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TCNOISE: A COMPUTER PROGRAM TO CALCULATE NOISE LEVELS AND DIRECTIVITY FROM A JET ENGINE TEST CELL

by

T.W. Lancey, California State University, Fullerton
C.A. Kodres, NFESC

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13. ABSTRACT (Maximum 200 words) This report presents the Fortran program TCNOISE (Test Cell NOISE). The program predicts noise emitted by jet engine test cells. It is to be used in conjunction with the Naval Facilities Engineering Service Center's jet engine test cell aerothermal performance computer model, reading output files from this code to acquire the flow properties necessary for the calculation of jet noise and surface noise. The theoretical basis of TCNOISE, instructions for running the program, example runs, and comparisons of program predictions with measured noise emissions are included in the report.				
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EXECUTIVE SUMMARY

Noise emissions from the Navy's standard T-10 jet engine test cells are exceeding their design limits. This is a problem, in particular, for test facilities that are near residential areas. Several Naval Air Stations have received official complaints from adjacent neighborhoods. As the expansion of other communities brings them closer to jet engine test facilities, this problem will continue to grow.

Noise is an aerothermal phenomenon, and there are several active programs that could result in changes to the aerothermal characteristics of the Navy's test cells. Solving one problem while unknowingly exacerbating another problem would be a mistake. To avoid this, the development of a test cell noise emissions model was made an early milestone in the Naval Facilities Engineering Service Center's (NFESC) jet engine test cell NOx reduction project. The model will be used to determine changes in noise emissions that would be induced by test cell modifications made to decrease chemical and particulate emissions. It can also be used to quantitatively evaluate cell modifications specifically for the purpose of decreasing noise.

This report is a user's manual for the computer program TCNOISE (Test Cell NOISE), a Fortran code that predicts noise emitted by jet engine test cells. It is to be used in conjunction with the NFESC's jet engine test cell aerothermal performance model, reading output files from this program to acquire the flow properties necessary for the calculation of jet noise and surface noise. The theoretical basis of TCNOISE, instructions for running the program, and example runs are included in the report.

The accuracy of TCNOISE is assessed by comparing predicted noise emissions with sound pressure levels measured when the J52 and the TF30 engines were tested in the T-10 test cell at NAS Cubi Point, Republic of the Philippines, and the F404 was tested in Test Cell No. 3 at NAS Lemoore, California. Differences between calculated sound pressure levels and measured values are typically near 1 dB, with the maximum difference less than 3 dB.

Most test cell modifications affect noise generation by changing gas velocities and turbulence. However, three test cell dimensions that influence noise emissions have relatively small or no effect on noise generation: the length of the tube, the height of the exhaust stack, and the augmentor shell diameter. The influence of these dimensions can be examined without first rerunning the aerothermal model. Of these parameters, the effect of increasing the height of the exhaust stack is the most pronounced. For example, if the height of the exhaust stack of Test Cell No. 3 at NAS Lemoore is increased to approximately the height of the intake stack, far field noise, during tests of an afterburning F414 engine, will be decreased by about 7 dB.

Another Navy program that could affect noise emissions from jet engine test cells is the switch from a round to a square augmentor tube. TCNOISE predicts the Navy's T-10 test cell with a 13.7-foot square augmentor tube to be about 0.5 dB noisier than the standard T-10. Although gas velocities and turbulence through the square tube are lower because of the larger cross-sectional area, the jet noise is approximately 13 percent greater. This is primarily attributable to the lack of a transition section at the beginning of the augmentor tube to smooth out the flow.

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BACKGROUND

Noise emissions from the Navy's standard T-10 jet engine test cells are exceeding their design limit. This is a problem, in particular, for test facilities that are near residential areas. Several Naval Air Stations have received official complaints from adjacent neighborhoods. As the expansion of other communities brings them closer to jet engine test facilities, this problem will continue to grow.

Noise is an aerothermal phenomenon, and there are several active programs that could result in changes to the aerothermal characteristics of the Navy's test cells. Solving one problem while unknowingly exacerbating another problem would be a mistake. To avoid this, the development of a model to predict test cell noise emissions was made an early milestone in the Naval Facilities Engineering Service Center's (NFESC) jet engine test cell NOx reduction project. The model will be used to determine changes in noise emissions that would be induced by test cell modifications made to decrease chemical and particulate emissions. It can also be used to quantitatively evaluate cell modifications specifically for the purpose of decreasing noise.

This report is a user's manual for the Fortran model TCNOISE (Test Cell NOISE). The program predicts noise emitted by jet engine test cells. The program is run in conjunction with NFESC's jet engine test cell aerothermal performance computer model (Kodres, 1996), reading output files from this code to acquire the flow properties necessary for the calculation of jet noise and surface noise. The theoretical basis of TCNOISE, instructions for running the program, example runs, and comparisons of program predictions with measured noise emissions are included in the report.

THEORETICAL/MATHEMATICAL BASIS OF PROGRAM

The acoustical calculations of this program are centered around the noise producing mechanisms of jet (and self) noise, surface noise, and the reverberant noise field in the augmentor section. Noise reduction techniques considered are absorption in the augmentor section, the reactive muffler effect of the augmentor section, the diffraction of the exit ramp as a barrier, the refraction of the noise emanating from the jet, the noise reduction across the augmentor shell, the directivity of the sound emanating from the end of the augmentor tube, and the spherical divergence of the noise as it travels through the air to the stations 250 feet (76.2 meters) from the jet nozzle.

Jet Noise

The jet noise is calculated using the results of several research programs and combining jet shear noise with self noise (Jones, 1965; Lush, 1971; MacGregor, 1973):

$$W = 0.00004\rho U^8 D^2 / c^5 \quad (\text{Watts}) \quad (1)$$

where W is the acoustic power, ρ the gas density, U the jet velocity, D the jet diameter, and c the ambient velocity of sound; all are in consistent SI units.

Effects of refraction in the jet are considered at 180 degrees (on-axis) where the refraction reduces the transmitted sound by 15.8 dB, and at 150 degrees, where the sound is increased 5.3 dB (Morris, 1973). These effects decrease at lower angles. This has a direct bearing on sound incident on the augmentor wall, but which alone provides a 41 dB attenuation so that the sound transmitted through the wall is much less than that transmitted out the augmentor tube.

Surface Noise

Equations for the prediction of the surface noise are also provided in the literature (Ffowcs, 1972; Nelson, 1982). With the Strouhal Number (St) at a given frequency (f) defined as $St \equiv f D/U$ and setting $\sigma = 0.03$ (the open area ratio of the augmentor tube), $z = 12.56637 St$ is used in the solution for a Struve function of the first kind,

$$ALST = 0.0063662((z^{0.67}) - (z^{0.089}) + (z^{0.0038})) \quad (2)$$

The surface noise per unit area (WA) is then calculated using:

$$WA = \rho \pi^3 (TI)^2 U^6 St (ALST) / 96 \sigma c^3 \quad (3)$$

where TI is the turbulence intensity.

Noise Reverberation and Absorption

The steady state reverberant field is given by:

$$WR = (W + WA/AS)/a \quad (4)$$

where AS is the duct sound producing surface area and a is the absorptivity of the augmentor section,

$$a = \alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3 + \dots + \alpha_n S_n \quad (5)$$

The α_i 's are the absorption coefficients and the S_i 's are the surface areas of the i th surfaces in the augmentor section.

Noise Reduction

Reactive Muffler. Noise reduction caused by the expansion and contraction of the augmentor section is given by Wilson (1989) as:

$$TL = 10 \log[1 + 0.25(m - 1/m)^2 \sin^2(kC)] \quad (6)$$

where m = augmentor shell area/augmentor tube area, k is the wave number ($k = 2\pi f/c$), and C is the augmentor tube length.

Diffraction over Ramp Barrier. Noise reduction is accomplished by the diffraction of sound as it crosses the exit ramp (Wilson, 1989), here treated as a barrier. The noise reduction is calculated approximately by:

$$TL = 5 + 20\text{Log}[(2\pi N)^{0.5}/\tanh((2\pi N)^{0.5})] \quad (7)$$

where $N = 2f(A+B-C)/c$, and A is the distance from the top of the augmenter tube to the top of the ramp, B is the distance from the top of the ramp to the 250-foot station, and C is the straight line distance from the top of the augmenter tube to the 250-foot station.

Directivity of Sound Leaving Augmenter Tube. The directivity of the sound is similar to that of a round piston (Kinsler, 1962). The directivity relative to the on-axis maximum at 180 degrees is

$$I/I_0 = [2J_1(X)/X]^2 \quad (8)$$

I is the intensity at angle $180-\theta$ and $X=ka \sin\theta$, where 'a' is the radius of the augmenter tube. $J_1(X)$ is the Bessel function of the first kind and order one.

Attenuation by Spherical Divergence. The reduction in intensity level as the spherical wave grows from R to r is

$$\Delta L = 20 \text{ Log}[R/r] \quad (9)$$

USER'S MANUAL

TCNOISE is a Fortran 90 program, solving Equations 1 through 9 for test cell noise emissions and far field sound pressure levels. It was developed and compiled using the Lahey LF90 compiler (Lahey, 1995). The program is being distributed with both the Fortran listing of the code, TCNOISE.FOR, and the compiled version, TCNOISE.EXE. If a compiler is available, the code can be modified and run, for example, when the augmenter tube grid is changed. The compiled program can be run by simply typing its name. A listing of the code is included as an appendix to this report.

The program requires output files from NFESC's jet engine test cell aerothermal performance model as input. The aerothermal model uses the Phoenix CFD code (Spalding, 1996) to solve the governing equations. The main section of TCNOISE reads the Phoenix output file required for the jet noise calculation, NOISE.JET, and calls subroutines that calculate jet and surface noise and reverberation. The Phoenix file used for surface noise calculations, NOISE.WAL, is read from the surface noise subroutine. The format for the Phoenix files to be read into the NOISE.JET and NOISE.WAL files of TCNOISE is (2F10.1, F10.4, E13.3, 3I5). These files contain velocity, temperature, gas density, and turbulent kinetic energy of pertinent Phoenix nodes, as well as the "I,J,K" location of that node within the test cell.

In the jet noise subroutine, noise generated in the individual nodes is calculated using Equation 1 with node gas velocities acquired from the Phoenix input and the average cross-

section dimension of the node. The individual node noise is summed over all nodes, and the acoustic power is written to the output file SPLOUT to verify that the more distant nodes contribute little to the overall acoustic power. The noise from an afterburning TF30 is calculated using Equation 1 but with the nozzle velocity and diameter of the jet as input. This provides a reference for the acoustic power.

Noise through the augmenter tube wall is also calculated. This is accomplished in three steps. First, the transmission losses across the pillows (10 dB), wall liner (1.5 dB), and the steel tube (41 dB) are set. Second, the geometric expansion of the spherical wave from the engine to the wall, at angles of 30, 60, and 90 degrees off-axis are calculated. Third, the effects of the jet refraction at off-axis angles of 30 degrees (+5.3 dB), 60 degrees (+3.0 dB), 90 degrees (+1.0), and 120 degrees (-5.0 dB) are added.

In the surface noise subroutine, the surface noise is calculated using the Phoenix output to acquire gas velocities and turbulence intensity along the augmenter tube wall for approximately the final 60 percent of the tube. The acoustic power for each element is summed as the calculations proceed.

The reverberation calculation uses the acoustic power from the jet and surface noise subroutines. The sum of these sources is considered to be the total noise source within the augmenter tube. Absorbing objects are the pillows, wall liner, and the tube entrance and exit, where sound is 100 percent transmitted. The surface areas of the pillows and the wall liner are calculated and multiplied by their respective absorption coefficients to yield the individual component absorptive areas. These areas are then summed to yield the total effective absorptive areas of the wall liner, the pillows, and the entrance and exit. Reverberant acoustic intensity is found by dividing the source acoustic power (in watts) by the effective absorptive area (in square meters).

Noise reduction of the test cell varies with the frequency (engine size and exit velocity). Maximum noise from the test cell is on-axis, and the results indicate that the noise reduction from the source at the engine exit to the on-axis 250-foot station is approximately 37 dB, but is dependent on frequency. If there were no test cell present, refractive effects would cause the maximum noise to occur at approximately 30 degrees off-axis where the jet noise field would be amplified by 5.3 dB. The noise reduction would therefore be approximately 42 dB, comparing the noise at 30 degrees with no test cell to the on-axis noise with the test cell.

Instructions for Running TCNOISE

The compiled Fortran program is TCNOISE.EXE. Phoenix output files for jet noise and for surface (wall) noise are presumed to be in files named *filename.jet* and *filename.wal*, respectively. Examples of these files are included in subsequent sections. The following procedure is required to run TCNOISE:

1. Type -- COPY *FILENAME.JET* NOISE.JET
COPY *FILENAME.WAL* NOISE.WAL
(the program recognizes only these file names)
2. Type -- TCNOISE (running the compiled version of the program)

3. The user is then prompted to enter the:

(i) AUGMENTER TUBE DIAMETER (all dimensions are in meters, e.g., 3.505 meters for Test Cell No. 3 at NAS Lemoore and 4.175 meters for the T-10 at NAS Cubi Point)

(ii) AUGMENTER SHELL DIAMETER (e.g., 5.5 meters for the T-10 test cells)

(iii) AUGMENTER TUBE LENGTH (e.g., 18.3 meters for Test Cell No. 3 at NAS Lemoore; 24.63 meters for the T-10 test cells)

(iv) THE INTEGER, 10 OR 14, DEPENDING ON WHETHER THE AUGMENTER TUBE DIAMETER IS NEAR 10 FEET (3.048 METERS) OR 14 FEET (4.27 METERS)

(v) THE VERTICAL DISTANCE FROM THE AUGMENTER TUBE TO THE TOP OF THE RAMP (e.g., 2.18 meters for Test Cell No. 3 at NAS Lemoore and 1.52 meters for the T-10 at NAS Cubi Point)

(vi) NUMBER OF SURFACE NODES IN THE AXIAL DIRECTION, AN INTEGER DEPENDING ON THE AUGMENTER TUBE LENGTH (the number of cells the augments tube was divided into for the aerothermal calculations (Kodres, 1996), e.g., 25 for Test Cell No. 3 at NAS Lemoore and 30 for the T-10 test cell at NAS Cubi Point)

Output

The output is printed on the monitor screen and sent to the file SPLOUT. Examples of output files are included in subsequent sections:

- The top 16 lines of SPLOUT list the acoustic power at each of the first 16 axial stations (as defined in the aerothermal code) downstream of the engine; they show the relatively small contribution of the more distant stations to the total jet acoustic power.
- Line 17 shows the jet acoustic power of the afterburning TF30 engine as calculated using Lighthill's theory with an empirical constant applied.
- Line 18 shows the total jet acoustic power predicted by TCNOISE for the engine being analyzed.
- Line 19 shows the sound pressure level (SPL; ref. 20 μ Pa) of the noise transmitted through the tube at angles of 30, 60, 90, and 120 degrees off-axis, at a distance of 250 feet from the engine. The angles on line 19 are rotated 180 degrees from the downstream sense (they are referenced from the axis, looking upstream).
- The remaining seven lines of SPLOUT present additional sound pressure levels calculated using TCNOISE; all SPLs are FLAT, that is, they are unfiltered. To obtain an approximation for dBA (SPL on the A-scale), subtract 22 dB from dB FLAT. The last

four lines of the output list the SPLs at the usual microphone locations, allowing direct comparison with measured noise levels.

ACCURACY OF THE PROGRAM

The accuracy of TCNOISE was assessed by comparing predicted noise emissions with SPLs measured at NAS Cubi Point (Schmidt, 1987) and NAS Lemoore (Glass, 1985). Polar graphs making the comparisons are presented as Figures 1 through 4 when the J52 (Mil) and the TF30 (both Mil and A/B) were tested in the T-10 test cell at NAS Cubi Point and the F404 (A/B) was being tested in Test Cell No. 3 at NAS Lemoore. Differences between the calculated SPLs and measured values were typically near 1 dB, with some exceptions to 3 dB. The comparisons are summarized in Table 1. Also included in Table 1, in anticipation of the arrival of an F-18E/F Super Hornet squadron, are noise emissions predicted by TCNOISE when an afterburning F414 engine is tested in Test Cell No. 3 at NAS Lemoore.

Table 1. Comparisons of Noise Emissions Predicted by TCNOISE and Measured at NAS Cubi Point and NAS Lemoore (predicted/measured noise in dBA 250 feet from the engine nozzle; 180 degrees is directly behind the test cell)

Location	Engine	Power	180 deg	150 deg	120 deg	90 deg
NAS Cubi Point	J52	Military	79.5/77.5	74./73.4	67/68.7	65/66.7
	TF30	Military	84.3/81.1	78.8/77.9	71.8/70.4	69.8/70
	TF30	A/B	96.5/96.5	91/88.7	84/85.1	82/80.4
NAS Lemoore	F404	A/B	92.8/94	90.5/88	86.9/88	86.2/87
	F414	A/B	98.8/	96.5/	92.9/	92.2/

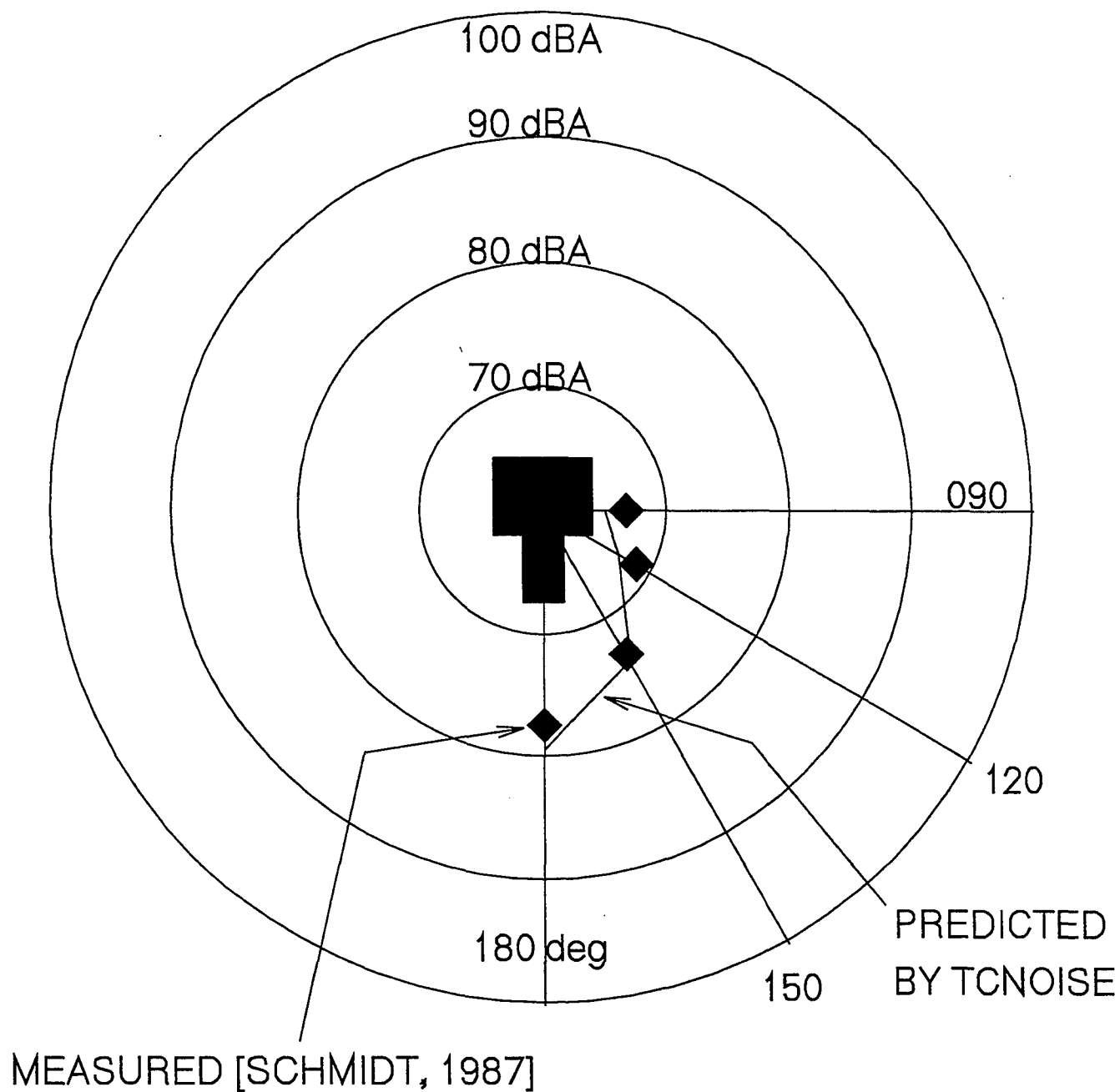


Figure 1
Comparison of T-10 test cell noise emissions predicted by TCNOISE with measured values
when running a J52 at Mil power (noise in dBA 250 feet from engine nozzle).

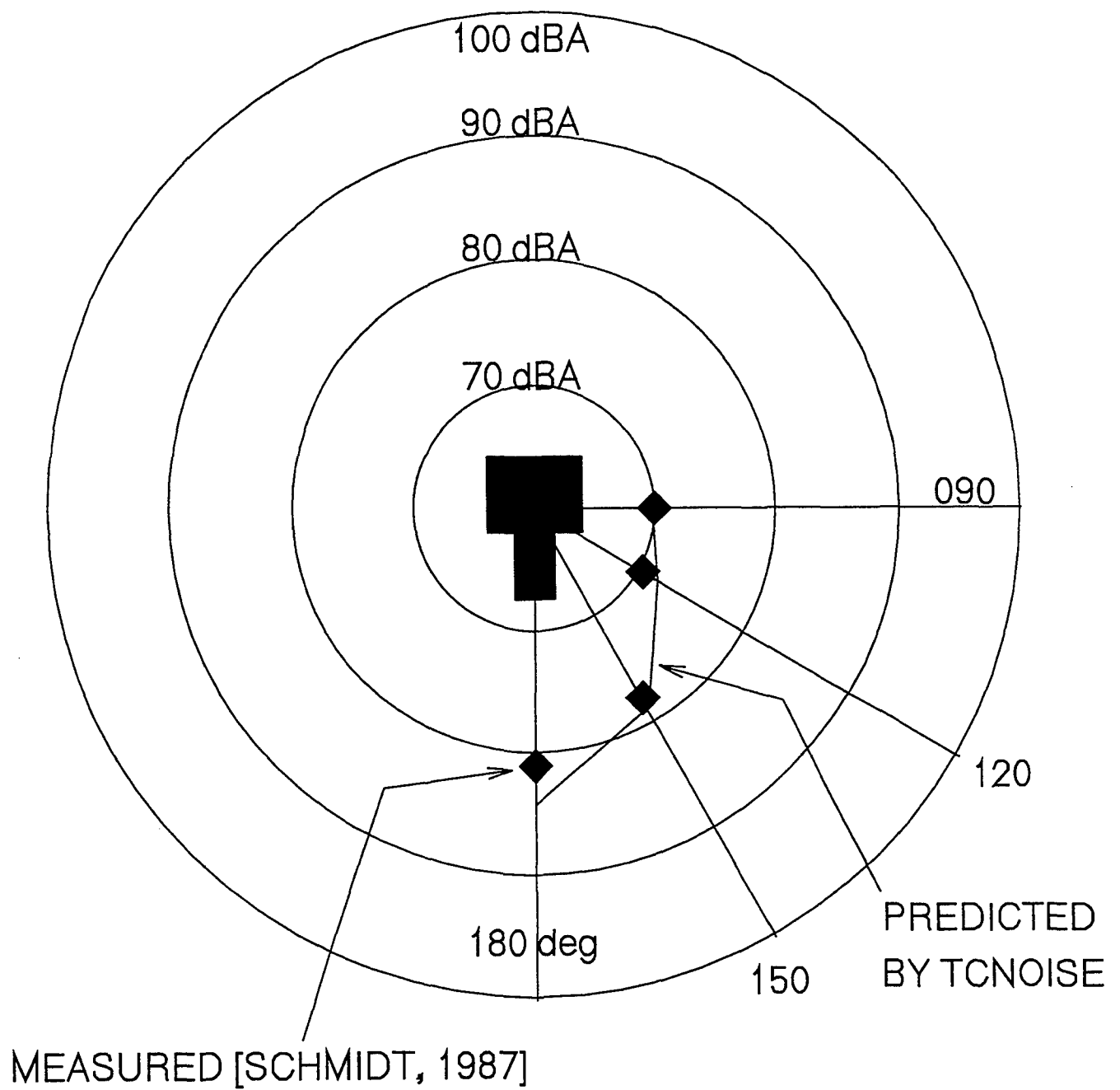


Figure 2
Comparison of T-10 test cell noise emissions predicted by TCNOISE with measured values when running a TF30 at Mil power (noise in dBA 250 feet from engine nozzle).

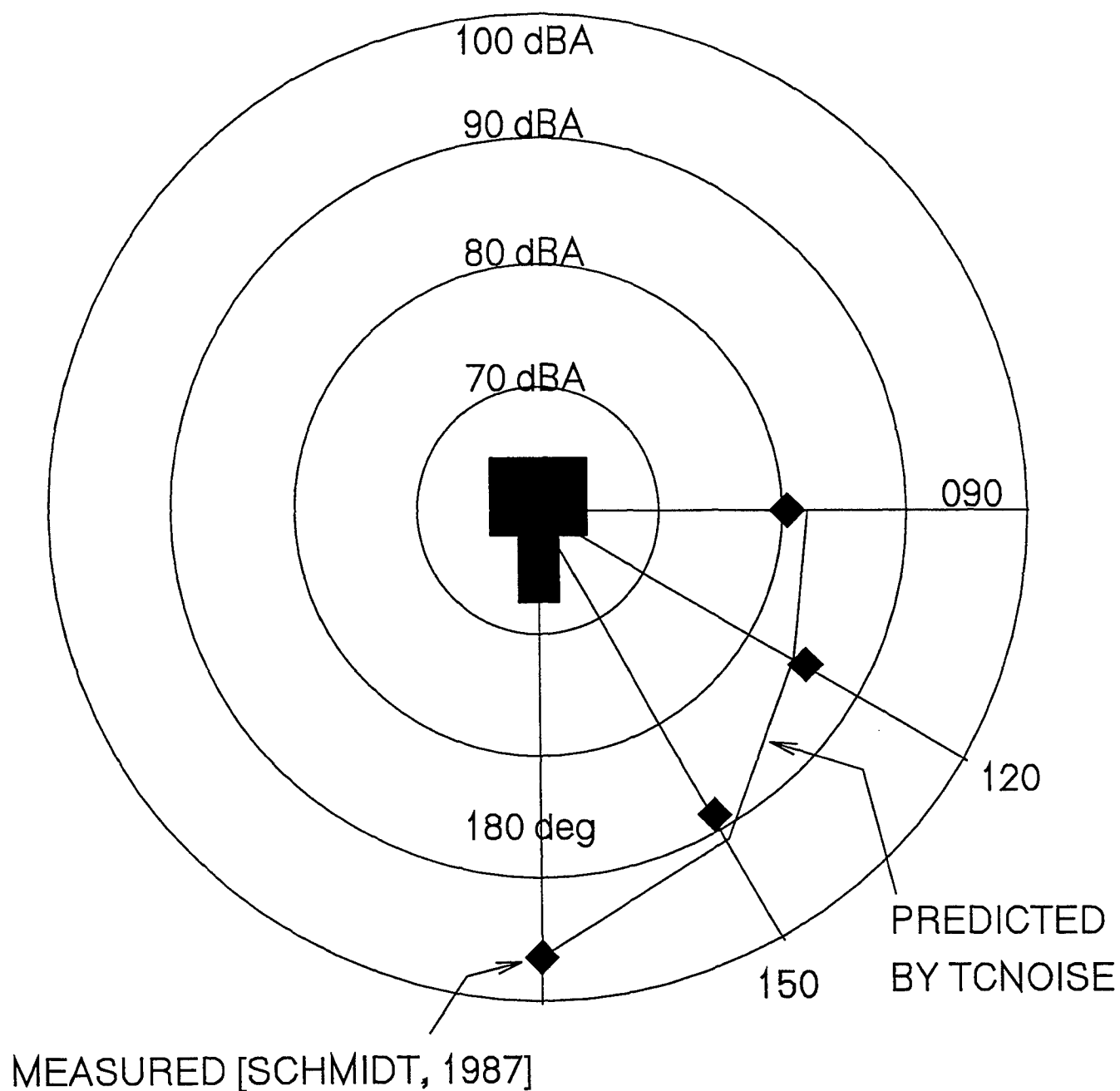


Figure 3
Comparison of T-10 test cell noise emissions predicted by TCNOISE with measured values when running an afterburning TF30 (noise in dBA 250 feet from engine nozzle).

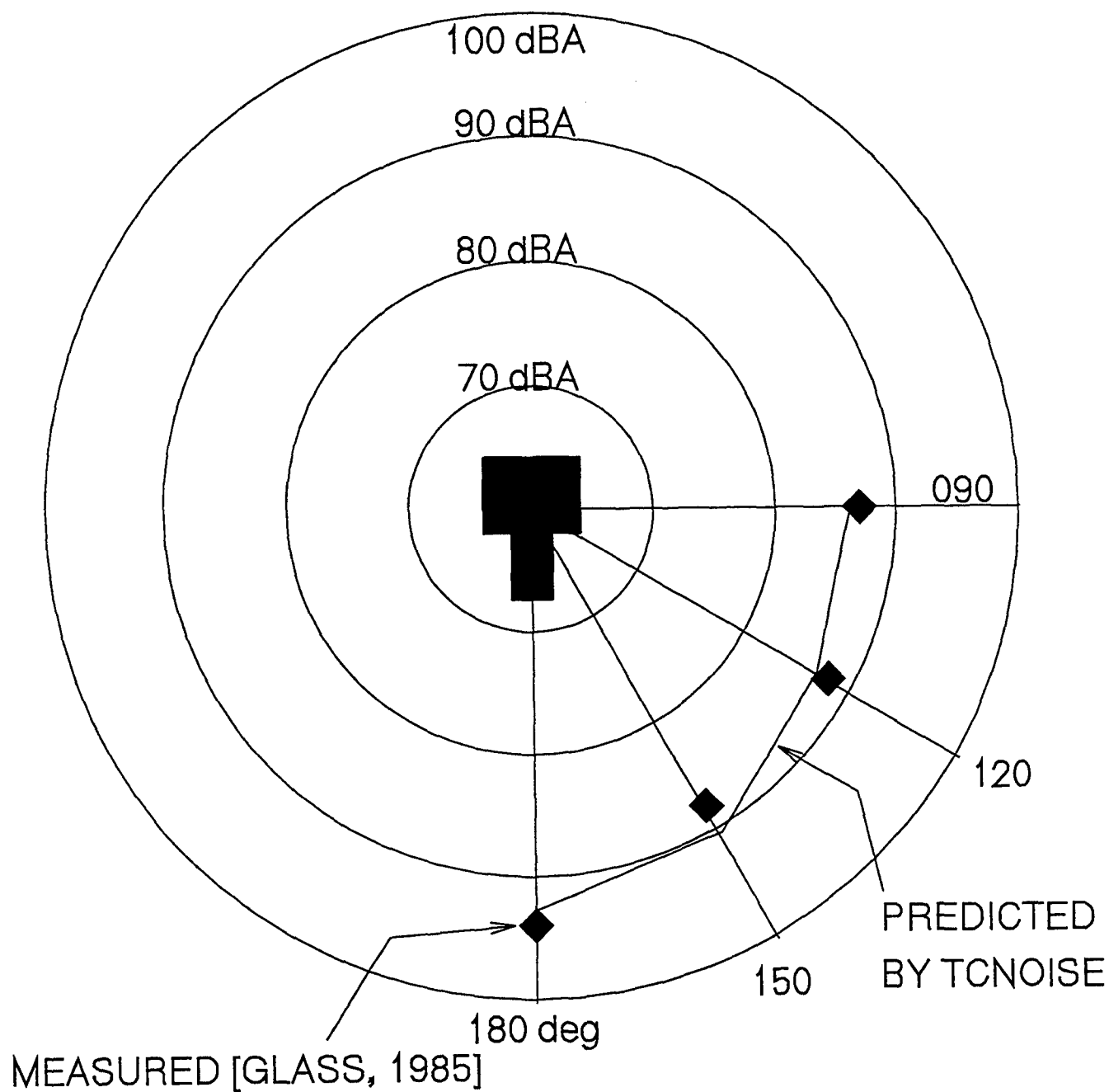


Figure 4
Comparing predicted and measured noise emissions from JETC No. 3 at NAS Lemoore
when running an afterburning F404 (noise in dBA 250 feet from engine nozzle).

EXAMPLE RUNS

Two example runs are provided to further illustrate the use of TCNOISE. The first example is the TF30 being tested at military power in the T-10 Test Cell at NAS Cubi Point:

1. The output files from the aerothermal model were given the file name TF30MIL. Segments from these files are included as Tables 2 and 3. Therefore:

```
COPY TF30MIL.JET NOISE.JET
COPY TF30MIL.WAL NOISE.WAL
```

2. Type TCNOISE to run the compiled version of the program.

3. The following inputs are in response to the prompts:

```
4.175
5.5
24.63
14
1.52
30
```

The output file, always called SPLOUT, is included as Table 4. Noise emissions when testing an engine at military power or lower are not a problem. Predicted noise levels in this example are much lower than the design limit of 90 dBA (CFR, 1995) measured at a distance of 250 feet from the engine.

The second example is an afterburning F414 engine being tested in Test Cell No. 3 at NAS Lemoore. As mentioned above, this engine has never been tested in this facility, but its arrival is anticipated shortly, and it would be desirable to know if there will be any noise problems.

1. The output files from the aerothermal model were given the file name F414AB. Segments from these files are included as Tables 5 and 6. Therefore:

```
COPY F414AB.JET NOISE.JET
COPY F414AB.WAL NOISE.WAL
```

2. Type TCNOISE to run the compiled version of the program.

Table 2. Input File NOISE.JET Used to Predict Noise Emissions from the T-10 Test Cell at NAS Cubi Point While Testing a TF30 Engine at Military Power

VEL (m/sec)	TEMP (degK)	DENSITY (kg/m**3)	TURB KE (m/sec)**2	I	J	K
12.7	293.0	1.1865	0.853E+00	3	2	35
18.0	293.0	1.1848	0.130E+01	4	2	35
21.3	293.1	1.1839	0.158E+01	5	2	35
21.4	295.7	1.1742	0.149E+01	6	2	35
18.3	293.0	1.1845	0.133E+01	7	2	35
...	...	...	...			
14.2	293.0	1.1878	0.322E-01	8	3	35
13.6	293.1	1.1871	0.833E+02	3	4	35
21.3	312.1	1.1128	0.808E+04	4	4	35
716.2	837.8	0.4078	0.136E+04	5	4	35
616.3	721.8	0.5006	0.487E+03	6	4	35
19.9	292.3	1.1833	0.596E+03	7	4	35
14.2	293.0	1.1875	0.332E-02	8	4	35
13.0	293.3	1.1865	0.198E+03	3	5	35
18.1	326.9	1.0645	0.633E+04	4	5	35
607.5	721.9	0.5023	0.514E+03	5	5	35
584.1	712.6	0.5261	0.196E+03	6	5	35
19.3	293.0	1.1806	0.143E-03	7	5	35
13.8	293.0	1.1869	0.171E-04	8	5	35
...	...	...	...			
18.8	293.0	1.1835	0.161E+01	7	2	36
12.8	293.0	1.1858	0.120E+01	8	2	36
13.7	293.0	1.1838	0.428E+01	3	3	36
21.6	297.6	1.1642	0.195E+04	4	3	36
36.0	303.8	1.1377	0.126E+05	5	3	36
45.8	317.2	1.0909	0.892E+04	6	3	36
15.9	287.7	1.2038	0.959E+03	7	3	36
15.2	293.0	1.1844	0.256E+00	8	3	36
15.9	293.1	1.1828	0.295E+02	3	4	36
23.2	304.7	1.1359	0.808E+04	4	4	36
617.6	713.4	0.4683	0.308E+04	5	4	36
498.3	600.8	0.5667	0.112E+04	6	4	36
...	...	...	...			
74.9	316.4	1.0677	0.727E+03	8	7	50

Table 3. Input File NOISE.WAL Used to Predict Noise Emissions from the T-10 Test Cell At NAS Cubi Point While Testing a TF30 Engine at Military Power

VEL (m/sec)	TEMP (degK)	DENSITY (kg/m**3)	TURB KE (m/sec)**2	I	J	K
-1.0	321.5	1.0354	0.487E+01	2	1	46
40.5	314.4	1.0565	0.596E+01	3	1	46
44.6	316.3	1.0509	0.284E+01	4	1	46
39.6	323.5	1.0287	0.136E+01	5	1	46
33.1	312.8	1.0644	0.228E+01	6	1	46
40.0	315.4	1.0544	0.464E+01	7	1	46
36.5	319.5	1.0389	0.831E+01	8	1	46
-25.1	324.3	1.0264	0.532E+01	9	1	46
...	...	...	...			
29.5	317.2	1.0485	0.999E+00	2	1	47
53.6	313.5	1.0692	0.136E+03	3	1	47
59.2	318.5	1.0581	0.280E+03	4	1	47
55.9	324.3	1.0411	0.273E+03	5	1	47
49.7	314.8	1.0723	0.261E+03	6	1	47
55.0	316.3	1.0657	0.163E+03	7	1	47
51.6	319.3	1.0504	0.418E+02	8	1	47
23.7	324.1	1.0291	0.183E+01	9	1	47
17.9	308.8	1.0758	0.689E+00	2	8	47
43.6	308.8	1.0843	0.704E+01	3	8	47
45.9	313.5	1.0719	0.663E+01	4	8	47
35.5	315.8	1.0636	0.357E+01	5	8	47
15.0	311.7	1.0771	0.541E+00	6	8	47
-15.9	314.9	1.0665	0.775E+00	7	8	47
-15.8	315.9	1.0635	0.509E+00	8	8	47
-23.7	318.3	1.0528	0.183E+01	9	8	47
...	...	...	...			
-18.7	316.4	1.0638	0.138E+01	7	8	48
-27.1	320.9	1.0492	0.247E+01	8	8	48
-32.7	323.6	1.0383	0.404E+01	9	8	48
40.1	316.7	1.0578	0.770E+01	2	1	49
60.4	317.5	1.0584	0.569E+03	3	1	49
68.0	322.9	1.0424	0.752E+03	4	1	49
65.9	325.0	1.0367	0.742E+03	5	1	49
...	...	...	...			
44.9	352.5	1.0064	0.734E+01	9	8	75

Table 4. Output File SPLOUT from TCNOISE When Used to Predict Noise Emissions from
the T-10 Test Cell At NAS Cubi Point When Testing
the TF30 Engine at Military Power

k= 1 Jet Noise Power= 137976. Watts
k= 2 Jet Noise Power= 34019. Watts
k= 3 Jet Noise Power= 16504. Watts
k= 4 Jet Noise Power= 9558. Watts
k= 5 Jet Noise Power= 5761. Watts
k= 6 Jet Noise Power= 3873. Watts
k= 7 Jet Noise Power= 3678. Watts
k= 8 Jet Noise Power= 3460. Watts
k= 9 Jet Noise Power= 3083. Watts
k= 10 Jet Noise Power= 2677. Watts
k= 11 Jet Noise Power= 2254. Watts
k= 12 Jet Noise Power= 1387. Watts
k= 13 Jet Noise Power= 853. Watts
k= 14 Jet Noise Power= 536. Watts
k= 15 Jet Noise Power= 342. Watts
k= 16 Jet Noise Power= 219. Watts

EMPIRICAL EQUATION NOISE= 3626056. Watts (TF30,A/B)
Sum of jet noise from nodes = 226187. Watts

NOISE THROUGH PIPE 150,120,90,60 = 71.69 69.40 67.39 61.40 dB @ 250'

Jet noise source field,augmenter tube exit= 137.966 dB
Surface noise field,augmenter tube exit= 129.077 dB
Reverberation field intensity level,IL= 142.982 dB

SPL,180DEG,250FT= 106.277 dB FLAT
SPL,150DEG,250FT= 100.777 dB FLAT
SPL,120DEG,250FT= 93.777 dB FLAT
SPL, 90DEG,250FT= 91.777 dB FLAT
For approximate dBA, subtract 22 dB from dB FLAT.

Program by T.W. Lancey at NFESC, 5/97 - 7/97.

Table 5. Input File NOISE.JET Used to Predict Noise Emissions from NAS Lemoore
Test Cell No. 3 While Testing an Afterburning F414 Engine

VEL (m/sec)	TEMP (degK)	DENSITY (kg/m**3)	TURB KE (m/sec)**2	I	J	K
9.5	293.0	1.1862	0.735E+00	3	2	35
13.6	293.0	1.1852	0.104E+01	4	2	35
16.2	293.0	1.1842	0.108E+01	5	2	35
15.9	293.0	1.1844	0.103E+01	6	2	35
14.4	293.0	1.1847	0.114E+01	7	2	35
10.0	293.0	1.1861	0.788E+00	8	2	35
9.8	293.0	1.1853	0.157E+03	3	3	35
24.8	297.6	1.1654	0.238E+04	4	3	35
45.6	316.8	1.0924	0.188E+05	5	3	35
62.1	362.6	0.9540	0.137E+05	6	3	35
22.7	276.7	1.2524	0.308E+04	7	3	35
10.8	293.0	1.1851	0.237E+03	8	3	35
9.5	293.3	1.1840	0.751E+03	3	4	35
47.3	326.5	1.0600	0.148E+05	4	4	35
1101.6	1999.0	0.1721	0.336E+04	5	4	35
940.7	1696.2	0.2104	0.467E+04	6	4	35
23.9	288.4	1.1968	0.143E+05	7	4	35
10.4	293.0	1.1852	0.937E+03	8	4	35
9.1	293.4	1.1838	0.689E+03	3	5	35
54.2	347.5	0.9972	0.120E+05	4	5	35
...	...	...	...			
10.6	293.1	1.1855	0.116E+01	3	2	36
15.5	293.0	1.1847	0.143E+01	4	2	36
18.6	293.0	1.1839	0.132E+01	5	2	36
18.7	293.0	1.1840	0.132E+01	6	2	36
16.2	293.0	1.1842	0.152E+01	7	2	36
12.1	292.9	1.1859	0.139E+01	8	2	36
11.3	293.7	1.1824	0.311E+03	3	3	36
35.8	310.0	1.1181	0.519E+04	4	3	36
71.5	350.3	0.9874	0.246E+05	5	3	36
90.0	403.6	0.8574	0.187E+05	6	3	36
...	...	...	...			
...	...	...	...			
79.7	582.7	0.6335	0.426E+04	8	7	50

Table 6. Input File NOISE.WAL Used to Predict Noise Emissions from NAS Lemoore
Test Cell No. 3 While Testing an Afterburning F414 Engine

VEL (m/sec)	TEMP (degK)	DENSITY (kg/m**3)	TURB KE (m/sec)**2	I	J	K
-21.3	518.6	0.6847	0.351E+01	2	1	42
40.3	467.3	0.7589	0.392E+04	3	1	42
51.1	458.5	0.7747	0.487E+04	4	1	42
55.6	453.1	0.7846	0.536E+04	5	1	42
53.9	445.2	0.7987	0.528E+04	6	1	42
47.8	438.4	0.8103	0.472E+04	7	1	42
40.5	435.3	0.8149	0.385E+04	8	1	42
14.8	475.5	0.7462	0.170E+01	9	1	42
-109.5	578.8	0.6097	0.455E+02	2	8	42
-111.1	596.9	0.5918	0.394E+02	3	8	42
-105.3	585.7	0.6038	0.347E+02	4	8	42
-90.4	561.6	0.6290	0.251E+02	5	8	42
...	...	...	...			
54.0	451.2	0.7913	0.402E+04	8	1	43
23.9	476.7	0.7495	0.285E+01	9	1	43
-112.7	578.8	0.6118	0.567E+02	2	8	43
-111.6	598.7	0.5908	0.502E+02	3	8	43
-106.2	587.4	0.6021	0.439E+02	4	8	43
-92.8	565.2	0.6251	0.336E+02	5	8	43
...	...	...	...			
17.4	478.1	0.7502	0.542E+04	5	1	44
75.2	472.5	0.7596	0.531E+04	6	1	44
70.4	468.1	0.7669	0.483E+04	7	1	44
64.7	466.8	0.7689	0.410E+04	8	1	44
...	...	...	...			
-111.4	582.6	0.6119	0.577E+02	2	8	44
-102.6	601.1	0.5922	0.467E+02	3	8	44
-98.8	592.8	0.6001	0.418E+02	4	8	44
-87.2	576.1	0.6173	0.332E+02	5	8	44
...	...	...	...			
83.9	493.9	0.7295	0.506E+04	4	1	45
84.3	490.0	0.7359	0.532E+04	5	1	45
82.2	485.3	0.7433	0.520E+04	6	1	45
78.3	481.8	0.7488	0.477E+04	7	1	45
...	...	...	...			
11.3	584.3	0.6503	0.506E+01	9	8	66

3. The following inputs are in response to the prompts:

3.048
5.5
18.3
10
2.2
25

The output file is included as Table 7. This will be a noisy test. As shown on Table 1, the relatively small Test Cell No. 3 at NAS Lemoore, when testing the afterburning F414, is more than 2 dB noisier than the standard T-10 when testing an afterburning TF30 engine.

SOME PARAMETRIC ANALYSES

TCNOISE is coupled to the aerothermal model to the extent that most changes to the geometry of the test cell that affect noise emissions affect these emissions by changing the aerothermal performance of the facility; for example, changing velocities and turbulence. Therefore, for new test cells and for most major changes in the design of an existing facility, accurate input files, NOISE.JET and NOISE.WAL, must be generated before running TCNOISE. The program, by itself, is certainly of value in assessing trends (most are already well known qualitatively but not quantitatively) and may be used, with some discretion, as a design tool for predicting noise emissions, varying the dimensions of the facility.

Several test cell dimensions have only a minor influence on the aerothermal performance of the facility: the augmenter shell diameter, the length of the tube, and the height of the exhaust stack. Table 8 compares the effects of changing each of these parameters, assuming an afterburning F414 engine is being run in Test Cell No. 3 at NAS Lemoore. Of these parameters, the effect of increasing the height of the exhaust stack is the most pronounced, decreasing the far field noise by about 7 dB when increased to the height of the intake stack.

Switching from a round augmenter tube to a rectangular tube in the Navy's T-10 jet engine test cell design is expected to save \$540K on the construction costs of each new facility (Ference, 1995). Based on aerothermal performance predicted by the NFESC test cell model, both the 13.7-foot (4.17-meter) square and 9x15-foot (2.7x4.6-meter) rectangular augmenter tube configurations are acceptable alternatives to the current 13.7-foot diameter round tube (Kodres, 1996). The effects of these tube modifications on test cell noise emissions are another factor that will influence the switch. With this in mind, TCNOISE is used to predict noise generation in a T-10 test cell constructed with each of the potential replacement augmenter tubes. An afterburning TF30 engine is being tested. The results are summarized in Table 9.

Table 7. Output File SPLOUT from TCNOISE When Used to Predict Noise Emissions
from NAS Lemoore Test Cell No. 3 When Running an
Afterburning F414 Engine

k= 1 Jet Noise Power= 4339071. Watts
k= 2 Jet Noise Power= 1705316. Watts
k= 3 Jet Noise Power= 658610. Watts
k= 4 Jet Noise Power= 299424. Watts
k= 5 Jet Noise Power= 292062. Watts
k= 6 Jet Noise Power= 329762. Watts
k= 7 Jet Noise Power= 106347. Watts
k= 8 Jet Noise Power= 29552. Watts
k= 9 Jet Noise Power= 8828. Watts
k= 10 Jet Noise Power= 2838. Watts
k= 11 Jet Noise Power= 980. Watts
k= 12 Jet Noise Power= 369. Watts
k= 13 Jet Noise Power= 152. Watts
k= 14 Jet Noise Power= 67. Watts
k= 15 Jet Noise Power= 32. Watts
k= 16 Jet Noise Power= 16. Watts

EMPIRICAL EQUATION NOISE= 3626056. Watts (TF30,A/B)
Sum of jet noise from nodes = 7773435. Watts

NOISE THROUGH PIPE 150,120,90,60 = 87.05 84.76 82.75 76.76 dB @ 250'

Jet noise source field,augmenter tube exit= 153.327 dB
Surface noise field,augmenter tube exit= 129.338 dB
Reverberation field intensity level, IL= 160.620 dB

SPL,180DEG,250FT= 120.768 dB FLAT
SPL,150DEG,250FT= 118.468 dB FLAT
SPL,120DEG,250FT= 114.868 dB FLAT
SPL, 90DEG,250FT= 114.168 dB FLAT
For approximate dBA, subtract 22 dB from dB FLAT.

Program by T.W. Lancey at NFESC, 5/97 - 7/97.

Table 8. Effects of Test Cell Modifications on Noise Emissions Predicted by TCNOISE
When Running an Afterburning F414 Engine in Test Cell No. 3 at
NAS Lemoore (predicted noise in dBA 250 feet from the engine nozzle;
180 degrees is directly behind the test cell)

Modification	180 deg	150 deg	120 deg	90 deg
Existing Configuration	98.8	96.5	92.9	92.2
Incr. Aug. Shell Diameter by 1 m.	98.2	95.9	92.3	91.6
Incr. Aug. Length by 6 m.	98.7	96.4	92.8	92.1
Incr. Exh. Stack Height by 4 m.	91.4	89.1	85.5	84.8

Table 9. Effects of T-10 Test Cell Augmenter Tube Modifications on Noise Emissions When
Running an Afterburning TF30 Engine (predicted noise in dBA 250 feet from the
engine nozzle; 180 degrees is directly behind the test cell)

Modification	180 deg	150 deg	120 deg	90 deg
Standard T-10 Test Cell	96.5	91	84	82
T-10 JETC with 13.7-ft Square Tube	97	91.5	84.5	82.5
T-10 with 9x15-ft Rectangular Tube	97	94.7	91.1	90.4
T-10 with Square Tube, no Secondary	94.6	89.1	82.1	80.1

The T-10 configuration with a 13.7-foot. square augmenter tube is about 0.5 dB noisier than the standard T-10. This is somewhat of a surprise. Tube gas velocities and generated turbulence are lower (Kodres, 1996) through the square augmenter tube because of the larger cross-sectional area. However, the square tube configuration was assumed to have no transition section to smooth out the flow at the beginning of the augmenter tube. The jet noise is approximately 13 percent greater.

Switching to a 9x15-foot rectangular augmenter tube will result in a much noisier test cell. Gas velocities and turbulence are greater through the smaller cross section of the tube. Again, this configuration was assumed to have no transition section.

Eliminating the secondary inlet decreases the mass flows through the facility and, as a result, greatly decreases the noise emissions.

ACKNOWLEDGMENTS

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APPENDIX

FORTTRAN LISTING OF TCNOISE

```
PROGRAM TCNOISE
C Program to calculate noise emissions from jet engine test cells or
C hush houses...used in conjunction with the Naval Facility Engineering
C Service Center's test cell aerothermal model....
C Developed by Timothy W. Lancey at the NFESC, Port Hueneme, CA.
C Date of this version: 1 Jul 1997
C
C Dimension arrays for jet velocity, density, temperature and turbulence
C intensity.
  REAL, DIMENSION(10,10,120) :: U,RHO1,TMP1,XKE,X,Y
  REAL, DIMENSION(60) :: Prprtion,EngnNois
  COMMON U,RHO1,TMP1,XKE,X,Y,Prprtion,EngnNois
  COMMON DD,AugTubeL,AugShelD,BarrierH,kc
  REAL DD,AugTubeL,AugShelD,BarrierH
  COMMON R,G,GAMMA
C
C Open the file which contains the U,RHO1,TMP1,XKE input from the
C aerothermal program.
  PRINT*, "i-node no.@ j-node no@ axial"
  PRINT*, "position k position k node k VELOCITY DENSITY"
  & , " TEMP TURB INTNS"
  ic=6
  jc=6
  kcount=16
  OPEN (UNIT=1,FILE='NOISE.JET',STATUS='OLD')
  REWIND 1
C Get file ready to read
  DO 100 k=1,kcount
C k= axial node locations from jet <60
  DO 100 j=1,jc
C i= nodes at axial position k , i<20
  DO 100 i=1,ic
    READ(1,500) U(i,j,k),Tmp1(i,j,k),RHO1(i,j,k),xke(i,j,k)
    WRITE(5,510)I,j,k,U(i,j,k),Tmp1(i,j,k),RHO1(i,j,k),xke(i,j,k)
  100 CONTINUE
  PRINT*,"Enter the augmenter tube diameter, in meters: "
  READ*,DD
  PRINT*,"Enter the augmenter shell diameter, in meters: "
  READ*,AugShelD
```

```

PRINT*, "Enter the augments tube length, in meters: "
READ*, AugTubeL
PRINT*, "Enter the integer 10 or 14, depending on whether the "
PRINT*, "augments tube diameter is closer to 10 feet or 14 feet: "
READ*, MTubeDia
PRINT*, "Enter the vertical distance from the augments tube to "
PRINT*, "the top of the ramp, in meters: "
READ*, BarrierH
PRINT*, "Enter the number of surface noise nodes in the axial "
PRINT*, "direction, an integer dictated by the augments length: "
READ*, kc
PRINT*, "The augments tube diameter= ", DD, " meters."
PRINT*, "The augments tube length= ", AugTubeL, " meters."
PRINT*, "The augments shell diameter= ", AugShellD, " meters."
PRINT*, "The aug tube to ramp barrier height= ", BarrierH, " meters."
WRITE(5,504)kc
C
C specific heat ratio
  gamma=1.3
C the acceleration of gravity in meters/second^2
  g=9.80665
C and gas constant for air in meter*Newton/Kg*Kelvin
  R=286.996
C Write to SPLOUT
  OPEN (UNIT=9,FILE='SPLOUT',STATUS='REPLACE')
C
  CALL JETNOISE(GAMMA,G,R,AUGjet,DD,AugTubeL,AugShellD,SUMJET)
  CALL SURFNOISE(GAMMA,G,R,AUGSURF,DD,AugTubeL,AugShellD,kc,WSURF)
C At the augments tube exit, the source noise from the jet combines
C with the reverberant field and the surface noise.
  CALL REVERB(SUMJET,WSURF,DD,AugTubeL,AugShellD,AUGREVRB)
C
  PRINT*, "Jet noise source field, augments tube exit=", AUGJET
  PRINT*, "Surface noise field, augments tube exit=", AUGSURF, "dB"
  PRINT*, "Reverberation field intensity level, IL=", augrevrb, " dB"
  ABAR=SQRT(6.1**2+BARRIERH**2)
C Ref: C.E.Wilson"NOISE CONTROL" P77-79
  AXISL=76.2-AugTubeL
C from aug tube to 250 feet.
  RAMP250=AXISL-6.1
C ramp to 250 feet
  BBAR=SQRT(RAMP250**2+BARRIERH**2)
  FRESNEL=2.0*125.0*(ABAR+BBAR-AXISL)/343.0
C Fresnel No. at 125 Hz
C Celerity C=343M/SEC

```

```

      FRSNLARG=SQRT(6.28*FRESNEL)
C  SQRT(2*PI*Fresnel No.)
      e1=EXP(FRSNLARG)
      HYPTan=(e1-(1.0/e1))/(e1+(1.0/e1))
      dIL=5.0+20.0*LOG10(FRSNLARG/HYPTan)
      PRINT*,"BARRIER ATTENUATION DUE TO DIFFRACTION=",dIL
      PRINT*,"DD, AugTubeL, AugShelD=",DD, AugTubeL, AugShelD
      XPREVERB=AUGREVRB/10.0
      XPJETSRC=AUGJET/10.0
      SUMNOIS=(10.0**XPREVERB)+(10.0**XPJETSRC)
      SUMLOGIL=10.0*LOG10(SUMNOIS)
      SPL250180=SUMLOGIL-(dIL)-20.0*LOG10(AXISL/1.524)
C  noise at exit of augments tube - barrier diffraction - spherical
C  expansion to 250 feet.
      IF (MTubeDia==10) THEN
        SPL250150=SPL250180-2.3
C  Using radiation from baffled piston
        SPL250120=SPL250180-5.9
C  of radius=a, with lamda=2.74a.
        SPL25090=SPL250180-6.6
        GO TO 111
      END IF
      SPL250150=SPL250180-5.5
C  Using radiation from baffled piston,
      SPL250120=SPL250180-12.5
C  of radius=a, with lamda=2a.
      SPL25090=SPL250180-14.5
111 PRINT*, "SPL,180DEG,250FT=",SPL250180,"dB FLAT"
      PRINT*, "SPL,150DEG,250FT=",SPL250150,"dB FLAT"
      PRINT*, "SPL,120DEG,250FT=",SPL250120,"dB FLAT"
      PRINT*, "SPL,90DEG,250FT=",SPL25090,"dB FLAT"
      PRINT*,"For approximate dBA, subtract 22 dB from dB FLAT."
      WRITE(9,460)AUGJET
      WRITE(9,465)AUGSURF
      WRITE(9,470)AUGREVRB
      WRITE(9,475)SPL250180
      WRITE(9,480)SPL250150
      WRITE(9,485)SPL250120
      WRITE(9,490)SPL25090
      WRITE(9,492)
      WRITE(9,493)
460 FORMAT("Jet noise source field,augments tube exit=",F8.3," dB")
465 FORMAT("Surface noise field,augments tube exit=",F8.3," dB")
470 FORMAT("Reverberation field intensity level,IL=",F8.3," dB")
475 FORMAT("SPL,180DEG,250FT=",F9.3," dB FLAT")

```

```

480 FORMAT("SPL,150DEG,250FT=",F9.3," dB FLAT")
485 FORMAT("SPL,120DEG,250FT=",F9.3," dB FLAT")
490 FORMAT("SPL, 90DEG,250FT=",F9.3," dB FLAT")
492 FORMAT("For approximate dBA, subtract 22 dB from dB FLAT.")
493 FORMAT("Program by T.W. Lancey at NFESC, 5/97 - 7/97.")
500 FORMAT(2F10.1,F10.4,E13.3)
504 FORMAT("Number of axial surface noise nodes=",I3)
510 FORMAT(5X,I3,5X,I3,5X,I3,8X,F8.3,3X,F8.3,3X,F8.3,3X,E14.3)
520 FORMAT(5X,I3,8X,I3,8X,F8.3)
  STOP
  END
C
  SUBROUTINE JETNOISE(GAMMA,G,R,AUGjet,DD,AugTubeL,AugShelD,SUMJET)
  COMMON U,RHO1,Tmp1,XKE,X,Y,Prprtion,EngnNois
C Calculate jet noise power using Lighthill's Eqn & empirical factor
  REAL DD,AugTubeL,AugShelD
  REAL JETD,Xjnois,d2,A,FacMach,vj,r,EmprNois
  REAL, DIMENSION(120) :: NodJNois,EngnNois,PrPrtion
  REAL, DIMENSION(10,10,120) :: RHO1,U,TMP1,XKE
  EmprNois=0.0
C the speed of sound at ambient temperature, m/sec
  c1=350.0
C jet velocity, m/sec
  vj=904.0
C ambient density, Kg/m^3
  ro=1.203
C the diameter of the jet nozzle, meters
  jetd=0.942
C  $Mc=0.65*vj/c1$ 
  ic=6
  jc=6
  kc=16
  FacMach=1.0
  EmprNois=0.00004*ro*(jetd**2)*(FacMach)*(vj**8)/(c1**5)
  PRINT*, " From Lighthill's empirical equation,Acoustic
/ power of the jet =",EmprNois
  PRINT*, "EMPIRICAL NOISE=",EmprNois
  DO 150 K=1,kc
    NodJNois(k)=0.0
150 CONTINUE
    SumJet=0.0
    DO 220 k=1,kc
C calc noise at axial location k, with
C k=1 at engine exit plane. Noise from
C each axial location is found, then

```

C all noise levels are calculated.

```
PRINT*, "GAMMA=", GAMMA, " G=", G, " R=", R
```

```
A=0.00004*ro/((C1)**5)
```

```
DO 200 i=1,ic
```

```
DO 200 j=1,jc
```

```
vj=U(i,j,K)
```

```
FacMach=1.0
```

```
d2=0.1233
```

```
XJnois=A*d2*FacMach*((vj)**8)
```

```
NodJNois(k)=NodJNois(k)+XJNois
```

```
PRINT*, "NodJNois(", k, ")=", NodJNois(k)
```

```
200 CONTINUE
```

```
SumJet=SumJet+NodJNois(k)
```

C NodJNois is the acoustic power from all of the i,j nodes at the k

C location from the jet exit plane.

C SumJet is the sum of the power from all of the k locations.

```
220 CONTINUE
```

```
cc  !!  * * * * *
```

```
cc  !!  31      36
```

```
cc  !!  * * * * *
```

```
cc  !!  25      30
```

```
cc  !!  * * * * * <---Mesh pattern for each axial
```

```
cc  !!  19 21 22 24 station k.
```

```
cc  !!  * * * O * * *
```

```
cc  !!  13 15 16 18
```

```
cc  !!  * * * * *
```

```
cc  !!  7      12
```

```
cc  !!  * * * * *
```

```
cc  !!  1 2 3 4 5 6
```

```
cc  !!  * * * * *
```

```
SUMJET=(1.0)*SUMJET
```

```
PRINT*, "Sum of jet noise from nodes =", SumJet
```

```
DO 224 K=1,kc
```

```
Prprtion(K)=(1.0*NodJNois(k))/SumJet
```

C Proportion of noise

C from each axial location to total jet engine noise

```
224 CONTINUE
```

```
DO 230 K=1,kc
```

```
EngnNois(k)=Prprtion(k)*SumJet
```

C Corrected jet noise at each axial k location.

```
PRINT*, " k=", K, " Jet Noise Power=", EngnNois(k)
```

```
WRITE(9,225)k,EngnNois(k)
```

```
225 FORMAT ("k=", I3, " Jet Noise Power=", F14.4, " Watts")
```

```

230 CONTINUE
  PRINT*, "EMPIRICAL EQUATION NOISE=", EmprNois
  WRITE(9,232)EmprNois
  WRITE(9,235)SumJet
232 FORMAT("EMPIRICAL EQUATION NOISE=",F14.4," Watts (TF30,A/B)")
235 FORMAT("Sum of jet noise from nodes =",F14.4,"Watts")
222 FORMAT (F14.4)
C The source field is modified (1) by the jet radial expansion from
C approx 1 m to the 18' (5.5 m) outer pipe and (2) by jet refraction
C and absorption, for a 15.8 dB attenuation, on-axis. Then we need
C only consider SumJet, and not the individual k contributions.
  PipeSpher=3.1416*4.0*(AugShelD/2.0)**2
C area of approx 5.5m sphere
  AUGJET=10.0*LOG10((SumJet/PipeSpher)/1.0E-12)-15.8
C dB at augmenter tube exit for the near 0n-axis noise. The
C maximum source noise is realized from the 0n-axis component.
C
  PRINT*, "Jet noise source field at augmenter tube exit=", AUGJET
C
C NOISE AT OUTER PIPE
C
C Calculate noise at outside of outer pipe - varies along Z -
C sound from jet expands from D=1 to D=5.5 at wall and varies with angle
C      (r=2.25 meter)
C and refraction (also a function of angle). At outside of pipe,
C PIPONL= EXPANDIL-10dBpillows-1.5dBliner-41dBpipewall+REFRACTION
  PIPINT30=0.0
  PIPINT60=0.0
  PIPINT90=0.0
  DO 260 K=1,kc
    JETSRC=EngnNois(k)/(4.0*3.1416*1.0**2)
C Watts/M^2
    PIPint30=PIPINT30+jetsrc/((4.5 *2.0)**2)
    PIPINT60=PIPINT60+jetsrc/((4.5/0.866)**2)
    PIPINT90=PIPINT90+JETSRC/((4.5*1.0)**2)
C Watts/M^2
260 CONTINUE
C PIPINT120=PIPINT60
  PIPIL30=10.0*LOG10(PIPINT30/1.0E-12)-10.0-1.5-41.0+5.3
  PIPIL60=10.0*LOG10(PIPINT60/1.0E-12)-10.0-1.5-41.0+3.0
  PIPIL90=10.0*LOG10(PIPINT90/1.0E-12)-10.0-1.5-41.0+1.0
  PIPIL120=10.0*LOG10(PIPINT60/1.0E-12)-10.0-1.5-41.0-5.0
  SPL25030=PIPIL30-20.0*LOG10(76.2/4.5)
  SPL25060=PIPIL60-20.0*LOG10(76.2/2.6)
  SPL25090=PIPIL90-20.0*LOG10(76.2/2.25)

```

```

      SPL250120=PIPI120-20.0*LOG10(76.2/2.6)
      WRITE(9,275)SPL25030,SPL25060,SPL25090,SPL250120
275  FORMAT("NOISE THROUGH PIPE 150,120,90,60 =",4F7.2," dB @ 250")
C
      PRINT*, "NOISE THROUGH PIPE 30,60,90,120 =",SPL25030," ",
      /      SPL25060," ",SPL25090," ",SPL250120," dB @ 250"
280  FORMAT("WA=",E12.4," SURFACEW=",E12.4," i,j,k,m=",4I2)
285  FORMAT("surfpower=",E12.4," SURFACEW=",E12.4," i,j,k,m=",4I2)
290  FORMAT("m=",i3,"**SURFACEW ATAXIALNODE",i3,"=",e12.4," P=",e12.4)
600  FORMAT(12X,F8.3,6X,F8.3,6X,F8.3)
610  FORMAT(5X,I3,8X,I3,8X,I3,8X,F8.3,6X,F8.3,6X,F8.3,6X,F8.3)
620  FORMAT(5X,I3,8X,I3,8X,i3,6X,F12.3)
      END SUBROUTINE JETNOISE
C
      SUBROUTINE SURFNOISE(GAMMA,G,R,AUGSURF,DD,AugTubeL,
1 AugShelD,kc,WSURF)
      REAL, DIMENSION(10,10,120) :: U,RHO1,TMP1,XKE,SURFPOWER
      COMMON U,RHO1,Tmp1,XKE,X,Y,Prprtion,EngnNois
      REAL DD,AugTubeL,AugShelD
      REAL INTENS,WSURF,SRFP
      REAL, DIMENSION(9) :: F
      DATA DELTAZ/0.6/
      mc=4
      jc=2
      ic=8
      kend=2*kc
      kstart=kc+1
      OPEN (UNIT=2,FILE='NOISE.WAL',STATUS='OLD')
      REWIND 1
C  Get file ready to read
      DO 101 k=1,kc
C  k= axial node locations from jet <60
      DO 101 j=1,jc
C  i= nodes at axial position k , i<20
      DO 101 i=1,ic
          READ(2,360) U(i,j,k),Tmp1(i,j,k),RHO1(i,j,k),xke(i,j,k)
          y=ABS(U(i,j,k))
          IF(Y<0.100) THEN
              U(i,j,k)=0.50
          END IF
101  CONTINUE
      DO 102 k=kstart,kend
C  k= axial node locations from jet <60
      DO 102 j=1,jc
C  i= nodes at axial position k , i<20

```

```

DO 102 i=1,jc
  READ(2,360) U(i,j,k),Tmp1(i,j,k),RHO1(i,j,k),xke(i,j,k)
  y=ABS(U(i,j,k))
  IF(Y<0.100) THEN
    U(i,j,k)=0.50
  END IF
102 CONTINUE
C Open area ratio, SI = %0pen/100, D = HOLE DIAMETER
SI=0.3
D=0.02
C calculate total duct area in length DELTAZ
DUCTA=3.1416*DD*DELTAZ
C calculate duct cross section area
CROSSA=0.7854*DD**2
C mean flow speed nearest augments tube end, near ID = U(I,J,K)
C F(i) = FREQUENCY(Hz)
DATA F(1),F(2),F(3),F(4)/125.0,250.0,500.0,1000.0/
C Analyze at 4 frequencies
WSURF=0.0
SRFP=0.0
DO 30 I=1,IC
DO 30 J=1,JC
DO 30 K=1,kc
SURFPOWER(i,j,k)=0.0
C Initialize array to zero
30 CONTINUE
DO 320 m=1,mc
DO 310 k=1,kC
SURFACEW=0.0
DO 300 i=1,ic
DO 300 j=1,jc
VJ=ABS(U(i,j,k))
T=TMP1(i,j,k)
C temperature in degrees kelvin
TI=SQRT(XKE(i,j,k)/VJ**2.0)
rho=rho1(i,j,k)
C=(GAMMA*G*R*T)**0.5
35 FORMAT(" frequency=", F8.2," Hz")
C Calculate Strouhal Number based on hole diameter
ST=F(M)*D/VJ
C Calculate variable of Struve Function of the first kind
z=12.56637*ST
C Find Strouhal No. dependence by use Strouhal & Struve Functions
ALST=0.0063662*((Z**0.667)-(Z**0.0888)+(Z**0.0038)-(Z**0.000081))
C Calculate the sound power radiated per unit area

```

```

      WA=RHO*0.322982*((TI**2)*(VJ**6)*ST*ALST)/(SI*C**3)
      WA=ABS(WA)
C Calculate the sound power radiated
      SURFACEW=SURFACEW+WA
C Power/Area at each axial location
300 CONTINUE
C End i,j loops
      SURFACEW=SURFACEW*DUCTA
C where DUCTA=PI*(AUG TUBE DIA)*DELTAZ
      SRFP=SRFP+SURFACEW
310 CONTINUE
C End of k loop
      SURFPOWER(ic,jc,kc)=SRFP
      WSURF1=SURFPOWER(ic,jc,kc)
C Total power from nodes near exit
320 CONTINUE
C End loop through spectrum
      WSURF=0.0
      SRFP=0.0
      DO 40 I=1,jc
      DO 40 J=1,ic
      DO 40 K=kstart,kend
      SURFPOWER(i,j,k)=0.0
C Initialize array to zero
40 CONTINUE
      DO 620 m=1,mc
      DO 610 k=kstart,kend
      SURFACEW=0.0
      DO 600 i=1,jc
      DO 600 j=1,ic
      VJ=ABS(U(i,j,k))
      T=TMP1(i,j,k)
C temperature in degrees kelvin
      TI=SQRT(XKE(i,j,k)/VJ**2.0)
      rho=rho1(i,j,k)
C TF=9.0*((T-273.0)/5.0)+32.0    !! deg F
      C=(GAMMA*G*R*T)**0.5
C Calculate Strouhal Number based on hole diameter
      ST=F(M)*D/VJ
C Calculate variable of Struve Function of the first kind
      z=12.56637*ST
C Find Strouhal No. dependence by use Strouhal & Struve Functions
      ALST=0.0063662*((Z**0.667)-(Z**0.0888)+(Z**0.0038)-(Z**0.000081))
C Calculate the sound power radiated per unit area
      WA=RHO*0.322982*((TI**2)*(VJ**6)*ST*ALST)/(SI*C**3)

```

```

      WA=ABS(WA)
C Calculate the sound power radiated
      SURFACEW=SURFACEW+WA
C Power/area at each axial location
C
600 CONTINUE  !!! End i,j loops
      SURFACEW=SURFACEW*DUCTA    !where DUCTA=PI*(aug tube dia)*DELTAZ
      SRFP= SRFP+SURFACEW
610 CONTINUE
C End of k loop
      SURFPOWER(ic,jc,kc)=SRFP
      WSURF2=SURFPOWER(ic,jc,kc)
C Total power from nodes near exit
620 CONTINUE
C End loop through spectrum
      WSURF=WSURF1+WSURF2
      PRINT*, "TOTALSURFACENOISE POWER=",WSURF,"WATTS",ic,jc,kc
340 FORMAT("WA=",E12.4," SURFACEW=",E12.4," i,j,k,m=",4I2)
341 FORMAT("surfpower=",E12.4," SURFACEW=",E12.4," i,j,k,m=",4I2)
641 FORMAT("surfpower=",E12.4," SURFACEW=",E12.4," i,j,k,m=",4I2)
C
C Calculate intensity at augments tube exit
      INTENS=WSURF/CROSSA
      PRINT*, " INTENSITY = ",INTENS,"WATTS/M^2"
      AUGSURF=10.0*LOG10(ABS(INTENS)/1.0E-12)
360 FORMAT(2F10.1,F10.4,E13.3)
365 FORMAT(5X,I3,5X,I3,5X,I3,8X,F8.3,3X,F8.3,3X,F8.3,3X,E14.3)
      END SUBROUTINE SURFNOISE
C
      SUBROUTINE REVERB(SUMJET,WSURF,DD,AUGTubeL,AUGShelD,AUGREVRB)
C Calculate the reverberant field in and around the augments tube. The
C jet noise and the surface noise are the noise sources.
      REAL DD,AUGTubeL,AUGShelD
      REAL WSURF,SUMJET
      CROSSA=0.785*DD**2
      PILLOA=3.1416*2.0*(DD+1.5)*(AUGTubeL)
C =2*PI*PILLOD*DUCTL=PILLOW AREA
      PILOALFA=0.9
      LINERA=3.1416*(AUGShelD)*(AUGTubeL)
C =PI*LINERD*DUCTL =OUTER PIPE LINER
      LINRALFA=0.3
      AUGA=2.0*CROSSA
C =2*(PI/4)*DUCTD^2= entrance and exit areas
      AUGALFA=1.0
C Calculate absorptive power = sum of AREAi*ALFAi=WABS

```

```

WABS=PILLOA*PILOALFA+LINERA*LINRALFA+AUGA*AUGALFA
PRINT*, "WABS=",WABS," SUMJET=",SUMJET," WSURF=",WSURF
PRINT*, "DD,AugTubeL,AugShelD,CROSSA=",DD,AugTubeL,AugShelD,CROSSA
C steady state acoustic intensity = power sources/absorptive power
INTENS=(SUMJET+WSURF)/WABS
C The reverberant IL is reduced by the losses in the expansion
C chamber (test cell). deltaIL=10Log(1+(m-1/m)^2*sin^2(kC))
C where m=A2/A1=3.23,C=augtubeL=18.3m, and sin(kC) varies from
C 0<sin(kC)<1 across the spectrum, so use sin(kC)=0.707 (RMS).
C So deltaIL=10Log(1+1.06)=3.1 dB.
A2=0.785*(AugShelD**2)
C Shell area=pi*(AugShelDia^2)/4
A1=7.3
C Area of entrance to augments tube
m=A2/A1
ExpChmbr=0.5*(1.0+((m-1.0)/m))**2
DeltaIL=10.0*LOG10(ExpChmbr)
AUGREVRB=10.0*LOG10(INTENS/1.0E-12)-(DeltaIL)
C Intensity level
PRINT*, "Reverberation field intensity level,IL=",augrevrb," dB"
END SUBROUTINE REVERB

```