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TECHNICAL NOTE

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EFFECTS OF GEOMETRIC VARIATIONS ON LIFT AUGMENTATION OF SIMPLE-PLENUM-CHAMBER GROUND-EFFECT MODELS

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TECHNICAL NOTE D-756

EFFECTS OF GEOMETRIC VARIATIONS ON LIFT AUGMENTATION OF SIMPLE-PLENUM-CHAMBER GROUND-EFFECT MODELS

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SUMMARY

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Considerable interest has been shown during recent years in ground-effect vehicles. Of the various types proposed, the simple-plenum-chamber vehicle has indicated promise because, although the lift augmentation obtainable appears to be less than that of an annular jet, it may be somewhat less complicated structurally.

The present investigation was undertaken to study the effects of some geometric variations upon lift augmentation of a simple plenum chamber within ground proximity. The variables included the ratio of inlet area to exit area, plenum-chamber depth, and entrance configuration. An optimum plenum-chamber depth appeared to be between 5 and 10 percent of the plenum-chamber diameter with a ratio of inlet diameter to plenum-chamber diameter of 0.15 for the range of plenum-chamber depths investigated. The most important effect of multiple inlets was the elimination of negative lift augmentation, which was experienced with single sharp-edged inlets, at intermediate heights. Installation of a flared inlet and a turning-vane assembly improved lift augmentation of a single-inlet configuration at intermediate heights.

INTRODUCTION

During recent years interest in ground-effect vehicles has become very great. These vehicles, which are supported by an air cushion, are limited to operation within ground proximity at a height which is usually a small percentage of the maximum dimension of the base portion of the vehicle. The desirable feature of an air-cushion vehicle is that it can travel over relatively unprepared land areas and is naturally amphibious. Of the various types proposed (for example, refs. 1 to 4), the simple-plenum-chamber configuration is of some interest because, although the lift augmentation obtainable appears to be less than that of an annular jet (ref. 1, fig. 6, p. 36), it may be less complicated structurally.

This investigation was initiated to determine the effects of some variations in plenum-chamber geometry on lift augmentation. Preliminary studies indicated that the ratio of plenum-chamber depth to plenum-chamber diameter was a parameter to be considered with respect to lift augmentation. In order to determine more completely these effects, several skirts and base plates were built to provide a series of test models. The results of the early part of the investigation pointed to the importance of the ratio of inlet diameter to plenum-chamber diameter. Test data were therefore obtained to study this effect of diameter ratio and also the effects of multiple inlets and inlet configurations.

L 1 3 5 2

SYMBOLS

D_e	plenum-chamber inlet diameter (equivalent diameter where a rectangular inlet is used, fig. 1(a)), $\sqrt{\frac{4}{\pi}\text{ Inlet area}}$, in.
D_p	plenum-chamber exit diameter, in.
g	acceleration due to gravity, 32.2 ft/sec^2
h	height of model above ground board (measured from bottom edge of skirt), in.
h_s	plenum-chamber depth, in.
L	measured lift, lb
K	orifice coefficient of gap between edge of plenum chamber and ground
wV_j	calculated momentum lift, lb
w	measured mass flow, slugs/sec
p	ambient pressure, lb/sq ft
p_{static}	static pressure measured at ground-board orifices, lb/sq ft
p_t	total pressure in plenum-chamber inlet, lb/sq ft
R	gas constant, $\frac{\text{ft-lb}}{\text{lb-}^{\circ}\text{R}}$
T	stagnation temperature (measured in the plenum chamber), $^{\circ}$R

V_j calculated jet velocity (isentropic expansion to ambient pressure is assumed), $\sqrt{\frac{2\gamma}{(\gamma - 1)} RTg\left[1 - \left(\frac{p}{p_t}\right)^{\frac{\gamma-1}{\gamma}}\right]}$, ft/sec

γ ratio of specific heats (Air = 1.4)

ρ mass density of air, slugs/cu ft

MODEL AND APPARATUS

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A sketch of the model and apparatus is presented in figure 1(a) and a photograph of the general test arrangement is shown as figure 1(b). The plenum-chamber models were affixed to and supported by an air supply chamber which in turn was secured to a strain-gage balance system, so designed as to allow the operating air to pass directly through the structure. The models were supplied with air from the supply chamber through interchangeable wooden nozzles. The plenum-chamber models consisted of circular plywood plates to which were attached various cylindrical aluminum skirts. For the multiple inlet configurations, the models were modified to include a distribution chamber as shown in figure 1(c). Also tested was a turning-vane-type plenum-chamber entrance designed to fill more effectively the plenum chamber with air. A sketch of this device, which was of welded aluminum, is shown in figure 1(d). All models were sealed to prevent leakage. The plywood ground board for all tests was suitably braced to prevent distortion.

The total pressure of the air in the model inlet and static-pressure distribution on the ground board were measured with a manometer. The mass flow of air to the model was measured by means of a standard sharp-edged-orifice type of flow meter. The total pressure at the inlet was held constant throughout the ground-board height range for any one model by varying mass flow, but the value of this total pressure was not held constant for all models. Calibrations of the strain-gage balance indicated no effect of internal pressure.

RESULTS AND DISCUSSION

The results of the investigation are presented in terms of lift augmentation as a function of model height in figures 2 to 7. A distribution of pressure on the ground board is shown in figure 8. As a matter of interest the experimental results are compared with incompressible simple-plenum-chamber theory for lift augmentation. A brief discussion of this theory precedes the discussion of the results.

The plenum chamber is assumed to be a pressure vessel from which air is leaking between the edge and the ground. Under this assumption the lift for a circular chamber is given by the following expression:

$$L = \left(p_t - p\right)\frac{\pi}{4} D_p^{\,2} \tag{1}$$

The momentum of the air escaping between the plenum chamber and the ground is equal to the thrust that would be obtained in a perfect nozzle at the same pressure - that is,

$$\text{Thrust} = wV_j = \rho\pi D_p hKV_j^{\,2} \tag{2}$$

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where K is the orifice coefficient of the gap between the edge of the plenum chamber and the ground. If incompressible flow conditions are assumed, the exit velocity is

$$V_j = \sqrt{\frac{\left(p_t - p\right)}{\rho/2}} \tag{3}$$

Substituting equation (3) into the expression for thrust (eq. (2)) yields

$$wV_j = 2\left(p_t - p\right)\pi D_p hK \tag{4}$$

Then, if equation (1) is divided by equation (4), the lift augmentation becomes

$$\frac{L}{wV_j} = \frac{1}{8Kh/D_p} \tag{5}$$

Effect of Relative Inlet Diameter and Plenum-Chamber Depth

The results obtained with a series of plenum-chamber models in which D_e/D_p and h_s/D_p were systematically varied are presented in figures 2 and 3, respectively. The orifice effect of the gap between the edge of the plenum chamber and the ground causes the development of an appreciable pressure in the plenum chamber which, in turn, produces a lift augmentation. The data of figure 2, in which D_e/D_p was varied while h_s/D_p was held constant at 0.10, show that

L/wV_j increased when D_e/D_p was increased. Also, it should be noted that all the values of lift augmentation of the simple-plenum-chamber models fell below the theoretical values for $K = 1.0$. This latter condition was probably due to a secondary flow induced within the plenum chamber, which is not considered in the simple theory. For either a simple plenum chamber or a flat plate (plenum chamber with $h_s = 0$), at some distance above the ground there is a secondary flow induced by entrainment action of the primary air flowing outward along the ground as shown in the following sketch:

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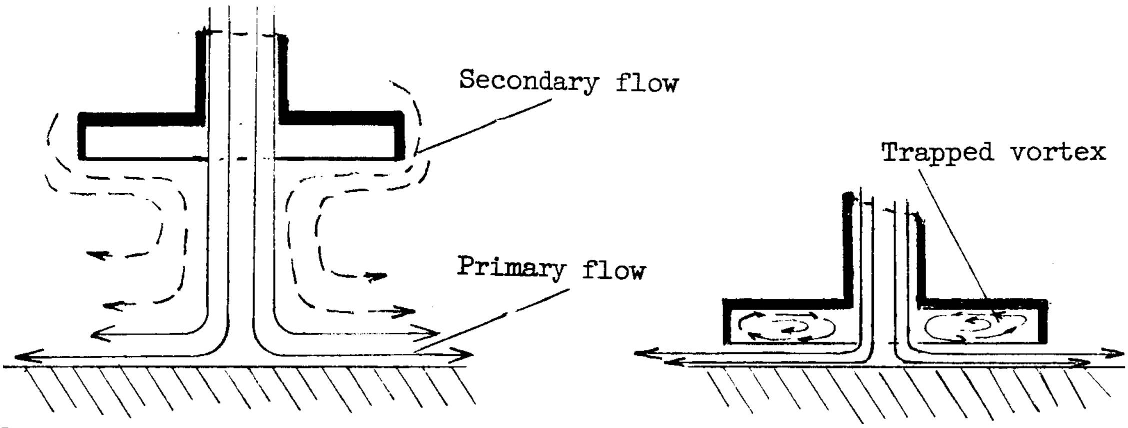

When the plate or plenum chamber is brought close enough to the ground so that the primary flow fills the gap between the ground and the edge of the plate or plenum chamber, the secondary flow changes to a trapped vortex between the plate and the primary flow. The effect of the trapped vortex is to reduce the lift augmentation considerably from that predicted by theory. Apparently, the strength of this vortex and the augmentation obtained are strongly a function of the geometry.

The rectangular nozzle represented by the supply chamber (plate, skirt, and insert removed) was superior to any simple-plenum-chamber model which had a sharp-edged inlet and produced a lift augmentation slightly greater than that predicted by theory for $K = 1.0$. With this simple nozzle, $D_e/D_p = 1.0$, the trapped vortex is eliminated. A rather extensive study of the flows experienced by a series of plenum-chamber models was reported in reference 4.

The effect of changing plenum-chamber depth is shown in figures 3(a) and 3(b); the data indicate that maximum lift augmentation (for $D_e/D_p = 0.15$) occurs at depths between 5 and 10 percent of the plate diameter. A cross plot of the data of figure 3 is shown in figure 4. This figure more readily shows the effects of the secondary flow when the plate is brought closer to the ground by decreasing plenum chamber depth while the model height, as defined by the gap between the bottom of the skirt and ground board, is held constant. The limiting case here would be that with the skirt removed $\left(h_s/D_p = 0\right)$.

Effect of Plenum-Chamber Inlet Configuration

In view of the preceding discussion of the flow inside a simple plenum chamber, it was thought that the lift characteristics could be improved if the flow from the inlet could be deflected so as to fill the plenum chamber and eliminate or reduce the strength of the trapped vortex. In an attempt to accomplish this improvement, a flared inlet and a welded aluminum turning-vane assembly (fig. 1(d)) were installed in a model. The lift characteristics obtained with this model in the order in which it was assembled are shown in figure 5. It can be seen that the simple nozzle, which was the supply chamber alone, was no longer superior in producing lift augmentation. It is interesting to note that the use of the flared entrance eliminated the negative lift augmentation at intermediate heights which had been experienced by the single-inlet models of figure 2. Apparently this flared entrance or diffusing section did work as it had been hoped by more effectively filling the plenum chamber. The deflector vanes improved the flow conditions further but were not needed in addition to the flared entrance to prevent negative lift augmentation. The theoretical curve for $K = 0.7$ more closely matches the experimental data obtained with the flared entrance (with and without the deflector vanes) than does the curve for $K = 1.0$ (fig. 5).

The effect of holding the inlet area constant while varying the number of inlets in the model was the last effect of variation in geometry studied. The results of this study are shown in figure 6 for the three models shown in figure 1(c). The use of either two or four symmetrically placed inlets eliminated the negative lift augmentation experienced with the single-sharp-edged-inlet configuration at intermediate heights. This change apparently did not entirely eliminate the flow condition involved, as indicated by the fact that the lift augmentation obtained at intermediate heights was still less than that expected from theory and less than that obtained for $D_e/D_p = 1.0$ shown in figure 2. The multiple inlets probably produced smaller trapped vortices which absorbed less energy. As mentioned briefly in the section entitled "Model and Apparatus," no attempt was made to hold a constant condition of p_t in succeeding configurations. With this fact in mind a summary of the results obtained with four selected models is presented in figure 7. This figure more conveniently shows the relative merits of the various types of plenum-chamber models studied in this investigation.

Pressure Profiles

In addition to measurements of lift, data on ground-board pressure beneath the model were obtained. Some typical pressure data for the model having a plate diameter of 20 inches, for which lift data are shown in figure 2, are presented in figure 8. The negative pressures which cause the negative lift augmentation experienced by this model at $h/D_p = 0.10$ are clearly shown. Values of lift obtained by integrating the areas beneath the pressure curves agreed reasonably well with those obtained from the strain-gage balance system.

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CONCLUSIONS

Results of an investigation of a series of simple-plenum-chamber models to determine the effects of some variations in model geometry upon lift augmentation has indicated the following conclusions:

1. For a simple single-inlet configuration, lift augmentation increased when the ratio of inlet diameter to plenum-chamber diameter was increased. The limiting case, a simple rectangular nozzle (with a ratio of equivalent inlet diameter to plenum-chamber diameter equal to 1.00), was superior to any plenum chamber tested which had a sharp-edged inlet.

2. Over the range of the investigation, a ratio of plenum-chamber depth to plenum-chamber diameter between 0.05 and 0.10 produced an optimum lift augmentation for a single-inlet configuration having a ratio of inlet diameter to plenum-chamber diameter of 0.15.

3. The use of a flared inlet improved the performance of a simple single-inlet plenum-chamber model.

4. Installation of a flared inlet and a turning-vane assembly in the plenum chamber improved lift augmentation of a single-inlet configuration at intermediate heights.

5. The use of multiple inlets eliminated the negative lift augmentation experienced by single-sharp-edged-inlet configurations at intermediate heights.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., January 24, 1961.

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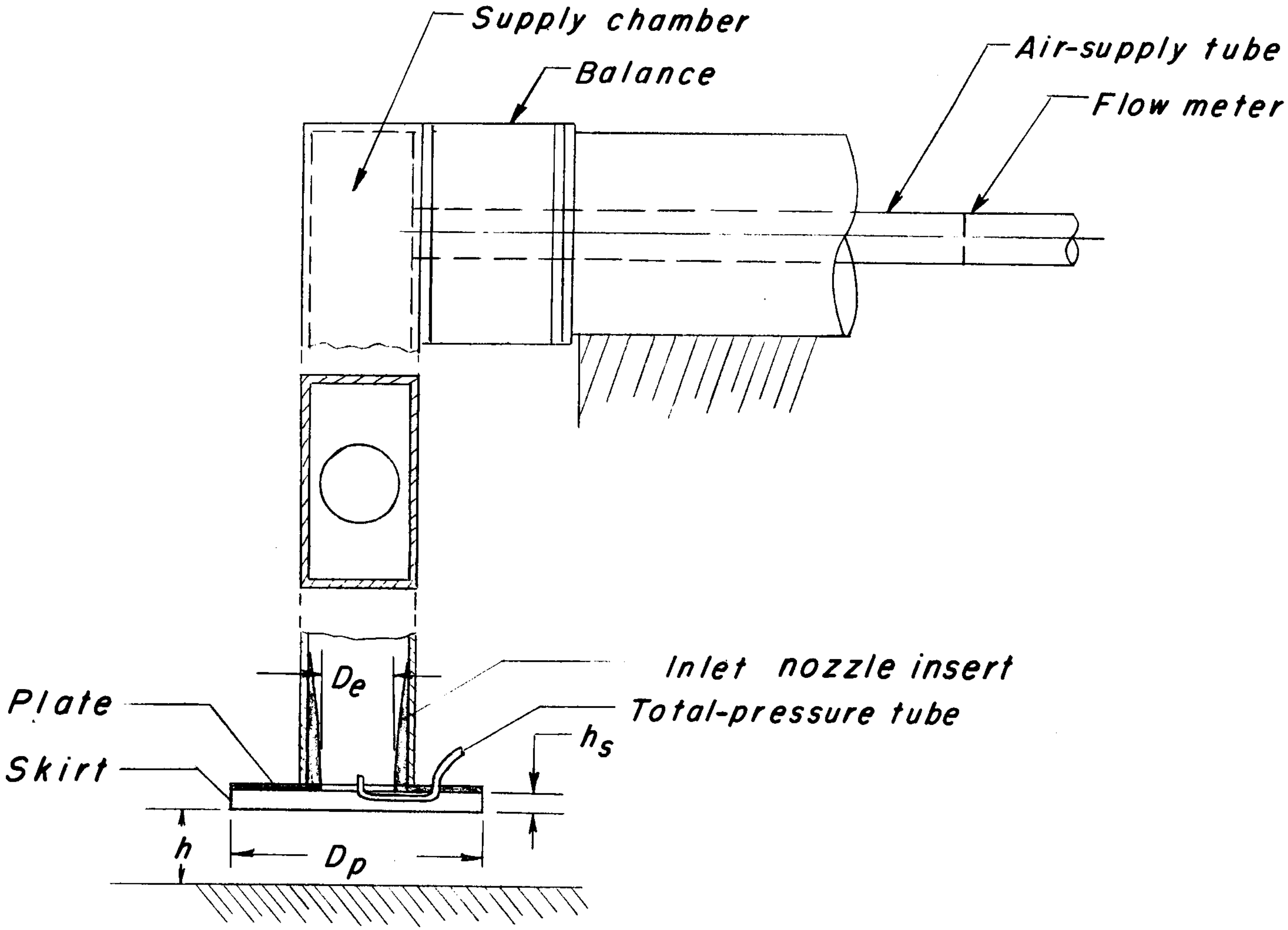
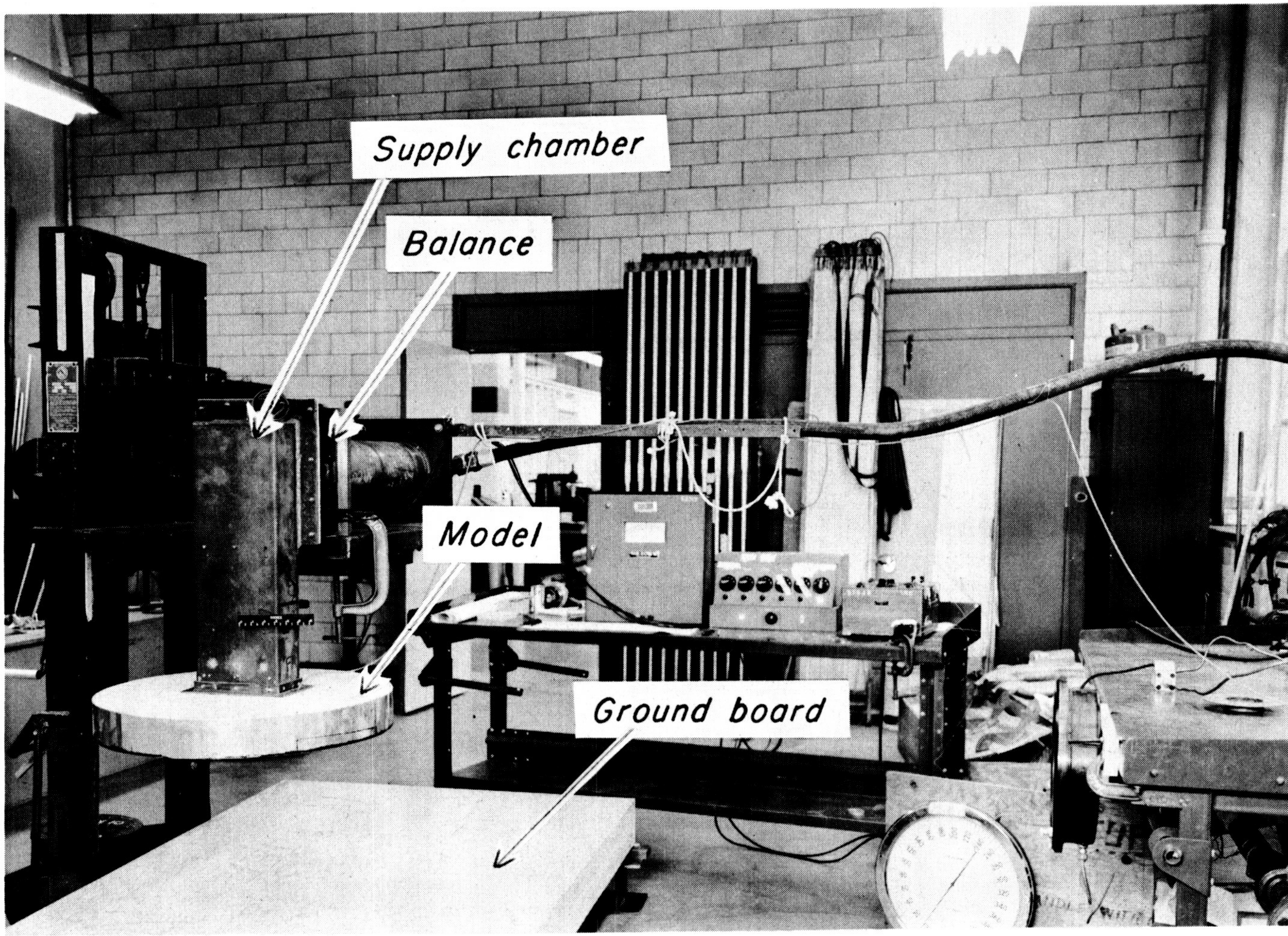
3. Jackson, Roy P., and Southcote, Murray F.: Potential of the Air-Cushion Vehicle. Paper No. 60-15, Inst. Aero. Sci., Jan. 1960.

4. Wright, Dean E.: The Effect of Configuration on the Lift Augmentation Ratio of a Two Dimensional Open Plenum Ground Effect Machine. Rep. No. 516 (Contract No. DA44-177-TC-524), Dept. Aero. Eng., Princeton Univ., May 1960.



(a) Schematic arrangement of model and apparatus.

Figure 1.- Model details.



(b) Typical model setup. L-59-7874.1

Figure 1.- Continued.

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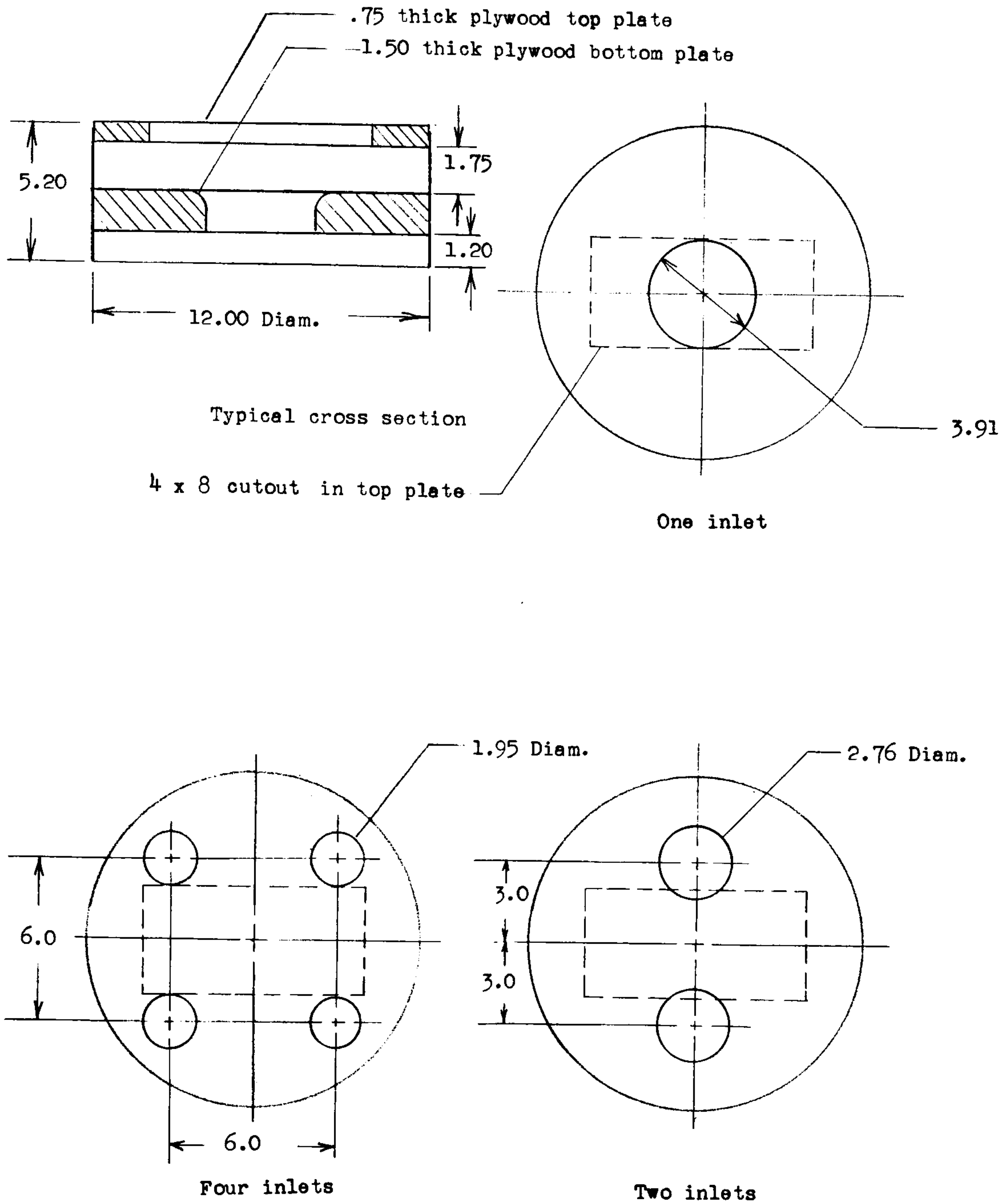
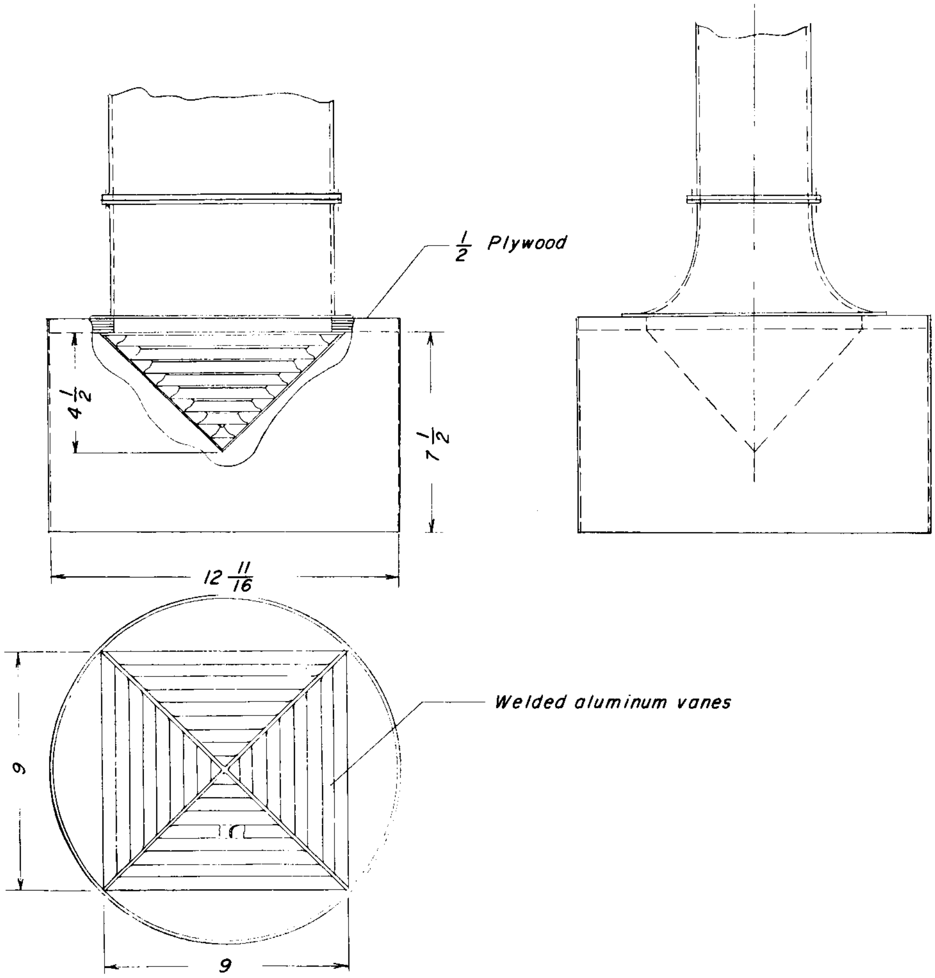


(c) Details of models with multiple inlets. All dimensions are in inches.

Figure 1.- Continued.



(d) Details of flared inlet and turning vanes. All dimensions are in inches.

Figure 1.- Concluded.

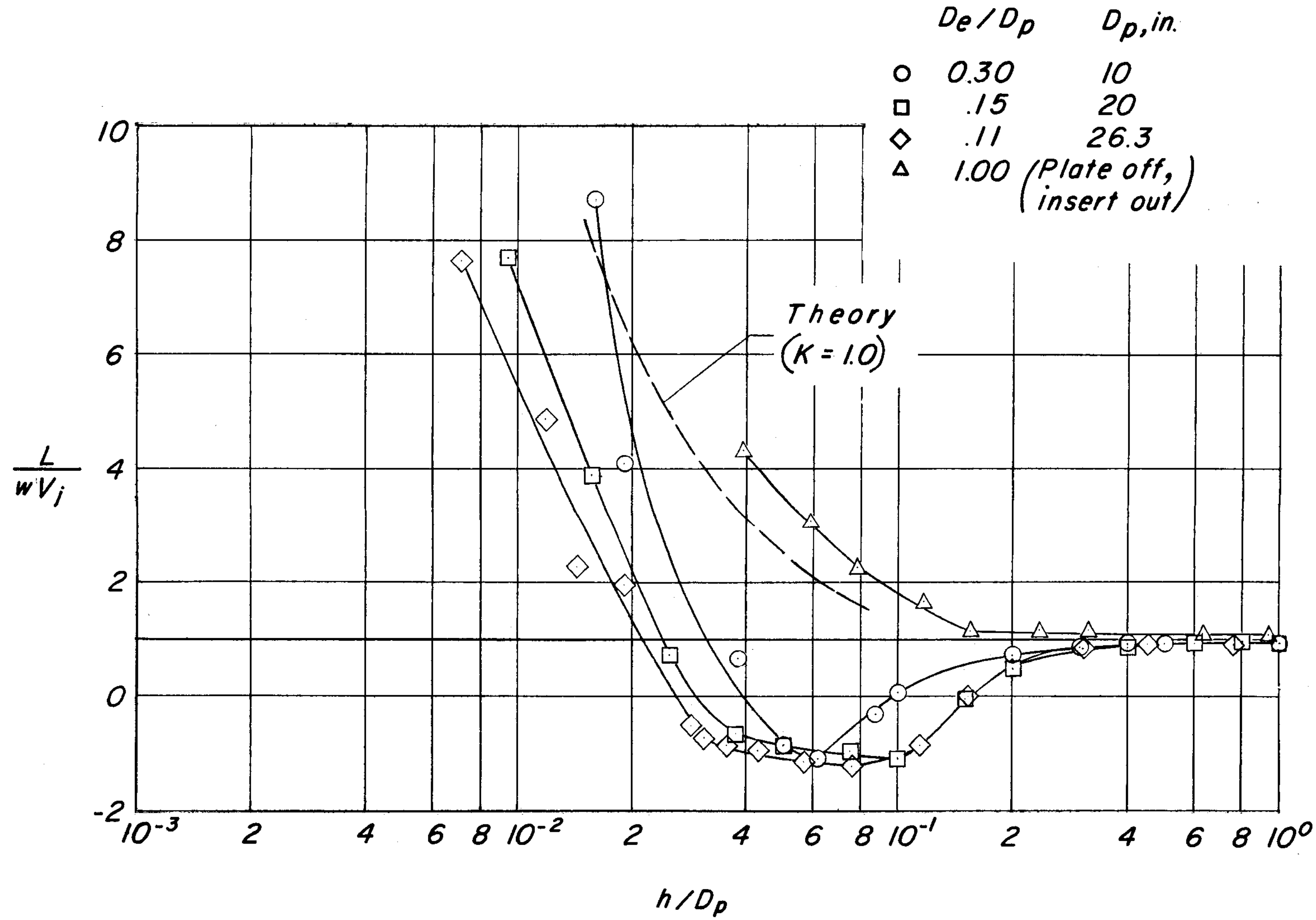
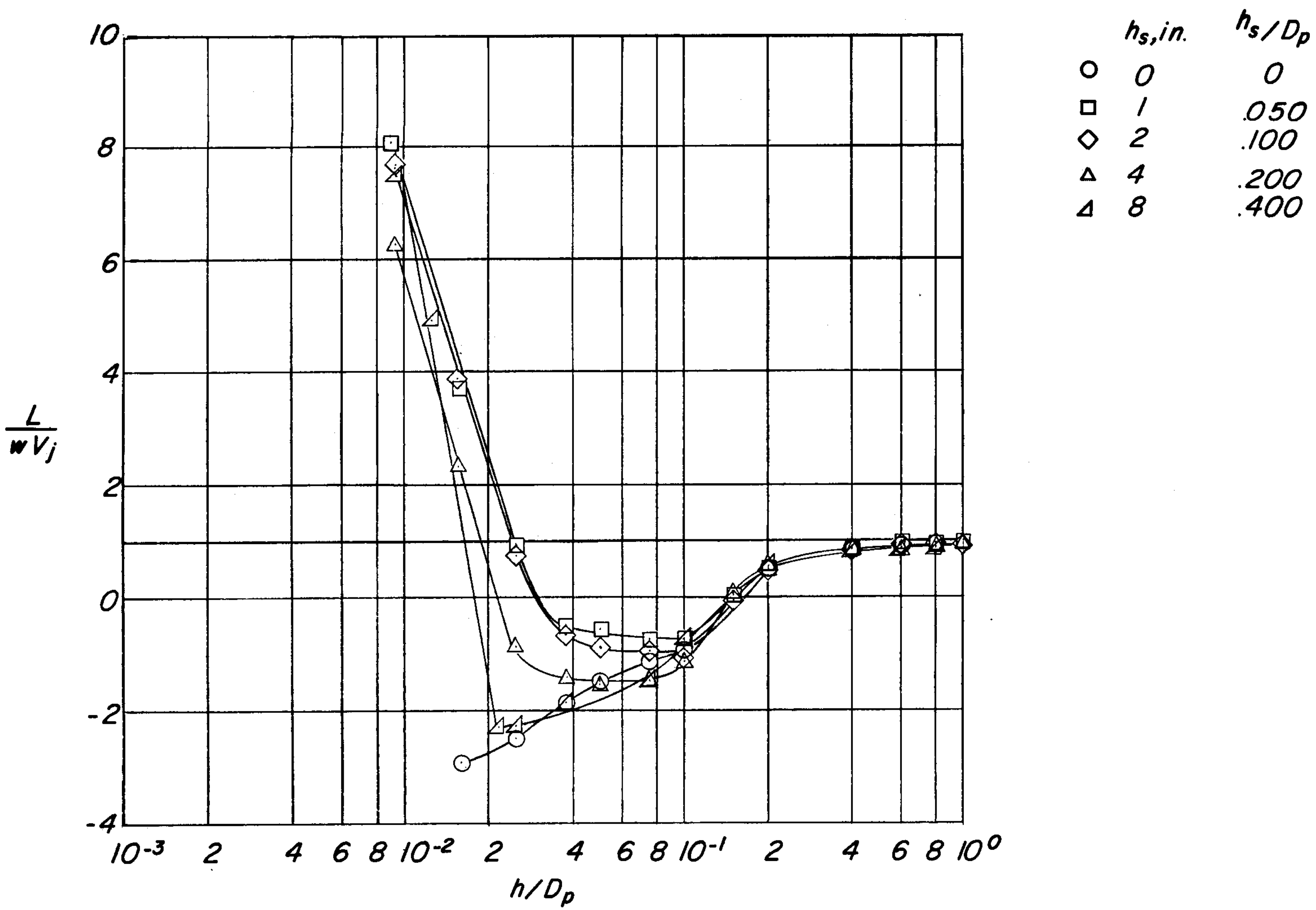


Figure 2.- Effect of D_e/D_p on lift augmentation. $h_s/D_p = 0.10$.



(a) h_s from 0 to 8 inches. $D_e/D_p = 0.15$.

Figure 3.- Effect of plenum-chamber depth on lift augmentation.

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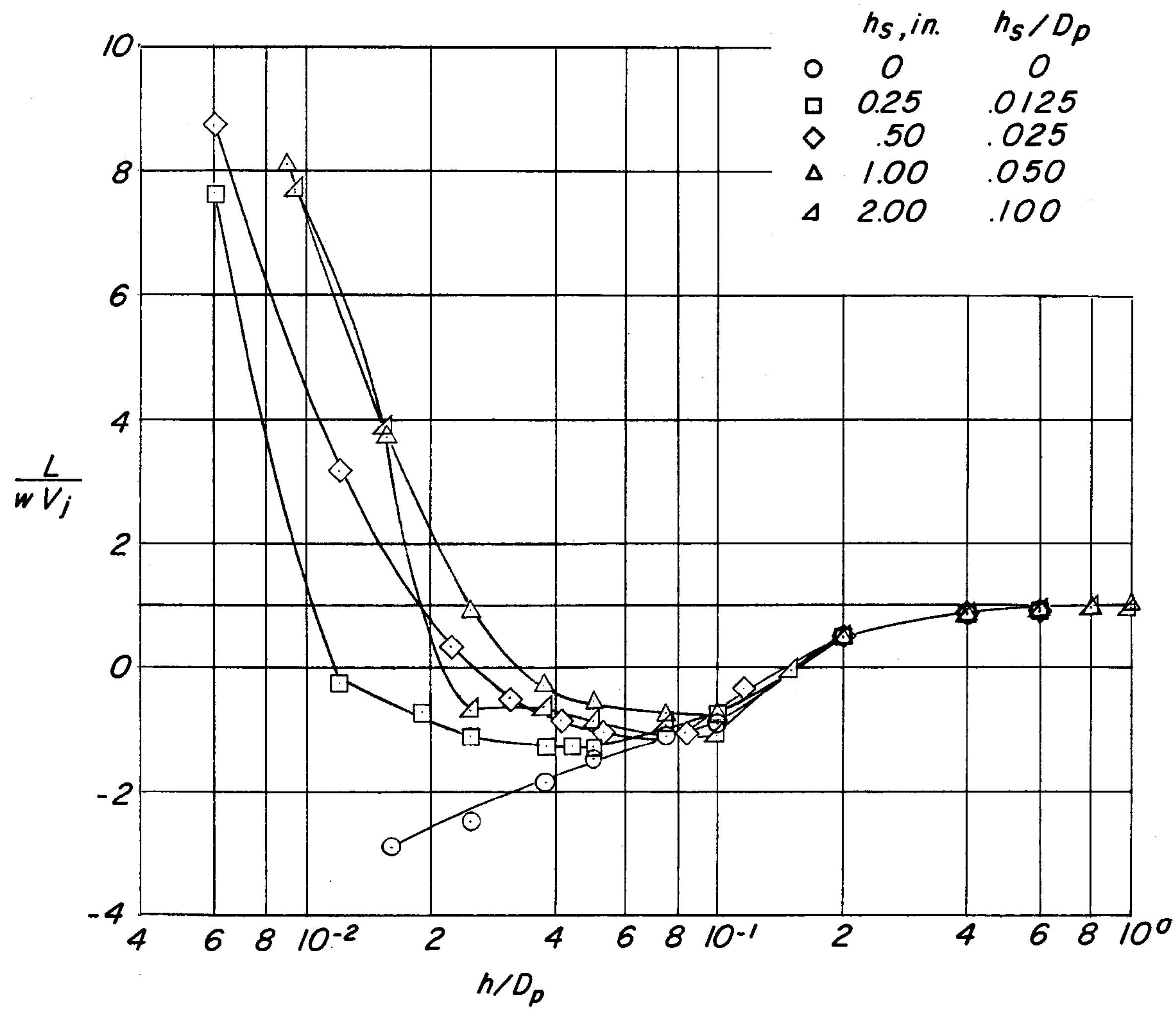

(b) h_s from 0 to 2 inches. $D_e/D_p = 0.15$.

Figure 3.- Concluded.

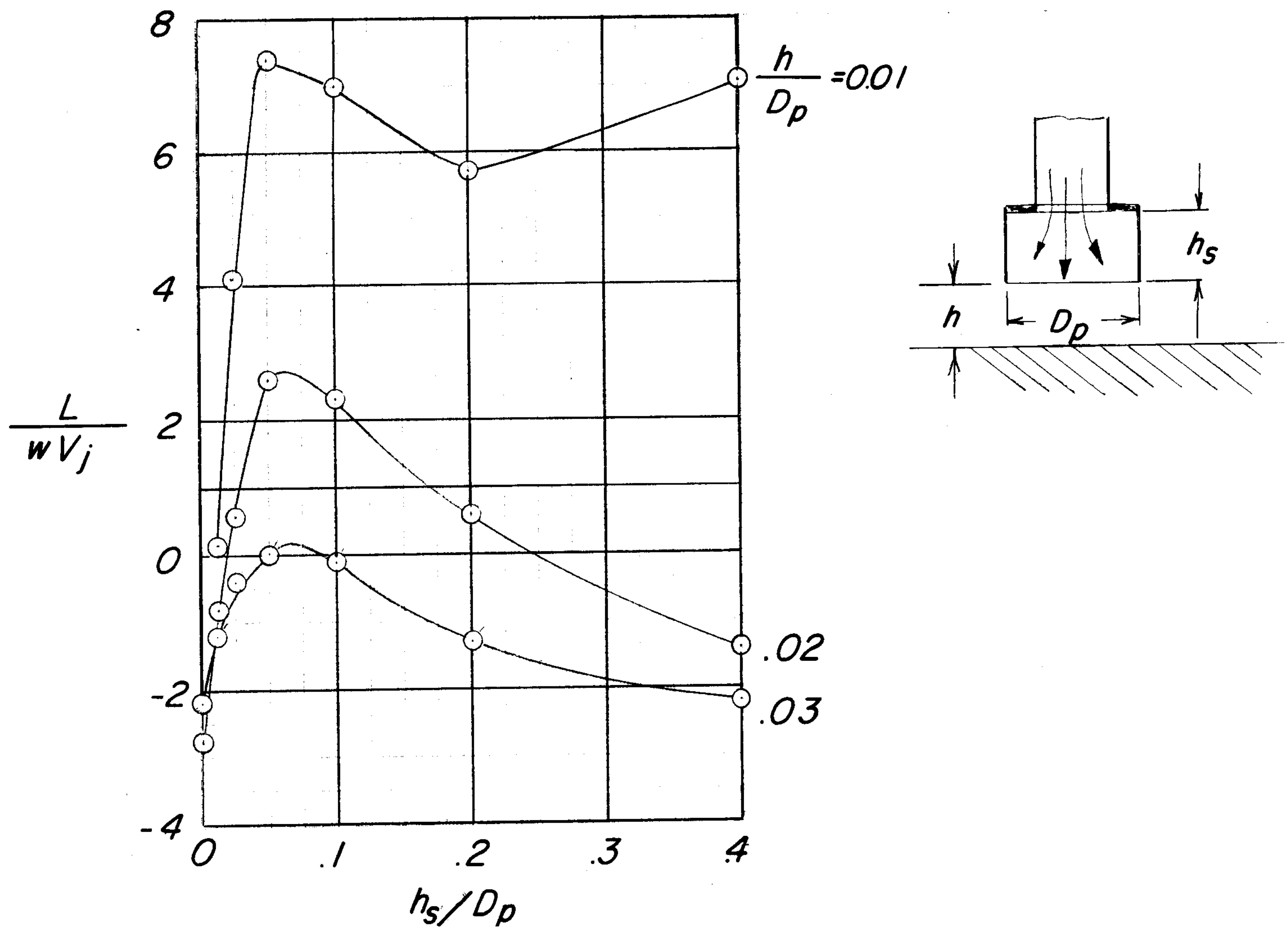

Figure 4.- Effect of plenum-chamber depth on lift augmentation. $D_e/D_p = 0.15$.

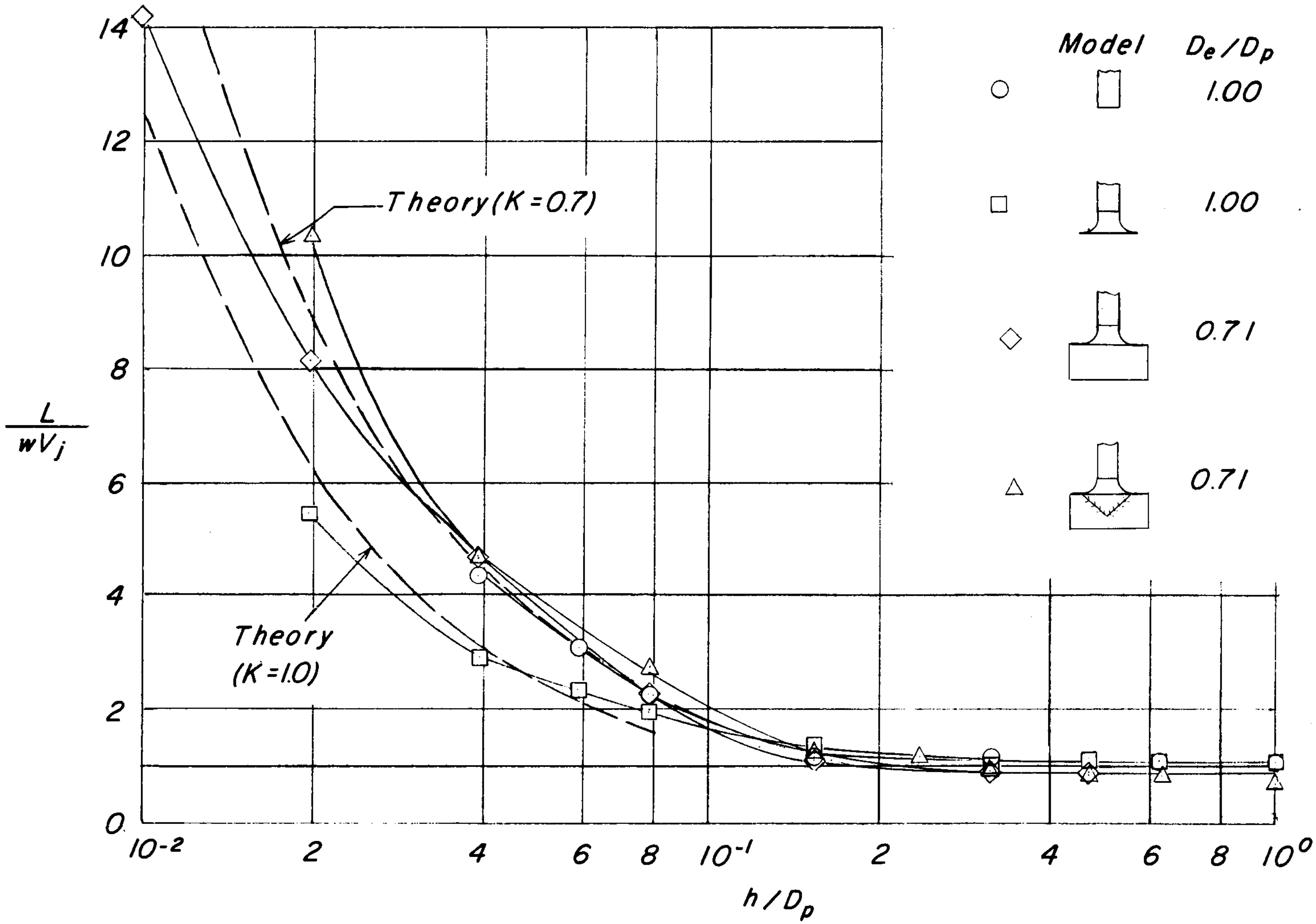

Figure 5.- Lift augmentation of component parts of a model with flared inlet and turning-vane assembly.

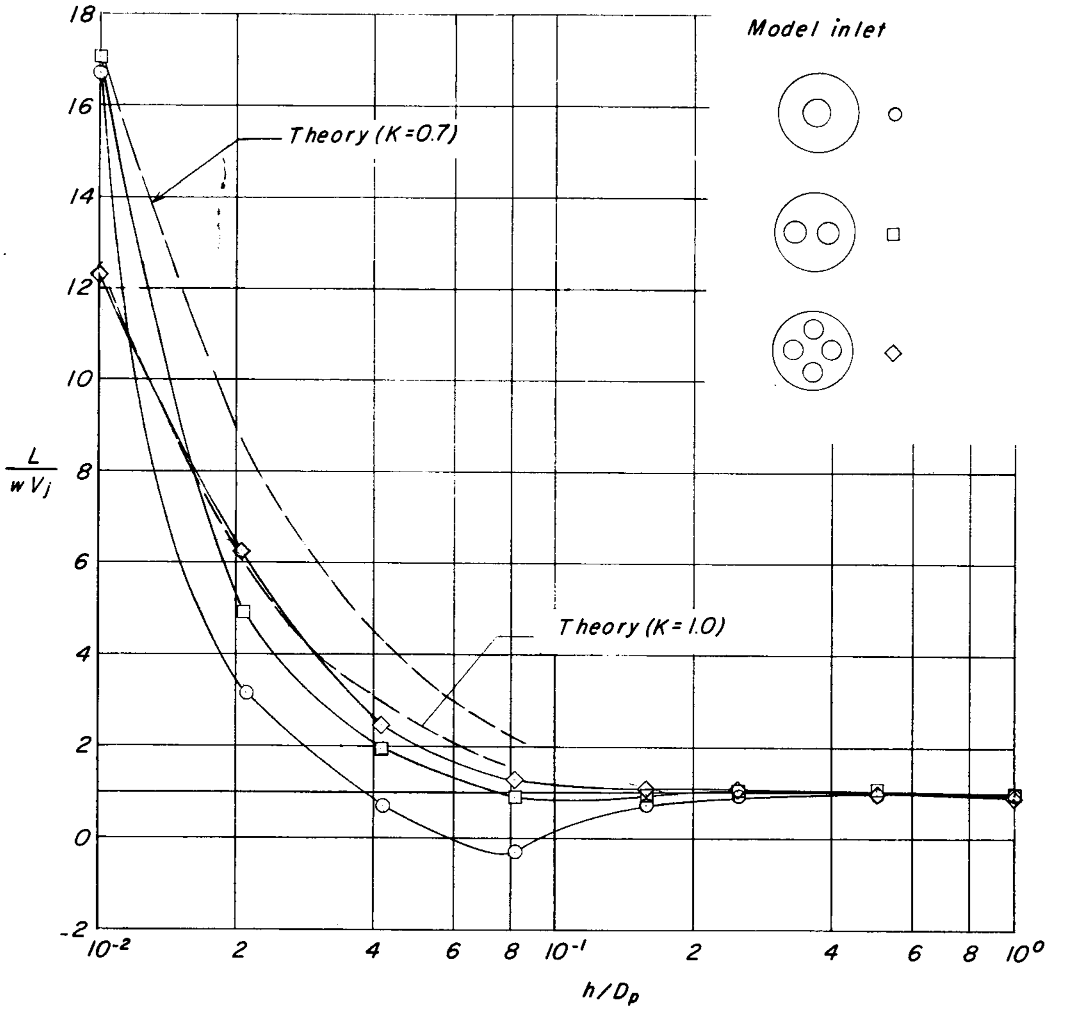

Figure 6.- Effect of multiple inlets on lift augmentation. Ratio of inlet area to plenum-chamber area constant at 0.11; D_p = 12.0 inches; h_s/D_p = 0.10; D_e/D_p = 0.37.

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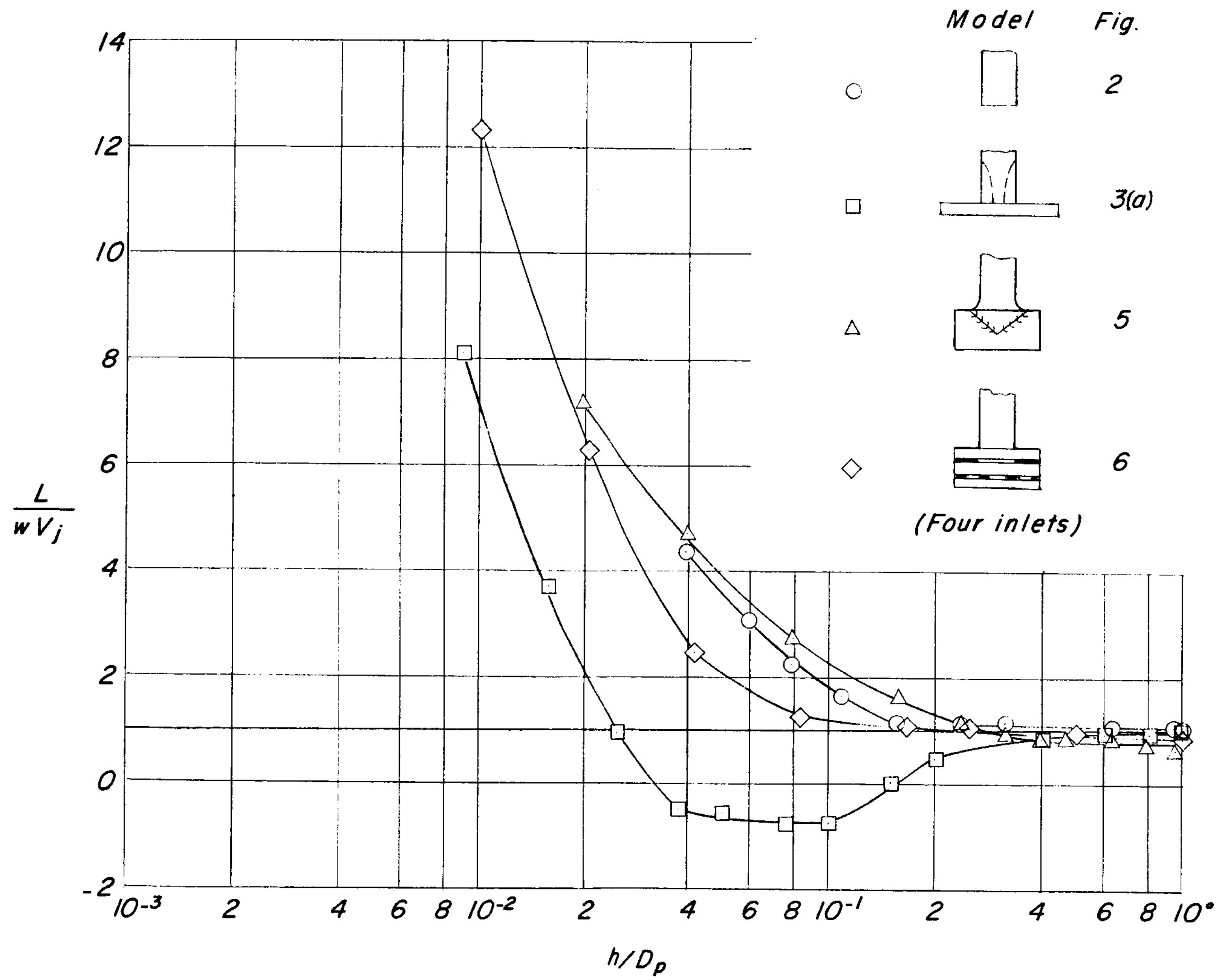

Figure 7.- Summary of data for four different plenum-chamber models.

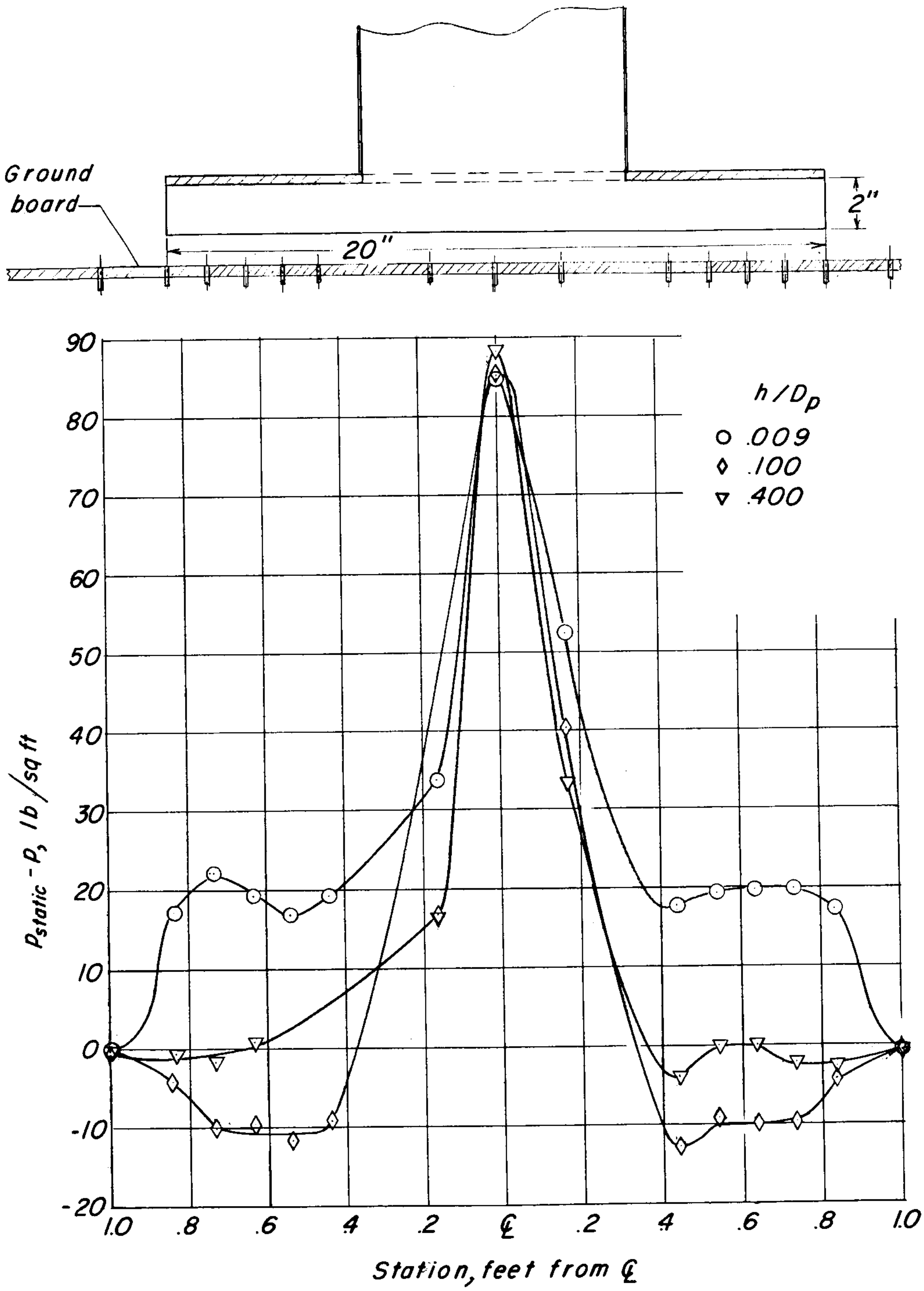

Figure 8.- Measured pressures on ground board.

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