General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)
A COMPUTER PROGRAM FOR THE IDENTIFICATION OF HELICOPTER IMPULSIVE NOISE SOURCES

Albert Lee
Massachusetts Institute of Technology
Department of Aeronautics and Astronautics
Fluid Dynamics Research Laboratory
Cambridge, Massachusetts 02139

January 1977

Prepared under NASA Grant NSG 2095
NASA Ames Research Center
Moffett Field, California
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. SUMMARY</td>
<td>1</td>
</tr>
<tr>
<td>2. ALGORITHM</td>
<td>4</td>
</tr>
<tr>
<td>3. DATA CARD</td>
<td>6</td>
</tr>
<tr>
<td>4. EXAMPLE</td>
<td>8</td>
</tr>
<tr>
<td>APPENDIX</td>
<td></td>
</tr>
<tr>
<td>FIGURES</td>
<td></td>
</tr>
</tbody>
</table>
ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Mr. John P. Rabbott, Mr. James C. Biggers, and Mr. Robert H. Stroub for their valuable suggestions and help during the course of this effort.

The work reported here was sponsored by NASA Ames Research Center, under NASA Grant NSG 2095. The technical monitor is Mr. John P. Rabbott, Large Scale Aerodynamics Branch, NASA Ames Research Center.
1. SUMMARY

A computer program, named INSL, is written for the calculation of the source location of impulsive noise. The main program is listed in Appendix 1. The algorithm is basically solving the triangulation equation:

\[ r^4 + A_2(\psi)r^3 + A_2(\psi) + A_1(\psi)r + A_0(\psi) = 0 \] (1)

where

\[
A_0(\psi) = [E - (T - \frac{\psi}{\omega}) U_0 F]^2 - E (T - \frac{\psi}{\omega})^2 C^2
\]

\[
A_1(\psi) = 2 [2A - (T - \frac{\psi}{\omega}) U_0 B] [E - (T - \frac{\psi}{\omega}) U_0 F]
\]

\[
-2A(T - \frac{\psi}{\omega})^2 C^2
\]

\[
A_2(\psi) = 2 [2A - (T - \frac{\psi}{\omega}) U_0 B]^2 + 2[E - (T - \frac{\psi}{\omega}) U_0 F]^2
\]

\[
- (T - \frac{\psi}{\omega})^2 C^2
\]

\[
A_3(\psi) = 2 [2A - (T - \frac{\psi}{\omega}) U_0 B]
\]

\[ A = (-y_1 \sin \psi + g \sin \alpha_s \cos \psi + x_1 \cos \psi) \cos \beta_0 \]

\[ + (g \cos \alpha_s + z_1) \sin \beta_0 \]

\[ E = x_1^2 + y_1^2 + z_1^2 + g (g + 2x_1 \sin \alpha_s + 2z_1 \cos \alpha_s) \]

\[ F = -g \sin \alpha_s - x_1 \]

\[ B = -\cos \beta_0 \cos \psi \]

\[ C = 1052 + 1.143 \ T \ E \ M \]

\[ \beta_0 = \beta - \alpha_s \cos \psi \]

\[ \beta = a_0 - a_{ls} \cos \psi - b_{ls} \sin \psi \]
and

\[ r, \psi = \text{Coordinates of source in ft and radian, respectively} \]

\[ T = \text{Time between acoustical signature and } \psi = 0 \text{ index} \]

\[ U_0 = \text{Tunnel velocity in ft/sec} \]

\[ \omega = \text{Rotor rotational velocity in Rad/sec} \]

\[ g = \text{Shaft length above pivot in ft} \]

\[ \alpha_s = \text{Shaft angle of attack in radian} \]

\[ \alpha_o = \text{Coning angle in radian} \]

\[ a_{ls} = \text{Longitudinal flapping coefficient} \]

\[ b_{ls} = \text{Lateral flapping coefficient} \]

\[ TEM = \text{Tunnel temperature in deg F} \]

\[ x, y, z = \text{Coordinates of microphone in ft} \]

The coordinates and symbols are illustrated in Figure 1. For detail
formulation and discussion of the triangulation techniques, one should
be referred to NASA CR 151996.

For each azimuthal location \( \psi \), a library subroutine is used to solve
this fourth order equation, and all four roots are obtained. The algorithm
picks out the meaningful roots, i.e., those which are inside the rotor
radius, then these roots are double-checked to ensure their accuracy. The
procedures are then repeated for a different value of \( \psi \). Variable step
sizes of \( \psi \) are used to accelerate the computations.

The computer program is written in FORTRAN for CDC 7600. The
inputs are rotor operating conditions and the time intervals \( T \) between
rotor 1/rev index and impulsive noises as measured by different micro-
phones. The outputs are the possible noise source locations in terms
of rotor radial and azimuthal coordinates. Typical computer time for a run of six microphone measurements is 1.5 sec, and the cost is about 12 cents for the CDC 7600 at NASA Ames Research Center.
2. **ALGORITHM**

The block diagram is shown in Figure 2. The flow chart is shown in Figure 3. The coefficients of equation (1) are first calculated at an azimuthal angle $\psi$ based on the input data. A library subroutine ZPOLR is then called to solve equation (1) for radial location $r$. Four roots are obtained. They may be complex, real or mixed. Only positive real roots whose value are within rotor radius are meaningful, and those values are automatically selected. The value of $\psi$ is then decreased by one step, and the calculations proceed.

Two step sizes of $\psi$ are used. A coarse step size is used initially until a meaningful $r$ is obtained. The azimuth, $\psi$, is then backed up one step size, and calculation proceeds with a fine step size. After a succession of calculation, there is a value of $\psi$ beyond which no meaningful $r$ is obtained. The calculations with fine step size persist beyond this point for several steps which is controlled as an input. If there is still no meaningful $r$ obtained, the calculation proceeds with coarse steps until the range of $\psi$ is reached, or until a meaningful $r$ is obtained again. In the former case, the calculations re-initiate for the next microphone measurement. In the latter case, the step size is changed again in the manner previously described.

The scheme of variable step size can save a large amount of computer time. Typically, the course step is 2 degrees and the fine step is 1 degree for the first calculation. Depending on microphone locations
and other parameters, source lines extend either from the outer edge of the disk to the rotor hub or terminate at the middle. When calculated results show source lines which terminate at the middle of the rotor disk, it may be real or may be due to the improper step size in $\psi$. A smaller step size should then be used to recalculate for the source line within this rather small range of azimuth. For example, some calculations with 0.1 degree step size within an azimuthal range of $2^\circ$ have been performed to obtain results shown in NASA CR 151996. If the source lines really terminate in the middle of the rotor disc, subsequent reduction of step size will not change this result.

The range of azimuth for calculation should be noted. For two bladed rotors, there are two acoustical impulses for each rotor period which is marked by $1/\text{rev}$ index. The source location can be either before $\psi = 0$ ($1/\text{rev}$ index) or after it. The azimuth range of calculation should cover both positive and negative azimuth. Either of the two acoustical impulses in a period can be chosen for calculation, although only one yields meaningful results. This situation must be resolved by physical arguments based on the characteristics of the noise source.
### DATA CARDS

A total of eleven (11) input data cards are used.

<table>
<thead>
<tr>
<th>Card Number</th>
<th>Format</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2A10</td>
<td>20 alphameric characters used for labeling of output</td>
</tr>
<tr>
<td>2</td>
<td>F10.3</td>
<td>Rotor angular velocity in rad/sec</td>
</tr>
<tr>
<td></td>
<td>F10.4</td>
<td>Rotor shaft tilt angle in rad/sec, positive shaft tilt aft</td>
</tr>
<tr>
<td></td>
<td>F10.4</td>
<td>Tip path plane angle in radians, positive leading edge up</td>
</tr>
<tr>
<td></td>
<td>F10.1</td>
<td>Tunnel temperature in °F</td>
</tr>
<tr>
<td></td>
<td>F10.3</td>
<td>Tunnel velocity in ft/sec</td>
</tr>
<tr>
<td>110</td>
<td>F10.4</td>
<td>Number of microphones. Any number up to 6 can be specified</td>
</tr>
<tr>
<td>3</td>
<td>6F10.4</td>
<td>X-coordinates of microphones, in ft</td>
</tr>
<tr>
<td>4</td>
<td>6F10.4</td>
<td>Y-coordinates of microphones, in ft</td>
</tr>
<tr>
<td>5</td>
<td>6F10.4</td>
<td>Z-coordinates of microphones, in ft</td>
</tr>
<tr>
<td>6</td>
<td>6F10.4</td>
<td>Time (in sec) between the 1/rev index and impulsive noise as measured by microphones. The values should be consistent with the sequence of microphones specified in Cards 3, 4, and 5</td>
</tr>
<tr>
<td>7</td>
<td>F10.4</td>
<td>Coarse step size of ψ in radius</td>
</tr>
<tr>
<td></td>
<td>F10.4</td>
<td>Fine step size of ψ in radius</td>
</tr>
<tr>
<td>No.</td>
<td>Format</td>
<td>Description</td>
</tr>
<tr>
<td>-----</td>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>8</td>
<td>F10.4</td>
<td>Criterion of selecting real roots</td>
</tr>
<tr>
<td></td>
<td>F10.4</td>
<td>Criterion of distinguishing double roots</td>
</tr>
<tr>
<td></td>
<td>F10.4</td>
<td>Criterion in the double-check</td>
</tr>
<tr>
<td></td>
<td>I10</td>
<td>Number of calculation with fine increment after a succession of obtaining meaningful</td>
</tr>
<tr>
<td>9</td>
<td>F10.4</td>
<td>Largest value of azimuth $\psi$ in radians</td>
</tr>
<tr>
<td></td>
<td>F10.4</td>
<td>Smallest value of azimuth $\psi$ in radians</td>
</tr>
<tr>
<td>10</td>
<td>F10.2</td>
<td>Length of shaft in feet</td>
</tr>
<tr>
<td></td>
<td>F10.4</td>
<td>Coning angle in radians</td>
</tr>
<tr>
<td>11</td>
<td>F10.4</td>
<td>Radius of rotor in feet</td>
</tr>
</tbody>
</table>
4. **EXAMPLE**

As an example, program INSL is applied to a data point of high speed rotor noise measured in the 40- by 80-Foot Wind Tunnel at the NASA Ames Research Center.

The rotor, test conditions, and input criteria are tabulated below:

<table>
<thead>
<tr>
<th>Rotor and Test Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of blades</td>
</tr>
<tr>
<td>Blade precone angle</td>
</tr>
<tr>
<td>Rotor radius</td>
</tr>
<tr>
<td>Blade chord</td>
</tr>
<tr>
<td>Blade twist</td>
</tr>
<tr>
<td>Airfoil</td>
</tr>
<tr>
<td>Hub articulation</td>
</tr>
<tr>
<td>Shaft height above the pivot</td>
</tr>
<tr>
<td>Tip speed ratio, V/ΩR</td>
</tr>
<tr>
<td>Rotor rotational speed</td>
</tr>
<tr>
<td>Rotation tip Mach number</td>
</tr>
<tr>
<td>Tip speed</td>
</tr>
<tr>
<td>Shaft angle of attack</td>
</tr>
<tr>
<td>Tip path plane</td>
</tr>
<tr>
<td>Tunnel temperature</td>
</tr>
<tr>
<td>Tunnel speed</td>
</tr>
</tbody>
</table>
**Microphones**

Number of microphones: 6

<table>
<thead>
<tr>
<th>X (ft)</th>
<th>Y (m)</th>
<th>Z (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>68.24</td>
<td>20.80</td>
<td>2.457</td>
</tr>
<tr>
<td>6.99</td>
<td>2.131</td>
<td>0.381</td>
</tr>
<tr>
<td>68.58</td>
<td>20.90</td>
<td>2.460</td>
</tr>
<tr>
<td>13.84</td>
<td>-4.215</td>
<td>10.92</td>
</tr>
<tr>
<td>68.83</td>
<td>20.98</td>
<td>3.328</td>
</tr>
<tr>
<td>12.41</td>
<td>3.783</td>
<td>2.134</td>
</tr>
</tbody>
</table>

Time between 1/rev index and acoustical index (in sec): .1390, .0565, .1300, .0235, .1255, .0610

**Input Criteria**

Coarse step: 2 deg (.0349 radian)
Fine step: 1 deg (.0175 radian)
Criterion of real root: 1
Criterion of double root: .5
Double-check criterion: .001
Largest $\psi$: 6.94 rad
Smallest $\psi$: -3.14 rad

The input data deck to program INSL is shown in Appendix 2.

The printout of the calculation is shown in Appendix 3. The first portion is the printout of input data. It then proceeds to print the results of the calculations. The first two columns are the coordinates...
of source line in terms of their radial location $r$ and azimuth location $\psi$. DIS is the distance between source and microphone. TIME is the time for sound to travel from source to microphone, including effects of tunnel wind. CTIME is the calculated time between 1/rev and acoustical impulse and should be consistent with input time (T). A plot of source lines in this sample calculation is shown in Figure 4.
APPENDIX 1

This program is called IM3L (Impulsive Noise Source Locating), and written by Ying-Chieh Albert Lee.
This program is to calculate the noise source locations of helicopter rotor blade slap, the tunnel speed effect on sound speed was taken into account. The input data are the locations of microphone and the time between 1/rev pulse and acoustical signals, in addition to rotor parameters, the output is the noise source in terms of its azimuthal (θ) and radial (r) positions. The meaning of symbols are as follows:

G is the shaft length in feet
Aθ is the angular velocity of rotor in rad/sec
Aα is the shaft tilt angle in radians
AT is the tip path plane angle in radians
Aα is the pre-coned angle of the teetering rotor in radians
Tθ is the temperature in degrees F
U is the tunnel speed in ft/sec
M is the number of microphone
X, Y, Z are the microphone location, in ft
The coordinate origin is at the mid-point between ball centers
T is the time between 1/rev and acoustical pulse, in sec
Tθ is the angle between the vector from microphone to sound source and tunnel velocity vector
DS is the azimuthal angular increment, in radians
DSθ is the fine azimuthal angular increment, in radians
EP1 is the accuracy of radial location, in ft
EP2 is the accuracy of azimuthal angle, in radians
EP3 is the check for real roots
EP4 is the check for double root
EP5 is the check in double check calculations
Kθ is the number of times of fine increment calculation after the end of success of obtaining accurate roots
Sθ1 is the initial azimuthal angle
Sθ is the final azimuthal angle
Did is distance between source and microphone
Time is the sound traveling time from source to microphone, including the wind effect.
Ctime is the calculated time between 1/rev and acoustical impulse

Complex Z:
Dimension X(6), Y(6), Z(6), T(6), A(6), Z(6), R(6,550), ANG(6,550), C(4), 1K(5), CN(5), CP(5), C1(5), TEST(2), YS(6)
1 FORMAT (F10.5,F10.4,F10.4,F10.4,F10.3,F10.8)
2 FORMAT (6F10.4)
3 FORMAT (F10.4,F10.4,F10.4,F10.4,F10.4)
4 FORMAT (1H,2HZ,6F8.2)
DO 100 I=1,M
Y(I)=Y(I)
Z(I)=Z(I)
100 X(I)=X(I)

DO 1V I=1,M
K0=0
K=3
SI=SI

AP*:X(I)*SIN(SI)+G*SIN(AS)*COS(SI)+Y(I)*COS(SI))COS(AZ-AT*
1CO*:X(I)+G*COS(AS)=Z(I))SIN(AZ-AT*COS(SI))
BE=C*S(AZ-AT*COS(SI))COS(SI)
S=1052.+1.1434*TEM
D0=1-I-S1/AH
E=X(I)**2+Y(I)**2+Z(I)**2+G**2+Y(I)*S1+(AS)=2.*Z(I)*COS(AS)
F=G*SIN(AS)=Y(I)
C1=2.,4AP=0*U*B
C2=E=0*U*F
A(1)=1.,
A(2)=2.,C1
L1=0,2.*S**2
A(3)=C1**2+2.*C2=D1
A(4)=2.*C1*C2-2.*A*P*D1
A(5)=C2**2=E*D1
CALL ZPOLR(A,4,ZI,IER)
C
FOUND ZEROS OF 4TH ORDER POLYNOMIAL
C
START TO SELECT THE REAL ZERO
J=0
DO 50 I=1,N
IF (ABS(AIMAG(ZI(I)))) LE. EP3) GO TO 51
GO TO 60
51 J=J+1.
C(J)=REAL(ZI(I))
50 CONTINUE
C
SELECTED THE REAL ZERO
C
START TO SELECT THE CORRECT ZERO
J=1
IF (J. EQ. 0) GO TO 160
DO 60 J2=1,J
IF (C(J2). GE. 0., AND. C(J2). LE. RADIUS) GO TO 55
GO TO 60
55 N=#+1
C(J)=C(J2)


60 CONTINUE
*3=0
IF (.*=1) 160,65,165
C TREAT MULTIPLE (DOUBLES) ROUTS AS ONE ROUT IF THEIR DIFFERENCE
C IS WITHIN EP4
165 J33=-1
*2=0
GO 167 J3=1,J33
IF (ABS(C(J3)=C(J3+1)) LE, EP4) GO TO 166
C TREAT MULTIPLE (DOUBLES) ROUTS AS SEPARATE ROUTS IF THEIR
C DIFFERENCE IS NOT WITHIN EP4
*3=K3+1
CN(K3)=C(J3)
GO TO 167
166 CN=C(J3)
*2=K2+1
167 CONTINUE
IF (*2=1) 206,66,65
*5=CN(1)
C SELF-TED THE CORRECT ZERO
C C START DOUBLE CHECK
66 DIS=(C**2+2,CM*AP+E)**0,5
YY1=++CMB
SS=STU*YY1/DIS
11'='E=DIS/SS
CTIME=SI/AN+TIME
IF (ABS(TI(1)=CTIME) GE, EP5) GO TO 160
C END IF DOUBLE CHECK
C C USE TWO DIFFERENT INCREMENT DS AND DS1
205 IF (*0=1) 210,221,221
210 SI=SI+DS-DS1
*K0=1
GO T- 188
206 IF (*0=1) 160,207,207
C DOUBLE CHECK MULTIPLE (DOUBLES) ROUTS WHOSE DIFFERENCE IS NOT
C WITHIN EP4
C C 207 *K6=0
*K33=-3=1
*U 2A K5=1,K33
DIS=(CN(K5)**2+2,CM[K5]*AP+E)**0,5
YY1=++CM[K5]*A
SS=SU*YY1/DIS
TIRE=DIS/SS
CTIME=ST/AM+TIME
IF (ABS(ST(1)-CTIME)) GE. FPS1 GO TO 208
K6=K6+1
CP(K6)=CN(K5)
208 CONTINUE
IF (K6=1) 160, 222, 222
222 IF (M=1) 210, 226, 226
226 WRITE (6, 22) K6
DO 223 K4=1, K6
K4=K4+1
K(I,K)=CN(K4)
ANG(I,K)=SI
DEG=180.*SI/3.1416
WRITE (6, 12) R(I,K), ANG(I,K), DEG, I, K, DIS, TIME, CTIME
WRITE (6, 23)
GO TO 224
221 K4=K4+1
R(I,K)=CM
ANG(I,K)=SI
C OBTAINED THE CORRECT H AND SI
DEG=180.*SI/3.1416
WRITE (6, 12) R(I,K), ANG(I,K), DEG, I, K, DIS, TIME, CTIME
224 K1=K1+1
K1=K1+1
223 SI=SI+0.5
GO TO 160
160 IF (M=1) 190, 230, 240
240 K1=K1+1
IF (M=K1) 230, 230, 250
250 K0=0
190 SI=SI+0.5
180 IF (SI, GE, S1F) GO TO 150
K1(I)=K1
WRITE (6, 18)
10 CONTINUE
END OF ALL M MICROPHONES CALCULATION;
C
IF COMPARISONS ARE NEEDED, THE DECK SHOULD BE INSERTED HERE,
290 STOP
END
## APPENDIX 2

<table>
<thead>
<tr>
<th>T437 RUN 24.2</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>34.245</td>
<td>0</td>
<td>68.58</td>
<td>70.</td>
<td>241.09</td>
</tr>
<tr>
<td>68.24</td>
<td>0</td>
<td>68.58</td>
<td>-13.84</td>
<td>68.84</td>
</tr>
<tr>
<td>-20</td>
<td>5</td>
<td>0</td>
<td>10.92</td>
<td>20</td>
</tr>
<tr>
<td>8.06</td>
<td>1.25</td>
<td>8.07</td>
<td>-1.08</td>
<td>10.06</td>
</tr>
<tr>
<td>1390</td>
<td>0.0565</td>
<td>1.300</td>
<td>0.0235</td>
<td>1.256</td>
</tr>
<tr>
<td>0.0349</td>
<td>0.0175</td>
<td>1.00</td>
<td>0.0360</td>
<td>0.610</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
<td>0.001</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>6.2852</td>
<td>-3.1416</td>
<td>1.00</td>
<td>0.0360</td>
<td>3</td>
</tr>
<tr>
<td>6.94</td>
<td>0.0349</td>
<td>1.00</td>
<td>0.0360</td>
<td>0.610</td>
</tr>
<tr>
<td>R</td>
<td>A(^G)</td>
<td>R</td>
<td>A(^G)</td>
<td>R</td>
</tr>
<tr>
<td>-----</td>
<td>--------</td>
<td>-----</td>
<td>--------</td>
<td>-----</td>
</tr>
<tr>
<td>23.9</td>
<td>2,1300</td>
<td>23.7</td>
<td>2,1125</td>
<td>23.4</td>
</tr>
<tr>
<td>23.4</td>
<td>2,0950</td>
<td>23.1</td>
<td>2,0775</td>
<td>22.8</td>
</tr>
<tr>
<td>23.1</td>
<td>2,0775</td>
<td>22.8</td>
<td>2,0600</td>
<td>22.4</td>
</tr>
<tr>
<td>21.0</td>
<td>1,9900</td>
<td>20.4</td>
<td>1,9725</td>
<td>19.7</td>
</tr>
<tr>
<td>16.8</td>
<td>1,9025</td>
<td>15.5</td>
<td>1,8850</td>
<td>14.0</td>
</tr>
<tr>
<td>14.0</td>
<td>1,8675</td>
<td>12.4</td>
<td>1,8500</td>
<td>10.6</td>
</tr>
<tr>
<td>8.5</td>
<td>1,8150</td>
<td>6.3</td>
<td>1,7975</td>
<td>4.0</td>
</tr>
<tr>
<td>1.5</td>
<td>1,7625</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

END OF 1=PRINT

1 ROOTS
R = 16.3 A\(^G\) = 5944 = 34.06 deg I = 4 K = 1 DIS = 6.7 TIME = .0674 CTIME = .1300

1 ROOTS
R = 19.4 A\(^G\) = 5769 = 33.05 deg I = 2 K = 2 DIS = 7.0 TIME = .0657 CTIME = .1300

1 ROOTS
R = 20.2 A\(^G\) = 5594 = 32.04 deg I = 4 K = 3 DIS = 7.3 TIME = .0672 CTIME = .1300

END OF MULTIPLE ROOTS

END OF MULTIPLE ROOTS

END OF MULTIPLE ROOTS
<table>
<thead>
<tr>
<th>ROOTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Re 20.8 A<em>G</em> 0.5419 = 31.05 DEG</td>
</tr>
<tr>
<td>END OF MULTIPLE ROOTS</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Re 21.4 A<em>G</em> 0.5244 = 30.05 DEG</td>
</tr>
<tr>
<td>END OF MULTIPLE ROOTS</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Re 21.9 A<em>G</em> 0.5069 = 29.04 DEG</td>
</tr>
<tr>
<td>END OF MULTIPLE ROOTS</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Re 22.4 A<em>G</em> 0.4894 = 28.04 DEG</td>
</tr>
<tr>
<td>END OF MULTIPLE ROOTS</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Re 22.9 A<em>G</em> 0.4719 = 27.04 DEG</td>
</tr>
<tr>
<td>END OF MULTIPLE ROOTS</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Re 23.3 A<em>G</em> 0.4544 = 26.04 DEG</td>
</tr>
<tr>
<td>END OF MULTIPLE ROOTS</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Re 23.7 A<em>G</em> 0.4369 = 25.03 DEG</td>
</tr>
<tr>
<td>END OF MULTIPLE ROOTS</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Re 4.5 A<em>G</em> 0.4194 = 24.03 DEG</td>
</tr>
<tr>
<td>Re 3.7 A<em>G</em> 0.4019 = 23.03 DEG</td>
</tr>
<tr>
<td>Re 2.9 A<em>G</em> 0.3844 = 22.02 DEG</td>
</tr>
<tr>
<td>Re 2.1 A<em>G</em> 0.3669 = 21.02 DEG</td>
</tr>
<tr>
<td>Re 1.3 A<em>G</em> 0.3494 = 20.02 DEG</td>
</tr>
<tr>
<td>Re 1.5 A<em>G</em> 0.3319 = 19.02 DEG</td>
</tr>
<tr>
<td>END OF 1-PRINT</td>
</tr>
</tbody>
</table>
FIGURE 1.—DEFINITION OF COORDINATES
START

INPUT

INITIATION

SOLVE TRIANGULATION EQUATION

CHECK OF SOLUTIONS

STORE AND PRINT r, \psi

OPTIONAL

OBTAIN COMMON VALUES OF r, \psi OF MICROPHONES

NEXT STEP OF \psi

NEXT MICROPHONE

FIGURE 2.- BLOCK DIAGRAM
FIGURE 4.- RESULTS OF ACOUSTICAL TRIANGULATION