMAX=U1(I)
  END IF
  IF(YMIN.GT.U1(I))THEN
    YMIN=U1(I)
  END IF
END DO
V1B=ABS(YMAX-VB)
V2B=ABS(YMIN-VB)
IF(V1B.GT.V2B)LBC=2
IF(V1B.LE.V2B)LBC=1
RETURN
END
```


PPENDIX (15)

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STREAM WISE VELOCITY SIMILARITY COEFFICIENTS FOR P.S.

-4.437291	-0.6923521	24.06095	6.442854	-11.09686
-36.16734	4.120391	-5.940045	-42.19020	17.21724

STREAM WISE VELOCITY SIMILARITY COEFFICIENTS FOR S.S.

-1.766988	-9.354028	10.52312	15.54892	-56.50724
-14.89127	69.40664	-3.801168	-35.69545	6.992999

NORMAL TO ST. W. VELOCITY SIMILARITY COEFFICIENTS FOR P.S.

-9.701885	4.211868	46.82669	-0.2626059	23.70155
-67.00800	85.16730	3.439559	352.8968	30.48882

NORMAL TO ST. W. VELOCITY SIMILARITY COEFFICIENTS FOR S.S.

0.3768752	7.562159	1.268623	-3.016922	128.2379
-1.584785	2.193926	3.331635	558.3389	0.6539518

RADIAL VELOCITY SIMILARITY COEFFICIENTS FOR P.S.

-4.583558	-25.19154	20.20266	46.01228	-104.1201
-26.68644	68.06309	-25.03348	-154.9673	11.51351

RADIAL VELOCITY SIMILARITY COEFFICIENTS FOR S.S.

-1.841811	8.620841	16.37308	6.527948	16.39819
-25.23149	-0.1861497	-10.17580	-70.28263	11.76377

AXIAL VELOCITY SIMILARITY COEFFICIENTS FOR P.S.

-2.458985	-5.265493	14.85932	17.06853	-6.603851
-22.80084	29.57180	-11.63844	64.24017	10.91360

AXIAL VELOCITY SIMILARITY COEFFICIENTS FOR S.S.

-1.708338	18.02673	17.17150	-25.73053	4.743873
-28.76915	5.069771	11.86855	-55.95181	14.33064

RELATIVE TANG. VELOCITY SIMILARITY COEFFICIENTS FOR P.S.

-2.601651	-6.348581	16.34996	-10.17636	-140.4774
-27.31442	73.60799	13.27614	-350.1769	14.26450

RELATIVE TANG. VELOCITY SIMILARITY COEFFICIENTS FOR S.S.

1.075126	39.78035	7.088243	-76.03127	82.01340
-18.05488	3.119642	44.23762	265.6893	10.94979

TOTAL REL. VELOCITY SIMILARITY COEFFICIENTS FOR P.S.

0.9325148	-17.55704	-2.077667	28.03687	-118.7887
3.448313	132.5065	-6.896341	-107.8042	-1.589195

TOTAL REL. VELOCITY SIMILARITY COEFFICIENTS FOR S.S.

4.834514	56.42396	-6.850853	-84.92850	261.0581
0.1228798	-220.5368	30.36969	285.5233	2.704879

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RESULTS OF VELOCITY COMPONENTS SIMILARITY COEFFICIENTS
IN THE PRESSURE DISTORTION REGIME

INCIDENCE ANGLES TO BE USED FOR THE CORRELATIONS= -2 -2 0.0 2.7

5.5 2.7 0.0 -2

CIRCUMFERENTIAL LOCATIONS TO BE USED FOR THE CORRELATIONS=-180

-90 -45. -22.5 0.0 22.5 45.0 90.0

STREAM WISE VELOCITY SIMILARITY COEFFICIENTS FO P.S.

0.2081272 -1.018002 -3.1831760E-02 0.2809817 27.08703
 4.3566160E-02 34.17518 1.441586

STREAM WISE VELOCITY SIMILARITY COEFFICIENTS FOR S.S.

0.6476904 -1.624988 3.1831227E-02 0.8113266 18.26480
 6.0490061E-02 -2.881993 1.926427

NORMAL TO ST. W. VELOCITY SIMILARITY COEFFICIENTS FOR P.S.

0.5289086 1.890083 0.1591583 4.471613 -43.44872
 -0.1522494 62.79162 -5.232414

NORMAL TO ST. W. VELOCITY SIMILARITY COEFFICIENTS FOR S.S.

0.4567657 -5.105750 -3.1832043E-02 3.315006 75.24636
 0.2078951 173.3462 6.149368

RADIAL VELOCITY SIMILARITY COEFFICIENTS FOR P.S.

0.1888690 -3.542368 3.1831525E-02 1.022247 66.32780
 0.2369023 -36.02769 7.464322

RADIAL VELOCITY SIMILARITY COEFFICIENTS FOR S.S.

1.258247 0.8794343 6.3663110E-02 0.4728568 -14.39685
 -0.1592646 -38.70396 -4.562433

AXIAL VELOCITY SIMILARITY COEFFICIENTS FOR P.S.

0.1131579 -0.5761708 5.4519487E-09 0.8284654 21.93868
 -4.3082689E-03 10.80221 0.1639461

AXIAL VELOCITY SIMILARITY COEFFICIENTS FOR S.S.

0.6192141 -5.168230 -9.5495321E-02 1.015427 117.9552
 0.8361968 107.4668 23.18154

REL.TANG. VELOCITY SIMILARITY COEFFICIENTS FOR P.S.

5.5770513E-02 -1.386626 6.7699051E-09 -0.9665471 31.18346
 6.8571474E-03 20.51122 -0.1006084

REL.TANG. VELOCITY SIMILARITY COEFFICIENTS FOR S.S.

0.6017993 -1.205580 -3.1832114E-02 0.7024547 40.58205
 0.2970076 85.43820 7.444129

TOTAL REL. VELOCITY SIMILARITY COEFFICIENTS FOR P.S.

0.4635528 -1.341530 3.1831592E-02 3.423878 40.72187
 0.1968833 85.02616 5.350094

TOTAL REL. VELOCITY SIMILARITY COEFFICIENTS FOR S.S.

0.8298688 -2.855670 -9.5494419E-02 0.9133809 11.31350
 0.1704425 52.29199 5.270200

APPENDIX (16)

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STRAM WISE TURBULENCE SELF PRESERVATION COEFFICIENTS FORP.S.

-1.275804	-18.69526	8.299288	29.90394	-130.8330
-12.21523	267.0062	2.667922	231.6609	5.920414

STRAM WISE TURBULENCE SELF-PRESERVATION COEFFICIENTS FORS.S.

-4.928805	2.036981	24.99864	21.03630	124.8831
-34.70403	-35.17274	-19.77219	392.7158	15.19953

NORMAL TO ST. W. TURBULENCE SELF-PRES COEFFICIENTS FORP.S.

-6.921568	-27.94406	27.87902	64.45021	-109.8178
-34.61257	30.77843	-41.00436	-427.8142	14.34422

NORMAL TO ST. W. TURBULENCE SELF-PRES COEFFICIENTS FORS.S.

-3.525322	-44.24004	13.97902	91.37194	-143.9662
-15.88691	191.8619	-40.73689	-6.559372	6.183876

RADIAL TURBULENCE SELF-PRESERVATION COEFFICIENTS FOR P.S.

-12.02438	-28.03312	53.82707	92.47849	74.34990
-72.24754	-20.74061	-60.25304	160.3423	31.20724

RADIAL TURBULENCE SELF-PRESERVATION COEFFICIENTS FOR S.S.

-4.040016	-5.443587	21.57665	9.258631	-89.81139
-30.57663	38.40718	-6.337001	-269.8506	13.59902

AXIAL TURBULENCE SELF-PRESERVATION COEFFICIENTS FOR P.S.

-5.966335	19.04255	33.77430	26.30613	256.8480
-49.29306	149.3100	-20.24906	1260.599	21.91113

AXIAL TURBULENCE SELF-PRESERVATION COEFFICIENTS FOR S.S.

-3.856885	6.376301	19.94926	21.45857	161.7265
-26.53006	-92.42211	-24.40536	283.7868	11.03622

TANG. TURBULENCE SELF-PRESERVATION COEFFICIENTS FOR P.S.

1.167292	48.56430	6.395403	-49.85999	301.4978
-16.72285	-106.2936	16.88939	630.2132	10.00035

TANG. TURBULENCE SELF-PRESERVATION COEFFICIENTS FOR S.S.

3.947366	233.6143	22.55286	-139.0016	1678.113
-42.69252	-633.9843	-0.7932447	3646.927	19.64692

=====

APPENDIX (17)Decay analysis ;

Consider the virtual origin as B, for a certain value of B,

$$u = X - B$$

where X is the nondimensional axial distance or the nondimensional stream wise distance .

$$Y = A_1 u_K^{P_1} + A_2 u_K^{P_2}$$

The error in the fitting point will be,

$$\begin{aligned} f_k &= y_k - y = y_k - (A_1 u_K^{P_1} + A_2 u_K^{P_2}) \\ \sum_{k=1}^m f_k^2 &= \sum_{k=1}^n [y_k - (A_1 u_K^{P_1} + A_2 u_K^{P_2})]^2 \\ \frac{\partial f_k}{\partial a_1} &= 0, \quad \frac{\partial f_k}{\partial a_2} = 0 \end{aligned}$$

$$\begin{aligned} \sum_{k=1}^n [y_k - (a_1 u_K^{P_1} + a_2 u_K^{P_2})] u_K^{P_1} &= 0 \\ \sum_{k=1}^n [y_k - (a_1 u_K^{P_1} + a_2 u_K^{P_2})] u_K^{P_2} &= 0 \end{aligned}$$

$$a_1 \sum_{k=1}^n u_K^{2P_1} + a_2 \sum_{k=1}^n u_K^{P_1+P_2} = \sum_{k=1}^n y_K u_K^{P_1}$$

$$a_1 \sum_{k=1}^n u_K^{P_1+P_2} + a_2 \sum_{k=1}^n u_K^{2P_2} = \sum_{k=1}^n y_K u_K^{P_2}$$

By solving the last two equations , we can obtain A and A .

This process can be repeated for each value of B , to obtain the value which gives minimum overall standard deviation.

APPENDIX (18)

C
C

```

PROGRAM DECAY
DIMENSION YK(230),FM(230),U(50)
DO II=1,8
  READ(1,')MM
  READ(1,')(U(I),FM(I),I=1,MM)
  P2=0.0
  P1=1.0
  C11=0.0
  C12=0.0
  C22=0.0
  B1=0.0
  B2=0.0
  BB=0.0
  DO KK=1,MM
    IF(U(KK).LE.0.0)STOP'ERROR IN DATA'
    C11=C11+U(KK)**(2*P1)
    C12=C12+U(KK)**(P1+P2)
    C22=C22+U(KK)**(2*P1)
    B1=B1+FM(KK)*U(KK)**P1
    B2=B2+FM(KK)*U(KK)**P2
  END DO
  D=C11*C22-C12*C12
  A1=(B1*C22-B2*C12)/D
  A2=(C11*B2-C12*B1)/D
  DIV=0.0
  DO KK=1,MM
    DIV=DIV+(FM(KK)-A1*U(KK)**P1-A2*U(KK)**P2)**2
  END DO
  DIV=SQRT(DIV/MM)
  WRITE(,',')'A1',A2',DIV'=',A1,A2,DIV
  END DO
  STOP
  END
  SUBROUTINE CAL(YK,NN,FMIN)
  DIMENSION YK(23)
  FMIN=1.0E20
  DO I=1,23
    IF(FMIN.GT.YK(I))THEN
      FMIN=YK(I)
      NN=I
    END IF
  END DO
  RETURN
  END
  SUBROUTINE CAL1(YK,NM,FMAX)
  DIMENSION YK(23)
  FMAX=-1.0E20
  DO I=1,23
    IF(FMAX.LT.YK(I))THEN
      FMAX=YK(I)
      NN=I
    END IF
  END IF

```


END DO
RETURN
END

APPENDIX (19)

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=====
      A1              A2              XO
DECAY CONSTANTS OF VELOCITY COMPONENTS IN THE STREAM WISE FRAME OF
REFERENCE FROM THE HUB TO THE TIP.
STREAM WISE VELOCITY LOAD (I)
  7.6647252E-02  0.1964750      -1.999998
  0.1315672     -2.8600430E-03  0.0000000E+ 00
  0.1853240     -9.9790152E-03  0.0000000E+ 00
  0.2698063     -5.0765993E-03  0.0000000E+ 00
  0.3746171     3.5084706E-02   0.0000000E+ 00
  1.211861      -9.8452948E-02   -1.409999
STREAM WISE VELOCITY LOAD (II)
 -4.5658227E-02  0.3833370      -1.949998
  0.1398191     -1.0381351E-03  0.0000000E+ 00
  0.2143518     -1.1847079E-02  0.0000000E+ 00
  0.2476856     -1.8012810E-02  0.0000000E+ 00
  0.3449931     -1.6784366E-02  0.0000000E+ 00
  0.7496881     -0.1085969      0.0000000E+ 00
STREAM WISE VELOCITY LOAD (III)
 -0.1519298     0.5492346      -1.719999
  0.1786534     2.4954497E-03  -2.9999999E-02
  0.2638864     -1.1169080E-02  0.0000000E+ 00
  0.3085746     -1.4628390E-02  0.0000000E+ 00
  0.3568513     -3.2210276E-02  0.0000000E+ 00
  0.7327570     -0.2423150     -3.9999999E-02
NORMAL TO STREAM WISE VELOCITY LOAD (I)
  4.4544186E-02  4.1624927E-04  -9.9999998E-03
  7.6511815E-02 -2.7839576E-03  0.0000000E+ 00
  8.4497392E-02 -7.8172125E-03  0.0000000E+ 00
  0.1207359     -6.1949836E-03  0.0000000E+ 00
  0.1492136     -1.9162226E-02  0.0000000E+ 00
  0.3136132     -2.4327343E-02  -0.9399994
NORMAL TO STREAM WISE VELOCITY LOAD (II)
  1.3202569E-02  7.2416820E-02   -1.999998
  8.0775991E-02 -1.1518211E-03  0.0000000E+ 00
  0.1011937     -8.7725399E-03  0.0000000E+ 00
  0.1227638     -1.5201031E-02  0.0000000E+ 00
  0.1478096     -2.9556725E-02  0.0000000E+ 00
  0.1360564     2.5629038E-02  0.0000000E+ 00
NORMAL TO STREAM WISE VELOCITY LOAD (III)
  2.8089639E-03  0.1008995      -1.829999
  7.4984998E-02  1.2272921E-03  -3.9999999E-02
  0.1516982     -1.1405142E-02  0.0000000E+ 00
  0.1914646     -2.3331473E-02  0.0000000E+ 00
  0.1766672     -2.5005281E-02  0.0000000E+ 00
  6.2825732E-02  6.6992581E-02  -3.9999999E-02
RADIAL VELOCITY IN THE STREAM WISE FRAME OF REFERENCE LOAD (I)
  5.3339183E-02  2.0528527E-03  -7.0000000E-02
  4.0316757E-02 -6.9663586E-04  0.0000000E+ 00
  5.2820604E-02 -2.9251752E-03  0.0000000E+ 00
  7.0797145E-02 -5.0179106E-03  0.0000000E+ 00
  9.6767232E-02 -5.5539105E-03  0.0000000E+ 00
  0.2623336     -2.2753879E-02  -1.639999
RADIAL VELOCITY IN THE STREAM WISE FRAME OF REFERENCE LOAD (II)
  8.2153874E-03  9.6744657E-02   -1.999998

```


4.1209657E-02	3.8650303E-04	-2.0000000E-02
5.0161071E-02	-1.8269629E-03	0.0000000E+00
6.2588081E-02	-5.1722820E-03	0.0000000E+00
8.9181095E-02	-1.2447571E-02	0.0000000E+00
0.1298366	-2.3930683E-03	-2.9999999E-02

RADIAL VELOCITY IN THE STREAM WISE FRAME OF REFERENCE LOAD (III)

-8.7134037E-03	0.1212502	-1.7999999
4.5674004E-02	2.6116902E-03	-0.1300000
5.2836228E-02	-3.8045304E-04	0.0000000E+00
6.0202315E-02	-2.0845924E-03	0.0000000E+00
8.3479412E-02	-1.0788053E-02	0.0000000E+00
6.5854944E-02	2.9854609E-02	-3.9999999E-02

VELOCITIES IN THE TURBOMACHINER FRAME OF REFERENCE

AXIAL VELOCITY LOAD (I)

0.1601018	1.0203720E-02	-0.1600000
5.6865640E-02	3.3260379E-03	-8.9999996E-02
5.1536858E-02	3.3788169E-03	-0.1500000
5.7080153E-02	4.8883939E-03	-0.2300000
6.3145585E-02	5.4208720E-03	-0.2500001
0.1137619	6.9336114E-03	-0.2000000

AXIAL VELOCITY LOAD (II)

0.1725930	1.5218766E-02	-0.2200000
7.5609006E-02	5.5569741E-03	-0.1200000
6.4955302E-02	5.0040376E-03	-0.1800000
5.4501496E-02	3.6096589E-03	-0.1800000
5.7851084E-02	3.8996499E-03	-0.2000000
9.6737318E-02	9.0684192E-03	-0.2800000

AXIAL VELOCITY LOAD (III)

0.2010823	1.8156100E-02	-0.2200000
0.1201572	7.6307589E-03	-9.9999994E-02
0.1007433	1.7794876E-03	-2.9999999E-02
9.0097591E-02	6.1553814E-03	-0.1900000
6.7024224E-02	6.3041956E-03	-0.2700000
0.1056852	1.3202949E-02	-0.3400000

RELATIVE TANGENTIAL VELOCITY LOAD (I)

0.1315287	1.2207342E-02	-0.2300000
3.9083637E-02	4.3711052E-03	-0.1900000
3.6252484E-02	3.1460880E-03	-0.2000000
4.5341056E-02	5.0431155E-03	-0.2900000
5.5334453E-02	5.4369220E-03	-0.2700000
9.5267877E-02	6.1028837E-03	-0.2100000

RELATIVE TANGENTIAL VELOCITY LOAD (II)

0.1454709	1.6501106E-02	-0.2800000
5.4455657E-02	6.4108595E-03	-0.2100000
5.1099207E-02	3.1881749E-03	-0.1500000
4.1508712E-02	3.1950618E-03	-0.2100000
4.8682097E-02	4.0657101E-03	-0.2400001
8.8786162E-02	7.1640410E-03	-0.2500001

RELATIVE TANGENTIAL VELOCITY LOAD (III)

0.1713510	1.5944179E-02	-0.2300000
9.4303198E-02	4.5755962E-03	-7.0000000E-02
7.9428203E-02	6.9393672E-04	-9.9999998E-03
7.4967764E-02	4.2882962E-03	-0.1600000
5.6086011E-02	4.5775976E-03	-0.2400001

9.5614351E-02	9.9930642E-03	-0.3000000	
RADIAL VELOCITY IN THE TURBOMACHINERY FRAME OF REFERENCE			LOAD (I)
4.8521392E-02	1.6120767E-03	-7.9999998E-02	
1.9820204E-02	8.5430901E-04	-6.0000002E-02	
1.8519972E-02	9.5832610E-04	-0.1200000	
1.8442767E-02	8.7810919E-04	-0.1300000	
2.1152189E-02	1.0766544E-03	-0.1600000	
3.1926423E-02	1.5475876E-03	-0.1600000	
RADIAL VELOCITY IN THE TURBOMACHINERY FRAME OF REFERENCE			LOAD (II)
5.1391929E-02	2.6246302E-03	-0.1300000	
2.5557740E-02	1.6414626E-03	-9.9999994E-02	
2.1836586E-02	1.5074164E-03	-0.1600000	
1.8479720E-02	1.0069794E-03	-0.1500000	
1.8931929E-02	7.2776387E-04	-0.1200000	
2.8307198E-02	1.8972404E-03	-0.2100000	
RADIAL VELOCITY IN THE TURBOMACHINERY FRAME OF REFERENCE			LOAD (III)
5.4952499E-02	4.1505075E-03	-0.1900000	
3.4932651E-02	2.7888054E-03	-0.1300000	
3.0976761E-02	1.1937082E-03	-8.9999996E-02	
2.6654854E-02	2.0942241E-03	-0.2100000	
2.1239486E-02	1.4723847E-03	-0.2100000	
2.9909676E-02	2.9695337E-03	-0.2900000	

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TURBULENCE IN STREAMWISE FRAME OF REFERENCE

STREAM WISE TYRBULENCE			LOAD (I)
4.555717	0.2708245	-0.1700000	
10.31803	-0.5339655	0.0000000E+00	
10.68032	-0.9963561	0.0000000E+00	
15.46381	-1.184330	0.0000000E+00	
20.41971	-1.773254	0.0000000E+00	
41.23574	-2.798253	-0.5799997	

STREAM WISE TYRBULENCE			LOAD (II)
4.594617	0.5667114	-0.3100000	
8.950456	-0.1435600	0.0000000E+00	
13.36826	-0.7880691	0.0000000E+00	
14.53597	-2.173125	0.0000000E+00	
16.38205	-2.718204	0.0000000E+00	
14.94465	9.413864	0.0000000E+00	

STREAM WISE TYRBULENCE			LOAD (III)
6.783200	1.336265	-0.4599999	
8.152351	0.2431868	-6.0000002E-02	
17.41432	-1.277144	0.0000000E+00	
21.01962	-2.631834	0.0000000E+00	
16.65491	-2.413747	0.0000000E+00	
-38.29490	57.40415	-3.9999999E-02	

NORMAL TO THE STREAM WISE TURBULENCE			LOAD (I)
34.62322	0.6483997	-6.0000002E-02	
53.86787	5.539458	-0.2300000	
85.83592	0.9481980	-3.9999999E-02	
95.24896	0.3103575	-9.9999998E-03	
97.59904	-3.978333	0.0000000E+00	
185.0857	-11.57326	-0.4899998	

NORMAL TO THE STREAM WISE TURBULENCE			LOAD (II)
33.74503	0.9859797	-8.9999996E-02	
69.30721	11.98535	-0.3799999	

83.78282	2.210177	-9.9999994E-02
93.78316	-1.251643	0.0000000E+00
111.0155	-7.816012	0.0000000E+00
70.51902	37.09924	0.0000000E+00
NORMAL TO THE STREAM WISE TURBULENCE LOAD (III)		
24.84704	0.6591448	-7.0000000E-02
54.25040	2.348371	-9.9999994E-02
84.22152	-0.6929635	0.0000000E+00
104.8822	-2.318612	0.0000000E+00
121.4927	-5.991904	0.0000000E+00
-63.91520	155.6678	-3.9999999E-02
RADIAL TURBULENCE IN THE STREAM WISE FRAME OF REFERENCE LOAD (I)		
12.81684	-0.1174918	0.0000000E+00
4.197137	0.1841293	-6.0000002E-02
4.418582	6.5621808E-02	-3.9999999E-02
5.168373	-4.1104019E-02	0.0000000E+00
12.76661	-0.2778428	0.0000000E+00
31.53976	-3.5175975E-02	0.0000000E+00
RADIAL TURBULENCE IN THE STREAM WISE FRAME OF REFERENCE LOAD (II)		
10.27663	-0.1980785	0.0000000E+00
7.620205	0.7292318	-0.1400000
7.469252	-2.8945602E-02	0.0000000E+00
4.663478	6.4876452E-02	-5.0000001E-02
10.90699	-0.4482768	0.0000000E+00
16.86985	-0.6408295	0.0000000E+00
RADIAL TURBULENCE IN THE STREAM WISE FRAME OF REFERENCE LOAD (III)		
8.356174	0.4700263	-0.1400000
10.81633	0.2366472	-5.0000001E-02
12.36003	0.2894264	-8.9999996E-02
16.20257	-1.056903	0.0000000E+00
17.65823	-3.667861	0.0000000E+00
-19.28759	39.64366	-3.9999999E-02
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TURBULENCE IN THE TURBOMACHINERY FRAME OF REFERENCE		
AXIAL TURBULENCE LOAD (I)		
4.340009	0.2089548	-0.1200000
3.048548	8.1521228E-02	-2.9999999E-02
3.642787	-3.4539856E-02	0.0000000E+00
4.678803	2.1729939E-02	-2.0000000E-02
5.206666	1.8563824E-02	-2.0000000E-02
17.29436	0.2922769	-6.0000002E-02
AXIAL TURBULENCE LOAD (II)		
3.911682	0.2250757	-0.1400000
3.932340	0.3477162	-0.1400000
6.015635	4.1393917E-02	-2.0000000E-02
4.175701	-0.1750421	0.0000000E+00
3.926628	-6.3528068E-02	0.0000000E+00
8.476989	-0.1092342	0.0000000E+00
AXIAL TURBULENCE LOAD (III)		
5.734149	0.4616771	-0.2100000
5.042795	0.4977863	-0.1700000
7.347918	-2.8302595E-02	0.0000000E+00
8.285926	-0.2960219	0.0000000E+00
4.584484	7.3258579E-02	-6.0000002E-02
4.725072	2.8835401E-02	-2.0000000E-02

TANGENTIAL TURBULENCE LOAD (I)

46.76035	8.628736	-0.3899999
6.052070	0.2707854	-6.0000002E-02
4.045487	5.9361629E-02	-2.9999999E-02
4.437707	0.1731189	-0.1100000
4.702533	-1.4796973E-02	-9.9999998E-03
5.510456	8.0963753E-02	-5.0000001E-02

TANGENTIAL TURBULENCE LOAD (II)

36.62988	4.489258	-0.2700000
9.257919	0.8755079	-0.1600000
6.874717	0.2917920	-8.9999996E-02
4.241312	6.5072807E-03	-9.9999998E-03
3.838796	-4.0726524E-02	0.0000000E+00
5.049506	0.1027336	-7.9999998E-02

TANGENTIAL TURBULENCE LOAD (III)

402.9319	25.11561	-0.1300000
12.03795	0.4704031	-5.0000001E-02
11.40226	-0.1476128	0.0000000E+00
7.844687	2.1107229E-03	-9.9999998E-03
5.128540	0.1519830	-9.9999994E-02
5.511985	0.5129186	-0.2700000

RADIAL TURBULENCE IN THE TURBOMACHINERY FRAME OF REFERENCE LOAD (I)

14.31629	-0.1135820	0.0000000E+00
4.343603	0.1978222	-6.0000002E-02
4.239517	6.0957801E-02	-3.9999999E-02
4.553391	-4.5573197E-02	0.0000000E+00
10.18533	-0.2358895	0.0000000E+00
32.99831	0.3371916	-2.9999999E-02

RADIAL TURBULENCE IN THE TURBOMACHINERY FRAME OF REFERENCE LOAD (II)

10.89259	-0.2683237	0.0000000E+00
7.657675	0.7062110	-0.1300000
6.390439	2.7077207E-02	-9.9999998E-03
4.978460	4.6382483E-02	-3.9999999E-02
8.508156	-0.3449849	0.0000000E+00
20.21999	-0.7856730	0.0000000E+00

RADIAL TURBULENCE IN THE TURBOMACHINERY FRAME OF REFERENCE LOAD (III)

7.559957	0.2936100	-8.9999996E-02
7.652861	0.2027326	-2.9999999E-02
7.254046	0.3850819	-0.1200000
6.201210	0.1086276	-5.0000001E-02
8.287170	-0.2140114	0.0000000E+00
14.26342	-0.3673787	0.0000000E+00

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REYNOLDS STRESSES IN THE STREAM WISE FRAME OF REFERENCE

STREAM WISE REYNOLDS STRESSES LOAD (I)

5.8986163E-03	3.4706452E-04	-0.1700000
2.3481792E-02	-2.0016849E-03	0.0000000E+00
3.0592142E-02	-4.5790635E-03	0.0000000E+00
4.1224759E-02	-6.9142925E-03	0.0000000E+00
-0.1561744	0.2223849	-0.5299998
6.6976376E-02	-6.8030134E-03	-1.999998

STREAM WISE REYNOLDS STRESSES LOAD (II)

5.5231201E-03	5.3241785E-04	-0.2600001
1.6577289E-02	-9.7255781E-04	0.0000000E+00
5.3066075E-02	-5.3170864E-03	0.0000000E+00

5.1113270E-02	-1.0102811E-02	0.0000000E+00
-0.1108418	0.1633634	-0.5899997
1.6879704E-02	1.4984737E-02	0.0000000E+00

STREAM WISE REYNOLDS STRESSES LOAD (III)

5.3639156E-03	1.0968626E-03	-0.4599999
9.1419406E-03	-1.0735442E-04	0.0000000E+00
2.4315244E-02	-1.8028967E-03	0.0000000E+00
5.6250501E-02	-1.0357922E-02	0.0000000E+00
-9.1275997E-02	0.1629430	-0.6199997
-8.0996007E-02	0.1086714	-3.9999999E-02

NORMAL TO THE STREAM WISE REYNOLDS STRESSES LOAD (I)

4.9700574E-03	1.1503744E-05	-9.9999998E-03
4.0188660E-03	-3.0042656E-04	0.0000000E+00
3.9665527E-03	-5.8393896E-04	0.0000000E+00
6.0651051E-03	-8.2993007E-04	0.0000000E+00
-5.4860961E-02	7.9602383E-02	-0.5299998
4.8588153E-02	-4.9956213E-03	-1.9999998

NORMAL TO THE STREAM WISE REYNOLDS STRESSES LOAD (II)

2.7813625E-03	-5.0446513E-05	0.0000000E+00
3.6657399E-03	-1.0732766E-04	0.0000000E+00
9.6434262E-03	-1.0521273E-03	0.0000000E+00
8.2358001E-03	-1.4910881E-03	0.0000000E+00
-3.9393429E-02	6.0813185E-02	-0.5899997
4.2557097E-03	1.1827286E-02	0.0000000E+00

NORMAL TO THE STREAM WISE REYNOLDS STRESSES LOAD (III)

2.7535043E-03	1.8032861E-04	-0.1600000
2.5619797E-03	3.3434189E-05	-2.9999999E-02
6.8794922E-03	-5.7100982E-04	0.0000000E+00
1.2928528E-02	-2.1845121E-03	0.0000000E+00
-2.9501544E-02	4.7843825E-02	-0.6199997
-4.2305000E-02	5.6675907E-02	-3.9999999E-02

RADIAL REYNOLDS STRESSES IN THE STREAM WISE FRAME OF REFERENCE LOAD (I)

1.9392101E-03	6.8392204E-05	-9.9999994E-02
2.2215906E-03	-1.3975117E-04	0.0000000E+00
3.8646560E-03	-4.8425159E-04	0.0000000E+00
5.2569616E-03	-9.0896816E-04	0.0000000E+00
-5.5161808E-02	7.9217933E-02	-0.5399998
2.3682980E-02	-2.7914590E-03	-1.9999998

RADIAL REYNOLDS STRESSES IN THE STREAM WISE FRAME OF REFERENCE LOAD (II)

1.1532310E-03	1.7032873E-05	-3.9999999E-02
1.8061550E-03	-1.7824981E-05	0.0000000E+00
9.5894672E-03	-1.1646346E-03	0.0000000E+00
5.8585196E-03	-8.7334024E-04	0.0000000E+00
-3.2210574E-02	5.1013395E-02	-0.5899997
5.8290497E-03	9.1812359E-03	0.0000000E+00

RADIAL REYNOLDS STRESSES IN THE STREAM WISE FRAME OF REFERENCE LOAD (III)

9.8609854E-04	1.0001261E-04	-0.2500001
1.5471826E-03	-1.0896449E-05	0.0000000E+00
3.8994616E-03	-1.9149036E-04	0.0000000E+00
6.0436251E-03	-9.6185110E-04	0.0000000E+00
-2.0109609E-02	3.3362787E-02	-0.6199997
-3.1172449E-02	4.3280248E-02	-3.9999999E-02

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REYNOLDS STRESSES IN THE TURBOMACHINERY FRAME OF REFERENCE

AXIAL REYNOLDS STRESSES LOAD (I)

7.7496208E-03	1.7533360E-04	-5.0000001E-02
4.8216609E-03	-5.3915086E-05	0.0000000E+00
2.3915125E-03	-2.7415921E-05	0.0000000E+00
2.6044864E-03	2.3028504E-05	-3.9999999E-02
4.0892484E-03	-3.4142049E-05	0.0000000E+00
4.0660682E-03	3.7390016E-06	0.0000000E+00

AXIAL REYNOLDS STRESSES LOAD (II)

8.7060491E-03	8.6974818E-04	-0.2500001
6.3984841E-03	1.9015062E-05	0.0000000E+00
7.3595662E-03	6.5403525E-05	-2.9999999E-02
3.0222384E-03	-6.5592692E-05	0.0000000E+00
3.0122022E-03	-8.3341729E-05	0.0000000E+00
3.8288899E-03	3.6161829E-05	-3.9999999E-02

AXIAL REYNOLDS STRESSES LOAD (III)

1.1658844E-02	5.1825756E-04	-0.1100000
9.1135232E-03	1.0433946E-04	-9.9999998E-03
1.5390814E-02	-6.1803136E-04	0.0000000E+00
8.3716903E-03	-1.8649362E-04	0.0000000E+00
4.2480459E-03	-1.1734353E-05	-9.9999998E-03
4.2154812E-03	2.9646928E-04	-0.2200000

TANGENTIAL REYNOLDS STRESSES LOAD (I)

9.8299664E-03	-5.8337464E-05	0.0000000E+00
1.5305800E-03	9.3114140E-05	-7.0000000E-02
1.1784671E-03	2.1942957E-05	-5.0000001E-02
8.7183545E-04	4.3962618E-06	-3.9999999E-02
1.8470872E-03	-9.3785362E-05	0.0000000E+00
1.6302633E-03	7.8047677E-05	-0.1600000

TANGENTIAL REYNOLDS STRESSES LOAD (II)

5.6705400E-03	-2.7936045E-04	0.0000000E+00
2.7792021E-03	3.1589967E-04	-0.1500000
2.1120820E-03	1.1809039E-05	-2.0000000E-02
8.9311722E-04	8.3092318E-06	-3.9999999E-02
1.3699589E-03	-7.0234521E-05	0.0000000E+00
1.2593258E-03	-3.2097028E-05	0.0000000E+00

TANGENTIAL REYNOLDS STRESSES LOAD (III)

2.9643187E-03	8.2091872E-05	-6.0000002E-02
2.9574700E-03	1.0731009E-04	-5.0000001E-02
2.9380547E-03	-6.4284359E-06	-9.9999998E-03
1.5587468E-03	1.0443399E-05	-2.9999999E-02
1.1449702E-03	-8.0335330E-06	-9.9999998E-03
1.3192125E-03	2.0300871E-05	-6.0000002E-02

RADIAL REYNOLDS STRESSES IN THE TURBOMACHENRY FRAME OF REFERENCE LOAD (I)

3.5178396E-03	-2.6473106E-05	0.0000000E+00
1.0822207E-03	2.1678410E-05	-2.0000000E-02
8.2011812E-04	8.7428843E-06	-2.9999999E-02
8.6082600E-04	3.8825210E-06	-2.9999999E-02
1.9984469E-03	-5.8884420E-05	0.0000000E+00
1.9350655E-03	1.1914664E-04	-0.2000000

RADIAL REYNOLDS STRESSES IN THE TURBOMACHENRY FRAME OF REFERENCE LOAD (II)

2.8585345E-03	-5.6564386E-05	0.0000000E+00
1.9803343E-03	1.1039385E-04	-7.9999998E-02
2.1709446E-03	3.9694019E-06	-2.0000000E-02

6.8336178E-04 3.3208173E-06 -2.9999999E-02
1.8178081E-03 -9.3454932E-05 0.0000000E+00
1.6192336E-03 -6.3784020E-05 0.0000000E+00
RADIAL REYNOLDS STRESSES IN THE TURBOMACHENRY FRAME OF REFERENCE LOAD
(III)

1.9198974E-03 6.8179266E-05 -7.9999998E-02
2.3298177E-03 2.7478420E-05 -9.9999998E-03
3.0210454E-03 -3.3272659E-05 0.0000000E+00
2.0971249E-03 1.2729104E-05 -2.9999999E-02
1.6230970E-03 -4.0469888E-05 0.0000000E+00
1.9958820E-03 2.3256173E-06 -2.0000000E-02
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CONSTANT FOR THE DECAY OF VELOCITY COMPONENTS IN THE STREAM WISE FRAME
OF REFERENCE IN THE DISTORTION MODE AT B.M.H.

8.8907138E-02 4.2125965E-03 -0.1400000 CIR. POS. (5)
9.3898624E-02 6.0326825E-03 -0.1700000 CIR. POS. (4)
7.8936391E-02 4.1317353E-03 -0.1400000 CIR. POS. (3)
9.1240488E-02 4.5242095E-03 -0.1400000 CIR. POS. (2)
0.1167885 6.2978249E-03 -0.1500000 CIR. POS. (1)
9.1618575E-02 5.6833420E-03 -0.1700000 CIR. POS. (8)
8.5524678E-02 3.7135796E-03 -0.1200000 CIR. POS. (7)
8.6942025E-02 4.7025559E-03 -0.1500000 CIR. POS. (6)
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NORMAL TO STREAM WISE VELOCITY CONSTANTS
IN THE DISTORTION MODE

3.2173559E-02 1.0868858E-03 -9.9999994E-02
3.9483648E-02 3.4555027E-03 -0.2300000
2.8157836E-02 1.2960628E-03 -0.1300000
2.8158922E-02 2.8048400E-04 -2.0000000E-02
2.3939900E-02 8.3676458E-04 -8.9999996E-02
3.1570572E-02 1.5014175E-03 -0.1300000
3.0877503E-02 5.2424520E-04 -3.9999999E-02
3.4437649E-02 2.4045398E-03 -0.1900000
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RADIAL VELOCITY CONSTANTS IN THE DISTORTION MODE

3.5176348E-02 9.4030017E-04 -7.9999998E-02
3.3624694E-02 1.0258007E-03 -7.9999998E-02
3.7000354E-02 8.9826604E-04 -6.0000002E-02
3.4433704E-02 -8.1249294E-05 0.0000000E+00
3.9587103E-02 2.6773929E-04 -9.9999998E-03
3.4854166E-02 6.7004364E-04 -5.0000001E-02
3.5231154E-02 9.0313947E-04 -7.0000000E-02
3.2661743E-02 9.7515888E-04 -7.9999998E-02
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AXIAL VELOCITY CONSTANTS IN THE TURBOMACHINER FRAME OF REFERENCE IN
THE DISTORTION MODE.

4.4838805E-02 6.1849464E-04 -3.9999999E-02
4.8730973E-02 1.4253226E-03 -7.9999998E-02
4.4010900E-02 9.1231545E-04 -5.0000001E-02
5.7340302E-02 1.0575249E-03 -5.0000001E-02
6.9316819E-02 1.5890247E-03 -6.0000002E-02
5.1876862E-02 1.7670679E-03 -8.9999996E-02
4.8757058E-02 8.4632746E-04 -5.0000001E-02
4.4470068E-02 8.4544934E-04 -5.0000001E-02

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RELATIVE TANGENTIAL VELOCITY CONSTANTS IN THE DISTORTION MODE.

3.5740033E-02	7.2517392E-04	-6.0000002E-02
4.0330283E-02	1.7956872E-03	-0.1200000
3.4596704E-02	1.0256901E-03	-7.9999998E-02
4.3346580E-02	2.3666620E-03	-0.1500000
5.8568157E-02	2.4628690E-03	-0.1100000
4.0519964E-02	2.1628621E-03	-0.1400000
3.7057374E-02	6.9406012E-04	-5.0000001E-02
3.5411887E-02	6.7259977E-04	-5.0000001E-02

=====

RADIAL VELOCITY CONSTANTS IN THE TURBOMACHINERY
FRAME OF REFERENCE IN THE DISTORTION MODE.

2.4925711E-02	2.9097375E-04	-2.9999999E-02
2.5638392E-02	5.5644364E-04	-6.0000002E-02
2.8331885E-02	2.8831765E-04	-2.9999999E-02
3.0497123E-02	-1.6989224E-04	0.0000000E+00
3.3946317E-02	5.6866789E-05	0.0000000E+00
2.7456082E-02	3.5845977E-04	-2.9999999E-02
2.6850570E-02	4.1761683E-04	-3.9999999E-02
2.4107294E-02	4.0147835E-04	-3.9999999E-02

=====

APPENDIX (20)

```

PROGRAM LOCAL SLOPE
DIMENSION R(6),Y(6)
DATA R/.125,.15,.175,.2,.225,.25/
PRINT *, 'ENTER NUMBER OF POINTS'
N=6
READ(1,')(Y(I),I=1,N)
PRINT ', 'ENTER RADIAL POSITION AND ITS VALUE'
DO K=1,6
  FF=0.0
  DO 10 I=1,N
    FL=0.0
    DO 20 J=1,N
      IF(J.EQ.I)GO TO 20
      F=1/(R(I)-R(J))
      DO 30 RR=1,N
        IF(RR.EQ.I.OR.RR.EQ.J)GO TO 30
        F=F*((R(K)-R(RR))/(R(I)-R(RR)))
30      CONTINUE
      FL=FL+F
20      CONTINUE
      FF=FF+FL*Y(I)
10      CONTINUE
    WRITE(2,*) 'FOR R(K) = ',R(K), 'LOCAL SLOPE IS ',FF
  END DO
  STOP
END

```


APPENDIX (21)

RESULTS OF RADIUS = 0.1250000

GROUP 111.0000

T R I A L N U M B E R 12

C O N V E R G E N C E = T

1.306048 -1.053986 .3690547 1.8840669E-02 1.353239 -.1355313

7.8216918E-02 -1.0104918E-02

RESULTS OF RADIUS = 0.1500000

GROUP 211.0000

T R I A L N U M B E R 7

C O N V E R G E N C E = T

1.644533 -.1861853 0.2093810 1.2456563E-02 1.690371 -.1873598

3.9387782E-02 -1.1489998E-02

RESULTS OF RADIUS = 0.1750000

GROUP 311.0000

T R I A L N U M B E R 7

C O N V E R G E N C E = T

1.593688 -.1489767 0.3349171 2.0115413E-02 1.615405 -.1477933

3.0850191E-02 -7.8140544E-03

RESULTS OF RADIUS = 0.2000000

GROUP 411.0000

T R I A L N U M B E R 9

C O N V E R G E N C E = T

1.488850 -.1202839 0.4669361 2.0281298 1.502328 -.1211136

3.0949740E-02 -4.8329988E-03

RESULTS OF RADIUS = 0.2250000

GROUP 511.0000

T R I A L N U M B E R 11

C O N V E R G E N C E = T

1.335154 -9.9494934E-02 0.4914548 2.4658920E-02 1.302776 -9.4107099E-02

4.4210952E-02 -5.5890065E-03

RESULTS OF RADIUS = 0.2500000

GROUP 611.0000

TRIAL NUMBER 6

CONVERGENCE = T

 0.9115400 -8.1868909E-02 0.5270855 2.7101178E-02 .8050221 -7.3911659
 9.0586677E-02 -1.1701908E-02

RESULTS OF RADIUS = 0.1250000
 GROUP 121.0000

TRIAL NUMBER 7

CONVERGENCE = T

 1.58382 -.1014239 0.3562715 1.9134384E-02 1.268246 -0.1488215
 0.1018097 -1.1298021E-02

RESULTS OF RADIUS = 0.1500000
 GROUP 221.0000

TRIAL NUMBER 37

CONVERGENCE = T

 1.710821 -.1865207 0.2211794 1.2727764E-02 1.611351 -.1821508
 5.0848532E-02 -1.2179776E-02

RESULTS OF RADIUS = 0.1750000
 GROUP 321.0000

TRIAL NUMBER 6

CONVERGENCE = T

 1.611219 -.1539347 0.3469957 2.1527670E-02 1.594864 -.1411448
 3.4787454E-02 -8.7009184E-03

RESULTS OF RADIUS = 0.2000000
 GROUP 421.0000

TRIAL NUMBER 6

CONVERGENCE = T

 1.488993 -.1256672 0.4240352 2.2170063E-02 1.493269 -.114468
 3.1959713E-02 -6.8321484E-03

RESULTS OF RADIUS = 0.2250000
 GROUP 521.0000

TRIAL NUMBER 9

CONVERGENCE = T

1.36437 -.1119069 0.4962147 2.1802917E-02 1.355199 -8.9228876E-02
3.6805848E-02 -5.3214943E-03

RESULTS OF RADIUS = 0.2500000
GROUP 621.0000

TRIAL NUMBER 9

CONVERGENCE = T

0.8144118 -9.2014059E-02 0.5296071 2.6745496E-02 1.032726 -6.6153795E-02
7.7358276E-02 -8.4547456E-03

RESULTS OF RADIUS = 0.1250000
GROUP 131.0000

TRIAL NUMBER 12

CONVERGENCE = T

1.164464 -.1412281 0.3665032 1.8723074E-02 1.158268 -.1651362
0.1298611 -1.3289995E-02

RESULTS OF RADIUS = 0.1500000
GROUP 231.0000

TRIAL NUMBER 8

CONVERGENCE = T

1.351555 -0.1714064 0.3665032 1.8723074E-02 1.424622 -.1768048
0.1287597 -2.1237357E-02

RESULTS OF RADIUS = 0.1750000
GROUP 331.0000

TRIAL NUMBER 13

CONVERGENCE = T

1.407744 -.1437909 0.4496725 1.1291000E-02 1.430009 -.127137
7.8957140E-02 -1.5060331E-02

RESULTS OF RADIUS = 0.2000000
GROUP 431.0000

TRIAL NUMBER 9

CONVERGENCE = T

1.425343 -.126045 0.5226020 1.8784103E-02 1.444465 -.1143607
4.3255422E-02 -7.1286927E-03

RESULTS OF RADIUS = 0.2250000
GROUP 531.0000

TRIAL NUMBER 20

CONVERGENCE = T

1.355019 -9.8371454E-02 0.4962147 2.1802317E-02 1.360135 -9.12987E-02
3.9852392E-02 -6.1634625E-03

RESULTS OF RADIUS = 0.2500000
GROUP 631.0000

TRIAL NUMBER 6

CONVERGENCE = T

1.40566 -8.7430872E-02 0.5262387 2.7411019E-02 1.097565 -7.160229E-02
8.4775813E-02 -8.6414833E-03

RESULTS OF RADIUS = 0.1875000
GROUP 105.0000

TRIAL NUMBER 7

CONVERGENCE = T

2.1876317E-02 3.773344 -1.8346243E-02 6.1130039E-03 6.5847933E-02
0.7063992 0.2169369 -1.596682

RESULTS OF RADIUS = 0.1875000
GROUP 104.0000

TRIAL NUMBER 6

CONVERGENCE = T

2.0350713E-02 3.742180 -1.7640809E-02 5.9443167E-03 6.6352688E-02
0.6887640 0.2779152 -2.092461

RESULTS OF RADIUS = 0.1875000
GROUP 103.0000

TRIAL NUMBER 6

CONVERGENCE = T

3.3097940E-03 1.145947 -2.1090718E-02 5.6062643E-03 5.7143725E-02
0.8071093 0.1494249 -0.9767588

RESULTS OF RADIUS = 0.1875000
GROUP 102.0000

TRIAL NUMBER 7

CONVERGENCE = T

-1.8104224E-02 -1.282783 -2.1318406E-02 5.1048989E-03 5.2043408E-02
 0.8565111 0.1788911 -1.114328

RESULTS OF RADIUS = 0.1875000

GROUP 101.0000

TRIAL NUMBER 8

CONVERGENCE = T

0.7096257 -0.7601724 -1.6825033E-02 0.5343342 3.119751
 1.428214 -6.3173281E-04 1.2377993E-04

RESULTS OF RADIUS = 0.1875000

GROUP 108.0000

TRIAL NUMBER 6

CONVERGENCE = T

-2.1197414E-02 -1.641379 -2.1815361E-02 4.9076760E-03 5.0802723E-02
 0.8572683 0.1227840 -0.7749743

RESULTS OF RADIUS = 0.1875000

GROUP 107.0000

TRIAL NUMBER 6

CONVERGENCE = T

8.4584975E-04 0.9938884 -2.0848697E-02 5.5288789E-03 5.6341857E-02
 0.8276074 0.1537330 -0.9796228

RESULTS OF RADIUS = 0.1875000

GROUP 106.0000

TRIAL NUMBER 5

CONVERGENCE = T

7.4637053E-03 1.655646 -1.5015195E-02 6.5727234E-03 6.4082183E-02
 0.6103669 0.6419203 -5.428127

Appendix (22)

```

PROGRAM DRAW
INTEGER RAKM(200),CD
REAL M(800),MM(800),M1(800)
CHARACTER'4 REC
DIMENSION
D(800),E(800),B(800),S(800),SC1(9),SC2(9),XX(9)
1,YY(9),DD(800),BB(800),EE(800),D1(800),B1(800),E1(800)
1,SS(800),S1(800)
CALL CC1012
CALL DEVSPE(4800)
CALL DEVPAP(360.,270.,0)
CALL PICCLE
CALL WINDO2(0.0,360.,0.0,270.)
READ(3,')(SC1(KMX),SC2(KMX),KMX=1,4)
CALL PENSEL(1,0.0,0)
CALL MOVTO2(20.,20.)
CALL LINBY2(255.,0.0)
CALL LINBY2(0.0,170.)
CALL LINBY2(-255.,0.0)
CALL LINBY2(0.0,-170.)
CALL MOVTO2(20.,40.)
CALL LINBY2(255.0,0.0)
DO I=1,3
FCD=37.5'I+40.0
CALL MOVTO2(20.0,FCD)
CALL LINBY2(255.0,0.0)
END DO
DO I=1,6
FCDD=I'36.42+20
CALL MOVTO2(FCDD,40.0)
CALL LINBY2(0.0,150.)
END DO
CALL CHAANG(90.0)
CALL MOVTO2(15.0,150.)
CALL PENSEL(2,0.0,0)
CALL CHASIZ(2.5,2.5)
CALL CHAHOL(16H DISP. THICK'.)
CALL MOVTO2(15.0,40.)
CALL PENSEL(4,0.0,0)
CALL CHAHOL(44H MOM.
THICK'.)
CALL MOVTO2(15.0,40.)
CALL PENSEL(3,0.0,0)
CALL CHAHOL(30H ENERGY THICK'.)
CALL MOVTO2(15.0,40.0)
CALL CHAHOL(28H SHAPE FACTOR '.)
CALL CHAANG(0.0)
CALL CHASWI(0)
DO J=1,7
CALL CHASIZ(1.5,1.7)
IF(J.GT.1)NI=6
IF(J.EQ.1)NI=5
DO I=1,NI
DO K=1,3
READ(1,')D(K),M(K),E(K),S(K)

```


20

```

READ(2,' )B(K)
DD((I-1)'3+K)=D(K)
MM((I-1)'3+K)=M(K)
EE((I-1)'3+K)=E(K)
SS((I-1)'3+K)=S(K)
BB((I-1)'3+K)=B(K)
END DO
END DO
DO NN=1,NI
DO NB=1,3
D1(NB)=DD((NN-1)'3+NB)
B1(NB)=BB((NN-1)'3+NB)
END DO
KMC=1
MK=4
XX(J)=(J-1)'36.42+22.42
YY(J)=(MK-1)'37.5+42.5
IF(NN.GT.1)GO TO 20
CALL AXIPOS(0,XX(J),YY(J),33.0,1)
CALL AXIPOS(0,XX(J),YY(J),34.0,2)
CALL AXISCA(3,3,0.0,10.0,1)
CALL AXISCA(3,3,SC1(KMC),SC2(KMC),2)
CALL AXIDRA(+1,1,1)
CALL AXIDRA(-1,-1,2)
NL=NN
IF(NL.EQ.5)NL=1
IF(NL.EQ.6)NL=2
CALL PENSEL(NL,0.0,0)
WRITE(7,' )'B1,D1',(B1(JG),D1(JG),JG=1,3)
CALL GRASYM(B1,D1,3,NN,0)
CALL GRAPOL(B1,D1,3)
WRITE(' ',' )'NN',NN
END DO
DO NN=1,NI
DO NB=1,3
M1(NB)=MM((NN-1)'3+NB)
B1(NB)=BB((NN-1)'3+NB)
END DO
KMC=2
MK=3
XX(J)=(J-1)'36.42+22.42
YY(J)=(MK-1)'37.5+42.5
IF(NN.GT.1)GO TO 30
CALL AXIPOS(0,XX(J),YY(J),33.0,1)
CALL AXIPOS(0,XX(J),YY(J),34.0,2)
CALL AXISCA(3,3,0.0,10.0,1)
CALL AXISCA(3,3,SC1(KMC),SC2(KMC),2)
CALL AXIDRA(+1,1,1)
CALL AXIDRA(-1,-1,2)
NL=NN
IF(NL.EQ.5)NL=1
IF(NL.EQ.6)NL=2
CALL PENSEL(NL,0.0,0)
WRITE(7,' )'B1,M1',(B1(JG),M1(JG),JG=1,3)
CALL GRASYM(B1,M1,3,NN,0)

```

30


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CALL GRAPOL(B1,M1,3)
END DO
DO NN=1,NI
DO NB=1,3
E1(NB)=EE((NN-1)'3+NB)
B1(NB)=BB((NN-1)'3+NB)
END DO
KMC=3
MK=2
XX(J)=(J-1)'36.42+22.42
YY(J)=(MK-1)'37.5+42.5
IF(NN.GT.1)GO TO 40
CALL AXIPOS(0,XX(J),YY(J),33.0,1)
CALL AXIPOS(0,XX(J),YY(J),34.0,2)
CALL AXISCA(3,3,0.0,10.0,1)
CALL AXISCA(3,3,SC1(KMC),SC2(KMC),2)
CALL AXIDRA(+1,1,1)
CALL AXIDRA(-1,-1,2)
40 NL=NN
IF(NL.EQ.5)NL=1
IF(NL.EQ.6)NL=2
CALL PENSEL(NL,0.0,0)
WRITE(7,')'B1,E1',(B1(JG),E1(JG),JG=1,3)
CALL GRASYM(B1,E1,3,NN,0)
CALL GRAPOL(B1,E1,3)
END DO
DO NN=1,NI
DO NB=1,3
S1(NB)=SS((NN-1)'3+NB)
B1(NB)=BB((NN-1)'3+NB)
END DO
KMC=4
MK=1
XX(J)=(J-1)'36.42+22.42
YY(J)=(MK-1)'37.5+42.5
IF(NN.GT.1)GO TO 50
CALL AXIPOS(0,XX(J),YY(J),33.0,1)
CALL AXIPOS(0,XX(J),YY(J),34.0,2)
CALL AXISCA(3,3,0.0,10.0,1)
CALL AXISCA(3,3,SC1(KMC),SC2(KMC),2)
CALL AXIDRA(+1,1,1)
CALL AXIDRA(-1,-1,2)
50 NL=NN
IF(NL.EQ.5)NL=1
IF(NL.EQ.6)NL=2
CALL PENSEL(NL,0.0,0)
WRITE(7,')'B1,S1',(B1(JG),S1(JG),JG=1,3)
CALL GRASYM(B1,S1,3,NN,0)
CALL GRAPOL(B1,S1,3)
END DO
END DO
CALL CHASIZ(3.0,2.0)
CALL ITALIC(12.0)
CALL MOVTO2(87.5,33.0)
CALL PENSEL(1,0.0,0)

```



```

      CALL CHAHOL(52HF'LIG  FLOW THICKNESSES VARIATION WITH
THE INCS
      1. '.)
      CALL MOVTO2(95.0,22.5)
      CALL CHAHOL(40H'U  AND THE STREAM WISE DISTANCE  '.)
      CALL CHASWI(0)
      CALL DEVEND
      STOP
      END
      FUNCTION FMAX(B1,MIN)
      DIMENSION B1(138)
      FMAX=-1.0E20
      DO 10 NCASE=1,MIN
      IF(FMAX.LT.B1(NCASE))FMAX=B1(NCASE)
10  CONTINUE
      RETURN
      END
      FUNCTION FMIN(B1,MIN)
      DIMENSION B1(138)
      FMIN=1.0E20
      DO 10 NCASE=1,MIN
      IF(FMIN.GT.B1(NCASE))FMIN=B1(NCASE)
10  CONTINUE
      RETURN
      END

```