NASA TECHNICAL
MEMORANDUM

NASA TM X-62,129

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(NASA-.M-X-62129) PRESSURE SIGNATURES FOR A .00053 SCALE MODEL OF THE SATURN 5-APOLLO LAUNCH VEHICLE WITH SIMULATED EXHAUST PLUMES (NASA) 31 p HC $3.75 CSCL 22B G3/31

N73-30830

Unclas 12111

PRESSURE SIGNATURES FOR A .00053 SCALE MODEL OF THE SATURN V – APOLLO LAUNCH VEHICLE WITH SIMULATED EXHAUST PLUMES

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July 1973

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ABSTRACT

Wind tunnel pressure signatures are presented for 10 Mach numbers over a range from 3.01 to 7.29 for a .00053-scale model of the Saturn V-Apollo launch vehicle complete with escape tower and solid body simulated exhaust plumes for each Mach number. The effect of simulated plume length on the wind tunnel pressure signature was investigated at Mach 4.01. An analysis of the error incurred by extrapolating pressure signatures having strong shock waves by weak shock procedures is presented.

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SUMMARY

Wind tunnel pressure signatures are presented for 10 Mach numbers over a range from 3.01 to 7.29 for a .00053-scale model of the Saturn V-Apollo launch vehicle complete with escape tower and solid body simulated exhaust plumes for each Mach number. Two simulated plumes with lengths of 1-1/2 and 2-1/2 body lengths were investigated at Mach 4.01 to determine the effect of plume length on the measured pressure signature. The results of the investigation showed that for plume lengths greater than 1-1/2 body lengths the effect on signature length was large whereas the effect on the amplitude and positive area of the signature was negligible. Hence, the predicted peak overpressure at ground level should be reliable if the plume contour is accurate. Pressure signatures were measured at two different distances from the model axis at Mach 4.01 to evaluate a technique for the extrapolation of strong shock waves.

NOTATION

h	distance from model axis to overpressure probe, meters
l	model length, meters
l_p	simulated plume length, meters
M	Mach number
p	reference pressure, N/m^2
p_t	total pressure, cm Hg
α	angle of attack, degrees
Δp	sonic boom overpressure, N/m^2
Δx	distance along abscissa of pressure signature, meters

INTRODUCTION

An investigation is underway to evaluate and improve the methods for estimating the sonic boom overpressures generated by aircraft with large exhaust plumes maneuvering at hypersonic Mach numbers. The method currently employed consists of testing a small scale model of the proposed aircraft with a solid body simulation of the exhaust plume. The pressure signatures obtained from the tests are extrapolated to flight distances by the method of reference 1 to estimate the ground overpressures for the full-scale aircraft.

The first phase of the evaluation consisted of a study of the overpressures created by a vehicle without exhaust plumes in flight at supersonic and hypersonic Mach numbers. The test vehicles used for this phase were the Apollo 15 and 16 command modules. Sonic boom overpressures generated by the spacecraft during reentry into the Earth's atmosphere were recorded by pressure sensors placed on board ships stationed along the groundtrack. These groundtrack overpressures have been compared with extrapolated wind tunnel data over a Mach number range from 1.16 to 9.71 (references 2 and 3). The agreement between extrapolated wind tunnel data and flight data was good at all Mach numbers thus validating the extrapolation procedure for vehicles without exhaust plumes maneuvering at supersonic and hypersonic Mach numbers.

The second phase of the evaluation consisted of correlation studies for vehicles with exhaust plume effects. The test vehicles used for this phase were the Saturn V-Apollo 16 and 17 launch configurations. Groundtrack overpressures recorded during ascent of the Saturn V-Apollo 16 launch vehicle were compared with extrapolated wind tunnel pressure signatures measured during testing of a .00337-scale model with solid body simulated plumes (reference 4). In general, the extrapolated wind tunnel data gave a lower value of peak overpressure than the corresponding flight data. The most probable cause of the poor correlation of wind tunnel data with flight data was found to be the conical shape and short length of the simulated plumes of reference 4 (the plume lengths were 1/2 of the body length of the Saturn model). Hence, more precisely contoured plumes of nearly parabolic shape with lengths of at least 1-1/2 model lengths were designed for wind tunnel testing at Mach numbers ranging from 3.01 to 7.29[1]. These plumes were tested in conjunction with a .00053 scale model of the Saturn V-Apollo launch vehicle. The pressure signatures obtained from these tests are presented herein. Extrapolations of these signatures will be compared with groundtrack overpressure measurements for the Saturn V-Apollo 16 and Saturn V-Apollo 17 launch vehicles and will be reported later.

MODEL AND TEST PROCEDURE

A .00053-scale model of the Saturn V-Apollo launch vehicle complete with escape tower and simulated exhaust plume was tested in the super-

[1] The plume contours were calculated by Mr. Jess H. Jones of the George C. Marshall Space Flight Center.

sonic and hypersonic wind tunnels of the Jet Propulsion Laboratory (JPL). The Mach numbers for which data were obtained and the corresponding wind-tunnel total pressures are given in the table below:

M	P_t cm-Hg
3.01	100
3.27	100
3.51	100
4.01	100
4.25	100
4.56	100
4.81	100
5.02	400
6.05	800
7.29	1500

A drawing of the model without plume is shown in figure 1. A table containing the coordinates of the simulated plumes for each test Mach number is shown in figure 2. At Mach 4.01 plumes of 1-1/2 body lengths (l_p = .083 m) and 2-1/2 body lengths (l_p = .138 m) were tested to determine the effect of plume length on the wind tunnel pressure signature. A photograph of the long Mach 4.01 plume attached to the model is shown in figure 3. A photograph showing the same model configuration installed in the JPL 20-inch supersonic wind tunnel is shown in figure 4.

PRESENTATION OF DATA AND DISCUSSION

Schlieren photographs of the Saturn V-Apollo model taken during testing are shown in figure 5. No photograph is shown for Mach 6.05 because of film damage incurred during development.

Wind tunnel pressure signatures obtained during testing are presented in figure 6. It was not possible to record the full signature at Mach numbers of 5.02, 6.05 and 7.29 because the length of the signature exceeded the axial travel of the linear actuator used to position the model along the longitudinal axis of the test section. However, only the positive portion of the wind tunnel signature is required since the parameter of primary interest in this study is the peak groundtrack overpressure, which can be calculated from the overpressures and positive area of the measured signatures. All pressure signatures were measured at zero angle of attack at a distance of 3.56 body lengths (based on the model without plume, see figure 1) from the model axis except for an additional signature measured at 2.56 body lengths from the model at Mach 4.01 (figure 6(e)). The purpose of obtaining the signature at the smaller distance will be discussed later in this section.

Two simulated plumes with lengths of 1-1/2 body lengths and 2-1/2 body lengths were tested at Mach 4.01. The purpose in testing different plumes was to establish the effect of plume length on the positive portion of the wind tunnel signature. The simulated plume need only be long enough to give an accurate definition of the positive portion of the wind tunnel pressure signature for reliable prediction of the peak ground overpressure. The wind tunnel pressure signatures generated by the model with the two different plumes are shown in figures 6(d) and 6(f). The signatures have been replotted in figure 7 to give a clear picture of the effect of plume length. Note that the positive area of the signature generated by the model with the short plume is only slightly less than the corresponding area for the model with the long plume; the predominant effect being a decrease in total signature length with decreasing plume length. Hence, a plume 1-1/2 body lengths long appears to be sufficient for prediction of the peak ground overpressure if the plume contour is approaching the asymptotic diameter at the point of truncation. This condition was met for all plumes tested except the plume for Mach 3.01. The theoretical plume contour for Mach 3.01 showed a "bell" shape (see figure 5(a)) and hence termination of the plume at 1-1/2 model lengths would be expected to produce a tunnel signature with positive area too small to accurately predict the ground overpressure. No attempt was made to construct a longer plume for Mach 3.01 because the theoretical coordinates were questionable at this Mach number and because the rapidly increasing plume diameter would have exceeded tunnel blockage requirements within 2 body lengths.

During this investigation bow shock strengths ($(\Delta p/p)_{max}$) greater than .5 were measured at all Mach numbers greater than 3.51. Therefore, the weak shock extrapolation procedure of reference 1 cannot be used to extrapolate the tunnel signatures to full scale distances. It is recommended that the wind tunnel signatures exhibiting overpressures ($\Delta p/p$) greater than .5 be extrapolated by the strong shock method of reference 4 to a distance where $(\Delta p/p)_{max}$) is less than .5 (extrapolation to a distance of 6 body lengths should be sufficient for the signatures of figure 6). The resulting signatures can then be extrapolated from the intermediate distance of 6 body lengths to the far field by the weak shock method of reference 1. A brief study was included in this investigation at Mach 4.01 to explore the error involved in extrapolating pressure signatures with overpressure ($\Delta p/p$) greater than .5 by the weak shock method. The pressure signature measured at 2.56 body lengths from the model (figure 6 (e)) was extrapolated to a distance of 3.56 body lengths by both the strong shock and weak shock methods for comparison with the signature measured at 3 body lengths (figure 6(d)). The comparison is shown in figure 8. This figure illustrates the error involved in extrapolating pressure signatures with large overpressures by the weak shock method. Note that extrapolation by the weak shock method produces a signature with lower peak overpressure and less positive area than exhibited by either the measured signature or the strong shock extrapolation. The error incurred by extrapolating signatures with strong shocks by weak shock procedures increases with increasing overpressure, so that the error involved in extrapolating the signature measured at Mach 7.29 by the weak shock method would be appreciable. The small difference between the measured signature and the strong shock extrapolation should be investigated in an effort to improve the technique for extrapolating signatures with strong shock waves.

Future tests are planned during which pressure signatures generated by a wind tunnel model with high pressure nitrogen plumes will be measured. These pressure signatures will be compared with signatures obtained from a model with solid body simulations of the nitrogen plumes to gain a better understanding of the problems involved in exhaust plume simulation.

REFERENCES

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

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

3. Garcia, Frank, Jr.; Hicks, Raymond M.; and Mendoza, Joel P.: A Wind Tunnel Flight Correlation of Apollo 16 Sonic Boom. NASA TM X-62,073, March 1973.

4. 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 1972.

Note: All dimensions are in meters

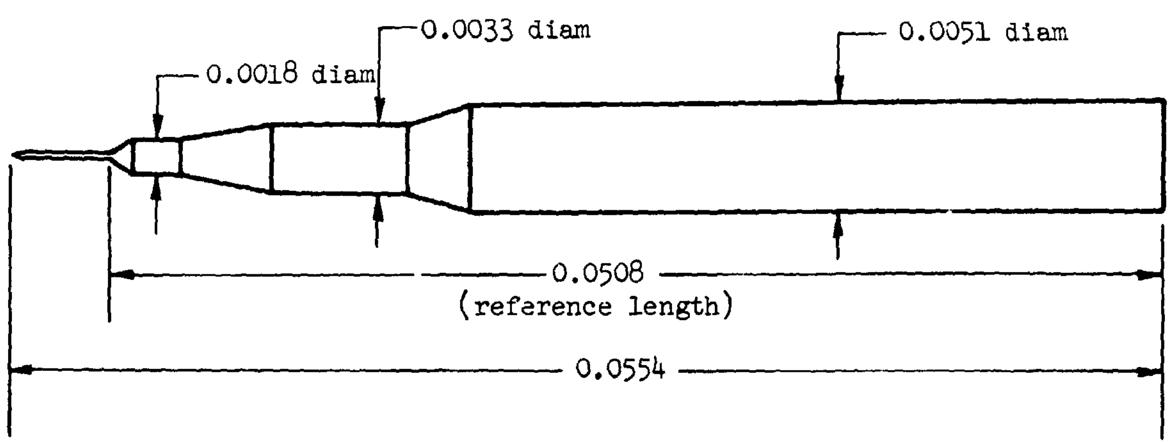
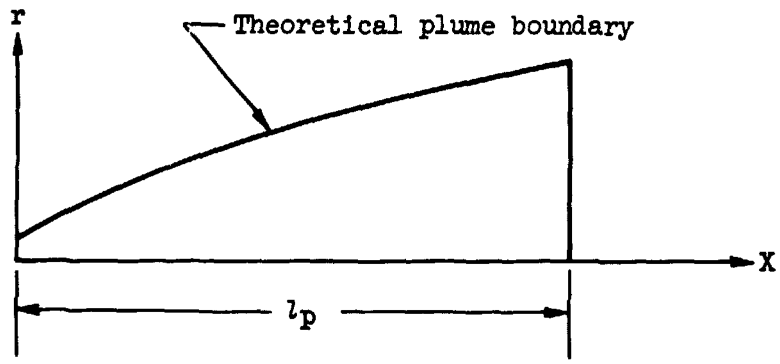


Figure 1.- Drawing of 0.00053 scale Saturn-Apollo test model.



Note: Coordinate values are in centimeters

M	3.01	3.27	3.51	4.01	4.01	4.25	4.56	4.81	5.02	6.05	7.29
X	r	r	r	r	r	r	r	r	r	r	r
0	0.254	0.254	0.254	0.254	0.254	0.254	0.254	0.254	0.254	0.254	0.254
0.508	0.559	0.584	0.635	0.635	0.635	0.635	0.711	0.711	0.711	0.737	0.940
1.016	0.838	0.838	0.904	0.914	0.914	0.965	1.041	1.041	1.092	1.168	1.422
1.524	1.067	1.092	1.143	1.169	1.169	1.245	1.321	1.321	1.422	1.549	1.854
2.540	1.397	1.499	1.575	1.626	1.626	1.727	1.829	1.880	1.981	2.184	2.540
3.048	1.575	1.702	1.753	1.803	1.803	2.057	2.057	2.134	2.235	2.464	2.946
4.064	1.854	1.981	2.134	2.235	2.235	2.464	2.489	2.591	2.692	2.997	3.632
5.080	2.134	2.286	2.469	2.616	2.616	2.718	2.845	2.997	3.124	3.531	4.242
6.350	2.591	2.616	2.845	3.048	3.048	3.175	3.327	3.505	3.658	4.166	5.029
7.620	3.200	2.921	3.175	3.429	3.429	3.531	3.734	3.962	4.242	4.699	5.766
8.306	3.708	3.073	3.302	3.607	3.607	3.658	3.912	4.267	4.420	4.978	6.147
10.160					3.962						
11.430					4.191						
12.700					4.394						
13.843					4.547						

Figure 2.- Table of coordinates for simulated plumes.

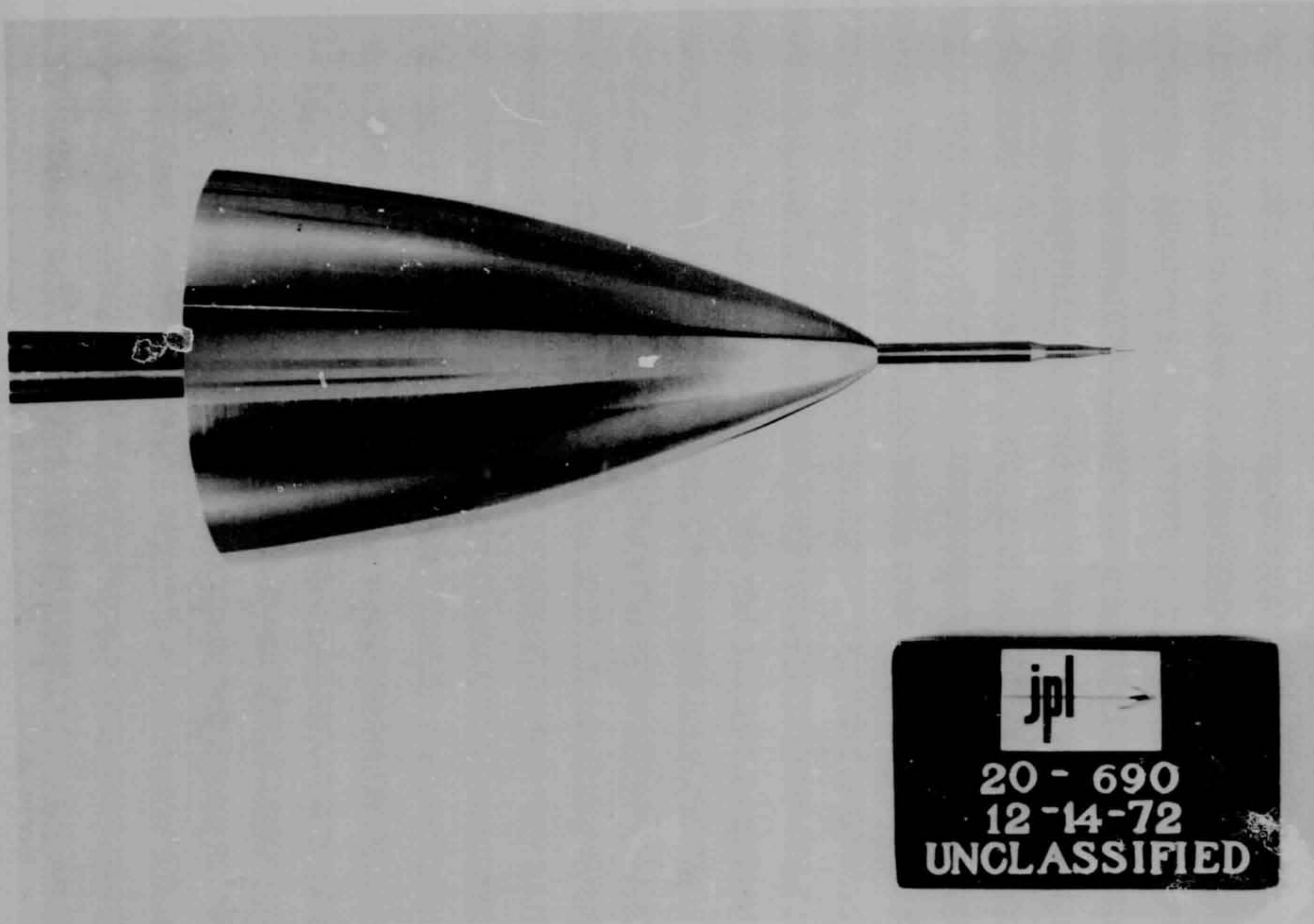


Figure 3.- Photograph of model with Mach 4.01 plume; l_p = 0.138 m.

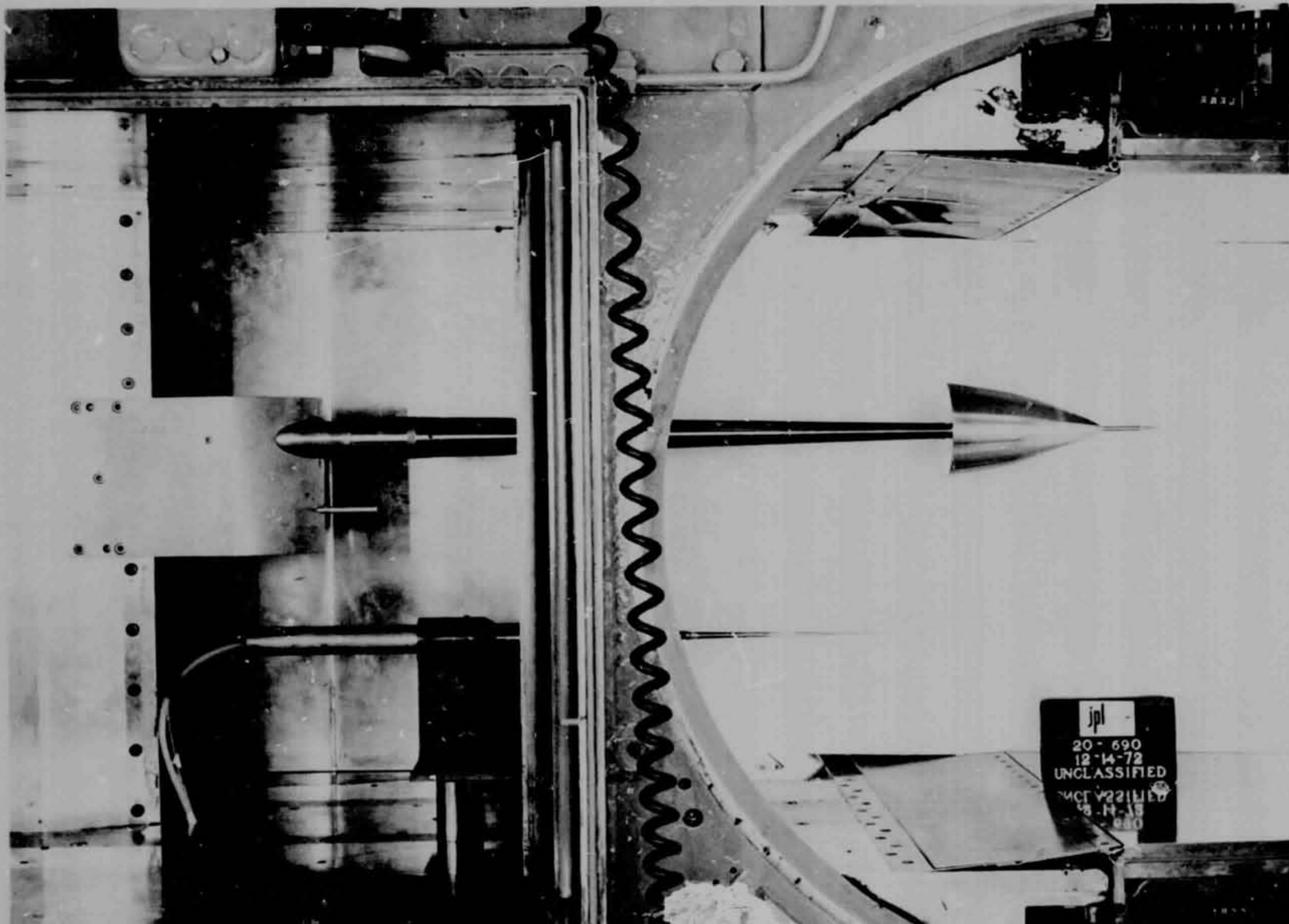
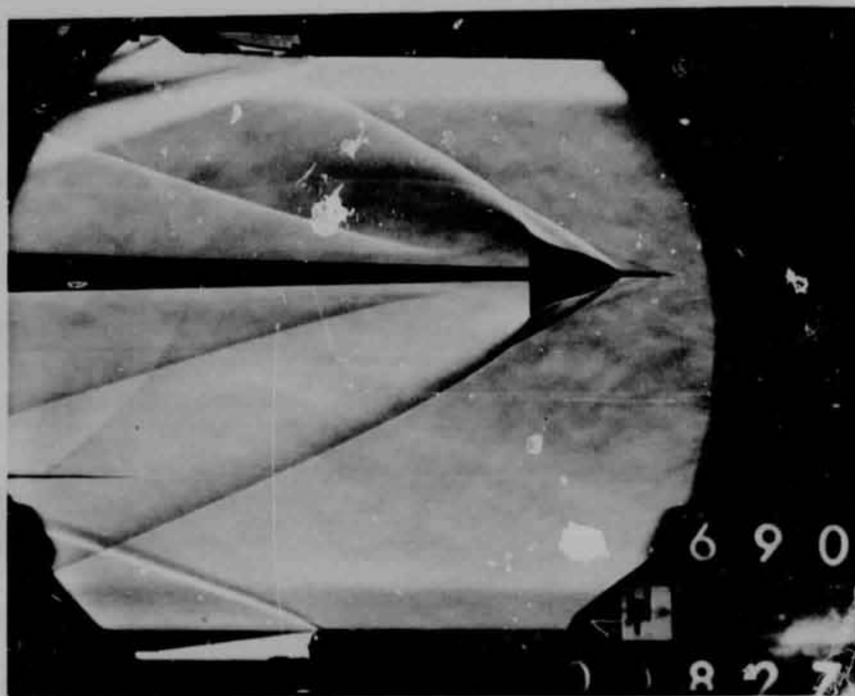


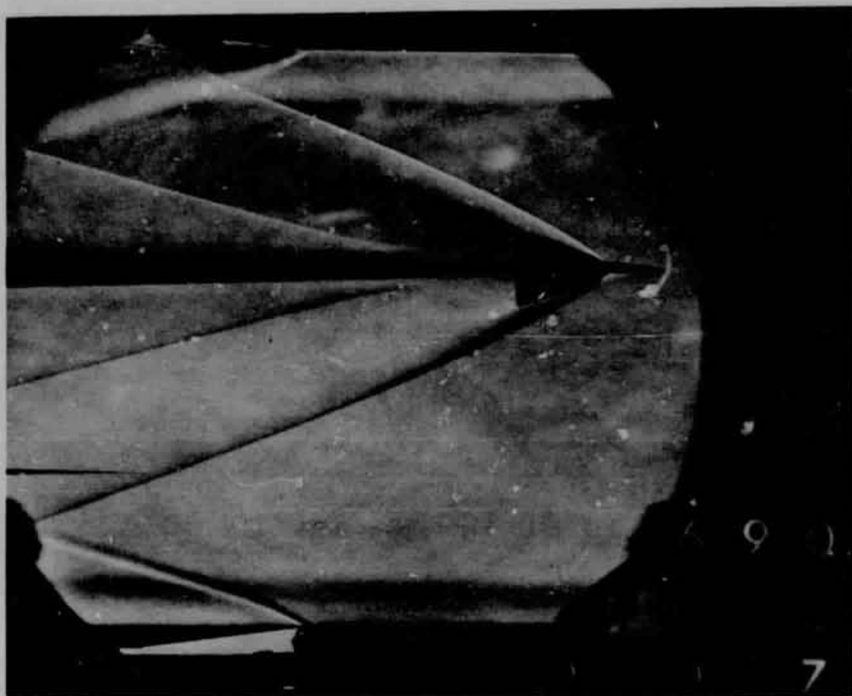
Figure 4.- Model with Mach 4.01 plume installed in [illegible] 20-Inch Supersonic Wind Tunnel; l_p = 0.138 m.



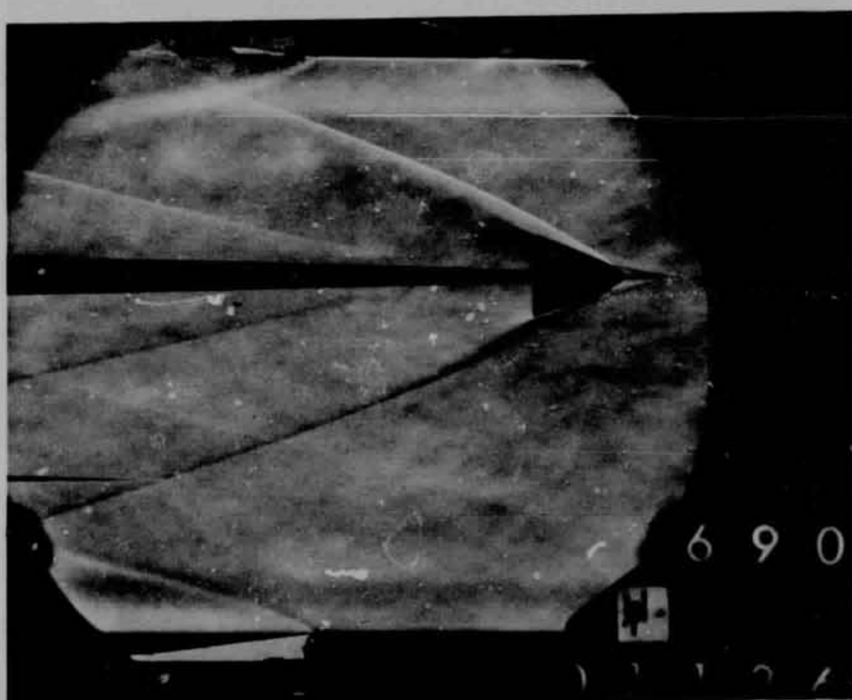
(a) M = 3.01, l_p = 0.083 m

(b) M = 3.27, l_p = 0.083 m

Figure 5.- Schlieren photographs.

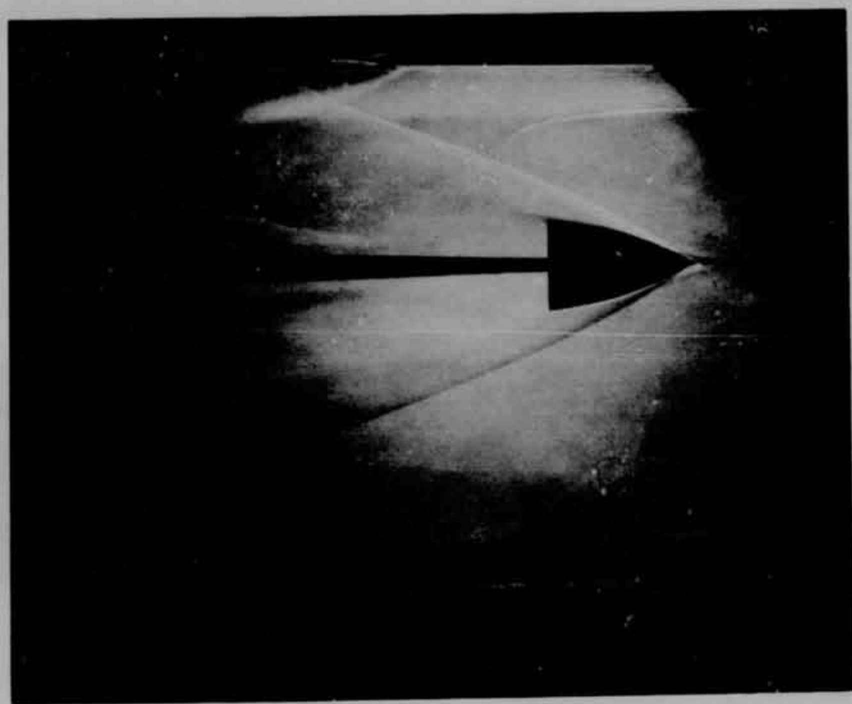


(c) $M = 3.51$, $l_p = 0.083$ m

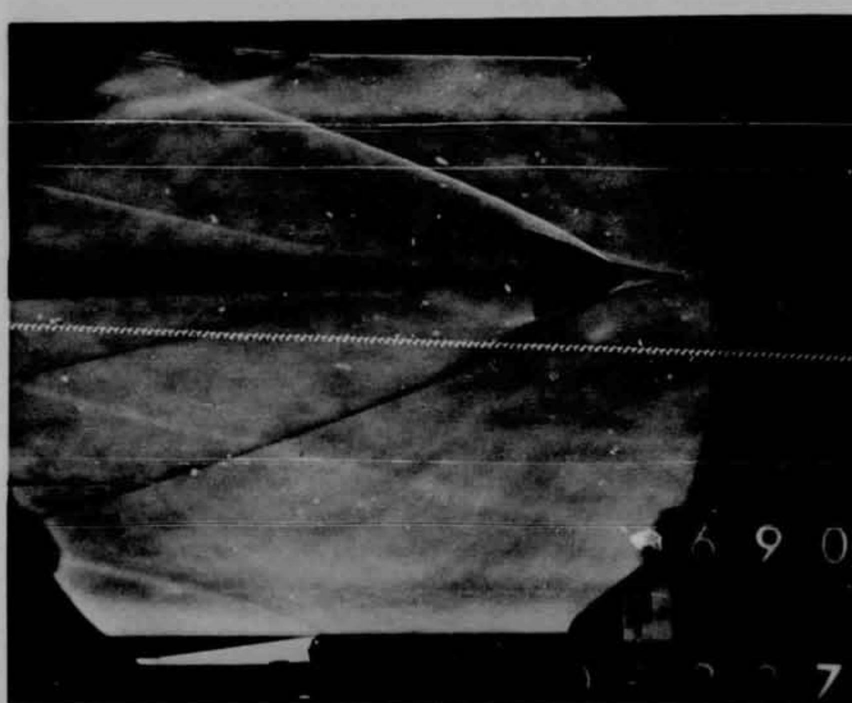


(d) $M = 4.01$, $l_p = 0.083$ m

Figure 5.- Continued.

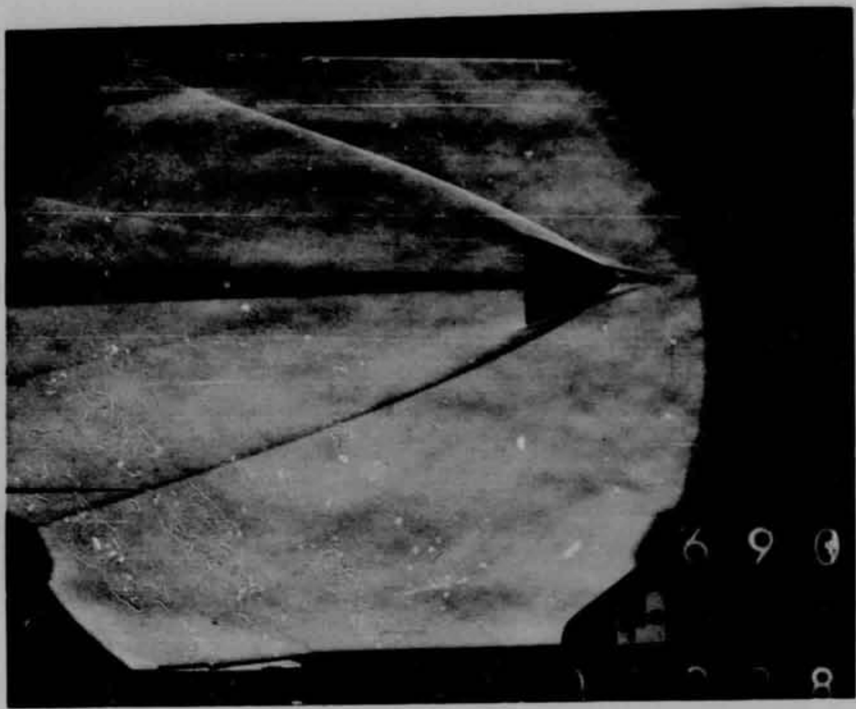


(e) $M = 4.01$, $l_p = 0.138$ m

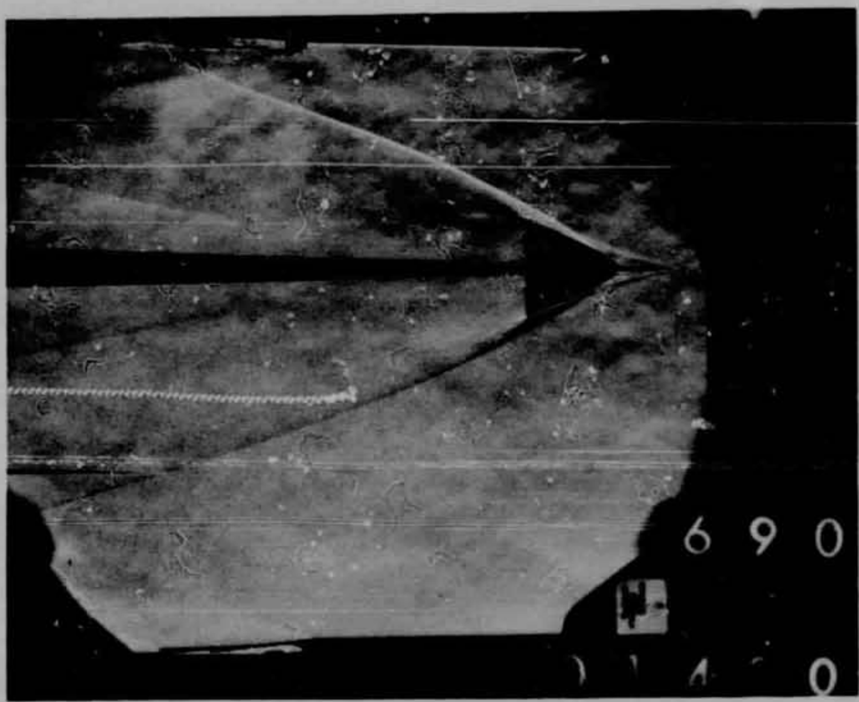


(f) $M = 4.25$, $l_p = 0.083$ m

Figure 5.- Continued.

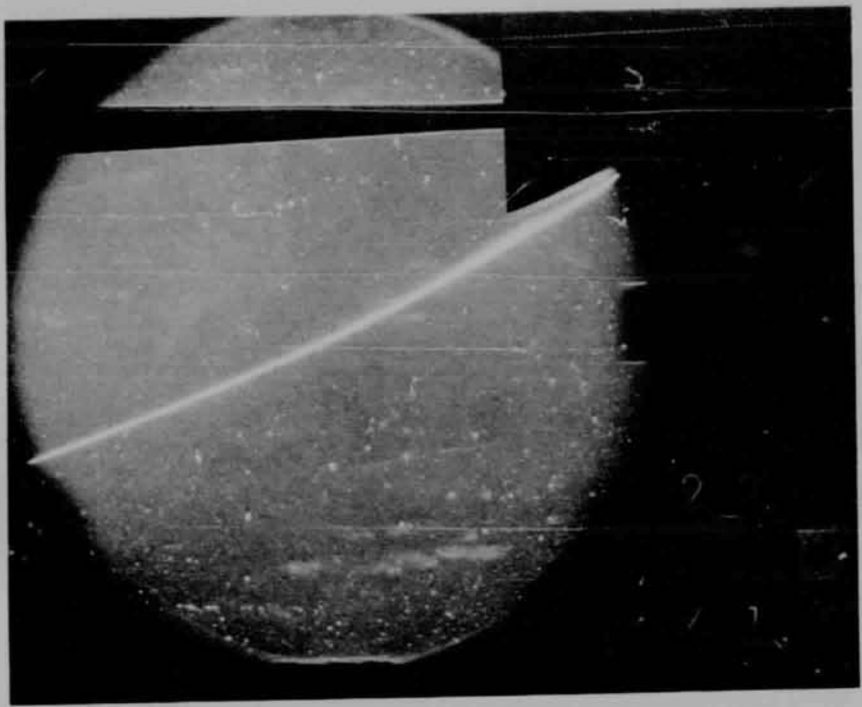


(g) $M = 4.56$, $l_p = 0.083$ m

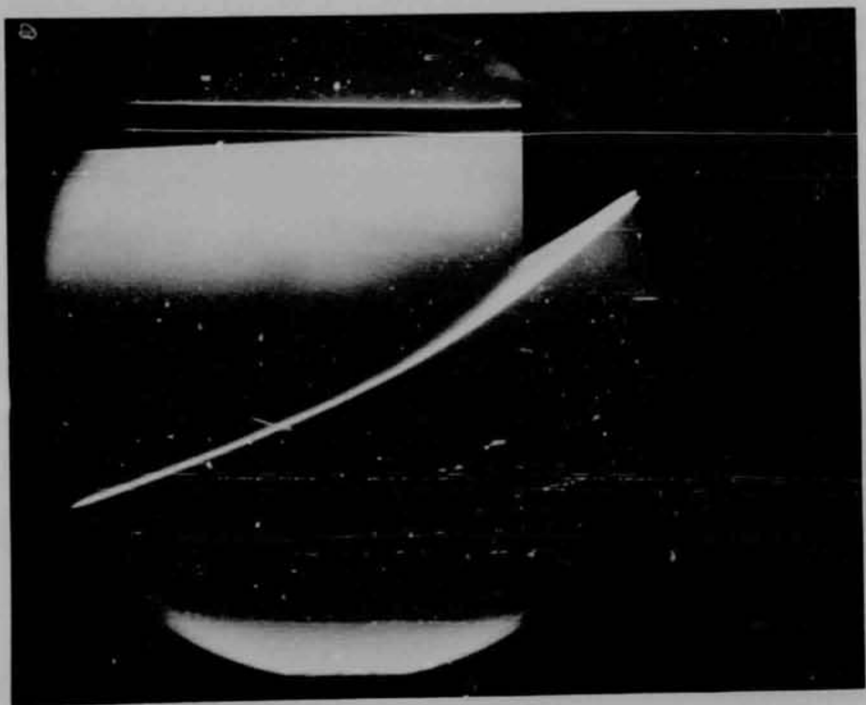


(h) $M = 4.81$, $l_p = 0.083$ m

Figure 5.- Continued.

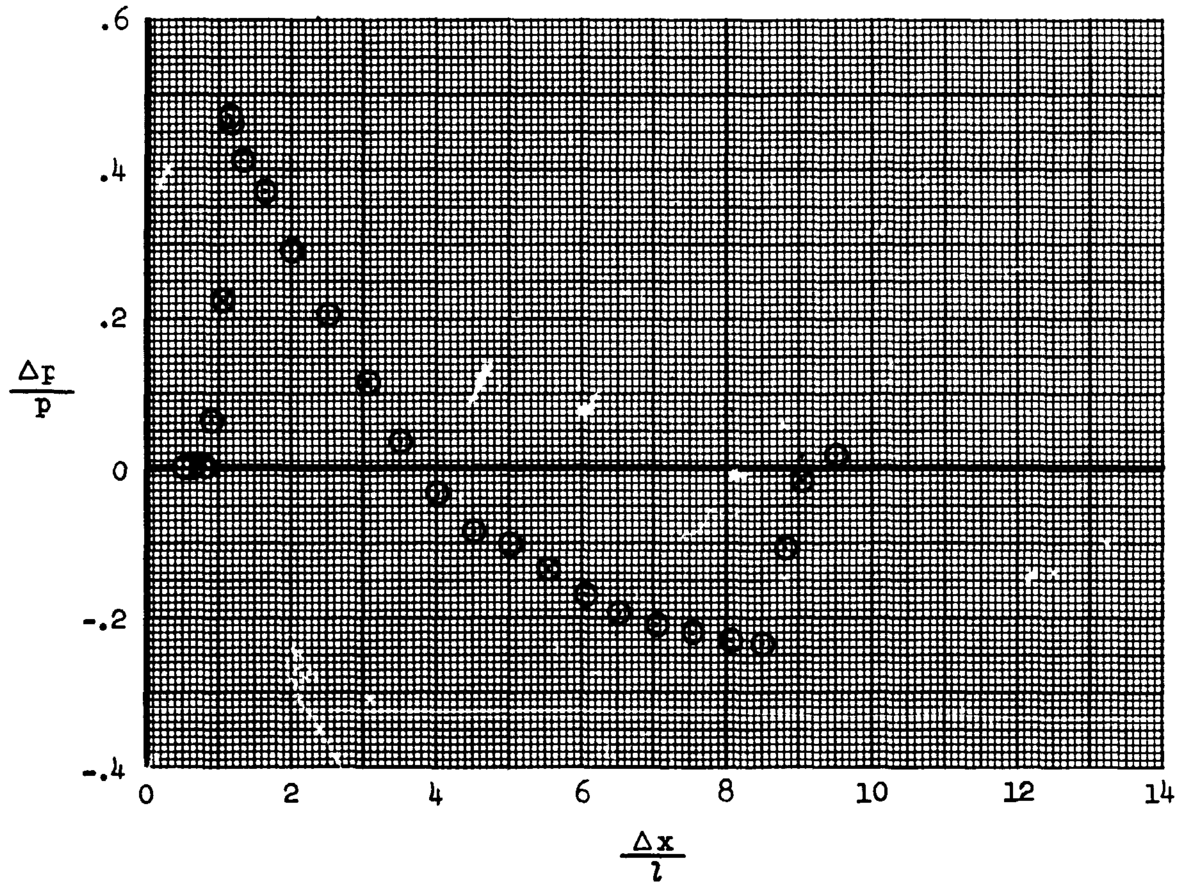


(i) $M = 5.02$, $l_p = 0.083$ m



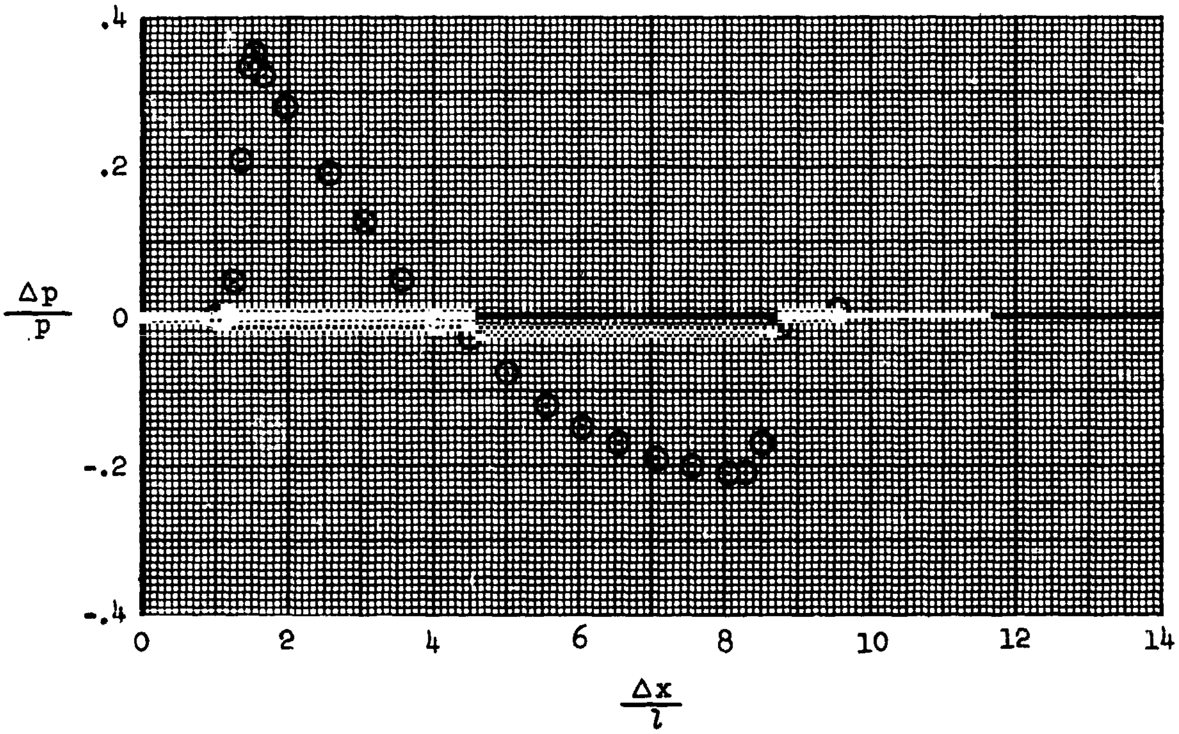
(j) $M = 7.29$, $l_p = 0.083$ m

Figure 5.- Concluded.



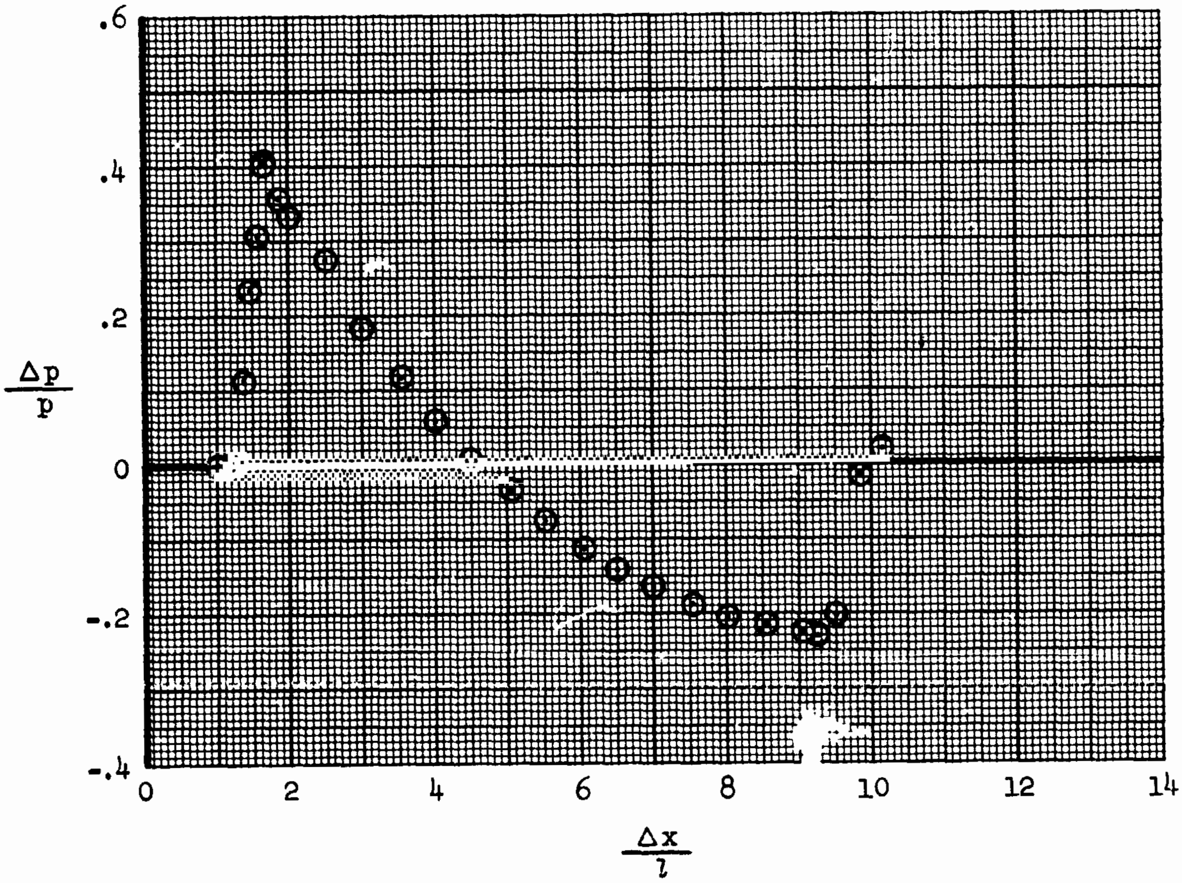
(a) $M = 3.01$, $h/l = 3.56$, $l_p = 0.083$ m

Figure 6.- Wind tunnel pressure signatures for Saturn V-Apollo model with simulated exhaust plume; $l = 0.0508$ m, $\alpha = 0$ deg.



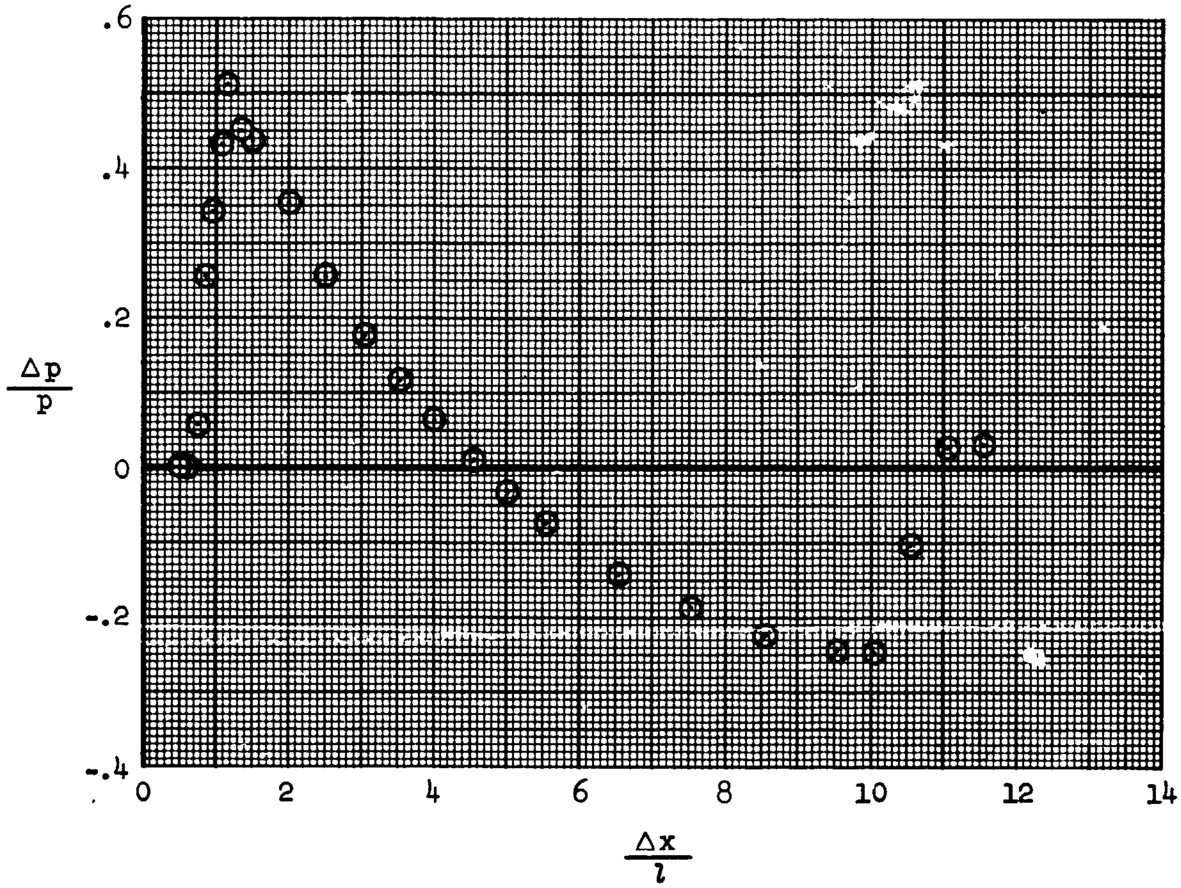
(b) $M = 3.27$, $h/l = 3.56$, $l_p = 0.083$ m

Figure 6.- Continued.



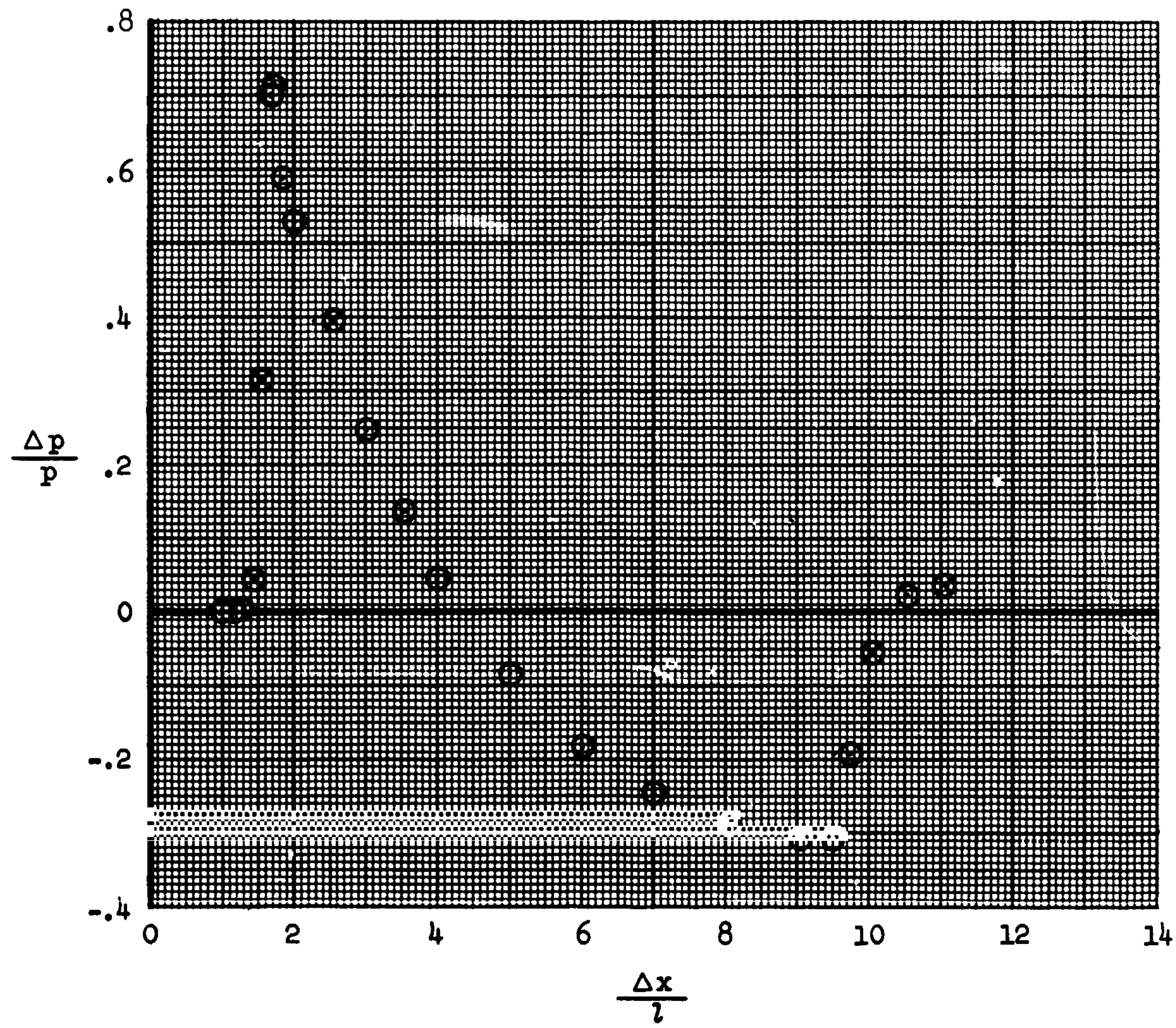
(c) $M = 3.51$, $h/l = 3.56$, $l_p = 0.083$ m

Figure 6.- Continued.



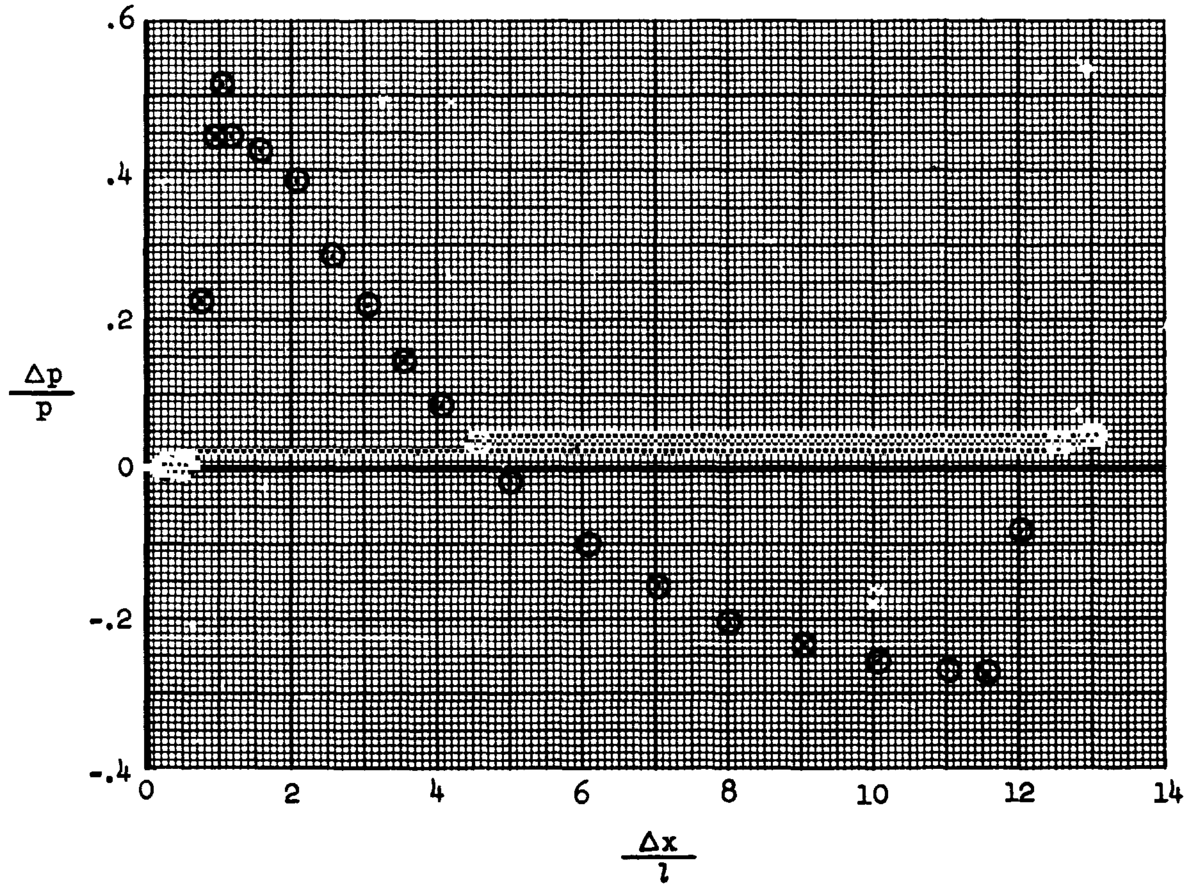
(d) $M = 4.01$, $h/l = 3.56$, $l_p = 0.083$ m

Figure 6.- Continued.



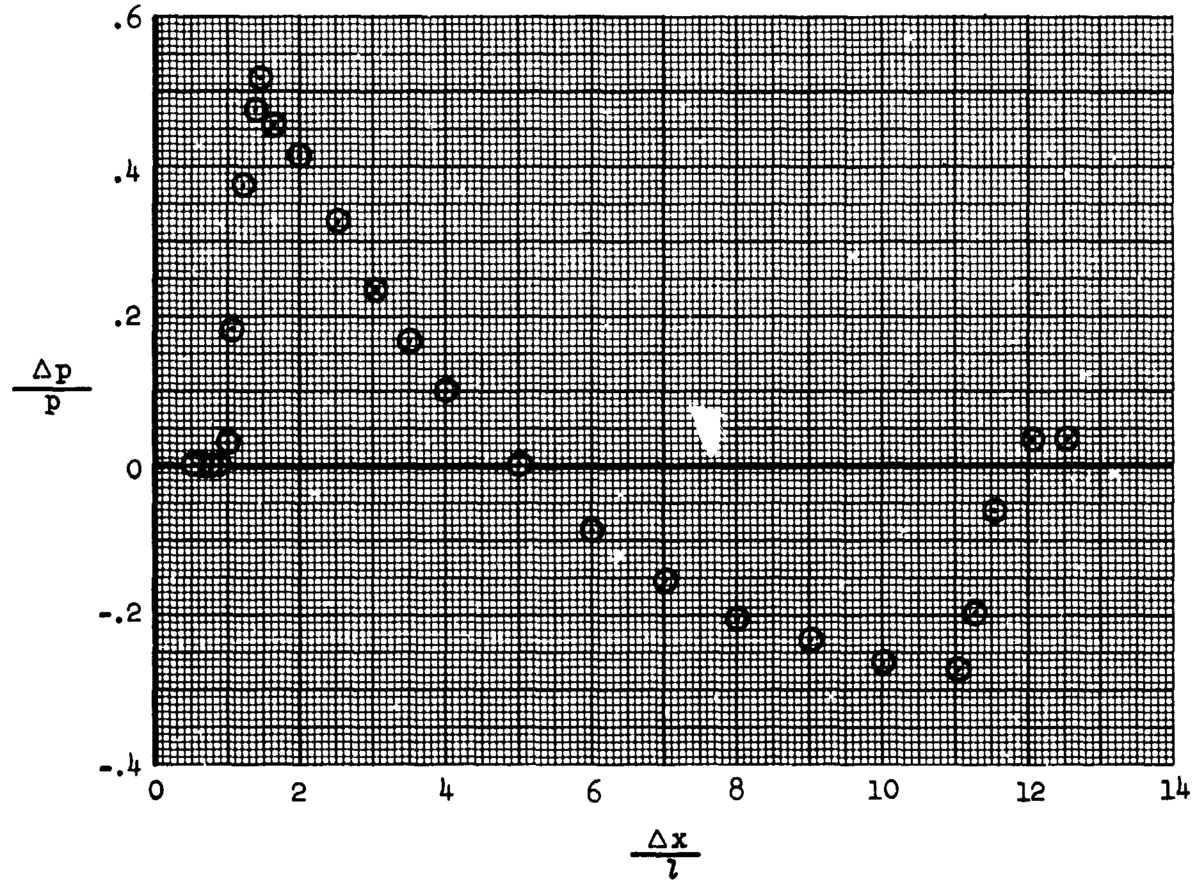
(e) $M = 4.01$, $h/l = 2.56$, $l_p = 0.083$ m

Figure 6.- Continued.



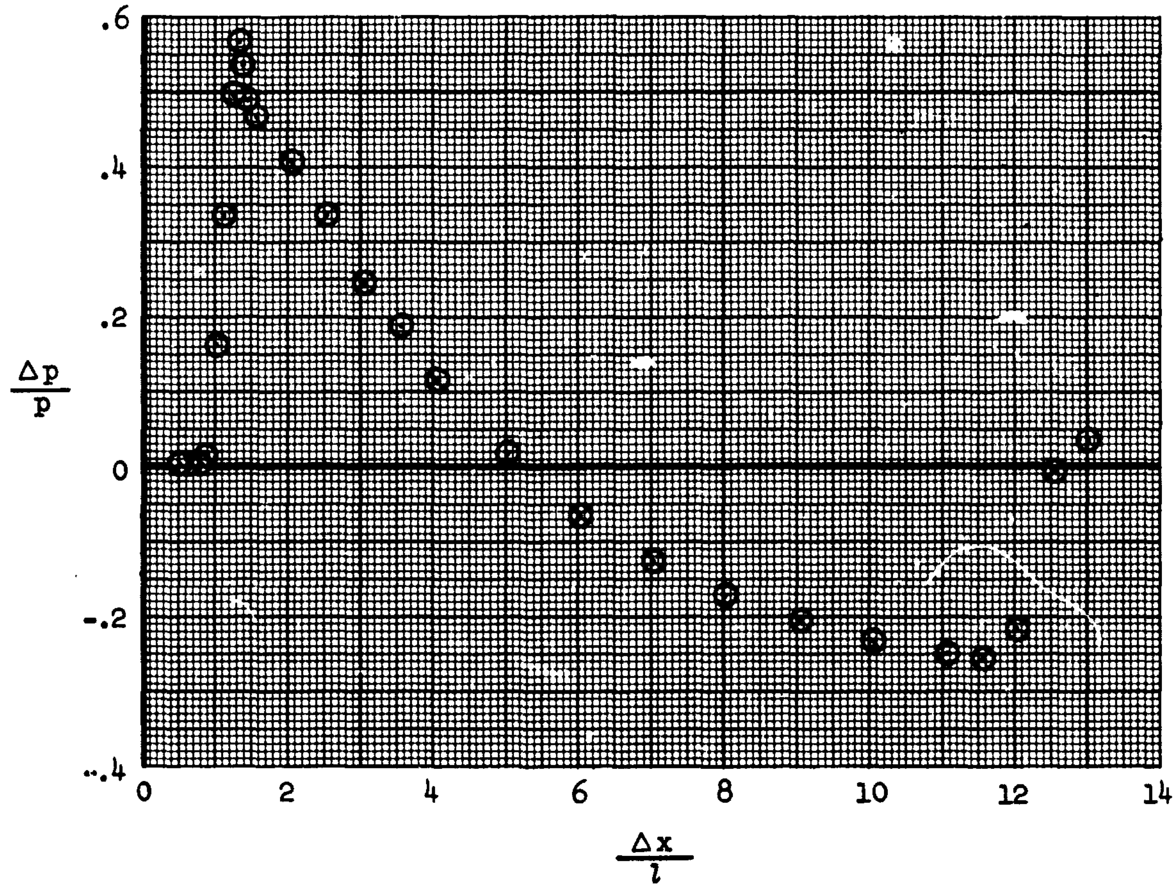
(f) $M = 4.01$, $h/l = 3.56$, $l_p = 0.138$ m

Figure 6.- Continued.



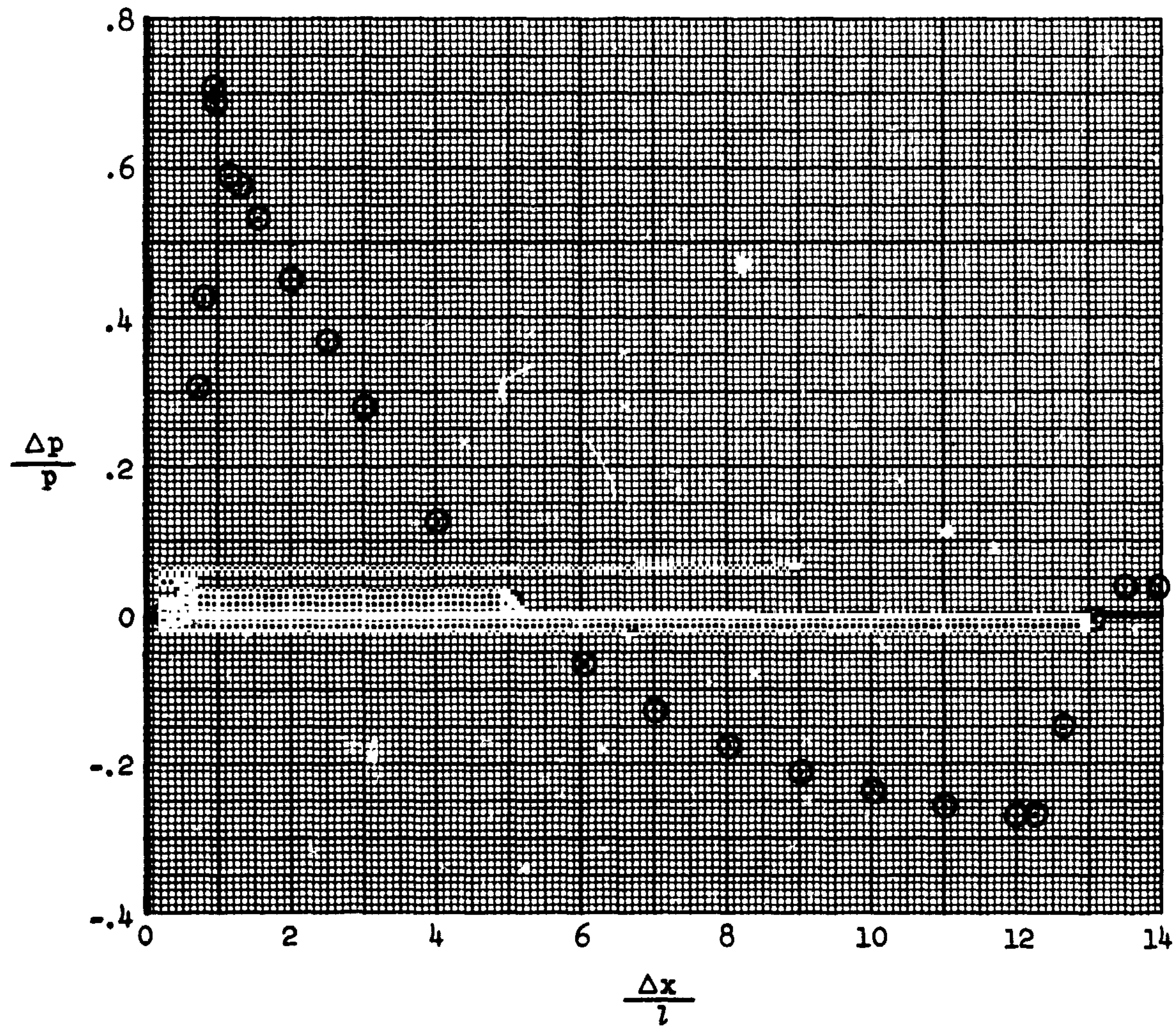
(g) $M = 4.25$, $h/l = 3.56$, $lp = 0.083$ m

Figure 6.- Continued.



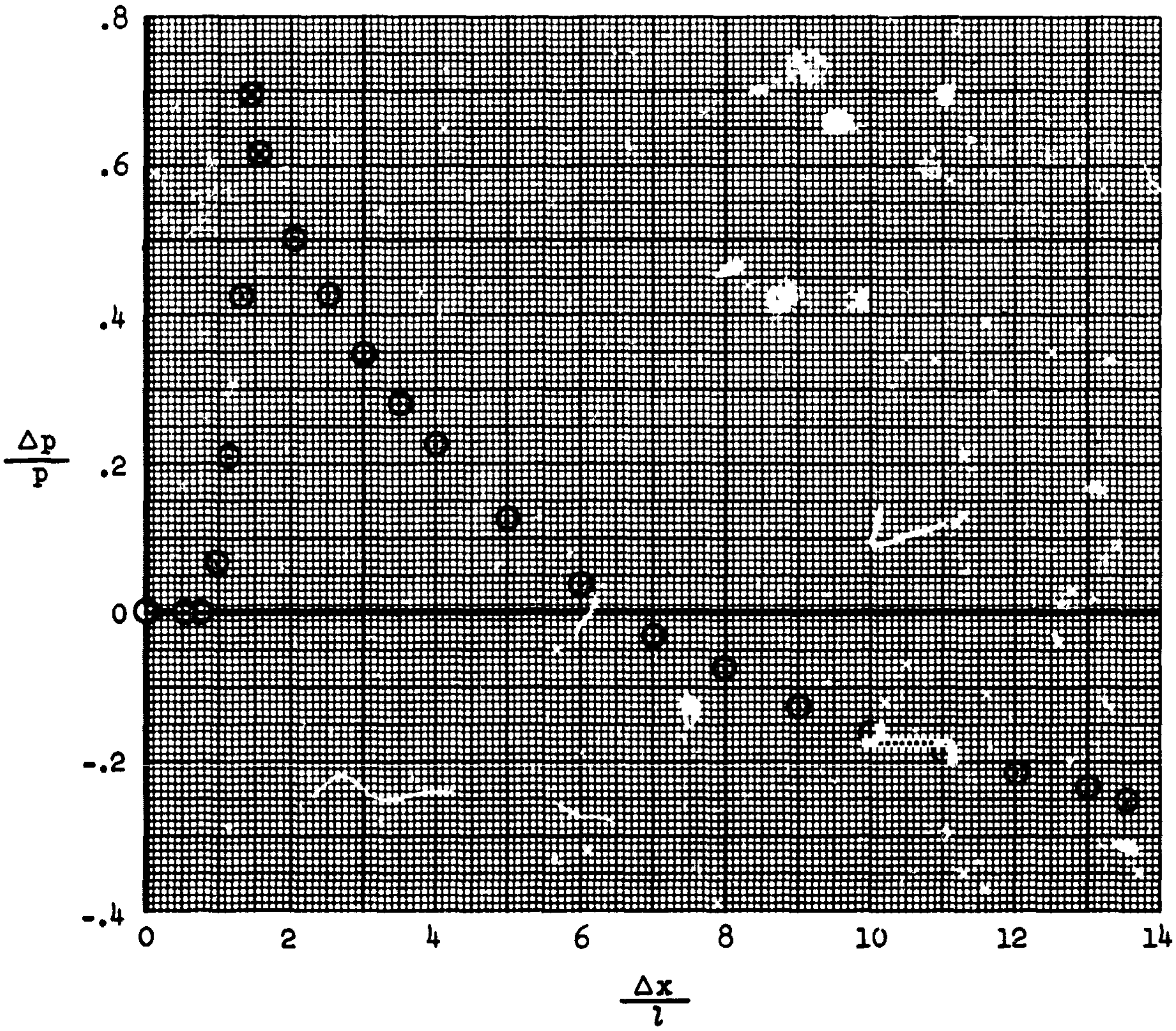
(h) $M = 4.56$, $h/l = 3.56$, $l_p = 0.083$ m

Figure 6.- Continued.



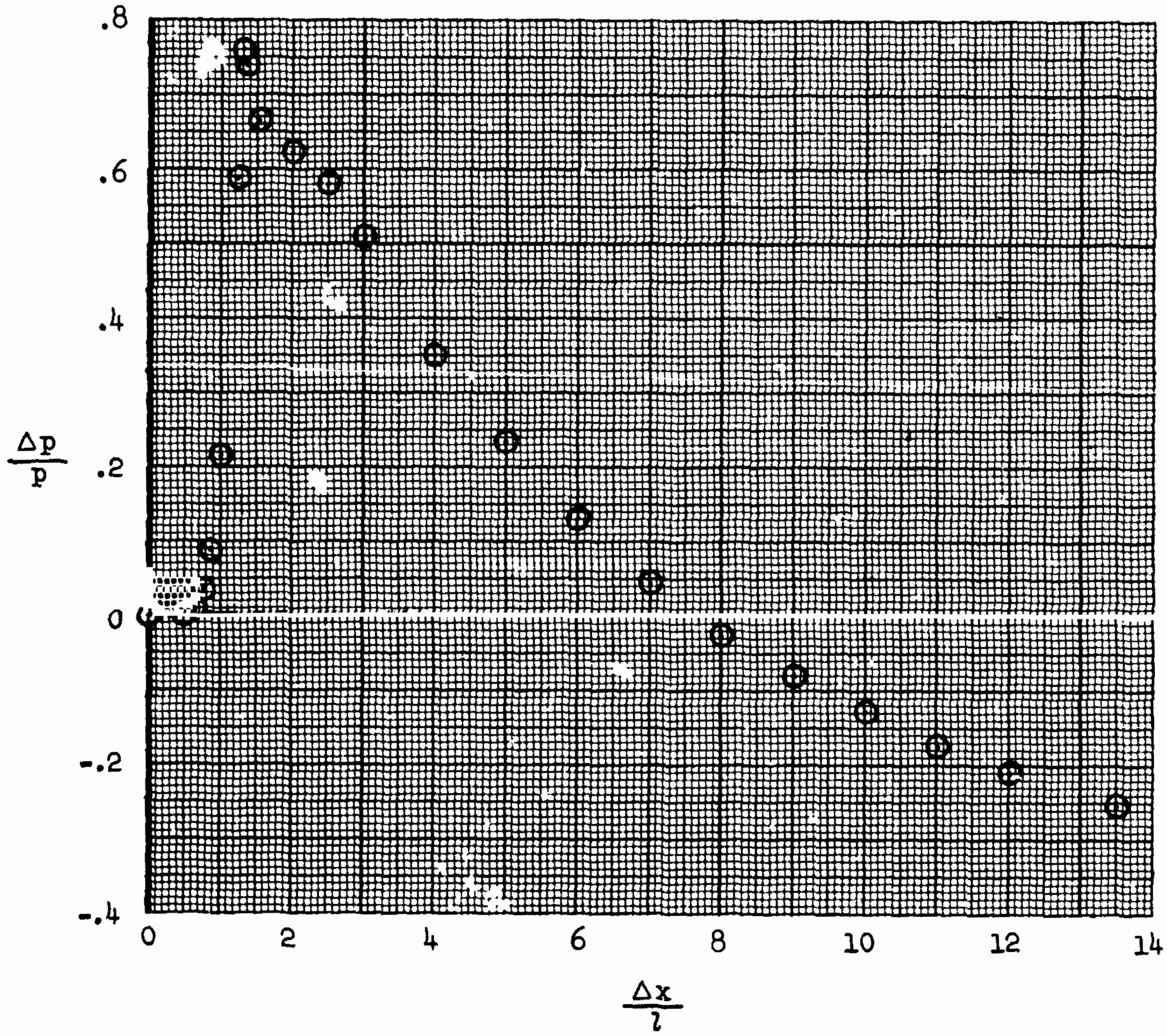
(i) $M = 4.81$, $h/l = 3.56$, $l_p = 0.083$ m

Figure 6.- Continued.



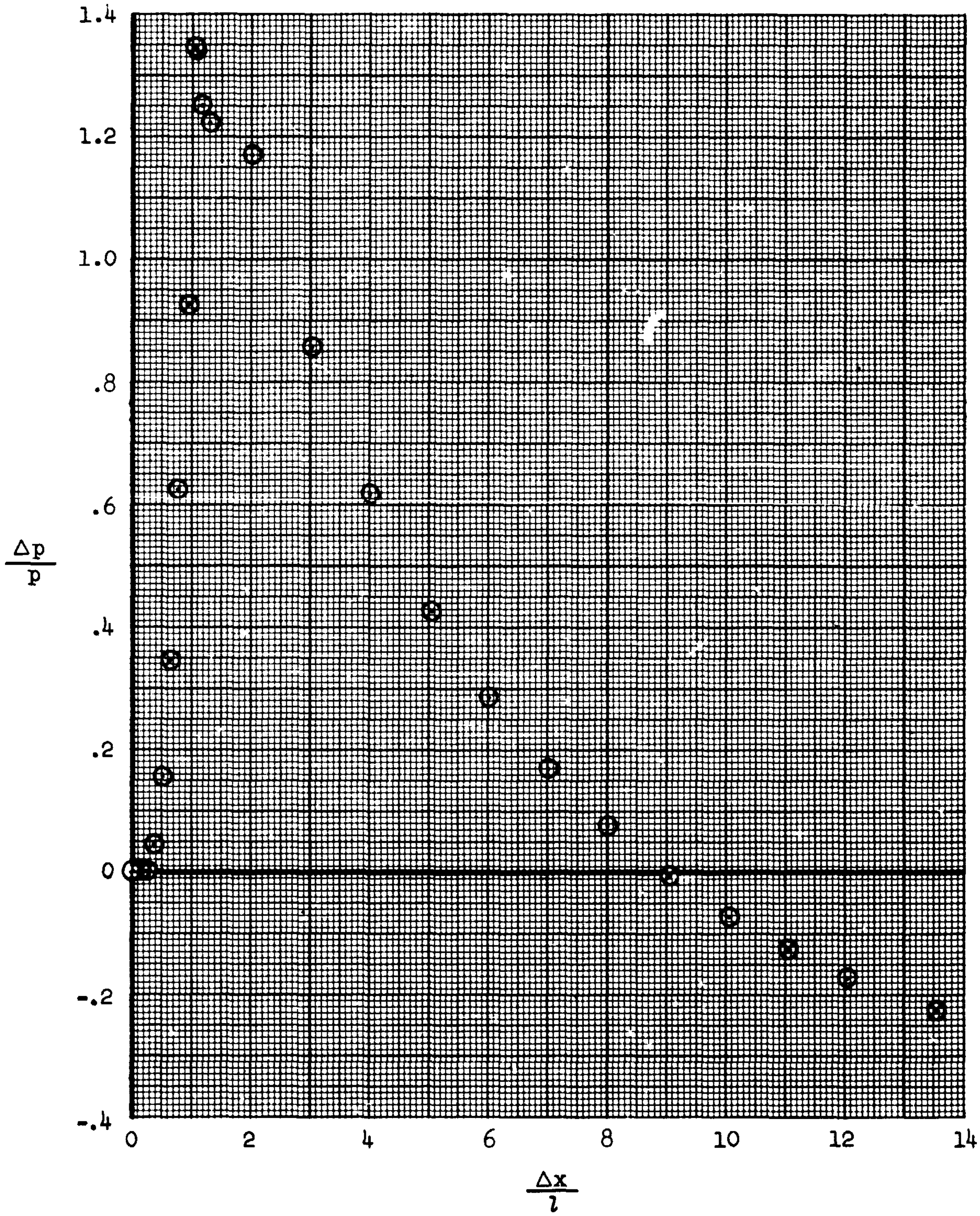
(j) $M = 5.02$, $h/l = 4.32$, $l_p = 0.083$ m

Figure 6.- Continued.



(k) $M = 6.05$, $h/l = 4.32$, $l_p = 0.083$ m

Figure 6.- Continued.



(l) $M = 7.29$, $h/l = 4.719$, $l_p = 0.083$ m

Figure 6.- Concluded.

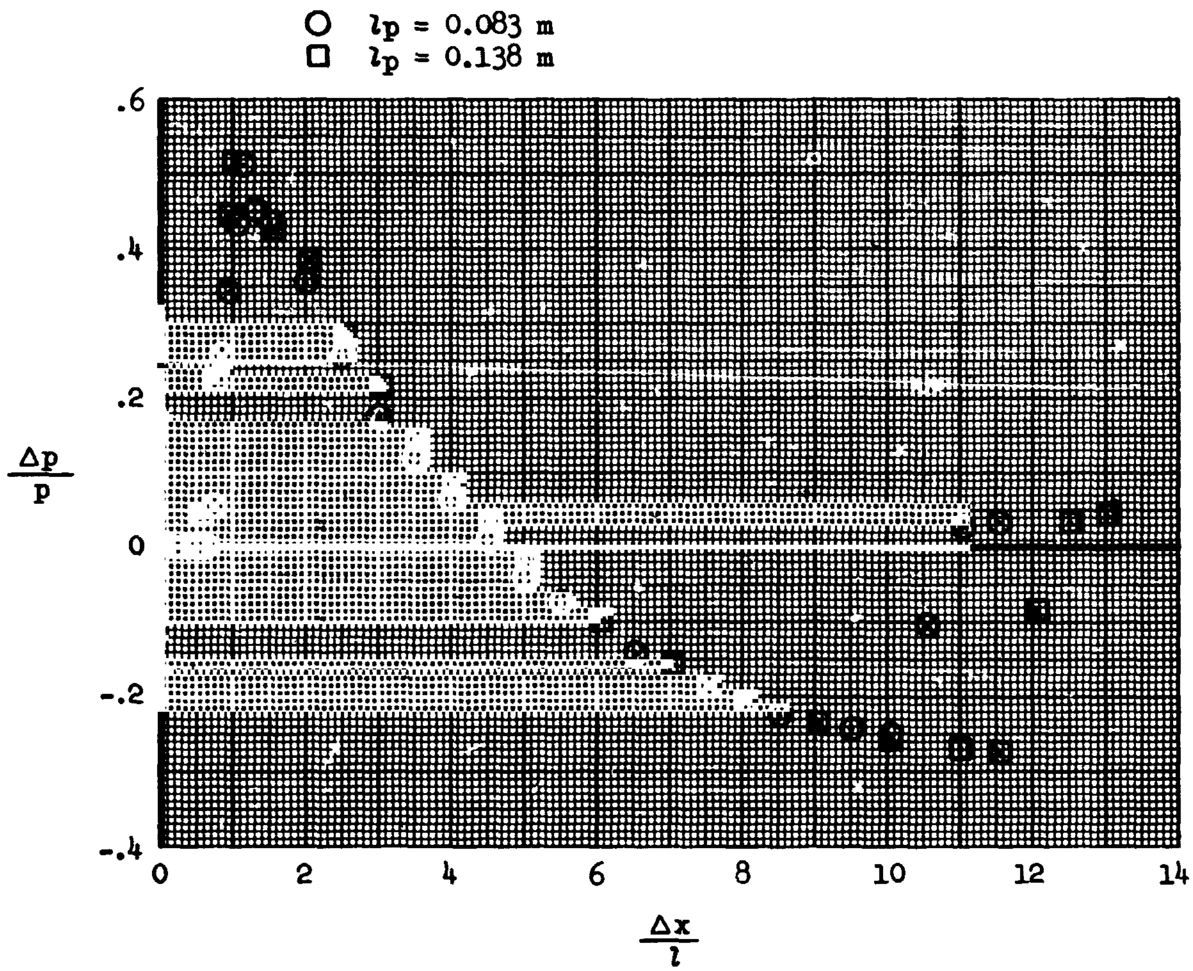


Figure 7.- Effect of simulated plume length on the wind tunnel pressure signature of the Saturn V-Apollo model; $M = 4.01$, $h/l = 3.56$, $\alpha = 0$ deg.

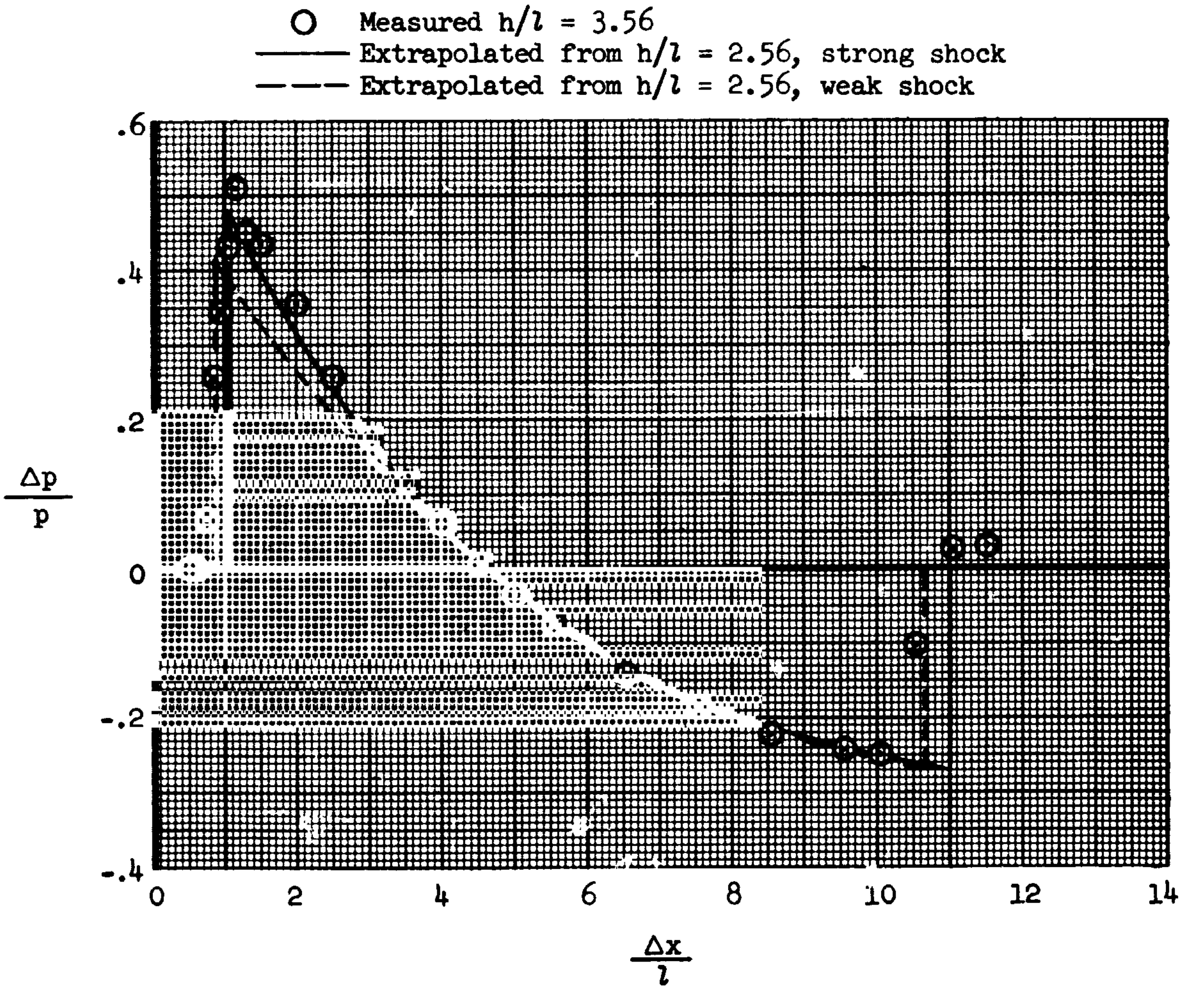


Figure 8.- Comparison of measured and extrapolated pressure signatures for the Saturn V-Apollo model with simulated exhaust plume; $M = 4.01$, $\alpha = 0$ deg.