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OVER-WATER ASPECTS OF GROUND-EFFECT VEHICLES

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INTRODUCTION

The large thrust augmentation obtainable with annular-jet configurations in ground proximity has led to the serious investigation of ground-effect machines. The basic theoretical work on these phenomena has been done by Chaplin and Boehler (for example, refs. 1 through 3). Large thrust-augmentation factors, however, can be obtained only at very low heights, that is, of the order of a few percent of the diameter of the vehicle. To take advantage of this thrust augmentation therefore the vehicle must be either very large or must operate over very smooth terrain. Over-land uses of these vehicles then will probably be rather limited. The water, however, is inherently smooth and those irregularities that do exist, that is waves, are statistically known. It appears therefore that some practical application of ground-effect machines may be made in over-water application.

NASA research related to ground-effect machines has been directed primarily to obtaining basic data on the ground-effect phenomena with a view to determine the potential and limitations of its application. Most of this work is reviewed in reference 4. In the present paper this work will be reviewed from the point of view of over-water application.

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SYMBOLS

L	measured lift, lb
D	measured drag, lb
D_e	effective total drag, lb
d	diameter of model, ft
T	calculated jet thrust, lb
h	height above ground or mean free-water surface, ft
Δh	amplitude of oscillation of height, ft
h'	height above displaced water surface, ft
H	wave height, ft
λ	wave length, ft
l	length of model, ft
q_{max}	maximum dynamic pressure of airflow along surface, lb/sq ft
V	forward speed, ft/sec
M	moment, ft-lb
α	attitude with respect to free-water surface, deg
σ	angle of spray sheet from free-water surface, deg
p_T	total pressure, lb/sq ft
P_T	total power required, hp
$\left(\frac{L}{D}\right)_e$	effective lift-drag ratio
m	mass flow, slugs/sec
V_j	jet velocity, ft/sec
W	model weight, lb

S total plan-form area, sq ft

t jet thickness, in.

THE SURFACE OF THE SEA

In considering the over-water application of ground-effect vehicles some knowledge of the surface conditions to be encountered is necessary. Water, of course, seeks to maintain a smooth surface. The action of the wind, however, can create very high waves in the open ocean. The combinations of wave height and wave length that can be experienced are plotted in figure 1. These data (taken from ref. 5) represent some 128 observations taken by 15 different investigators from various localities, ranging from a pond at Kensington Park, London, to the trade-wind belt of the North Atlantic. In compliance with the conventional practice for reporting wave heights, the heights shown represent the average of the highest one-third of the waves observed. Thus, individual waves may be somewhat higher than the data points shown.

The U.S. Hydrographic Office scale of sea-state conditions is shown at the right of figure 1. These sea states are described in the U.S. Hydrographic Office scale of sea conditions as presented in table I. Swell conditions are presented in table II. "Sea" and "swell" are usually differentiated by defining "sea" as an irregular train of waves in which a large wave may be followed by one or two small waves which again may be followed by a single large wave or by several large waves. The "swell," on the other hand, is a fairly regular train of waves, each succeeding wave being of about the same height as the preceding wave, although over a series of five or six waves the height may change appreciably. A "swell" is usually the decaying form of the sea condition created by a storm. Sea waves, on the other hand, are usually wind created waves and are created by the mixing of several wave trains. These wave trains are not all traveling in the same direction but are approaching from various angles, thus, at any given point the crest of one wave may coincide with the trough of another to result in a low wave or a trough. On the other hand, if the crest from two or more waves coincide at a given point a very high wave results. In a typical sea no predominant wave front can be distinguished. A "swell," on the other hand, is characterized by a pronounced wave front that can be followed for miles. Additional information on the surface of the sea can be found in references 6 to 9.

It can readily be seen from figure 1 that the combinations of wave height and wave length that a ground-effect vehicle may encounter cover a wide range. There are limitations to the heights that can be obtained however. According to the simple trochoidal wave theory (Lamb, ref. 10) waves having height-length ratios less than 1/7 are not physically possible. As can be seen from figure 1, only the shorter waves approach this limit. Most of the longer waves are much lower than the theoretical maximum.

The empirical theory of wind waves, as reviewed in reference 6, on the other hand, indicates rather low waves (fig. 1). This theory, however, applies to a single wave train generated by wind action on a surface that, without the wind, would be calm. The actual sea surface, as discussed previously, is formed by the action of a series of interacting wave trains, some of which were created by winds that have ceased to act.

The result of this superposition of wave trains is sea heights that are frequently higher than those predicted by wind theory.

If a large ground-effect vehicle is operating over short waves, the vehicle would be able to bridge the waves, as shown in the sketch at the upper left of figure 1. Under these conditions the height that the vehicle would have to attain would have to be such that it could clear the tops of the highest waves. The theoretical maximum as predicted by Lamb would indicate a height of 1/7 of the length or a height of about 14 percent. This, however, is measured to the trough of the waves. If the waves were perfect sine waves, the height could probably be measured from the average height of the wave or midway between the crest and the trough. Under this condition, a height of only about 7 percent of the diameter would be required. In practice, however, waves do not follow a simple sine pattern. In the open ocean, large waves may be followed by a few small waves, followed again by several large waves. The average water height would then be considerably less than half of the maximum wave height. Under these conditions, the altitude the vehicle would have to attain would probably lie somewhere between 10 and 14 percent of its diameter or length.

If a relatively small vehicle were operating at low speeds in large swells such as shown in the sketch at the upper right of figure 1, the vehicle could follow the contour of the swells. Under these conditions it would only have to bridge the smaller waves and a relatively low height-to-diameter ratio might be sufficient. It should be noted, however, that this operation could be followed only so long as the waves are not breaking. In the cases where the waves are breaking, the vehicle will have to be able to attain a height so as to clear the crest of the breaking waves. Some of the characteristics of a ground-effect machine operating over swells have been investigated in the Langley hydrodynamic towing tank and will be discussed in a later section of this paper.

HOVERING CHARACTERISTICS

Augmentation Characteristics Over Water

A primary question concerning the over-water characteristics of annular jets is: How much thrust augmentation can be obtained over water? To investigate this, a 42-inch-diameter model was used to measure the thrust-augmentation characteristics over water and over fixed ground. The results, shown in figure 2, indicate a reduction in augmentation factor over water when the height is measured from the free-water level. The thrust augmentation of an annular-jet configuration arises from the buildup of pressure under the base of the model. This base pressure displaces water beneath the model. When this displacement is calculated using the measured base pressures and the thrust augmentation is presented with respect to the height measured from the displaced water level, an augmentation factor slightly greater than that obtained over fixed ground is obtained. This improvement in augmentation is probably due to the local distortion of the water surface directly under the annular jet. This local distortion causes a greater curvature of the jet curtain similar to that which would be obtained if the jets were inclined inward (ref. 1).

Spray

A problem that may be of considerable concern in over-water operation is the spray produced by the outward flow of air from the jet. Photographs of the spray experienced in the tests of the 42-inch-diameter model are shown in figure 3 for several conditions. These pictures were taken during the tests to determine the thrust-augmentation factors over water and were run at constant fan rpm. As a result, the lift is not constant but decreases rapidly with increasing height. Reduction in spray shown then is not primarily a function of height but is a combination of factors.

The primary factor determining the onset of spray with hovering aircraft has been found to be the dynamic pressure of the air flowing radially outward along the surface of the water. In reference 11 and from related observations in winds on the open ocean (ref. 9) it was found that spray would not be formed if the maximum dynamic pressure of the outward flow of air did not exceed about 1.5 to 2.5 pounds per square foot. In the present tests, spray was not observed below a dynamic pressure of about 2.2 pounds per square foot. Additional information on the decay of the dynamic pressure of the outward flow of air as a function of the height of the ground-effect vehicle is contained in reference 4.

The effects of spray in hovering can be reduced appreciably by the addition of spray deflectors, as shown by the photographs of figure 4. These deflectors intercept the spray and deflect it out laterally away from the model. Care must be exercised in locating spray deflectors, however, to assure that they are not placed too low or made too wide so that when operating over the ground they create a download due to the secondary induced flows, as experienced by flat plates as discussed in reference 12.

The problem of spray is most serious in hovering and at low forward speeds. As forward speed is increased most of the spray is produced at the sides of the vehicle and this is quickly left behind as discussed in reference 4.

Effect of Size on Spray

The spray produced by the model naturally brings up the question: Does the spray produced by a model represent the spray that a full-scale vehicle will produce? Experience with ship and flying-boat hulls has indicated that the spray produced by a model hull is geometrically similar to that produced by the full-scale hull when the Froude scaling laws are used in determining the model weight and speed.

An experimental investigation has been undertaken to determine whether or not these same scaling laws hold for spray produced by the air jets from a ground-effect vehicle. The first preliminary results are presented in figure 5. For the purposes of this investigation a segment of the periphery of a ground-effect vehicle was simulated and arranged so that the slot width, height above the water, and internal total pressure could be varied. Photographs of the profile of the spray produced, as depicted in the sketch at the top of figure 5, were taken for a variety of simulated sizes and total pressures.

The slope of the spray front has been used in figure 5 as an index to the spray formation because it could be defined more easily than the height or horizontal extent of the spray. Two limits are indicated on figure 5. Obviously a spray front angle of greater than 90° can not exist with this apparatus, and no spray will be produced when the dynamic pressure of the air at the surface of the water is below about 2 to 2.5 pounds per square foot, as previously discussed. For a height equal to the jet thickness, reference 4 indicates that this surface dynamic pressure is essentially equal to the jet total pressure.

According to Froude scaling laws, the weight of a half-scale model would be 1/8 of full scale and the area 1/4 of full scale. The pressures then would be given by the scale factor or 1/2 of full scale.

Comparison of the data for the 4-inch slot at total pressures of about 8 to 16 lb/sq ft with the data for the 2-inch slot at corresponding scaled-down pressures (4 to 8 lb/sq ft) indicates that in this range the Froude scaling laws are being followed. At lower total pressures, however, the scaled-down pressures for the 2- and 1-inch slot approach the spray threshold and therefore could not be expected to scale properly. Comparison of the data for the 1- and 2-inch slots does not indicate agreement with the Froude scaling laws. However, here the 1-inch-slot data are approaching either the spray threshold limit or the 90° limit, which may account for the lack of agreement shown.

In general, on the basis of the limited results available from this investigation and the experience with model hulls, it is believed that the spray envelope from ground-effect vehicles will scale according to Froude scaling laws provided the spray front does not too closely approach the vehicle and as long as the dynamic pressure of the air blowing along the surface of the water in the model tests is appreciably greater than the spray threshold of 2 to 2.5 lb/sq ft.

Attitude Stability

Ground-effect vehicles, in general, exhibit inherent attitude stability over fixed ground when operating at very low altitudes. This stability usually decreases with altitude and changes to instability at heights of 5 to 10 percent of the diameter depending upon the base configuration (refs. 4 and 13). A comparison of the attitude stability measured on a circular model over land and over water is presented in figure 6. The expected trends over land are shown. Over water, however, the attitude stability is, in general, decreased appreciably for this model for large angles with respect to the surface. At very small angles this model exhibits attitude stability at all heights investigated including the highest height where the model was unstable over fixed ground.

Stability depends upon the distribution of pressure on the base of the model. Over water the same pressures which act on the base of the model also act on the surface of the water and displace the water surface. The displacement of the water results in a change in the basic pressure distribution and thus a reduction in either stability or instability as the case may be. It can, in fact, result in a change from stability to instability or from instability to stability as indicated in figure 7 (slopes measured over ±2°).

The characteristics of a configuration with a recessed bottom are shown in figure 8. In this case an additional factor enters the considerations of stability. A side force can act on the internal-vertical sides of the recess when the vehicle is at an angle to the surface. The contribution of this side force to the attitude stability depends upon the vertical position of the center of gravity of the configuration as shown in figure 8. Other factors which affect the stability of ground-effect vehicles over land and which will probably also affect the characteristics over water include the use of compartmentation by adding additional air slots in the base and by changes in plan form. These have been reviewed in reference 1.

General conclusions regarding the stability of ground-effect vehicles cannot be drawn from the limited amount of research work completed to date. However, this work indicates that for over-water applications the stability characteristics should be determined from tests over water.

FORWARD SPEED CHARACTERISTICS

Drag Over Water

The effect of the base pressure under a hovering ground-effect vehicle in displacing water has already been discussed. There had been some concern that at forward speeds there would be a large drag associated with this displacement of water similar to that experienced by a ship's hull. Such a displacement wave drag, if expected at all, would only be experienced under deep-water conditions. For the depth of the tank used in these tests (12 feet), the critical speed is about 18 feet per second. Below this speed the tank would correspond to deep water and displacement wave drag would be experienced on the conventional hull. If a displacement drag were associated with an annular jet over water it would only be experienced in the present tests at speeds below about 18 feet per second. Tests were made with a 42-inch-diameter model in the hydrodynamic towing tank. For this investigation plywood ground boards were installed in part of the tank to simulate the fixed ground surface. The results are shown in figure 9. As can be seen, there are no significant differences between the drag measured over water and over the fixed ground boards. There are several factors involved in the fact that no difference in drag could be measured. First of all, an appreciable displacement of the water was observed only while hovering and at low forward speeds. A ground-effect vehicle displaces water through the action of the base pressure. At forward speeds this base pressure is felt by a particle of water under the machine only for a finite period of time: the time required for the length of the machine to pass a given point. Thus the greater the speed the shorter the time that the base pressure has to act on a given particle of water and the smaller the displacement of the water. In the present tests an appreciable displacement of the water and the associated displacement wave train were observed only at speeds of less than 5 feet per second. At this speed the drag is so low that accuracy considerations alone preclude detecting any difference in drag that may arise over water.

The more important consideration, however, is that in these tests the model was held at zero angle of attack. At zero angle of attack with the flush bottom as used on this model, there is no obvious way that the effects of displacing the water could be transmitted to the model so that they would show up as a change in drag force. If the model had been free to trim, however, the inherent stability at a height 0.05d would have caused the model to attempt to aline itself with the displaced water contour. This displaced water contour, which is displaced in accordance with the period of time the base pressure has to act, would assume a slope as shown in the sketch on figure 9, with the greatest displacement at the rear of the model. Thus the model would seek to trim in a noseup attitude and the lift vector would be inclined rearward, producing a drag force as a component inclined lift vector.

The results of tests made with a model mounted free to rise and free to trim are shown in figure 10. The curves presented represent a time history of the attitude and rise height obtained as the model was slowly accelerated from 0 to 50 feet per second. In hovering, the model exhibited neutral stability for a small angle range and the effect of the spray impinging on the overhanging bow caused the model to trim at a noseup attitude of about 1.8°. The expected increase in trim angle due to the slope of the water contour beneath the model caused by the displacement due to the base pressure occurred at about 10 feet per second where a noseup trim attitude of about 3.5° is experienced. This is the speed at which the largest slope of the water surface beneath the model is experienced. Above this speed the short period of time that the base pressure has to act results in the water surface more nearly approaching the level condition. The increased trim angle experienced at the highest speeds is believed to be due to the noseup moment arising from the inlet momentum drag of the air entering the relatively high placed intake.

At low speeds the bow wave set up by the forward jet was in contact with the bow of the model. At a forward speed of about 6 feet per second the drag force due to the green water on the forward lip produced a nose-down moment, and this moment, coupled with a rapid increase in rise of the center of gravity, resulted in a sudden decrease in trim to near zero degrees. Above 6 feet per second, the bow wave disappeared and there was no visible contact between the water and the model other than that due to loose spray thrown by the jet.

Height Over Water

Over fixed ground this model would fly at a height of about 3 percent of the model length (bottom of fig. 10). Over water, however, the effect of the base pressure in displacing the water beneath the model results in the model operating at a much lower height during hovering and at low speeds. In this case a height of about 1 percent of the length is experienced. The effects of the shortened period of time that these base pressures have to act on the water as speed is increased result in the model rising with speed so that above a speed of about 15 feet per second the model rode at about the same height over water as over fixed ground.

Operation Over Swells

The dynamic model used in the investigation of trim angle and rise height in smooth water was also operated over 2-inch swells varying in length from 12 to 24 feet. The results of this work are presented in figures 11 and 12. The flight of this model over swells was characterized by a vertical oscillation of the flight path at exactly the frequency of the wave swell passage. The mean flight path height as measured from the mean water level is presented in figure 11 and indicates that, when operating over swells, essentially the same or slightly greater mean height is obtained as that over smooth water.

The oscillation in height, however, can become appreciably greater than the swell height as shown in figure 12. In this case the maximum height oscillation is obtained at a wave passage frequency of about 1.8 cycles per seconds. Tulin in reference 14 presents a theoretical analysis of the vertical response of a ground-effect vehicle. This theory predicts that the frequency for peak response of the present model at a height of 2 inches $\left(\frac{h}{l} = 0.03\right)$ would be 2.2 cycles per second or slightly greater than the 1.8 cycles per second shown on figure 12. An experimental check on the natural frequency of vertical oscillation was made at zero forward speed by dropping the model with power on from several heights and recording the resulting oscillation. Very high damping was experienced and as a result less than one complete cycle was required to completely damp the oscillation. The best estimate that could be made from the partial cycle obtained was that the static natural frequency was about 2.2 cycles per second, which agrees with this theory but is slightly greater than the frequency at which peak response was obtained in the forward speed runs over swells. This would indicate that there is probably some effect of forward speed on the effective spring constant for this model. At the higher frequencies which correspond to higher velocities the amplitude of the oscillation of the flight path decreased rapidly.

There appears to be little effect of wave length with the three longest waves, however the data for the 12-foot waves show significantly lower response than for the other conditions. The model used in this case had a length of 5 feet. If the model length was appreciably greater than the wave length relatively little vertical response to the swells would be expected. In the present case for the wave length of 12 feet and a model length of 5 feet these effects of wave length to model length are already being felt.

Power Required

In order to obtain some idea of the effective lift-drag ratios obtainable with ground-effect vehicles, measurements of the power required for the 42-inch-diameter model were made and are presented in figure 13. This is the air horsepower required, that is, assuming a 100-percent efficient thrust system and pumping system and assuming zero internal losses. The propulsive power, of course, includes the rather high parasite power drag of the present model and the power required to overcome the inlet momentum drag.

The measured power required can be used to calculate an effective drag and an effective lift-drag ratio as follows:

$$P_T = \frac{D_e V}{550}$$

then

$$\left(\frac{L}{D}\right)_e = \frac{LV}{550 P_T}$$

The effective lift-drag ratio of the 42-inch-diameter model using the total power required from figure 13 is presented in figure 14. The lift-drag ratios obtained are quite small. Even if the parasite drag were reduced to zero, the lift-drag ratios would be small when compared to those of a conventional airplane (12 to 15) or to a helicopter or planing craft (5 to 7). Higher lift-drag ratios can be obtained by operating at much lower heights than the 5 percent of the diameter used in figure 14. However, this would result in considerable compromise in the sea-state condition in which the vehicle could operate or would require extreme size. Clearly, if the ground-effect machine is to achieve appreciable range, considerable improvement in lift-drag ratios will have to be obtained.

In order to increase the effective lift-drag ratio, the power required must be reduced. Improved streamlining will help, but only to the extent shown for zero parasite drag in figure 14. In order to further reduce the power required, the inlet momentum drag and the jet power must be decreased. The same forward speeds that produce the inlet momentum drag can also be used to produce aerodynamic lift. If the vehicle is properly shaped so that aerodynamic lift can be obtained to reduce the base pressure and jet lift required, it will be possible to reduce the inlet mass flow and thus the inlet and jet power required. Perhaps some marriage of the ground-effect machine with a conventional airplane can be achieved such that the ground-effect phenomena need only be used in hovering and at low forward speeds.

CONCLUDING REMARKS

Results of NASA research on lift augmentation of annular-jet configurations in proximity to the ground are in general agreement with other work, in that large augmentation can be obtained. However, the heights involved are only a small percent of the diameter.

The effects of operating over water in hovering are primarily the generation of a large amount of spray and a reduction in hovering height for a given weight due to the displacement of the water by the base pressure. The spray problem, however, can be reduced appreciably by the addition of spray deflectors.

Inherent attitude stability is a function of base-plate configuration but, in general, over land is limited to heights of 10 percent of the diameter or less. The stability characteristics change appreciably over water and the stability characteristics of any vehicle expected to operate over water should be investigated in model form in over-water tests.

At low forward speeds over water, the ground-effect vehicle tends to trim in a noseup attitude due to the slope of the displaced water surface beneath the configuration. As speed is increased, the noseup trim reaches a peak and with further increase in speed the trim angle decreases. A drag force will be experienced due to noseup trim because of the rearward inclination of the lift vector.

Operation of the ground-effect machine at forward speeds over swells results in a vertical oscillation of the vehicle that is greater than the wave height at wave-passage frequencies approximately equal to the static natural frequency of the vehicle in vertical motion. At speeds at wave-passage frequencies greater than the natural frequency the amplitude of vertical motion decreases rapidly.

Although large thrust augmentation can be obtained in hovering, the inlet momentum drag of the air required to produce the jet results in relatively high drags at forward speeds and relatively low lift-drag ratios. The inlet momentum drag will probably have to be reduced by transferring some of the lift to something approaching airplane-type wings (to reduce the jet thrust and base lift required), if reasonably high speeds and long ranges are expected.

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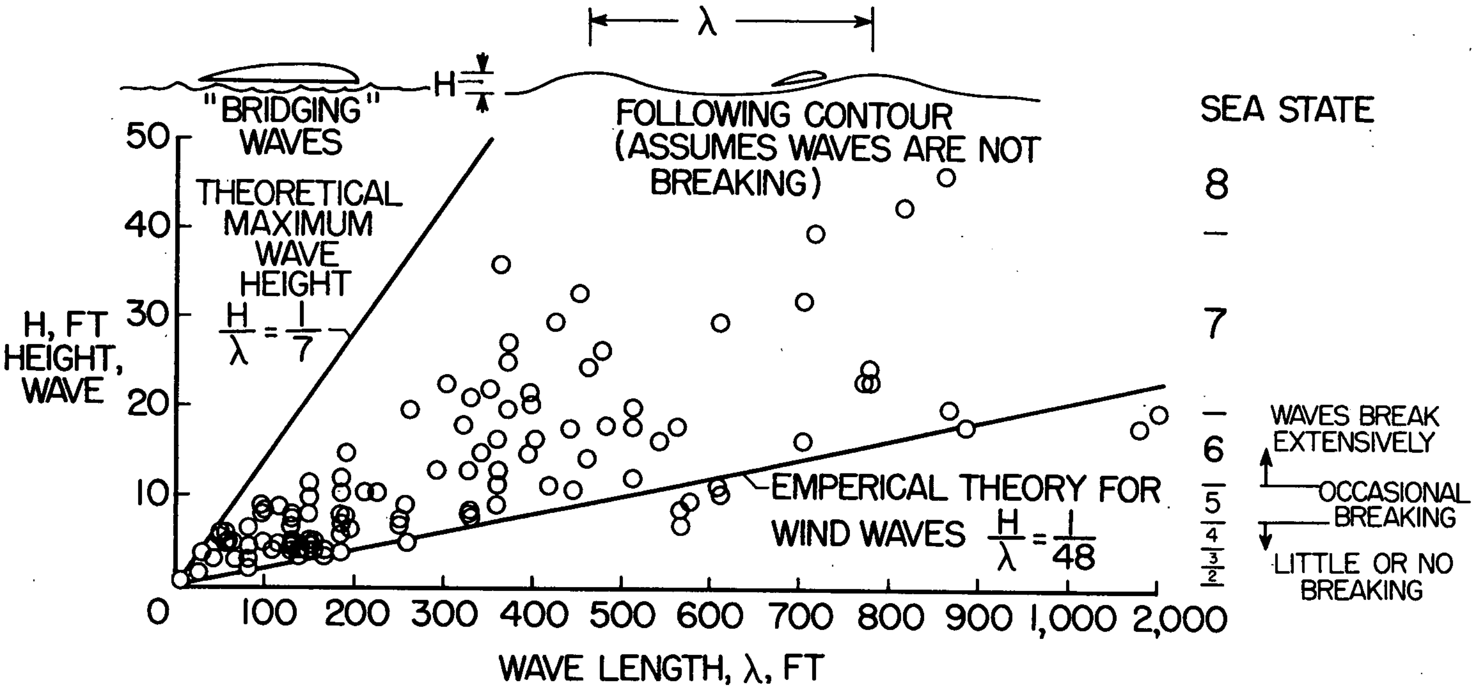
TABLE I.- SEA CONDITIONS, U.S. HYDROGRAPHIC OFFICE SCALE

Code figure	Approximate height of sea	Seaman's description
0	0	Calm - Sea like mirror.
1	Less than 1 foot	Smooth - Small wavelets or ripples with the appearance of scales but without crusts.
2	1 to 3 feet	Slight - The waves or small rollers are short and more pronounced, when capping the foam is not white but more of a glassy appearance.
3	3 to 5 feet	Moderate - The waves or large rollers become longer and begin to show whitecaps occasionally. The sea produces short rustling sounds.
4	5 to 8 feet	Rough - Medium waves that take a more pronounced long form with extensive whitecapping and white foam crests. The noise of the sea is like a dull murmur.
5	8 to 12 feet	Very rough - The medium waves become larger and begin to heap up, the whitecapping is continuous, and the seas break occasionally; the foam from the capping and breaking waves begins to be blown along in the direction of the wind. The breaking and capping seas produce a perpetual murmur.
6	12 to 20 feet	High - Heavy, whitecapped waves that show a visible increase in height and are breaking extensively. The foam is blown in dense streaks along in the direction of the wind. The sea begins to roll and the noise of the breaking seas is like a dull roar, audible at greater distance.
7	20 to 40 feet	Very high - High, heavy waves developed with long overhanging crests that are breaking continuously, with a perpetual roaring noise. The whole surface of the sea takes on a white appearance from the great amount of foam being blown along with the wind. The rolling of the sea becomes heavy and shocklike.
8	40 feet and over	Mountainous - The heavy waves become so high that ships within close distances drop so low in the wave troughs that for a time they are lost from view. The rolling of the sea becomes tumultuous. The wind beats the breaking edge of the seas into a froth, and the whole sea is covered with dense streaks of foam being carried along with the wind. Owing to the violence of the wind the air is so filled with foam and spray that relatively close objects are no longer visible.
9		Note - Qualifying condition applicable to the previous conditions, e.g., (5-9). A very rough, confused sea.

TABLE II.- SWELL CONDITIONS, U.S. HYDROGRAPHIC OFFICE SCALE

Code figure	Approximate height in feet	Description		Approximate length in feet
0	0	No swell		0
1	1 to 6	Low swell	Short or average	0 to 600
2			Long	Above 600
3	6 to 12	Moderate	Short	0 to 300
4			Average	300 to 600
5			Long	Above 600
6	Greater than 12	High	Short	0 to 300
7			Average	300 to 600
8			Long	Above 600
9	-------	Confused		



NASA

Figure 1.- Wave height and length. Height H, is average height of highest one-third of waves observed.

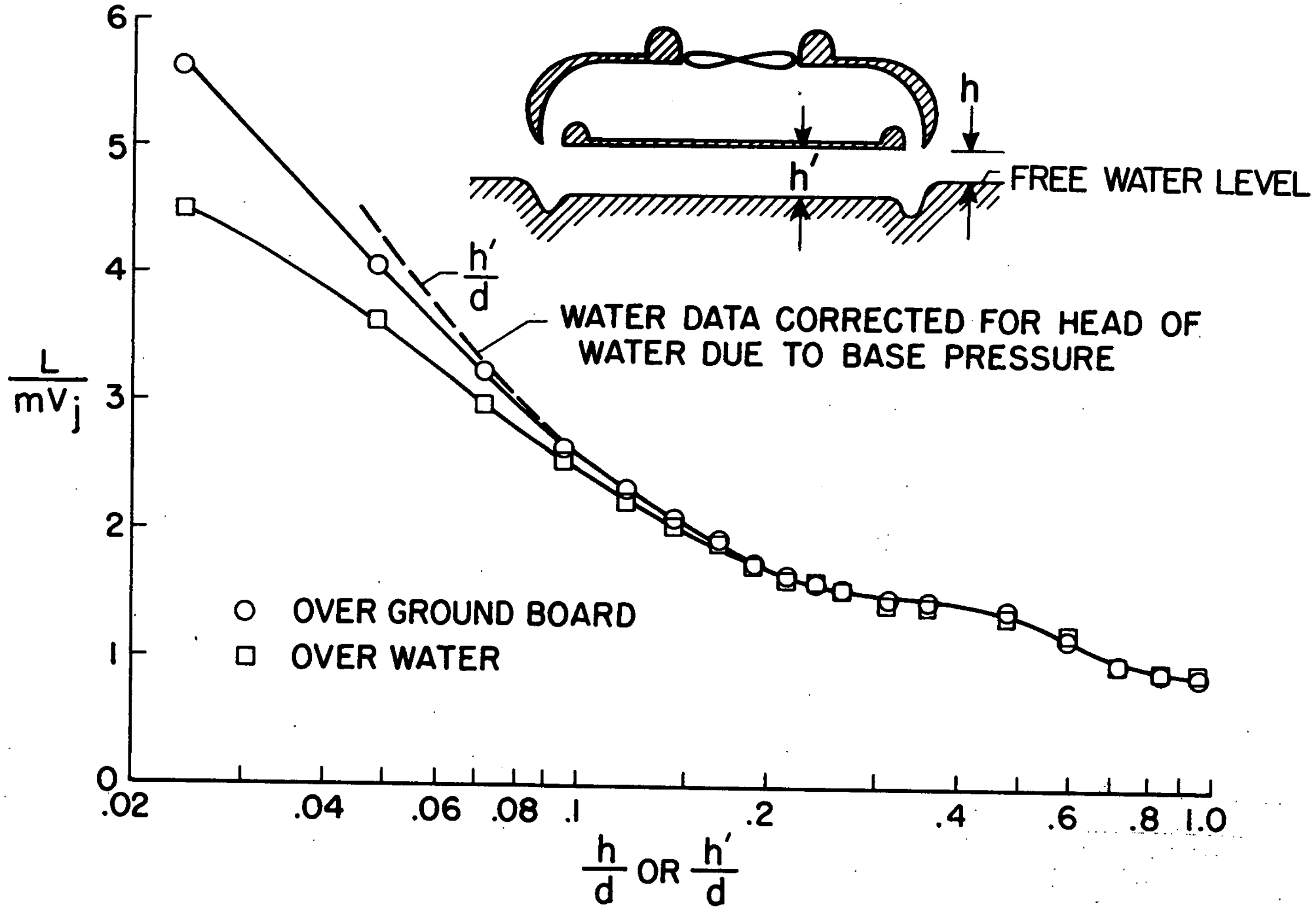


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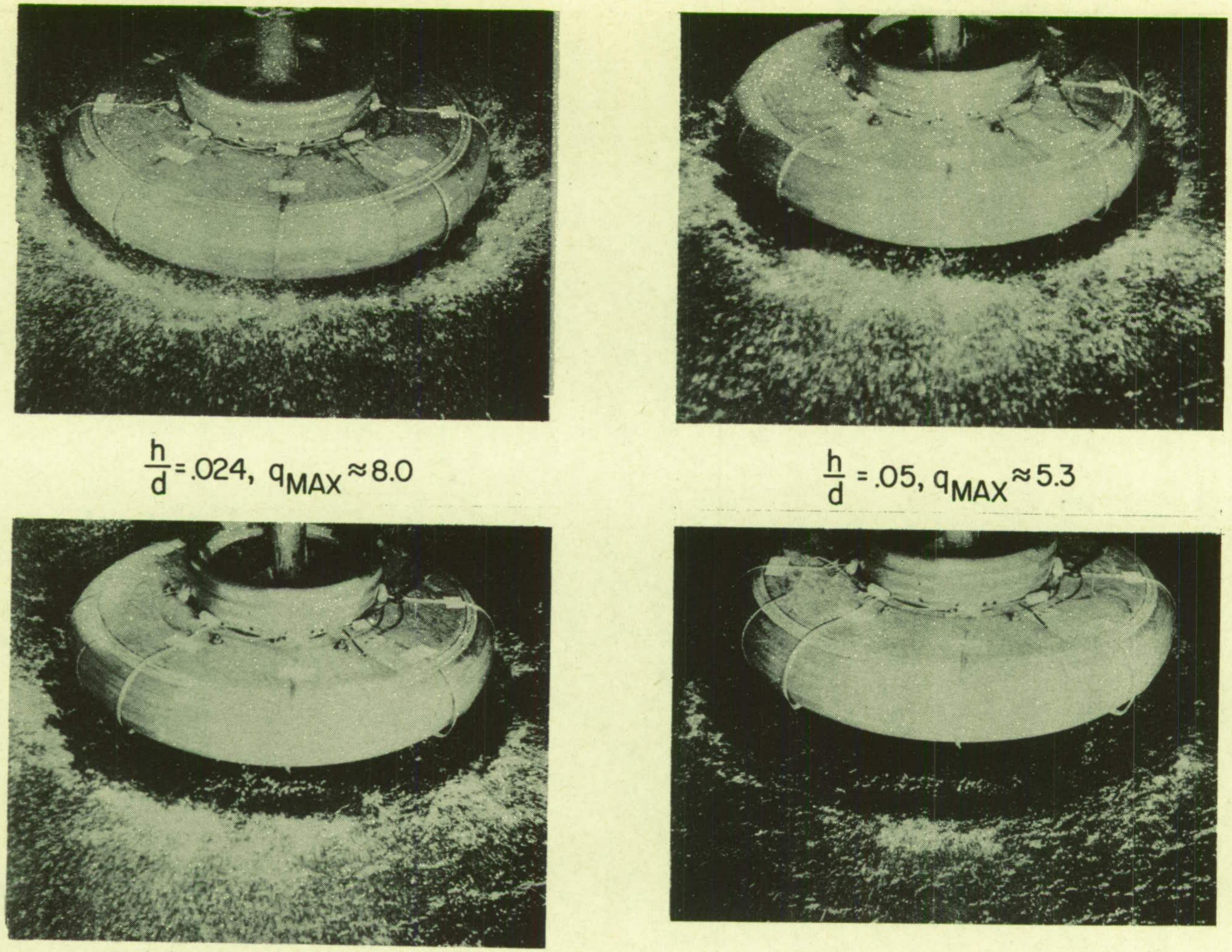
Figure 2.- Comparison of thrust augmentation obtained over water and over fixed groundboard.



$\frac{h}{d} = .024,\ q_{MAX} \approx 8.0$

$\frac{h}{d} = .05,\ q_{MAX} \approx 5.3$

$\frac{h}{d} = .095,\ q_{MAX} \approx 3.3$

$\frac{h}{d} = .143,\ q_{MAX} \approx 2.4$

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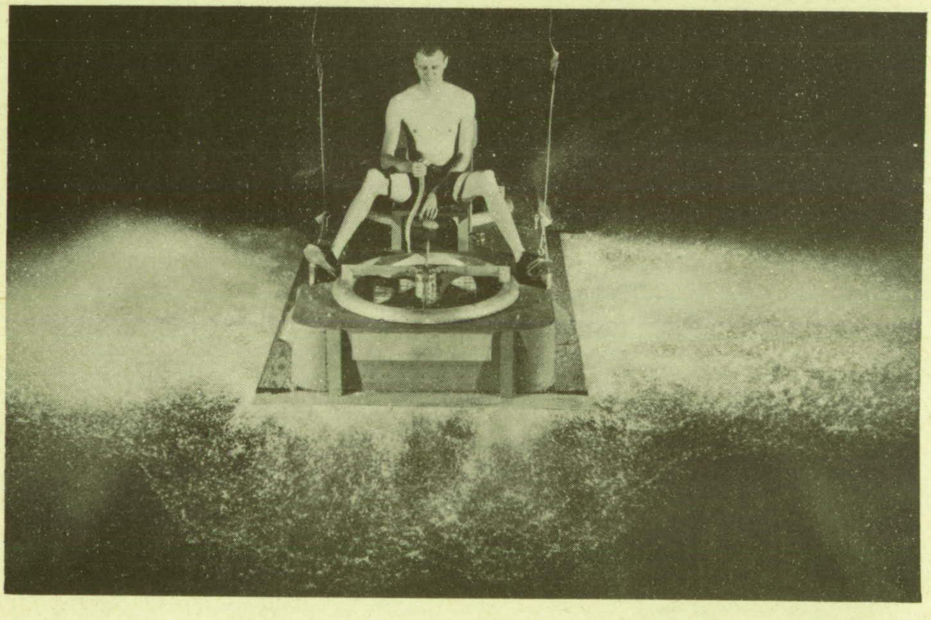
Figure 3.- Spray experienced with 42-inch-diameter model in hovering.

SPRAY DEFLECTORS OFF



SPRAY DEFLECTORS ON

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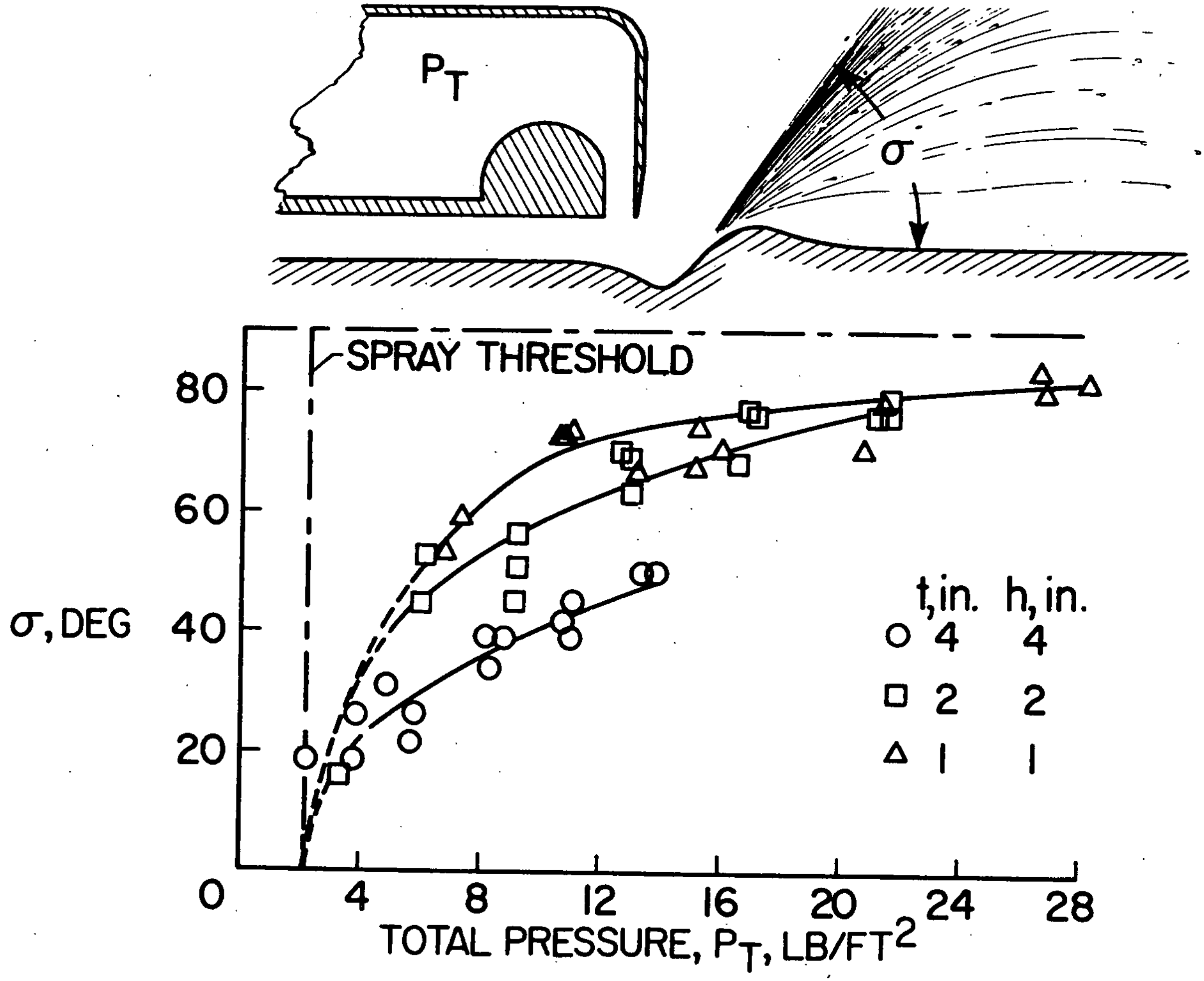
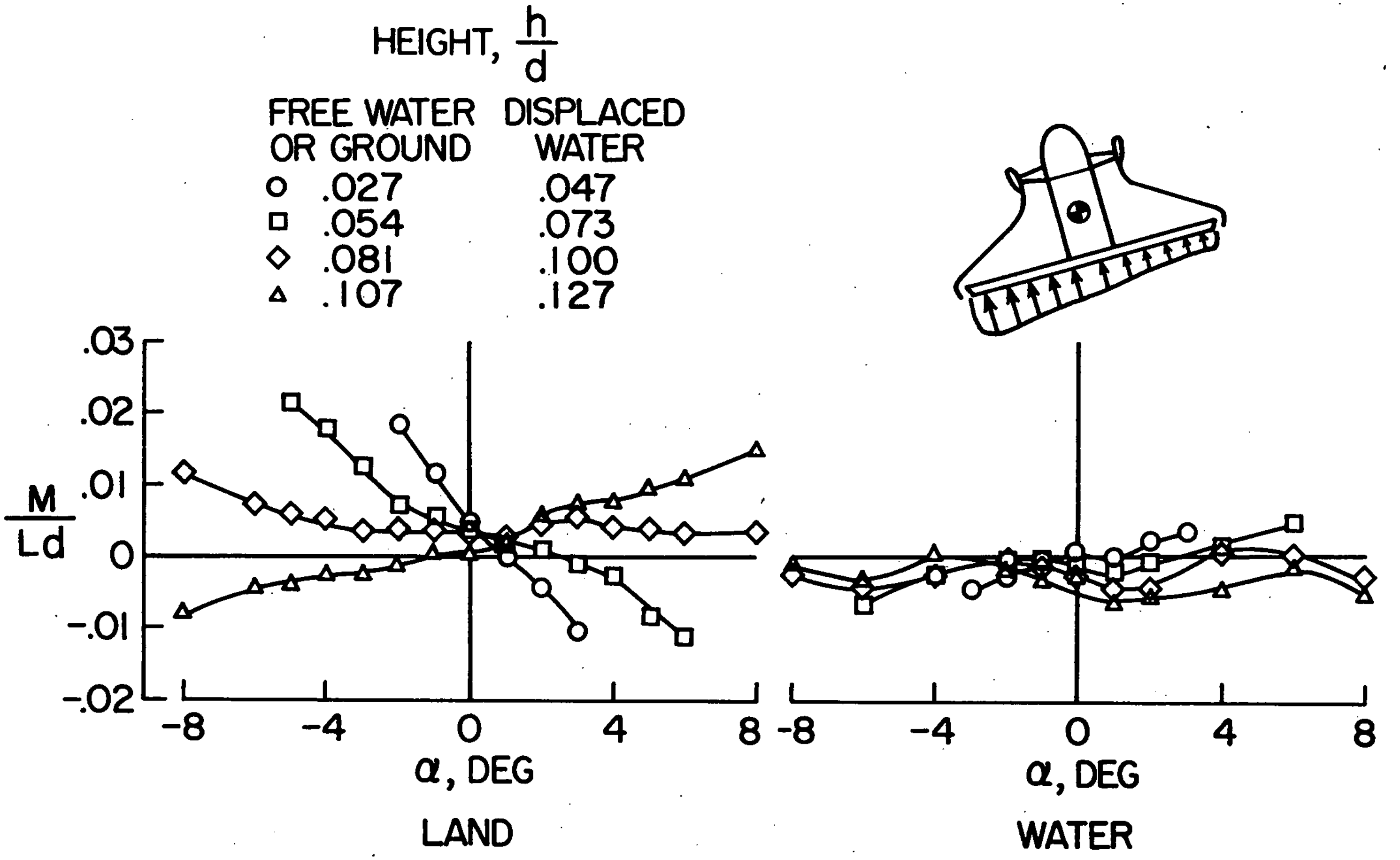
Figure 4.- Effect of spray deflectors.



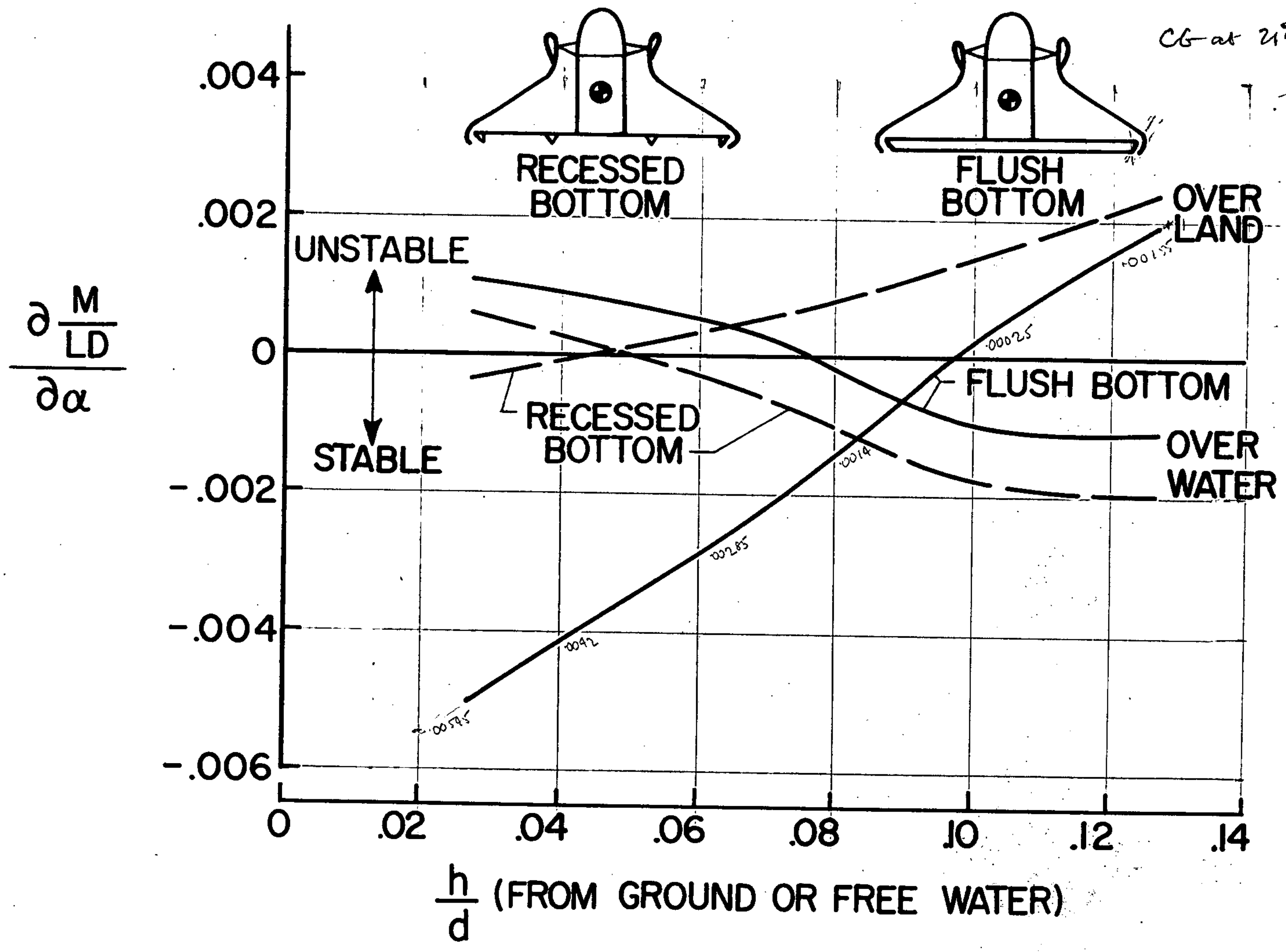
NASA

Figure 5.- Effect of size on spray.



NASA

Figure 6.- Comparison of stability over land and over water.



CG at 21% D above flat base.

$\frac{2.9}{13.8}$

$\frac{h}{D}$ · 0.21

$\frac{h}{D}$ · .025

NASA

Figure 7.- Summary of stability characteristics.

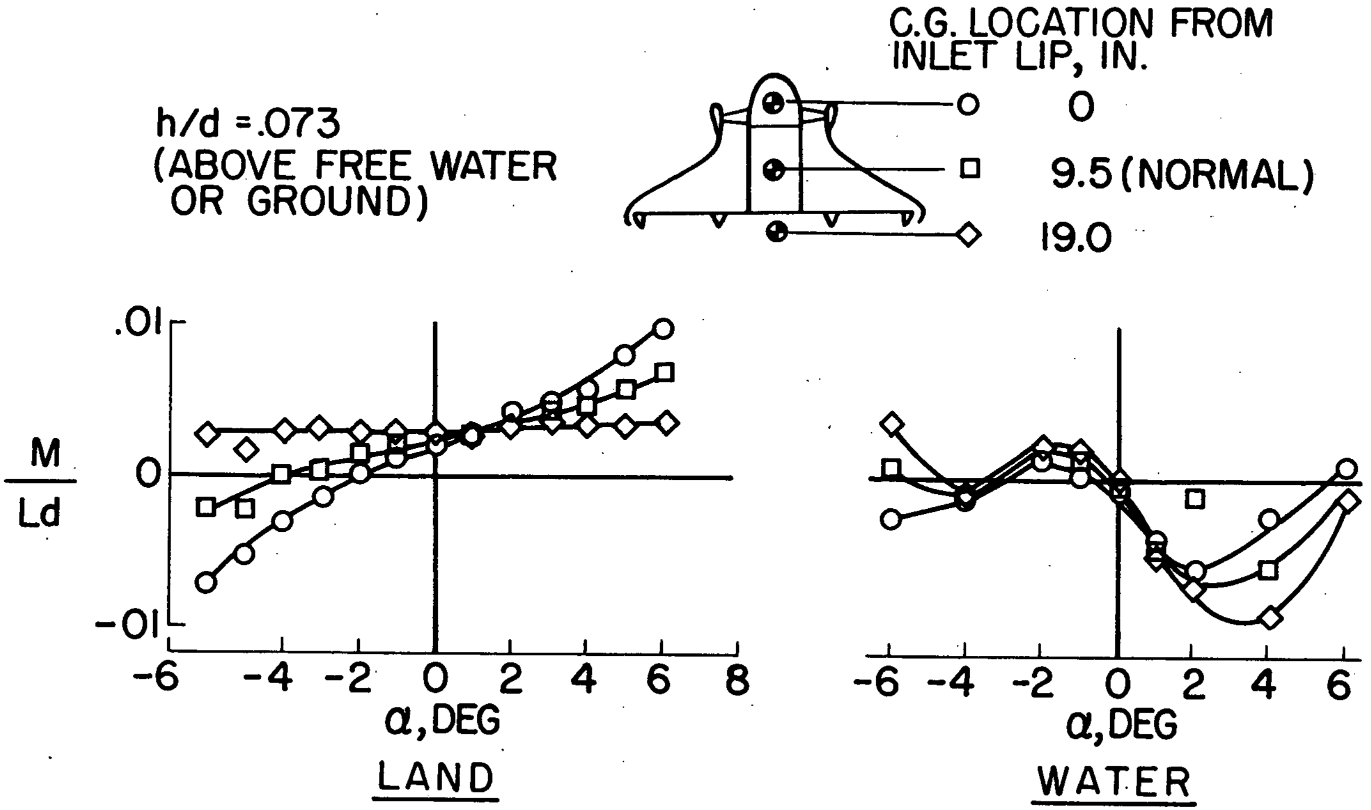


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Figure 8.- Effect of center-of-gravity position on stability of configuration with recessed bottom.

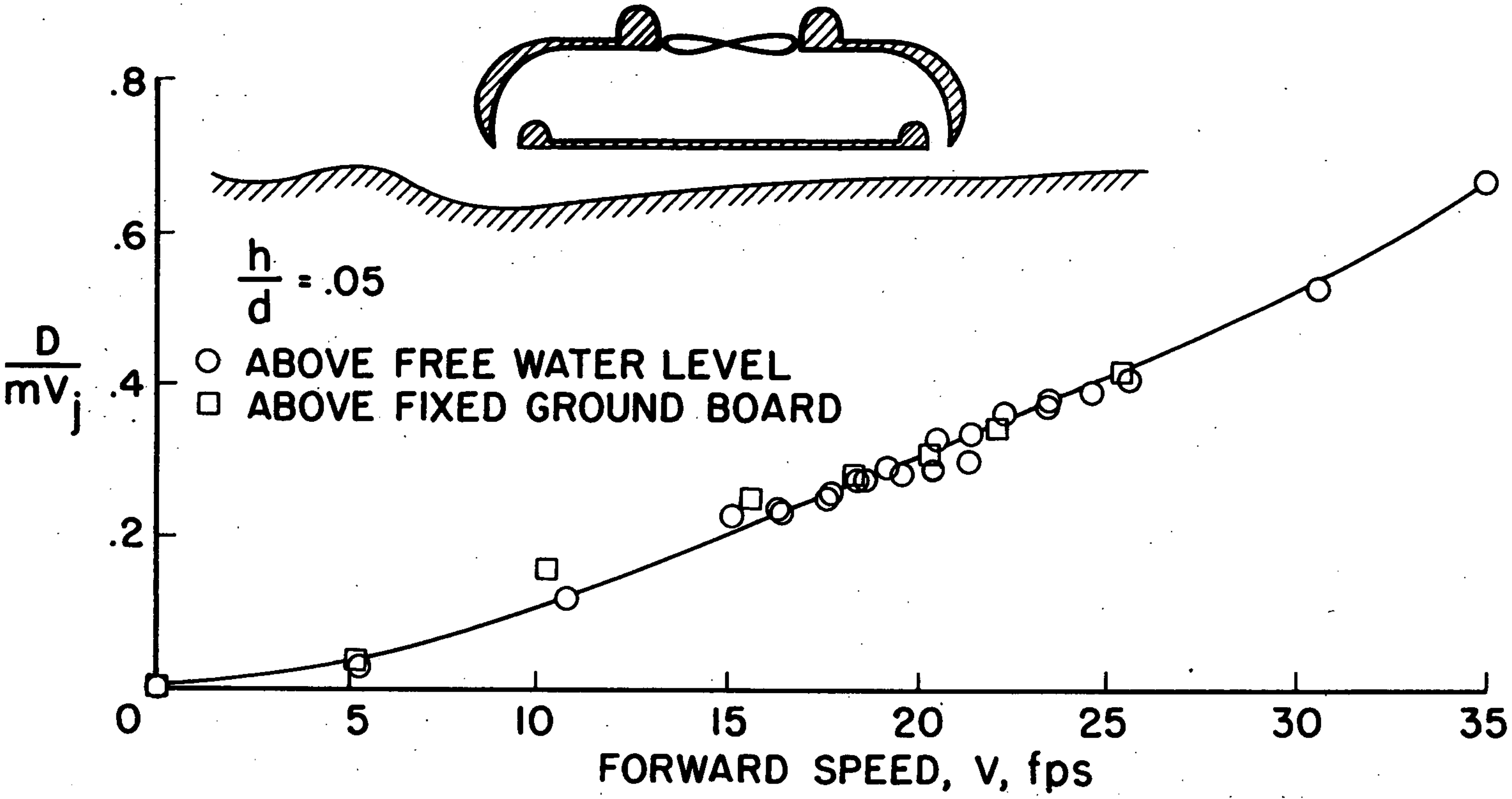

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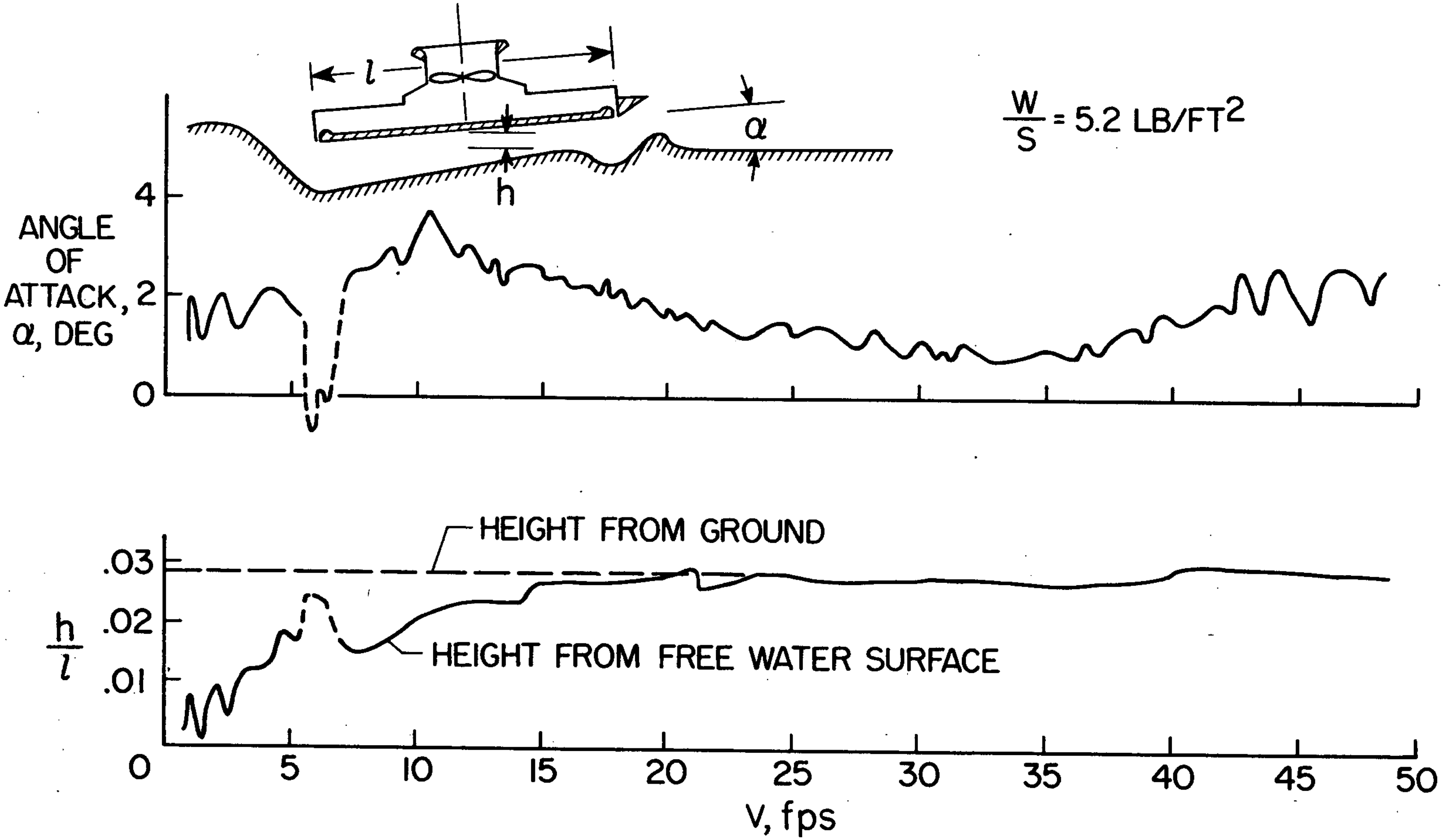
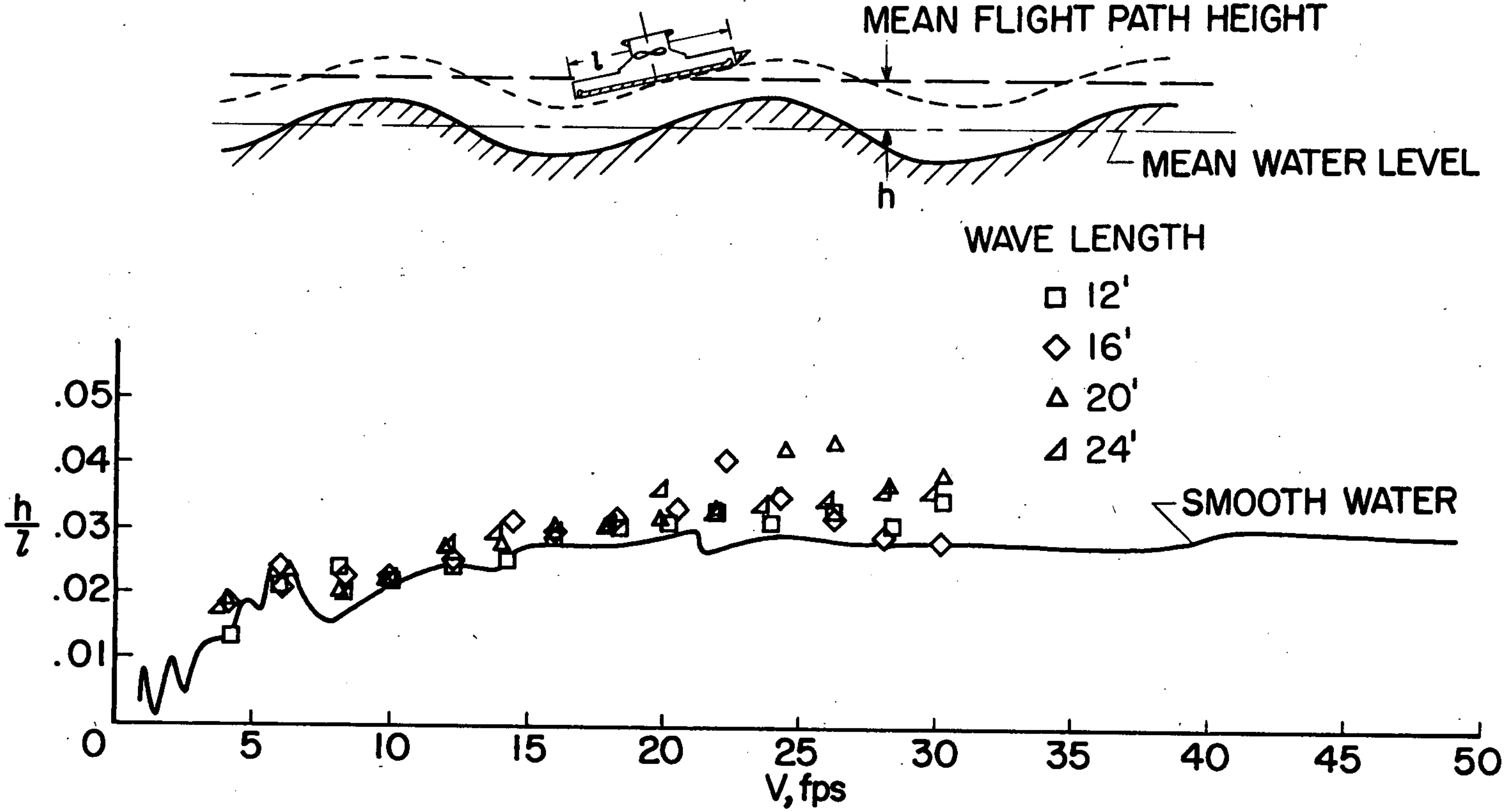
Figure 9.- Comparison of drag of 42-inch-diameter model over water and over fixed groundboard. ($\alpha = 0$).



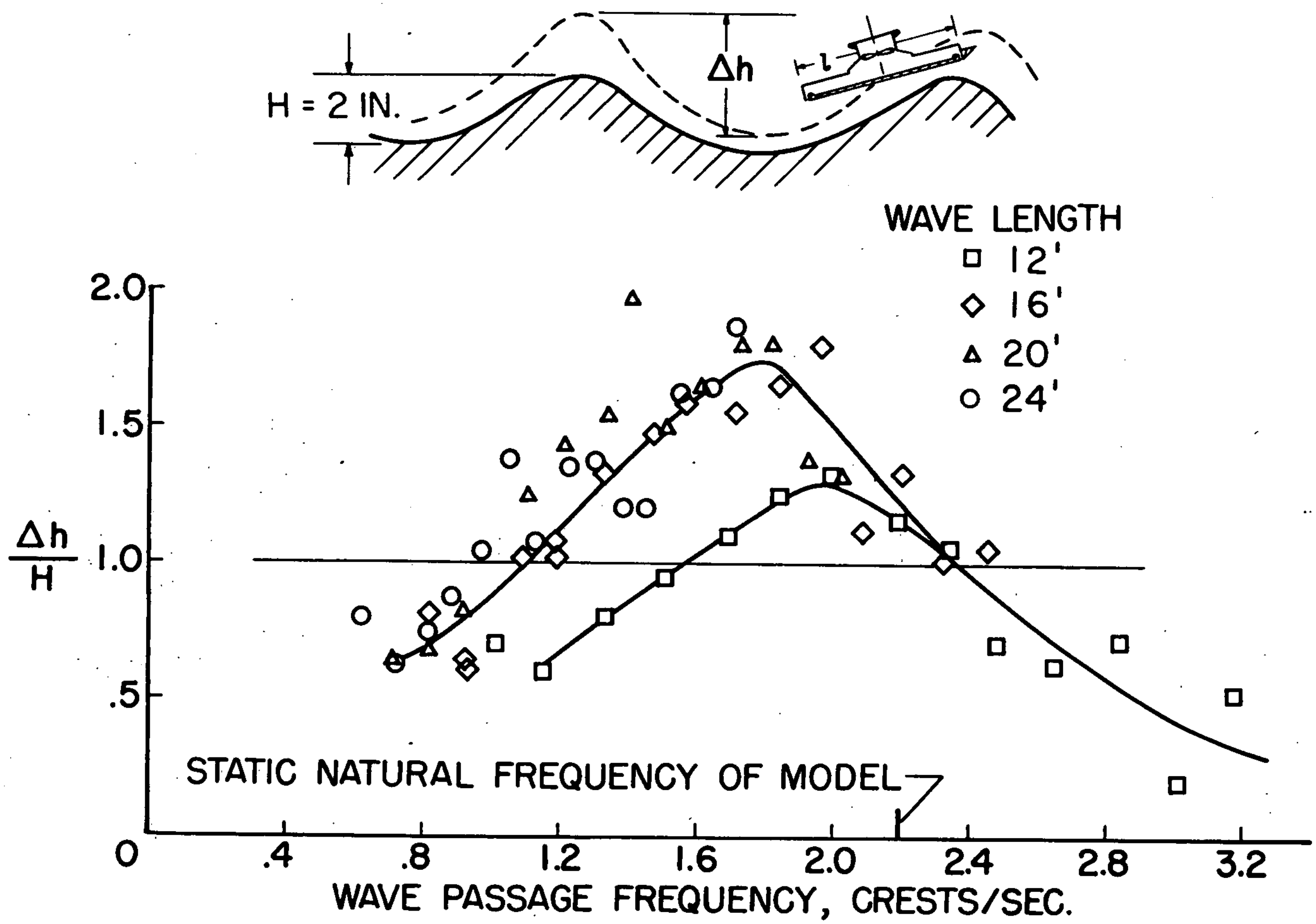
NASA

Figure 10.- Effect of forward speed on trim angle and height.



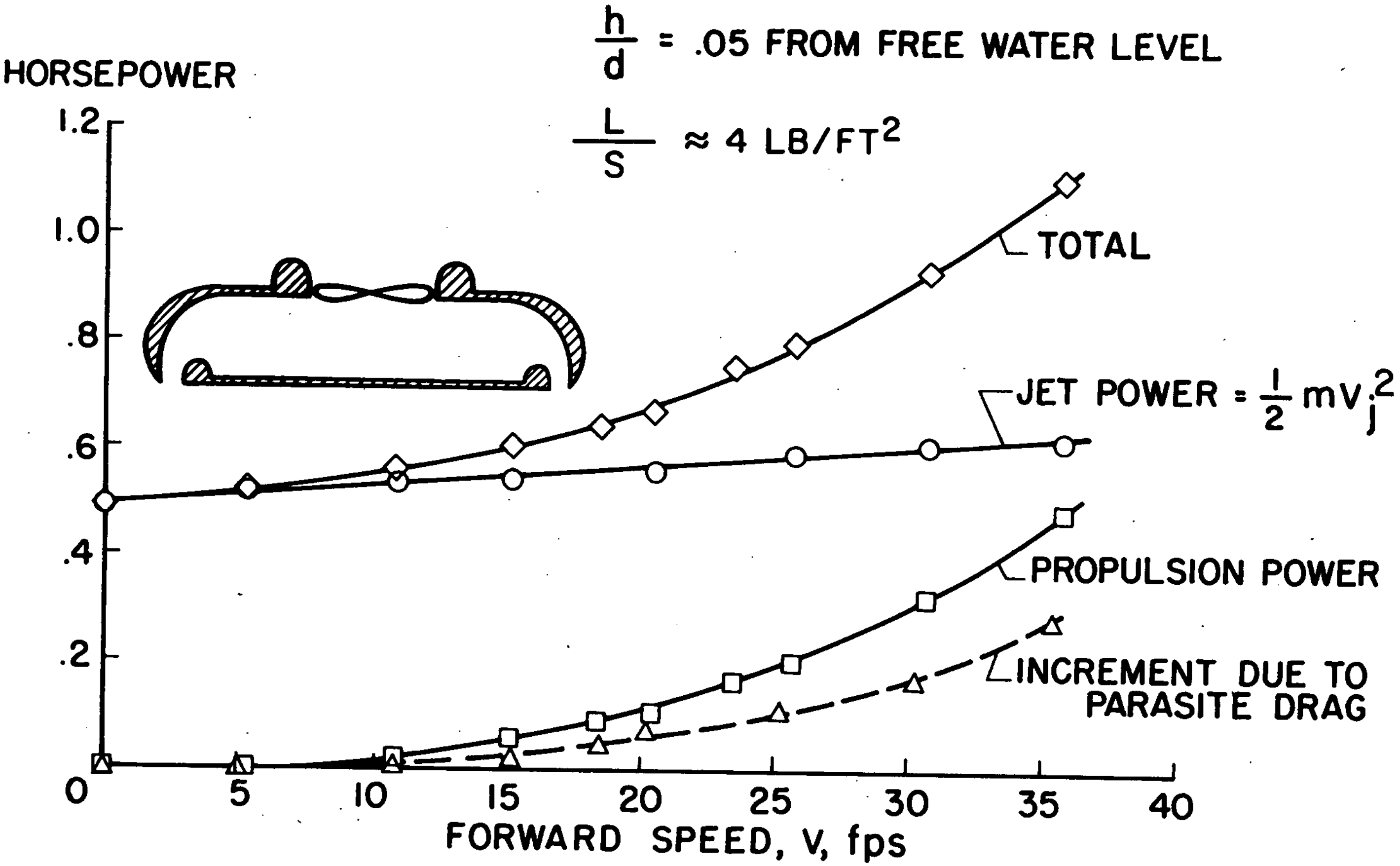
NASA

Figure 11.- Effect of swells on mean flight path height.



NASA

Figure 12.- Amplitude of vertical motion of model operating over swells.



NASA

Figure 13.- Power required by the 42-inch-diameter model (Lift = 40 lb, α = 0.)

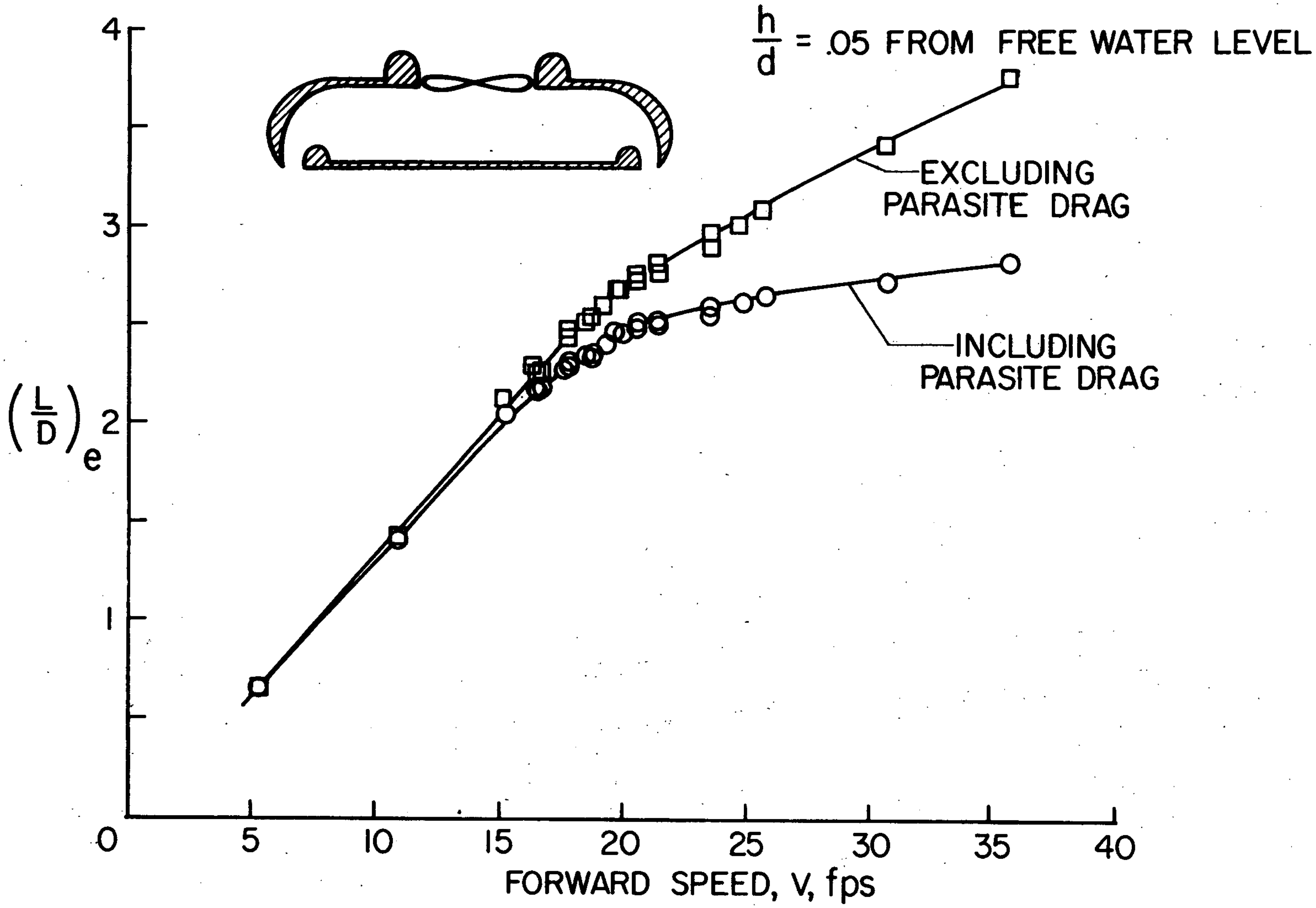


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Figure 14.- Effective lift-drag ratio of the 42-inch-diameter model. (Lift = 40 lb, α = 0.)