Changes in Draft in Shoal Water

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INTRODUCTION

In the available references, chief concern with the problem of a vessel's "squatting" in shoal water has been with the relationship between this tendency and the resistance of the vessel. Data available is generally for small warships operating at high speeds in fairly deep channels. The purpose of this series of tests, however, is to measure the tendency to "squat" in models of ordinary commercial vessels operating with eleven feet or less clearance with the bottom of the channel. Chief concern is with the tendency of a moving vessel to touch bottom in depths somewhat greater than its initial draft.

THEORETICAL BACKGROUND

The tendency of vessels to increase their draft can be explained in terms of venturi effect, using Bernoulli's principle. The total head H of a fluid is taken as the sum of three linear quantities, velocity head, pressure head, and potential head: $H = V^2/2g + h + x$. V is feet per second, h is the pressure divided by the unit density of the fluid, and x is the distance above a reference point. If a body is floating in the fluid, the buoyant force acting on the body is the integral of w h dA and equals the weight of the body. If the system is static, H is the sum of h and x. If the body is moving through the fluid, this sum remains constant but the total head in relation to the body, H_1, increases by $V^2/2g$, the velocity head. However, if this movement causes the fluid passing under the body to move with greater velocity in relation to the body than the body is moving in relation to the bulk of the fluid--if the moving body forces some of its supporting fluid to move with velocity v in the opposite direction than the body is moving--there is no further increase in H_1. H_1 then equals $(V + v)^2/2g + h + x$. $\int w\,h\,dA$ cannot change because the weight of the floating body is constant. Therefore, to maintain the equality, x must decrease to offset the additional velocity head, and the body "squats" to a draft greater by the change in x.

In the case of a vessel operating in deep water, this effect is small. In shoal water, however, the decreased depth causes restriction of flow from three-dimensional to two-dimensional. Water passing under the ship as it moves is forced through what is in effect a venturi tunnel, and its velocity in relation to the ship is increased from V, the velocity of the ship, to V + v, with the corresponding "squat" decrease in x. The size of v depends on the flow lines around and under the ship in shoal water at each speed. Channel width would also have an effect, for water must move in relation to the ship at the rate of A x V cubic feet per second, where A is the midship area and V the velocity of the ship; this movement is either around the ship or under it, depending on its form and the restriction.

TANK TESTING

The tests were run in the University of Michigan Naval Tank between March 9 and March 17. Two models were used: the first of a Pittsburgh Steamship type ore carrier of 26,500 long tons displacement in fresh water, 629'-3" LBP, and .872 block coefficient; the second of a VC2-S-AP3 "Victory" Ship of 14,495 long tons displacement in fresh water, 436'-6" LBP, and .674 block coefficient. Design drafts were 25'-0" and 28'-0" respectively. Both models were to a 1/4" scale.

The false bottom of the tank was raised to scale depths of 21', 25', and 27' to simulate the upbound and downbound channels of the Detroit River and the proposed channel depth of the St. Lawrence Seaway. Speeds were limited by the tendency of models to run aground or by the reaching of the speed of a shallow-water trochoidal wave of 1.25 times the vessel's length, according to Taylor a "hump" in the resistance curve beyond which a medium-speed ship cannot ordinarily be pushed, (3). This speed, v, is found by the formula

$$v^2 = \frac{\epsilon^{\frac{4\pi d_0}{\ell}} - 1}{\epsilon^{\frac{4\pi d_0}{\ell}} + 1} \left(\frac{g\ell}{2\pi}\right)$$

where d_0 is the channel depth and ℓ is the wave length. Below this speed, the curves of squat and trim are fairly orderly; near it and above, they are rather confused. This speed represents a point of maximum resistance, a "hump" in the resistance curve beyond which vessels powered for medium speed cannot be pushed. The limiting speeds in the models tested were about 17.6 mph in the 21' channel, 19.1 in the 25' channel, and 19.8 in the 27' channel. Practically speaking, of course, a vessel will lose speed on hitting shoal water.

Changes in draft were measured by means of two small lights placed at the perpendiculars of the models so that they would project their beams on graduated cards. These cards were read by observers on the platform below the car. The accuracy of the readings is estimated at plus or minus .05" or 0.2 scale feet. Because of labor limitations, readings were generally taken alternately rather than simultaneously. Two series of tests were run with simultaneous readings at set intervals; results of one are shown in Fig. 1.

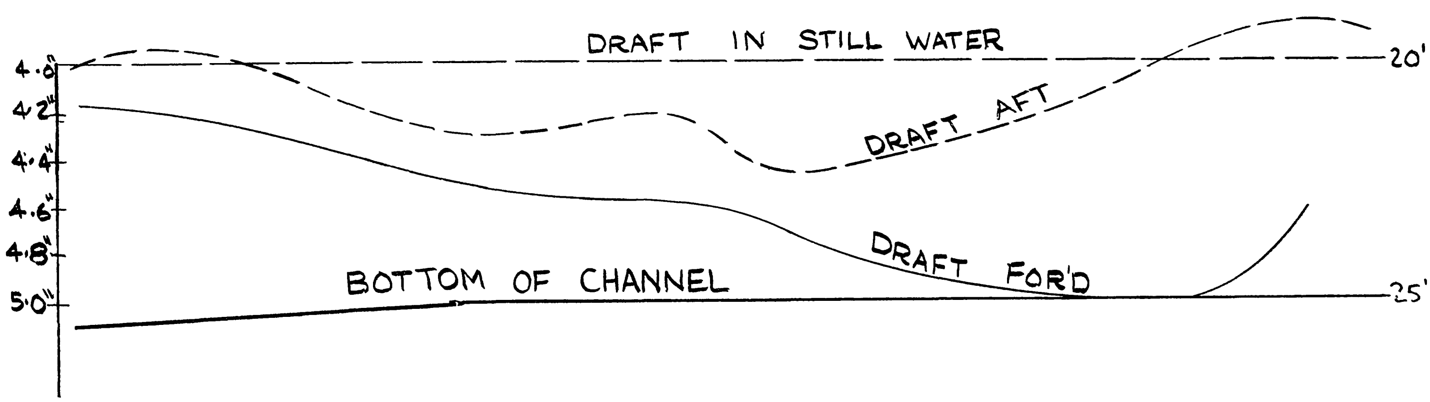

Fig. 1 Changes in Draft Plotted Against Distance: Pittsburgh Class, 20' Draft in 25' Channel, 16 MPH

It can be seen that these changes in draft are not a steady sort of thing. Also, because of the general irregularity of readings no such curve could be plotted accurately for most of the results. Therefore, rather than actually determining trim and squat at an instant, the maximum drafts forward and aft have been taken to have occurred simultaneously, an assumption that is convenient but not necessarily true. In the results, changes in draft forward and aft are taken as these maximum values, squat is taken as the mean between them, and trim as the difference. It must be emphasized that these are fictitious values, that squat and trim are based on values of draft change that may have occurred at different times. However, it was felt that these fictitious values are useful because of their convenience and because they represent maximum values, the main point of interest in shallow channels.

In addition, it should be mentioned that several effects are not taken into account in the tank tests, that of the propeller in particular. The effect of the propeller could be expected to be a slightly greater tendency to trim by the stern. The influence of wind and waves would also call for a margin of safety.

THE TENDENCY TO SQUAT

The shallow water effect will be taken in two parts, squatting and trimming. Squat gives the mean draft and trim is the trim at that draft, the two together giving the draft change at each perpendicular.

Results of the tests were first plotted against speed at each draft and the results faired within the limits of test accuracy. It was found that the logarithm of squat plots nearly as a straight line against speed. In such a plot, the line representing the squat of the Victory Ship generally had somewhat the greater slope of those for the two types of hull. With few exceptions, the value of squat in a given draft-depth situation was greater at each speed-length ratio for the Pittsburgh-class ore carrier than for the Victory. For this reason it was decided to include a factor for the size of the ship, and beam was finally selected. The semi-log plots of squat over beam versus speed-length ratio for the Victory Ship and the ore carrier generally cross, with those for the Victory Ship having the higher slope. Further correction for differences in form would involve parameters using fractional powers; this would seem to be an over-refinement for the amount of data available from the tank tests.

Fig. 2 shows a summary of the results of the tests on the ore carrier. The ratio of draft to channel depth finally chosen as a parameter is not entirely satisfactory; it called for some rather drastic cross-fairing in some cases. The final curves can be used to estimate squat within an accuracy of about .10" in the 1/4" scale models. Although drawn for the ore carrier only, the curves in Fig. 2 are reasonably accurate for both hulls; errors tend generally to be on the conservative side. Fig. 3 shows two random samples of correlation between curves plotted from the summary in Fig. 2 and the actual data.

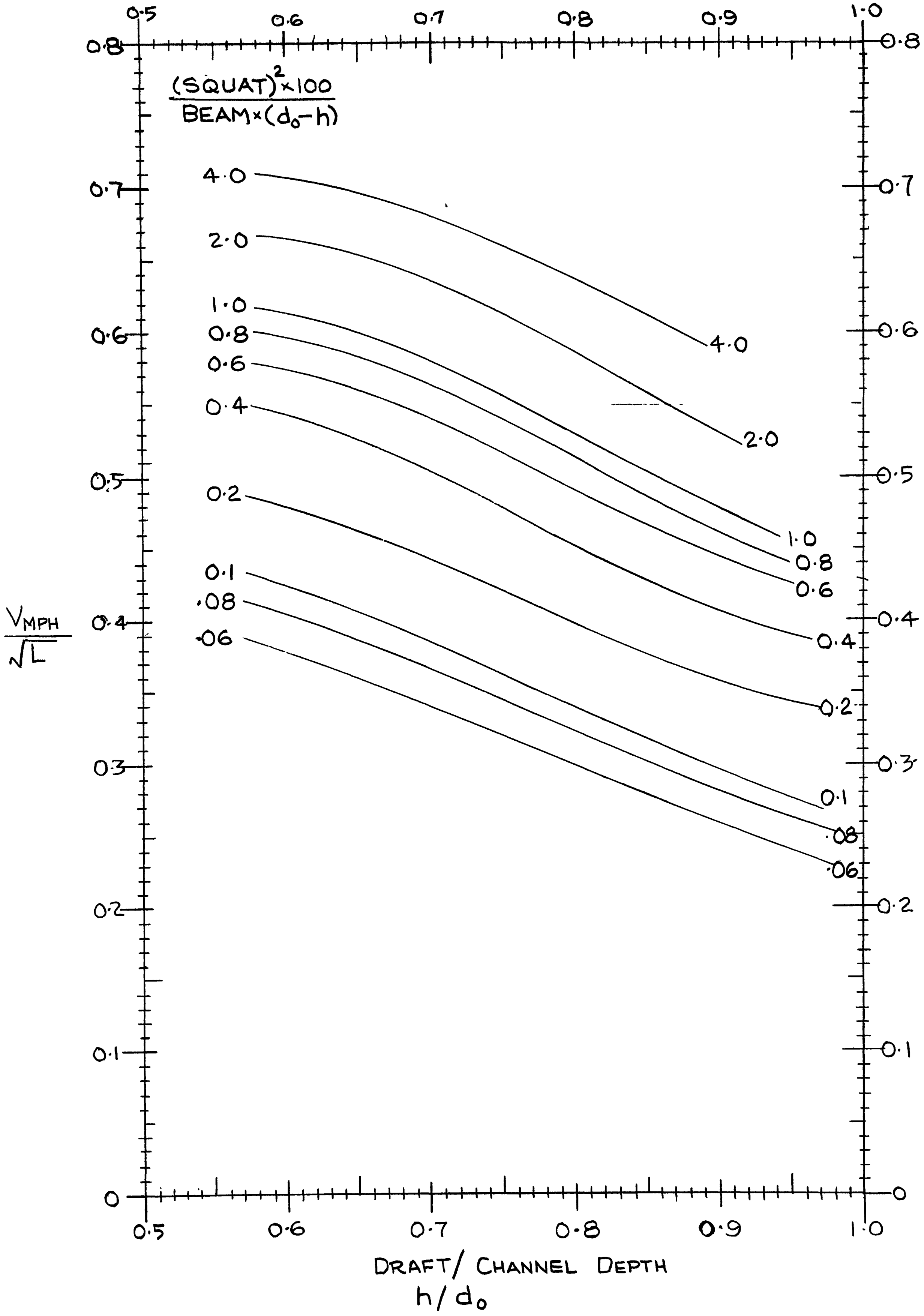

Fig. 2 Summary of Squat Results, Pittsburgh-Type Ore Carrier

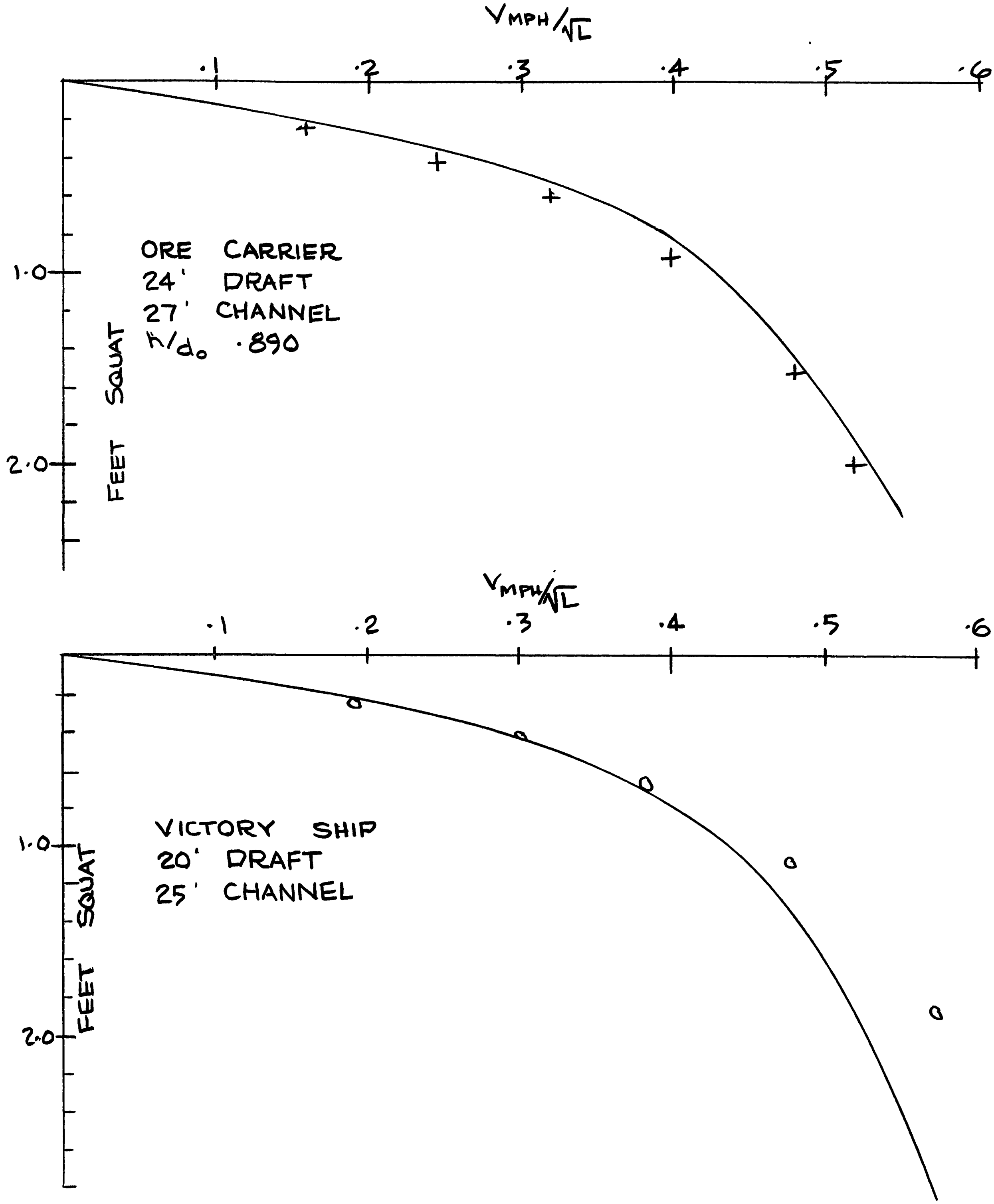

Fig. 3 Correlation Between Test Results and Squat Predicted from Fig. 2

THE TENDENCY TO CHANGE TRIM

Unlike squat, which could be reduced to a reasonable pattern, the tendency to change trim in shallow water does not appear possible to generalize from the data of the tests. Fig. 4 shows summary curves of trim/length plotted against the speed-length ratio; those for the ore carrier are dashed and for the Victory Ship, solid.

Of possible interest in the comparison of the trim results is the following table for the centers of flotation:

	$\frac{\text{CF from Fore Perpendicular}}{\text{Length}}$	
Draft	Victory Ship	Ore Carrier
16	.4736	.4892
17	.4739	.4913
18	.4742	.4930
20	.4746	.4971
22	.4753	.5014
24	.4764	.5061

THE EFFECT OF INITIAL TRIM

Because of the general inclination of the vessel to trim by the head when moving through shoal water, it would appear that an initial trim by the stern would be advantageous in offsetting the likelihood of grounding forward. There is, however, a possibility that flow and pressure patterns would be altered by this initial trim and that the initially trimmed vessel would gain additional trim aft to ground there. To check this possibility, two tests were run with the ore carrier in a trimmed condition and one with the Victory Ship. At a 16' draft in a 21' channel and trimmed 2' by the stern, the ore carrier exhibited both the same trim and squat characteristics, gaining draft forward at a greater rate than aft. With 20' draft, 4' trim aft, and 27' channel, the change in trim was nearly nil, but the squat curve was a bit lower. The Victory Ship, trimmed 4' aft at a draft of 16' in the 21' channel, showed the same squat and trim change characteristics as in the even keel condition; however, the change in trim forward was not great enough to offset the high initial trim aft, and the vessel grounded aft at about the same speed it would have grounded forward had it been in the even keel condition. These three tests suggest that two to four feet trim by the stern is generally useful in preventing grounding--that the flow and pressure distribution patterns are not substantially altered.

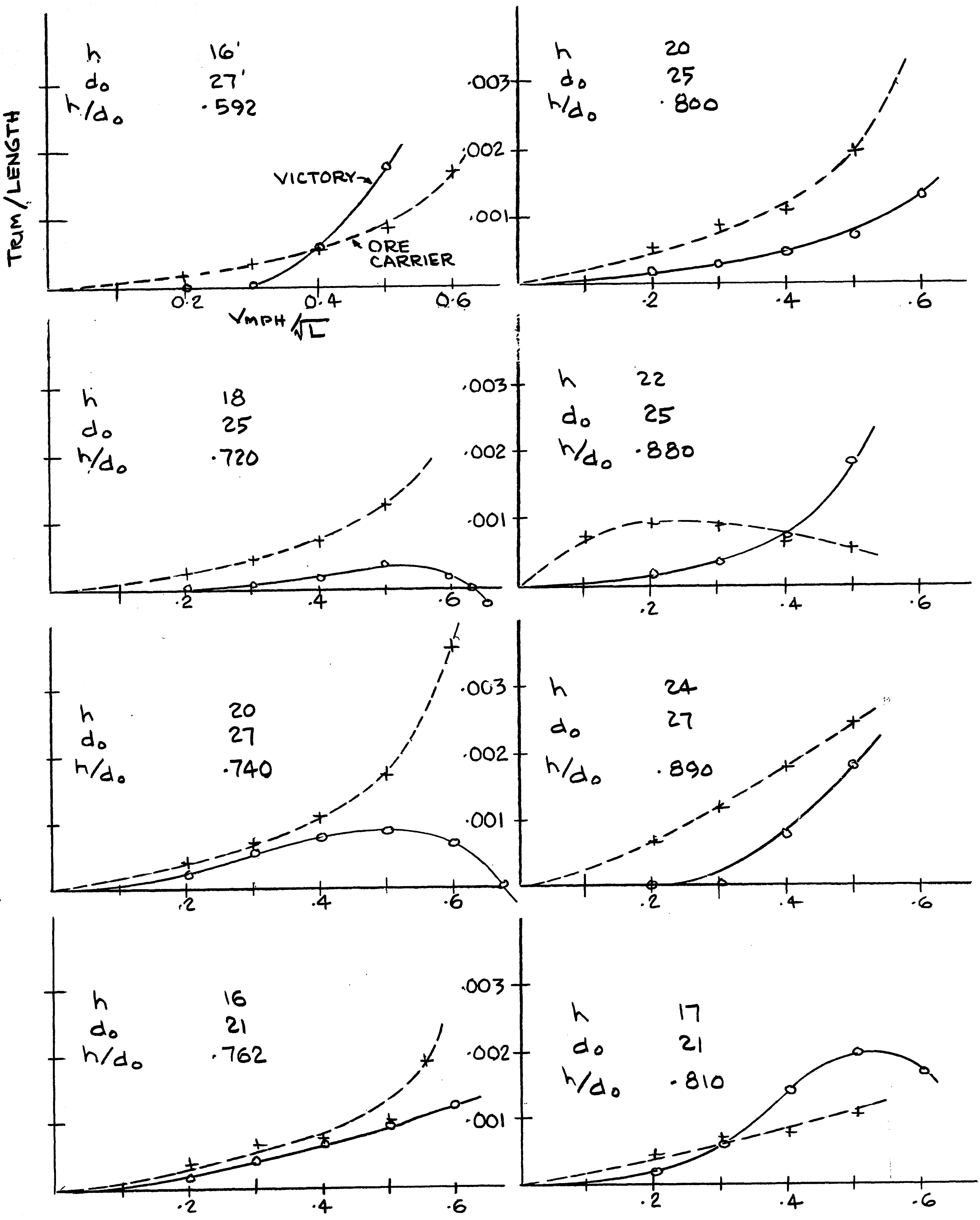

Fig. 4 Trim/Length

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