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WIND-TUNNEL INVESTIGATION OF A 3/8-SCALE AUTOMOBILE MODEL OVER A MOVING-BELT GROUND PLANE

by Thomas R. Turner

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SUMMARY

An investigation of the effect of ground-plane boundary layer in wind-tunnel testing of a model automobile over a fixed ground plane has been made by using the endless moving-belt ground plane in the 17-foot test section of the Langley 300-MPH 7- by 10-foot tunnel. A 3/8-scale automobile model was tested with the ground-plane belt at free-stream velocity (i.e., with the boundary layer eliminated) as well as at a reduced velocity and zero velocity (i.e., with boundary layers).

The results indicated that the boundary layer on the ground plane tends to increase the lift but has negligible effect on other components. The lift increment due to ground-plane boundary layer was smaller than that due to crosswinds or configuration changes such as a flush fairing on the underbody.

INTRODUCTION

The automobile industry has been using wind tunnels for some time to investigate the aerodynamic characteristics of scaled model automobiles. These aerodynamic characteristics of necessity have to be determined in the presence of a ground plane. One of the problems in determining the aerodynamic characteristics of the model near the ground in a wind tunnel with a conventional fixed ground plane is accounting for the effects of the boundary layer. One method of eliminating the boundary layer is through use of the moving-belt ground-plane technique which has recently been developed and is used for tests of STOL aircraft models in the 17-foot test section of the Langley 300-MPH 7- by 10-foot tunnel (ref. 1). Upon learning of this technique, representatives of the automobile industry contacted the Bureau of Public Roads regarding the possibility of using the moving belt to test a model automobile. Conferences among representatives of the National Aeronautics and Space Administration, the Bureau of Public Roads, and the automobile industry resulted in an agreement that tests of a production passenger automobile model would be made in the 17-foot test section of the Langley 300-MPH 7- by 10-foot tunnel. The model would be furnished by Ford Motor Company and the data would be made generally available.

The main purpose of this investigation was to determine to what extent the boundary layer on ground planes affects model-automobile wind-tunnel data and whether a moving-belt ground plane is required or desirable. The 3/8-scale model was tested with the ground-plane belt moving and not moving. Most of the investigation was conducted at a free-stream velocity of 96 ft/sec (29 m/sec); however, some runs were made at lower velocities to check the effect of Reynolds number. The installation of a flush (smooth) underbody was the only external variation investigated.

SYMBOLS

A frontal cross-sectional area of model with standard underbody, 3.466 foot^2 (0.322 meter^2)

C_D drag coefficient, $\frac{\text{Drag}}{q_\infty A}$

C_L lift coefficient, $\frac{\text{Lift}}{q_\infty A}$

C_l rolling-moment coefficient, $\frac{\text{Rolling moment}}{q_\infty A l}$

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{q_\infty A l}$

C_n yawing-moment coefficient, $\frac{\text{Yawing moment}}{q_\infty A l}$

C_Y side-force coefficient, $\frac{\text{Side force}}{q_\infty A}$

l wheelbase (see fig. 10), 44.64 inches (113.38 centimeters)

q_∞ free-stream dynamic pressure, $\frac{\rho V_\infty^2}{2}$, pounds force/foot^2 (newtons/meter^2)

V_B belt velocity, feet/second (meters/second)

V_l local velocity, feet/second (meters/second)

V_∞ free-stream velocity, feet/second (meters/second)

ρ air mass density, 0.002378 slug/foot^3 (1.22557 kilograms/meter^3)

ψ angle of yaw (positive when nose is to right), degrees

MODEL AND APPARATUS

The model used for this investigation was a 3/8-scale 1965 Ford Galaxie two-door hardtop furnished by Ford Motor Company (figs. 1, 2, and 3). The model shell was of reinforced fiber-glass construction and had a removable top and front-end section. Internal wood bulkheads were used and an aluminum box structure provided an attachment for the internal six-component strain-gage balance. The model details were carefully scaled and constructed. The detailed underbody was a scaled reproduction of the actual car in all respects, as shown in figure 4. A flush underbody was made in three approximately equal length sections to fit over the detailed underbody to give a smooth bottom surface from front to rear bumper (figs. 5, 6, and 7). The overall length of the model was 6.56 feet (1.997 meters).

Engine cooling airflow was simulated by having an open grill and screens in place of the radiator to provide the proper pressure drop. The airflow could be shut off by a sliding panel behind the grill. When the flush underbody was used, exits for the cooling air were provided. Flush panels were used to close these exits when cooling airflow was not being simulated.

The model was equipped with treadless aluminum wheels 9.6 inches (24.38 cm) in diameter, each axle being driven by a small variable-speed motor mounted within the model. The tire diameter was reduced so that when the wheels cleared the belt surface by 0.150 inch (0.381 cm), the model was at the proper design height from the ground. Magnetic pickups at the wheel hubs were used to count wheel revolutions.

Some details of the moving-belt ground plane installed in the 17-foot test section are shown in figure 8, with a complete description given in reference 1. The endless belt is 12.0 feet (3.66 meters) wide and runs at velocities of up to 100 ft/sec (30.48 m/sec) on two rollers mounted with their centers 10 feet (3.048 meters) apart. The belt is made of a woven wool material and consequently has a slightly fuzzy and textured finish. This finish causes the boundary-layer thickness, for the belt at zero velocity, to build up approximately twice as fast as it does for a hard, smooth plate. For regular wind-tunnel testing, the belt would be driven at free-stream velocity; however, some of the present tests were run also at zero belt velocity and at a belt velocity required to give a boundary-layer profile approaching that for a conventional ground plane in the University of Maryland wind tunnel.

Boundary-layer profiles at three stations for several belt velocities in the 17-foot test section along with the profile over a conventional ground plane in the University of Maryland wind tunnel are shown in figure 9. These data indicated that the boundary layer is much thicker over the belt at zero belt velocity than over the conventional ground plane.

A belt velocity of 33.3 ft/sec (10.15 m/sec) for a dynamic pressure of 11 lbf/ft^2 (526.7 N/m^2) was used to give a boundary layer similar to that over the fixed ground plane in the University of Maryland wind tunnel.

TEST CONDITIONS

The use of the moving-belt ground plane gives a simulation of an automobile operating in a no-wind condition. A wind from any direction (headwind, crosswind, etc.) would produce a velocity profile that depends largely on the contour of the ground as well as other obstructions near the highway. No attempt was made to simulate such a velocity profile. Crosswinds were simulated by yawing the model with respect to the airstream through a range of yaw angles from -10° to 20° for several belt velocities.

Most of the tests were made at a dynamic pressure of 11 lbf/ft^2 (526.7 N/m^2) and a free-stream velocity of 96 ft/sec (29 m/sec) with the model level and the wheels 0.150 inch (0.381 cm) above the belt. An electrical pitch and roll indicator was installed in the model so that the pitch and roll could be corrected (leveled) before the forces and moments were read out for each data point. A motor-driven counterweight was installed in the model to correct for the deflection of the roll beam of the strain-gage balance by unloading the roll beam. The sidewise position of this counterweight was calibrated in terms of rolling moment.

As the strain-gage balance was rather flexible, some difficulty was encountered with model oscillations in pitch, roll, and yaw. These difficulties were overcome by installing two dashpots between the model and sting and a small cable from the tunnel ceiling through a clearance hole in the top of the car to the model support sting at the yaw pivot. None of these devices had any measurable effect on the readout system.

No corrections were applied to the data. The axis system used in computing the data is shown in figure 10.

RESULTS AND DISCUSSION

The results are presented in the following figures:

	Figure
Effect of belt velocity and yaw angle	11
Effect of varying the ratio of belt velocity to free-stream velocity	12
Effect of fairing the underbody	13 and 14
Effect of Reynolds number	15
Effect of wheel operation	16
Effect of cooling airflow	17

Inasmuch as the main purpose of this investigation was to determine the effect that the boundary layer on a fixed ground plane has on the aerodynamic characteristics of an automobile in a wind-tunnel test, the discussion is limited primarily to the effects of the boundary layer and those variations in automobile configurations that may have a bearing on or relationship to the effect of the boundary layer. However, data showing the effects of wheel operation, cooling airflow, and model heights are discussed briefly.

As was previously indicated, the boundary layer over the textured surface of the belt (with the belt stopped) was thicker than that which would be obtained over the smooth, hard-surface ground plane normally used in wind-tunnel tests of automobiles. Results are shown in figure 11 for three conditions: zero belt speed, a belt speed 0.35 times as high as V_∞ to produce a boundary layer similar to that obtained over a conventional ground plane, and a belt speed equal to V_∞ to eliminate the boundary layer. For the detailed-underbody model representing a conventional automobile (fig. 11(a)), the effect of variations in belt velocity, and therefore in boundary layer, is negligible for all data components, with the exception of lift which is higher with the boundary layer present ($V_B = 0$) than with the boundary layer removed ($V_B = V_\infty$). This boundary-layer effect on lift is, however, much smaller than the effect on lift of crosswinds that result from increasing the model yaw angle from 0° to 20° (see fig. 11(a)). The yawing-moment and side-force data generally indicate a lateral misalinement of about 2.5°. The tunnel stream misalinement is believed to be about 0.5°. Apparently the model and mounting had about 2.0° effective yaw asymmetry. (For example, see fig. 11(b).)

For the model with the flush underbody (see figs. 11(b) and 12), eliminating the boundary layer by operating the belt at $V_B = V_\infty$ causes a somewhat larger reduction in lift than for the model with the detailed underbody (see figs. 11(a) and 12) and also induces some variation in pitching moment. The other components, however, remain unaffected by the presence or absence of the boundary layer. Generally, the effect of the boundary layer on the lift of the model with the flush underbody (see fig. 12) is no larger than the effect on lift of changing from a detailed to a flush underbody (see figs. 12 and 13). As can be seen from figure 14, for the test sequence used in this investigation most of the effect of fairing the underbody for both belt velocities ($V_B = V_\infty$ and $V_B = 0.347V_\infty$) is achieved with only the front third of the fairing installed. The reasons for the large effects of the presence or absence of the boundary layer on lift for the model with the flush underbody (fig. 11(b)) are not fully understood, but are probably associated with the fact that, with the smooth underbody, the air velocity under the car is increased and the rate of loss of energy of the air flowing under the car is probably greatly reduced.

An investigation of the effect of Reynolds number over a limited range, from approximately 1×10^6 to 2×10^6, was made by operating at successively increased dynamic pressures with $\psi = 0^\circ$ and the radiator closed. As can be seen from figure 15, the effects of Reynolds number are negligible within the test range.

Driving the wheels of the model to match the free-stream velocity had no measurable effect on the aerodynamic characteristics (fig. 16). The wheels were treadless, as mentioned previously, and therefore may not have had as much effect as scaled-tread wheels would have had.

The effects of cooling airflow on the aerodynamic forces and moments were investigated by closing the flow through the radiator. In general, these effects (fig. 17) were small particularly when compared with the effects of crosswinds.

A few tests were made to investigate the effect of increased ground clearance, the results of which are shown in figure 18. It should be noted that as the ground clearance increased, the gap between wheels and the ground increased by the same increment. Increasing the ground clearance decreased the lift, drag, and pitching-moment coefficients.

Limited surveys were made of the flow approaching and beneath the model for comparison with similar data obtained over a conventional ground plane (ref. 2). The same rake and mount were used for both series of tests. Except near the ground, the profile obtained under the front bumper with the belt moving is in fair agreement with that obtained over a conventional ground plane. Under the rear bumper, the moving belt gives a higher velocity than the conventional ground plane, especially near the ground (fig. 19). The increase in velocity under the car with an increase in belt velocity indicates that more of the air approaching the car flows underneath as is indicated also by the tuft studies just ahead of the model (fig. 20).

CONCLUDING REMARKS

An investigation of the effect of ground-plane boundary layer in wind-tunnel tests of a model automobile over a fixed ground plane has been made by using the endless moving-belt ground plane in the 17-foot test section of the Langley 300-MPH 7- by 10-foot tunnel. A 3/8-scale automobile model was tested with the ground-plane belt at free-stream velocity (i.e., with the boundary layer eliminated) and at a reduced velocity and zero velocity (i.e., with boundary layers).

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Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., June 30, 1967,
126-13-01-47-23.

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1. Turner, Thomas R.: A Moving-Belt Ground Plane for Wind-Tunnel Ground Simulation and Results for Two Jet-Flap Configurations. NASA TN D-4228, 1967.
2. Kessler, Jay C.; and Wallis, Stanley B.: Aerodynamic Test Techniques. Presented at SAE Junior Activity – Detroit Section, Feb. 7, 1966.

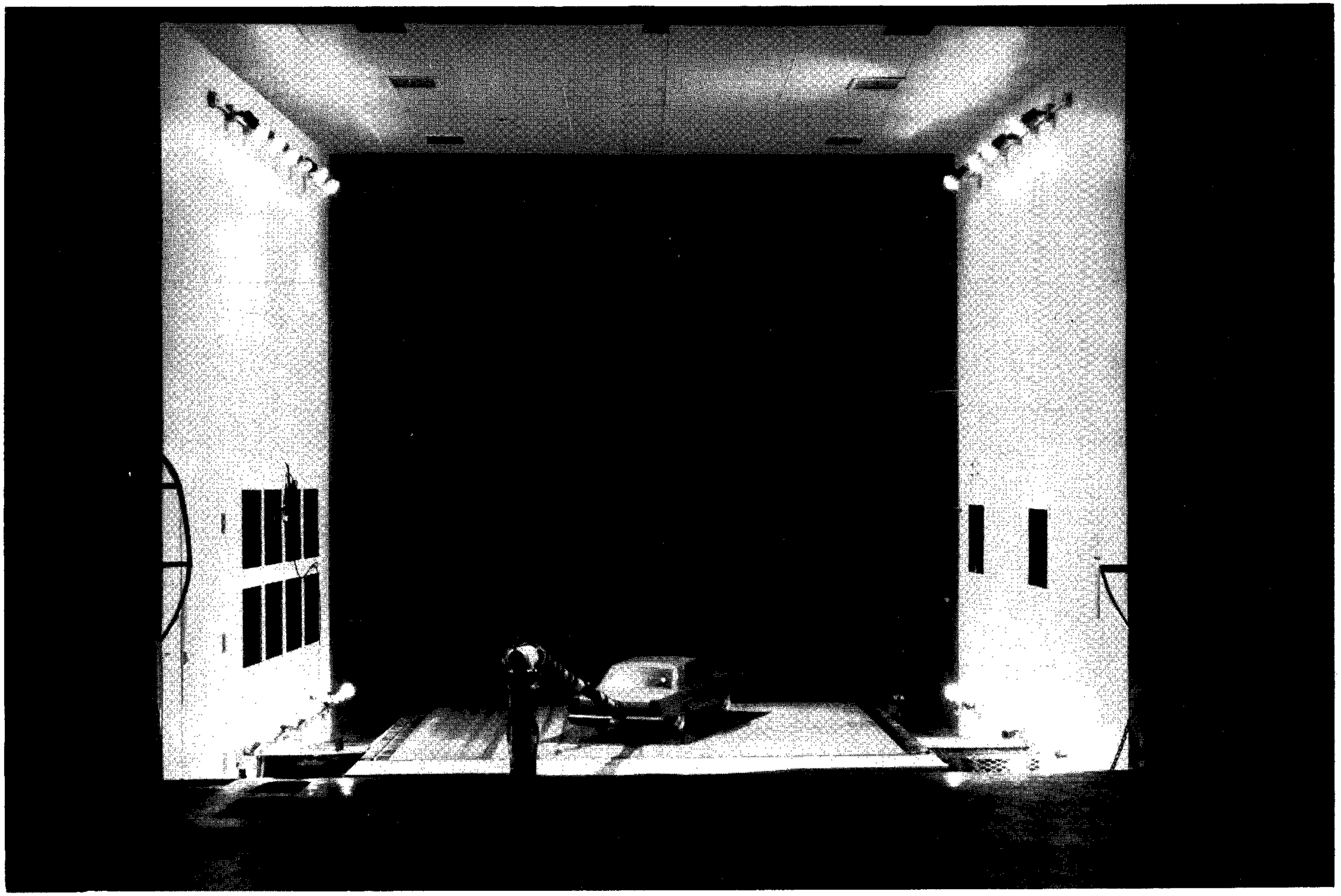


Figure 1.- Photograph of model mounted over moving-belt ground plane.

L-66-96

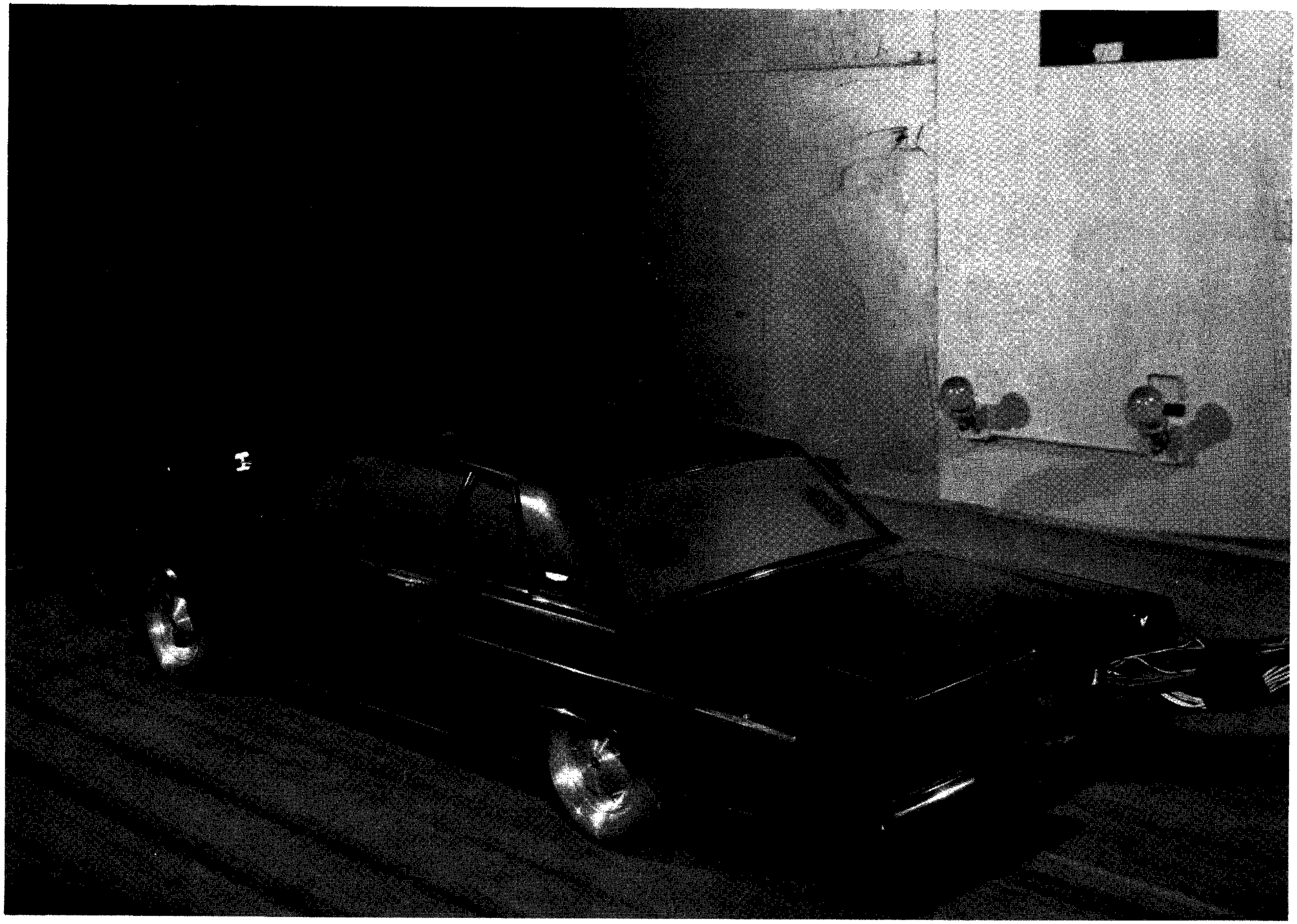


Figure 2.- Rear view of model. L-65-8860

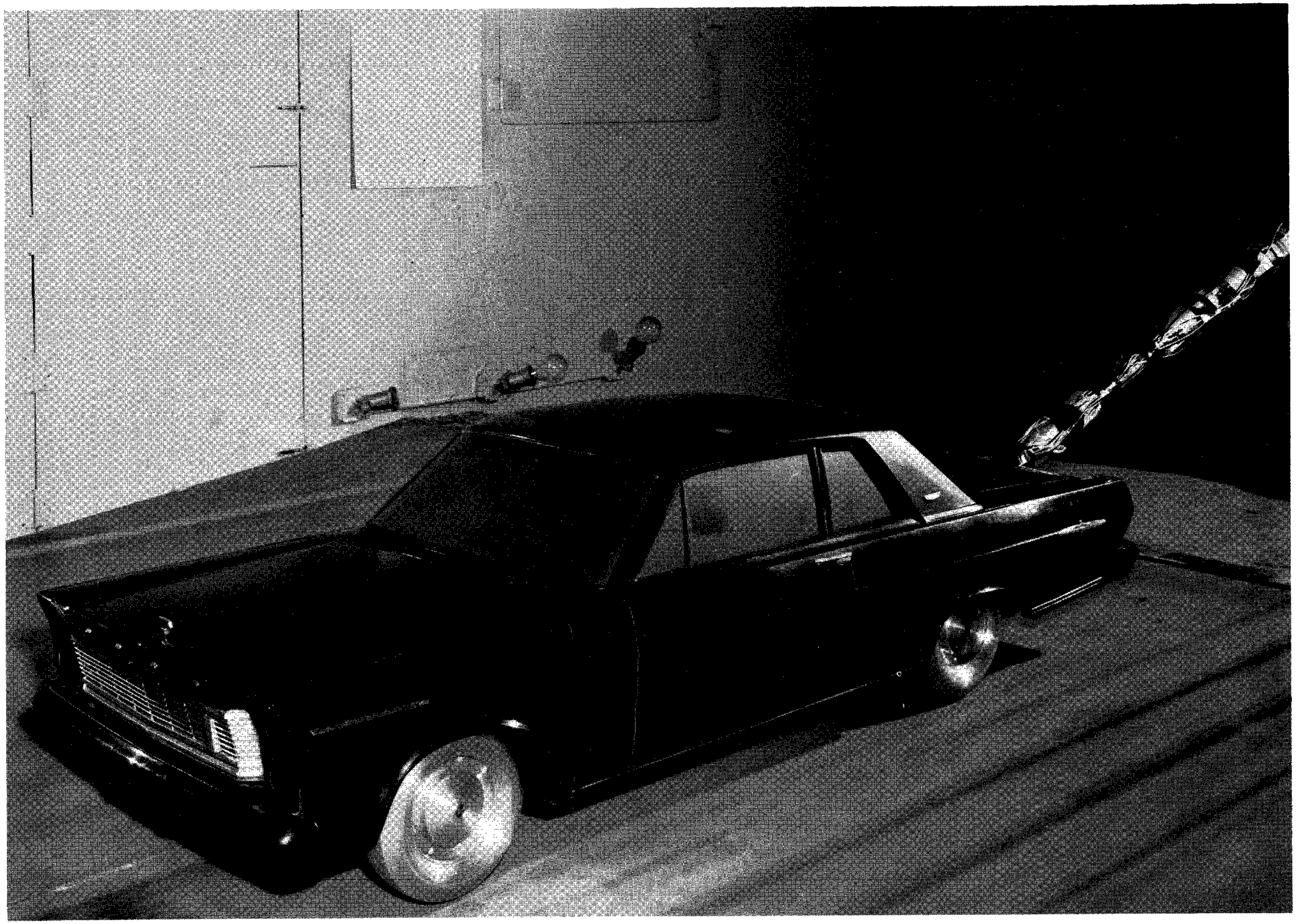


Figure 3.- Front view of model.

L-65-8858

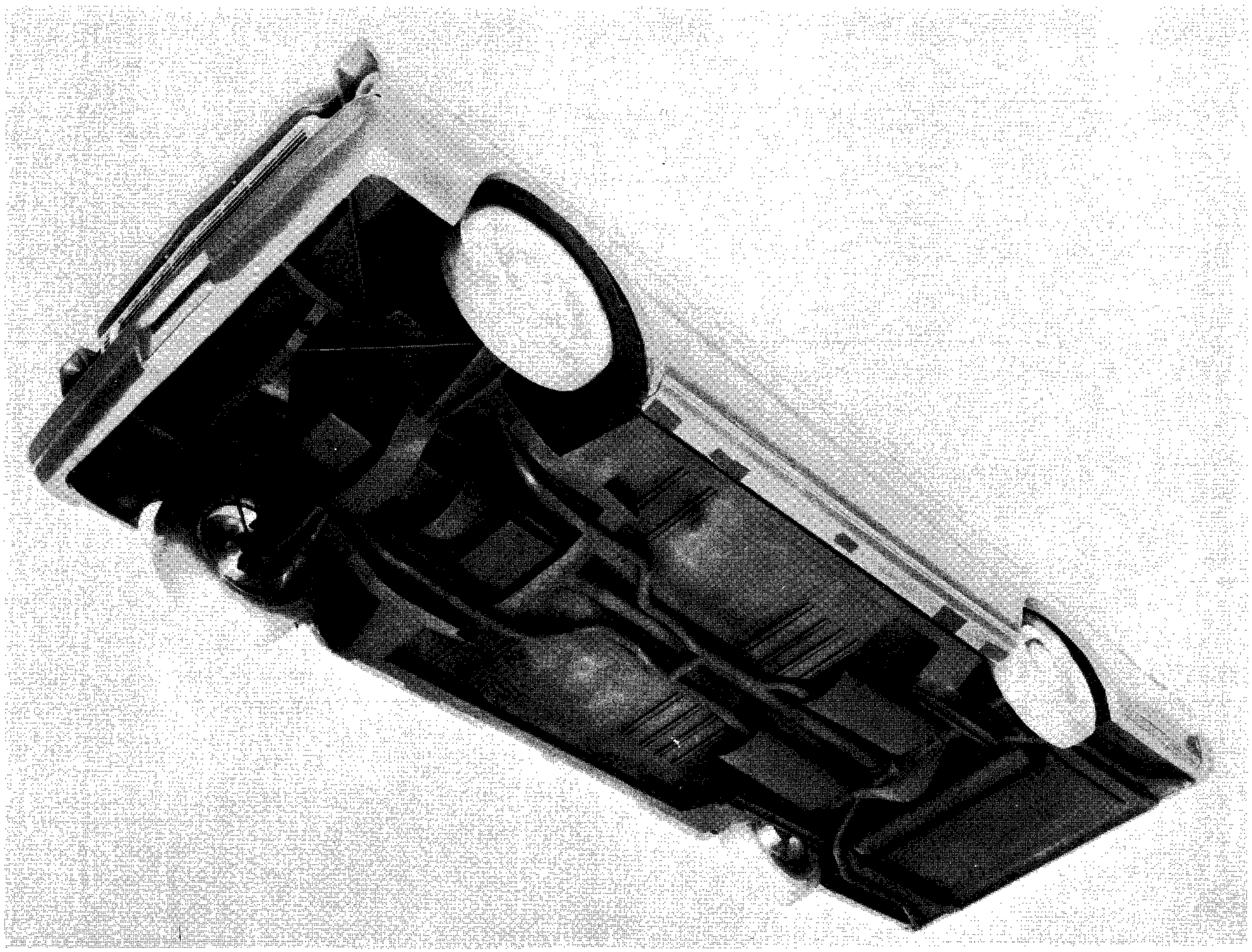


Figure 4.- Model with detailed underbody.

L-67-1075

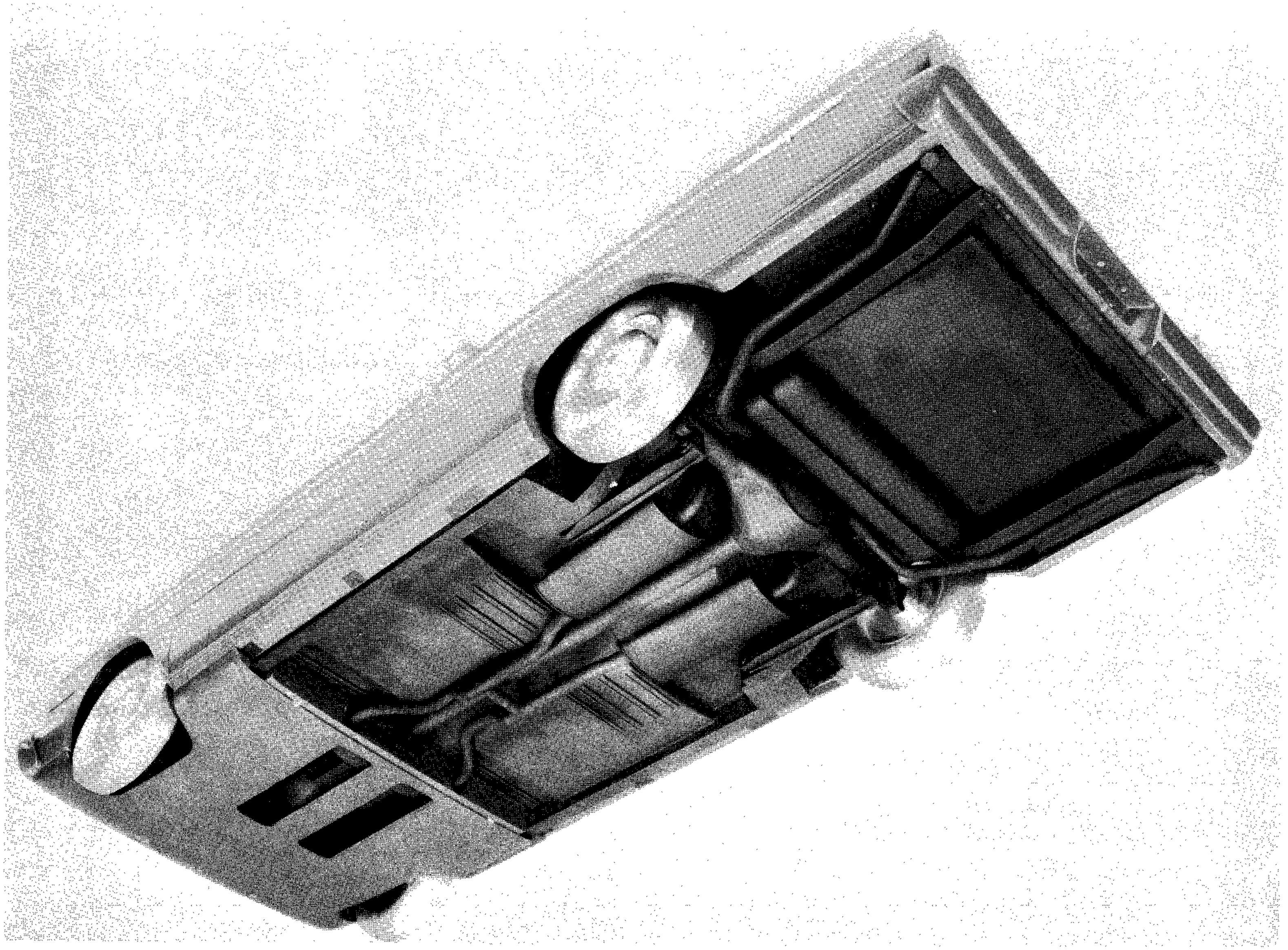


Figure 5.- Model with 1/3-flush underbody.

L-67-1076

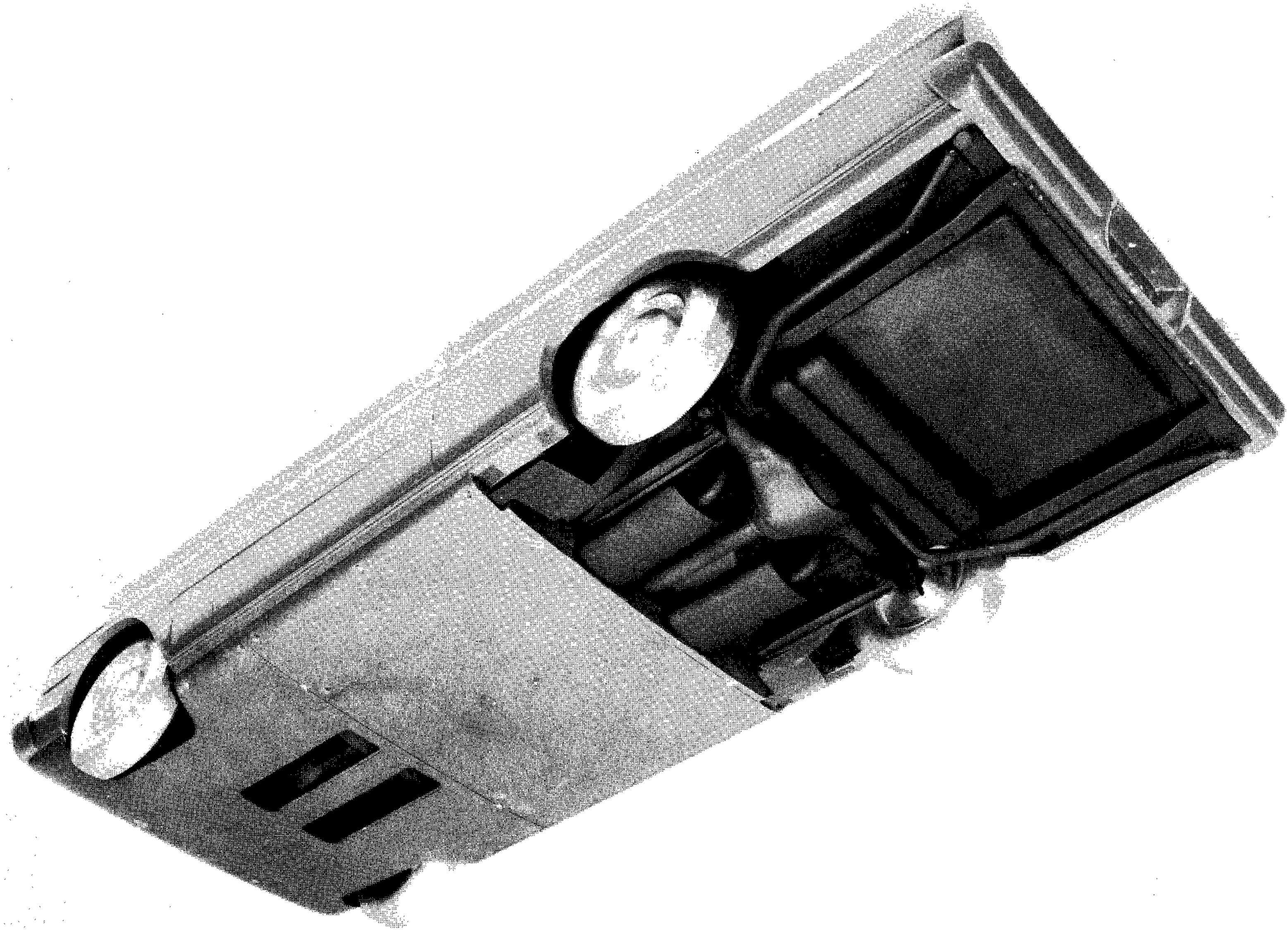


Figure 6.- Model with 2/3-flush underbody.

L-67-1077

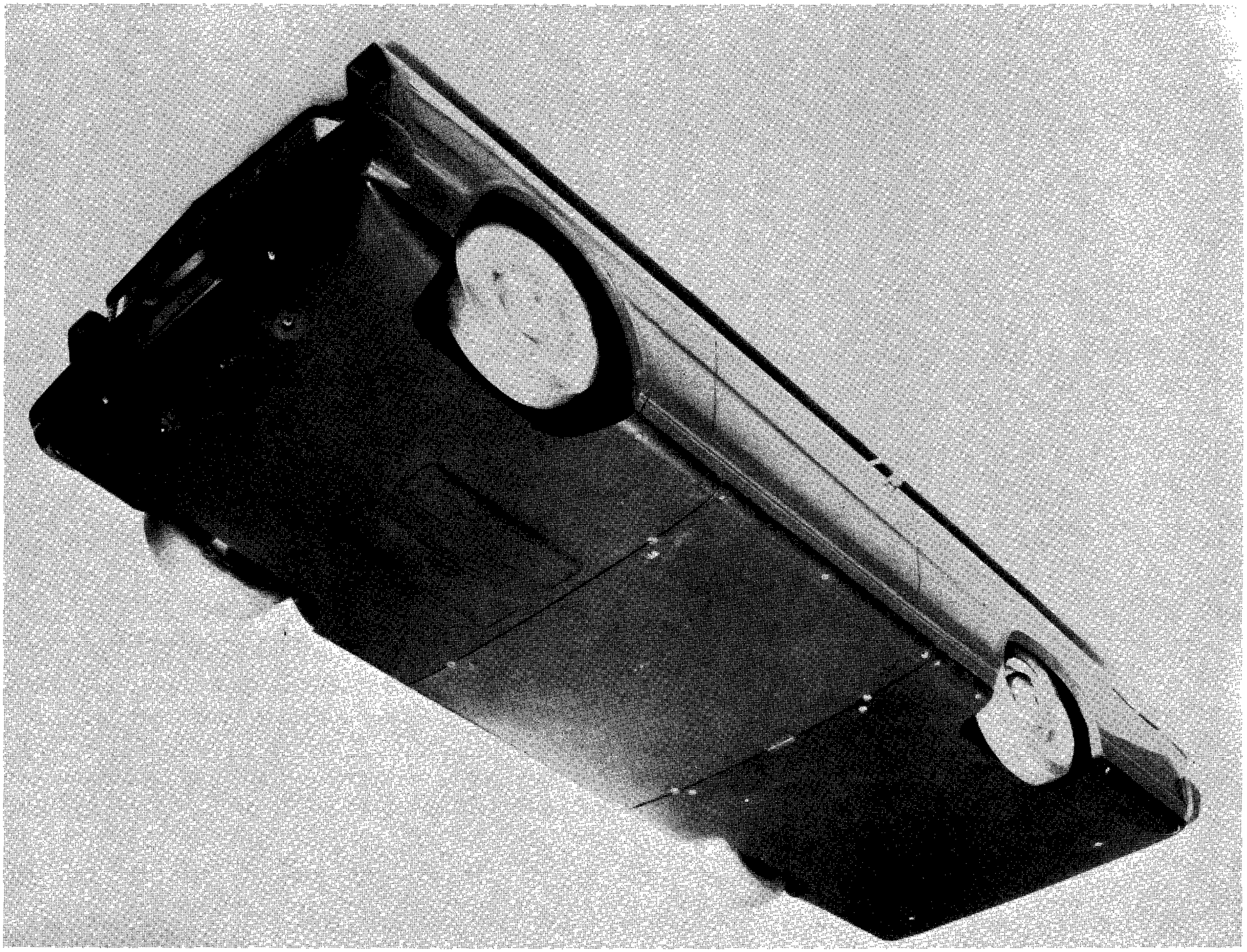


Figure 7.- Model with full-flush underbody. L-67-1078

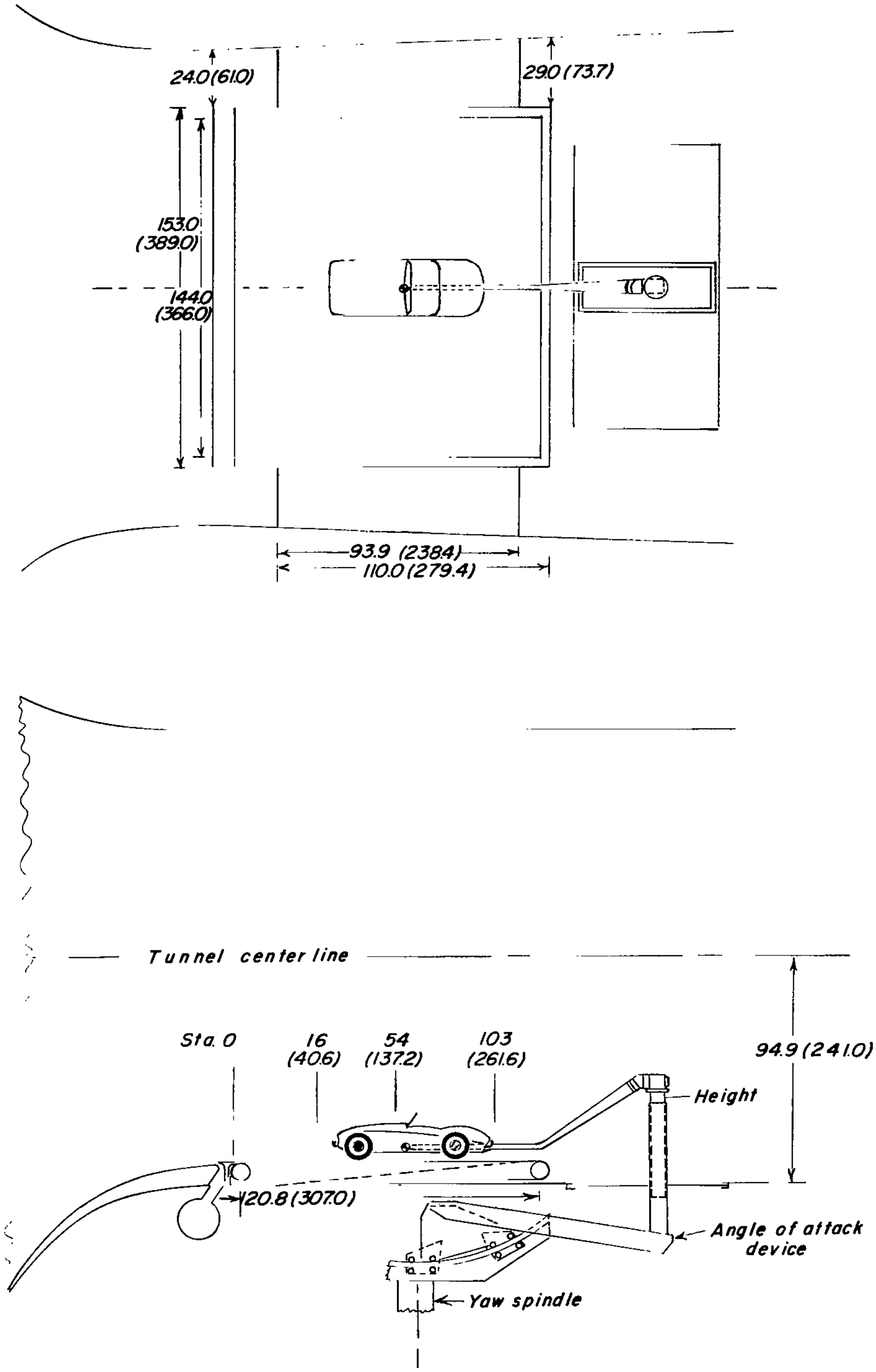
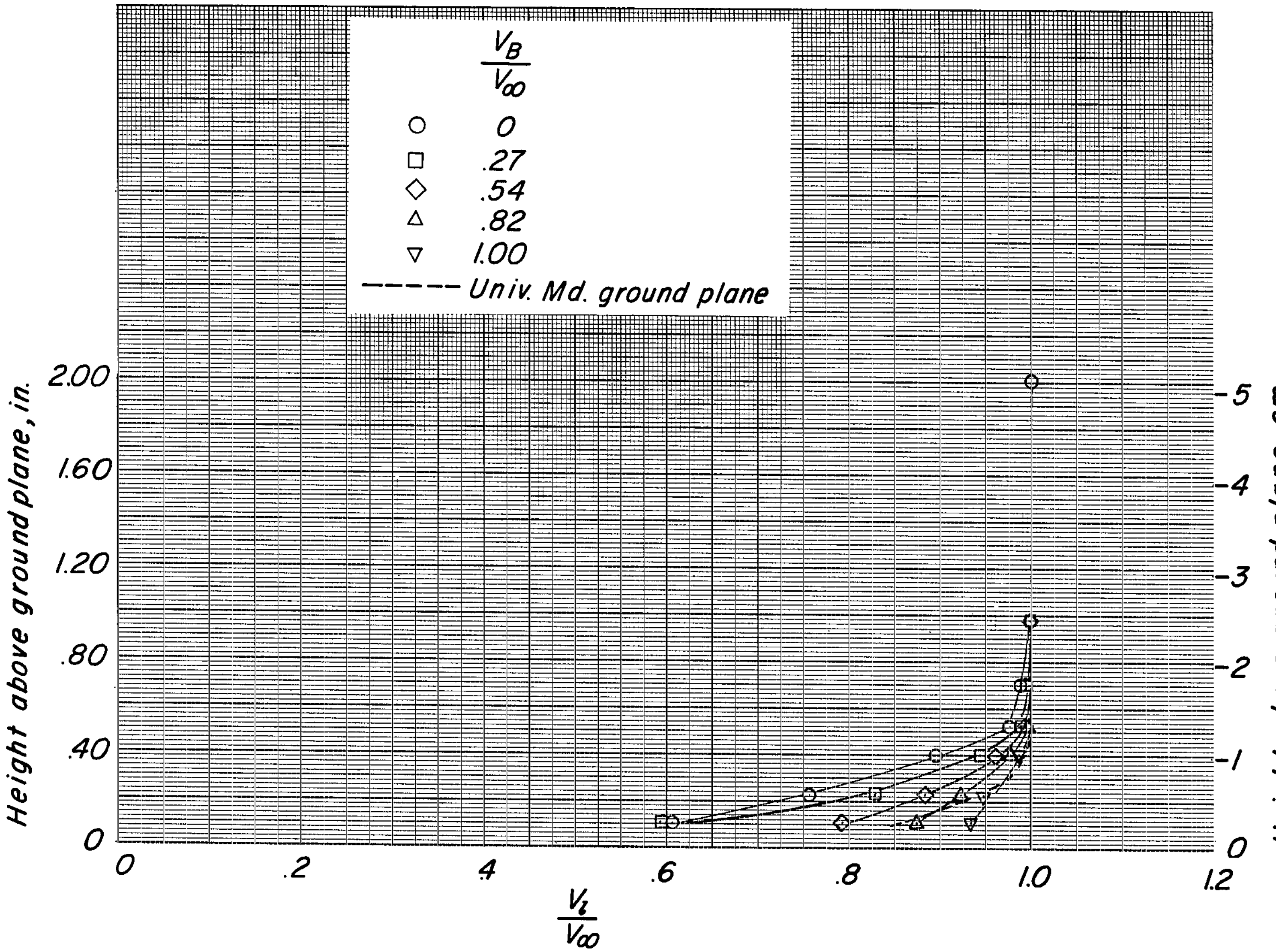
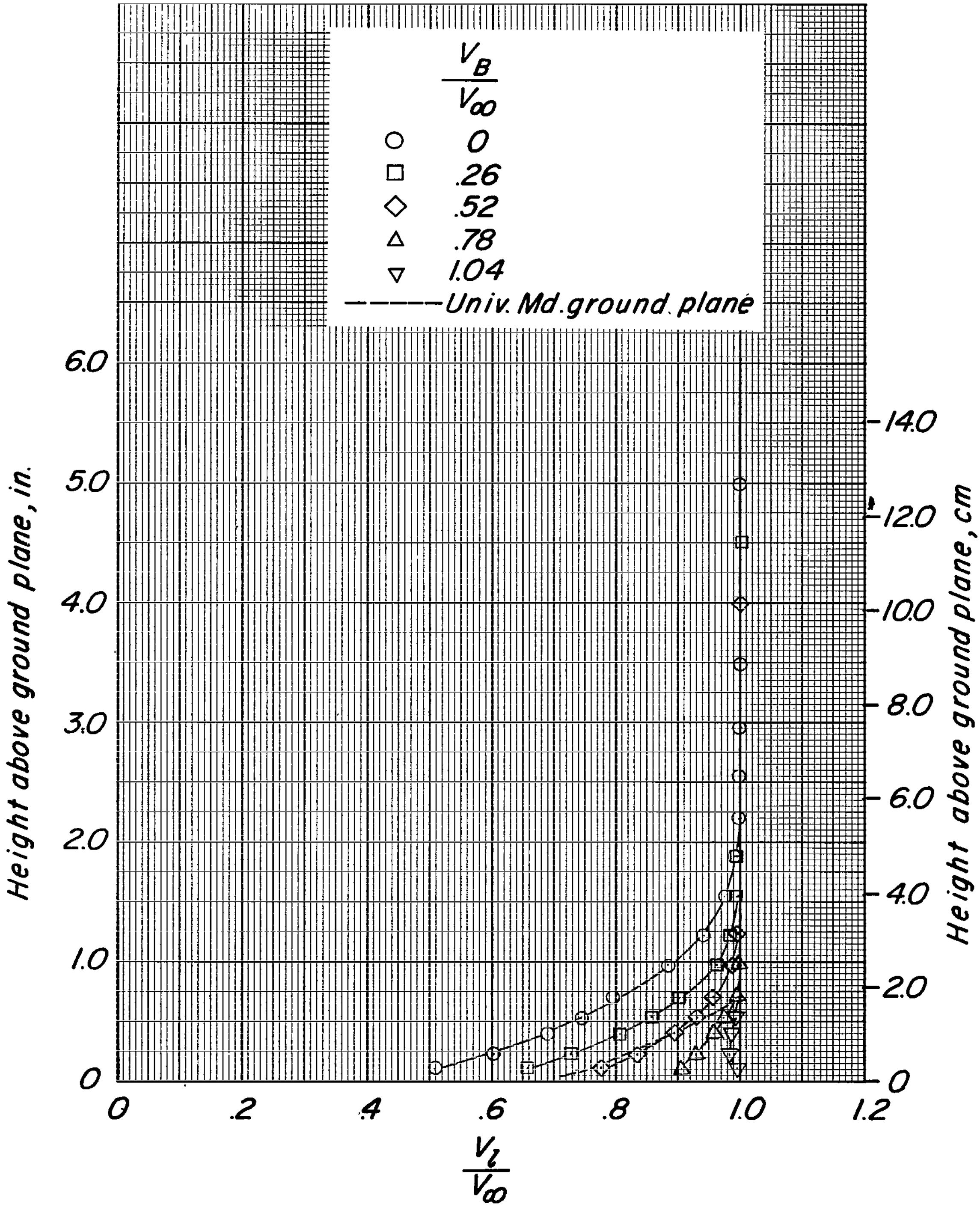


Figure 8.- Sketch of moving-belt ground-plane setup. Dimensions are given first in inches and parenthetically in centimeters.



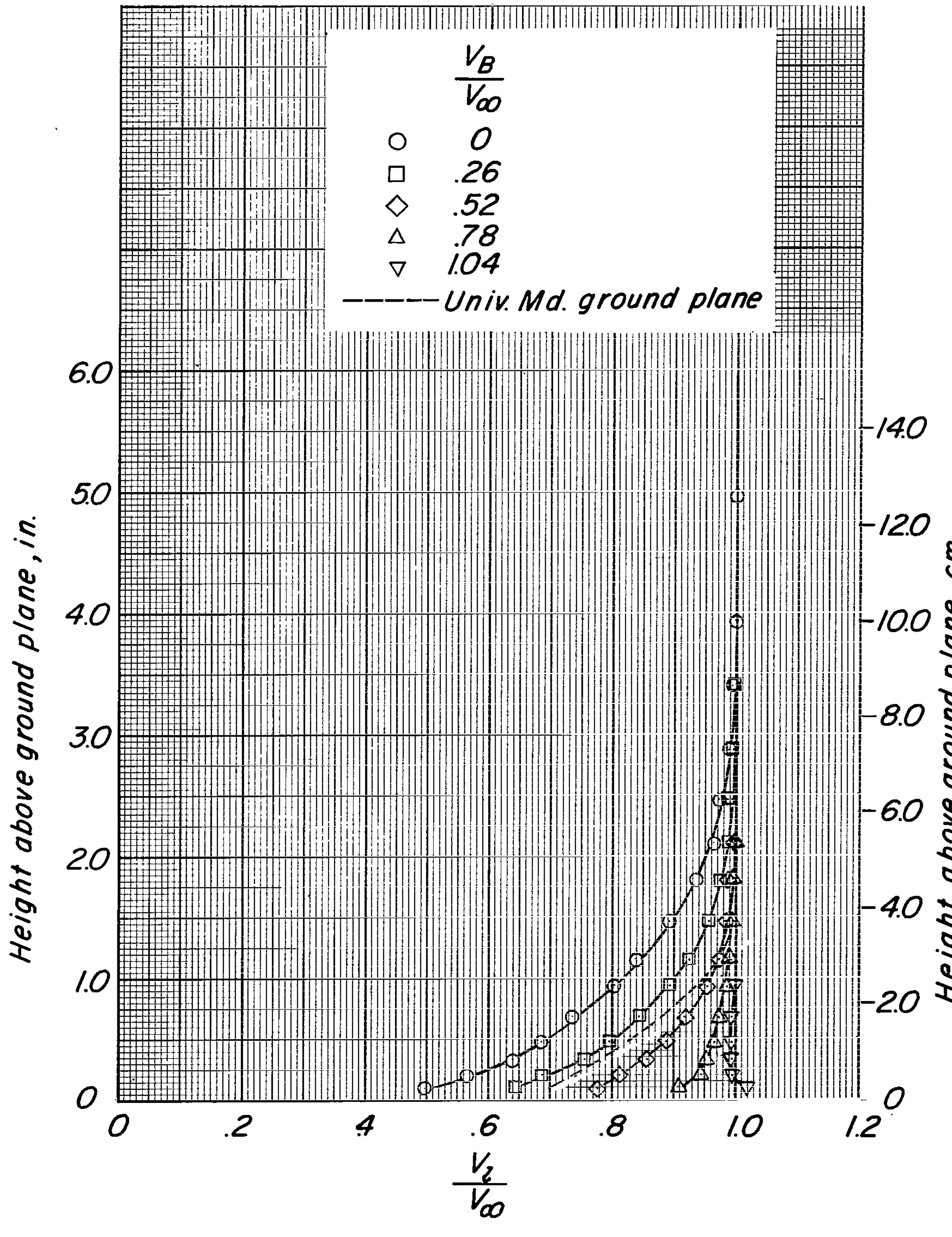
(a) Station 16.

Figure 9.- Boundary-layer profile over moving-belt ground plane. (Results over fixed ground plane in University of Maryland wind tunnel are shown for comparison.)



(b) Station 54.

Figure 9.- Continued.



(c) Station 103.

Figure 9.- Concluded.

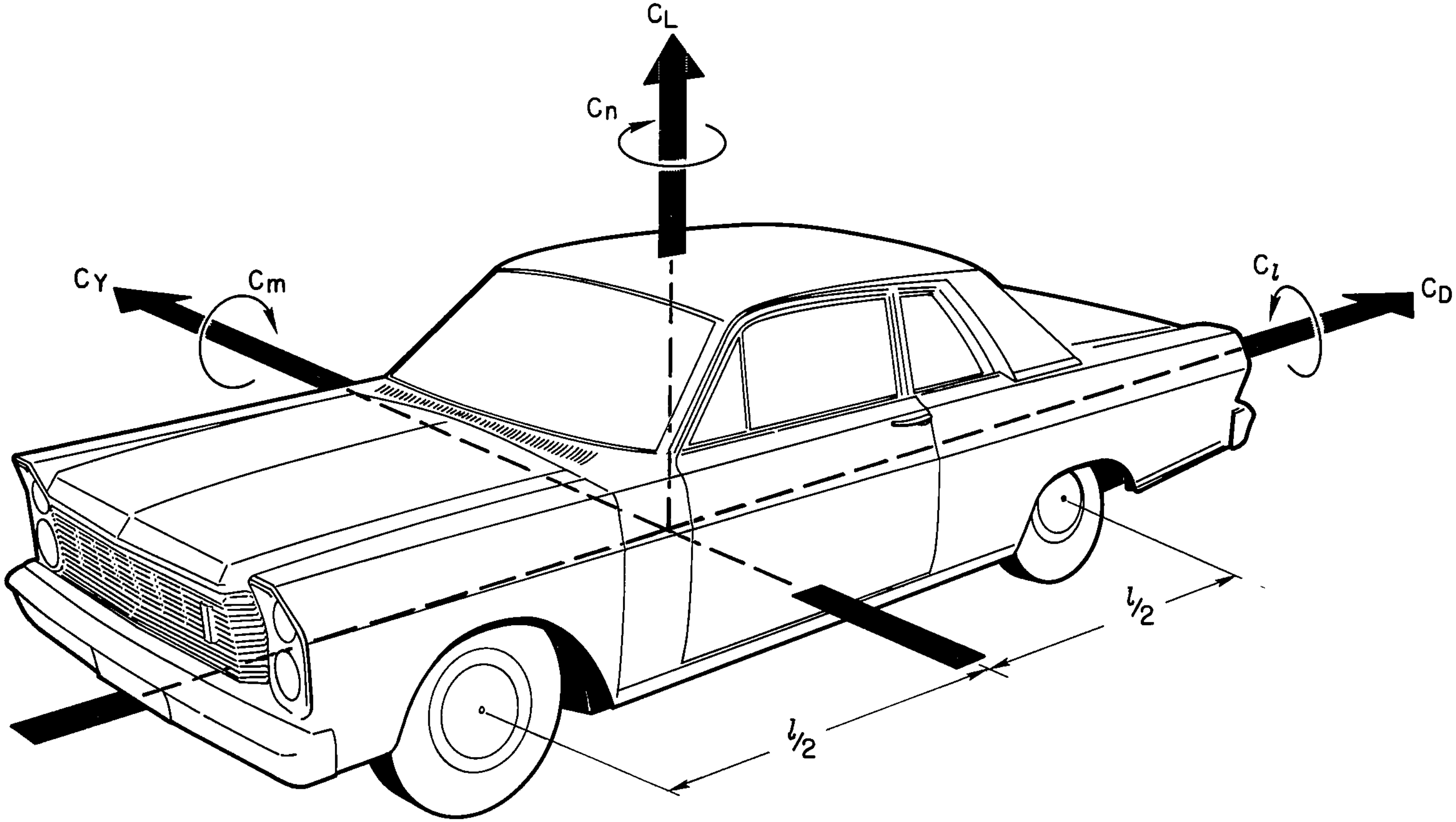
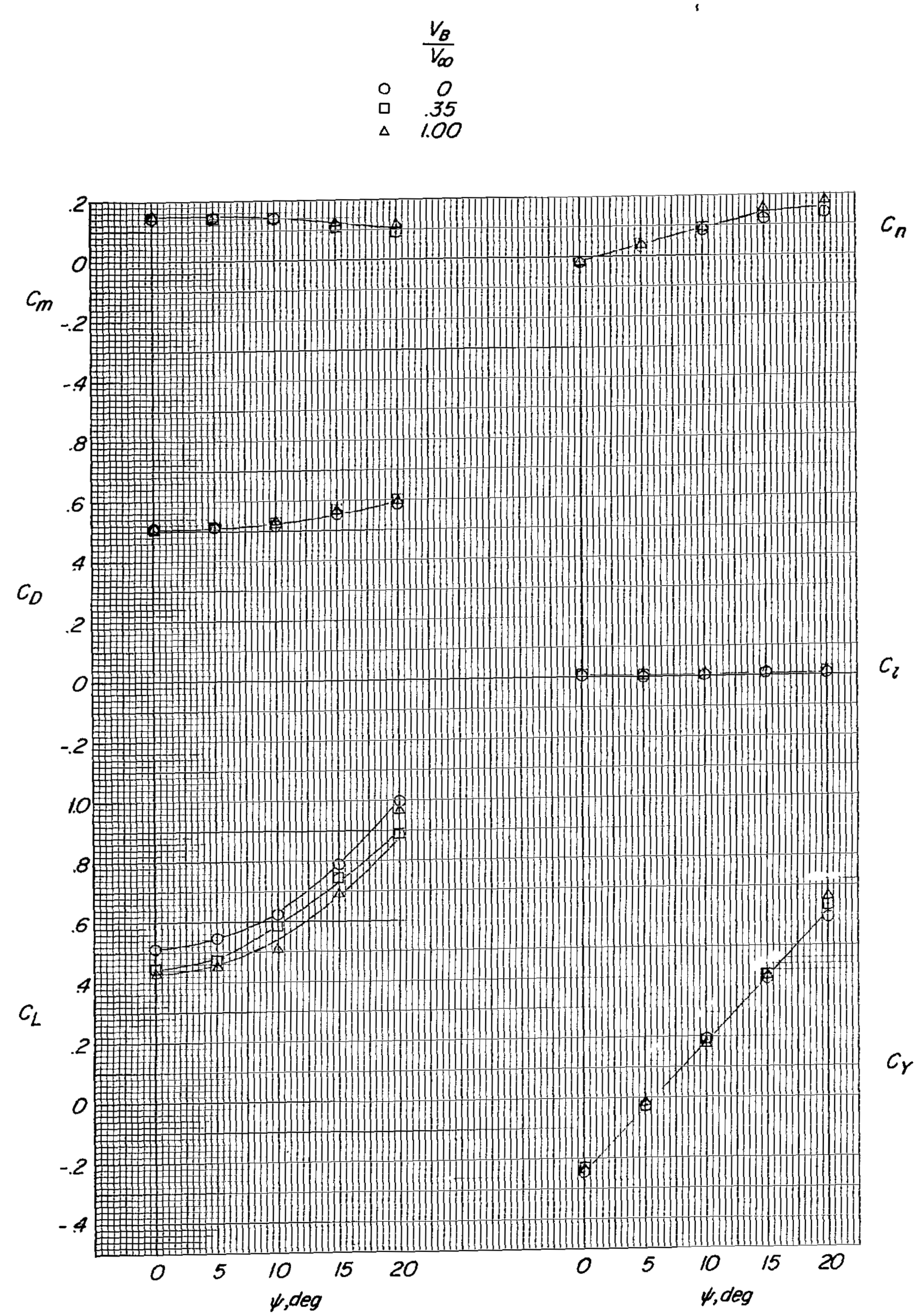
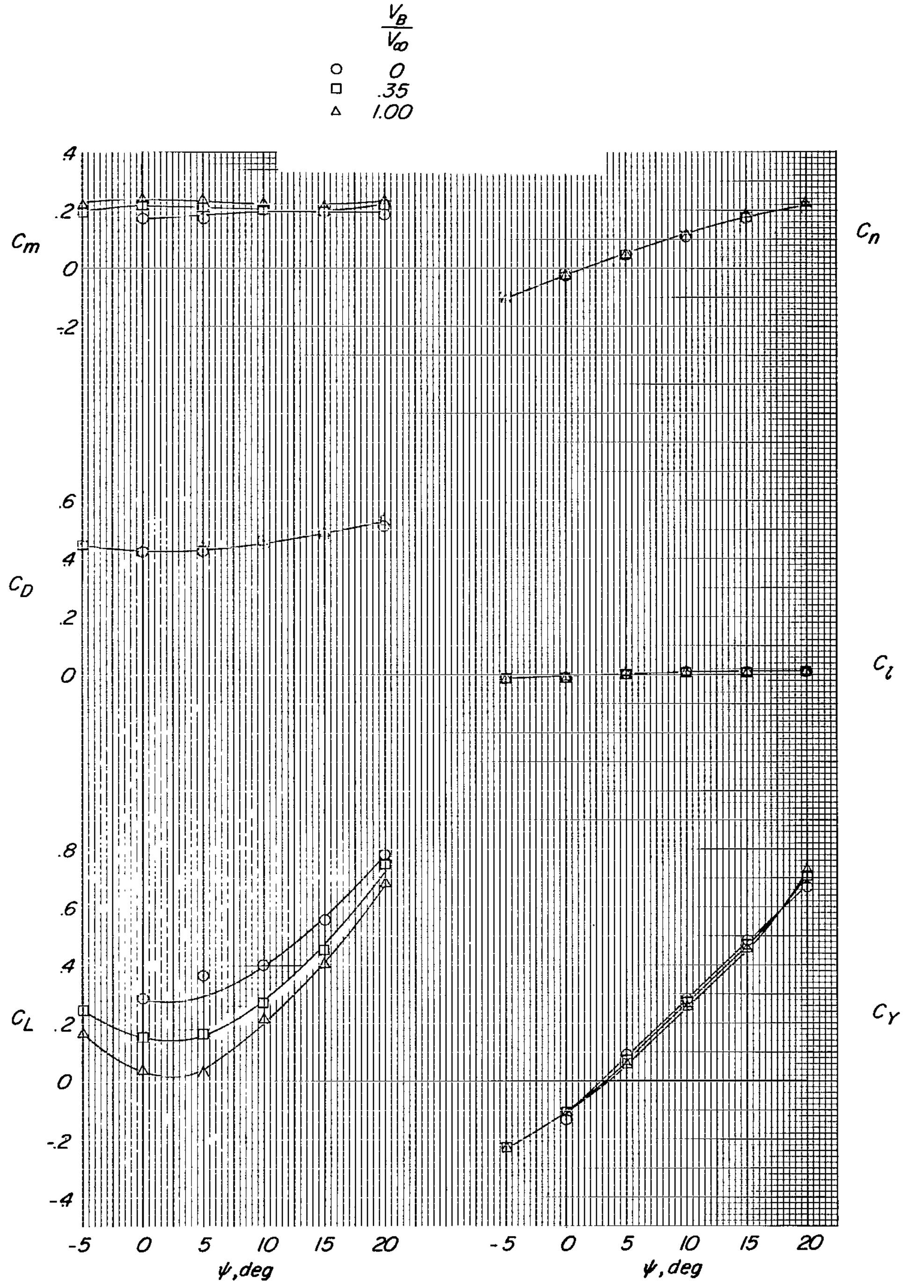


Figure 10.- Sketch showing axis system.



(a) Detailed underbody.

Figure 11.- Effect of belt velocity on the model aerodynamic characteristics. Wheel rpm = 0; radiator open.



(b) Flush underbody.

Figure 11.- Concluded.

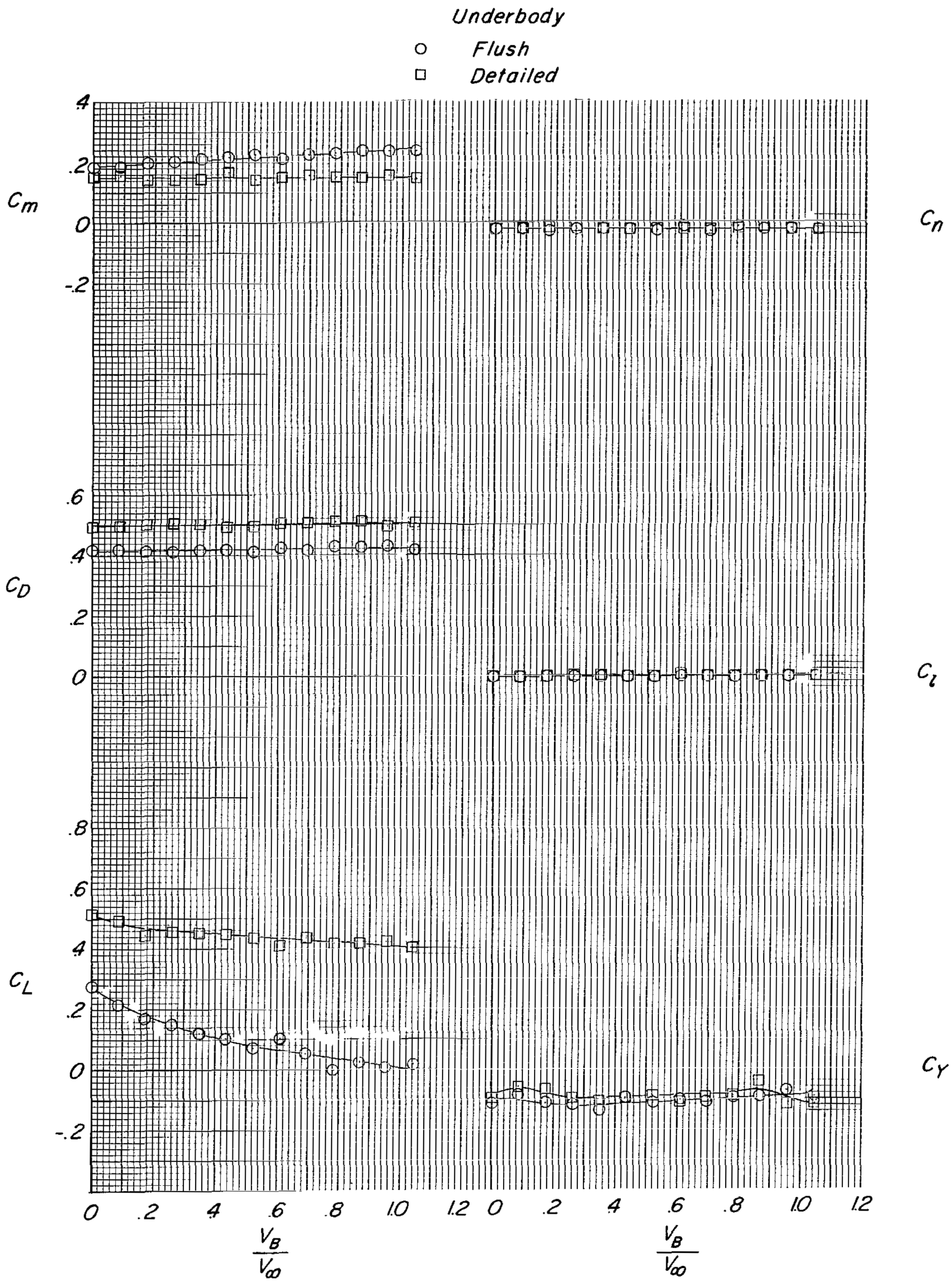


Figure 12.- Effect of varying belt velocity on the model aerodynamic characteristics. Wheel rpm = 0; radiator open; $\psi = 0^{\circ}$.

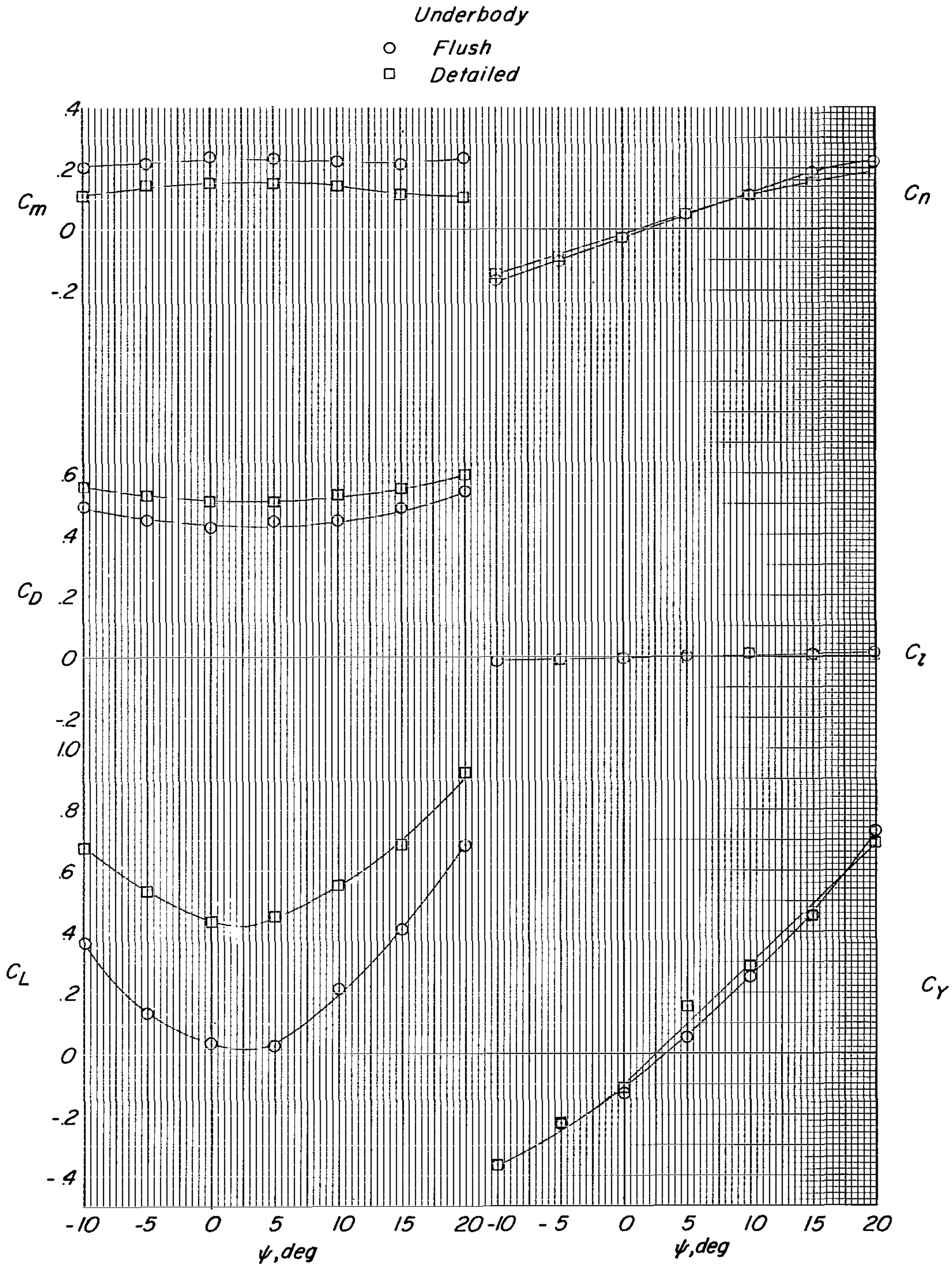
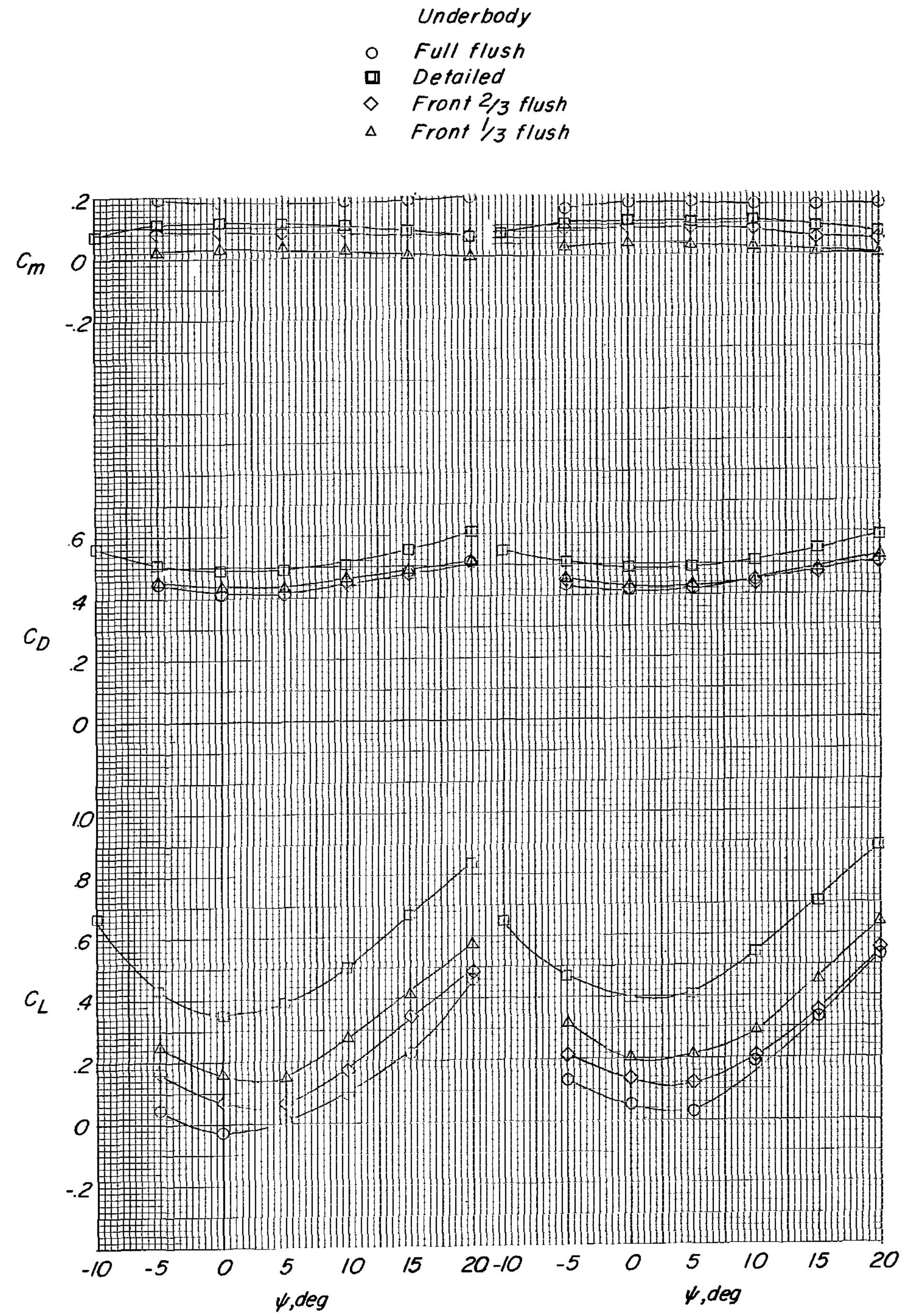


Figure 13.- Comparison of detailed- and flush-underbody aerodynamic characteristics. $V_B = V_\infty$; wheel rpm = 0; radiator open.



(a) $V_B = V_\infty$.

(b) $V_B = 0.347V_\infty$.

Figure 14.- Effect of flush fairing the underbody. Wheel rpm = 0; radiator closed.

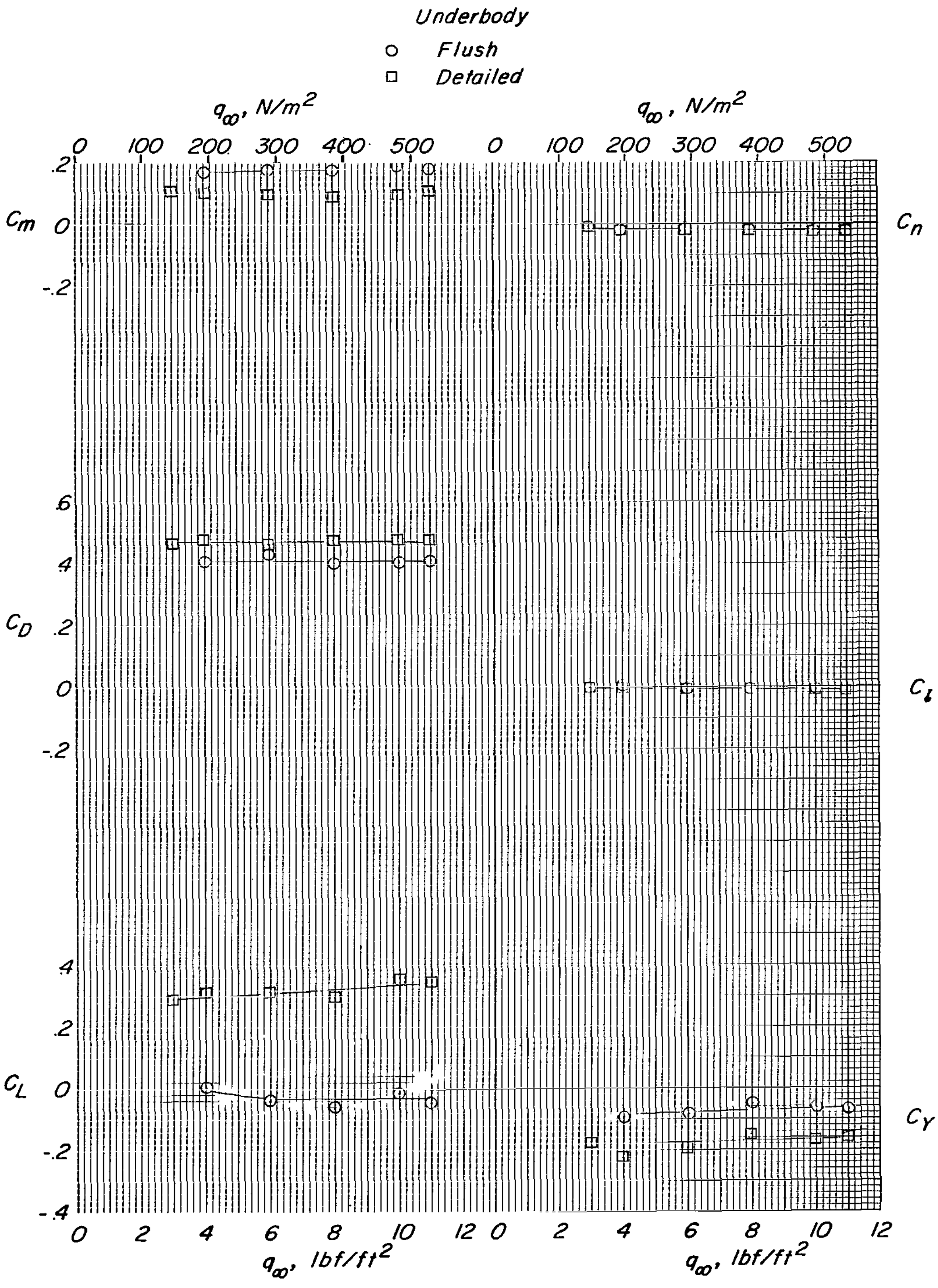


Figure 15.- Effect of Reynolds number on aerodynamic characteristics of model. $V_B = V_\infty$; radiator closed; $\psi = 0^0$.

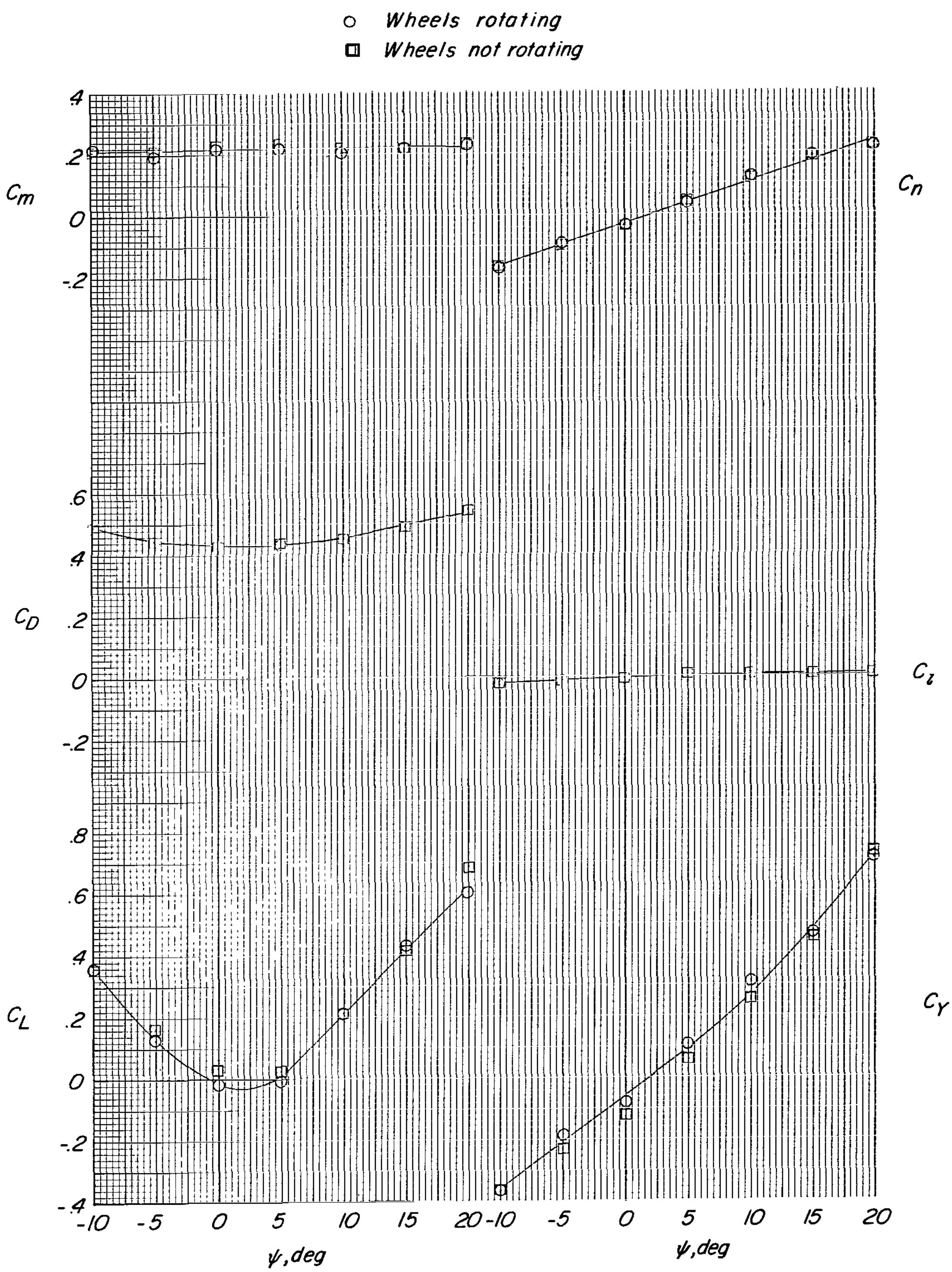
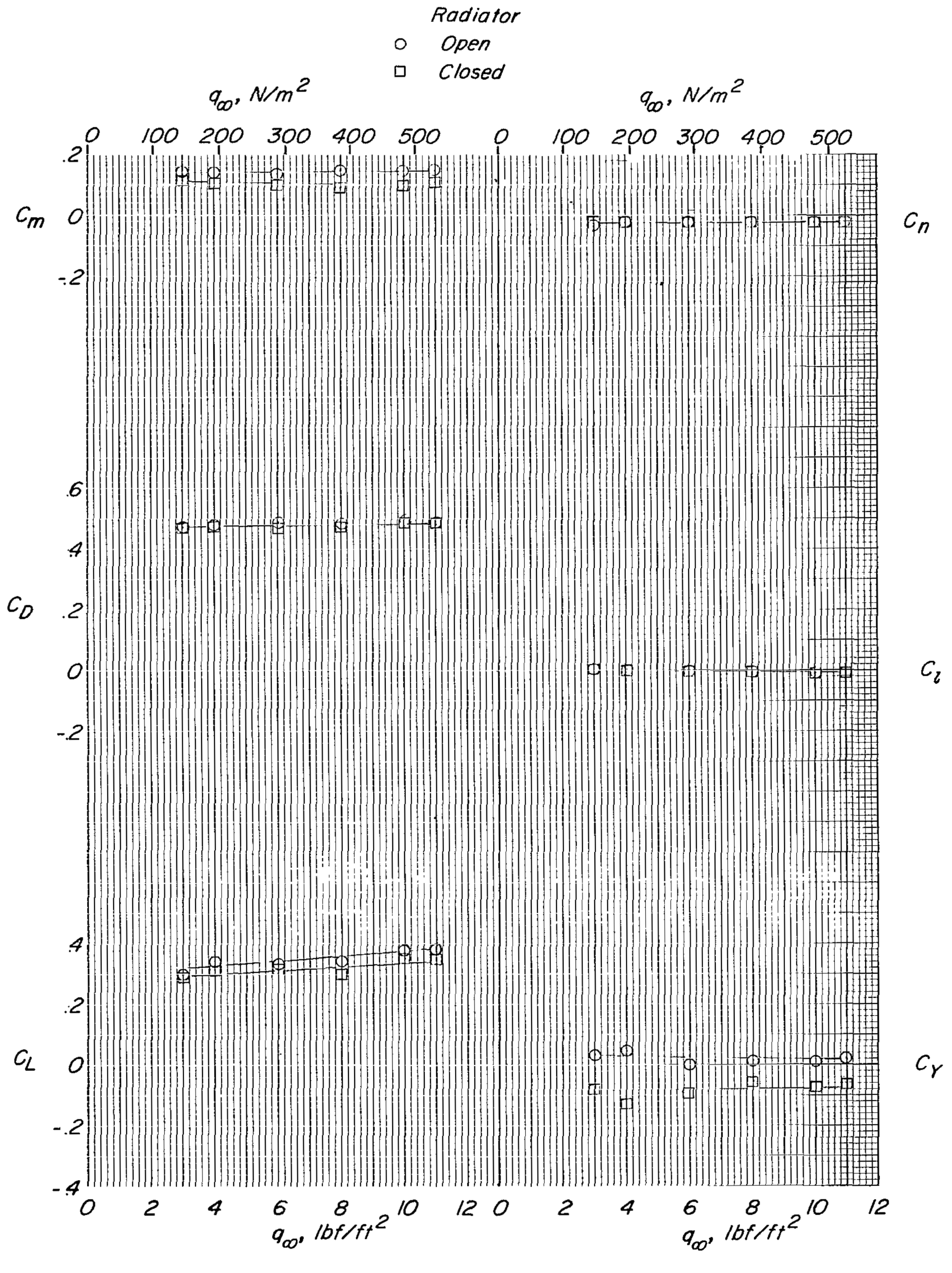
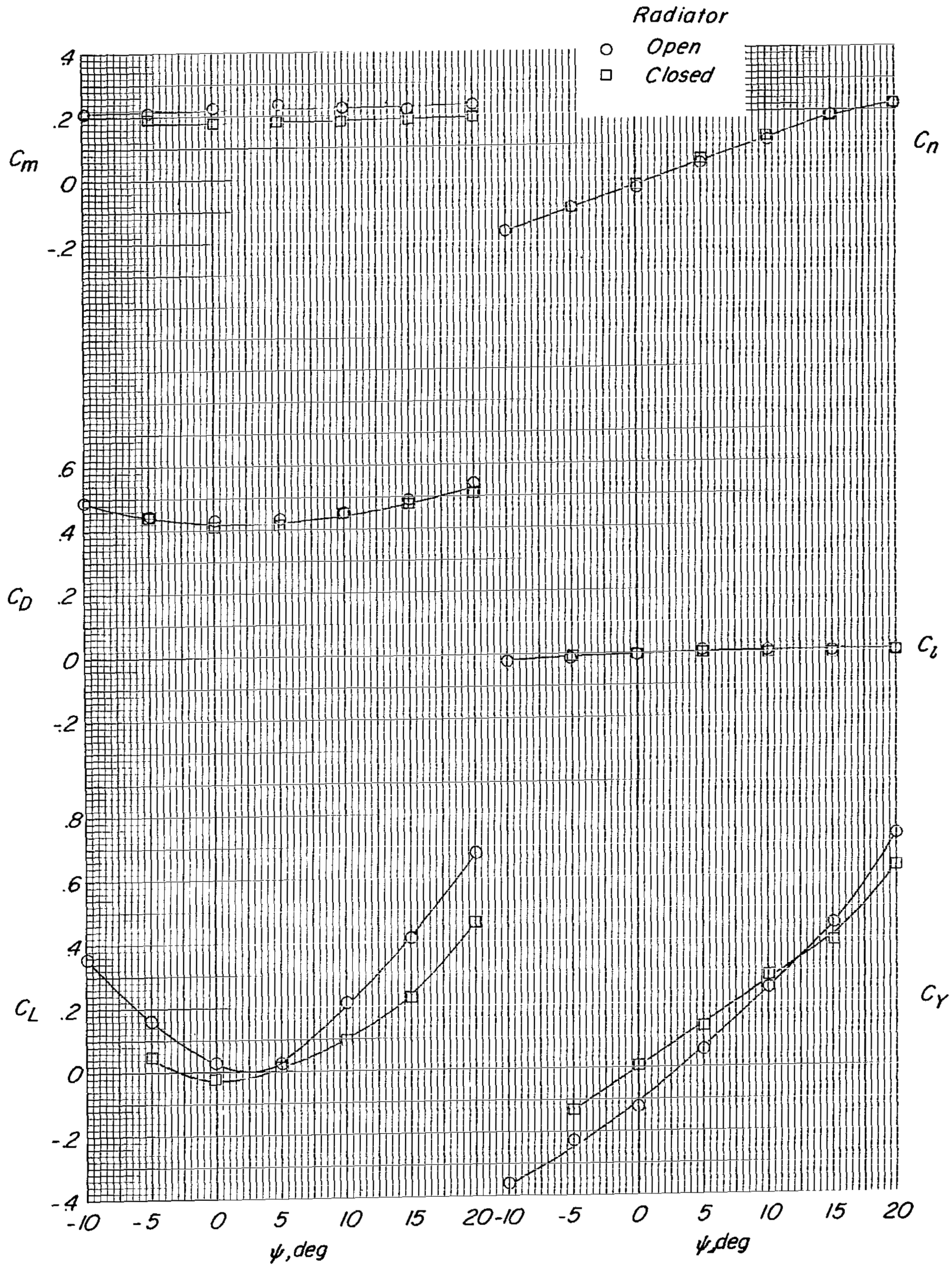


Figure 16.- Effect of wheel operation on model aerodynamic characteristics. $V_B = V_\infty$; flush underbody; radiator open.



(a) Detailed underbody, $\psi = 0^0$.

Figure 17.- Effect of cooling airflow on the aerodynamic characteristics. $V_B = V_\infty$.



(b) Flush underbody.

Figure 17.- Concluded.

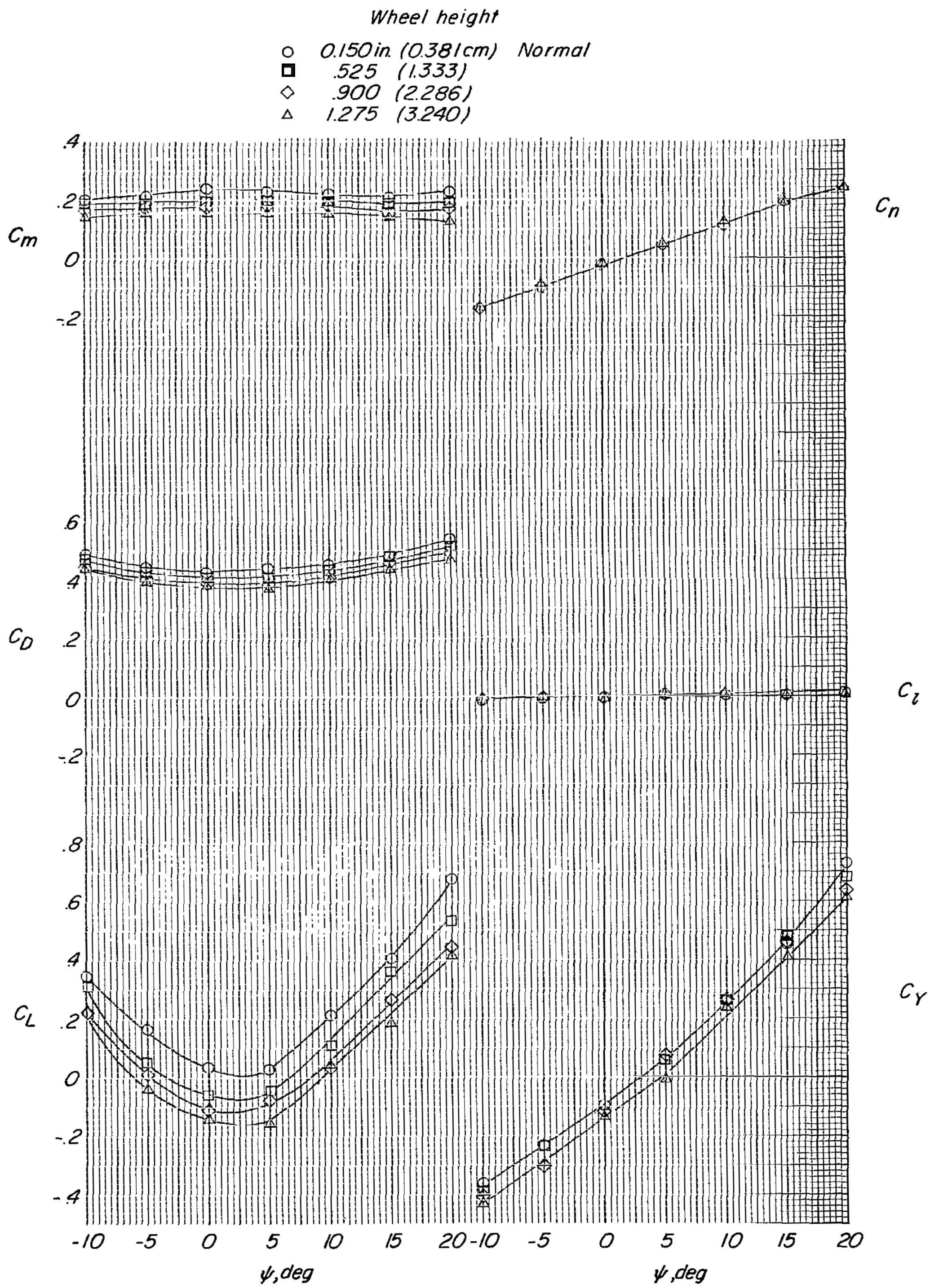


Figure 18.- Effect of varying the height of the model above the ground plane. Flush underbody; $V_B = V_\infty$; radiator open.

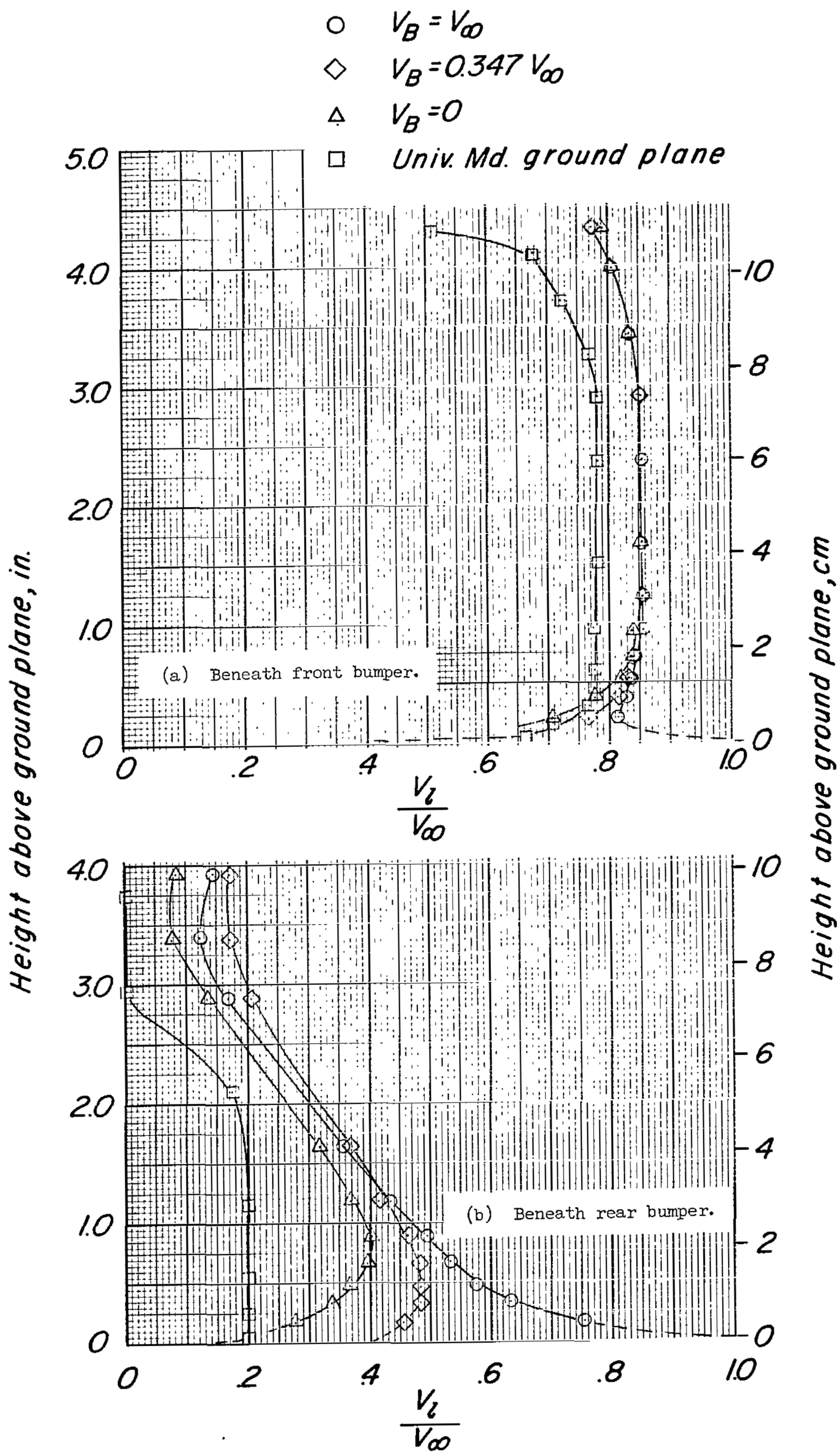
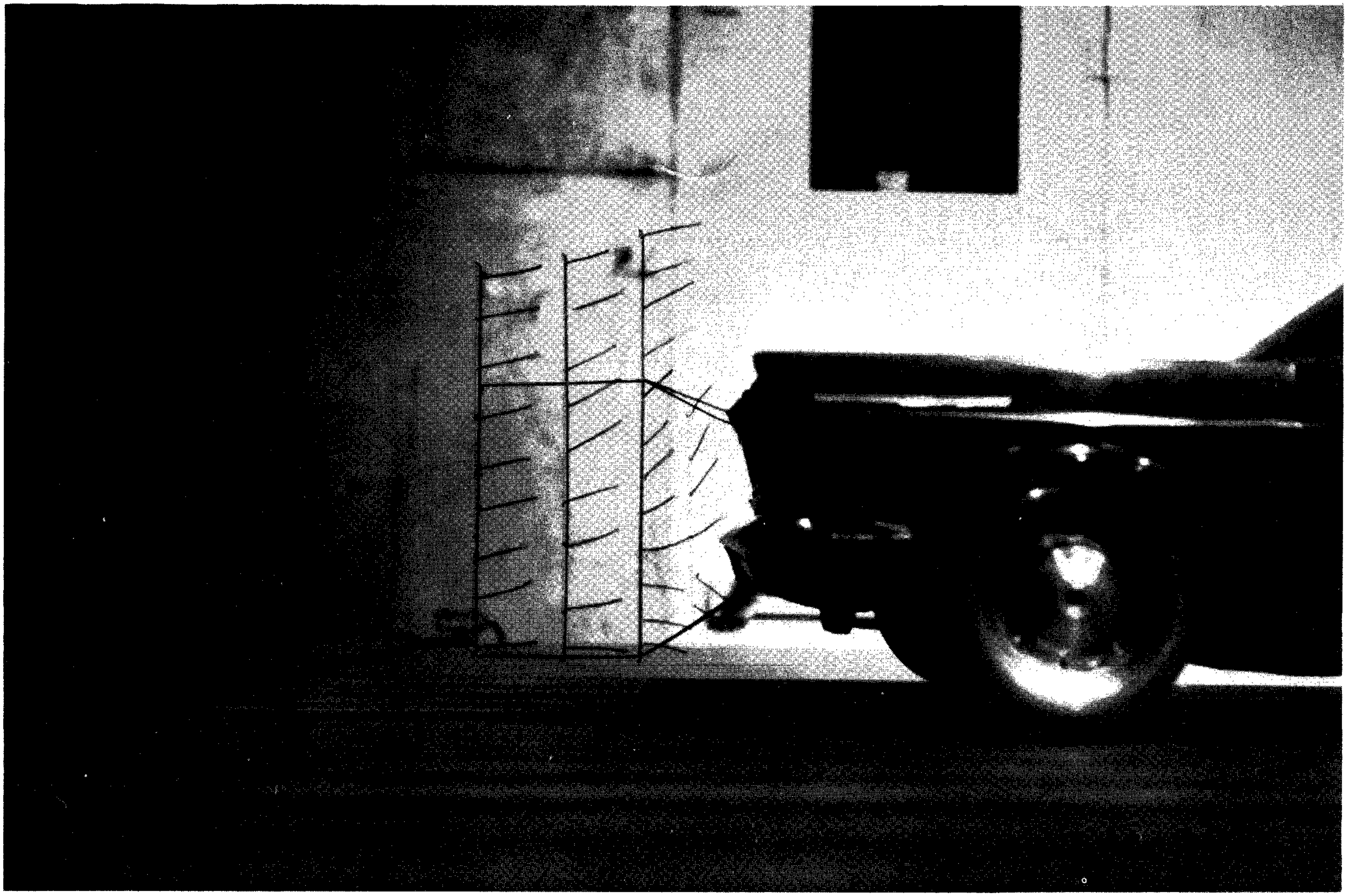
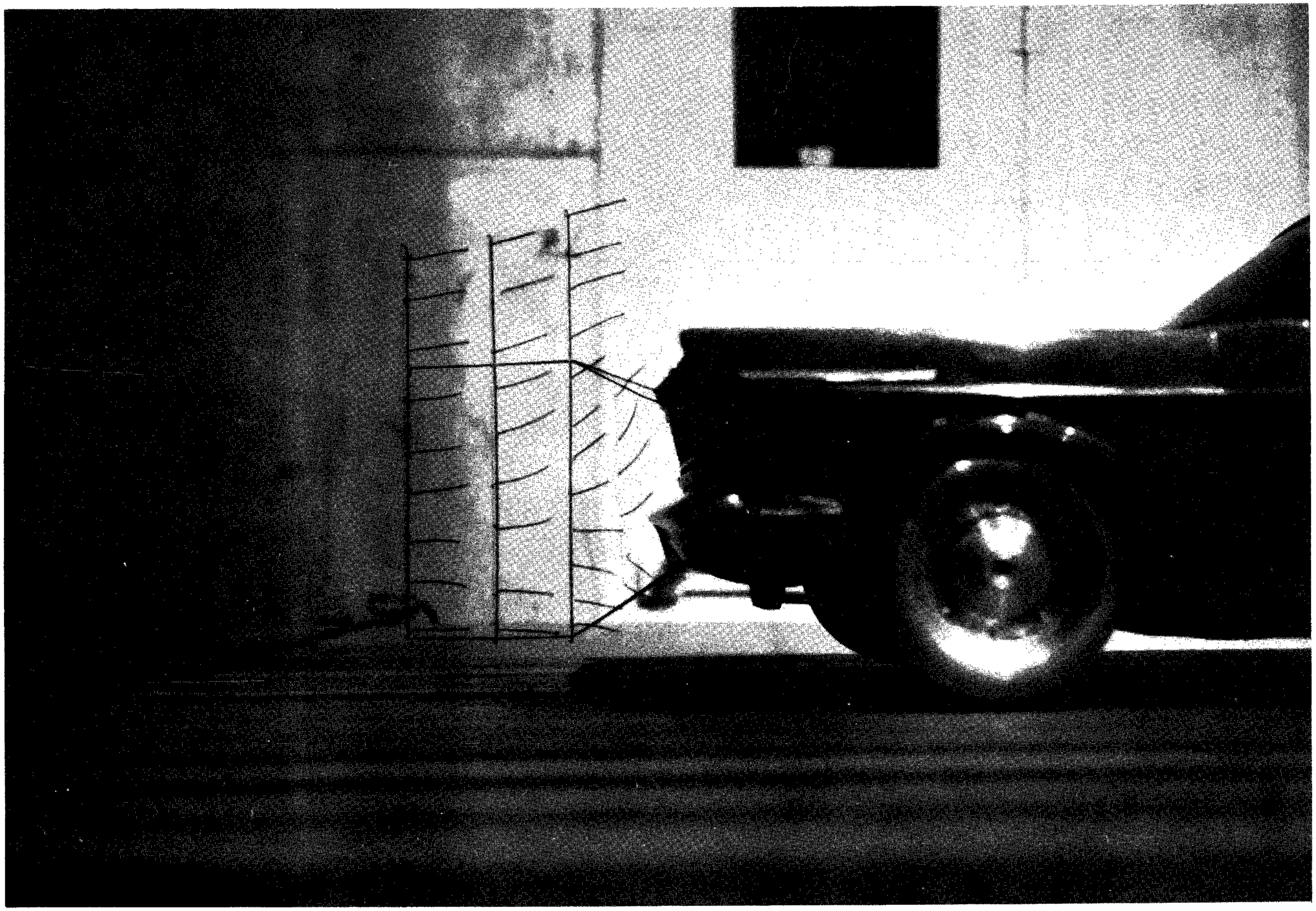


Figure 19.- Velocity distribution beneath automobile. Detailed underbody; radiator closed; $\psi = 0^0$.



(a) $V_B = 0.347V_\infty$; radiator open. L-67-1079

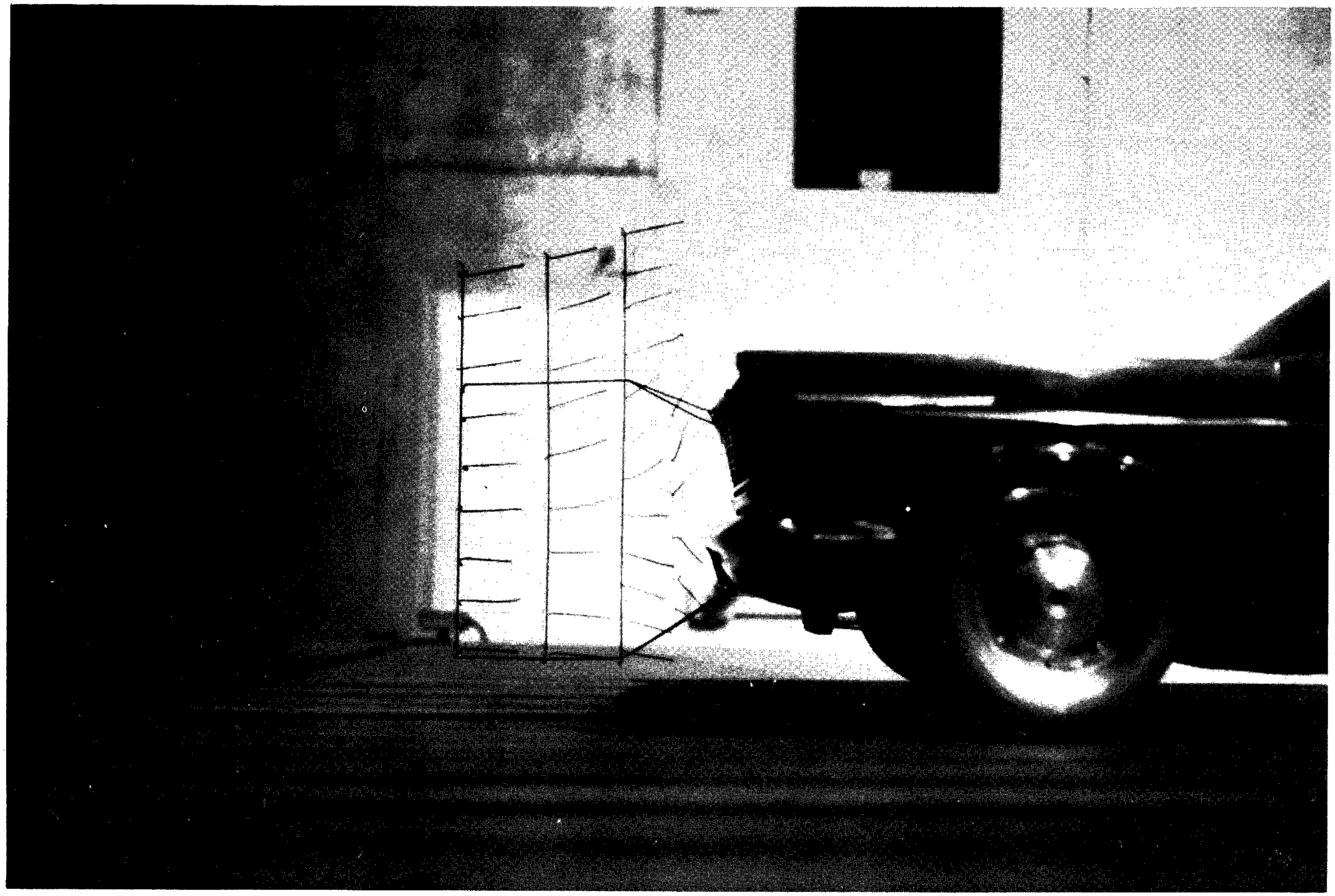
Figure 20.- Tuft study in front of car with grid at center line. Detailed underbody; $\psi = 0^o$.



L-67-1080

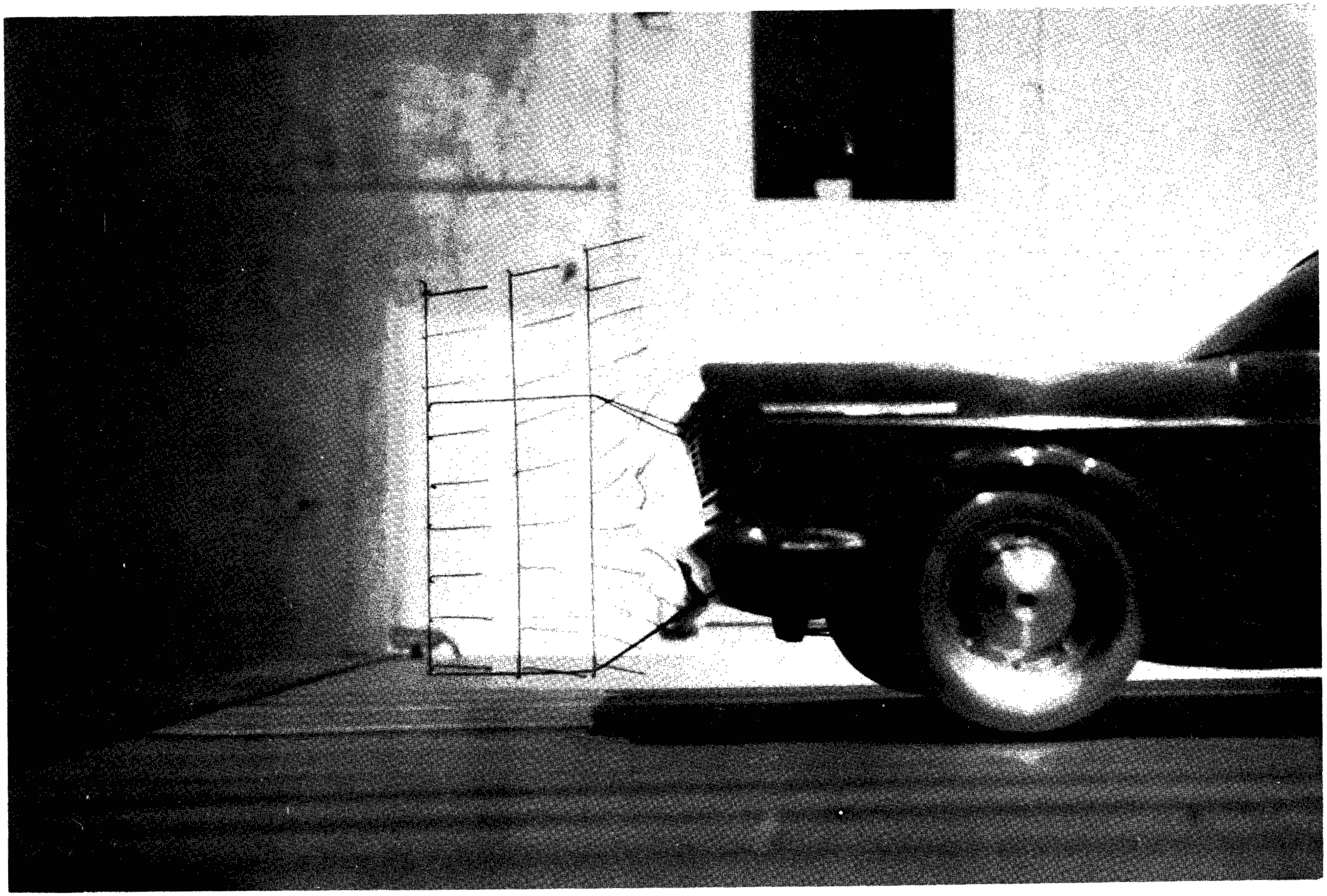
(b) $V_B = V_\infty$; radiator open.

Figure 20.- Continued.



(c) $V_B = 0.347V_\infty$; radiator closed. L-67-1081

Figure 20.- Continued.



L-67-1082

(d) $V_B = V_\infty$; radiator closed.

Figure 20.- Concluded.

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