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PTA EN ROUTE NOISE MEASUREMENTS

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EN ROUTE NOISE TECHNICAL ISSUES

Development of the advanced turboprop has led to concerns about en route noise. Advanced turboprops generate low frequency, periodic noise signatures of relatively high levels. As demonstrated in a flight test of NASA LeRC's Propfan Test Assessment (PTA) airplane in Alabama in October 1987, the noise of an advanced turboprop operating at cruise altitudes can be audible on the ground. The assessment of the en route noise issue is difficult due to the variability in received noise levels caused by atmospheric propagation and the uncertainty in predicting community response to the relatively low-level en route noise, as compared to noise associated with airport operations.

The En Route Noise Test was designed to address the atmospheric propagation of advanced turbroprop noise from cruise altitudes and consisted of measuring the noise of an advanced turboprop at cruise in close proximity to the turboprop and on the ground. The in-flight noise measurements were made by flying an instrumented airplane in formation with the PTA airplane. The ground measurements were made by flying the PTA airplane over a microphone array.

PTA EN ROUTE NOISE MEASUREMENTS

TECHNICAL ISSUES

- PROPAGATION INDUCED VARIABILITY
- SUBJECTIVE RESPONSE

Figure 1

EN ROUTE NOISE TEST GOALS

The En Route Noise experiment had three goals. To acquire a long-range propeller noise database designed to study propagation, to investigate propeller noise variability, and to compare measured propagation data with ray-tracing propagation model predictions.

- ACQUIRE LONG RANGE (VERTICAL) PROPELLER NOISE DATA BASE DESIGNED TO STUDY PROPAGATION
- INVESTIGATE PROPELLER NOISE VARIABILITY
- COMPARE MEASURED AVERAGED PROPAGATION DATA WITH RAY TRACING PROPAGATION MODEL

Figure 2

EN ROUTE NOISE TEST APPROACH

The approach taken to achieve these goals was to perform at White Sands Missile Range a flight experiment using the Propfan Test Assessment airplane. The flight experiment would use multiple-microphone array technology to measure on the ground the noise levels of an advanced turboprop operating at cruise conditions. The in-flight noise directivity of the advanced turboprop blade passage harmonics would be measured by flying an instrumented aircraft in formation with the test airplane. The in-flight measured directivity of the turboprop would be used as input in propagation models to predict the ground-measured average noise values. Participates in the En Route Noise experiment were NASA Lewis Research Center, the FAA, and NASA Langley Research Center. NASA LeRC was responsible for providing and operating the PTA, and performing the in-flight noise measurements.

- **CONDUCT PTA FLIGHT TEST AT WSMR WITH CONCURRENT WEATHER PROFILES**
- **USE MULTIPLE-MICROPHONE ENSEMBLE-AVERAGING DATA ANALYSIS**
- **MEASURE IN-FLIGHT SOURCE DIRECTIVITY**

Figure 3

PROPFAN TEST ASSESSMENT AIRPLANE

The PTA airplane is shown in this photograph. The PTA airplane is a Gulfstream II with an advance turboprop and engine mounted on its left wing. The advanced turboprop is an eight bladed, 9 ft diameter, single propeller in a tractor configuration. The advanced turboprop operated with supersonic helical tip Mach numbers. The PTA airplane was instrumented with microphones mounted on the inboard boom on the left wing and with surface-mounted microphones on the outside of the fuselage. Engine and turboprop parameters, as well as other pertinent flight parameters, were also measured on board the test airplane.

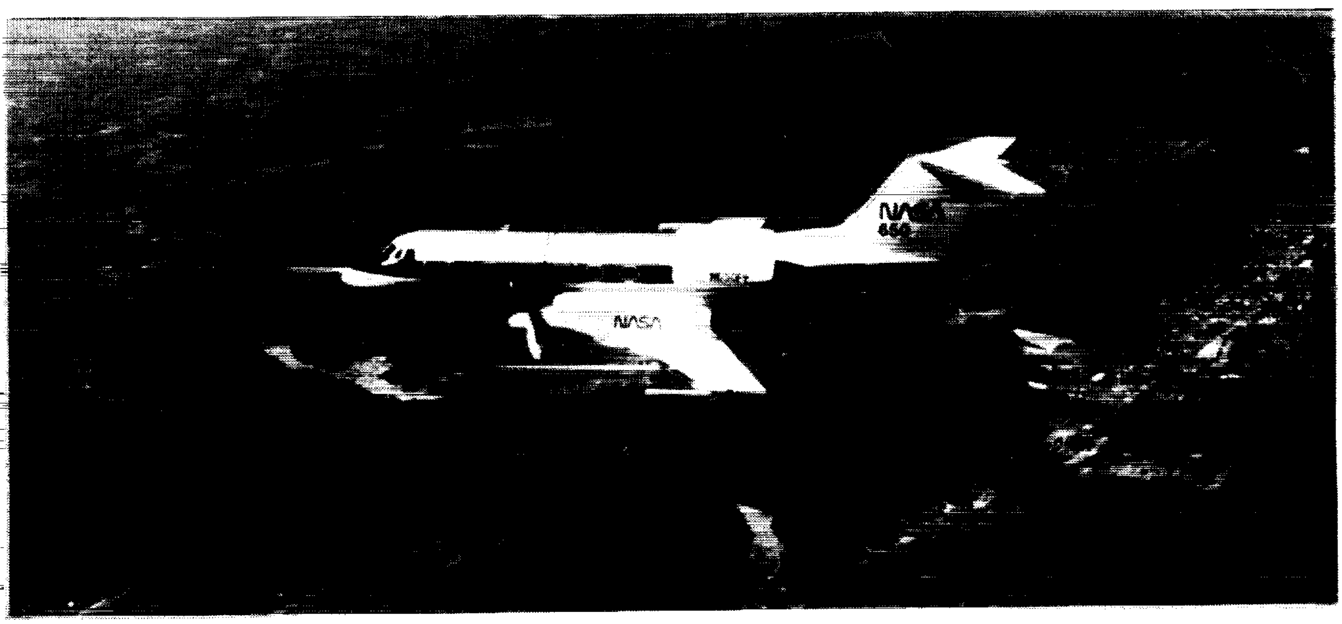
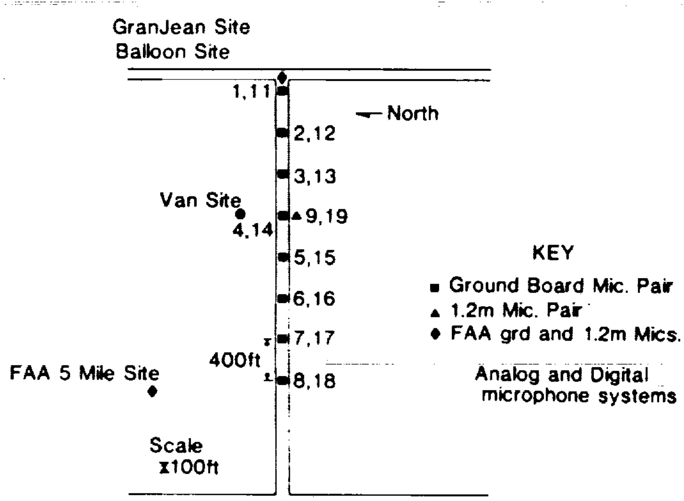


Figure 4

EN ROUTE NOISE TEST MICROPHONE ARRAY

The microphone array used in the En Route Noise test was basically an eight-element linear array with a 400-ft element spacing. The microphone array was located at Gran Jean site in the North Range of WSMR.* Each of the eight array elements was equipped with an analog and a digital microphone system mounted on ground boards. Co-located at one array element were an analog and digital microphone pair mounted 1.2 m above the ground. The FAA had a ground-mounted and a 1.2 m mounted microphone at another element of the microphone array and at a site located approximately5 miles north of the microphone array. The digital microphone systems consisted of standard 1/2-in. condenser microphones with an analog-to-digital converter located in the microphone power supply boxes. In the power supply boxes the analog signal from the microphone was digitized at the rate of 2344 samples per second. The data presented in this paper are from the digital microphone systems. The test airplane flight path was parallel and over the microphone array.



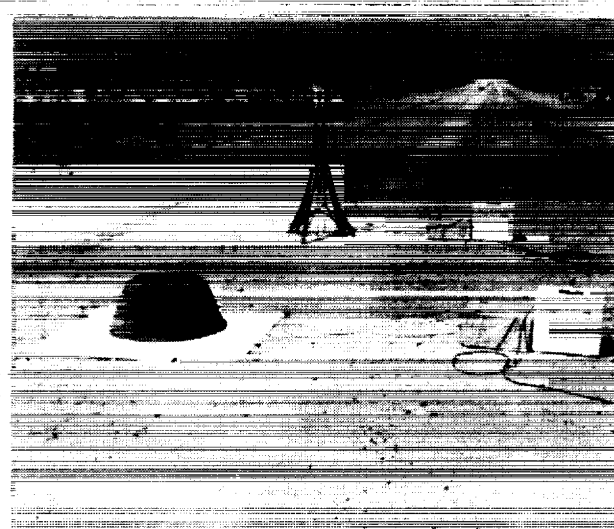


Figure 5

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*White Sands Missile Range

EN ROUTE NOISE TEST WEATHER MEASUREMENTS

The various means used to measure weather information are illustrated in this photograph. The primary weather information was obtained from free balloon radiosonde releases. The radiosondes were released from the microphone array site before and after each test session. A typical test session was an hour to an hour and a half. The next important source of weather measurements was a tethered weather balloon system which continuously made profiles up to 1500 m during a test session. Six weather stations of various heights were located in a half-mile circle around the microphone array. An acoustic sounder was located 4 miles northeast of the microphone array.

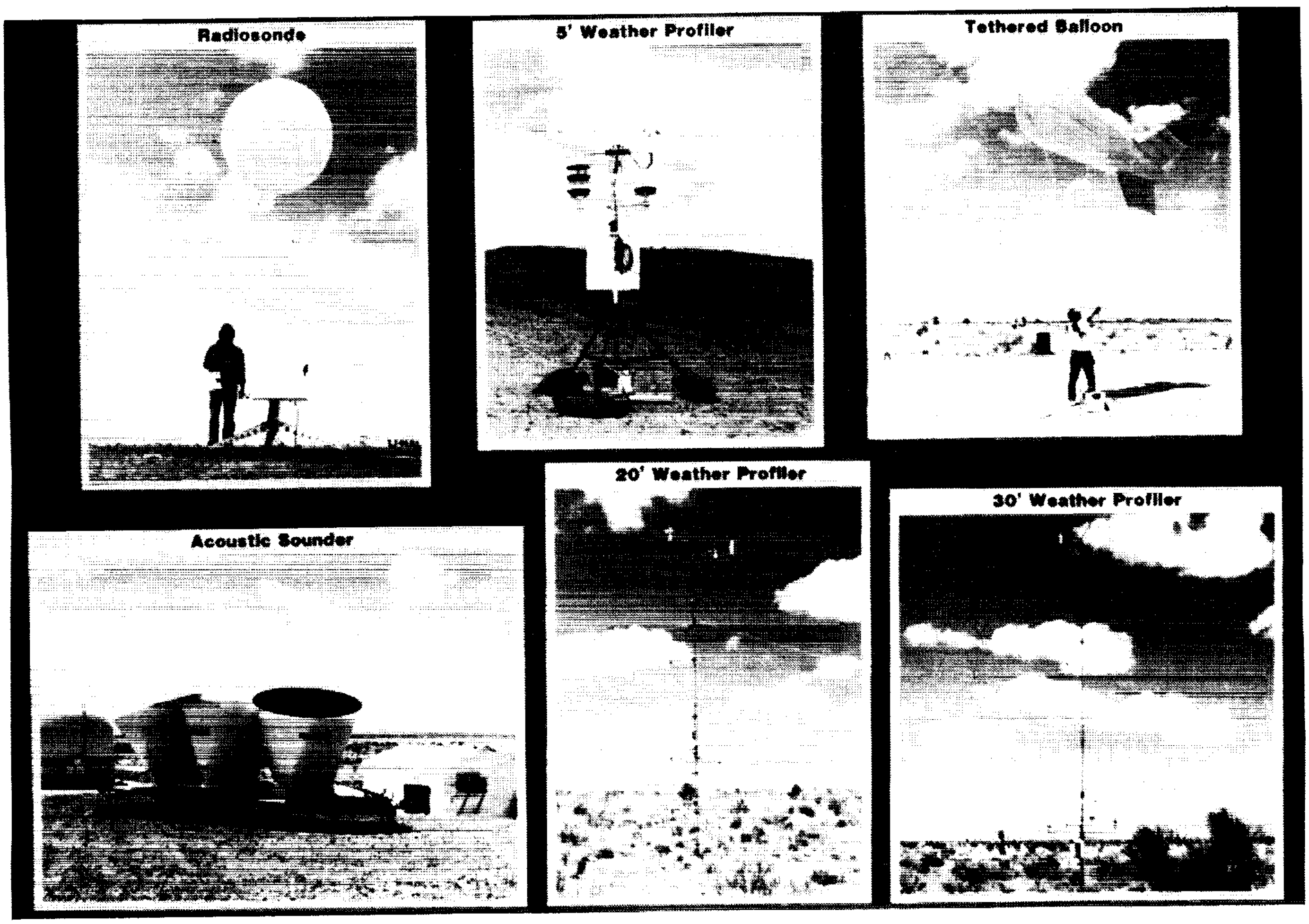

Figure 6

ORIGINAL PAGE
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EN ROUTE NOISE TEST COMPLETED TEST MATRIX

The completed test matrix is illustrated in this table. Eighty-eight runs or passes over the microphone array were recorded. The primary test parameters were aircraft Mach number and altitude. The majority of the runs were the high-altitude cruise conditions with a tip speed of 800 ft/s for the advanced turboprop. However, for a limited amount of runs the advanced turboprop tip speed was varied through the range of 620 to 840 ft/s.

PTA SPEED, M	ALTITUDE, 1000 FT. AGL			
	2	9	15	30
.5	4	4	23	
.7			19	32
.77				6

TOTAL RUNS: 88

Figure 7

ENSEMBLE AVERAGING

The data to be presented in this paper were obtained through ensemble averaging of the eight ground-mounted digital microphone systems. The steps in the ensemble process are the individual microphone time histories are high passed filtered at 80 Hz to minimize the influence of wind noise; individual microphone 1/2-second mean square pressure time histories are calculated; each microphone time history is shifted in time based on measured ground speed of the test airplane along the microphone array to give all microphone time histories a common time base; finally the eight shifted time histories are averaged together to form an ensemble average 1/2-second mean square pressure time history. Illustrated in the figure are noise level time histories. However, the ensemble averaging is done on a linear pressure squared basis. The ensemble result, the last plot in the figure, exhibits less variability than the individual microphone time histories.

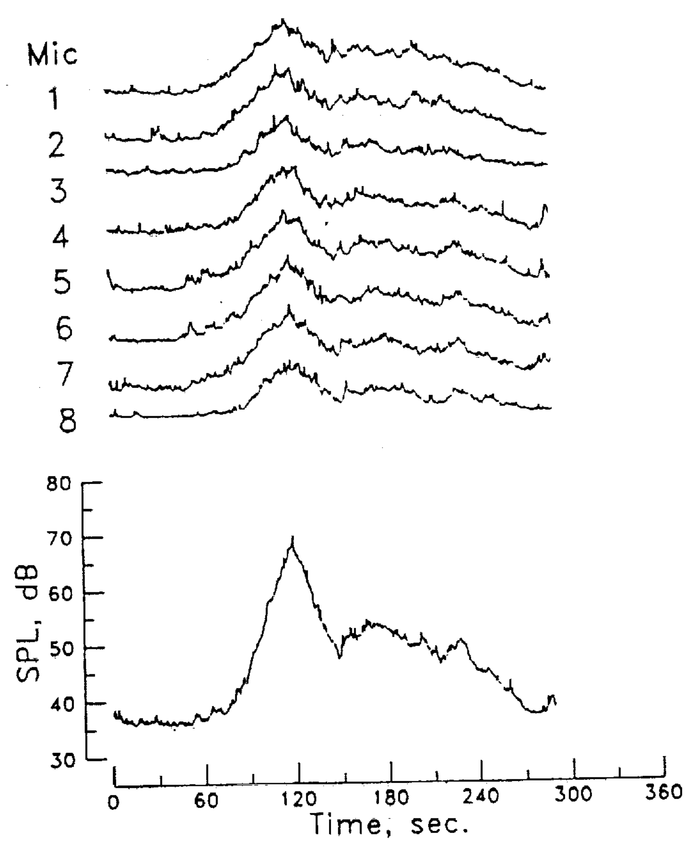


Figure 8

EN ROUTE NOISE TEST ENSEMBLE AVERAGE RESULT

The previous ensemble average result is magnified in this figure for illustration. This example is for a test condition of an airplane speed of Mach .7 and 30,000 ft AGL* altitude. Plotted with the ensemble result are the 80-percent confidence intervals for the average. The 80-percent confidence intervals bound an area in which there is an 80-percent probability that the true average exists. It should be noted that this result and every result to be presented in this paper are from as measured ground level data. The effect of pressure doubling due to the ground-mounted microphones remains in the measured results. Ensemble average time histories like this were calculated for each run. The maximum 1/2-second Overall Sound Pressure Level (SPL) from the ensemble average time histories were determined. In this example the maximum Overall SPL is 70 dB.

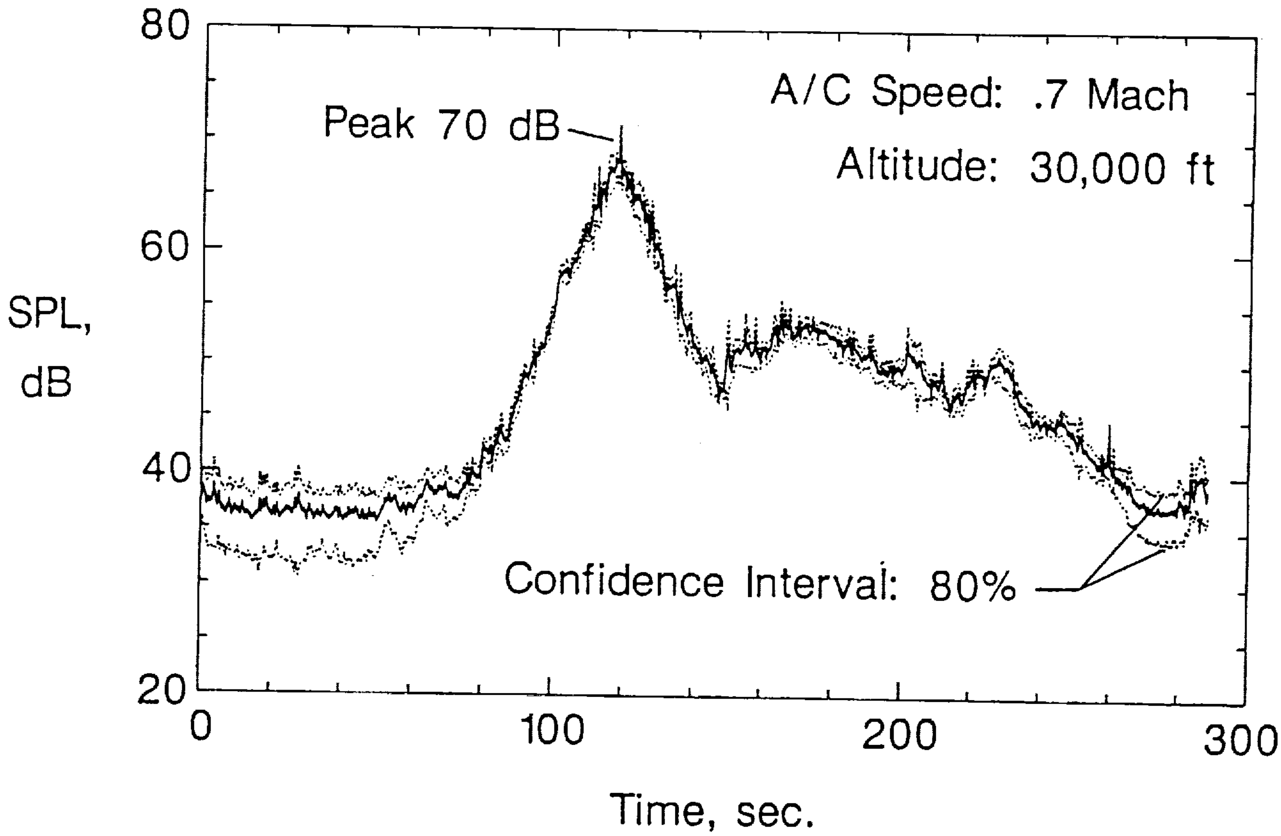


Figure 9

*Above ground level

EN ROUTE NOISE TEST AVERAGE MAXIMUM OVERALL SPL

Average ground level maximum 1/2-second Overall SPL's are given in this table averaged over like-test conditions for the whole database. Average values and the range of the values which went into the averages are given in the table. Approximately 20 runs were averaged for each of the 15 and 30-thousand-foot altitude results. Four runs each were averaged in the 2 and 9-thousand-foot altitude averages. One thing which stands out is the large range associated with the averages. Another is that expected trends might be obscured in the averages by the wide data ranges. For example, in the two 15,000-ft altitude test conditions, there is no change in the average overall SPL for the two test speeds. The lower test speed would be expected to have a lower noise level.

Altitude, 1000 ft AGL

Mach #	2	9	15	30	
.5	91 (86–93)	81 (80–81)	73 (70–75)		Avg Range
.7			73 (66–76)	68 (60–73)	Avg Range

Figure 10

EN ROUTE NOISE TEST DAILY AVERAGE MAXIMUM OVERALL SPL

In this table are presented daily averages for like-test conditions of maximum ground level maximum 1/2 second Overall SPL. Standard deviations and number of runs in the daily averages are also given in the table. In general there was good repeatability on a daily basis for like-test condition. The standard deviations are often less than 1 dB. On April the 8th, the standard deviation for 11 like-runs was -.8 to .7 dB. However, there was considerable day-to-day variability. For the 30,000 ft, .7-M test condition there was a 12 dB range in average levels. The advanced turboprop source noise, measured in flight, was very consistent within a test day and from test day to test day. The observed average level day-to-day variability is propagation-induced.

		TEST DATE							
TEST CONDITION	KEY	3	4	5	6 A.M.	6 P.M.	8	11	13
30,000 FT., .7 M	AVG, dB	60.8	69.0	60.7	65.1			67.8	72.2
	σ, dB	-1.6/1.2	-.7/.6	-.2/.2	-1./.8			-3.5/1.9	-1./.8
	No.	2	4	4	4			3	4
15,000 FT., .7 M	AVG, dB	75.0	72.6	67.7	69.7	75.0			74.3
	σ, dB	-2.2/1.5	-.5/.5	-1.3/1.0	-1./.8	-2./1.3			-2.1/1.4
	No.	2	2	4	4	3			4
15,000 FT., .5 M	AVG, dB	72.2		70.7	70.2	74.7	74.4		
	σ, dB	-.6/.6		-1.1/.9	-.2/.2	-.1/.1	-.8/.7		
	No.	2		4	3	2	11		

Figure 11

EN ROUTE NOISE TEST AVERAGE SINGLE MICROPHONE DEVIATION

Another way to look at the variability of the ground measured PTA turboprop noise is to look at the distribution of the eight microphones about the ensemble average for the eight microphones. Plotted in this figure is the probability density function of the deviation of the eight single microphones about the ensemble average of four 30,000-ft, .7-M runs measured on the same day. Deviation in this figure is expressed as a percentage and is defined as the difference between a 1/2 second time shifted mean square pressure estimate for a single microphone and the corresponding 1/2-second ensemble average estimate. The difference is then divided by the ensemble average. Deviations were calculated for each microphone time history approximately 20 seconds on either side of the time associated with the maximum overall Sound Pressure Level. The average of the deviations is zero as it should be with a standard deviation of 64 percentage points. Once the actual probability density function is established, probabilities of certain values of deviation can be ascertained. The general shape of the probability density function is skewed to the left with the probability that the deviation from the average is less than 0 being 62 percent. The shape of the PDF and the associated probabilities are typical of the ones measured for other runs and other days.

30,000 FT., .7 M TEST CONDITION

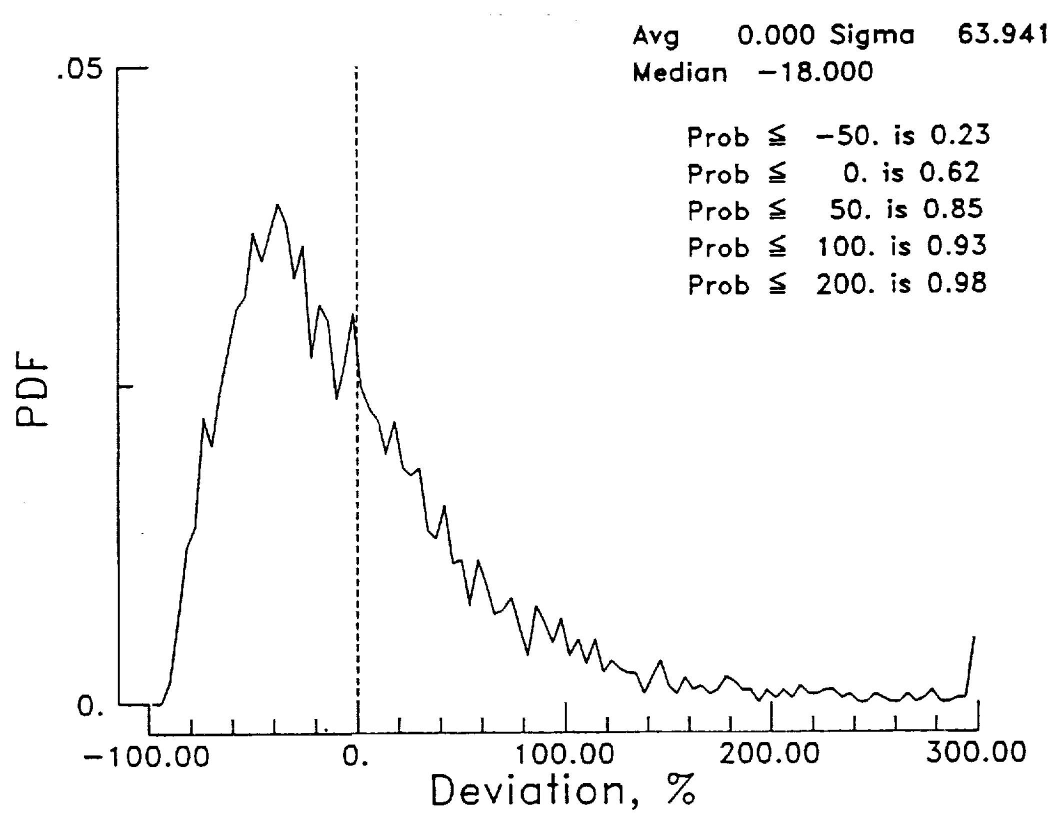


Figure 12

EN ROUTE NOISE TEST NOISE PREDICTION METHOD

In order to produce ray-tracing results to compare with the ground-measured PTA advanced turboprop noise, the following procedure was used. The PTA advanced turboprop source noise levels used as input to the ray-tracing propagation model were predicted using Langley's Aircraft Noise Prediction Program (ANOPP). Measured averaged flight parameters were used to generate a prediction for each test condition. Compared to the measured in-flight noise levels, the ANOPP predicted noise levels were over predicted. In-flight measured noise levels from the chase airplane were used to empirically correct the amplitude of the predicted directivity patterns. The predicted directivity patterns agreed well with the measured ones and were used in the ray tracing because the predicted directivities covered a larger angle range than the measured directivity patterns. The ray-tracing model employed was a 2-dimensional model. Measured flight paths and atmospheric profiles were used in the ray-tracing model. Atmospheric absorption was calculated by the ANSI standard method. A hard ground assumption, 6 dB for pressure doubling for the ground-mounted microphones, was used in the model.

- **Source prediction performed with ANOPP**
  - **measured flight conditions**
  - **source level corrected using "in flight" measured data**
  - **predicted source directivity used**

- **Propagation performed by 2-D ray tracing program**
  - **flight path from C-band radar**
  - **atmospheric profile from free flight balloon launch**
  - **atmospheric absorption by ANSI standard method**
  - **hard ground**

Figure 13

EN ROUTE NOISE TEST COMPARISON OF GROUND MEASURED DATA WITH RAY-TRACE PREDICTION

Run 112

A comparison of a ray-tracing result with ensemble average PTA data is given in this figure for a 30,000-ft, .7-M run. The 80% confidence bounds are included with the ensemble average measured result. The ray-tracing result is the bold solid line. The agreement between measurement and prediction for the flyover is good in amplitude and in shape.

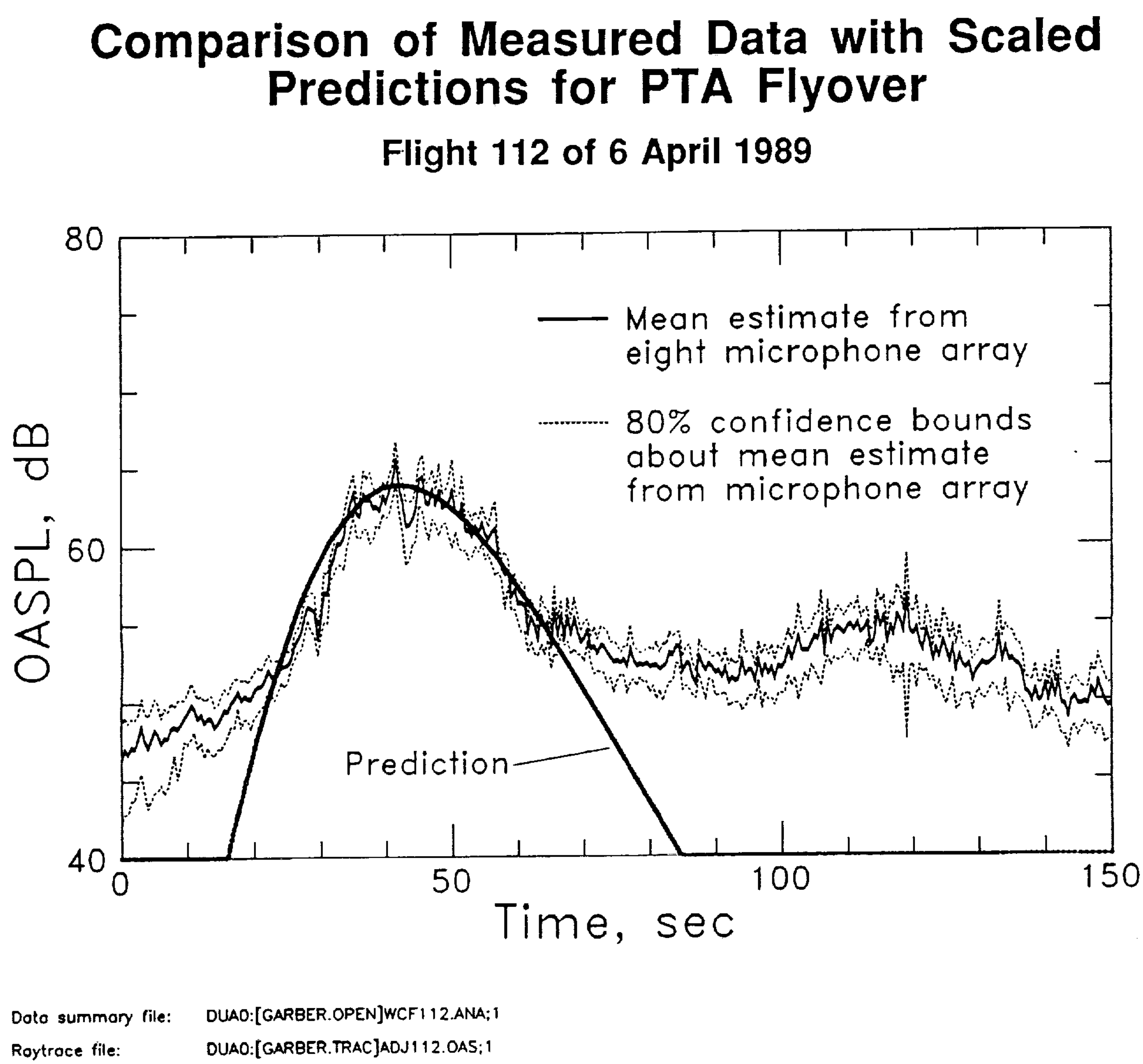


Figure 14

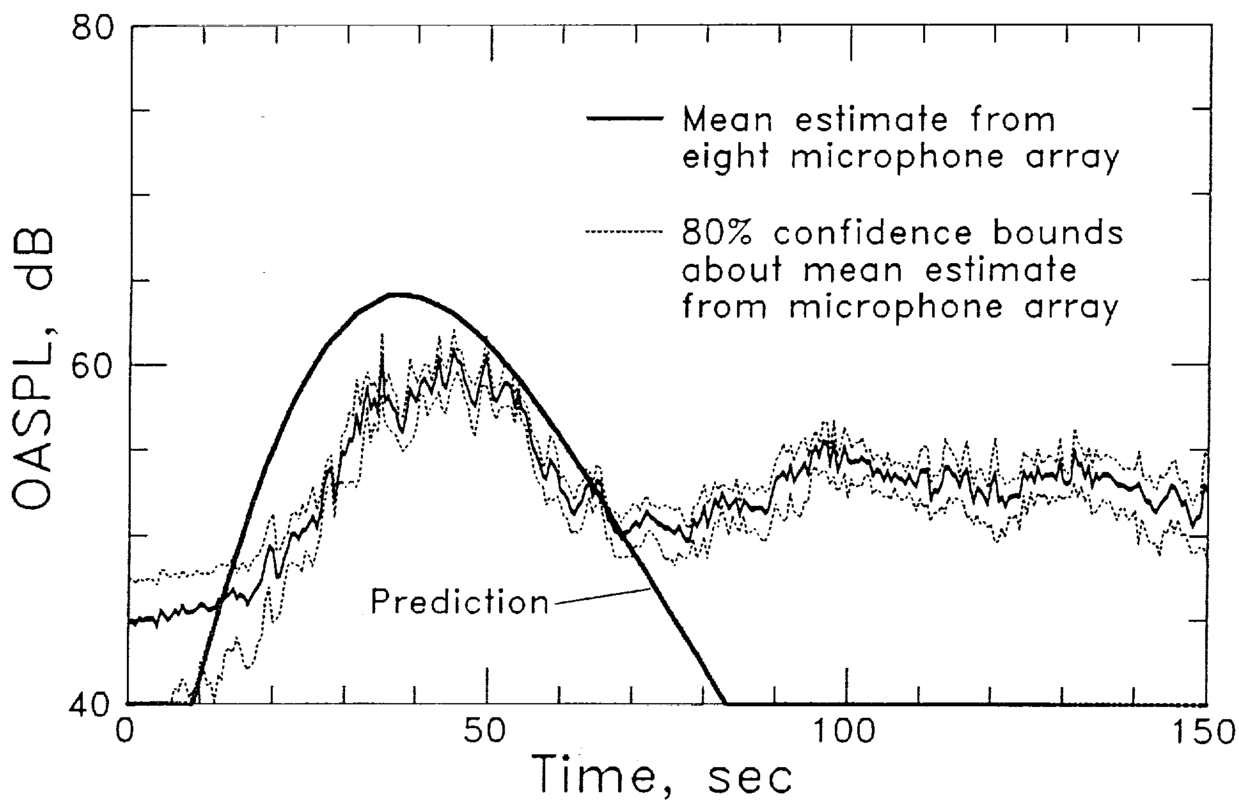
EN ROUTE NOISE TEST COMPARISON OF GROUND MEASURED DATA WITH RAY-TRACE PREDICTION

Run 110

Lest anyone think that there is no problem, in this figure is another comparison between measurement and prediction for another 30,000-ft, .7-M run. The agreement is not as good as in the previous comparison. In this figure the ray-tracing result over-predicted the measured result, and the predicted flyover shape is a little off. Ray tracing does not predict all of the day-to-day variability seen in the measured results. For the 30,000-ft, .7-M test condition, the ray-tracing predictions showed approximately 7 dB variation throughout the test, as compared to the 12 dB variation in the measured average peak 1/2-second Overall SPL

Comparison of Measured Data with Scaled Predictions for PTA Flyover

Flight 110 of 5 April 1989



Data summary file: DUA0:[GARBER.OPEN]WCF110.ANA;1

Raytrace file: DUA0:[GARBER.TRAC]ADJ110.OAS;1

Figure 15

EN ROUTE NOISE TEST CONCLUDING REMARKS

In conclusion, a long-range advanced turboprop en route noise database was obtained with weather, tracking, and onboard measurements. In-flight noise directivity measurements were made. Data repeatability within a test day was excellent. Day-to-day variability existed and is not completely understood and therefore not predicted. Comparison of a two-dimensional ray-tracing propagation model with the ensemble average ground-measured data was good; however, as stated above, the day-to-day data variability was not completely predicted.

Future research will include looking at alternative propagation models. Three-dimensional ray tracing, fast field program, and the parabolic equation are possibilities. The effect of turbulence needs to be accessed.

- **A LONG-RANGE PROPELLER DATA BASE WAS OBTAINED**

- **DATA REPEATABILITY WITHIN A TEST DAY WAS GOOD - VARIABILITY BETWEEN DAYS IS NOT COMPLETELY UNDERSTOOD**

- **COMPARISON OF RAY TRACING PROPAGATION MODEL TO ENSEMBLE-AVERAGED GROUND MEASUREMENTS WAS GOOD - DAY TO DAY VARIABILITY NOT COMPLETELY PREDICTED**

Figure 16