No. 205
September 1978

MANEUVERING CHARACTERISTICS OF GREAT LAKES VESSELS

by

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INTRODUCTION

Recently, a new regulation, USCG 33 CFR 164.35(g) [1]*, went into effect, requiring that the following information shall be prominently displayed on a fact sheet in the wheelhouse:

> "(1) For full and half speed, a turning circle diagram to port and starboard that shows the time and the distance of advance and transfer required to alter the course 90 degress with maximum rudder angle and constant power settings.
>
> "(2) The time and distance to stop the vessel from full and half speed while maintaining approximately the initial heading with minimum application of rudder.
>
> "(3) For each vessel with a fixed propeller, a table of shaft revolutions per minute for a representative range of speeds.
>
> "(4) For each vessel with a controllable pitch propeller, a table of control settings for a representative range of speeds.
>
> "(5) For each vessel that is fitted with an auxiliary device to assist in maneuvering, such as a bow thruster, a table of vessel speeds at which the auxiliary device is effective in maneuvering the vessel.
>
> "(6) The maneuvering information for the normal load and normal ballast condition for —
>
> (i) Calm weather — wind 10 knots or less, calm sea;
> (ii) No current;
> (iii) Deep water conditions — water depth twice the vessel's draft or greater; and
> (iv) Clean hull.
>
> "(7) At the bottom of the fact sheet, the following statement:
>
> WARNING
>
> The response of the (name of the vessel) may be different from that listed above if any of the following conditions, upon which the maneuvering information is based, are varied:
> (1) Calm weather — wind 10 knots or less, calm sea;
> (2) No current;
> (3) Water depth twice the vessel's draft or greater;
> (4) Clean hull; and
> (5) Intermediate drafts or unusual trim."

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*References are listed at the end of the paper.

Since this regulation was issued, Great Lakes operators have been running maneuvering trials to gather the required information. A student project was proposed to the Great Lakes and Great Rivers Section of the Society of Naval Architects and Marine Engineers for the collection of the maneuvering information from these operators. These data were to be analyzed and recommendations made concerning the accuracy of the data, the testing procedures, and the format of the charts. It was also hoped that this would be a first step toward obtaining a general description of the maneuvering characteristics of Great Lakes bulk carriers.

This paper is a result of that project, which was partially successful in meeting the above goals.

NOMENCLATURE

A Advance [ft], defined as the distance traveled in the original direction of motion, starting when the turn begins and ending when it is completed (See Figure 1);

H Headreach [ft], defined as the distance traveled by the ship during a stopping maneuver;

T Transfer [ft], defined as the distance traveled in the direction perpendicular to the original direction of motion, measured at the completion of a 90° turn (See Figure 1);

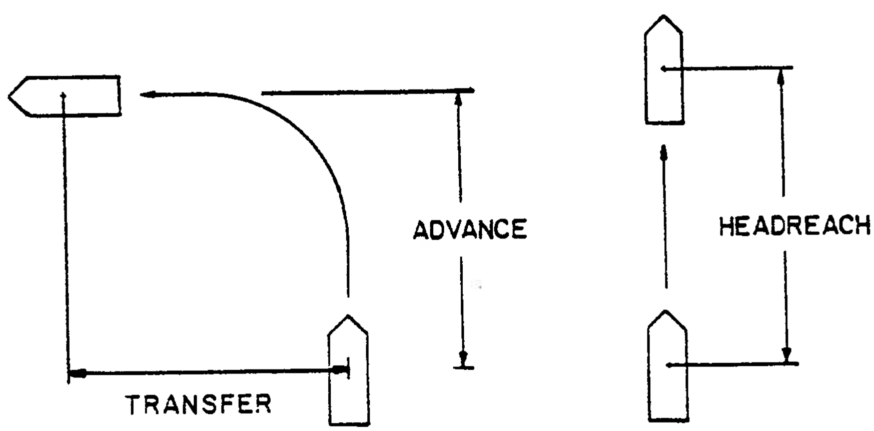


FIGURE 1

L	Ship length [ft];
R	Ship resistance at start of maneuver [lbs];
t_S	Time to stop [sec];
t_T	Time to complete a 90° turn [sec];
V	Initial speed of ship [ft/sec];
Δ	Ship displacement [tons].

DATA AVAILABLE

Data from 31 ships were used in the analysis in this paper. Table 1 gives a breakdown of these ships by length. The longest ship was 858 ft, the shortest, 352 ft.

TABLE 1

Breakdown of Ships Reported by Length

Under 500 ft	2
500 - 600 ft	5
600 - 700 ft	18
700 - 800 ft	5
Over 800 ft	1

Only two maneuvers are considered, turns and stops, since very little information was obtained on other maneuvers. Also because of the small amount of data, only a few variables are used in the analysis. In the turning analysis, the variables are advance (A), transfer (T), time to turn (t_T), initial speed (V), and ship length (L). In the stopping analysis, the variables are headreach (H), time to stop (t_S), initial speed (V), and ship length (L). Table 2 shows the number of ships from which measurements of these variables were available.

The data were collected using radar or visual sightings on buoys either set in place by the Coast Guard or dropped over the

TABLE 2

Number of Data Points Available

Variable	Number of Ships: Full Info.	Number of Ships: Partial Info.
A	22	5
H	19	6
T	23	3
t_S	25	5
t_T	24	6

side. Some visual sightings were taken by dropping a block near the bow every time the last block dropped passed by a reference point along the ship. Table 3 gives a breakdown of the measurement methods used by the various ships. Some operators mentioned that they used both radar and visual sightings but gave no specific breakdown.

TABLE 3

Measurement Method Used

Maneuver	Radar	Visual	Visual w/blocks	Radar & Visual	Unknown
90° Turns	19	0	0	5	7
Stops	3	0	15	5	7

TURNING

Most of the data for the turning tests were taken with the ship completing just a 90° turn; thus the data reflect the actions taken by the master to pull out of the turn. A few ships reported advance and transfer data taken during a full turning circle maneuver; these are not considered further because of their small number.

It may be noted that the USCG regulation does not specify what turning maneuver is to be used in collecting these data.

The 90° turns were executed to both port and starboard. Since the ships were single-screw ships, the data varied considerably between port and starboard turns. Insufficient data were available to distinguish generally between port and starboard turning characteristics, however, and so such data (where available) were averaged.

Three nondimensional coefficients are used in the 90° turn analysis: (1) A/L , (2) T/L , (3) L/Vt_T . The first two give advance and transfer, each nondimensionalized by the ship length. The third coefficient is the reciprocal of the product of ship initial speed and time to complete a 90° turn, also nondimensionalized by ship length. These quantities appeared to be the most reasonable for use in this analysis, and they gave the best fit of all the coefficients considered.

Figures 2 and 3 show T/L and A/L plotted against the speed/length ratio, $V/\sqrt{L}$. (An auxiliary scale shows the equivalent nondimensional quantity, $V/\sqrt{gL}$, which is, of course, the Froude number.) In these figures, if a single straight-line curve were to be fitted to the data points, it would be very nearly a a horizontal line, indicating that A and T do not change much with speed. Advance increases slightly with increased speed, but transfer is practically unchanged. The small variation in advance with speed may be caused by the ship sideslipping at higher speed.

Figure 4 shows L/Vt_T plotted against $V/\sqrt{L}$. A straight line through these points would have a greater downward slope than the slight upward slope of the curves in Figures 2 and 3. Now L/Vt_T can be interpreted as $(L/\text{Path traveled}) \times (V_{ave}/V)$, where V_{ave} is the average speed through the turn. The path length traveled is fairly independent of V, since A and T are practically independent of V. Thus the slope in the L/Vt_T line comes mainly from a decrease in V_{ave}/V . This implies that there

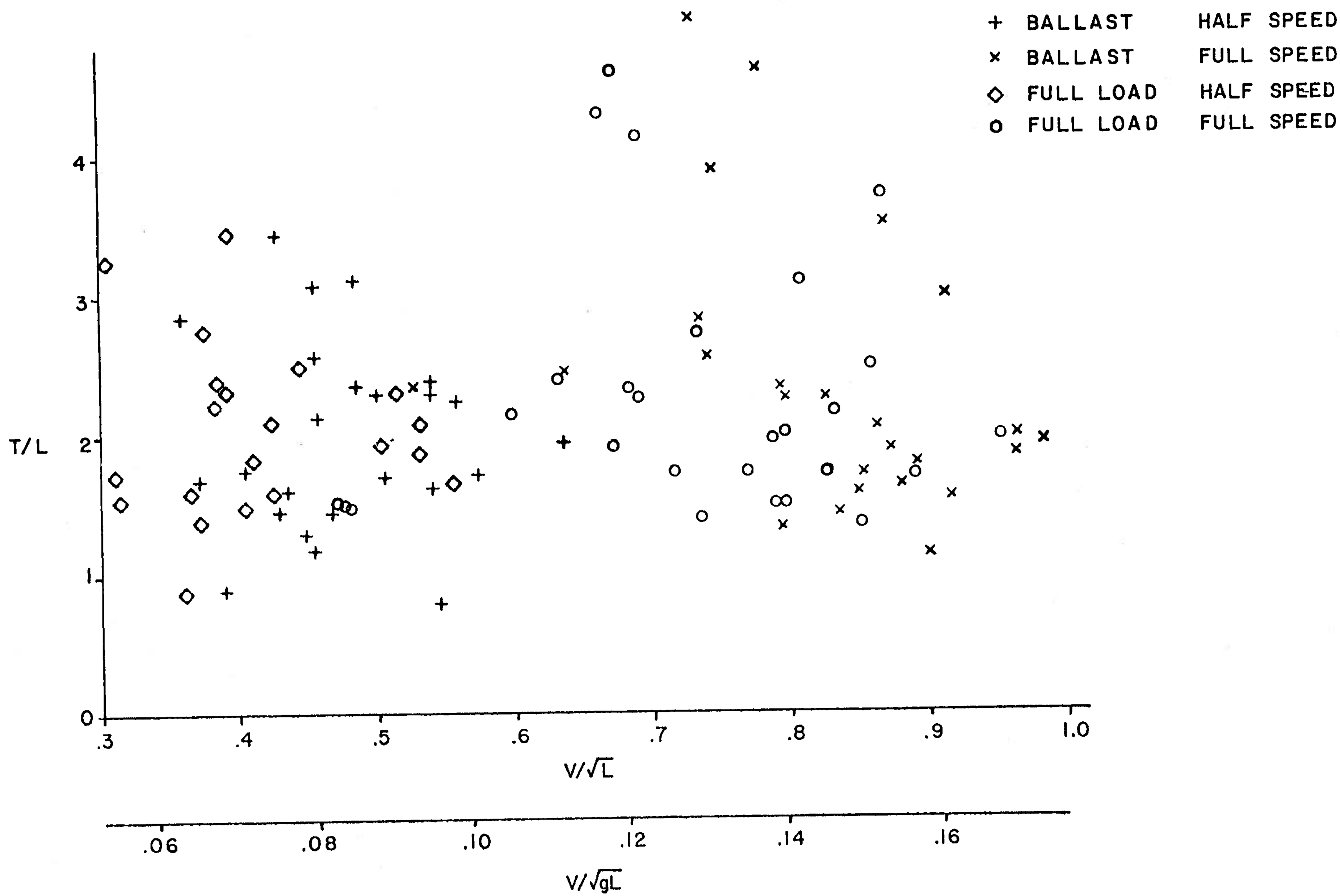


FIGURE 2 : TRANSFER , 90° TURN

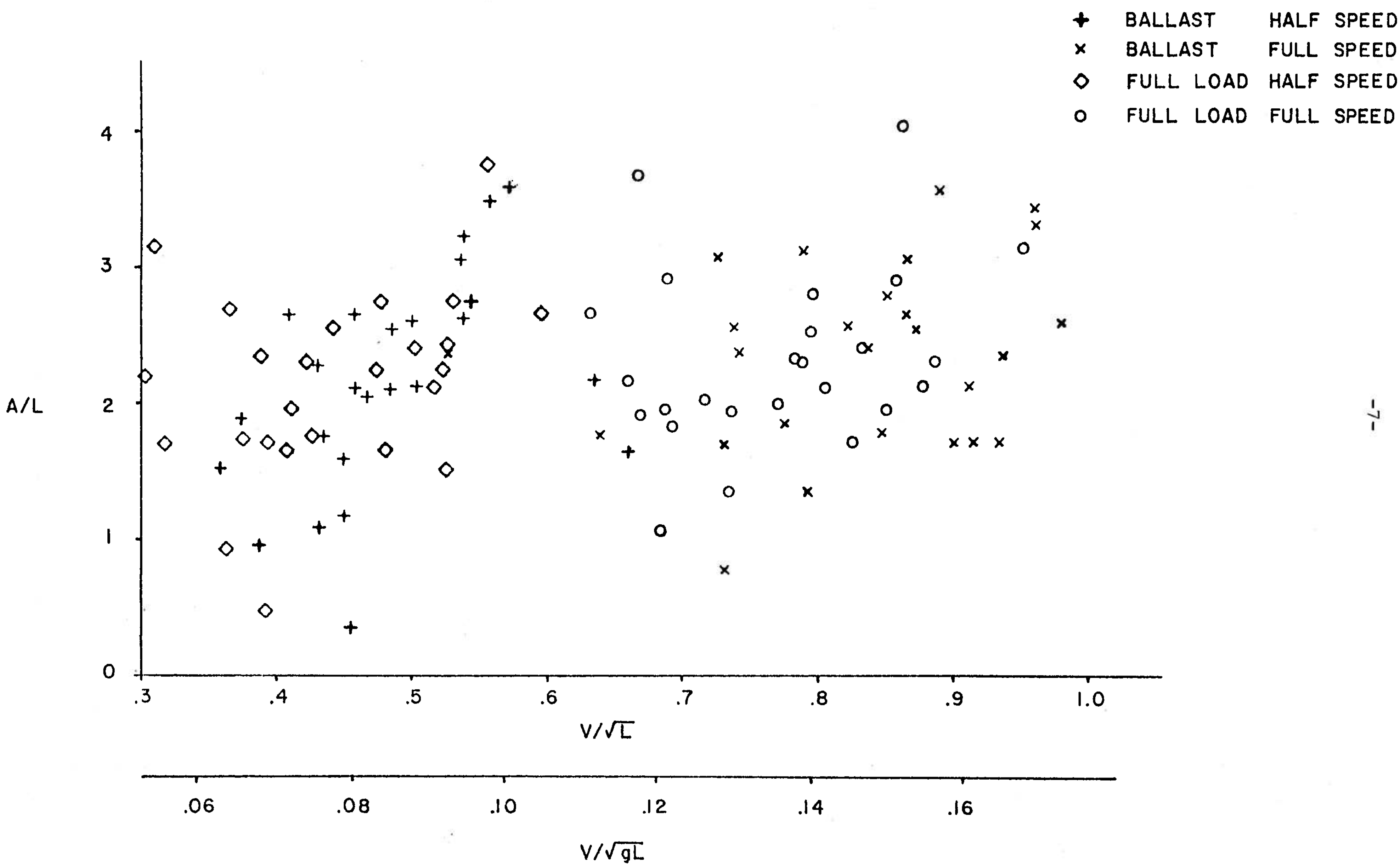


FIGURE 3 : ADVANCE , 90° TURN

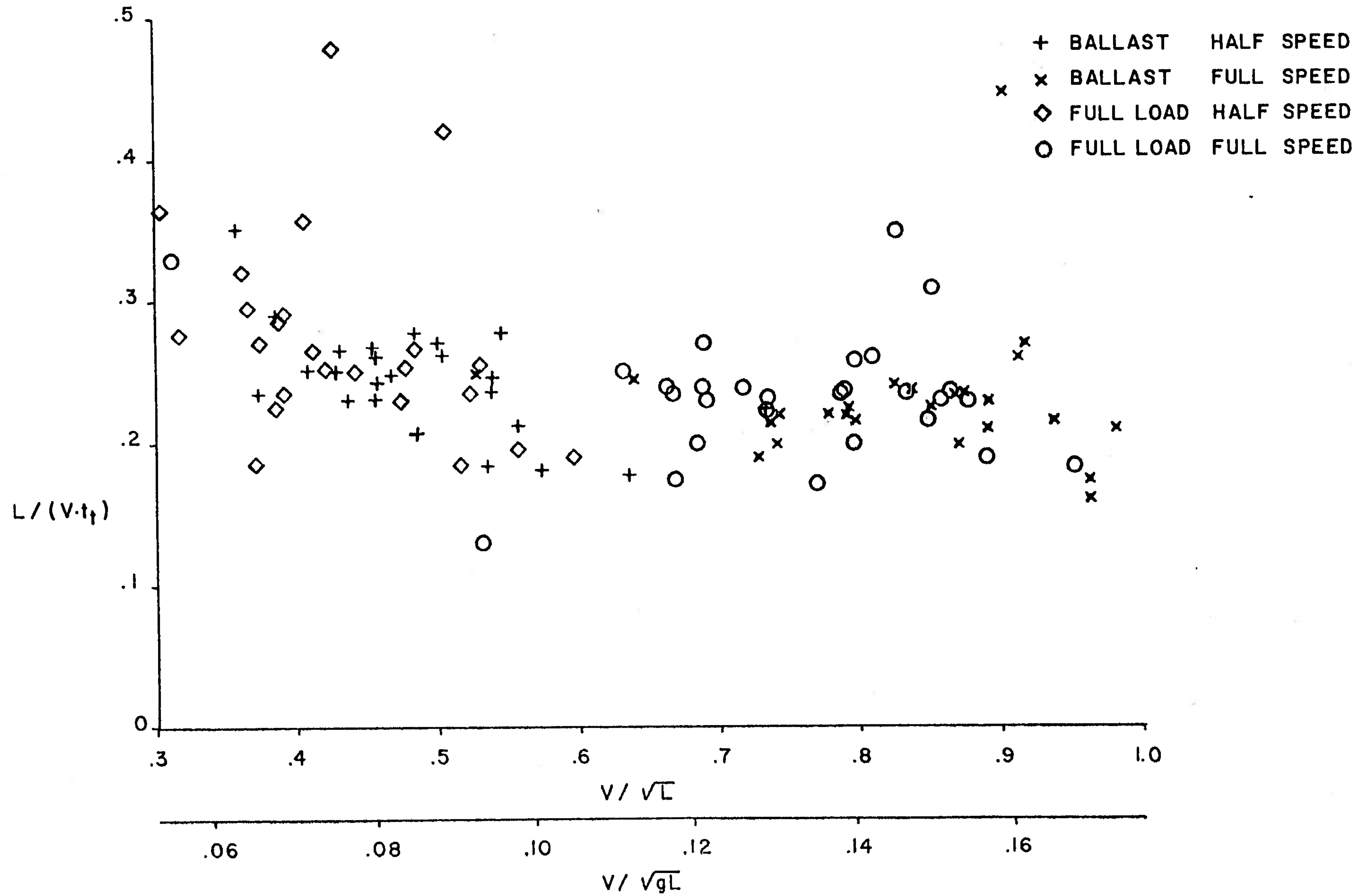


FIGURE 4 : L / (V·t_t) , 90° TURN

is a greater loss of speed in a turn starting at a larger initial speed.

The two plots of A/L and T/L show a large amount of scatter, so much that no attempt was made to fit a line or curve through the points. Part of this is due to errors in the data. Some ships reported exactly the same advance and transfer for port and starboard turns. This seems unlikely for a single-screw ship. There are undoubtedly other sources of error in the data. In addition, some scatter may be from trying to describe a complex process by a few variables. There are many differences among the ships for which data are available, and it is not obvious that the quantities A/L and T/L depend only on the speed/length ratio.

The plot of L/Vt_T shows much less scatter than the plots of A/L or T/L . This is probably because time is much more easily measured than distance.

STOPPING

The second set of maneuvers were stops. In these maneuvers the ships were stopped as quickly as possible without veering off course. The Coast Guard regulation requires that the ship maintain approximately the initial heading with a minimum application of rudder. Only a few ships reported the actual amount of the change in course at the end of the stopping maneuver, and no ship reported the amount of rudder that was needed to minimize the change in heading.

Three nondimensional coefficients are used in the analysis of the stopping maneuver, H/Vt_S , $V/\sqrt{gH}$, and L/Vt_S . The first is actually the ratio average speed/initial speed. The second is based on Reference 2, where it is indicated that

$$R \sim \Delta V^2/H .$$

This is analogous to Newton's Law; here the acceleration is V^2/H . (The square root, that is $V/\sqrt{H}$, was used to reduce the scatter.) The last coefficient, L/Vt_S , provided the best fit of a group of coefficients that contained just t_S (not H).

Figure 5 shows H/Vt_S plotted against $V/\sqrt{L}$. It shows that the typical average velocity during a stop is between 40% and 50% of the initial speed and the ratio does not change strongly with speed.

The figures show a larger amount of scatter than expected. A large part is due to bad data. Some of the data is unbelievable. For example, the point at $H/Vt_S = 1.09$ implies that the average speed during the stop for that ship was higher than the initial speed. And, as before, another part of the scatter is from trying to describe a complex process by a few variables.

Figure 6 is a plot of $V/\sqrt{gH}$ against $V/\sqrt{L}$. There is a noticeable difference between the values for full load and ballast conditions. This may be due to the greater mass at full load.

Figure 7 shows L/Vt_S plotted against $V/\sqrt{L}$. There is little difference between full and ballast conditions. This implies that the stopping times are about the same, which is very interesting, since the headreach is greater for the full load condition.

CONCLUSIONS

In this paper, I have tried to analyze the data to see if the maneuvering characteristics of Great Lakes ships can be related to a few basic parameters. The graphs show that there is some relationship among the parameters chosen, but the only possible way to see how strong these relationships are is to improve the accuracy of the data and to standardize the maneuvering tests.

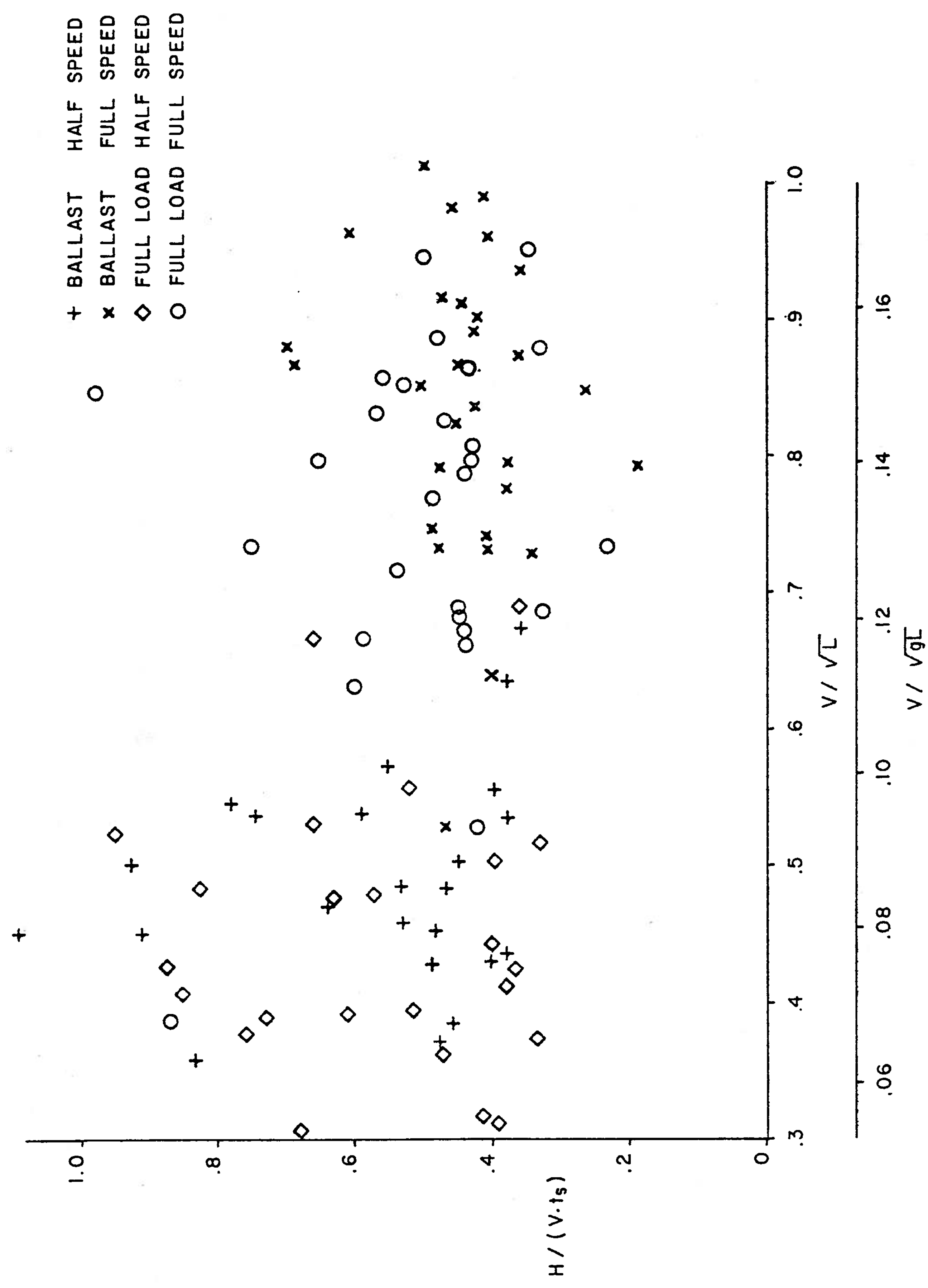


FIGURE 5 : $H / (V \cdot t_s)$, STOPPING

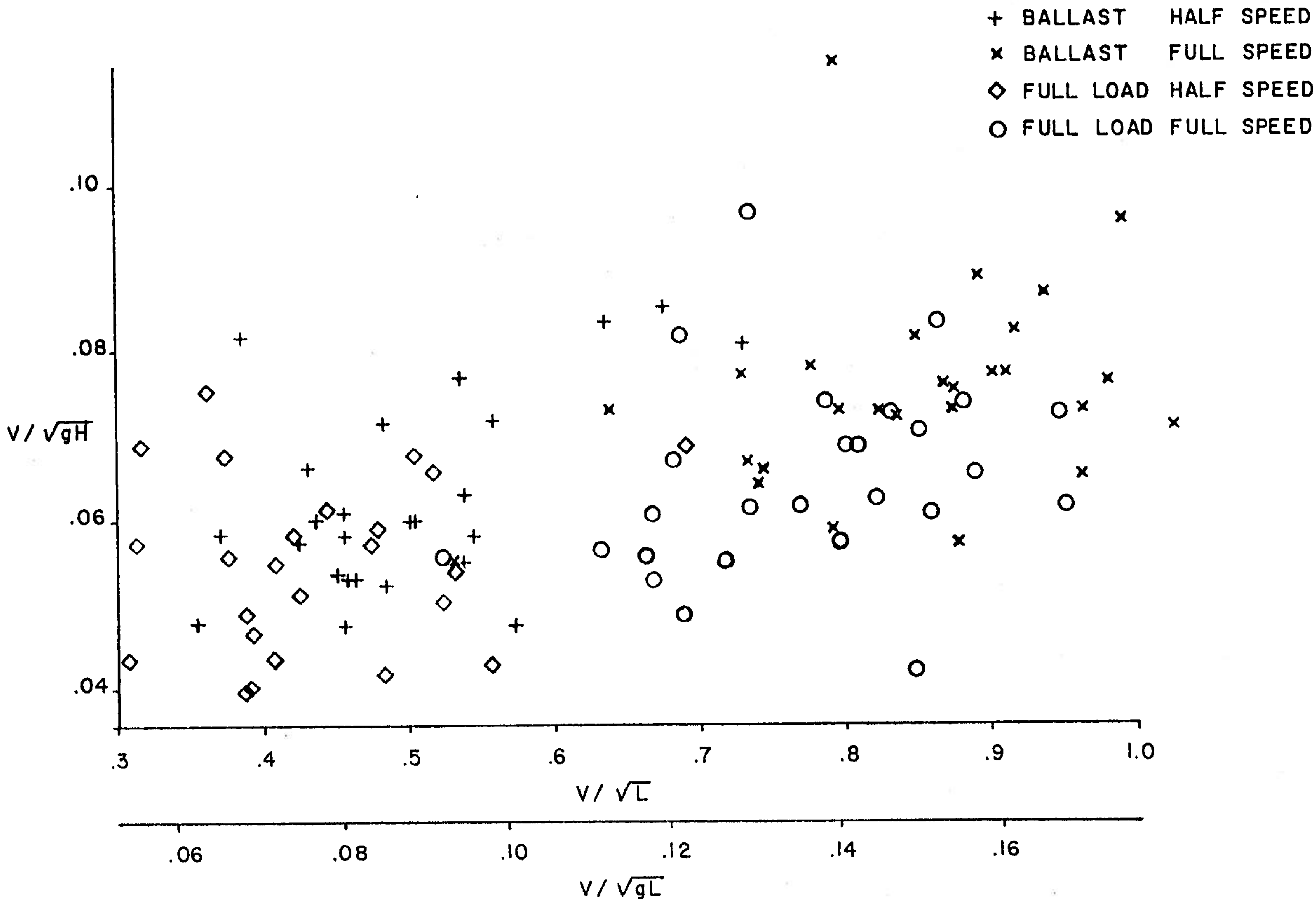


FIGURE 6 : $V/\sqrt{gH}$, STOPPING

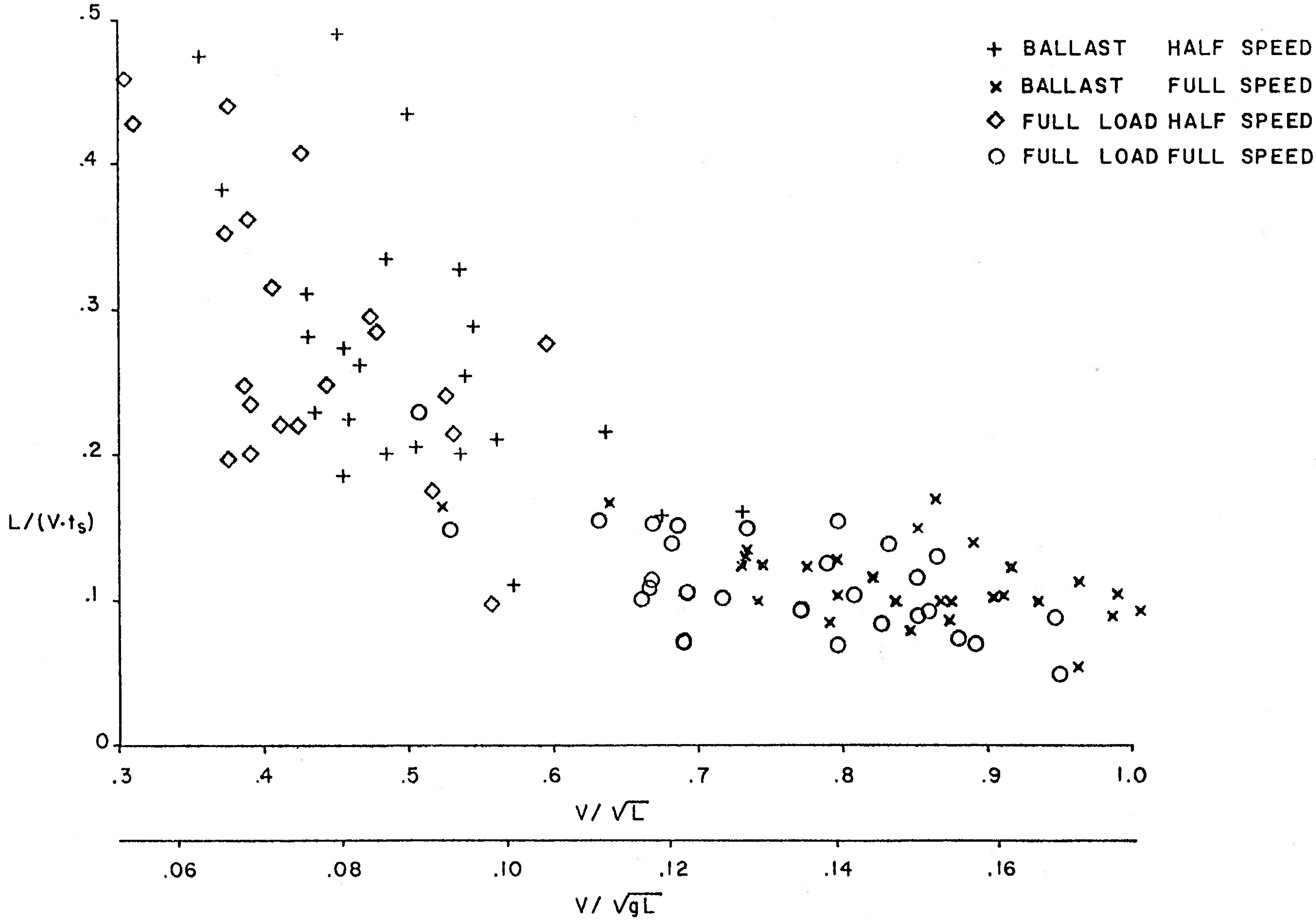


FIGURE 7 : $L/(V \cdot t_s)$, STOPPING

A number of qualitative generalizations may be drawn from the series of maneuvering data plots. Figures 2 and 3 indicate that the advance and transfer for a 90° turn do not increase rapidly with speed. Figure 4 shows that the average speed through a turn becomes a smaller fraction of the initial speed when the initial speed is increased. For the stopping tests, Figure 5 indicates that the average speed during a stop is 40% to 50% of the initial speed. Figures 6 and 7 show that while a ship in the full load condition has a larger headreach than in the ballast condition, the stopping times for both conditions are about the same.

One purpose of this project was to estimate the level of accuracy of the maneuvering parameters obtained from available data. This cannot be done becuase of the lack of a sufficiently large body of data and because of the large data scatter. However, if we assume that the radar has an error of at most 60 feet, and if the crew members are able to use good techniques and make acceptable engineering measurements, then the error could be around 5%. This is good enough accuracy for the maneuvering charts, since the information will only be valid for certain displacements and "ideal" conditions (no current, calm weather, clean hull, deep water, etc.), which can be vastly different from the conditions encountered during an emergency.

RECOMMENDATIONS

The results show that there is a lot of scatter in the data. More information is needed, and the accuracy of the information needs improvement. The testing procedures need standardization so that comparison between ships will be more meaningful.

More information is needed because the body of data used in the analysis was just too small. A larger body of data is necessary so that extreme values can be averaged out. Also, more information on the ships themselves (such as the type of propeller and powerplant, rudder area and angle, etc.) will help.

The accuracy of the information needs improvement. One way to improve it is to use radar in all measurements. (Not all of the ships used radar.) Radar is an easier and more accurate method of measurement than either tossing blocks over the side or visual sighting. Also, by placing a sheet of plastic over the radarscope and marking the reference buoys' positions with a pen (and making a note of the scale), a permanent record is made that can be rechecked later. Another reason for using radar is that it is relied upon in poor visibility, when an emergency maneuvering situation is more likely to arise.

Accuracy can also be improved by establishing a set of standard test procedures. These will give the crew a set of guidelines to follow, which can reduce human error.

One goal in this project was to develop feasible procedures for obtaining the maneuvering data. These procedures should result in a high level of accuracy in the data, require no special skills or equipment, and not be time consuming. Also, by setting down a set of standard procedures, comparisons using the maneuvering data of different ships will be more meaningful.

The following is a set of procedures developed by gathering together all those used by the ships in this analysis and keeping the best features.

(1) A buoy and radar should be used for the turning and stopping tests. By fitting a piece of plastic over the radarscope, marking the positions of the buoys on the scope with a pen, and knowing the ship heading, all of the information needed for the maneuvering chart can be collected.

(2) For both the turns and the stops, tests should be run

at full and half speed in both full load and ballast conditions.

(3) If the turns are 90° to both port and starboard, the data should be taken when the order to turn is given, and again when the ship is stabilized on a course 90° from the original direction of motion. Twin screw ships should leave both propellers at the same rpm and pitch during the turn. If the turns are 360° full-circle turns, the data should be taken every 10 to 15 seconds. The points can be plotted later, and the advance, transfer, and times can be taken from the plots.

(4) The stops should be run so that the ship maintains the approximate initial heading with a minimum use of the rudder. Data should be taken when the order to stop is given and again when the ship is dead in the water. (Another possibility is to take the data every 10 - 15 seconds during the stop. The ship path then can be plotted and the amount of variation of the initial course shown.) Notes should be made of the time and magnitude of rudder changes.

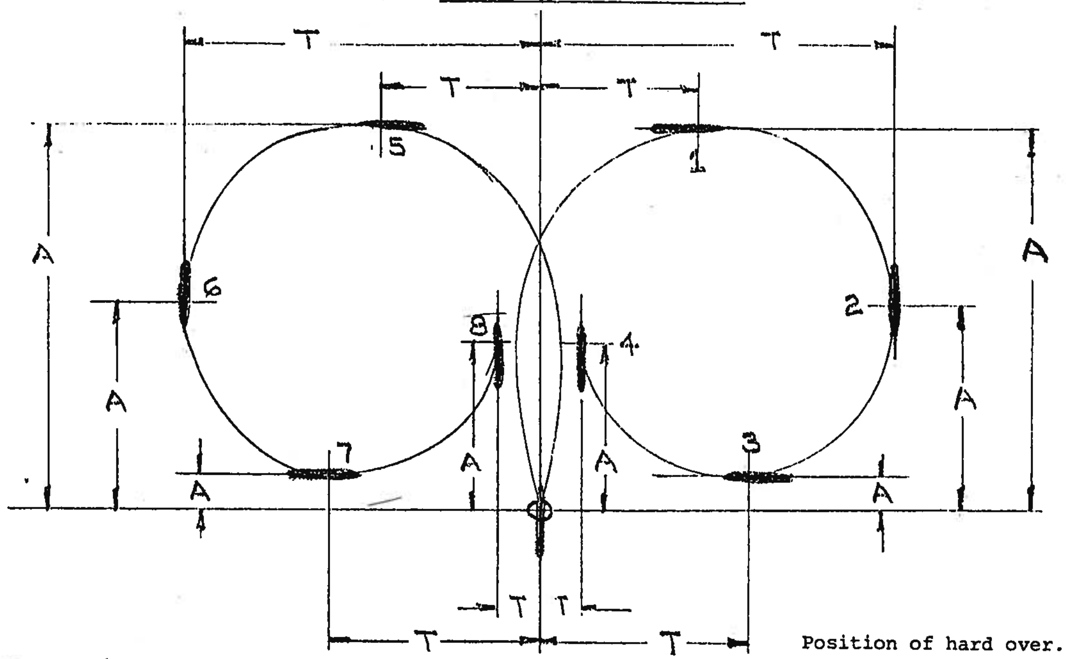
(5) Tests should be conducted to determine speed, rpm, and propeller pitch corresponding to a group of helm orders (full ahead, half ahead, etc.).

(6) Tests should be run with the bow and stern thrusters. The tests can be run by turning on the thruster, leaving the rudder in the normal ahead position, and running the ship through a range of speeds. The angular changes can be noted from the compass. After every change in speed, the ship should return to the original course to minimize the possible variations caused by wind and waves.

Another goal of this project was to examine the maneuvering charts in use and to propose one single format that included the best features of all. This chart would have to satisfy USCG inspectors. One possible chart format is shown in Figure 8. It was developed by V. A. Phelps, P.E., Department of Naval Architec-

MANEUVERING CHARACTERISTICS

MV/SS ______________________



Position of hard over.

	NORMAL LOADED CONDITION Mean Draft: Appr.___Ft. ___M Trim: Appr. Even Keel								NORMAL BALLAST CONDITIONS Mean Draft: Appr. ___Ft. ___M Trim: Appr. ___Ft. ___M Aft.							
	FULL SPEED RPM or Pitch____ Max Rudder___°				HALF SPEED RPM or Pitch____ Max Rudder___°				FULL SPEED RPM or Pitch____ Max Rudder___°				HALF SPEED RPM or Pitch____ Max Rudder ___°			
POSITION	TIME Min. Sec.	SPEED KTS	ADVANCE	TRANSFER	TIME Min. Sec.	SPEED KTS	ADVANCE	TRANSFER	TIME Min. Sec.	SPEED KTS	ADVANCE	TRANSFER	TIME Min. Sec.	SPEED KTS	ADVANCE	TRANSFER
			Nautical Miles				Nautical Miles				Nautical Miles				Nautical Miles	
1																
2																
3																
4																
5																
6																
7																
8																

(Maintain Approximately the Initial Heading With Minimum Use Of Rudder and Engines Full Astern)

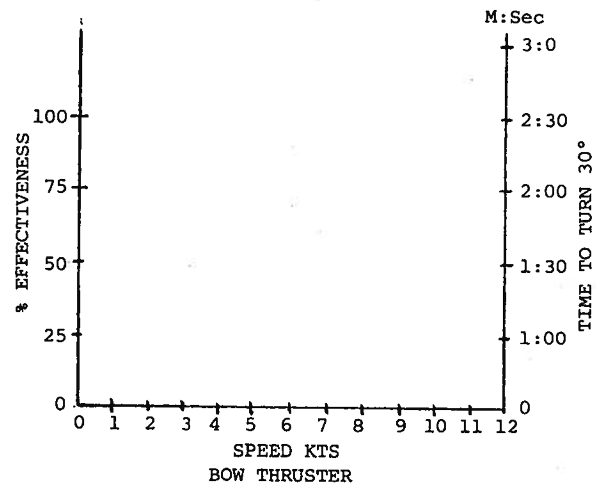
CONDITION	INITIAL SPEED AHEAD	ASTERN SPEED FULL___RPM	ENGINE AHEAD TO FULL ASTERN SEC	TIME FROM FULL ASTERN ORDER TO DEAD IN WATER: TIME Min - Sec	TIME FROM FULL ASTERN ORDER TO DEAD IN WATER: DISTANCE Naut. Miles
LOADED CONDITION Mean Draft: ___Ft ___M Trim: Appr. Even Keel	Full___RPM				
	Half___RPM				
BALLAST CONDITION Mean Draft: ___Ft ___M Trim: Appr.___Ft ___M AFT	Full___RPM				
	Half___RPM				

	ENGINE ORDER	RPM Pitch Setting	APPROXIMATE SPEED Loaded Condition	APPROXIMATE SPEED Ballast Condition	THRUSTER EFFECTIVENESS Loaded Bow Stern	THRUSTER EFFECTIVENESS Ballast Bow Stern
AHEAD	Dead Slow					
	Slow					
	Half					
	Full					
ASTERN	Dead Slow					
	Slow					
	Half					
	Full					

WARNING

The response of this ship may be different from that listed above if any of the following conditions, upon which the maneuvering information is based, are varied:

(1) Calm weather--wind 10 knots or less, calm sea;
(2) No current;
(3) Water depth twice the vessel's draft or greater;
(4) Clean hull; and
(5) Intermediate drafts or unusual trim.



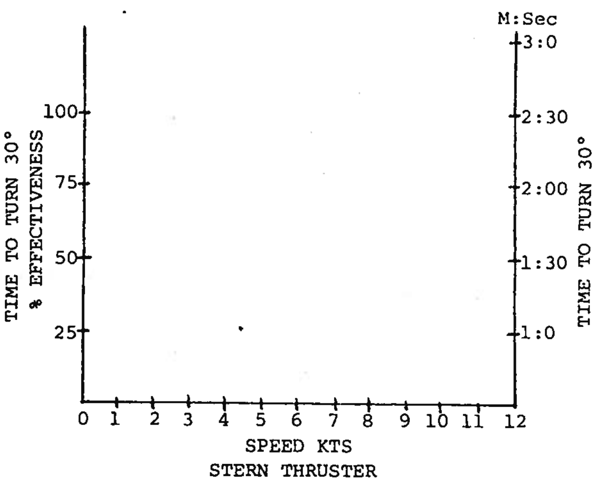


Fig 8

ture and Marine Engineering, The University of Michigan, after consultation with personnel in the Coast Guard Marine Safety Offices in Detroit, Cleveland, and Washington. It apparently meets USCG regulations.

In this chart, turning data are obtained from 360° full-circle turns instead of just 90° turns. The full-circle turns were used in anticipation that the rules would be modified to match IMCO rules, which require full-circle turns. It may be noted that such full-circle turns yield data that are not subject to the operational variations of different masters in pulling out of a turn. For this reason, full-circle data provide more reliable information about the turning characteristics of the ship itself.

ACKNOWLEDGEMENTS

I thank the following operators for providing information and for responding to questions that were raised:

American Steamship Company
Cleveland Cliffs Iron Co.
Ford Motor Co.
Hanna Mining Co.
Imperial Oil, Ltd.
Interlake Steamship Co.
Oglebay Norton Co.
United States Steel Corp.

I especially thank Dr. Armin Troesch for his invaluable help.

Finally, I express my gratitude to the Great Rivers and Great Rivers Section of the Society of Naval Architects and Marine Engineers for making this project possible through their funding.

REFERENCES

[1] The Federal Register, February 1977, pp. 40-41.

[2] "Guide to the Selection of Backing Power," Technical and Research Bulletin No. 3-5, The Society of Naval Architects and Marine Engineers, 1954.