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COMPARISON OF MEASURED AND CALCULATED AIRCRAFT LIFT GENERATED PRESSURES

by

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June 1975

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16. Abstract

Proposed widespread use of very large, heavy, aircraft for commercial and military purposes has caused concern about the lift generated pressures that will be produced at or near ground level due to low altitude operations. Such pressure may have significant effects on objects and structures in the immediate vicinity of airports.

Aircraft lift generated pressures were calculated using elementary airfoil theory, and these values were compared with ground level measurements made during an overflight program. The predicted and the measured values were in relatively good agreement.

Due to lack of experimental investigations of this phenomenon, opportunity was taken during an overflight program to use a specially instrumented test range to measure the ground pressures produced for a range of aircraft weights and distances.

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COMPARISON OF MEASURED AND CALCULATED

AIRCRAFT LIFT GENERATED PRESSURES

By Donald S. Findley

INTRODUCTION

The proposed widespread use of very large, heavy aircraft for commercial and military purposes has caused concern about the lift generated pressures that will be produced at or near ground level due to low altitude operations. Such pressures may have significant effects on objects and structures in the immediate vicinity of airports.

Prandtl and Tietjens in reference 1 have dealt with the problem of the transfer of the weight (lift) of an aircraft to the surface of the ground. Expressions are given in reference 1 for the pressure increment due to aircraft lift as a function of distance, where the distance is assumed to be large compared to the dimensions of the lifting surface.

Due to the lack of experimental investigations of this phenomena, opportunity was taken during a recent overflight program to use a specially instrumented test range to measure the ground pressures produced for a range of aircraft weights and distances. The purpose of this paper is to present measurements of the ground pressures and to compare them with calculations made by the theory of reference 1.

ANALYTICAL STUDIES

The main concepts of the theory of reference 1 and a definition of the quantities involved are illustrated in figure 1. An aircraft flying at low speed, and at a distance above the ground large compared to its dimensions, is assumed to generate a pressure pattern which has rotational symmetry with respect to the location of the airplane. By means of elementary airfoil theory, the lift generated pressure at any point below an aircraft is predicted by the relationship

$$p = \frac{Lh}{2\pi R^3}$$

where p = the incremental pressure over ambient pressure
L = the lift (or weight) of the aircraft
h = the altitude of the aircraft above the ground
R = the slant range distance between the aircraft and the point on the ground where the pressure is observed

For the overhead position of the aircraft, where $R = h$, it can be seen from the equation, that the incremental pressures are proportional to the weight of the aircraft and inversely proportional to the square of the distance between the aircraft and the point of observation.

Using the above equation, calculations were made of the incremental pressure that would be produced below an aircraft, for various distances from the point of observation to the aircraft. The results of these calculations are presented as incremental pressure per unit weight of the aircraft as a function of lateral distance from the ground track for several altitudes in figure 2. It can be seen from the figure that the calculated incremental pressures are relatively high under the aircraft and decrease rapidly with lateral distance for low altitudes. On the other hand at higher altitudes, the maximum incremental pressure values are lower and they decrease at a markedly slower rate as a function of lateral distance. It follows that the relatively high incremental pressures associated with low airplane altitudes are confined to the region near the ground track.

At a given point on the ground, the lift generated incremental pressures will vary as a function of time as the aircraft passes overhead. Based on an assumed speed of 150 kts, the time histories of pressure per unit aircraft weight associated with two different altitudes are given in figure 3. It can be seen that pressure increments are predicted for time spans of several seconds, the shorter time and the higher pressure being associated with the lower altitude.

To indicate the order of magnitude of incremental pressure predicted for various combinations of aircraft weight and altitude, the calculated data of figure 4 are presented. The incremental pressures are those predicted on the ground track and hence are the maximum values. For instance the maximum incremental pressure predicted for a 750,000 pound aircraft at a distance of 200 feet is about 3 psf.

For comparison with the values of lift generated incremental pressures of figure 4 some data for changes in pressures due to altitude and wind velocity are presented in figures 5 and 6. The pressure change, p_a, as a function of altitude was taken from reference 2 and indicates that a value of 3 psf is associated with an altitude change near sea level of about 40 feet.

The pressure exerted as a function of wind velocity is predicted from the expression

$$p_w = 1/2 \rho V^2 \sin \emptyset$$

where p_w is the impact pressure, ρ is the density of the air, V is the wind velocity and $\emptyset$ is the angle of the wind vector relative to the impingement surface ($\emptyset$ is assumed to be 90° for the calculations of figure 6. For instance, a pressure value of 3 psf is associated with a wind velocity of about 30 kts.)

EXPERIMENTAL STUDIES

Test Conditions

For direct comparison with the calculations, measurements were made of the lift generated pressure fields of two different aircraft during a recent overflight program at the NASA Wallops Station, Virginia. The test site, which is approximately 30 feet above sea level, is generally flat with some wooded areas. The measurement location was in a large open paved area, as shown in the sketch of figure 7, with the nearest buildings, trees, and other large objects at least 100 feet away. Flight tests were made in the second and third weeks in November 1967, during which time the weather was generally fair. Strong winds, however, did occur on one day, and the adverse effects of wind on the measurements are noted.

The two aircraft used during the tests are illustrated in figure 8(a) and (b). Airplane A was a large four-engine turbofan-powered military transport operated by the Air Force. Airplane B was a large four-engine turbojet-powered civilian transport operated by the Federal Aviation Administration. The scheduled aircraft ground track passed about 140 feet north of the measurement site in a west to east direction. The aircraft were tracked by radar for all flights. Pertinent information about the operating conditions and the positions of the aircraft are given in Table I.

Instrumentation

A microphone system similar to that presented in figure 9 was used. It has a useable frequency range of zero Hz to 10 KHz, and maximum sound pressure level capability of 140 dB. The system consisted of a specially modified condenser microphone, an FM tuning unit and an amplifier. To monitor and examine the signals, an oscilloscope and a graphic level recorder were used. All data signals, an IRIG time code signal, and a voice description of the tests were recorded on an FM tape recorder.

RESULTS AND DISCUSSION

The results of the tests are presented in figures 10 through 12. Figure 10(a) and (b) contains example pressure time history data for two different frequency ranges for a typical flyover of airplane A. Figure 10(a) relates to the conventional noise frequencies (10 - 10,000 Hz) whereas the data of figure 10(b) relate to the lift-generated pressures which are slowly varying (non-oscillating) in nature and are represented by that part of the spectrum near zero frequency (for convenience 0 - 5 Hz). It can be seen that the high-frequency pressures increase in amplitude gradually to a peak value which occurs after the aircraft has passed overhead. The lift pressure trace on the other hand reaches a peak value near the time that the aircraft is closest to the measuring station. It can be seen that the lift pressure trace is generally similar in nature to the calculated traces of figure 3.

Measured pressure data obtained from records such as in figure 10(b) are plotted in figure 11 for three different flight conditions of airplane B. Shown also on the figure are calculated curves for the same flight conditions for direct comparison. It can be seen that the measured and calculated data are in general agreement. It should be noted, however, that the calculated maximum values (corresponding to the shortest slant range) exceed the measured maximum values in each case. An additional finding is that small negative pressure values are measured after the aircraft has passed by, whereas the theory predicts only positive values. The presence of these small negative pressures has been confirmed even though the measurement accuracy may be degraded because of the response of the measurement system to atmospheric pressure disturbances which are of the same order of magnitude. These small negative pressures may be associated with near-field effects not accounted for by the theory of reference 1.

The data of figure 12 are similar in nature to those of figure 11 but for airplane A and for somewhat different flight conditions, as listed in Table I. Airplane A was heavier than airplane B and hence the maximum incremental pressures were somewhat higher than those of figure 11 for roughly the same operating conditions. The spread of the data points is believed due to the gusty winds of 7 to 14 kts which were observed at the microphone location. Gusty winds have associated with them pressure variations which are superposed on the lift pressures, and it is sometimes difficult to separate them. Thus, the data of figure 12 are not believed to be as accurate as those of figure 11 because of the adverse weather conditions.

CONCLUSIONS

Aircraft lift generated pressures were calculated using elementary airfoil theory, and these values were compared with ground level measurements made during an overflight program. The predicted and the measured values were in relatively good agreement.

As an indication of the order of magnitude of the pressures involved, a 750,000-pound airplane at a distance of 200 feet would produce an incremental pressure due to lift of about 3 psf. This pressure change would roughly correspond either to a change in altitude near sea level of 40 feet or the impact pressure of a 30-kt wind.

REFERENCES

1. Prandtl, L.; and Tietjens, O. G.: Applied Hydro- and Aeromechanics, Dover, New York, 1934.

2. U.S. Standard Atmosphere. U.S. Committee on Extension to the Standard Atmosphere, 1966.

TABLE I. - AIRCRAFT OPERATING CONDITIONS

DATE	MISSION	AIRCRAFT	WEIGHT (POUNDS)	INDICATED AIRSPEED (KNOTS)	ALTITUDE (FEET)	LATERAL DISTANCE FROM FLIGHT TRACK (FEET)	R (FEET)
8 Nov	56-A	A	187,000	250	180	209	276
	61-A	A	185,000	250	400	170	434
	69-A	A	202,000	219	470	131	488
14 Nov	231-B	B	152,000	191	230	185	295
	232-B	B	149,000	204	380	188	424
	233-B	B	148,000	190	610	122	622

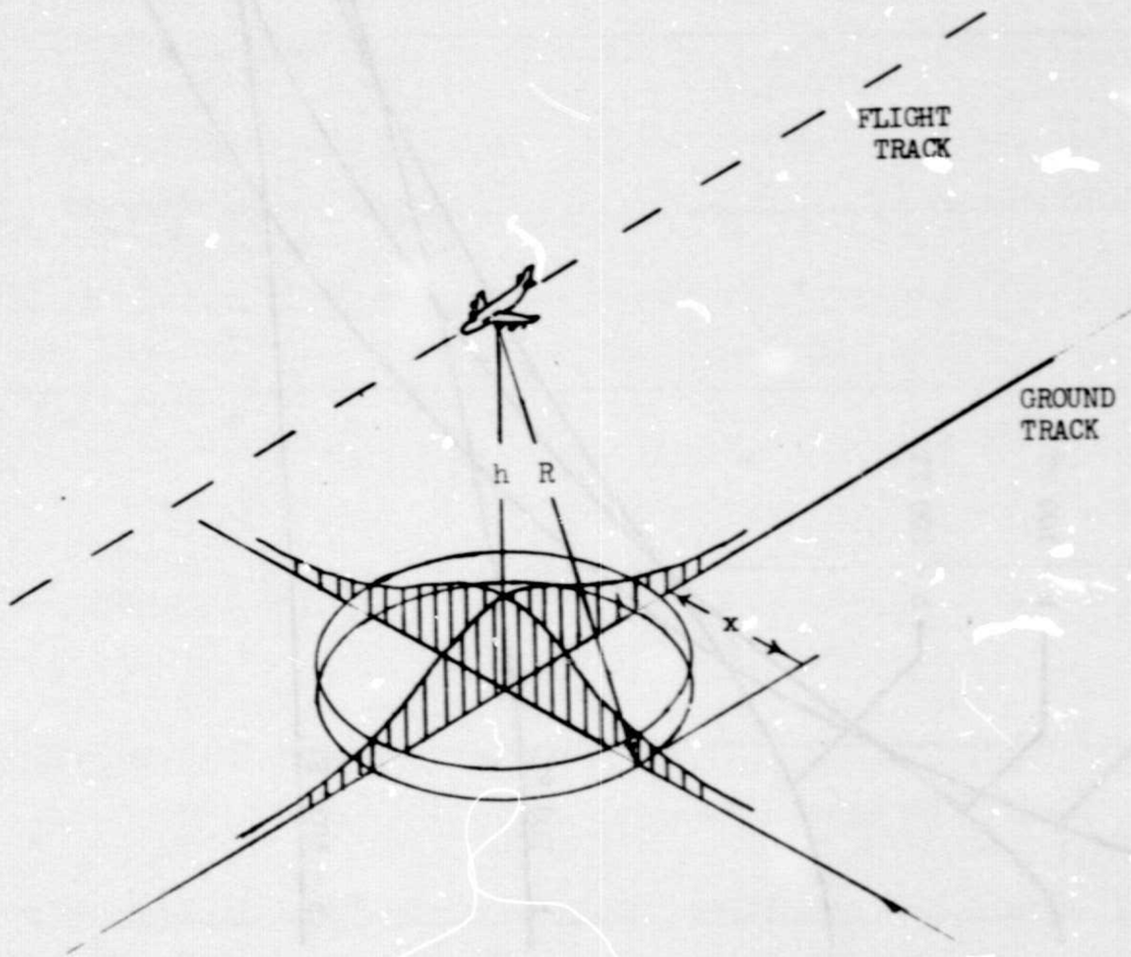


Figure 1. - THE LIFT GENERATED PRESSURE DISTRUBUTION BENEATH AN AIRCRAFT
(ADAPTED FROM REF.1)

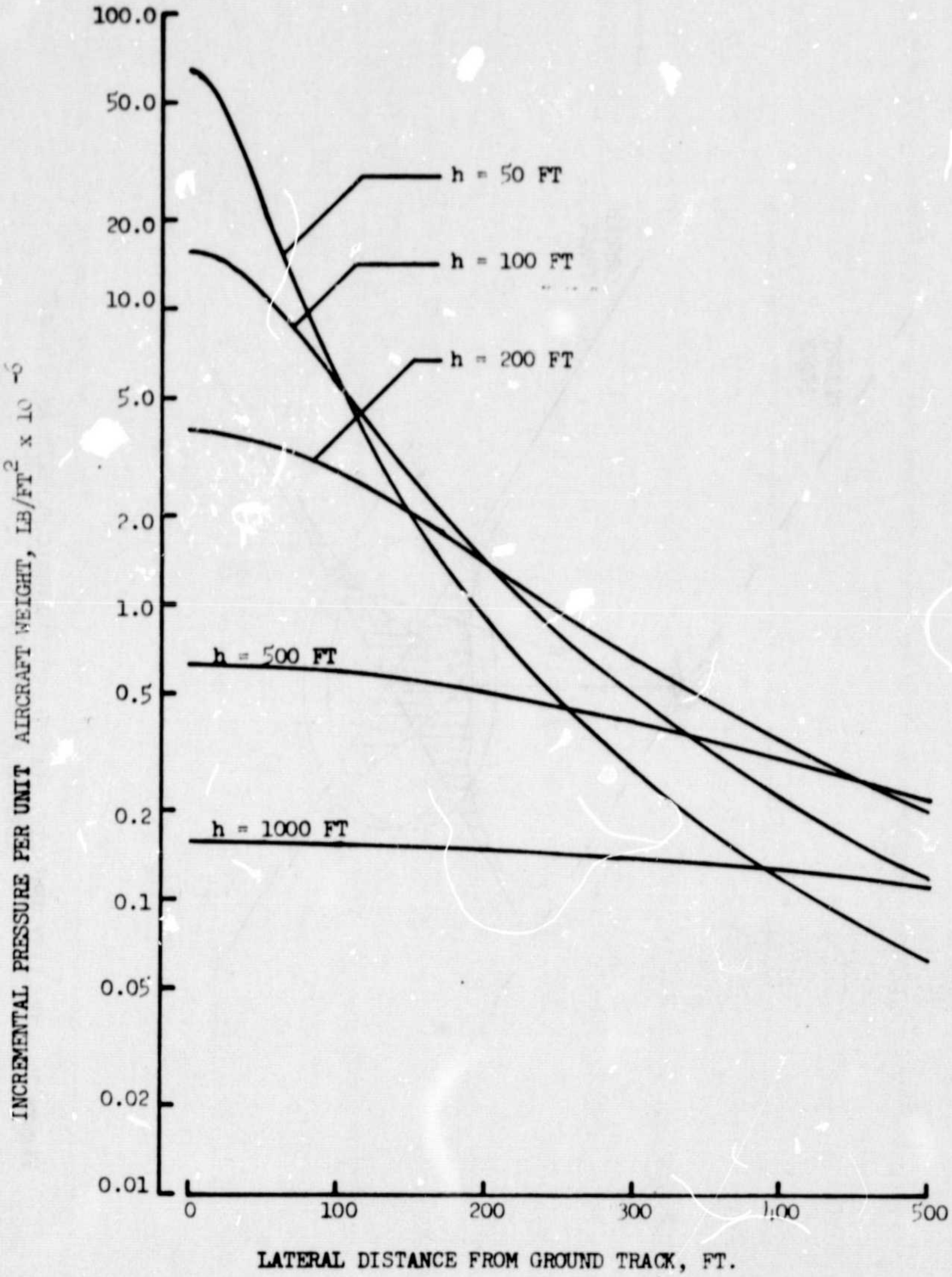


Figure 2. - Calculated incremental pressures per unit aircraft weight as a function of lateral distance from the ground track for altitudes of 50 ft., 100 ft., 200 ft., 500 ft., and 1000 ft.

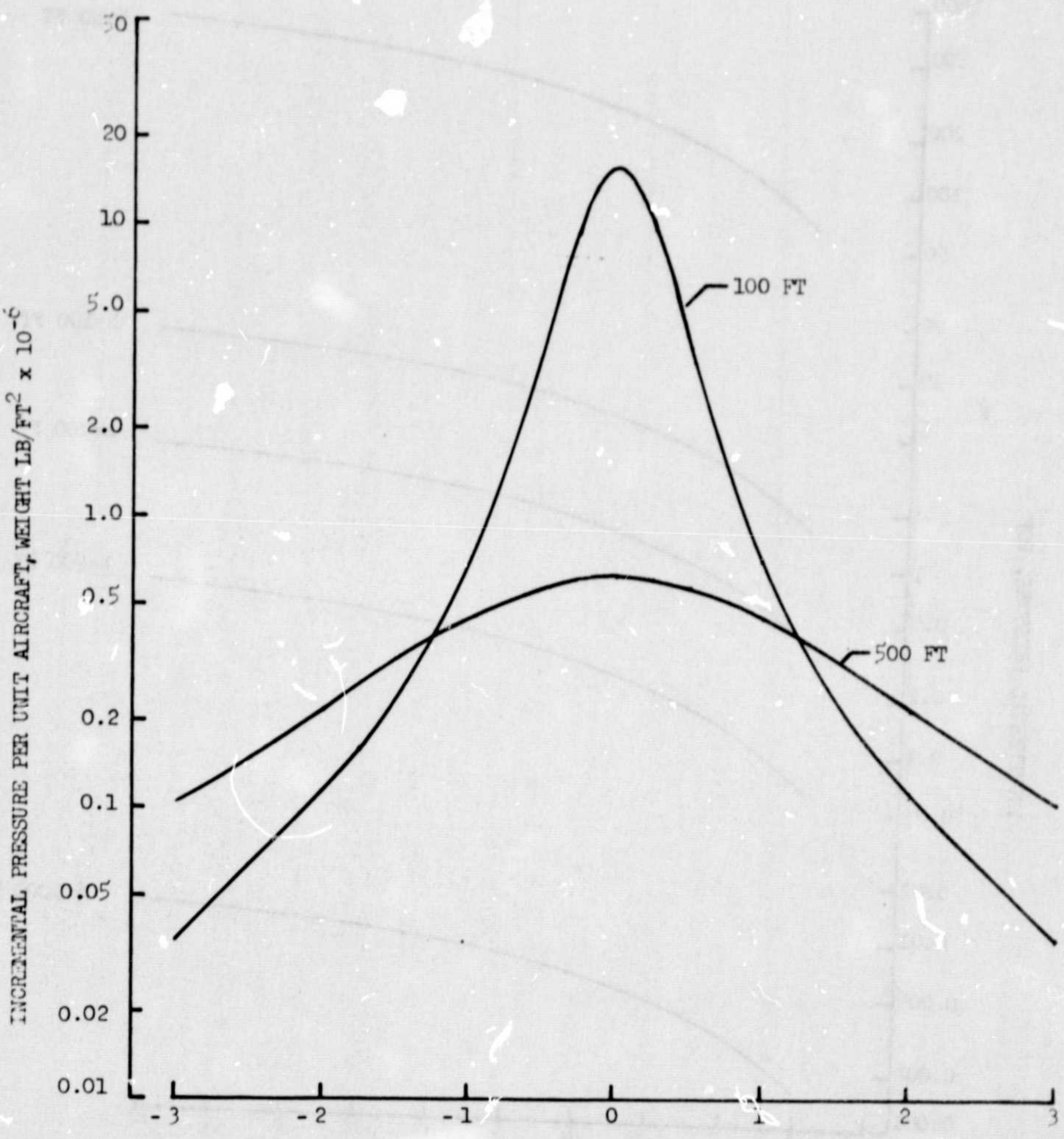


Figure 3. - **Calculated** incremental pressures per unit aircraft weight as function of time. Data are for a point on the ground track and for altitudes of 100 feet and 500 feet.

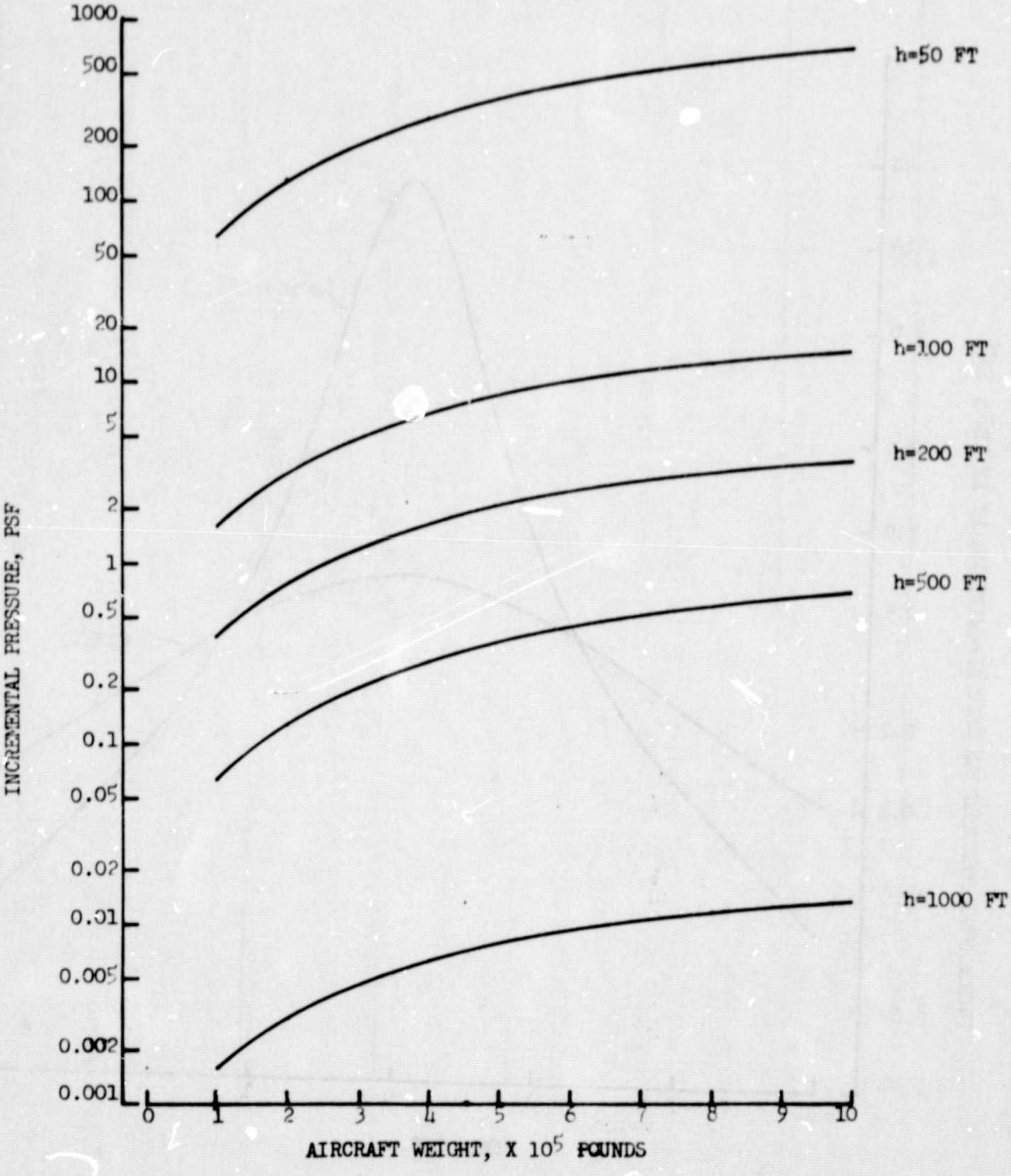


Figure 4. - PREDICTED MAXIMUM INCREMENTAL PRESSURES ON THE GROUND TRACK FOR DIFFERENT AIRCRAFT WEIGHTS AND ALTITUDES

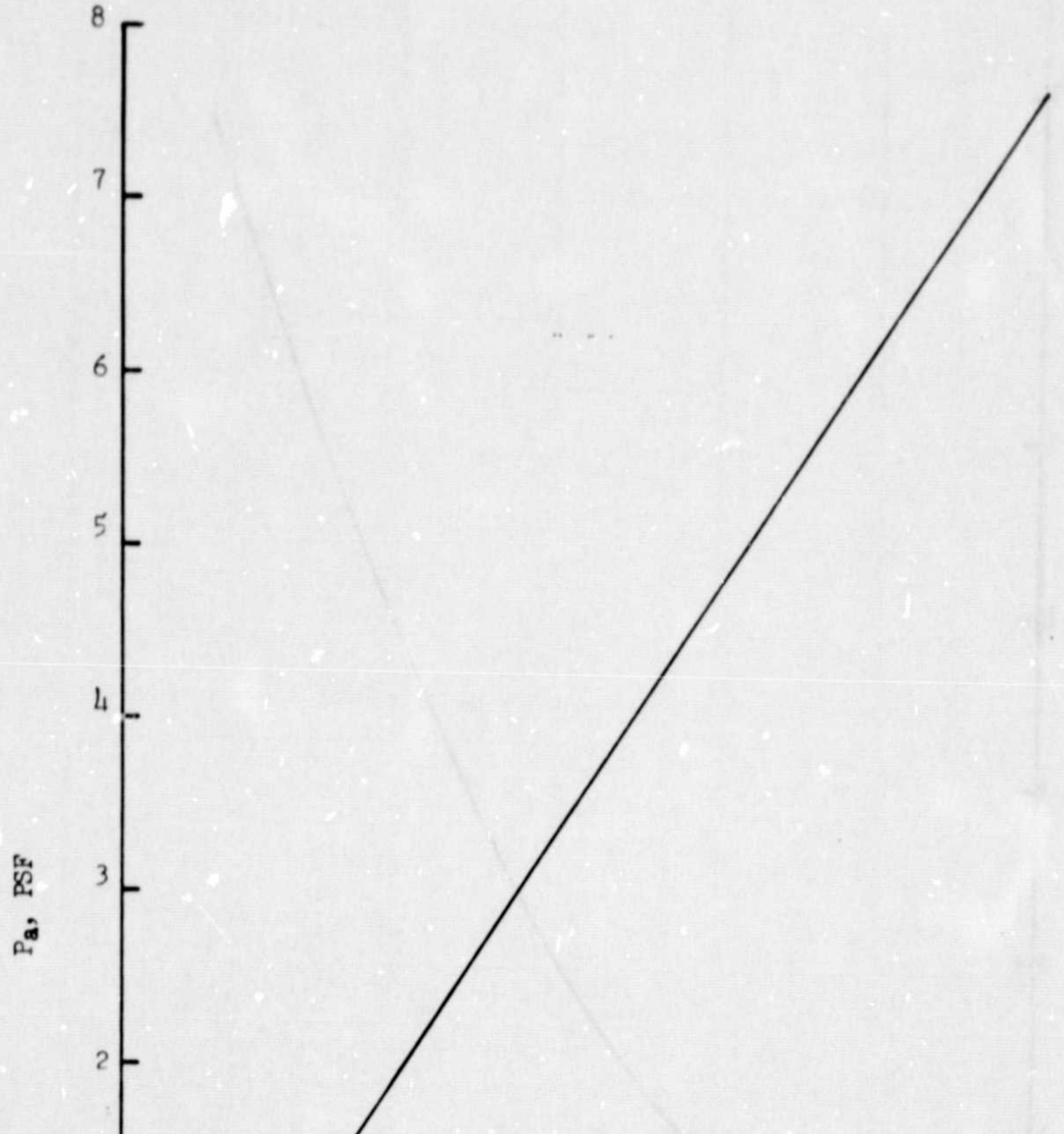


FIGURE 5. - CHANGE IN ATMOSPHERIC PRESSURE AS A FUNCTION OF CHANGE IN ALTITUDE NEAR SEA LEVEL

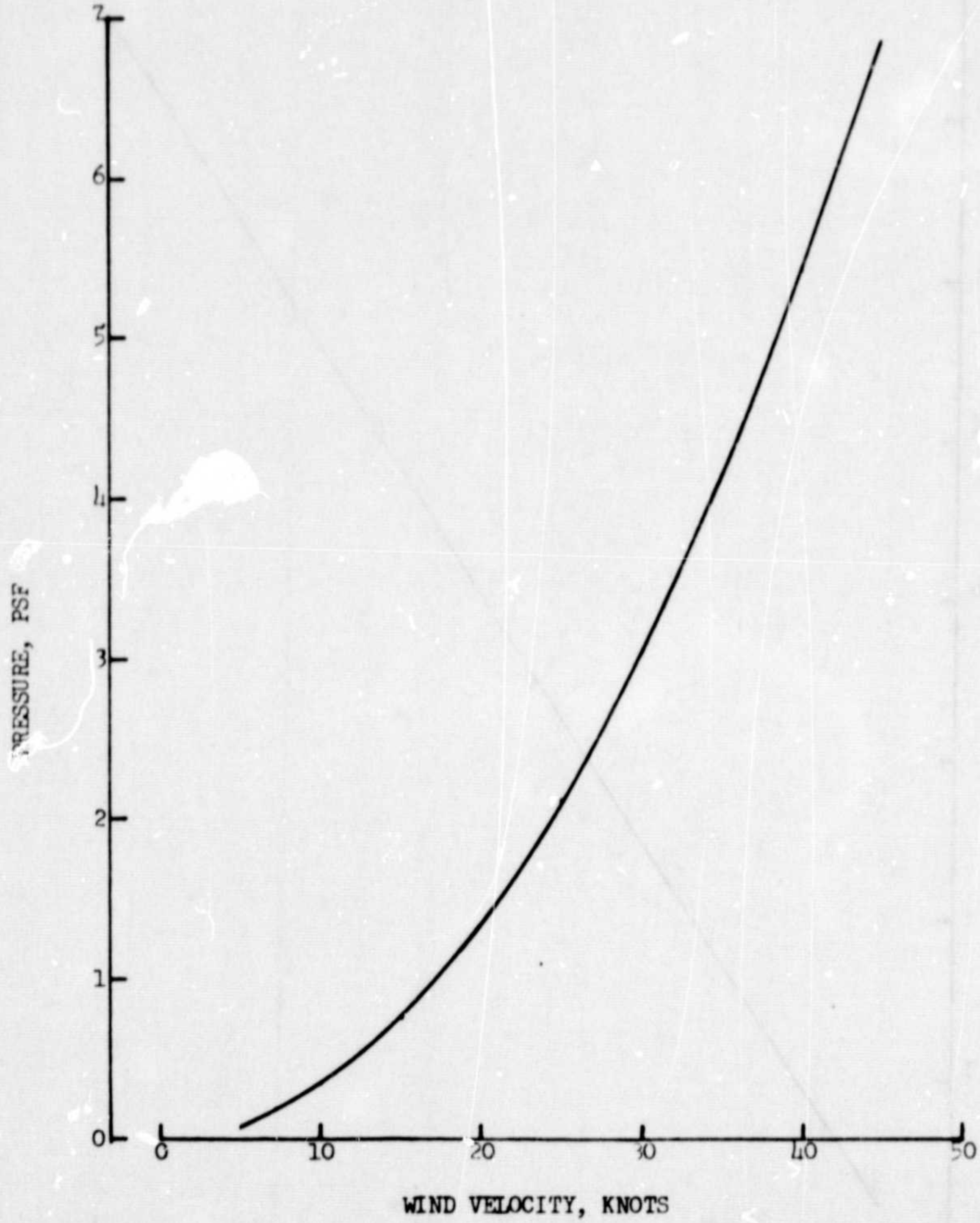


FIGURE 5. - PRESSURE EXERTED BY THE WIND AS A FUNCTION OF VELOCITY.

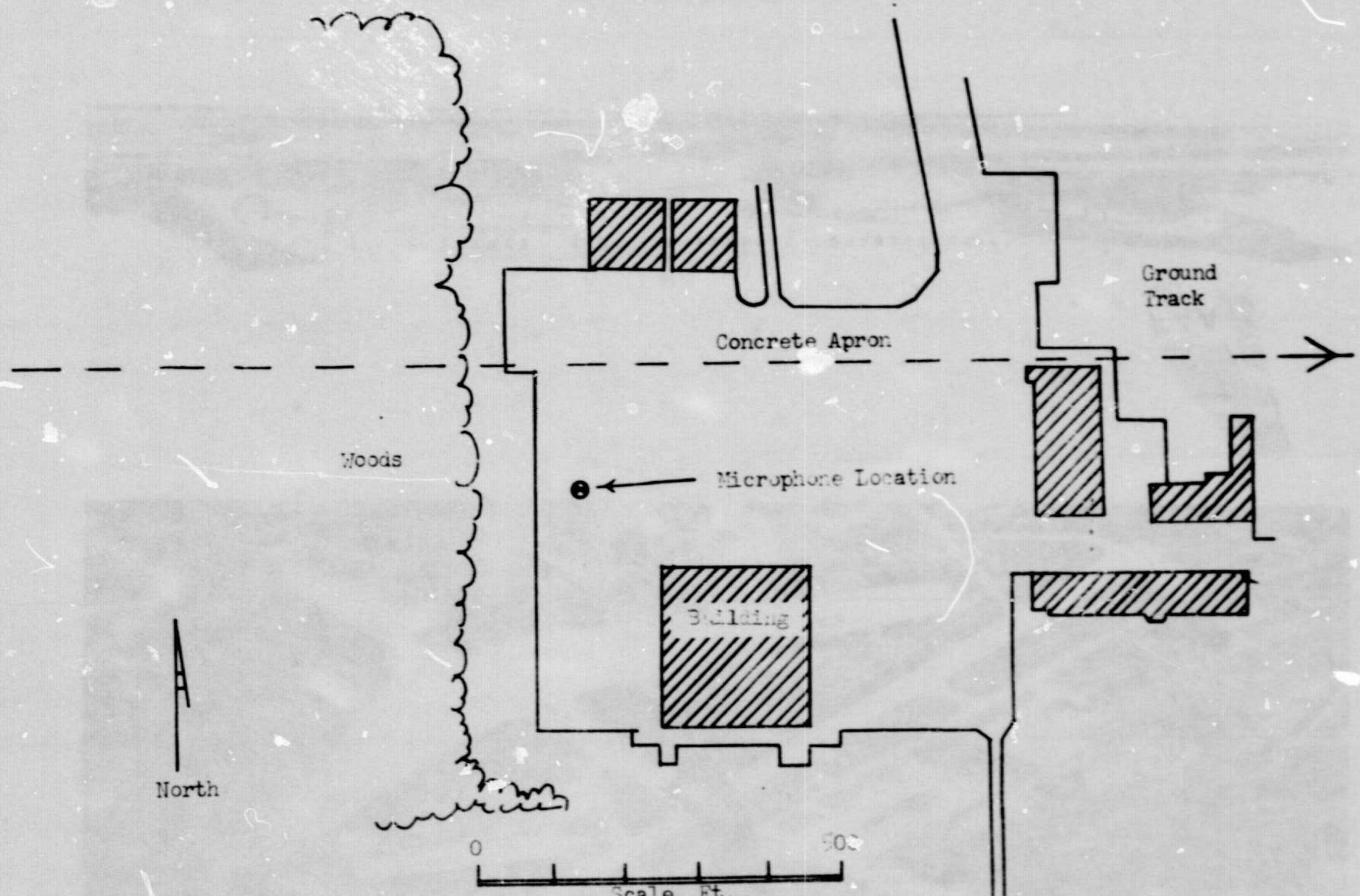
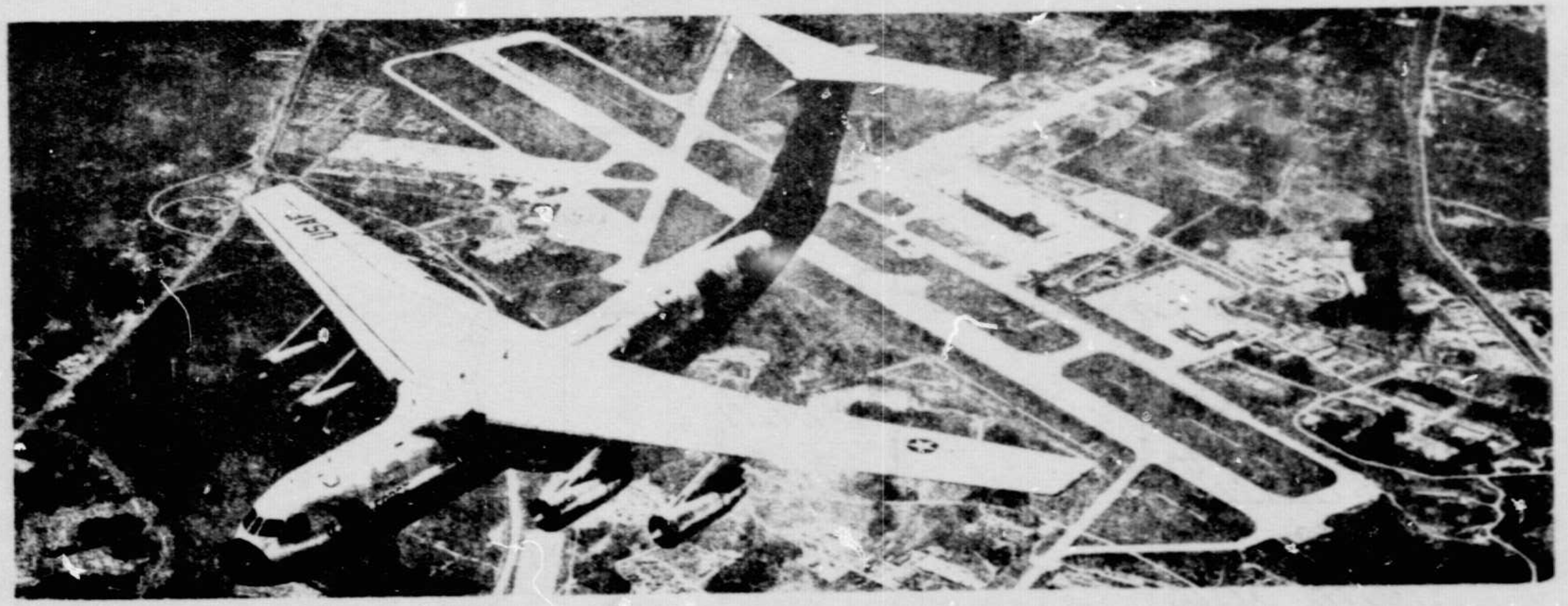


FIGURE . - SKETCH OF TEST AREA SHOWING MICROPHONE LOCATION.



(a) Aircraft A

(b) Aircraft B

Figure 8.- Photographs of the aircraft used in the tests.

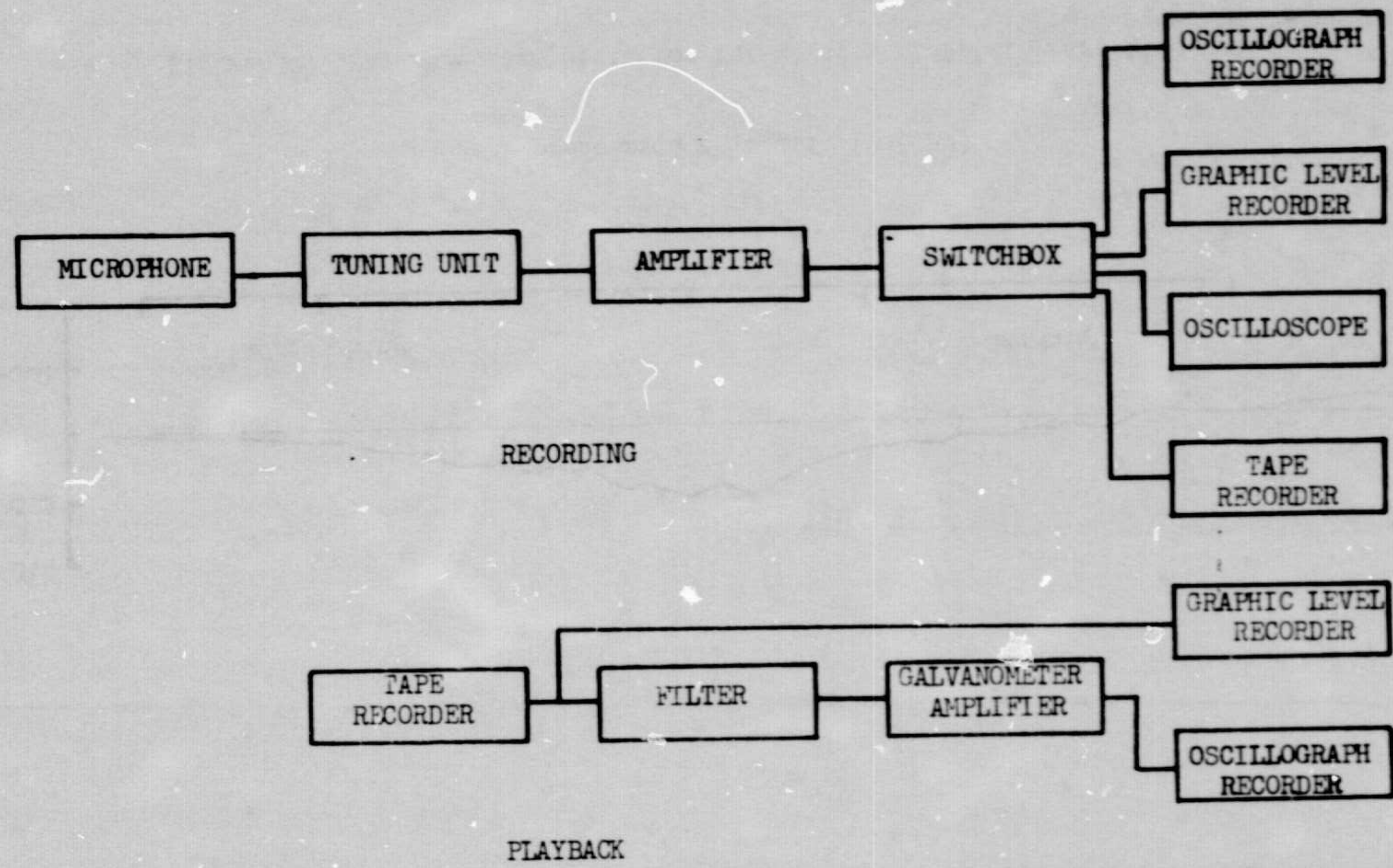
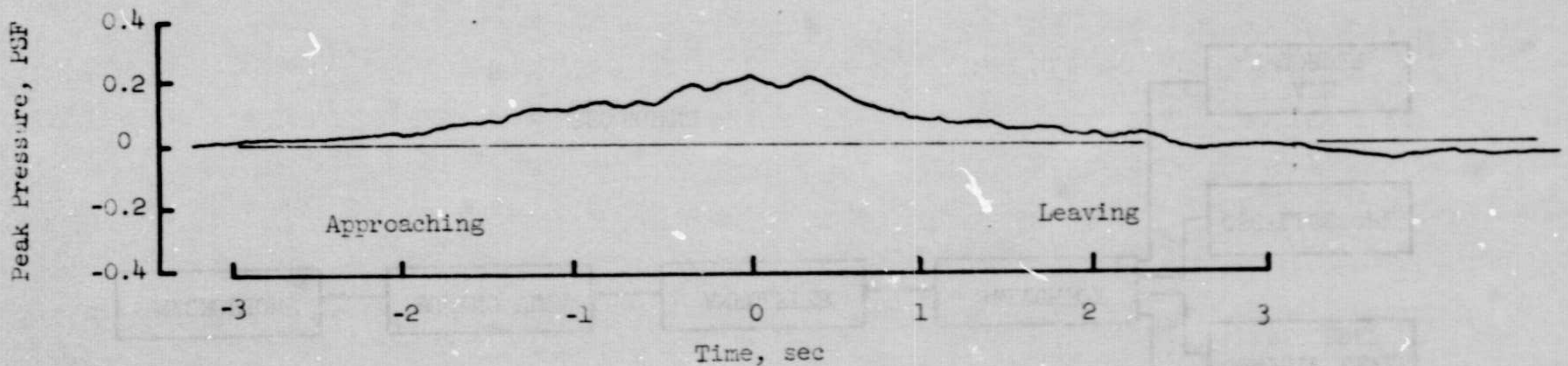


Figure 9.-Block diagrams of the instrument systems used in the tests.

(a) rms Pressure (10-10,000 Hz)



(b) Peak pressure due to lift (0-5 Hz)

Figure 10.- Pressure time histories for mission 61-A (aircraft A)

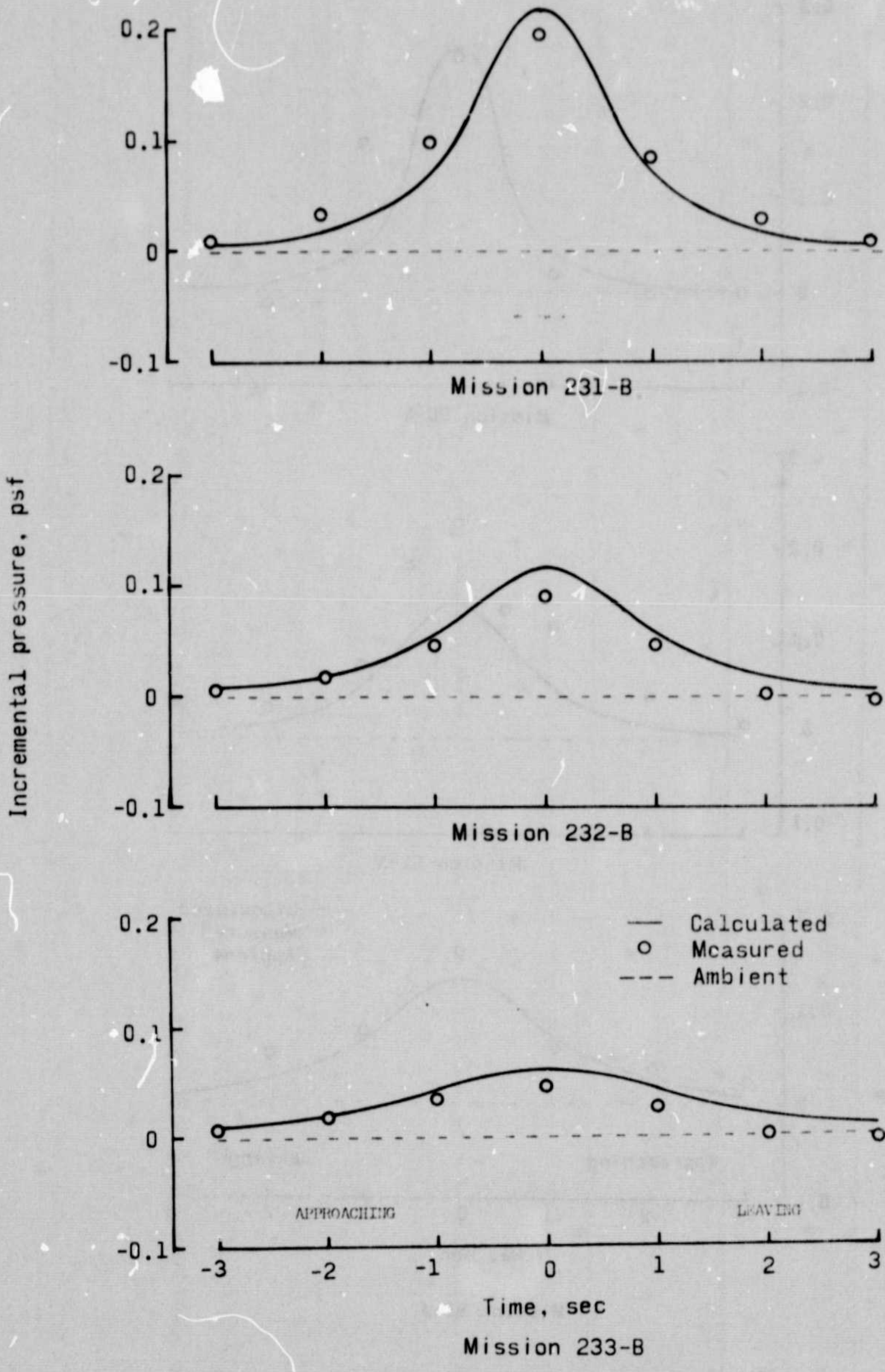


Figure 11.- Calculated and measured incremental pressure time histories for three different missions of aircraft B.

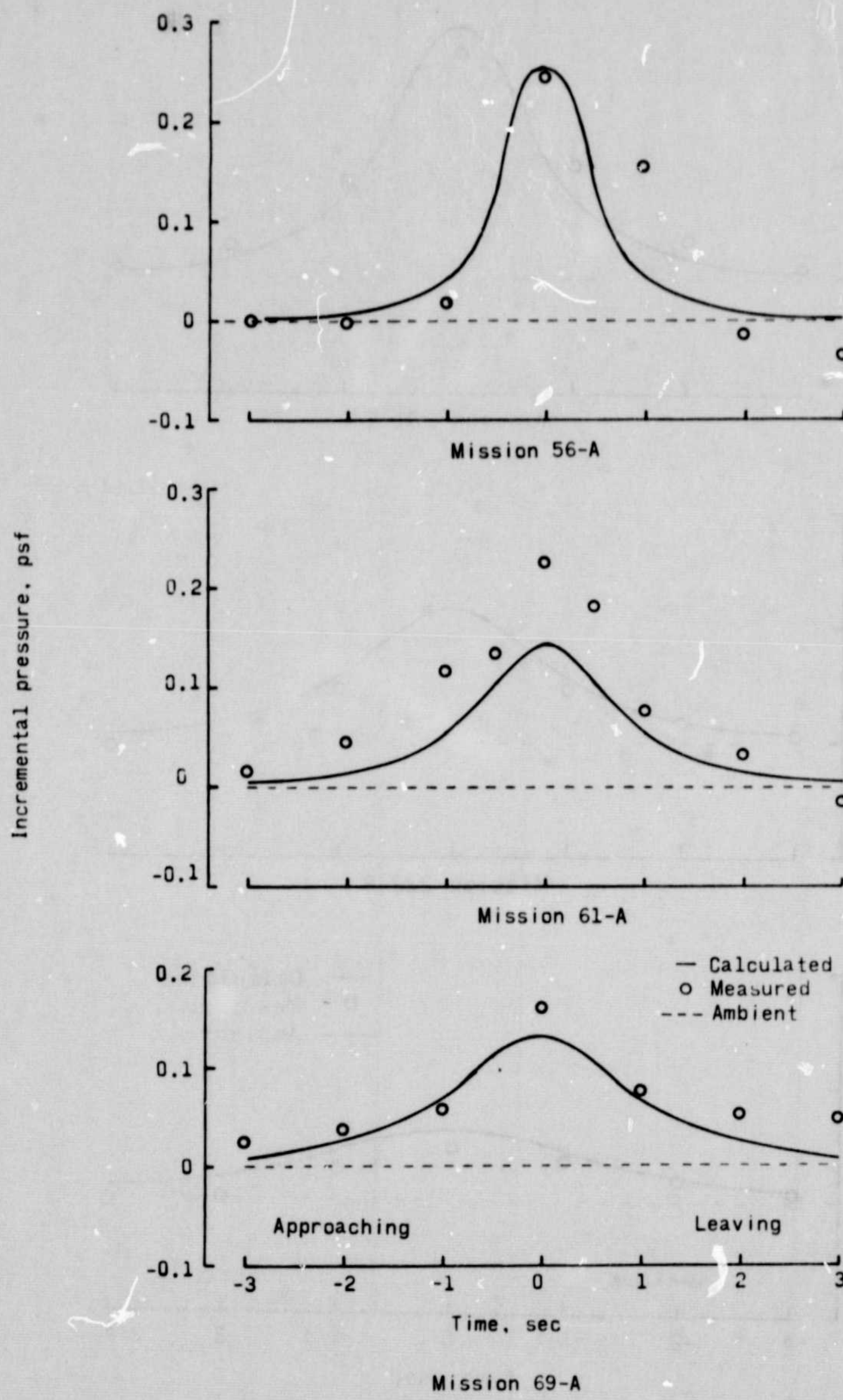


Figure 12.- Calculated and measured incremental pressure time histories for three different missions of aircraft A.