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RESEARCH AND DEVELOPMENT CENTER**



Bethesda, Maryland 20084

MANEUVERING PERFORMANCE OF THE T-ATF 166 CLASS  
FLEET OCEAN TUG AS REPRESENTED BY THE  
USNS NAVAJO (T-ATF 169)

by

Grant A. Rossignol

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MAY 13 1981  
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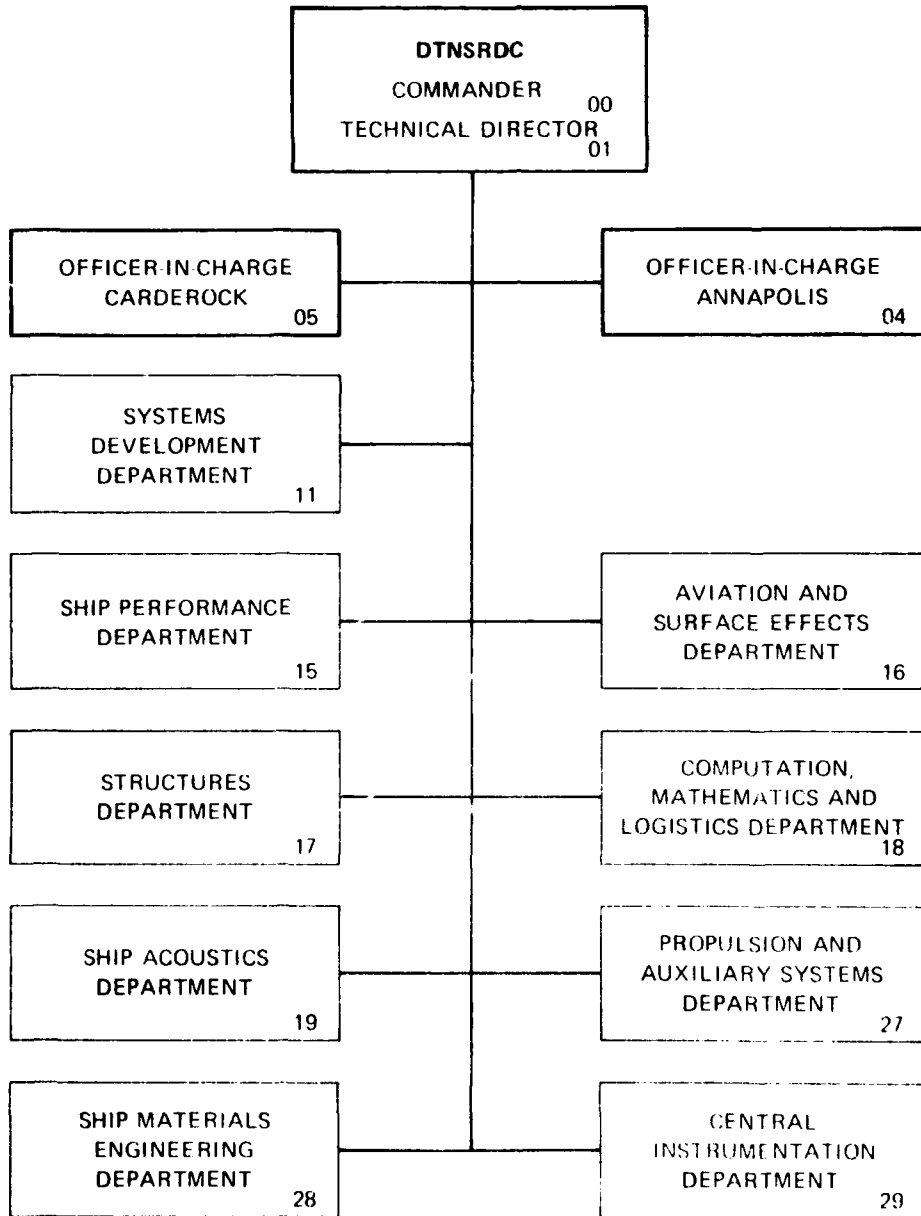
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## NOTATION

AP	After perpendicular
B	Maximum beam of the ship at the design waterline
FP	Forward perpendicular
$L_{pp}$	Length between perpendiculars
T	Draft
V	Ship speed
x	Longitudinal position coordinate of the ship's path
y	Transverse position coordinate of the ship's path
$\Delta$	Displacement (weight) of ship
$\delta_r$	Rudder angle
$\psi$	Heading (yaw) angle
$\dot{\psi}$	Rate of change of heading (yaw rate)

## ABSTRACT

This report presents the results of a maneuvering trial conducted on the USNS NAVAJO (T-ATF 169) which represents the T-ATF 166 Class fleet ocean tug. The ahead turning and maneuvering, astern maneuvering, and docking characteristics of the ship were investigated in calm environmental conditions.

Steering with the bow thruster provides the best means of achieving good coursekeeping and maneuverability during astern operations at any speed, while maneuvering ahead with the rudders should present no problems. The turning performance of the ship should be the same in either left or right turns. The docking performance of the ship should be excellent with or without the bow thruster in calm environmental conditions.

## ADMINISTRATIVE INFORMATION

This work was authorized by Naval Sea Systems Command Work Request N0002480 WROH518. The work was performed under David W. Taylor Naval Ship Research and Development Center Work Unit Number 1568-845.

## INTRODUCTION

The Naval Sea Systems Command (NAVSEA) requested the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) to conduct a maneuvering trial on a fleet ocean tug of the T-ATF 166 Class. Ship availability dictated that the trial be conducted on the USNS NAVAJO (T-ATF 169) which was located and built at the Marinette Marine Corporation in Marinette, Wisconsin. NAVSEA decided to have the trial conducted because of reports that the T-ATF 166 Class:

- a. did not steer astern in a straight course;
- b. did not dock and undock well from piers;
- c. did not exhibit equal left and right turning characteristics.

Possible reasons for these reported maneuvering problems included an inherent lack of astern directional stability in the hull design, improper use of steering controls, unbalanced port and starboard control settings, and adverse environmental conditions.

The design of the T-ATF 166 Class is based on commercial offshore supply-tug vessels used in the petroleum industry. As a unit of the Mobile Logistics Support Force, the ship's general mission will be to salvage and take in tow ships of the Fleet which are battle damaged or nonoperational. Additional operations are to

perform towing at sea, conduct rescue and limited salvage at sea, support limited diving, conduct firefighting on ships in distress at sea, provide limited self-defense, and perform open sea oil spill cleanup. The T-ATF 166 Class ships will be manned and operated by a Military Sealift Command (MSC) civilian crew.

The maneuvers conducted during the trial consisted of ahead, astern, and docking maneuvers. The ahead maneuvers were turning using left and right execute rudder angles, coursekeeping, spiral, zigzag and coasting. The ship was maneuvered astern through spiral, zigzag, and coursekeeping maneuvers. The docking maneuvers involved approaching and laying both port and starboard sides alternately to a simulated pier location and then walking away from that dockage point. Various combinations of rudder, bow thruster, and differential propulsion control were used for all of the maneuvers.

#### OBJECTIVES

The purposes of this trial were to:

- a. Determine the ability of the ship to back in a straight line using various combinations of rudder control, differential port and starboard propulsion, and bow thruster control.
- b. Attempt to determine the ahead and astern directional stability and rudder controllability of the ship.
- c. Determine the ability of the ship to lay alongside and move away from a simulated pier location.
- d. Determine the effect of initial turning direction on the turning performance of the ship.
- e. Determine the rudder angle required to steer the ship ahead in a straight line (neutral angle).
- f. Determine the port and starboard propeller pitch settings required to steer the ship ahead in a straight line.
- g. Correlate propulsion control settings and speed log readings with various ship speeds.
- h. Determine the ability of the ship to coast ahead in a straight line upon reducing the propulsion control settings to the neutral position.

#### DESCRIPTION OF SHIP PARTICULARS

The principal characteristics of the USNS NAVAJO are given in Table 1. Some of these characteristics are different from those projected for the fully loaded and

equipped ship. The NAVAJO has a length overall of 225 feet (68.6 meters) and a maximum beam of 42 feet (12.8 meters). During the trial, the ship operated at a displacement of 2,392 long tons (2,430 tonnes) and with drafts of 14.6 feet (4.5 meters) and 16.0 feet (4.9 meters) at the forward and aft perpendiculars, respectively. The ship is steered by twin, spade rudders and propelled by twin, controllable pitch propellers with kort nozzles. Additional control is provided by a bow thruster, and a centerline skeg is installed. The ship propulsion system can be operated in either a propeller pitch/RPM integrated mode or a split mode. In the integrated mode, both the propeller pitch and RPM increase until a certain speed is reached and then only the RPM increases beyond that point. In the split mode, either the RPM or propeller pitch can be held constant while the other is varied.

A photograph of the NAVAJO while underway is presented as Figure 1. Figures 2, 3, and 4 are photographs showing details of the bow thruster, skeg, rudders, kort nozzles, and controllable pitch propellers. During the trial, the maximum ahead and astern speeds which the ship was capable of were 14.5 and 9.5 knots, respectively. The rudder rate is 2.4 degrees per second and was measured as the average rate between right 30 degrees and left 30 degrees during a right 40 degree to left 40 degree swing. The opposite direction was also checked.

#### INSTRUMENTATION SETUP

The ship's path was tracked by a portable DTNSRDC tracking system. This system consists of two shore stations which were located 7 nautical miles apart on the coast of Green Bay, a transmitter/receiver unit installed on the main mast, and a minicomputer installed in the DTNSRDC Portable Data Collection Center (PORDACC) trailer which was located on the main deck. The northernmost shore station was located at Stoney Point (latitude of 45°11.77' north and longitude of 87°32.27' west), while the southernmost shore station was located at Red Arrow Park (latitude of 45°05.12' north and longitude of 87°35.16' west). A wind meter was installed on the main mast to measure wind speed and direction. Heel angle, heading, and rate of change of heading (yaw rate) were measured by roll, heading, and yaw rate gyroscopes, respectively, which were installed on the PORDACC trailer. Rudder angle was measured by a string potentiometer installed on the hydraulic ram in after steering and ship speed was obtained from the shore tracking system. Port and starboard propeller pitch and RPM were measured by string potentiometers installed on the controllable pitch mechanism and tachometers installed on the shafts,

respectively. The instrumentation necessary for signal conditioning and recording of all measurements was installed in the PORDACC trailer, which was located on the main deck at Frame 75, 10 feet (3.0 meters) to the starboard side of the centerline.

#### MEASUREMENTS AND DATA REDUCTION

Time histories of the following signals were recorded using combinations of digital tape, analog tape, and strip charts:

- a. wind speed;
- b. wind direction;
- c. longitudinal position coordinate of the ship's path
- d. transverse position coordinate of the ship's path;
- e. heading;
- f. rate of change of heading (yaw rate);
- g. heel angle;
- h. rudder angle;
- i. ship speed;
- j. port propeller pitch setting;
- k. starboard propeller pitch setting;
- l. port propeller RPM;
- m. starboard propeller RPM.

The data was reduced both manually and on a minicomputer during the trial to enable preliminary assessments of the ship's maneuverability and any necessary trial agenda changes. Additional processing on the minicomputer and manual data reduction/analysis was performed at DTNSRDC after the trial to provide the results presented in this report.

#### TRIAL CONDITIONS AND PROCEDURE

The trial was conducted in the waters of Green Bay near Marinette, Wisconsin between the latitudes of 45°03.3' and 45°13.9' north and the longitudes of 87°21.8' and 87°28.1' west. The water depth varied from 60 to 80 feet (18.3 to 24.4 meters) and the wind speed ranged from 2 to 6 knots. The location was selected so that no appreciable waves or current prevailed. This trial operation area turned out to be ideal for accurately establishing a calm water baseline of T-ATF 166 Class maneuverability considering the weather conditions, water depth, and proximity to the shore tracking stations (3 to 10 nautical miles).

The ahead maneuvers conducted during the trial were coursekeeping, turning, spiral, zigzag, and coasting. The coursekeeping maneuvers were run to calibrate ship speed, determine the rudder angle required for a steady course (neutral angle), and check the symmetry between port and starboard propeller pitch settings required for a steady course, all at ship speeds ranging from 3 to 14.5 (maximum) knots. The propeller pitch settings were checked while the ship was operated in the split mode with the RPM held constant and the propeller pitch varied to make the ship steer straight. The bow thruster was not used for any ahead maneuvers. Left and right turns were made using execute rudder angles of 30 degrees at ship approach speeds of 7.5 and 14.5 knots and 44 degrees at a speed of 14.5 knots. Once the rudder execution was begun, the throttle control positions were not changed until the turn was complete. The rudder execute angles were held until the ship's heading had changed 540 degrees from the approach course. The 540 degree turn is made so that the turning path can be corrected for any set and drift of the ship due to wind, waves, or current. The ahead directional stability of the ship was checked by conducting a spiral maneuver at a speed of 5 knots ( $V/\sqrt{L_{PP}} = 0.35$ ). The ahead directional stability was also checked, along with the rudder controllability, by conducting a zigzag maneuver at 5 knots using 10 degree rudder executes at 10 degree heading changes from the approach course. For both the spiral and zigzag maneuvers, the throttle control positions were not changed after the ship was steadied on course. The coasting maneuvers were conducted to show how steady a course the ship will maintain after the propulsion controls are reduced down to the neutral positions. The ship was steadied on course at a speed of 14.5 knots and then the propulsion controls were reduced to the neutral positions (settings for zero speed). As the bow would start to swing either left or right, an opposite rudder angle was put on to attempt to check the swing of the bow until the ship slowed to dead in the water.

The astern portion of the trial consisted of coursekeeping, spiral, and zigzag maneuvers. The coursekeeping maneuvers were conducted using various modes of steering at ship speeds of 1, 3, 5, 7, and 9.5 (maximum) knots. The bow thruster was used for steering up to 9.5 knots with the rudders set amidship and the propulsion held constant for a particular speed. The rudders were used up to 9.5 knots with bow thruster off and the propulsion constant. With the bow thruster off and the rudders amidship, the port and starboard propulsion controls were varied while attempting to maintain heading at speeds up to 5 knots. The rudders and

differential propulsion were then used in combination for steering with the bow thruster off at speeds up to 7 knots. The propulsion controls were operated in only the integrated mode for all of the astern maneuvers. At a constant propulsion control position, spiral and zigzag maneuvers were attempted at a speed of 3 knots ( $V/L_{PP} = 0.21$ ). The spiral maneuver was attempted using the rudders with the bow thruster off but could not be successfully conducted due to the inability of any reduction in rudder angle to slow down the swing of the stern. A zigzag maneuver was attempted using 5 degree rudder executes at 5 degree heading changes from the approach course, but, like the spiral maneuver, could not be conducted due to the inability of an opposite rudder angle to check the swing of the stern with the bow thruster off. With the rudders amidship, the bow thruster was used to successfully conduct a zigzag maneuver. Fifty percent of the available bow thruster power was used at executes when the ship's heading had changed 5 degrees from the approach course.

The docking maneuvers were conducted using a buoy as a simulated pier. Using a combination of the bow thruster, rudders, and differential propulsion, the ship was walked alongside the buoy both port and starboard side to, stopped, and then was walked away. Using the rudders and differential propulsion without the bow thruster, the docking was done only starboard side to. The procedure used for docking was as follows:

- a. the ship approached the buoy at a speed of 3 knots using an approach course of 20 degrees relative to a line simulating the pier;
- b. when the ship was two shiplengths away from the desired docked position (bow even with the buoy and 0.2 shiplengths to the side), the ahead power was reduced to zero;
- c. the ship was walked to a stop;
- d. the ship was then walked away at a departure heading of 10 degrees relative to the simulated pier until a speed of 3 knots was reached.

Tables 2 and 3 present a summary of all maneuvers conducted during the trial.

#### PRESENTATION OF RESULTS

Figure 5 presents a speed calibration of the propulsion control positions obtained from ahead coursekeeping maneuvers. While operating in the integrated mode, the ship speed was obtained from the shore tracking system for a given propulsion control position. The same position was used for both port and starboard

controls. The changes in curvature are most likely due to the joint increases in propeller pitch and RPM. The accuracy of the doppler speed log on the ship is excellent as compared to the ahead speeds from the shore tracking system, according to the data shown in Figure 6.

Figure 7 through 10 present the ship's path from the astern coursekeeping maneuvers. Figures 7, 8, and 9 show the relative effectiveness of steering with the rudders, bow thruster, differential propulsion, and differential propulsion used jointly with the rudders at astern speeds of 3, 5, and 7 knots. At 3 knots, the mode of steering did not seem to make much difference; but as the speed increases, only the bow thruster and rudders are effective for good coursekeeping. The differential propulsion alone was so ineffective for coursekeeping that data could be obtained only at 5 knots. The coordination of the port and starboard propulsion was quite difficult and varying the power actually made the ship steer off course. Use of the rudders helped to counteract this effect. Use of the rudders provided good coursekeeping through 9.5 knots, although a malfunction prevented the 9.5 knot data from being presented. Although the bow thruster data appears no better than that for the rudders, the operational advantage of the bow thruster steering should be discussed. Astern coursekeeping with rudders required very attentive helmsmanship and should only be considered when the bow thruster is inoperative. Steering with the bow thruster presented no difficulty (less than 50 percent of the available power was required) up to 9.5 knots. Figure 10 shows the bow thruster coursekeeping data over the entire speed range. The ship responded much more quickly to changes in the bow thruster direction than to rudder angle direction changes and the location of the bow thruster control permitted better astern visibility.

The distinction between astern coursekeeping and astern maneuvering is quite important. While maintaining a steady course was possible without the bow thruster, maneuvering was not. Initiating and checking course changes with the bow thruster in calm water should not pose any problem with the rudders amidship and using constant propulsion settings. Should the bow thruster be inoperative, controlling the ship astern through course changes will be difficult, if not impossible, in even the calmest of conditions. While many types of ships exhibit good astern coursekeeping qualities up to about 6 knots, very few are capable of good astern maneuvering performance at any speed. Thus, the design of this ship does not seem to be particularly poor from an astern maneuvering viewpoint as compared to other ships. The key seems to lie in the bow thruster. Should the bow thruster be inoperative, the ship

may not be able to fulfill its mission requirements, especially under adverse environmental conditions.

Table 4 presents data from astern zigzag maneuvers at a speed of 3 knots separately using bow thruster and rudder modes of steering. Only with the bow thruster could the maneuver be completed. Although 50 percent port and starboard bow thruster power was used, substantially smaller overshoot yaw angles would have resulted with more bow thruster power. An astern spiral maneuver at 3 knots was attempted but could not be successfully conducted. However, this maneuver cannot be done on most ships.

The ship exhibits excellent ahead coursekeeping ability using minimal rudder activity. No significant left or right rudder angle was required to steer a straight course (neutral rudder angle was left 0.8 degrees). A spiral maneuver conducted at 5 knots and presented in Figure 11 indicates a high degree of directional stability which is inherently related to good ahead coursekeeping ability. Reasonable ahead coursekeeping ability was also achieved with the rudders amidship and using only differential propeller pitch for steering. With the propulsion controls in the split mode (constant RPM and variable propeller pitch), a fairly steady course was obtained with approximately equal pitch settings on both propellers. Initiating and checking course changes ahead was fairly easy as evidenced by the ahead zigzag data presented in Table 4 for a speed of 5 knots. Using 10 degree rudder executes at 10 degree course changes (10-10 zigzag), overshoot yaw angles of only 6 degrees were measured. These overshoots compare well to those obtained for almost any type of ship and are related to the excellent ahead directional stability.

Figure 12 presents tactical diameters obtained from turns made with the NAVAJO as compared to those previously obtained for the POWHATAN (T-ATF 166). Although a large discrepancy existed between left and right turns for the POWHATAN, the turning performance seems to be the same for left and right turns for the NAVAJO (as evidenced by Figures 12 through 15). With the rudders physically amidship, the scale in after steering was carefully compared to the rudder readout in the pilothouse. Other possible asymmetries such as the propeller pitch were also checked. The calm environmental conditions and 540 degree turns (corrected for set and drift) also contributed to the accuracy of the data. The turning performance of the ship is excellent as compared to other types of ships and the tactical diameters are independent of ship speed up to 14.5 knots (full power ahead). The ship turns with a tactical diameter of approximately 2.1 shiplengths at a rudder angle of 44 degrees

(full rudder). The ship heeled nearly 13 degrees when turning at full speed, full rudder.

Figure 16 presents the results of ahead coasting maneuvers. These maneuvers were conducted to determine the extent to which the course could be maintained using the rudders once the ahead power was reduced to zero. The ship was powered ahead on a steady course at a speed of 14.5 knots. The propulsion controls were then moved to the neutral position. Attempts were then made to maintain the course as long as possible using any degree of rudder activity. Almost immediately after the propeller flow past the rudders ceased, the ship started to swing to one side (no particular bias) and even full rudder to the opposite side would not stop the swing. Only two attempts were made at this maneuver and, as can be seen in Figure 16, the ship drifted to the left during one maneuver and to the right during the other. The direction of the drift seemed to be only a function of any slight bow swing existing at the moment the ahead power was reduced. The direction of the drift does not seem to be as important as the fact that substantial drift did occur. Reasonable steering can probably be achieved by maintaining some forward power. Propulsion control settings, which correspond to a ship speed of at least 5 knots, should be used. In consideration of these results and other observations made during the trial, slowing to a stop instead of coasting should provide much more rudder control and safe handling.

The ability of the ship to walk to and away from a simulated pier location is best presented qualitatively. Two modes of operation were used: (a) bow thruster, rudders, and differential propulsion; (b) rudders and differential propulsion. A buoy was used as the simulated pier for safety considerations and, although not totally realistic, served as a fixed reference point. The ability of the ship to walk to and away from either port or starboard side to was excellent. Even when the bow thruster was not used, the performance was excellent. This maneuver was actually more difficult using a buoy instead of a pier since a pier would have provided a line of reference instead of merely a point. In addition, use of a pier would have resulted in a cushion of water between the ship and the pier to aid in the final approach. The effects of winds greater than 8 to 10 knots may make these maneuvers much more difficult than the calm conditions during the trial.

Considerable effort was made to find quantitative data and operational information for similar ships to which the results of this trial can be compared. Little to no quantitative data exists since only commercial offshore supply vessels are

really comparable to the T-ATF 166 design. The commercial owners are usually satisfied to meet minimum United States Coast Guard requirements. The expense of trials would only deplete funds planned for the acquisition of additional vessels. Furthermore, the real point made by commercial operators is that this and other similar designs have performed satisfactorily over several years. Apparently, operational experience must be gained in a wide range of environmental conditions to qualify the crews. Based on the results of this trial and operator comments of other similar ships, the T-ATF 166 Class design should perform well, at least under mild environmental conditions. Only trials in rough weather can assess any degradation in maneuvering which may occur.

#### CONCLUSIONS

Based upon the results of this trial, the following conclusions are drawn for the T-ATF 166 Class:

- a. The best mode of operation for astern coursekeeping and maneuvering at any speed is using the bow thruster for steering with the rudders amidship and leaving the propulsion controls set in one position. Should the bow thruster be inoperative, adequate coursekeeping can be achieved using the rudders but course changes should be avoided when operating in calm weather.
- b. Maneuvering astern with the bow thruster should pose no problem provided that greater than 50 percent of the bow thruster power is used.
- c. The ahead maneuvering performance of the ship is excellent.
- d. The turning performance of the ship appears to be independent of whether the turns are left or right. The tactical diameter will be independent of ship approach speed and will be 2.1 ship lengths at full rudder (44 degrees).
- e. When coasting to a stop, the ship will swing to one side (no particular bias) independent of rudder action. For adequate rudder control and safe handling, the ship should be slowed to a stop and never coasted.
- f. The ability of the ship to walk to and away from a pier in calm weather should be excellent with or without the bow thruster.

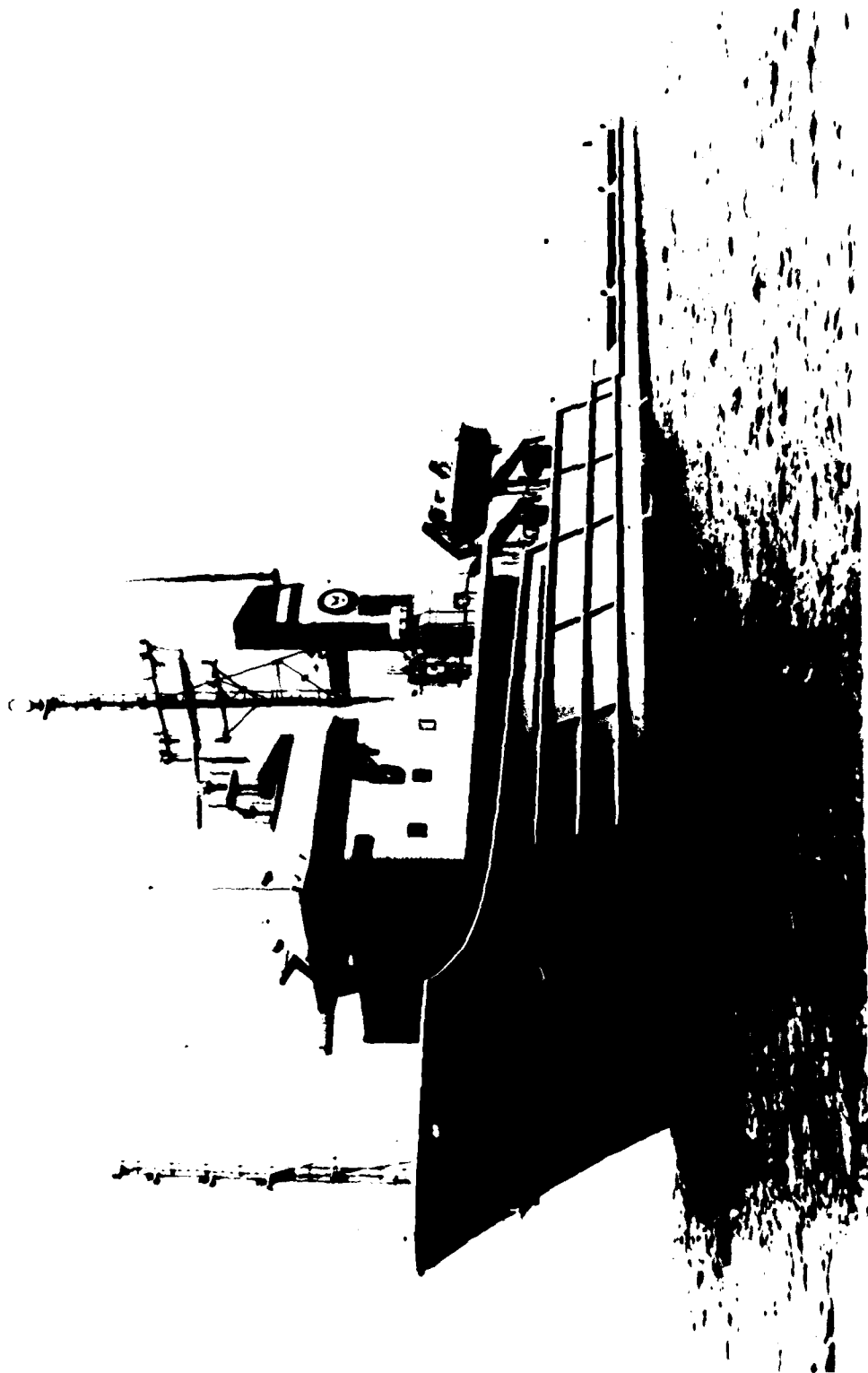


Figure 1 - Photograph of the USNS NAVAJO (T-ATF 169)



Figure 2 - Photographs of the Bow Thruster on the USNS NAVAJO (T-ATF 169)

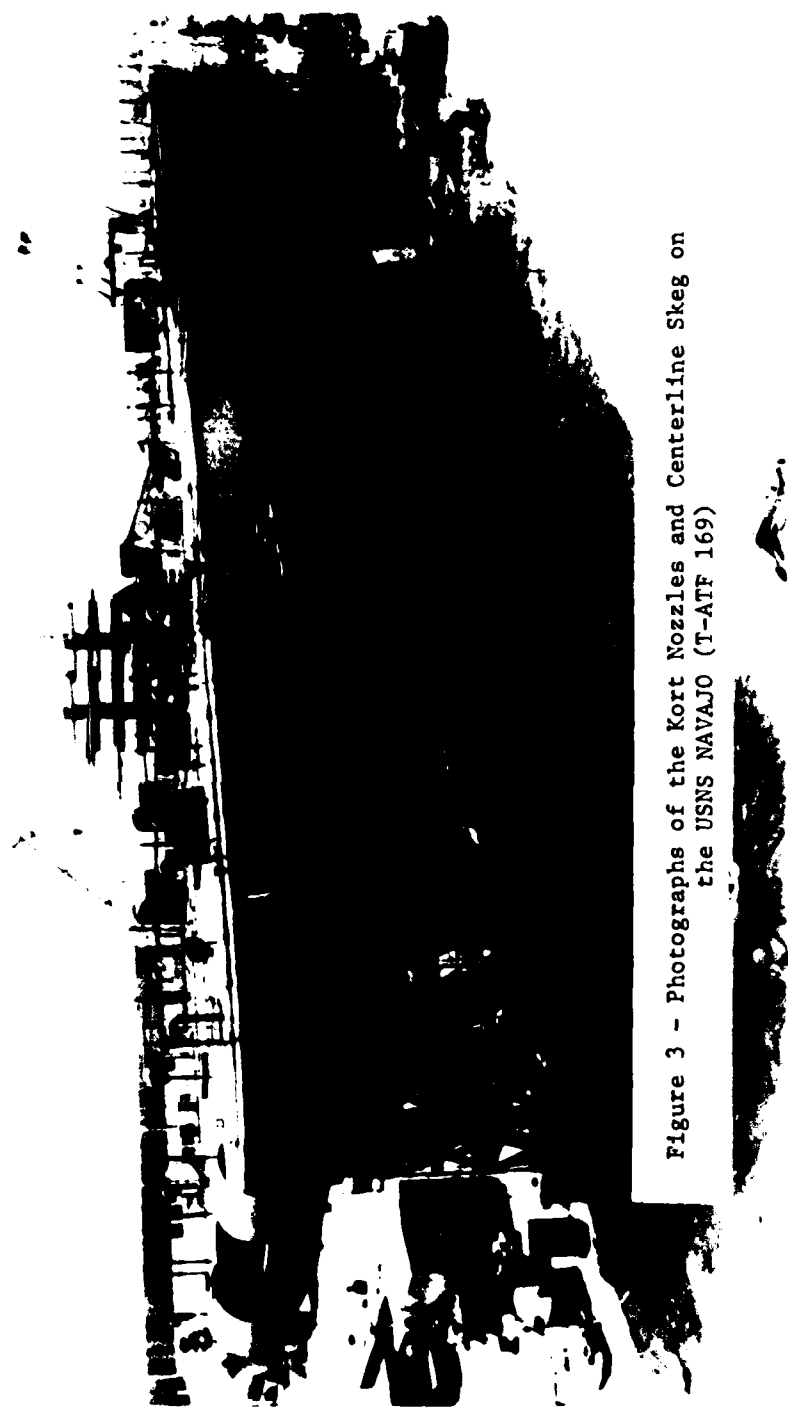


Figure 3 - Photographs of the Kort Nozzles and Centerline Skeg on  
the USNS NAVAJO (T-ATF 169)

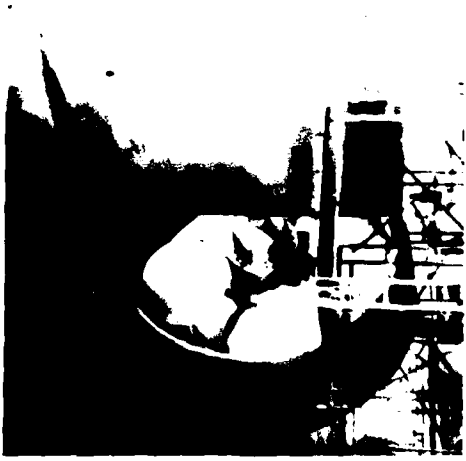


Figure 4 - Photographs Showing Details of the Kort Nozzles, Controllable Pitch Propeller, Skeg, and Rudders on the USNS NAVAJO (T-ATF 169)

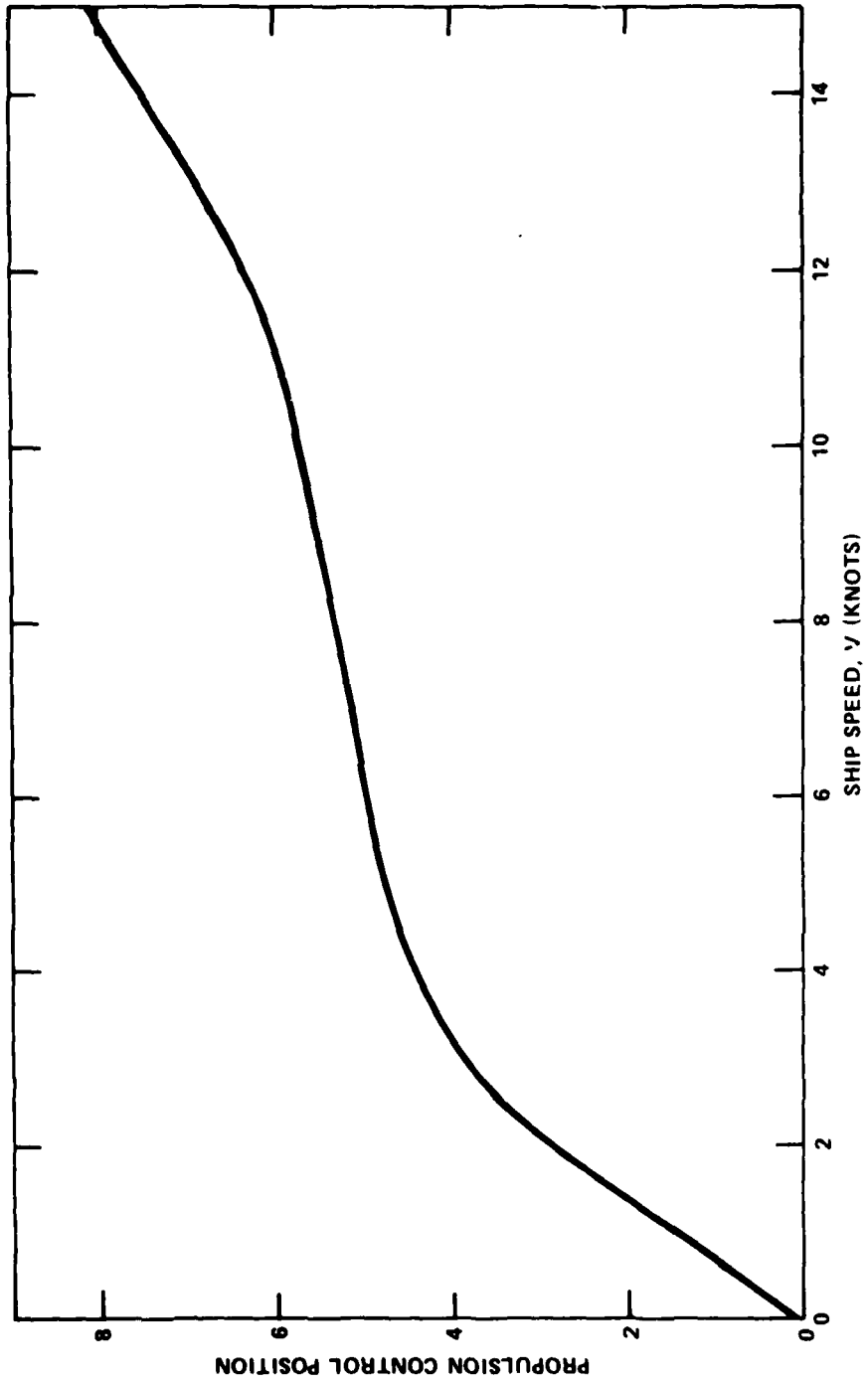


Figure 5 - Calibration of Measured Ahead Ship Speed versus Propulsion Control Position from Ahead  
Coursekeeping Maneuvers Conducted on the USNS NAVALJO (T-ATF 169)

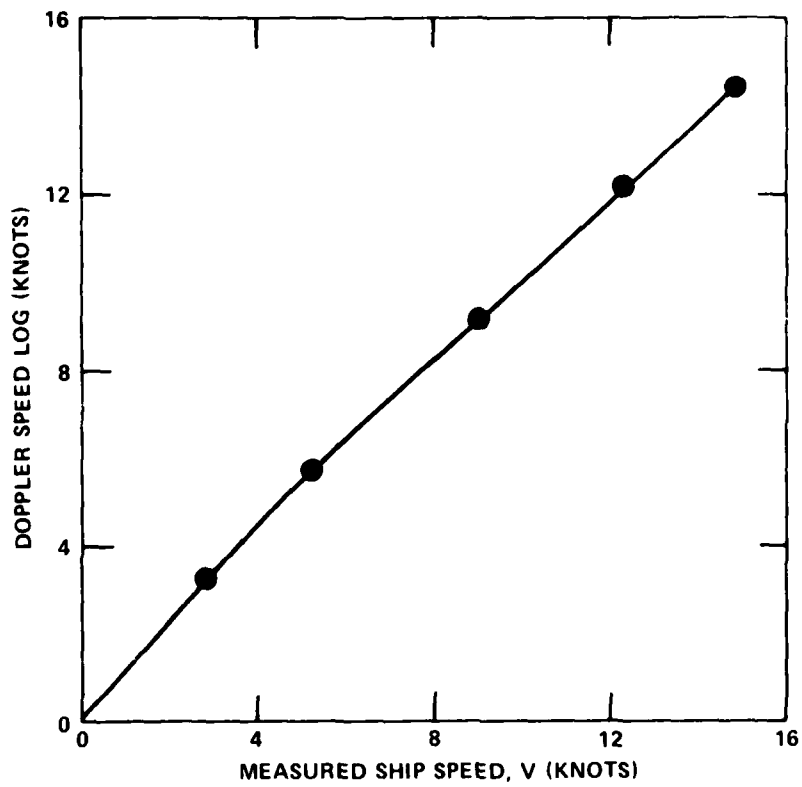


Figure 6 - Measured Ahead Ship Speed versus Doppler Speed Log from Ahead Coursekeeping Maneuvers Conducted on the USNS NAVAJO (T-ATF 169)

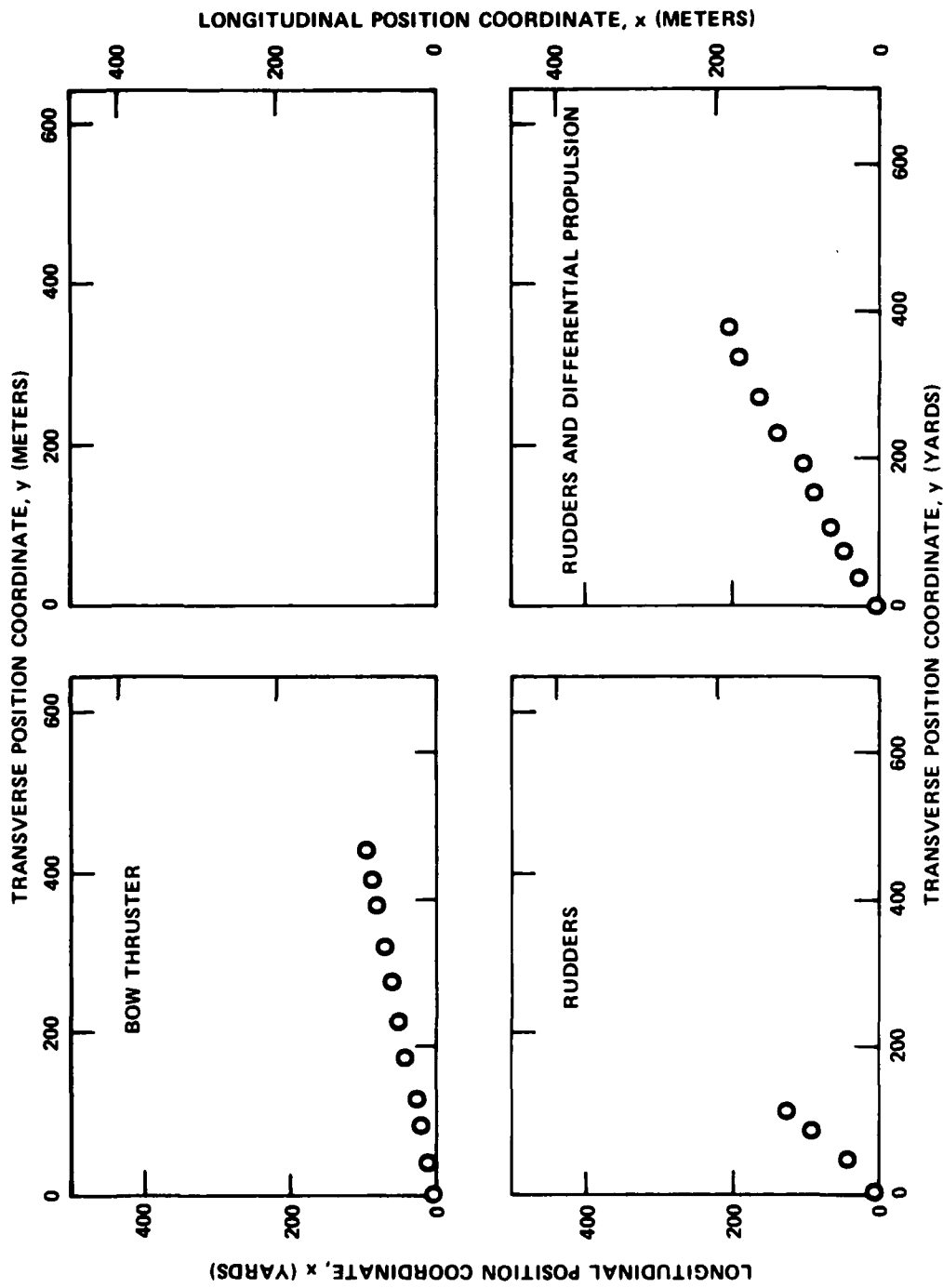


Figure 7 - Ship's Path during Astern Coursekeeping Maneuvers Conducted on the USNS NAVAJO (T-ATF 169) at an Astern Ship Speed of 3 Knots Using Various Modes of Steering

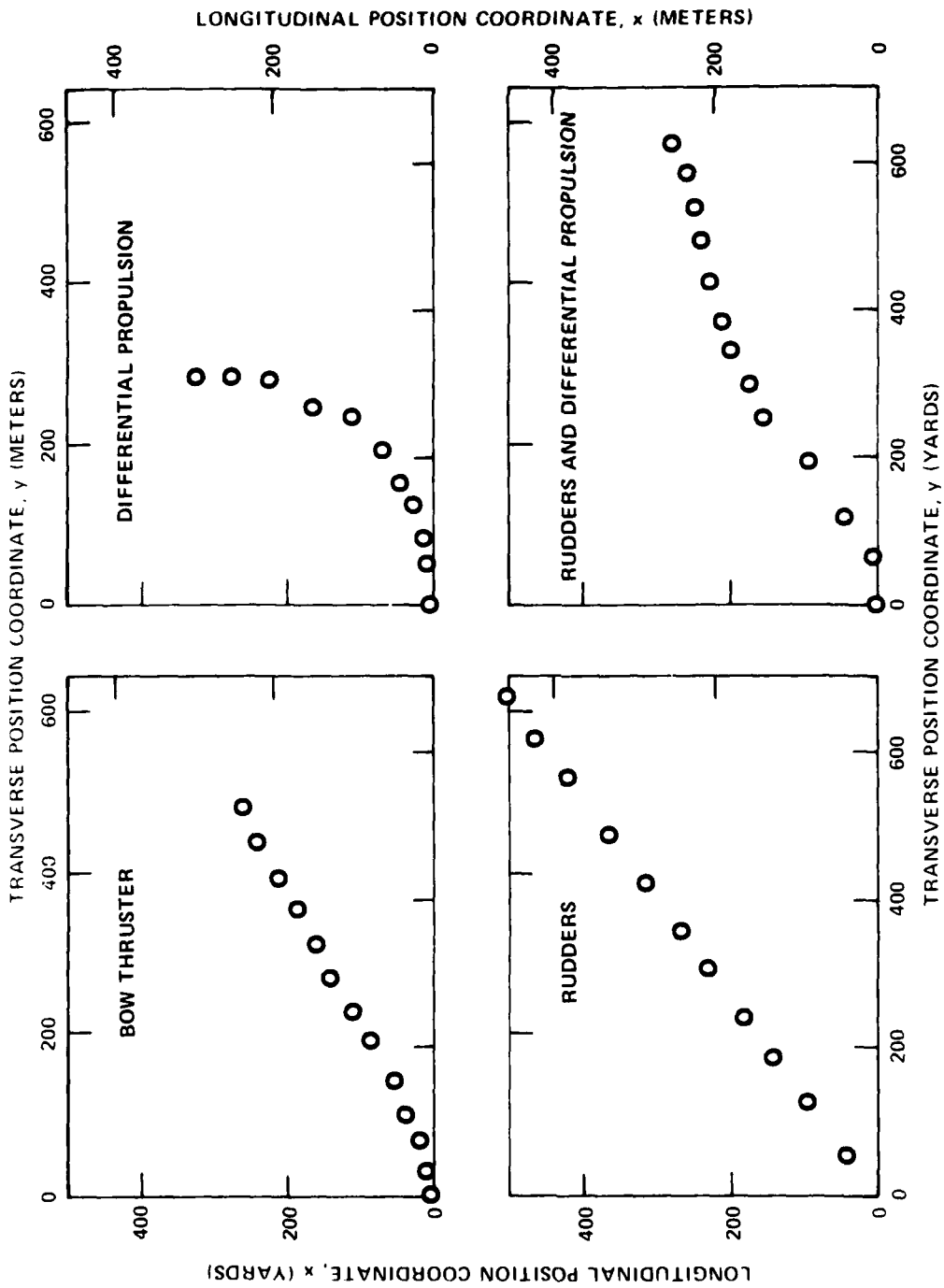


Figure 8 - Ship's Path during Astern Coursekeeping Maneuvers Conducted on the USNS NAVAJO (T-ATF 169) at an Astern Ship Speed of 5 Knots Using Various Modes of Steering

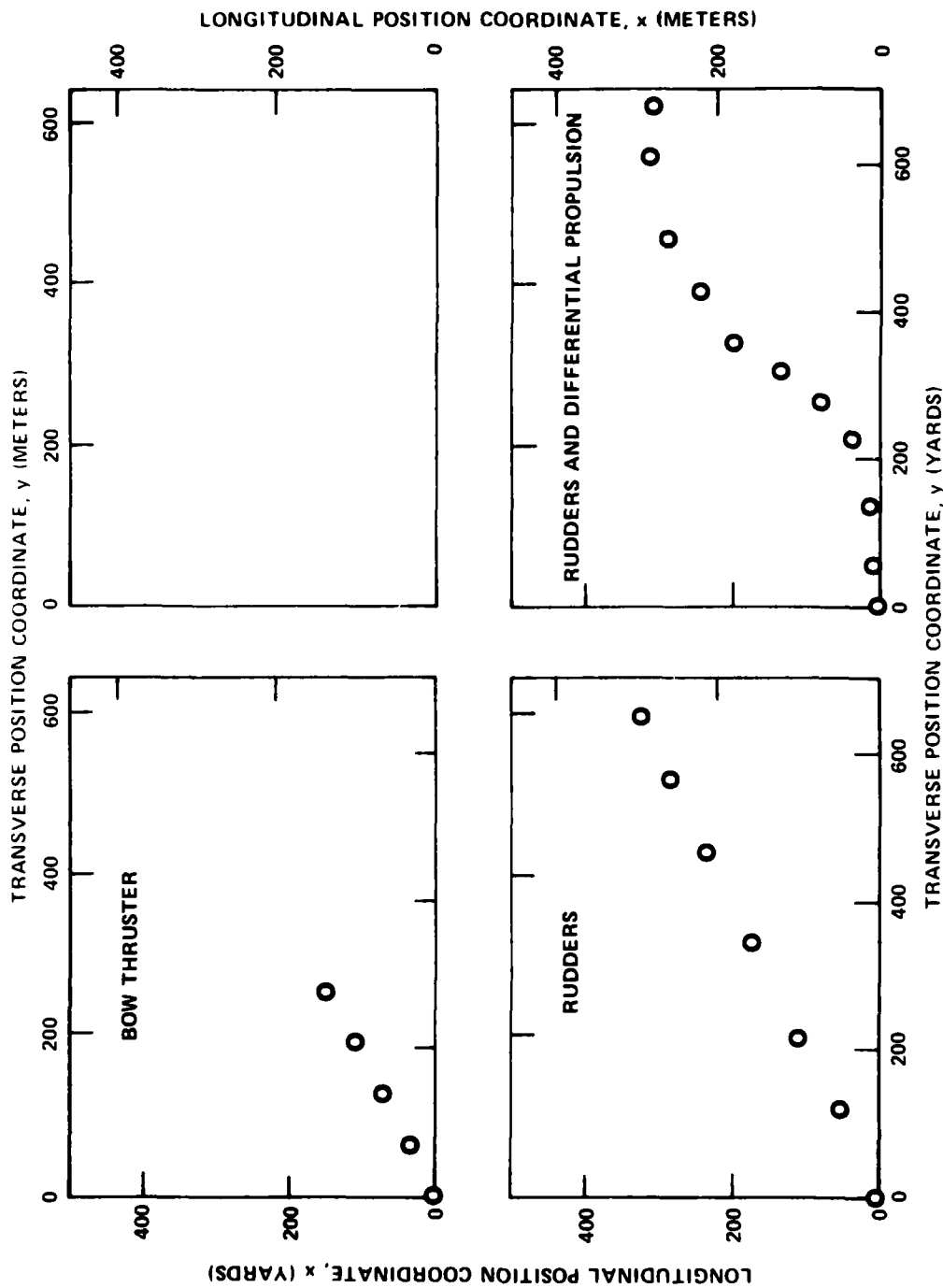


Figure 9 - Ship's Path during Astern Coursekeeping Maneuvers Conducted on the USNS NAVAJO (T-ATF 169) at an Astern Ship Speed of 7 Knots Using Various Modes of Steering

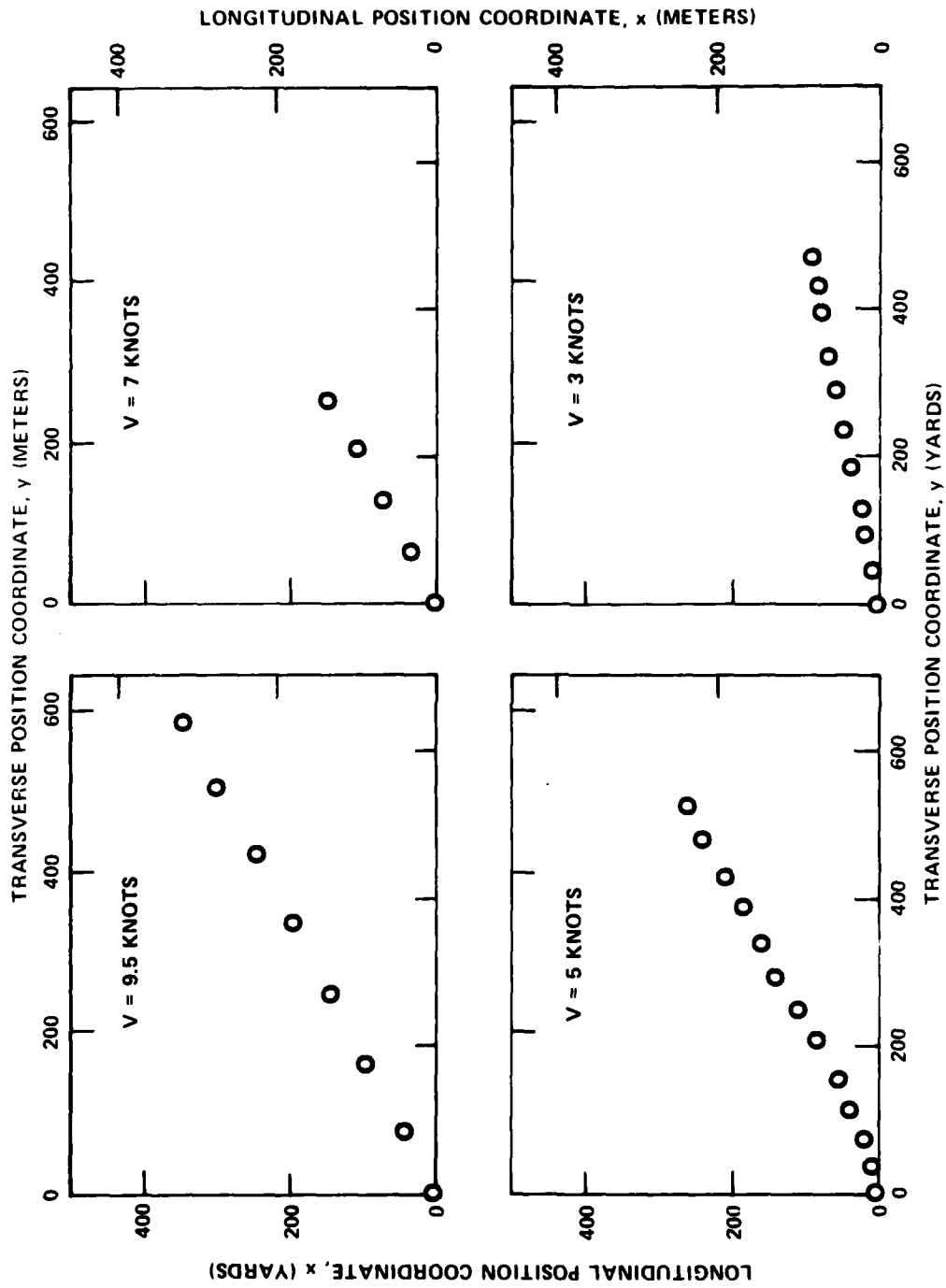


Figure 10 - Ship's Path during Astern Coursekeeping Maneuvers Conducted on the USNS NAVAJO (T-ATF 169) Using the Bow Thruster for Steering at Various Astern Ship Speeds

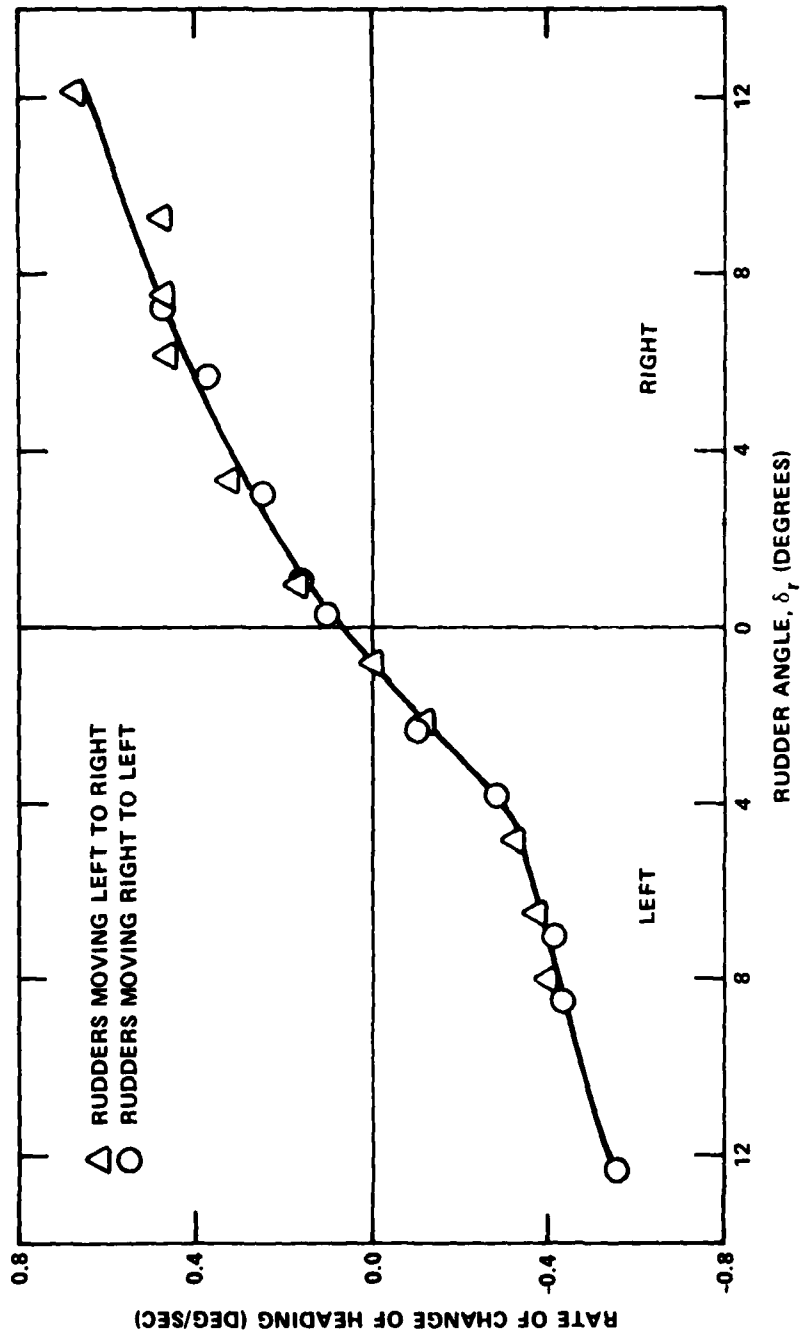


Figure 11 - Rate of Change of Heading versus Rudder Angle from Ahead Spiral Maneuver Conducted on the USNS MAVAJO (T-ATF 169) at a Ship Speed of 5 Knots

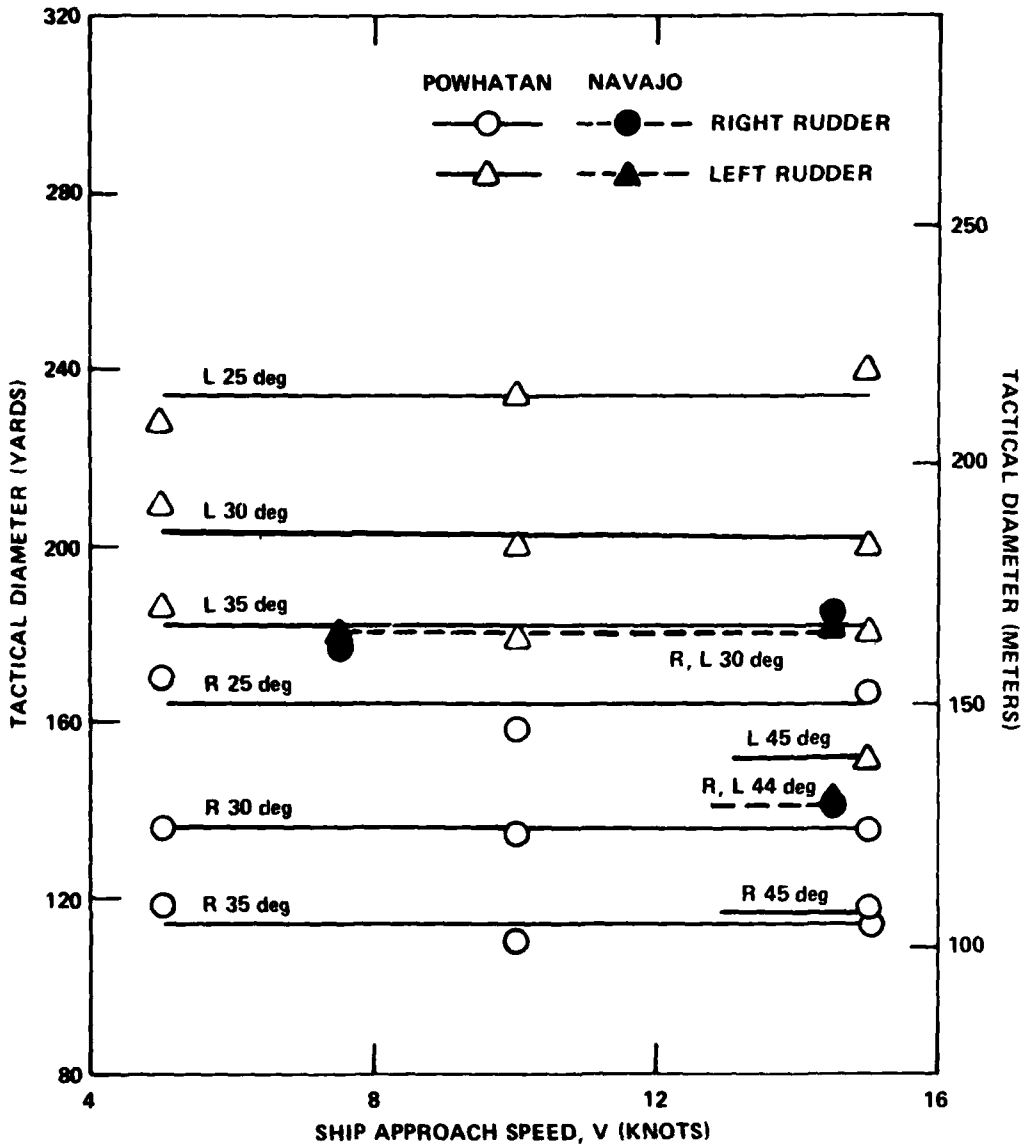


Figure 12 - Tactical Diameter versus Ship Approach Speed Comparing Results from Turning Maneuvers Conducted on the USNS POWHATAN (T-ATF 166) and the USNS NAVAJO (T-ATF 169) for Various Left and Right Execute Rudder Angles

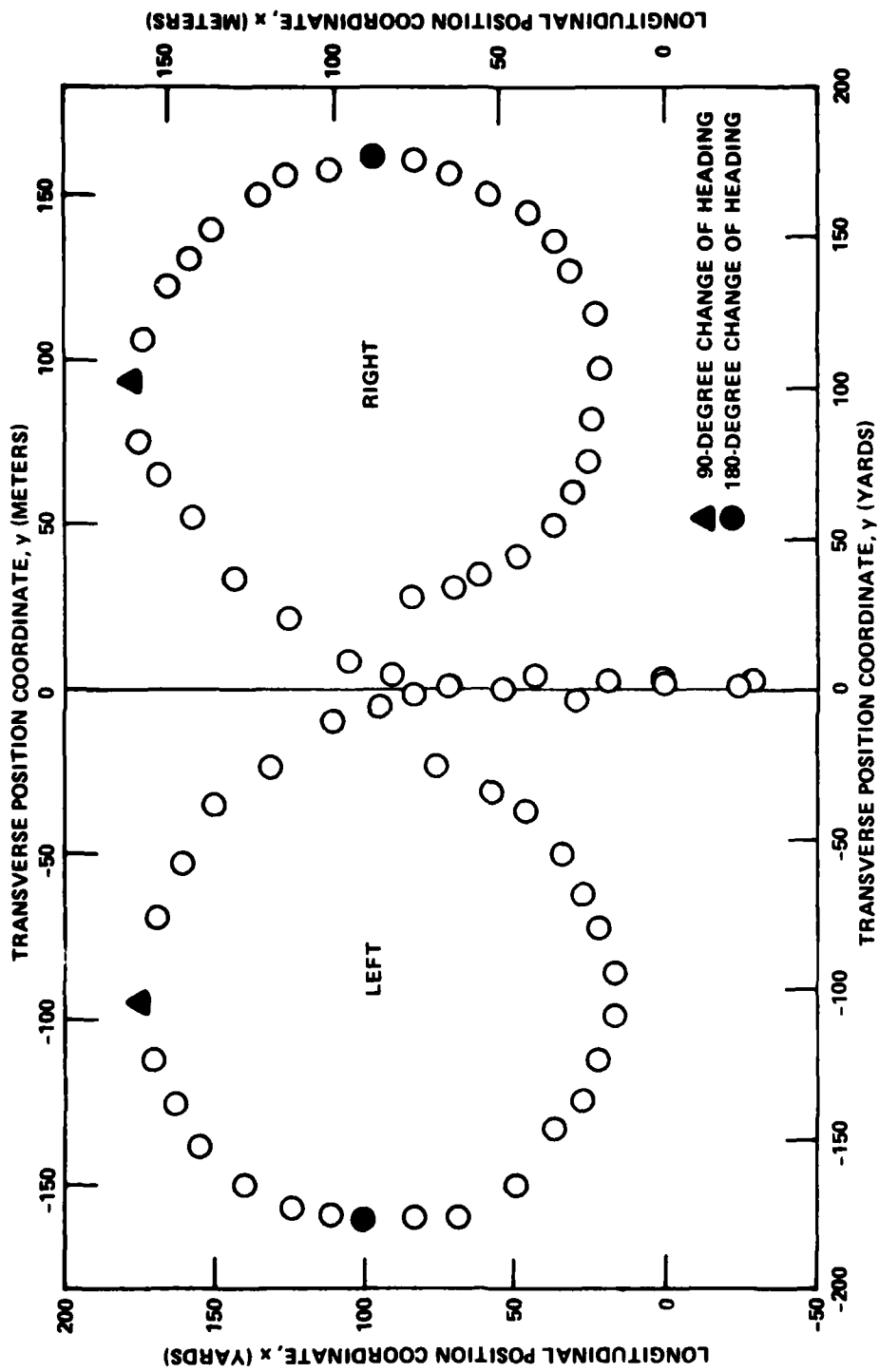


Figure 13 - Ship's Path during Turning Maneuvers Conducted on the USNS NAVAJO (T-ATF 169) at an Ahead Ship Approach Speed of 7.5 Knots Using Execute Rudder Angles of Left and Right 30 Degrees

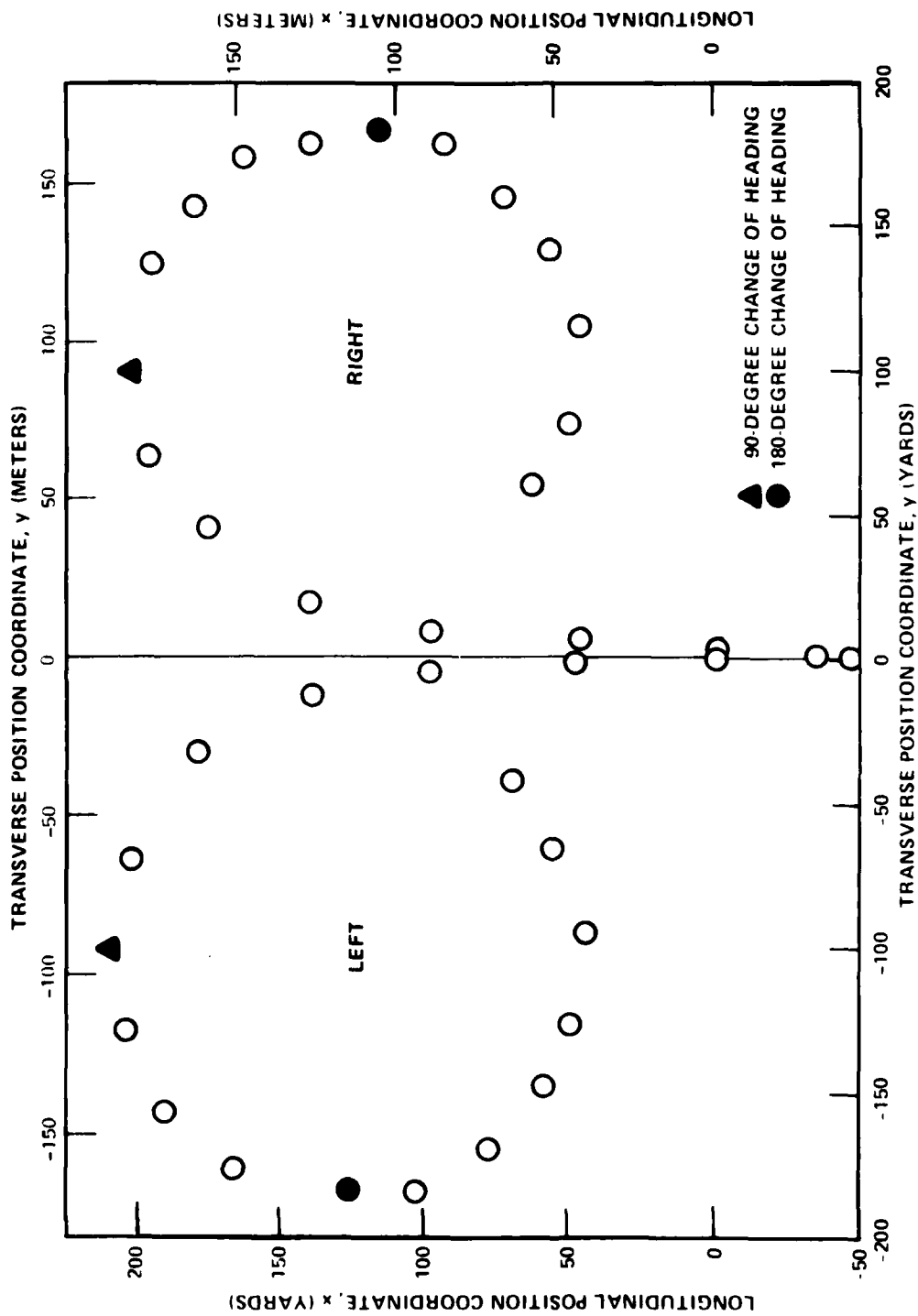


Figure 14 - Ship's Path during Turning Maneuvers Conducted on the USNS NAVAJO (T-ATF 169) at an Ahead Ship Approach Speed of 14.5 Knots Using Execute Rudder Angles of Left and Right 30 Degrees

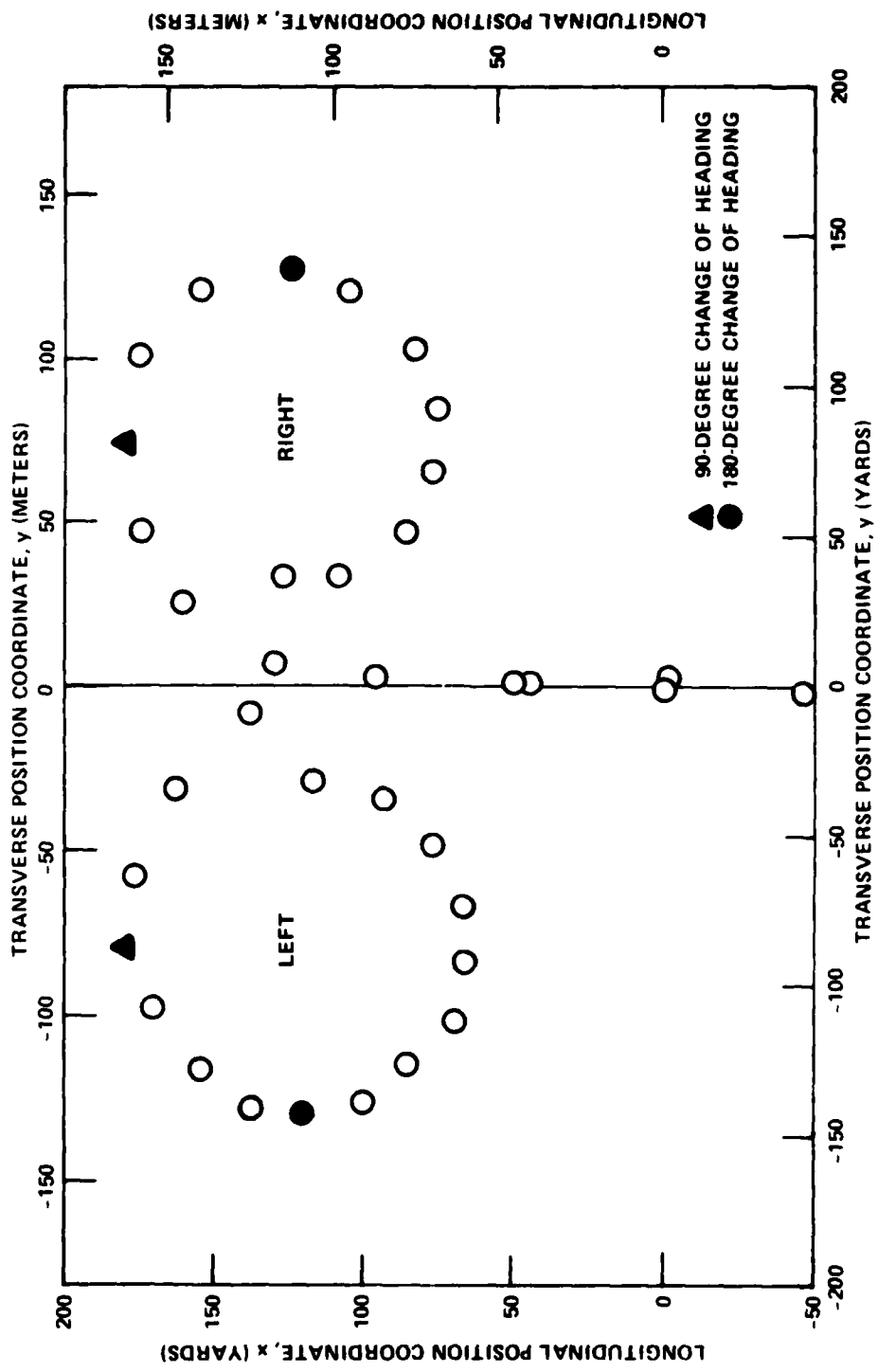


Figure 15 - Ship's Path during Turning Maneuvers Conducted on the USNS NAVAJO (T-ATF 169) at an Ahead Ship Approach Speed of 14.5 Knots Using Execute Rudder Angles of Left and Right 44 Degrees

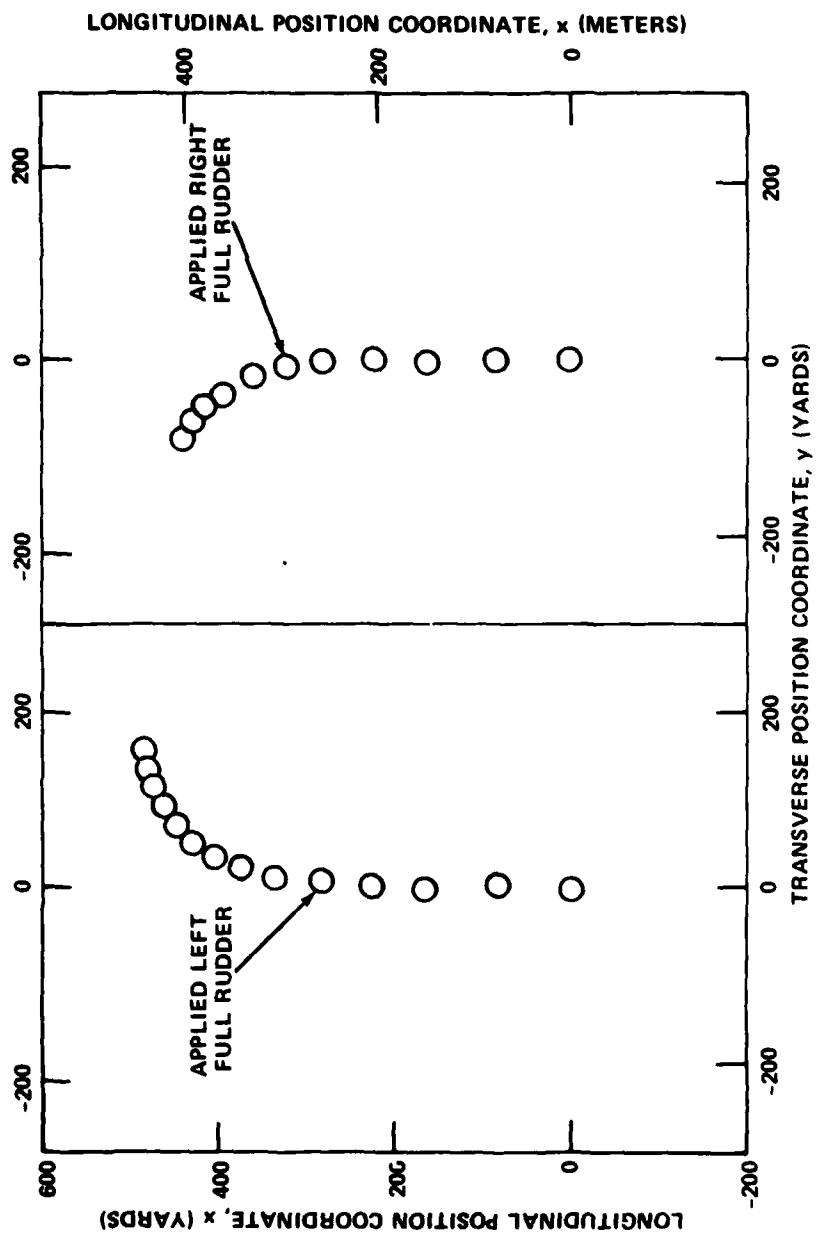


Figure 16 - Ship's Path during Ahead Coasting Maneuvers Conducted on the USNS NAVAJO (T-ATF 169) at a Ship Approach Speed of 14.5 Knots with the Bow Initiating Swinging Left and Right

TABLE 1 - PARTICULARS OF THE USNS NAVAJO (T-ATF 169)

LOA, ft (m)	225.0 (68.6)
L <sub>PP</sub> , ft (m)	210.0 (64.0)
B, ft (m)	42.0 (12.8)
T <sub>FP</sub> , ft (m)	14.6 (4.5)
T <sub>AP</sub> , ft (m)	16.0 (4.9)
Δ, tons, S.W. (tonnes)	2,392 (2,430)
Trim by Stern, ft (m)	1.4 (0.4)
Speed (sustained), knots	14.5
Speed (cruising), knots	13.0
Speed (towing), knots	6.0
Speed (astern), knots	9.5
Rudder Rate, deg/sec	2.4
Number of Propellers	2
Propeller Diameter, ft (m)	9.0 (2.7)
Number of Rudders	2
Rudder Area (each), ft <sup>2</sup> (m <sup>2</sup> )	63.0 (5.9)

TABLE 2 - SUMMARY OF ASTERN MANEUVERS CONDUCTED  
ON THE USNS NAVAJO (T-ATF 169)

Type of Maneuver	Mode of Steering	Shaft RPM	Propeller Pitch	Bow Thruster	Rudder Angle degrees	Ship Speed knots
Coursekeeping	Bow Thruster	Constant	Constant	Variable	0	1
						3
						5
						7
						9.5
	Rudders and Differential Propulsion	Variable	Variable	Off	Variable	1
						3
						5
	Rudders	Constant	Constant	Off	Variable	7
						1
						3
						5
Differential Propulsion	Variable	Variable	Off	0	7	
					9.5	
					1	
Spiral	Rudders	Constant	Constant	Off	Variable	3
						5
						7
Zigzag	Rudders	Constant	Constant	Off	R5-1.5	3
	Bow Thruster	Constant	Constant	50%S-50%P	0	3

TABLE 3 - SUMMARY OF AHEAD MANEUVERS CONDUCTED  
ON THE USNS NAVAJO (T-ATF 169)

Type of Maneuver	Mode of Steering	Shaft RPM	Propeller Pitch	Bow Thruster	Rudder Angle degrees	Ship Speed knots
Coursekeeping	Rudders	Constant	Constant	Off	Variable	3 6 9 12 14.5
	Differential Propeller Pitch	Constant	Variable	Off	0	9 14.5
Spiral	Rudders	Constant	Constant	Off	Variable	5
Zigzag	Rudders	Constant	Constant	Off	R10-L10	5
Turning	Rudders	Constant	Constant	Off	R30	7.5 14.5
					L30	7.5 14.5
					R44	14.5
					L44	14.5
Coasting	Rudders	Constant	Constant	Off	Variable	14.5
Walking Stbd Side To & Away	All	Variable	Variable	Variable	Variable	3-0
Walking Port Side To & Away	All	Variable	Variable	Variable	Variable	3-0
Walking Stbd Side To & Away	Rudders & Differential Propulsion	Variable	Variable	Off	Variable	3-0

TABLE 4 - SUMMARY OF THE RESULTS OF ZIGZAG MANEUVERS CONDUCTED  
ON THE USNS NAVAJO (T-ATF 169)

	Astern Bow Thruster	Astern Rudders	Ahead Rudders
Ship Approach Speed, knots ( $V/\sqrt{L_{pp}}$ )	3(0.21)	3(0.21)	5(0.35)
Execute Rudder Angle, degrees	---	5	10
Execute Bow Thruster Power, %	50	---	---
Deviation from Base Course at Executes, degrees	5	5	10
Time from 1st to 2nd Executes, seconds	30	45	42
3rd	149	---	130
4th	488	---	223
5th	770	---	312
6th	1185	---	396
Travel from 1st to 2nd Executes, Shiplengths	0.72		1.69
3rd	3.58	---	5.22
4th	11.71	---	8.97
5th	18.48	---	12.55
6th	28.44	---	15.92
Overshoot after 2nd Execute, degrees	10	0	6
3rd	81	---	6
4th	59	---	5
5th	103	---	7
6th	73	---	5
Reach, seconds	142	---	122
Shiplengths	3.41	---	4.91
Period, seconds	---	---	181
Shiplengths	---	---	7.28

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