## IMPEDANCE MATCHING IN

## AURAL PROSTHESIS

Bу

PAUL WAYNE WHALEY

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1971

Submitted to the Faculty of the Graduate College of the Oklahoma State University in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE May, 1973

OKLAHOMA STATE UNIVERSITI LIBRARY

OCT 9 1973

## IMPEDANCE MATCHING IN

## AURAL PROSTHESIS

Thesis Approved:

Adviser Thes M

Dean of the Graduate College

#### PREFACE

The purpose of this work was to determine whether impedance matching concepts could yield significant improvements in aural prosthesis. This did not imply the design of an appropriate device to achieve such a match.

One problem with considerations of impedance of human ears is the absence of reliable methods to measure impedance offered to hearing aids at high frequencies. For this reason, a device had to be developed that could be used to measure impedance at higher frequencies.

This work was supported by a Biomedical Sciences grant from the OSU Research Foundation and by the OSU Center for the Systems Science. This support made possible the purchase of equipment used in the experimental phase of the work. My special thanks go to my thesis adviser, Dr. Larry Zirkle, who provided many helpful suggestions and comments. Also, thanks are in order to the OSU Library and Computer Center for their assistance. My thanks go to Dr. Richard Lowery for his valuable assistance with the instrumentation. Special gratitude is extended to my wife, Karen Whaley, for her assistance with the rough draft copies and for her patience and sacrifice during the long hours spent in the laboratory. A note of thanks is given to Mrs. Lynn Danvers for her comments on the manuscript and preparation of the final copy.

## TABLE OF CONTENTS

Chapter		Page
1.	INTRODUCTION	1
	Hearing Aid Fitting	1
	Impedance Matching , , . ,	2
	Objectives and Procedures	3
II.	MATHEMATICAL MODEL ,	7
	Physical Model	7
	Derivation of Equations	7
	Model Parameters	12
	Matching Impedances	13
III.	EXPERIMENTAL PROCEDURE	24
	Introduction	24
	Impedance Measuring Device	25
	Calibration Procedure	27
	Measurement Procedure	29
	Discussion of Results	33
IV.	CONCLUSIONS	39
	Summary	39
	Recommendations	40
SELECTEI	D BIBLIOGRAPHY ,,	42
APPENDIX	ES,,,,,,,	44
<b>A.</b>	COMPUTER PROGRAMS	45
в.	CALIBRATION CURVES AND MODEL IMPEDANCE	
	CURVES AS A FUNCTION OF DISTANCE	61

# LIST OF FIGURES

Figure		Page
1.	Mathematical Model	8
2.	Parts of the Ear , , ,	8
3.	Free Body Diagram of Eardrum Model	11
4.	Acoustical Impedance for Mathematical Model in CGS Ohms	14
5.	Impedance Matching Device , ,	15
6.	Computer Results	<b>2</b> 1
7.	Performance of Impedance Matching Device ,	22
8.	Acoustical Impedance Measuring Device	26
9,	Calibration Procedure , ,	28
10.	Measurement Setup	30
11.	Photograph of Experimental Setup	30
12.	Wiring Diagram for Testing Session	31
13.	Acoustical Impedance of Human Ear for Two Different Sessions With Beat Phenomenon	34
14.	Acoustical Impedance of Human Ear for Two Sessions Without Beat Phenomenon	35
15.	Drawing Representing How Far Into the Ear Canal the Ear Mold Goes	36

## NOMENCLATURE

k	spring constant in mathematical model
m	piston mass in mathematical model
Ъ	damping coefficient in mathematical model
P <sub>i</sub>	incident pressure wave
Pr	reflected pressure wave
ω	radian frequency of pressure wave
c	speed of sound in air
K	wave number, $\omega/c$
xx	distance from eardrum
U	volume velocity
A	area of piston in mathematical model
L	length of tube in mathematical model
Zo	input acoustical impedance of mathematical model
Α	amplitude of incident pressure wave
В	amplitude of reflected pressure wave
Ze	acoustical impedance at the piston of the mathematical
	model
al	length of acoustical impedance matching device
R <sub>T</sub>	radius of acoustical impedance matching device

Rad	radius of hole drilled in wall of impedance matching
	device
λ	wave length of pressure wave
L	generalized inductance
C	generalized capacitance
v	volume
P	power
R <sub>e</sub>	resistance of mathematical model
x <sub>e</sub>	reactance of mathematical model
p <sub>r</sub>	reference pressure
<sup>p</sup> k	source calibration pressure
G <sub>s</sub> (jw)	transfer function of source probe
Øs	phase angle between $p_r$ and $p_k$
U <sub>k</sub>	volume velocity through coupler cavity
<sup>p</sup> m	microphone calibration pressure frequency response
$G_{m}^{(j_w)}$	probe microphone transfer function
Øm	phase angle between $p_r$ and $p_m$
G <sub>mm</sub> (j <sub>ω</sub> )	overall measured transfer function for impedance
ø <sub>mm</sub>	overall measured phase shift for impedance
<sup>p</sup> e	pressure inside ear canal

## CHAPTER I

## INTRODUCTION

### Hearing Aid Fitting

Conventional hearing aid fitting follows a procedure developed by Davis<sup>1</sup> in 1947. At the end of World War II many servicemen were returning home with hearing impairments, and there was no general technique of hearing aid fitting. The procedure that was developed was one which relied heavily on trial and error using audiogram data as a guide. All patients were fitted with hearing aids possessing the same basic types of frequency response curves, specified by slightly differing slopes.

Present-day hearing aid fitting is hampered by technical difficulties. It has been suggested that aural prosthesis should be accomplished with hearing aids having wider frequency ranges and less harmonic distortion.<sup>2</sup> This would provide better hearing aid performance for the patient whose hearing loss is in higher frequencies and would provide music enjoyment for the hard of hearing.<sup>3</sup> Technical improvements are needed so that these improvements can be made possible. The performance characteristics of hearing aids are measured by connecting them to acoustical cavities which approximate the imaginary part of human ear impedance. These cavities, known as artificial ears, represent the average of many human ears, and any single person's hearing might not conform to that average. Consequently, the hearing aid may not perform the same in the real ear as it did in the artificial ear, and the audiologist may not really know whether the hearing aid is effective or not. Since artificial ears used in testing hearing aid esign indicates some consideration of the loading effect of the ear. This attempt is not successful, however, as artificial ears include only a reactive component of impedance. Basic considerations of impedance matching should be included in aural prosthesis.

#### Impedance Matching

Any sort of improvement in aural prosthesis must be undertaken from a scientific point of view as the human ear is an extremely complicated mechanism. Hearing is dynamic in nature and has been characterized as nonlinear and unsymmetric, qualities that can best be analyzed by engineering methods.<sup>4</sup> Many peculiarities have been noted about the hearing mechanism, not the least of which is the wide range of sound intensities that can be heard by the healthy ear. The acoustic reflex protects the ear from extremely loud sounds by contraction of the middle ear muscles, and the middle ear ossicles are known to

vibrate in two distinct stable modes, <sup>5</sup> The human ear has three degrees of freedom for positive pressures and only one degree of freedom for negative pressures, <sup>6</sup> Such a complicated mechanism can have a large variety of things go wrong, and yet audiologists must attempt to correct this wide variety of defects with hearing aids of the same basic type.

When the output impedance of the hearing aid is matched to the input impedance of the ear, maximum power will be transferred. Experience has shown that this impedance match improves the performance of the entire system. Therefore, in addition to improvements in power requirements, there would be improvements in dynamic qualities. The power requirements of the hearing aid might be made smaller, its dynamic characteristics could be improved, and the audiologist would have more complete information regarding the performance of the hearing aid in the actual ear.

#### **Objectives and Procedures**

It is the intention of this thesis to determine if improvements in hearing aid performance are possible by means of impedance matching. This will be done by establishing a mathematical model of the human ear to determine those parameters that are important in input impedance to the human ear. The parameters of this model are determined from existing data on the properties of the middle ear, and then adjusted after computations to make the model more like a real ear.

The input acoustical impedance of a human ear is measured and compared to the input acoustical impedance of the mathematical model. Results show that the model impedance is similar to a real ear.

An acoustical device is proposed which might be used to match the output impedance of the transducer to the input impedance of the ear. This device is similar to the tubes that connect conventional hearing aid receivers to the ear with a few additions, so the resulting impedance match is representative of what probably exists in hearing aids. The impedance match is attempted by a curve fit on the computer to determine the properties of the proposed device that represent optimum behavior. The quality of the impedance match by this device is rather poor.

Chapter III describes the measurement of ear impedance on a human subject, and results are given which are similar to that found in the literature. Certain variables are suggested as an explanation for the wide discrepancies observed in ear impedance, and it becomes obvious that impedance matching must reflect these periodic fluctuations. Therefore, impedance matching becomes the fitting of the device into some acceptable band of impedances that are found by a statistical analysis of human ear impedance.

A nonlinear phenomenon was discovered during testing which has not been reported before. The subject heard beats when the stimulus signal was a pure tone, and it is believed that these beats result from either almost periodicity or the superposition of a subharmonic signal

on the primary signal to cause periodic fluctuations which sound like beats.

Chapter IV is a summary of the work done and conclusions that were reached. Recommendations are given for future research on impedance matching in aural prosthesis.

#### FOOTNOTES

<sup>1</sup>H. Davis, <u>Hearing Aids: An Experimental Study of Design</u> Objectives, (Cambridge, Massachusetts, 1947).

<sup>a</sup>Anne Harrison, "Better Amplifying Prosthesis," <u>Journal of the</u> <u>Audio Engineering Society</u>, Vol. 19, April, 1971, pp. 316-318.

<sup>3</sup> Ibid.

<sup>4</sup>Georg Von Bekesy, "The Mechanical Properties of the Ear," in S. S. Stevens (ed.), <u>Handbook of Experimental Psychology</u> (New York, 1960), pp. 1086-1087.

<sup>5</sup>Ibid.

<sup>6</sup>Ibid.

#### CHAPTER II

### MATHEMATICAL MODEL

## Physical Model

The model that will be used here consists of a cylinder terminated at its right end with a piston that is connected to a spring and damper (Figure 1). Certainly the behavior of a membrane should be more like the real ear than that of a piston, but a damped inner boundary condition on a membrane model makes it difficult to solve the resulting eigenvalue problem. This simplification was necessary in order to obtain a solution to the resulting equations, and since the eardrum behaves like a piston at frequencies below 1000 hz., the simplification is justified.<sup>1</sup> It is felt that this model can be made to behave sufficiently like the real ear (Figure 2) by appropriate adjustment of the physical parameters. Although the ear is known to behave nonlinearly, this nonlinear effect is small for low intensities and may be neglected.

#### Derivation of Equations

The input acoustical impedance of the mathematical model may be determined in terms of known quantities in Figure 1. The



k = spring constant b = damping coefficient
m = piston mass xx = distance to eardrum
Figure 1. Mathematical Model



Figure 2. Parts of the Ear<sup>2</sup>

mechanical impedance at the right end is denoted by  $Z_e$ . When incident sound waves enter the cylinder, some are reflected from the right end and some are transmitted. Denoting those quantities incident by subscript i and those reflected by subscript r, the acoustical impedance at a distance x becomes

$$Z = \frac{\mathbf{P}_{i} + \mathbf{P}_{r}}{\mathbf{U}_{i} + \mathbf{U}_{r}}$$
(1)

where

 $P_{i} = A e^{j(\omega t - Kx)}$   $P_{r} = B e^{j(\omega t + Kx)}$  p = pressure  $\omega = angular velocity$   $K = wave number, \omega/c$  xx = distance

The volume velocities may be related to the pressures for plane waves

as

$$U_{i} = \frac{P_{i}A_{1}}{\rho c} , U_{r} = \frac{-P_{r}A_{1}}{\rho c}$$

where

$$A_1 = area$$
  
 $\rho = density of air$   
 $c = speed of sound in air$ 

The insertion of these relationships into Equation (1) yields

$$Z_{o} = \frac{Ae^{-jKx} + Be^{jKx}}{Ae^{-jKx} - Be^{jKx}}, \frac{\rho c}{A_{1}}$$
(2)

In terms of the coordinate system indicated, there are two equations that result from applying boundary conditions:

$$Z|_{\mathbf{x}=\mathbf{0}} = \frac{\mathbf{A} + \mathbf{B}}{\mathbf{A} - \mathbf{B}} \cdot \frac{\mathbf{\rho}\mathbf{c}}{\mathbf{A}_{\mathbf{1}}}$$
(3)

$$Z|_{\mathbf{x}=\boldsymbol{\ell}} = Z_{\mathbf{e}} = \frac{\mathbf{A} e^{-j\mathbf{K}\boldsymbol{\ell}} + \mathbf{B} e^{j\mathbf{K}\boldsymbol{\ell}}}{\mathbf{A} e^{-j\mathbf{K}\boldsymbol{\ell}} - \mathbf{B} e^{j\mathbf{K}\boldsymbol{\ell}}} \cdot \frac{\rho c}{\mathbf{A}_{\mathbf{1}}}$$
(4)

By combining Equations (3) and (4), the input impedance is determined in terms of known quantities and  $Z_{p}$ 

$$Z_{o} = \frac{\rho c}{A_{1}} \cdot \frac{Z_{e} + j\frac{\rho c}{A_{1}} \tan K\ell}{\frac{\rho c}{A_{1}} + jZ_{e} \tan K\ell}$$
(5)

For further information see Kinsler and Frey (1962). Taking a free body diagram of the mass in Figure 1, the equation of motion may be obtained by using Newton's second law. This free body diagram is shown in Figure 3, and the resulting differential equation is:

$$\dot{\mathbf{mx}} + \dot{\mathbf{bx}} + \mathbf{kx} = \mathbf{P}\mathbf{A}_{1} e^{j\omega t}$$
(6)

To determine the steady state response assume  $x = Xe^{j\omega t}$  and substitute into Equation (5).

$$-\omega^{2}mXe^{j\omega t} + bj\omega Xe^{j\omega t} + kXe^{j\omega t} = PA_{1}e^{j\omega t}$$

Solving for X, x may be determined in terms of the input pressure.

$$\mathbf{x} = \frac{\mathbf{P} \mathbf{A}_{1} e^{j\omega t}}{(\mathbf{k} - \omega^{2} \mathbf{m}) + jb\omega}$$
(7)

Differentiating Equation (7) and forming the ratio of  $PA_1$  to  $\dot{x}$ , the

mechanical impedance results.

$$Z_{m} = b + j(\omega m - \frac{k}{\omega})$$



Figure 3. Free Body Diagram of Eardrum Model

The acoustical impedance may be obtained by dividing  $\mathbf{Z}_{m}^{}$  by  $\mathbf{A_{1}^{2}},$ 

$$Z_{e} = \frac{b}{A_{1}^{2}} + \frac{j(\omega m - \frac{k}{\omega})}{A_{1}^{2}}$$
(8)

Equation (5) represents the input acoustical impedance of the mathematical model in terms of known quantities and may be used to compute impedance for various distances from the eardrum,

#### Model Parameters

The model parameters may be approximated using existing information. Because of physical appearance it is felt that the principal mass effect is due to the malleus. This effect may be any combination of translational mass or rotational moment of inertia as is common knowledge in elementary dynamics. The mass to be used in the mathematical model may be approximated by an effective mass that includes the translational and rotational mass effects of the ossicles. Since the malleus is directly connected to the eardrum, its mass will be taken as a first guess for m. The mass of the malleus as determined by Bekesy<sup>3</sup> is 23 mg.

The cross-sectional area and length of the ear canal are given as  $.5 \text{ cm.}^3$  and 2.7 cm., respectively,<sup>4</sup> The spring constant of the eardrum was approximated by Onchi<sup>5</sup> as  $5.49 \times 10^6$  dynes/cm.<sup>2</sup> so this value is taken for k. Bekesy<sup>6</sup> measured the frictional forces in the middle ear over moderate frequencies as 100 gm./sec., so this value is taken for b. These parameters were used as an initial guess, and the input impedance was calculated for different distances from the eardrum. Comparisons with impedance data from other researchers indicated that the parameters were in error, so they were adjusted to make the mathematical model fit the real ear impedance more closely.<sup>7</sup> The adjusted parameters were

$$m = 25, mg, \qquad l = 2.0 cm$$

$$k = 10^6$$
 dyne/cm.  $A_1 = .5$  cm.<sup>2</sup>  
b = 100 gm./sec.

The resulting curves of input acoustical impedance as a function of x are shown in Appendix B. The variation in impedance with distance from the eardrum indicates that this distance is important in impedance matching. For purposes of modeling, a representative distance will be chosen for use in deriving the criteria for impedance matching.

It is felt that since the hearing aid insert is closer to the eardrum than is the ear canal opening, then the distance for impedance matching should be less than  $\ell$ . The values of xx = 1.5 is arbitrarily chosen as a representative distance for impedance matching purposes, and the impedance curves for this condition are shown in Figure 4.

#### Matching Impedances

The criterion for impedance matching is that a maximum power be transferred from the source to the load. The acoustical device shown in Figure 5a is similar to the receiver of conventional hearing aids. The equivalent electrical circuit is easier to work with and is shown in Figures 5b and 5c.

The equivalent electrical circuit is determined by a system of analogies. The acoustical volume is analogous to capacitance, acoustical resistance is analogous to resistance, and changes of area are analogous to inductance. Volume velocity is analogous to current, and





a.) Acoustical System



b.) Equivalent Electrical Circuit



c.) Simplified Equivalent Electrical Circuit



pressure is analogous to voltage. The conditions under which this equivalent electrical circuit is valid are that the physical dimensions of the acoustical transducer be small compared to a wavelength which means that the acoustical model may be considered as a lumped parameter model.<sup>8</sup> The length of a tube must be less than a quarter wavelength, or resonance will occur. The limitations on dimensions that were used here are:

$$a\ell < \frac{\lambda}{4}$$
, Rad  $< \frac{\lambda}{20}$ ,  $R_T < \frac{\lambda}{20}$ 

where  $\lambda$  = wavelength of the incoming pressure wave. If the device is to be used up to a frequency of 8500 hz., these dimensions become:

 $a_{\ell}$  < 1.00 cm,, Rad < .2 cm.,  $R_{T}$  < .2 cm.

This device may be thought of as one generating a constant volume velocity, and the lumped elements can be determined from the physical dimensions above.<sup>9</sup>

$$L = \frac{\rho L'}{\pi R_T}$$
,  $C = \frac{V}{\rho c^2}$ 

where

 $\rho$  = density of air

c = speed of sound in air

V = acoustical volume

C = equivalent capacitance

L = equivalent inductance

Substitution of L' = 16 Rad/ $3\pi$  and V =  $\pi R_T^2 a\ell$  yields

$$L = \frac{16\rho \, \text{Rad}}{3\pi^2 R_{\text{T}}}$$

and

$$C = \frac{\pi R_T^{2al}}{\rho c^{2}}$$

For a more complete discussion of this, see Kinsler and Frey (1962).

The equivalent electrical circuit of Figure 5b is simplified to that shown in Figure 5c by summing admittances of parallel combinations. This makes it easier to solve for the conditions of maximum power transfer.

For the circuit shown in Figure 5c, the power delivered to the ear is

$$\overline{P} = L_2^2 R_e ,$$

$$L_2 = \frac{I |X_h(\omega)|}{\sqrt{(R + R_e)^2 + (X_h + X_e)^2}}$$

and

$$X_{h}(\omega) = \frac{j\omega L}{1 - \omega^{2} LC}$$

Combining these two expressions the power becomes

$$\overline{P} = \frac{I^{2}X_{h}(\omega)^{2}R_{e}}{(R + R_{e})^{2} + (X_{h}(\omega) + X_{e})^{2}}$$
(9)

Then using the concept of a circuit "Q",  $Q = X_e / R_e$ , the expression for power becomes

$$\overline{P} = \frac{I^2 X_h^2(\omega) R_e}{(R + R_e)^2 + (X + Q R_e)^2}$$
(10)

The conditions for maximum power transfer may be determined by taking the derivative of power with respect to  $R_e$ .

$$\frac{d\overline{P}}{dR_{e}} = \frac{I^{2}X_{h}^{2}(\omega) \left[ (R+R_{e})^{2} + (X_{h}(\omega) + QR_{e})^{2} \right]}{\left[ (R+R_{e})^{2} + (X_{h} + QR_{e})^{2} \right]^{2}}$$
$$- \frac{I^{2}X_{h}^{2}(\omega)R_{e} \left[ 2(R+R_{e}) + 2Q(X_{h}(\omega) + QR_{e}) \right]}{\left[ (R+R_{e})^{2} + (X_{h} + QR_{e})^{2} \right]^{2}}$$

By solving this for the values of  $R_e$  which make this expression zero, the value of  $R_e$  is determined as

$$R_e = \frac{|Z|}{\sqrt{1+Q^2}}$$

where

$$Z = R + jX_{h}(\omega)$$

Substituting this expression into Equation (10) and simplifying, the result is

$$\overline{P}_{\max} = \frac{I^{2}X_{h}^{2}(\omega)}{2|Z|\sqrt{1+Q^{2}}+2(R+QX_{h}(\omega))}$$
(11)

The maximum value of  $\overline{P}_{max}$  may be determined by computing the derivative with respect to Q.

$$\frac{d\overline{P}_{max}}{dQ} = \frac{-I^{2} X_{h}(\omega)^{2} [2 | Z | \frac{Q}{\sqrt{1 + Q^{2}}} + 2 X_{h}(\omega)]}{[2 | Z | \sqrt{1 + Q^{2}} + 2 (R + Q X_{h}(\omega))]^{2}}$$

Solving for Q to make this expression zero,  $Q = \pm X/R$ . To determine which value to take, substitute back into Equation (11),

$$\overline{P}_{\max \max} = \frac{I^2 X_h^2(\omega) R}{2 |Z| \sqrt{R^2 + X_h^2(\omega)} + 2(R^2 \pm X_h^2(\omega))}$$

and it is obvious that Q = -X/R will result in more power being transferred. Then the following equations may be used to determine those conditions that are necessary for a maximum power transfer.

$$Q = \frac{-X_{h}(\omega)}{R}$$

$$R_{e} = \frac{\sqrt{R^{2} + X_{h}^{2}(\omega)}}{\sqrt{1 + \frac{X_{h}^{2}(\omega)}{R^{2}}}} = R$$

$$X_{e} = QR_{e} = -\frac{X}{R}R_{e} = -X$$

So these conditions are

$$R = R_e$$
,  $X_h(\omega) = -X_e$ 

In order to achieve a perfect impedance match at any frequency, this condition must be met at that frequency. Since the resistance of the acoustical device is a constant over the entire frequency range and the resistance of the ear is not, it is obvious that this criterion cannot be met exactly at every frequency. In addition, for resonant circuits a perfect impedance match is possible only at a specific frequency. Therefore, the perfect impedance match is not possible, and the curve fitting process is the next best method to try to make the impedance match optimum. The indicated curve fit was performed on the computer using subroutine GRID4 with the performance index being the integral of the difference between the impedance curves of the mathematical model and the impedance curve calculated for the circuit shown in Figure 5c. An alternate performance index of maximizing power transfer was tried, but results indicated that this performance index was the best one. The physical parameters that resulted from the curve fit are shown in Figure 6a and the resulting reactance, power in, power, and sound pressure level produced in the ear are shown in Figures 6 and 7.

The success of the impedance match may be determined in Figures 6 and 7. First, considering the two power curves, the output power delivered to the ear is much less than that produced by the device. The optimum power delivered is half that produced by the source. On this basis, the impedance match is not very good (Schure, 1958). In addition, a comparison of the reactance curve of Figure 4 with the reactance curve of Figure 6 indicates a very poor reactance match. Improvements in the reactance match may be achieved by using a device whose reactance starts large and positive for low frequencies and decreases with increased frequency. Such a requirement cannot be met with passive elements whose reactances occur in the form k/w and wm. Active elements might be used to fit the reactance requirements.



.







Figure 6. Computer Results



a.) Output Sound Pressure Level Delivered to the Ear Model



b.) Power Transmitted to the Ear Model in DB



#### FOOTNOTES

<sup>1</sup>Georg Von Bekesy, Experiments in Hearing (New York, 1960).

<sup>2</sup>Peter B. Denes and Elliot N. Rinson, <u>The Speech Chain</u> (Bell Telephone Laboratories, 1963), p. 68.

<sup>3</sup>Georg Von Bekesy, "Mechanical Properties of the Ear," <u>Handbook of Experimental Psychology</u>, in S. S. Stevens (ed.) (New York, 1960), p. 1079.

<sup>4</sup>Ibid.

<sup>5</sup>Y. Onchi, "Mechanisms of the Middle Ear," <u>Journal of the</u> <u>Acoustical Society of America</u>, Vol. 33, 1969, p. 802.

<sup>6</sup>Georg Von Bekesy, <u>Experiments in Hearing</u> (New York, 1960), p. 104.

<sup>7</sup>J. Y. Morton and R. A. Jones, "The Acoustical Impedance Presented by Some Human Ears to Hearing Aid Earphones of the Insert Type," <u>Acustica</u>, Vol. 6, 1956, p. 329.

<sup>8</sup>Lawrence E. Kinsler and Austin R. Frey, <u>Fundamentals of</u> Acoustics (New York, 1962), p. 186.

<sup>9</sup>Ibid., p. 191.

#### CHAPTER III

#### EXPERIMENTAL PROCEDURE

#### Introduction

The input acoustical impedance of the mathematical model described in Chapter II was compared to existing ear impedance measurements. However, these existing measurements do not include all frequencies encountered in speech so impedance data should be taken at higher frequencies. Individual testing should also indicate individual variations in ear impedance. For these reasons it is felt that input acoustical impedance to human ears should be measured in an attempt to further validate the mathematical model of Chapter II and determine other variables that may be present in ear impedance,

There are two basic methods that have been used to measure acoustical impedance: comparison and direct. A comparison method is similar to an electrical wheatstone bridge that compares an unknown impedance to a variable known impedance. By nulling the pressure difference between the two impedances the unknown impedance may be determined. A direct method depends on a source with a large enough internal impedance so that an approximately constant volume velocity can be generated. For further information concerning impedance measuring, see Ayers, Aspenall and Morton (1956).

#### Impedance Measuring Device

The direct method was chosen as the most appropriate for this application, because impedance measurements were required over a large frequency range and because of the lack of a dependable null reference. The problem of size is one that is always present in acoustical impedance measurement. The source must be small enough to fit in the human ear canal alongside a microphone, and still have large internal impedance. The only way this can be accomplished is by use of probe tubes. Since the mathematical model indicates that the impedance is a function of distance from the eardrum, it is desirable to measure ear impedance at different distances from the ear canal. This was not done because medical personnel were not available to assure the safety of measuring this distance on a subject and because of physical limitations on the device used.

A horn driver used on conventional loudspeakers was chosen as a sound source. An acoustic coupler shaped like a reversed exponential horn was used to connect the horn driver to a probe tube. This device had unreliable phase characteristics (see Appendix B), so a B&K onequarter inch condenser microphone was placed near the inlet to the probe tube, and the phase shift was measured between this microphone and the probe tube output. The measuring microphone used a B&K one-half inch condenser microphone, and a probe tube. A photograph of this device is shown in Figure 8. Henceforth in this study, the subscript s will signify the source reference microphone, and subscript m will signify the measuring microphone.



Figure 8. Acoustical Impedance Measuring Device

An adequate seal around the outside of the probe tubes was achieved using a receiver seal furnished by Beltone Hearing Aid Service. The receiver seal was then filled in with silicon rubber sealer, as it had to be sheared in order to insert the microphone probe tube. Both probe tubes were filled partially with steel wool damping material to smooth out the resonant peaks that occur in acoustical transmission tubes. Since the horn driver is so massive and the probe tube so small and highly damped, it is felt that the assumption of high internal source impedance is a good one,

#### Calibration Procedure

The calibration of the measuring probe tube consisted of finding a transfer function that could be used to relate actual pressures at the probe input to measured pressure at the probe tip. For the high impedance source the calibration consisted of relating measured pressures to volume velocity. The experimental setup and equivalent electrical circuit shown in Figure 9 were used to determine a source transfer function. Again, the equivalent electrical circuit is included to help understand the physical process.

The volume velocity going through the calibration volume will be approximately the same as that delivered to the ear because of the large internal impedance of the source. This volume is the standard artificial ear volume used with hearing aid earphones, so even if the source internal impedance were not large compared to the ear, the calibration impedance is similar to a real ear impedance, and the results can be expected to be reasonable. The assumption of lumped parameter acoustical elements can be used here to determine the volume velocity because the diameter of the coupler cavity is small compared to a wavelength.



a.) Experimental Setup



b.) Equivalent Electrical Circuit



When the calibration output pressure  $p_k$  is measured over the desired frequency range for any given reference pressure  $p_r$ , the following transfer function may be calculated:

$$\frac{P_k}{P_r} = |G_s(j\omega)| e^{j\emptyset_s}$$
(12)

The volume velocity may then be calculated by writing a loop equation for the pressure drop through the coupler cavity shown in Figure 9.
$$p_{k} = \frac{U_{k}}{j_{\omega}C}$$
(13)

where

$$C = \frac{V}{\rho c^2}$$

U<sub>k</sub> = volume velocity.

Then the volume velocity may be computed in terms of the measured pressure by combining Equations (12) and (13).

$$U_{k} = j\omega Cp_{r} |G_{s}(j\omega)| e^{j\emptyset s}$$
(14)

A similar calibration procedure may be used for computing the probe microphone transfer function.

$$\frac{\mathbf{p}_{m}}{\mathbf{p}_{r}} = |\mathbf{G}_{m}(j\omega)| e^{j\boldsymbol{\emptyset}_{m}}$$
(15)

Using Equation (15), the measured pressure may be related to the actual pressure in the ear. These calibration curves are shown in Appendix B.

## Measurement Procedure

The ear mold was inserted into the subject's ear, and the pressures in the reference microphone and measuring microphone were measured. The relationship between the measured pressures and phase angles and the desired ear impedance may be obtained by using the transfer functions indicated in Figure 10.



a.) Block Diagram Representation



b.) Arrangement of Probes in Subject's Ear





Figure 11. Photograph of Experimental Setup

It was difficult at first to get an adequate seal, and the subject had to learn how to insert the ear mold himself. There was a slight problem with inserting the probes because the ear canal opening is not perpendicular to the head. If the probes are not inserted straight, the microphone probe tube may be closed off. This problem was corrected by having the subject tilt his head slightly. A photograph of the device and subject is shown in Figure 11, and the list of equipment used, along with wiring details, is described in Figure 12.



Figure 12. Wiring Diagram for Testing Session

The overall measured transfer function described in Figure 10 can be expressed as

$$\frac{p_{m}}{p_{r}} = |G_{mm}(j\omega)|e^{j\emptyset_{mm}}$$
(16)

The pressure in the ear may be computed in terms of Equation (16) as

$$\frac{\mathbf{p}_{m}}{\mathbf{p}_{e}} = |\mathbf{G}_{m}(\mathbf{j}_{w})| e^{\mathbf{j}\boldsymbol{\emptyset}_{m}}$$
(17)

and the relationship between  $p_p$  and  $p_m$  becomes

$$\frac{P_{e}}{P_{r}} = \frac{|G_{mm}(j\omega)|}{|G_{m}(j\omega)|} e^{j(\emptyset_{mm} - \emptyset_{m})}$$
(18)

upon combining Equations (16) and (17). Since the volume velocity may be computed using Equation (14), the ear impedance becomes

$$Z_{e} = \frac{P_{e}}{U_{e}} = \frac{|G_{mm}(j\omega)|e^{j(\emptyset_{mm} - \emptyset_{m} - \emptyset_{s})}}{|j\omega c|G_{m}(j\omega)||G_{s}(j\omega)|} .$$
(19)

The ear impedance in Equation (19) was computed using the computer program shown in Appendix A for several test sessions. The device is unreliable above about 5000 hz., which is no surprise because of the unreliable phase characteristics at those frequencies. This is because the assumption of lumped parameter modeling became invalid above a certain frequency, and the effect of reflected waves was no longer negligible. Experimental accuracy also proved to be a problem which is easily recognizable whenever the resistance becomes negative. This is due to slight error which pushes the ear impedance phase angle from the first to the fourth quadrant making the sine function change signs. When this happens, the calculated resistance may be assumed to be zero, and the reactance is not affected very much.

# Discussion of Results

The test subject reported hearing a beat phenomenon which depended both on stimulus intensity and frequency. The beats were noticed every time the intensity exceeded about 105 DB and the frequency of the beat changed with the frequency of the stimulus. Since ear nonlinearity becomes more pronounced with increased intensity, it is likely that this phenomenon is associated with the ear's nonlinearity (Bekesy, 1960a). Since it is desirable to obtain data for impedance both with and without this phenomenon present, data was collected for two testing sessions at each intensity level. The results are shown in Figures 13 and 14.

There are several human variables associated with ear impedance that can affect the results of this experiment. It is known that ear impedance may change if the testing session lasts too long.<sup>1</sup> This may be due to fatiguing of muscles or adaptation of the ear to a new environment. Consequently, testing sessions were limited to about 15 minutes each.

Notice in Figures 13 and 14 that the ear impedance varies with the different testing sessions. These changes are quite large and are most noticeable for frequencies below about 1000 hz. Since the



Frequency in Cycles/Sec.

Figure 13. Acoustical Impedance of Human Ear for Two Different Sessions With Beat Phenomenon



Figure 14. Acoustical Impedance of Human Ear for Two Sessions Without Beat Phenomenon

impedance calculated on the mathematical model indicates a change in impedance with a change in the distance to the eardrum, it seems logical to consider differences in the extension of the ear mold as an explanation for these differences. However, since the ear mold is of constant size, it seems that it was always inserted approximately the same distance as indicated in Figure 15. Therefore, this may not be an explanation for large fluctuations.



Figure 15. Drawing Representing How Far Into the Ear Canal the Ear Mold Goes

In further attempts to explain the variations, the subject was questioned concerning his state of fatigue, mental activity, and tension. During the first testing session the subject was extremely tired. During the second testing session the subject reported excessive mental activity and tension. During the third and fourth testing sessions, the subject was rested and mental activity was controlled. It seems that all these factors may be involved in ear impedance, but on the basis of the work here, it is not possible to relate specific impedance changes to the factors mentioned above. Further controlled experiments must be undertaken to determine whether fatigue, mental activity, and tension affect ear impedance, and if so, how.

The impedance curves that result from measurement look similar in shape to the impedance curves calculated from the mathematical model. The hump in the resistance curve and the inflection in the reactance curve consistently appear at about 500 hz. Other researchers have not observed these factors when using lower stimulus intensity, so it is likely that they are related to the properties of the ear at higher intensity.<sup>2</sup> The reason for this similarity is that the real eardrum behaves like a piston for lower frequencies.<sup>3</sup>

The wide variation in measured impedance indicates that impedance matching will involve the fitting of device impedance into acceptable bands of ear impedance. Further testing is necessary in order to determine the properties of these bands based on the variation of ear impedance for a particular person and based on variation of ear impedance between persons.

# FOOTNOTES

<sup>1</sup>J. Y. Morton and R. A. Jones, "The Acoustical Impedance Presented by Some Human Ears to Hearing Aid Earphones of the Insert Type," <u>Acustica</u>, Vol. 6, 1956, p. 329.

# <sup>2</sup>Ibid.

<sup>3</sup>Georg Von Bekesy, <u>Experiments in Hearing</u> (New York, 1960), p. 102.

# CHAPTER IV

# CONCLUSIONS

## Summary

A mathematical model was developed which approximates the input acoustical impedance to the human ear. An acoustical device similar to what is used in conventional hearing aids was proposed as a means of impedance matching, and the impedance match was performed by a curve fit on the computer. Results indicate that this impedance match is not very good.

Passive elements cannot provide very much improvement in impedance matching because of requirements on the reactance. Reactive components must start large and positive for low frequency and decrease with an increase in frequency in order to fit the criteria developed. The conclusion is that improvements in aural prosthesis are possible by consideration of impedance matching, but such improvements require active devices as passive devices fail to satisfy the reactive requirement.

The input acoustical impedance of the human ear was measured, and variations were noted which make an exact impedance match impossible. These variations may be caused by fatigue, tension, and mental activity, factors which are difficult to control. This means that any attempts at impedance matching will never exactly fit the criterion but must settle for fitting into some acceptable band of impedance requirements.

# Recommendations

A beat phenomenon was discovered during testing which should be studied further. Since this phenomenon occurred only at higher intensities, it is likely that it is associated with ear nonlinearity. Nonlinear systems have been known to exhibit almost periodic behavior which can cause beats, and subharmonics can superimpose themselves on the primary signal to generate sounds like beats. A nonlinear analysis of hearing should be used to characterize and study this phenomenon.

Although the acoustical device that was used here did not match impedances very well, other devices might represent significant improvements. A comparison of the reactances of the proposed device and the ear indicates that they are the reason for the poor curve fit. This problem is common with resonant circuits, but if a device could be found whose reactance is more similar in shape to ear reactance, then significant improvements might result. If more work is to be done with this idea, more testing will be required in order to characterize the acceptable bands for the impedance of human ears. This will involve improvements in the impedance measuring device in order to make measurements at higher frequencies more reliable. In the course of carrying out this study it was observed that conventional artificial ears used in earphone calibration procedures attempt to approximate ear impedance with a reactive component alone. An improvement in artificial ears could be achieved by including a resistive component in the form of a damper and piston similar to the mathematical model that was included here. Certainly this would represent a more accurate picture of what the hearing aid sees when it is fitted to a human ear. Using conventional artificial ears for testing, the hearing aid sees a load that does not dissipate power. Certainly the ear does dissipate power, so the inclusion of resistance would come closer to the real ear. This improvement in artificial ears might give audiologists a better idea of the true performance of hearing aids. The improved artificial ear might be built similar to the mathematical model of the ear proposed here which does include damping,

# SELECTED BIBLIOGRAPHY

Ayers, E. W., E. Aspinall, and J. Y. Morton.

- 1956 "An Impedance Measuring Set for Electrical, Acoustical, and Mechanical Impedances." <u>Acustica</u>, Vol. 6, pp. 11-16.
- Bekesy, G. V.
  - 1960 <u>Experiments in Hearing</u>. New York: McGraw-Hill Publishing Company.

Bekesy, G. V., and W. A. Rosenblith.

1960 "The Mechanical Properties of the Ear." In S. S. Stevens (ed.), <u>Handbook of Experimental Psychology</u>, New York: Wiley.

## Carhart, R.

1946 "Selection of Hearing Aids," <u>Archives of Otolaryngology</u>, Vol. 44, pp. 1-18.

## Davis, H.

1946 "The Selection of Hearing Aids." Laryngoscope, Vol. 56, pp. 85-115.

### Ithell, A. H.

1963 "The Measurement of the Acoustical Input Impedance of Human Ears." Acustica, Vol. 13, pp. 140, 311.

Kinsler, L. E., and A. R. Frey.

1962 Fundamentals of Acoustics. New York: Wiley.

## Metz, O.

1946	"The Acoustic ]	Impedance	Measured or	n Norma	l and Patho-
	logical Ears,"	Acta Oto-	Laryngology	, Vol. 6	3.

## Morton, J. Y., and R. A. Jones.

1956 "The Acoustical Impedance Presented by Some Human Ears to Hearing Aid Earphones of the Insert Type." Acustica, Vol. 6, p. 329.

Nielsen, A. K.

1954 "The Design of an Acoustic Impedance Meter," <u>Acustica</u>, Vol. 4, p. 120.

Onchi, Y.

- 1949 "A Study of the Mechanism of the Middle Ear." <u>Acous-</u> <u>tical Society of America Journal</u>, Vol. 21, p. 404.
- 1961 "Mechanisms of the Middle Ear." Journal of the Acoustical Society of America, Vol. 33, p. 802.

Reddell, R. C., and D. R. Calvert.

1966 "Selecting a Hearing Aid by Interpreting Audiological Data." Journal of Audio Research, Vol. 6, pp. 445-452.

Schure, Alexander.

1958 Impedance Matching, New York: J. F. Rider.

# APPENDIXES

# APPENDIX A

# COMPUTER PROGRAMS

```
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
С
C COMPUTER PROGRAM TO COMPUTE THE INPUT ACOUSTICAL IMPEDANCE TO THE
C
 HUMAN EAR.
C DEFINITION OF PARAMETERS.
 R=DAMPING COEFFICIENT.
 S = CROSS SECTIONAL AREA OF EAR CANAL.
RK = SPRING CONSTANT ON EARDRUM MODEL.
  RM = EQUIVALENT MASS OF MALLEUS, INCUS, STAPES.
 CA= WAVE PROPOGATION VELOCITY OF AIR.
 DENS= DENSITY OF AIR.
1
  RL= LENGTH OF EAR CANAL.
 DELXX= STEP IN LONGITUDINAL DIRECTION IN EAR CANAL.
 DELFRQ= FREQUENCY STEP.
      DIMENSION ZI(10,100),ZR(10,100)
      DIMENSION XARRAY (101), YARRAY (101)
      READ(5,100) R,S,RM,RK,CA,DENS,RL ;DELXX ,DELFRQ
      WRITE(6,150) R.S.RM, RK, CA, DENS
      L=99
      XX=RL
      DO 6 I=1,10
      FRQ=100.
     DO 7 K=1,L
      KK = K - 1
2
      FRR=FRQ*(2.*3.141592)
      CHAR=(DENS*CA)/S
      RE=R7(S*S)
      XE=(FRR*RM-RK/FRR)/(S*S)
      VAL 1=ABS((FRR*XX/CA)-(.5*3.141592))
      VAL2=ABS((FRR*XX/CA)+(1.5*3.141592))
      IF(VAL1.LT.1.00E-02.0R.VAL2.LT.1.00E-02) GO. TO 5
      DUF=(CHAR-XE*TAN(FRR*XX/CA))*(CHAR-XE*TAN(FRR*XX/CA))
     1 + (RE*TAN(FRR*XX/CA))*(RE*TAN(FRR*XX/CA)).
      ZR(I,K)=CHAR*CHAR*RE*(1.+(TAN(FRR*XX/CA))*(TAN(FRR*XX/CA)))/DUF
C
      ZI(I,K)=(XE*CHAR+(XE*XE+RE*RE)*TAN(FRR*XX/CA)+
     1 CHAR*(TAN(FRR*XX/CA))*(TAN(FRR*XX/CA)))/DUF
      IF(VAL1.GE.1.00 E-02.AND.VAL2.GE.1.00E-02) G0 T0 7
    5 ZR(I,K)=ZR(I,KK)
      ZI(I,K)=ZI(I,KK)
    7 FRQ=FRQ+DELFRQ
    6 XX=XX-DELXX
С
C GENERATE XARRAY FOR CALCOMP PLOT.
      FRQ=100.
      DO 4 K=1.L
      XARRAY(K)=ALOGIO(FRQ)
    4 FRQ=FRQ+DELFRQ
      XX=RL
      CALL PLOTS
     DO 8 I=1,10
```

```
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
     CALL PLOTC(0.0,-11.,-3)
C DO-LOOP TO PLOT REACTANCE AT DISCRETE PDINTS ALONG EAR CANAL.
     DD 9 K=1,L
      YARRAY(K) = ZI(I,K)
    9 CONT INUE
     CALL PLOTC (0.0,5.5,2)
     CALL PLOTC(8.5,5.5,3)
      CALL PLOTC(8.5,0.0,2)
     CALL PLUTC(0.0,0.0,2)
     CALL PLOTC (0.0, 1.5,-3)
     CALL PLOTC(2.0,0.0,-3)
3
 SCALE VALUES AND DRAW AXES
     CALL SCALE(XARRAY, 5.0, 99, 1)
     CALL SCALE(YARRAY,2.0,99,1)
     CALL AXIS(0.0,0.0, LOG FREQUENCY ,-13, 5. 0, 0. 0, XARRAY (100),
     1 XARRAY(101))
     CALL AXIS(0.0,0.0, REACTANCE',9,2.0,90.0, YARRAY(100), YARRAY(101))
     CALL LINE(XARRAY, YARRAY, 99,1,10,75)
     CALL PLOTC(-2.0,4.0,-3)
C DO -LOOP TO PLOT RESISTANCE AT DISCRETE POINTS ALONG EAR CANAL.
     DO 10 K=1,L
     YARRAY(K) = ZR(I,K)
   10 CONTINUE
     CALL PLOTC(0.0,5.5,2)
     CALL PLOTC(8.5,5.5,3)
     CALL PLOTC(8.5,0.0,2)
     CALL PLOTC(0.0,0.0,2)
     CALL PLOTC(0.0,1.5,-3)
     CALL PLOTC(2.0,0.0,-3)
2
 SCALE VALUES AND DRAW AXES
     CALL SCALE (XARRAY, 5.0,99,1)
     CALL SCALE(YARRAY, 2.0,99,1)
     CALL AXIS (0.0,0.0, "LOG FREQUENCY", -13, 5.0, 0.0, XARRAY( 100),
     1 XARRAY(101))
     CALL AXIS(0.0,0.0, 'RESISTANCE', 10,2.0,90.0, YARRAY(100), YARRAY(101)
    11
C PLOT POINTS.
     CALL LINE(XARRAY, YARRAY, 99, 1, 10, 75)
     CALL SYMBOL (4.00,2.00,.14, XX=*,0.0,3)
     CALL NUMBER (4.50,2.00,.14,XX,0.0,2)
     CALL PLOTC(8.0,-6.5,-3)
    8 XX=XX-DELXX
  100 FORMAT(4E15.4/4E15.4/E15.4)
 150 FORMAT(10H DAMPING= E10.4,20H AREA OF EAR CANAL= E10.4//
     1 5H RM= E10.4,5H RK= E10.4,5H CA= E10.4,7H DENS= E10.4//)
     STOP
      E ND
```

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
      DIMENSION XL(9), XR(9), XLOW(9), XHIGH(9), X(9)
      N=4
      READ(5,100) (XL(I),XR(I),I=1,N)
      MPRINT=1
      MPRINT=0
      F=.1
      F=.01
      R=.667
      CALL GRID4(N, MPRINT, XL, XR, F, R, Y, X, XLOW, XHIGH, NN)
      WRITE(6,48) Y,NN,F
   48 FOR MAT(//
     254H NUMBER OF FUNCTION EVALUATIONS USED DURING SEARCH ..., 115/
     354H FRACT. REDUCTION IN INTERVAL OF UNCERTAINTY EXTANT ..., E15.8/)
      DO 101 I=1,N
  101 WRITE(6,102) XLOW(I),X(I),XHIGH(I)
  100 FORMAT(8E10.2)
  102 FORMAT (5HXLOW=E15.8, 2X, 2HX=E15.8, 2X, 6HXHIGH=E15.8)
      STOP
      END
      SUBROUT INE MER IT4(U,Y)
      DIMENSION ZI(100), ZR(100), YI(100), YR(100), XI(100), XH(100)
      DIMENSION U(1)
C DEFINITION OF PARAMETERS.
C R=DAMPING COEFFICIENT.
C S = CROSS SECTIONAL AREA OF EAR CANAL.
C RK = SPRING CONSTANT ON EARDRUM MODEL.
C RM = EQUIVALENT MASS OF MALLEUS, INCUS, STAPES.
C CA= WAVE PROPOGATION VELOCITY OF AIR.
C DENS= DENSITY OF AIR.
C RL= LENGTH OF EAR CANAL.
C DELXX= STEP IN LONGITUDINAL DIRECTION IN EAR CANAL.
C DELFRQ= FREQUENCY STEP.
C RH=RESISTANCE OF HEARING AID IMPEDANCE MATCHING DEVICE.
C RAD=RADIUS OF HOLE DRILLED IN TUBE OF IMPEDANCE MATCHING DEVICE.
C AL =LENGTH OF ACOUSTICAL COMPLIANCE.
C RT=RADIUS OF ACOUSTICAL COMPLIANCE.
      U(1)=RA
Ċ
      U(2)=RAD
C
С
      U(3)=AL
С
      U(4)=RT
      R=1.00E 02
      S=5.00E-01
      RM=2.50E-02
      RK=1.00E 06
      CA=3.62E 04
      DENS=1.23E-03
      RL=1.5
      DEL FRQ=1.00E 02
С
      L=99
      XX = RL
      FRQ=100.
      00 7 K=1,L
```

•

123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890 KK=K-1 С FRR=FRQ\*(2.\*3.141592) CHAR=(DENS\*CA)/S RE=R/(S\*S) XE=(FRR\*RM-RK/FRR)/(S\*S) VAL 1=ABS((FRR\*XX/CA)-(,5\*3.141592)) VAL 2= ABS((FRR \*XX/CA)-(1.5\*3.141592)) IF(VAL1.LT.1.00E-02.0R.VAL2.LT.1.00E-02) GD TO 5 DUF={CHAR-XE\*TAN(FRR\*XX/CA))\*{CHAR-XE\*TAN(FRR\*XX/CA)} 1 + (RE\*TAN(FRR\*XX/CA))\*(RE\*TAN(FRR\*XX/CA)) ZR(K) =CHAR\*CHAR\*RE\*(1.+(TAN(FRR\*XX/CA))\*(TAN(FRR\*XX/CA)))/DUF С ZI(K) = (XE\*CHAR-{XE\*XE+RE\*RE}\*TAN(FRR\*XX/CA)+ 1 CHAR\*(TAN(FRR\*XX/CA))\*(TAN(FRR\*XX/CA)))/DUF IF(VAL1.GE.1.00E-02.AND.VAL2.GE.1.00E-02) GO TO 6 5 ZR(K) = ZR(KK)ZI(K)=ZI(KK)6 CONTINUE RH=U(1) XH(K)=FRR\*DENS\*1.7\*U(2)/( 3.141592\*U(2)\*U(2) 1-FRR\*FRR\*1.7\*U(2)\*((3.141592\*U(4)\*U(4)\*U(3))/(CA\*CA))) 7 FRQ=DELFRQ+FRQ Z = 1 + ABS(ZR(20) - RA)Z2=1 + ABS(ZI(20)+XH(20)) PI=Z1+Z2Y=1./PI RETURN END SUBROUTINE GRID4(N, MPRINT, XL, XR, F, R, Y, X, XLOW, XHIGH, NN) GRI 0010 SUBROUTINE GRID4(N, MPRINT, XL, XR, F, R, Y, X, XLON, XHIGH, NN) GRI CCCC С GRID SEARCH C GRI CCCC C C GRI CCCC THIS SUBROUTINE EXERCISES A GRID SEARCH IN A MERIT HYPERSURFACE GRI CCCC С OF UPTO EIGHT DIMENSIONS BY CALLING SUBROUTINE MERIT4(X,Y) GRI CCCC С GRI CCCC Ċ CALLING PROGRAM REQUIREMENTS GRI CCCC С GRI CCCC С PROVIDE A DIMENSION STATEMENT AS FOLLOWS. GRI CCCC C C GRI CCCC DIMENSION XL(9), XR(9), XLOW(9), XHIGH(9), X(9) GRI CCCC GRI CCCC C С NOMENCLATURE GRI CCCC ., R. С GRI CCCC Č N = NUMBER OF INDEPENDENT VARIABLES GRI CCCC MPRINT = 0 CONVERGENCE MONITOR DOES NOT PRINT С GRI CCCC С = 1 CONVERGENCE MONITOR WILL PRINT GRI CCCC XL = ORIGINAL LOWER EXTREMITY OF INTERVAL OF UNCERTAINTY XR = ORIGINAL UPPER EXTREMITY OF INTERVAL OF UNCERTAINTY C GRI CCCC GRI CCCC C F = FRACTIONAL REDUCTION IN INTERVAL OF UNCERTAINTY DESIRED GRI CCCC С C R = FRACTIONAL GRID REDUCTION UTILIZED GRI CCCC С Y = EXTREME ORDINATE TO MERIT SURFACE DISCOVERED BY GRID SEARCH GRI CCCC X = COLUMN VECTOR OF ABSCISSAS CORRESPONDING TO Y XLOW = FINAL LOWER EXTREMITY OF INTERVAL OF UNCERTAINTY GRI CCCC GRI CCCC С r

0:000000001111111111112222222222333333333444444444	89/80 LIST	
C       XHIGH = FINAL UPPER EXTREMITY OF INTERVAL OF UNCERTAINTY NN = NUMBER OF FUNCTION EVALUATIONS EXPENDED IN GRID SEARCH GRI CCCC DIMENSION XL(9), XR(9), XI(9), XLOM(9), XHIGH(9), CENTER(9), SAVEX(9) GRI CCCC IF(N-8)11,11,12 ICCC IF(N-8)11,11,12 ICCCC IF(N-8)11,11,12 IZ WRITE(6,13) IS FORMAT(4)H *****ERROR MESSAGE SUBROUTINE GRID4*****,/, GRI 0050 IS HAITE(6,13) IN HIF=1,10)14,14,15 IS WRITE(6,16)F IN HITE(6,16)F IN HITE(6,16)F IN HITE(6,16)F IN HITE(6,16)F IN FRURN IN AS=,E15.8,16H GREATER THAN 8.) RETURN IN FRURN IN AS=,E15.8,16H GREATER THAN 1.) RETURN IN FRURN IN FRURN	000000000111111111122222222233333333333	77777778 34567890
C       GRI D220       GRI D220         C       DIMENSION XL(9),XR(9),XL(9),XL(DM(9),XHIGH(9),CENTER(9),SAVEX(9)       GRI D220         C       GRI CCCC       GRI CCCC         C       IF(N=8)11,11,12       GRI D020         12 WRITE(6,13)N       GRI D020         13 FORMAT(4)H *****ERROR MESSAGE SUBROUTINE GRID4****,/,       GRI D050         19 H       II=,13,16H GREATER THAN 8.)       GRI D050         19 H       II=,13,16H GREATER THAN 8.)       GRI D070         11 FF(F=1,0)14,14,15       GRI D070       GRI D010         15 WRITE(6,16)F       GRI D010       GRI D010         16 FORMAT(4)H *****ERROR MESSAGE SUBROUTINE GRID4*****,/,       GRI D120         14 D0 50 I = 1,N       GRI D120       GRI D120         15 WRITE(6,52)I,XLL,1,XR       GRI D150       GRI 0150         11 STE(6,52)I,XLL,1,XR       GRI D150       GRI 0150         19 H       A3,11,2H)=,FI5.8,16H GREATER THAN A4(,I1,2H)=,EI5.8)       GRI 0210         19 H       A3,11,2H)=,FI5.8,16H GREATER THAN A4(,I1,2H)=,EI5.8)       GRI 0120         19 H       A3,11,2H)=,FI5.8,16H GREATER THAN A4(,I1,2H)=,EI5.8)       GRI 0210         19 H       A3,11,2H)=,FI5.8,16H GREATER THAN A4(,I1,2H)=,EI5.8)       GRI 0210         19 A GRETURN       GRI 0220       GRI 0220 <td>C XHIGH = FINAL UPPER EXTREMITY OF INTERVAL OF UNCERTAINTY C NN = NUMBER OF FUNCTION EVALUATIONS EXPENDED IN GRID SEARCH</td> <td>GRI CCCC GRI CCCC</td>	C XHIGH = FINAL UPPER EXTREMITY OF INTERVAL OF UNCERTAINTY C NN = NUMBER OF FUNCTION EVALUATIONS EXPENDED IN GRID SEARCH	GRI CCCC GRI CCCC
C       PROTECTION       GRI CCCC         C       IF(N-B)11.11.12       GRI CCCC         12       WRITE(6,13)N       GRI 0040         13       FORMAT(64)H *****ERROR MESSAGE SUBROUTINE GRID4*****,/,       GRI 0050         19       II=,13.16H GREATER THAN 8.)       GRI 0050         19H       II=,13.16H GREATER THAN 8.)       GRI 0050         19H       II=,13.16H GREATER THAN 8.)       GRI 0050         10H       AGRI 0.120       GRI 0.010         10H       AGRI 0.120       GRI 0.020         14       DO 50 I = 1.N       GRI 0.120         110H       AS=,EI5.8.16H GREATER THAN 1.)       GRI 0.120         110H       AS=,EI5.8.16H GREATER THAN 1.)       GRI 0.120         110H       AS=,EI5.8.16H GREATER THAN 1.)       GRI 0.120         110H       AS       GRI 0.120       GRI 0.120         110H       AS       GRI 0.120 <td>C DIMENSION XL(9),XR(9),X(9),XLOW(9),XHIGH(9),CENTER(9),SAVEX(9)</td> <td>GRI CCCC GRI 0020 GRI CCCC</td>	C DIMENSION XL(9),XR(9),X(9),XLOW(9),XHIGH(9),CENTER(9),SAVEX(9)	GRI CCCC GRI 0020 GRI CCCC
IF(N=8)11,11,12       GRI 0030         12 WRITE(6,13)N       GRI 0040         13 FORMAT(4)H *****ERROR MESSAGE SUBROUTINE GRID4****,/, GRI 0050       GRI 0060         19 II=,13,16H GREATER THAN 8.)       GRI 0077         11 IF(F-1,0)14,14,15       GRI 0070         15 WRITE(6,16)F       GRI 0070         16 FORMAT(4)H *****ERROR MESSAGE SUBROUTINE GRID4*****,/, GRI 0100       REI 0070         110H       A5=,E15.8,16H GREATER THAN 1.)       GRI 0100         100F       A5=,E15.8,15H,5G       GRI 0100         110H       A5=,E15.8,15H,5G       GRI 0120         14 0D 50 I = 1,N       GRI 0120       GRI 0130         15 WRITE(6,52)1,XLL,1,XRR       GRI 0150       GRI 0150         12 RETURN       GRI 0170       GRI 0160         19 A3(,11,2H)=,E15.8,16HGREATER THAN A4(,11,2H)=,E15.8)       GRI 0180         19 A3(,11,2H)=,E15.8,16HGREATER THAN A4(,11,2H)=,E15.8)       GRI 0220         50 C0HTINUE       GRI 0220       GRI 0220         10 FIR-2,073,0153,54,54       GRI 0220         51 SRR       GRI 0220       GRI 0220         52 FORMAT(4)H *****ERROR MESSAGE SUBROUTINE GRID4*****,/, GRI 0220       GRI 0220         53 WRITE(6,5),53 F3       GRI 0220       GRI 0220         54 IF(R-1,0)58,58,53       GRI 0240 <t< td=""><td>C PROTECTION</td><td>GRI CCCC GRI CCCC</td></t<>	C PROTECTION	GRI CCCC GRI CCCC
13 FORMAT(4)H *****ERROR MESSAGE SUBROUTINE GRID4*****,/,       GRI 0050         19 H       11=,13,164 GREATER THAN 8.)       GRI 0060         RETURN       GRI 0070         11 F(F-1,0)14,14,15       GRI 0070         15 WRITE(6,16)F       GRI 0070         16 FORMAT(4)H ****ERROR MESSAGE SUBROUTINE GRID4*****,/,       GRI 0100         10H       A5=,E15.8,16H GREATER THAN 1.)       GRI 0100         10H       A5=,E15.8,16H GREATER THAN 1.)       GRI 0110         RETURN       GRI 0120       GRI 0120         14 DD 50 I = 1,N       GRI 0130       GRI 0140         15 XRT = XR(1)       GRI 0150       GRI 0150         xLL = XL(1)       GRI 0160       GRI 0170         52 FORMAT(4)H *****FRROR MESSAGE SUBROUTINE GRID4*****,/,       GRI 0180         19H       A3(,11,2H)=,E15.8,16HGREATER THAN A4(,11,2H)=,E15.8)       GRI 0210         refurn       GRI 0220       GRI 0220       GRI 0220         54 IF(R-1.0)58,58,53       GRI 0220       GRI 0220         55 FORMAT(4)H *****ERROR MESSAGE SUBROUTINE GRID4*****,/,       GRI 0220         64 OTNINWE       GRI 0220       GRI 0220         55 FORMAT(4)H *****ERROR MESSAGE SUBROUTINE GRID4*****,/,       GRI 0220         56 ONTINWE       GRI 0220       GRI 0220      <	IF(N-8)11,11,12 12 WRITE(6,13)N	GRI 0030 GRI 0040
RETURN       GRI 0079         11 IFFF-1.0]14,14,15       GRI 0080         15 WRITE(6,16)F       GRI 0090         16 FORMAT(41H *****ERROR MESSAGE SUBROUTINE GRID4*****,/,       GRI 0100         100H       A5=,E15.8,16H GREATER THAN 1.)       GRI 0120         14 D0 50 I = 1,N       GRI 0120         14 D0 50 I = 1,N       GRI 0120         15 XRT = XR(1)       GRI 0150         XLL = XL(1)       GRI 0160         WR = XR(1)       GRI 0170         52 FORMAT(41H *****ERROR MESSAGE SUBROUTINE GRID4****,/,       GRI 0170         52 FORMAT(41H *****ERROR MESSAGE SUBROUTINE GRID4****,/,       GRI 0220         54 IF(R-1.0)58,58,53       GRI 0220         55 FORMAT(41H *****ERROR MESSAGE SUBROUTINE GRID4****,/,       GRI 0220         54 IF(R-1.0)58,58,53       GRI 0220         55 FORMAT(41H *****ERROR MESSAGE SUBROUTINE GRID4****,/,       GRI 0220         76       GRI 0220       GRI 0220         77       GRI 0220       GRI 0220         78 WITE(6,52)R       GRI 0220       GRI 0220         79 M A6=,E15.8,33H DOES NOT LIE BETWEEN 2/3 AND 1.0)       GRI 0220         70 IF(MPRINT)1.3,1       GRI 0220       GRI 0220         71 MITILIZE *****       GRI 0320       IIIA (4N NN SIDE Y X(1) X(2) X(3) X(4) GRI 0330	13 FORMAT(41H *****ERROR MESSAGE SUBROUTINE GRID4******// 19H I1=,I3,16H GREATER THAN 8.)	GRI 0050 GRI 0060
16 FORMAT(4)H *****ERROR MESSAGE SUBROUTINE GRID4*****,/, GRI 0100 10H A5=,E15.8,16H GREATER THAN 1.) GRI 0120 14 DO 50 I = 1.N GRI 0120 14 DO 50 I = 1.N GRI 0130 15 KRR = XR(1) GRI 0150 16 F(R(1)-X(1))51,51,50 GRI 0160 17 F(R(1)-X(1))51,51,50 GRI 0160 19 M A3,11,2H)=,E15.8,16HGREATER THAN A4(,11,2H)=,E15.8) GRI 0180 19 M A3,11,2H)=,E15.8,16HGREATER THAN A4(,11,2H)=,E15.8) GRI 0190 19 M A3,11,2H)=,E15.8,16HGREATER THAN A4(,11,2H)=,E15.8) GRI 0220 50 CONTINUE 17 (R-2,0/3,0)53,54,54 GRI 0220 53 WRITE(6,55)R GRI 0220 54 IF(R-1,0)58,58,53 GRI 0220 55 FORMAT(41H *****ERROR MESSAGE SUBROUTINE GRID4*****,/, GRI 0220 19 M A6=,E15.8,33H DDES NOT LIE BETWEEN 2/3 AND 1.0) GRI 0220 C INITILIZE GRI CCCC 58 NN = 0 GRI CCC	RETURN 11 IF(F-1.0)14,14,15 15 HPITE(6.16)E	GRI 0070 GRI 0080 GRI 0090
RETURN       GRI 0120         14 00 50 I = 1,N       GRI 0130         If(XR(I)-XL(I))51,51,50       GRI 0140         51 XRR = XR(I)       GRI 0150         xRITE(6,52)I,XLL,IXRR       GRI 0160         wRITE(6,52)I,XLL,IXRR       GRI 0170         94 A3(,11,2H)=,E15.8,16HGREATER THAN A4(,11,2H)=,E15.8)       GRI 0180         194 A3(,11,2H)=,E15.8,16HGREATER THAN A4(,11,2H)=,E15.8)       GRI 0200         95 COMTINUE       GRI 0210         16(RI 0220       GRI 0220         95 COMTINUE       GRI 0220         16(RI 0220       GRI 0220         95 COMTINUE       GRI 0220         17(R1C,10,3,153,54,54       GRI 0220         96 C       GRI 0250         194 A6=,E15.8,33H DOES NOT LIE BETWEEN 2/3 AND 1.0)       GRI 0250         97 CC       GRI 0250         98 NN = 0       GRI 0220         98 NN = 0       GRI 0220         98 NN = 0       GRI 0220         99 NATE(6,2)       X(1)         90 SIDE = 1.0       GRI 0220         91 HWITE(6,2)       GRI 0300         92 C AMAT(37HICONVERGENCE MONITOR SUBROUTINE GRID4,//,       GRI 0310         93 D0 4 I=1,N       GRI 0320         94 I124H       NN SIDE Y       X(1)       <	16 FORMAT(41H *****ERROR MESSAGE SUBROUTINE GRID4*****/, 110H A5=,E15.8,16H GREATER THAN 1.)	GRI 0100 GRI 0110
IF{XR(1)-XL(1))51,51,50       GRI 0140         51 XRP = XR(1)       GRI 0150         XLL = XL(1)       GRI 0150         WRITE(6,52)I,XLL,I,XRR       GRI 0170         PH       A3(,11,2H)=,E15.8,16HGREATER THAN A4(,11,2H)=,E15.8)       GRI 0190         19H       A3(,11,2H)=,E15.8,16HGREATER THAN A4(,11,2H)=,E15.8)       GRI 0200         50 CONTINUE       GRI 0220       GRI 0220         19H       A3(,11,2H)=,E15.8,16HGREATER THAN A4(,11,2H)=,E15.8)       GRI 0220         51 KRE       GRI 0220       GRI 0220         51 KRE       GRI 0220       GRI 0220         52 FORMAT(4LH *****ERDR MESSAGE SUBROUTINE GRID4*****,/,       GRI 0220         53 WPITE(6,55)R       GRI 0240         54 IF(R-1,0)58,58,53       GRI 0250         19H       A6=,E15.8,33H DOES NOT LIE BETWEEN 2/3 AND 1.0)       GRI 0260         RETURN       GRI 0270       GRI 0270         C       INITILIZE       GRI 0280         SIDE = 1.0        GRI 0280         IF(MPRINT)1,3,1       GRI 0280       GRI 0280         INTE(6,2)       X(1)       X(2)       X(3)         2 K(5)       X(6)       X(7)       X(8)       BIGGEST Y,/)       GRI 0320         2 K(5)       X(	RETURN 14 DO 50 I = 1,N	GRI 0120 GRI 0130
ALL - ALTI       GRI 0100         WRITE(6,52) I,XLL,I,XRR       GRI 0170         52 FORMAT(4)H *****ERROR MESSAGE SUBROUTINE GRID4****,/,       GRI 0190         19H       A3(,11,2H)=,E15.8,16HGREATER THAN A4(,11,2H)=,E15.8)       GRI 0190         19K       GRI 0200       GRI 0200         50 CONTINUE       GRI 0210       GRI 0220         54 IF(R-2,0/3,0)53,54,54       GRI 0220         54 IF(R-1.0)58,58,53       GRI 0230         55 FORMAT(4)H *****ERROR MESSAGE SUBROUTINE GRID4****,/,       GRI 0220         19H       A6=,E15.8,33H DOES NOT LIE BETWEEN 2/3 AND 1.0)       GRI 0250         19H       A6=,E15.8,33H DOES NOT LIE BETWEEN 2/3 AND 1.0)       GRI 0220         19H       A6=,E15.8,33H DOES NOT LIE BETWEEN 2/3 AND 1.0)       GRI 0220         19H       A6=,E15.8,33H DOES NOT LIE BETWEEN 2/3 AND 1.0)       GRI 0220         19H       A6=,E15.8,33H DOES NOT LIE BETWEEN 2/3 AND 1.0)       GRI 0220         19H       A6=,E15.8,33H DOES NOT LIE BETWEEN 2/3 AND 1.0)       GRI 0220         19H       A6=,E15.8,33H DOES NOT LIE BETWEEN 2/3 AND 1.0)       GRI 0220         19H       A6=,E15.8,33H DOES NOT LIE BETWEEN 2/3 AND 1.0)       GRI 0220         19H       A6=,E15.8,33H DOES NOT LIE BETWEEN 2/3 AND 1.0)       GRI 0220         19H       A6=,E15.8,33H DOES	IF(XR(I)-XL(I))51,51,50 51 XRR = XR(I)	GRI 0140 GRI 0150 GRI 0160
19H       A3(,11,2H)=,F15.8,16HGREATER       THAN       A4(,11,2H)=,F15.8)       GRI       0190         RETURN       GRI       0200         50       CONTINUE       GRI       0220         154       IF(R-2.0/3.0)53,54,54       GRI       0220         54       IF(R-1.0)59,58,53       GRI       0220         55       FORMAT(41H       *****ERROR       MESSAGE       SUBROUTINE       GRI 0240         55       FORMAT(41H       *****ERROR       MESSAGE       SUBROUTINE       GRI 0240         55       FORMAT(41H       *****ERROR       MESSAGE       SUBROUTINE       GRI 0250         19H       A6=,E15.8,33H       DOES       NOT LIE       BETWEEN 2/3 AND 1.0)       GRI 0260         RETURN       GRI 0250       GRI 0220       GRI 0220       GRI 0220         19H       A6=,E15.8,33H       DOES       NOT LIE       BETWEEN 2/3 AND 1.0)       GRI 0220         19H       A6=,E15.8,33H       DOES       NOT LIE       BETWEEN 2/3 AND 1.0)       GRI 0220         19H       A6=,E15.8,33H       DOES       NOT LIE       BETWEEN 2/3 AND 1.0)       GRI 0220         19H       A6=,E15.8,33H       DOES       GRI 0220       GRI 0220       GRI 0220	XLL = XLVIJ WRITE(6,52)I,XLL,I,XRR 52 FORMAT(4)H *****ERROR MESSAGE SUBROUTINE GRID4******/.	GRI 0170 GRI 0180
50 CONTINUE       GRI 0210         IF(R-2.0/3.0)53,54,54       GRI 0220         54 IF(R-1.0)58,58,53       GRI 0230         53 WRITE(6,55)R       GRI 0240         55 FORMAT(41H *****ERDOR MESSAGE SUBROUTINE GRID4*****,/, GRI 0250       GRI 0240         19H       A6=,E15.8,33H DOES NOT LIE BETWEEN 2/3 AND 1.0)       GRI 0260         RETURN       GRI CCCC       GRI CCCC         C       INITILIZE       GRI 0220         S5 NN = 0       GRI 0270       GRI 0220         S1DE = 1.0       GRI 0220       GRI 0220         IH(MPRINT)1,3,1       GRI 0290       GRI 0290         IF(MPRINT)1,3,1       GRI 0310       GRI 0320         114H       NN SIDE       Y       X(1)       X(2)       X(3)       X(4) GRI 0330         2 X(5)       X(6)       X(7)       X(8)       BIGGEST Y,/)       GRI 0350         C CNTER(1) = 0.5       GRI 0350       GRI 0350       GRI 0350       GRI 0350         JJ = 0       GRI 0200       GRI 0220       GRI 0390       GRI 0350       GRI 0350         C LL UNNORM(N,XL,XR,CENTER)       GRI 0400       GRI 0400       GRI 0400       GRI 0400       GRI 0400         CALL REGION(N,XL,XR,CENTER)       GRI 0410       GRI 0410	19H A3(,11,2H)=,E15.8,16HGREATER THAN A4(,11,2H)=,E15.8) RETURN	GRI 0190 GRI 0200
54       IF(R-1.0758,58,53)       GRI 0230         53       WRITE(6,55)R       GRI 0240         55       FORMAT(41H *****ERROR MESSAGE SUBROUTINE GRID4*****,/,       GRI 0250         19H       A6=,E15.8,33H DOES NOT LIE BETWEEN 2/3 AND 1.0)       GRI 0220         RETURN       GRI 0220         C       INITILIZE       GRI 0220         SIDE = 1.0       GRI 0220         If(MPRINT)1.3,1       GRI 0290         IF(MPRINT)1.3,1       GRI 0210         102 FORMAT(37H1CONVERGENCE MONITOR SUBROUTINE GRID4,//,       GRI 0320         1114H       NN SIDE       Y X(1)       X(2)       X(3)         112H       NN SIDE       Y X(1)       X(2)       X(3)       X(4)       GRI 0320         1114H       NN SIDE       Y X(1)       X(2)       X(3)       X(4)       GRI 0320         2 FORMAT(37H1CONVERGENCE MONITOR SUBROUTINE GRID4,//,       GRI 0320       GRI 0320       1114H       NN SIDE       Y X(1)       X(2)       X(3)       X(4)       GRI 0320         2 STOR       X(5)       X(6)       X(7)       X(8)       BIGGEST Y,/)       GRI 0340       GRI 0340         3 DO 4 I=1,N       GRI 0320       GRI 0320       GRI 0320       GRI 0320       GRI 0360	50 CONTINUE IF(R-2.0/3.0)53,54,54	GRI 0210 GRI 0220
19H       A6=,E15.8,33H DOES NOT LIE BETWEEN 2/3 AND 1.0)       GRI 0260         RETURN       GRI 0270         C       GRI 0270         C       GRI CCCC         C       GRI CCCC         58       NN = 0         SIDE = 1.0       GRI 0280         If(MPRINT)1.3,1       GRI 0290         IF(MPRINT)1.3,1       GRI 0300         1 WRITE(6,2)       GRI 0310         2 FORMAT(37H1CONVERGENCE MONITOR SUBROUTINE GRID4,//,       GRI 0320         1114H       NN SIDE       Y X(1)       X(2)       X(3)         2 X(5)       X(6)       X(7)       X(8)       BIGGEST Y,/)       GRI 0340         3 DO 4 I=1,N       GRI 0350       GRI 0350       GRI 0350         C CONTINUE	54 IF(R=1+0)58,58,53 53 WRITE(6,55)R 55 FORMAT(41H ★★★★★FRROR MESSAGE SUBROUTINE GRID4★★★★★./.	GRI 0250 GRI 0240 GRI 0250
C       INITILIZE       GRI CCCC         C       GRI CCCC       GRI CCCC         58 NN = 0       GRI 0280         SIDE = 1.0       GRI 0290         IF(MPRINT)1.3.1       GRI 0300         1 WRITE(6.2)       GRI 0310         2 FORMAT(37HICONVERGENCE MONITOR SUBROUTINE GRID4.//, GRI 0320       GRI 0320         1114H       NN SIDE       Y         X(1)       X(2)       X(3)         2 X(5)       X(6)       X(7)         3 D0 4 I=1.N       GRI 0340         CENTER(I) = 0.5       GRI 0350         JJ = 0	19H A6=,E15.8,33H DOES NOT LIE BETWEEN 2/3 AND 1.0) RETURN	GRI 0260 GRI 0270
58 NN = 0       GRI 0280         SIDE = 1.0       GRI 0290         IF(MPRINT)1.3,1       GRI 0300         1 WRITE(6,2)       GRI 0310         2 FORMAT(37H1CONVERGENCE MONITOR SUBROUTINE GRID4,//,       GRI 0320         1114H       NN SIDE       Y       X(1)       X(2)       X(3)       X(4)       GRI 0320         2 X(5)       X(6)       X(7)       X(8)       BIGGEST Y,/)       GRI 0340         3 D0 4 I=1,N       GRI 0350       GRI 0350       GRI 0350         C ENTER(I) = 0.5       GRI 0350       GRI 0350         JJ = 0       GRI 0360       GRI 0370         JJ = 0       GRI 0320       GRI 0380         C       JJ = 0       GRI 0220         CALL UNNORM(N,XL,XR,CENTER)       GRI 0220         CALL WNORM(N,XL,XR,CENTER)       GRI 0390         CALL MERIT4(CENTER, YMID)       GRI 0410         NN = NN + 1       GRI 0420         CALL NORMAL(N,XL,XR,CENTER)       GRI 0420         CALL NORMAL(N,XL,XR,CENTER)       GRI 0430	C INITILIZE	GRI CCCC GRI CCCC
IF(MPRINT)1,3,1       GRI 0300         1 WRITE(6,2)       GRI 0310         2 FORMAT(37HICONVERGENCE MONITOR SUBROUTINE GRID4,//,       GRI 0320         1114H       NN SIDE       Y       X(1)       X(2)       X(3)       X(4)       GRI 0330         2 X(5)       X(6)       X(7)       X(8)       BIGGEST Y,/)       GRI 0340         3 DD 4 I=1,N       GRI 0350       GRI 0350       GRI 0350         CENTER(I) = 0.5       GRI 0360       GRI 0360         JJ = 0       GRI 0380       GRI 0380         C       JJ = 0       GRI 0380         C       JJ = 0       GRI 020         C       DETERMINE CENTRAL MERIT ORDINATE       GRI 0380         C       JJ = 0       GRI 020         C       DETERMINE CENTRAL MERIT ORDINATE       GRI 0200         C       DETERMINE CENTRAL MERIT ORDINATE       GRI 0200         CALL REGION(N,XL,XR,CENTER)       GRI 0400       GRI 0400         CALL MERIT4(CENTER, YMID)       GRI 0410       GRI 0420         NN = NN + 1       GRI 0420       GRI 0420         CALL NORMAL(N,XL,XR,CENTER)       GRI 0430	58  NN = 0 $SIDE = 1.0$	GRI 0280 GRI 0290
2 FORMAT(3)HICONVERGENCE MUNITOR SOBROUTINE GRID4,77,       GRI 0320         1114H       NN SIDE       Y       X(1)       X(2)       X(3)       X(4)       GRI 0330         2 X(5)       X(6)       X(7)       X(8)       BIGGEST Y,7)       GRI 0340         3 D0 4 I=1,N       GRI 0350       GRI 0350       GRI 0350         CENTER(I) = ^.5       GRI 0360       GRI 0370         JJ = 0       GRI 0380       GRI 0380         C       JJ = 0       GRI 0380         C       DE TERMINE CENTRAL MERIT ORDINATE       GRI 0200         C ALL REGION(N,XL,XR,CENTER)       GRI 0400       GRI 0400         CALL MERIT4(CENTER, YMID)       GRI 0410       GRI 0410         NN = NN + 1       GRI 0420       GRI 0430         CALL NORMAL(N,XL,XR,CENTER)       GRI 0430       GRI 0430	IF(MPRINT)1,3,1 1 WRITE(6,2)	GRI 0300 GRI 0310
3 D0 4 I=1,N       GRI 0350         CENTER(I) = ^.5       GRI 0360         4 CONTINUE       GRI 0370         JJ = 0       GRI 0380         C       JJ = 0         C       DETERMINE CENTRAL MERIT ORDINATE         C       GRI CCCC         C       GRI 0390         CALL REGION(N,XL,XR,CENTER)       GRI 0400         CALL MERIT4(CENTER,YMID)       GRI 0410         NN = NN + 1       GRI 0420         CALL NORMAL(N,XL,XR,CENTER)       GRI 0430	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	GRI 0320 GRI 0330 GRI 0340
4 CONTINUE       GRI 0370         JJ = 0       GRI 0380         C       JJ = 0         C       DETERMINE CENTRAL MERIT ORDINATE         C       GRI CCCC         GRI CCCC       GRI CCCC         C       GRI CCCC         C       GRI CCCC         C       GRI 0390         CALL NNORM(N,XL,XR,CENTER)       GRI 0390         CALL REGION(N,XL,XR,CENTER)       GRI 0400         CALL MERIT4(CENTER,YMID)       GRI 0410         NN = NN + 1       GRI 0420         CALL NORMAL(N,XL,XR,CENTER)       GRI 0430	3  DO  4  I=1.N CENTER(I) = $0.5$	GRI 0350 GRI 0360
CJJ = 77GRI CCCCC DETERMINE CENTRAL MERIT ORDINATEGRI CCCCCGRI CCCCGRI CCCCCCALL UNNORM(N,XL,XR,CENTER)GRI 0390CALL REGION(N,XL,XR,CENTER)GRI 0400CALL MERIT4(CENTER,YMID)GRI 0410NN = NN + 1GRI 0420CALL NORMAL(N,XL,XR,CENTER)GRI 0430	4 CONTINUE JJ = 0	GRI 0370 GRI 0380 GRI 6666
CALL UNNORM(N,XL,XR,CENTER)       GRI 0390         CALL REGION(N,XL,XR,CENTER)       GRI 0400         CALL MERIT4(CENTER, YMID)       GRI 0410         NN = NN + 1       GRI 0420         CALL NORMAL(N,XL,XR,CENTER)       GRI 0430	C DETERMINE CENTRAL MERIT ORDINATE	GRI CCCC
CALL MERIT4(CENTER, YMID)GRI 0410NN = NN + 1GRI 0420CALL NORMAL(N,XL,XR,CENTER)GRI 0430	CALL UNNORM(N,XL,XR,CENTER) CALL REGION(N,XL,XR,CENTER)	GRI 0390 GRI 0400
	CALL MERIT4(CENTER,YMID) NN = NN + 1 CALL NORMAL(N-XL-XR-CENTER)	GRI 0410 GRI 0420 GRI 0430
		with the second

الم المراجع الم

	00 5 I+1 N	CD T	0440
	$X_{10} = 1$	COT	0440
5		COT	0440
	CONTINUE	GRI	00000
	YBIG = YMID	GRT	0470
		GRI	0000
	DETERMINE MERIT ORDINATES IN GRID. NOTE LARGEST	GRI	0000
10	STEP = SIDE/3.0	GRI	0480
		GRI	2222
	AT EVERY GRID REDUCTION OCCASION, ALTERNATE BETWEEN A	 GR I	CCCC
	SQUARE SURVEY PATTERN AND A STAR SURVEY PATTERN,	 GRI	CCCC
		GR I	2222
	DEPENDING ON OODNESS OR EVENNESS OF JJ.	 GR I	CCCC
	IF(JJ/2+2-JJ)600,510,600	GRI	0490
		GR I	CCCC
	SQUARE GRID SURVEY	 GR I	C CC C
		GRI	CCCC
51.0	DD 500 I=1,N	GR I	0500
	X(I) = XLOW(I)	GRI	0510
500	CONTINUE	GRI	0520
_	GO TO (71,72,73,74,75,76,77,78),N	GR I	0530
78	18 = 0	GRI	0540
88	I8 = I8 + 1	GRI	0550
	X(8) = X(8) + STEP	GRI	0560
11		GRI	0570
87	1/=1/+1	GRI	0580
	X(I) = X(I) + SIEP	GRI	0590
10	10 = 11	GRI	0600
80	10 = 10 + 1	GRI	0610
75	X(0) = X(0) + S(0)	GKI	0620
12	15 = 0	COL	0650
69	10 - 10 + 1 1(5) - 1(5) + (5)	CPT	0640
74	$\frac{1}{16} = 0$	CPT	0660
94	14 = 16	CPT	0670
94	Y(4) = Y(4) + STEP	GRI	0680
73	$\mathbf{I3} = 0$	GRI	0690
83	13 = 13 + 1	GRI	0700
	X(3) = X(3) + STEP	GRI	0710
72	I2 = 0	GRI	072 0
82	12 = 12 + 1	GR I	0730
	X(2) = X(2) + STEP	GRI	0740
71	$\mathbf{I1} = 0$	GR I	0750
81	I1 = I1 + 1	GR I	0760
	X(1) = X(1) + STEP	GR I	0770
	CALL UNNORM(N,XL,XR,X)	GR I	0780
	CALL REGION(N,XL,XR,X)	GR I	0790
	CALL MERITA(X,Y1)	GRI	0800
	NN = NN + 1	GR T	0810
	CALL NORMAL(N,XL,XR,X)	GRI	0820
	CALL NORMAL(N,XL,XR,X) IF(Y1-YBIG) 171,171,6	GRI GRI	0820
6	CALL NORMAL(N,XL,XR,X) IF(Y1+YBIG) 171,171,6 YBIG = Y1	GRI GRI GRI	0820 0830 0840

۰. ۱

30	CONTINUE						GRÍ	0870
	IF(I1.EQ.2) GO TO 171					1 e	GRI	0880
	GO TO 81						GRÌ	0890
171	X(1) = XLOW(1)						GRÍ	0900
	IF(N.EQ.1) GO TO 501						GR I	0910
	IF(I2,EQ.2) GO TO 172	,					GRI	0920
	GO TO 82						GRI	0930
172	X(2) = XLDW(2)			• •			GR I	0940
	IF(N.EQ.2) GO TO 501						GRI	0950
	IF(I3.EQ.2) GO TO 173						GR I	0960
	GD TO 83	· .		¥ .			GRI	0970
173	X(3) = XLOW(3)						GRI	0980
	IF(N.EQ.3) GO TO 501						GR I	0990
	IF(14.EQ.2) GO TO 174		•				GRI	1000
	GO TO 84						GRI	1010
174	X(4) = XLOW(4)						GRI	1020
	IF(N.EQ.4) GO TO 501						GRI	1030
	IF(15.EQ.2) GO TO 175	100 A.					GRI	1040
							GRI	1050
175	$X(\mathbf{D}) = \mathbf{X} \mathbf{L} \mathbf{U} \mathbf{W} \mathbf{D} \mathbf{J}$						GRI	1060
	IF(N.EQ.5) GU TU 501						GRI	10/0
	IFLID-EQ-27 GU TO 176						GKI	1080
17/							GRI	1100
110	ALOF = ALUMIOJ TE(N EG 4) CO TO 501						GKI CÖT	1110
	171N-EQ-07 60 10 571						GRI	1120
	17117+CQ+23 60 10 177 -	1					G KI CD T	1120
177	V(7) ~ V(04(7)						CDT	1140
111	ALTJ = ALUMITJ 15(N 50 71 CD 10 501						CDT	1150
	171114EQUIT OU TO 291 16/19 EO 21 CO TO 179						CDT	1160
	TO TO 88						CPT	1170
179	V(8) = VINW(8)						GPT	1190
1.0	60  TO  501						GRI	1190
	00 10 211						GRI	1113
	STAR SHRVEY PATTERN						GRI	0000
		•					GRI	0000
600	00 601 I=1.N						GRT	1200
<b>.</b>	X(T) = CENTER(T)						GRI	1210
601	CONTINUE	:					GRI	1220
	D0 620 I=1.N						GRI	1230
	X(I) = CENTER(I)+STEP						GRI	1240
	CALL REGION (N, XL . XR . X)						GRI	1250
	CALL UNNORM (N, XL, XR, X)						GRÍ	1260
	CALL MERIT4(X,YPLUS)						GR I	1270
	NN = NN + 1						GRI	1280
	CALL NORMAL(N,XL,XR,X)						GRI	1290
	IF( YPLUS-YBIG) 611,611,610						GR I	1300
610	YBIG = YPLUS						GRI	1310
	DO 612 K=1,N						GRI	1320
	SAVEX(K) = X(K)						GRI	1330
612	CONT INUE						GRI	1340
611	X(I) = CENTER(I) - STEP						GR I	1350
	CALL UNNORM(N,XL,XR,X)						GR I	1360
	CALL REGION(N,XL,XR,X)						GRI	1370
					•			

and the second secon

CALL MERITA (X,YMINUS)         GRI 1380           NN = NN + 1         GRI 1390           CALL NORMAL(N,XL,XR,X)         GRI 1400           TF(YMINUS-YEIG614,616,613)         GRI 1410           GIJ YDIG = YMINUS         GRI 1420           OD 615 K=1,N         GRI 1420           SAVEX(K) = X(K)         GRI 1440           GIJ K=1,N         GRI 1440           GIJ G = YMINUS         GRI 1440           GIJ (= CENTER(I)         GRI 1440           GZ CONTINUE         GRI 1440           GZ MERCK DASSELF NOT SUFFICIENTLY SMALL SELECT LARGEST         GRI 1200           GZ MERCK DASSELF NOT SUFFICIENTLY SMALL SELECT LARGEST         GRI 1200           GZ MERCK DASSELF NOT SUFFICIENTLY SMALL SELECT LARGEST         GRI 1200           GZ MERCK DASSELF NOT SUFFICIENTLY SMALL SELECT LARGEST         GRI 1200           GZ MERCK DASSELF NOT	96 12	00000 23450	00001111111112222222222223333333333444444444	23450	7778 57890
NN = NN + 1         GR 1390           CALL NORMALIN, XL, XR, XL         GR 1400           13 YBIG = YMINUS         GR 1410           613 YBIG = YMINUS         GR 1440           00 615 K=1,N         GR 1440           615 CONTINUE         GR 1440           614 CONTINUE         GR 1460           620 CONTINUE         GR 1460           621 CONTINUE         GR 1460           622 CONTINUE         GR 1460           623 CONTINUE         GR 1460           624 CONTINUE         GR 1460           627 CONTINUE         GR 1460           628 CONTINUE         GR 1250           629 CONTINUE         GR 1250           620 CONTINUE         GR 1250           621 SIZE NOT SUFFICIENTLY SMALL SELECT LARGEST         GR 1250           631 SIZE NOT SUFFICIENTLY SMALL, SELECT LARGEST         GR 1250           641 SIZE NOT SUFFICIENTLY SMALL, SELECT LARGEST         GR 1250           7         GR 1510         GR 1510           7         GR 1510         GR 1510           7         GR 1510         GR 1510           7         GR 1510         GR 1520           7         GR 1510         GR 1520           7         GR 1510			CALL MERTTA (X. YN INUS)	GRI	1380
"ALL NORMAL(W,XL,XR,X)       GRT 1400         1613 WBIG = YMINUS       GRT 1410         013 WBIG = YMINUS       GRT 1420         02 015 K=1,N       GRT 1420         03 WBIG = YMINUS       GRT 1420         04 CONTINUE       GRT 1440         614 CONTINUE       GRT 1440         614 CONTINUE       GRT 1440         620 CONTINUE       GRT 1440         621 CONTINUE       GRT 1440         621 CONTINUE       GRT 1440         621 CONTINUE       GRT 1440         631 F(THSTG-YMID144,444,453       GRT 1440         631 F(TYBIG-YMID144,44,433       GRT 1520         73 YMID = YBIG       GRT 1520         74 CONTINUE       GRT 1540         75 CONTINUE       GRT 1540         76 CONTINUE       GRT 1540         77 GRT 44,44,43,41       GRT 1540         78 MID = YBIG       GRT 1540         79 CONTINUE       GRT 1540         70 CONTINUE       GRT 1550				CPT	1390
CEL UNDER DIG 1614,613         GRI 1410           613 Y01G = YHNUS         GRI 1410           00 G15 K=1,N         GRI 1420           SAVEX(K) = X(K)         GRI 1430           614 CONTINUE         GRI 1430           614 CONTINUE         GRI 1440           614 CONTINUE         GRI 1440           614 CONTINUE         GRI 1470           627         GRI 14170           637         GRI 1440           64         GRI 1440           66         GRI 1470           67         GRI 1470           68         GRI 1470           67         GRI 1470           68         GRI 1470           67         GRI 1470           68         GRI 1470           68         GRI 1470           67         GRI 1470           68         GRI 1470           67         GRI 1417           68         GRI 14170           67         GRI 14170           68         GRI 14170           67         GRI 1500           68         GRI 1500           68         GRI 1500           69         GRI 1510           70         GRI 1510			A = A = A = A = A = A = A = A = A = A =	COT	1400
613 Y01G = YMINUS       GRI 1420         613 Y01G = YMINUS       GRI 1420         00 615 K=1,N       GRI 1420         614 CONTINUE       GRI 1440         615 CONTINUE       GRI 1440         614 CONTINUE       GRI 1440         620 CONTINUE       GRI 1440         611 FINDER       GRI 1440         620 CONTINUE       GRI 1440         621 CONTINUE       GRI 1440         622 CONTINUE       GRI 1440         623 CONTINUE       GRI 1440         624 CONTINUE       GRI 1640         625 CONTINUE       GRI 1520         626 CONTINUE       GRI 1520         627 CONTINUE       GRI 1520         628 CONTINUE       GRI 1520         629 CONTINUE			CALL NORMALINJALJANJAJ	CPT	1410
01 01 01 51 K=1,N       GRI 1420         01 02 51 K=1,N       GRI 1430         5AVEX(K) = X(K)       GRI 1440         615 CONTINUE       GRI 1440         614 CONTINUE       GRI 1440         614 CONTINUE       GRI 1440         617 CONTINUE       GRI 1440         618 CONTINUE       GRI 1440         617 CONTINUE       GRI 1440         618 CONTINUE       GRI 1440         619 CONTINUE       GRI 1440         610 CONTINUE       GRI 1440         611 J = JJ+1       GRI 1470         617 CONTINUE       GRI 1440         618 CONTINUE       GRI 1450         619 CONTINUE       GRI 1460         610 J = JJ+1       GRI 1450         611 IF(FSIDEJ32,45,45       GRI 1500         611 IF(FSIDEJ32,45,45       GRI 1500         611 ISCONTINUE       GRI 1500         611 ISCONTINUE       GRI 1510         731 YHD = YBIC       GRI 1520         741 CALL UNNDRIN, XL, XR, CENTER)       GRI 1520         741 CALL UNNDRIN, XL, XR, CENTER)       GRI 1520         751 GALL UNNRAL(N, XL, XR, CENTER)       GRI 1520         752 CALL UNNRAL(N, XL, XR, CENTER)       GRI 1620         753 SIDE = SIDE*R       GRI 1620		(1)		CDT	1410
DD 015 M21,W       GRI 1430         615 CONTINUE       GRI 1440         616 CONTINUE       GRI 1450         620 CONTINUE       GRI 1460         620 CONTINUE       GRI 1460         620 CONTINUE       GRI 1470         620 CONTINUE       GRI 1470         620 CONTINUE       GRI 1470         620 CONTINUE       GRI 1470         621 CONTINUE       GRI 1470         622 CONTINUE       GRI 1470         620 CONTINUE       GRI 1470         621 CONTINUE       GRI 1470         622 CONTINUE       GRI 1470         621 CONTINUE       GRI 1470         621 CONTINUE       GRI 1470         621 CONTINUE       GRI 1490         621 CONTINUE       GRI 1500         621 CONTINUE       GRI 1500         621 CONTINUE       GRI 1500         622 CONTINUE       GRI 1500         622 CONTINUE       GRI 1510         7       SMILER GRID ABOUT THIS POINT.       GRI 1520         7       GRI 1510       GRI 1520         7       GRI 1520       GRI 1520         7       GRI 1530       GRI 1520         7       GRI 1550       GRI 1550         7		012		GRI	1420
SAVENTIAUE       GRI 1440         615 CONTINUE       GRI 1450         614 CONTINUE       GRI 1450         620 CONTINUE       GRI 1460         615 CONTINUE       GRI 1470         620 CONTINUE       GRI 1470         615 CONTINUE       GRI 1470         62       CHECK TO SEE IF GRID SIZE IS SMALL ENOUGH       GRI CCCC         501 JJ = JJ+1       GRI CCCC         701 JF - SIDE 32,455,455       GRI 1490         71 GRID SIZE NOT SUFFICIENTLY SMALL, SELECT LARGEST GRI CCCC       GRI CCCC         71 ORDINATE LOCATION FROM GRID AND CENTER NEXT       GRI CCCC         72 IF(YBIG-YMID)44,44,33       GRI 1520         73 YMID = YBIG       GRI 1520         74 O CONTINUE       GRI 1540         75 OCTTER(K) = SAVEX(K)       GRI 1540         76 CONTINUE       GRI 1540         77 CONTINUE       GRI 1540         78 GRI 1541       GRI 1540         79 CONTINUE       GRI 1540         70 CONTINUE       GRI 1540         70 CONTINUE       GRI 1540         70 CONTINUE       GRI 1540         71 CALL UNDRMIN, XL, XR, CENTER)       GRI 1550         72 CALL UNDRMIN, XL, XR, CENTER)       GRI 1560         73 SIDE = SIDERR				GRI	1430
G19 CONTINUE       GRI 1450         G14 CONTINUE       GRI 1460         X(I) = CENTER(I)       GRI 1470         G20 CONTINUE       GRI CCCC         G21 GUARDANE LOCATION FROM GRID AND CENTER NEXT       GRI 1500         G21 F19BG-YMID) 44,44,33       GRI 1490         G22 F19BG-YMID) 44,444,33       GRI 1510         G23 IF19BG-YMID) 44,444,33       GRI 1520         G2 OU 40 K=1,N       GRI 1520         G2 OUT TNUE       GRI 1520         G3 YMID = YBIG       GRI 1520         G4 CONTINUE       GRI 1530         G2 OUT TNUE       GRI 1520         G1 CCCC       GRI 1530         G2 OUT TNUE       GRI 1520         G1 CCCC       GRI 1550         G2 OUT TNUE       GRI 1550         G2 OUT TNUE		4 1 E	SAVEXINJ = X(N)	GRI	1440
bitCUNTINUEGRI 1400x(1) = CENTER(1)GRI 147062 CHECK TO SEE IF GRID SIZE IS SMALL ENOUGHGRI 1470c GRIC CCCGRI CCCC501 JJ = JJ+1GRI 1490GRI CCCC GRID SIZE MOT SUFFICIENTLY SMALL, SELECT LARGEST GRI CCCC ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC ORDINATE LOCATION FROM GRID AND CONTINUE GRI CCCC ORDINATE LOCATION FROM GRID AND CONTINUE SEARCH GRI CCCC IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, CD SO GRI CCCC IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, CD SO GRI CCCC ALDUCE SIZE OF GRID AND CONTINUE SEARCHGRI 1550 REDUCE SIZE OF GRID AND CONTINUE SEARCHGRI 1600 REDUCE SIZE OF GRID AND CONTINUE SEARCHGRI 1620 REDUCE SIZE OF GRID AND CONTINUE SEARCHGRI 1620 REDUCE SIZE OF GRID AND CONTINUE SEARCHGRI 1620<	· .	012		GRI	1420
All J = CENTER(1)GR I 1440620 CONTINUEGR I CCCC621 CONTINUEGR I CCCC622 CONTINUEGR I CCCC623 CONTINUEGR I CCCC624 CONTINUEGR I CCCC625 CONTINUEGR I CCCC626 CONTINUEGR I CCCC627 CONTINUEGR I CCCC628 CONTINUEGR I S10629 CONTINUEGR I S20629 CONTINUEGR I S50620 CONTINUEGR I S50620 CONTINUEGR I S50621 CCCCGR I S50622 CONTINUEGR I S50629 CONTINUEGR I S50620 CONTINUEGR I S50620 CONTINUEGR I S50621 CCCCGR I S50622 CONTANTE SIDE/YMID, (CENTER(1), I=1, 8), YB IG622 CONTANTE SIDE/YMID, (CENTER(1), I=1, 8), YB IG620 CONTINUE621 CCCC63 SIDE = SIDE*R631 CCCC63 SIDE = SIDE*R641 CALL UNNORMIN, XL, XR, CENTER)652 CONTINUE653 CALL UNNORMIN, XL, XR, XLOWI654 CONTINUE6550 CALL UNNORMIN, XL, XR, XLOWI651 CCCC650 CONTINUE650 CALL UNNORMIN, XL, XR, XLOWI651 CALL UNNORMIN, XL, XR, XLOWI655 CALL UNNORMIN, XL, XR, XLOWI655 CALL UNNORMIN, XL, XR, XLOWI750 CALL NORMAL (N, XL, XR, XLOWI751 CALL NORMAL (N, XL, XR, SAVEX) <td></td> <td>014</td> <td></td> <td>GRI</td> <td>1400</td>		014		GRI	1400
CV       CM I 1400       GR I 1400         C       CHECK TO SEE IF GRID SIZE IS SMALL ENDUGH       GR I CCCC         501       JJ = JJ+1       GR I 1400         IF(F-SIDE)32,45,45       GR I 1500         C       GRID SIZE NOT SUFFICIENTLY SMALL, SELECT LARGEST GRI CCCC         C       GRID SIZE NOT SUFFICIENTLY SMALL, SELECT LARGEST GRI CCCC         C       GRID ADDUT THIS PDINT.         C       GRI CCCC         32       IF(YBIG-YWID) 44,44,33         GR I 1510       GR I 1520         DD 40 K=1,N       GR I 1520         C ENTER(K) = SAVEX(K)       GR I 1530         GR I CCCC       GR I 1540         GR I 1540       GR I 1550         C IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, DO SD GR I CCCC         G ALL NUNDRM(N,XL,XR,CENTER)       GR I 1550         MR ITE16,42 INN,SIDE,YMID,(CENTER (I),I=1,B),YBIG       GR I 1560         GAL NORMAL(N,XL,XR,CENTER)       GR I 1560         GAL NORMAL(N,XL,XR,CENTER)       GR I 1660         CALL NORMAL(N,XL,XR,CENTER)       GR I 1660         CALL NORMAL(N,XL,XR,CENTER)       GR I 1660         CALL NORMAL(N,XL,XR,XLOH)       GR I 1620         SD 502 CONTINUE       CALL NORMAL(N,XL,XR,XHGH)       <		(	$\lambda(1) = \text{Center(1)}$	GKI	1470
C CHECK TO SEE IF GRID SIZE IS SMALL ENOUGHGRI CCCC501 JJ = JJ+1GRI CCCCIF(F-SIDE)32,45,45GRI 1500C GRID SIZE NOT SUFFICIENTLY SMALL, SELECT LARGEST GRI CCCC ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC SMALLER GRID ABOUT THIS PDINT GRI CCCC SMALLER GRID ABOUT THIS PDINT GRI CCCC STALLER GRID AABOUT THIS PDINT GRI CCCC STALLER GRID AABOUT THIS PDINT GRI CCCC IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, CD SD GRI CCCC IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, CD SD GRI CCCC REDUCE SIZE OF GRID AND CONTINUE SEARCH GRI CCCC REDUCE SIZE OF GRID AND CONTINUE SEARCH GRI CCCC REDUCE SIZE OF GRID AND CONTINUE SEARCH GRI CCCC REDUCE SIZE OF GRID AND CONTINUE SEARCH GRI 1600CALL UNNORMI(N,XL,XR,XLOW)CALL UNNORMI(N,XL,XR,XLOW)CALL NORMAL(N,XL,XR,XLOW)CALL NORMAL(N,XL,XR,XLOW)CALL NORMAL(N,XL,XR,XLOW)CALL NORMAL(N,XL,XR,XLOW)CALL NORMAL(N,XL,XR,XLOW)CALL NORMAL(N,XL,XR,XHIGH)GRI 1720CALL NORMAL(N,XL,XR,XHIGH)GRI 1720CALL NORMAL(N,XL,XR,XHIGH)GRI 1720CALL NORMAL(N,XL,XR,XHIGH)GRI 1720 </td <td>6</td> <td>0217</td> <td></td> <td>GRI</td> <td>1480</td>	6	0217		GRI	1480
501       JJ = JJ+1       GRI CCCC         501       JJ = JJ+1       GRI CCCC         1F(F-SIDE)32,45,45       GRI 1500         C       GRID SIZE NOT SUFFICIENTLY SMALL, SELECT LARGEST GRI CCCC         GRID SIZE NOT SUFFICIENTLY SMALL, SELECT LARGEST GRI CCCC         GRID SIZE NOT SUFFICIENTLY SMALL, SELECT LARGEST GRI CCCC         GRID GUT THIS POINT.         32       IF(YBIG-YHID)44,44,33         33       GRI 1520         00 40 K=1,N       GRI 1520         CENTER(K) = SAVEXIK)       GRI 1520         GC 0NTINUE       GRI 1520         CENTER(K) = SAVEXIK)       GRI 1550         GC IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, DO SD GRI CCCC         GRI 1560       GRI 1560         GRI 1560       GRI 1570         GRI 1560       GRI 1560         GRI 1560       GRI	L.			GRI	
501       JJ = JJ+1       GRI 1490         IF(F-SIDE)32,45,45       GRI 1500         GRID SIZE NOT SUFFICIENTLY SMALL, SELECT LARGEST GRI CCCC       GRI CCCC         GRID SIZE NOT SUFFICIENTLY SMALL, SELECT LARGEST GRI CCCC       GRI CCCC         GRID SIZE NOT SUFFICIENTLY SMALL, SELECT LARGEST GRI CCCC       GRI CCCC         SMALLER GRID ABOUT THIS POINT.       GRI 1510         SMALLER GRID ABOUT THIS POINT.       GRI 1520         SMALLER GRID ABOUT THIS POINT.       GRI 1520         IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, DD SD GRI CCCC       GRI 1560         IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, DD SD GRI CCCC       GRI 1560         REDUCE SIZE OF GRID AND CONTINUE SEARCH       GRI 1560         REDUCE SIZE OF GRID AND CONTINUE SEARCH       GRI 1620         REDUCE SIZE OF GRID AND CONTINUE SEARCH       GRI 1620         REDUCE SIZE OF GRID AND CONTINUE SEARCH       GRI 1620         REDUCE SIZE OF GRID AND CONTINUE SEARCH       GRI 1620	ž		CHECK TO SEE IF GRID SIZE IS SHALL ENDUGH	GKI	
Dif JJ = JJ1       GRI 1500         IF(F-SIDE J32,45,45       GRI 1500         C       GRID SIZE NOT SUFFICIENTLY SMALL, SELECT LARGEST GRI CCCC         ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC         ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC         ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC         ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC         ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC         SMALLER GRID AADUT THIS POINT.         GRID SIZE NOT SUFFICIENTLY SMALL, SELECT LARGEST GRI CCCC         OF PRINTIAL (N, 44,44,33         GRID SIZE NOT SUFFICIENTLY SMALL         GRID SIZE NOT SUFFICIENTLY SMALL         GRID SIZE NOT SUFFICIENTLY         GRID CCCC         IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, CD SD GRI CCCC         IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, CD SD GRI CCCC         IF PRINTIAL, XR, CENTER)       GRI 1550         REDUCE SIZE OF GRID AND CONTINUE SEARCH       GRI 1600         REDUCE SIZE OF GRID AND CONTINUE SEARCH       GRI 1620         REDUCE SIZE OF GRID AND CONTINUE SEARCH       GRI 1620         REDUCE SIZE OF GRID AND CONTINUE SEARCH       GRI 1620         REDUCE SIZE OF GR	1	ċ.e.t		GRI	
IF(F-SIDE J32, 49, 45)GRI 1500GRI DSIZE NOT SUFFICIENTLY SMALL, SELECT LARGEST GRI CCCCGRI CCCC GRID SIZE NOT SUFFICIENTLY SMALL, SELECT LARGEST GRI CCCCGRI CCCC GRID ARE LOCATION FROM GRID AND CENTER NEXT GRI CCCCGRI CCCC32 IF(YBIG-YMID) 44, 44, 33GRI 151033 YMID = YBIGGRI 1520DO 40 K=1, NGRI 1530CENTER(K) = SAVEX(K)GRI 1530CENTER(K) = SAVEX(K)GRI 1540GRI CCCCGRI 1540C IF PRINTING DF CONVERGENCE MONITOR IS REQUIRED, DD SD GRI CCCC44 IF(MPRINT)41, 43, 41GRI 1560WRITE(6, 42) NN, SIDE, YMID, (CENTER(I), I=1, 8), YB IGGRI 1580GRI CCCCGRI 156042 FORMAT(1X, IS, 11E10.3)GRI 1600CALL NORMAL(N, XL, XR, CENTER)GRI 1600CALL NORMAL(N, XL, XR, CENTER)GRI 1600CALL NORMAL(N, XL, XR, CENTER)GRI 1620AXIDH(1) = CENTER(I)-SIDE/2.0GRI 1620XLOW(I) = CENTER(I)-SIDE/2.0GRI 1640SIDE = SIDE*RGRI 1620CALL UNNORM(N, XL, XR, XLOW)GRI 1640CALL NORMAL(N, XL, XR, XLOW)GRI 1640CALL NORMAL(N, XL, XR, XLOW)GRI 1640CALL NORMAL(N, XL, XR, SAVEX)GRI 1700CALL NORMAL(N, XL, XR, SAVEX)GRI 1720C GRID SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCHC43 SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCHCGRI 1720CGRI 1720CALL NORMAL(N, XL, XR, SAVEX)GRI 1720CGRID SIZE S		201	11 = 11 + 12	GRI	1490
GRI CCCC GRI CC	~		1+(+-510) 132,49,49	GRI	1500
ORID SIZE NOT SUPFICIENTLY SMALL, SELECT LAXGEST GRI CCCC ORDINATE LOCATION FROM GRID AND CENTER NEXT GRI CCCC SMALLER GRID ABOUT THIS POINT GRI CCCC SMALLER GRID ABOUT THIS POINT GRI CCCC GRID CCCC GRI CCCC GRID CCCC GRI CCCC IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, CD SD GRI CCCC IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, CD SD GRI CCCC IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, CD SD GRI CCCC IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, CD SD GRI CCCC IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, CD SD GRI CCCC REDUCE SIZE OF GRID AND CONTINUE SEARCH GRI 1620 REDUCE SIZE OF GRID AND CONTINUE SEARCH REDUCE SIZE OF GRID AND CONTINUE SEARCH REDUCE SIZE OF GRID AND CONTINUE SEARCH GRI 1640 GRI 1650 GRI 1650 GRI 1650.	2			GRI	
SMALLER GRID ABOUT THIS POINT.GRI CCCC32 IF(YBIG-YMID)44,44,33GRI 151033 YMID = YBIGGRI 1520DD 40 K=1,NGRI 1520CENTER(K) = SAVEX(K)GRI 1530CENTER(K) = SAVEX(K)GRI 1530CENTER(K) = SAVEX(K)GRI 1550GONT INUEGRI CCCC IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, DD SD GRI CCCC41 FI MPRINT)41,43,41GRI 1570WRITE(6,42)NN,SIDE,YMID,(CENTER(I),I=1,8),YBIGGRI 1570WRITE(6,42)NN,SIDE,YMID,(CENTER(I),I=1,8),YBIGGRI 1590CALL NORMAL(N,XL,XR,CENTER)GRI 1600CALL NORMAL (N,XL,XR,CENTER)GRI 1600CALL NORMAL (N,XL,XR,CENTER)GRI 1620XLOW(I) = CENTER(I)-SIDE/2.0GRI 1630XHIGH(I) = CENTER(I)-SIDE/2.0GRI 1630XHIGH(I) = CENTER(I)-SIDE/2.0GRI 1640CALL UNNORM(N,XL,XR,XLOW)GRI 1660CALL UNNORM(N,XL,XR,XLOW)GRI 1660CALL UNNORM(N,XL,XR,XLOW)GRI 1660CALL NORMAL(N,XL,XR,XHIGH)GRI 1700CALL NORMAL(N,XL,XR,XHIGH)GRI 1710CALL NORMAL(N,XL,XR,XHIGH)GRI 1720GO TO 10GRI 1720CALL NORMAL(N,XL,XR,XHIGH)GRI 1720CALL NORMAL(N,XL,XR,XHIGH)GRI 1720CALL NORMAL(N,XL,XR,XHIGH)GRI 1720CALL NORMAL(N,XL,XR,XANGW)GRI 1720CALL NORMAL(N,XL,XR,XANGW)GRI 1720CALL NORMAL(N,XL,XR,XANGW)GRI 1720CALL NORMAL(N,XL,XR,XANGW)GRI 1720CALL NORMAL(N,XL,XR,XANGW)GRI 1720CALL REGION(N,X	ž		GRID SIZE NOT SUFFICIENTLY SMALL, SELECT LARGEST	GRI	
31       SMALLER GRID ABOUT THIS POINT.       GRI CCCC         32       IF(YBIG-YMID)44,44,33       GRI 1510         33       YMID = YBIG       GRI 1520         DD 40 K=1,N       GRI 1520         CENTER(K) = SAVEX(K)       GRI 1540         40       CONTINUE       GRI CCCC         IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, DD SD GRI CCCC       GRI CCCC         41       IF(MPINT)41,43,41       GRI 1560         42       IF(MPINT)41,43,41       GRI 1560         41       CALL UNNORM(N,xL, XR, CENTER)       GRI 1570         WRITE(6,421)NN,SIDE,YMID, (CENTER(I), I=1,8),YBIG       GRI 1580         42       FORMAT(1X,15,11E10.3)       GRI 16600         GRI CCCC       REDUCE SIZE OF GRID AND CONTINUE SEARCH       GRI CCCC         43       SIDE = SIDE*R       GRI 1610         DD 502       I=1,N       GRI 1620         XLIGH(I) = CENTER(I)-SIDE/2.0       GRI 1640         SO2       CONTINUE       GRI 1640         GAL UNNORM(N,XL,XR,XLOW)       GRI 1650         CALL UNNORM(N,XL,XR,XLOW)       GRI 1650         CALL UNNORM(N,XL,XR,XLOW)       GRI 1660         CALL UNNORM(N,XL,XR,XHIGH)       GRI 1690         CALL UNNORM(N,XL,XR,XHIGH) </td <td>5</td> <td></td> <td> URDINATE LUCATION FROM GRID AND CENTER NEXT</td> <td>GRI</td> <td></td>	5		URDINATE LUCATION FROM GRID AND CENTER NEXT	GRI	
32       IF(YBIG-YMID)44,44,33       GRI LCCC         33       YMID = YBIG       GRI 1520         DD 40 K=1,N       GRI 1520         CENTER(K) = SAVEX(K)       GRI 1530         40       CONTINUE       GRI 1550         60       GRI CCCC       GRI CCCC         41       IF(MPRINT)41,43,41       GRI 1560         41       CALL UNNORM(N,XL,XR,CENTER)       GRI 1560         41       GALL UNNORMIN,XL,XR,CENTER)       GRI 1560         42       FORMAT(1X,15,11E10.3)       GRI 1600         64       CALL NORMAL(N,XL,XR,CENTER)       GRI 1600         67       CCCC       GRI CCCC         43       SIDE = SIDE*R       GRI 1600         70       SO 502 ICI+N       GRI CCCC         43       SIDE = SIDE*R       GRI 1610         70       SO 502 ICONTINUE       GRI 1620         71       XLOW(I) = CENTER(I)-SIDE/2.0       GRI 1630         72       XLOW(I) = CENTER(I)-SIDE/2.0       GRI 1660         73       SIDE = SIDE*R       GRI 1660         74       GRI 10N(N,XL,XR,XLOW)       GRI 1660         752       CONTINUE       GRI 1660         764       CALL NORMAL(N,XL,XR,XLOW)       GRI 1660			••••• SMALLER GRID ABOUT THIS PUINT.	GRI	
32       IF(YBIG-YMID) 44,44,33       GRI 1510         33       YMID = YBIG       GRI 1520         D0 40 K=1,N       GRI 1530         CENTER(K) = SAVEX(K)       GRI 1550         40       CONTINUE       GRI 1550         IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, DO SD GRI CCCC       GRI CCCC         41       CALL UNNORMIN,XL,XR,CENTER)       GRI 1560         wRITE(6,42)NN,SIDE,YMID, (CENTER(I),I=1,8),YBIG       GRI 1580         42       FORMAT(IX,IS,IEG,YMID, (CENTER))       GRI 1590         CALL NORMAL(N,XL,XR,CENTER)       GRI 1590         cALL NORMAL(N,XL,XR,CENTER)       GRI 1600         GRI CCCC       GRI 1600         502       CALL NORMAL(N,XL,XR,CENTER)       GRI 1600         value       GRI 10 AND CONTINUE SEARCH       GRI 1600         502       GRI 10 AND CONTINUE SEARCH       GRI 1620         XLDW(I) = CENTER(I)-SIDE/2.0       GRI 1630       GRI 1640         XLUGUNIN,XL,XR,XLOWI       GRI 1650       GRI 1660         CALL UNNORM(N,XL,XR,XLOWI)       GRI 1660       GRI 1670         CALL UNNORM(N,XL,XR,XLOWI)       GRI 1660       GRI 1700         CALL NORMAL(N,XL,XR,XLOWI)       GRI 1660       GRI 1700         CALL NORMAL(N,XL,XR,XLOWI)	3			GRI	CCCC
33 YMID = YBIG       GRI 1520         D0 40 K=1,N       GRI 1530         CENTER(K) = SAVEX(K)       GRI 1550         40 CONTINUE       GRI 1550         GRI 1550       GRI 1550         GRI CCCC       GRI CCCC         41 CALL UNNORM(N,XL,XR,CENTER)       GRI 1550         WRITE(6,42)NN,SIDE,YMID, (CENTER(I),I=1,B),YBIG       GRI 1550         42 FORMAT(IX,IS,IIE0,3)       GRI 1550         CALL NORMAL(N,XL,XR,CENTER)       GRI 1600         WRITE(6,42)NN,SIDE,YMID, (CENTER(I),I=1,B),YBIG       GRI 1590         CALL NORMAL(N,XL,XR,CENTER)       GRI 1600         GRI CCCC       GRI 1600         CALL NORMAL(N,XL,XR,CENTER)       GRI 1620         XLOW(I) = CENTER(I)-SIDE/2.0       GRI 1610         XLOW(I) = CENTER(I)-SIDE/2.0       GRI 1650         CALL UNNORM(N,XL,XR,XLOW)       GRI 1650         CALL UNNORM(N,XL,XR,XLOW)       GRI 1660         CALL REGIDN(N,XL,XR,XLOW)       GRI 1660         CALL NORMAL(N,XL,XR,XLOW)		32	IF( YBIG-YMID) 44,44,33	GRI	1510
DU 40 K=1,N       GRI 1530         CENTER(K) = SAVEX(K)       GRI 1550         40 CONTINUE       GRI 1550         center(K) = SAVEX(K)       GRI 1550         GRI 1550       GRI 1550         center(K) = SAVEX(K)       GRI 1550         GRI 1550       GRI 1550         center(K) = SAVEX(K)       GRI 1550         GRI 1560       GRI 1560         GRI 1561       GRI 1560         GRI 1570       GRI 1560         write(6,42)NN,SIDE,YMI0,(CENTER(I),I=1,8),YBIG       GRI 1580         42 FORMAT(1x,I5,11E10,3)       GRI 1600         CALL NORMAL(N,XL,XR,CENTER)       GRI 1600         call to NORMAL(N,XL,XR,CENTER)       GRI 1600         call to SIDE = SIDE*R       GRI 1620         D0 502 I=1,N       GRI 1620         xLOW(I) = CENTER(I)-SIDE/2.0       GRI 1630         xHIGH(I) = CENTER(I)+SIDE/2.0       GRI 1640         502 CONTINUE       GRI 1660         CALL UNNORM(N,XL,XR,XLOW)       GRI 1660         CALL UNNORM(N,XL,XR,XLOW)       GRI 1660         CALL UNNORM(N,XL,XR,XLOW)       GRI 1660         CALL NORMAL(N,XL,XR,XLOW)       GRI 1660         CALL NORMAL(N,XL,XR,XLOW)       GRI 1660         CALL NORMAL(N,XL,XR,XLOW)       GRI		33	YMID = YBIG	GRI	1520
CENTER(K) = SAVEX(K) 60 CONTINUE 60 CALL NORMAL(N,XL,XR,CENTER) 60 CALL NORMAL(N,XL,XR,XLOW) 60 CALL NORMAL(N,XL,XR,XLOW) 60 CALL NORMAL(N,XL,XR,XLOW) 60 CALL NORMAL(N,XL,XR,XLOW) 60 CALL REGION(N,XL,XR,XHIGH) 60 CALL NORMAL(N,XL,XR,XHIGH) 60 CALL NORMAL(N,XL,XR,XAVEX) 60 CALL NORMAL(N,XL,XR,SAVEX) 60 CALL NORMA			DU 40 K=1 •N	GRI	1530
40CUNTINUEGRI 155061GRI CCCCGRI CCCC62GRI CCCCGRI CCCC64IF(MPRINT)41,43,41GRI 156061CALL UNNORM(N,XL,XR,CENTER)GRI 157062WRITE(6,42)NN,SIDE,YMID,(CENTER(I),I=1,8),YBIGGRI 158062FORMAT(1X,I5,11E10.3)GRI 160062GRI MDRMAL(N,XL,CENTER)GRI 160063GIDE = SIDE*RGRI CCCC64SIDE = SIDE*RGRI 161070D0 502 I=1,NGRI 162071XLOW(1) = CENTER(1)-SIDE/2,0GRI 164072SOZ CONTINUEGRI 164074GIDNNRM(N,XL,XR,XLOW)GRI 164075CALL UNNORM(N,XL,XR,XLOW)GRI 167074CALL NORMAL(N,XL,XR,XLOW)GRI 167075CALL NORMAL(N,XL,XR,XHIGH)GRI 170076GRI D SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCHGRI 772076CALL UNNORM(N,XL,XR,SAVEX)GRI 1740			CENTER(K) = SAVEX(K)	GRI	1540
GRI CCCC 44 IF(MPRINT)41,43,41 41 CALL UNNORM(N,XL,XR,CENTER) WRITE(6,42)NN,SIDE,YMID,(CENTER(I),I=1,8),YBIG 42 FORMAT(1X,I5,11E10.3) CALL NORMAL(N,XL,XR,CENTER) 42 FORMAT(1X,I5,11E10.3) CALL NORMAL(N,XL,XR,CENTER) 43 SIDE = SIDE*R DO 502 I=1,N XLOW(I) = CENTER(I)-SIDE/2.0 XLOW(I) = CENTER(I)-SIDE/2.0 XHIGH(1) = CENTER(I)-SIDE/2.0 CALL UNNORM(N,XL,XR,XLOW) CALL UNNORM(N,XL,XR,XLOW) CALL NORMAL(N,XL,XR,XLOW) CALL REGION(N,XL,XR,XLOW) CALL NORMAL(N,XL,XR,XLOW) CALL NORMAL(N,XL,XR,XLOW) CALL NORMAL(N,XL,XR,XR,XLOW) CALL NORMAL(N,XL,XR,XR,XLOW) CALL NORMAL(N,XL,XR,XR,XLOW) CALL NORMAL(N,XL,XR,XR,XLOW) CALL NORMAL(N,XL,XR,SAVEX) CALL REGION(N,XL,XR,XR,SAVEX) CALL REGION(N,XL,XR,XR,SAVEX) CALL REGION(N,XL,XR,XR,SAVEX) CALL REGION(N,XL,XR,XR,YAVEX) CALL REGION(N,XL,XR,YAVEX) CALL NORMAL(N,XL,XR,YAVEX) CALL NORMAL(N,XL,XR,YAVEX) CALL NORMAL(N,XL,YR,YAVEX) CALL NORMAL(N,XL,YR,YAVEX) CALL NORMAL(N,XL,YR,YAVEX) CALL NORMAL(N,XL,YR,YAVEX) CALL NORMAL(N,XL,	-	40	CONTINUE	GRI	1550
C IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, DU SD GRI CCCC GRI CCCC 44 IF(MPRINT)41,43,41 41 CALL UNNORM(N,XL,XR,CENTER) WRITE(6,42)NN,SIDE,YMID,(CENTER(I),I=1,8),YBIG 62 FORMAT(IX,I5,ILEIO.3) CALL NORMAL(N,XL,XR,CENTER) GRI 1580 CALL NORMAL(N,XL,XR,CENTER) GRI CCCC 43 SIDE = SIDE*R DO 502 I=1,N XLOW(I) = CENTER(I)-SIDE/2.0 XHIGH(I) = CENTER(I)-SIDE/2.0 XHIGH(I) = CENTER(I)+SIDE/2.0 GRI 1630 XHIGH(I) = CENTER(I)+SIDE/2.0 GRI 1660 CALL UNNORM(N,XL,XR,XLOW) CALL UNNORM(N,XL,XR,XLOW) CALL NORMAL(N,XL,XR,XLOW) CALL NORMAL(N,XL,XR,XLOW) CALL NORMAL(N,XL,XR,XLOW) CALL NORMAL(N,XL,XR,XHIGH) CALL NORMAL(N,XL,XR,XHIGH) CALL NORMAL(N,XL,XR,XHIGH) GRI 1670 CALL NORMAL(N,XL,XR,XHIGH) GRI 1670 CALL NORMAL(N,XL,XR,XHIGH) GRI 1710 GRI 1710 GRI CCCC 45 CALL UNNORM(N,XL,XR,SAVEX) CALL REGION(N,XL,XR,SAVEX) GRI 1730 CALL REGION(N,XL,XR,SAVEX) GRI 1740	2			GR I	CCCC
C GRI CCCC 44 IF(MPRINT)41,43,41 GRI 1560 41 CALL UNNORM(N,XL,XR,CENTER) GRI 1570 WRITE(6,42)NN,SIDE,YMID,(CENTER(I),I=1,8),YBIG GRI 1580 42 FORMAT(1X,I5,11E10.3) GRI 1590 CALL NORMAL(N,XL,XR,CENTER) GRI CCCC REDUCE SIZE OF GRID AND CONTINUE SEARCH GRI CCCC 43 SIDE = SIDE*R GRI COCC GRI COCC 43 SIDE = SIDE*R GRI 1610 DO 502 I=1,N GRI 1620 XLOW(I) = CENTER(I)-SIDE/2.0 GRI 1620 XLOW(I) = CENTER(I)+SIDE/2.0 GRI 1650 CALL UNNORM(N,XL,XR,XLOW) GRI 1650 CALL UNNORM(N,XL,XR,XLOW) GRI 1660 CALL UNNORM(N,XL,XR,XLOW) GRI 1660 CALL REGION(N,XL,XR,XHIGH) GRI 1660 CALL NORMAL(N,XL,XR,XHIGH) GRI 1690 CALL NORMAL(N,XL,XR,XHIGH) GRI 1690 CALL NORMAL(N,XL,XR,XHIGH) GRI 1690 CALL NORMAL(N,XL,XR,XHIGH) GRI 1720 GRI 1720 GRI CCCC GRID SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCH GRI CCCC 45 CALL UNNORM(N,XL,XR,SAVEX) GRI 1730	C		IF PRINTING OF CONVERGENCE MONITOR IS REQUIRED, DO SO	GRI	CCCC
44       IF(MPRINT)41,43,41       GRI 1560         41       CALL UNNORM(N,XL,XR,CENTER)       GRI 1570         wRITE(6,42)NN,SIDE,YMID,(CENTER(I),I=1,8),YBIG       GRI 1580         42       FORMAT(1X,I5,11E10.3)       GRI 1590         CALL NORMAL(N,XL,XR,CENTER)       GRI 1600         CALL NORMAL(N,XL,XR,CENTER)       GRI 1600         CALL NORMAL(N,XL,XR,CENTER)       GRI 0CCCC         REDUCE SIZE OF GRID AND CONTINUE SEARCH       GRI 0CCCC         43       SIDE = SIDE*R       GRI 1610         D0       502 I=1,N       GRI 1620         XLOW(I) = CENTER(I)-SIDE/2.0       GRI 1630         XHIGH(I) = CENTER(I)+SIDE/2.0       GRI 1640         502 CONTINUE       GRI 1660         CALL UNNORM(N,XL,XR,XLOW)       GRI 1660         CALL UNNORM(N,XL,XR,XHIGH)       GRI 1660         CALL NORMAL(N,XL,XR,XLOW)       GRI 1660         CALL NORMAL(N,XL,XR,XHIGH)       GRI 1710         GO TO 10       GRI 1710         CALL NORMAL(N,XL,XR,SAVEX)       GRI 1720         GRI 1730       GRI 1730         CALL UNNORM(N,XL,XR,SAVEX)       GRI 1730         GRI 1730       GRI 1730	C			GRI	CCCC
41 CALL UNNORM(N,XL,XR,CENTER) WRITE(6,42)NN,SIDE,YMID,(CENTER(I),I=1,8),YBIGGRI 1570 GRI 158042 FORMAT(1X,IS,IE10,3) CALL NDRMAL(N,XL,XR,CENTER)GRI 1600 GRI 160064 COLL NORMAL(N,XL,XR,CENTER)GRI 1600 GRI CCCC65 COLL NORMAL(N,XL,XR,CENTER)GRI 1610 GRI CCCC67 GRI CCCC GRI CCCCGRI 1610 GRI 161070 STOR E SIDE * R DO 502 I = 1, N XLOW(I) = CENTER(I) - SIDE/2.0 XLOW(I) = CENTER(I) - SIDE/2.0 GRI 1630 CALL UNNORM(N,XL,XR,XLOW) CALL UNNORM(N,XL,XR,XLOW) GRI 1650 CALL UNNORM(N,XL,XR,XLOW) GALL REGIDN(N,XL,XR,XLOW) GALL REGIDN(N,XL,XR,XLOW) GALL NORMAL(N,XL,XR,XLOW) GALL NORMAL(N,XL,XR,XLOW) GALL NORMAL(N,XL,XR,XLOW) GALL NORMAL(N,XL,XR,XLOW) GALL NORMAL(N,XL,XR,XLOW) GALL NORMAL(N,XL,XR,XLOW) GALL NORMAL(N,XL,XR,XLOW) GALL NORMAL(N,XL,XR,XLOW) GALL NORMAL(N,XL,XR,XHIGH) GALL NORMAL(N,XL,XR,XLOW) GALL NORMAL(N,XL,XR,XLOW) GALL NORMAL(N,XL,XR,XLOW) GALL NORMAL(N,XL,XR,XALOW) GALL NORMAL(N,XL,XR,SAVEX) GALL REGION(N,XL,XR,SAVEX)GRI 1720 GRI 1720 GRI 1730 GRI 1730		44	IF(MPRINT)41,43,41	GR I	1560
WRITE(6,42)NN,SIDE,YMID, (CENTER(I), I=1,8),YBIG       GRI 1580         42 FORMAT(1x,I5,11E10.3)       GRI 1590         CALL NDRMAL(N,XL,XR,CENTER)       GRI 1600         CALL NDRMAL(N,XL,XR,CENTER)       GRI CCCC         43 SIDE = SIDE*R       GRI 1610         D0 502 I=1,N       GRI 1620         XLOW(I) = CENTER(I)-SIDE/2.0       GRI 1630         XHIGH(I) = CENTER(I)+SIDE/2.0       GRI 1650         CALL UNNORM(N,XL,XR,XLOW)       GRI 1660         CALL UNNORM(N,XL,XR,XLOW)       GRI 1660         CALL REGION(N,XL,XR,XLOW)       GRI 1660         CALL REGION(N,XL,XR,XLOW)       GRI 1670         CALL NORMAL(N,XL,XR,XLOW)       GRI 1670         CALL NORMAL(N,XL,XR,XLOW)       GRI 1670         CALL NORMAL(N,XL,XR,XLOW)       GRI 1670         CALL NORMAL(N,XL,XR,XLOW)       GRI 1710         GO TO 10       GRI 1710         C       GRID SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCH       GRI CCCC         45 CALL UNNORM(N,XL,XR,SAVEX)       GRI 1730         CALL REGION(N,XL,XR,SAVEX)       GRI 1740		41	CALL UNNORM(N,XL,XR,CENTER)	GRI	1570
42FOR MAT(1x,15,11E10.3)GRI 1590CALL NORMAL(N,XL,XR,CENTER)GRI 1600CALL NORMAL(N,XL,XR,CENTER)GRI CCCC43SIDE = SIDE*RGRI CCCC43SIDE = SIDE*RGRI 1610D0 502I=1,NGRI 1620XLOW(I) = CENTER(I)-SIDE/2.0GRI 1640XHIGH(I) = CENTER(I)+SIDE/2.0GRI 1650502CONTINUEGRI 1660CALL UNNORM(N,XL,XR,XLOW)GRI 1660CALL REGION(N,XL,XR,XLOW)GRI 1660CALL REGION(N,XL,XR,XLOW)GRI 1690CALL NORMAL(N,XL,XR,XHIGH)GRI 1710GO TO 10GRI 1710GO TO 10GRI 1720C GRID SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCHGRI CCCC45CALL UNNORM(N,XL,XR,SAVEX)GRI 1730CALL REGION(N,XL,XR,SAVEX)GRI 1740			WRITE(6,42)NN,SIDE,YMID, (CENTER(I),I=1,8),YBIG	GRI	1580
CALL NDRMAL(N,XL,XR,CENTER)GRI 1600GRI CCCCGRI CCCCGRI CCCCGRI CCCC43 SIDE = SIDE*RGRI 1610D0 502 I=1,NGRI 1620XLOW(I) = CENTER(I)-SIDE/2.0GRI 1620XHIGH(I) = CENTER(I)+SIDE/2.0GRI 1650CALL UNNORM(N,XL,XR,XLOW)GRI 1660CALL REGION(N,XL,XR,XLOW)GRI 1660CALL REGION(N,XL,XR,XLOW)GRI 1680CALL NORMAL(N,XL,XR,XLOW)GRI 1690CALL NORMAL(N,XL,XR,XLOW)GRI 1700CALL NORMAL(N,XL,XR,XLOW)GRI 1700CALL NORMAL(N,XL,XR,XLOW)GRI 1700CALL NORMAL(N,XL,XR,XLOW)GRI 1700CALL NORMAL(N,XL,XR,XLOW)GRI 1700CALL NORMAL(N,XL,XR,XLOW)GRI 1700CALL NORMAL(N,XL,XR,XLOW)GRI 1710GO TO 10GRI 1700C GRID SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCHC GRID SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCHC GRI SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCHC		42	FOR MAT(1X, I5, 11E10.3)	GR I	1590
GRI CCCC ••••• REDUCE SIZE OF GRID AND CONTINUE SEARCH •••••• GRI CCCC •3 SIDE = SIDE*R DO 502 I=1,N XLOW(I) = CENTER(I)-SIDE/2.0 XLOW(I) = CENTER(I)+SIDE/2.0 GRI 1630 XHIGH(I) = CENTER(I)+SIDE/2.0 GRI 1650 CALL UNNORM(N,XL,XR,XLOW) CALL NORM(N,XL,XR,XLOW) CALL REGION(N,XL,XR,XLOW) CALL REGION(N,XL,XR,XLOW) CALL REGION(N,XL,XR,XLOW) CALL NORMAL(N,XL,XR,XLOW) CALL NORMAL(N,XL,XR,XHIGH) GRI 1680 CALL NORMAL(N,XL,XR,XHIGH) GRI 1690 CALL NORMAL(N,XL,XR,XHIGH) GRI 1700 GRI 1700 GRI 1700 GRI 1720 GRI 1720 GRI CCCC ••••• GRID SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCH •••••• GRI CCCC 45 CALL UNNORM(N,XL,XR,SAVEX) GRI 1740			CALL NORMAL (N, XL, XR, CENTER)	GRI	1600
c REDUCE SIZE OF GRID AND CONTINUE SEARCHGRI CCCC43 SIDE = SIDE*RGRI 1610D0 502 I=1,NGRI 1620XLOW(I) = CENTER(I)-SIDE/2.0GRI 1630XHIGH(I) = CENTER(I)+SIDE/2.0GRI 1640502 CONTINUEGRI 1660CALL UNNORM(N,XL,XR,XLOW)GRI 1660CALL REGION(N,XL,XR,XLOW)GRI 1660CALL REGION(N,XL,XR,XLOW)GRI 1660CALL NORMAL(N,XL,XR,XLOW)GRI 1690CALL NORMAL(N,XL,XR,XLOW)GRI 1690CALL NORMAL(N,XL,XR,XLOW)GRI 1670CALL NORMAL(N,XL,XR,XHIGH)GRI 1690CALL NORMAL(N,XL,XR,XHIGH)GRI 1700GO TO 10GRI 1720C GRID SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCHC GRID SIZE SUFFICIENTLY SMALLC GRI 1730C	2		· · · · · · · · · · · · · · · · · · ·	GRI	0000
C       GRI CCCC         43 SIDE = SIDE*R       GRI 1610         D0 502 I=1,N       GRI 1620         xLOW(I) = CENTER(I)-SIDE/2.0       GRI 1630         xHIGH(I) = CENTER(I)+SIDE/2.0       GRI 1640         502 CONTINUE       GRI 1650         CALL UNNORM(N,XL,XR,XLOW)       GRI 1660         CALL UNNORM(N,XL,XR,XHIGH)       GRI 1660         CALL REGION(N,XL,XR,XLOW)       GRI 1660         CALL REGION(N,XL,XR,XHIGH)       GRI 1690         CALL NORMAL(N,XL,XR,XLOW)       GRI 1690         CALL NORMAL(N,XL,XR,XHIGH)       GRI 1690         CALL NORMAL(N,XL,XR,XHIGH)       GRI 1690         CALL NORMAL(N,XL,XR,XHIGH)       GRI 1700         GO TO 10       GRI 1710         GO TO 10       GRI 1720         C       GRI CCCC         45 CALL UNNORM(N,XL,XR,SAVEX)       GRI 1730         CALL REGION(N,XL,XR,SAVEX)       GRI 1740	2		••••• REDUCE SIZE OF GRID AND CONTINUE SEARCH •••••	GR I	CCCC
43 SIDE = SIDE*R       GRI 1610         D0 502 I=1,N       GRI 1620         xLOW(I) = CENTER(I)-SIDE/2.0       GRI 1630         xHIGH(I) = CENTER(I)+SIDE/2.0       GRI 1640         502 CONTINUE       GRI 1650         CALL UNNORM(N,XL,XR,XLOW)       GRI 1660         CALL UNNORM(N,XL,XR,XLOW)       GRI 1660         CALL REGION(N,XL,XR,XLOW)       GRI 1660         CALL REGION(N,XL,XR,XLOW)       GRI 1690         CALL NORMAL(N,XL,XR,XLOW)       GRI 1690         CALL NORMAL(N,XL,XR,XLOW)       GRI 1690         CALL NORMAL(N,XL,XR,XLOW)       GRI 1690         CALL NORMAL(N,XL,XR,XLOW)       GRI 1700         GO TO 10       GRI 1700         C       GRID SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCH         C	0			GRI	CCCC
DO 502 I=1,N XLOW(I) = CENTER(I)-SIDE/2.0 XHIGH(I) = CENTER(I)+SIDE/2.0 GRI 1640 502 CONTINUE CALL UNNORM(N,XL,XR,XLOW) CALL REGION(N,XL,XR,XLOW) CALL REGION(N,XL,XR,XHIGH) CALL REGION(N,XL,XR,XLOW) CALL NORMAL(N,XL,XR,XLOW) CALL NORMAL(N,XL,XR,XLOW) CALL NORMAL(N,XL,XR,XLOW) CALL NORMAL(N,XL,XR,XHIGH) GO TO 10 CALL NORMAL(N,XL,XR,XHIGH) GO TO 10 C C 45 CALL UNNORM(N,XL,XR,SAVEX) CALL REGION(N,XL,XR,SAVEX) GRI 1730 GRI 1740 GRI 1740 GRI 1740 GRI 1740		43	SIDE = SIDE R	GR I	1610
xLOW(1) = CENTER(1)-SIDE/2.0       GRI 1630         xHIGH(I) = CENTER(I)+SIDE/2.0       GRI 1640         502 CONTINUE       GRI 1650         CALL UNNORM(N,XL,XR,XLOW)       GRI 1660         CALL UNNORM(N,XL,XR,XLOW)       GRI 1670         CALL REGION(N,XL,XR,XLOW)       GRI 1680         CALL REGION(N,XL,XR,XLOW)       GRI 1690         CALL NORMAL(N,XL,XR,XLOW)       GRI 1690         CALL NORMAL(N,XL,XR,XLOW)       GRI 1700         CALL NORMAL(N,XL,XR,XLOW)       GRI 1710         GO TO 10       GRI 1720         C       GRID SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCH         C       GRI SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCH         C			DO 502 I=1,N	GR I	1620
XHIGH(1) = CENTER(1)+SIDE/2.0       GRI 1640         502 CONTINUE       GRI 1650         CALL UNNORM(N,XL,XR,XLOW)       GRI 1660         CALL UNNORM(N,XL,XR,XLOW)       GRI 1670         CALL REGION(N,XL,XR,XLOW)       GRI 1680         CALL REGION(N,XL,XR,XLOW)       GRI 1690         CALL NORMAL(N,XL,XR,XLOW)       GRI 1690         CALL NORMAL(N,XL,XR,XLOW)       GRI 1690         CALL NORMAL(N,XL,XR,XLOW)       GRI 1700         CALL NORMAL(N,XL,XR,XHIGH)       GRI 1710         GO TO 10       GRI 1720         C       GRI D SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCH         C       GRI CCCC         45 CALL UNNORM(N,XL,XR,SAVEX)       GRI 1730         CALL REGION(N,XL,XR,SAVEX)       GRI 1740			XLOW(I) = CENTER(I)-SIDE/2.0	GRI	1630
502       CONTINUE       GRI 1650         CALL UNNORM(N,XL,XR,XLOW)       GRI 1660         CALL UNNORM(N,XL,XR,XHIGH)       GRI 1670         CALL REGION(N,XL,XR,XLOW)       GRI 1680         CALL REGION(N,XL,XR,XLOW)       GRI 1690         CALL NORMAL(N,XL,XR,XLOW)       GRI 1690         CALL NORMAL(N,XL,XR,XHIGH)       GRI 1690         CALL NORMAL(N,XL,XR,XLOW)       GRI 1700         CALL NORMAL(N,XL,XR,XHIGH)       GRI 1710         GO TO 10       GRI 1720         C       GRI 0512E SUFFICIENTLY SMALL, EXIT FROM SEARCH         C       GRI 0512E COCC         45       CALL UNNORM(N,XL,XR,SAVEX)         CALL REGION(N,XL,XR,SAVEX)       GRI 1730         CALL REGION(N,XL,XR,SAVEX)       GRI 1740	÷ .		xHIGH(I) = CENTER(I)+SIDE/2.0	GRI	1640
CALL UNNORM(N,XL,XR,XLOW)       GRI 1660         CALL UNNORM(N,XL,XR,XHIGH)       GRI 1670         CALL REGION(N,XL,XR,XKIGH)       GRI 1680         CALL REGION(N,XL,XR,XKIGH)       GRI 1690         CALL NORMAL(N,XL,XR,XHIGH)       GRI 1690         CALL NORMAL(N,XL,XR,XLOW)       GRI 1700         CALL NORMAL(N,XL,XR,XLOW)       GRI 1710         GO TO 10       GRI 1720         C       GRI CCCC         C       GRI CCCC         C       GRI CCCC         45       CALL UNNORM(N,XL,XR,SAVEX)         CALL REGION(N,XL,XR,SAVEX)       GRI 1730		502	CONTINUE	GRI	1650
CALL UNNORM(N,XL,XR,XHIGH)       GRI 1670         CALL REGION(N,XL,XR,XLOW)       GRI 1680         CALL REGION(N,XL,XR,XHIGH)       GRI 1690         CALL NORMAL(N,XL,XR,XHIGH)       GRI 1670         CALL NORMAL(N,XL,XR,XHIGH)       GRI 1700         CALL NORMAL(N,XL,XR,XLOW)       GRI 1710         GO TO 10       GRI 1720         C       GRI CCCC         45       CALL UNNORM(N,XL,XR,SAVEX)         CALL REGION(N,XL,XR,SAVEX)       GRI 1730         CALL REGION(N,XL,XR,SAVEX)       GRI 1740			CALL UNNORM(N,XL,XR,XLOW)	GRI	1660
CALL REGION(N,XL,XR,XLOW)       GRI 1680         CALL REGION(N,XL,XR,XHIGH)       GRI 1690         CALL NORMAL(N,XL,XR,XHIGH)       GRI 1700         CALL NORMAL(N,XL,XR,XLOW)       GRI 1710         GO TO 10       GRI 1720         C       GRID SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCH         C       GRI CCCC         45       CALL UNNORM(N,XL,XR,SAVEX)         CALL REGION(N,XL,XR,SAVEX)       GRI 1730			CALL UNNORM(N,XL,XR,XHIGH)	GR I	1670
CALL REGION(N,XL,XR,XHIGH)       GRI 1690         CALL NORMAL(N,XL,XR,XLOW)       GRI 1700         CALL NORMAL(N,XL,XR,XHIGH)       GRI 1710         GO TO 10       GRI 1720         C       GRI 0.512E         C       GRI 1.730         CALL REGION(N,XL,XR,SAVEX)       GRI 1740			CALL REGION(N,XL,XR,XLOW)	GRI	1680
CALL NORMAL(N, XL, XR, XLOW)       GRI 1700         CALL NORMAL(N, XL, XR, XHIGH)       GRI 1710         GD TO 10       GRI 1720         C       GRI CCCC         C       GRID SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCH         C       GRI CCCC         C       GRID SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCH         C       GRI CCCC         C       GRI CCCC         GRI CCCC       GRI CCCC         C       GRI 1730         CALL REGION(N, XL, XR, SAVEX)       GRI 1740			CALL REGION(N,XL,XR,XHIGH)	GRI	1690
CALL NORMAL(N,XL,XR,XHIGH)       GRI 1710         GO TO 10       GRI 1720         C       GRI 000000000000000000000000000000000000			CALL NORMAL(N, XL, XR, XLOW)	GRI	1700
GO TO 10         GRI 1720           C         GRI CCCC           C         GRID SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCH           GRI CCCC         GRI CCCC           45 CALL UNNORM(N,XL,XR,SAVEX)         GRI 1730           CALL REGION(N,XL,XR,SAVEX)         GRI 1740			CALL NORMAL(N,XL,XR,XHIGH)	GRI	1710
C GRI CCCC C GRID SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCH GRI CCCC GRI CCCC 45 CALL UNNORM(N,XL,XR,SAVEX) CALL REGION(N,XL,XR,SAVEX) GRI 1730 GRI 1740			GO TO 10	GRI	1720
C GRID SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCH GRI CCCC GRI CCCC 45 CALL UNNORM(N,XL,XR,SAVEX) CALL REGION(N,XL,XR,SAVEX) GRI 1730 GRI 1740	C			GRI	0000
C GRI CCCC 45 CALL UNNORM(N,XL,XR,SAVEX) GRI 1730 CALL REGION(N,XL,XR,SAVEX) GRI 1740	0		••••• GRID SIZE SUFFICIENTLY SMALL, EXIT FROM SEARCH •••••	GRI	0000
45 CALL UNNORM(N, XL, XR, SAVEX) GRI 1730 CALL REGION(N, XL, XR, SAVEX) GRI 1740	C			GRI	0000
CALL REGION(N,XL,XR,SAVEX) GRI 1740		45	CALL UNNORM(N, XL, XR, SAVEX)	GRI	1730
			CALL REGIUN(N,XL,XR,SAVEX)	gr í	1740

and the second second

	80/80	LIST			
1990.00 2345(	00001111111111222222222233333333 57890123456789012345678901234567	334444444	44455555555555666 7890123456789012	566666667777777 34567890123456	7778
	CALL MERITA (SAVEX.Y)			GRI	1750
	NN = NN + T			GRI	1760
	CALL NORMAL (N.XI. XR. SAVEX)			GRI	1770
	DD 46 K=1.N			GRI	1780
	X(K) = SAVEX(K)			GRI	1790
	IF(CENTER(K)-SAVEX(K))60.61.62			GRI	1800
60	XLOW(K) = CENTER(K)			GR I	1810
	XHIGH(K) = CENTER(K) + SIDE/2.0			GRI	1820
	GO TO 46			GRI	1830
61	XLOW(K) = CENTER(K)-SIDE/2.0			GR I	1840
	XHIGH(K) = CENTER(K)+SIDE/2.0			GRI	1850
	GO TO 46			GRÌ	1860
62	XLOW(K) = CENTER(K) - SIDE/2.0	÷		GRI	1870
	XHIGH(K) = CENTER(K)			GRI	1880
46	CONTINUE			GRI	1890
	CALL UNNORM(N,XL,XR,XLGW)			GR I	1900
	CALL UNNORM(N, XL, XR, XHIGH)			GRI	1910
	CALL UNNORM(N,XL,XR,SAVEX)			GR I	1920
	CALL UNNORM(N, XL, XR, X)		1	GR I	1930
•	IF(MPRINT)47,49,47			GRI	1940
47	FF = SIDE			GRI	1950
	WRITE(6,48)Y,NN,FF		:	GRI	1960
48	FORMAT(/+			GRI	1970
				÷÷	
1	154H LARGEST MERIT ORDINATE FOUN	D DURING S	SEARCH	., E15.8,/, GRI	1980
1	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI	D DURING S	SEARCH DURING SEARCH	,E15.8,/,GRI ,I15,/, GRI	1980 1990
1	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA	DURING S DNS USED I L OF UNCE	SEARCH DURING SEARCH RTAINTY EXTANT .	•,E15•8,/,GRI •,I15,/, GRI •,E15•8,/)GRI	1980 1990 2000
	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N	ID DURING S ONS USED I AL OF UNCEI	SEARCH DURING SEARCH RTAINTY EXTANT .	•,E15•8,/,GRI •,I15,/, GRI •,E15•8,/)GRI GRI	1980 1990 2000 2010
1	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I)	ID DURING S DNS USED I AL OF UNCE	SEARCH DURING SEARCH RTAINTY EXTANT .	.,E15.8,/,GRI .,I15,/, GRI .,E15.8,/)GRI GRI GRI	1980 1990 2000 2010 2020
1	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 190 I=1,N X1 = XLOW(I) X2 = SAVEX(I)	ID DURING S ONS USED I IL OF UNCE	SEARCH DURING SEARCH RTAINTY EXTANT .	,E15.8,/,GRI ,I15,/, GRI ,E15.8,/)GRI GRI GRI GRI	1980 1990 2000 2010 2020 2030
1	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I)	ID DURING S ONS USED I AL OF UNCE	SEARCH DURING SEARCH RTAINTY EXTANT .	,E15.8,/,GRI ,I15,/, GRI ,E15.8,/)GRI GRI GRI GRI GRI	1980 1990 2000 2010 2020 2030 2040
1	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3	ID DURING S ONS USED I IL OF UNCE	SEARCH DURING SEARCH RTAINTY EXTANT .	., E15.8,/, GRI .,I15,/, GRI .,E15.8,/)GRI GRI GRI GRI GRI GRI	1980 1990 2000 2010 2020 2030 2040 2050
101	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8	ID DURING S ONS USED I L OF UNCE	SEARCH DURING SEARCH RTAINTY EXTANT .	., E15.8,/, GRI .,I15,/, GRI .,E15.8,/)GRI GRI GRI GRI GRI GRI GRI	1980 1990 2000 2020 2020 2030 2040 2050 2060
101	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 12HX(,I1,2H)=,E15.8,2X,6HXHIGH(,	ID DURING S ONS USED I L OF UNCEI ,2X, I1,2H) =,E	SEARCH DURING SEARCH RTAINTY EXTANT .	., E15.8,/, GRI .,I15,/, GRI .,E15.8,/)GRI GRI GRI GRI GRI GRI GRI GRI	1980 1990 2000 2010 2020 2030 2040 2050 2060 2070
101 100	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 12HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONTINUE	ID DURING S DNS USED I L OF UNCE ,2X, I1,2H) =,E	SEARCH DURING SEARCH RTAINTY EXTANT .	., E15.8,/, GRI .,I15,/, GRI .,E15.8,/)GRI GRI GRI GRI GRI GRI GRI GRI GRI	1980 1990 2000 2010 2020 2030 2040 2050 2060 2070 2080
101 100 49	<pre>L54H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DD 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 I2HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONTINUE RETURN</pre>	ID DURING S ONS USED I L OF UNCEI ,2X, I1,2H) =,E	SEARCH DURING SEARCH RTAINTY EXTANT .	., E15.8,/, GRI .,I15,/, GRI .,E15.8,/)GRI GRI GRI GRI GRI GRI GRI GRI GRI GRI	1980 1990 2010 2020 2030 2030 2040 2050 2050 2060 2070 2080 2090
101 100 49	<pre>L54H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 12HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONTINUE RETURN END</pre>	ID DURING S ONS USED I L OF UNCEI ,2X, I1,2H) =,E	SEARCH DURING SEARCH RTAINTY EXTANT .	., E15.8,/, GRI .,I15,/, GRI .,E15.8,/)GRI GRI GRI GRI GRI GRI GRI GRI GRI GRI	1980 1990 2010 2020 2030 2030 2050 2050 2050 2050 205
101 100 49	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,II,2H)=,E15.8 12HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONT INUE RETURN END SUBROUTINE NORMAL(N,XL,XR,XNORM	ID DURING S ONS USED I L OF UNCEI ,2X, I1,2H) =,ES	SEARCH DURING SEARCH RTAINTY EXTANT .	., E15.8,/, GRI , I15,/, GRI , E 15.8,/)GRI GRI GRI GRI GRI GRI GRI GRI GRI GRI	1980 1990 2000 2010 2020 2030 2050 2050 2050 2050 2070 2080 2090 2100 0010
101 100 49	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 12HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONT INUE RETURN END SUBROUTINE NORMAL(N,XL,XR,XNORM DIMENSION XL(9),XR(9),XNORM(9)	ID DURING S ONS USED I L OF UNCEI ,2X, I1,2H) ≈,E	SEARCH DURING SEARCH RTAINTY EXTANT .	., E15.8,/, GRI , I15,/, GRI , E 15.8,/)GRI GRI GRI GRI GRI GRI GRI GRI GRI GRI	1980 1990 2000 2010 2020 2030 2050 2050 2050 2050 2070 2080 2090 2100 0010 0020
101 100 49	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 12HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONTINUE RETURN END SUBROUTINE NORMAL(N,XL,XR,XNORM DIMENSION XL(9),XR(9),XNORM(9) DO 1 I=1,N	ID DURING S ONS USED I L OF UNCEI ,2X, I1,2H) =,E	SEARCH DURING SEARCH RTAINTY EXTANT .	., E15.8,/, GRI ., I15,/, GRI ., E15.8,/)GRI GRI GRI GRI GRI GRI GRI GRI GRI GRI	1980 1990 2010 2020 2030 2030 2050 2050 2050 2070 2080 2090 2100 0010 0020 0020
101 100 49	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 12HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONTINUE RETURN END SUBROUTINE NORMAL(N,XL,XR,XNORM DIMENSION XL(9),XR(9),XNORM(9) DO 1 I=1,N XNORM(I)=(XNORM(I)-XL(I))/(XR(1)	ID DURING S ONS USED I L OF UNCEI ,2X, ,11,2H) =,E 1)	SEARCH DURING SEARCH RTAINTY EXTANT .	., E15.8,/, GRI ., I15,/, GRI ., E15.8,/)GRI GRI GRI GRI GRI GRI GRI GRI GRI GRI	1980 1990 2010 2020 2030 2040 2050 2050 2050 2070 2080 2090 2100 0010 0020 0030 0040
101 100 49	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DD 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 12HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONTINUE RETURN END SUBROUTINE NORMAL(N,XL,XR,XNORM DIMENSION XL(9),XR(9),XNORM(9) DD 1 I=1,N XNORM(I)=(XNORM(I)-XL(I))/(XR(1))	ID DURING S ONS USED I L OF UNCE ,2X, I1,2H) =,E I) I)	SEARCH DURING SEARCH RTAINTY EXTANT .	•, E15•8,/, GRI •,I15,/, GRI •,E15•8,/)GRI GRI GRI GRI GRI GRI GRI GRI GRI GRI	1980 1990 2010 2020 2030 2040 2050 2050 2050 2070 2080 2090 2100 0010 0020 0030 0040 0050
101 100 49	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 12HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONTINUE RETURN END SUBROUTINE NORMAL(N,XL,XR,XNORM DIMENSION XL(9),XR(9),XNORM(9) DO 1 I=1,N XNORM(I)=(XNORM(I)-XL(I))/(XR(I) CONTINUE RETURN	ID DURING S ONS USED I L OF UNCE ,2X, I1,2H) =,E I) ) - XL (I))	SEARCH DURING SEARCH RTAINTY EXTANT .	•, E15•8,/, GRI •,I15,/, GRI •,E15•8,/)GRI GRI GRI GRI GRI GRI GRI GRI GRI GRI	1980 1990 2010 2020 2030 2040 2050 2060 2070 2080 2070 2080 2070 2080 2070 2080 0010 0020 0010 0050 0050 0050
101 100 49	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 12HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONTINUE RETURN END SUBROUTINE NORMAL(N,XL,XR,XNORM DIMENSION XL(9),XR(9),XNORM(9) DO 1 I=1,N XNORM(I)=(XNORM(I)-XL(I))/(XR(I) CONTINUE RETURN END SUBDOUTINE WENDER(N, Y,	ID DURING S ONS USED I L OF UNCEI ,2X, I1,2H) =,E: I) (}-XL(I))	SEARCH DURING SEARCH RTAINTY EXTANT .	,E15.8,/,GRI ,I15,/, GRI ,E15.8,/)GRI GRI GRI GRI GRI GRI GRI GRI GRI GRI	1980 1990 2010 2020 2030 2040 2050 2050 2050 2060 2070 2080 2070 2080 2090 2100 0010 0020 0050 0050 0050 0050
101 100 49	<pre>L54H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 L2HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONTINUE RETURN END SUBROUTINE NORMAL(N,XL,XR,XNORM DIMENSION XL(9),XR(9),XNORM(9) DO 1 I=1,N XNORM(I)=(XNORM(I)-XL(I))/(XR(I) CONTINUE RETURN END SUBROUTINE UNNORM(N,XL,XR,EX) SUBROUTINE UNNORM(N,XL,XR,EX)</pre>	ID DURING S ONS USED I L OF UNCER ,2X, I1,2H) =,ES I) () - XL (I))	SEARCH DURING SEARCH RTAINTY EXTANT .	, E15.8,/, GRI , I15,/, GRI , E15.8,/)GRI GRI GRI GRI GRI GRI GRI GRI GRI GRI	1980 1990 2000 2020 2030 2030 2050 2050 2050 205
101 100 49	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 12HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONT INUE RETURN END SUBROUTINE NORMAL(N,XL,XR,XNORM()) DO 1 I=1,N XNORM(I)=(XNORM(I)-XL(I))/(XR(1) CONTINUE RETURN END SUBROUTINE UNNORM(N,XL,XR,EX) DIMENSION XL(9),XR(9),EX(9) DO 1 I=1,1 SUBROUTINE UNNORM(N,XL,XR,EX) DIMENSION XL(9),XR(9),EX(9)	ID DURING S ONS USED I L OF UNCEI ,2X, I1,2H) =,ES	SEARCH DURING SEARCH RTAINTY EXTANT .	, E15.8,/, GRI , I15,/, GRI , E15.8,/)GRI GRI GRI GRI GRI GRI GRI GRI GRI GRI	1980 1990 2000 2020 2030 2030 2050 2050 2050 205
101 100 49	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 12HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONT INUE RETURN END SUBROUTINE NORMAL(N,XL,XR,XNORM()) DO 1 I=1,N XNORM(I)=(XNORM(I)-XL(I))/(XR(I) CONTINUE RETURN END SUBROUTINE UNNORM(N,XL,XR,EX) DIMENSION XL(9),XR(9),EX(9) DO 1 I=1,N SUBROUTINE UNNORM(N,XL,XR,EX) DIMENSION XL(9),XR(9),EX(9) DO 1 I=1,N	ID DURING S ONS USED I L OF UNCEI ,2X, I1,2H) ≈,E I)	SEARCH DURING SEARCH RTAINTY EXTANT .	., E 15.8, /, GR I ., I15, /, GR I ., E 15.8, /) GR I GR I GR I GR I GR I GR I GR I GR I	1980 1990 2000 2020 2020 2030 2050 2050 2050 205
101 100 49	<pre>L54H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DD 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 L2HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONTINUE RETURN END SUBROUTINE NORMAL(N,XL,XR,XNORM DIMENSION XL(9),XR(9),XNORM(9) DD 1 I=1,N XNORM(I)=(XNORM(I)-XL(I))/(XR(I) CONTINUE RETURN END SUBROUTINE UNNORM(N,XL,XR,EX) DIMENSION XL(9),XR(9),EX(9) DO 1 I=1,N END SUBROUTINE UNNORM(N,XL,XR,EX) DIMENSION XL(9),XR(9),EX(9) DO 1 I=1,N EX(I)=XL(I)+EX(I)*(XR(I)-XL(I))</pre>	ID DURING S ONS USED I L OF UNCE ,2X, I1,2H) ≃,E I)	SEARCH DURING SEARCH RTAINTY EXTANT .	•, E15•8,/, GRI •, I15,/, GRI •, E15•8,/) GRI GRI GRI GRI GRI GRI GRI GRI GRI GRI	1980 1990 2010 2020 2030 2030 2050 2050 2050 2050 205
101 100 49 1	<pre>L54H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 L2HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONTINUE RETURN END SUBROUTINE NORMAL(N,XL,XR,XNORM DIMENSION XL(9),XR(9),XNORM(9) DO 1 I=1,N XNORM(I)=(XNORM(I)-XL(I))/(XR(I) CONTINUE RETURN END SUBROUTINE UNNORM(N,XL,XR,EX) DIMENSION XL(9),XR(9),EX(9) DO 1 I=1,N EX(I)=XL(I)+EX(I)*(XR(I)-XL(I)) CONTINUE EX(I)=XL(I)*(XR(I)-XL(I))</pre>	ID DURING S ONS USED I L OF UNCE ;2X, I1,2H) =,E ]	SEARCH DURING SEARCH RTAINTY EXTANT .	•, E15•8,/, GRI •, I15,/, GRI •, E15•8,/) GRI GRI GRI GRI GRI GRI GRI GRI GRI GRI	$\begin{array}{c} 1980\\ 1990\\ 2900\\ 2010\\ 2020\\ 2030\\ 2050\\ 2050\\ 2050\\ 2070\\ 2080\\ 2070\\ 2080\\ 2070\\ 2080\\ 2090\\ 2070\\ 0010\\ 0050\\$
101 100 49 1	<pre>154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 12HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONTINUE RETURN END SUBROUTINE NORMAL(N,XL,XR,XNORM(9) DO 1 I=1,N XNORM(I)=(XNORM(I)-XL(I))/(XR(I) CONTINUE RETURN END SUBROUTINE UNNORM(N,XL,XR,EX) DIMENSION XL(9),XR(9),EX(9) DO 1 I=1,N XNORM(I)=(I)+EX(I)*(XR(I)-XL(I)) CONTINUE RETURN END SUBROUTINE UNNORM(N,XL,XR,EX) DIMENSION XL(9),XR(9),EX(9) DO 1 I=1,N EX(I)=XL(I)+EX(I)*(XR(I)-XL(I)) CONTINUE RETURN EX(I)=XL(I)+EX(I)*(XR(I)-XL(I)) CONTINUE</pre>	ID DURING S ONS USED I L OF UNCER ,2X, I1,2H) =,E: I) (}-XL(I))	SEARCH DURING SEARCH RTAINTY EXTANT .	., E 15.8, /, GR I ., I15, /, GR I ., E 15.8, /) GR I GR I GR I GR I GR I GR I GR I GR I	$\begin{array}{c} 1980\\ 1990\\ 2900\\ 2010\\ 2020\\ 2030\\ 2050\\ 2050\\ 2050\\ 2050\\ 2050\\ 2050\\ 2050\\ 2050\\ 2050\\ 0010\\ 0050\\$
101 100 49 1	<pre>154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 12HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONTINUE RETURN END SUBROUTINE NORMAL(N,XL,XR,XNORM(9) DO 1 I=1,N XNORM(I)=(XNORM(I)-XL(I))/(XR(I) CONTINUE RETURN END SUBROUTINE UNNORM(N,XL,XR,EX) DIMENSION XL(9),XR(9),EX(9) DO 1 I=1,N SUBROUTINE UNNORM(N,XL,XR,EX) DIMENSION XL(9),XR(9),EX(9) DO 1 I=1,N EX(I)=XL(I)+EX(I)*(XR(I)-XL(I)) CONTINUE RETURN EX(I)=XL(I)+EX(I)*(XR(I)-XL(I)) CONTINUE RETURN END SUBROUTINE DECIDING WE ADD SUBROUTINE SUBROUTINE DECIDING WE ADD SUBROUTINE SUBROUTINE SUBR</pre>	ID DURING S ONS USED I L OF UNCEI ,2X, I1,2H) =,E: I) (}-XL(I))	SEARCH DURING SEARCH RTAINTY EXTANT .	., E 15.8, /, GR I ., I15, /, GR I ., E 15.8, /) GR I GR I GR I GR I GR I GR I GR I GR I	1980 1990 2010 2020 2030 2030 2050 2050 2050 2050 205
101 100 49 1	154H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DO 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 12HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONTINUE RETURN END SUBROUTINE NORMAL(N,XL,XR,XNORM(9) DO 1 I=1,N XNORM(I)=(XNORM(I)-XL(I))/(XR(I) CONTINUE RETURN END SUBROUTINE UNNORM(N,XL,XR,EX) DIMENSION XL(9),XR(9),EX(9) DO 1 I=1,N SUBROUTINE UNNORM(N,XL,XR,EX) DIMENSION XL(9),XR(9),EX(9) DO 1 I=1,N EX(I)=XL(I)+EX(I)*(XR(I)-XL(I)) CONTINUE RETURN EX(I)=XL(I)+EX(I)*(XR(I)-XL(I)) SUBROUTINE REGION(N,XL,XR,X) DIMENSION XL(9) YE(9) YEND SUBROUTINE REGION(N,XL,XR,X) DIMENSION YEND SUBROUTINE REGION(N,XL,XR,X) DIMENSION YEND SUBROUTINE REGION(N,XL,XR,X) DIMENSION YEND SUBROUTINE REGION(N,XL,XR,X) DIMENSION YEND	ID DURING S ONS USED I L OF UNCEI ,2X, I1,2H) ≈,ES	SEARCH DURING SEARCH RTAINTY EXTANT .	., E 15.8, /, GR I ., I15, /, GR I ., E 15.8, /) GR I GR I GR I GR I GR I GR I GR I GR I	1980 1990 2000 2020 2020 2030 2050 2050 2050 205
101 100 49 1	<pre>L54H LARGEST MERIT ORDINATE FOUN 254H NUMBER OF FUNCTION EVALUATI 354H FRACT. REDUCTION IN INTERVA DD 100 I=1,N X1 = XLOW(I) X2 = SAVEX(I) X3 = XHIGH(I) WRITE(6,101)I,X1,I,X2,I,X3 FORMAT(1X,5HXLOW(,I1,2H)=,E15.8 L2HX(,I1,2H)=,E15.8,2X,6HXHIGH(, CONTINUE RETURN END SUBROUTINE NORMAL(N,XL,XR,XNORM(9) DD 1 I=1,N XNORM(I)=(XNORM(I)-XL(I))/(XR(I) CONTINUE RETURN END SUBROUTINE UNNORM(N,XL,XR,EX) DIMENSION XL(9),XR(9),EX(9) DO 1 I=1,N END SUBROUTINE UNNORM(N,XL,XR,EX) DIMENSION XL(9),XR(9),EX(9) DO 1 I=1,N EXURN END SUBROUTINE REGION(N,XL,XR,X) DIMENSION XL(9),XR(9),X(9) DO 1 I=1,N EX(I)=XL(I)+EX(I)*(XR(I)-XL(I)) CONTINUE RETURN END SUBROUTINE REGION(N,XL,XR,X) DIMENSION XL(9),XR(9),X(9) DO 6 (I=1)</pre>	ID DURING S ONS USED I L OF UNCEI ,2X, I1,2H) =,E I)	SEARCH DURING SEARCH RTAINTY EXTANT .	., E 15.8, /, GR I ., I15, /, GR I ., E 15.8, /) GR I GR I GR I GR I GR I GR I GR I GR I	1980 1990 2010 2020 2020 2020 2020 2050 2050 205

والمراجع المراجع المراجع والمراجع والمراجع والمراجع والمراجع والمراجع والمراجع والمراجع والمراجع والمراجع

and the second secon

00000	10000111111111122222222233333333334444444444	555555666666666667777777	7778
12345	5678901234567890123456789012345678901234567890123	45678901234567890123456	7890
1	X(I)=XL(I)	REG	0050
	GO TO 4	REG	0060
2	IF(XR(I)-X(I))3,4,4	REG	0070
3	X(I)=XR(I)	REG	0080
4	CONTINUE	REG	0090
	RETURN	REG	0100
	END	REG	0110

```
80/80 LIST
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
      DIMENSION ZR(100),ZI(100),POWER0(100),PRESS(100),POWERI(100)
      DIMENSION XH(100)
      DIMENSION XARRAY(101), YARRAY(101)
      READ(5,100) RA, DENS, RAD, AL, RT, CA
      READ(5,200) U0,R,S,RM,RK,RL
C
     COMPUTE OUTPUT ACOUSTICAL IMPEDANCE OF IMPEDANCE MATCHING DEVICE.
      L=99
      FRQ=100.
      00 16 K=1,L
      XX=RL
      FRR=FRQ*(2.*3.141592)
      KK = K - 1
£
      CHAR=(DENS*CA)/S
      RE=R/(S*S)
      XE=(FRR*RM+RK/FRR)/(S*S)
      VAL 1=ABS((FRR*XX/CA)-(.5*3.141592))
      VAL2=ABS((FRR*XX/CA)-(1.5*3.141592))
      IF(VAL1.LT.1.00E-02.0R.VAL2.LT.1.00E-02) G0 T0 5
      DUF=(CHAR-XE*TAN(FRR*XX/CA))*(CHAR-XE*TAN(FRR*XX/CA))
     1 + (RE*TAN(FRR*XX/CA))*(RE*TAN(FRR*XX/CA))
      ZR(K) =CHAR*CHAR*RE*(1.+(TAN(FRR*XX/CA))*(TAN(FRR*XX/CA)))/DUF
С
      ZI(K) = (XE*CHAR-(XE*XE+RE*RE)*TAN(FRR*XX/CA)+
     1 CHAR*(TAN(FRR*XX/CA))*(TAN(FRR*XX/CA)))/OUF
      IF(VAL1.GE.1.00E-02.AND.VAL2.GE.1.00E-02) GO TO 6
    5 7R(K)=7R(KK)
      ZI(K)=ZI(KK)
    6 CONT INUE
      XH(K)=FRR*DENS*1.7*RAD/( 3.141592*RAD*RAD - FRR*FRR*1.7*RAD*
     1((3.141592*R T*R T*AL) /(CA*CA)))
С
      XARRAY(K) = ALOG10(FRQ)
С
      POWERD(K)=(UO+UO+XH(K)+XH(K)+ZR(K)/((RA+ZR(K))+(RA+ZR(K))+
     1 (XH(K)+ZI(K))*(XH(K)+ZI(K))))*1.00E-07
С
      POWERI(K)=(UO+UO+((RA+ZR(K))+(RA+ZR(K))+ZI(K)+ZI(K))+XH(K)/
     1 ((RA+ZR(K))*(RA+ZR(K))+(XH(K)+ZI(K))*(XH(K)+ZI(K)))*1.00E-07
      PRS=UD*XH(K)/SQRT((RA+ZR(K))*(RA+ZR(K))+(XH(K)+ZI(K))*(XH(K)+ZI(K)
     1))
      PRESS(K)=20.*ALOG10(PRS/.0002)
С
      WRITE(6,116) FRQ, POWERI(K), POWERO(K), XH(K), PRESS(K)
   16 FRQ=FRQ+100.
С
 ۰.
с
      CALL PLOTS
      CALL PLOTC(0.0,-11.,-3)
      00 9 K=1.L
      YARRAY(K)=XH(K)
    9 CONTINUE
С
```

• •

123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890 CALL PLOTC(0.0,5.5,2) CALL PLOTC(8.5,5.5,3) CALL PLOTC(8.5,0.0,2) CALL PLOTC(0.0,0.0,2) CALL PLOTC(0.0,1.5,-3) CALL PLOTC(2.0,0.0,-3) C SCALE VALUES AND DRAW AXES CALL SCALE (XARRAY, 5. 9,99,1) CALL SCALE(YARRAY, 2.0, 99, 1) CALL AXIS(0.0,0,0,\*LCG FREQUENCY\*,-13,5.0,0.0,XARRAY(100), 1 XARRAY(101)) CALL AX IS (0.0,0.0, 'REACTANCE', 9, 2.0, 90.0, YARRAY(100), YARRAY(101)) C PLOT POINTS. C PLOT POINTS. CALL LINE(XARRAY, YARPAY, 99, 1, 19, 75) CALL PLOTC(-2.0,4.0,-3) DO 1º K=1,L YARRAY(K)=10.\*ALOG10(POWERI(K)/(1.00E-12)) 10 CONTINUE c CALL PLOTC(0.0,5.5,2) CALL PLOTC (8.5,5.5,3) CALL PLOTC( 8.5, 0.0, 2) CALL PLOTC (1.0.0.0.2) CALL PLOTC( 1.0,1.5,-3) CALL PLOTC(2.0, 0.0,-3) С SCALE VALUES AND DRAW AXES CALL SCALE (XARRAY, 5. 9, 99, 1) CALL SCALE(YARRAY, 2.7,99,1) CALL AXIS(7.0, 1.9, LCG FREQUENCY 1, -13, 5. 1, 0.0, XARRAY(100), 1 XARRAY(101)) CALL AXIS(0.0,0.0, POWER IN\*, 8, 2.0, 90.0, YARRAY(100), YARRAY(101)) C PLOT POINTS. CALL LINE (XARRAY, YARRAY, 99, 1, 10, 75) CALL SYMBOL (4.10,2.50,.10, RH= 1,0.0,3) CALL NUMBER (4.5,2.50,.10, RA,0.0,2) CALL SYMBOL (4.0,2.35,.10, \*XX=\*,0.0,3) CALL NUMBER (4.50,2.35,.10,RL,0.0,2) CALL SYMBOL (4.00,2.20,.10, RAD= ,0.0,4) CALL NUMBER (4.50,2.20,.10,RAD,0.0,4) CALL SYMBOL (4.00,2.05,.10, "AL=",0.0,3) CALL NUMBER (4.50,2.05,.10,AL,0.0,4) CALL SYMBOL (4.00, 1.90, .10, 'RT=', 0.0, 3) CALL NUMBER(4.50,1.90,.10,RT,0.0,4) CALL PLOTC(8.0,-6.5,-3) C 00 11 K=1.L 11 YARRAY(K)=10.\*ALOGI0(POWERO(K)/(1.00E-12)) С С. CALL PLOTC( 7.7, 5.5, 2) CALL PLOTC(8.5,5.5,3) CALL PLOTC(8.5,0.0,2) CALL PLOTC( 0.0, 0.0, 2)

12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890 CALL PLOTC(2.0,0.0,-3) CALL PLOTC(0.0,1.5,-3) С SCALE AND LABEL AXES CALL SCALE(XARRAY, 5.0, 99, 1) CALL SCALE (YARR 44,2.0,99,1) CALL AXIS(0.0,0.0, LOG FREQUENCY', -13,5.0,0.0, XARRAY(100), 1 XARRAY(101)) CALL AXIS(0.0,0.0, POWER TRANSMITTED', 17, 2.0, 90.0, YARRAY (100 1), YARRAY(101)) С PLOT POINTS. CALL LINE (XARRAY, YARRAY, 99,1,10,75) CALL PLOTC(-2.0,4.0,-3) С DO 12 K=1,L 12 YARRAY (K)=PRESS(K) С CALL PLOTC(1.0,5.5,2) CALL PLOTC(8.5,5.5,3) CALL PLOTC(8.5,0.0.2) CALL PLOTC( 0.0,0.0,2) CALL PLOTC(2.0,0.0,-3) CALL PLOTC (0.0,1.5,-3) C SCALE AND LABEL AXES. CALL SCALE(XARRAY, 5.0, 99, 1) CALL SCALF (YARRAY, 2. 0,99,1) CALL AXIS(0.0,0.0, 'LOG FREQUENCY',-13,5.0,0.0, XARRAY(100), 1 XARRAY (101)) CALL AXIS(0.0,0.0, OUTPUT SPL IN DB',16,2.0,90.0, YARRAY(100), 1 YARRAY(101)) С PLCT POINTS. CALL LINE(XARRAY, YARRAY, 99,1,10,75) 100 FORMAT (3E20.8/3E20.8) 116 FORMAT(2X,5H FRQ=E10.4,9HPOWER IN=E20.8,10HPOWER OUT=E20.8, 1 4H XH=E20.8,9H PRESS = E27.8) 200 FORMAT(3E15.4/3F15.4) STOP END

58

.

#### 

С VRM= REFERENCE VOLTAGE FOR MICROPHONE CALIBRATION, IN VOLTS. VP.S= REFERENCE VOLTAGE FOR SOURCE CALIBRATION, IN VOLTS. £ VM = MICROPHONE FREQUENCY RESPONCE, IN DECIBELS RE 1 VOLT. C = SOURCE VOLTAGE EPEQUENCY RESPONCE +KNOWN IMPEDANCE IN DBV. С VK = PROBE MICROPHONE OPEN CIRCUIT SENSITIVITY. С SM = SOURCE MICROPHONE OPEN CIRCUIT SENSITIVITY. SS C FSK = SOURCE PHASE RESPONCE + KNOWN IMPEDANCE IN DBV. C FM = MICROPHONE PROBE TUBE PHASE RESPONCE, IN DEGREES. PM = PROBE MICROPHONE PRESSURE IN DYNES/SQUARE CM. С PS = SOUPCE PRESSURE IN DYNES/SQUARE CM. C FMM = PHASE DIFFERENCE BETWEEN SOURCE AND MICROPHONE, MEASURED. .C h GS = MAGNITUDE OF SOURCE TRANSFER FUNCTION. GSR = MAGNITUDE OF SOURCE OPEN CIRCUIT TRANSFER FUNCTION. С GM = MAGNITUDE OF MICROPHONE TRANSFER FUNCTION. С GMM = OPEN CIRCUIT TRANSFER FUNCTION, MEASURED FOR SOURCE. C FSR = OPEN CIRCUIT PHASE RESPONCE. FSM = OPEN CIRCUIT PHASE RESPONCE, MEASURED. C C ED = OPEN CIRCUIT VOLTAGE RESPONCE, IN VOLTS. c VO = OPEN CIRCUIT VOLTAGE RESPONCE, IN DBV. С VMM = VOLTAGE OF PROBE MICROPHONE, MEASURED IN DECIBELS. r VSM = VOLTAGE OF SOURCE MICROPHONE, MEASURED IN DECIBELS. C Ċ. VREF= MEASURING REFERENCE VOLTAGE. PE = RESISTANCE OF EAR. С = REACTANCE DE EAR. C XF = REFERENCE PRESSURE. C PR DIMENSION VM(22), VK(22), FSK(22), RE(22), XE(22), VMM(22), FMM(22), 1EM(22) READ(5,100) (VM(I),I=1,22), (VK(I),I=1,22), (FSK(I),I=1,22), 1(FM(I), I=1, 22)READ(5,105) (VMM(I), I=1,22), (FMM(I), I=1,22) READ(5,110) VRM, VRS, SM, SS, V, CA, DENS, VREE DEL FRQ= 100. FRQ=100. DG 10 I=1,22 FSK(I)=(3.141592/18^.)\*FSK(I) FM(I)=(3.141592/180.)\*FM(I) FMM(I)= (3.141592/180.)\*EMM(I) FRR=2.\*3.141592\*FRQ IF(FRQ.GE.1000.) DELERQ=500. EM=10.\*\*(VM(I)/20.) ES=10.\*\*(VK(1)/20.) EMM=10.\*\*(VMM(I)/20.) GM = EM \* SS/(VRM \* SM)GS = ES \* SS / (V R S \* SM) $GMS = EMM \neq SS/(VREF \neq SM)$ C=V/(DENS\*CA\*CA) F1 = FMM(I) - FM(I) - FSK(I)Pl=GMS/(GM\*GS\*FRR\*C) RF(I)=P1\*SIN(F1)XE(I)=-P1+COS(F1) PE=20.\*ALOG10(EMM/(SM\*GM\*.0002)) F2=F1\*180./3.141592 WRITE(6,200) FRQ, RE(I), XE(I), PE,P1,F2 11 FRQ=FRQ+DFLFRQ

.

# APPENDIX B

# CALIBRATION CURVES AND MODEL

# IMPEDANCE CURVES AS A

FUNCTION OF DISTANCE



Frequency



Frequency



Frequency


Frequency









. . .







y i sana

. .

يور مريد ال







A. Sec.

1.11

71

. . . . . . .

. . .



and the second







و و و و و و

and the second



,

.

. .



## VITA

## Paul Wayne Whaley

Candidate for the Degree of

Master of Science

## Thesis: IMPEDANCE MATCHING IN AURAL PROSTHESIS

Major Field: Mechanical Engineering

Biographical:

- Personal Data: Born in Duncan, Oklahoma, December 9, 1948, the son of Mr. and Mrs. John W. Whaley.
- Education: Graduated from Adrian High School, Adrian, Texas, in May, 1967; received Bachelor of Science degree in Mechanical Engineering from Oklahoma State University in May, 1971.
- Professional Experience: Graduate Teaching Assistant,
  Oklahoma State University, College of Engineering, 1971-1972; Graduate Research Assistant, Oklahoma State
  University, College of Engineering, 1972-1973; Associate
  Member, American Society of Mechanical Engineers.