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NASA TM X-62,166

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COMPARISON OF WIND TUNNEL AND FLYOVER NOISE MEASUREMENTS OF THE YOV–10A STOL AIRCRAFT

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June 1972

28p

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NOMENCLATURE

dB	decibel
EPNdB	effective perceived noise level - decibels
Hz	Hertz - cycles per second
PNL	perceived noise level - decibels
PNLT	perceived noise level tone corrected - decibels
RMS	root mean square
RPM	revolutions per minute
SPL	sound pressure level - decibels
STOL	short take off and landing
V/STOL	vertical and short take off and landing
α	angle of attack - pitch attitude with respect to horizontal

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SUMMARY

The YOV-10A Research Aircraft was flown to obtain flyover noise data that could be compared to noise data measured in the 40- by 80-foot (12.2 x 24.4 m) wind tunnel at NASA Ames Research Center.

The flyover noise measurements were made during the early morning hours on runway 32L at Moffett Field, California. A number of passes were made at 15.24 m (50 ft) altitude in level flight with an airplane configuration closely matching that tested in the wind tunnel. Two passes were selected as prime and were designated for full data reduction. The YOV-10A was flown over a microphone field geometrically similar to the microphone array set up in the wind tunnel. An acoustic center was chosen as a matching point for the data.

Data from the wind tunnel and flyover were reduced and appropriate corrections were applied to compare the data. Results show that wind tunnel and flight test acoustic data agreed closely.

INTRODUCTION

Ames Research Center is actively involved in advanced programs to develop STOL and V/STOL transport aircraft. A very important part of the research effort is concentrated in designing aircraft for low noise emission to the environment. The noise emitted by the aircraft during take off, landing, and flyover will have much to do with STOL and V/STOL acceptance by the public.

Ames measures noise generated by large scale research models in the 40- by 80-foot wind tunnel. The noise measurements are used both to predict noise characteristics of full scale aircraft and to evaluate the change in noise with aerodynamic parameters.

To determine the validity of the wind tunnel measurements, an existing flying research aircraft of the STOL type, the YOV-10A, was tested in the 40- by 80-foot wind tunnel and then flown over a similar microphone array at Moffett Field, California. The flyover data and wind tunnel data were reduced, analyzed, and compared on the same basis. This report summarizes those results.

AIRCRAFT AND INSTRUMENTATION

Aircraft

The YOV-10A Research Aircraft is a modified North American YOV-10 Navy aircraft. The aircraft was modified for STOL research by incorporating an improved propulsion system with power interconnect and a high lift flap system with rotating cylinders. The rotating cylinders are 12 inches (.305 m) in diameter and are driven by hydraulic motors. The maximum rotation speed is 1600 RPM. The cylinders provide a means for keeping the airflow attached to the wing surface over a larger speed range and angle of attack range than conventional flap systems resulting in increased lift throughout that range. The basic airplane has a wing span of 10.36 m (34 ft) with an aspect ratio of 4.75 and a modified 64_2A-3150 airfoil section. The propulsion system consists of two 4-blade propellers driven by Lycoming T53-L-11 engines. The propellers are 2.87 m (9.42 ft) in diameter and were designed for low noise emission. A schematic showing the YOV-10A detail is given in figure 1. Figure 2 shows the YOV-10A in flight and the wind tunnel installation.

Instrumentation

Wind tunnel test.- Wind tunnel noise measurements were made using $\frac{1}{2}$-inch (1.27 cm) condenser microphones (B&K 4133) with cathode follower (B&K 2615). The microphones and cathode followers were connected to signal conditioners, and the output from the signal conditioners were recorded on magnetic tape at 30 ips on an Ampex FR-1300A tape recorder. Before each run, each microphone was calibrated with a 250 Hz piston phone to 124 dB at .5 volt RMS. Overall system error is estimated at $\pm \frac{1}{2}$ dB.

The microphones were attached to 1.83 m (6-foot) microphone stands and had special bullet nose wind screens (B&K UA 0052). With the nose cones the microphones had omni-directional response. The microphones were pointed into the wind during the wind tunnel test. A schematic of the wind tunnel microphone array is shown in figure 3.

Sound van.- Flyover noise data measurements were made using a portable sound data van. The self contained van had all necessary equipment for data recording and on site data reduction.

The sound data measurements were made with 1.27 cm (½-inch) condenser microphones (B&K 4138) with cathode followers (B&K 2619). Each microphone and cathode follower was connected to a portable signal conditioner at the microphone site, and the portable conditioner was connected by long cables to a van signal conditioner. The van-to-portable conditioner arrangement allowed both on site and remote setting of signal gain. The signal output at the van was recorded on magnetic tape at 30 ips using a Honeywell tape recorder. In addition to microphone signals; time code, Fairchild camera signal, operators voice, and pilots voice were recorded.

Prior to testing, the long microphone cables, signal conditioners, and cathode followers were calibrated with a sine wave signal generator. The input to each system from the signal generator was 1 volt RMS at each 1/3 octave center frequency from 50 to 10,000 Hz. The output from each system was recorded on magnetic tape and was used for data correction.

Shortly before the day's flights, each microphone was calibrated with a 250 Hz piston phone to 124 dB and 1 volt RMS. Overall system error is estimated to be less than $\pm \frac{1}{2}$ dB.

The microphones were set on 1.83 m (6-foot) stands and adjusted to receive grazing incidence from the sound source. Each microphone had a wind screen made of polyurethane foam (B&K UA 0237). The microphone set up on the runway is shown in figure 4.

Wind velocity and direction, dry and wet bulb temperature, barometric pressure, and humidity were measured at a portable weather station located near the van. Weather conditions were obtained prior to each day's flights and if the wind velocity exceeded 5 knots, the relative humidity exceeded 90% or was below 30%, or temperature exceeded 86°F or was below 41°F the day's flights were cancelled.

Radar.- A portable radar was used to guide the pilot and aircraft along the flight path and to provide information on aircraft position with respect to the microphone field. The radar signal was received from a reflector attached to the nose wheel of the YOV-10A. The radar output was aircraft range, altitude above the runway surface, and displacement from the runway centerline.

Fairchild flight analyzer camera.- A Fairchild Flight Analyzer Camera was used to determine when the aircraft was directly over the reference acoustic center of the microphone field. The camera takes a series of photos on a single photo plate when swept across a viewing field. Careful set up of the camera allowed accurate determination of aircraft altitude and flight speed. In order to synchronize the camera with the sound data recordings, a pulse signal was emitted from the camera at each shutter click, the signal was recorded at the sound van simultaneously with the sound data. The set up distances for the camera are shown in figure 5. A sample photo plate is shown in figure 6.

DATA REDUCTION

Wind Tunnel Data

Data from wind tunnel noise measurements were reduced through a B&K real time 1/3-octave-analyzer. The analyzer had a parallel filter set and outputs digitized data from the analog signal from magnetic tape. The data were reduced using an averaging time of 15 seconds. The output from the analyzer was put on punched paper tape and formatted to be used in a data reduction program.

The data reduction program calculated overall sound pressure level and perceived noise level (PNL), and applied corrections for reverberations to the data. The output from the program consisted of overall SPL for each 1/3-octave center frequency, corrected and uncorrected overall SPL (total SPL for all bands) and PNdB corrected. A sample sheet is shown in figure 7.

Flyover Noise Data

Data from the flyovers were reduced on site using the reduction equipment in the sound van. The data were reduced through a General Radio real time 1/3-octave analyzer with parallel filter set using an averaging time of 1/8 second (due to speed of the aircraft). The output from the filter set was input to a mini-computer on board the van. The computer applied the electrical corrections from pre test calibrations and output a punched paper tape and a printed sheet. The punched paper tape was used for further data reduction as reported in reference 1. The computer PNL and PNLT for 80 data points 1/8 second apart. In addition, the 1/3-octave center frequency SPL were printed for each of the 80 points. An uncorrected EPNdB was printed for each set of data points. The data used for this report are the 1/3-octave SPL data produced on site from the van.

TEST PROCEDURE

Wind Tunnel

Wind tunnel noise data were taken at selected aerodynamic data points. Approximately 30 seconds of sound data were recorded for each condition. Voice inputs for airplane configuration, wind tunnel air velocity, airplane power setting, and microphone gain settings were recorded simultaneously with the sound data.

Flyover

The sound data recording equipment was turned on when the aircraft entered the approach path to the microphone field. The cue for turning on the recording equipment came from the radar operator who visually sighted the aircraft from the radar dish. The data recording continued until the aircraft lifted off at the end of the runway near the sound van. Data were recorded approximately 243.84 m (800 ft) on either side of the microphone field. Prior to the day's flights a background noise level was recorded on mag tape for reference when reducing data.

DATA ANALYSIS

In order to compare the data from the wind tunnel to the data from flyover, it was necessary to correct both sets of data to free field conditions. In addition, it was necessary to extrapolate the flyover noise data back to wind tunnel measurement distances, from source to microphone, by applying the spherical divergence law for sound attenuation (6 dB per double distance). Atmospheric absorption corrections were applied when significant.

Corrections to wind tunnel data were based on a point noise source calibration of the test section. An omni-directional horn driver located in the center of the test section was driven with pink noise through a 1/3-octave band filter set. Noise measurements were made at selected center frequencies and distances from the source. Free field sound pressure levels for the horn are reported in reference 2. The differences between the wind tunnel measurements and free field were used as corrections at each 1/3-octave center frequency SPL. The corrections account for the reverberation and reflection of the wind tunnel. The data used for the corrections are reported in reference 2.

Corrections to flyover noise data consisted of correcting the data for reflections off a hard surface, correcting for frequency shift where applicable, and correcting for distance attenuation. The corrections for reflections were based on references 3 and 4. The pure tone reflection corrections were based on reference 3 and all other corrections were based on reference 4. In order to use the corrections the following assumptions were made:

1) The aircraft was considered to be a point source with respect to each microphone.
2) The concrete surface of the runway was assumed to be a perfect reflector with no surface irregularities.
3) Spherical divergence was assumed for distance attenuation.

The corrections to data for frequency shifts were based on a simple application of the Doppler equation.

Data were compared on an equal basis by selecting the point in time where the flyover microphone data were directly comparable to wind tunnel data for a geometrically similar condition. Table 1 and Table 2 give information on aircraft configuration, power setting, and position with respect to the microphone fields.

RESULTS AND DISCUSSION

The reduced data were compared by plotting SPL versus 1/3 octave center frequency. The final resulting data are summarized in figures 8 through 12.

Sound data from microphones positions 1 and 3 (figures 8 and 10) show close correlation between wind tunnel and flyover data throughout the spectrum. These microphones were located at the acoustic center of the microphone fields. At the selected analysis time the aircraft was overhead and the relative velocity along a line connecting the aircraft and microphone was zero. Therefore, no frequency shifts took place so that wind tunnel and flyover data at these microphone positions are directly comparable after each set of data was corrected to free field and equal distance. The slight differences near the blade passing frequency (about 80 Hz) and second harmonic are due to the difference in averaging time used for the two sets of data during reduction. The shorter averaging time used for the flyover data allows lower frequency spikes to be weighted more heavily when averaged since the sample number is small (i.e. 80 Hz wave is sampled 10 times in 1/8 second and 1200 times in 15 seconds).

Microphones 2 and 4 (figures 9 and 11) were affected by frequency shift during flyover. Microphone 4 location was such that at the analysis time the aircraft sound source had relative motion away from the microphone and as a result the frequencies seen by the microphone were lower than the frequencies emitted by the source. When the Doppler equation was applied at the blade passing frequency and second harmonic, however, the frequencies don't shift out of their respective 1/3-octave bands. Therefore, no shifts of data were made for microphone 4. The analysis to account for pure tone reflections was, however, made using the Doppler equation calculated shift frequency.

Microphone 2 was located such that at the analysis time, the aircraft sound source had relative motion toward the microphone during flyover and so the frequencies measured at microphone 2 were higher than those emitted by the source. When the Doppler equation was applied to data at the blade passing frequency and second harmonic it showed that the frequencies did shift out of their respective 1/3-octave bands into the next higher band. The flyover data for microphone 2, therefore, have been shifted at the blade passing frequency and second harmonic to account for the Doppler effect. The SPL's used to replace the affected 1/3-octave band SPL's were the levels measured on both side of the affected band. Wind tunnel narrow band data analysis was used as a guide. Reflection corrections were based on shifted frequencies.

When the corrections were applied to data at microphones 2 and 4 and the Doppler affect applied to microphone 2, the flyover data and wind tunnel data showed good agreement. Microphone 2 data has some discrepancies at frequencies below 500 Hz; this may be due again to the shorter averaging time used to reduce flyover data. In addition, the reflection corrections are sensitive to airplane position.

Additional analysis of flyover data from microphone 2 was done for the source directly over the microphone. The Doppler effect and reflection correction errors are minimized for the source in that position. The resulting data are shown in figure 12 and compared to tunnel data. These data show the same close agreement as microphone 1 data. The comparisons made for all data show that closer agreement between wind tunnel and flyover data occurs at the non-Doppler affected microphone positions than occurs at the Doppler affected microphone positions.

The data give encouragement for the continued measurement of noise data from research aircraft models installed in the 40- by 80-foot wind tunnel.

CONCLUSIONS

1) When appropriate corrections are applied, flyover data and wind tunnel data show close agreement for 1/3-octave bands.
2) Wind tunnel tests can be used to estimate flyover type noise to be used to predict the noise emission from future aircraft.

3) At higher velocities the Doppler effect could become significant for flyover data. Energy shifts accompanying frequency shifts are hard to account for using simple 1/3-octave analysis. It will be necessary to use narrow band analysis to account for these shifts.

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3. Hoch, R.: Acoustics Effects Produced by a Reflecting Plane. SAE No. 31, September 1970.

4. Howes, Walton L.: Ground Reflection of Jet Noise. NASA Technical Report, R-35, 1959.

5. Morse, Phillip M., and Ingrad, K. Uno: Theoretical Acoustics, 1968.

6. Anon: Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity for Use in Evaluating Aircraft Flyover Noise. Society of Automotive Engineers Inc., August 31, 1964.

TABLE 1

CONFIGURATION DETAILS, ALTITUDE AND AIRSPEED COMPARISONS

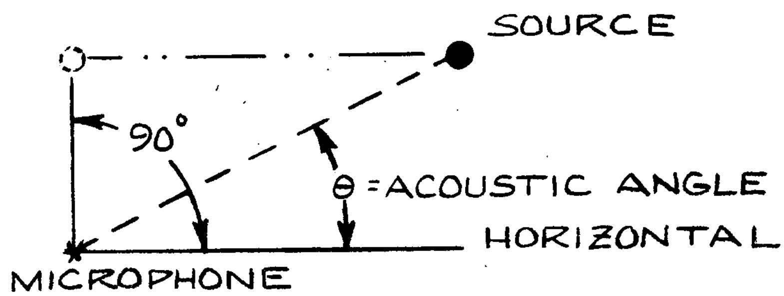
FLAP SETTING	AIRSPEED KNOTS	ALTITUDE METERS (FEET)	PROP RPM	BLADE ANGLE DEG	AIRCRAFT PITCH DEG	GROSS WEIGHT KG (LB)
FLYOVER						
30/15	77.9	16.46 (54)	1236	23	2.7	5114 (11,250)
WIND TUNNEL						
30/15	68	6.71 (22)	1250	27	2	DOES NOT APPLY

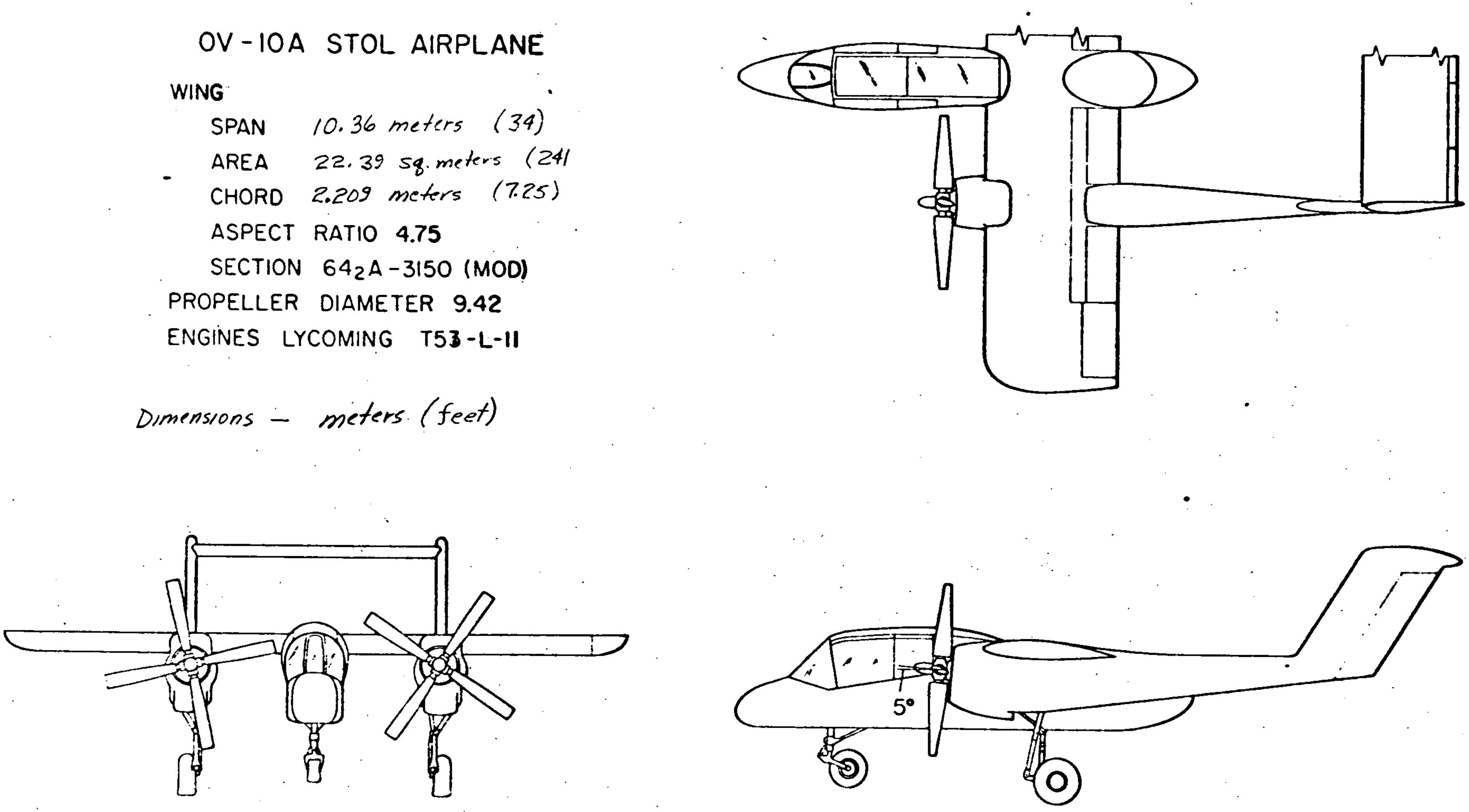
TABLE 2

SOUND SOURCE TO MICROPHONE DISTANCE AND ACOUSTIC ANGLE

FLYOVER	SOUND SOURCE TO MIC DISTANCE, METERS (FEET)		ACOUSTIC ANGLE DEG
MICROPHONE 1	14.63	(48.0)	90
MICROPHONE 2	59.74	(194.0)	14.3
MICROPHONE 3	22.22	(79.2)	37.3
MICROPHONE 4	38.40	(126.0)	22.4

WIND TUNNEL	SOUND SOURCE TO MIC DISTANCE, METERS (FEET)		ACOUSTIC ANGLE DEG
MICROPHONE 1	4.88	(16.0)	90
MICROPHONE 2	18.90	(62.0)	14.9
MICROPHONE 3	7.80	(25.6)	38.6
MICROPHONE 4	12.25	(40.2)	23.4





3 - view

Figure 1.- Geometry of the Airplane

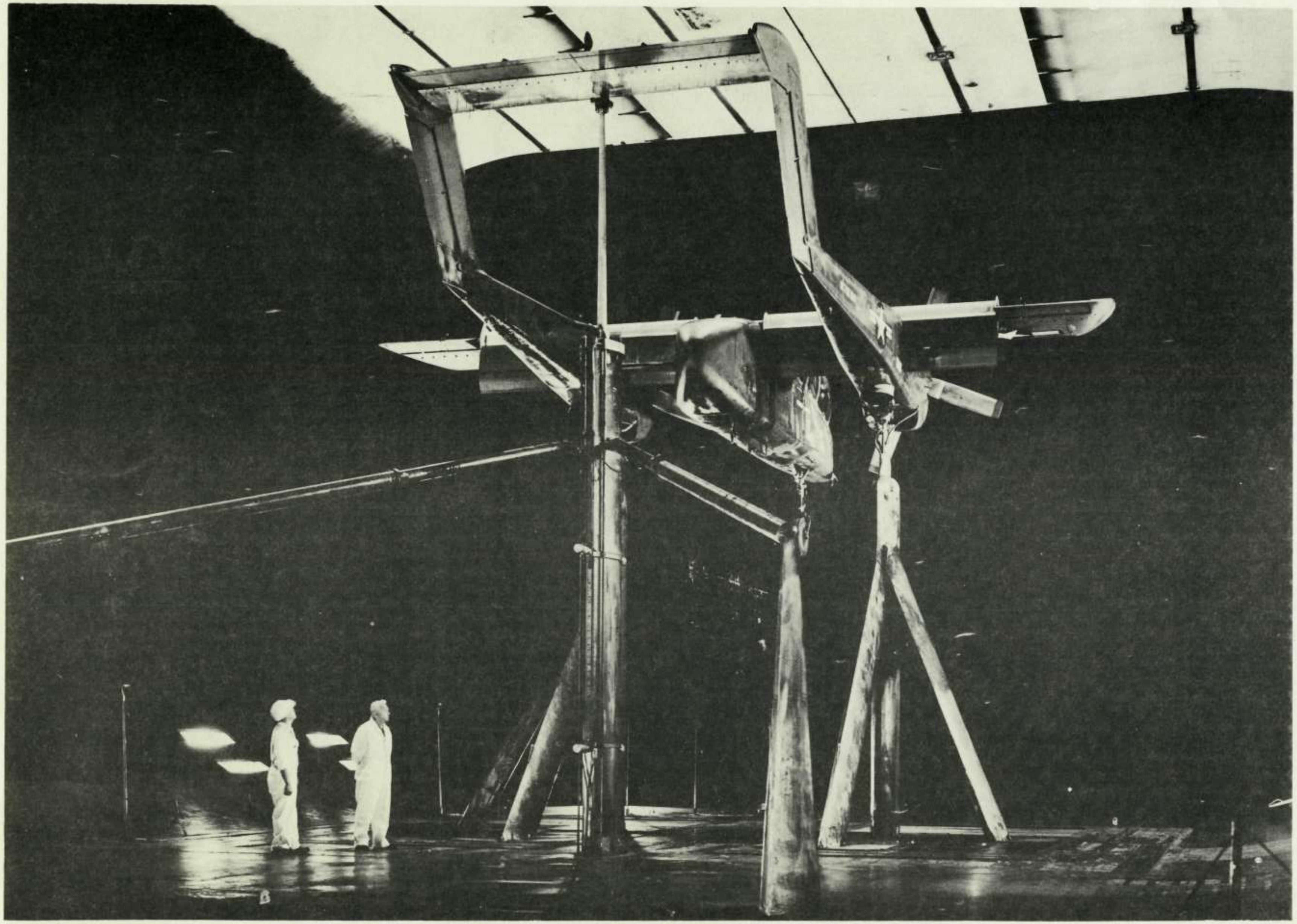


Figure 2.- Concluded

(b.) Wind tunnel installation

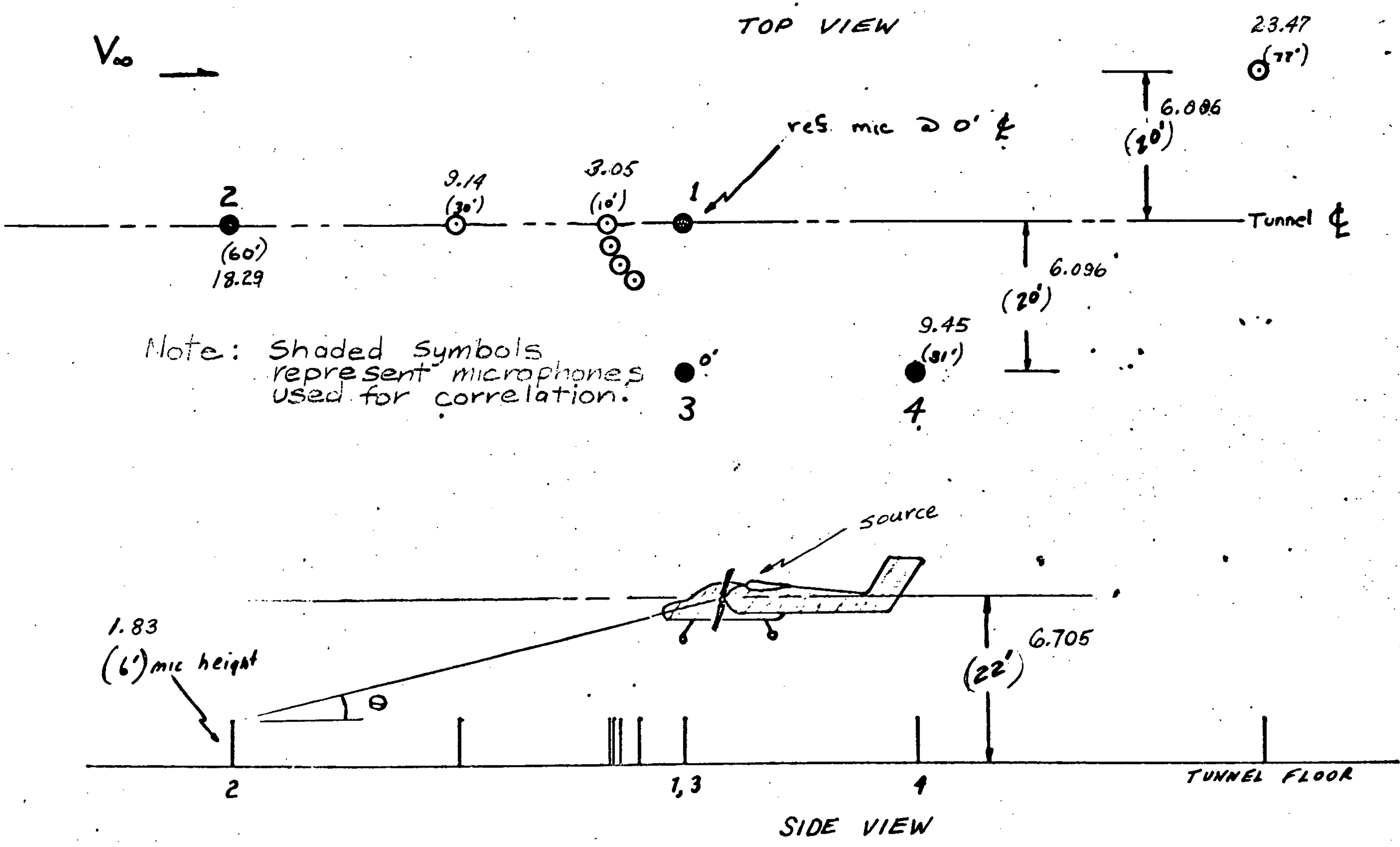


Figure 3.- Microphone Layout for 40-by-80-foot Wind Tunnel Test

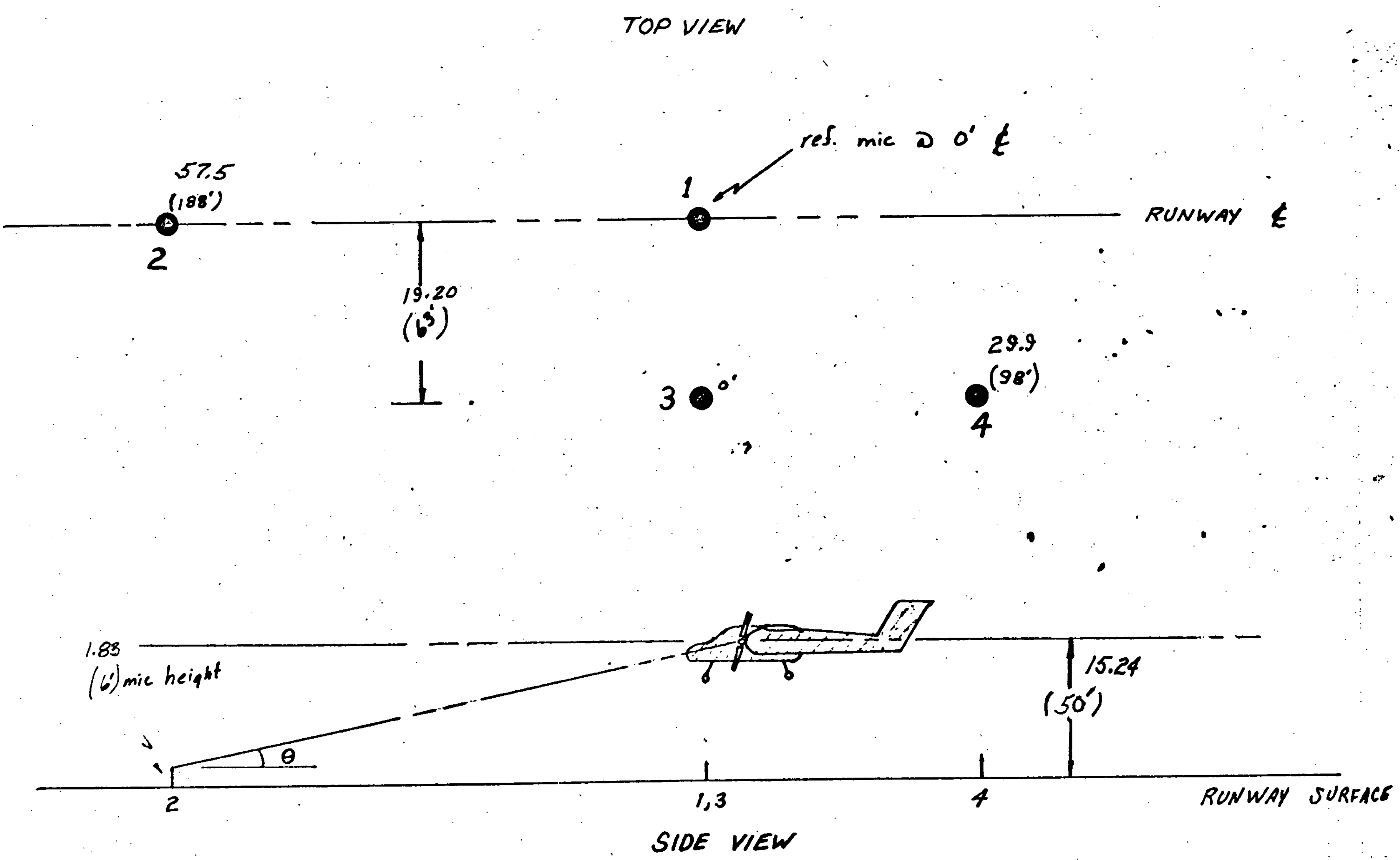


Figure 4.- Microphone Layout for Flyover Test

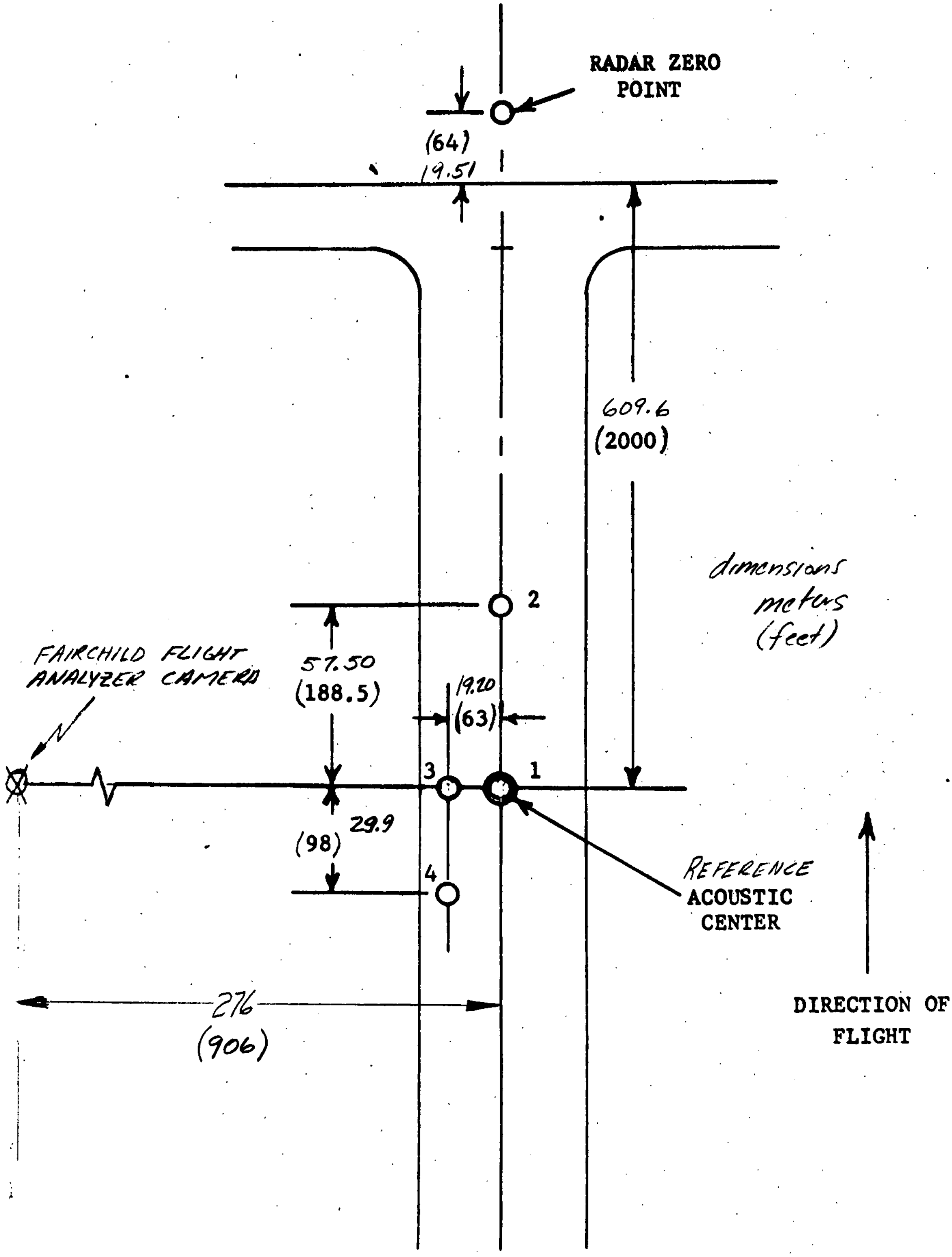


Figure 5.- Fairchild Flight Analyzer Camera Position

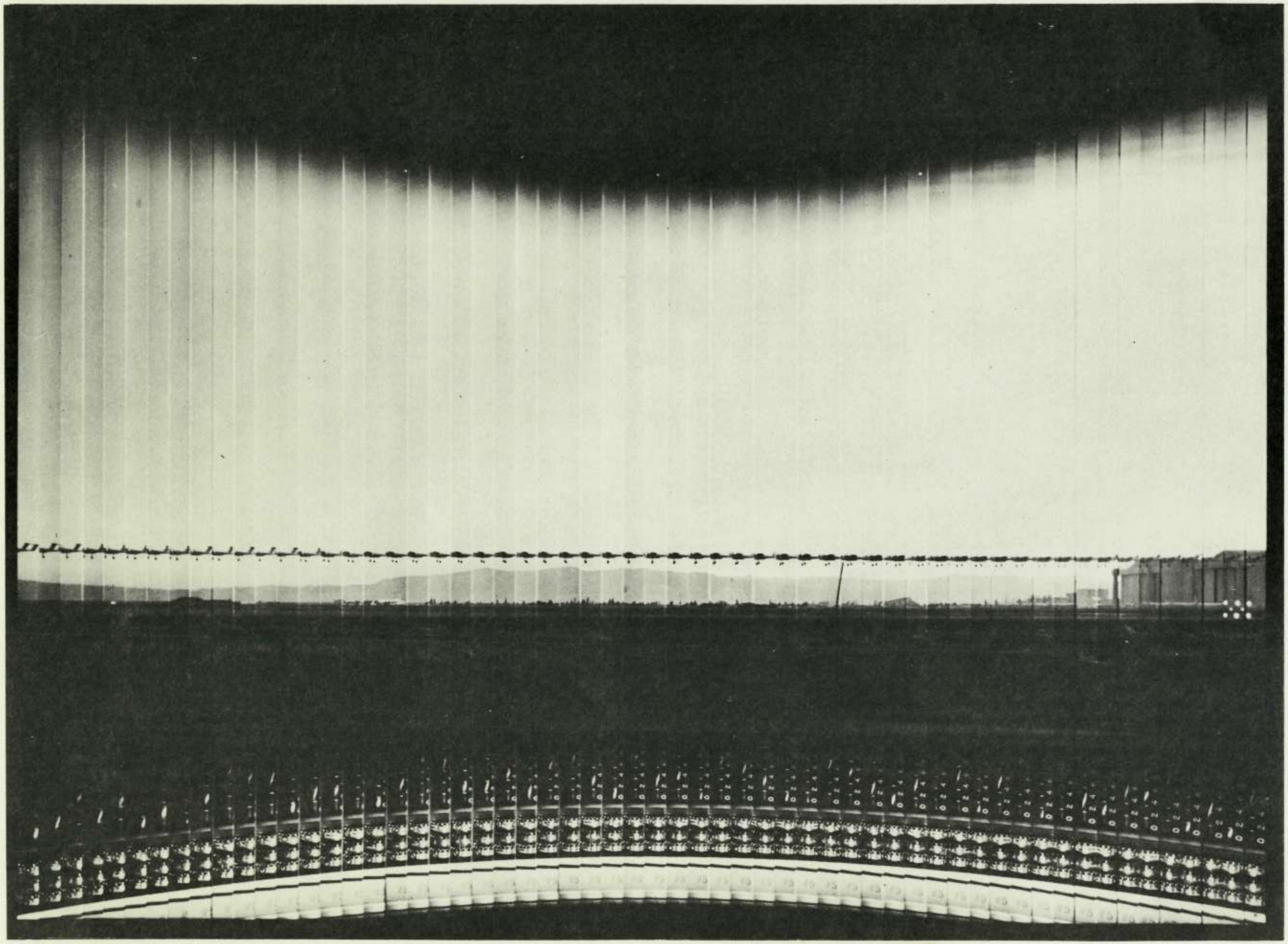


Figure 6.- Fairchild Flight Analyzer Photo Plate

NØISE DATA

ØV-10 IN 40X80 FT WIND TUNNEL

SPL IN DB REL. .0002 MICRØBAR

CØRRECTED FØR REVERBERATIØNS

TEST 388 RUN 45 DELTA 6

MICRØPHØNE:	1	2	3	4	5	6	7	8	9	10
ANGLE(DEG):	.0	.0	.0	15.0	30.0	45.0	90.0	.0	143.0	196.0
REF DIST(FT):	67.0	39.0	23.0	23.0	22.0	22.0	27.0	18.0	37.0	77.0
GAIN,	20	10	10	10	10	10	10	0	10	10
FREQ(HERTZ)										
25	70.8	76.0	80.8	82.8	82.8	82.2	80.8	85.6	80.8	76.2
31	74.0	77.4	82.2	81.4	83.2	82.2	83.0	83.8	82.0	76.6
40	70.8	76.8	83.2	82.4	83.2	83.2	84.0	86.0	83.0	75.8
50	70.6	77.0	81.6	83.2	84.2	83.8	82.6	84.8	81.8	75.0
63	71.0	77.8	82.8	83.6	83.0	85.0	83.0	88.2	82.2	75.0
80	84.6	92.4	92.0	100.6	104.0	101.2	101.6	100.0	94.0	91.4
100	79.8	86.8	93.2	93.4	93.2	91.4	91.6	92.8	86.8	81.2
125	84.2	93.4	93.8	97.2	96.8	95.8	96.8	100.4	92.2	83.2
160	94.0	101.4	103.8	103.2	102.2	98.0	97.6	113.8	91.8	88.0
200	82.6	89.8	93.0	92.8	92.4	90.8	89.8	100.2	87.2	78.4
250	86.0	89.8	92.0	97.0	98.4	97.2	92.0	96.4	90.2	82.8
315	81.8	92.2	95.4	93.6	94.6	93.6	92.8	96.4	90.6	79.4
400	81.8	89.6	93.2	92.8	93.8	95.2	92.0	96.0	87.8	78.4
500	80.6	88.0	93.0	92.6	93.4	93.0	92.0	96.0	86.4	78.0
630	79.2	87.4	92.0	92.2	92.2	91.4	91.0	95.0	87.4	76.4
800	80.6	87.2	93.0	91.4	91.4	92.0	90.2	95.8	87.6	78.2
1000	81.0	87.2	91.4	91.2	92.0	91.8	90.4	94.8	87.4	78.8
1250	79.0	86.2	90.2	90.4	90.6	91.0	90.4	94.4	86.8	77.2
1600	83.8	85.8	89.2	89.4	91.0	90.6	88.8	93.4	85.8	81.6
2000	82.8	85.0	88.8	89.0	90.6	90.2	88.4	92.8	85.0	80.8
2500	81.8	84.6	88.0	88.0	89.4	89.4	87.6	91.8	83.6	79.8
3150	78.0	84.6	88.4	88.6	88.8	88.6	88.0	91.0	83.8	74.8
4000	77.8	84.2	88.6	88.4	88.8	88.4	87.6	90.8	83.8	74.6
5000	77.0	84.0	88.2	88.0	88.8	88.4	87.4	91.0	83.4	73.8
6300	75.8	83.4	88.0	87.8	88.8	88.4	87.4	91.4	83.4	74.0
8000	73.6	82.0	87.6	87.2	88.0	87.6	86.6	90.8	81.6	72.8
10000	76.2	85.8	91.6	90.8	90.4	89.6	88.6	92.2	79.4	71.8
ØVERALL SPL UNCØRR	112.2	114.8	113.4	113.6	114.8	112.2	113.4	119.0	112.2	111.6
ØVERALL SPL CØRR	97.6	104.7	107.6	108.4	109.2	107.4	106.8	115.2	101.9	95.9
PNDB CØRR	106.3	112.3	115.9	116.2	116.7	116.2	115.2	121.6	111.1	104.2

Figure 7.- Wind Tunnel Noise Data Computer Output Sheet

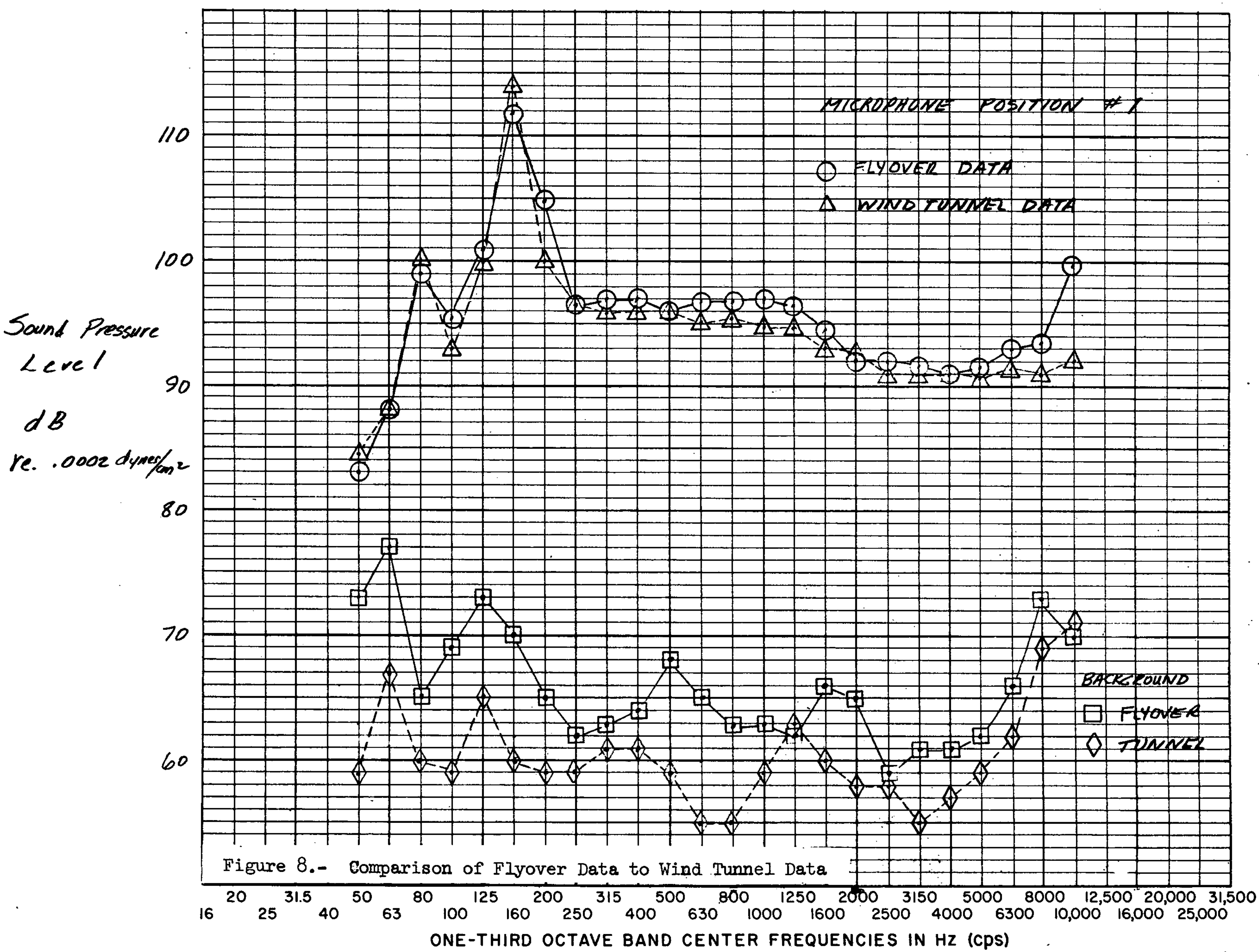


Figure 8.- Comparison of Flyover Data to Wind Tunnel Data

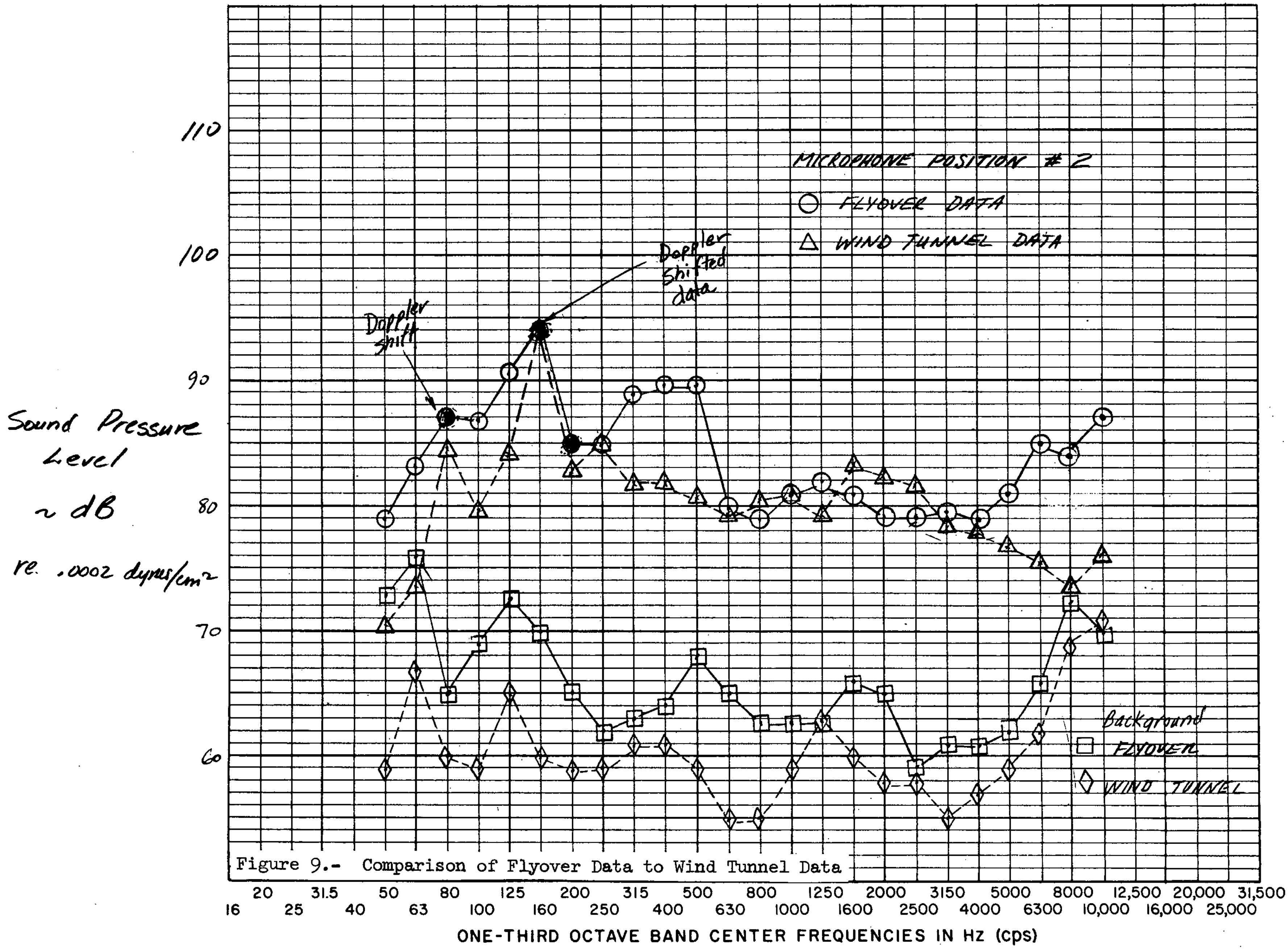


Figure 9.- Comparison of Flyover Data to Wind Tunnel Data

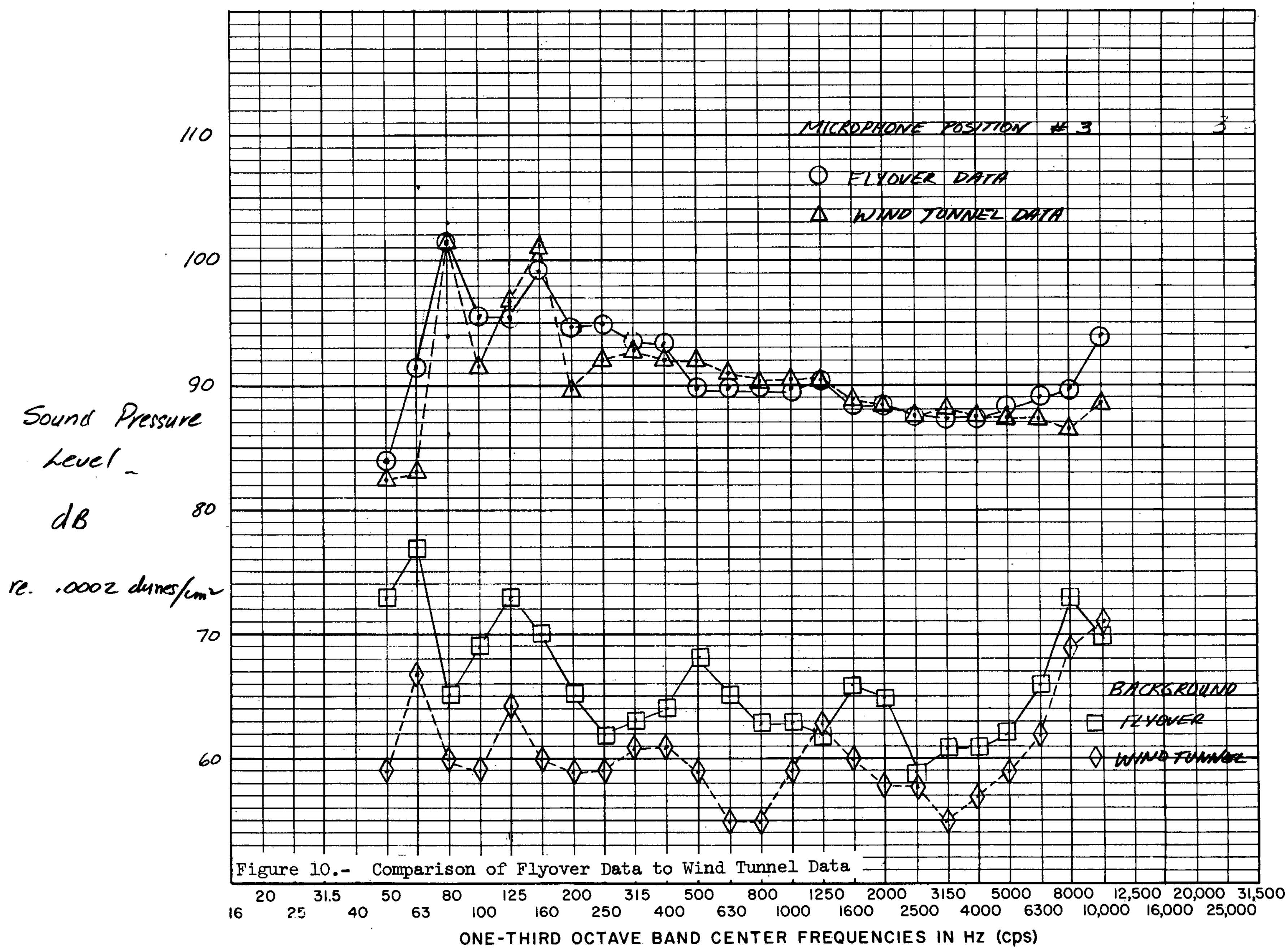


Figure 10.- Comparison of Flyover Data to Wind Tunnel Data

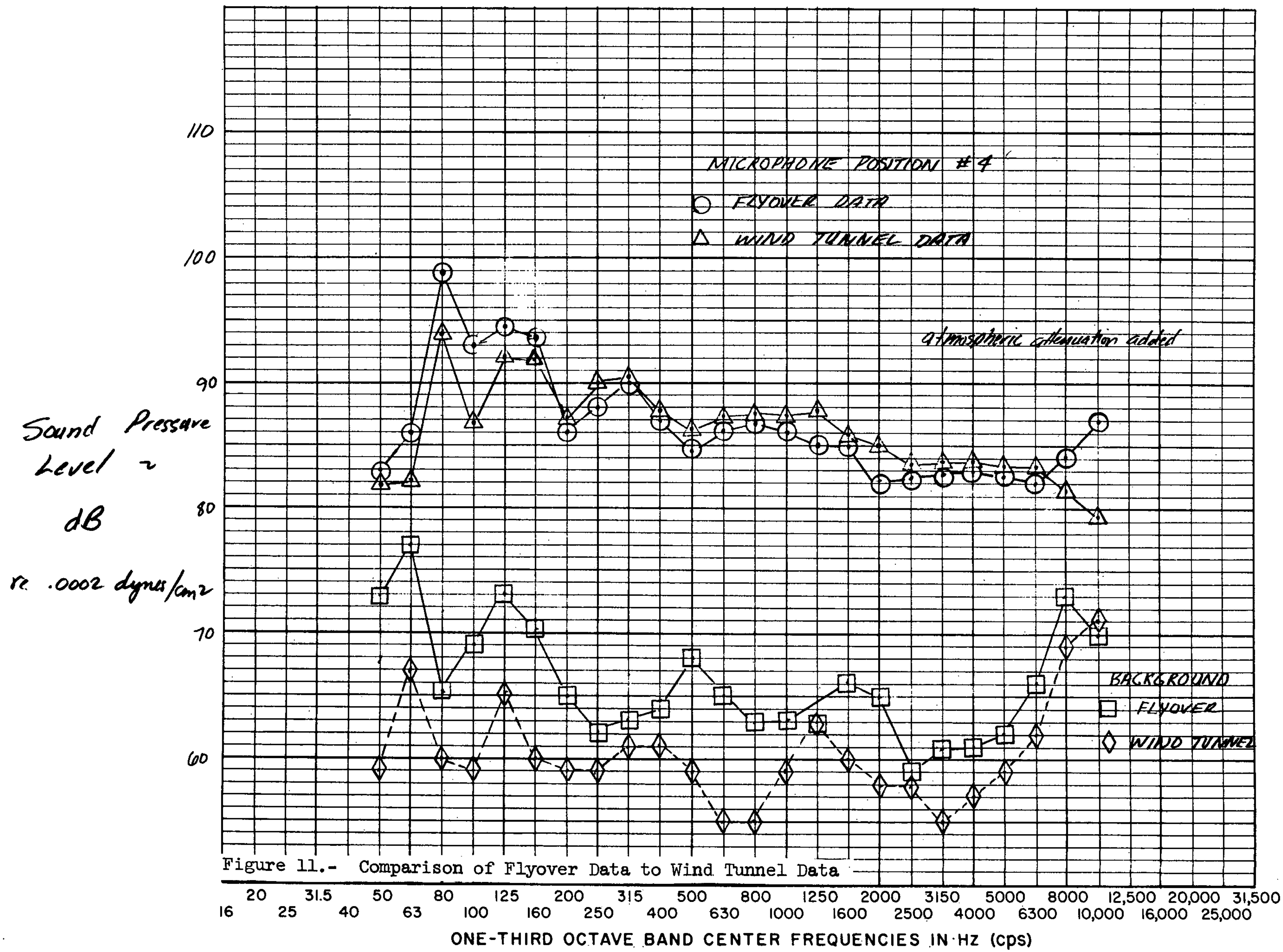


Figure 11.- Comparison of Flyover Data to Wind Tunnel Data

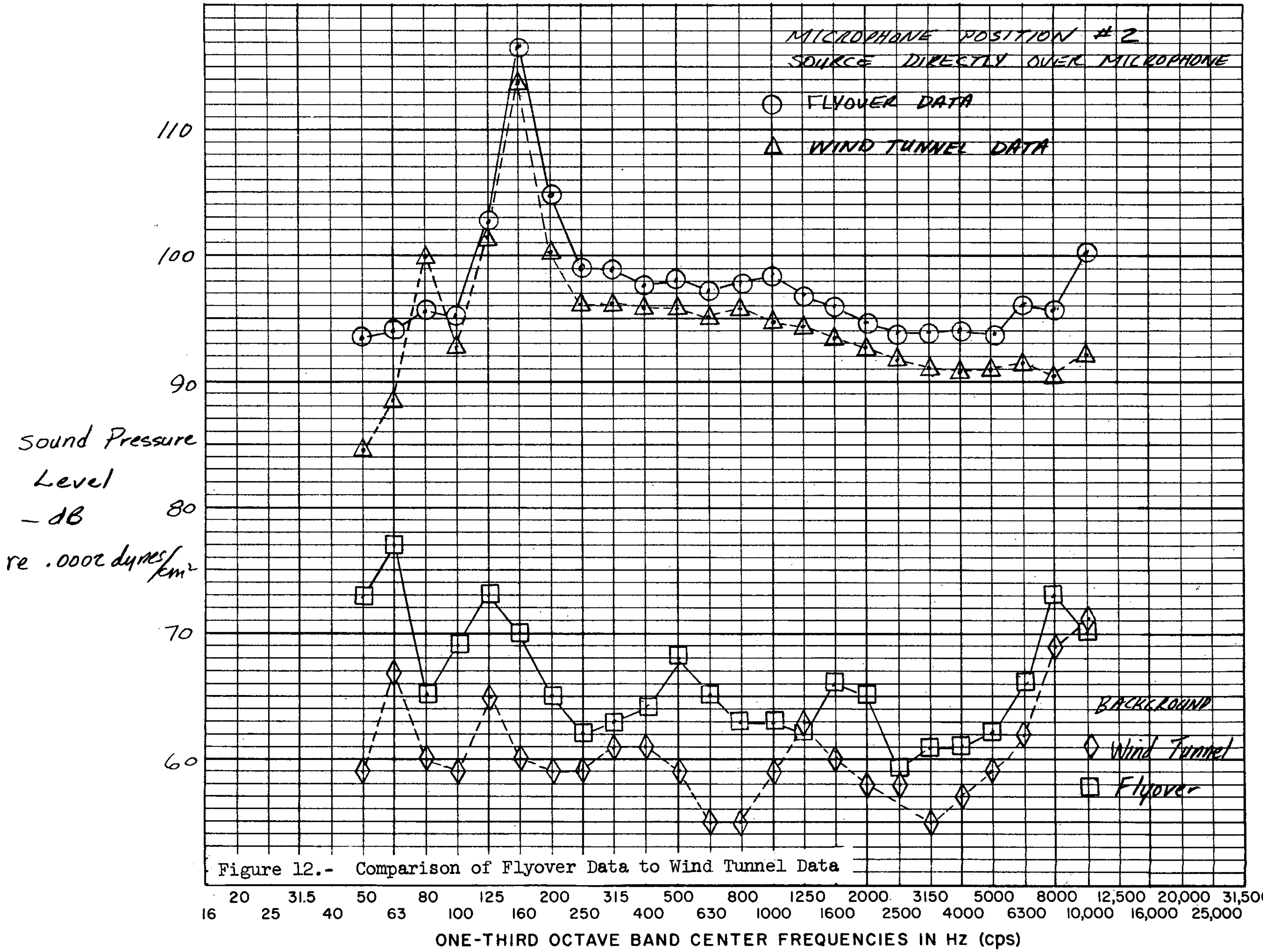


Figure 12.- Comparison of Flyover Data to Wind Tunnel Data