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AN ANALYSIS OF THE BERWICK BAY BRIDGE PASSAGE.(U)
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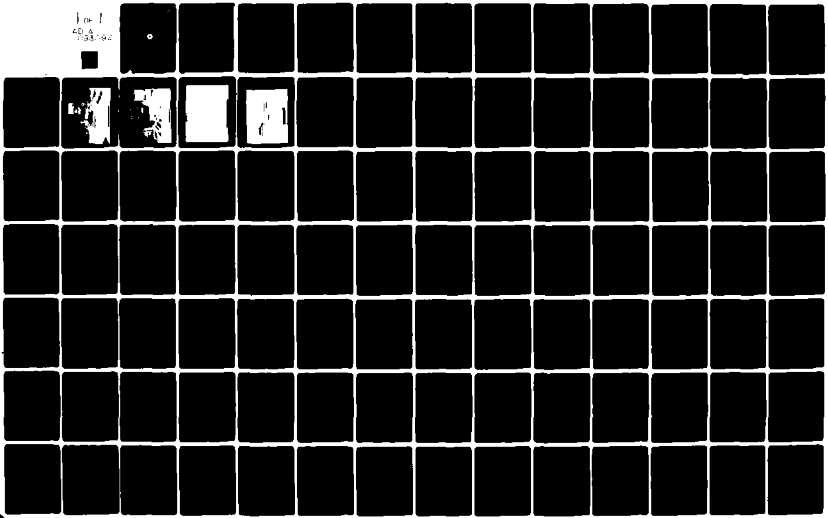

Report No. CG-D-68-80

LEVEL IV (12)

AN ANALYSIS OF THE BERWICK BAY BRIDGE PASSAGE

PETER VAN DYKE

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FINAL REPORT

JUNE 1980

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
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16. Abstract

A towboat simulator analysis of the Atchafalaya River at Berwick, La., has been carried out. Autopilot and manned passages were made on the simulator with different tow characteristics, going both upriver and downriver, and with and without bow thruster assistance. Five different power levels were represented by different engine RPM values, and this combined with the two different tow lengths results in ten HP/L ratios for analysis. In addition, a casualty analysis was made of an April 1, 1978 collision between a tow and the bridges over the river.

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METRIC CONVERSION FACTORS

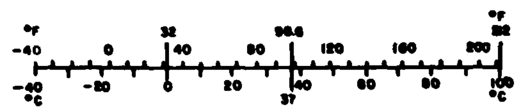
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



HYDRONAUTICS, Incorporated

TECHNICAL REPORT 7909-4

AN ANALYSIS OF THE BERWICK BAY BRIDGE PASSAGE

By

Peter Van Dyke

June 1980

Prepared for

United States Coast Guard
Washington, D. C.

Under

Contract No. DOT-CG-840165-A

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INTRODUCTION

The United States Coast Guard (USCG) Towboat Maneuvering Simulator was designed, built and tested under a contract with HYDRONAUTICS, Incorporated. The objective of the second phase of the work under this contract has been to demonstrate typical uses of the simulator system in areas of USCG interest involving evaluation of vessel maneuverability, navigation rules and casualty analysis. This objective was to be reached by conducting a series of simulations for a selected river location. The location selected was the portion of the Atchafalaya River at Morgan City/Berwick, Louisiana. In this area the river forms a bend and then passes under two highway bridges and one railroad bridge with a lift span. These bridges, and in particular the railroad bridge, are subjected to numerous rammings by tows, especially during periods of high water which result in fast down-river currents.

This section of the Atchafalaya River was selected for this study since, because of the numerous casualties there, considerable data exist on operating conditions and current velocities. Further, the USCG operates a Vessel Traffic Service (VTS) there which involves navigation rules with respect to vessel size as a function of river stage (current velocity). The simulation studies were directed at an evaluation of the effects of current, tow size, towboat horsepower, wind and the use of bow thrusters on path error during the passage of the bridges. These results can then be used to develop a further understanding of casualty situations, the effects of environmental conditions and a general correlation with the VTS navigation rules.

The first step in this study was to obtain a precise description of the current speed and direction in this section of the river. This was obtained from a computer river flow model run at the Waterways Experiment Station (WES) of the U.S. Army Corps of Engineers at Vicksburg, Mississippi under USCG sponsorship. This current data was then integrated into the simulation. An initial series of fast-time runs under the control of a track-following autopilot then were carried out. These runs involved variation of current velocity, tow size, towboat horsepower and wind direction. The results were used to narrow in on several specific cases for more detailed study. These cases were then investigated by more fast-time autopilot runs and by real-time runs using an experienced river pilot, an experienced towboat simulator user and a less experienced simulator user.

During the course of the study, a detailed National Transportation Safety Board (NTSB) Marine Accident Report concerning the April 1, 1978 collision between the M/V STUD and the railroad bridge was received. Based on this report, further analysis of the casualty was carried out. This analysis, which involved combined autopilot and real-time runs, investigated the effect of towboat power on the ability to maneuver out of an out-of-shape condition.

The following sections of this report present a description of the USCG towboat maneuvering simulator, a description of the Berwick Bay Bridge Passage, the results of the various simulation runs and conclusions.

DESCRIPTION OF THE USCG TOWBOAT MANEUVERING SIMULATOR

The Towboat Maneuvering Simulator consists of a mathematical description of the hydrodynamic response of an integrated river tow embodied in a computer program running continuously on a computer, with a control console and graphic and hard-copy devices attached for input and output. It is thus a real-time, interactive simulator, constantly responding to console commands and immediately updating the console displays. It can be used also in an auto-pilot mode, whereby the console is superceded by a mathematical control algorithm which calculates the rudder and throttle commands at every time step based on a prescribed path and desired RPM history.

The control console is shown in Figure 1, with the controls and indicators labeled. Figure 2 shows the controlling computer and hard-copy print device. Figure 3 shows the plan position display which is updated at specified time intervals on the graphic simulation control console.

The computer-generated visual scene shown in Figure 4 is a new addition to the simulator not included in the original descriptive reports (References 1-3). It is a perspective view of the scene from a specified viewing point, with a variable scale and perspective factor. For the Berwick Bridge simulations, the eye position was specified at the rear of the tow at a height of 30 feet above the water, looking out horizontally. The view approaching the bridges in Figure 4 shows the bow of the tow, the bridge piers on the west side of the highway bridge passage, with the bridges running above, the railroad bridge lift span, and the remainder of the railroad bridge at its 10 foot elevation above the water. The far bank beyond the bridges can be seen in the railroad span openings and above the rest of the railroad bridge.

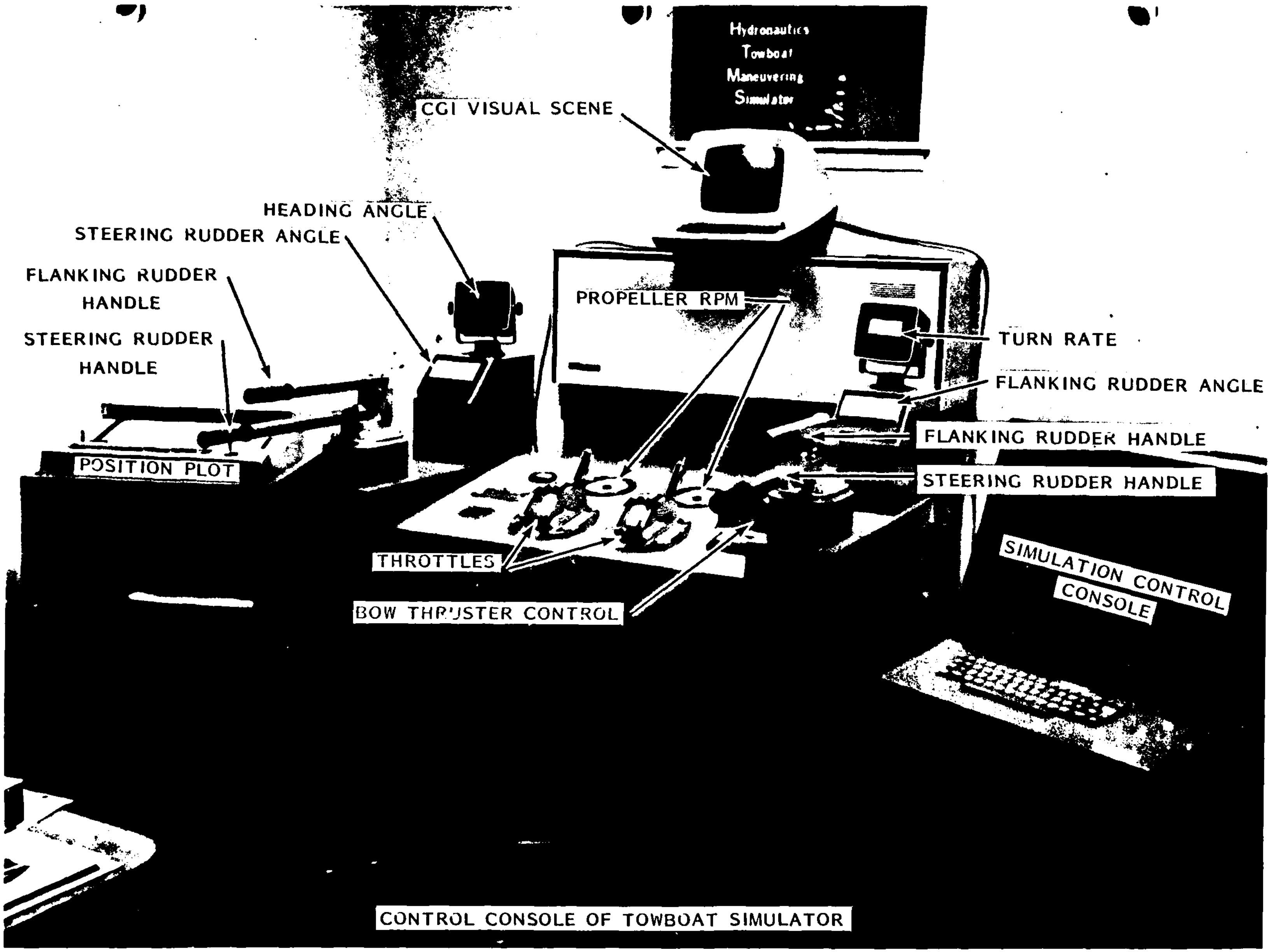

FIGURE 1 - CONTROL CONSOLE OF TOWBOAT SIMULATOR

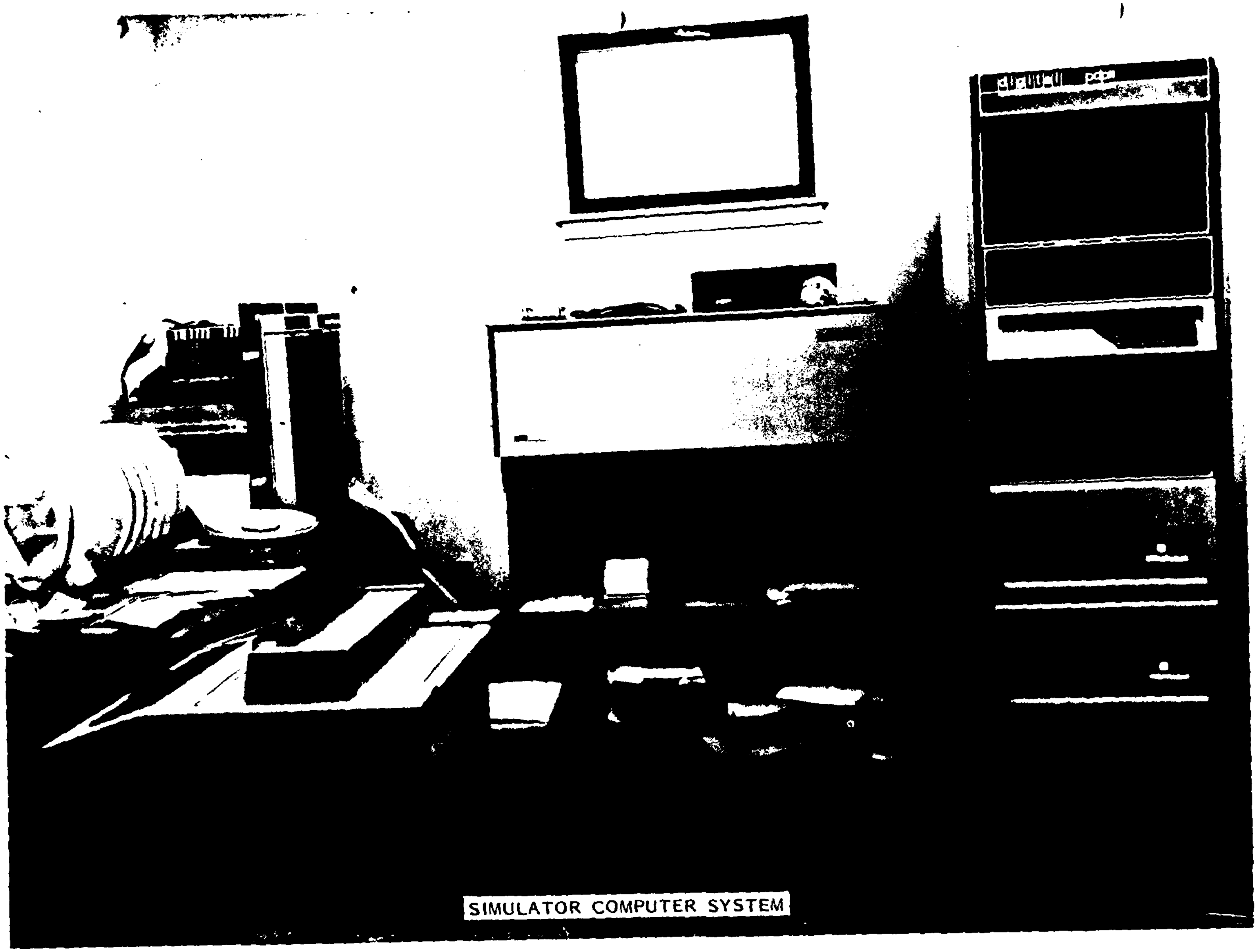

FIGURE 2 - SIMULATOR COMPUTER SYSTEM

FIGURE 3 - PLAN POSITION DISPLAY ON SIMULATION CONTROL CONSOLE

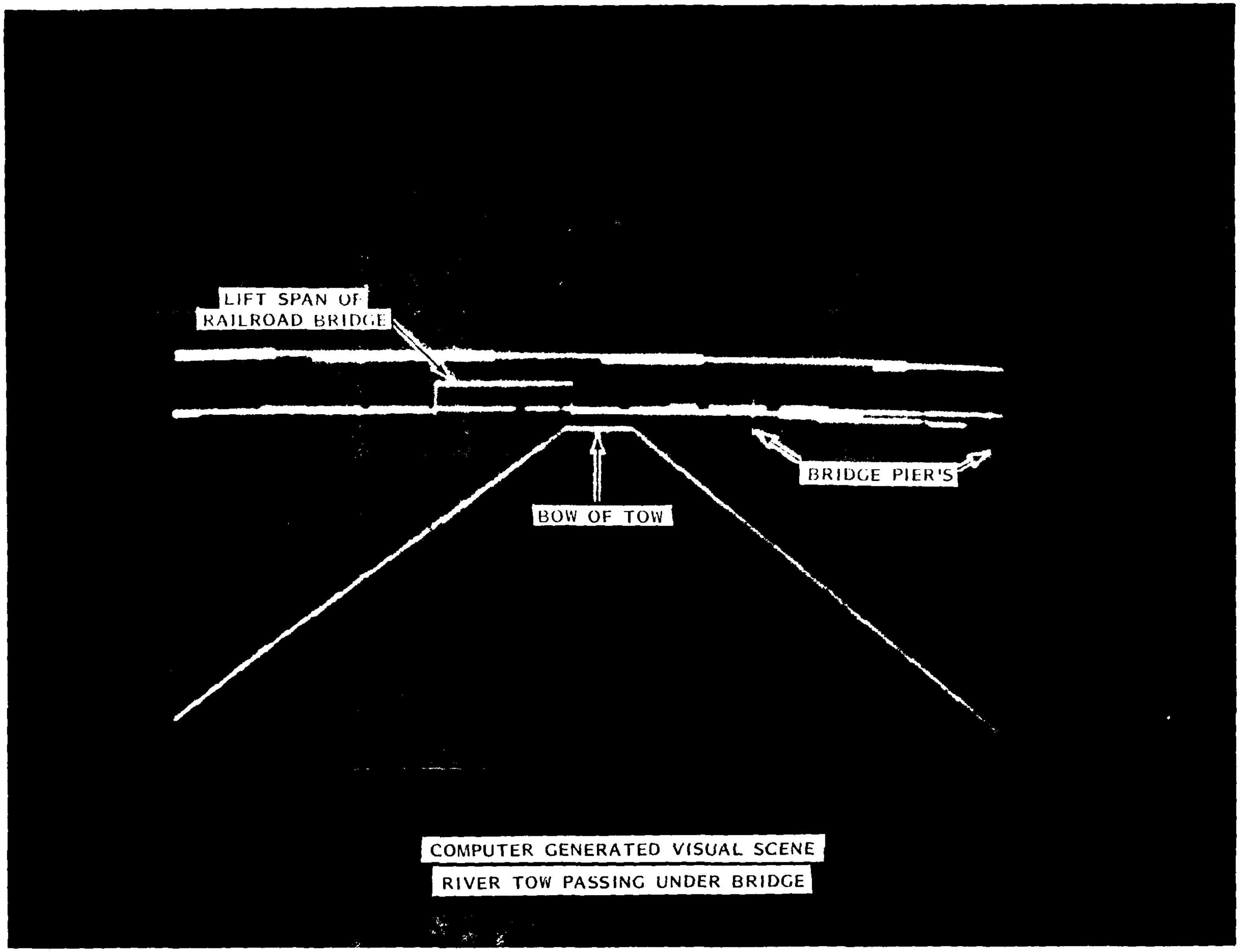

FIGURE 4 - COMPUTER GENERATED VISUAL SCENE, RIVER TOW PASSING UNDER BRIDGE

The visual scene was an important addition to the simulator for the manned runs. For the initial turn down the river (see Figure 3), the left (east) bank is shown clearly on the screen, and is used to judge distance from the bank. The intermediate passage toward the bridges is then carried out primarily referring to the plan position display on the graphic screen with the new tow position being drawn every 20 seconds. As the passage through the bridges nears, primary attention shifts to the visual scene, updating every 4 seconds, where alignment of the tow with the openings is immediately judged, and turn rates are apparent in the relative motions between the tow and the vertical bridge piers and lift span supports.

An autopilot to be used in fast-time runs through the bridge passage also has been developed subsequent to the original simulator version. This autopilot calculates a command steering rudder angle based on four parameters: instantaneous distance from and angle deviation from a prescribed track; instantaneous turning rate; and a time averaged value of previous command rudder values. The desired tracks are of two types: straight lines and circular arcs. Straight line segments are defined by an X and Y coordinate of the line origin, a length of the line segment, and its angular position. Circular arc sections are defined by the X and Y coordinates of the arc center, the radius of the arc, and the angle at which the arc ends. Positive and negative radii denote clockwise and counter-clockwise progression around the arc.

Four coefficients, a function of a particular vessel, are needed to determine the four components of the rudder position calculation. Distance off-track is the perpendicular distance from the track divided by the vessel length. The heading term is the difference between the vessel direction of travel (heading corrected by drift angle relative to the earth) and the desired track angle at the perpendicular track position. The rate term is the inertial angular velocity normalized by the tow length divided by the inertial velocity. The average heading command term is used in situations with a regular current, wind, or wave force acting on the vessel; for the Berwick Bay study, this term is not used.

Figure 5 shows the tracks set up for the Berwick Bay down-river passage. The first line segment holds the tow until the tow distance from the origin of the first line exceeds the line length. At this point, the circular arc segment is the desired track (negative radius for counter-clockwise travel) until the tow moves beyond the radius (or its extension) which ends the arc. The third and fourth segments control the tow as it comes off of the sharp turn, heading it down along the east bank until a final straight line segment takes it through the two highway bridges (slightly to the west of center) and through the center of the critical railroad span opening. A small positive arc segment then forces the tow to apply maximum rudder angle to turn around the next river bend.

The autopilot also has the ability to change RPM, in each track segment, holding it constant along each one. Bow thruster control may also be incorporated through logic in the autopilot control; for the runs with bow thruster specified, the thruster was used to aid the tow in turning in whatever direction the rudder was indicating, with full thruster power applied in either direction.

Updated versions of the User's Manual and Programmer's Manual (References 1 and 2) are also being prepared under contract to the USCG, and these provide a complete description of the version of the simulator used to make this Berwick Bay Bridge evaluation. (References 4 and 5.)

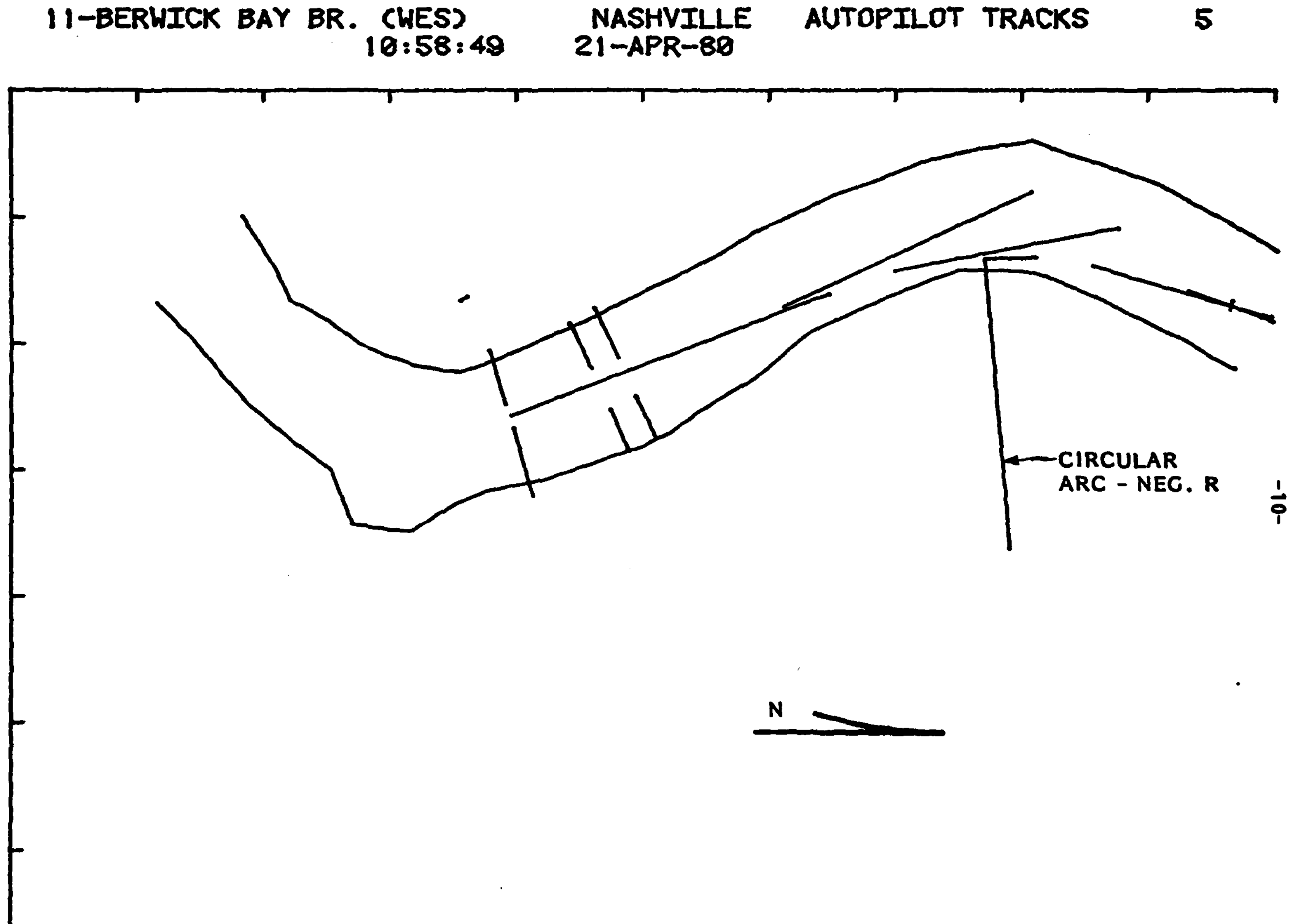

FIGURE 5 - SAMPLE AUTOPILOT TRACKS

THE BERWICK BAY BRIDGE PASSAGE

The Berwick Bay Bridge Passage consists of the passage of the Atchafalaya River between Morgan City and Berwick, Louisiana. The river describes a large figure "S" geometry as it flows south of Drews Island through Drews Pass, curves around the first bend at the Conrad Shipyard, flows through the Long Allen and New Highway bridges and then the Southern Pacific Railroad Lift Bridge, and then around the sharp bend west of Bateman Island (see Figure 6). Figure 5 shows the bank outline and bridge positions for the simulator model. Figures 7 and 8, from Reference 7, show the same outline with the recommended track for best passage, a schematic representation of the current directions, and a description of the strategy for best passage both down-river and up-river.

A detailed record of accidents involving the Berwick Bay Bridge Passage bridges is compiled in Reference 6, and an analysis of this data along with data on successful passage through the bridges, available because of the records of the USCG Vessel Traffic Service center on the east side of the railroad bridge span opening, is presented. The concept of horsepower-length ratio, the result of dividing total towboat engine horsepower by overall tow length, is used in the discussion of the casualty data to define a suggested restriction of $HP/L > 3$ to preclude the probability of accident.

The VTS rules for passage through the bridges currently in effect (Reference 8) restrict tow sizes at high water stages as follows:

8. <u>VESSEL AND TRAFFIC LIMITATIONS</u>.

a. <u>High Water Notification and Determination</u>. High water vessel traffic limitations will be put in effect and removed by Notice to Mariners. High water will be considered to exist when the Morgan City River Gage reads three feet mean sea level or more for five consecutive days and is anticipated to remain at

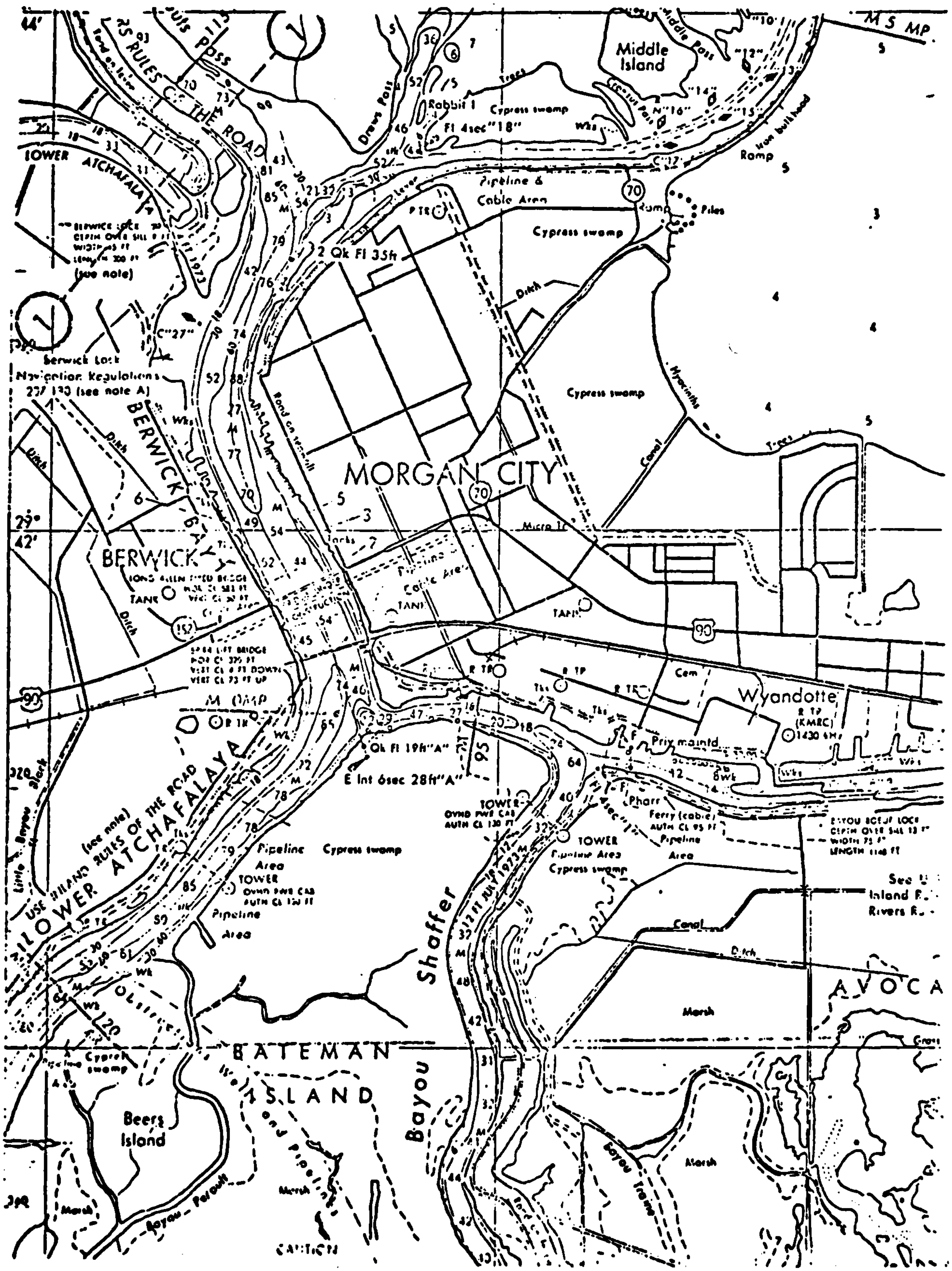

FIGURE 6 - CHART OF BERWICK BAY

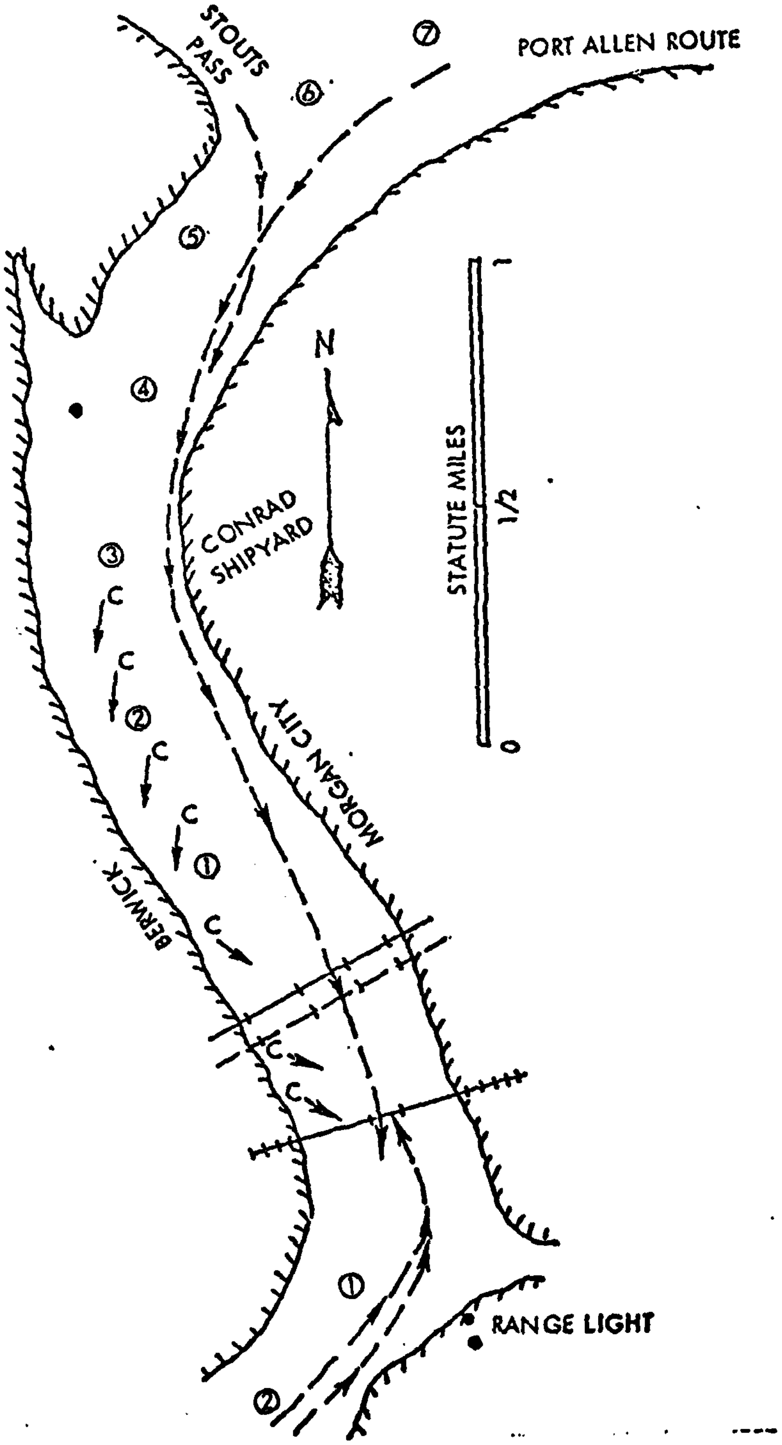

FIGURE 7 - BERWICK BAY PASSAGE

Downstream Operation

- Entering Berwick Bay from the Port Allen route hold the sailing line shown and reduce speed to about half ahead.
- Entering Berwick Bay from Stouts Pass cross the river between (5) and (6) and favor left descending shore.
- Generally hold slow speed between (4) and (3) with intermittent use of power to stay on course and close to shore.
- At (3) current will set tow toward right descending shore if out too far in river.
- Cut point at Conrad Shipyard (3) in close to prevent current from catching stern of tow and rotating it out toward mid-river.
- Run between slow and half speed at (3) to maintain steerage and control.
- Should be shaped up by (2). Current tends to get tow out-of-shape between (2) and (3).
- At (1) either drive or hold half speed depending on conditions.
- Enter highway bridge at mid span or just to the right of mid span depending on current conditions.
- Current will shift at highway bridge and operator must expect a strong left hand draft between bridges.
- Favor right descending pier of railroad bridge to offset current and to prepare for sharp right hand bend in river just below bridge.
- Under some conditions with a long tow you must back and flank as soon as you clear the railroad bridge in order to line up for the passage down river.

Upriver

- In general operator can hold middle of river during upstream approach.
- At (2) slow down and line up with railroad bridge.
- Favor Berwick pier (left ascending pier) to offset current just below and between bridges.

FIGURE 8 - OPERATOR STRATEGY

three feet or more for an additional five consecutive days. High water limitations will be removed when the Morgan City River Gage reads less than three feet for five consecutive days and is anticipated to remain at less than three feet for an additional five consecutive days.

b. High Water Vessel and Traffic Limitations. When the high water conditions exist, the following limitations apply to vessels transiting the navigational openings of the two highway bridges and the railroad bridge:

(1) Towing on a hawser in either direction is prohibited with exception of one vessel towing another vessel in a northbound direction.

(2) Barges and towing vessels must be arranged in tandem with exception of one vessel towing one other vessel alongside.

(3) Towing vessels with less than 1000 horsepower shall not tow barges with any dangerous cargo listed in paragraph 5.

(4) Southbound tow limitations:

(a) Non-integrated southbound tows without operable bow steering units shall not exceed 300 feet in length.

(b) Integrated southbound tows without operable bow steering units shall not exceed 600 feet excluding the towboat.

(c) Southbound tows with an operable bow steering unit shall not exceed 1180 feet including the towing vessel.

(5) Northbound tow limitations:

(a) Non-integrated northbound tows without bow steering units shall not exceed two barges.

(b) Integrated northbound tows shall not exceed 1180 feet including the towing vessel.

(c) Northbound tows with bow steering units shall not exceed 1180 feet including the towing vessel.

(d) Northbound tows with a second towboat used on the lead barge shall not exceed 1180 feet including the towing vessels.

A discussion of these restrictions, and also of HP/L ratio, will be given in the conclusion of this report.

Because of the major effect of current magnitude and direction on the bridge passage, a separate effort was made to determine an accurate current map at a typical high water stage condition. To develop this, Dr. L. Daggett of the U.S. Army Corp of Engineers

Waterways Experimental Station used a computer-based numerical flow evaluation procedure to investigate the Berwick Bay Passage, under USCG sponsorship. He made a very detailed determination of the river and bridge co-ordinates, using large-scale Corps of Engineers Hydrographic Survey maps. Conditions corresponding to April 22, 1973 at 1430 were selected as the example, with a flow of 464,000 cfs. in the main channel, and a flow into Shaffer Bayou (see Figure 6) of 12 percent of that in the main channel. Cross sections along the river were selected, and the surface currents, corrected for vertical distribution of current, were calculated at eight evenly spaced points along each of the 30 cross sections used by the simulator model. This resulted in 240 discrete current velocities and directions; the bridge co-ordinates were then converted into the flow model co-ordinates to ensure proper position relative to the river. The resulting current map is shown in Figure 9. The current vectors at the new highway bridge (middle of the three) are 8.61 fps to 6.10 fps across the river. In all cases, the flow directions are within three degrees of being normal to the cross sections selected, except immediately adjacent to the bank at the Shaffer Bayou intersection. An "average" current number would be 7.5 fps. A detailed description of this current determination work is given in Reference 9.

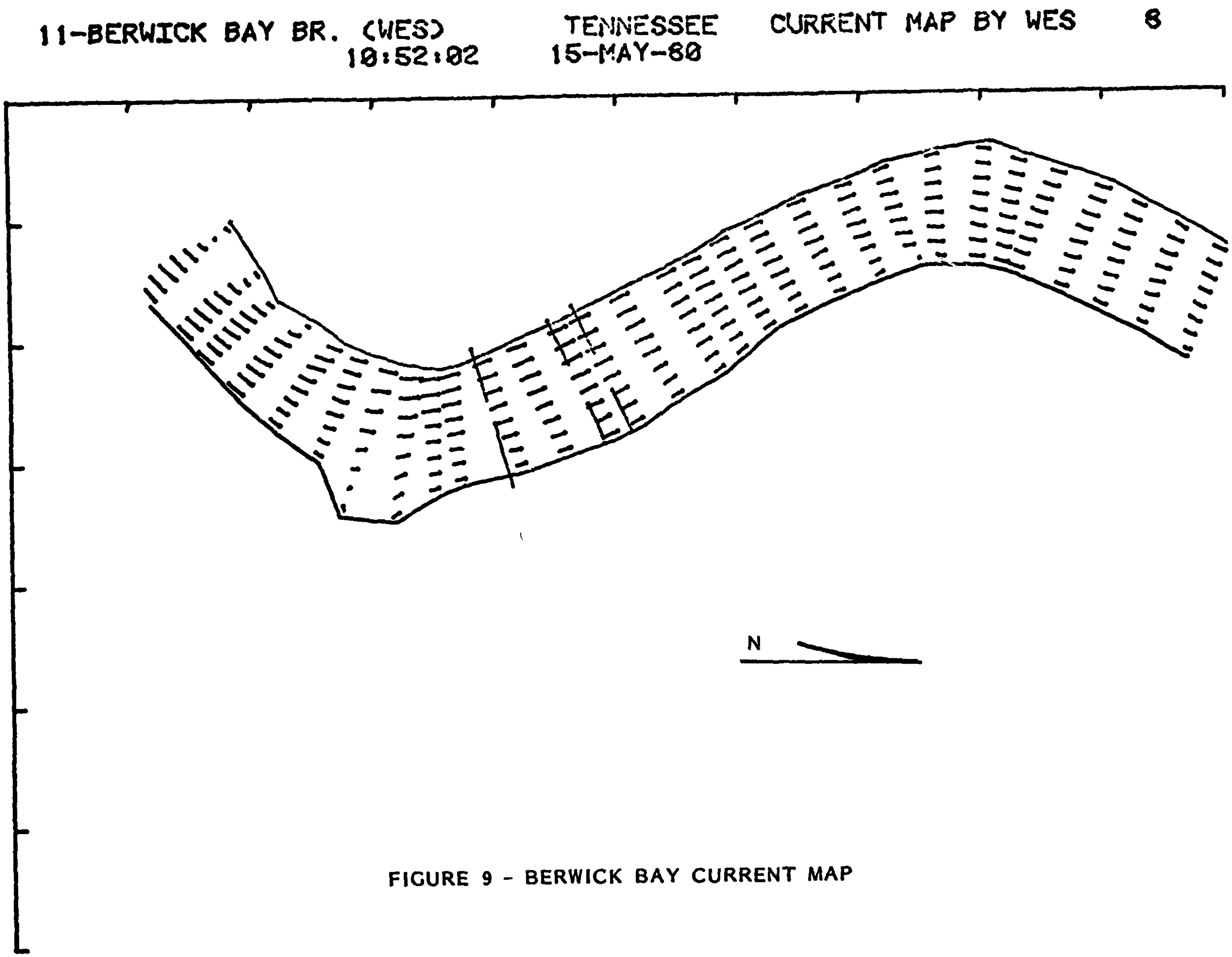

FIGURE 9 - BERWICK BAY CURRENT MAP

FAST-TIME AUTOPILOT RUNS

To begin the analysis, a first set of autopilot-controlled runs were made with the following parameters:

TOWS: Hydrodynamic and propulsion data which are available for two tows were used. The shorter, referred to in this study as the "Tennessee", represents a two barge fully-loaded integrated tow with a 150 foot, twin screw, tow boat. The overall length is 745 feet. The longer tow, referred to as the "Nashville", represents a three barge, fully-loaded integrated tow pushed by the same class tow boat. The overall length is 1160 feet. The towboat is a nominal 5000 horsepower vessel with twin screws, kort nozzles, and steering and flanking rudders. Additional characteristics of these tows are:

Towboat	
Length overall	150 ft
Beam	42 ft
Draft	8 ft 4½ in.
Propeller diameter	9 ft
Displacement	1056 Short Tons
BHP	5000
Appendages	Twin screws in kort nozzles with two steering and four flanking rudders.

Lead Barge Unit	
Length overall	297.5 ft
Beam	54 ft
Depth	12 ft
Draft	9 ft
Displacement	4038 Short Tons

18-Blank

Trail Barge Unit	
Length overall	297.5 ft
Beam	54 ft
Depth	12 ft
Draft	9 ft
Displacement	4278 Short Tons

Middle Barge Unit	
Length overall	415.0 ft
Beam	54 ft
Depth	12 ft
Draft	9 ft
Displacement	6300 Short Tons

The barges and tow boat are described in more detail in Reference 10. This reference also gives the hydrodynamic coefficients and maneuvering characteristics of the "Tennessee" tow. The hydrodynamic coefficients for the "Nashville" tow were estimated by extrapolating the "Tennessee" coefficients on a theoretical basis. This should be relatively accurate since all of the hard to predict hull-propeller-rudder coefficients are the same since the towboats are the same.

The engine characteristics of each tow are such that approximately 5000 horsepower is required to produce 200 rpm on the two propellers. A cubic relationship between rpm and horsepower is then assumed to model different horsepower engines for the two tows. RMPs of 200, 178, 156, 134 and 112 were used to produce Horsepower/Length ratios of 6.71, 4.73, 3.18, 2.02, and 1.18 for the shorter tow, and 4.31, 3.04, 2.04, 1.30, and 0.76 for the longer.

CURRENT: Three current conditions were selected, which were 0, 50, and 100 percent of the currents given by the WES study.

WIND: Two wind conditions were selected, 0 and 30 knots of wind and an angle of 245 degrees, which is a wind blowing roughly from east to west. This wind direction was selected because the fully loaded tows are relatively unaffected by wind (vs. lightly loaded tows where the barges present a large cross-section), with the major effect being rotation of the tow because of the surface area of the towboat itself at the rear of the tow.

AUTOPILOT: The autopilot tracks were selected in such a way as to allow the tows as much distance as possible along a single straight track before passing through the bridges (see Figure 5). For the down-river runs, the tracks consisted of an initial straight track to allow a settling-down from the initial starting conditions, a circular arc section to turn the tow as close to the bank as possible, and then two straight tracks to head the tow down along the east bank to a point where the single straight track would produce a reasonable path through all three bridges with a good alignment for the sharp turn after the last (railroad) bridge. The final turn was accomplished by describing a very small circular arc, thus causing all tows to turn as hard as possible to the right; because of the artificial nature of this final track, no distance and heading errors were accummulated along it, and, in reality, the performance of the tows around this bend is unrealistic in that flanking maneuvers would almost always be used to negotiate it.

The three autopilot coefficients were selected to minimize the offtrack and heading errors along the five tracks with no current in the river. Plots of root mean square heading angle and track error, measured every second during the run, were made for different values of one of the three coefficients varied while the other two were fixed. It was found that the minimum heading angle error and minimum track error occurred at different values, but a reasonable intermediate choice was made. A separate set of coefficients was selected for the two tows.

In addition to measuring the root-mean-square values (based on time with one second sampling rate) of heading angle and track distance error, root-mean-square command rudder angle, actual rudder angle, and relative velocity, were also measured. Six specific points along the fifth autopilot track, the one passing through the bridges, were also selected at which to measure single values of heading angle and track error, and command rudder angle. These points were: 1500 ft before the first (old highway) bridge, 750 ft before it, at the first bridge, at the second (new highway) bridge, midway between the second and third bridges, and at the third (railroad) bridge. The values of the autopilot coefficients for the first runs, based on no current and no wind, were as follows:

TENNESSEE

1 - 0.0	2 - 40.0	3 - 3.8	4 - 21.0

NASHVILLE

1 - 0.0	2 - 90.0	3 - 3.0	4 - 25.0

where 2 is distance error, 3 is heading error, and 4 is turn rate.

DISCUSSION OF RESULTS: The results of these first thirty runs are shown graphically in Figure 10. In general, all six TENNESSEE runs show good control of the tow even under the most severe wind and current conditions; with all five HP/L ratios over-plotted in each figure, the composite tow tracks pass through the bridge and make the turn to proceed down river. It can be seen that the wind rotation causes the tracks to shift down toward the critical east end of the railroad bridge. The NASHVILLE runs, at no current, display similar results, but the half-current and full-current plots show the onset and then full presence of control problems.

The results of the complete set of runs is shown in Figure 11, where R.M.S. track errors divided by tow length are plotted against HP/L ratios. The TENNESSEE values are all below the nominal bridge opening parameters of 0.177 for the 54 ft wide tow. The effect of the wind is shown, and the worst case is the lowest HP/L of 1.18 with full wind and current. The NASHVILLE runs show that at half current and full current, the track errors are at and above the nominal bridge opening parameter of 0.114. Non-dimensionalization of the track error by tow length brings the two tow configurations into something of a single broad trend line. The bridge opening parameter is useful in that it provides a measure of the magnitude of control required for a safe passage.

As a result of these first runs, it was decided to concentrate further tests on the large tow under full current conditions, and to consider an up-river and down-river with bow thruster case in addition to the down-river run.

Before making a second set of autopilot runs, it was decided to re-optimize the autopilot coefficients for the case of full current rather than no current. Also, the concept of swepth path,

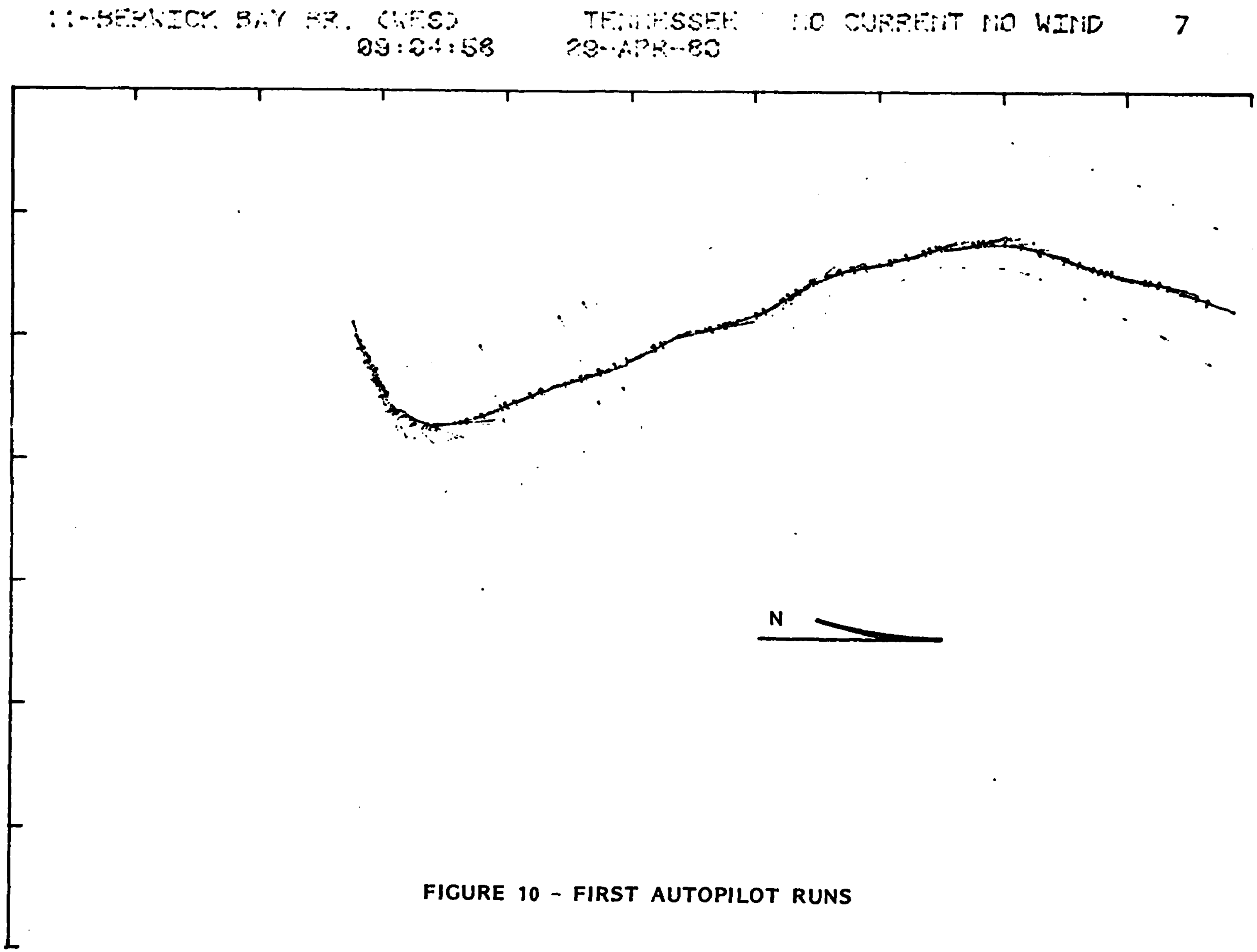

FIGURE 10 - FIRST AUTOPILOT RUNS

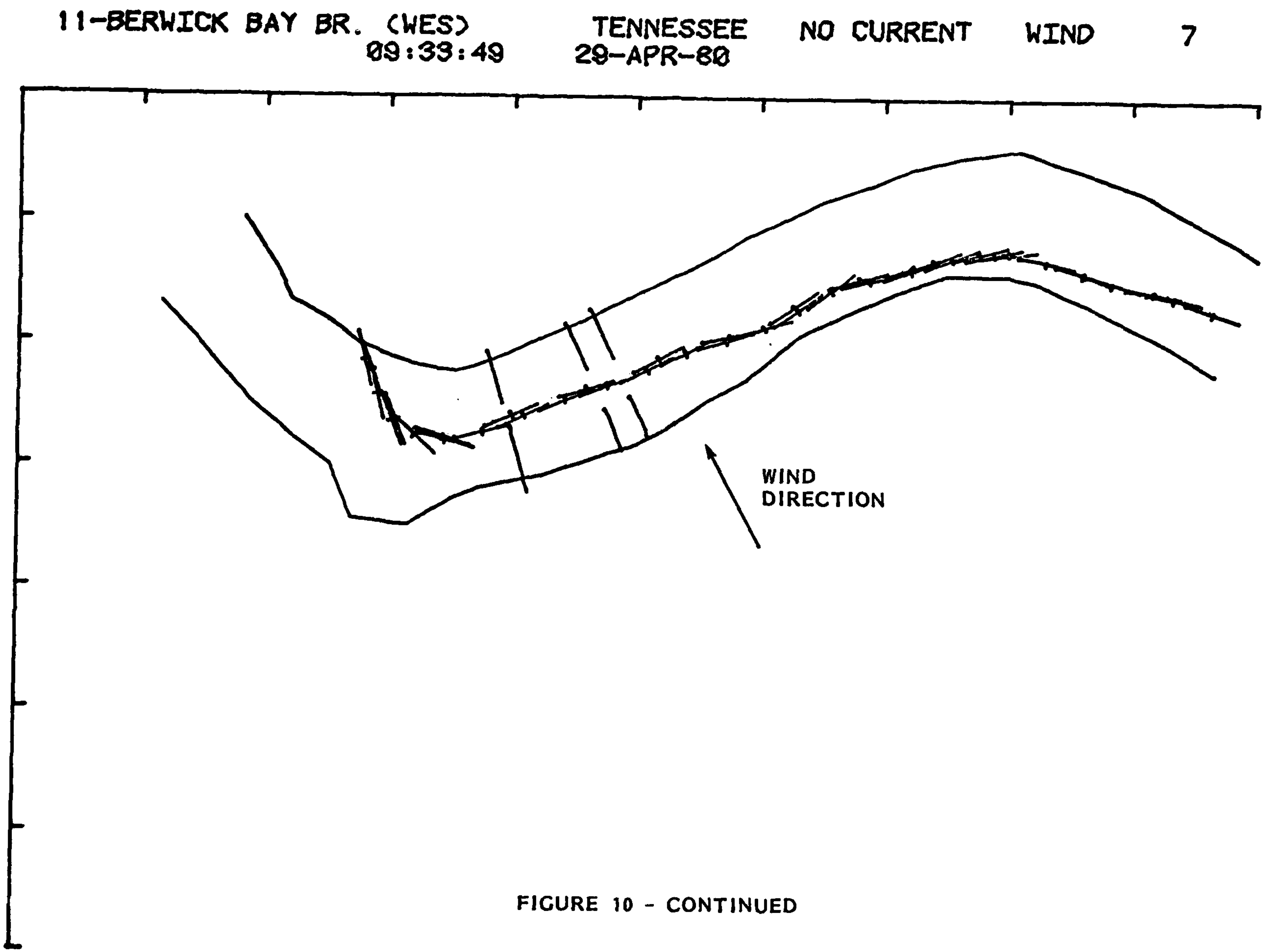

FIGURE 10 - CONTINUED

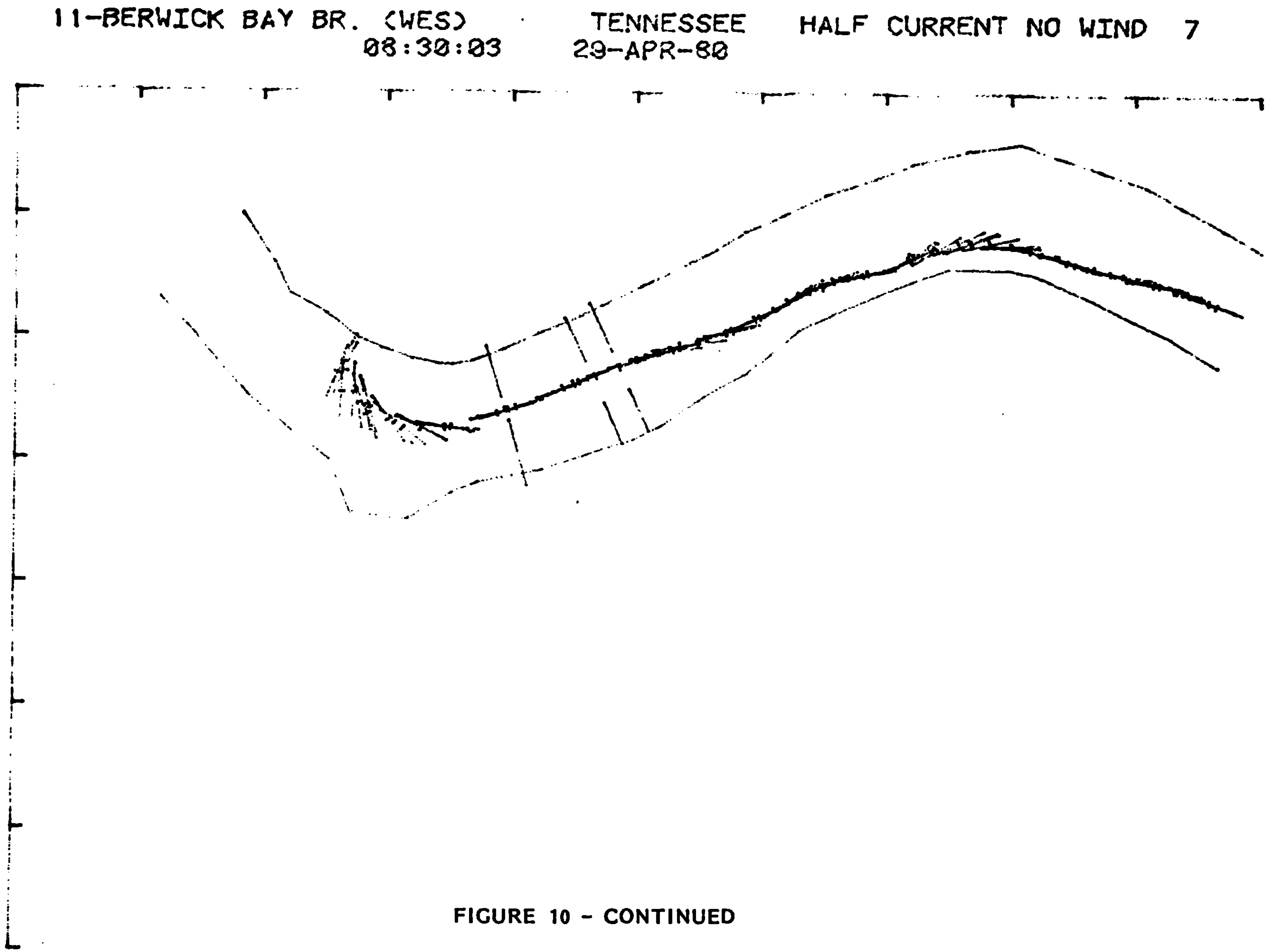

FIGURE 10 - CONTINUED

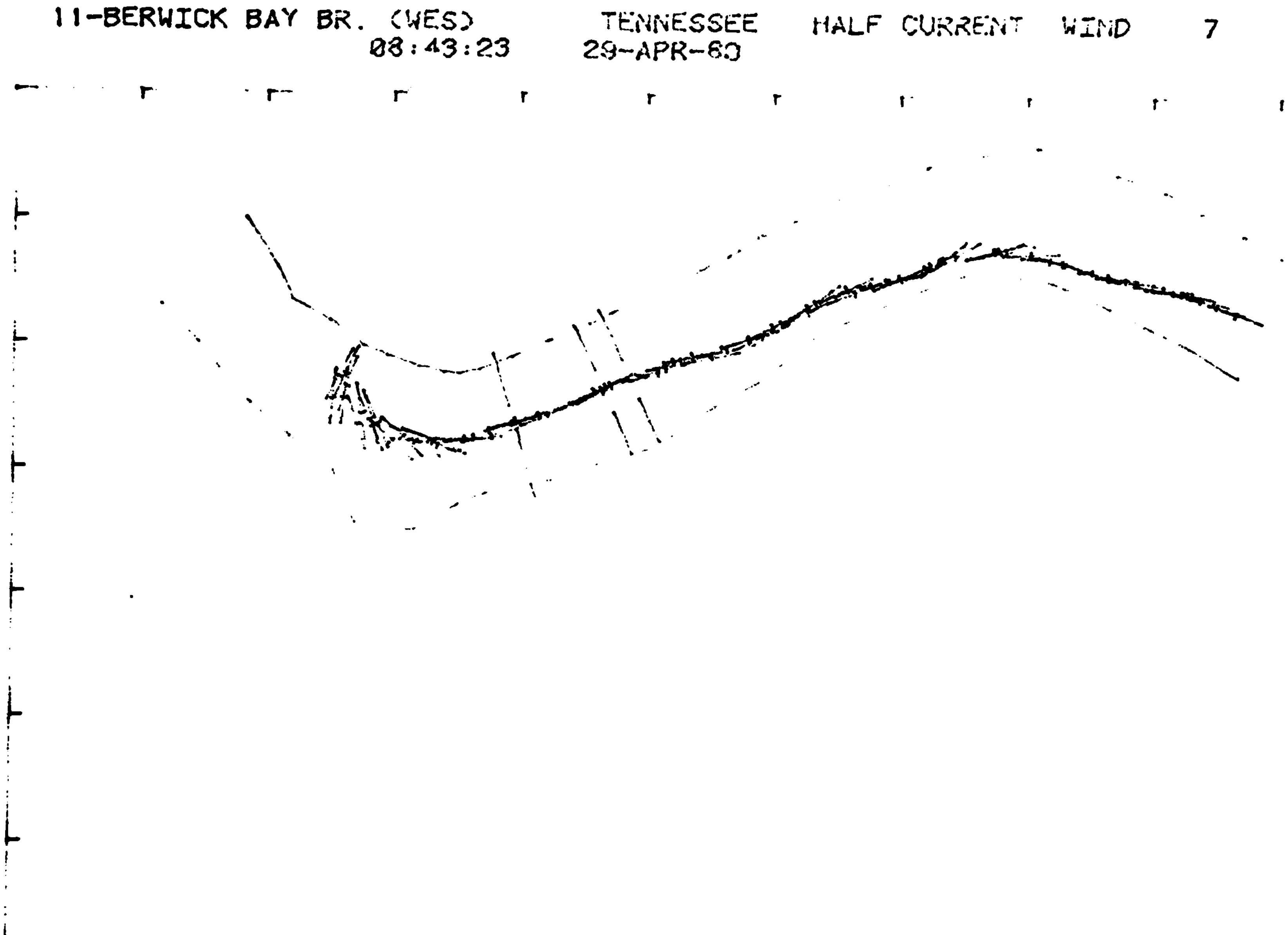

FIGURE 10 - CONTINUED

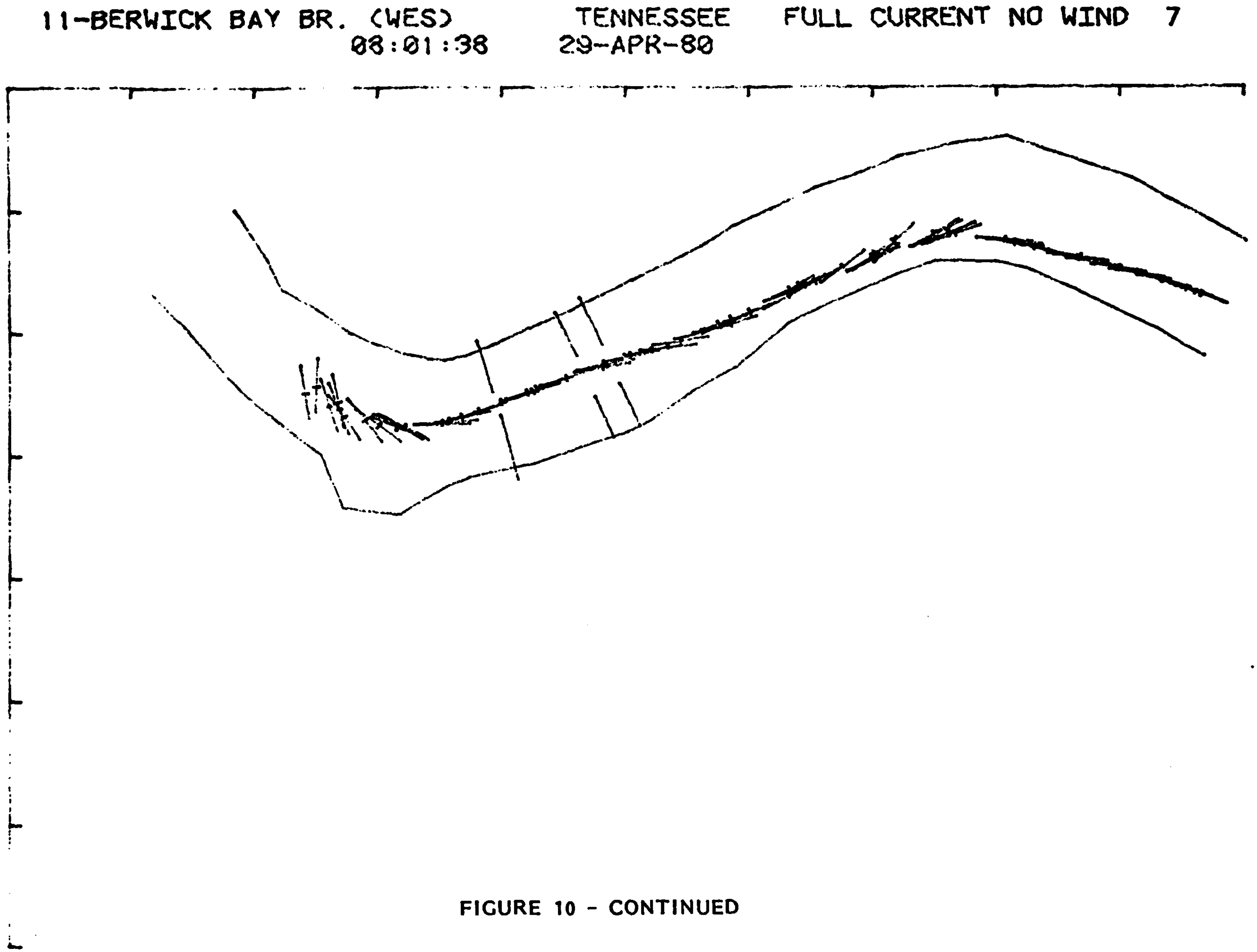

FIGURE 10 - CONTINUED

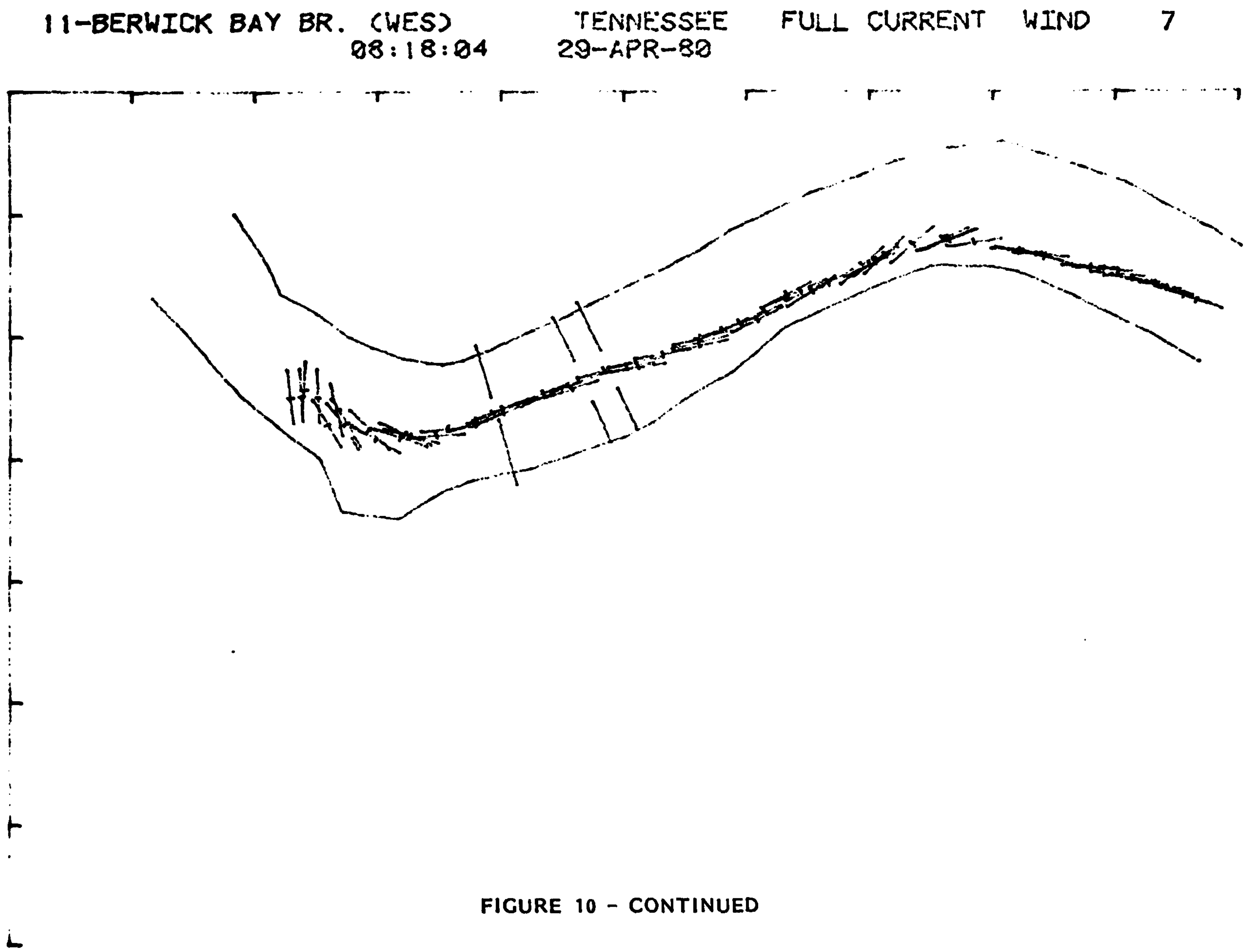

FIGURE 10 - CONTINUED

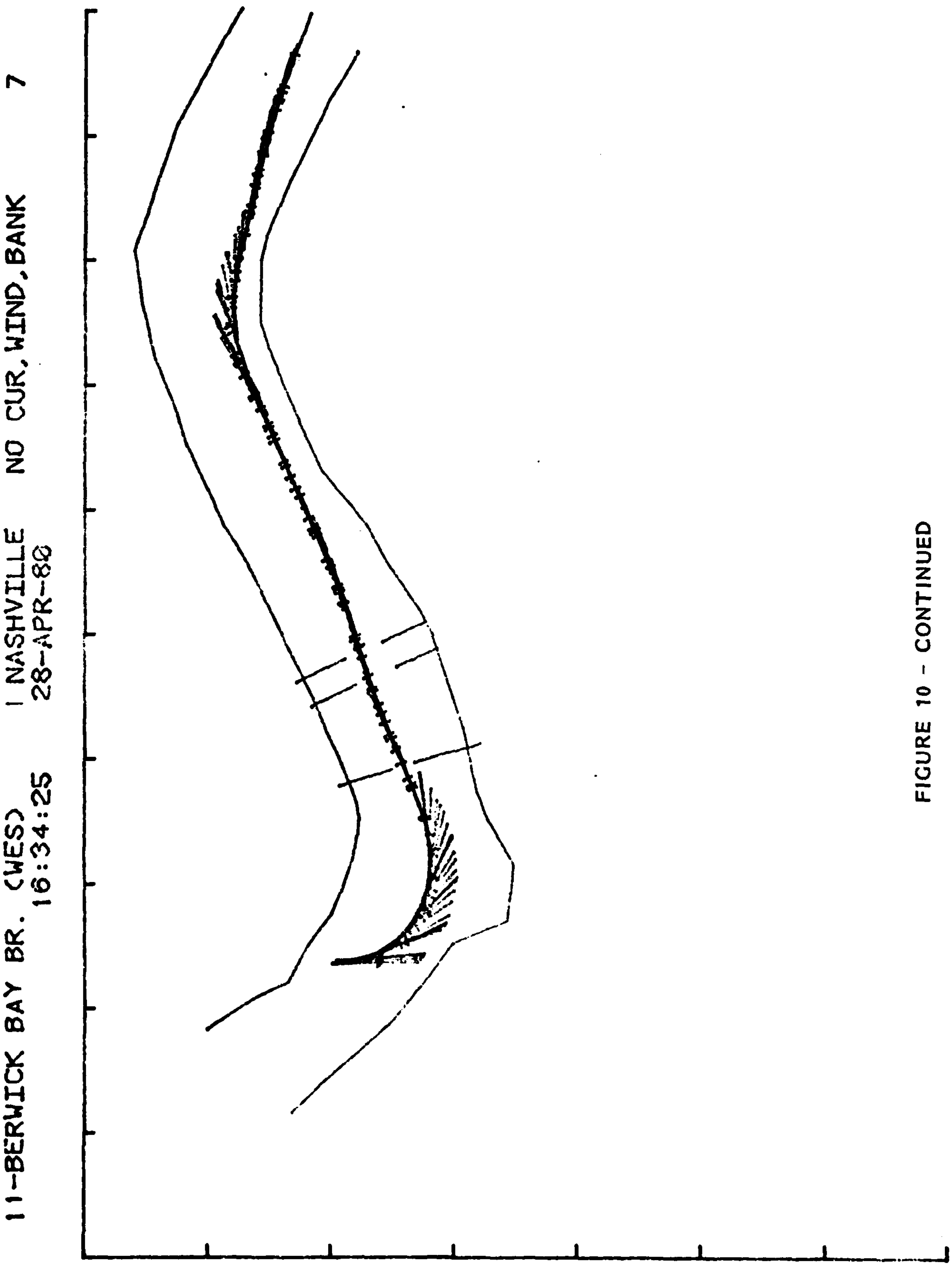

FIGURE 10 - CONTINUED

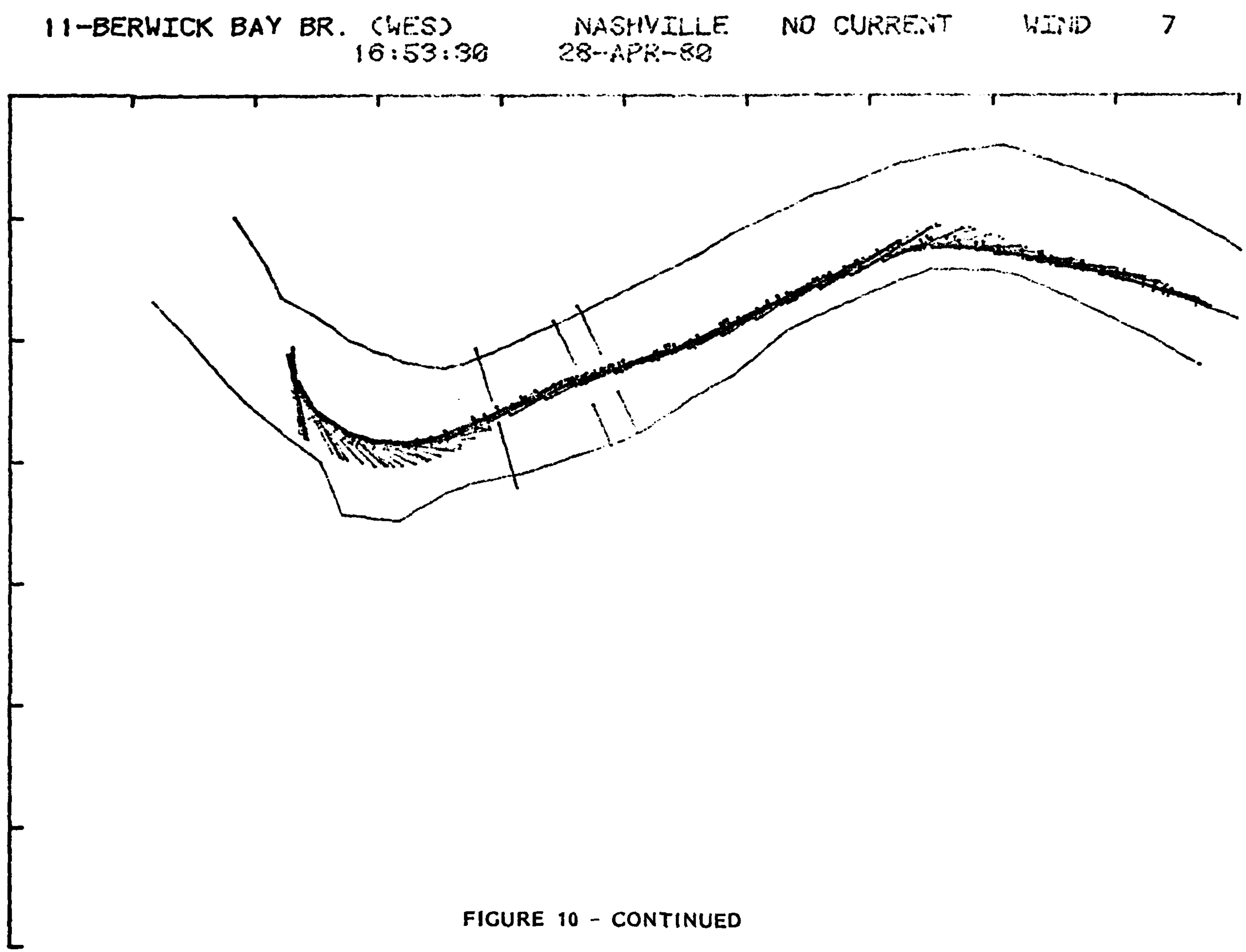

FIGURE 10 - CONTINUED

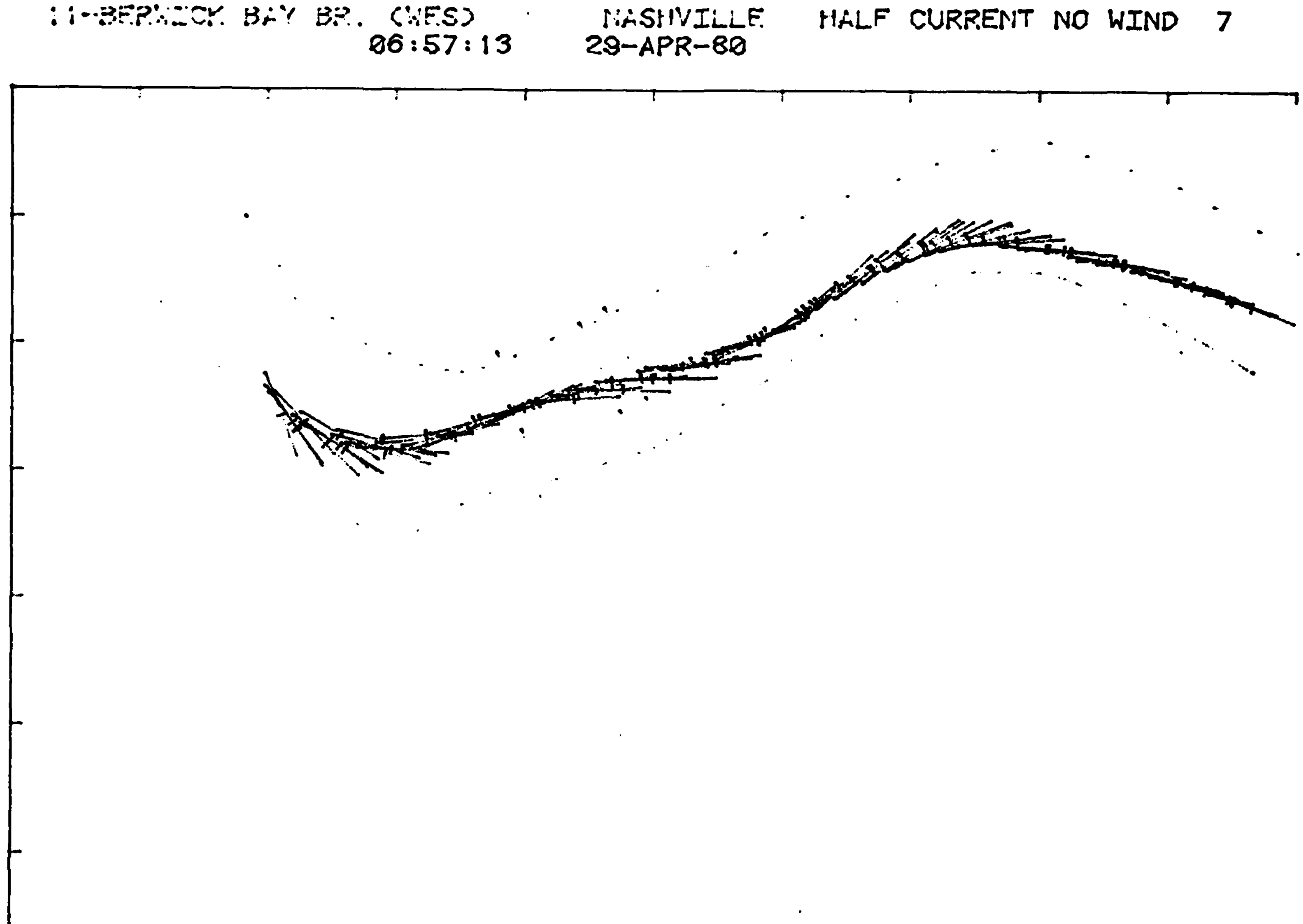

FIGURE 10 - CONTINUED

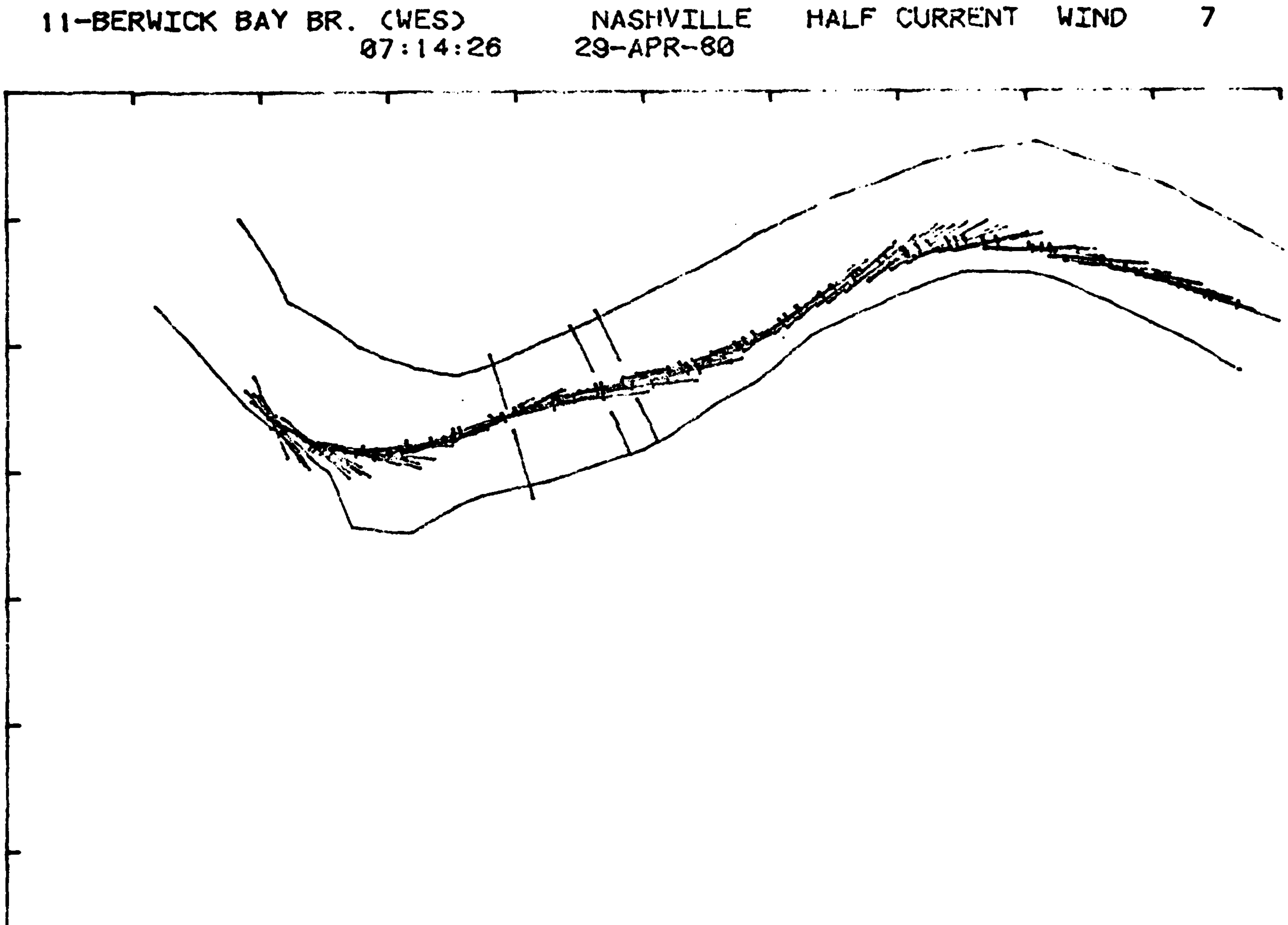

FIGURE 10 - CONTINUED

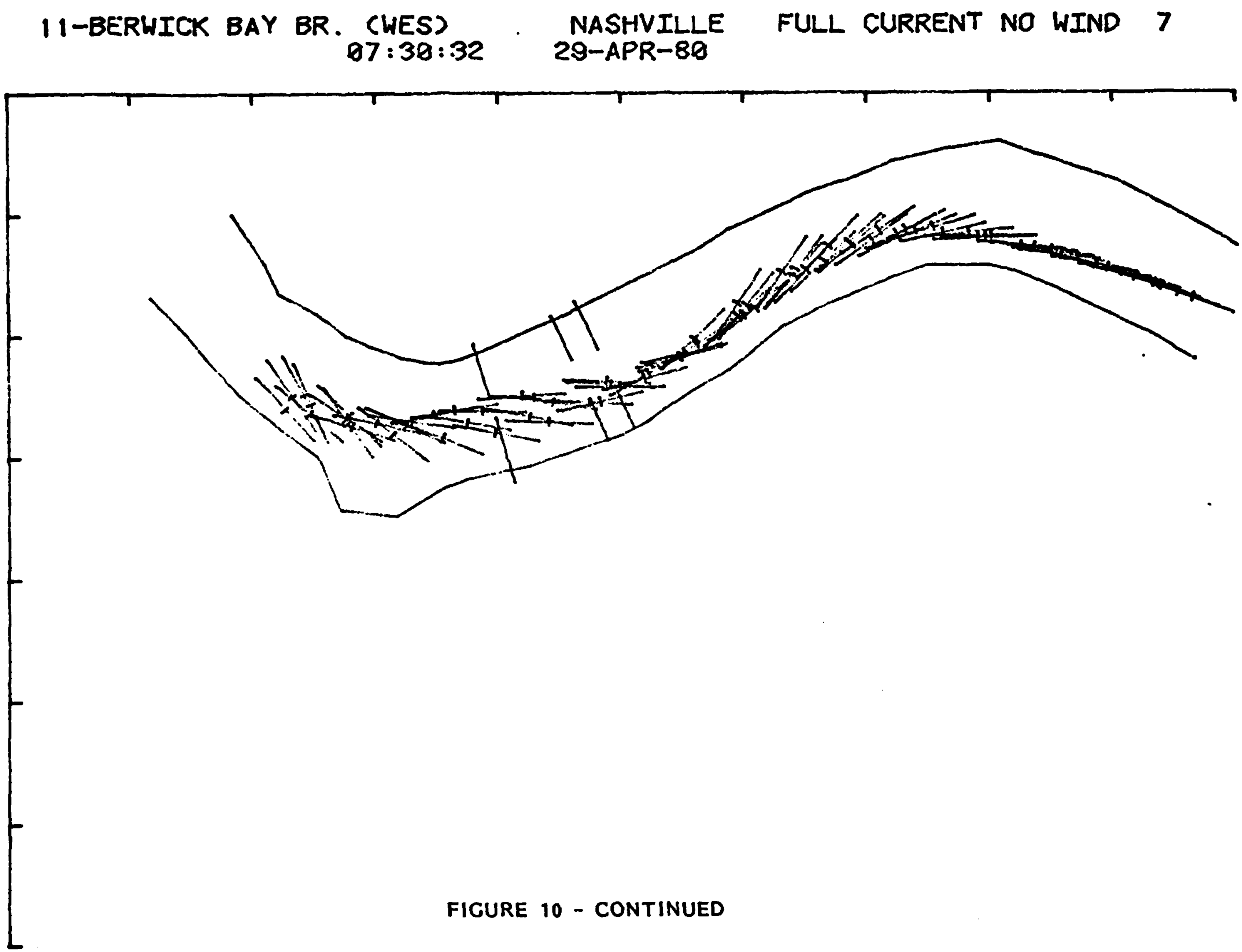

FIGURE 10 - CONTINUED

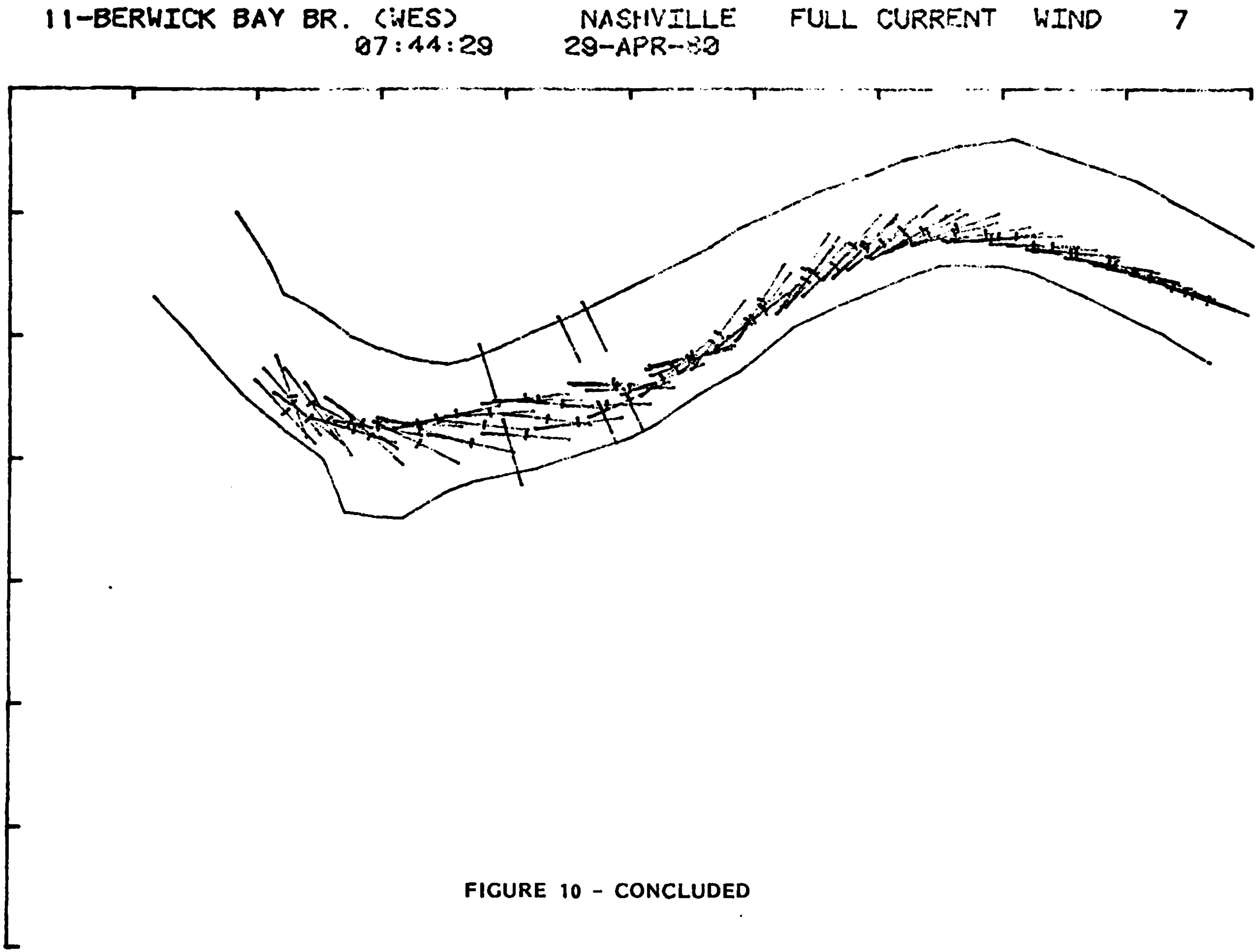

FIGURE 10 - CONCLUDED

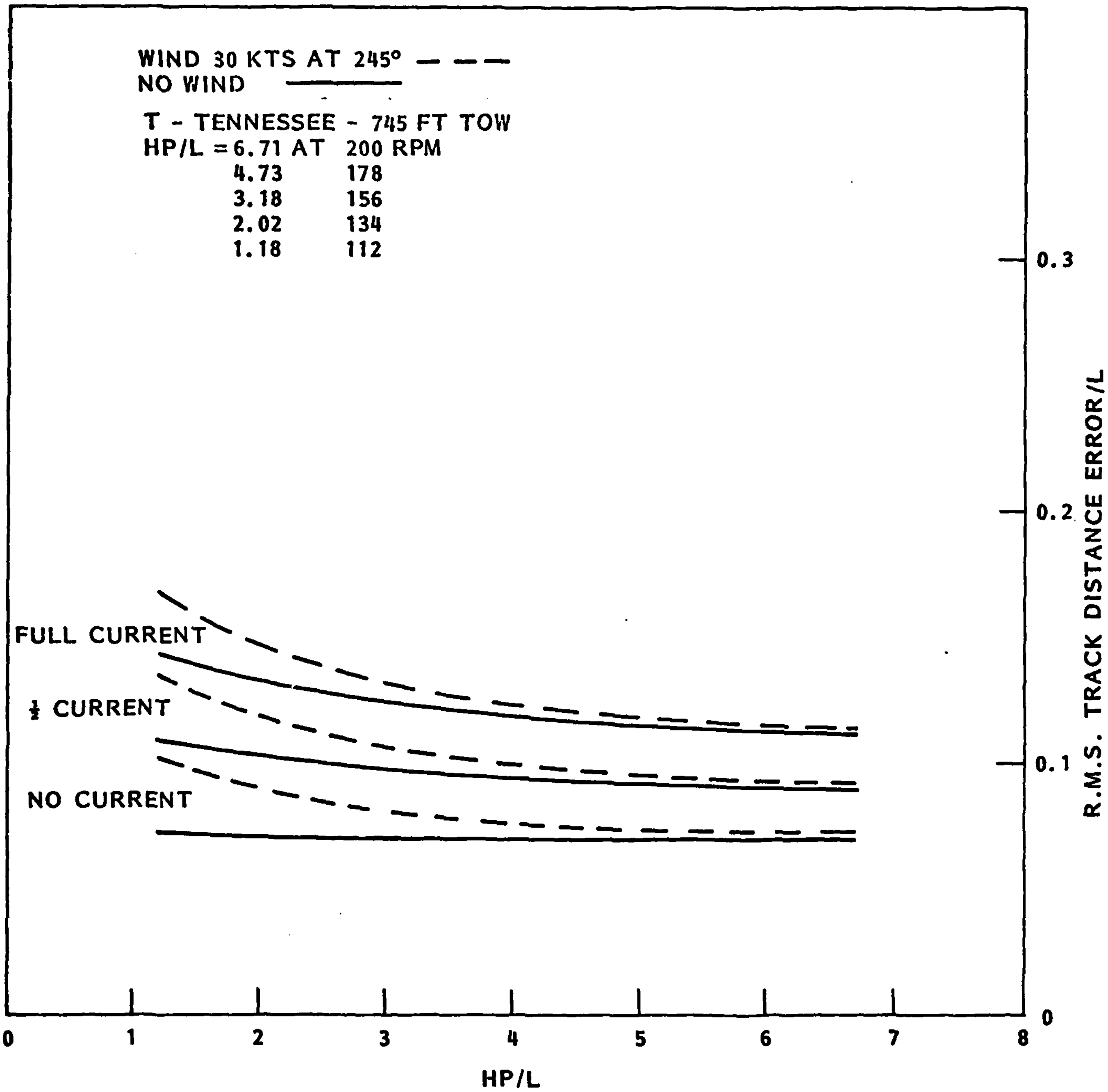

FIGURE 11a - RESULTS OF FIRST AUTOPILOT RUNS - TENNESSEE

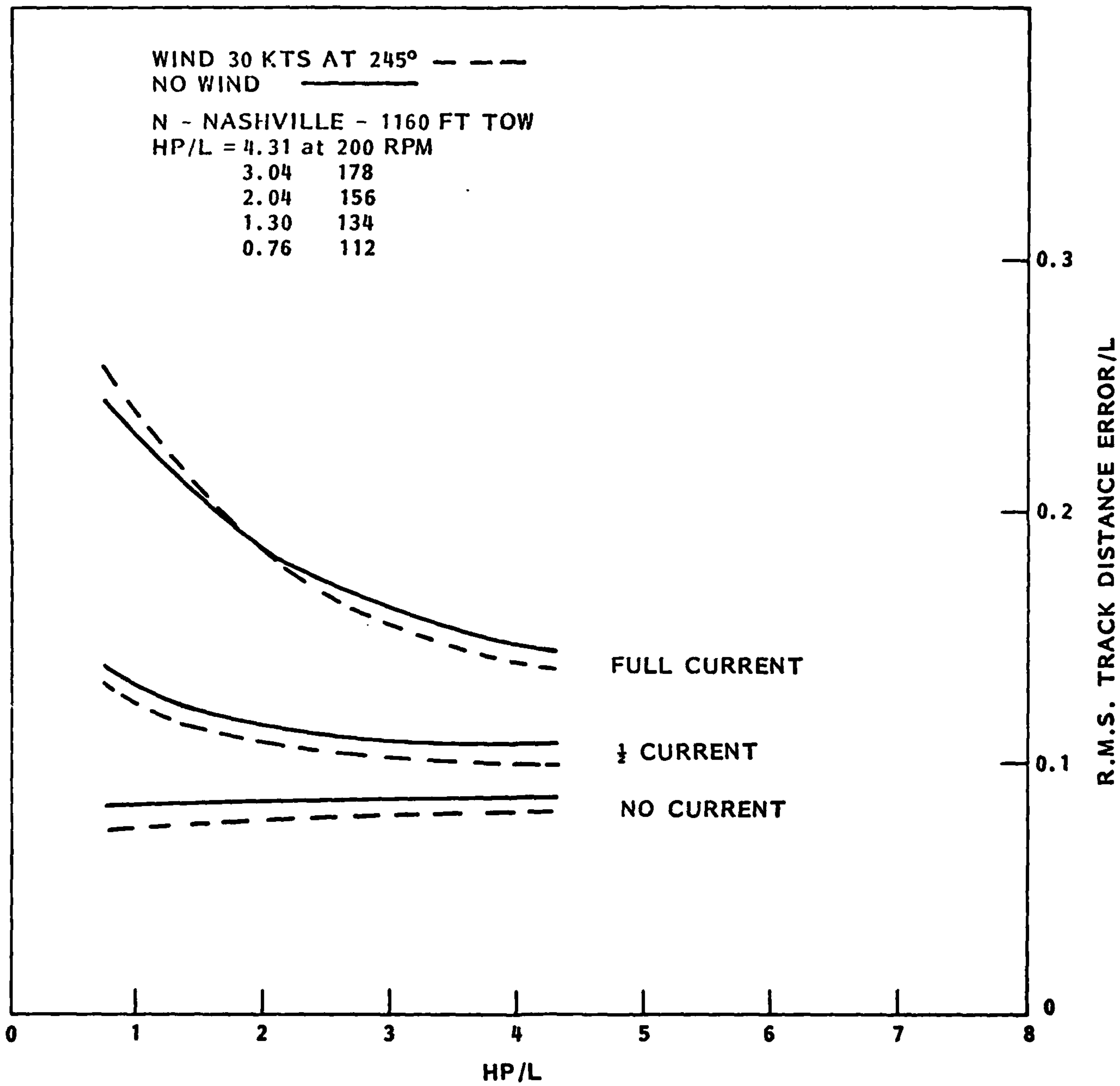

FIGURE 11b - RESULTS OF FIRST AUTOPILOT RUNS - NASHVILLE being the off-track distance of the furthest point on the tow (front or back of tow) at any time, was introduced as a measure of performance to act as a single optimization parameter. This is illustrated in Figure 12, where the track and heading errors and swept path are shown. The new autopilot coefficients for the tows were then:

TENNESSEE:				
	1 - 0.0	2 - 14.0	3 - 7.2	4 - 21.0
NASHVILLE down-river				
	1 - 0.0	2 - 107.0	3 - 5.4	4 - 42.0
NASHVILLE up-river				
	1 - 0.0	2 - 110.0	3 - 4.5	4 - 50.0

The TENNESSEE coefficients were obtained to allow comparison with the NASHVILLE full current results. The full current paths are shown in Figure 13. Again the TENNESSEE is fine, and the NASHVILLE has trouble. Figure 14 shows the general consistency of results when non-dimensionalized on length for off-track and swept path distances; the track error and swept path results show a consistent trend, with the better heading error results of the small tow at lower HP/L causing the largest differences between the two tows.

Figure 15 shows, in addition to the RMS values, the instantaneous track error and swept path values at the railroad bridge and the path value at the old highway bridge; these results show the tow to be under control for all HP/L values, with the path errors at or below the bridge opening parameter.

The same parameters for the large tow show the tow attempting to settle on the track through the bridges, as the railroad bridge errors are much smaller than the first bridge errors, but the whole set of results are at or above the bridge opening parameter on an RMS basis, and above for low HP/L at the railroad bridge and for all HP/L at the first bridge (Figure 16).

The up-river tests were run with the autopilot tracks shown in Figure 17, where RMS values are measured only for the first three tracks. The paths in Figure 18 show fairly good results, with the tracks close to the west bank allowing the longest

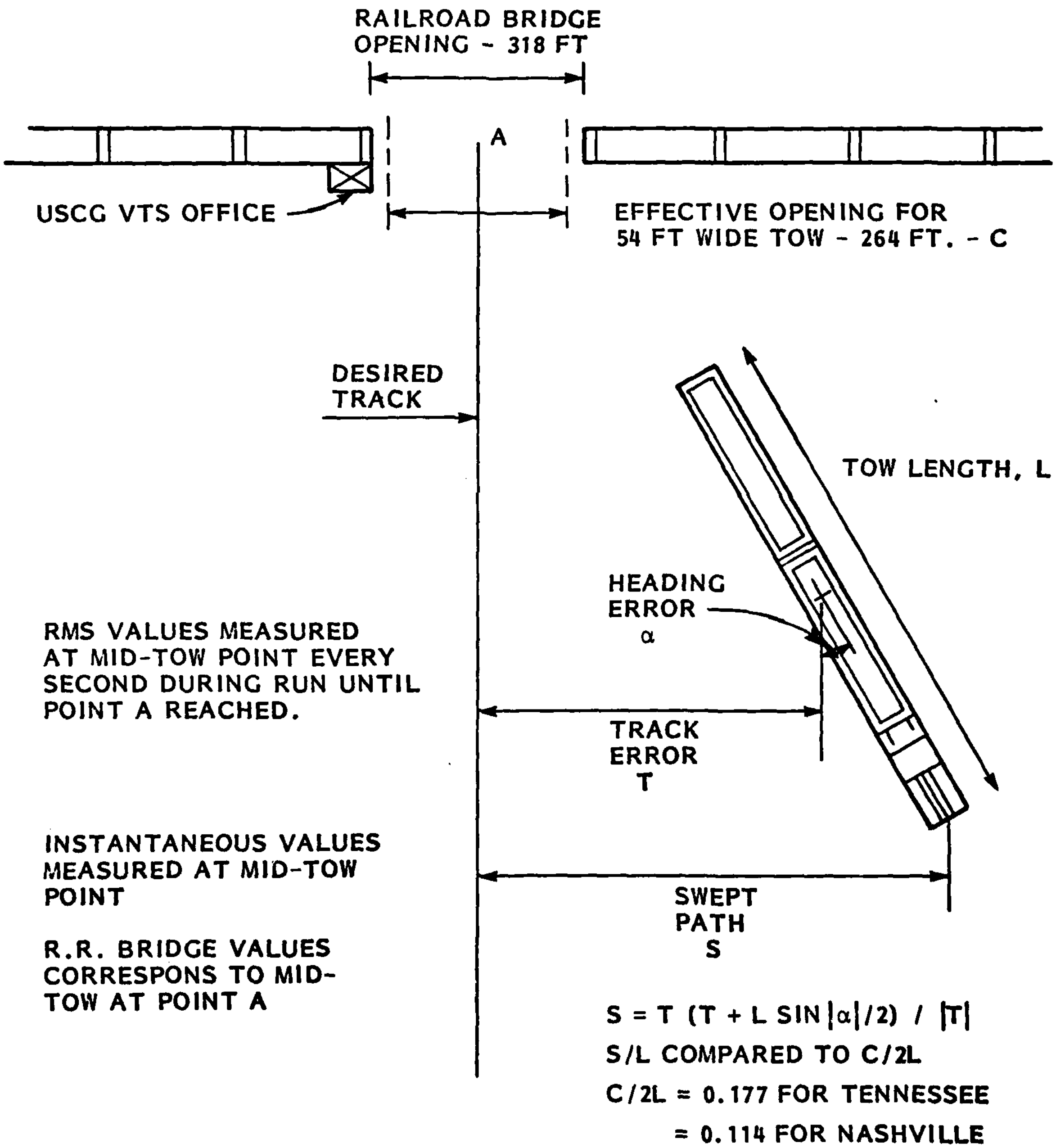

FIGURE 12 - BRIDGE OPENING AND SWEPT PATH GEOMETRY

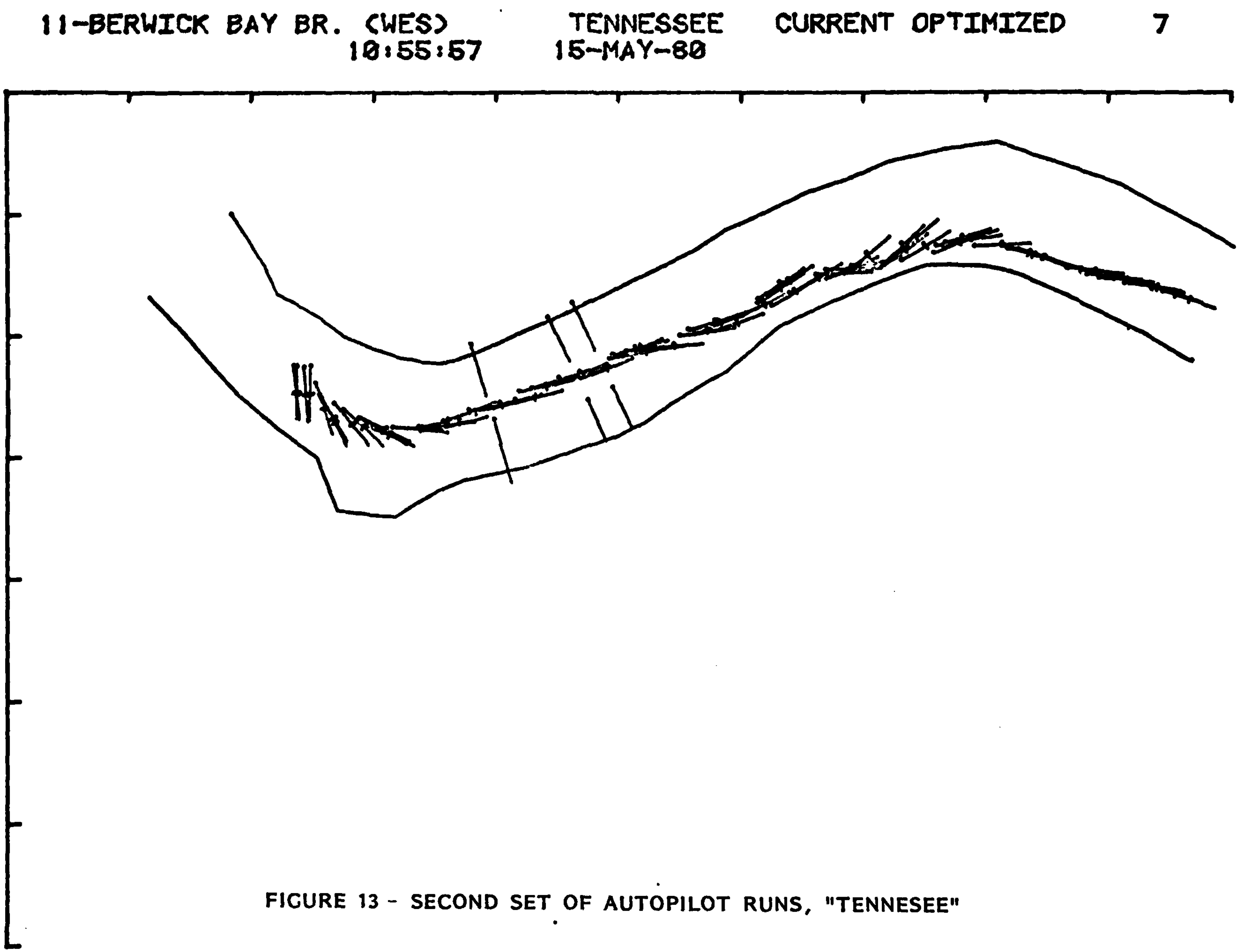

FIGURE 13 - SECOND SET OF AUTOPILOT RUNS, "TENNESEE"

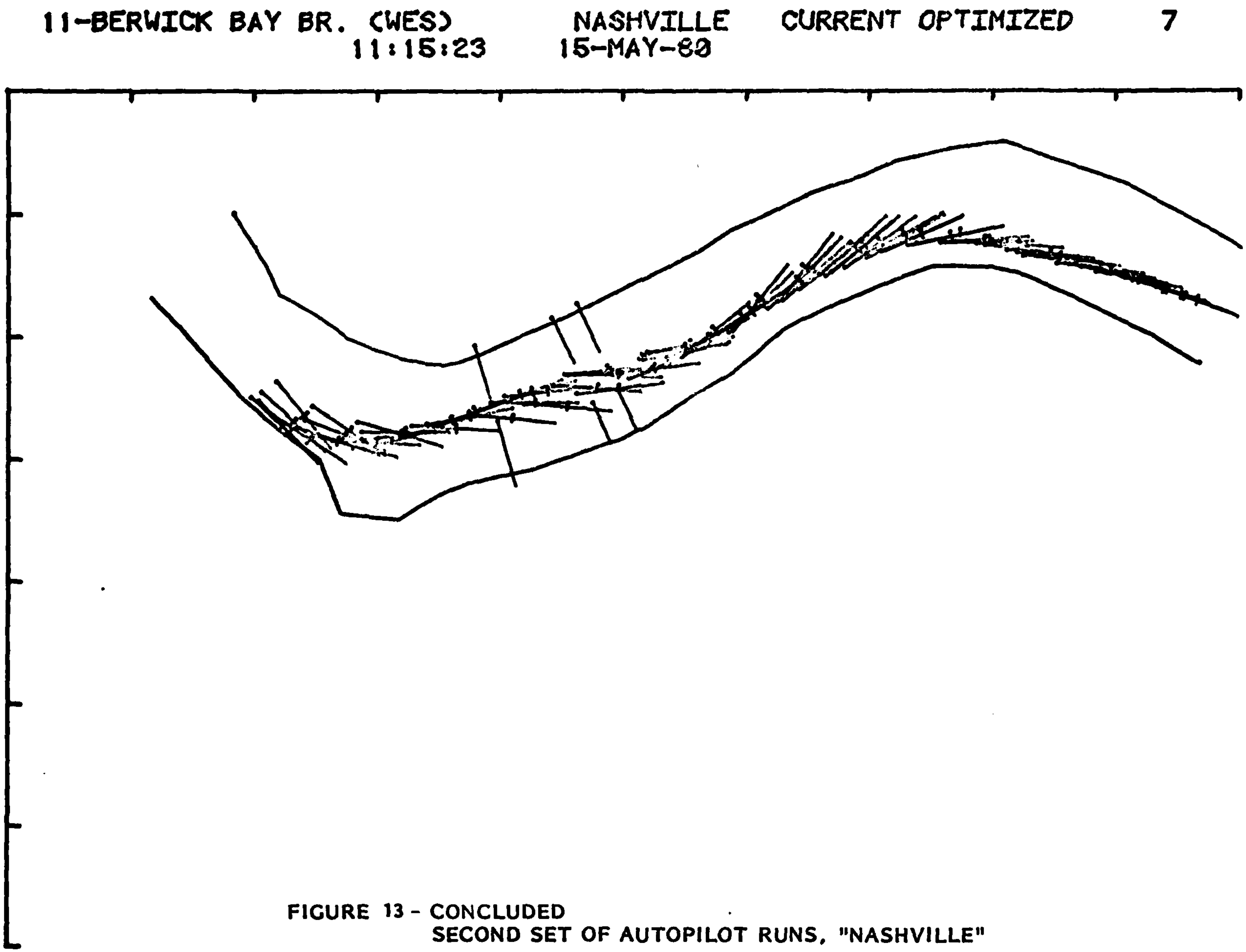

FIGURE 13 - CONCLUDED
SECOND SET OF AUTOPILOT RUNS, "NASHVILLE"

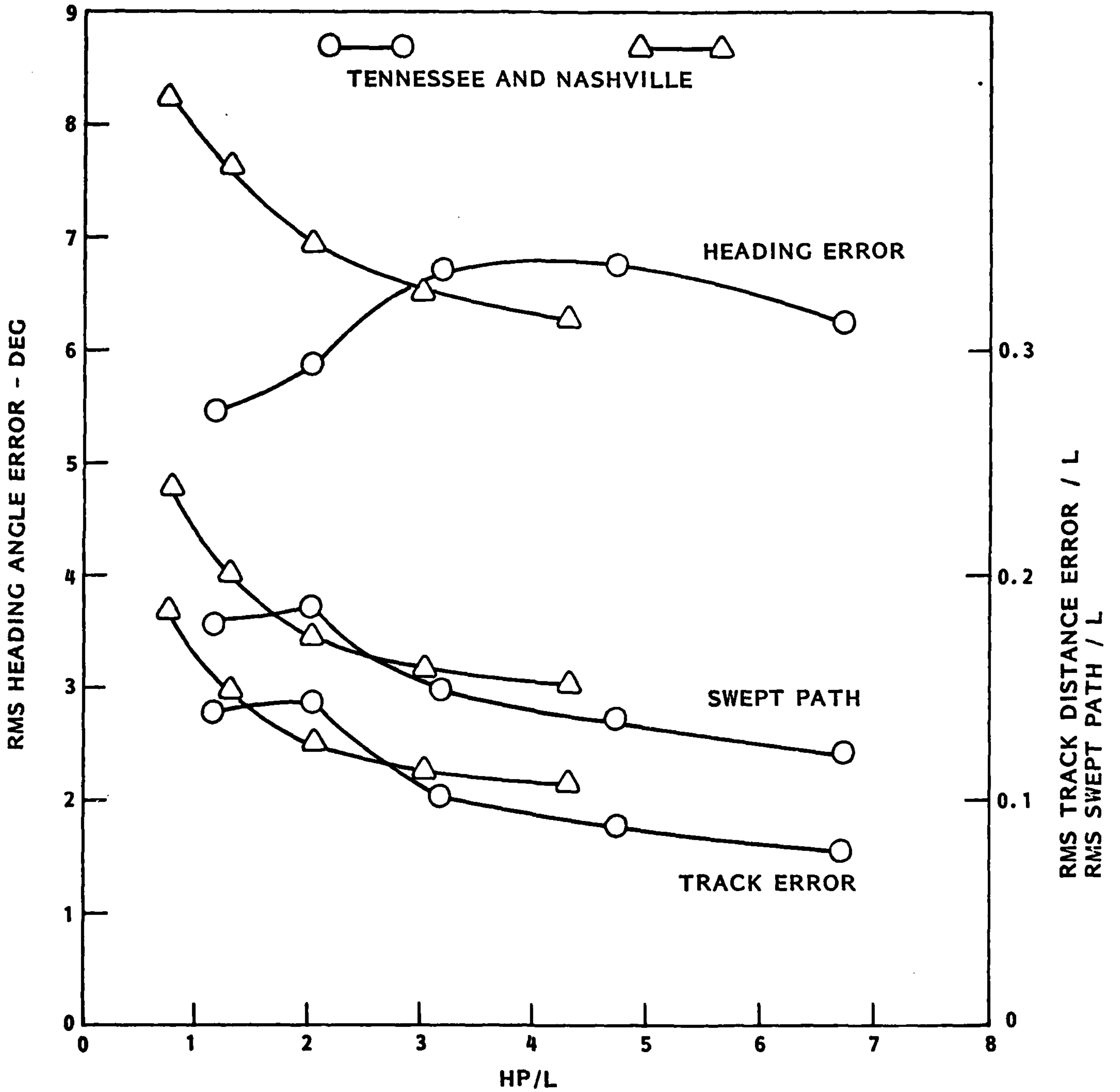

FIGURE 14 - RMS TRACK DISTANCE, SWEPT PATH AND HEADING ERRORS FROM SECOND SET OF AUTOPILOT RUNS

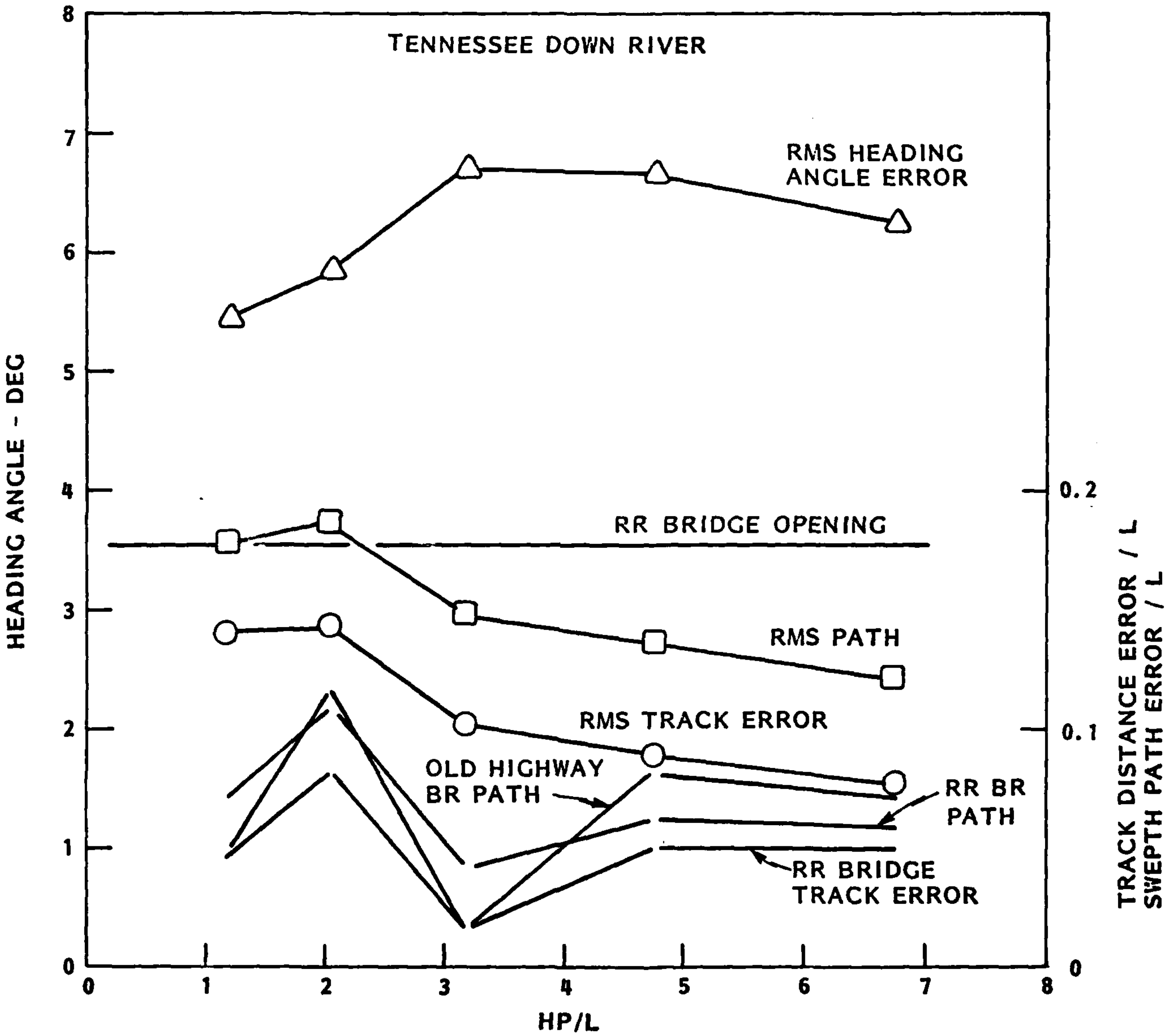

FIGURE 15 - TRACK DISTANCE, SWEPT PATH AND HEADING ERRORS FOR "TENNESEE", SECOND SET OF AUTOPILOT RUNS

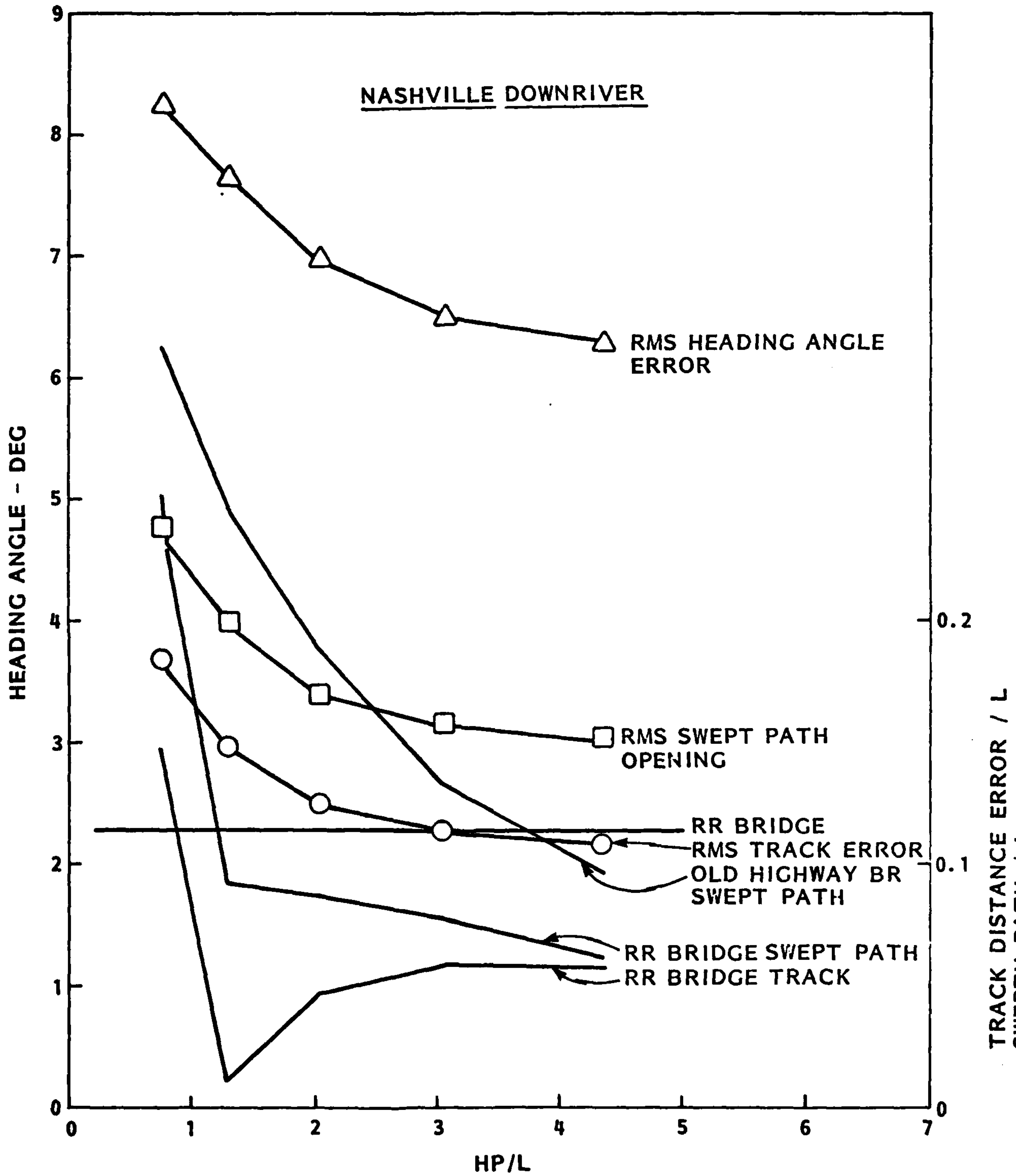

FIGURE 16 - TRACK DISTANCE, SWEPT PATH AND HEADING ERRORS FOR "NASHVILLE", SECOND SET OF AUTOPILOT RUNS

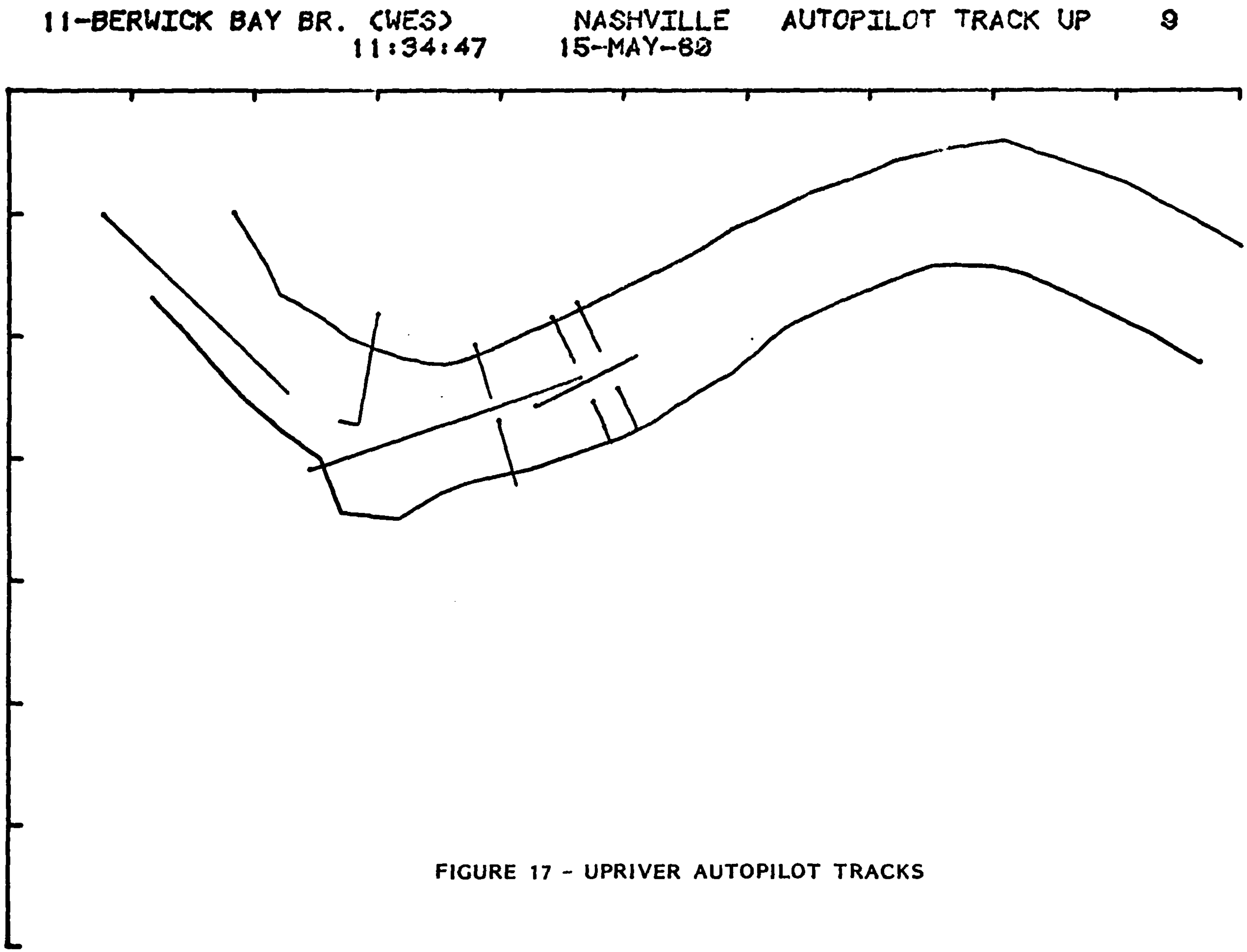

FIGURE 17 - UPRIVER AUTOPILOT TRACKS

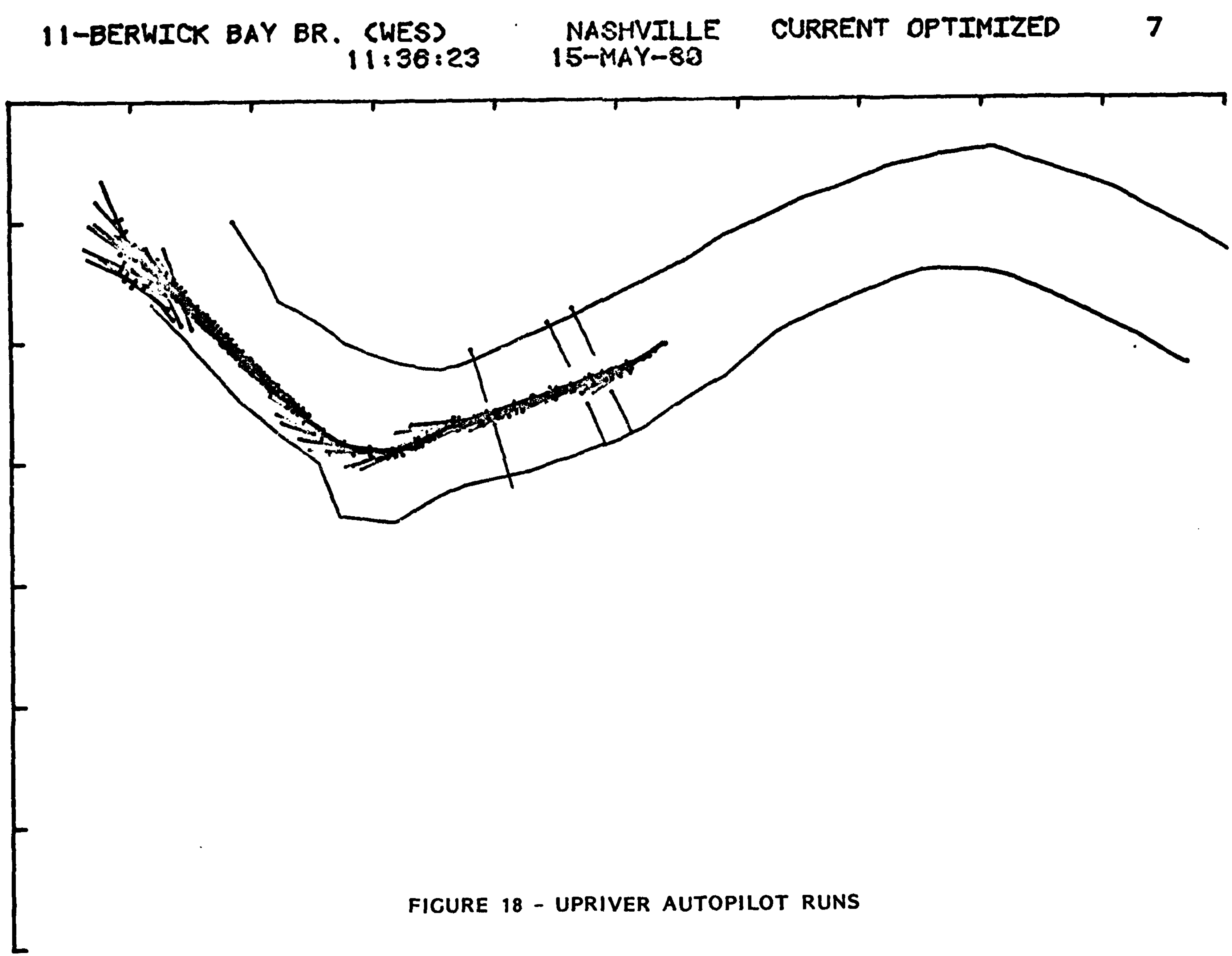

FIGURE 18 - UPRIVER AUTOPILOT RUNS

straight approach to the railroad bridge as possible. The lowest HP/L tow cannot overcome the current, and is swept away.

The numerical results of Figure 19 show paths at the bridge above the opening parameter, but not greatly above and not increasing with HP/L until the power limit is reached. Presumably some flanking maneuver by tows going up-river would help the alignment problem for this passage.

The final set of tests included a 10,000 pound thrust bow thruster attached to the front of the tow. This thruster was used to swing the tow in the direction desired by the command rudder angle. The lower the speed of the tow through the water, the higher the thrust obtained from this device. The paths in Figure 20 show some improvement, and the RMS values in Figure 21 are improved, especially at the lower HP/L ratios, where speed through the water is lower. For the up-river runs, this is also the case as shown in Figures 22 and 23, where, in addition, the longer times of the passages allow the thruster to improve heading error to the point where all swept path errors at the railroad bridge are below the nominal bridge value.

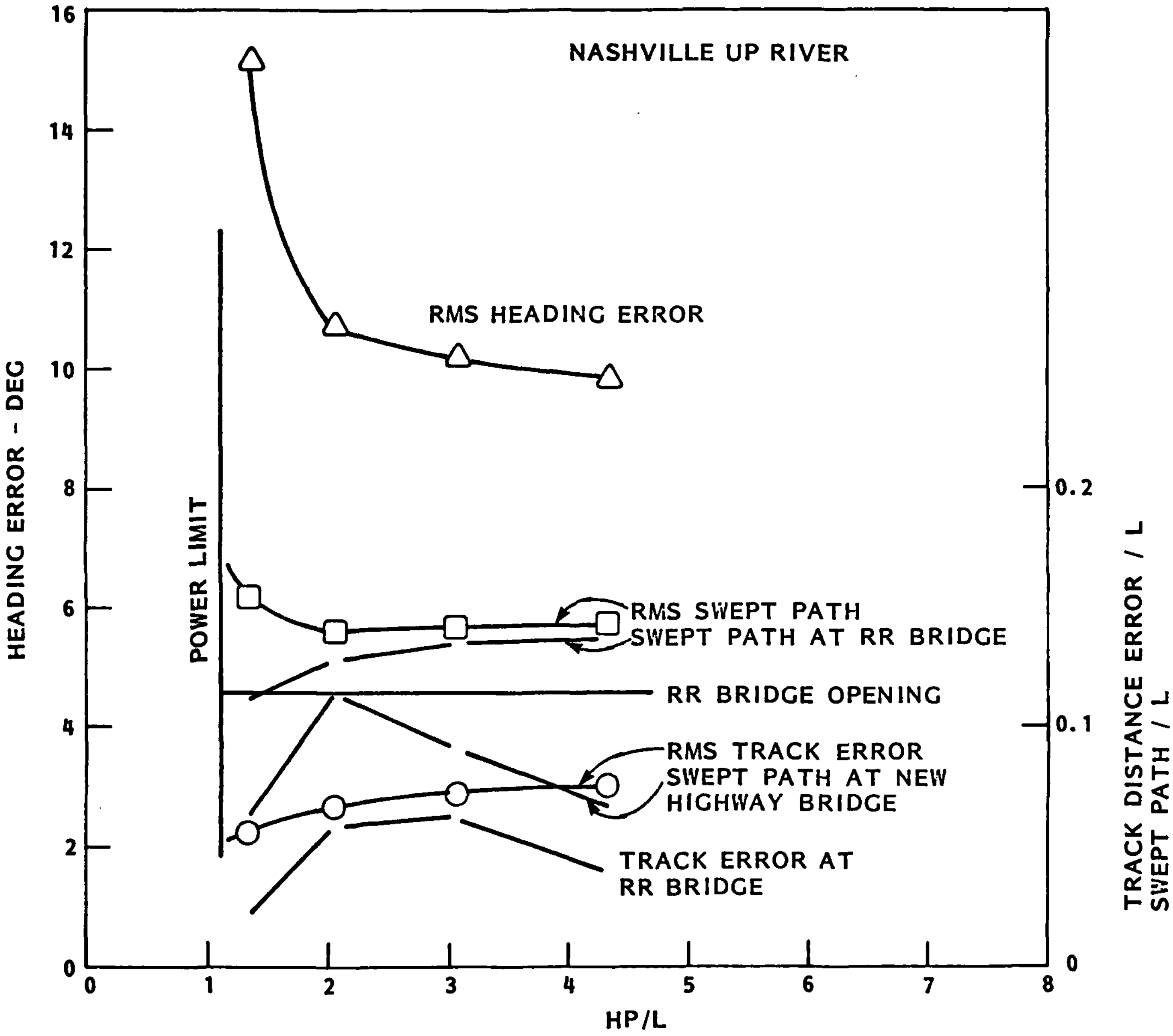

FIGURE 19 - RESULTS OF UPRIVER AUTOPILOT RUNS

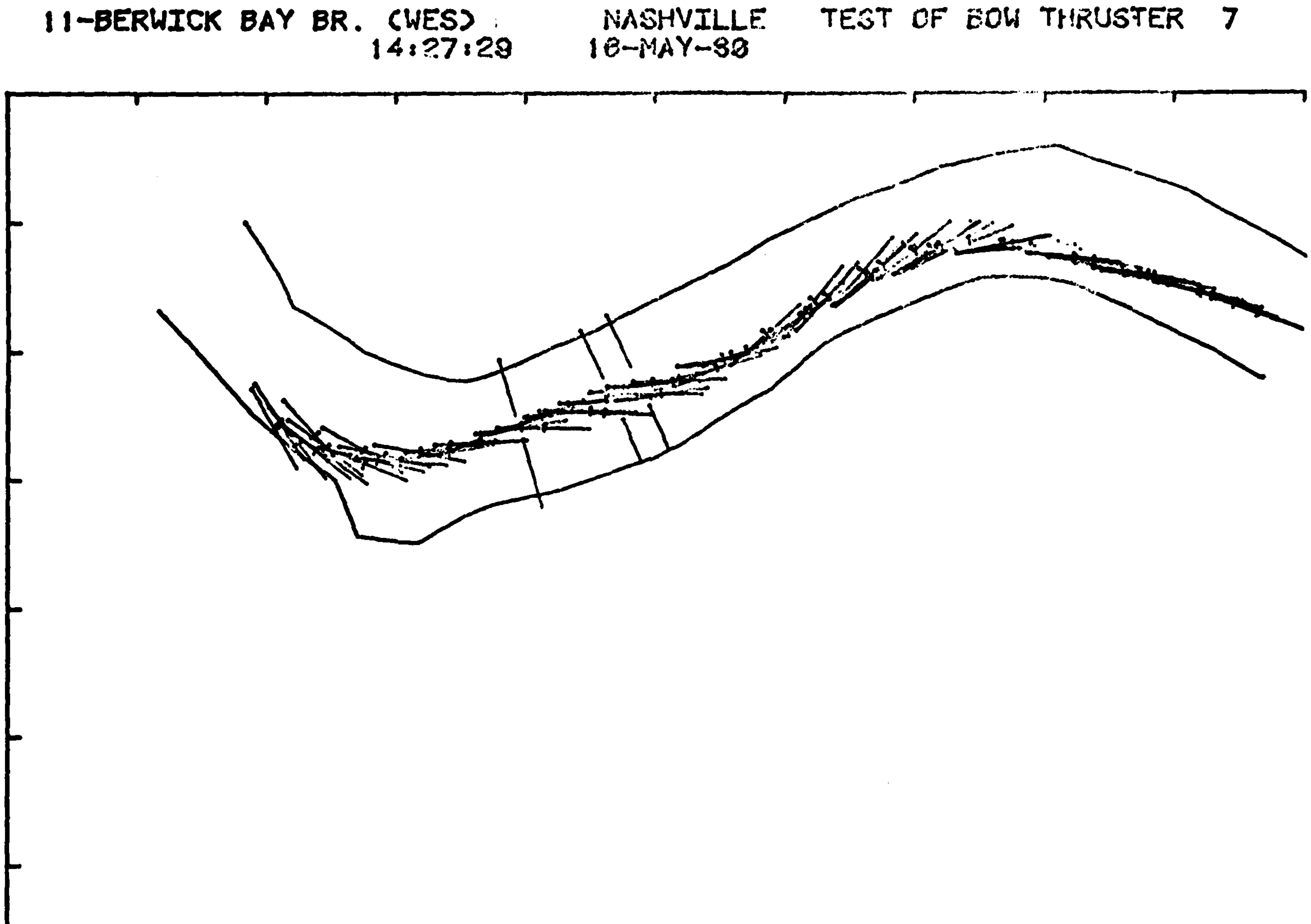

FIGURE 20 - DOWNRIVER AUTOPILOT RUNS WITH BOW THRUSTER

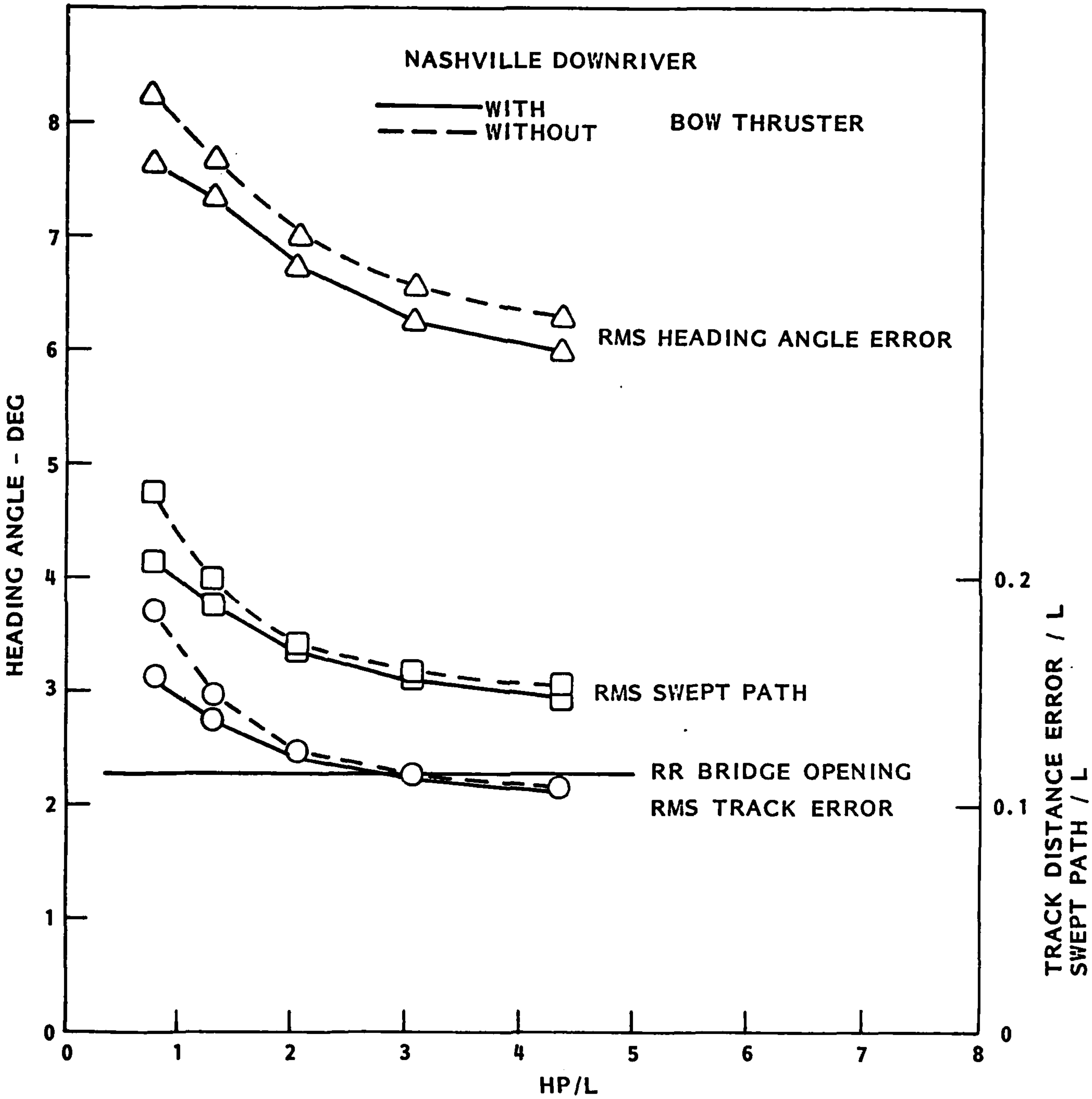

FIGURE 21 - RESULTS OF AUTOPILOT RUNS WITH BOW THRUSTER, DOWNRIVER

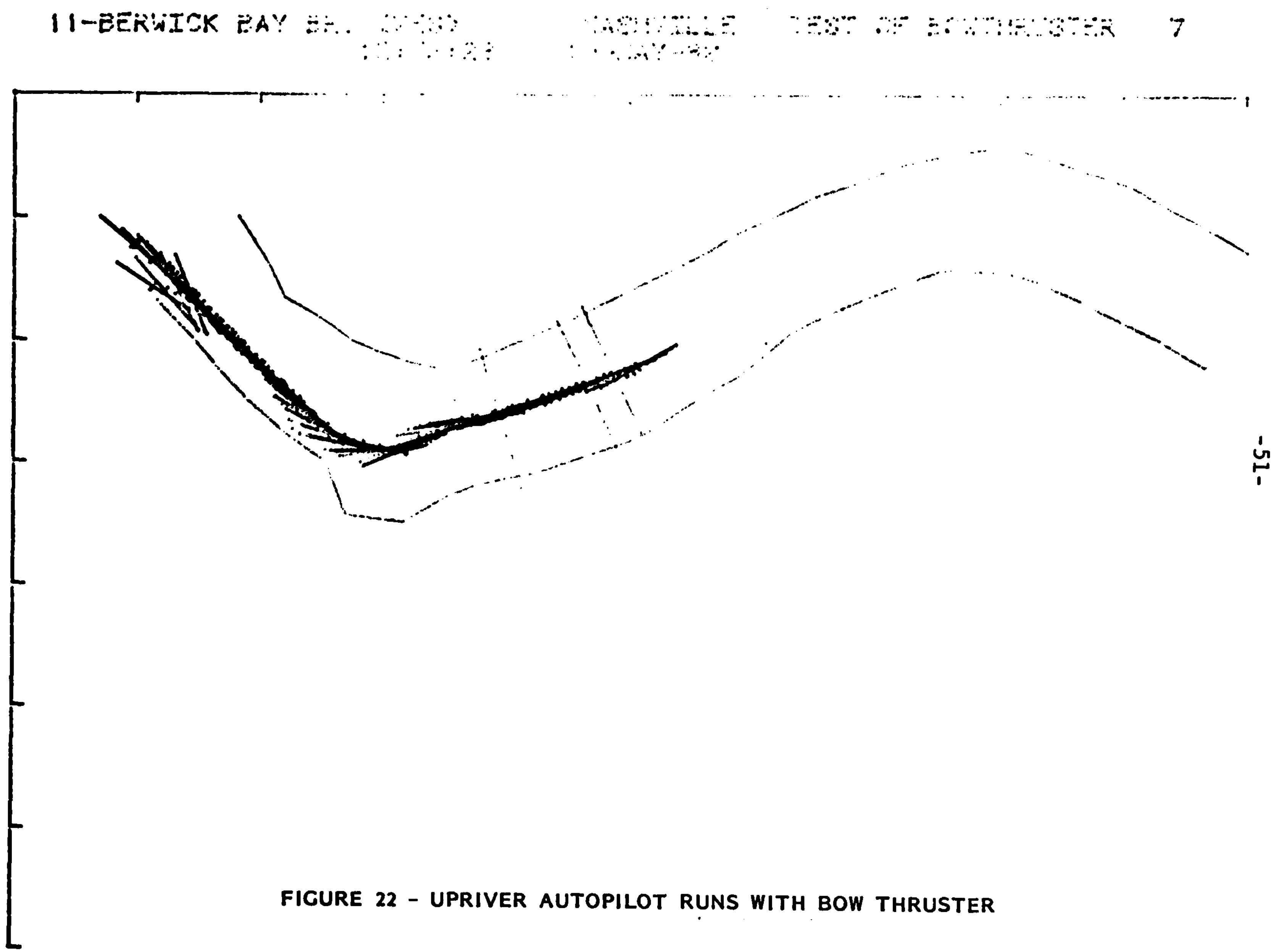

FIGURE 22 - UPRIVER AUTOPILOT RUNS WITH BOW THRUSTER

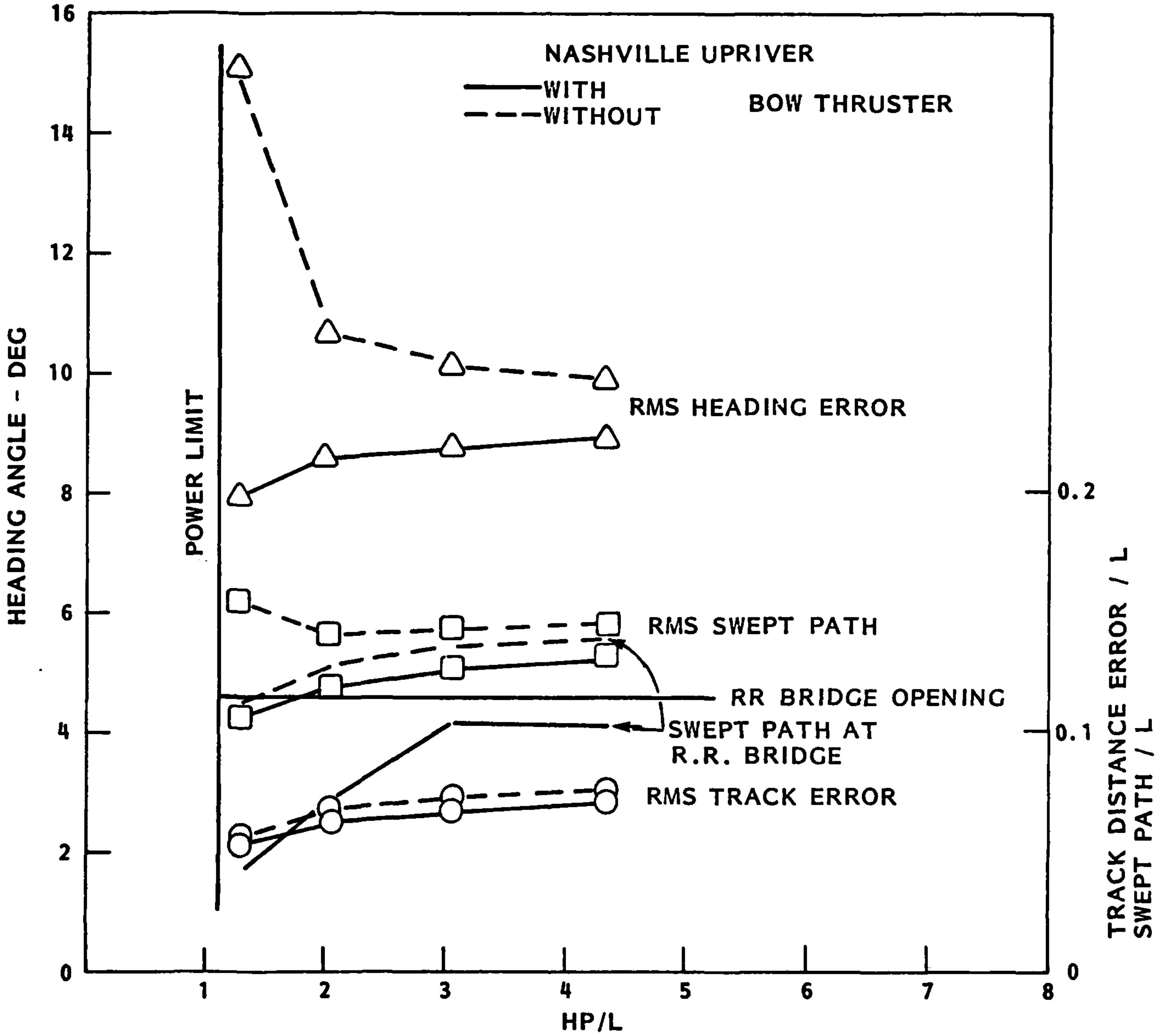

FIGURE 23 - RESULTS OF AUTOPILOT RUNS WITH BOW THRUSTER, UPRIVER

REAL-TIME OPERATOR RUNS

The real-time operator runs were carried out with three primary objectives:

1) To assess the ability of a human operator to follow the autopilot tracks as followed by the autopilot using primarily the plan position display.

2) To assess the ability of a human operator to make the passage using both the plan position display and the visual scene display.

3) To assess the ability of the bow thruster to aid the operator in making the passage.

Three operators were used to make the runs.

They were:

Capt. Irvin Gros, instructor at The Harry Lundeberg School of Seamanship, operated by the Seafarers International Union, on Piney Point in southern Maryland. Capt. Gros has over fifteen years experience as a towbaot master on inland rivers, and has made the Berwick Bay Bridge Passage numerous times. Capt. Gros had previously spent about three hours using the USCG simulator prior to the one day required to make his runs for this study.

Mr. Peter Van Dyke, of HYDRONAUTICS, Incorporated, who has been involved in the development of the USCG Towboat Simulator over the past two years. He has made several hundred runs on the simulator through the passage, but his towboat experience is limited to one run up-river and one run downriver through the bridges as an observer.

Mr. Eugene R. Miller, Jr., of HYDRONAUTICS, Incorporated, who has participated in the development of the Simulator through theoretical and experimental experience. He had spent about four hours using the simulator prior to making his runs, and also had made the passage as an observer on a towboat.

All operators were familiar with the current conditions used in the simulation (Figure 5), and knew the desired track and suggested procedures as shown in Figures 7 and 8. Capt. Gros, during the course of his runs, remarked on the desirability of maintaining as high an RPM as possible while making this passage, citing several specific examples he had encountered during his time as a towboat master. This confirmed our operating procedure during the autopilot tests, and then the manned runs, of maintaining constant, maximum RPM on all legs of the passage.

The sequence of runs were:

Two downriver runs with the TENNESSEE, the small tow, trying only to make the passage as cleanly as possible. Maximum RPM of 200 used throughout, no bow thruster used.

One downriver run with the addition of the availability of the bow thruster to aid in making the passage. RPM of 200.

Two downriver runs with the autopilot tracks drawn on the plan position display, with the operator asked to follow these tracks as closely as possible. RPM of 200.

Repeat of these five runs with the NASHVILLE, the long tow.

Repeat of these five long tow runs running upriver instead of downriver.

For the last two operators, an additional set of five runs were made downriver with the NASHVILLE at about 157 RPM.

These are summarized in Table 1.

TABLE 1

Manned Simulation Runs

Descriptors

Operators	Tows	Directions	
1 - Capt. Gros	T - TENNESSEE	D - Downriver	B - Bow Thruster
2 - P. Van Dyke	N - NASHVILLE	U - Upriver	F - Track Following
3 - E.R. Miller, Jr.			P - 157 RPM

Run No.	Operator	Description	Run No.	Operator	Description
1	1	T-D	28	2	N-U-F
2	1	T-D	29	2	N-U-F
3	1	T-D-B	30	2	N-D-P
4	1	T-D-F	31	2	N-D-P
5	1	T-D-F	32	2	N-D-B-P
6	1	N-D	33	2	N-D-F-P
7	1	N-D	34	2	N-D-F-P
8	1	N-D-B	35	3	T-D
9	1	N-D-F	36	3	T-D
10	1	N-D-F	37	3	T-D-B
11	1	N-U	38	3	T-D-F
12	1	N-U	39	3	T-D-F
13	1	N-U-B	40	3	N-D
14	1	N-U-F	41	3	N-D
15	2	T-D	42	3	N-D-B
16	2	T-D	43	3	N-D-F
17	2	T-D-B	44	3	N-D-F
18	2	T-D-F	45	3	N-D-P
19	2	T-D-F	46	3	N-D-P
20	2	N-D	47	3	N-D-B-P
21	2	N-D	48	3	N-D-F-P
22	2	N-D-B	49	3	N-D-F-P
23	2	N-D-F	50	3	N-U
24	2	N-D-F	51	3	N-U
25	2	N-U	52	3	N-U-B
26	2	N-U	53	3	N-U-F
27	2	N-U-B	54	3	N-U-F

Insofar as possible, the tests were made with a minimum amount of disturbance and discussion during the runs, with some discussion between runs concerning the objectives of the next run and possible methods to be employed. For instance, Capt. Gros on the free upriver runs tended to pass through the railroad bridge at a considerable angle (unlike the autopilot track, which is almost normal to the opening) and then turn upriver before passing through the new highway bridge; this strategy was discussed by the other two, less experienced operators prior to their runs.

One error made in the test procedure was to not emphasize that the operator should never "give up" before completing the run. In several cases, where the tow would be out-of-shape and hit the first bridge, the operator would not concentrate on completing the exercise as well as he could; this tended to magnify the high error results of some of the runs.

The test run numbers used to plot the results are shown in Table 1. Figures 24 through 31 show typical plan position plots for free, free with bow thruster, and track following runs. The run number refers to the operator as described above, with the tow identification and run type identified in the header.

The results of the track following runs are displayed in Figures 32 and 33. In general, all operators for all four run categories were able to maintain a heading angle error less than that of the autopilot (Figure 33), but the track distance errors were at or above those of the autopilot, resulting in swept path errors both greater and less then those of the autopilot, but never more than 15 percent different on average for any of the

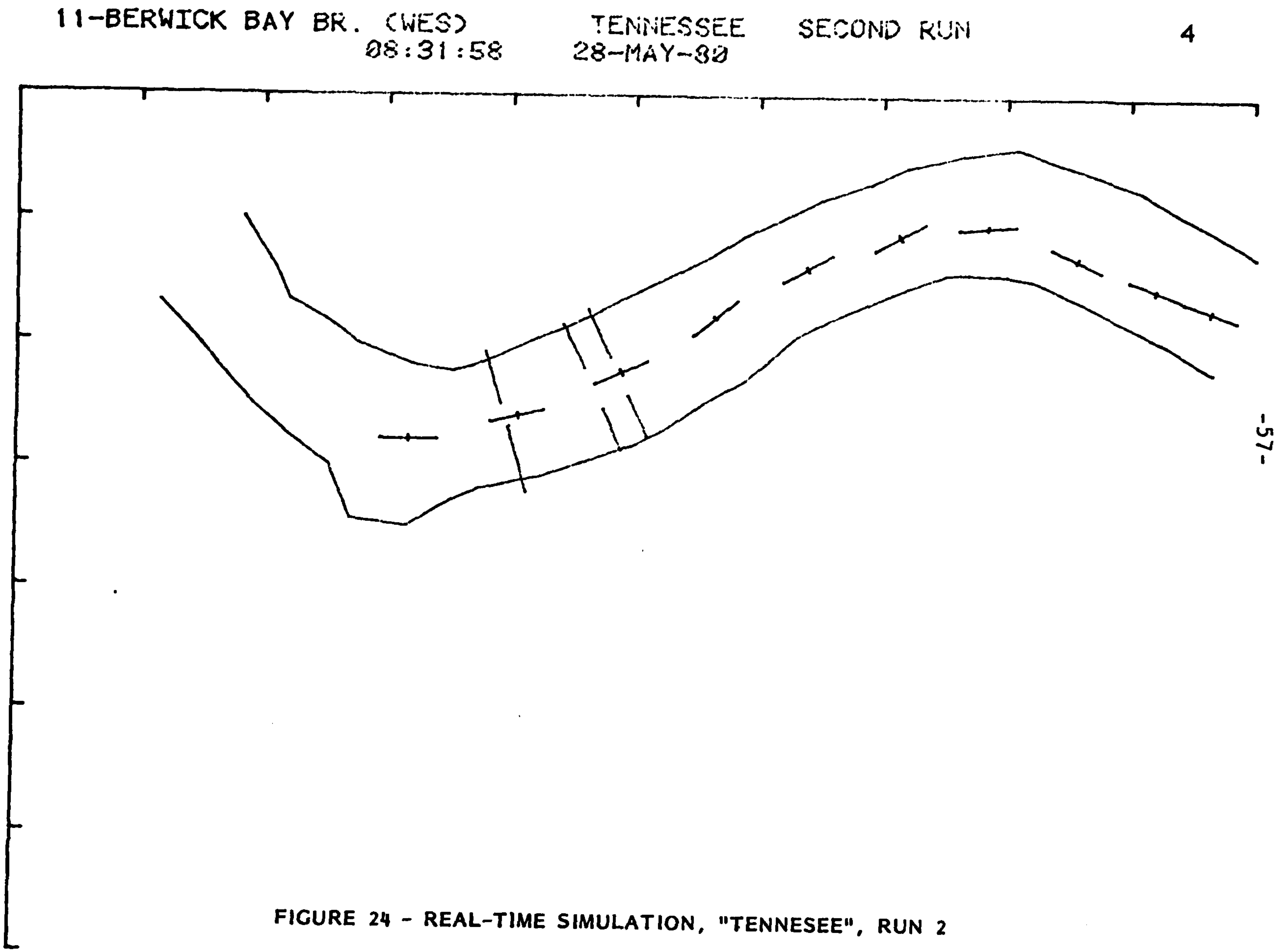

FIGURE 24 - REAL-TIME SIMULATION, "TENNESEE", RUN 2

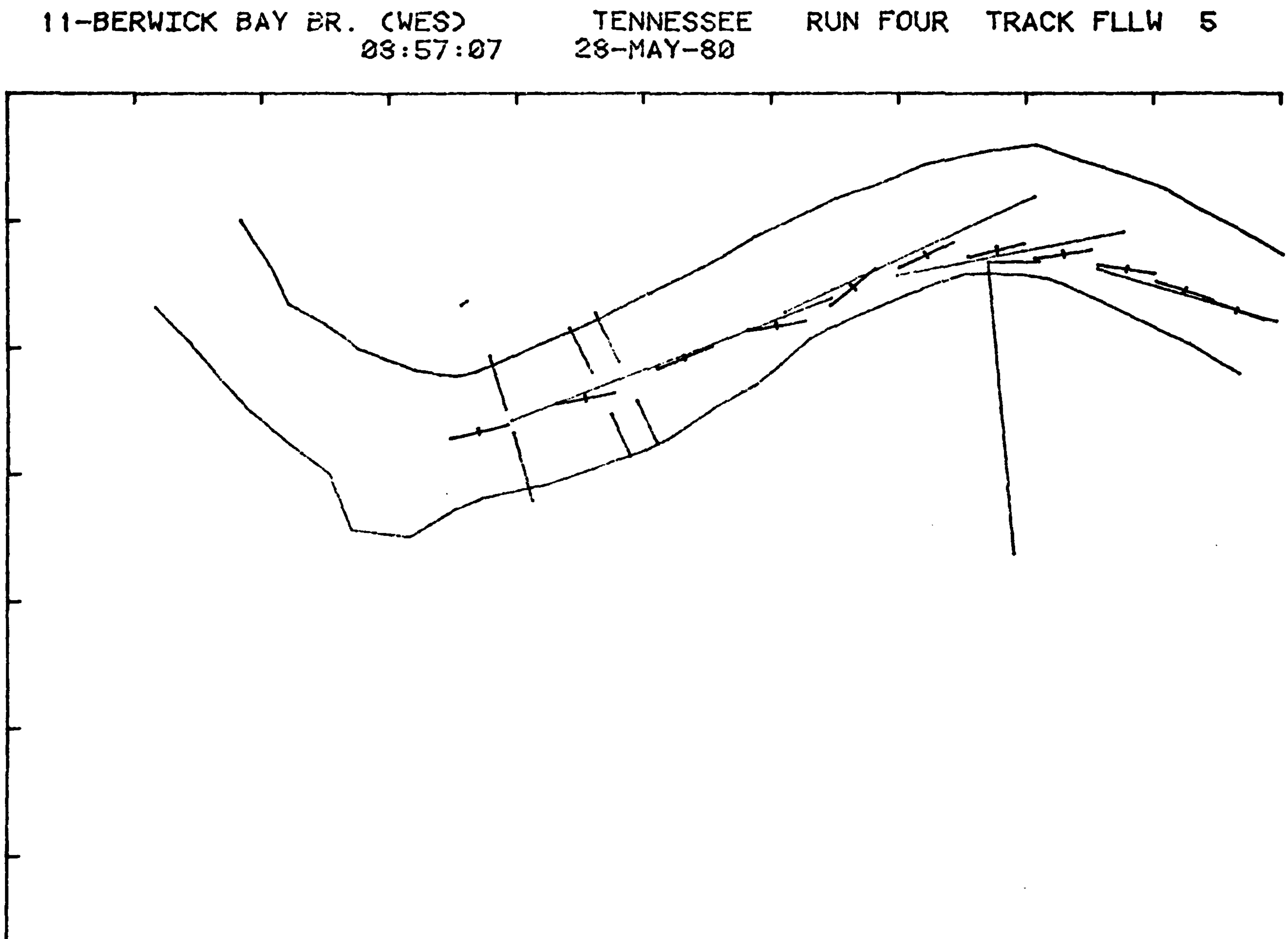

FIGURE 25 - REAL-TIME SIMULATION, "TENNESEE", RUN 4, TRACK FOLLOWING

11-BERWICK BAY BR. (WES)　　NASHVILLE　　RUN EIGHT BOW THRSTR　4
09:49:10　　28-MAY-80

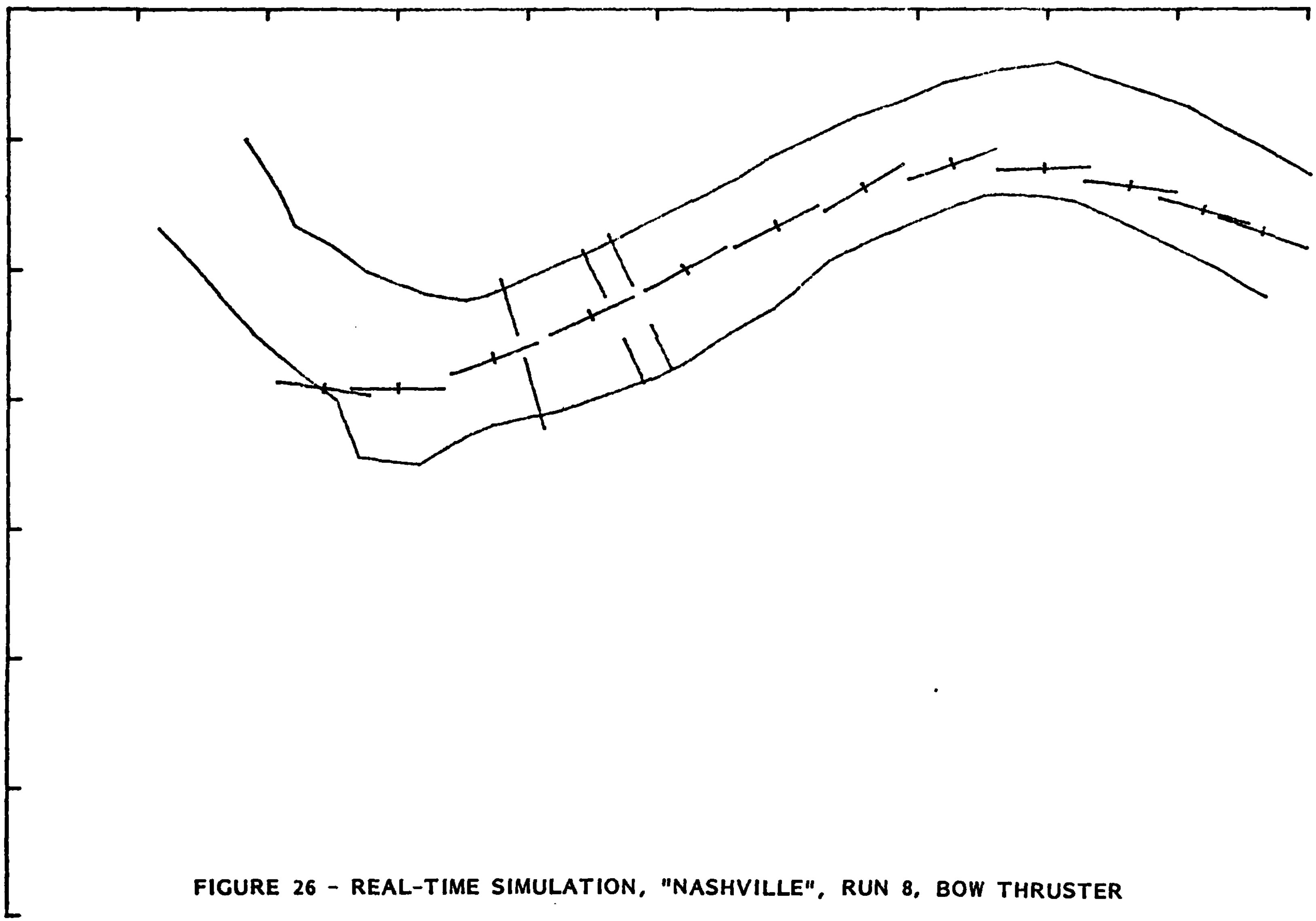

FIGURE 26 - REAL-TIME SIMULATION, "NASHVILLE", RUN 8, BOW THRUSTER

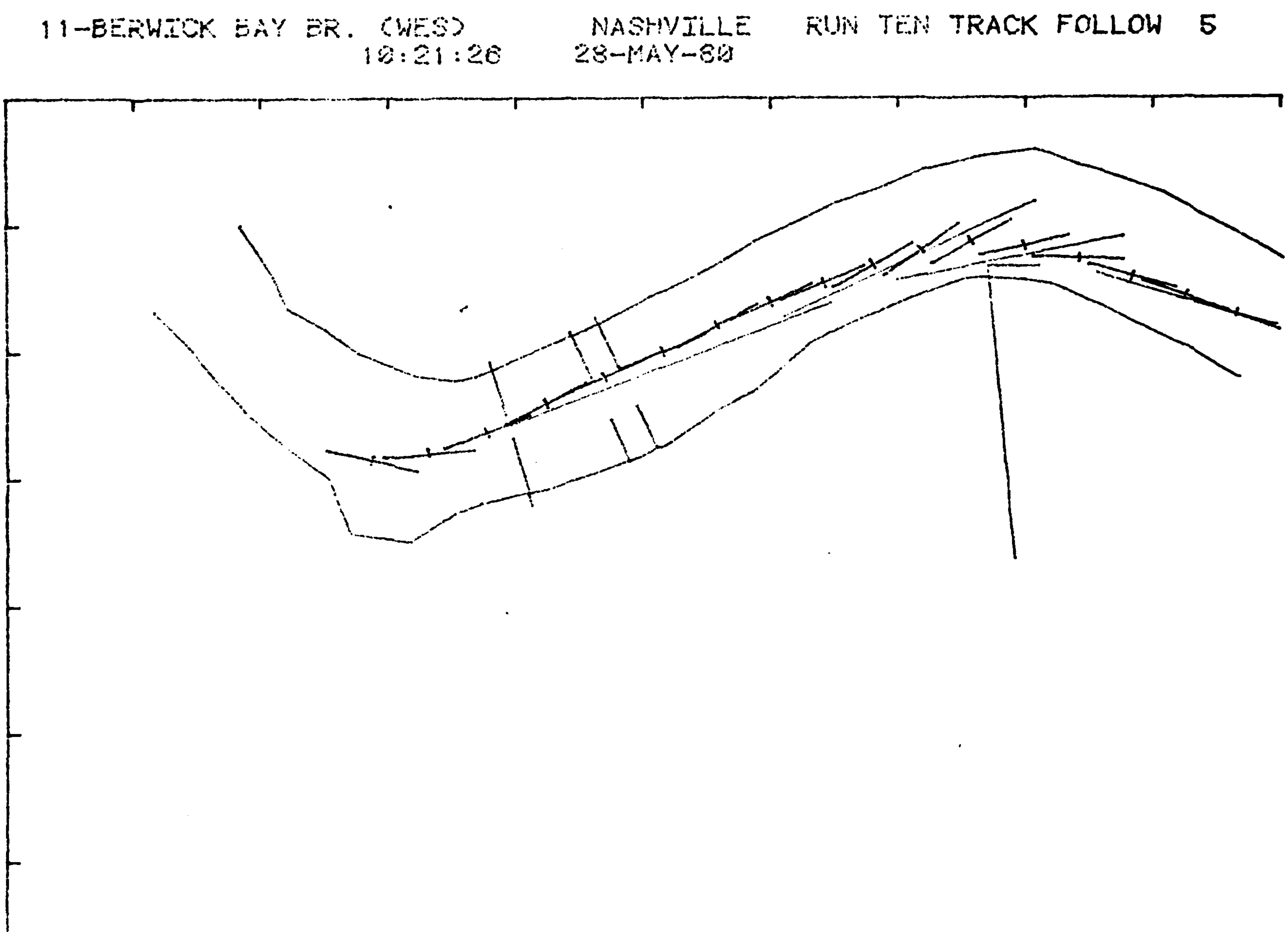

FIGURE 27 - REAL-TIME SIMULATION, "NASHVILLE", RUN 10, TRACK FOLLOWING

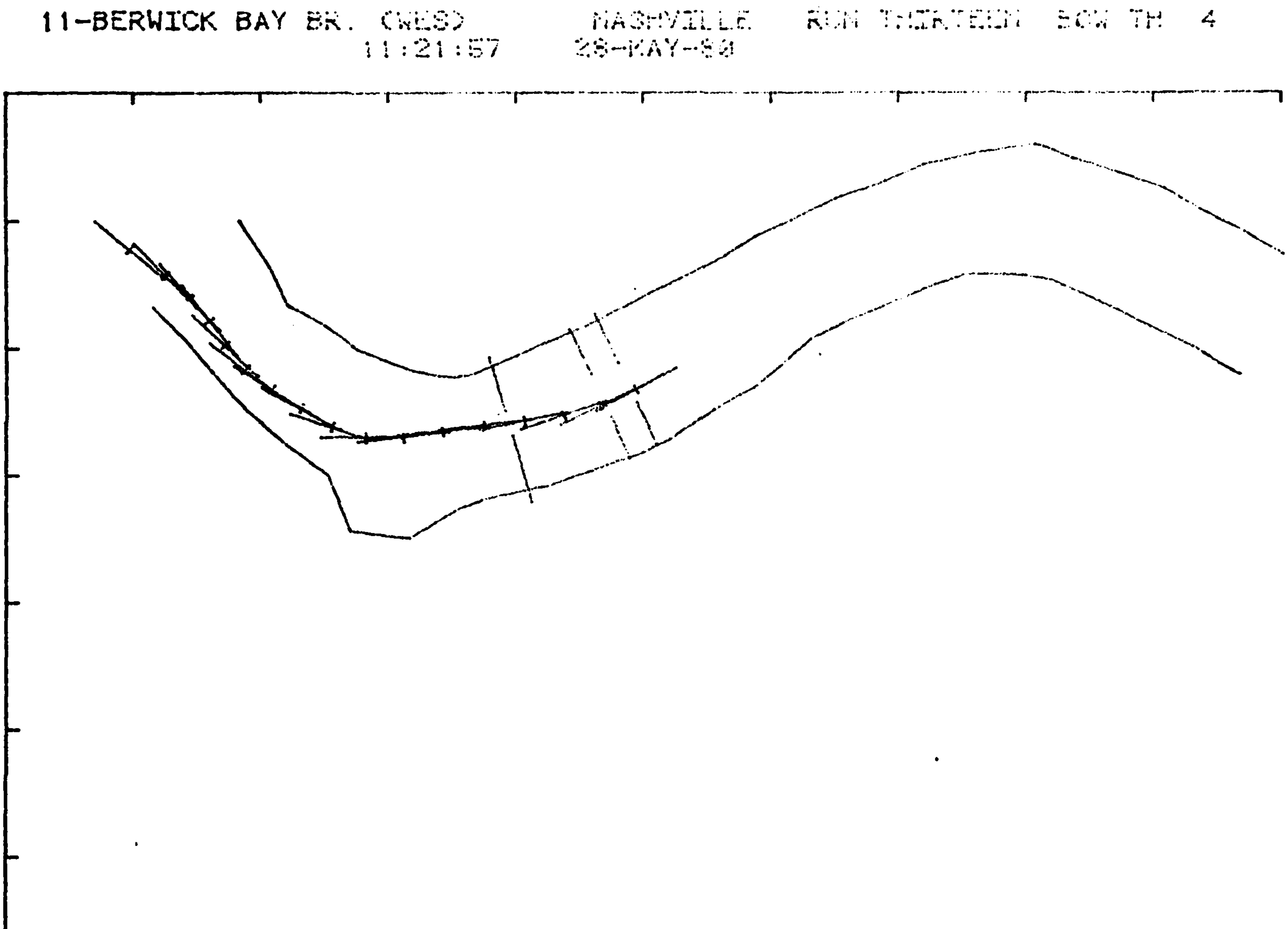

FIGURE 28 - REAL-TIME SIMULATION, "NASHVILLE", RUN 13, UPRIVER WITH BOW THRUSTER

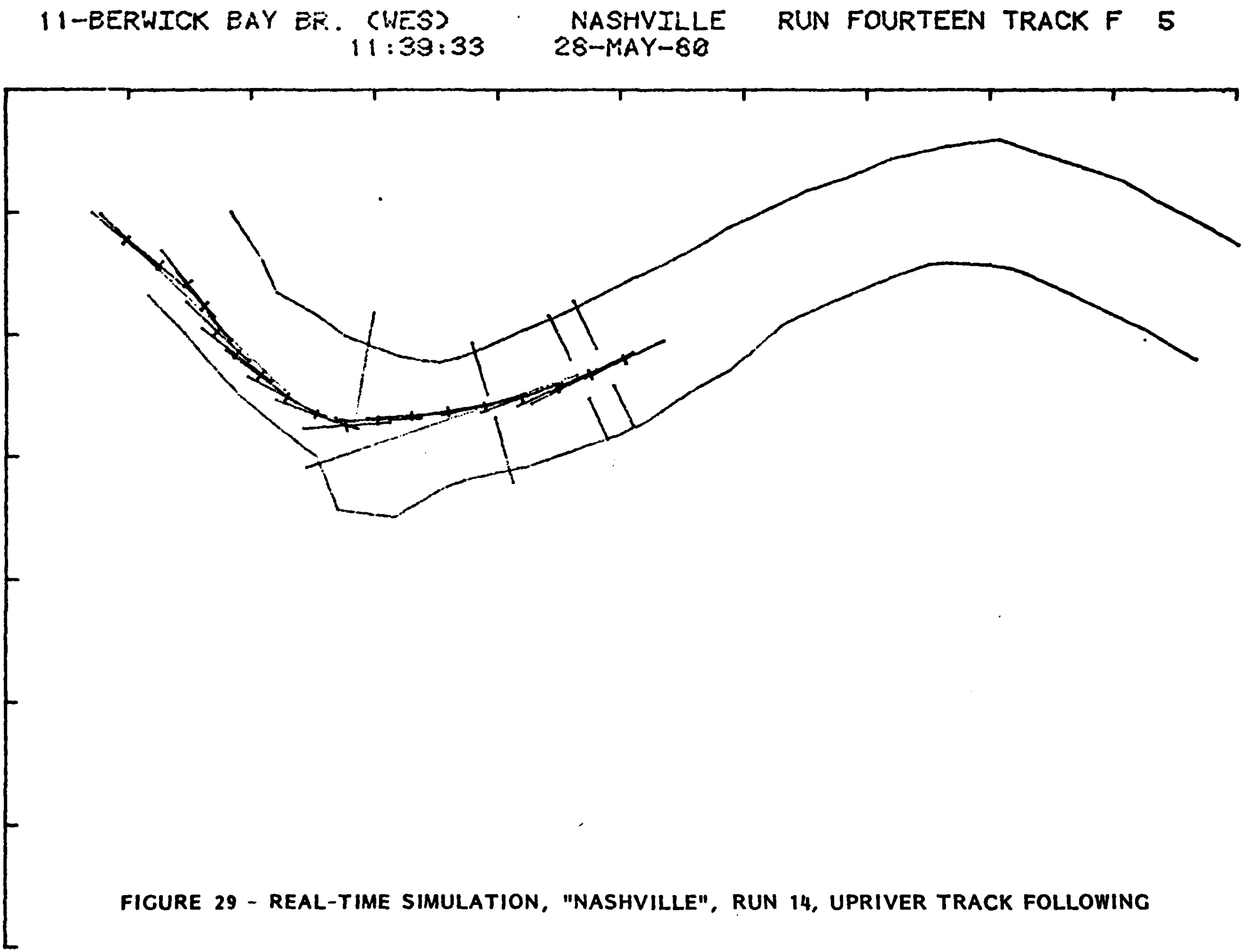

FIGURE 29 - REAL-TIME SIMULATION, "NASHVILLE", RUN 14, UPRIVER TRACK FOLLOWING

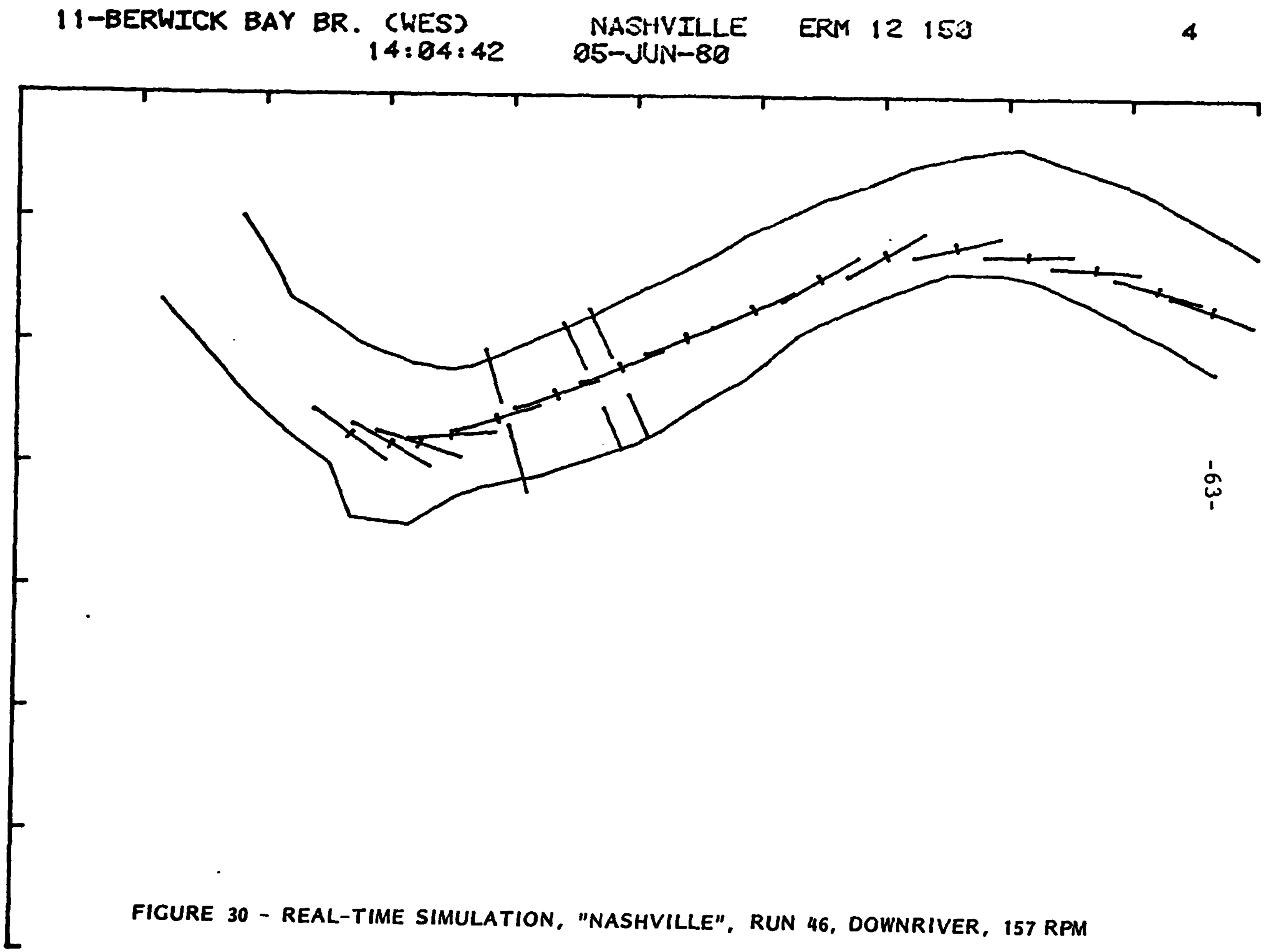

FIGURE 30 - REAL-TIME SIMULATION, "NASHVILLE", RUN 46, DOWNRIVER, 157 RPM

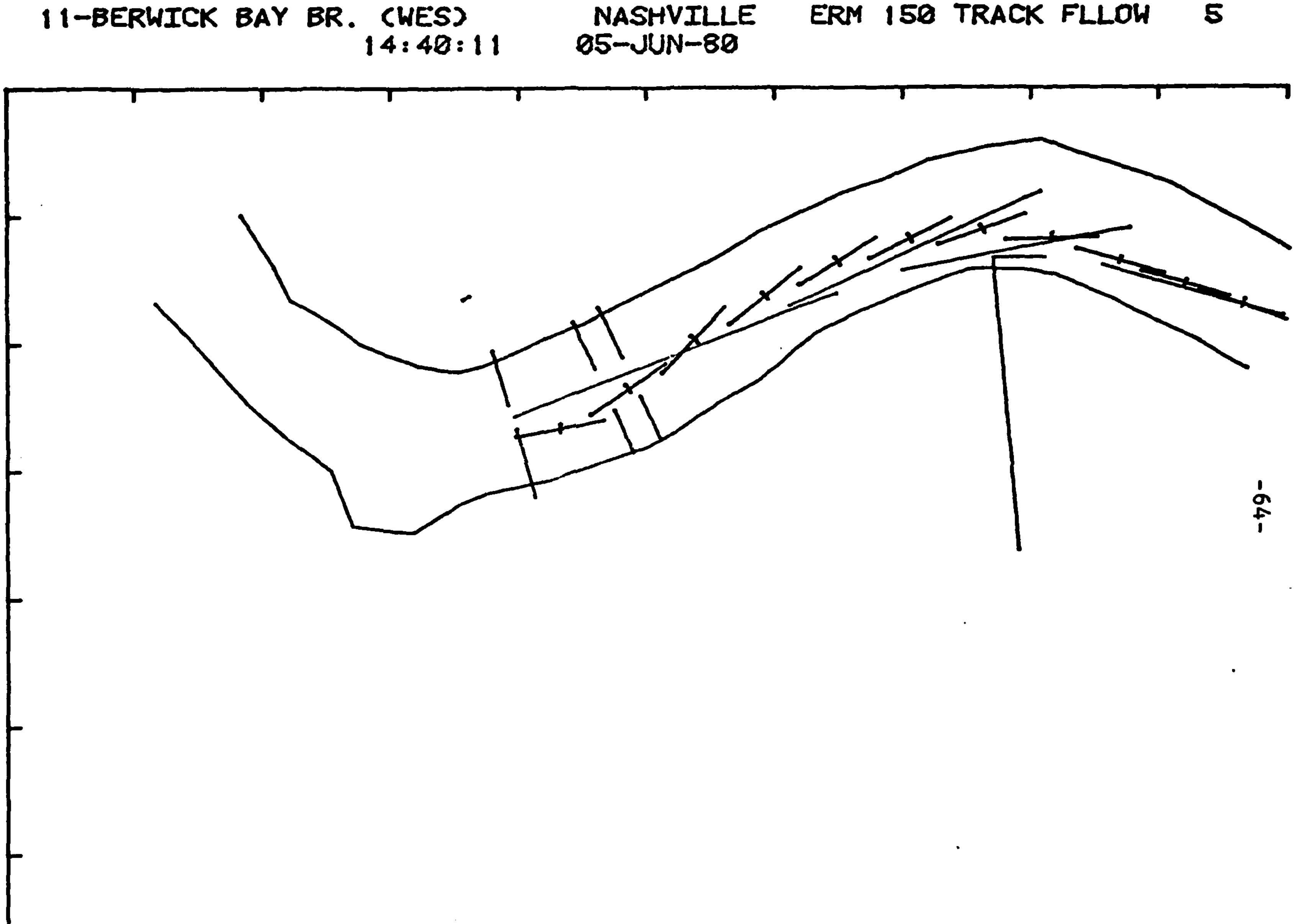

FIGURE 31 - REAL-TIME SIMULATION, "NASHVILLE", RUN 48, 157 RPM TRACK FOLLOWING

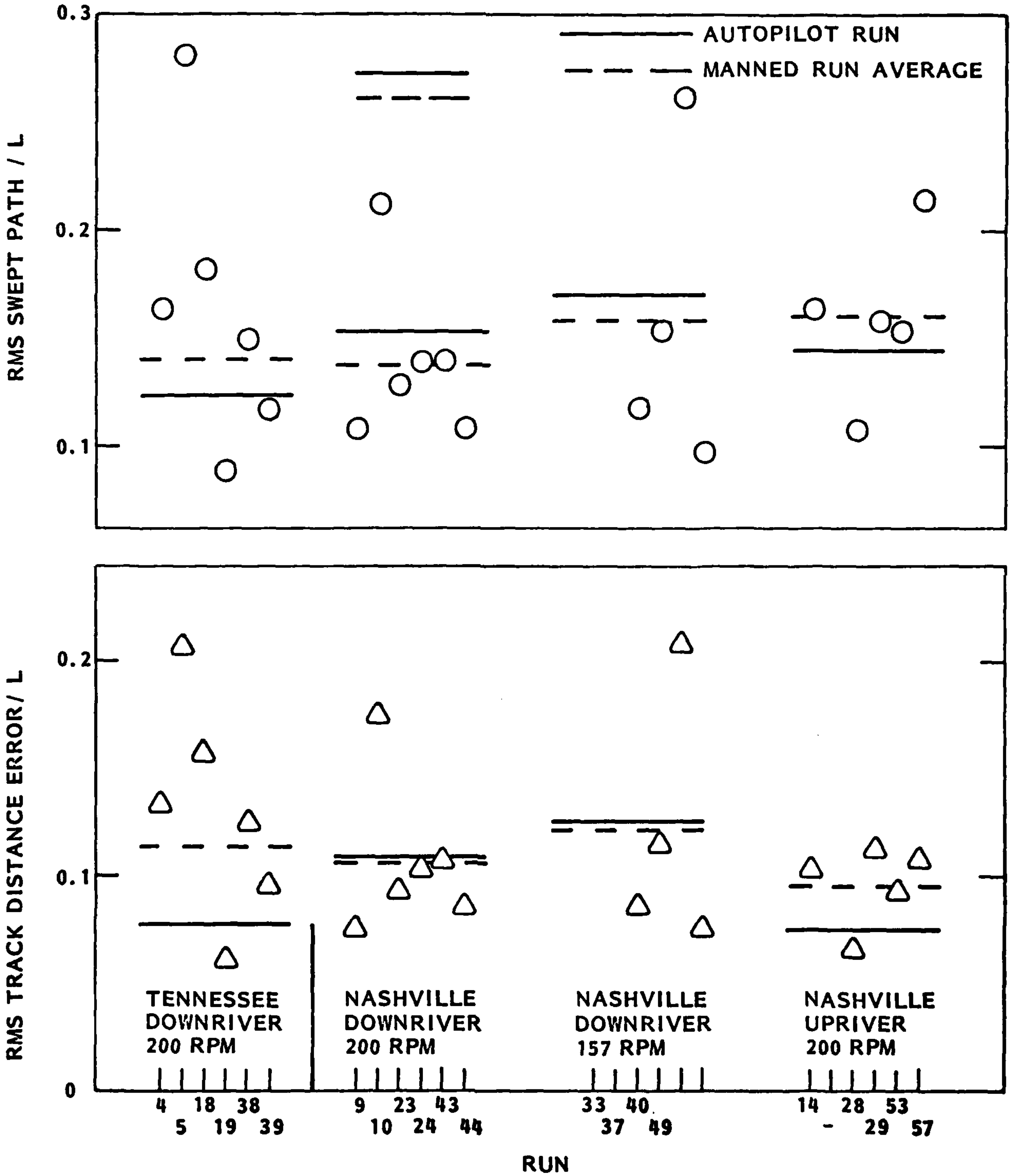

FIGURE 32 - RMS TRACK DISTANCE AND SWEPT PATH ERROR WHILE TRACK FOLLOWING

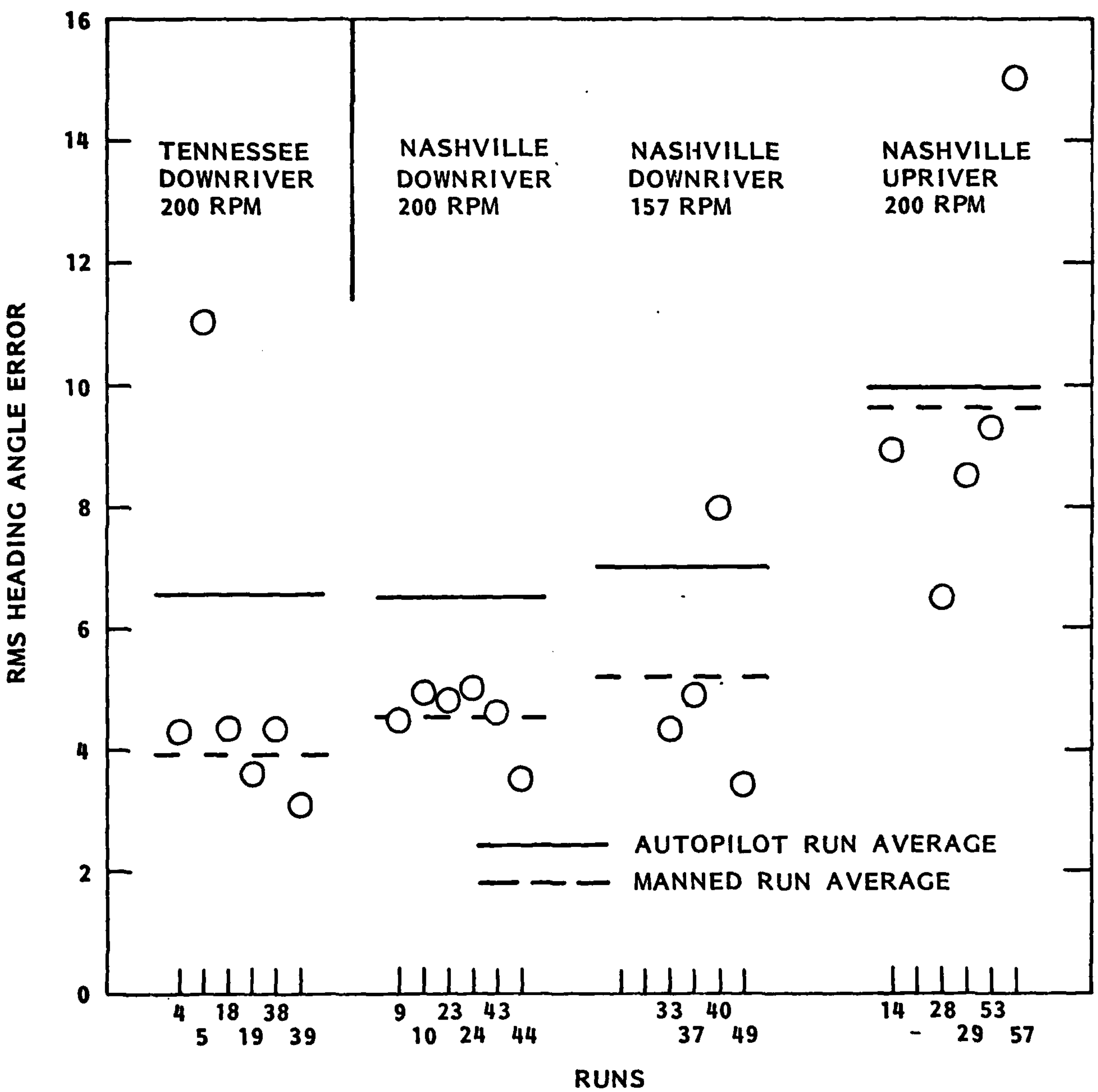

FIGURE 33 - RMS HEADING ERROR WHILE TRACK FOLLOWING

four categories of runs. The TENNESSEE tracks and the NASHVILLE upriver tracks were more difficult to follow, while both the 200 RPM and 157 RPM downriver NASHVILLE tracks were followed very closely in distance, with the improved heading following giving a better RMS swept path than that of the autopilot.

The results of the free run and free run with bow thruster are shown in Figure 34. Each of the four run categories has five average results for the track distance error at the railroad bridge, the swept path at the railroad bridge, and the heading angle error at the railroad bridge. Since these errors are measured relative to the autopilot track which passes to the left of center of the highway bridges, but through the center of the railroad bridge, the railroad bridge errors present the most significant measure of the operator results. The five average results are autopilot runs, autopilot with bow thruster, track following average, free run average, and free run with bow thruster average.

The TENNESSEE runs indicate, in general, track following results comparable to autopilot results, larger errors, but improved with use of the bow thruster (no autopilot with thruster runs were made for this tow). The NASHVILLE downriver results show very similar, almost identical results for all autopilot and manned runs at 200 RPM, but a definite ability of the operator to reduce angle errors over the autopilot, and thus the swept path in every case except track following. The NASHVILLE upriver runs show the ability of the bow thruster to limit heading error for the manned runs as in the autopilot runs. The large heading angle variations, and thus swept path values, may be due to the fact that Capt. Gros showed with his runs that a path quite different from that of the autopilot would produce good results.

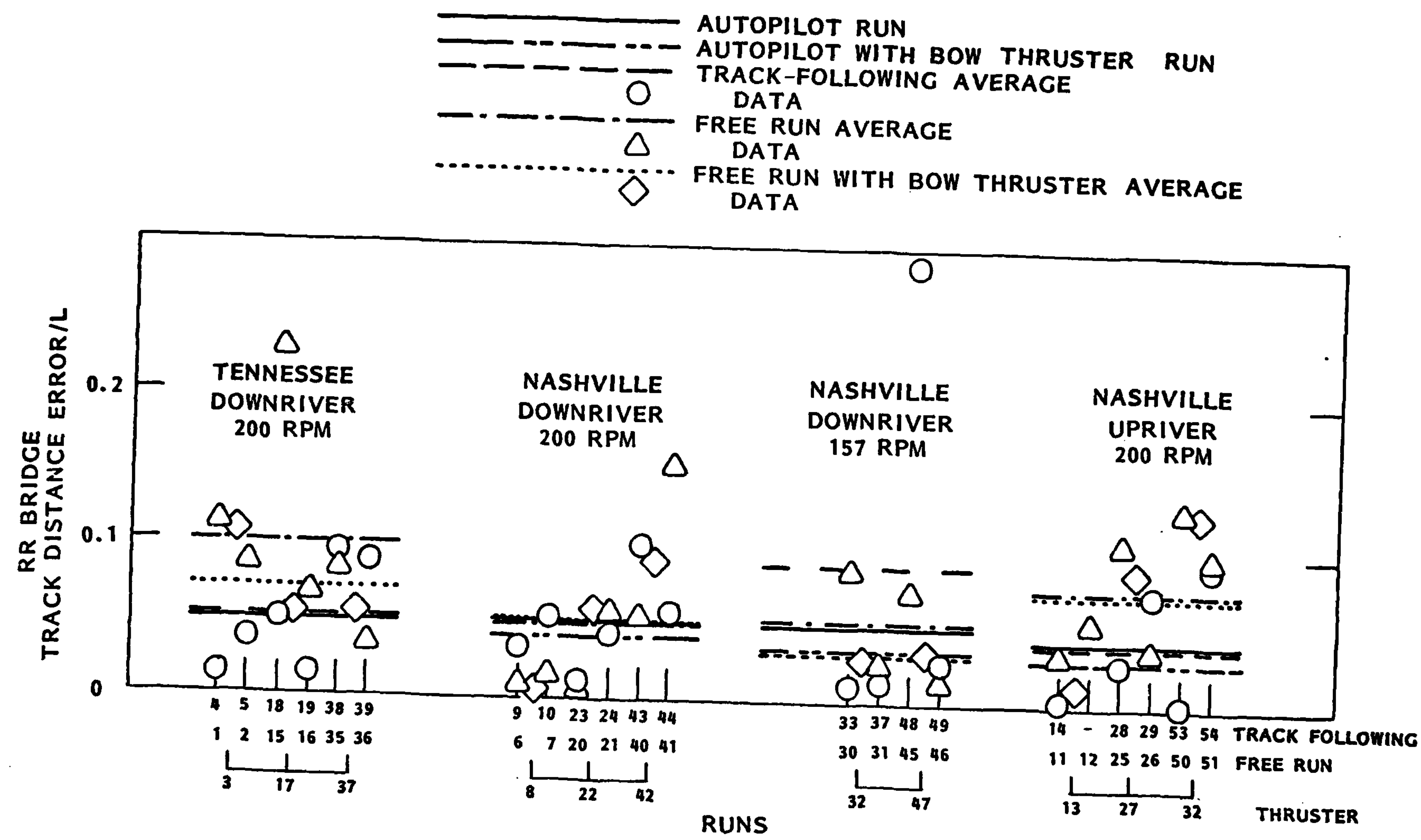

FIGURE 34A - TRACK DISTANCE AT RAILROAD BRIDGE

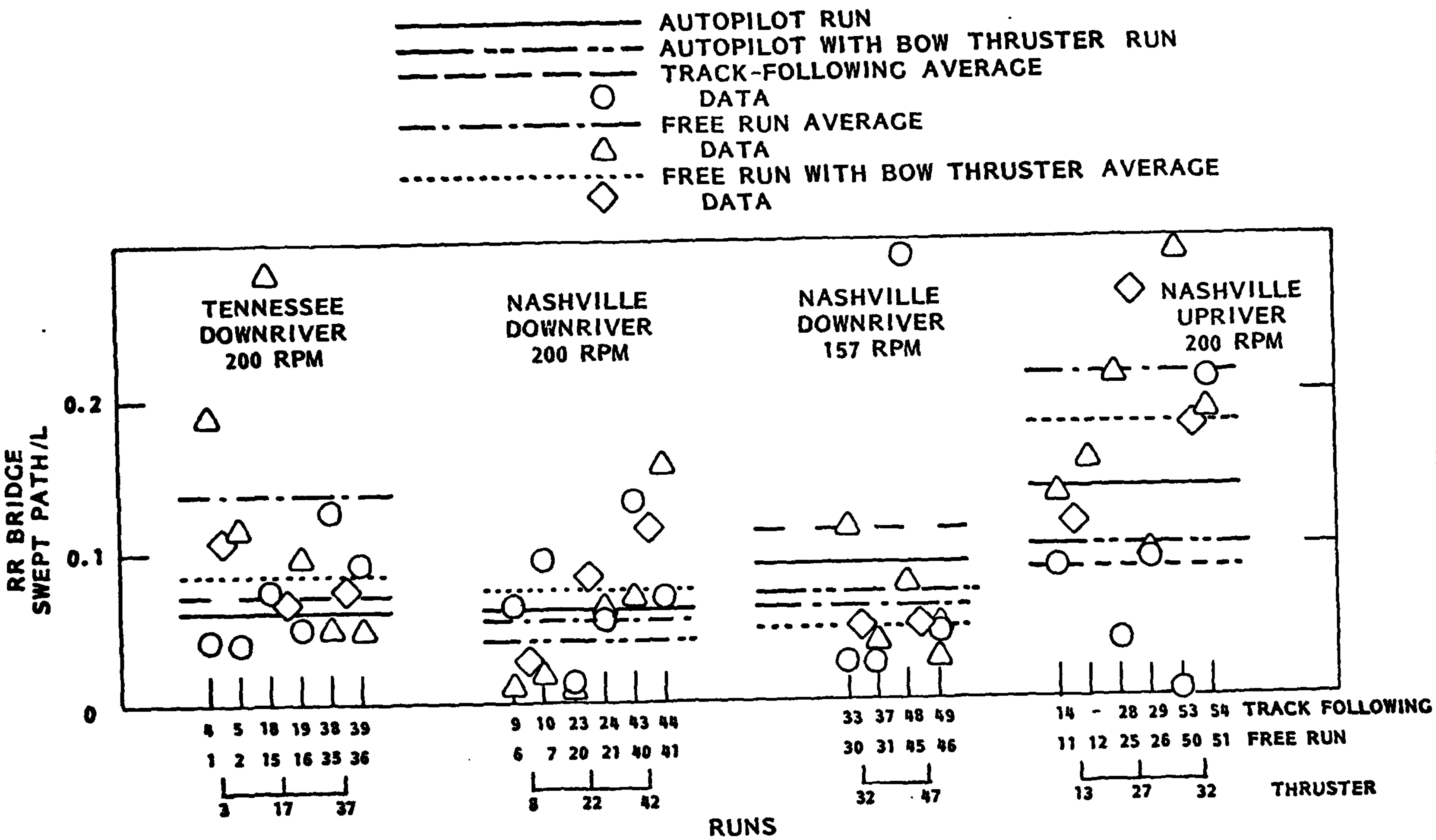

FIGURE 34B - SWEPT PATHS AT RAILROAD BRDIGE

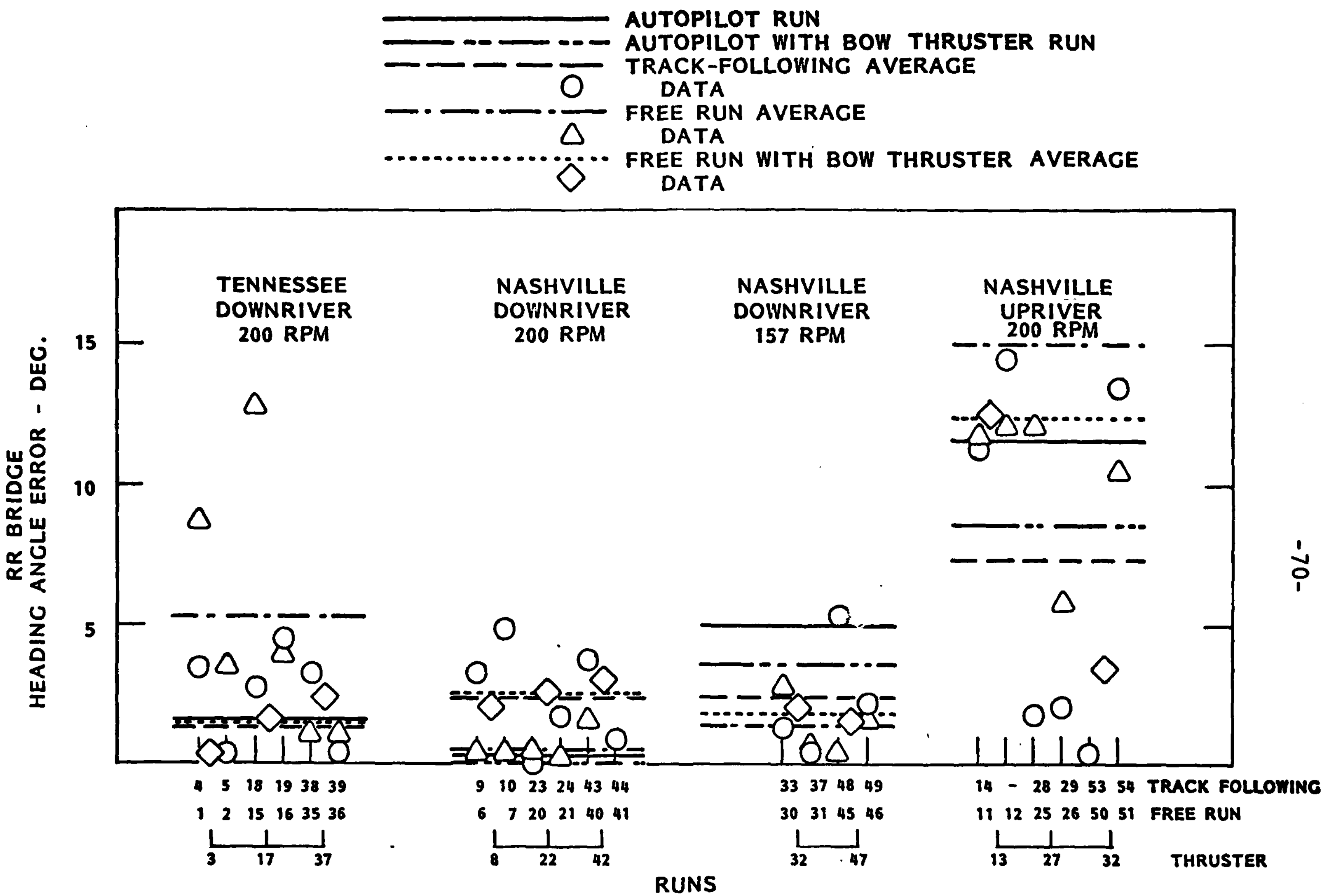

FIGURE 34C - HEADING ANGLE ERRORS AT RAILROAD BRIDGE

The results of all of the down river runs except the track following runs are shown in histogram format in Figure 35. In this figure, the fraction of the number of runs with swept path falling from 0 to 1/2 of the railroad bridge span opening, from 1/2 to full opening, and beyond full opening (collision) on either side of the mid-span position are shown. The average values are also presented. The effects of current seem apparent in these results, as the tendancy to be to the left of center when the mid-tow passes under the railroad bridge is clear. The average values, and histogram forms themselves, indicate that for the tow lengths and power used in the runs, no clear trend is present. A possible reason for the relatively poor results with the shorter tow is that these runs were the first for each operator, and were in some sense warmup runs. The bow thruster effect is greatest at smaller relative velocities, and inclusion of these results helped the lower power, longer tow average swept-path error.

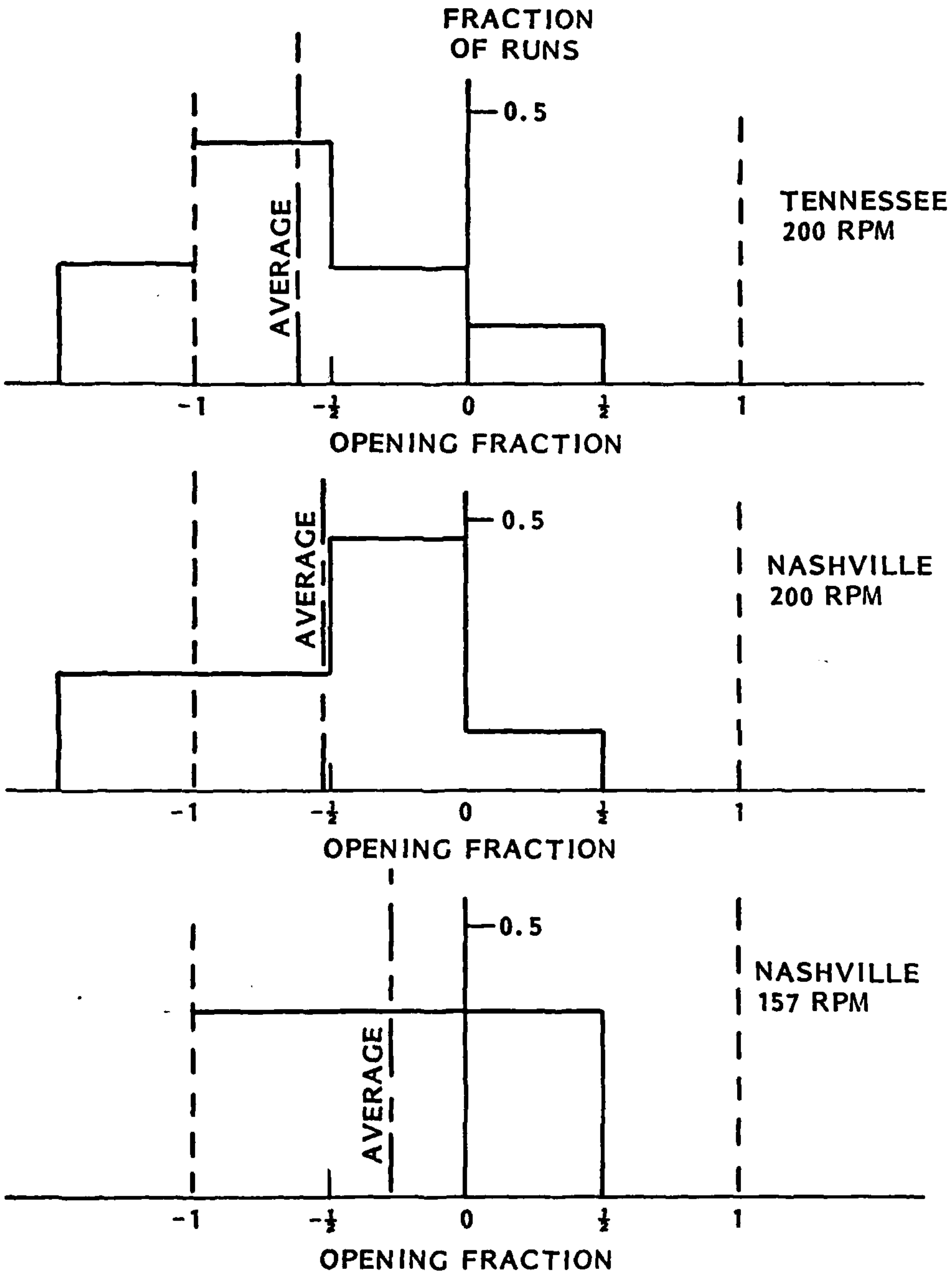

FIGURE 35 - HISTOGRAM OF SWEPT PATH ERROR AT RAILROAD BRIDGE FOR DOWN-RIVER RUNS WITH AND WITHOUT BOW THRUSTER

M/V STUD ACCIDENT SIMULATION

During the course of running the manned real-time passages, a copy of a National Transportation Safety Board Report concerning a Berwick Bay Passage collision was received (Reference 11). On April 1, 1978, the four-barge tow of the Motor Vessel STUD collided with the eastern fixed span of the railroad bridge over the river. The collision knocked the span from its supporting piers into the river but did not damage the barges. The National Transportation Safety Board determined that the probable cause of the accident was the failure of the master to properly align the underpowered tow on the approach north of the Berwick Bay bridges. Contributing to the cause were the inadequate criteria for commencing high water limitations in the Berwick Bay Vessel Traffice Service area, the inadequate horsepower of the STUD in relation to the towlength for maneuvering in the existing river conditions, and the fact that the master of the STUD did not have up-to-date information concerning the river stage and current velocity. It was decided that a simulation of this accident would be possible based on the information in this report and would demonstrate the use of the Simulator in casualty analysis.

The current conditions were estimated to be about 2.8 mph, which is 55 percent of that used in the simulation runs. The 780 ft length of the tow was modelled using the TENNESSEE. The accident report included an estimated path of the STUD, with times, which was modelled using the autopilot tracks shown in Figure 36. The first three tracks bring the tow along the estimated STUD track; for this simulation, the RPM variation was used, as the report indicated full RPM until point C, then half RPM to point A, at which point recovery was attempted by the STUD. To emulate the 690 horsepower, or 0.86 HP/L ratio, 100 RPM was taken

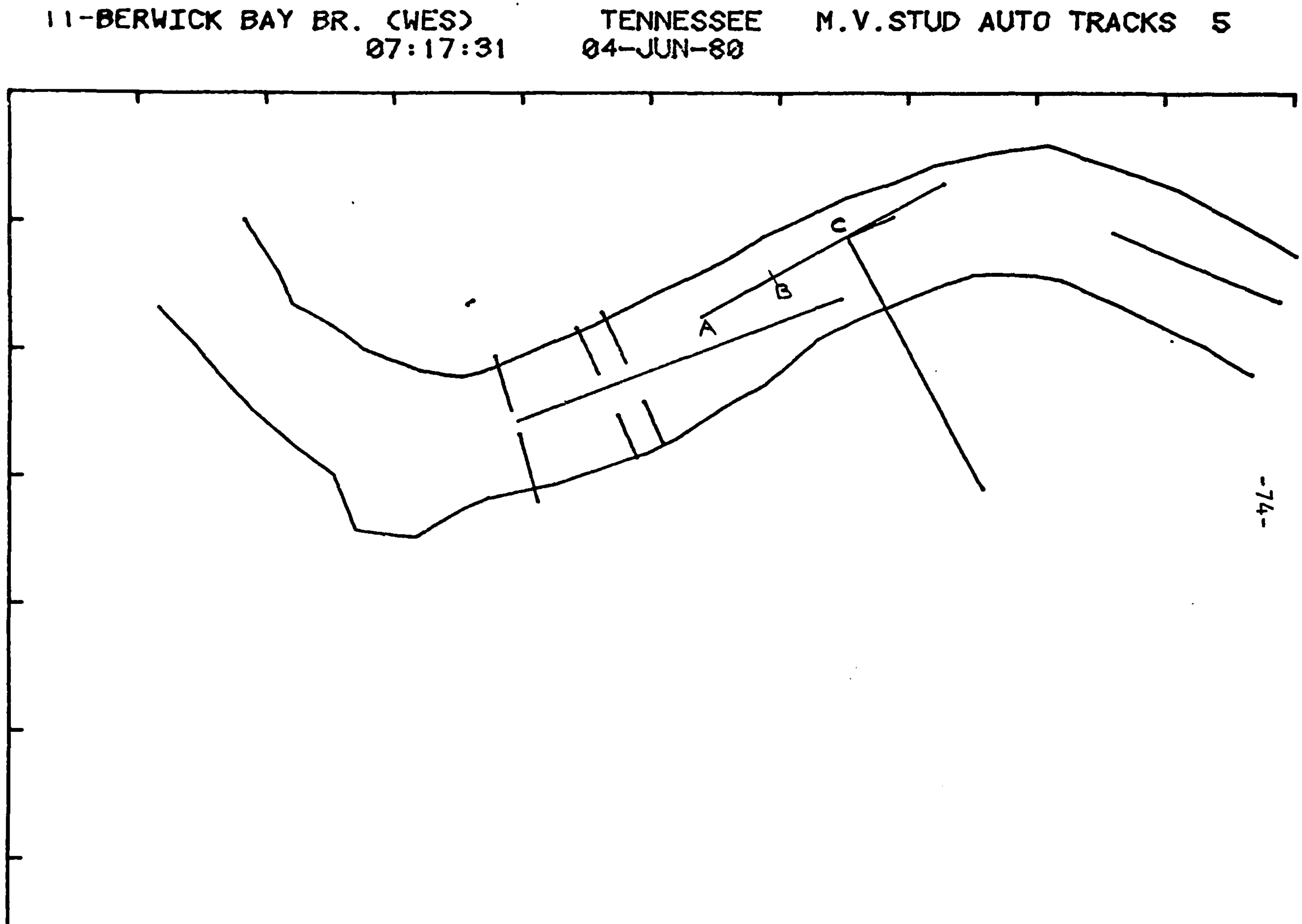

FIGURE 36 - AUTOPILOT TRACKS FOR "M/V STUD" CASUALTY ANALYSIS

as full power, and 50 RPM as half. The run from times 1730 to 1740 was correctly simulated; however, the half speed portion, reported as taking 10 minutes from 1740 to 1750 (a distance of about 1/2 mile) took much less time. The current velocity of 3 mph would cover 1/2 a mile in 10 minutes, indicating that the STUD was probably doing something other than maintaining half-speed during this time.

To assess the effect of power on the potential ability of the STUD to have avoided a collision with the bridges, which according to the pictures in Reference 11 first occurred with the western support of the old highway bridge, three points along the third track, A,B, and C, were selected, and the operator tried to navigate through the bridges by taking control from the autopilot as the tow reached these points. Table 1 summarizes the eighteen runs made by the three test operators. The error indicator was taken as the swept path at the old highway bridge and the railroad bridge. Two RPMs were considered; 100 to give the 0.86 HP/L ratio, and 150 for a HP/L of 3.0.

Typical plan position plots are shown in Figures 37 through 40. The early recovery point C allows alignment prior to the bridges (Figure 37), the half point B allows fairly good recovery (Figure 38), while the late point A results in collision with the railroad bridge if the highway bridge is avoided, (Figure 39), or immediately with the highway bridge (Figure 40).

The individual swept path results in Figure 41 show clearly the decreased swept paths as the recovery point is changed, and the general improvement in performance as power is increased.

TABLE 2

M/V STUD Runs

OPERATORS:

1 - Capt. Gros
2 - P. Van Dyke
3 - E.R. Miller, Jr.

POSITIONS (see Figure 36)

A - Late
B - Half
C - Early

Run	Operator	RPM	Position	P-HB	P-RRB	H*
1	1	100	A	0.366	0.180	H
2	1	150	A	0.358	0.483	H
3	1	100	C	0.386	0.379	H
4	1	100	C	0.064	0.093	
5	1	150	C	0.051	0.054	
6	2	100	A	0.354	0.189	H
7	2	100	C	0.166	0.137	
8	2	150	C	0.248	0.169	
9	2	150	A	0.329	0.378	H
10	2	150	B	0.168	0.089	
11	2	100	B	0.148	0.086	
12	2	150	B	0.075	0.070	
13	2	100	B	0.119	0.066	
14	3	150	A	0.348	0.420	H
15	3	100	B	0.440	0.658	H
16	3	100	B	0.385	0.417	H
17	3	150	B	0.332	0.423	H
18	3	150	B	0.207	0.166	

Note: P-HB - Swept path at highway bridge/tow length
P-RRB - Swept path at railroad bridge/tow length
H - H indicates bridge was struck

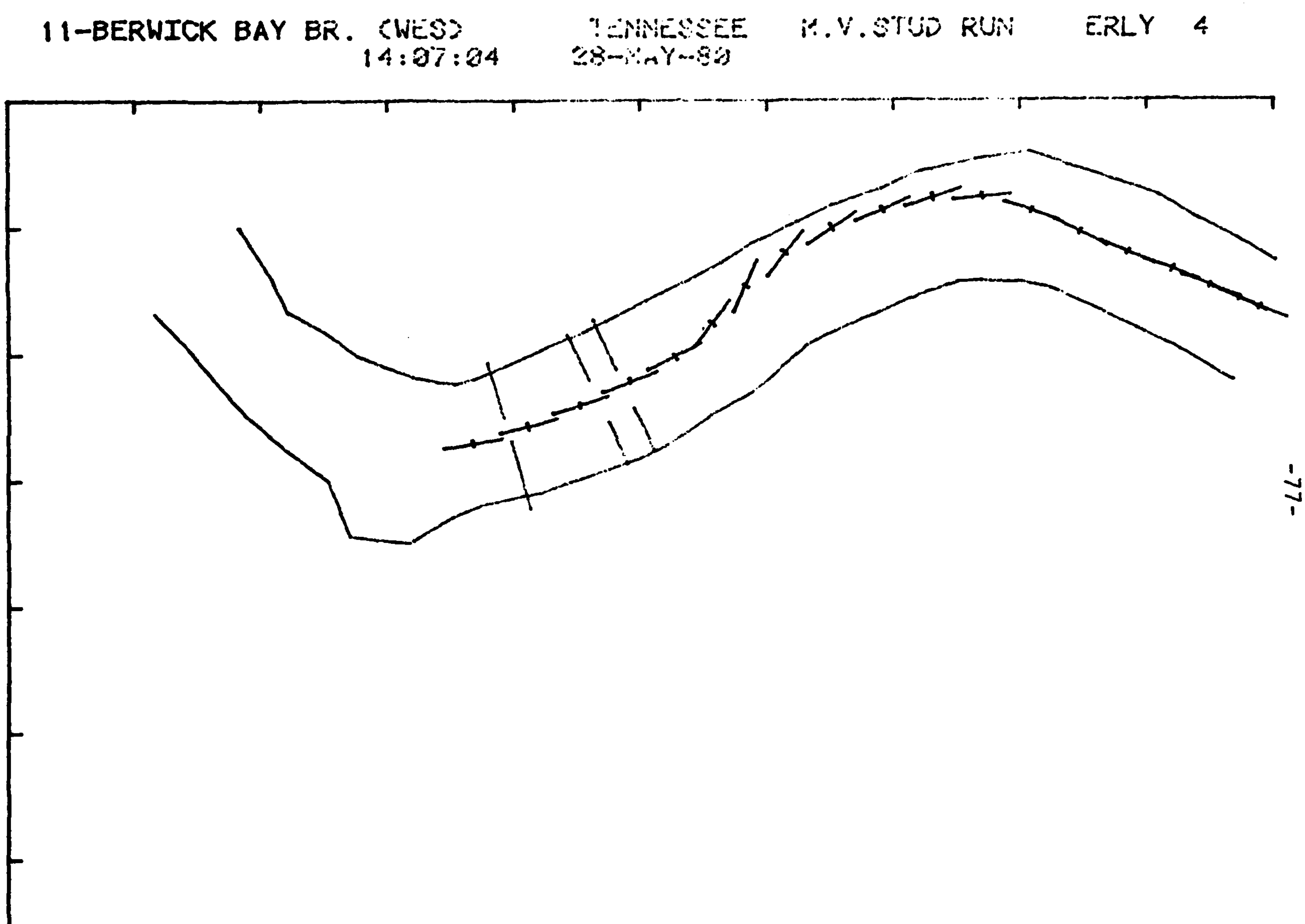

FIGURE 37 - "M/V STUD" RUN 4, RECOVERY STARTED AT POINT C, 100 RPM

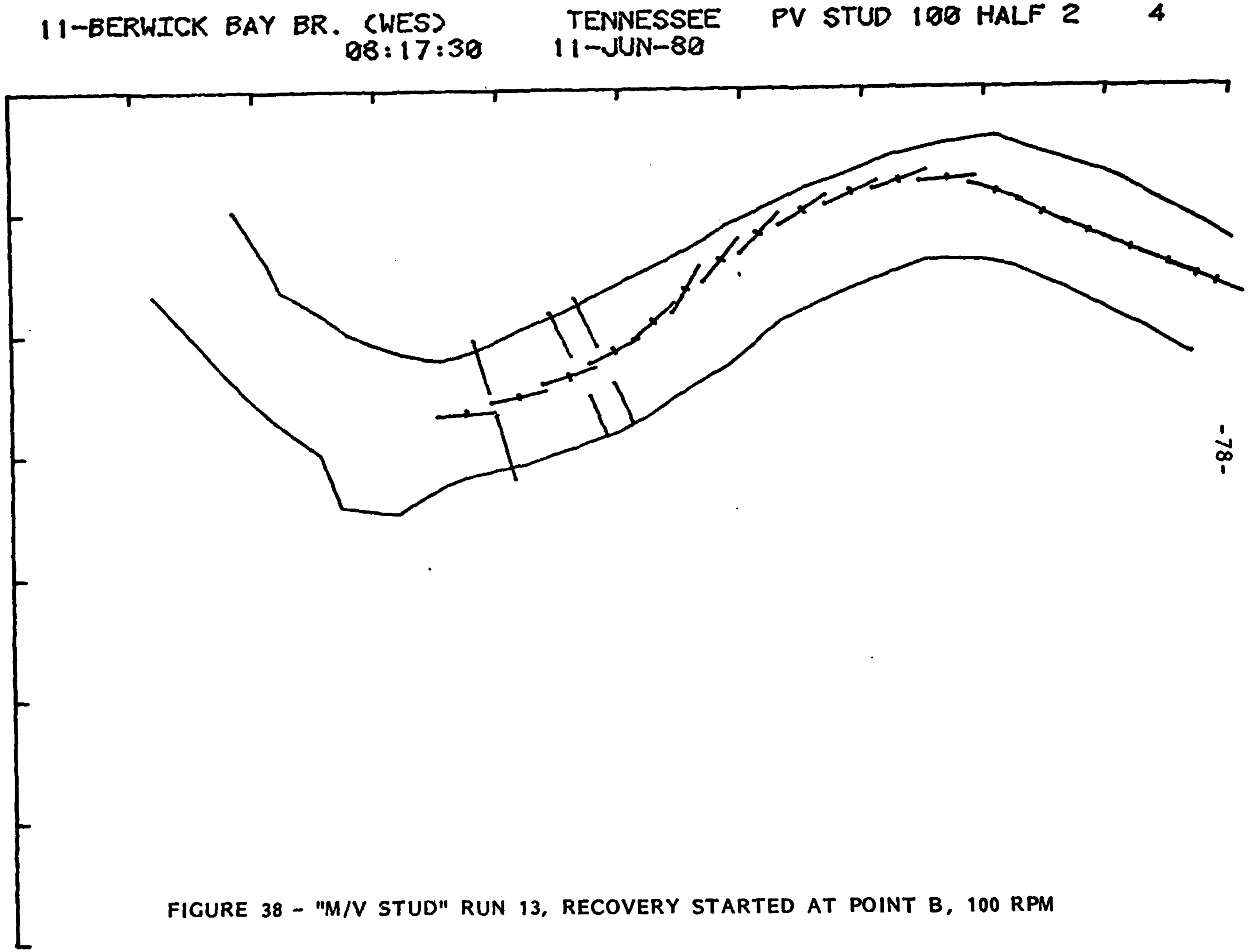

FIGURE 38 - "M/V STUD" RUN 13, RECOVERY STARTED AT POINT B, 100 RPM

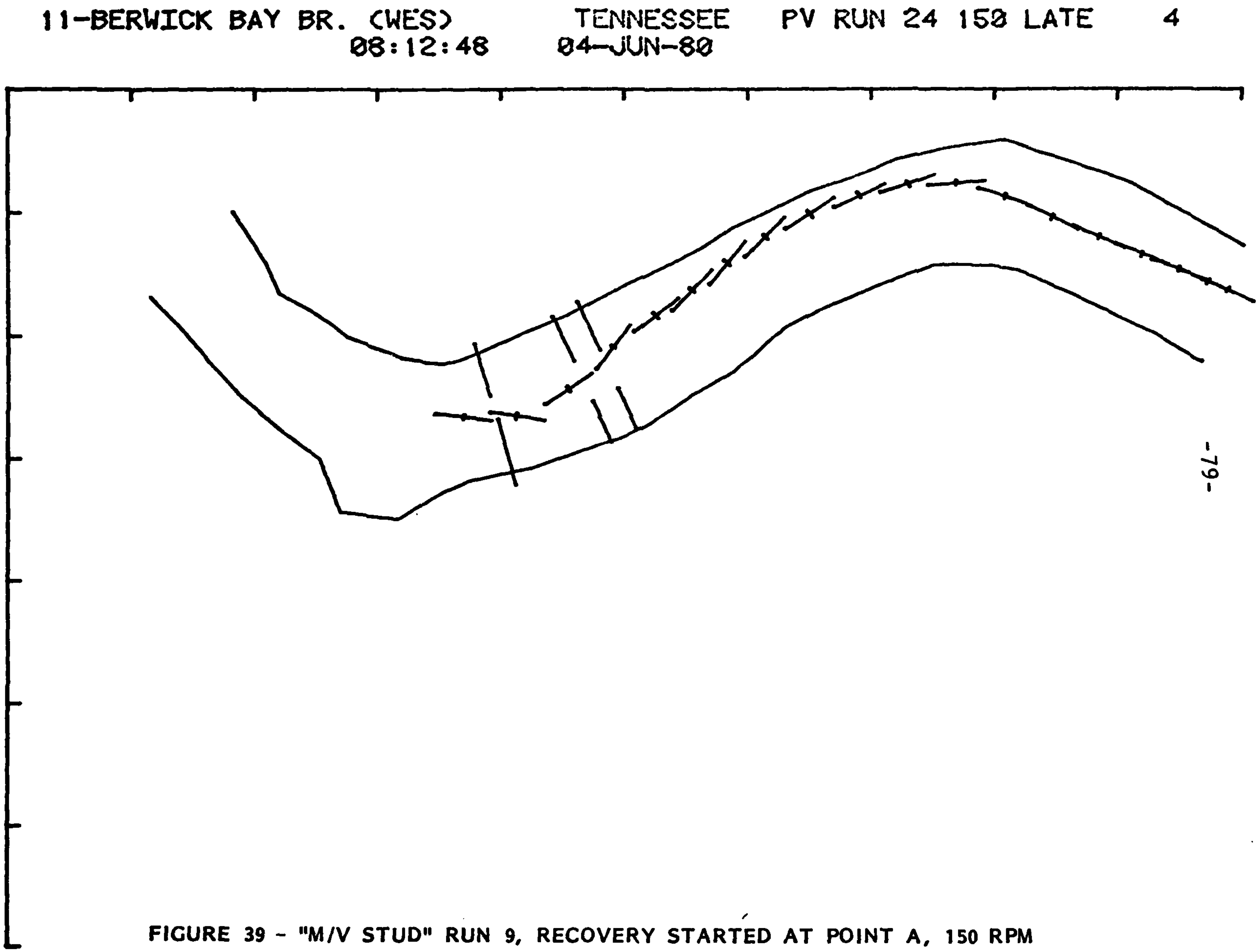

FIGURE 39 - "M/V STUD" RUN 9, RECOVERY STARTED AT POINT A, 150 RPM

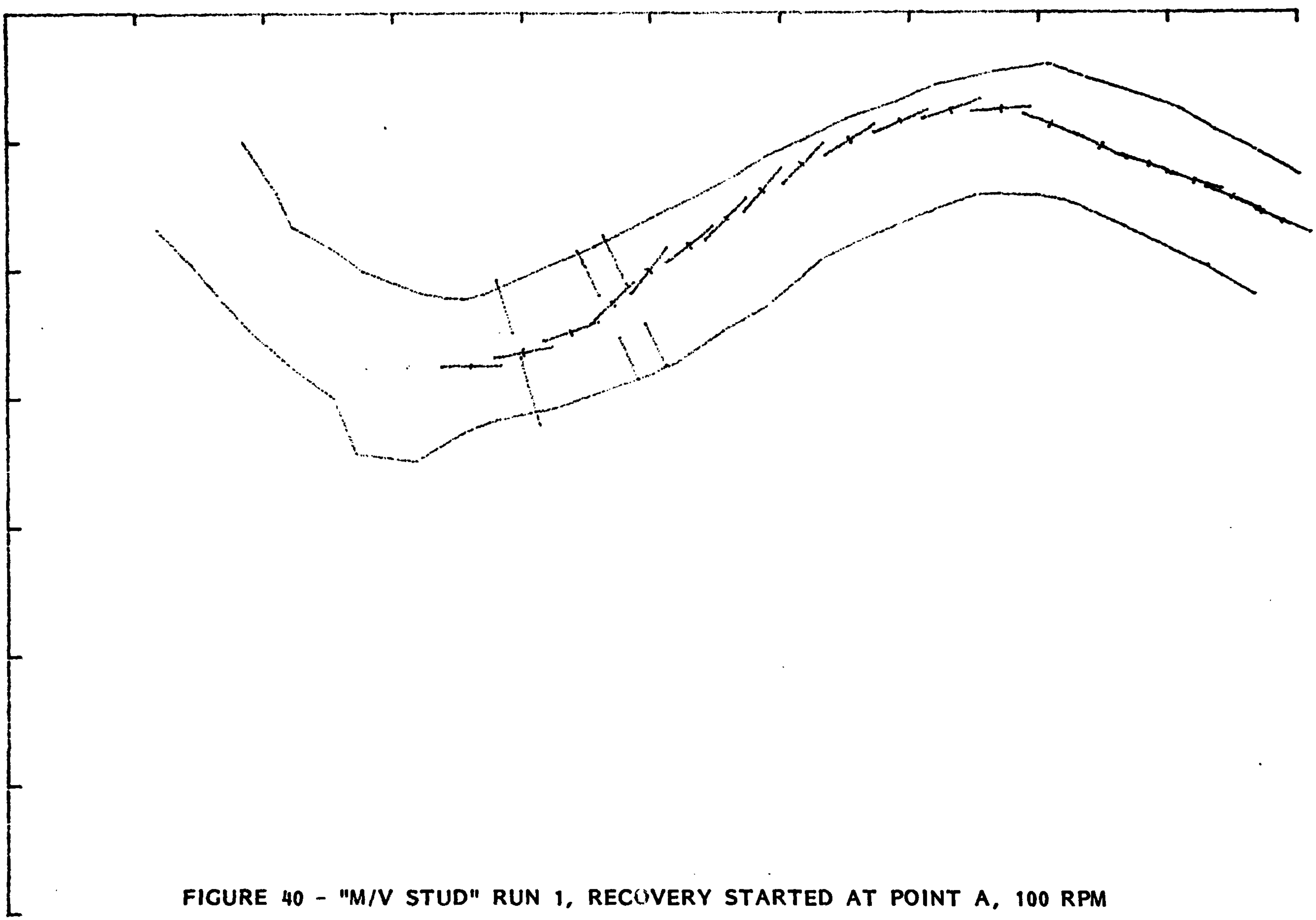

FIGURE 40 - "M/V STUD" RUN 1, RECOVERY STARTED AT POINT A, 100 RPM

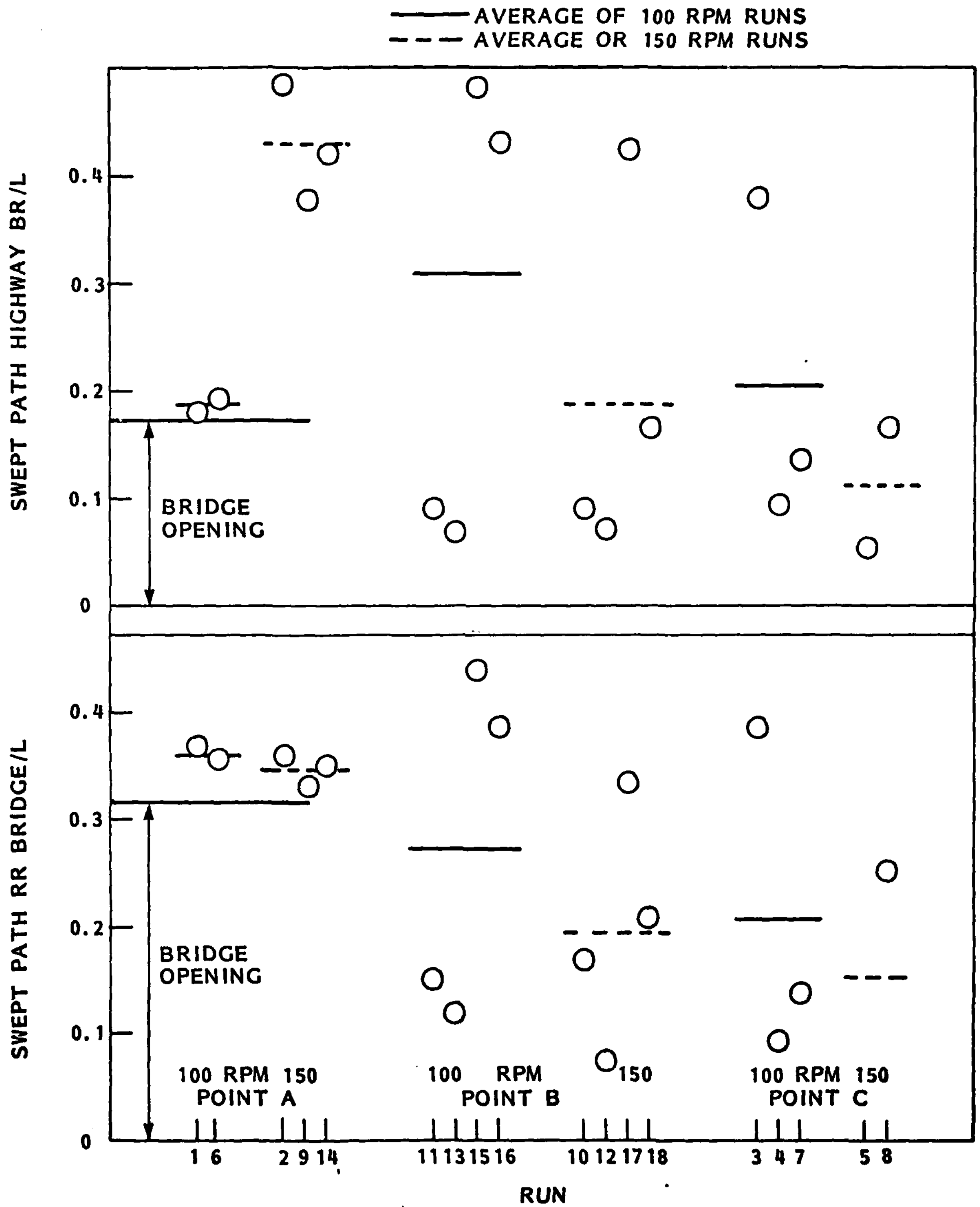

FIGURE 41 - "M/V STUD" SIMULATION RESULTS, SWEPT PATHS AT BRIDGES

CONCLUSIONS

The overall objective of this study was to demonstrate the use of the USCG Towboat Maneuvering Simulator in the analysis of vessel maneuverability, navigation rules and casualty analyses. This demonstration was provided by a simulator investigation of the passage of a tow on the Atchafalaya River through the bridges between Morgan City and Berwick Bay. For this specific river passage situation a number of conclusions can be developed for the parameters investigated. These include:

Current: The path and track errors were increased by the effects of current (see Figure 11). The largest effects occur for conditions of low towboat power and high current. Considering the bridge clearances available, the 100 percent current condition represented a much more difficult control problem than the 50 percent current case, particularly for the longer tows. When the present VTS rules on tow size are in effect, the current velocity exceeds the 50 percent case investigated. This is consistant with the simulation results.

Wind: The wind effects on the fully loaded tows used in this study were small. Wind effects may be significant for empty tows and thus should be investigated more completely.

Tow Length: For both the autopilot and real-time simulation runs, the path errors were about proportional to tow size. For the full current, full power cases the average swept path error at the railroad bridge was about 0.08 of the length for both cases. Since the comparable opening ratios are 0.114 for the long tow and 0.177 for the short tow, the short tow has a significantly greater margin for errors. Considering all real-time full current, full power passages the success ratio for the small tow was 0.87 and for the long tow 0.80.

22-Blank

Towboat Horsepower: For both the short and long tows, the path and track errors were not very sensitive to power until the HP/L was reduced to about 1 or less. Considering all real-time full current runs for the long tow, the path errors at the railroad bridge were about the same at HP/L ratios of 4.3 and 2.0. This is consistent with the autopilot run results. It should also be noted that, for the long tow during full current conditions, if the tow HP/L is reduced below about 2 it is very difficult to slow the tow enough to flank the bend below the railroad bridge.

Bow Thrusters: The effects of the use of a bow thruster on path error were not large for the downriver runs. This result was consistent between the autopilot and real-time runs. The bow thruster is most effective at low speeds through the water but under these conditions the maneuverability is reduced. The autopilot runs indicated a greater effect of thruster use on upriver runs, particularly those at low HP/L ratios when water speed is low.

The analysis of the casualty of the M/V STUD was primarily directed at determining if increased power would have had significant effects. From the position at which the pilot of the M/V STUD seems to have realized he was out-of-shape and started to maneuver into alignment, an increase in the HP/L ratio from 0.86 to 3 would not have prevented the casualty. If the maneuvering to properly align the tow had started 1000 ft further up river there would have been a good chance of making it (3 successful passages out of 4 trips) with the actual power available. From a position starting 2000 ft further up river the passage was made successfully two out of three attempts with the actual power and on both attempts with a HP/L ratio of 3. Thus, in this case an increase in the HP/L ratio from 0.86 to 3 increases the margin for error at which the tow must start to maneuver into alignment by about 1000 ft or 1-1/3 ship length.

The VTS rules for the Berwick Bay passage impose high water limitations. For the integrated tows considered in this study the applicable rules are:

1) Southbound (downriver) tows without bow thrusters shall not exceed 600 ft excluding the towboat (the TENNESSEE is at this limit), or 1180 ft including the towboat with an operable bow thruster unit (the NASHVILLE is 1160 ft).

2) Northbound (upriver) tows shall not exceed 1180 ft including the towing vessel.

Based on the results of this study, a number of comments about these navigation rules can be made. There is no clear relationship between the current velocity and the time high water limitations are in effect. The full current case, which represents a very high river stage, provided problems for the long tow and in same cases for the short tows. Some form of navigation regulations clearly seem justified for this case. The M/V STUD casualty analysis indicated a current velocity of 55 percent of the full current case just before high water limitations went into effect. Considering the improvement in path error which results when the current is reduced from the full to 50 percent case, it seems reasonable that navigation limitations go into effect for currents somewhere between the 50 and full current conditions studied. This is consistent with the present regulations.

The present regulations are based only on tow length. The simulations results shows that tow length is the most significant parameter. The scope of this study did not permit a large enough number of real-time runs to allow an absolute prediction of the relative risk of a casualty between the short and long tow. Considering both the real-time and autopilot runs it is felt that the present 600 ft length limit on downriver tows is reasonable for high water conditions.

The results using a bow thruster do not show an improvement in path error for the long tow sufficient to make its performance comparable to that of the short tow. Thus, it would be desirable to further investigate the provision which allows a 1180 ft tow with a bow thruster.

For the upriver runs, the simulation results indicate that the 1180 ft length limit may be slightly too long. However, the number of runs made was small and better results may have been obtained if the two subjects with only simulator experience had had more practice.

In addition to the length limits, some references such as 7 propose that an additional restriction on the minimum allowable HP/L ratio and suggest a value of 3. The simulation results do not show much effect of HP/L ratio until the ratio is reduced to 2 or below. This conclusion applies to cases in which the tow was basically in shape for the bridge passage. The analysis of the M/V STUD casualty indicates that higher HP/L ratios can improve the margin for error in cases in which the tow is out-of-shape. The overall importance of HP/L ratio should be investigated further.

In addition to the specific conclusions and comments that apply to the Berwick Bay passage, it is possible to provide more general conclusions with respect to the use of the towboat Maneuvering Simulator. These conclusions include:

Validation of Simulation: It is difficult to validate the results of towboat maneuvering simulation because of a lack of full-scale data. However, the results of this study show good qualitative agreement with descriptions of the passage provided by pilots. Further, the experienced pilot used for some of the real-time runs felt that the simulator reproduced the problems of the Berwick Bay passage very well. He was able to adapt to the simulator displays with little trouble.

Study Techniques: It is felt that the use of a combination of fast-time and real-time simulations is an efficient way to study problems such as this. The scope of this study did not allow a sufficient number of real-time runs to generate situations with high confidence levels. Considering this limitation, the real-time runs under pilot control gave results, in terms of absolute path error and trends, which were consistent with the autopilot runs. It was noted that the human operators tended to put more importance on heading error than the track-following autopilot. In future studies the autopilot could be adjusted to show this type of performance.

Simulator Use: It is felt that the results of this study do show that the Towboat Maneuvering Simulator can be used to assist in the solution of typical USCG problems related to vessel maneuverability, navigation rules and casualty analysis.

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END