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NASA TM X-62, 441

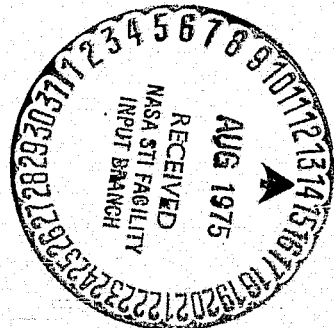
NASA TM X-62, 441

**SONIC BOOM PRESSURE SIGNATURES FOR THE SPACE SHUTTLE
LAUNCH VEHICLE**

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16. Abstract Sonic boom pressure signatures were measured in supersonic and hypersonic wind tunnels for models of the space shuttle launch vehicle at 0° angle of attack with and without solid body simulations of the exhaust plumes. Data were measured at 30° increments in roll angle from 90° to 180° at Mach numbers from 3.02 to 5.56.			
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SONIC BOOM PRESSURE SIGNATURES FOR THE SPACE SHUTTLE LAUNCH VEHICLE MODEL

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INTRODUCTION

At the time of the investigation — reported in reference 1 — of the sonic booms generated by the space shuttle launch vehicle during ascent, the launch vehicle consisted of a delta wing orbiter mounted on a fly-back, winged booster. Modifications of both the orbiter and booster elements made since that time have resulted in a completely different launch vehicle configuration. In particular, the booster underwent a drastic change: the fly-back winged booster was replaced by a non-recoverable external fuel tank and two recoverable solid propellant rocket boosters. Because of these configurational changes, an experimental sonic boom investigation was undertaken to measure pressure signatures for models of the current launch vehicle with simulated plumes. The results of the investigation are presented, without discussion, in this report.

SYMBOLS

h	model altitude
l	reference length, orbiter body length
M	Mach number
p	static pressure
z, r	exhaust plume coordinates
α	angle of attack
Δp	incremental pressure due to model flow field
Δx	distance along abscissa of the pressure signature
ϕ	model roll angle

Abbreviations:

ET	external fuel tank
SRB	solid propellant rocket booster
SSV	space shuttle vehicle

MODELS AND TEST PROCEDURES

An experimental investigation, in which sonic boom pressure signatures were measured for models of the space shuttle launch vehicle, was conducted in the 20-in. supersonic and in the 21-in. hypersonic wind tunnels (ref. 2) at the Jet Propulsion Laboratory. The models were tested with and without solid body simulations of the exhaust plumes.

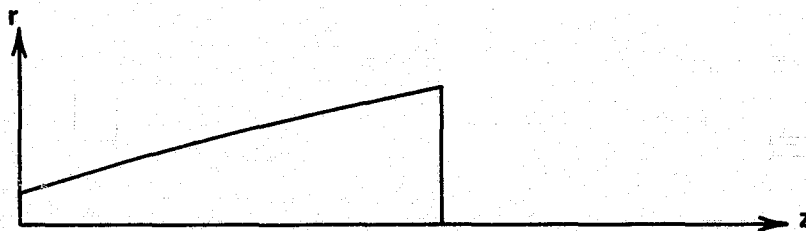
Two different models of the launch vehicle were tested in the present investigation: the 0.0041-in. and 0.00175-scale models. The models were tested in both the 20-in. supersonic and 21-in. hypersonic wind tunnels at 0° angle of attack with roll angles varying from 90° to 180° in 30° increments.

A 0.0041-scale launch vehicle model, shown in figures 1 and 2, was tested without simulated exhaust plumes. Each element of the launch vehicle model – the space shuttle vehicle (SSV), the external fuel tank (ET), and two solid propellant rocket boosters (SRB) – was designed to be tested by itself or in combination. The 0.0041-scale model was tested in the 20-in. supersonic wind tunnel at Mach numbers from 3.02 to 4.58 and at a total pressure of 133.22 kN/m^2 ; in the 21-in. hypersonic wind tunnel the Mach number and total pressure were 5.56 and 799.31 kN/m^2 , respectively.

The 0.00175-scale launch vehicle model was constructed for the tests with exhaust plume simulations. The model scale was based on the maximum sphere diameter (17.02 cm) that would permit establishment of wind tunnel flow at the highest test Mach number of 5.56. In the range of Mach numbers used here, the size of the exhaust plume is the largest at $M=5.56$. Each element of the launch vehicle model was constructed of brass with the exception of the solid body simulations of the mixing boundary plumes which were constructed from one piece of aluminum. Photographs and sketches of the 0.00175-scale launch vehicle model are shown, with simulated exhaust plumes, in figures 3 through 5. The 0.00175-scale model was tested in the 20-in. supersonic wind tunnel at Mach numbers from 3.20 to 4.14 at a total pressure of 153.21 kN/m^2 , and in the 21-in. hypersonic wind tunnel at Mach number 5.54 and a total pressure of 799.31 kN/m^2 .

The solid body simulations of the exhaust plumes, under various stages of construction, are shown in figure 6. The simulated plumes containing lobes represent the exhaust plume of the launch vehicle before the two solid propellant rocket boosters are jettisoned. Two of the three lobes represent the exhaust plumes from each of the two solid propellant rocket boosters, and the third lobe represents the combined exhaust plume from each of the three main engines of the space shuttle orbiter. The large simulated exhaust plume without lobes represents the exhaust plume of the launch vehicle after the solid propellant rocket boosters have been jettisoned.

The coordinates for the SSV and SRB simulated exhaust plumes are presented in tables 1 and 2. The coordinate system for the simulated exhaust plume is shown below.



The flow field static pressures (pressure signatures) were measured with a slender (2° included angle), conical, static pressure probe that was connected to a capacitance-type differential pressure transducer. The models were mounted on a linear actuator that permitted longitudinal travel along a straight line parallel to the centerline of the test section. The static pressure probe was mounted on spacers fixed to the floor of the test section; this arrangement made it possible to vary the distance between the floor and the static pressure probe to prevent the shockwaves (reflecting off the floor) from interfering with the measured pressure signatures. Schlieren photographs were taken at each test condition.

PRESENTATION OF THE DATA

Schlieren photographs for the launch vehicle models with and without simulated exhaust plumes are shown in figures 7 through 19 for the various Mach numbers and roll angles; pressure signatures are presented in figures 20 through 33.

REFERENCES

1. Hicks, Raymond M.; and Mendoza, Joel P.: A Brief Study of the Space Shuttle Sonic Boom During Ascent. NASA TM X-62,050, July 23, 1971.
2. Jet Propulsion Laboratory Wind Tunnel Facilities. JPL Technical Memorandum 33-335, 1967.

TABLE 1
COORDINATES FOR THE MIXING BOUNDARY EXHAUST PLUME FOR THE SSV^a

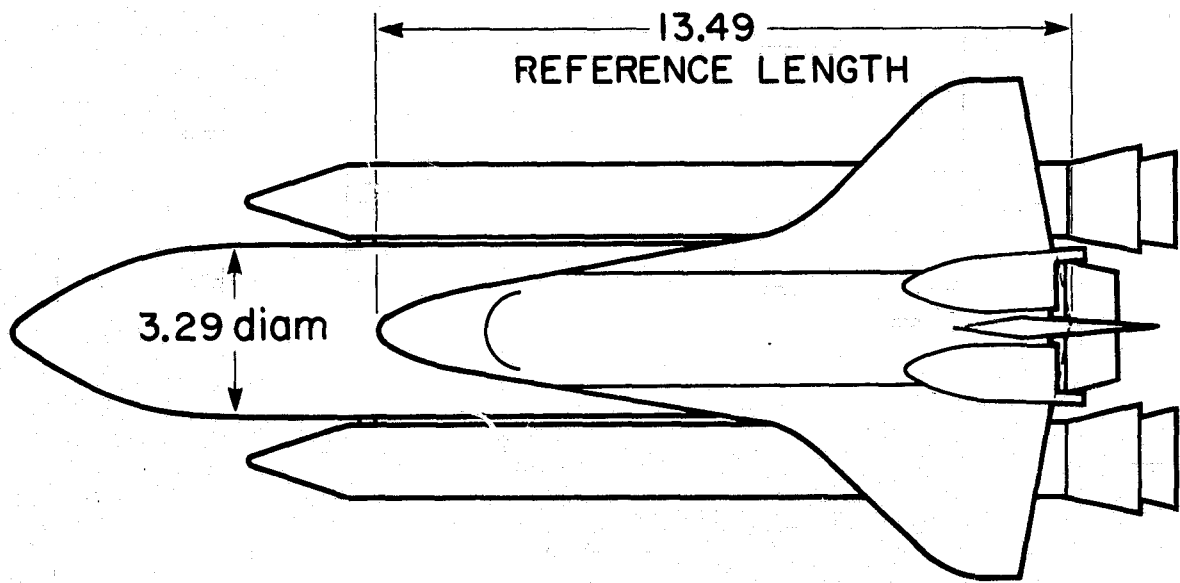
M	3.200	3.500	3.630	3.910	4.080	4.130	5.500
Z	r	r	r	r	r	r	r
0.0	0.353	0.353	0.353	0.353	0.353	0.353	0.353
0.442	0.589	0.610	0.625	0.640	0.665	0.671	0.937
0.886	0.808	0.848	0.879	0.909	0.955	0.968	1.488
1.331	1.008	1.072	1.113	1.163	1.224	1.250	2.007
1.773	1.189	1.278	1.328	1.400	1.473	1.514	2.492
2.220	1.359	1.471	1.532	1.618	1.714	1.775	2.936
2.664	1.514	1.648	1.720	1.821	1.941	2.024	3.340
3.109	1.659	1.816	1.897	2.019	2.154	2.250	3.741
3.553	1.791	1.976	2.065	2.207	2.355	2.451	4.122
3.998	1.915	2.126	2.225	2.383	2.548	2.664	4.488
4.442	2.035	2.266	2.372	2.545	2.733	2.875	4.834
4.887	2.144	2.403	2.517	2.708	2.913	3.071	5.174
5.331	2.243	2.537	2.657	2.865	3.089	3.256	5.502
5.776	2.344	2.664	2.791	3.018	3.254	3.437	5.819
6.220	2.443	2.789	2.918	3.162	3.411	3.607	6.124
6.665	2.530	2.903	3.040	3.299	3.564	3.782	6.426
7.109	2.609	3.007	3.155	3.426	3.711	3.955	6.718
7.554	2.682	3.109	3.266	3.553	3.856	4.115	7.008
7.998	2.753	3.208	3.373	3.663	3.998	4.265	7.287
8.443	2.822	3.305	3.472	3.797	4.135	4.425	7.572
8.887	2.888	3.399	3.569	3.909	4.265	4.585	7.854
9.332	2.959	3.490	3.670	4.026	4.394	4.740	8.128
9.776	3.035	3.576	3.777	4.140	4.519	4.887	8.400

^aThe plume coordinates for the space shuttle vehicle were calculated by Mr. Jess H. Jones of the George C. Marshall Space Flight Center.

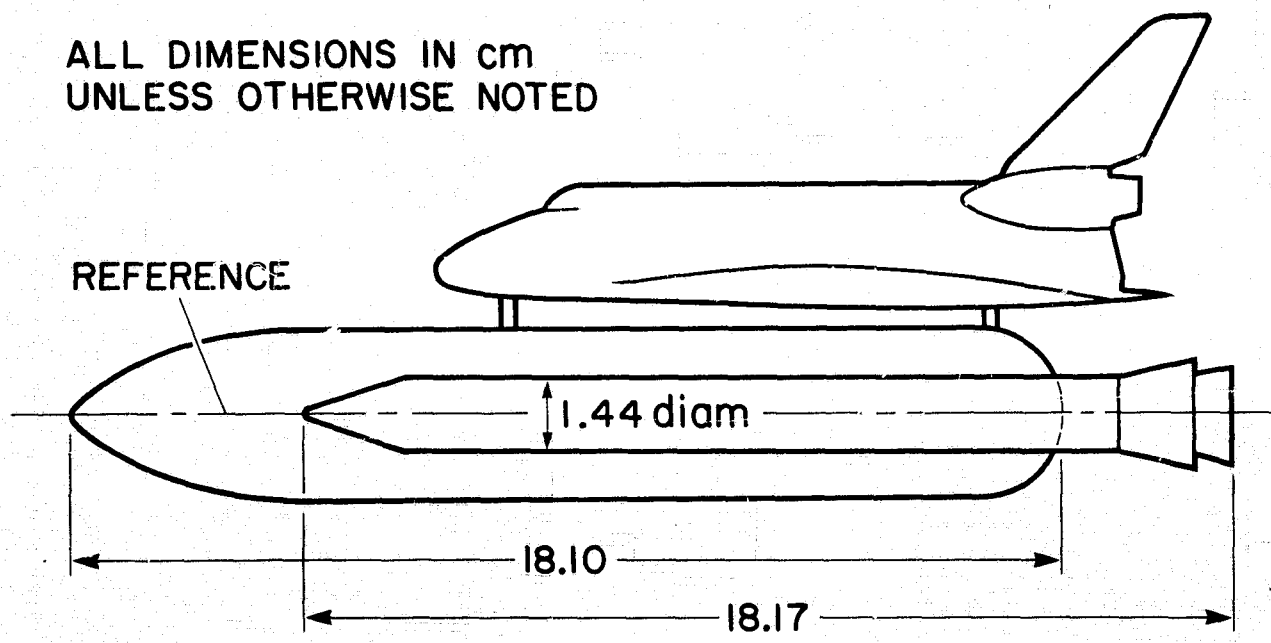
TABLE 2
 COORDINATES FOR THE MIXING BOUNDARY EXHAUST PLUME
 FOR THE SRB^a

M	3.200	3.500	3.630	3.910	4.080	4.130
Z	r	r	r	r	r	r
0.0	0.317	0.317	0.317	0.317	0.317	0.317
0.442	0.734	0.792	0.843	0.897	0.767	0.620
0.886	1.087	1.204	1.293	1.377	1.158	0.886
1.331	1.382	1.549	1.661	1.763	1.491	1.120
1.775	1.613	1.834	1.953	2.052	1.763	1.318
2.220	1.882	2.116	2.240	2.344	2.032	1.514
2.664	2.154	2.377	2.497	2.609	2.278	1.697
3.109	2.385	2.619	2.746	2.863	2.510	1.869
3.553	2.591	2.842	2.977	3.101	2.723	2.029
3.998	2.794	3.056	3.198	3.327	2.931	2.184
4.442	2.984	3.251	3.409	3.541	3.132	2.332
4.887	3.165	3.447	3.604	3.752	3.317	2.474
5.331	3.332	3.635	3.790	3.955	3.487	2.609
5.776	3.495	3.815	3.975	4.143	3.658	2.736
6.220	3.653	3.990	4.155	4.318	3.820	2.857
6.665	3.805	4.155	4.326	4.496	3.978	2.974
7.109	3.955	4.310	4.488	4.666	4.122	3.089
7.554	4.097	4.463	4.646	4.826	4.267	3.195
7.998	4.229	4.613	4.798	4.976	4.404	3.297
8.443	4.359	4.755	4.943	5.128	4.536	3.399
8.874	4.478	4.887	5.080	5.276	4.666	3.498
9.332	4.600	5.019	5.215	5.418	4.790	3.597

^aThe plume coordinates for the solid propellant rocket booster were calculated by Mr. Jess H. Jones of the George C. Marshall Space Flight Center.

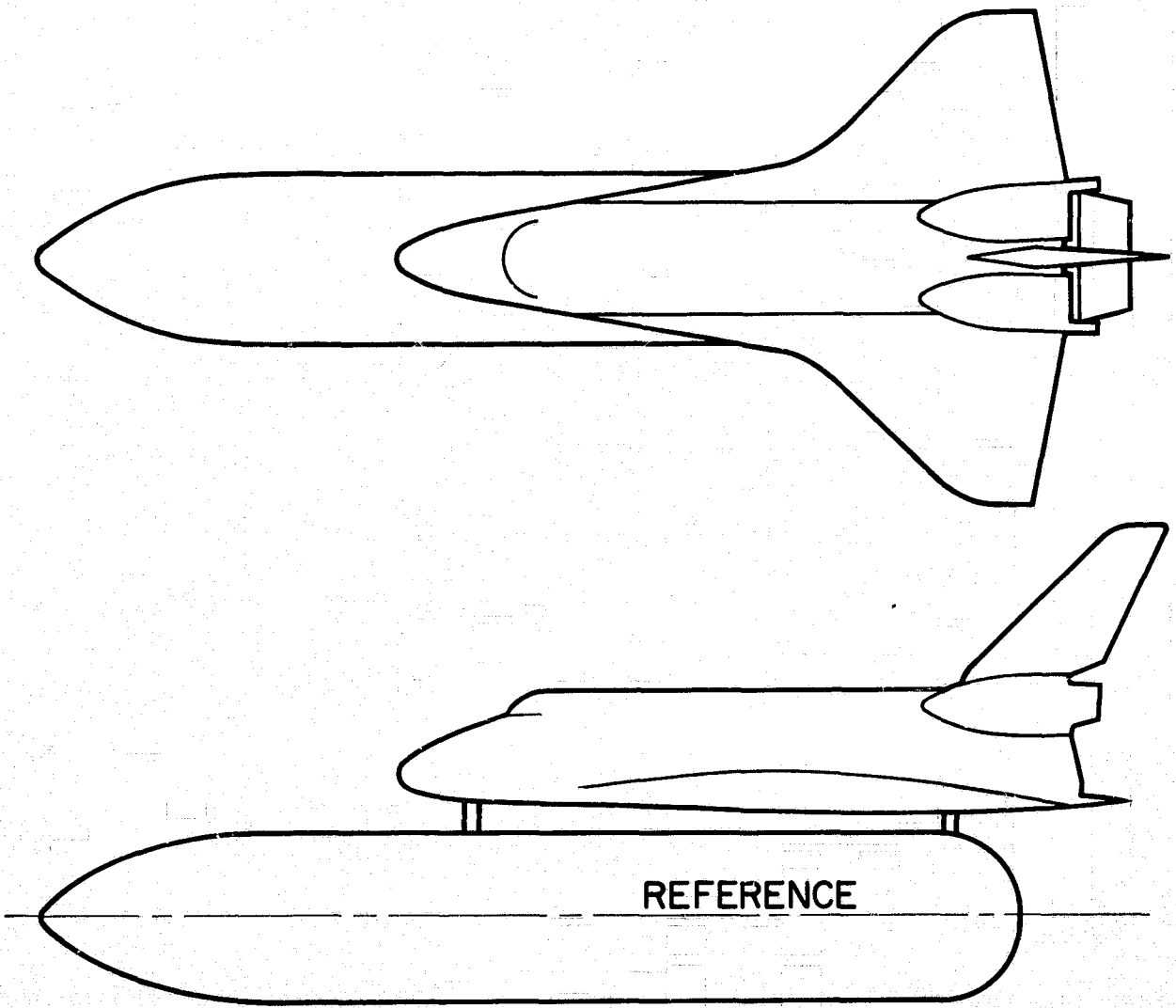


ALL DIMENSIONS IN cm
UNLESS OTHERWISE NOTED



(a) With solid rocket boosters.

Figure 1. - Sketch of the 0.0041-scale model of the space shuttle launch vehicle.



(b) Without solid rocket boosters.

Figure 1. — Concluded.

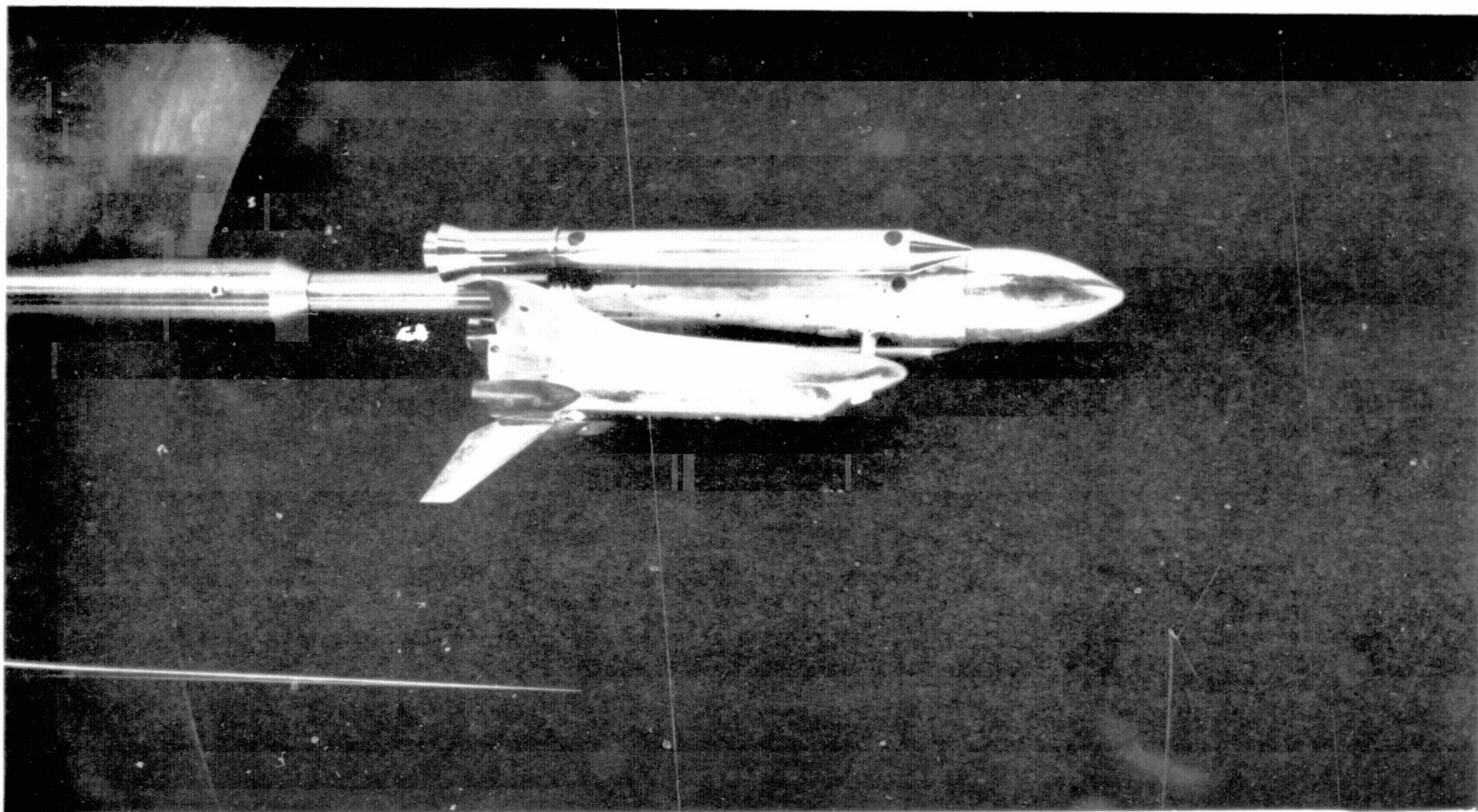
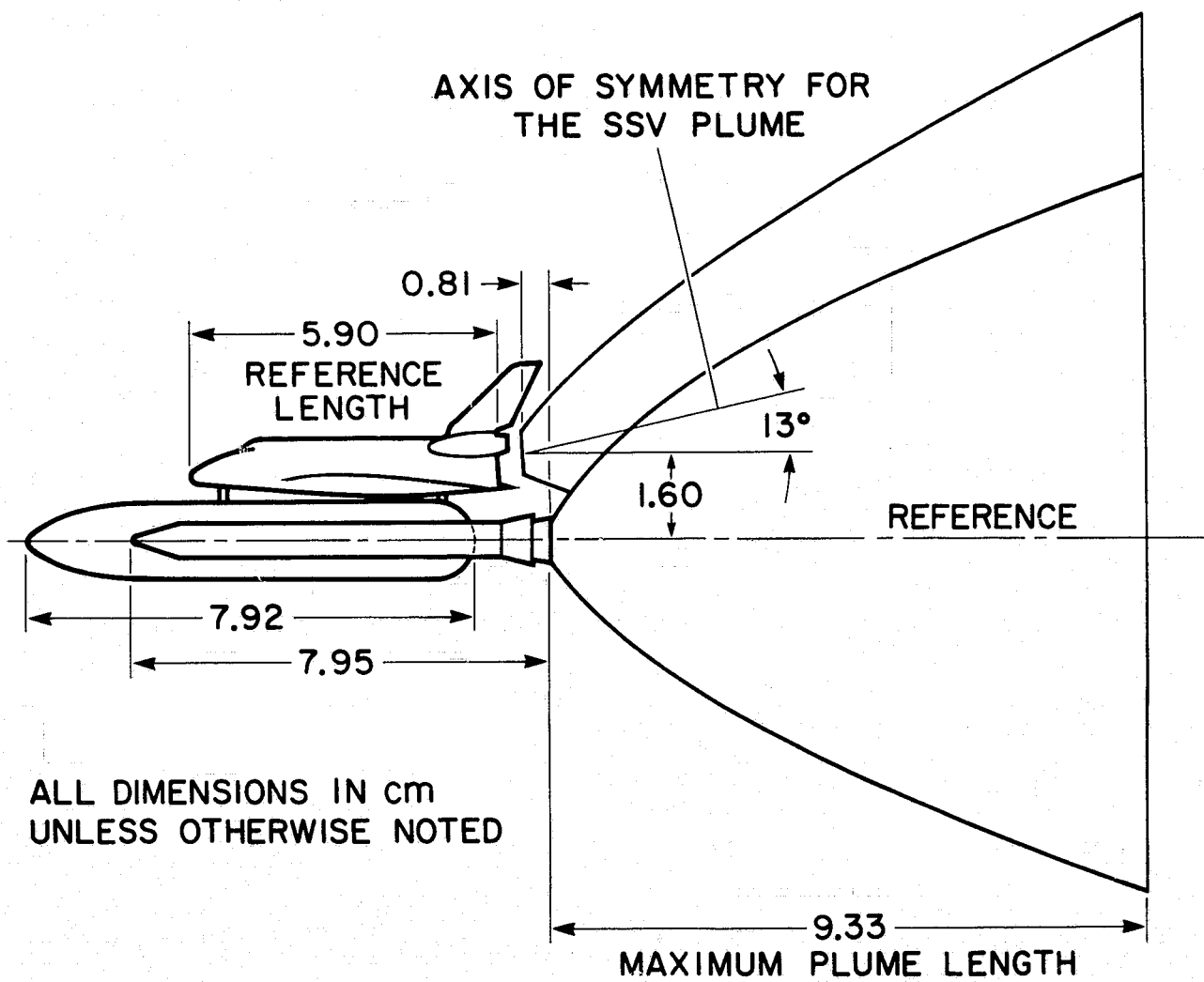
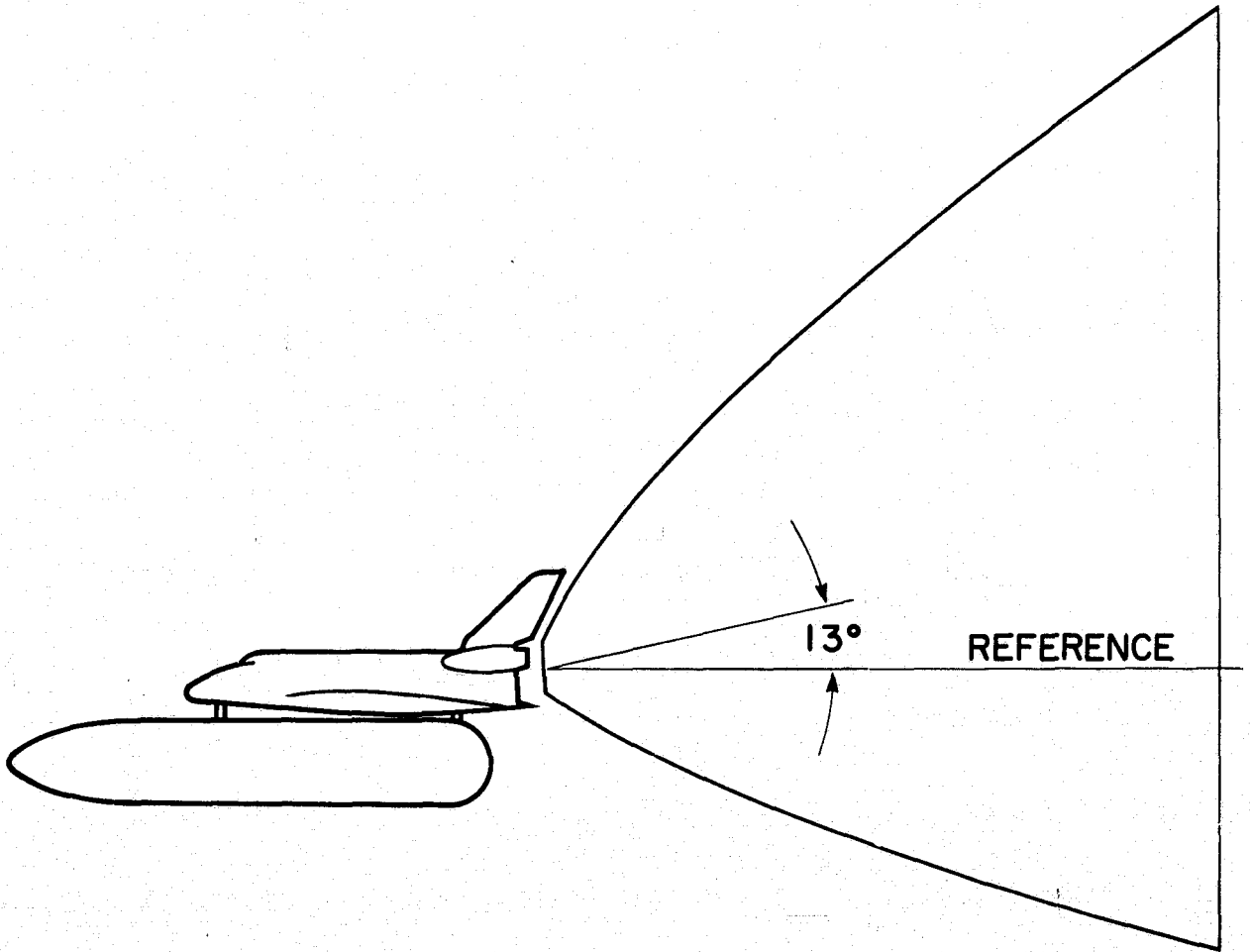


Figure 2. – Installation photograph of the 0.0041-scale model of the space shuttle launch vehicle in the 20-in. supersonic wind tunnel at the Jet Propulsion Laboratory.



(a) With solid rocket boosters.

Figure 3. — Sketch of the 0.00175-scale model of the launch vehicle with simulated exhaust plumes.



(b) Without solid rocket boosters.

Figure 3. — Concluded.

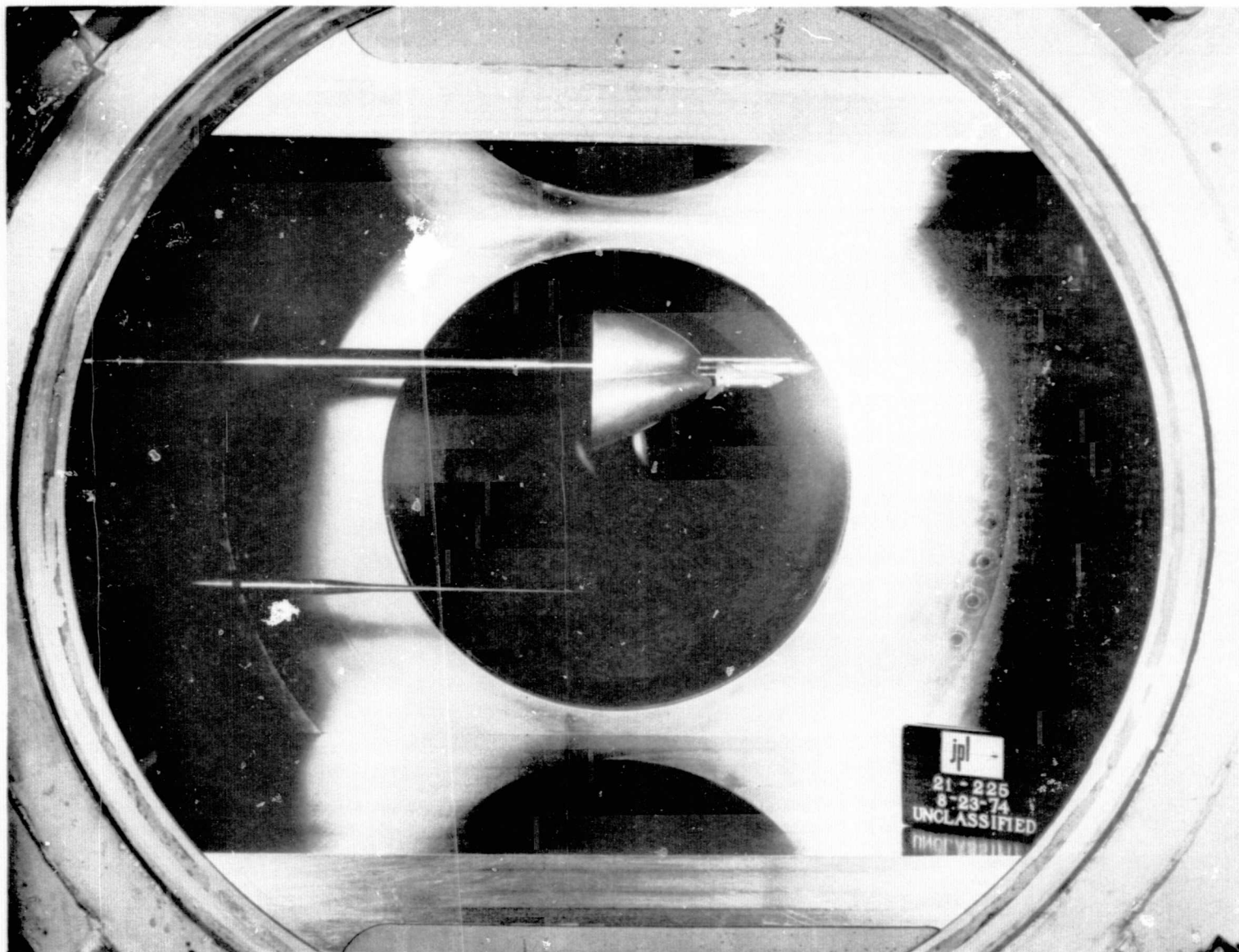


Figure 4. – Installation photograph of the 0.00175-scale model of the space shuttle launch vehicle with solid body simulations of the exhaust plume.

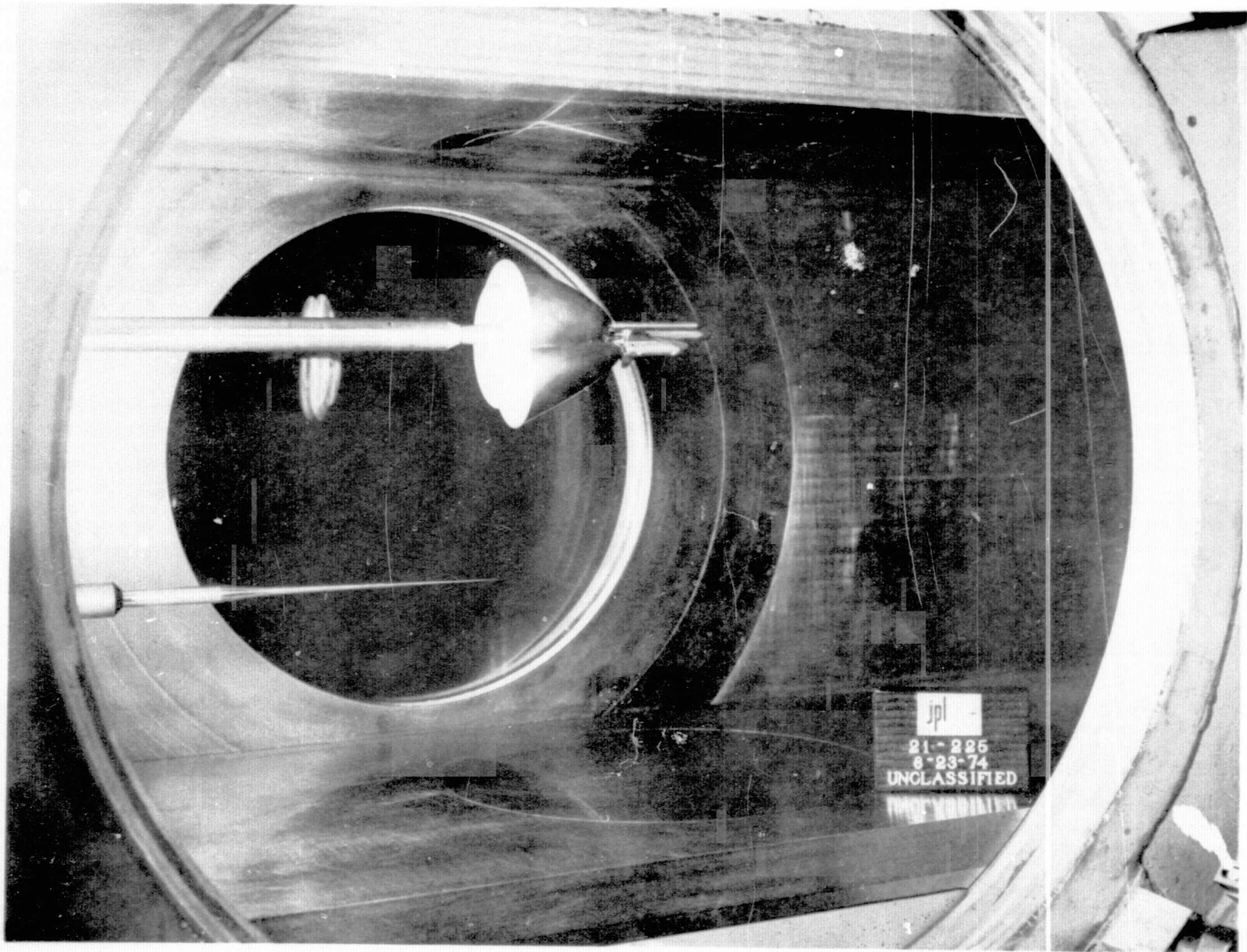


Figure 5. – Installation photograph of the 0.00175-scale launch vehicle model showing the simulated exhaust plume details.

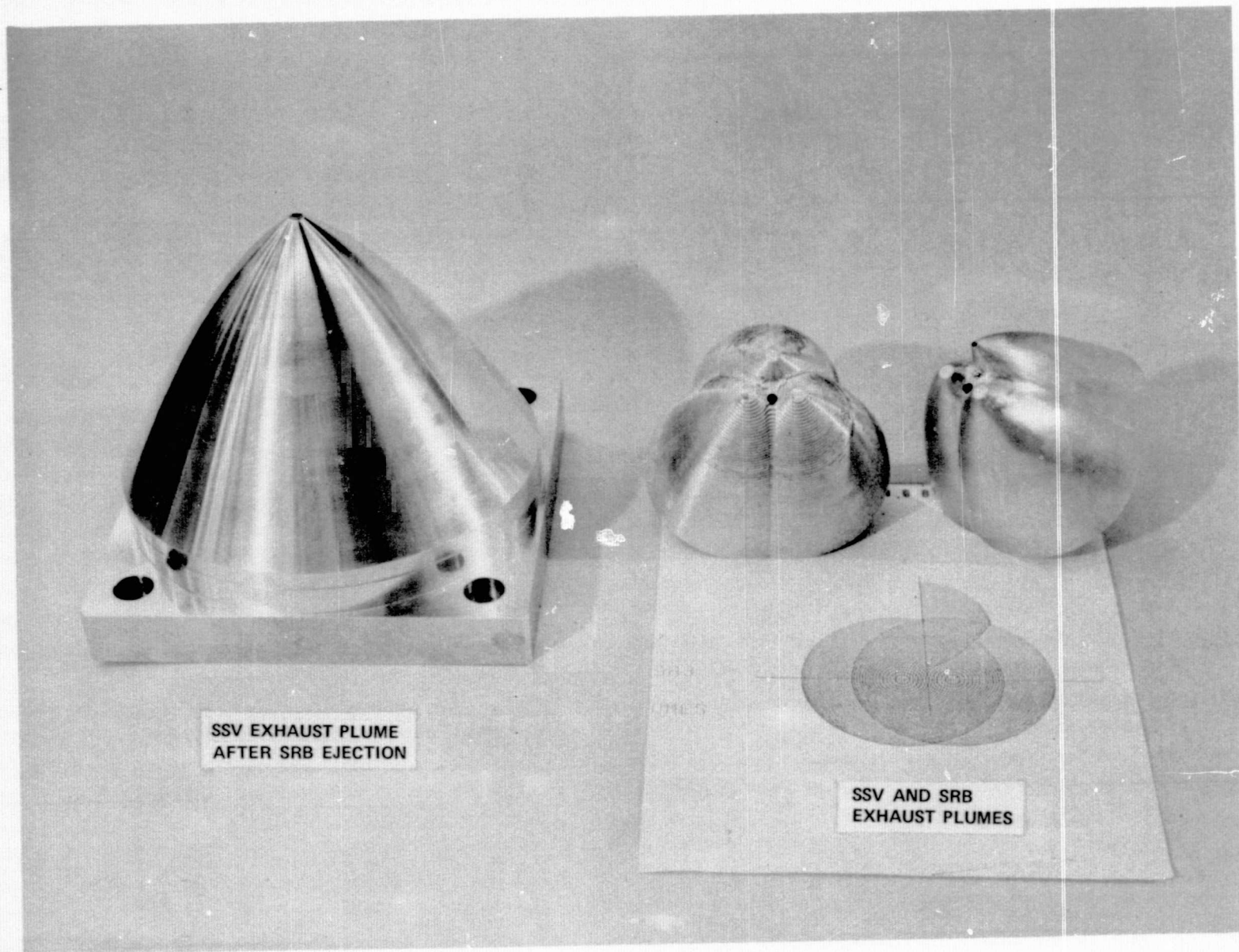
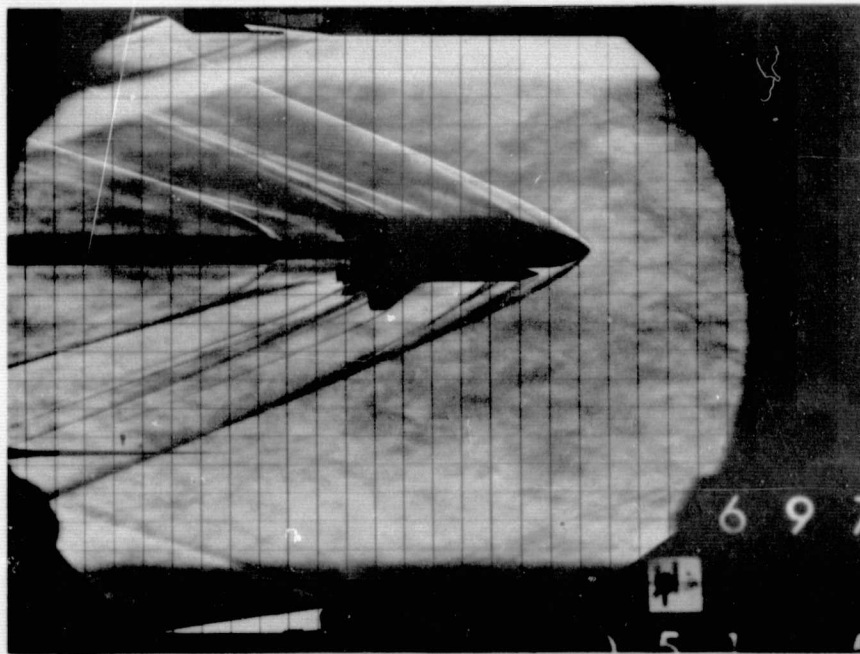
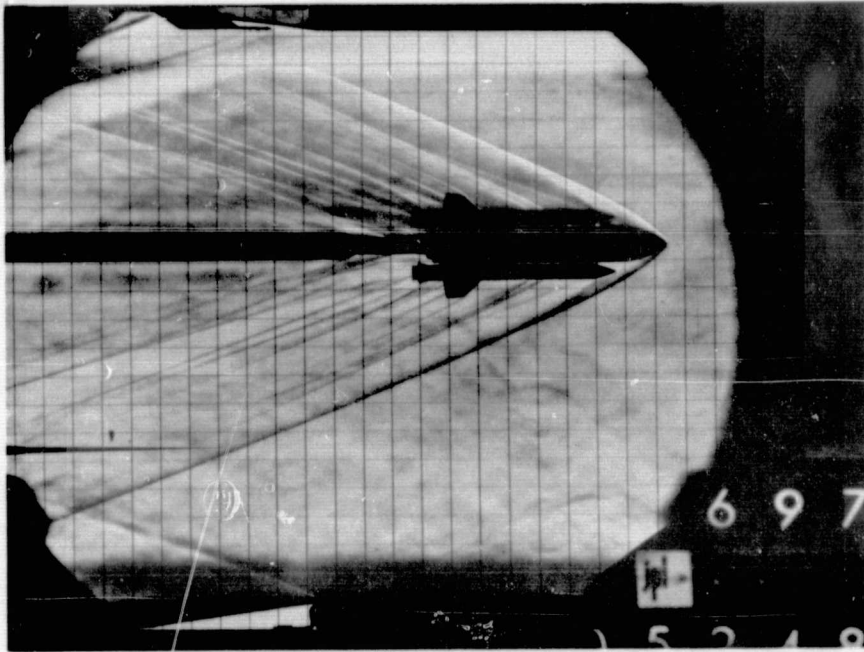
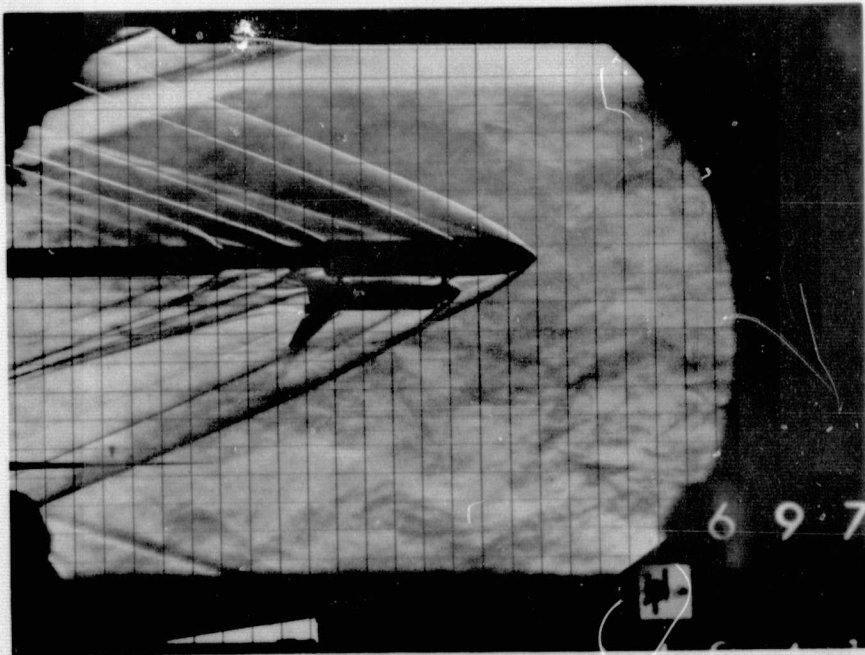
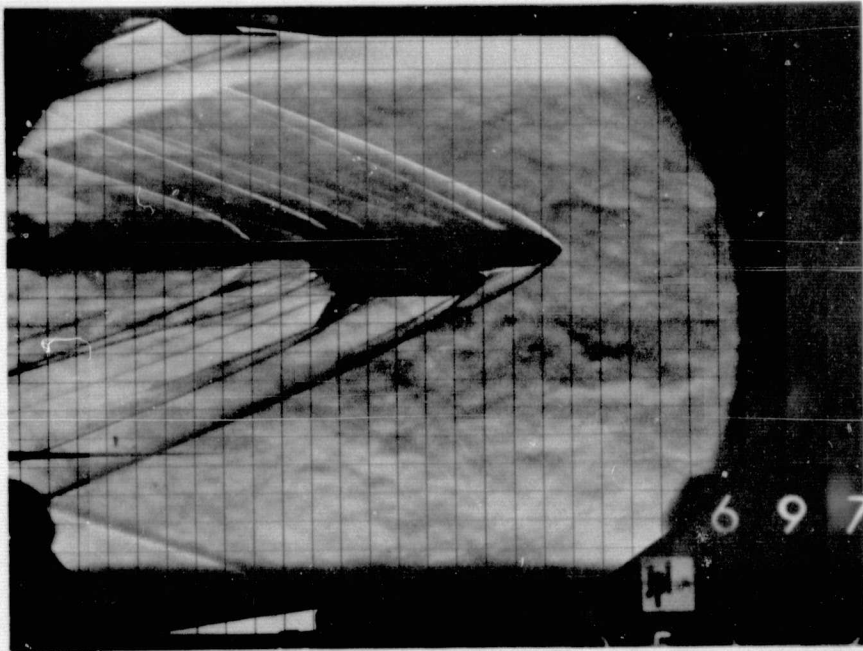


Figure 6. – Solid body simulations of the exhaust plumes.



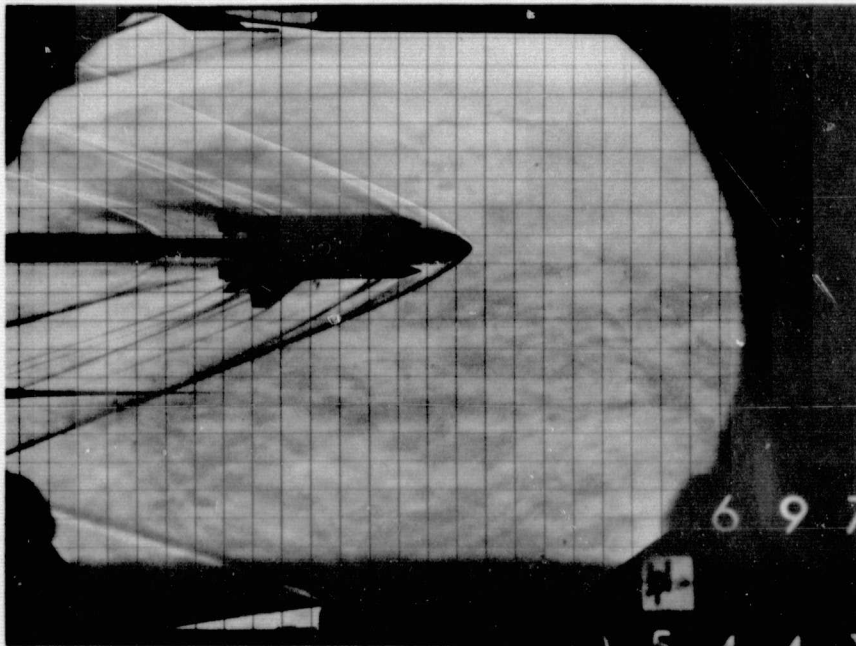
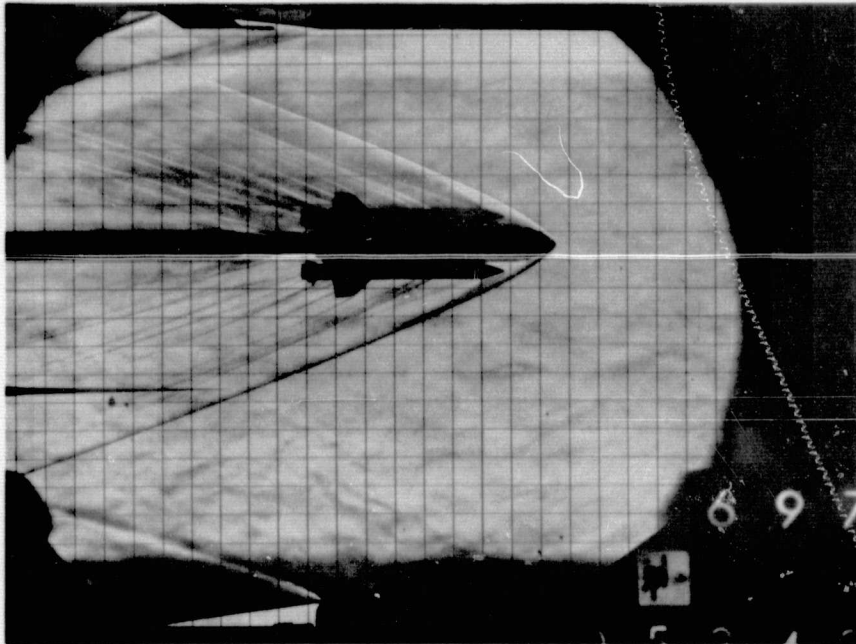
(a) $\phi = 90^\circ, 120^\circ$.

Figure 7. – Schlieren photograph of the launch vehicle model without simulated exhaust plumes, $M = 3.0$, $\alpha = 0^\circ$, $h/l = 1.365$.



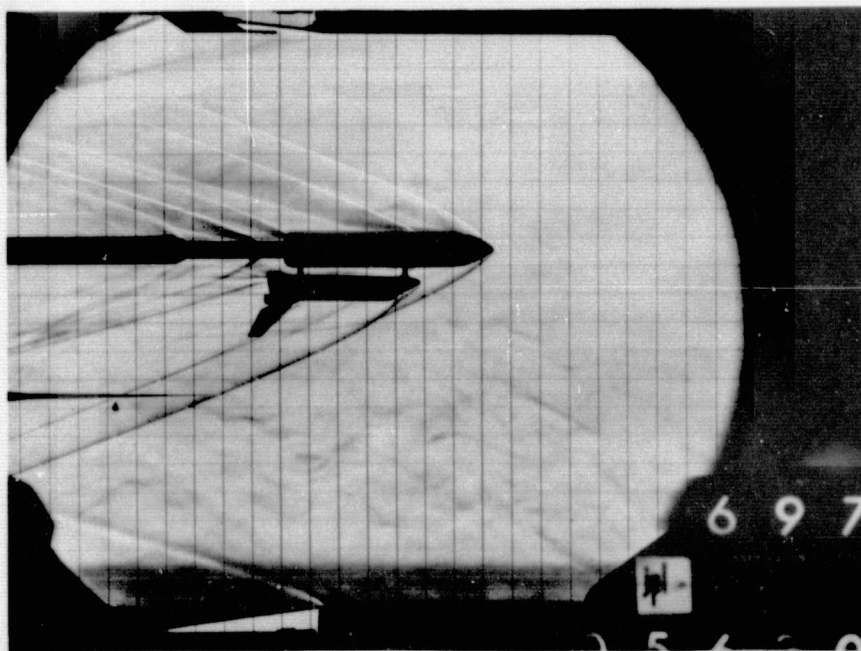
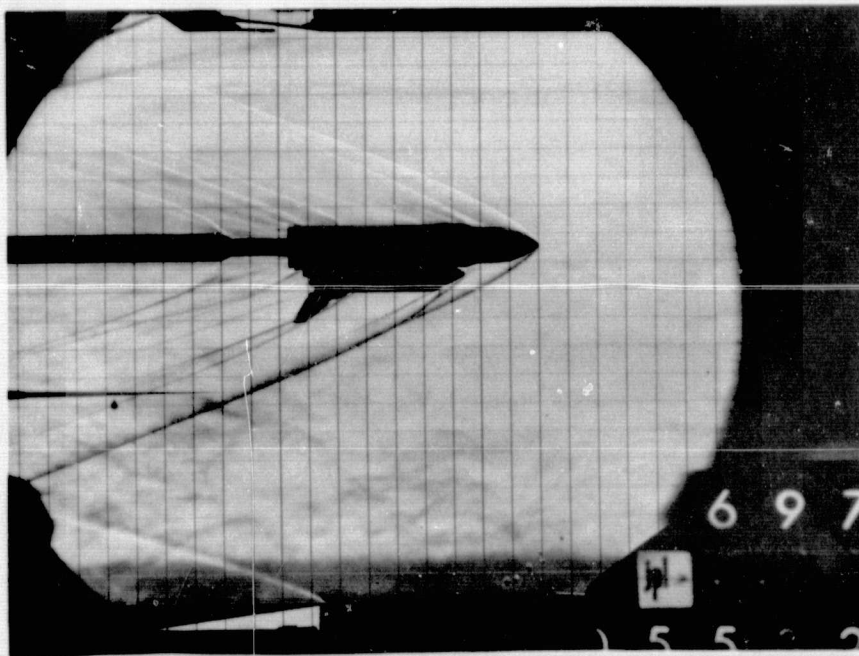
(b) $\phi = 150^\circ, 180^\circ$.

Figure 7. - Concluded.



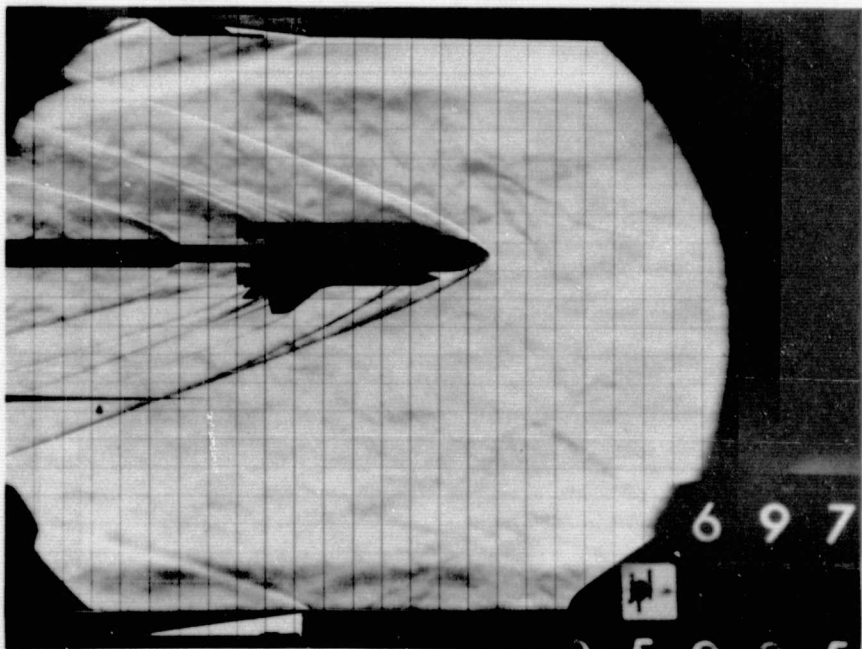
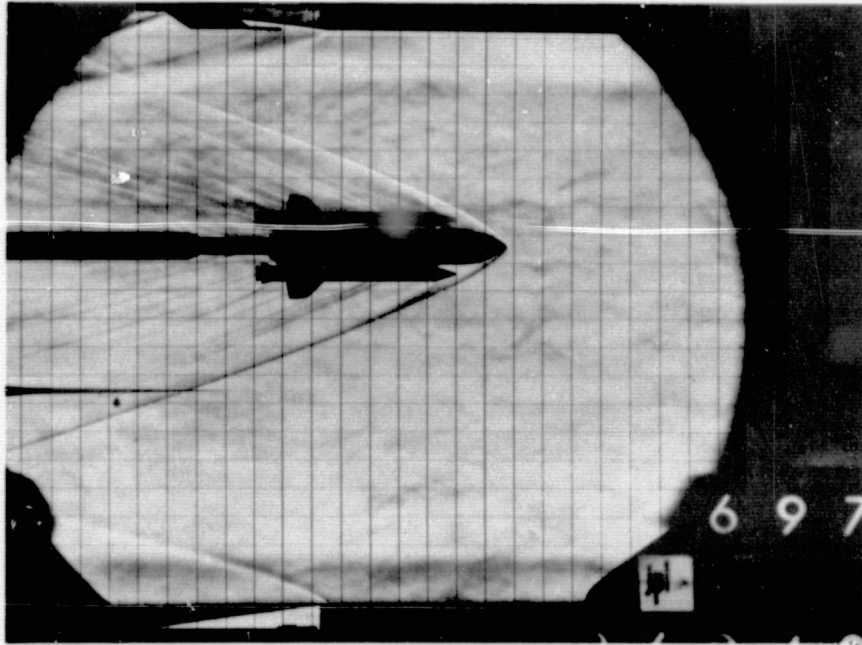
(a) $\phi = 90^\circ, 120^\circ$.

Figure 8. — Schlieren photographs of the launch vehicle model without simulated exhaust plumes,
 $M = 3.27, \alpha = 0^\circ, h/l = 0.988$



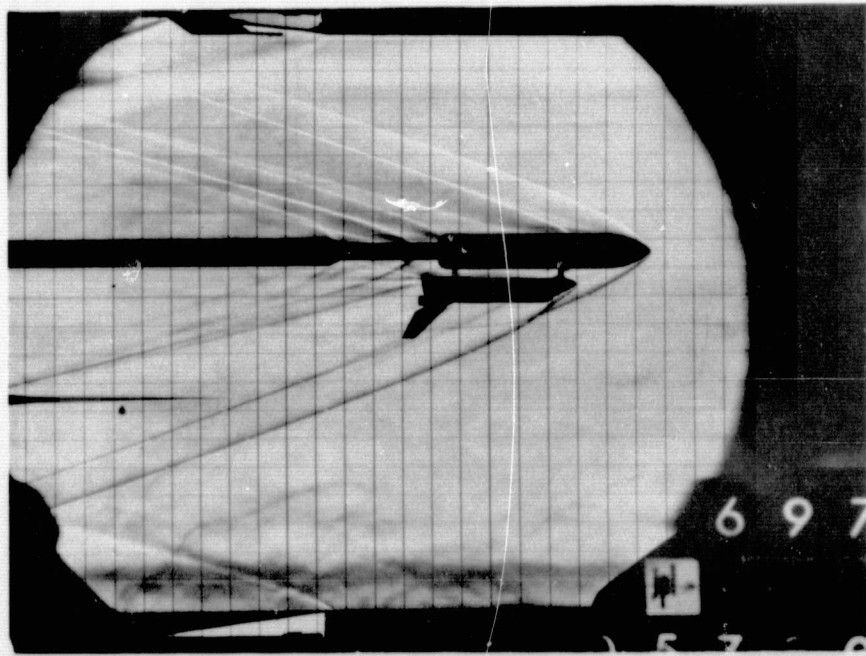
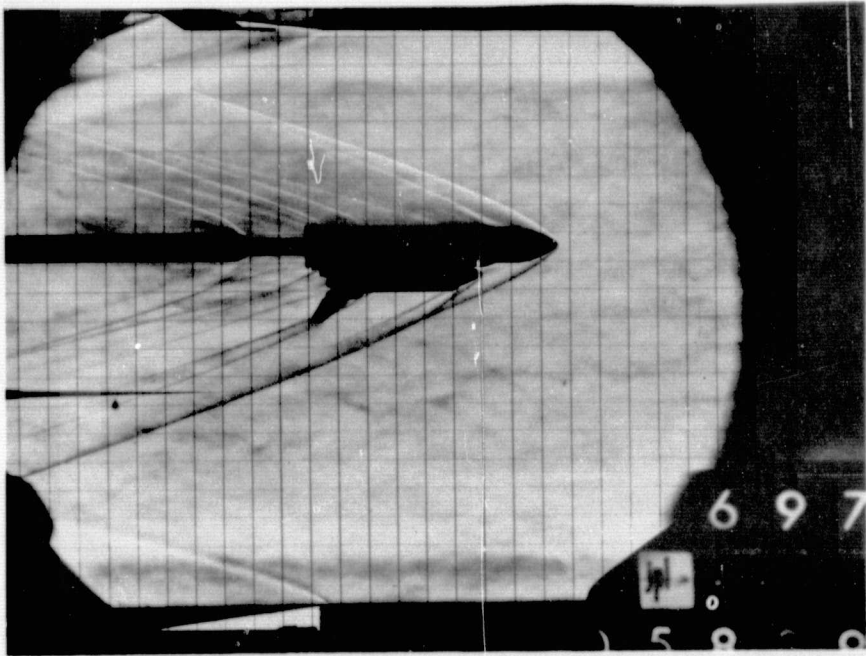
(b) $\phi = 150^\circ, 180^\circ$.

Figure 8. - Concluded.



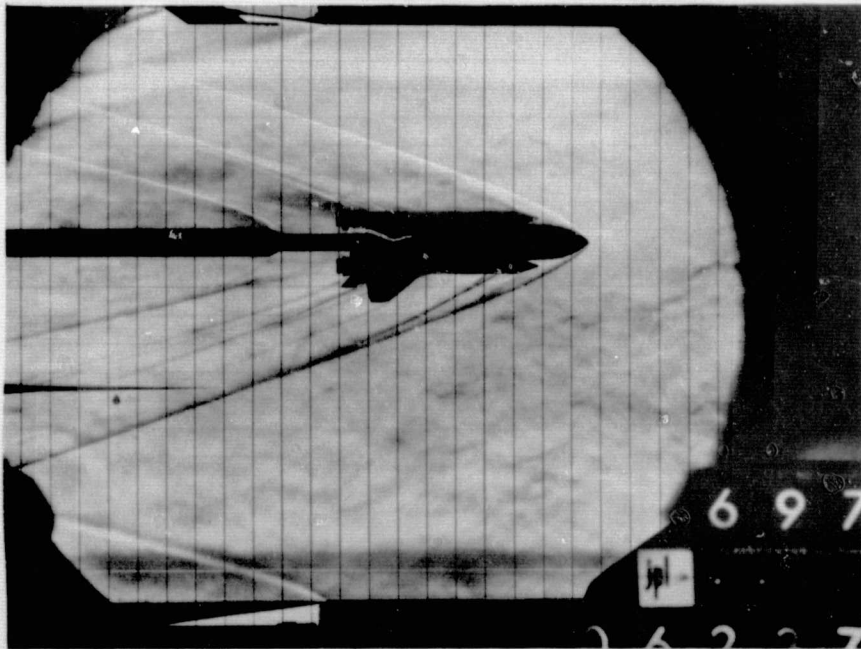
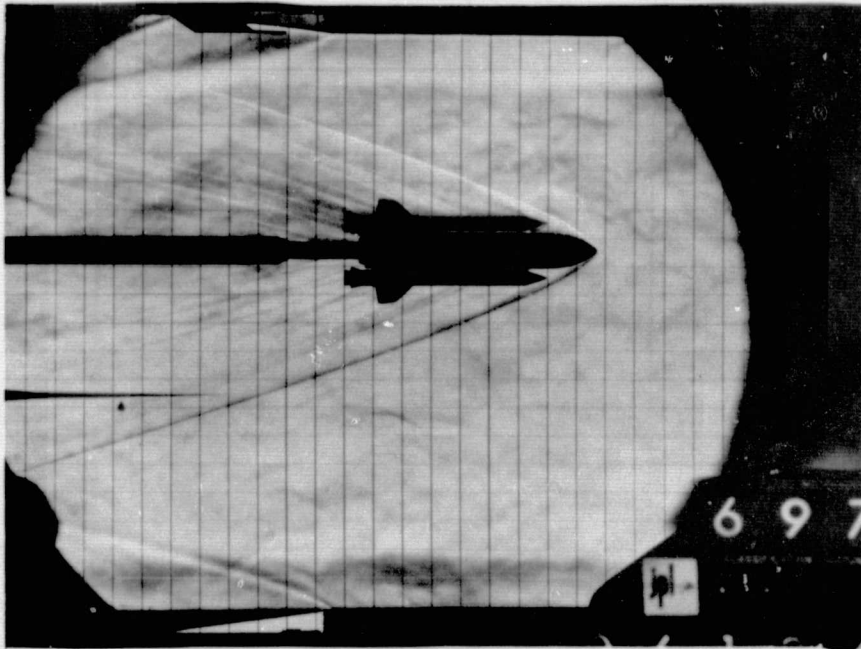
(a) $\phi = 90^\circ, 120^\circ$.

Figure 9. — Schlieren photographs of the launch vehicle model without simulated exhaust plumes, $M = 3.51$, $\alpha = 0^\circ$, $h/l = 0.988$.



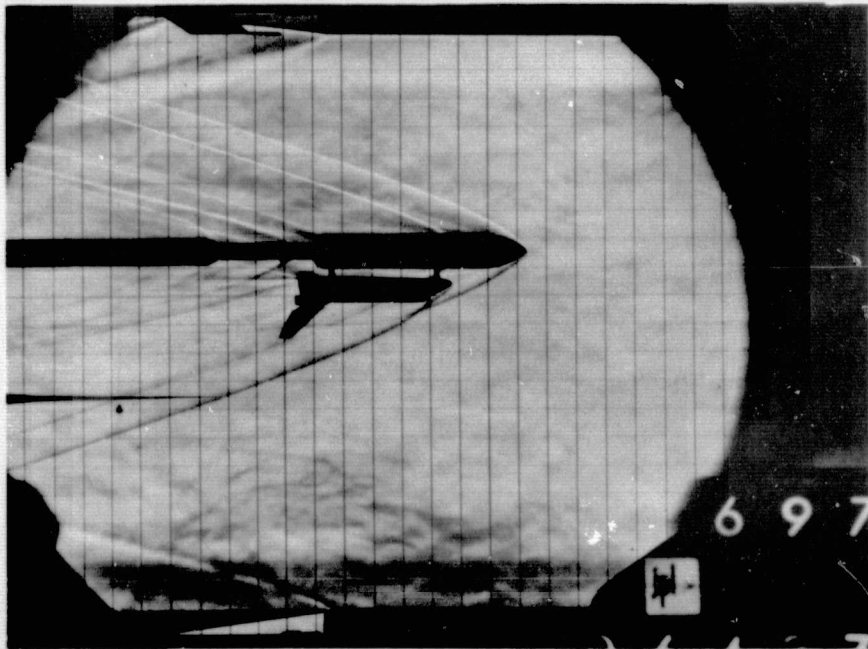
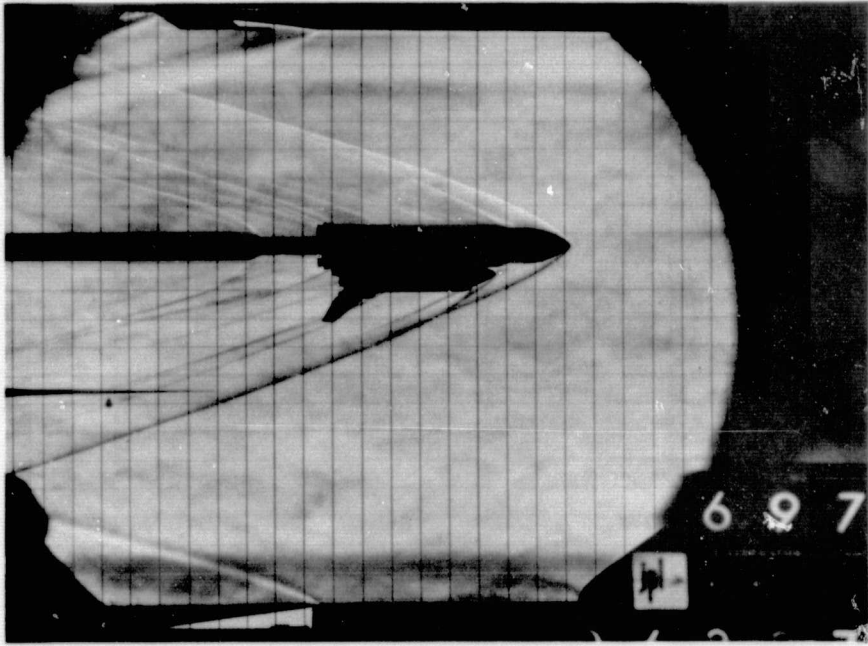
(b) $\phi = 150^\circ, 180^\circ$.

Figure 9. - Concluded.



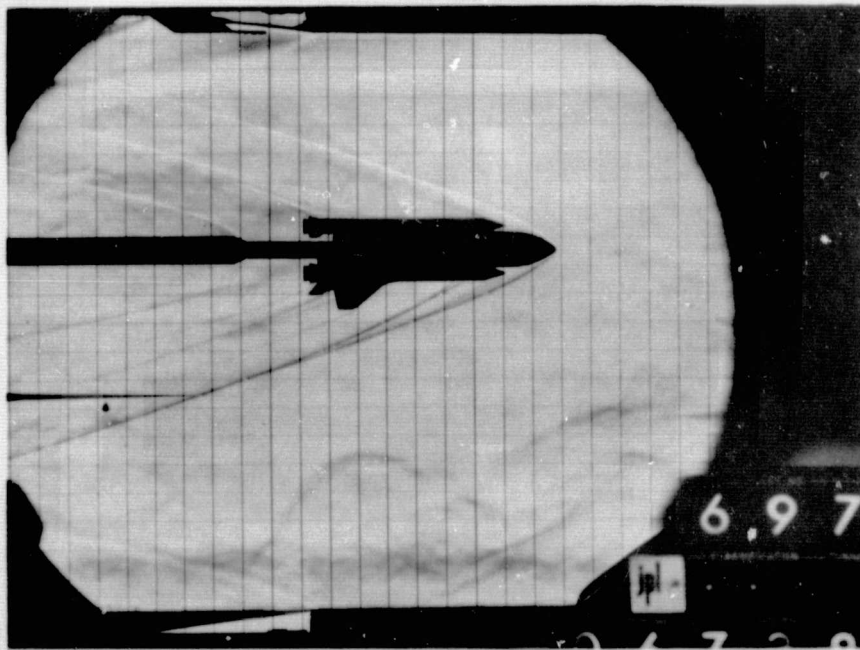
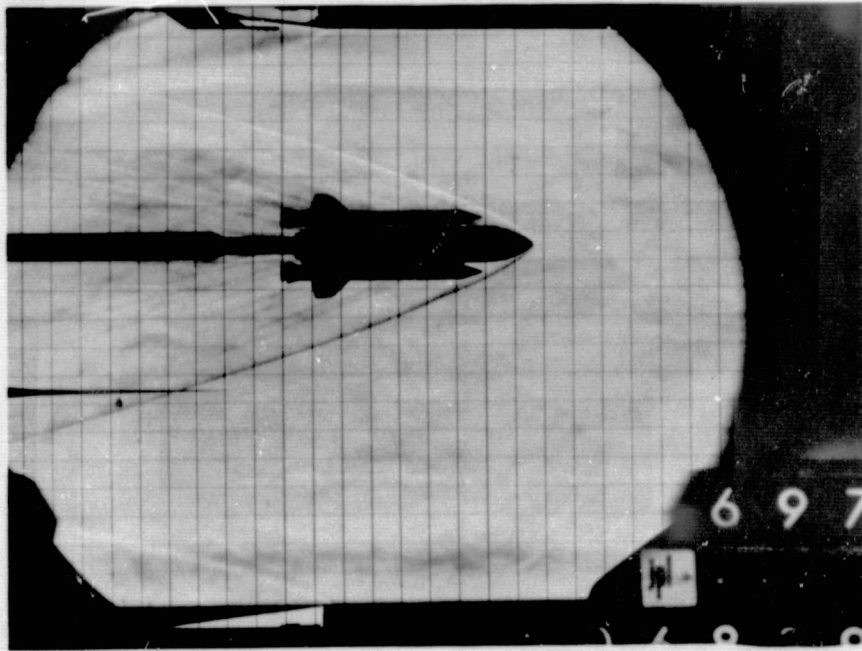
(a) $\phi = 90^\circ, 120^\circ$.

Figure 10. — Schlieren photographs for the launch vehicle model without simulated exhaust plumes, $M = 3.76$, $\alpha = 0^\circ$, $h/l = 0.988$.



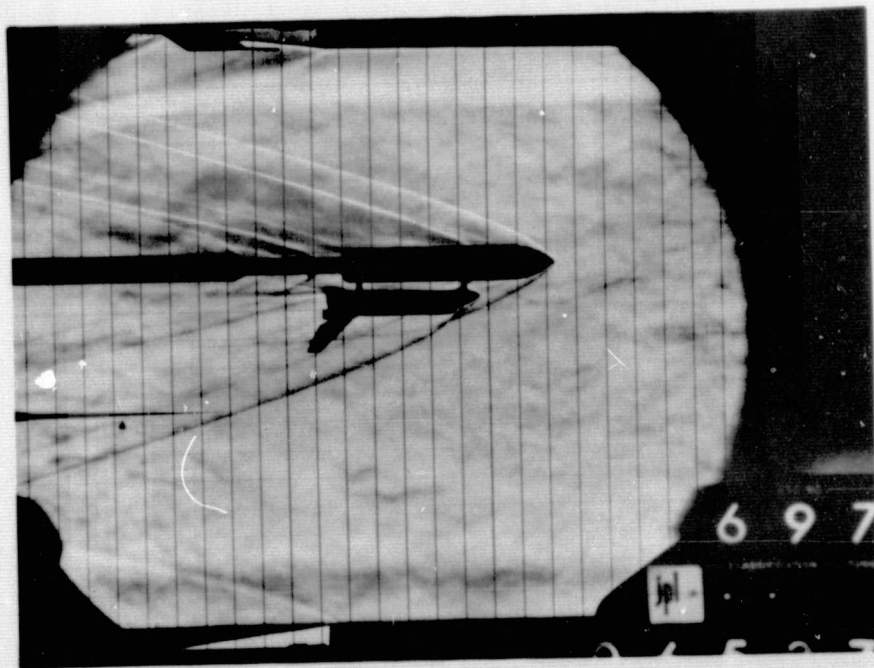
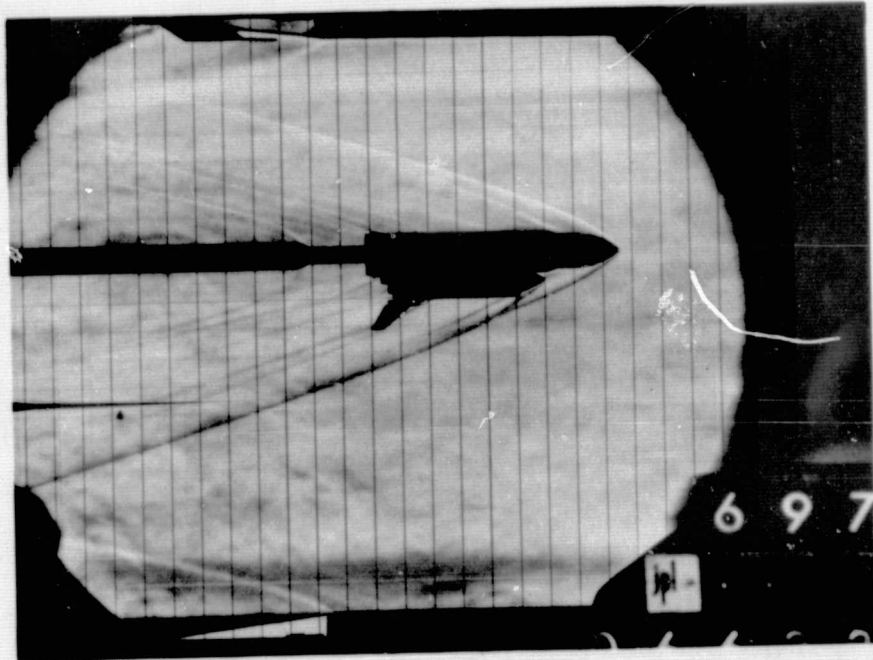
(b) $\phi = 150^\circ, 180^\circ$.

Figure 10. - Concluded.



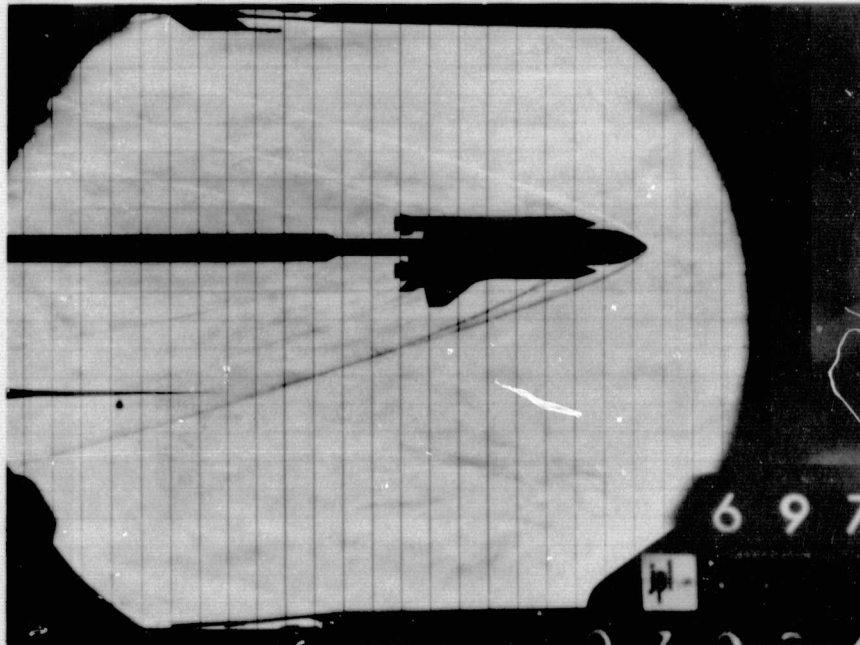
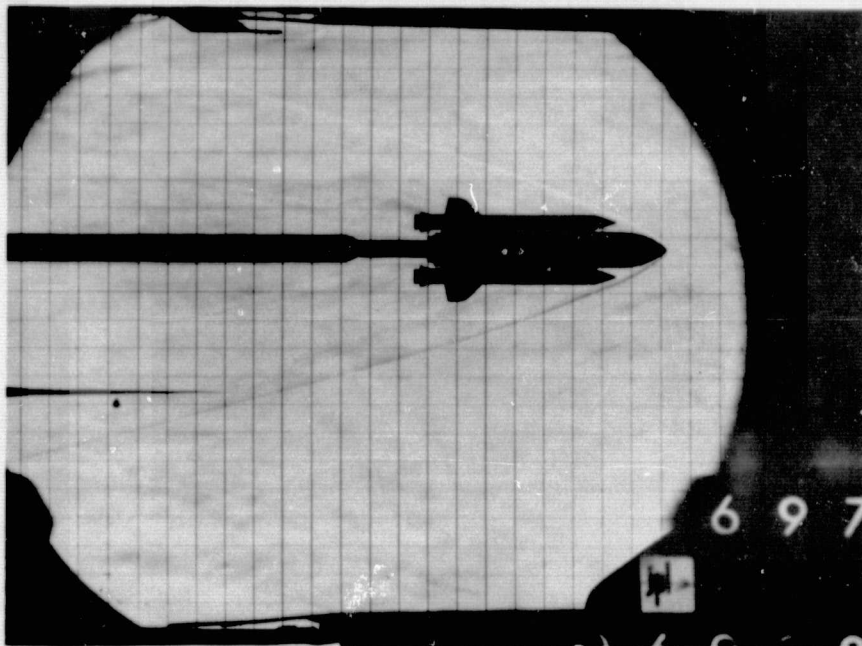
(a) $\phi = 90^\circ, 120^\circ$.

Figure 11. — Schlieren photographs for the launch vehicle model without simulated exhaust plumes, $M = 4.01$, $\alpha = 0^\circ$, $h/l = 0.988$.



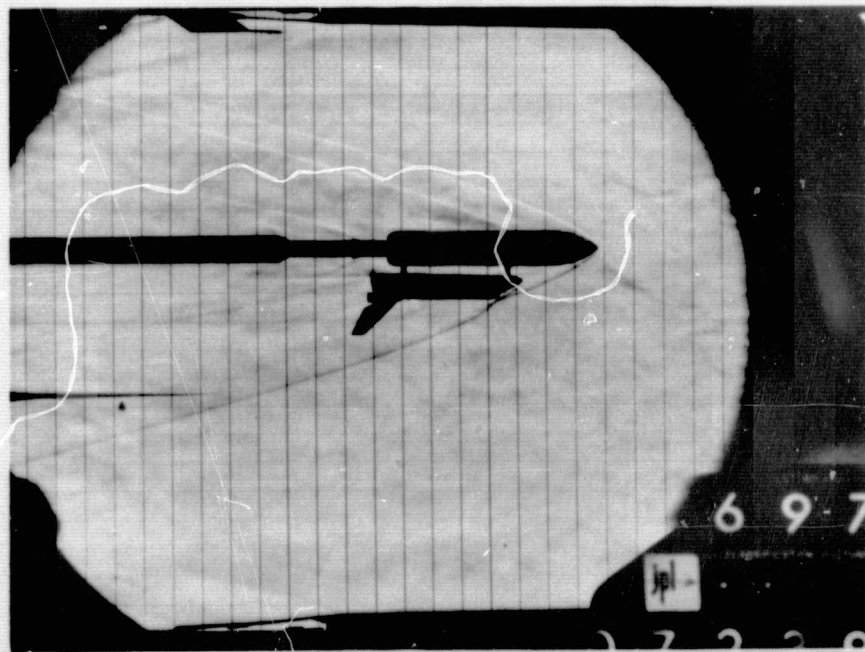
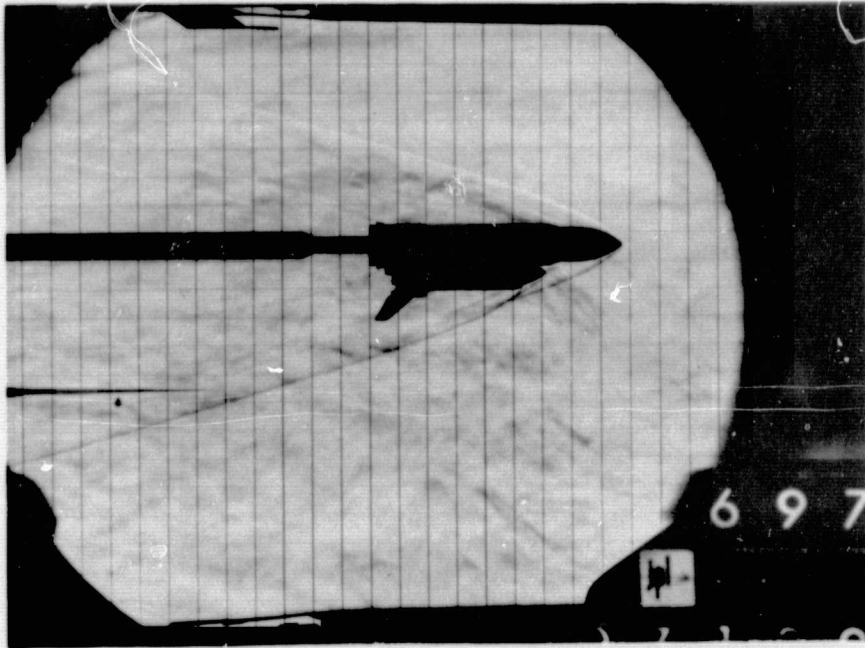
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Figure 11. - Concluded.



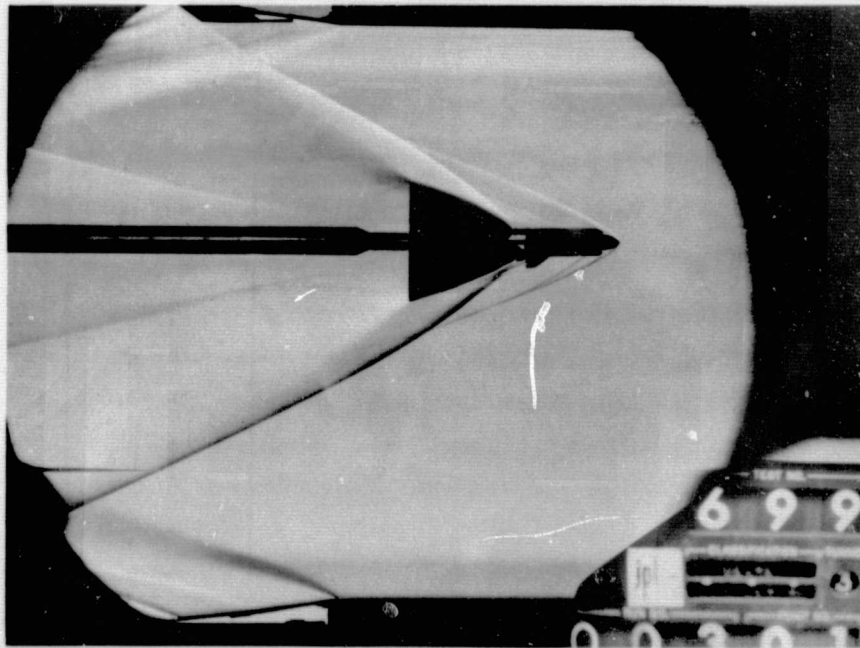
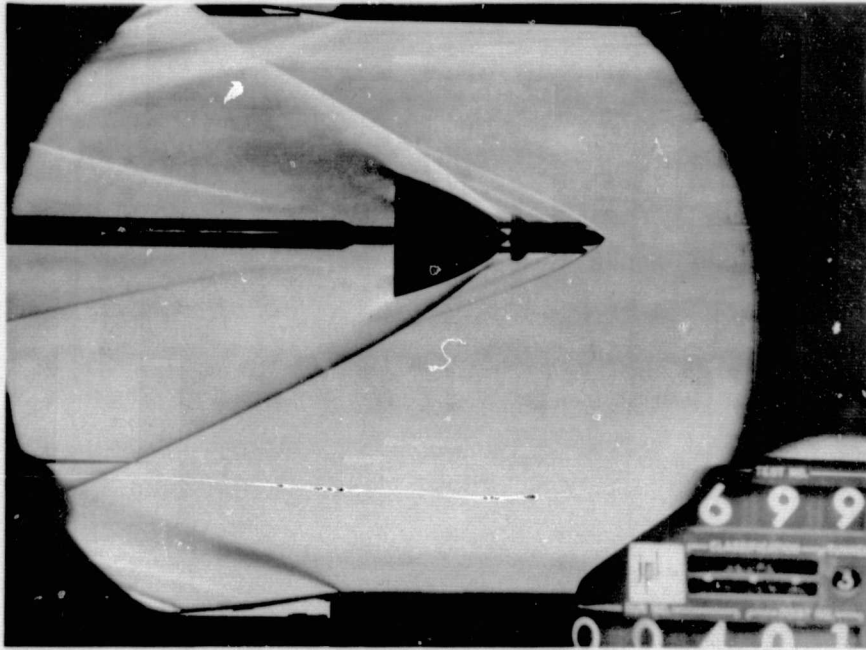
(a) $\phi = 90^\circ, 120^\circ$.

Figure 12. — Schlieren photographs for the launch vehicle model without simulated exhaust plumes, $M = 4.58$, $\alpha = 0^\circ$, $h/l = 0.988$.



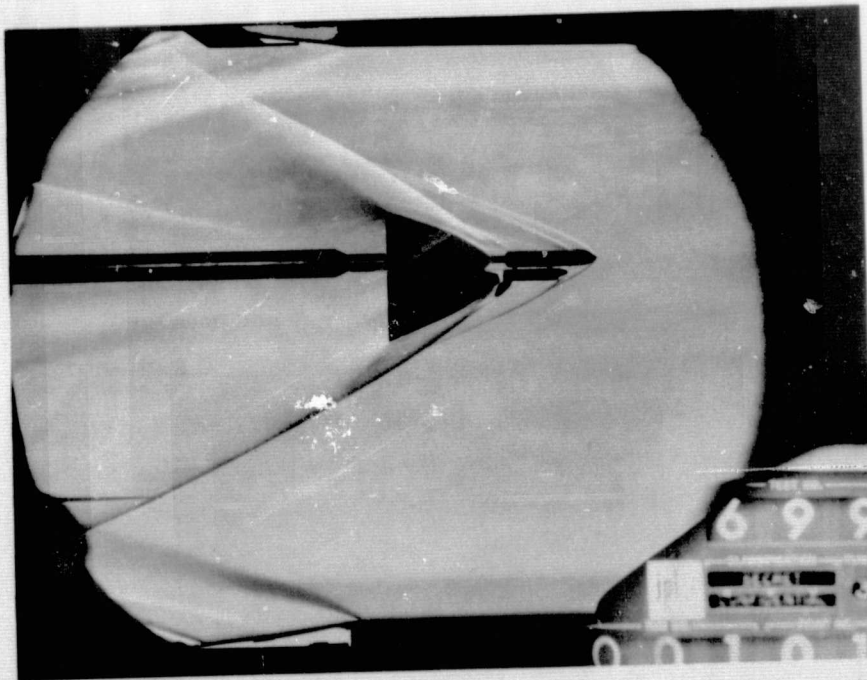
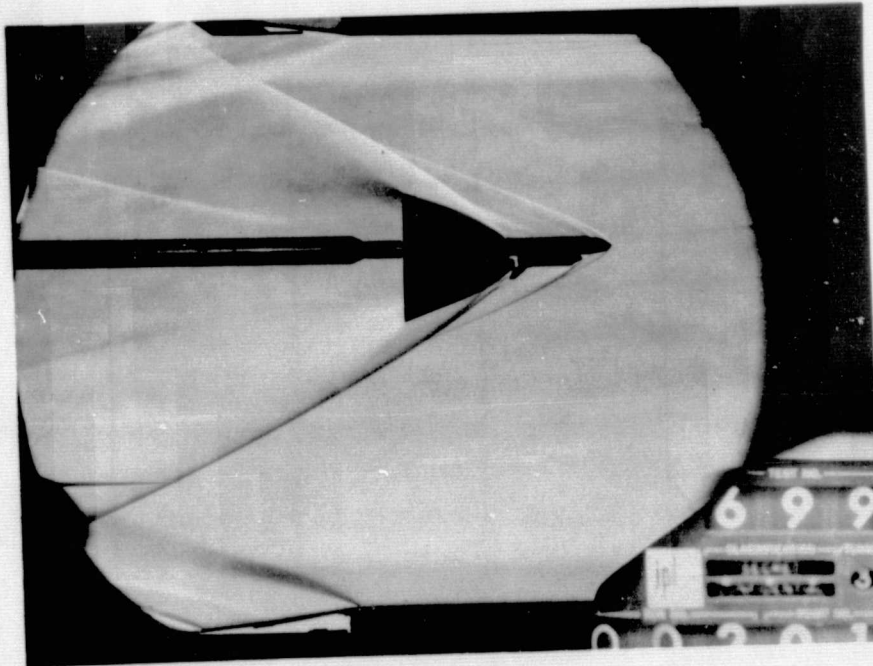
(b) $\phi = 150^\circ, 180^\circ$.

Figure 12. — Concluded.



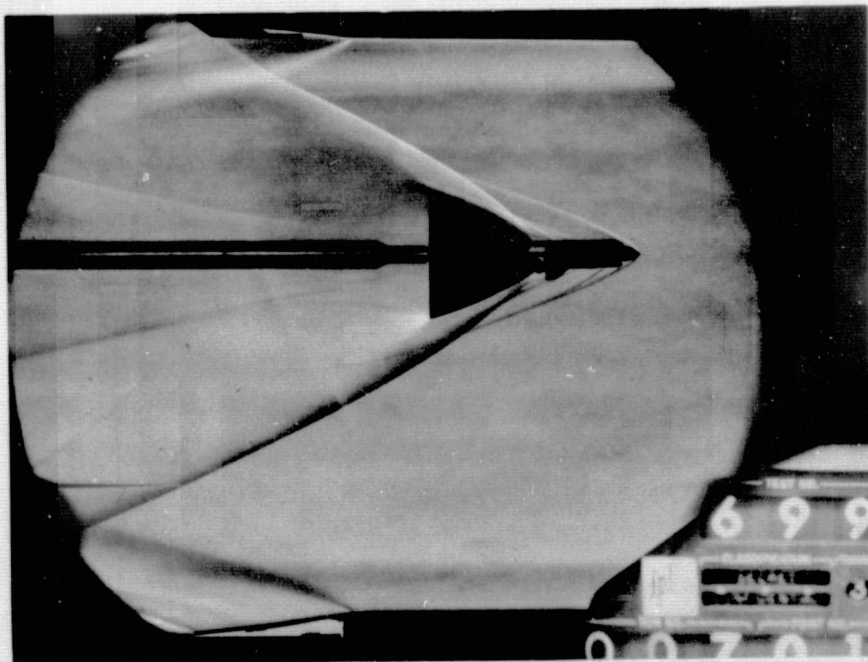
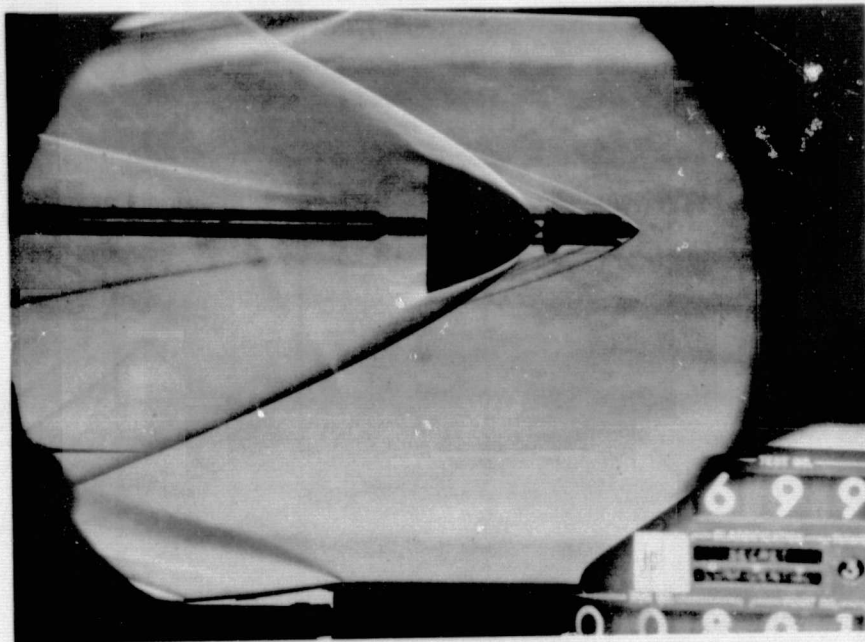
(a) $\phi = 90^\circ, 120^\circ$.

Figure 13. — Schlieren photographs for the launch vehicle model with simulated exhaust plums, $M = 3.20$, $\alpha = 0^\circ$, $h/l = 3.61$.



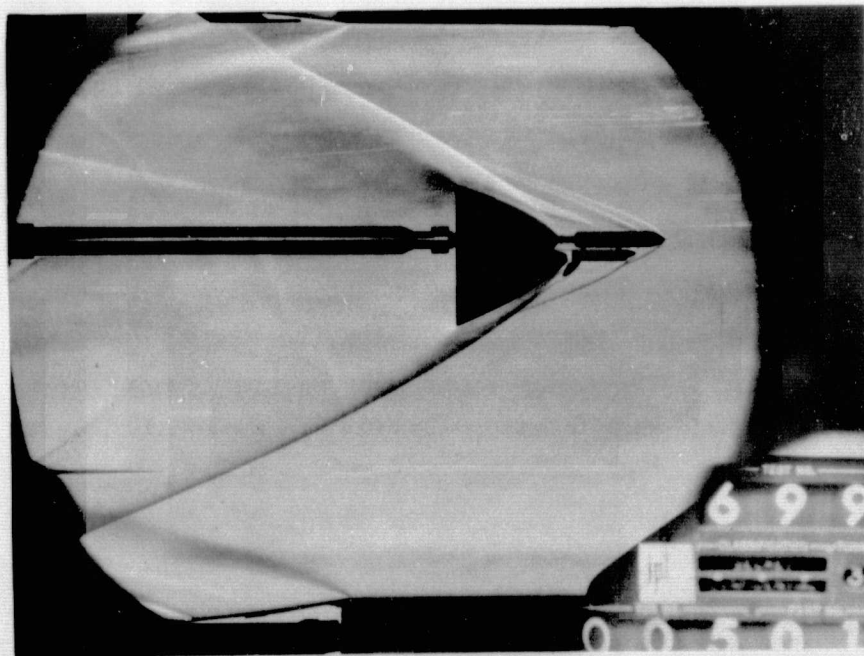
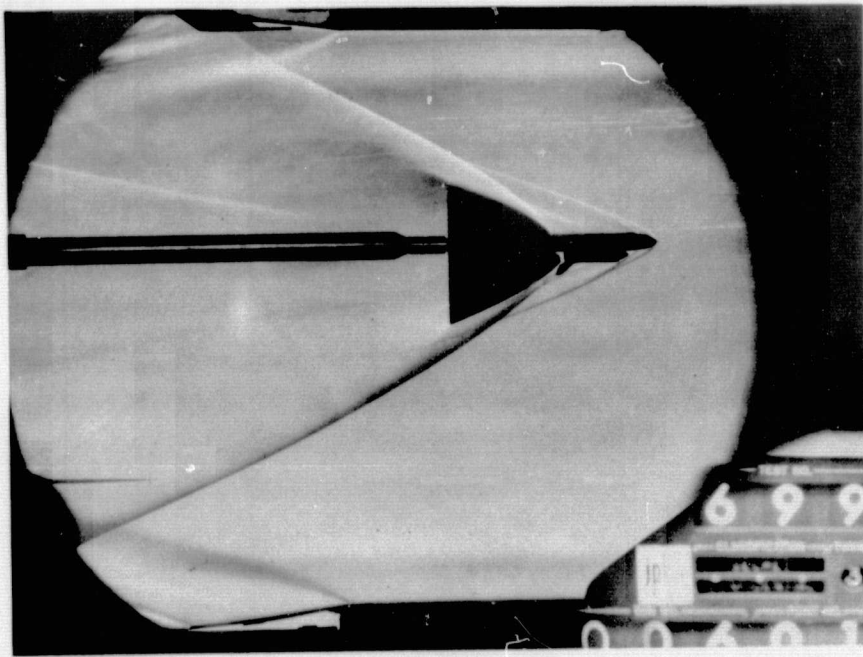
(b) $\phi = 150^\circ, 180^\circ$.

Figure 13. - Concluded.



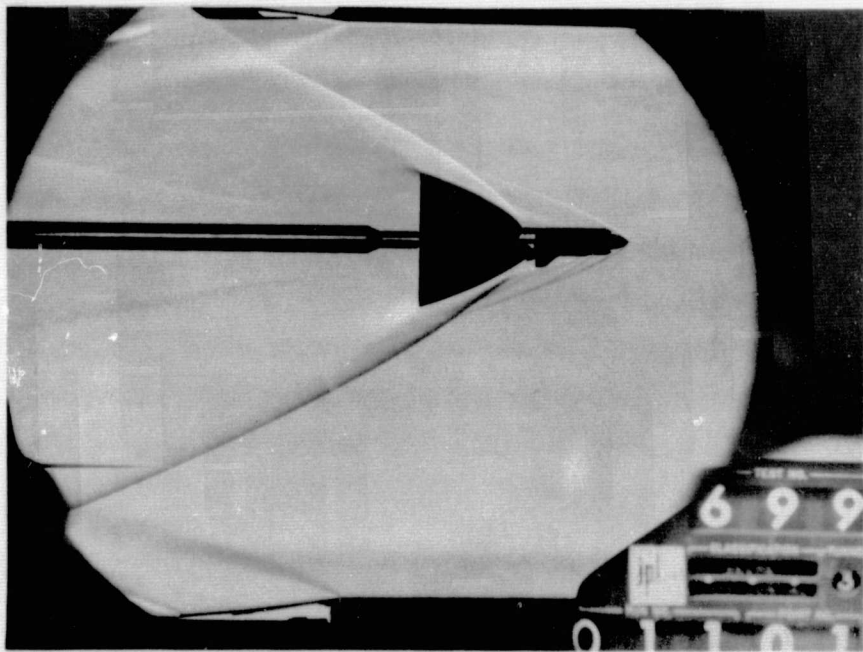
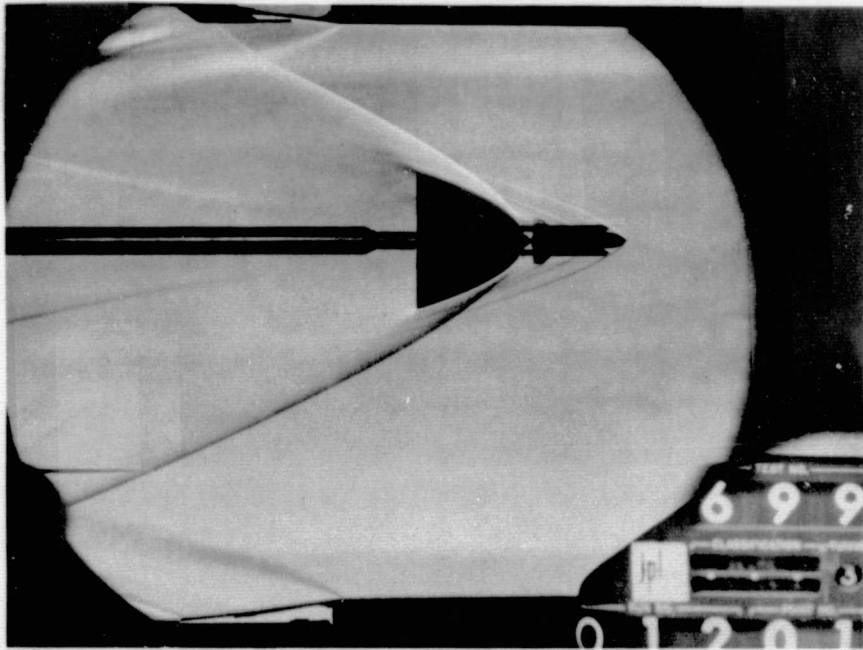
(a) $\phi = 90^\circ, 120^\circ$.

Figure 14. – Schlieren photographs for the launch vehicle model with simulated exhaust plumes, $M = 3.53$, $\alpha = 0^\circ$, $h/l = 3.61$.



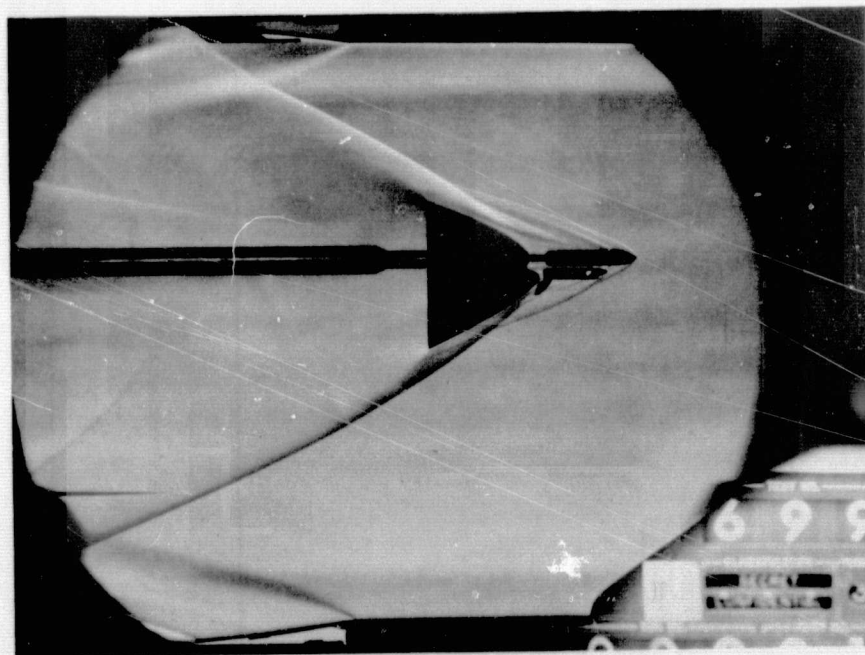
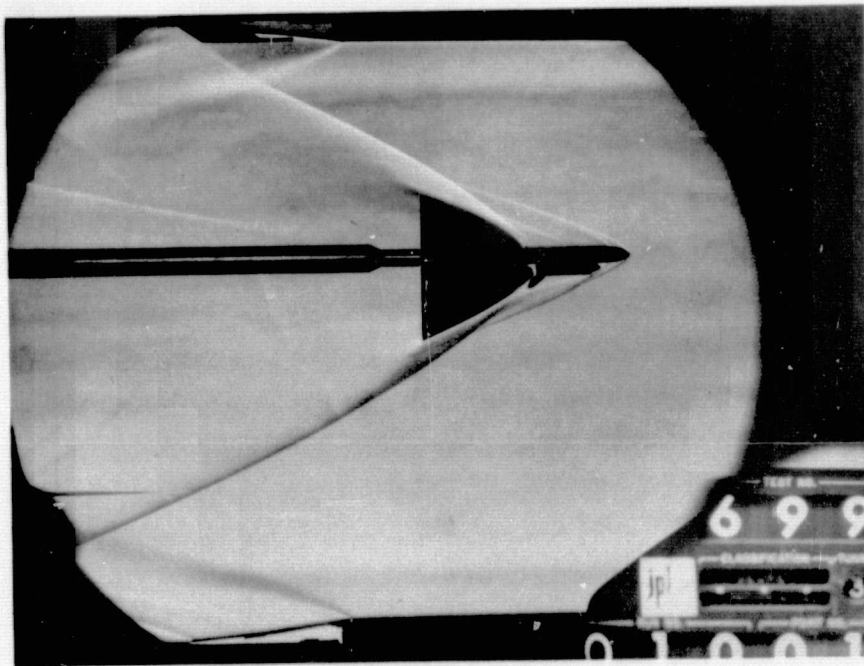
(b) $\phi = 150^\circ, 180^\circ$.

Figure 14. - Concluded.



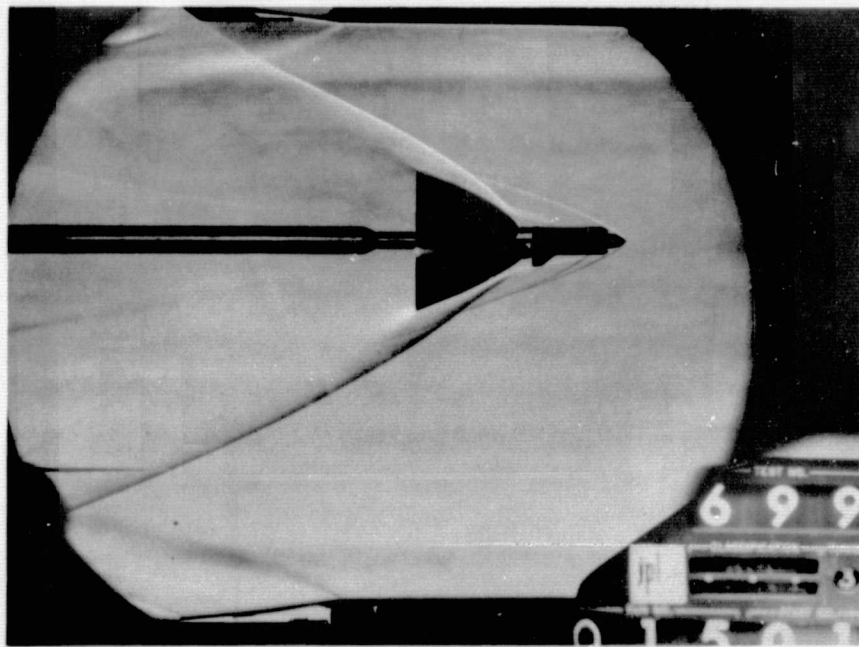
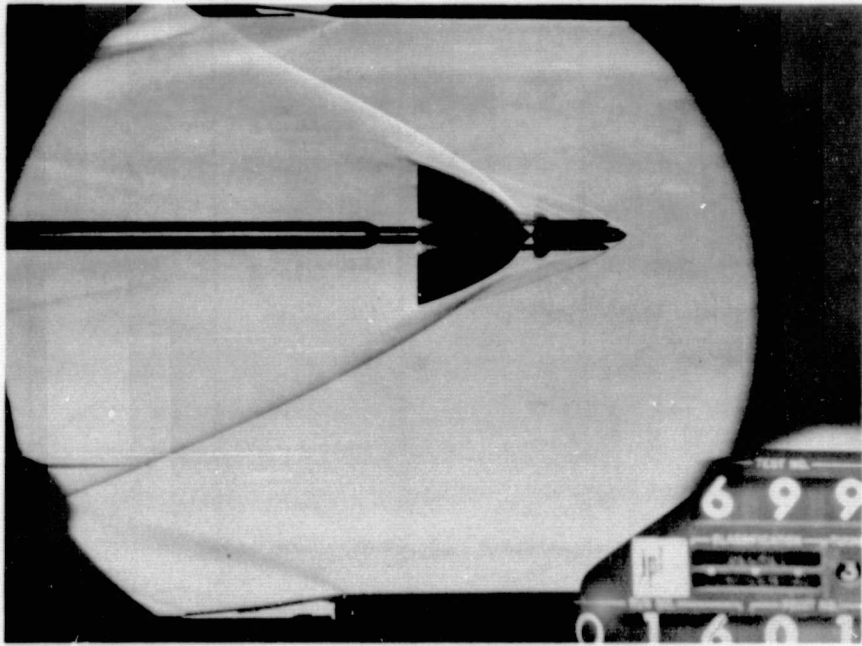
(a) $\phi = 90^\circ, 120^\circ$.

Figure 15. — Schlieren photographs for the launch vehicle model with simulated exhaust plumes, $M = 3.63$, $\alpha = 0^\circ$, $h/l = 3.61$.



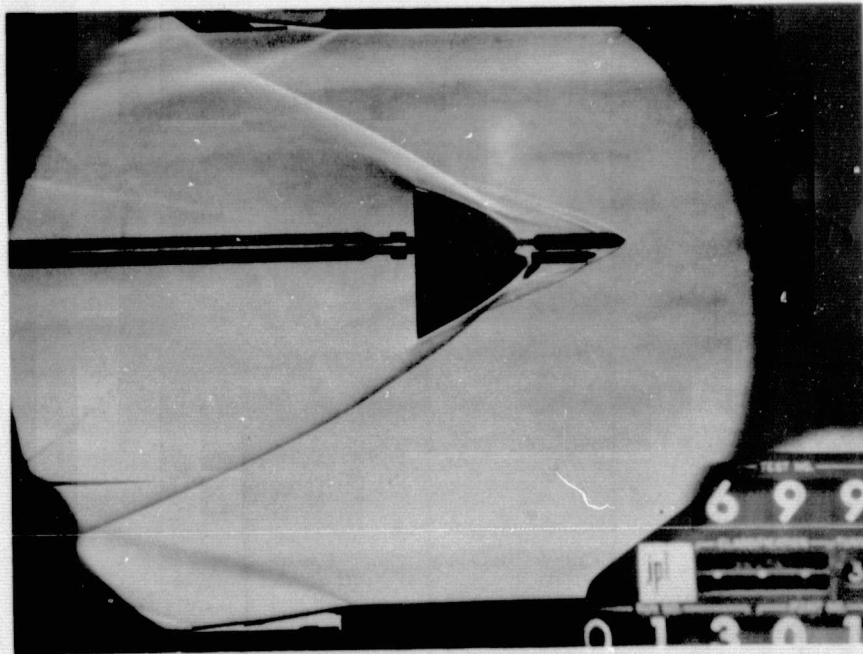
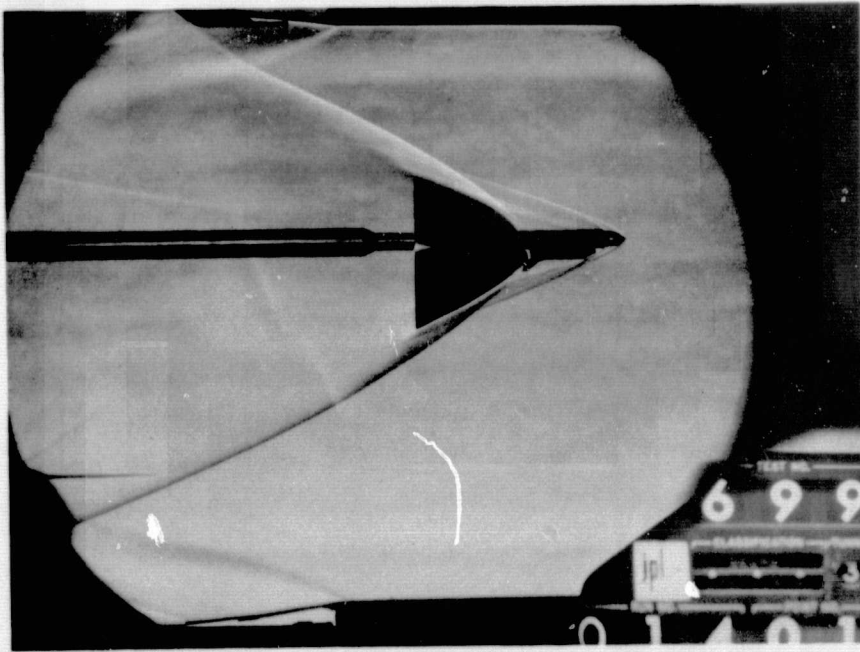
(b) $\phi = 150^\circ, 180^\circ$.

Figure 15. -- Concluded.



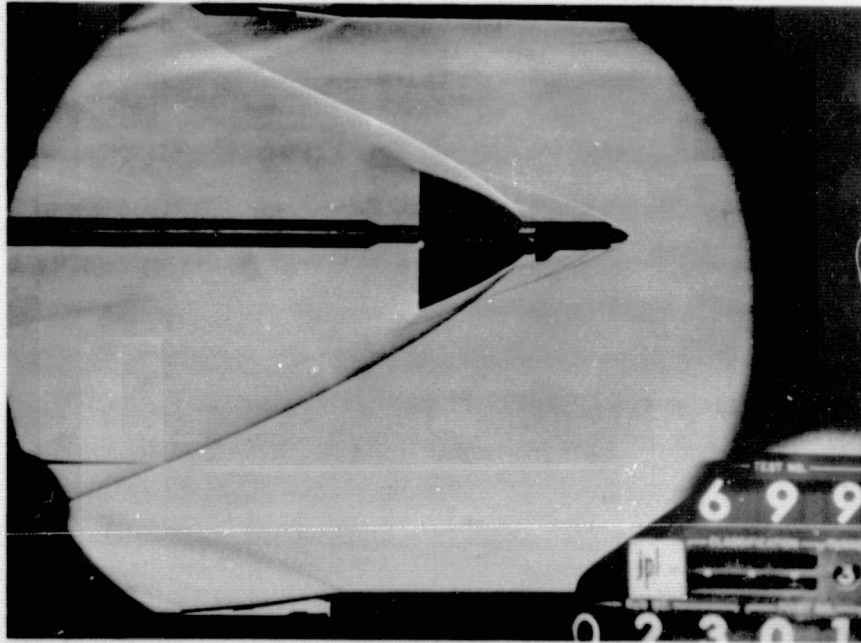
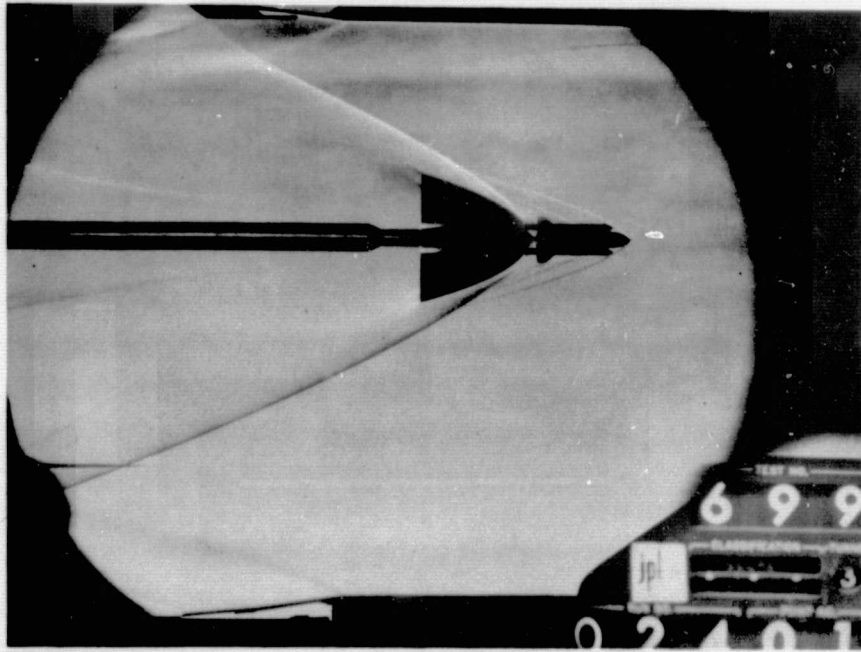
(a) $\phi = 90^\circ, 120^\circ$.

Figure 16. — Schlieren photographs for the launch vehicle model with simulated exhaust plumes, $M = 3.95$, $\alpha = 0^\circ$, $h/l = 3.61$.



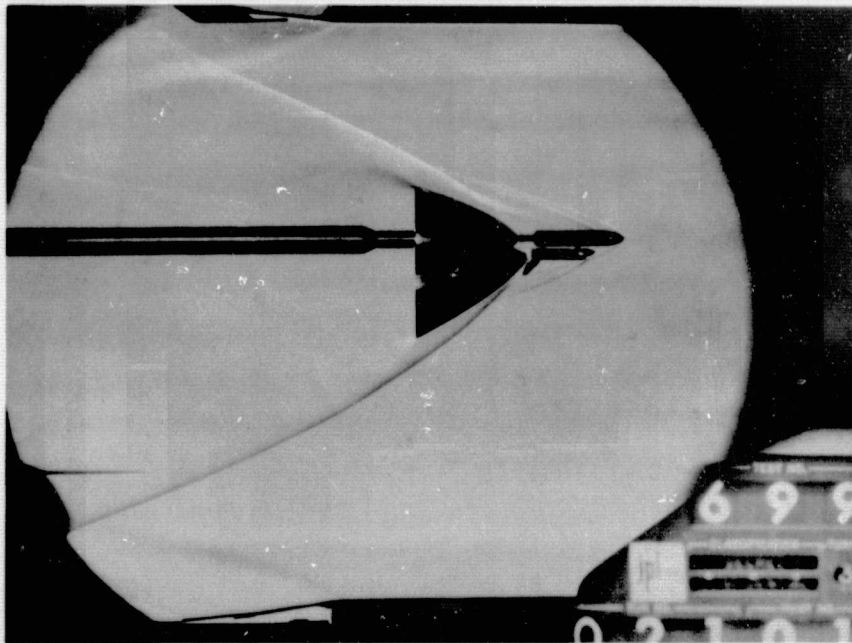
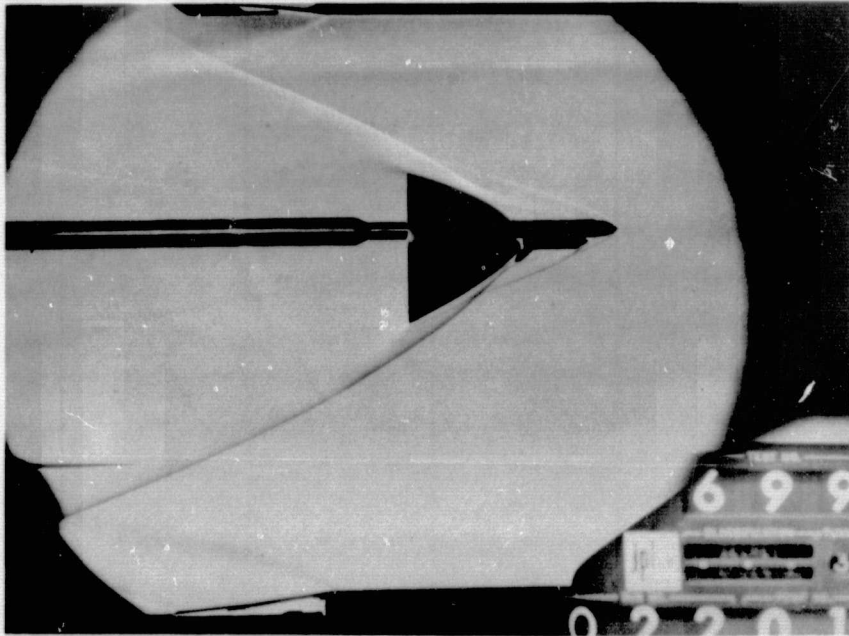
(b) $\phi = 150^\circ, 180^\circ$.

Figure 16. — Concluded.



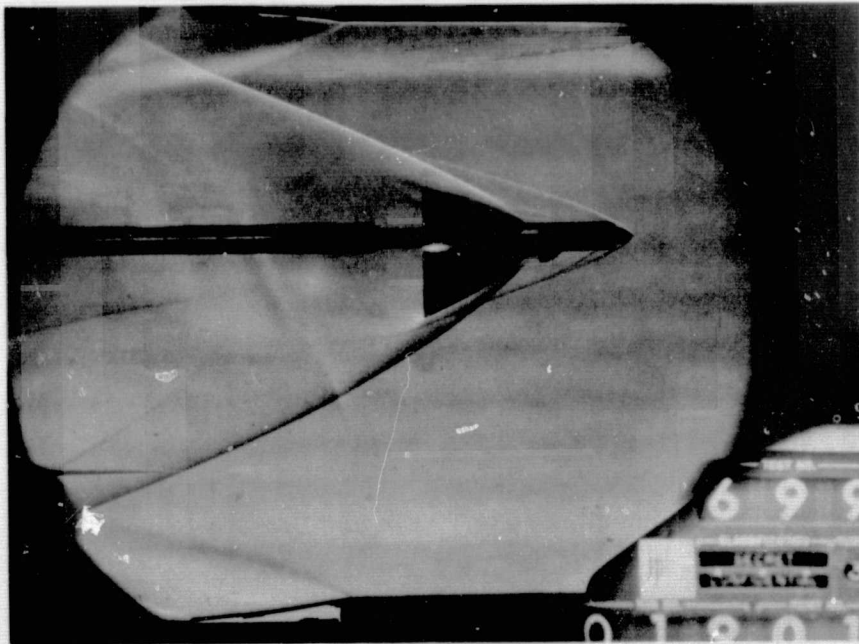
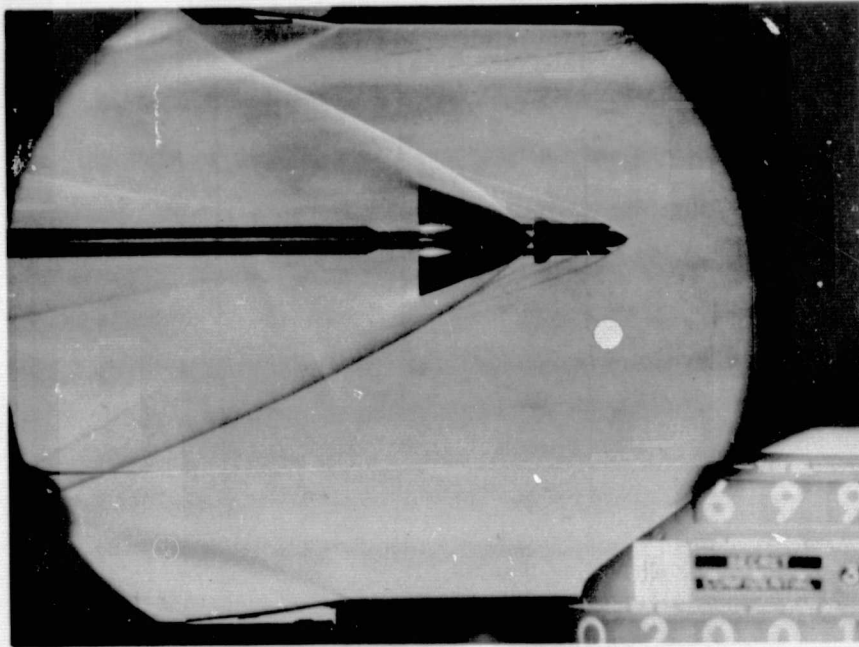
(a) $\phi = 90^\circ, 120^\circ$.

Figure 17. — Schlieren photographs for the launch vehicle model with simulated exhaust plumes, $M = 4.08$, $\alpha = 0^\circ$, $h/l = 3.61$.



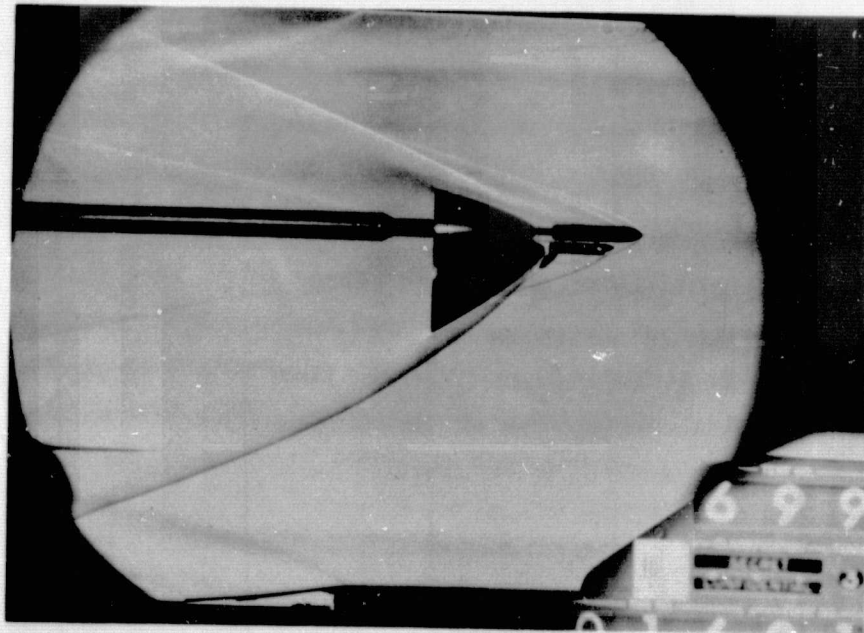
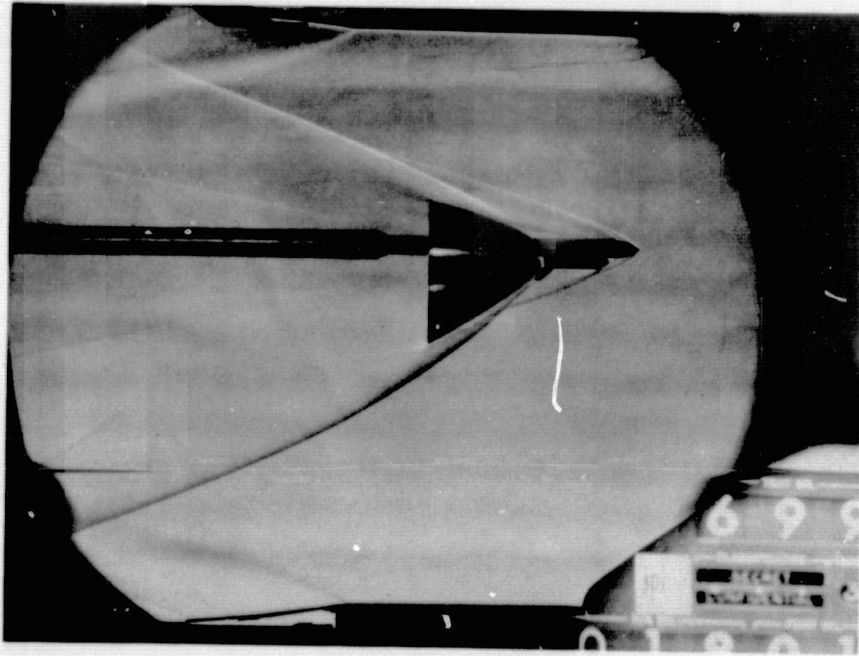
(b) $\phi = 150^\circ, 180^\circ$.

Figure 17. — Concluded.



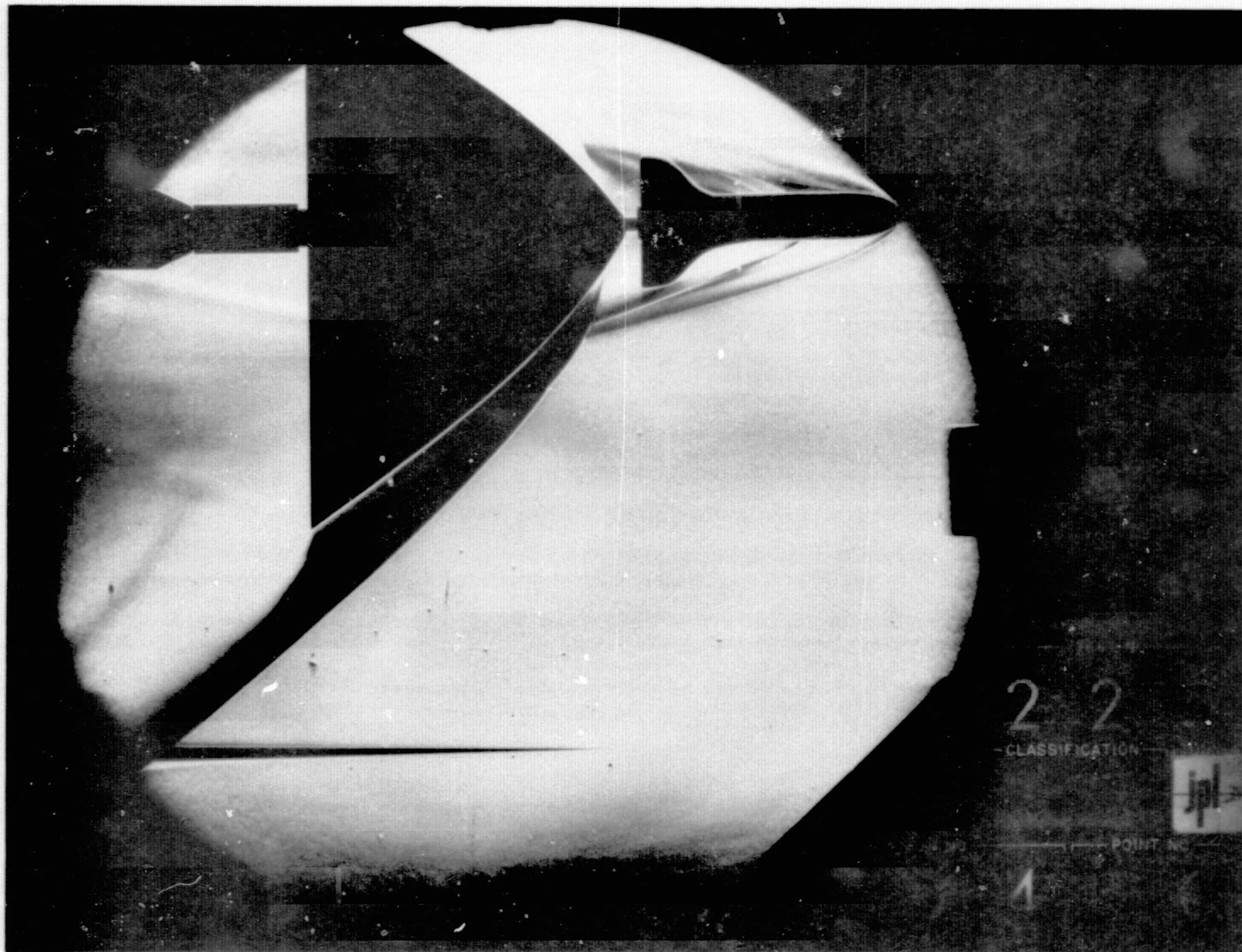
(a) $\phi = 90^\circ, 120^\circ$.

Figure 18. — Schlieren photographs for the launch vehicle model with simulated exhaust plumes, $M = 4.14$, $\alpha = 0^\circ$, $h/l = 3.61$.



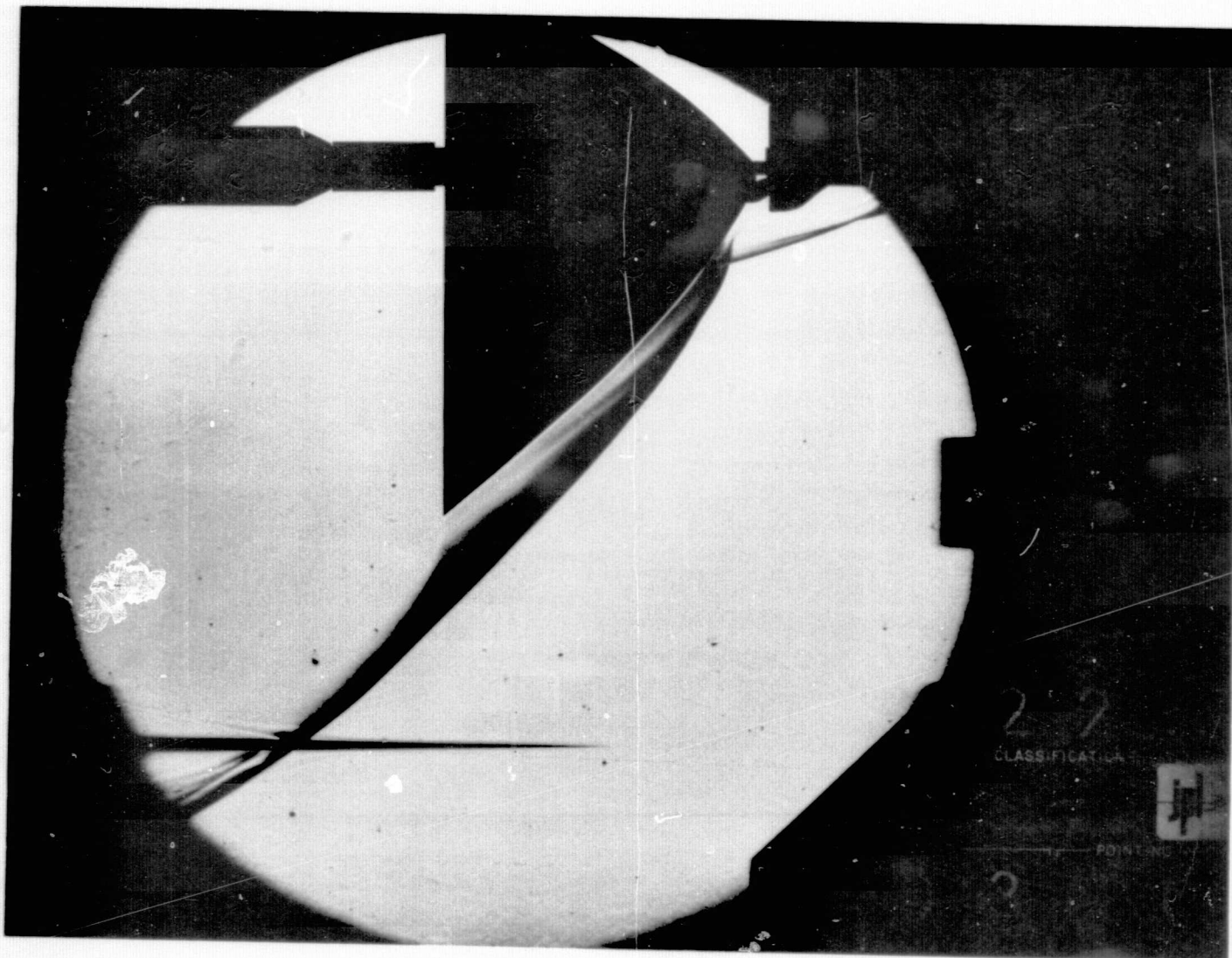
(b) $\phi = 150^\circ, 180^\circ$.

Figure 18. — Concluded.



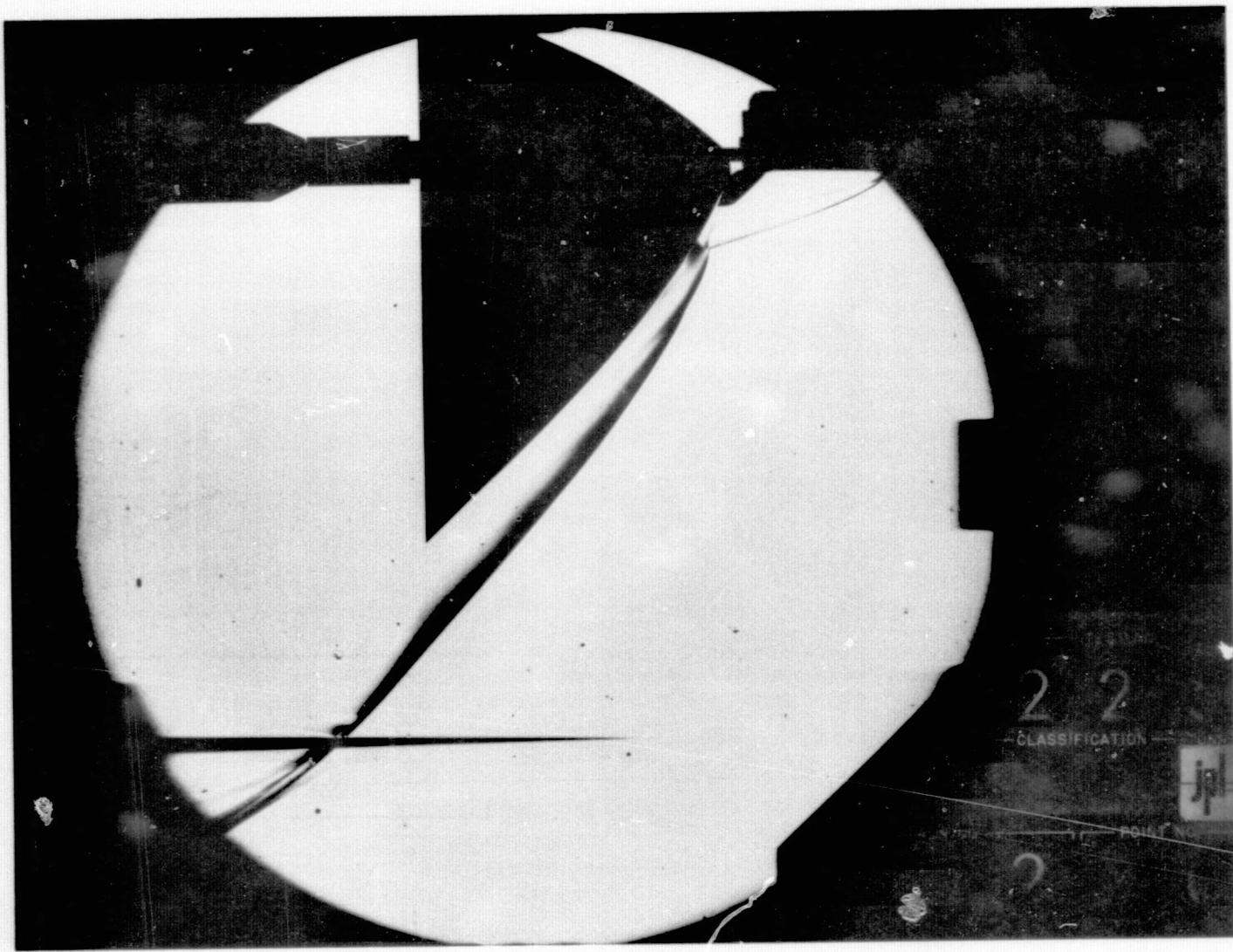
(a) $\phi = 90^\circ$.

Figure 19. – Schlieren photographs for the launch vehicle model with simulated exhaust plumes, $M = 5.54$, $\alpha = 0^\circ$, $h/l = 3.26$.



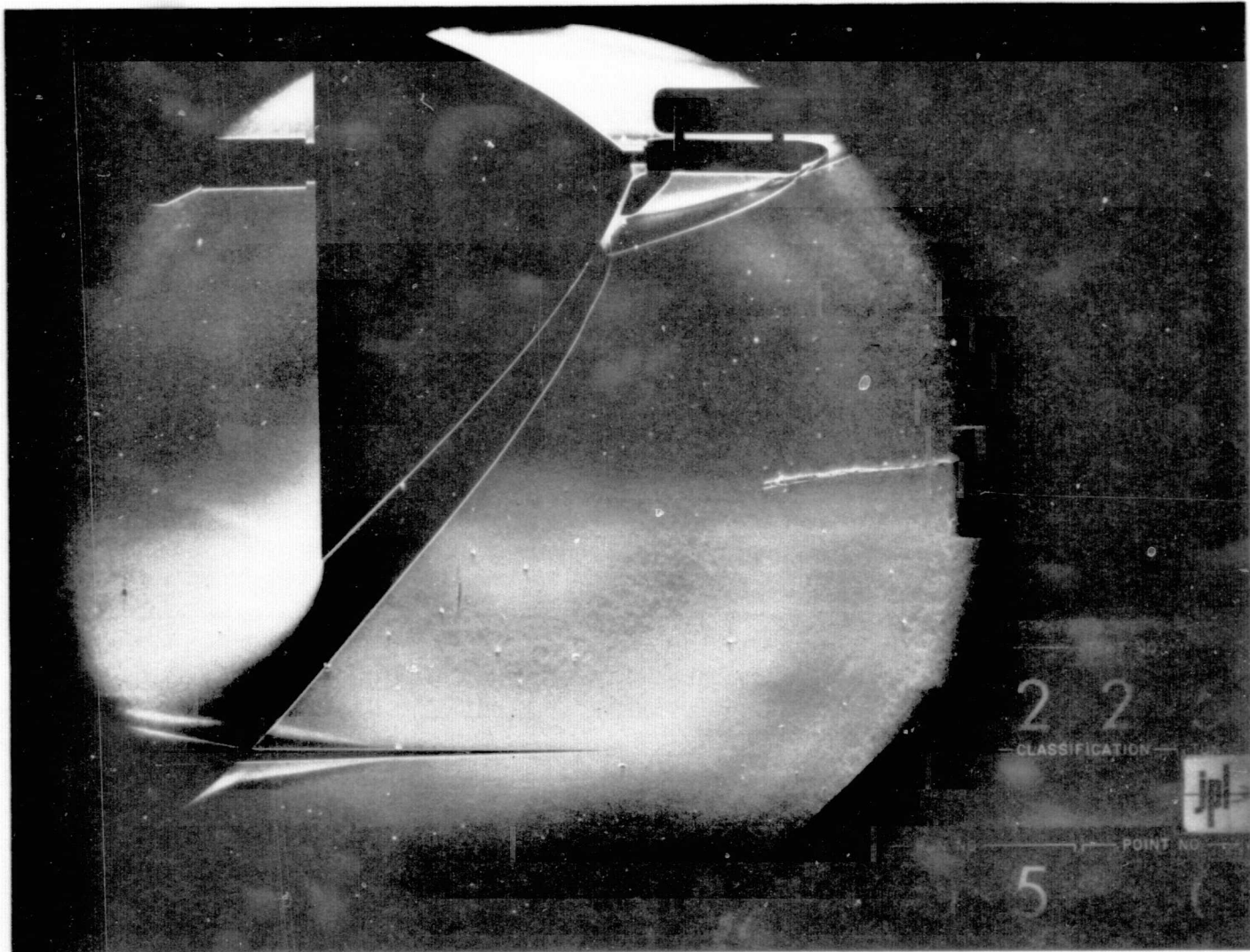
(b) $\phi = 120^\circ$.

Figure 19. - Continued.



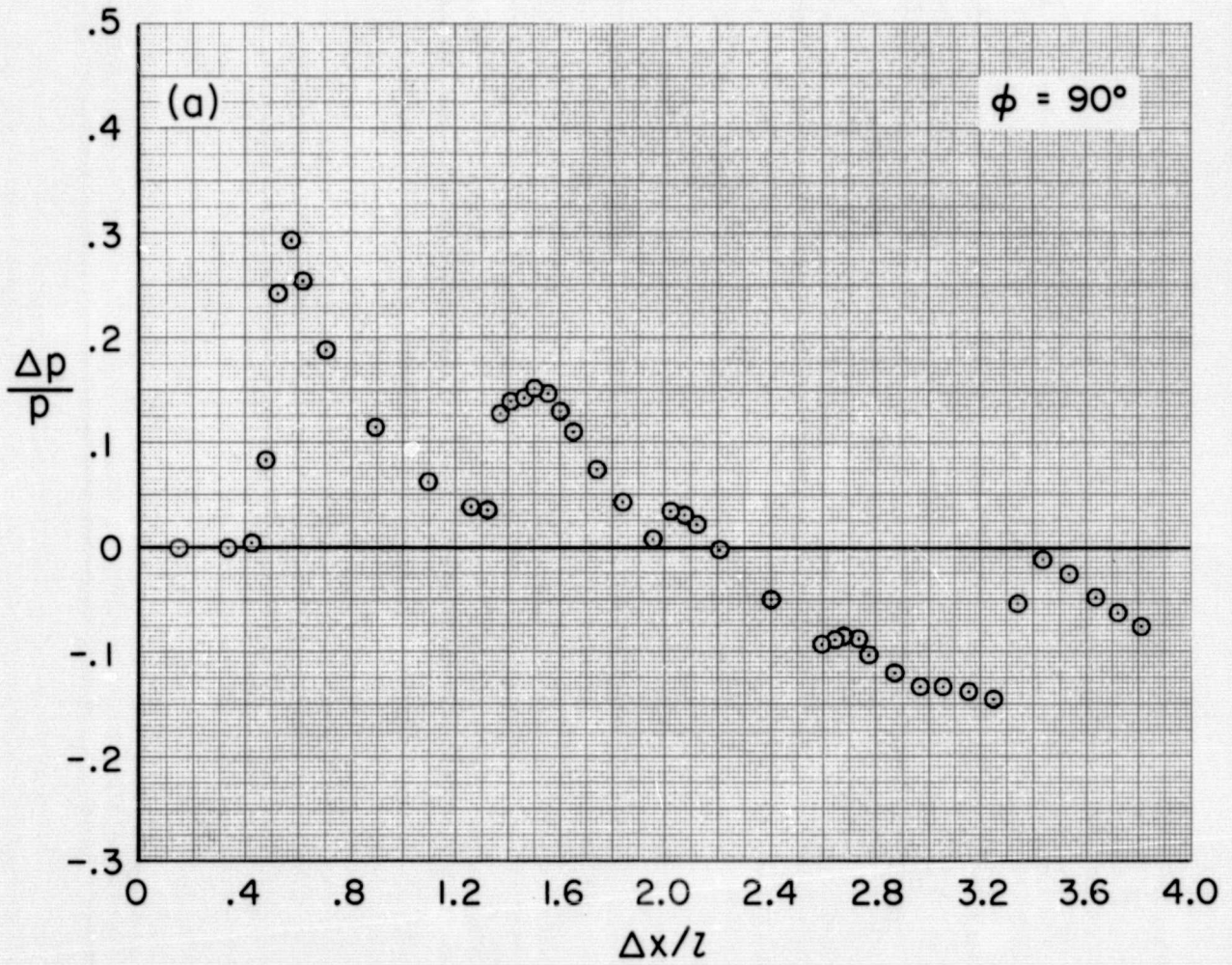
(c) $\phi = 150^\circ$.

Figure 19. - Continued.



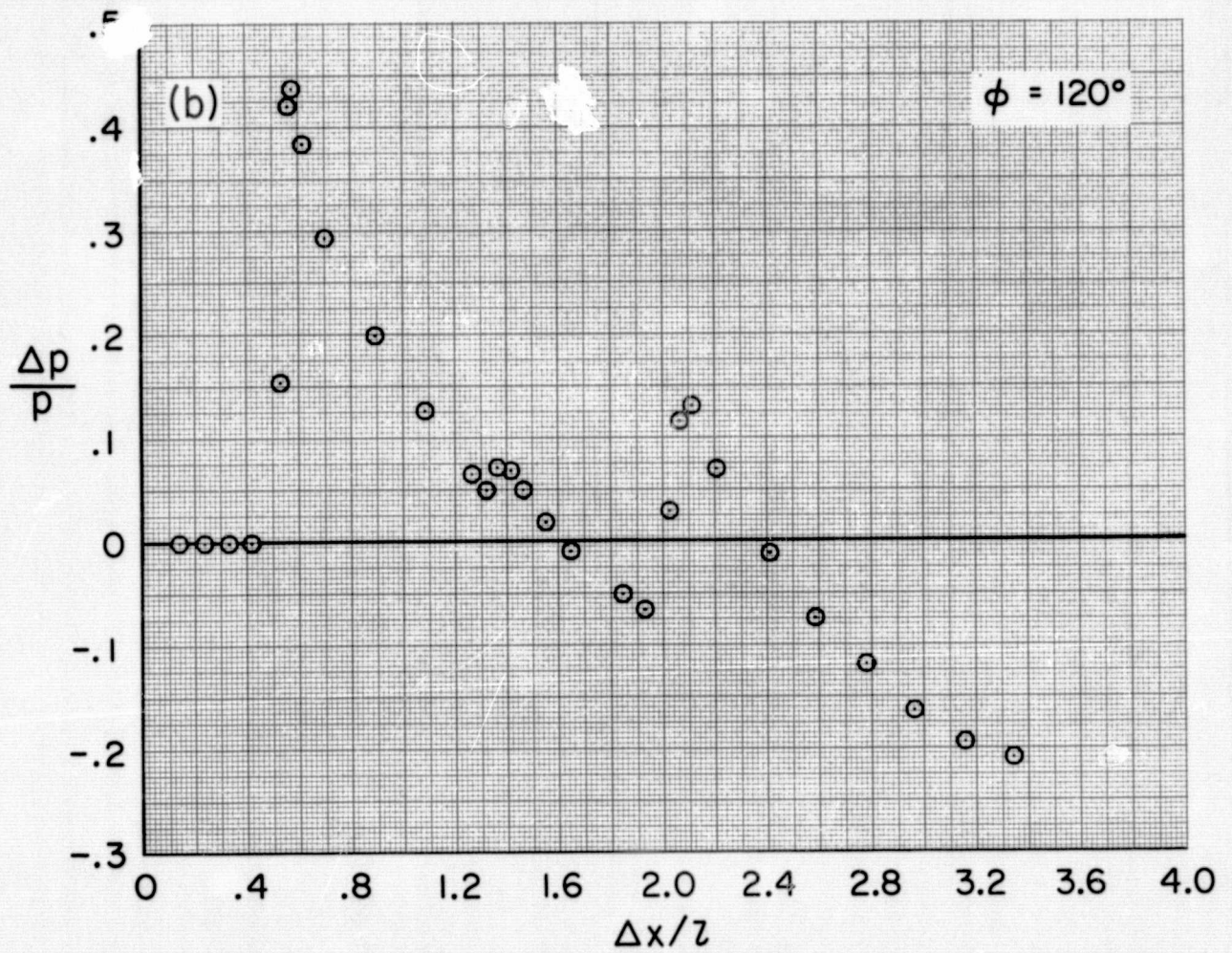
(d) $\phi = 180^\circ$.

Figure 19. – Concluded.



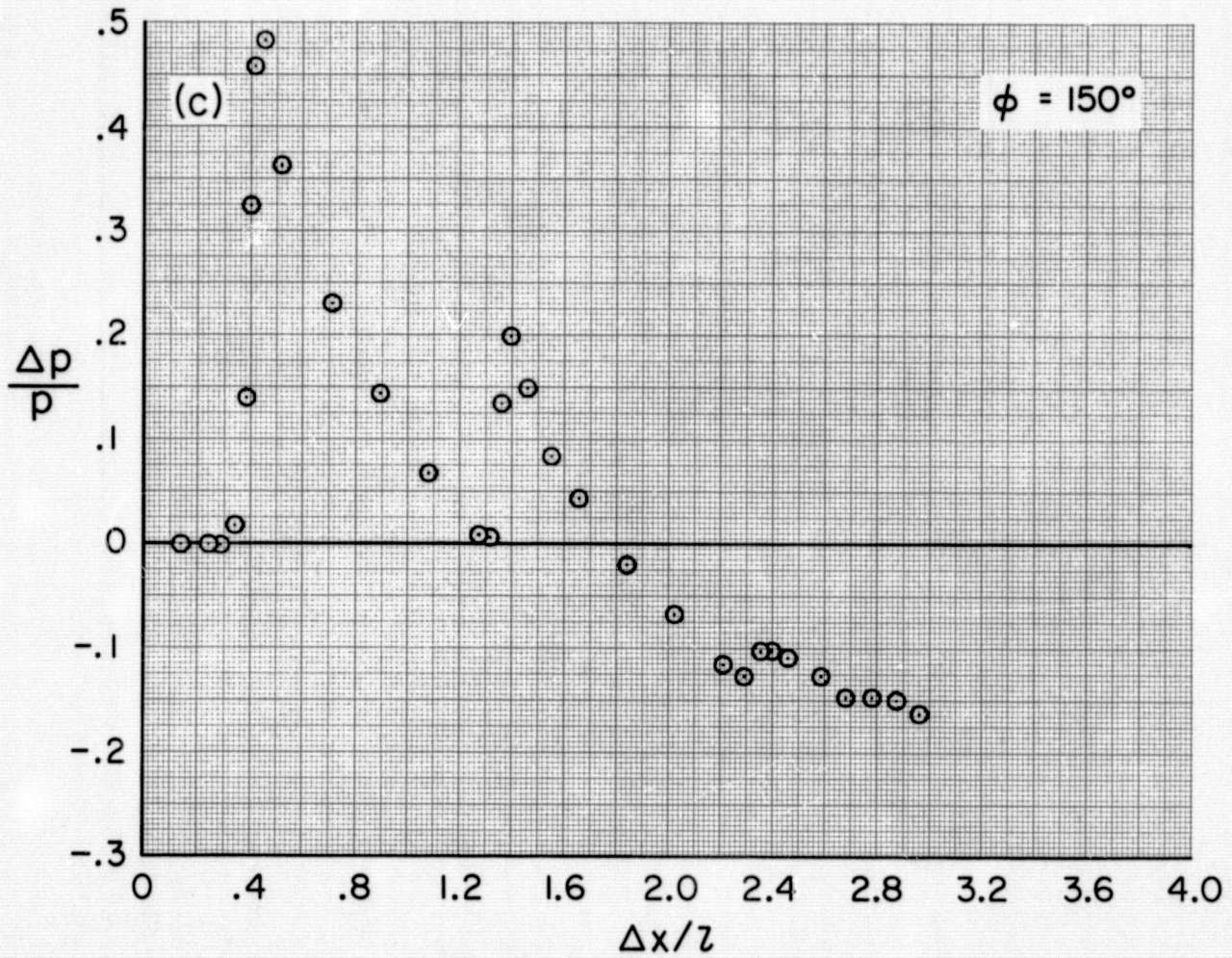
(a) $\phi = 90^\circ$.

Figure 20. — Pressure signatures for the launch vehicle model without simulated exhaust plumes, $M = 3.0$, $\alpha = 0^\circ$, $h/l = 1.365$.



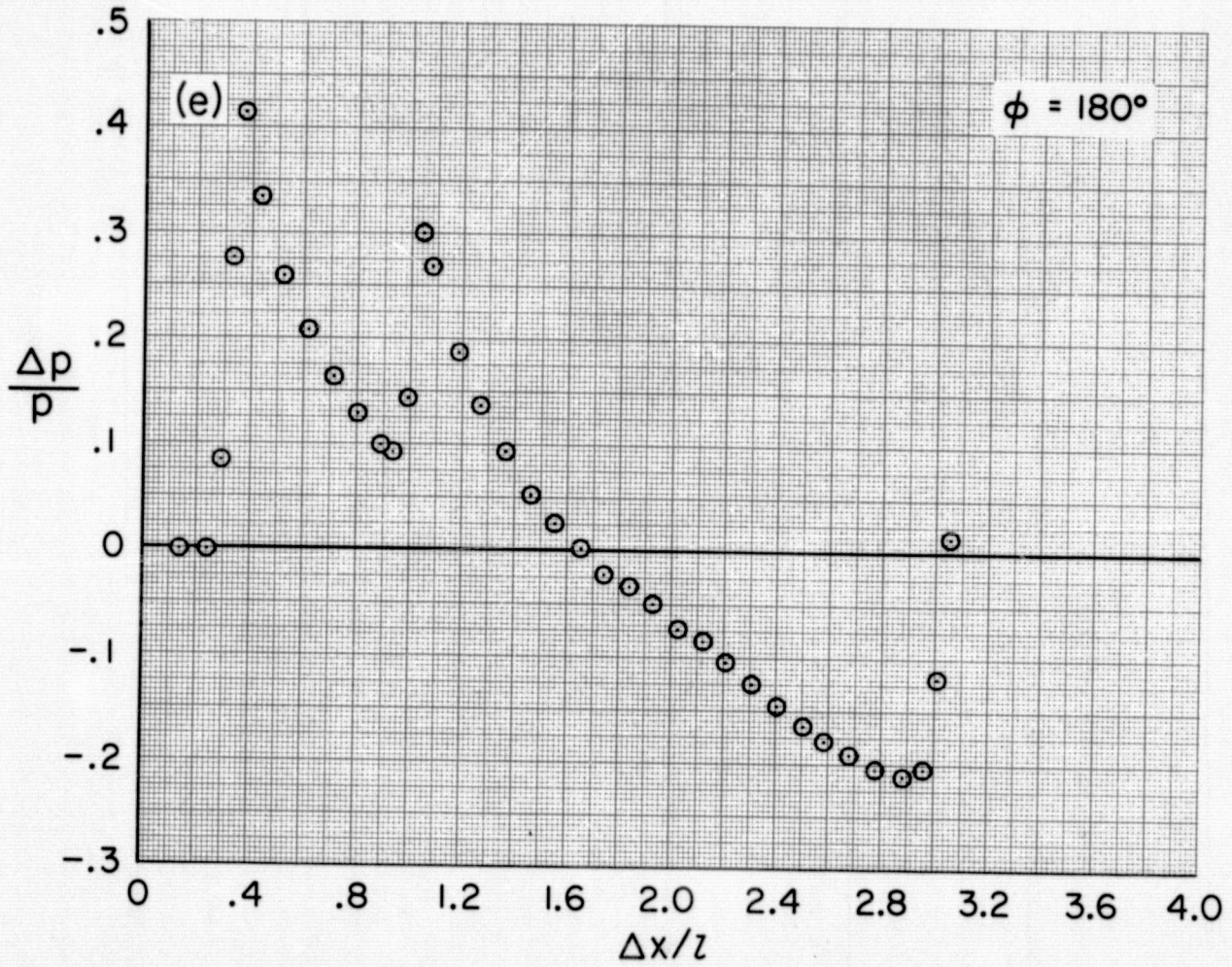
(b) $\phi = 120^\circ$.

Figure 20. - Continued.



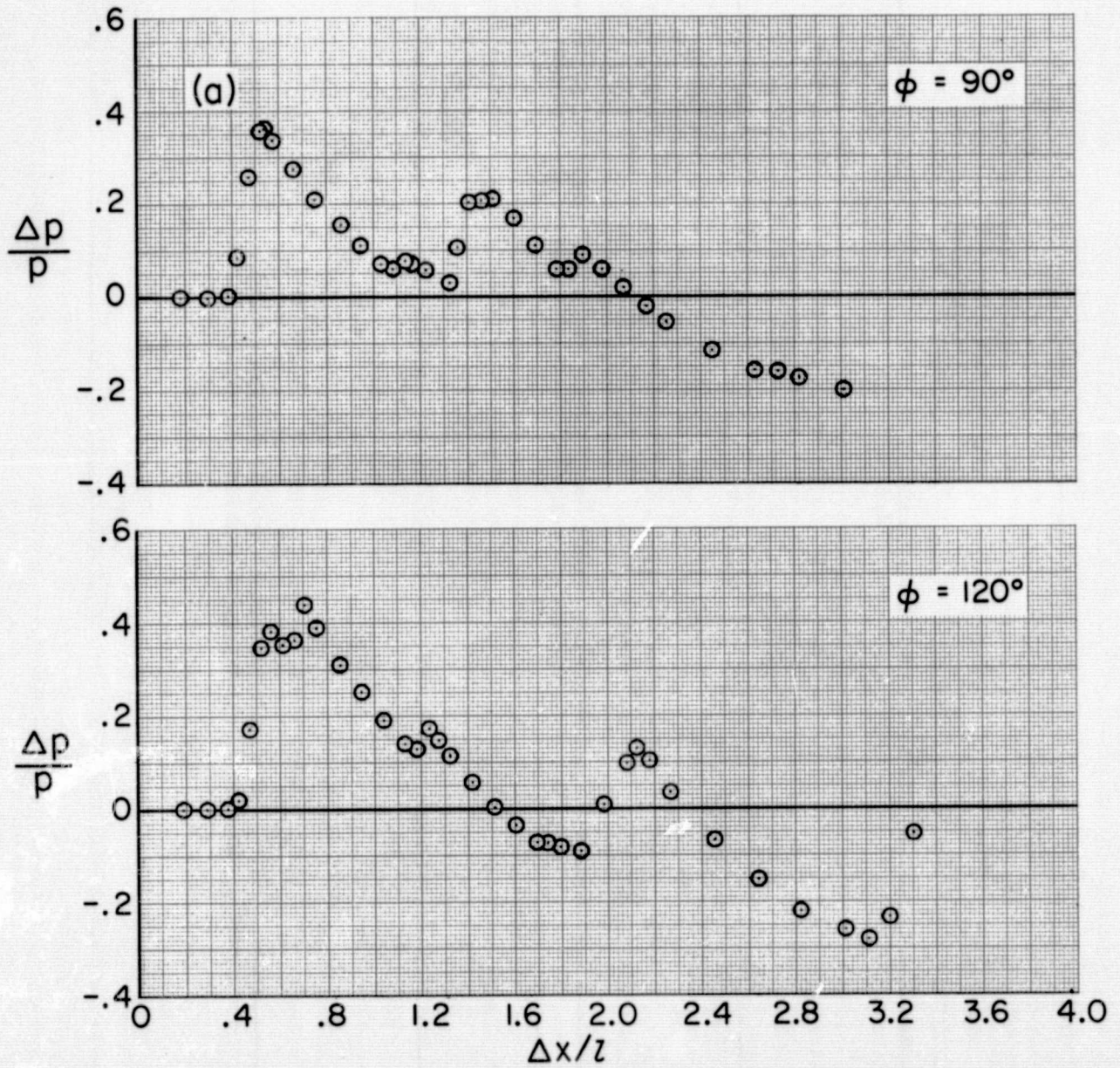
(c) $\phi = 150^\circ$.

Figure 20. - Continued.



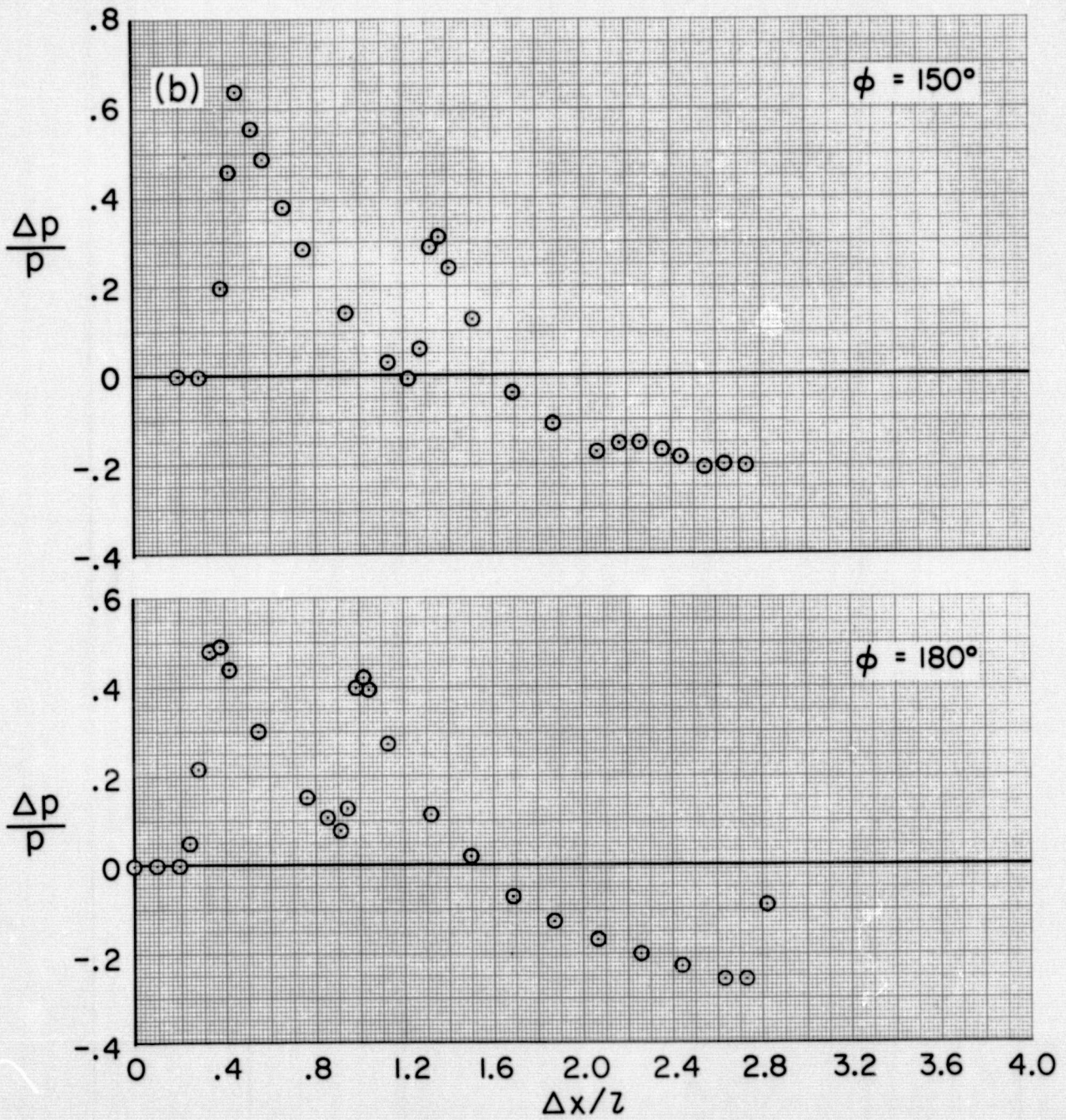
(d) $\phi = 180^\circ$.

Figure 20.— Concluded.



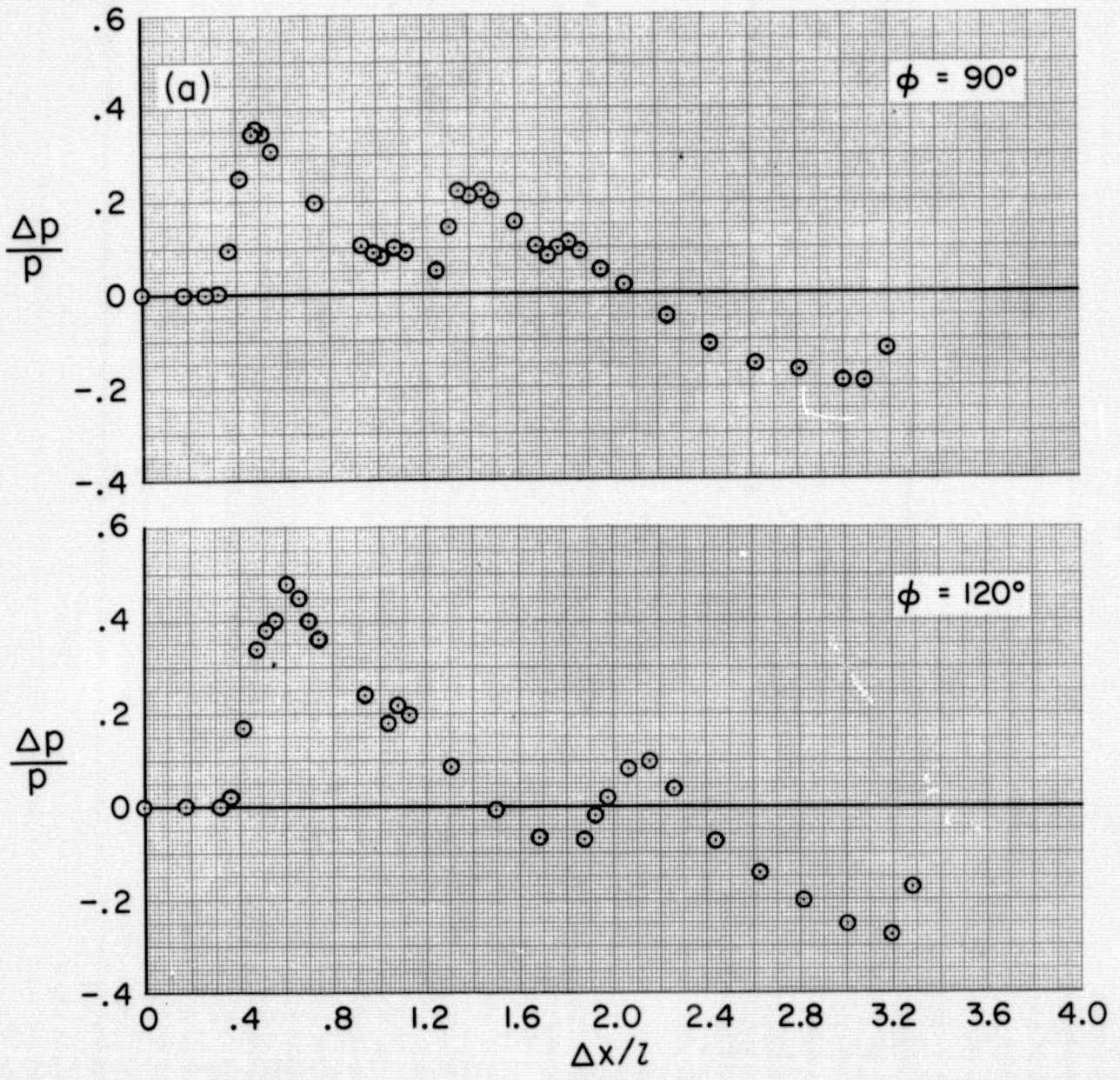
(a) $\phi = 90^\circ, 120^\circ$.

Figure 21. — Pressure signatures for the launch vehicle model without simulated exhaust plumes, $M = 3.27$, $\alpha = 0^\circ$, $h/l = 0.988$.



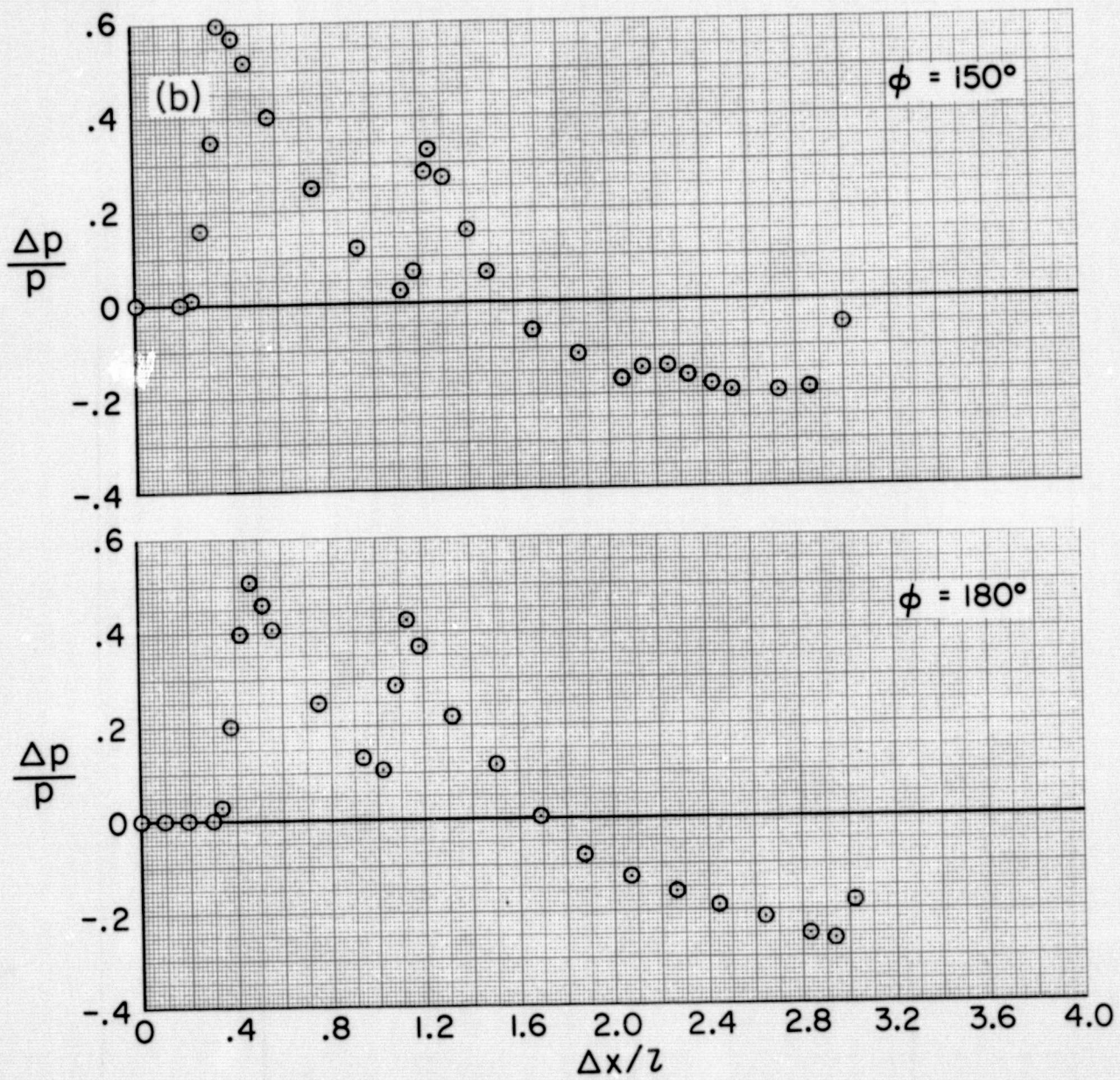
(b) $\phi = 150^\circ, 180^\circ$.

Figure 21. - Concluded.



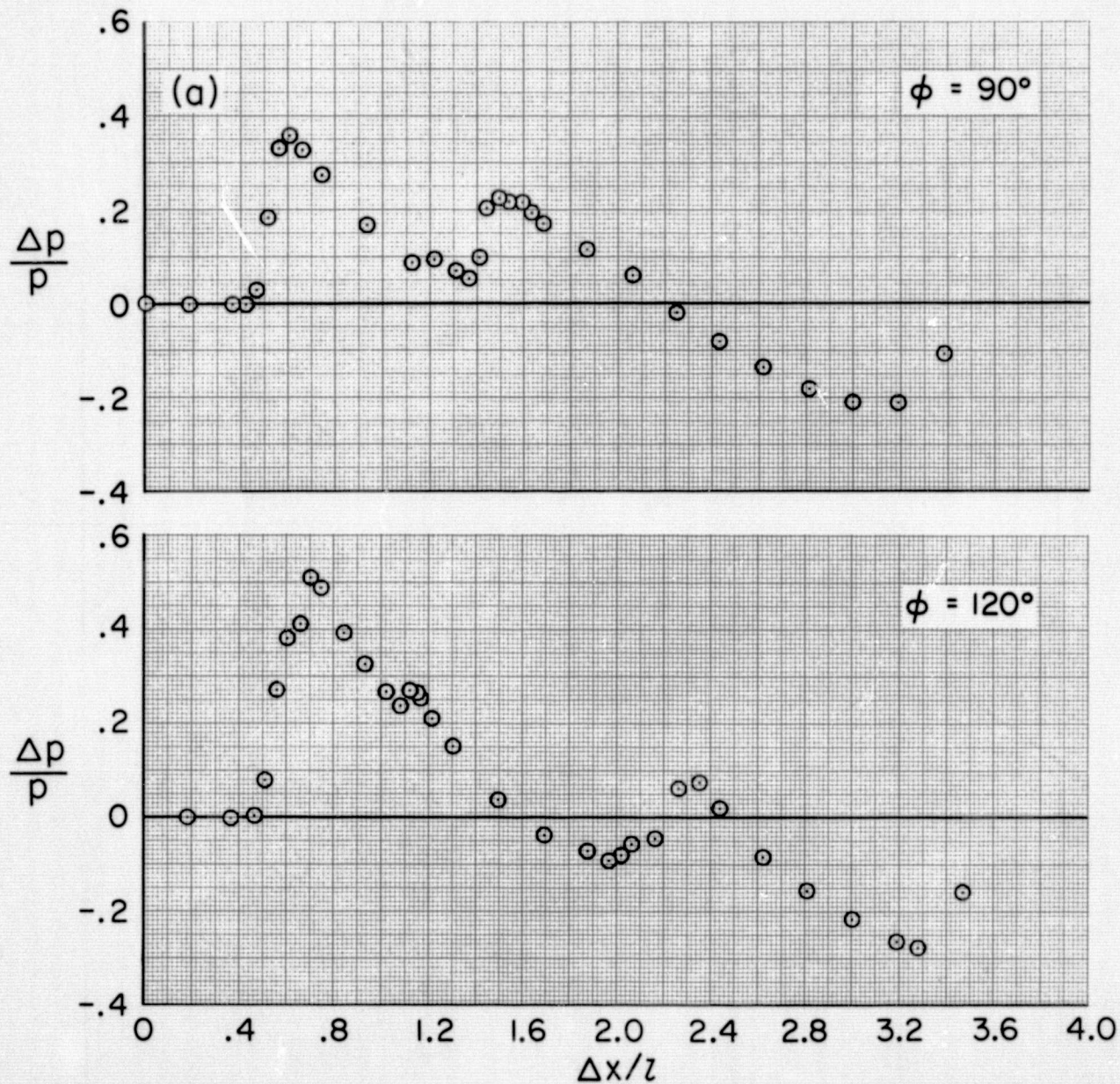
(a) $\phi = 90^\circ, 120^\circ$.

Figure 22. - Pressure signatures for the launch vehicle model without simulated exhaust plumes, $M = 3.51, \alpha = 0^\circ, h/l = 0.988$.



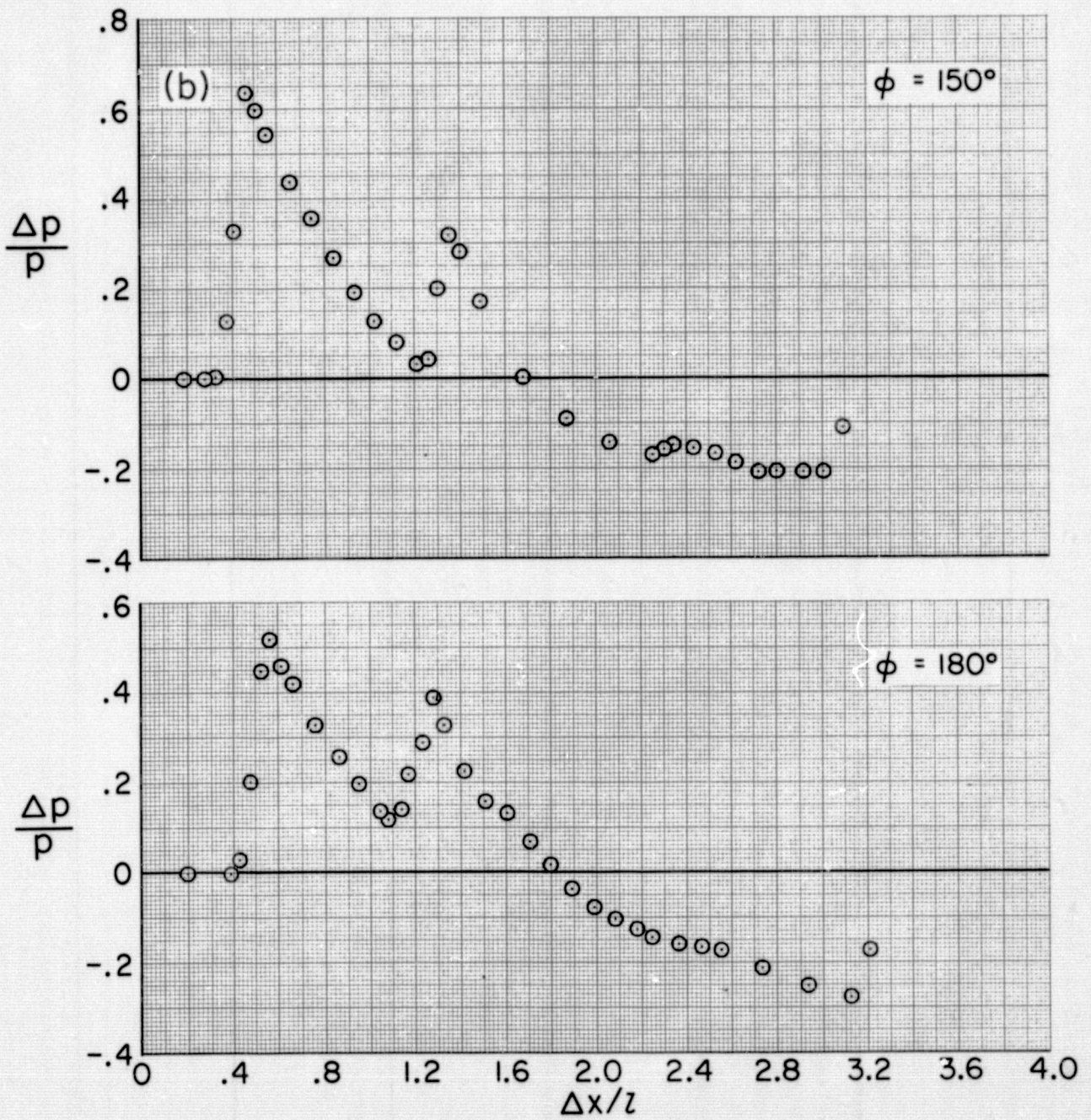
(b) $\phi = 150^\circ, 180^\circ$.

Figure 22. - Concluded.



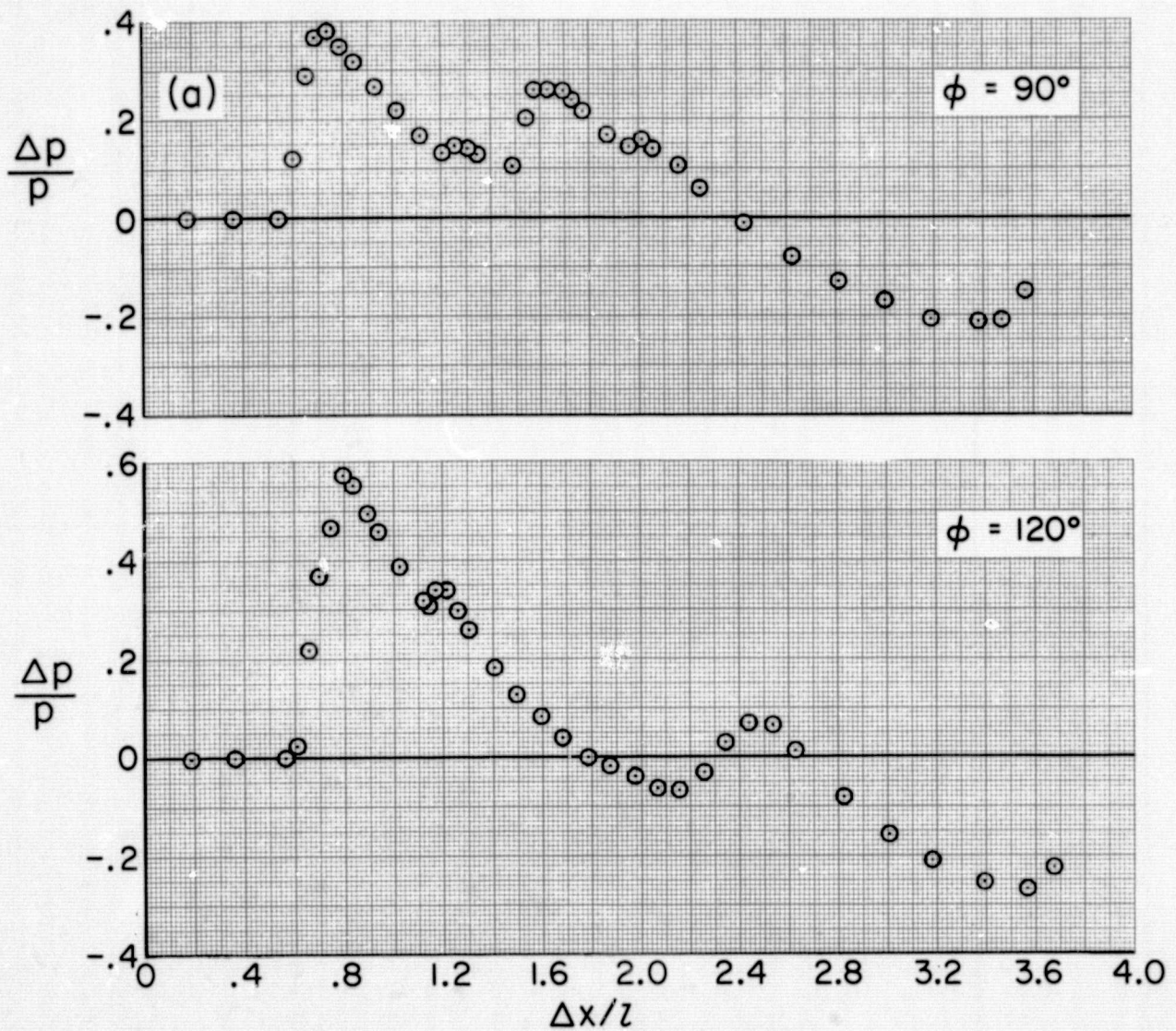
(a) $\phi = 90^\circ, 120^\circ$.

Figure 23. — Pressure signatures for the launch vehicle model without simulated exhaust plumes, $M = 3.76, \alpha = 0^\circ, h/l = 0.988$.



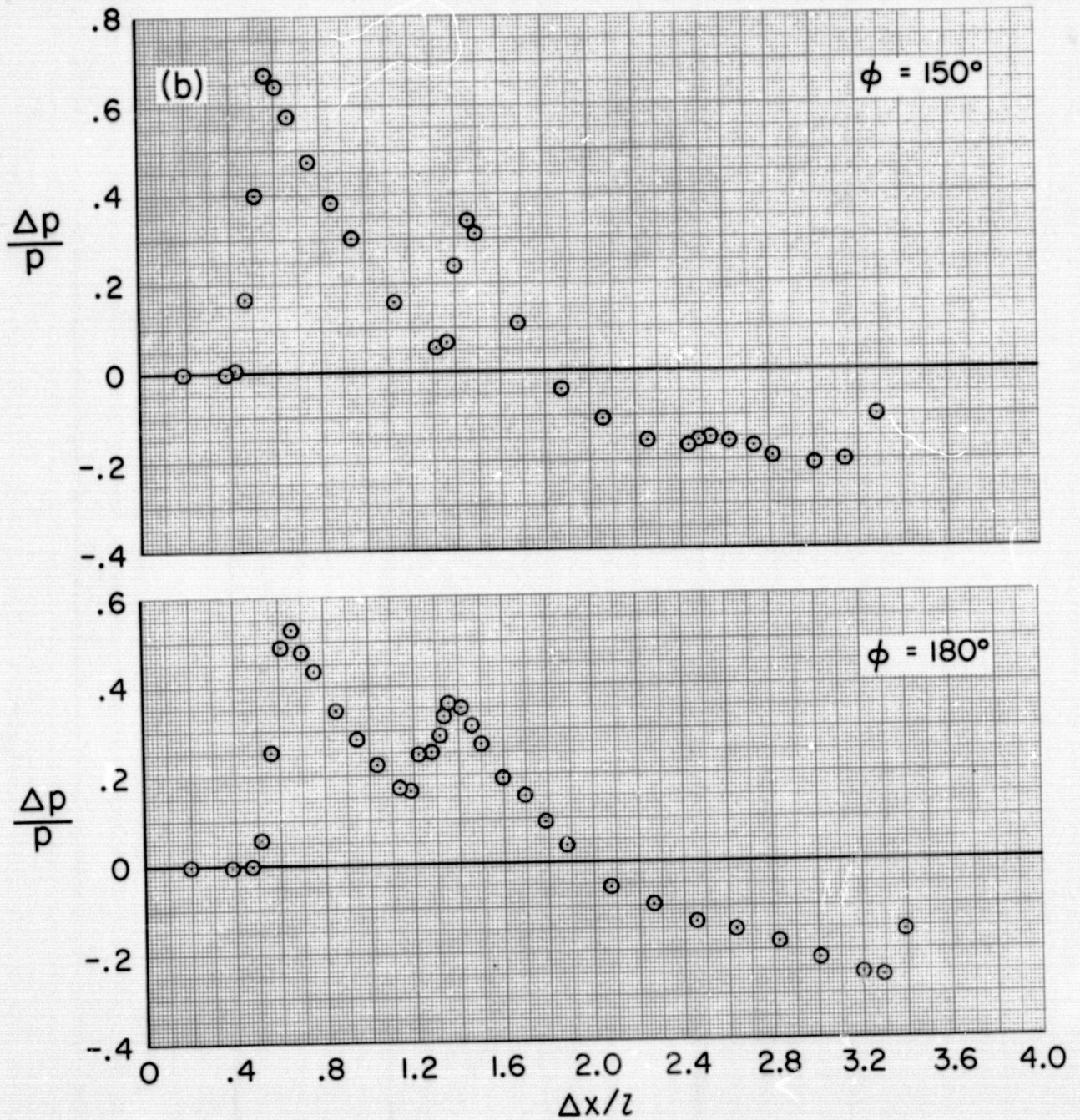
(b) $\phi = 150^\circ, 180^\circ$.

Figure 23. — Concluded.



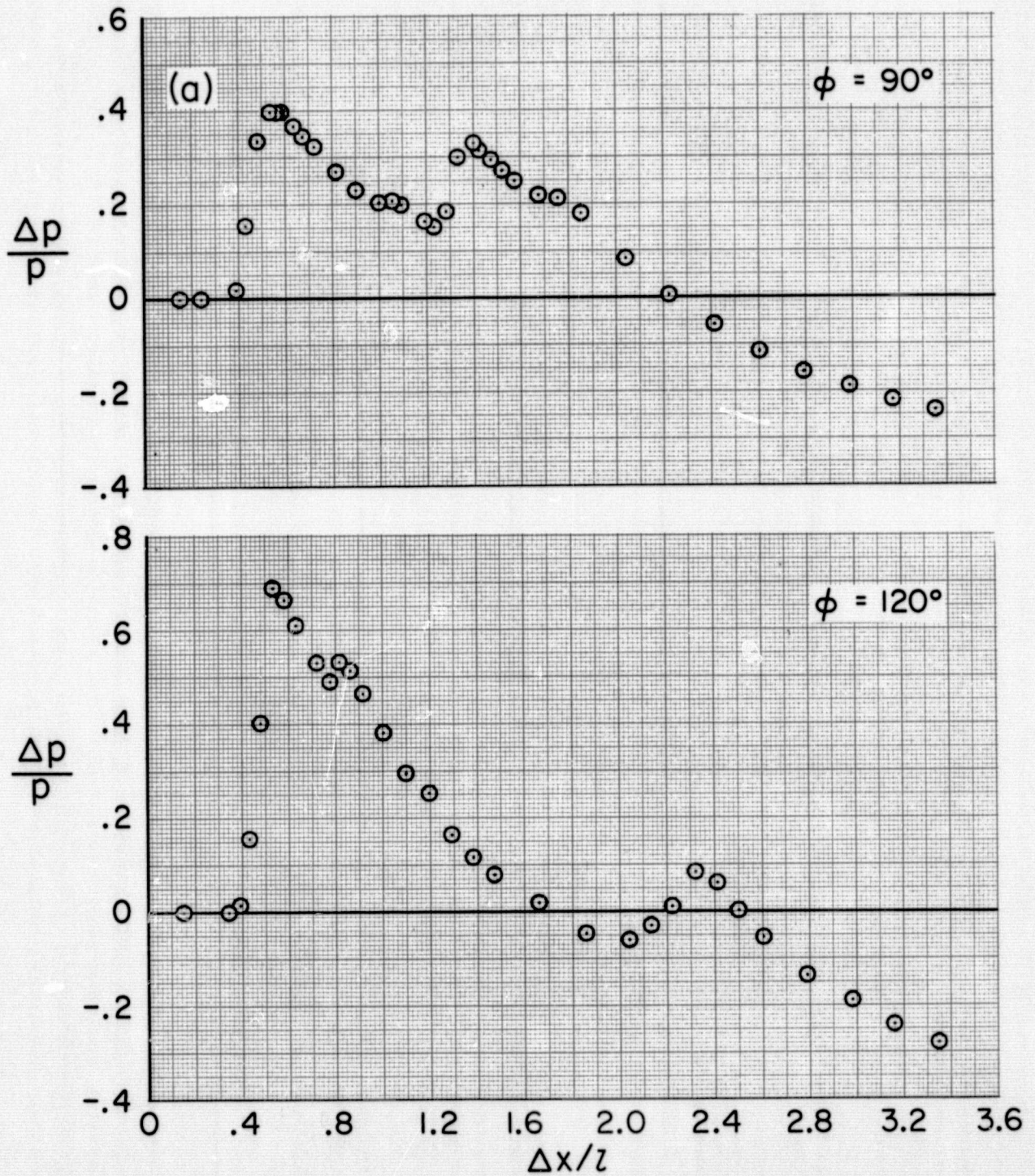
(a) $\phi = 90^\circ, 120^\circ$.

Figure 24. - Pressure signatures for the launch vehicle model without simulated exhaust plumes, $M = 4.01, \alpha = 0^\circ, h/l = 0.988$.



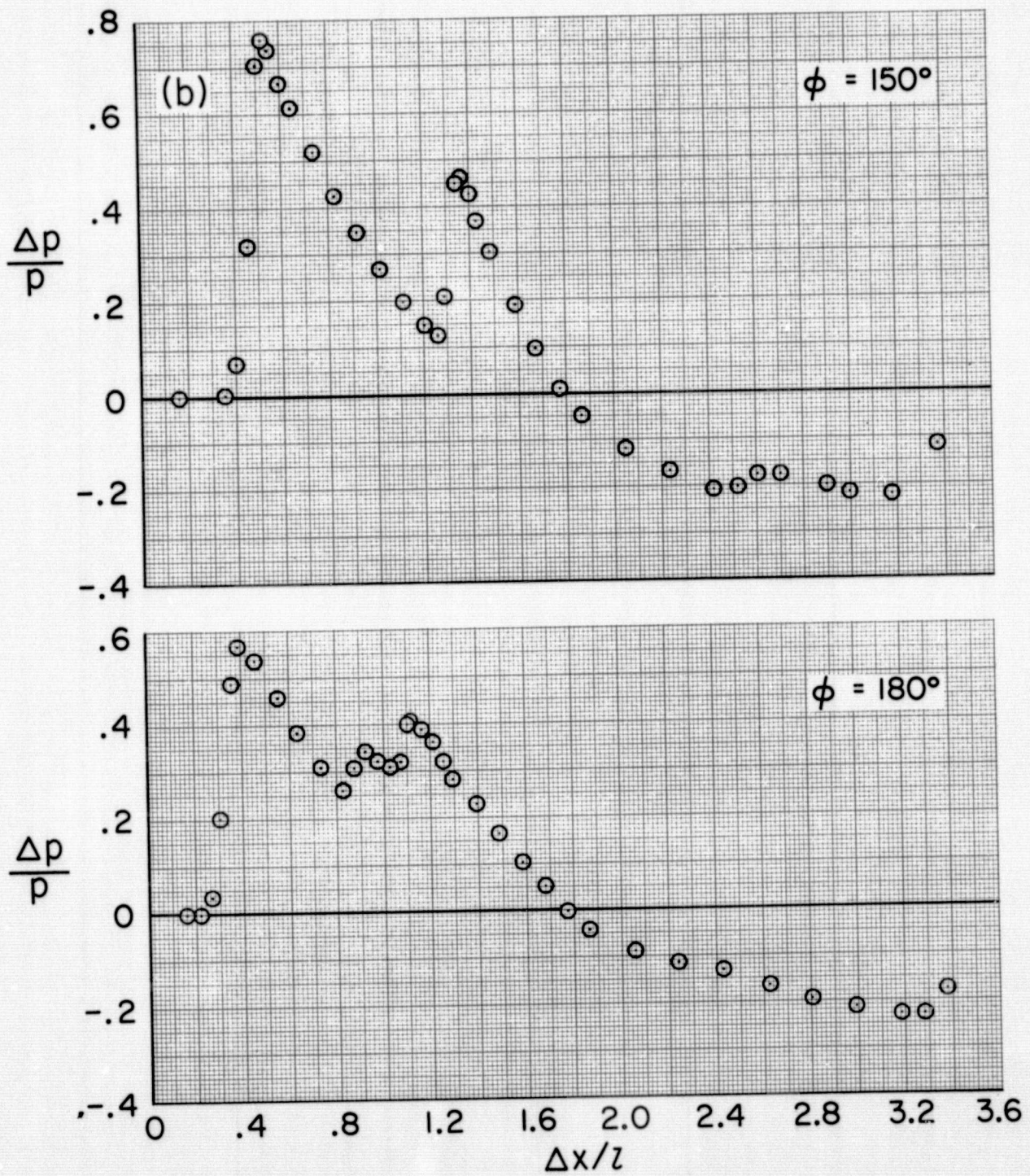
(b) $\phi = 150^\circ, 180^\circ$.

Figure 24. - Concluded.



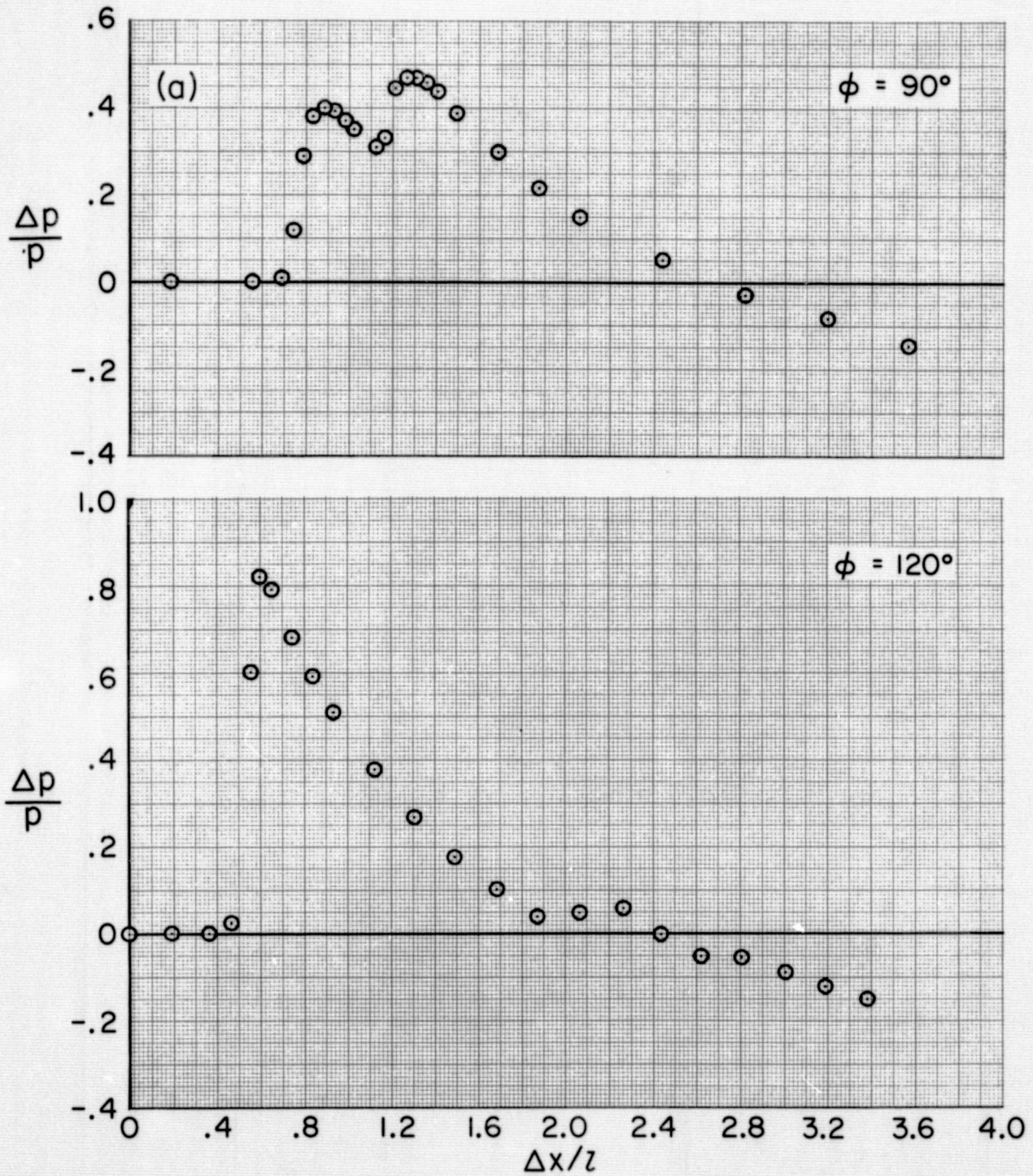
(a) $\phi = 90^\circ, 120^\circ$.

Figure 25. — Pressure signatures for the launch vehicle model without simulated exhaust plumes, $M = 4.58$, $\alpha = 0^\circ$, $h/l = 0.988$.



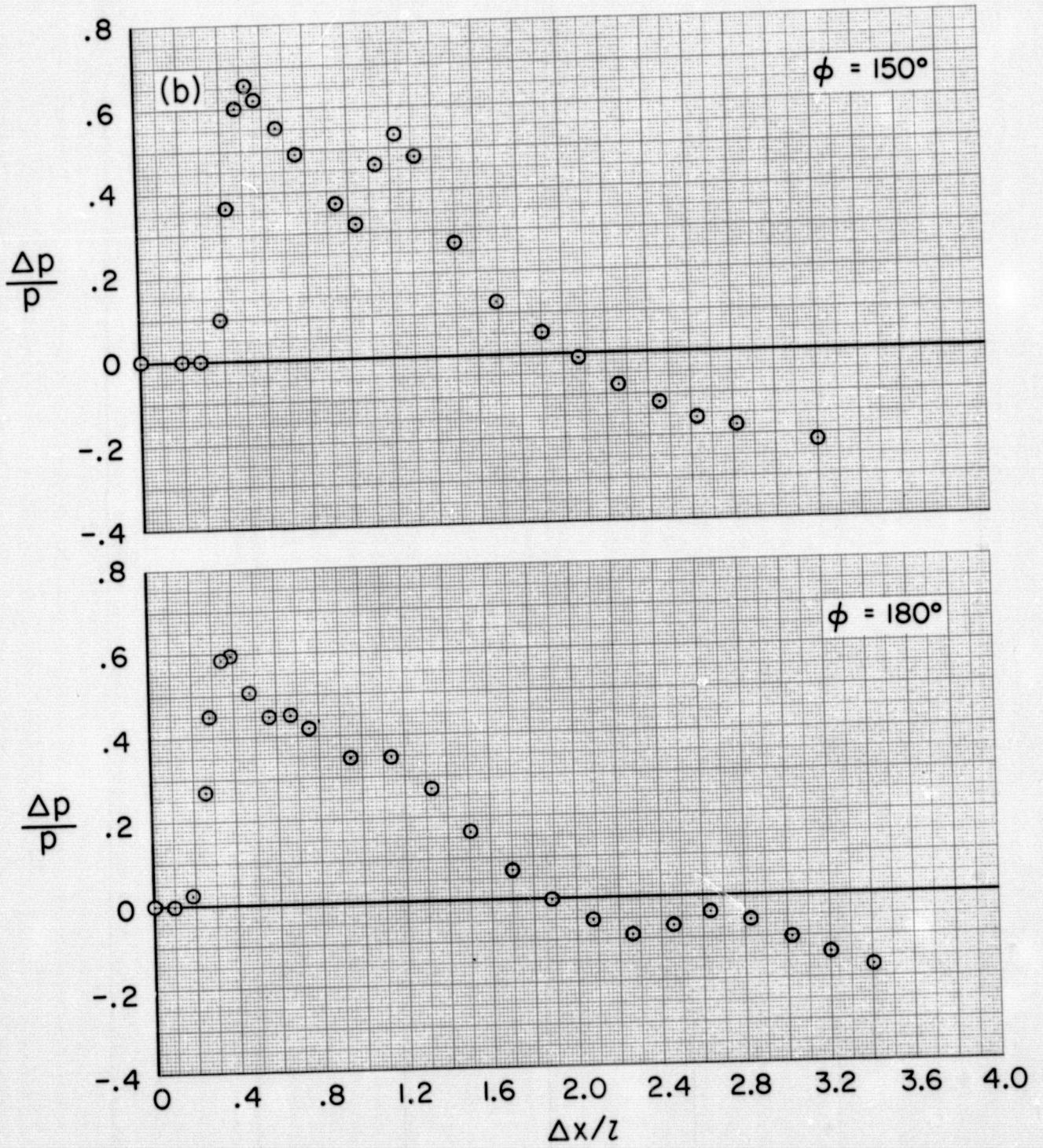
(b) $\phi = 150^\circ, 180^\circ$.

Figure 25. - Concluded.



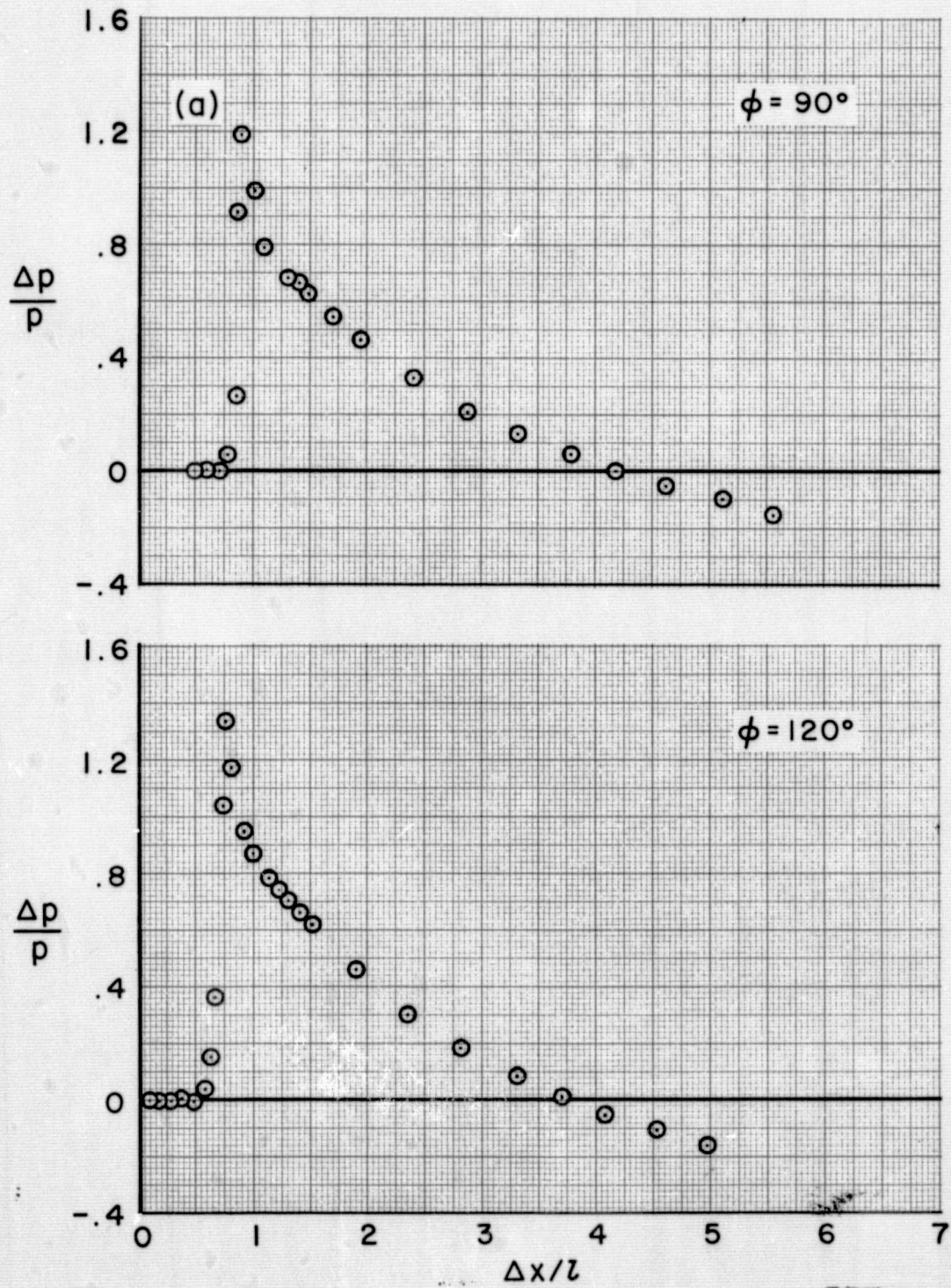
(a) $\phi = 90^\circ, 120^\circ$.

Figure 26. — Pressure signatures for the launch vehicle model without simulated exhaust plumes, $M = 5.56$, $\alpha = 0^\circ$, $h/l = 1.035$.



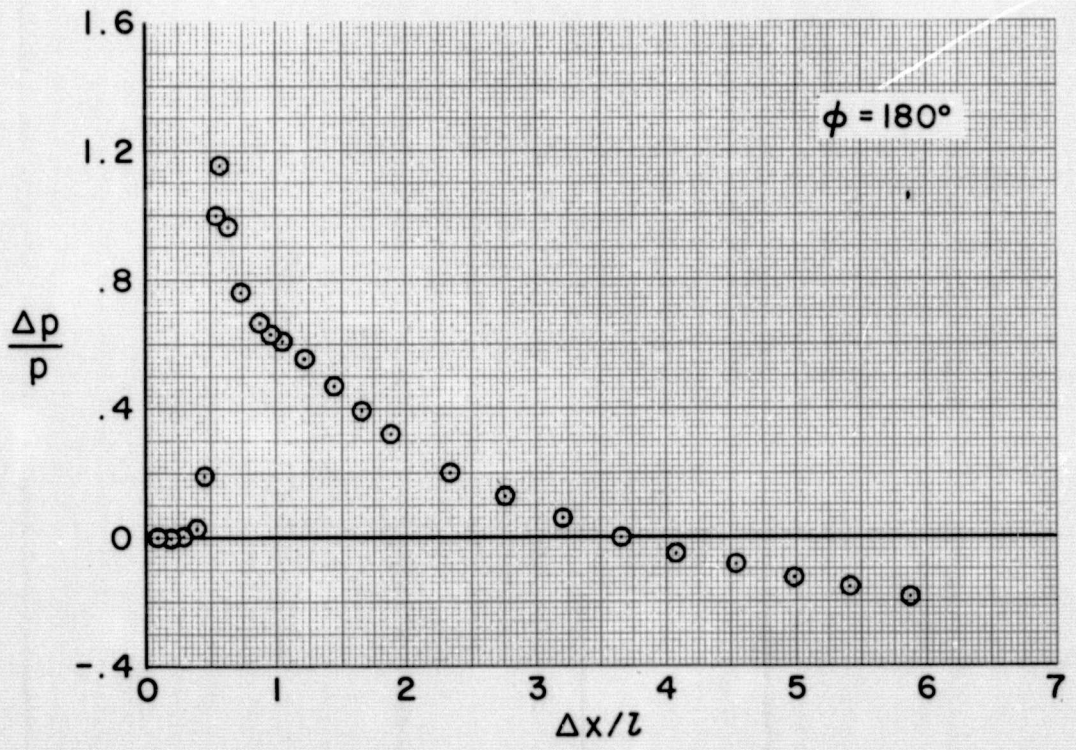
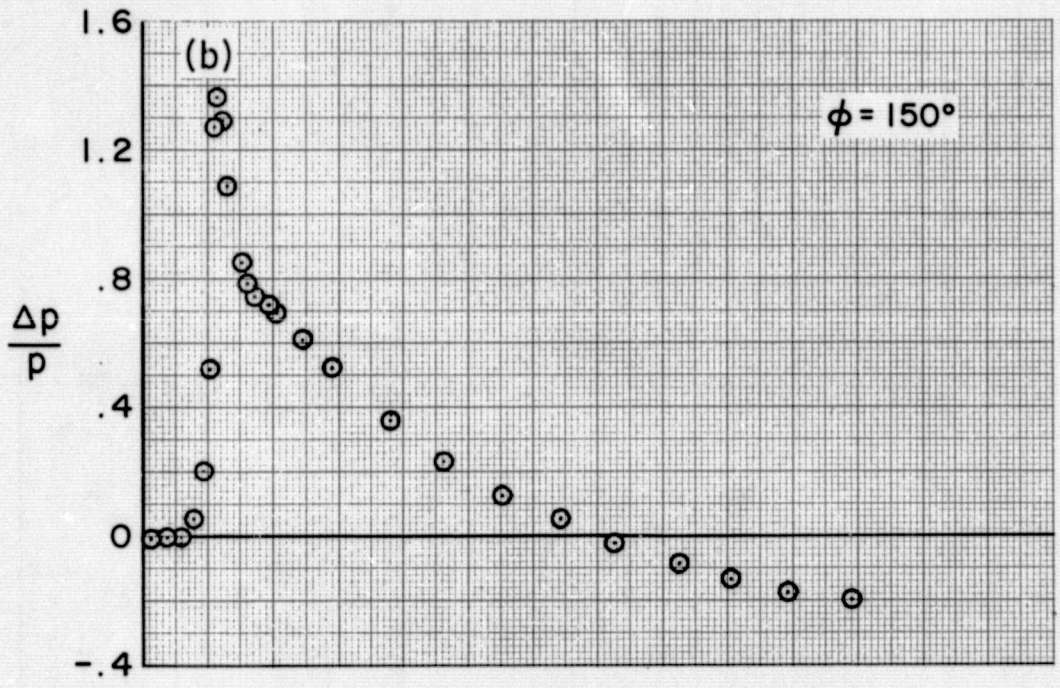
(b) $\phi = 150^\circ, 180^\circ$.

Figure 26. - Concluded.



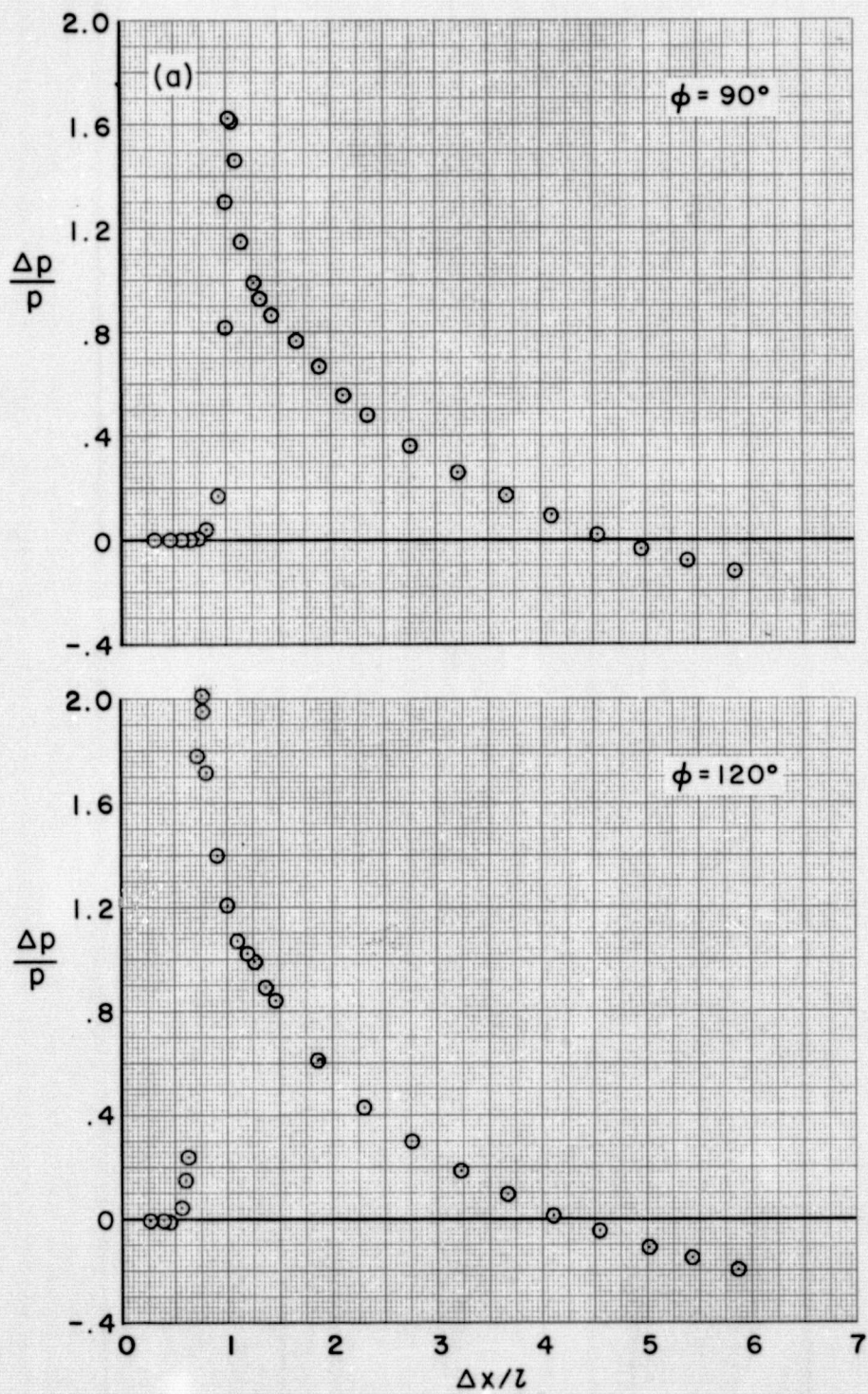
(a) $\phi = 90^\circ, 120^\circ$.

Figure 27. — Pressure signatures for the launch vehicle model with simulated exhaust plumes, $M = 3.20, \alpha = 0^\circ, h/l = 3.61$.



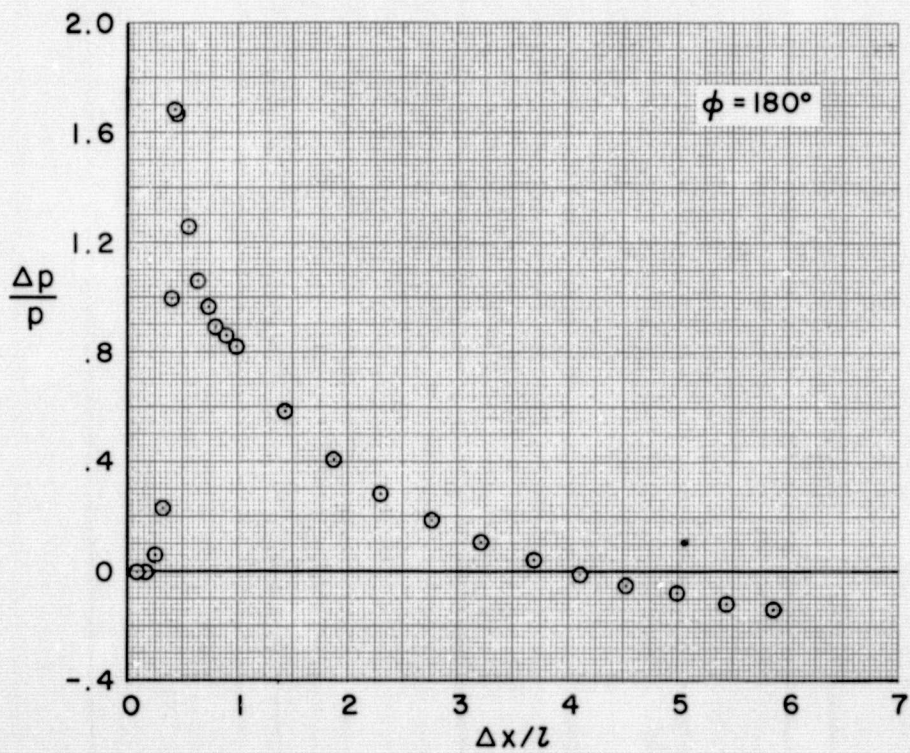
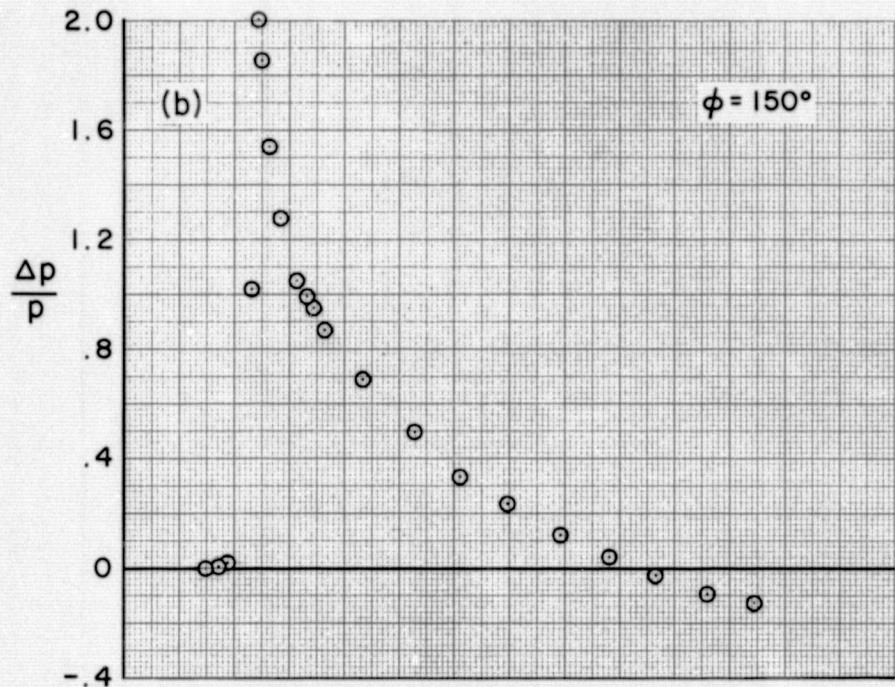
(b) $\phi = 150^\circ, 180^\circ$.

Figure 27. - Concluded.



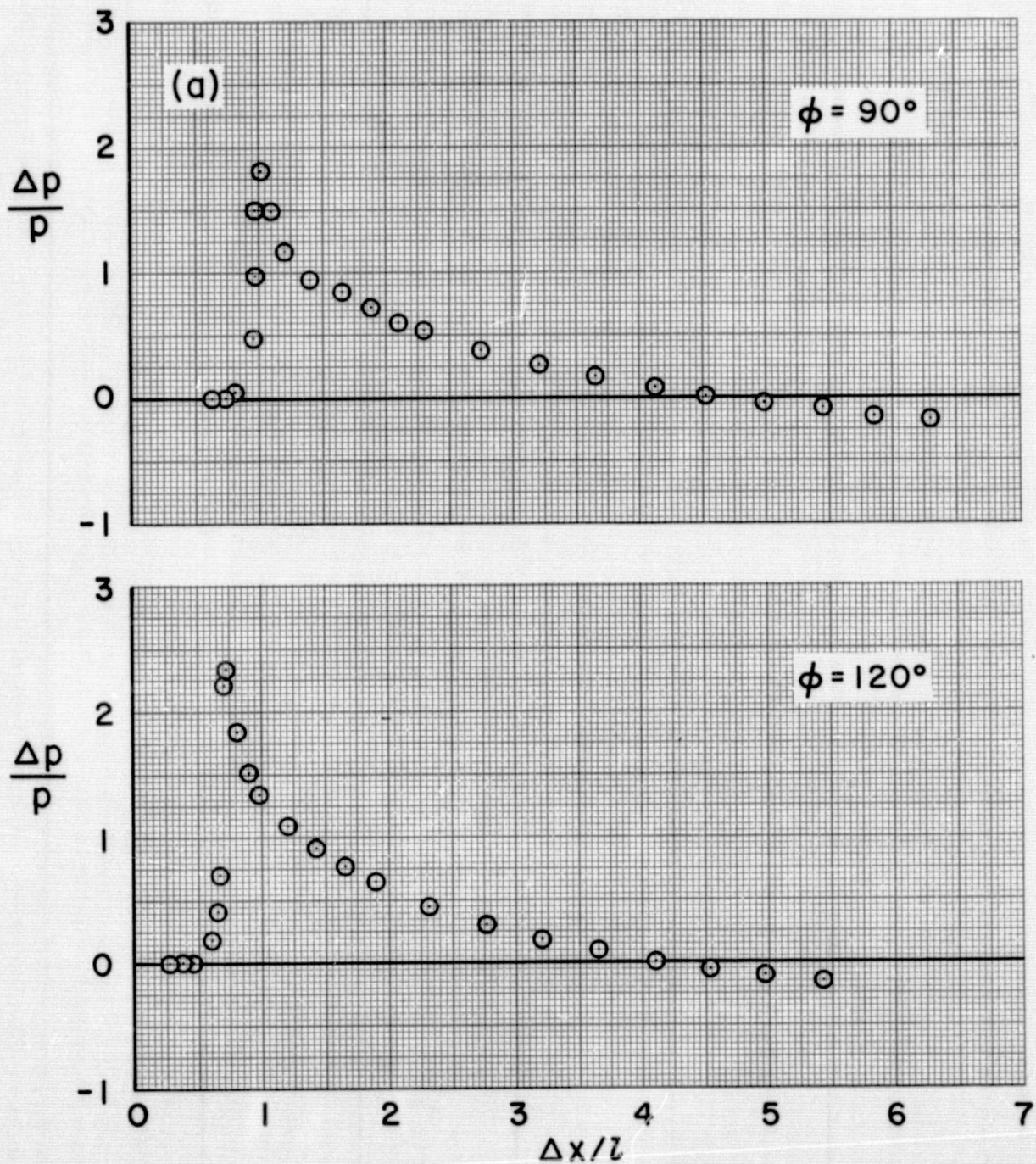
(a) $\phi = 90^\circ, 120^\circ$.

Figure 28. — Pressure signatures for the launch vehicle model with simulated exhaust plumes, $M = 3.53, \alpha = 0^\circ, h/l = 3.61$.



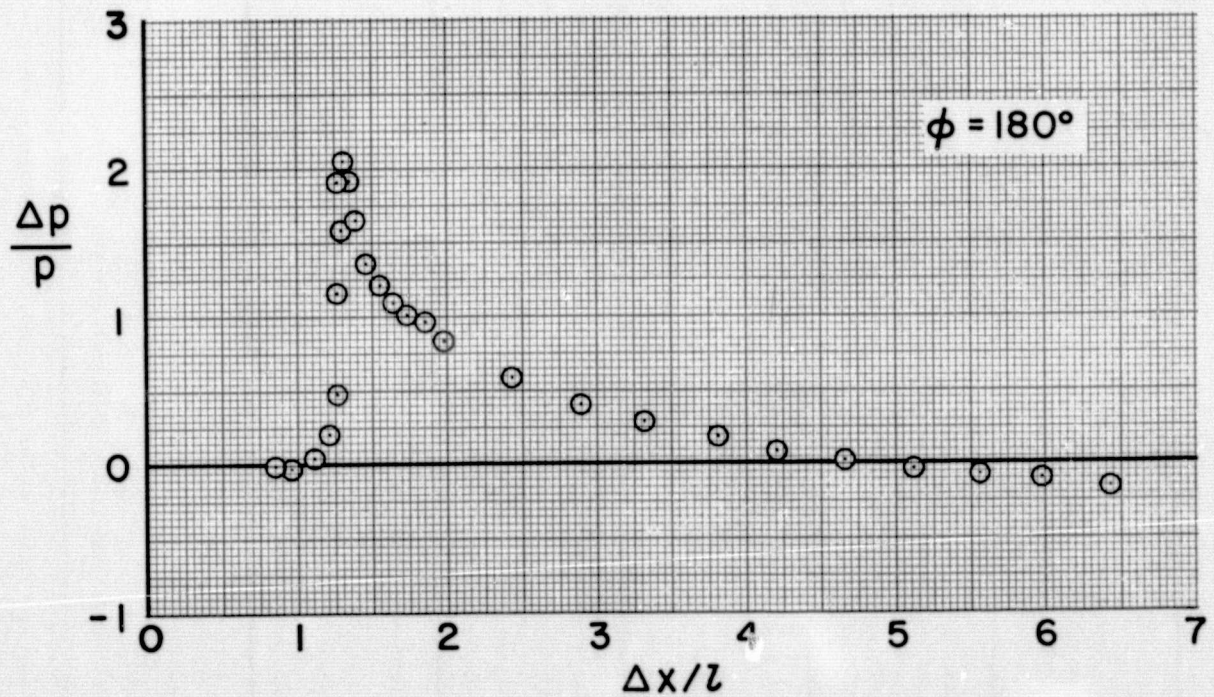
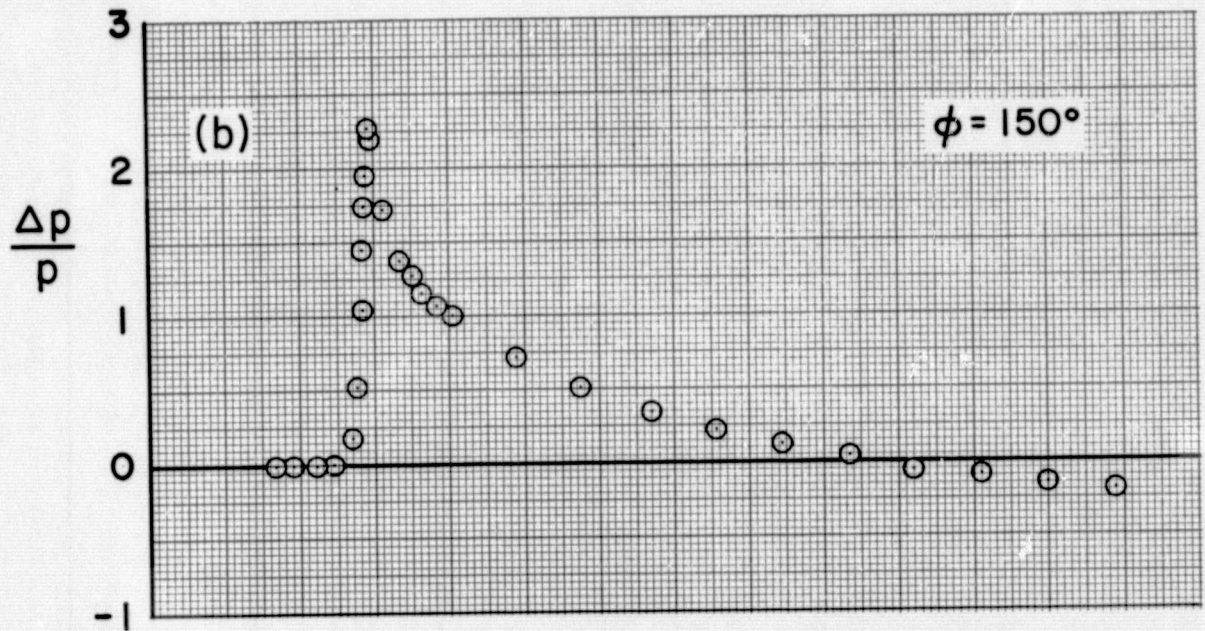
(b) $\phi = 150^\circ, 180^\circ$.

Figure 28. - Concluded.



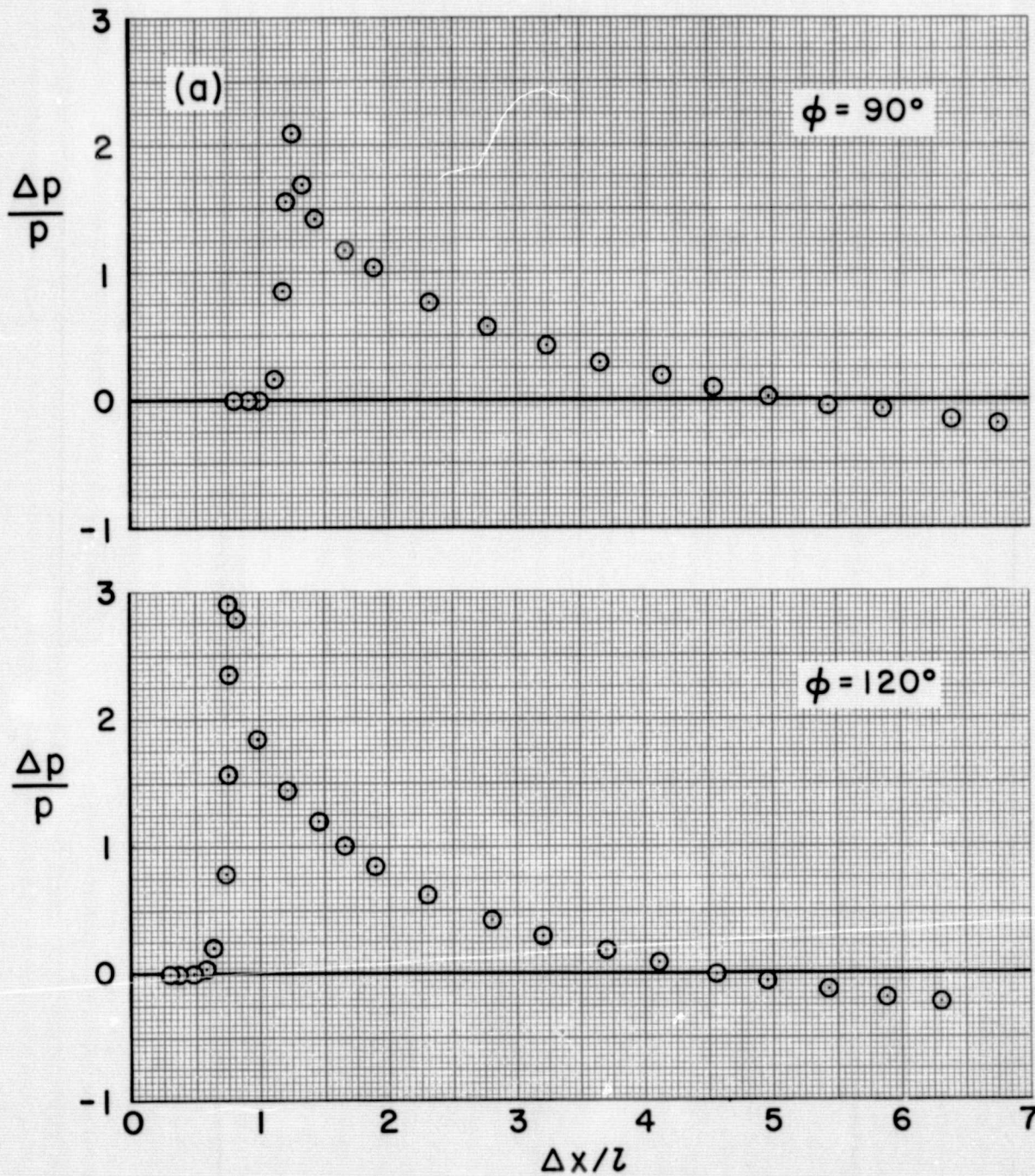
(a) $\phi = 90^\circ, 120^\circ$.

Figure 29. — Pressure signatures for the launch vehicle model with simulated exhaust plumes, $M = 3.63, \alpha = 0^\circ, h/l = 3.61$.



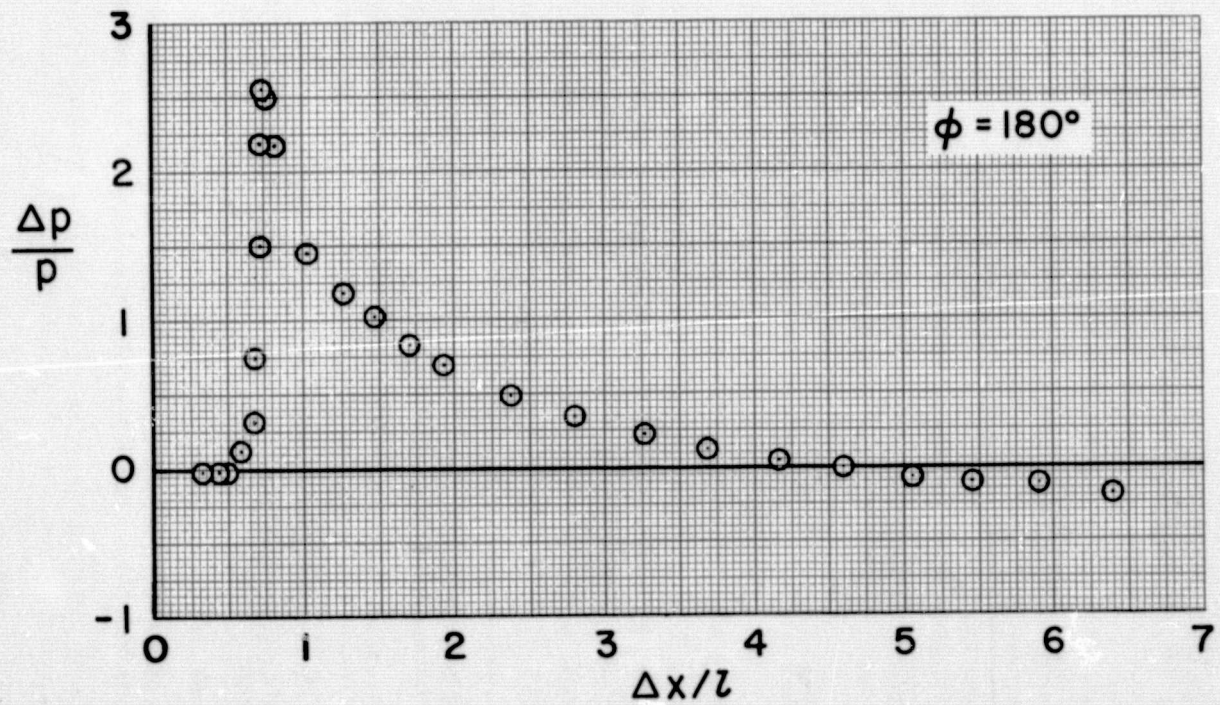
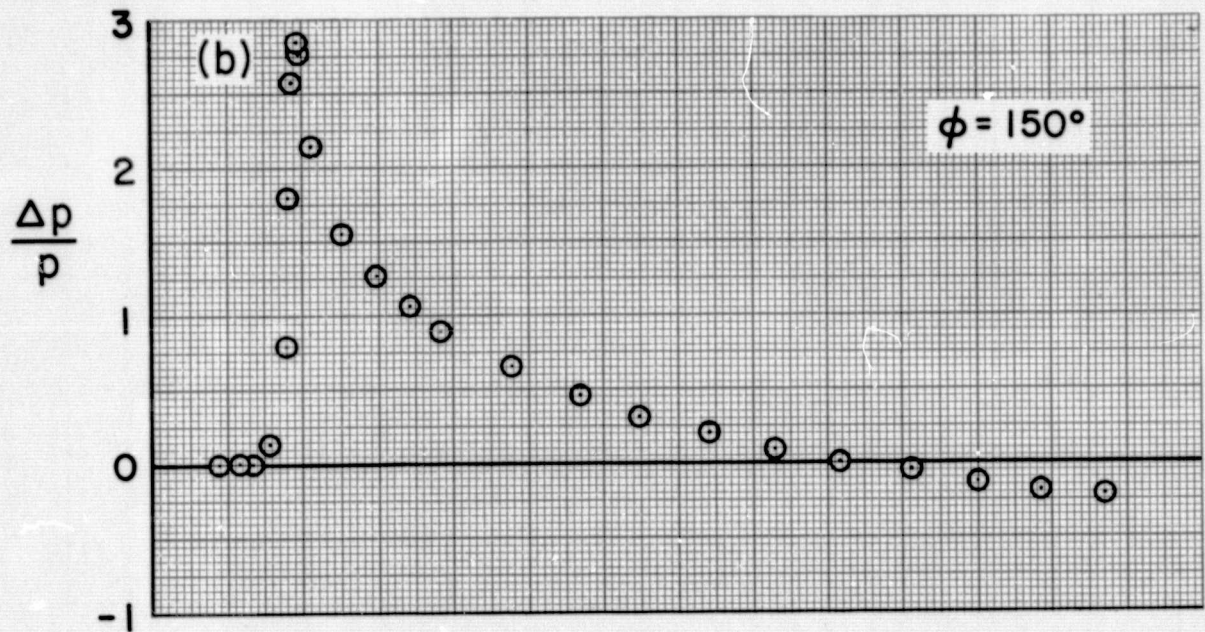
(b) $\phi = 150^\circ, 180^\circ$.

Figure 29. - Concluded.



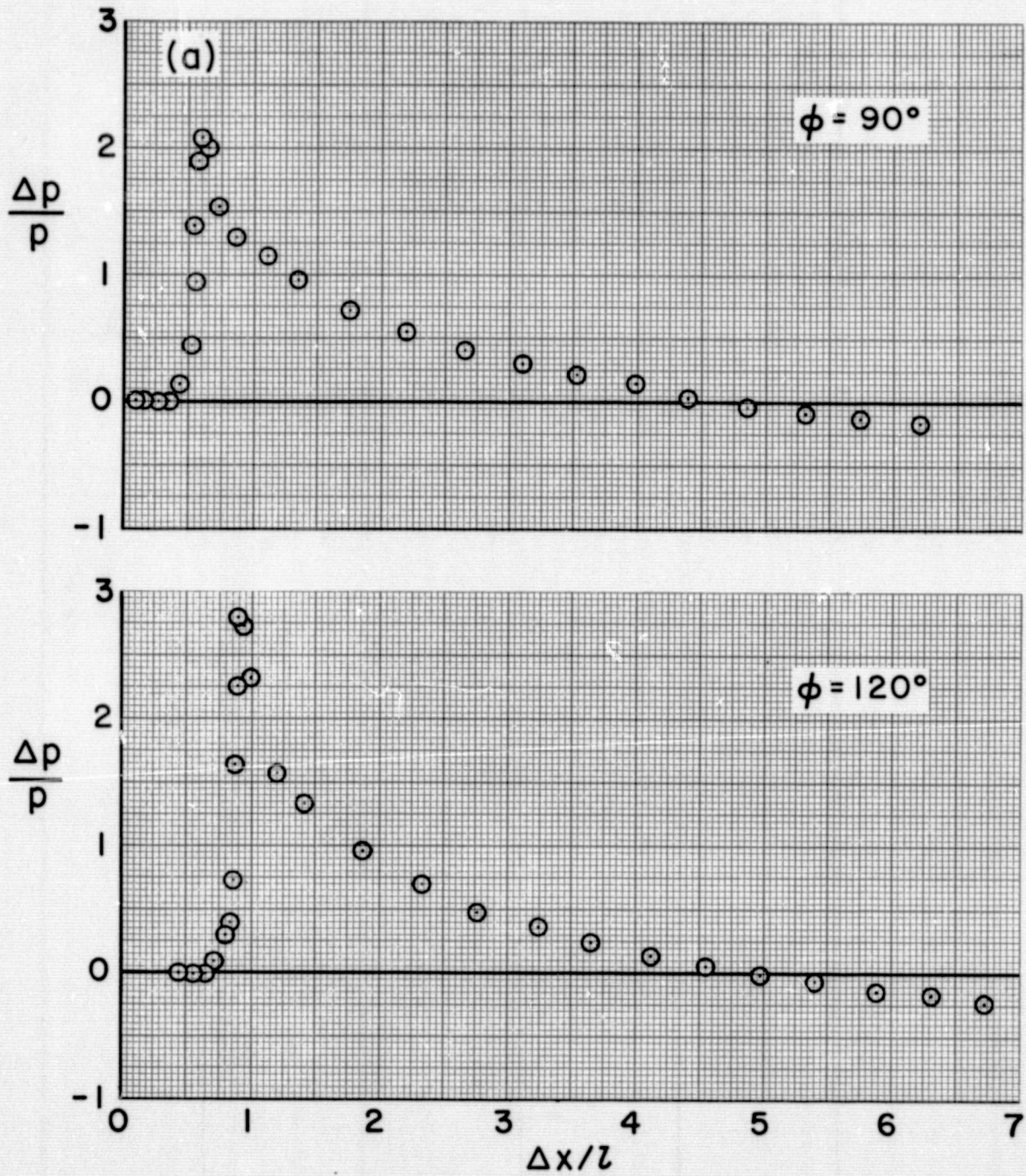
(a) $\phi = 90^\circ, 120^\circ$.

Figure 30. — Pressure signatures for the launch vehicle model with simulated exhaust plumes, $M = 3.95$, $\alpha = 0^\circ$, $h/l = 3.61$.



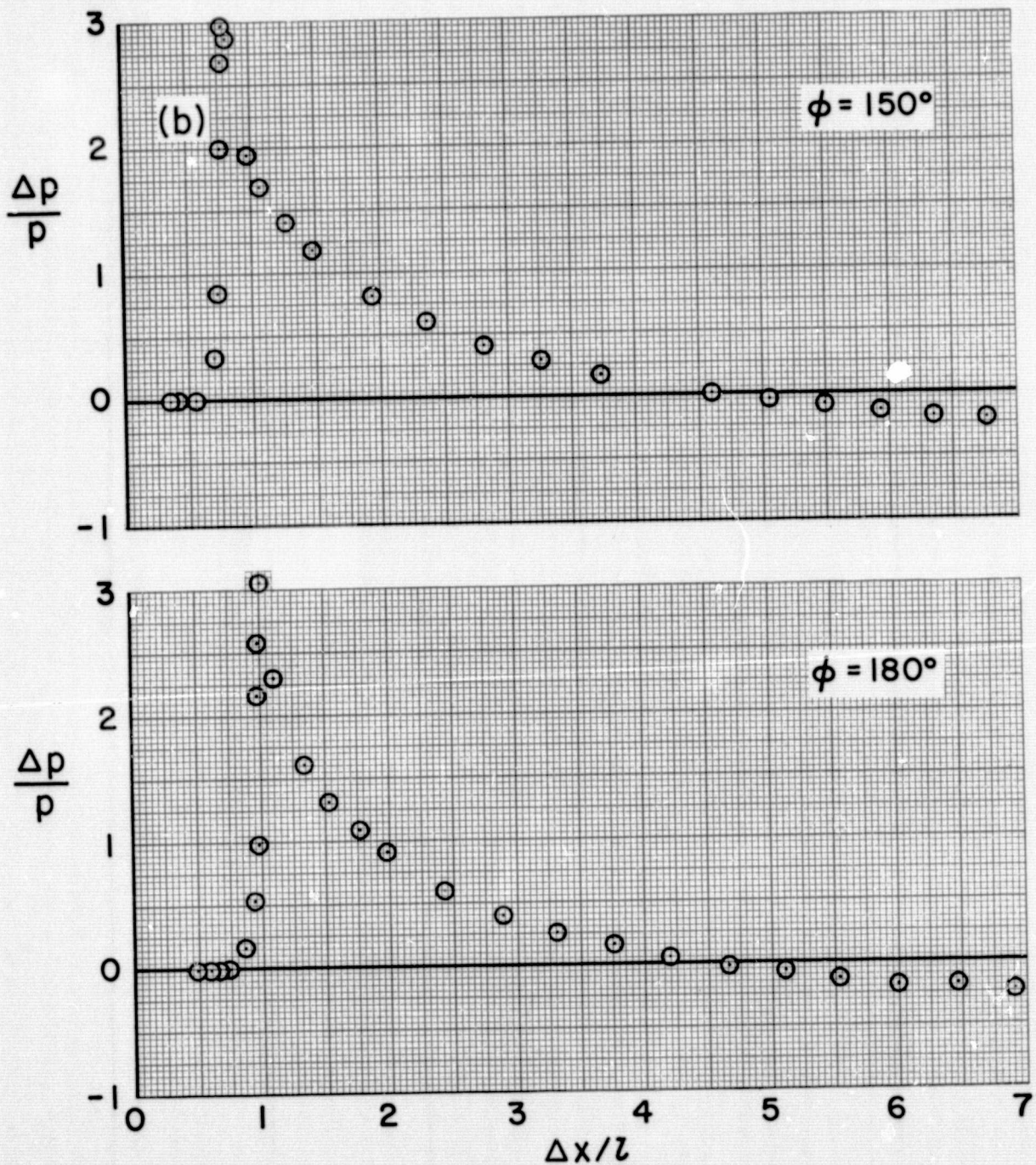
(b) $\phi = 150^\circ, 180^\circ$.

Figure 30. - Concluded.



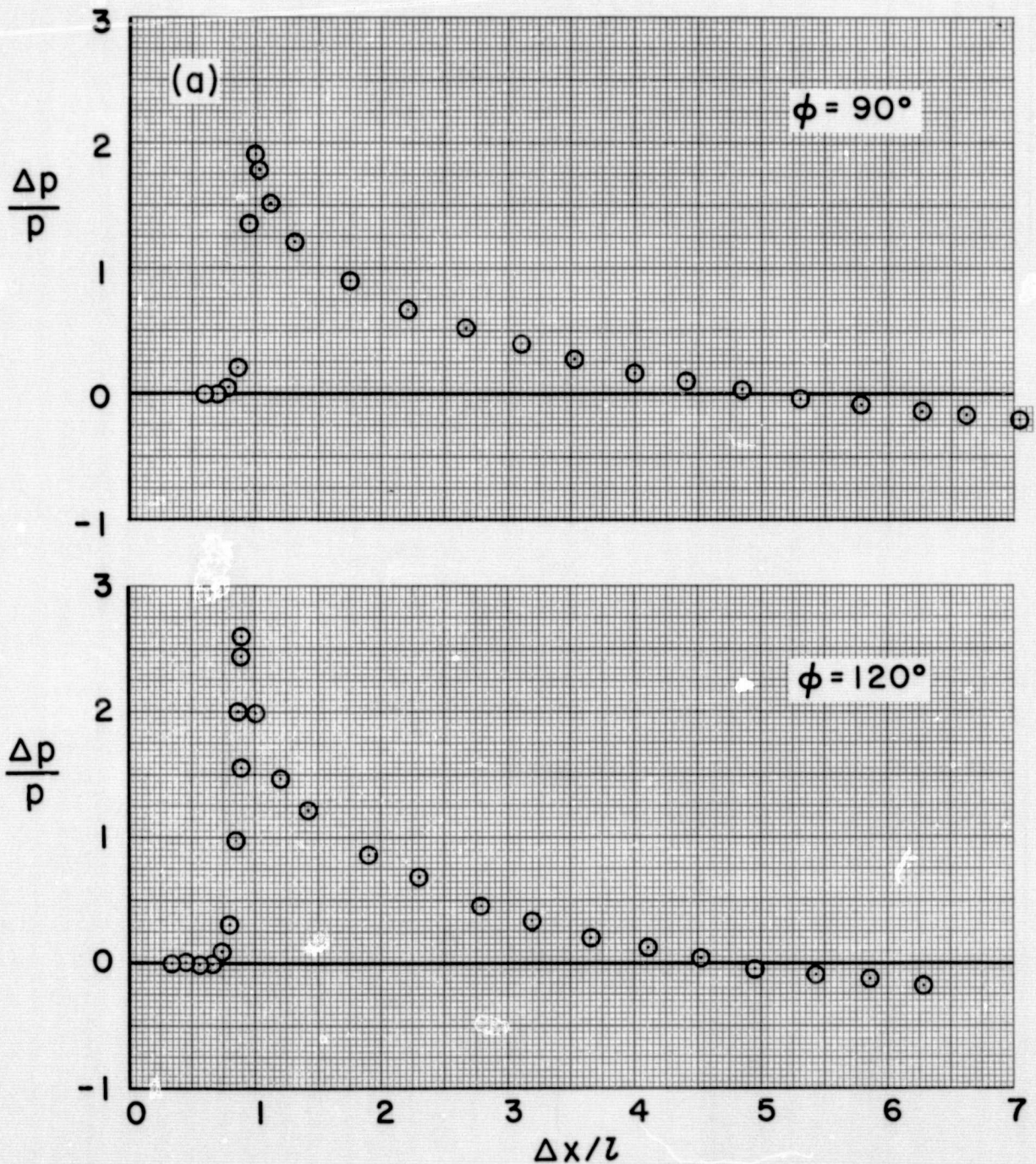
(a) $\phi = 90^\circ, 120^\circ$.

Figure 31. — Pressure signatures for the launch vehicle model with simulated exhaust plumes, $M = 4.08, \alpha = 0^\circ, h/l = 3.61$.



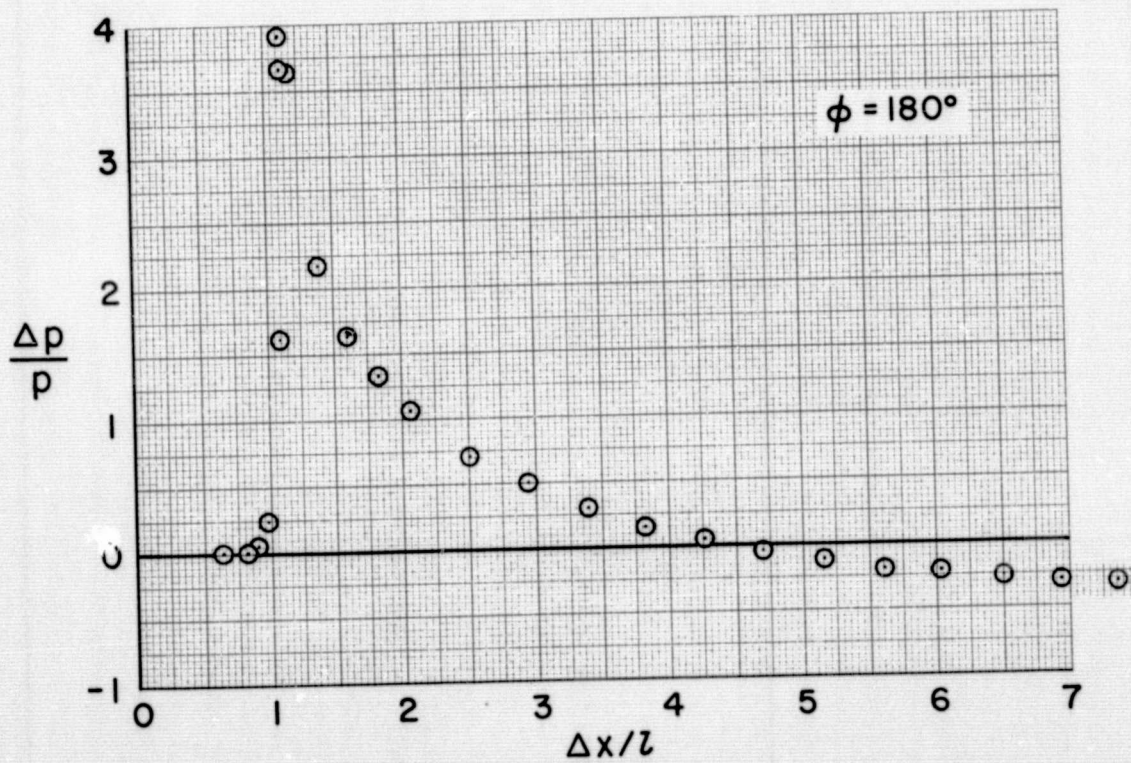
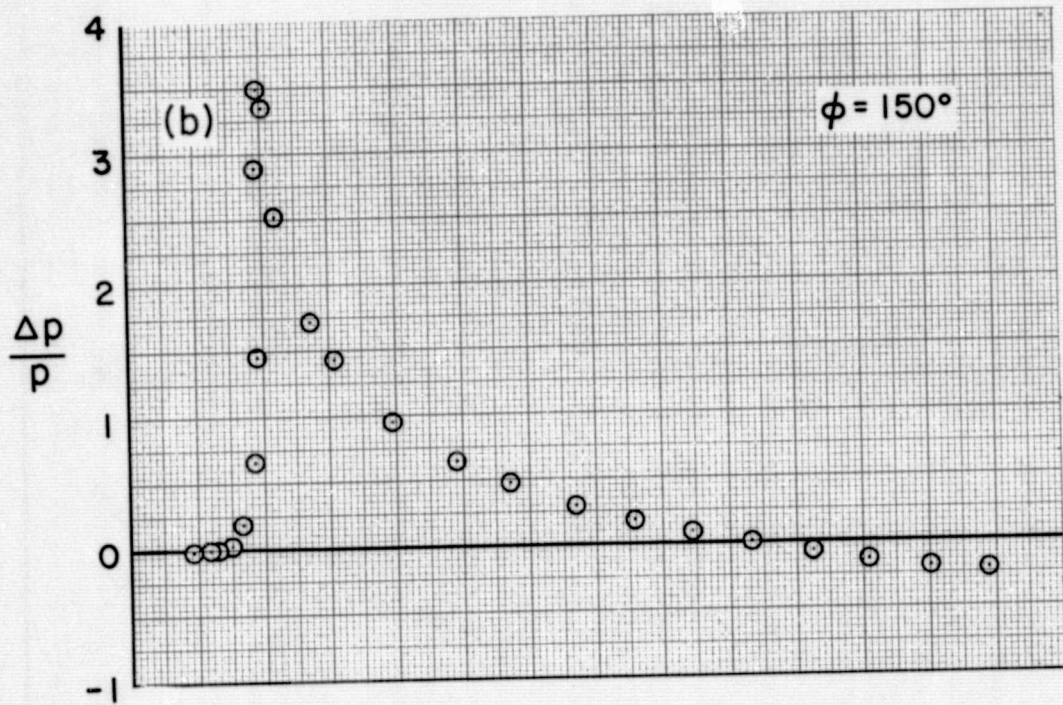
(b) $\phi = 150^\circ, 180^\circ$.

Figure 31. - Concluded.



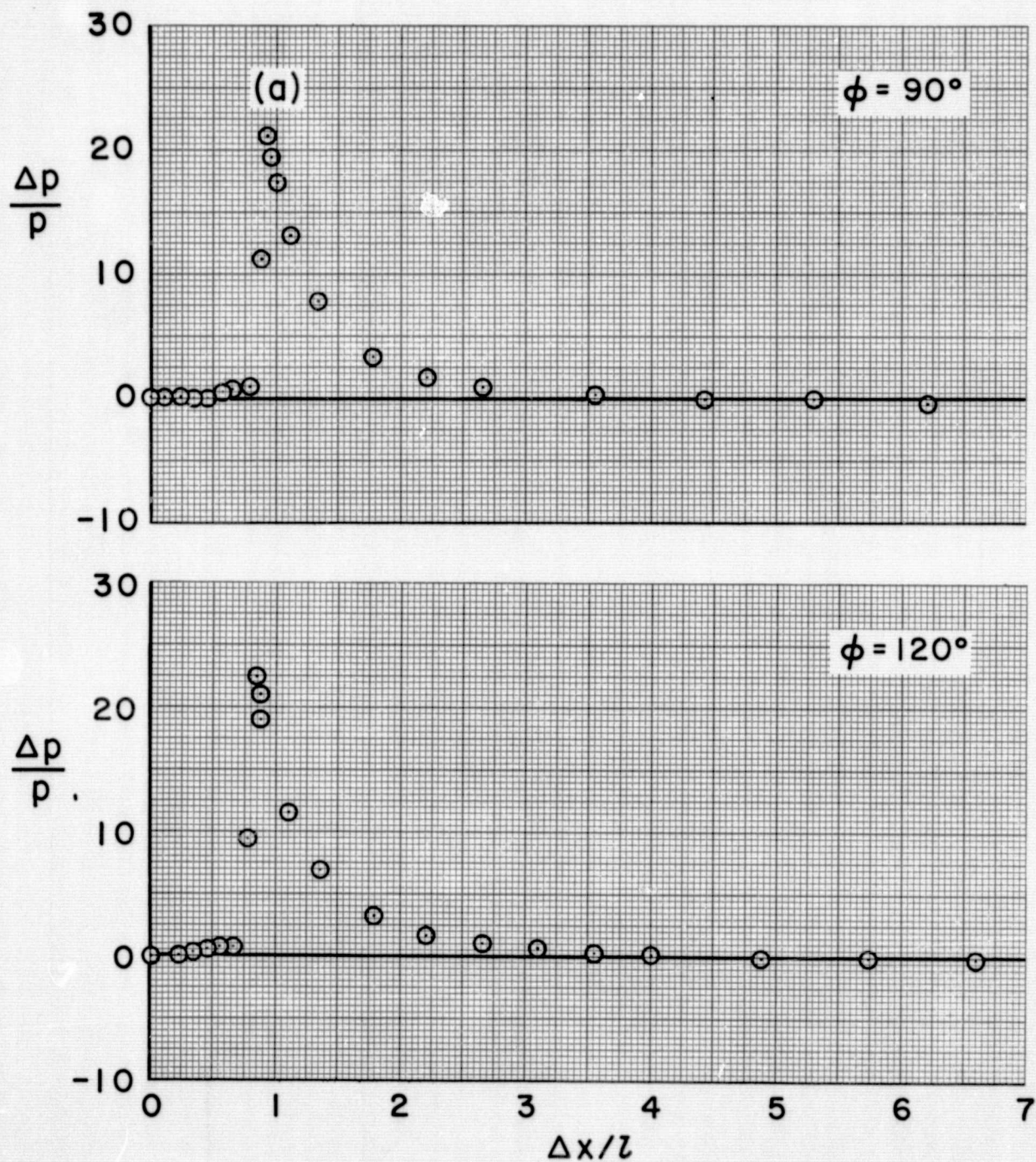
(a) $\phi = 90^\circ, 120^\circ$.

Figure 32. - Pressure signatures for the launch vehicle model with simulated exhaust plumes, $M = 4.14, \alpha = 0^\circ, h/l = 3.61$.



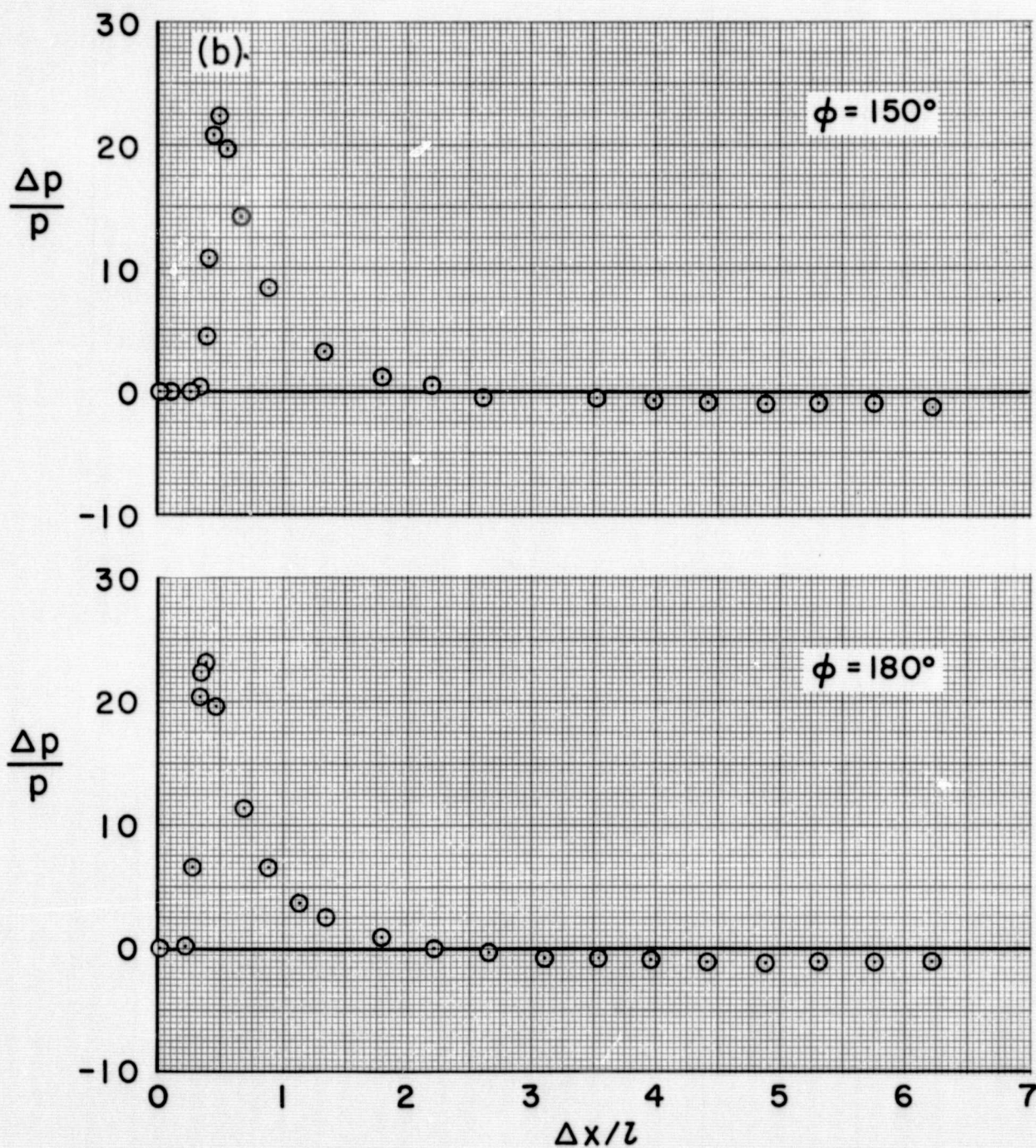
(b) $\phi = 150^\circ, 180^\circ$.

Figure 32. - Concluded.



(a) $\phi = 90^\circ, 120^\circ$.

Figure 33. — Pressure signatures for the launch vehicle model with simulated exhaust plumes, $M = 5.54, \alpha = 0^\circ, h/l = 3.26$.



(b) $\phi = 150^\circ, 180^\circ$.

Figure 33. - Concluded.