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MODELING THE NEAR ACOUSTIC FIELD OF A ROCKET DURING LAUNCH

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ABSTRACT

The design of launch pad structures is critically dependent upon the stresses imposed by the acoustical pressure field generated by the rocket engines during launch. The purpose of this effort is to better describe the acoustical field in the immediate launch area. Since the problem is not analytically tractable, empirical modeling will be employed so that useful results may be obtained for structural design purposes. The plume of the rocket is considered to be a volumetric acoustic source, and is broken down into incremental contributing volumes. A computer program has been written to sum all the contributions to find the total sound pressure level at an arbitrary point. A constant density source is initially assumed and the acoustic field evaluated for several cases to verify the correct operation of the program.

SUMMARY

This report documents an effort to model the acoustic near field of a rocket. The generating mechanisms are sufficiently complex that an empirical approach was found to be potentially more useful.

It was assumed that the acoustic source could be modeled as a collection of volumetrically distributed sources and that the acoustic field at any point could then be evaluated by incoherently summing contributions from elemental volumes.

A computer program was written to perform the numerical integration. The program is divided into logical sections and therefore is readily modifiable and extensible.

Test runs were made to verify the correct operation of the program. The results indicate linearity with respect to the source intensity of an arbitrary single cell and additivity with respect to a randomly selected pair of cells. For large ranges, the field decays with inverse square law behavior as does a point source.

SECTION I

INTRODUCTION

1.1 PROJECT DEFINITION

The intent of this effort is to develop a model for the general properties of the near acoustic field of rocket powered vehicles during launch. The lower portion of the acoustic spectrum, nominally less than 100 Hz, is of particular interest since mechanical structures respond primarily to these frequencies. In addition, the maximum spectral density typically occurs within this band.

1.2 PURPOSE

Acoustic power levels in the vicinity of a rocket engine exhaust can approach levels which are physically damaging to support structures, facilities, and even to the payload of the vehicle. Consequently the estimation of the sound pressure level (SPL) is important for future designs.

1.3 BACKGROUND

The acoustic energy generated by a rocket is principally due to the turbulent mixing of its high velocity exhaust gasses with the atmosphere. Although turbulence has been of interest since the late nineteenth century, as indicated by the work of Raleigh (1, 2) and Reynolds (3,4), little interest was shown in the acoustic field generated by jet flow until the work of Lighthill (5) in 1952. The far field analysis was extended by Williams (6) to include the Doppler shift induced by the advection of sound. Moffatt (7) and Goldstein (8) have pointed out the potential importance of the interaction of large scale fluctuations and small scale turbulence with respect to sound generation. Experimental work has been performed by Mollo-Christensen and Narasimha (9), Mollo-Christensen, Kolpin, and Martuccelli (10), Liu (11), Michalke and Fuchs (12), and Browand and Weidman (13). Progress in the field has been reviewed by Ffwcs Williams (14) and Goldstein. (op cit)

SECTION II

ANALYTICAL EFFORTS

2.1 PROBLEM DEFINITION

The generation of acoustic noise by a jet was considered in a landmark paper by Lighthill in 1952. Under the assumptions that the perturbed pressure and density variations are small compared to their mean value, the variation of entropy is negligible, and that the turbulent Mach number is small, his theoretical work led to a second order equation for density which has the form of a non-homogenous wave equation involving the instantaneous Reynolds stress tensor. He finds the acoustic source to have the form of acoustic quadrupoles, and finds approximate expressions for the spatial and temporal variations of the density and the time autocovariance of the density fluctuation.

Unfortunately, the statistics of the instantaneous Reynolds stress are not known. Therefore the author is ultimately forced to resort to similarity arguments to extend the analysis to arbitrary jet diameters and velocities; he finds that the mean squared density fluctuation varies with the square of the jet diameter and the eighth power of the Mach number.

2.2 LIMITATIONS

In addition to the assumptions already stated in the development of the theory, it is also assumed that the nature of the acoustic source does not change with Mach number and that the problem is indeed separable into a turbulence problem and an acoustic generation/propagation problem. It is not obvious that these assumptions are valid.

Even if one accepts all the assumptions involved, the analysis has been made only for the far acoustic field, while the current engineering interest is in the near field.

SECTION III

PROGRAM

3.1 APPROACH

In order to obtain an engineering approximation for the near acoustic field strength within a reasonable time, it will be necessary to resort to empirical techniques. Since the principal acoustic noise source of a rocket is associated with the plume of the rocket where its exhaust gasses mix with the atmosphere, this turbulent mixing region will be modeled as a volumetric noise source.

In the program developed herein, the source region has been broken into elemental volumes, source strengths associated with them, and the total sound field then estimated by evaluating the propagation loss from the elemental volume to the observer and forming an incoherent sum of these contributions. Since the source region has the approximate shape of a truncated cone, it has been most convenient to utilize a cylindrical coordinate system.

The program has been divided into functional modules so that it may be refined by upgrading the functional algorithms employed. As an example, the source generation function is, for initial purposes, considered uniform; this is rather primitive, and will be changed. Further refinements, such as modifications to the propagation loss model for paths which traverse the plume could also be incorporated.

As presently written, no disk files are utilized; all arrays reside in RAM. Although this limits the number of rockets, number (and hence size) of the incremental volume elements, number of observers and observation times, and so forth, the computational speed was considered sufficiently important that these limitations were considered acceptable at this time. Some of these limitations may be alleviated through the use of dynamically allocated arrays, which can free memory space. Larger memories are becoming common place in personal computers, and an alternative approach would be to utilize a RAM disk, which would allow operation faster than magnetic disks. Ultimately, it may well be that the computer resource requirements will force implementation on a larger, faster computer.

3.1.1 Program Variables and Arrays.

Variables and arrays have been assigned mnemonically. Therefore the program is easily read, and, more importantly, easily modified. The following is an alphabetical listing and description of the variables and arrays used in the program.

- ACCEL - Acceleration of vehicle, assumed constant, feet/sec^2
- ALTITUDE(INDXTIME) - Altitude of vehicle at time TIME(INDXTIME), feet
- BAND - Number of the frequency band currently of interest
- CONEAN - Semi-vertex angle of truncated cone approxi mating rocket plume, radians
- CONELEN - Length of cone which contributes to acoustic noise, feet
- CS(INDXDTHT) - Cosine of INDXDTHT * DTHTC
- CURDRC - Current size of DRC at this zc, feet
- CURRC - Current size of cone radius at this zc, feet
- CURROC - Number of rocket currently under considera tion
- CURZC - Axial position with respect to the cone apex currently considered, INDXDZC * DZC
- DEG2RAD - Conversion constant, degrees to radians

- o DV2OBSR2(CUROBS, INDXTIME, CURROC, INDXDZC, INDXDRC, INDXDTHT)
  - Square of the range between elemental source dV and observer for the current observer CUROBS at time TIME(INDXTIME) for the current rocket under consideration CURROC for a particular dV at INDXDZC * DZC, INDXDRC * CURDRC, and angle INDXDTHT * DTHTC, feet squared

- o DVSIZE(INDXDZC,INDXDRC) - Size of incremental volume for a particular distance from apex and angle, INDXDZC * DZC and INDXDRC * CURDRC, cubic feet

- o DVX, DVY, DVZ - Scalar position coordinates equivalent to DVXPOS(INDXTIME, CURROC, INDXDZC, INDXDRC, INDXDTHT) DVYPOS(INDXTIME, CURROC, INDXDZC, INDXDRC, INDXDTHT) DVZPOS(INDXTIME, CURROC, INDXDZC, INDXDRC, INDXDTHT)

- o DVXPOS(INDXTIME, CURROC, INDXDZC, INDXDRC, INDXDTHT)
  DVYPOS(INDXTIME, CURROC, INDXDZC, INDXDRC, INDXDTHT)
  DVZPOS(INDXTIME, CURROC, INDXDZC, INDXDRC, INDXDTHT)
  - X, Y, and Z coordinates of a particular elemental dV for a particular time, rocket, and cone related coordinates, feet

- o DZC - Thickness of incremental axial "slice", feet

- o EXDIA(CURROC) - Exit diameter of current rocket under consideration

- o EXVEL(CURROC) - Exit velocity of exhaust of current rocket under consideration

- o HELP$ - This parameter sets the help level. If set to Y or y program provides more verbose discussion of inputs, if N or n, omits discussion.

- o INDXDRC - Index used to select a particular value of radius, INDXDRC * CURDRC

- o INDXDTHT - Index used to select a particular value of angle theta, INDXDTHT * DTHTC

- o INDXDZC - Index used to select particular value of zc coordinate, INDXDZC * DZC

- o INDXTIME - Index used to select the time of observation, TIME(INDEXTIME)
- o MAXRC - Maximum cone radius at a particular zc, CURZC * TGCONEAN, feet
- o MININDDZ - Minimum index for zc such that zc is aft of the tail of the rocket
- o NOFBANDS - Number of frequency bands of interest
- o NOFDRC - Number of radial slices to use
- o NOFDZC - Number of axial slices to use
- o NOFOBS - Number of observers or locations to evaluate
- o NOFOBSTM - Number of observation times to evaluate
- o NOFROCS - Number of rockets in vehicle
- o NOFTHTC - Number of angular slices to use
- o OBSXPOS(CUROBS)
  OBSYPOS(CUROBS)
  OBSZPOS(CUROBS)
  - X, Y, and Z coordinates of current observer, feet.
- o PI - Constant, 3.14159
- o RELDVXPOS(INDXDZC, INDXDRC, INDXDTHT)
  RELDVYPOS(INDXDZC, INDXDRC, INDXDTHT)
  RELDVZPOS(INDXDZC, INDXDRC, INDXDTHT)
  - Coordinates of dV element relative to generic cone, x, y, and z
- o ROCXPOS(CURROC)
  ROCYPOS(CURROC)
  ROCZPOS(CURROC)
  - Initial position of current rocket relative to earth coordinates, X, Y, Z
- o SN(INDXDTHT) - Sine of INDXDTHT * DTHTC

- SPL(CUROBS, BAND, INDXTIME)
  - Sound pressure level for current observer, band number, and time

- SPLDB(CUROBS, BAND, INDXTIME) - Sound pressure level in dB

- SRCSTRTH(BAND, CURROC, INDXDZC, INDXDRC, INDXDTHT)
  - Source strength for current band number, rocket, and cone relative coordinates of interest

- SUMSPL - Used to accumulate the total contributions of all the elemental volumes

- TGCONEAN - Tangent of the semi-apex cone angle

- THRST(CURROC) - Thrust of current rocket, pounds

- TOTTHRST - Total thrust of vehicle, pounds

- VEHCLWT - Vehicle weight, pounds

- XDRIFT(INDXTIME)
  YDRIFT(INDXTIME)
  - Drift of rocket in X - Y (earth relative) plane at time TIME(IINDXTIME), feet

3.1.2 PROGRAM FUNCTIONAL MODULES.

The elements of the program are divided into seven modules so that the program may be readily modified or extended. The following sections are a discussion of their names and functions.

3.1.2.1 VEHICLE GEOMETRY AND PARAMETER DEFINITION SECTION.

All relevant numbers describing the system geometry, weight, and performance are defined in this section. Whenever the same system is to be used for many runs, it will be desirable to fix the data rather than reenter it, as was done for the program verification tests. At present, the exhaust velocity of each rocket is included in the data, but is not used in the program. The length of the laminar core in the plume is a function of the exhaust exit velocity, and it is anticipated that future programs

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will utilize this data.

The position of the rocket is described with respect to the earth. As viewed from above, the Y axis is defined to pass through the centers of the two SRBs and the external tank, and the X axis goes through the center of the external tank. Altitude, Z, is measured with respect to mean sea level.

For test purposes, the parameters for the program were selected to be approximately those of the shuttle system.

3.1.2.2 OBSERVER DEFINITION SECTION.

The sound pressure level (SPL) is evaluated at a number of points of observation, called observer locations. This section is used to define the earth relative positions (OBSXPOS, OBSYPOS, and OBSZPOS) for each point of interest.

3.1.2.3 GENERIC CONE GENERATION SECTION.

In order to save computation time, a "generic" cone is defined and divided into a large number of elemental volumes, dV. The semi-apex angle of the cone employed is 7.5 degrees, and the length of the cone which contributes to the generation of noise is considered to be 1000 feet. For test purposes, the cone is divided into 200 foot axial slices (DZC), 8 angular sectors (NOFTHTC), and 3 radial slices (NOFDRC). Since the maximum radius (MAXRC) changes with the current distance from the apex (CURZC), the value of the incremental change in radius changes (CURDRC). (It would also be possible to keep the incremental radial increment constant and change the summation appropriately.)

The size of the increments cited above are much too large to be considered incremental volumes, and will be reduced when the program is actually utilized. Smaller increments would have had severe impact on computing time and memory requirements; since inaccuracy in the integration is not a problem for program testing, the reduced time and memory were welcome.

The location and size of each dV are then calculated in a rectangular cone relative coordinate system, x,y,z. The cone relative system is defined to be parallel to the earth relative system.

3.1.2.4 SOURCE GENERATION SECTION.

The source generation section ascribes an acoustic intensity to each elemental volume for each rocket and each frequency band. The generic cone is effectively truncated at the top to the exit diameter of the rocket by summing only over an appropriate subset of the DZC index, from MININDDZ to NOFDZC.

3.1.2.5 RANGE AND RANGE SQUARED EVALUATION SECTION.

The range evaluation section calculates the position of each rocket relative to the earth at each time of interest. The initial acceleration is estimated using the vehicle weight (VEHCLHWT) and the total thrust (TOTTHRST). It is assumed that the change in the mass of the vehicle is negligible during the time of interest so that the altitude of a rocket is just its initial value plus one half the acceleration times the square of the elapsed time.

The possibility of horizontal drift is allowed through the variables XDRIFT AND YDRIFT. Such drifts could have drastic effects on the sound pressure level since the distance scales of interest are relatively small.

This section then calculates the square of the range (DV2OBSR2) from each elemental volume of each rocket to each observer for each time.

3.1.2.6 SOUND PRESSURE LEVEL EVALUATION SECTION.

This section sums the contributions from each dV to each observer for each time and band assuming inverse square law propagation. Intensities are added directly, which is tantamount to assuming that there is negligible coherence between sources.

3.1.2.7 TEST AND VERIFICATION SECTION.

This section contains subroutines which were generated to check the performance of components of the program and were called at the end of each section above, but have been deleted to save space in the report.

3.2 PROGRAM LISTING

The following is a listing of the computer program which performs the numerical integration to evaluate the total SPL at a point. Some cosmetic changes have been made in this listing.

```
   '  NEAR ACOUSTIC FIELD ROCKET NOISE PROGRAM (NAFRNOP?)
   '  RNFRPT17.BAS, 7/17/89; FOR SPL PROGRAM DOCUMENTATION
   '
   '  VEHICLE GEOMETRY AND PARAMETER DEFINITION SECTION
   '
   '  NORMALLY INPUT ALL DATA; FOR TEST PURPOSES DEACTIVATE
HELP,
   '  FIX SYSTEM; DE - REM FOR OPERATIONAL PROGRAM.  STATE-
MENTS
   '  REQUIRING ATTENTION ARE FULLY LEFT JUSTIFIED.
   '
REM:INPUT "DO YOU WANT HELP? (Y/N)", HELP$: PRINT " "
HELP$ = "N":          REM: FOR TEST PURPOSES.
REM:      PRINT "DEFINE VEHICLE GEOMETRY AND PARAMETERS:"
          PRINT " "
     IF HELP$ = "Y" OR HELP$ = "y" THEN PRINT "PLEASE INPUT
     VEHICLE WEIGHT IN POUNDS", VEHCLWT
     PRINT " "
VEHCLWT = 5000000: REM:  INPUT"VEHCLWT = ? ",VEHCLWT
     IF HELP$ = "Y" OR HELP$ = "y" THEN PRINT "HOW MANY
ROCKET ENGINES WILL BE ACTIVE?"
     PRINT " "
NOFROCS = 3:   REM:  INPUT"NOFROCS = ?",NOFROCS
     DIM ROCXPOS(NOFROCS), ROCYPOS(NOFROCS), ROCZPOS(NO-
FROCS),
          EXDIA(NOFROCS), EXVEL(NOFROCS), THRST(NOFROCS)
     IF HELP$ = "Y" OR HELP$ = "y" THEN PRINT "COORDINATE
     DISCUSSION":
     PRINT "
     THE xyz COORDINATE SYSTEM IS ASSOCIATED WITH THE
ROCKET.  IT REMAINS PARALLEL TO THE XYZ EARTH REFERENCE
SYSTEM."
     PRINT " "
     "PLEASE DEFINE THE ROCKET PARAMETERS, x, y, AND z
POSITIONS, EXIT DIAMETER, EXIT VELOCITY, AND THRUST FOR
EACH ENGINE."
'
'    (YOU MAY WISH TO FIX THE PARAMETERS WHICH ARE CONSTANT
```

```
'       FOR  A  SERIES OF RUNS TO  AVOID  EXCESSIVE  DATA
'       REENTRY.)
'      NOTE:  DATA APPROXIMATELY CONSISTENT WITH  SHUTTLE
'      SYSTEM
'
REM:       FOR CURROC = 1 TO NOFROCS
REM:       PRINT "FOR ROCKET ENGINE NUMBER "; CURROC
REM:INPUT"X =, Y =, Z =, EXDIA =, EXVEL =, THRST =";
ROCXPOS(CURROC),ROCYPOS(CURROC),ROCZPOS(CURROC),
EXDIA(CURROC),EXVEL(CURROC),THRST(CURROC)
REM:
REM: TEST DATA
ROCXPOS(1) = 28.08333: ROCYPOS(1) = 0: ROCZPOS(1) = 40:
EXDIA(1) = 13.567: EXVEL(1) = 10663: THRST(1) = 1198483:
ROCXPOS(2) = 0: ROCYPOS(2) = 20.8333:  ROCZPOS(2) = 40:
EXDIA(2) = 12.375: EXVEL(2) = 8202: THRST(2) = 264833
ROCXPOS(3) = 0: ROCYPOS(3) = -20.8333: ROCZPOS(3) = 40:
EXDIA(3) = 12.375: EXVEL(3) = 8202:  THRST(3) = 2648334:
REM:       NEXT CURROC
'
'
'     OBSERVER DEFINITION SECTION;
'     DEFINE NUMBER AND LOCATIONS OF OBSERVERS.
'
     IF HELP$ = "Y" OR HELP$ = "y" THEN PRINT "PLEASE
DEFINE NUMBER AND POSITIONS OF OBSERVERS RELATIVE TO XYZ
(EARTH) COORDINATES.":
' PRINT " "
REM: INPUT"HOW MANY OBSERVATION POINTS DO YOU WANT?",NOFOBS
REM: FOR TEST PURPOSES ONLY ONE OBSERVER
NOFOBS = 1:  REM: FOR TEST PURPOSES
     DIM OBSXPOS(NOFOBS), OBSYPOS(NOFOBS), OBSZPOS(NOFOBS)
REM:FOR CUROBS = 1 TO NOFOBS
REM:PRINT"X, Y, AND Z FOR OBSERVER NUMBER ";CUROBS;":"
REM:INPUT OBSXPOS(CUROBS),OBSYPOS(CUROBS),OBSZPOS(CUROBS)
REM:NEXT CUROBS     : REM: TEST DATA
     OBSXPOS(1) = 0: OBSYPOS(1) = 30000: OBSZPOS(1) = 0
'
'     GENERIC CONE GENERATION SECTION
'
     PI = 3.14159265#
     DEG2RAD = PI / 180
     CONEAN = 7.5 * DEG2RAD:  ' CENTRAL CONE ANGLE ASSUMED
     TGCONEAN = TAN(CONEAN):  ' TO BE 7.5 DEGREES.
     CONELEN  = 1000:
'  GENERATING  PART,  ASSUMED  =  1000'
```

```
DZC = 200:  ' 200 FOOT Z AXIS "SLICES" USED FOR TESTING.
     NOFDZC  =  INT(CONELEN / DZC + .5):
' CALC NO. OF Z SLICES.
NOFDRC = 3:  ' ASSUMES 3 SLICES ALONG RADIUS FOR TESTING.
NOFTHTC = 8:  ' ASSUMES 8 SEGMENTS IN CIRCLE FOR TESTING.
' CALCULATE SIZE OF DTHETA.
     DTHTC = 2 * PI / NOFTHTC
     DIM SN(NOFTHTC), CS(NOFTHTC),
     RELDVXC(NOFDZC, NOFDRC, NOFTHTC),
     RELDVYC(NOFDZC, NOFDRC, NOFTHTC),
     RELDVZC(NOFDZC), DVSIZE(NOFDZC, NOFDRC)
        FOR INDXDTHT = 1 TO NOFTHTC
        SN(INDXDTHT) = SIN(INDXDTHT * DTHTC)
        CS(INDXDTHT) = COS(INDXDTHT * DTHTC)
        NEXT INDXDTHT
        FOR INDXDZC = 1 TO NOFDZC
        CURZC = (INDXDZC - .5) * DZC
        MAXRC = CURZC * TGCONEAN
        CURDRC = MAXRC / NOFDRC
          FOR INDXDRC = 1 TO NOFDRC
          CURRC = (INDXDRC - .5) * CURDRC
            FOR INDXDTHT = 1 TO NOFTHTC
       RELDVXC(INDXDZC, INDXDRC, INDXDTHT) =
       CURRC * CS(INDXDTHT)
       RELDVYC(INDXDZC, INDXDRC, INDXDTHT) =
       CURRC * SN(INDXDTHT)
       RELDVZC(INDXDZC) = CURZC
       DVSIZE(INDXDZC, INDXDRC) = CURRC * CURDRC * DTHTC *
                                  DZC
            NEXT INDXDTHT
          NEXT INDXDRC
        NEXT INDXDZC
        PRINT "CONE RELATIVE DV POSITIONS CALCULATED."
'
REM: PRINT "ENTERING RELDVPOS/DVSIZE CHECK": GOSUB 2490:
REM: STOP: REM: TEST.  OK 7/11
'
'    SOURCE GENERATION SECTION
'
NOFBANDS = 1:    REM: FOR TEST PURPOSES
     DIM SRCSTRTH(NOFBANDS, NOFROCS, NOFDZC, NOFDRC,
NOFTHTC),
     MININDDZ(NOFROCS)
      FOR CURROC = 1 TO NOFROCS
      MININDDZ(CURROC) = INT(EXDIA(CURROC)
      / (2 * TGCONEAN) / DZC + .5)
```

```
      IF MININDDZ(CURROC) < 1 THEN MININDDZ(CURROC) = 1
      NEXT CURROC
      FOR BAND = 1 TO NOFBANDS
        FOR CURROC = 1 TO NOFROCS
          FOR INDXDZC = MININDDZ(CURROC) TO NOFDZC
            FOR INDXDRC = 1 TO NOFDRC
              FOR INDXDTHT = 1 TO NOFTHTC
              SRCSTRTH(BAND, CURROC, INDXDZC, INDXDRC,
INDXDTHT)
              = 2E+14 * DVSIZE(INDXDZC, INDXDRC)
              NEXT INDXDTHT
            NEXT INDXDRC
          NEXT INDXDZC
        NEXT CURROC
      NEXT BAND
'
REM:  FOR TEST, SET SELECTED dV SOURCES TO NON - ZERO
'
      PRINT "SOURCE STRENGTH CALCULATED."
'
REM:  GOSUB 2730:   STOP: REM:(TEST)  OK 7/11/89
'
'
'     RANGE AND RANGE SQUARED EVALUATION SECTION.
'     THIS SUBSECTION EVALUATES THE LOCATION OF EACH DV
'     ELEMENT FOR EACH ROCKET AT EACH TIME.
'
      IF HELP$ = "Y" OR HELP$ = "y" THEN PRINT
      "THE POSITION OF THE VEHICLE IS ESTIMATED AT A NUMBER
OF TIMES AFTER LIFT OFF.  PLEASE INDICATE HOW MANY TIME
VALUES YOU INTEND, THEN THE ACTUAL OBSERVATION TIMES"
PRINT " "
NOFOBSTM = 1:  REM:  INPUT"NOFOBSTM = ",NOFOBSTM
      DIM TIME(NOFOBSTM), ALTITUDE(NOFOBSTM), XDRIFT(NO-
FOBSTM),
      YDRIFT(NOFOBSTM)
      DIM DVXPOS(NOFOBSTM, NOFROCS, NOFDZC, NOFDRC,
NOFTHTC),
      DVYPOS(NOFOBSTM, NOFROCS, NOFDZC, NOFDRC, NOFTHTC),
      DVZPOS(NOFOBSTM, NOFROCS, NOFDZC)
REM:FOR INDXTIME = 1 TO NOFOBSTM
REM:INPUT"EVALUATE AT TIME AFTER LIFT OFF (SECS) = ",
          TIME(INDXTIME)
REM:NEXT INDXTIME
TIME(1) = 0
REM: FOR TEST PURPOSES, LET TIME = 0 IDENTICALLY.
```

```
      TOTTHRST = 0  REM: SET TOTAL THRUST TO 0
        FOR CURROC = 1 TO NOFROCS
        TOTTHRST = TOTTHRST + THRST(CURROC)
        NEXT CURROC
      PRINT "TOTAL THRUST = "; TOTTHRST
      ACCEL = (TOTTHRST - VECHLWT) * 32.16 / VEHCLWT
        FOR INDXTIME = 1 TO NOFOBSTM
        ALTITUDE(INDXTIME) = ACCEL / 2 * TIME(INDXTIME) ^ 2
        XDRIFT(INDXTIME)  =  0:
REM: CAN INTRODUCE DRIFT HERE
        YDRIFT(INDXTIME) = 0:  REM: IF DESIRED.
          FOR CURROC = 1 TO NOFROCS
            FOR INDXDZC = MININDDZ(CURROC) TO NOFDZC
              FOR INDXDRC = 1 TO NOFDRC
                FOR INDXDTHT = 1 TO NOFTHTC
DVXPOS(INDXTIME, CURROC, INDXDZC, INDXDRC, INDXDTHT) =
               ROCXPOS(CURROC) + XDRIFT(INDXTIME)
               + RELDVXC(INDXDZC, INDXDRC, INDXDTHT)
DVYPOS(INDXTIME, CURROC, INDXDZC, INDXDRC, INDXDTHT) =
               ROCYPOS(CURROC) + YDRIFT(INDXTIME)
               + RELDVYC(INDXDZC, INDXDRC, INDXDTHT)
DVZPOS(INDXTIME, CURROC, INDXDZC) =
              ROCZPOS(CURROC) + ALTITUDE(INDXTIME)
               - (INDXDZC + .5 - MININDDZ(CURROC)) * DZC
                NEXT INDXDTHT
              NEXT INDXDRC
            NEXT INDXDZC
          NEXT CURROC
        NEXT INDXTIME

        PRINT "DV POSITIONS CALCULATED FOR ALL ROCKETS."

REM:
REM:    PRINT "ENTERING DV POSITION CHECK.": GOSUB 3050:
REM:     (TEST) :  STOP : REM:    OK, 7/12/89
'
'
'    RANGE SQUARED SUBSECTION
'
DIM DV2OBSR2(NOFOBS, NOFOBSTM, NOFROCS, NOFDZC, NOFDRC,
NOFTHTC)
  FOR INDXTIME = 1 TO NOFOBSTM
    FOR CURROC = 1 TO NOFROCS
      FOR INDXDZC = MININDDZ(CURROC) TO NOFDZC
        FOR INDXDRC = 1 TO NOFDRC
          FOR INDXDTHT = 1 TO NOFTHTC
```

```
DVX = DVXPOS(INDXTIME, CURROC, INDXDZC, INDXDRC, INDXDTHT)
DVY = DVYPOS(INDXTIME, CURROC, INDXDZC, INDXDRC, INDXDTHT)
DVZ = DVZPOS(INDXTIME, CURROC, INDXDZC)
            FOR CUROBS = 1 TO NOFOBS
DV2OBSR2(CUROBS, INDXTIME, CURROC, INDXDZC, INDXDRC,
INDXDTHT)            = (DVX - OBSXPOS(CUROBS)) ^ 2 + (DVY -
OBSYPOS(CUROBS)) ^ 2
+ (DVZ - OBSZPOS(CUROBS)) ^ 2
            NEXT CUROBS
          NEXT INDXDTHT
        NEXT INDXDRC
      NEXT INDXDZC
    NEXT CURROC
  NEXT INDXTIME

PRINT "RANGE SQUARED VALUES CALCULATED FOR ALL dV AND
ROCKETS."
'
REM:
REM: PRINT "ENTERING RANGE SQUARED CHECK": GOSUB 4270:
STOP:
REM: (TEST)
REM: CHECKS ON TWO POINTS SELECTED AT RANDOM, 7/12/89
'
'
'     SOUND PRESSURE LEVEL EVALUATION SECTION
'
      DIM SPL(NOFOBS, NOFBANDS, NOFOBSTM),
      SPLDB(NOFOBS, NOFBANDS, NOFOBSTM)
        FOR CUROBS = 1 TO NOFOBS
          FOR INDXTIME = 1 TO NOFOBSTM
            FOR BAND = 1 TO NOFBANDS
            SUMSPL = 0
              FOR CURROC = 1 TO NOFROCS
                FOR INDXDZC = MININDDZ(CURROC) TO NOFDZC
                  FOR INDXDRC = 1 TO NOFDRC
                    FOR INDXDTHT = 1 TO NOFTHTC
                    SUMSPL = SUMSPL
+ SRCSTRTH(BAND, CURROC, INDXDZC, INDXDRC, INDXDTHT)
/ DV2OBSR2(CUROBS, INDXTIME, CURROC, INDXDZC, INDXDRC,
INDXDTHT)
REM:  PRINT "CURROC, INDXDZC, INDXDRC, INDXDTHT, AND SUMSPL
= ";
REM:  CURROC; INDXDZC; INDXDRC; INDXDTHT; SUMSPL
                    NEXT INDXDTHT
                  NEXT INDXDRC
```

```
                NEXT INDXDZC
              NEXT CURROC
SPL(CUROBS, BAND, INDXTIME) = SUMSPL
SPLDB(CUROBS, BAND, INDXTIME) =
10 * LOG(SPL(CUROBS, BAND, INDXTIME)) / LOG(10)
           PRINT "FOR OBSERVER ";
CUROBS; ", BAND "; BAND; " AND TIME "; TIME(INDXTIME); "THE
SPL IS "; SPLDB(CUROBS, BAND, INDXTIME); " DB."
           NEXT BAND
         NEXT INDXTIME
       NEXT CUROBS
       PRINT " SPL AND SPLdB CALCULATED"
REM:
REM: PRINT "ENTERING SPL CHECK.": GOSUB 5490
REM:
     STOP
REM:
REM: END OF PROGRAM
```

SECTION IV

RESULTS AND DISCUSSION

4.1 PROGRAM TEST RESULTS AND DISCUSSION

The sections of the program were checked individually by hand calculations at a few randomly selected points. In this section the program was employed under varying circumstances to verify overall performance. Shuttle vehicle data was used in the program. Source strength was set to a constant density and the level set arbitrarily for test purposes. Neither the constant density nor the arbitrary level have been correlated to actual sound levels; these runs are for test purposes only.

As a first case, data was generated for a polar plot in the X - Y plane. This data revealed little variation with angle; the pattern is omnidirectional within a fraction of a dB. There was a slight rise on the positive X axis which is probably attributable to the shuttle main engines.

The solid line in figure 4-1 shows the variation of the SPL generated by the rocket, as modeled by the cited distributed source, along the X (or Y) axis as a function of the logarithm of the range. The ranges considered were from 100 to 30000 feet. For comparison purposes, the + symbols show the performance of an equivalent point source obeying an ideal inverse square law. For large ranges, approximately 2000 feet or more, the distributed model and equivalent point model are indistinguishable. For small ranges, less than 2000 feet, the distributed model indicates lower sound levels than the point source. This behavior is logical.

Next, the SPL was evaluated along the Z axis and compared to the SPL evaluated along the X or Y axis. Figure 4-2 shows the Z axis variations, solid line, and the X axis variations, + symbol, as a function of the logarithm of range. For a given range along the Z axis the sound level is less than or equal to the level at the same range on the X axis. Moving along the Z axis takes the observer directly away from the source while moving along the X axis increases the range to the distributed source more slowly, once again a logical behavior. For ranges approaching zero, the observation points approach the origin and the

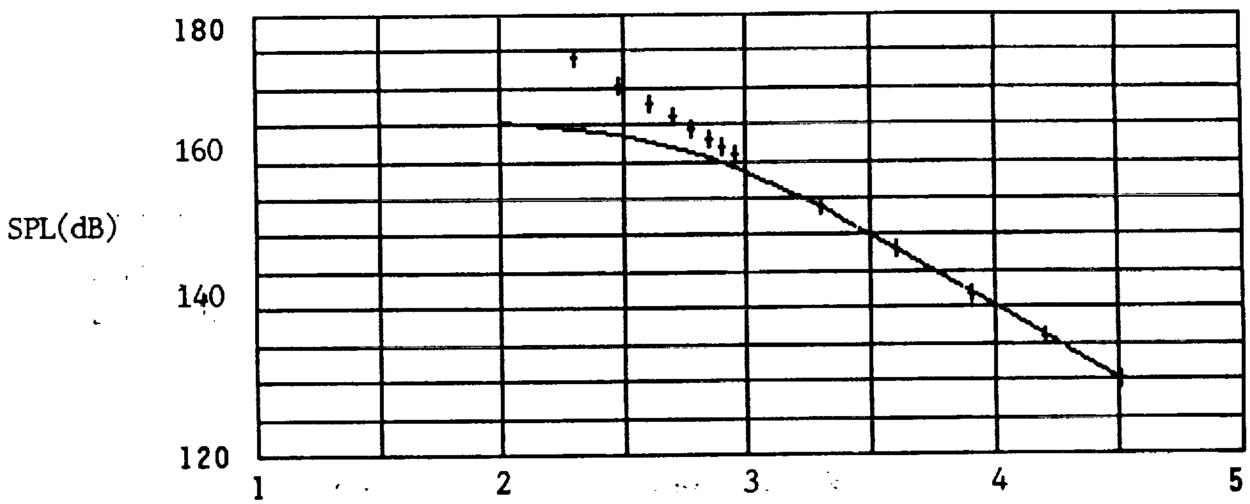

Figure 4-1. SPL IN dB AS A FUNCTION OF THE LOGARITHM OF X OR Y RANGE (point source and ideal inverse square law, + symbol)

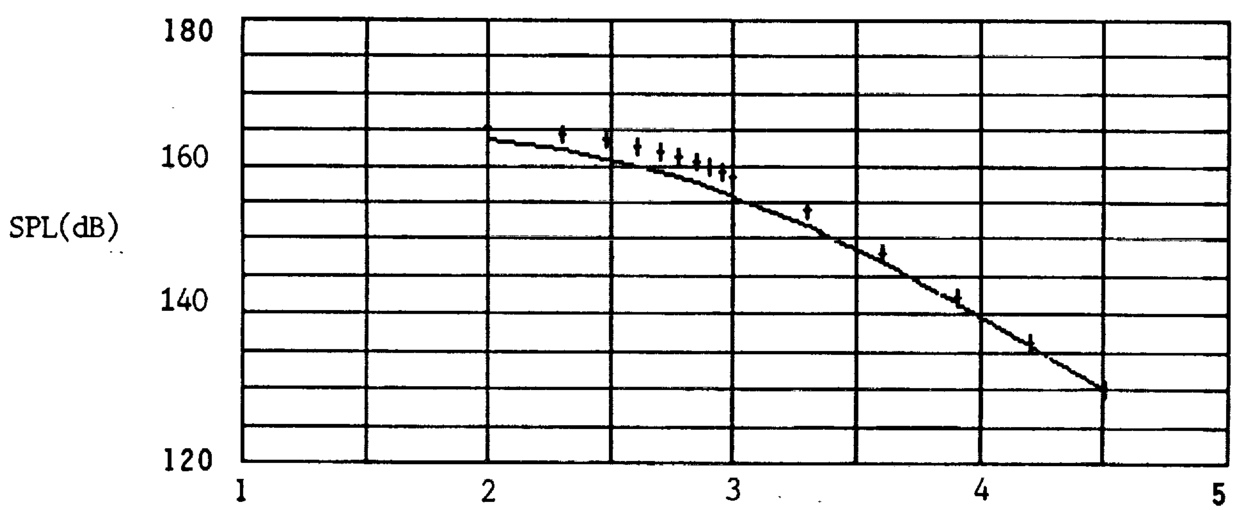

Figure 4-2. Z AXIS VARIATION IN SPL COMPARED TO X OR Y AXIS VARIATION (Z range, solid line, X or Y range, + symbol)

SPL must be the same; at large ranges, the distributed source behaves as a point source and both curves again coincide. The maximum difference appears to be at a range which is approximately the same as the length of the cone, about 1000 feet.

The SPL was then evaluated for an observer at a horizontal range of 100 feet, both as a function of vehicle altitude, figure 4-3, and time after lift off, figure 4-4. As the altitude of the vehicle increases, the distributed source is actually coming closer to the observer, so the SPL increases until its effective center passes the observer at a vehicle altitude of about 800 feet. The sound level then decreases as altitude continues to increase. In figure 4-4 the sound pressure level variation with time is graphed. The SPL increases very slowly at first since the vehicle position initially changes quite slowly, then rises to a peak at about 14 seconds, then falls as the vehicle recedes.

The SPL pattern was then explored around circular contours in the X - Z plane at ranges of 100, 500, 1000, and 3000 feet. Figures 4-5, 4-6, 4-7, and 4-8 are polar plots of the SPL calculated at these ranges respectively. Circles corresponding to 150 dB, 160 dB and 170 dB have been graphed on these plots for reference, while the SPL has been graphed with + symbols. For the 100 foot contour the variation in range to the source is small compared to the dimensions of the source and the variation of the SPL is only approximately 6 dB. Straight down, toward the bottom of the page, the observation point is near the top of the generating cones and the SPL exhibits a maximum. The maximum is skewed a bit toward the right (along the X axis), again presumably associated with the shuttle engines. The pattern exhibits much greater directionality for the 500 foot and 1000 foot contours, please see figures 4-6 and 4-7. These contours cut through the approximate middle and far end of the source cones, so the sound levels are most significantly different for these cases. The graph for the 3000 foot contour, figure 4-8, shows reduced directionality and is beginning to become omnidirectional as anticipated; the source is again approaching the behavior of a point source, as anticipated.

Finally, to compare these patterns more directly, the contours in the X - Z plane for ranges of 100, 500, 1000,

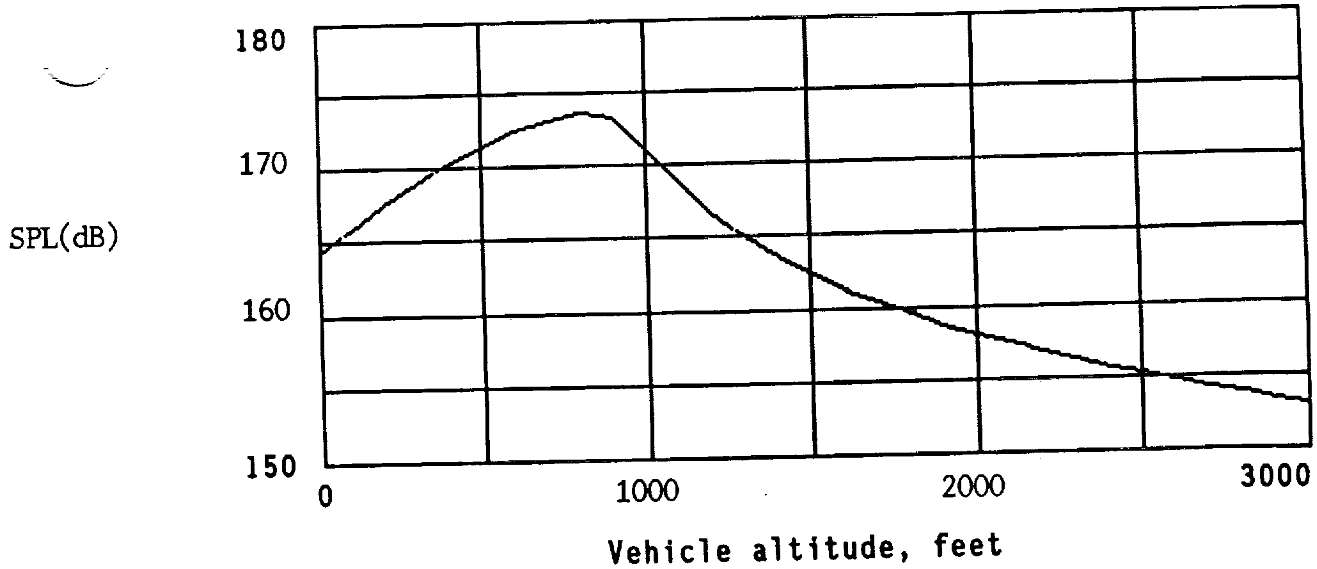

Figure 4-3. SPL AS A FUNCTION OF VEHICLE ALTITUDE at a horizontal range of 100 feet

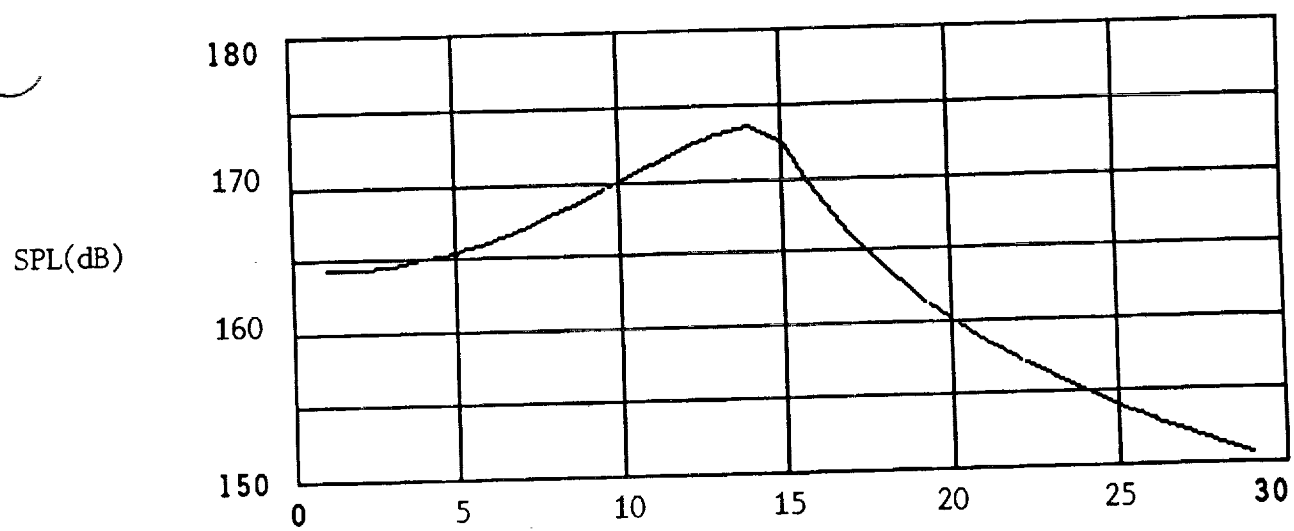

Figure 4-4. SPL AS A FUNCTION OF TIME AFTER LIFT OFF for a horizontal range of 100 feet

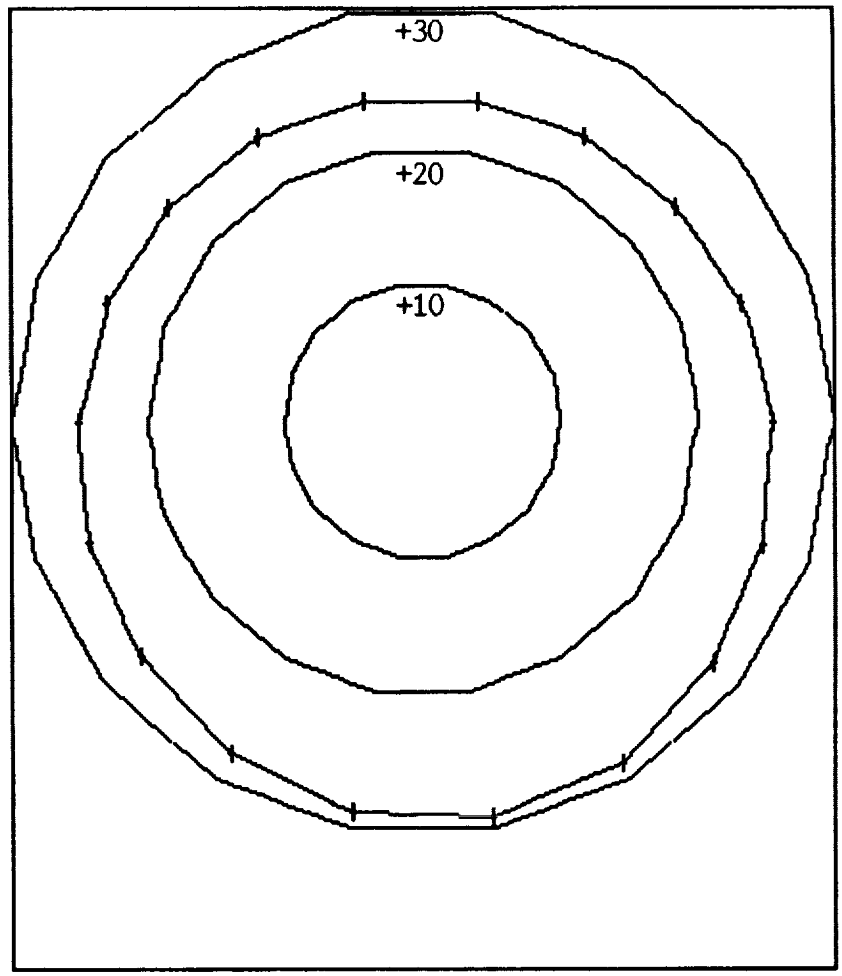

Figure 4-5. POLAR PLOT OF SPL re 140 dB FOR A RANGE OF 100 FEET
(in X - Z plane)

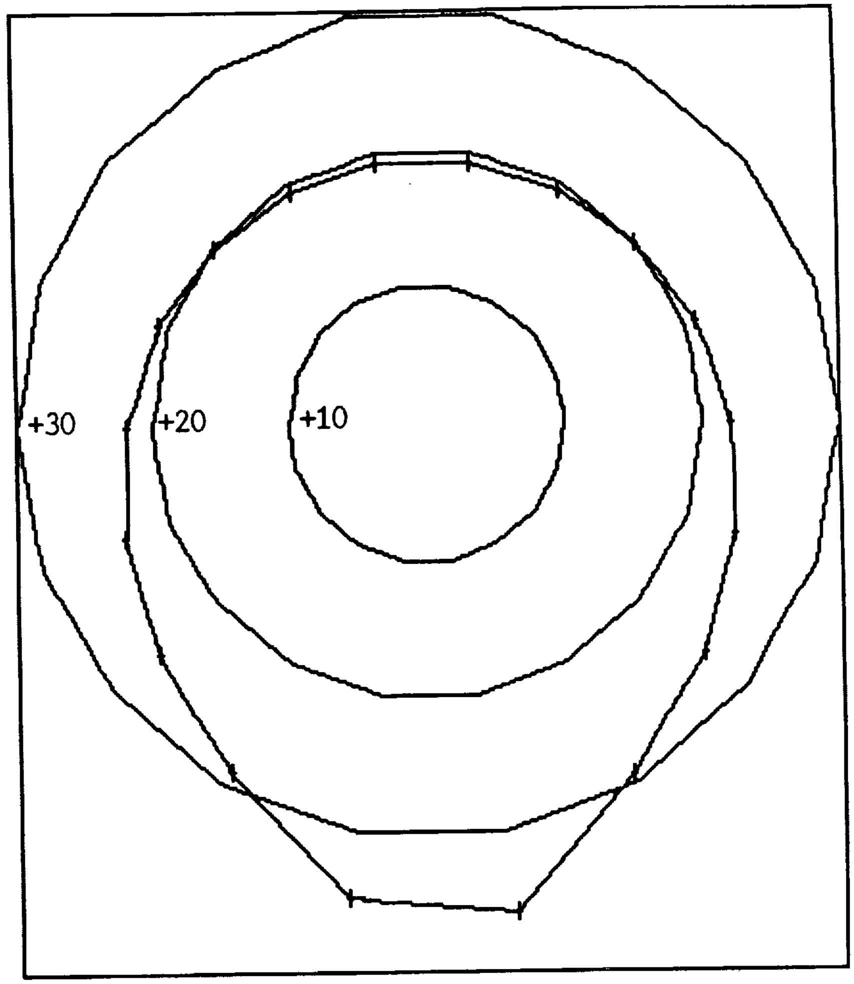

Figure 4-6. POLAR PLOT OF SPL re 140 dB FOR A RANGE OF 500 FEET
(in X - Z plane)

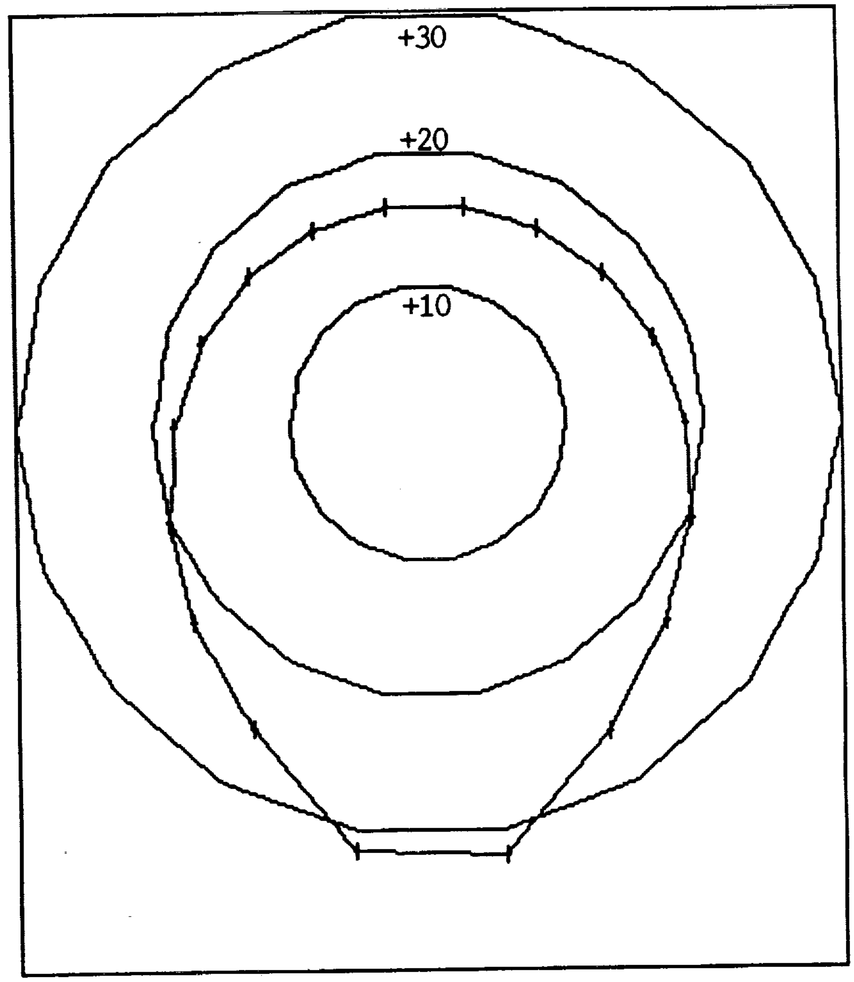

Figure 4-7. POLAR PLOT OF SPL re 140 dB FOR A RANGE OF 1000 FEET (in X - Z plane)

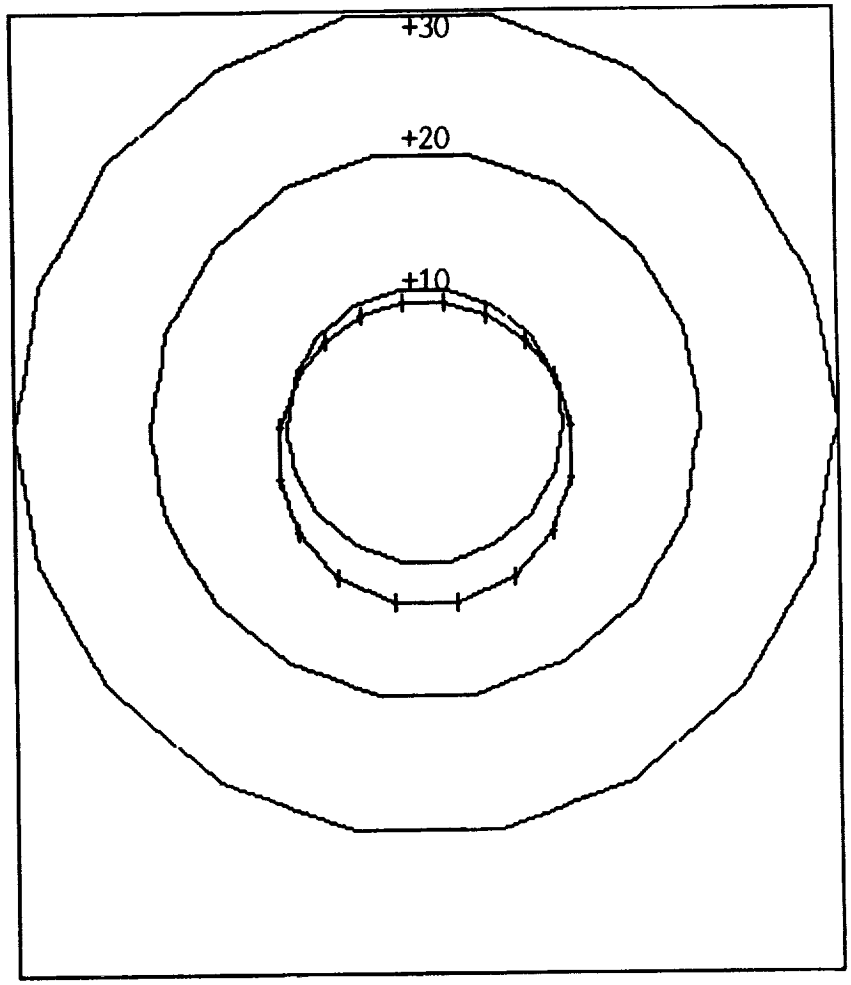

Figure 4-8. POLAR PLOT OF SPL re 140 dB FOR A RANGE OF 3000 FEET
(in X - Z plane)

and 3000 feet were plotted in figure 4-9 using +, x, rectangle, and diamond shaped symbols. The reference circles at 150, 160, and 170 dB have been deleted to avoid clutter. Except for straight down, the region of the rocket plume, the levels decrease monotonically as the range increases. The directionality and slight asymmetry are consistent and apparent. (Note: the software used to graph these curves does not maintain scale between X and Y axes, nor does the screen presentation accurately reflect the appearance of the graph.)

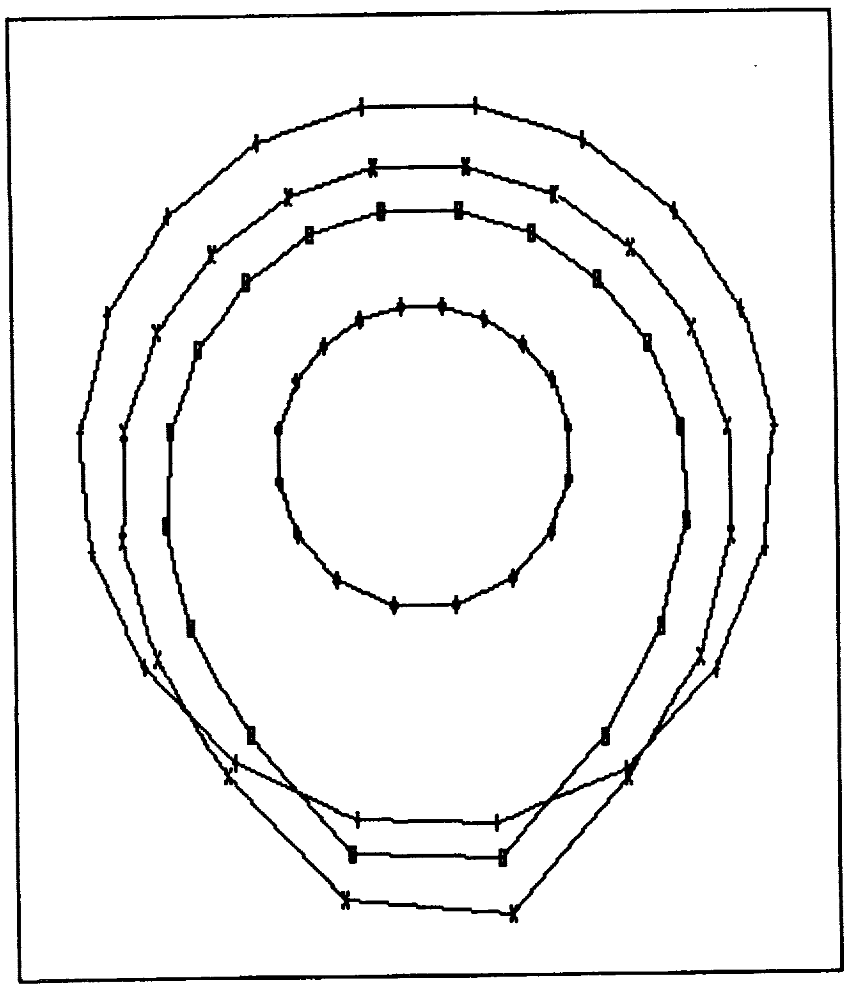

Figure 4-9. COMPARISON OF SPL PATTERNS IN THE X - Z PLANE FOR RANGES OF 100 (+), 500 (X), 1000 (RECTANGLE), AND 3000 (DIAMOND) FEET

SECTION V

CONCLUSIONS

5.1 CONCLUSIONS AND COMMENTS

The program designed and implemented to evaluate the near acoustic field of a rocket appears to function as intended. It employs superposition and assumes that the source is incoherent. For test purposes, a constant source density was used. During actual use experimental data need be employed to calibrate the model.

The use of BASIC and a personal computer were adequate for program definition and development, and were convenient. It may be desirable to utilize a more powerful computer in actual use, particularly if small integration steps are taken, many runs are required and/or the program is made more complex through the use of more elaborate mathematical models.

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