N73-21073

NASA TECHNICAL
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NASA TM X-62,073

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A WIND TUNNEL FLIGHT CORRELATION OF APOLLO 16 SONIC BOOM

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February 1973

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ABSTRACT

A correlation of sonic boom pressure signatures recorded during reentry of the Apollo 16 command module with wind-tunnel signatures extrapolated to flight distances has been made for Mach numbers of 1.83 and 9.71. The flight pressure signatures were recorded by microphones located onboard ships positioned near the ground track whereas the wind tunnel signatures were measured during a test of a 0.016-scale model of the command module. The agreement between estimates based on wind tunnel data and flight measurements was good at Mach 1.83 and Mach 9.71.

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SUMMARY

A correlation of sonic boom pressure signatures recorded during reentry of the Apollo 16 command module with wind tunnel signatures extrapolated to flight distances has been made for Mach numbers of 1.83 and 9.71. The flight pressure signatures were recorded by microphones located onboard ships positioned near the ground track whereas the wind tunnel signatures were obtained from tests of a 0.016 scale model of the command module. The average peak overpressure recorded during reentry differed from the extrapolated wind tunnel peak overpressures by 1.7 N/m^2 (.036 psf) at Mach 9.71 and 3.0 N/m^2 (.063 psf) at Mach 1.83. The flight signatures exhibited multiple shock waves while the extrapolated wind tunnel signatures were N-waves. This difference in signature shape is not understood at this time but may be due to reflected waves from the ship superstructure.

NOTATION

h	flight altitude, meters
l	length of model or full-scale vehicle, meters
M	Mach number
p	reference pressure, N/m^2
γ	flight path angle, degrees, positive above horizon
Δp	sonic boom overpressure, N/m^2
ϕ	ray path angle, degrees; the 0 ray direction is down; positive is left looking forward on aircraft
ψ	heading angle, degrees, north = 0 degrees; positive toward east
$\dot{}$	$\frac{d(\ )}{dt}$

INTRODUCTION

No theoretical methods are available for calculating the sonic boom overpressures generated by blunt vehicles with detached shock wave maneuvering at high Mach numbers. Therefore, sonic boom estimates for space shuttle type vehicles must be based on one of the currently available semi-empirical techniques (references 1 and 2; with these techniques near-field pressure signatures measured in wind tunnels are extrapolated to the far field). In order to extend the range of conditions for which these techniques have been validated, experiments were conducted using the Apollo 15 and 16 command modules as the test vehicles. The Apollo 15 study was reported in reference 3. The Apollo 16 results are reported herein. Personnel of the Langley Research Center employed microphones placed onboard ships located along the ground track of the command modules to obtain measurements of sonic boom overpressure generated during reentry into the Earth's atmosphere. These overpressures were compared with estimates based on the wind tunnel data of references 4 and 5 and the extrapolation procedure of reference 1.

TEST CONDITIONS

A photograph of the full-scale command module is shown in figure 1(a). A report giving a complete description of the technique used to record the pressure signatures generated by the command module during reentry and the resulting measurements is being prepared by Langley Research Center and will be published at a later date.

A 0.016-scale model of the Apollo command module (figure 1(b)) was tested at Mach numbers of from 1.5 to 10 in the Jet Propulsion Laboratory supersonic and hypersonic wind tunnels. A complete description of the test conditions along with the wind tunnel pressure signatures are presented in references 4 and 5.

RESULTS AND DISCUSSION

The reentry trajectory data for Apollo 16 is given in figure 2. The ground track along with the locations of the two ships with onboard microphones used to record the sonic boom overpressures generated during reentry are shown in figure 3.

The flight data (figure 2) and the pressure signatures measured in the wind tunnel (references 4 and 5) were used to predict the ground overpressures generated by the command module during reentry into the Earth's atmosphere. The signatures for Mach 1.83 and Mach 9.71 shown in figure 4 were obtained by interpolation of the wind tunnel data of references 4 and 5. In addition, the signatures were extrapolated to an h/l of 9.6 (figure 4) using the strong shock theory of reference 5. This was necessary because some of the wind tunnel signatures of reference 5 exhibited shock strengths too large to permit use of the extrapolation technique of reference 1 which was developed for weak shock waves.

The first step in the calculation of the ground overpressures was to determine the point on the flight path at which the pressure signals recorded by the onboard microphones of both ships originated. This was accomplished by choosing a point on the flight trajectory and then calculating the ground-ray intersection for the ray emanating from that point. If the intersection was different from the coordinates of the ship another point on the flight path was chosen and the procedure was repeated. This procedure was repeated until the difference between the calculated ground-ray intersection and the ship's coordinates was less than 100 meters (further iteration was found to have a negligible effect on the level of the ground overpressure). The results of the iteration showed that the pressure signal recorded onboard the USS Ponchatoula originated at Mach 9.71 and the signal received by the USS Ticonderoga originated at Mach 1.83.

The accelerations required in the extrapolation of the tunnel signatures to flight distances were obtained by measuring the slopes of the Mach number, flight path angle and heading angle curves shown in figure 2. The atmosphere employed in the extrapolation was taken from the 1966 U. S. standard atmosphere supplements for 15 degrees north, annual (reference 6). The wind velocity was assumed to be 0 at all altitudes since atmospheric soundings were not taken during reentry. A total of 8 microphones were placed onboard the ships to obtain flight measurements. A photograph showing the location of the microphones on the ships is shown in figures 5(a) and 5(b). The USS Ponchatoula which received the signal that originated at M = 9.71 had 7 microphones. Five of these were located on the deck and two above on the mast. Data from the 5 deck mounted microphones only was used in the comparisons of this report. The average of the five peak overpressures is 15.3 N/m^2 (.32 psf) for Mach 9.71. The calculated overpressure for this Mach number is 17.0 N/m^2 (.355 psf). The USS Ticonderoga had only one microphone onboard which measured a peak overpressure of 31.1 N/m^2 (.65 psf) for Mach 1.83. The predicted peak overpressure for the case is 34.1 N/m^2 (.71 psf).

Comparison of extrapolated wind tunnel data with flight measurements are shown in figures 6 and 7. Only the positive portion of the signatures predicted from the wind tunnel measurements have been shown at both Mach numbers since shockwave reflections from the floor of the wind tunnel prevented determination of the complete pressure signatures at the Mach numbers of interest in this study (references 4 and 5). The extrapolated wind tunnel pressure signature for Mach 9.71 is shown superimposed on each of the flight signatures recorded on the deck of the USS Ponchatoula (see figure 7).

The multiple shock waves suggested by the flight pressure signatures have not been satisfactorily explained. Some differences in signature shape might be expected for the following reasons: First, the flow conditions in the tunnel were different from the conditions present in the atmosphere during reentry (e.g. temperature, Reynolds' number, density and humidity); second, the model wake was different from the wake behind the full-scale vehicle due to sting effects; and third, shock reflections from the ship superstructure may have produced the peculiarities of the signatures measured on board the ships. However, the parameter of primary interest is the peak overpressure and the agreement between estimates and measurements for this parameter is good. A summary of the predicted overpressures for each Mach number is shown in figure 8. The flight measurements are shown parenthetically.

CONCLUDING REMARKS

A wind tunnel-flight correlation of the sonic boom characteristics of the Apollo 16 command module has been made. These results in conjunction with those of reference 3 indicate that the maximum overpressure generated by a blunt, maneuvering vehicle with strong detached shock waves can be satisfactorily predicted using currently available sonic boom extrapolation methods.

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1. Thomas, C. L.: Extrapolation of Sonic Boom Pressure Signatures by the Waveform Parameter Method. NASA TN D-6832, June 1972.

2. Hayes, W. D., Haefeli, R. C., and Kulsrud, H. E.: Sonic Boom Propagation in a Stratified Atmosphere, with Computer Program. Rept. No. 116, Aeronautical Research Associates of Princeton, Inc., Dec. 1968.

3. Hicks, Raymond M., Mendoza, Joel P., and Garcia, Frank: A Wind Tunnel-Flight Correlation of Apollo 15 Sonic Boom. NASA TM X-62,111, January 28, 1972.

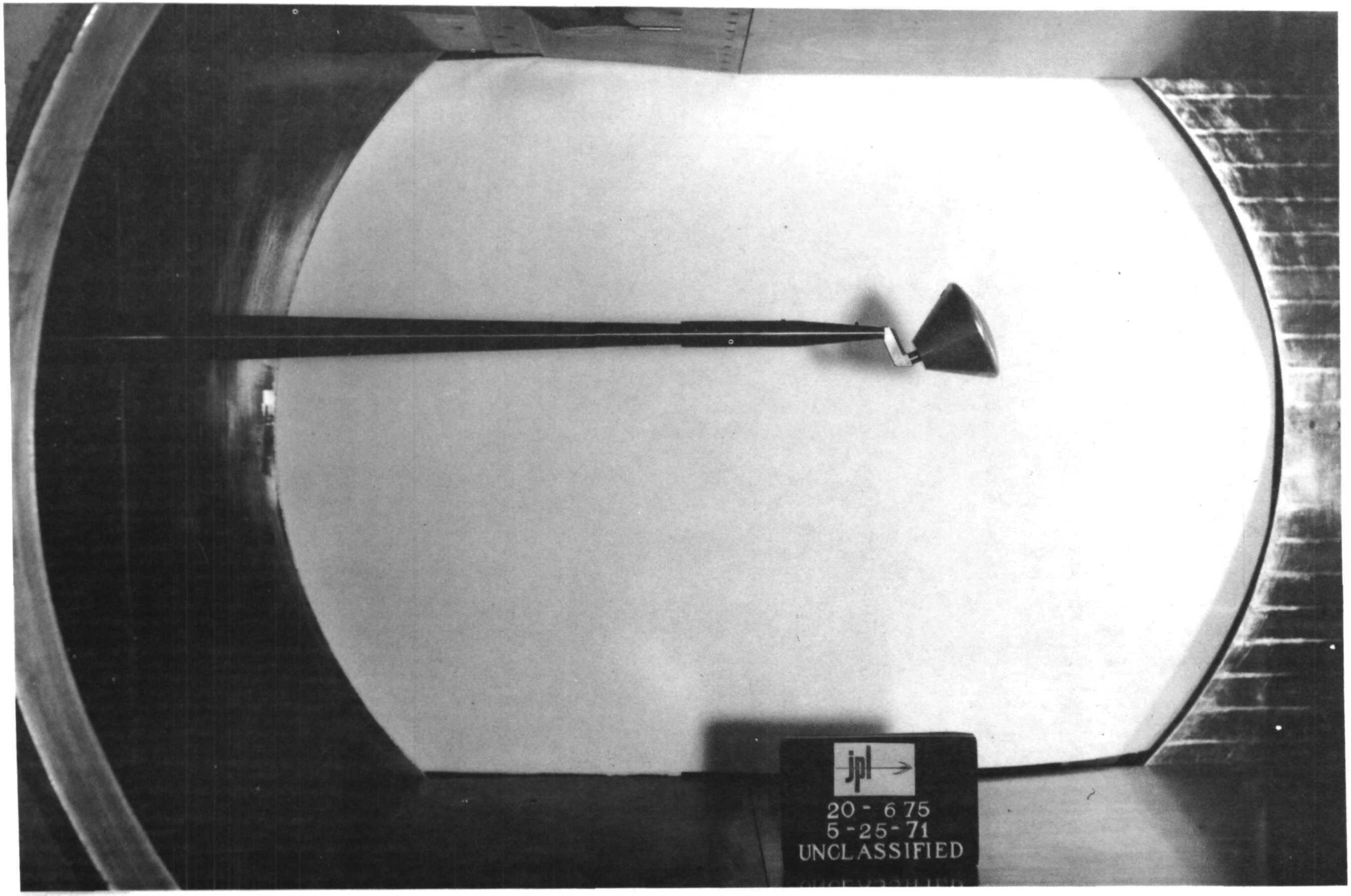
4. Mendoza, Joel P., and Hicks, Raymond M.: Wind Tunnel Pressure Signatures for a .016-Scale Model of the Apollo Command Module. NASA TM X-62,047, July 14, 1971.

5. Hicks, Raymond M., Mendoza, Joel P., and Thomas, Charles L.: Pressure Signatures for the Apollo Command Module and the Saturn V Launch Vehicle with a Discussion of Strong Shock Extrapolation Procedures. NASA TM X-62,117, April 6, 1972.

6. U. S. Standard Atmosphere Supplements, 1966. Environmental Science Services Administration, National Aeronautics and Space Administration, United States Air Force.

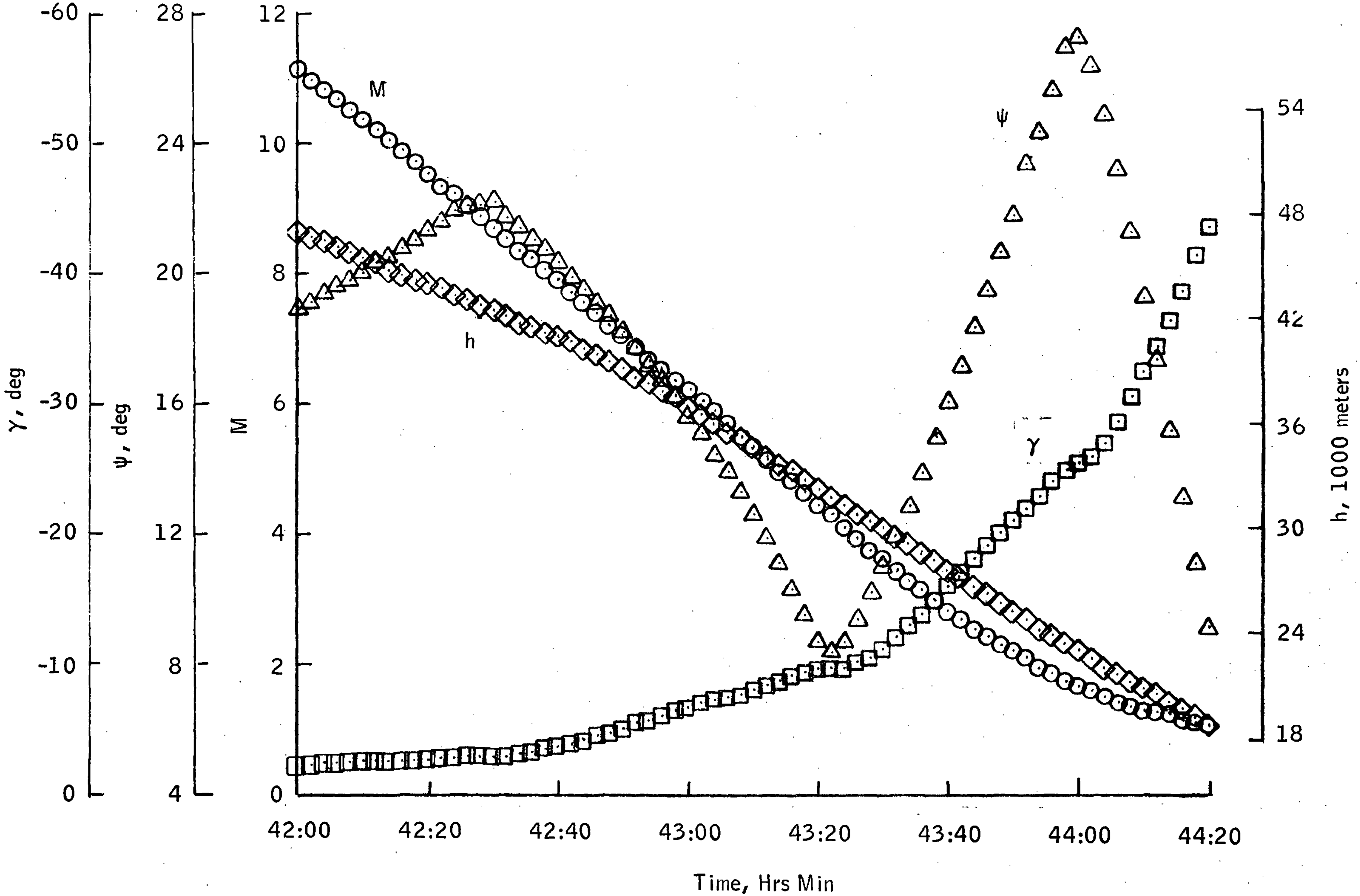
(a) Full scale vehicle.

Figure 1.- Photograph of an Apollo Command Module.



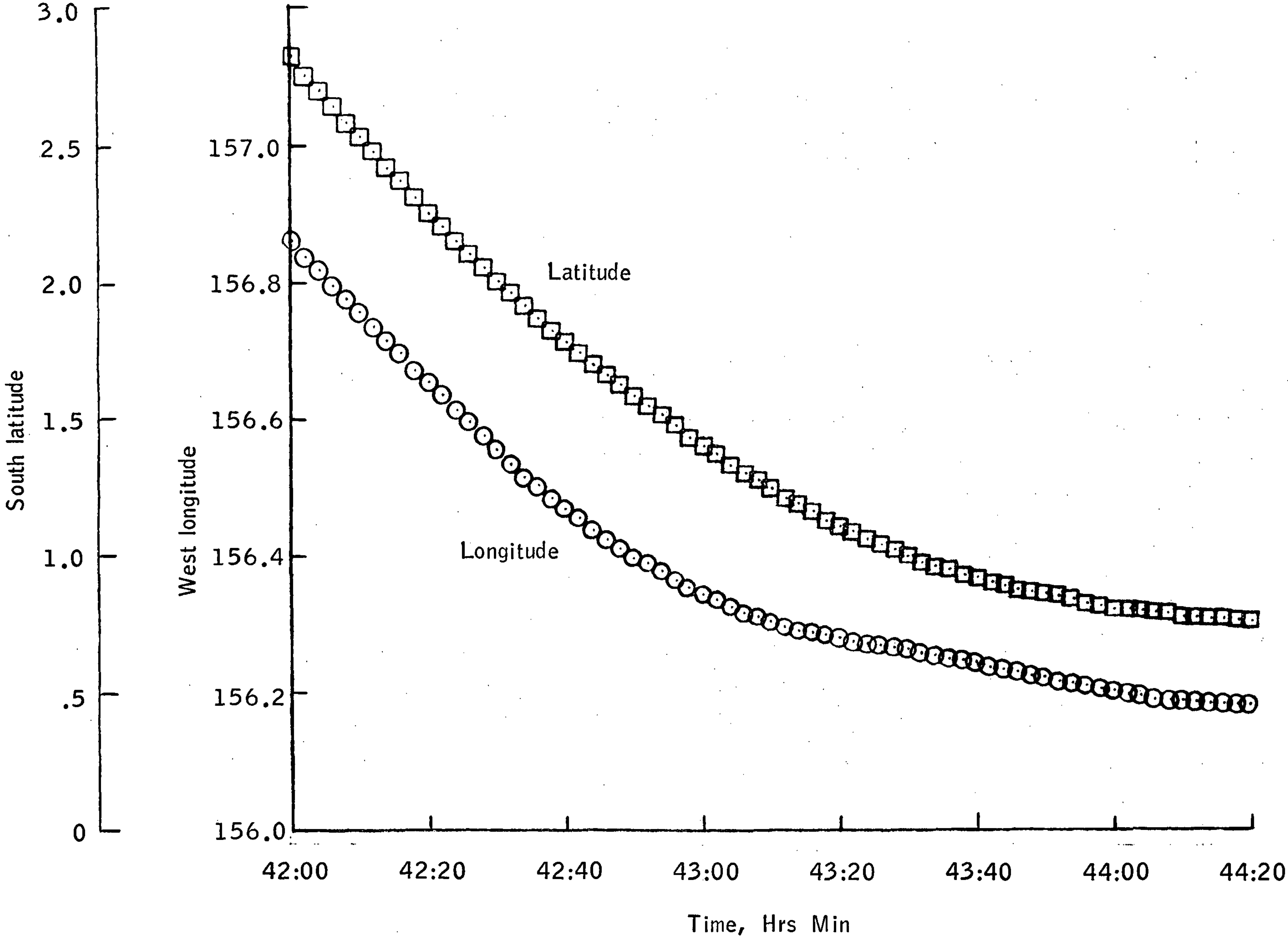
(b) Installation photograph showing model in 20-inch Supersonic Wind Tunnel at the Jet Propulsion Laboratory

Figure 1.- Concluded.



(a) Flight path angle, heading angle, Mach number and attitude.

Figure 2.- Apollo 16 reentry flight data.



(b) Longitude and latitude

Figure 2.- Concluded.

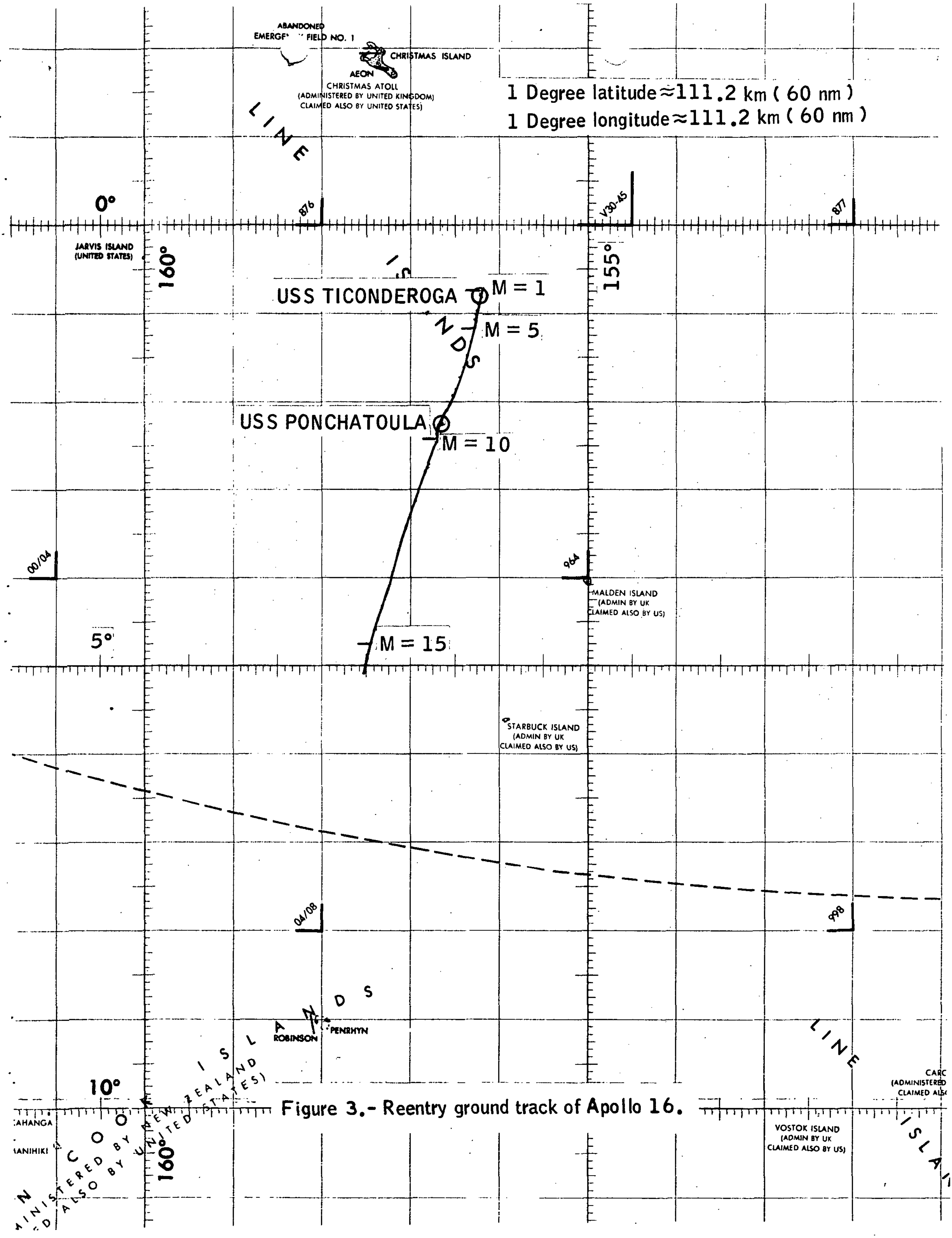


Figure 3.- Reentry ground track of Apollo 16.

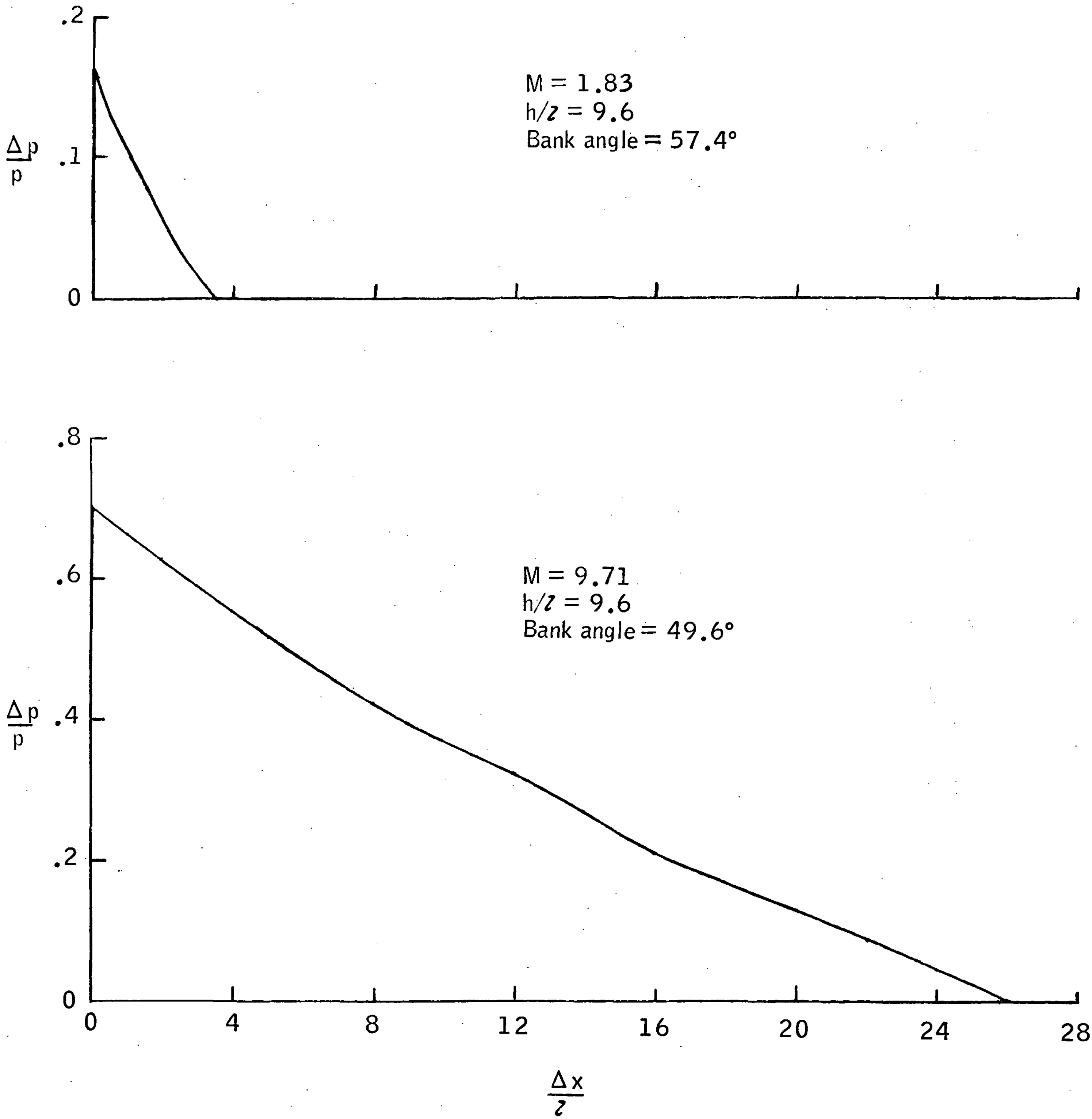
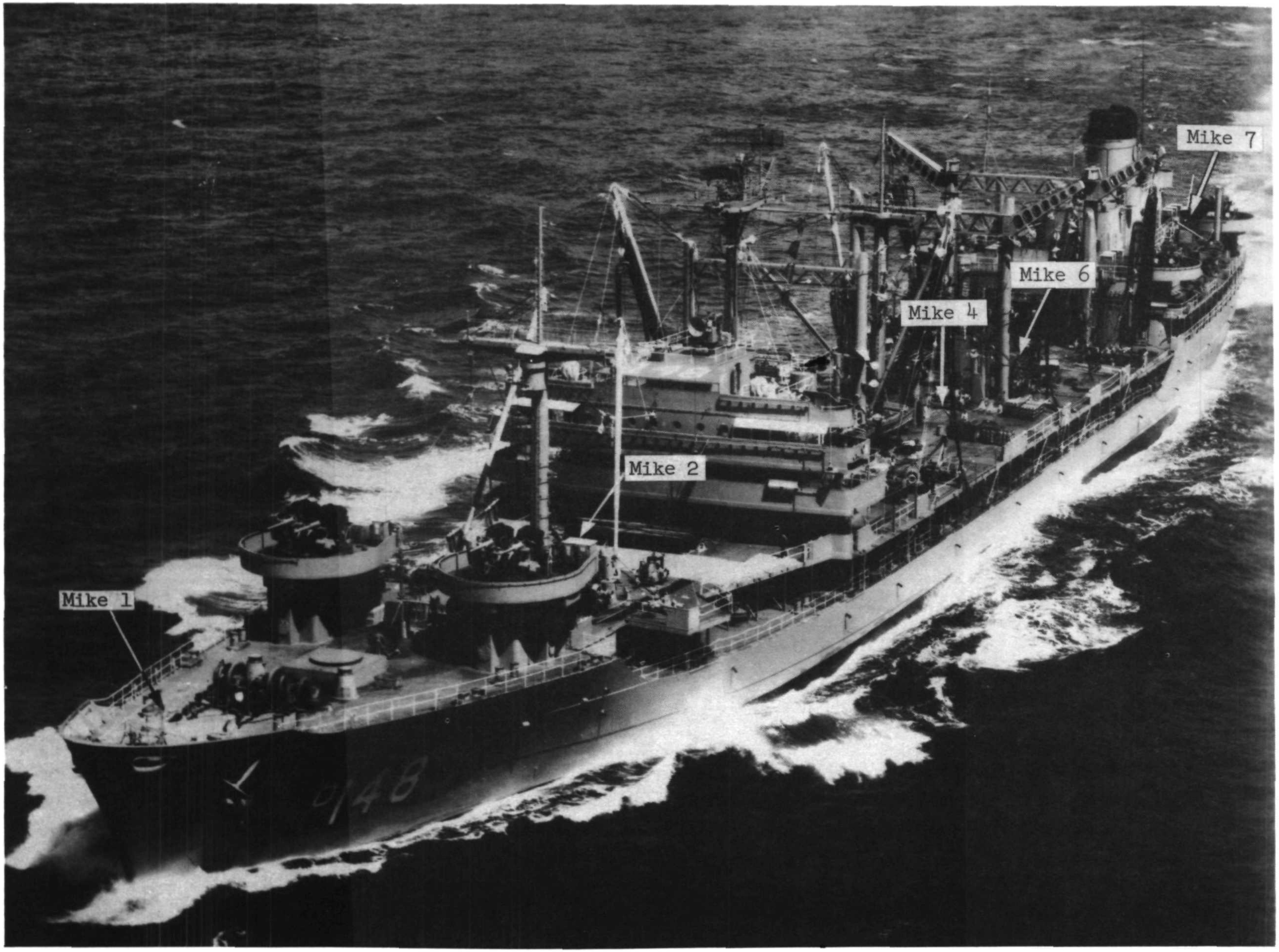


Figure 4.- Wind tunnel pressure signatures.



(a) USS Ponchatoula.

Figure 5.- Photograph showing location of microphones.

(b) USS Ticonderoga.

Figure 5.- Concluded.

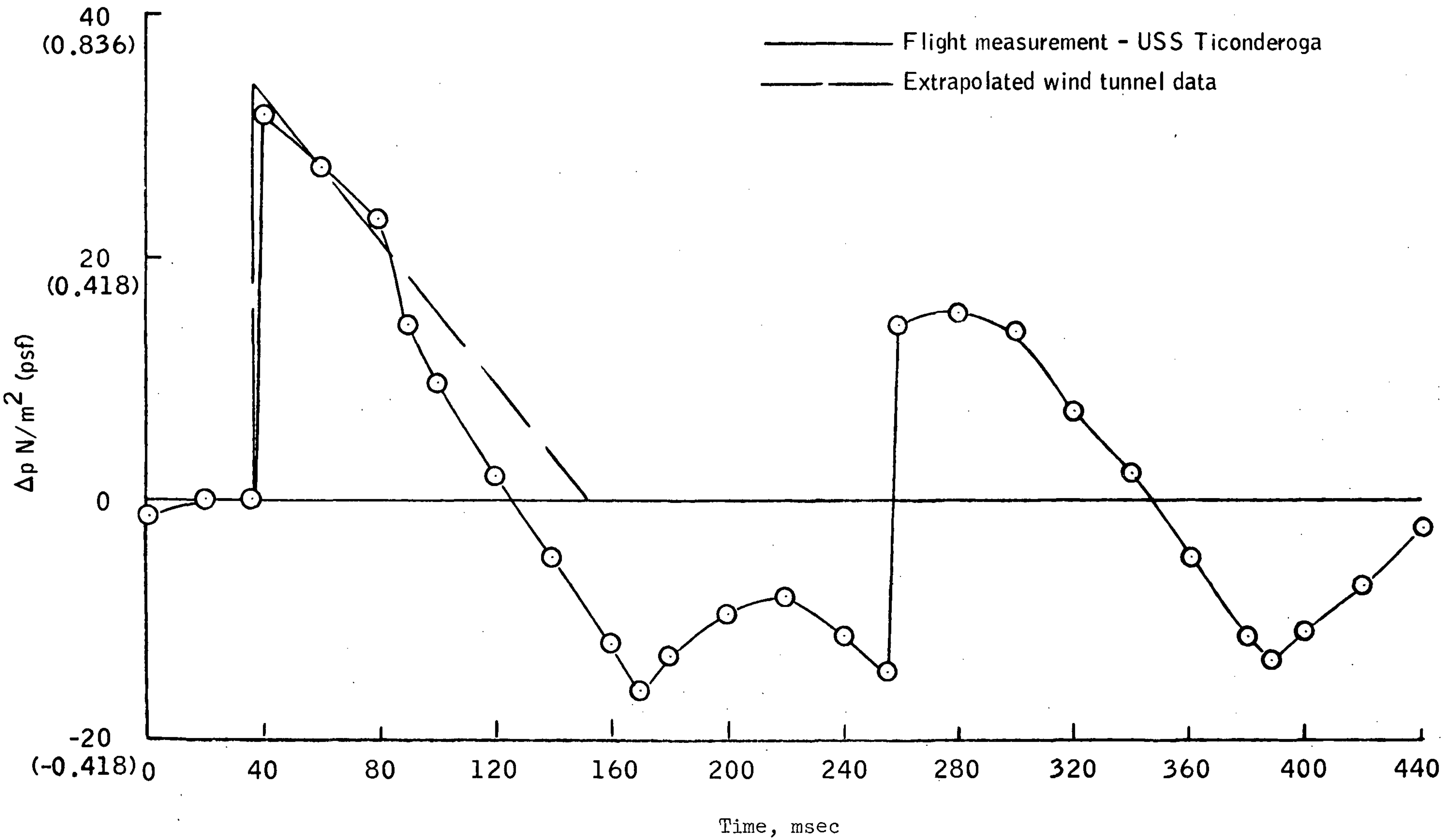
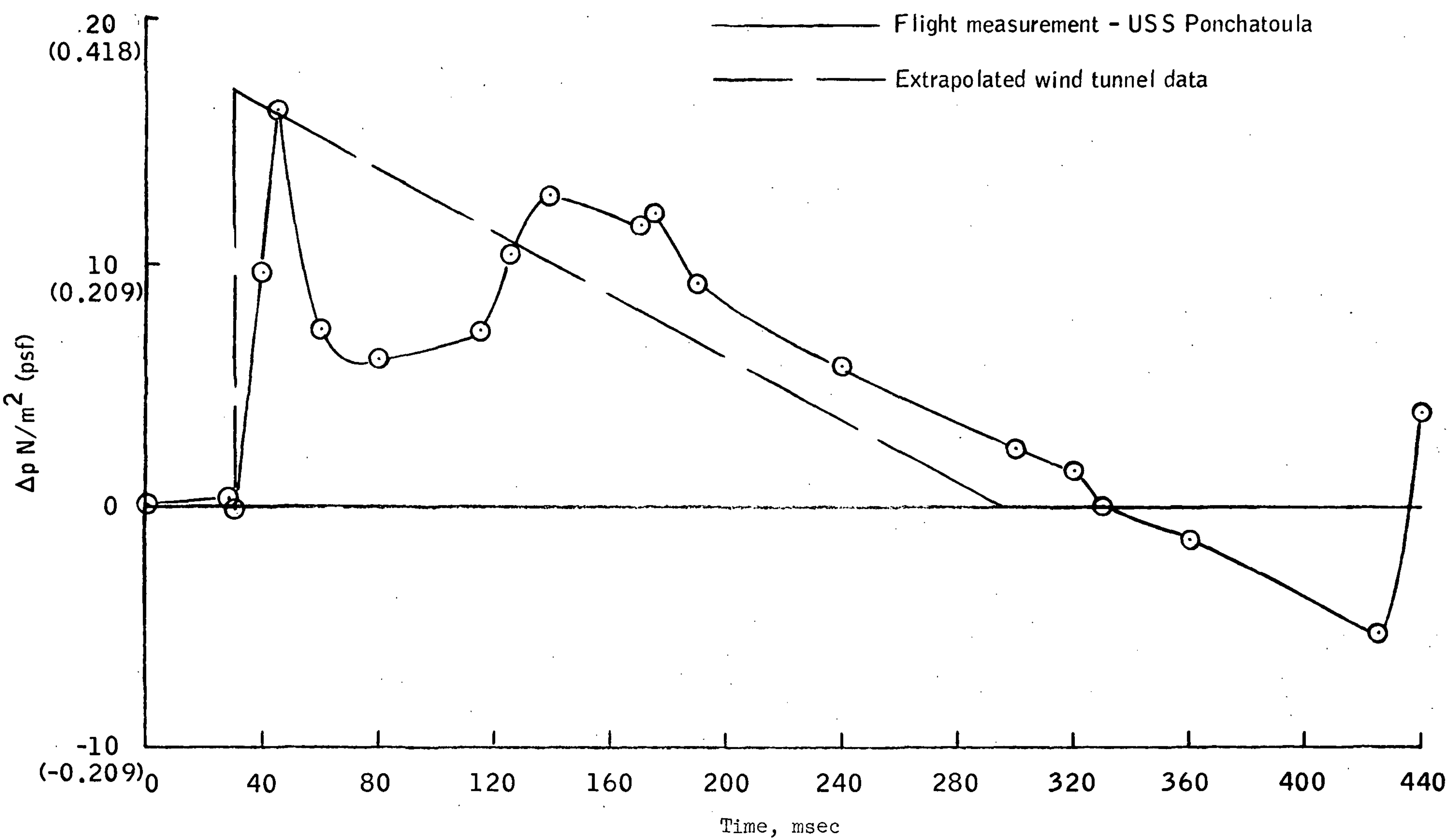
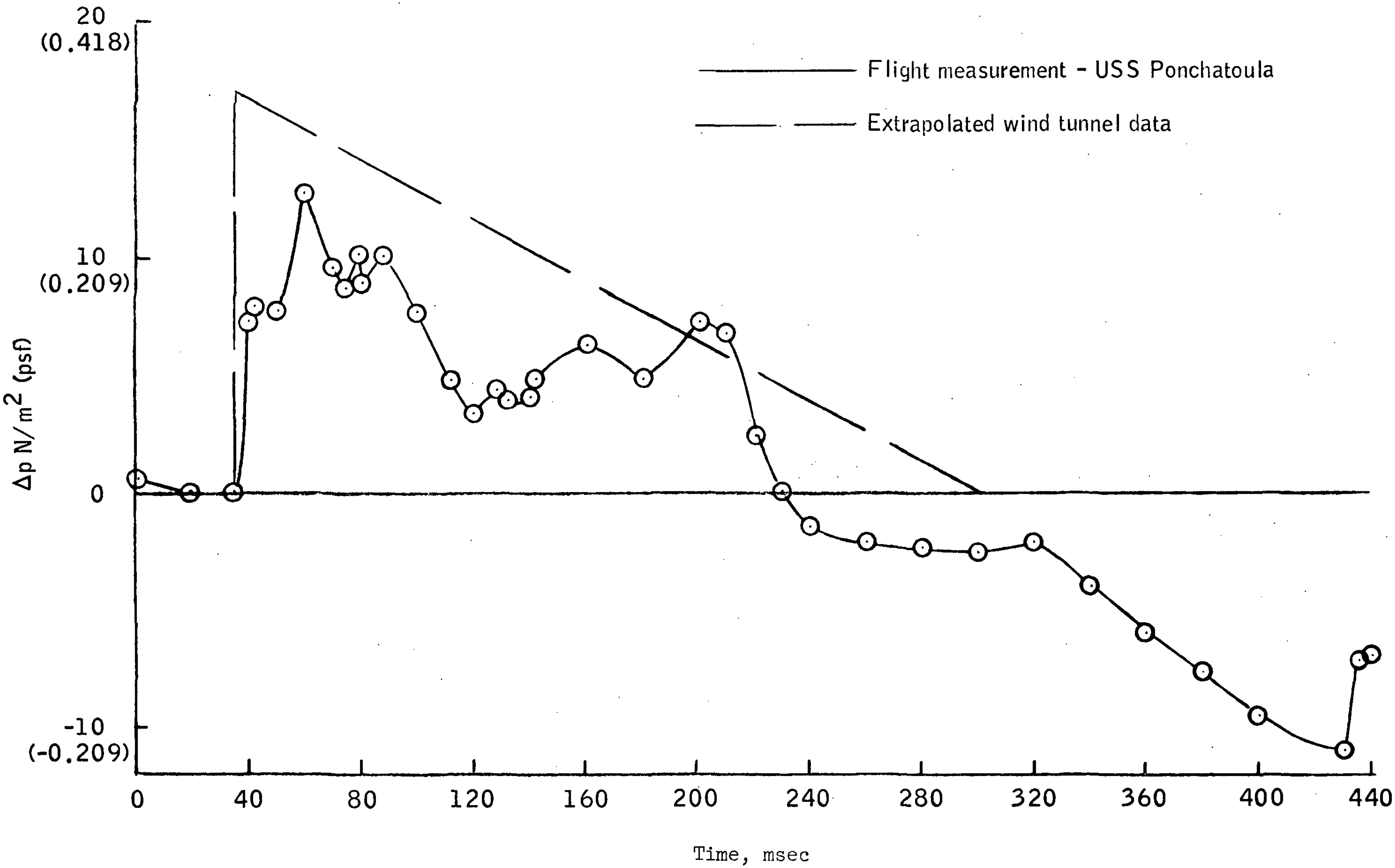


Figure 6.- Apollo 16 command module wind tunnel-flight correlation; $M = 1.83$, $\bar{h} = 23{,}652$ m ($77{,}\bar{5}99$ ft), $\psi = 26.3°$, $\gamma = -24.5°$, $\dot{M} = -.0488$/sec, $\dot{\psi} = 0.6°$/sec, $\dot{\gamma} = -0.43°$/sec, bank angle = $-57.4°$ $\Phi = 4.25°$.



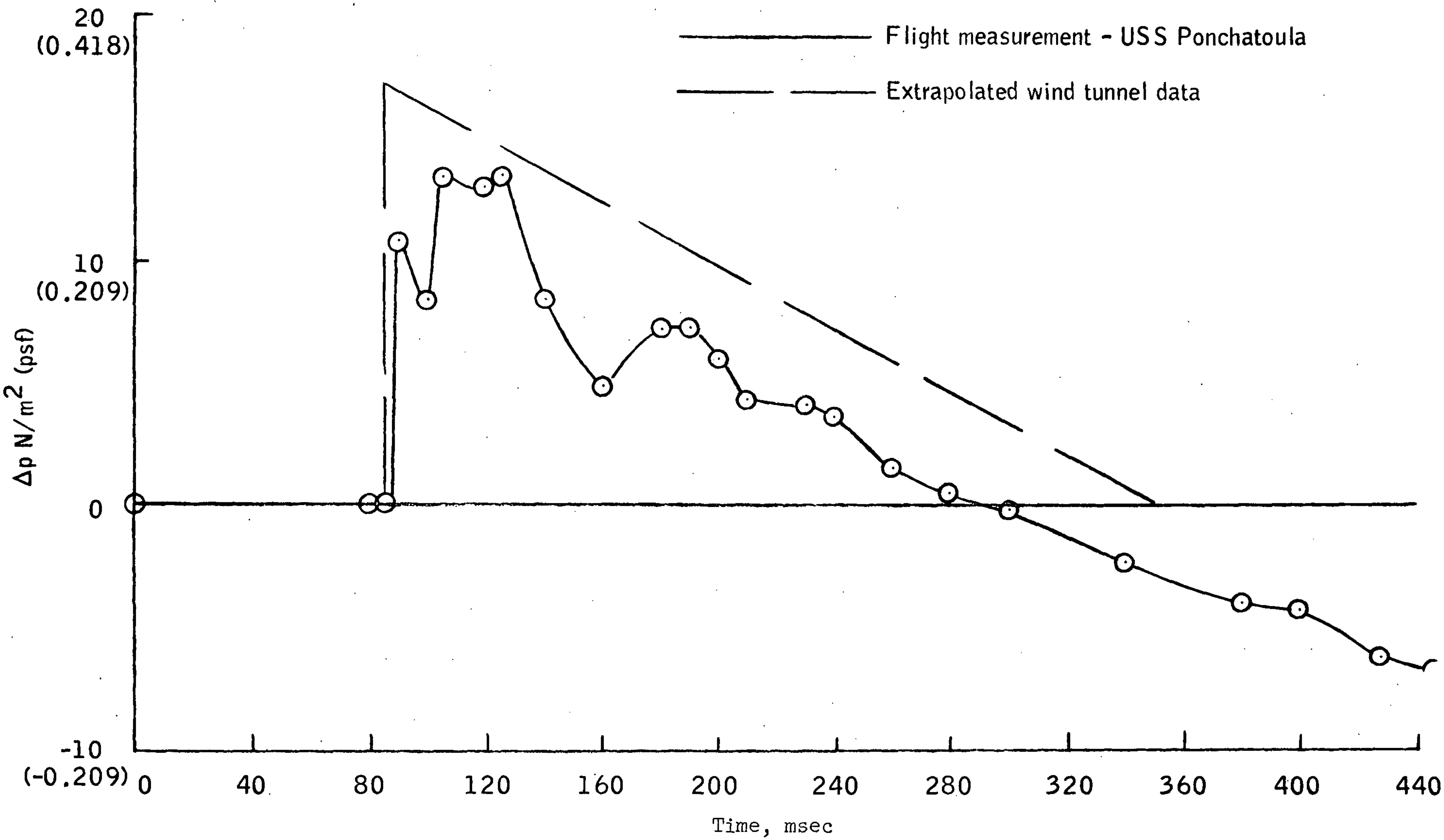
(a) Microphone 1

Figure 7.- Apollo 16 command module wind tunnel-flight correlation; M = 9.71, h = 44,113 m (144,730 ft), ψ = 21°, γ = -2.7°, $\dot{M}$ = -.0826/sec, $\dot{\psi}$ = 0.13°/sec, $\dot{\gamma}$ = -.03°/sec, bank angle = -49.6°, Φ = -1.5°.



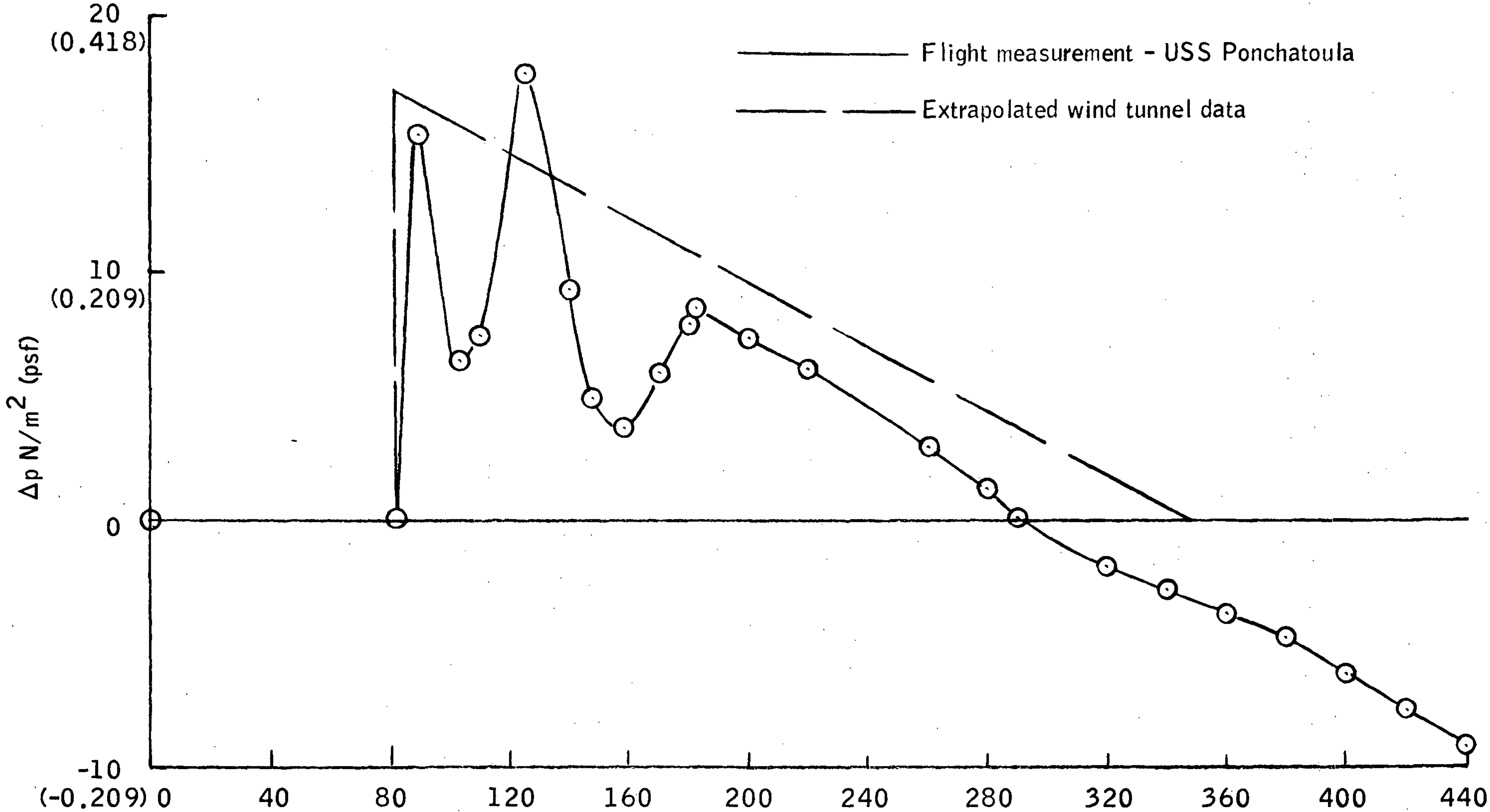
(b) Microphone 2

Figure 7.- Continued.



(c) Microphone 4

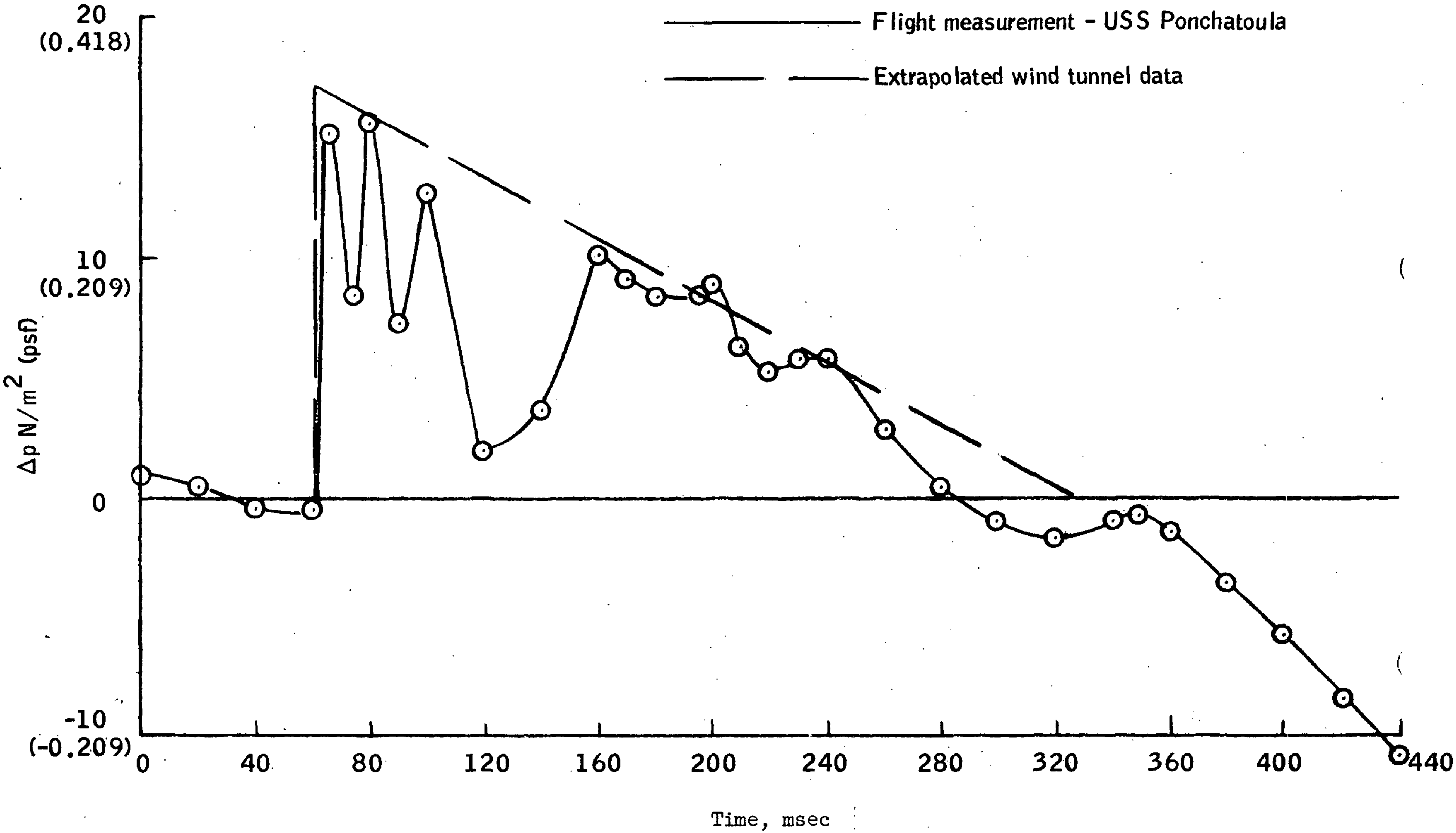
Figure 7.- Continued.



Time, msec

(d) Microphone 6

Figure 7.- Continued.



(e) Microphone 7

Figure 7.- Concluded.

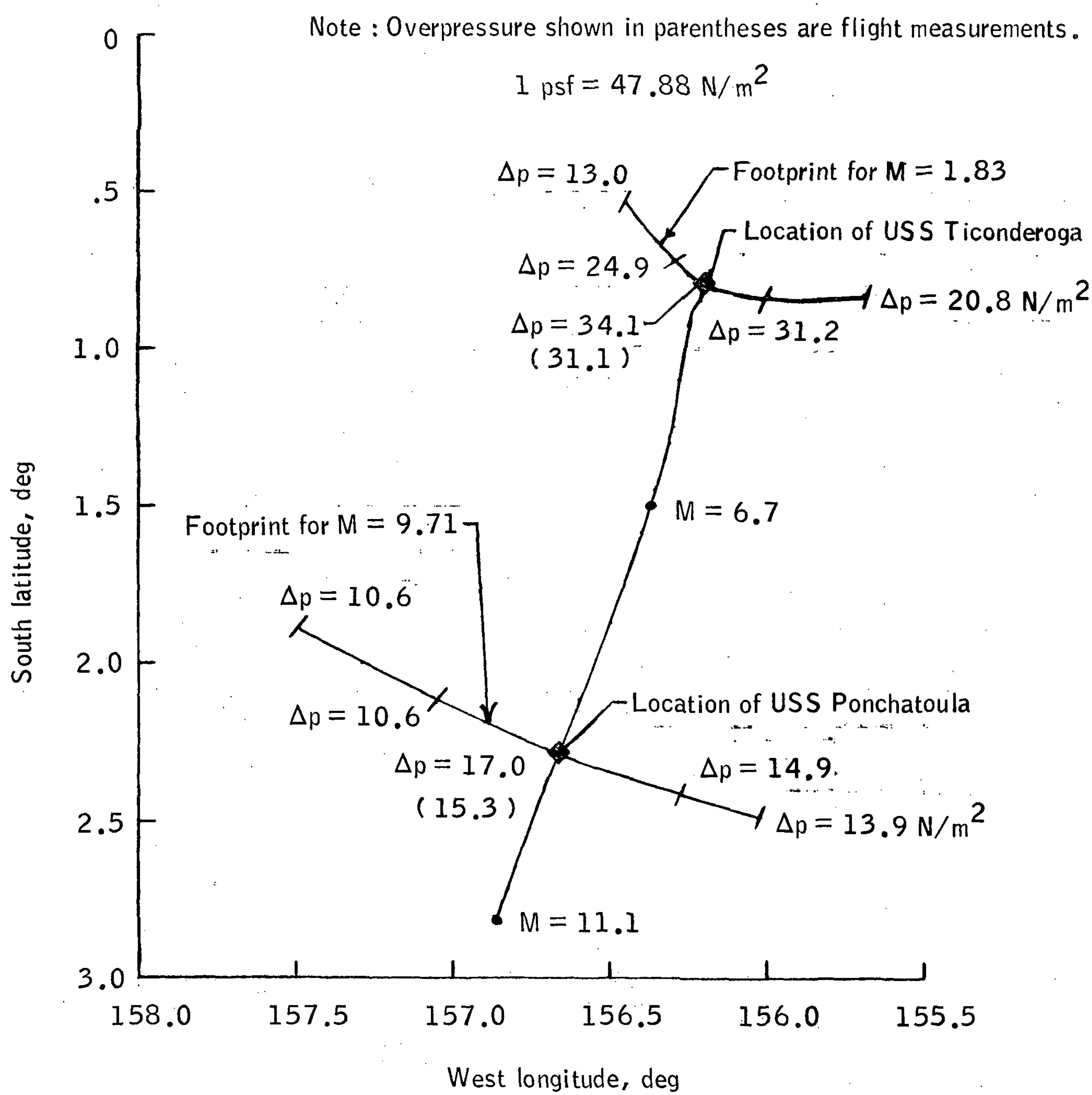


Figure 8.- Apollo 16 ground track with overpressures.