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By Paul Palo and
Linda Teragouchi

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Technical Note

VALIDATION OF THE SEADYN90 CABLE SIMULATION MODEL USING A THREE-DIMENSIONAL CABLE DEPLOYMENT DATA SET

ABSTRACT This report presents data from a full-scale, three-dimensional cable payout test and the corresponsing numerical simulations using the SEADYN90 computer model. The experiment, which was conducted at the Atlantic Undersea Test and Evaluation Center (AUTEC), deployed 10 miles of 3/4-inch-diameter cable from a vessel that followed a predetermined course. Ship position, cable payout rate, and current profile were measured, along with 11 cable descent trajectories at predefined intervals along the cable. The measured data were then input into SEADYN90 with minimal simplifications to ensure that modeling errors could be distinguished from input errors. Qualitative and quantitative comparisons between the numerical and measured trajectories were considered excellent when a normal drag coefficient of 2.54 ±0.1 (typical of strumming) was used. The results demonstrate that SEADYN90 is capable of accurately modeling realistically complex test scenarios with stochastic current profiles, ship velocities, and payout rates, and that the data set is complete and high quality.

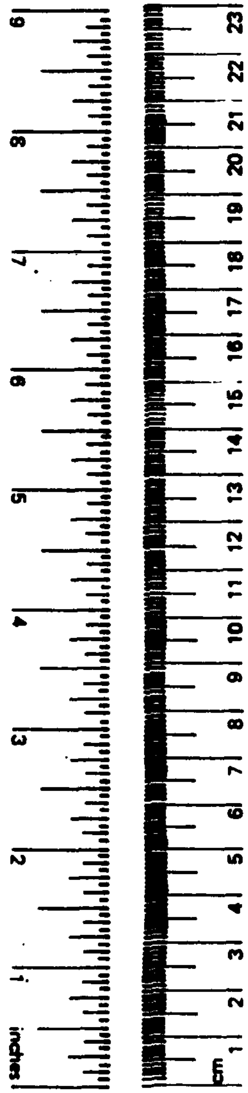
NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043-4328

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

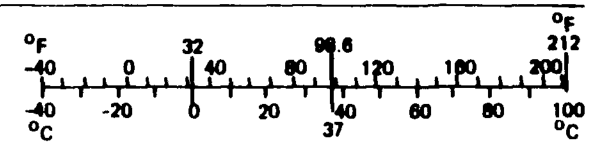
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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 (2,000 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 (1,000 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



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Paul Palo and Linda Teragouchi

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This report presents data from a full-scale, three-dimensional cable payout test and the corresponsing numerical simulations using the SEADYN90 computer model. The experiment, which was conducted at the Atlantic Undersea Test and Evaluation Center (AUTEC), deployed 10 miles of 3/4-inch-diameter cable from a vessel that followed a predetermined course. Ship position, cable payout rate, and current profile were measured, along with 11 cable descent trajectories at predefined intervals along the cable. The measured data were then input into SEADYN90 with minimal simplifications to ensure that modeling errors could be distinguished from input errors. Qualitative and quantitative comparisons between the numerical and measured trajectories were considered excellent when a normal drag coefficient of 2.54 $\pm$0.1 (typical of strumming) was used. The results demonstrate that SEADYN90 is capable of accurately modeling realistically complex test scenarios with stochastic current profiles, ship velocities, and payout rates, and that the data set is complete and high quality.

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CONTENTS

BACKGROUND

The Southern California Anti-Submarine Warfare (ASW) Range Phase II (SOAR II) was established to extend the existing range off the coast of San Clemente Island, California. This project was initiated to meet the Navy's requirements for an instrumented ASW Range to provide training and enhanced fleet ASW capabilities. The SOAR II Range uses Multiplexed Range Sensor Arrays (MRSA) which consist of 64 hydrophones on eight cables for an expanded range coverage of 500 square nautical miles.

To date, the Navy has never had a cable installation as technically complicated as this one. Each dynamic cable lay required precise placement of eight hydrophones on approximately 40 miles of cable, with variable bathymetry, varying currents, and multiple-curved cable tracks. The eight cable tracks and bathymetry are shown in Figure 1. Each hydrophone had to be placed within a 300-foot radius tolerance circle in 3,000 to 5,000 feet of water.

The Naval Facilities Engineering Command (NAVFAC), Chesapeake Division (CHESDIV) was assigned to procure the cable and install all the components of this ASW range. CHESDIV conducted the planning, engineering design, installation systems testing, and actual installation to execute the SOAR II installation while they maintained the fiscal and administrative control of the assigned tasks (Ref 1).

CHESDIV tasked Makai Ocean Engineering, Kailua, Hawaii, to create a real-time on-site computer model to estimate the cable shape in the water column from which payout rate, ship course, and ship velocity recommendations would be made to ensure placement of the hydrophones within the stringent tolerance circles. Due to the unproven experimental nature of such a computer model, the Naval Civil Engineering Laboratory (NCEL) was tasked to provide a backup capability to the Makai model. The original plans for this backup system called for extensive sets of payout tables created using simulations from the SEADYN90 computer model.

SEADYN90 is a general purpose, finite element, large displacement simulation model for arbitrary cable and truss structures (Ref 2). It was originally developed in 1974 with continual updates over the years. The last major revision occurred in 1990. It was concluded that an at-sea test was necessary to calibrate the SEADYN90 computer model for this particular application and to evaluate many of the mechanical systems to be used in the SOAR II installation. The test was conducted at the U.S. Navy Atlantic Undersea Test and Evaluation Center (AUTEC) Weapons Tracking Range east of Andros Island, Bahamas from 14 through 24 July, 1990. NCEL was responsible for data reduction and reporting, and all of the SEADYN90 simulations for this calibration effort.

OVERVIEW OF EXPERIMENT

Objective

The purpose of the SEADYN calibration test at AUTEC was to produce an extensive record of the cable trajectories, vessel track, cable payout rate, and environmental data to use as input for the SEADYN90 calibration effort.

Test Description

Seven experimental runs were completed at the AUTEC Weapons Tracking Range (see Table 1). Six tests consisted of instrumenting and deploying a 10-mile sample of cable with 11 acoustic tracking pingers (see Appendix A for hardware description). The cable was deployed along a predetermined path from the OCP SEACON, a 260-foot Navy construction barge equipped with a Voit-Schneider Propulsion System for accurate dynamic positioning. The descent trajectories of the tracking pingers were monitored by the AUTEC Range Control Center.

The test sequences for Runs 1, 2, 3, 6, and 7 were essentially the same in design. The barge held position while the anchor end of the cable was lowered and set on the seafloor. The barge then ramped to the steady-state speed, slowly paying out cable to obtain the dynamic equilibrium configuration. The barge maintained a 1.5-knot velocity with 11 percent cable slack for the remainder of the test. Approximately 10 miles of cable were deployed 500 to 1,000 yards to the east and/or south of the tracking range including 45-degree and 90-degree course changes. The five tests varied in barge course, attachment of in-line Multiplex Transmission Units (MTUs), and placement of acoustic pingers. As shown in Table 1, not all of the 11 pingers functioned appropriately for many of the tests.

The objective of Run 4 was to determine what effects an abrupt change in the barge's path had on the cable/pinger path. The testing scenario for this experiment was as follows. The barge maintained a straight line course at 1.5 knots through the entire descent of the first pinger to acquire a baseline model. Twenty minutes after the next functional pinger entered the water, the barge moved off track 750 feet. The barge returned to the original track upon touchdown of this pinger. The barge was again moved 750 feet off track 5 minutes after the last pinger was deployed. No postprocessing or analyses was completed for this experiment.

Table 1. Overview of SOAR Simulations

Run	Date	Type	MTU	Operational Pingers	SEADYN90 Analyses
1	7/15	90° Turn	N	8	0
2	7/16	45° Turn	N	8	2
3	7/18	0° Turn	N	0	0
4	7/19	Influence	N	3	0
5	7/20	Tow	N	3	5
6	7/22	90° Turn	Y	11	20
7	7/22	45° Turn	Y	11	12

Run 5 was completely different from the other six AUTEC tests conducted in this test series because it was a steady-state tow test with no payout. Run 5 was designed to find a drag coefficient appropriate for this particular type of cable. The cable was instrumented with three acoustic tracking pingers. They were spaced 600 feet apart, starting within 3 feet of the 275-pound concrete block anchor. The 1,800 feet of cable was lowered off the stern of the SEACON. The barge then maintained a straight line course with constant velocity until it was believed a steady-state tow configuration had been achieved. The steady-state speeds included 0.5, 1.0, and 1.5 knots.

DATA ACQUISITION

Data was collected at the AUTEC Range Control Center and aboard the OCP SEACON as summarized in Table 2. The Control Center monitored the descent of the acoustic tracking pingers attached to the cable. A pinger was also attached to the hull of the SEACON. This pinger provided an unbiased record of the ship's path during the experiments.

Table 2. Sources of Data

AUTEC (9-track tapes, plots)	
Time* Ship Pinger Current (Bounce Pingers)	Position* Velocity* Acceleration Advance*
Phrognav (5-1/4-inch disks, printout)	
Time Ship	Position Velocity Acceleration Advance Heading
Cable	Length Payout Rate*
Current (ADCP)	Velocity Heading
Manual Entry Notes	
Payout Tables	Time Distance along Track Ship Velocity Cable Length Payout Rate

*Data used for analyses.

The Range Control Center also logged the current velocity profile data gathered by the Bounce Pingers. For the majority of the tests, two Bounce Pingers were deployed simultaneously with a 1-mile separation to measure spatial variations. The Bounce Pingers had a maximum depth of 3,600 feet. Therefore, no information was gathered for the lowest quarter of the water column since the seafloor in the testing area was at 4,900 feet.

The Pelagos Phrognav Integrated Navigational System aboard the SEACON monitored the barge position, barge heading, and cable payout rate. The barge position data was acquired using a Sercel Syledis Radiopositioning System. Five Syledis antennas were installed on Andros Island for this project. The real-time positioning information received from Syledis was used to pilot the vessel. The Syledis positioning data was not used in the analysis because the pinger mounted on the hull provided unbiased barge position data that was consistent with the cable trajectory data.

Barge heading was acquired from the barge's gyro and recorded on disk by the Phrognav system. Phrognav also logged the cable payout rate and length gathered from a Red Lion Cable Counter.

The SEACON was also instrumented with a 150-kHz Acoustic Doppler Current Profiler (ADCP). The ADCP measured current profile data for the top 1,200 feet of the water column during each experiment. Due to the redundancy of the data gathered from the Range Control Center (i.e., the Bounce Pinger current profile data), the ADCP data was not used in later analyses.

ANALYSES

SEADYN90 Model

SEADYN90 was used as the primary model for simulating the data recovered from the AUTEC sea trials. SEADYN90 is a general purpose finite element cable model which can perform static, time domain dynamic, and modal analyses. SEADYN90 uses a discrete element approach to model cable systems. It can be considered a combination of the finite element method and the lumped parameter method where lines are modeled by the finite element method with bodies being lumped at the node points (Ref 3). SEADYN90 can simulate almost any cable problem of interest, including: three dimensions; multi-material lines; nonlinear stress-strain characteristics; arbitrarily positioned anchors and buoys; spatially and time-varying current fields; time-varying point loads and payout/reel-in; surface and bottom constraints; user-definable drag coefficients as a function of velocity; and user-defined nodal displacements, velocity, and accelerations (Ref 4). Using a SUN workstation Sparc 1 as the working platform for the SEADYN90 computer model, a 12-to-1 ratio of CPU-to-real-time was required for this application.

Input Data

Data retrieved from the tests were entered into SEADYN90 with minimal simplifications (see Appendix A). SEADYN90 is capable of accepting variations in current with respect to depth, and temporal variations in ship speed, ship heading, and payout rate. The ability to use actual test conditions with minimal simplifications was very important in that modeling errors could be identified separately from input errors. The variability shown in the measured nodal trajectories made this particularly important.

The Bounce Pingers, which were dropped simultaneously with a 1-mile separation, returned essentially the same data. The current data collected from these were applied for the entirety of each test. The data were edited and smoothed before they were entered into the SEADYN90 model. Since no current data was gathered for the lowest quarter of the water column, several trial profiles were constructed using apparent trends in the measured current data and cable trajectories. The three predominate trial profiles are presented in Appendix A.

The dynamic coordinates at the point of cable deployment (barge's stern position) were calculated and read by SEADYN90 from an ASCII data file. AUTEC Range Control Center provided a filtered estimate of the barge position once per second. This data was then edited for wild points, averaged over 30 seconds, and stored in ASCII input files. SEADYN accessed these files and interpolated barge speed and position versus time.

The cable payout rate was printed out once per minute by the Phrognav SINCS system aboard OCP SEACON. This data was smoothed and wild points removed before it was linked into SEADYN90 as a user-defined subroutine. The trends in the processed payout rate data were followed very closely to best emulate the dynamic characteristics of the cable descent.

There were a few minor simplifications made when creating the SEADYN90 discrete model. The positions along the cable of the modeled pingers were adjusted slightly (no more than 150 feet) to maintain consistent element lengths. Also, some simplifications were made in the vessel track and payout functions prior to the release of the first pinger (during the initial ramping period) to reduce modeling time. Sufficient time was given in the model prior to the deployment of the first pinger to allow the cable to numerically return to its natu configuration.

Validation

The validation efforts concentrated on Run 6. Twenty SEADYN90 simulations were executed for this test. A catalogue of pertinent simulation parameters can be seen in Table 3.

The initial simulations showed little agreement between the measured and simulated pinger trajectories. The current profile was changed; since no data was gathered for the lowest 1,300 feet of the water column, this appeared to be the most likely source of error. However, significant changes in the current profile for this section of the water column made no significant improvement on the cable trajectory comparisons. The next possible suspected error was the (default) normal drag coefficient of 1.27. The drag coefficient was doubled for simulation 6b, as the case when strumming occurs, and immediately the measured and simulated pinger trajectories closely compared.

Appendix B displays the comparison between the actual pinger trajectories and the numerically simulated data obtained using the double drag and "probable" current profile. These graphs indicate that SEADYN90 is able to accurately reproduce the cable response with respect to all of the applicable input parameters and a known drag coefficient (which was known only through inference using the measured data in this case). Qualitatively, the simulated nodal trajectories precisely followed the path of the AUTEC data for most of the pingers. On each graph there are three numbered points marked along the AUTEC (measured) cable path where the trajectory significantly altered course. At each of these points the SEADYN90 data also significantly altered direction. There is often a slight mismatch between the graphed surface points (the asterisks) of the AUTEC data and the SEADYN90 data. This is due to the fact that

Table 3. SEADYN90 Simulations for Run 6

Simulation Label	Drag Coefficient	Current Profile
a. first look	default	conservative
b. current change	default	extreme
f. double drag	double C_n[a] & C_t[b]	extreme
g. current change	double C_n & C_t	conservative
h. *reference run*	double C_n & C_t	probable
i. current change	double C_n & C_t	1.15*probable
l. drag change	2.4*C_n, double C_t	probable
q. drag change	1.8*C_n, double C_t	probable
p. current change	double C_n & C_t	no current
m. 9.5% slack	double C_n & C_t	probable
o. 2*element length	double C_n & C_t	probable
r. scale to 2 knots	double C_n & C_t	probable
s. shift shear depth	double C_n & C_t	probable + 400 ft
t. rotate current	double C_n & C_t	$V_x <==> V_y$

[a]C_n = normal drag coefficient.
[b]C_t = tangential coefficient.

the AUTEC pingers were pressure activated to start transmitting 30 to 100 feet below the water surface while the numerical trajectories were graphed from the time the simulated pinger left the vessel. Also, the pinger locations in the SEADYN90 model were adjusted slightly along the length of the cable (±150 feet) to maintain uniform element lengths; this introduces a bias which appears as an apparent difference in the trajectories.

The similarities in the numerical and measured nodal trajectories provided sufficient circumstantial evidence that the cable was strumming during descent. However, additional calibration of the increased drag coefficient was deemed necessary, so Runs 2 and 7, with 45-degree turns, were also modeled with the doubled drag coefficient. As with Test 6, the results were excellent (see figures in Appendix B). This further increased the confidence in the accuracy of the data, and reinforced the conclusion that the cable was strumming during the descent. Thus, the best (back-fitted) normal drag coefficient as determined from these simulations was approximately 2.54.

The SEADYN90 best-fit simulations imply that the cable was strumming during its entire descent through the water column. This is consistent with other cable drag measurements such as those reported in Reference 5. For additional verification of this hypothesis, the SOAR cable dynamic problem was discussed with a consultant. After review of the dynamic data for this cable's descent, the consultant agreed that the cable appeared to be strumming. From an independent strumming analysis, he estimated that the normal drag coefficient ranged from 2.3 near the surface and 1.7 near the seafloor. While the drag coefficient of 2.5 that was used in the "best-fit" SEADYN comparisons is slightly higher, it is much more realistic than the customary default value of 1.27.

The question of the distribution of the drag coefficient over the cable was further investigated by simulating the steady tow test - Run 5. As previously discussed, the objective of Run 5 was to measure the equilibirum cable configuration at three different tow speeds. More exactly, the objective was to measure the position of the three acoustic pingers attached to the cable. This was accomplished for 0.5-, 1.0-, and 1.5-knot steady tow speeds.

The tow test was then simulated twice using SEADYN90, with default and then doubled (strumming) drag coefficients assumed constant over the entire cable. The results are shown in Figure 2. In Figure 2, all lines with the "x" correspond to the 0.5-knot tow speed; the "o" and the "*" correspond to 1.0 and 1.5 knots, respectively. The solid line is merely a low-order polynomial fitted to aid the eye in visualizing the measured cable shape as defined only by the three pinger positions.

At the 0.5-knot speed, the cable is obviously nonstrumming since the strumming shape is unacceptably different compared to the measured shape. However, a variable drag coefficient is necessary to model the higher tow speeds. In both cases, the strumming coefficient is needed to accurately model the upper half of the cable, but it diverges over the lower half. A "best fit" would therefore involve a high drag over the top of the cable and a low drag drag over the lower portion (i.e., variable over the cable length).

This qualitative conclusion confirms the increased and variable coefficient predicted by the consultant.

Additional parametric simulations were completed on Run 6 to reinforce that the cable drag coefficient should be 2.54. The normal drag coefficient was varied by +20 percent and -10 percent (3.0 and 2.3). Even though these simulated cable trajectories generally followed the same patterns, the results from these additional SEADYN90 simulations did not match the actual cable path nearly as well as those from the simulation using 2.54 as the drag coefficient. The results from these simulations can be seen in Appendix C. This substantial evidence is considered reasonable proof that the value of 2.54 for the drag coefficient used in SEADYN90 is real and not artificial for numerical convenience. This completed the modeling of the AUTEC test data.

Parametric Analysis

Several additional parametric runs were made to further investigate the generic behavior of the SOAR cable during descent and to anticipate some of the questions expected in the "ship path-payout tables" simulation phase. These runs examined cable response versus payout function/percent slack, magnitude and incident angle of current, and element length. The cable response was observed for sensitivity to these parameters based on nodal position relative to the turn: before, during, and after. Figure A-2 in Appendix A illustrates that pingers 1 through 4 were not affected by the turn region, where pingers 5 through 7 fell within the turn region. Representative pinger trajectories for each parametric analysis can be seen in Appendix C.

Second, it was concluded that 30 suspended cable elements or, equivalently, 380-foot element lengths, are needed in SEADYN90 to accurately model the cable shape in the water column. An effort to use 20 suspended elements did not give accurate results. Decreasing the number of elements increases the element lengths (by 50 percent in this case) which in turn reduces the simulation time.

A significant effort was put into analyzing the effects of current on the cable trajectory. Three parametric cases were simulated where only the northing component of the current in the lowest quarter of the water column was altered. Changing the lowest magnitude of the current for this section from the "probable" +0.30 ft/sec to the "extreme" -0.15 ft/sec (a difference of 0.27 knots) caused a change in the touchdown position of the cable of up to 200 feet for nodes outside of the turn region. Within the turn region, this alteration in current was virtually insignificant.

One of the parametric cases studied the effects of eliminating the current. As expected, removing the current caused the cable trajectory to primarily follow the barge path outside of the turn region. This behavior was dissimilar to the snake-like path of the cable influenced by the current. However, within the turn region, there was minimal change in cable trajectory generated by removing the current.

Two final parametric analyses were conducted which involved manipulation of the current. The first simulation "shifted" the current down by adding 400 feet to each depth value (except at the surface) leaving the corresponding x and y current velocities the same. The second analysis "rotated" the current by swapping the x and y current velocities, effectively changing the incident angle of the current but not the magnitude or depth. As with the other current parametric analyses, significant differences in cable shape were seen outside the turn region with minimal dissimilarities found in the turn region. However, none of these changes improved the comparisons to the measured trajectories.

SUMMARY

There were many significant conclusions from this study. First, the SEADYN90 validation test at AUTEC produced an excellent data set. This data set records the three-dimensional deployment of 10 miles of cable, including one attached mass, in 4,900 feet of water. The cable trajectory during descent was measured in 11 positions at 1/2- to 1-mile intervals on the cable and was found to be quite complex. The actual barge track and cable payout were also recorded. The current profile was measured down to 3,600 feet.

Second, the numerical studies showed that comprehensive models like SEADYN90 are capable of efficiently modeling payout operations under realistic conditions. Only minimal simplifications were needed to create the input file. SEADYN90 is capable of handling variations in current with respect to depth and stochastic variations in ship speed, ship heading, and payout rate.

Third, it has been shown that the normal drag coefficient of the SOAR II cable in this deployment scenario is approximately 2.54 ±0.13. This increase in drag coefficient over the typical default value of 1.27 is due to the cable strumming during its descent through the water column. Calculations conducted by a consultant independently confirmed that the cable was strumming. The parametric analyses showed that it is extremely important to accurately model the drag on the cable. The uncertainty in selecting the correct drag coefficient is considered the largest source of error in the numerical cable modeling process.

Fourth, the SEADYN90 simulations also established that the cable has two separate behavioral responses dependent on the barge's path. When the cable is not affected by the barge changing course, it responds primarily to cross-track current and the payout rate. Other parameters have minimal effect on the cable while it is outside the turn region. However, within the turn region, the cable descent is relatively insensitive to the current. The barge's position and cable slack are the predominant influences.

Last, the calibration effort determined that SEADYN90 can accurately create a set of payout tables for the SOAR II installation. However, it would be impractical to create such an extensive set of payout tables. The SOAR installation requires precomputed information on ship's path and payout rate versus leg orientation, incident current profile (x,z,t), and bottom topography. A comprehensive examination of these parameters is not considered possible because of the inability to premeasure on-site conditions and also due to time/CPU constraints.

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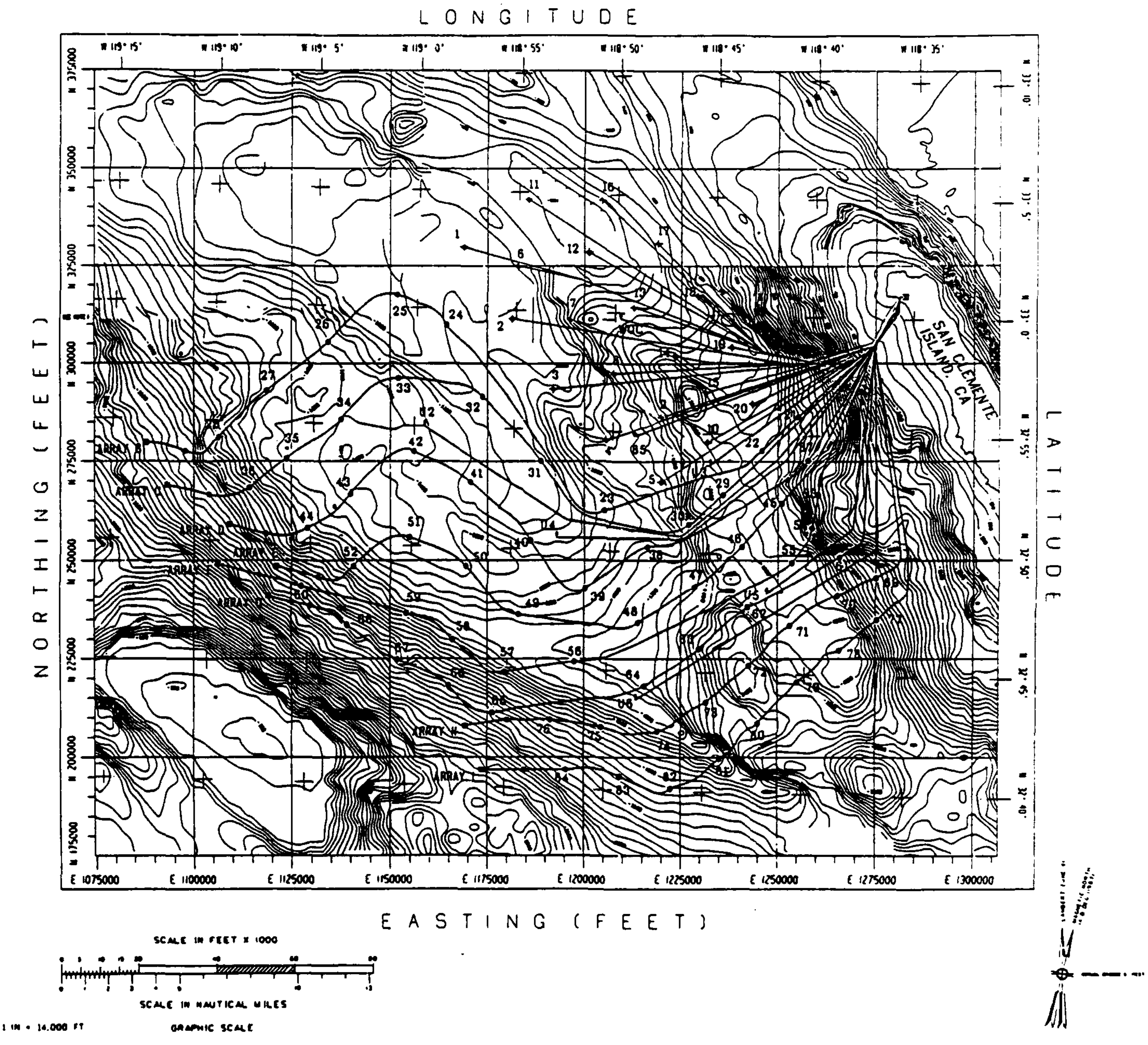

Figure 1. SOAR II configuration.

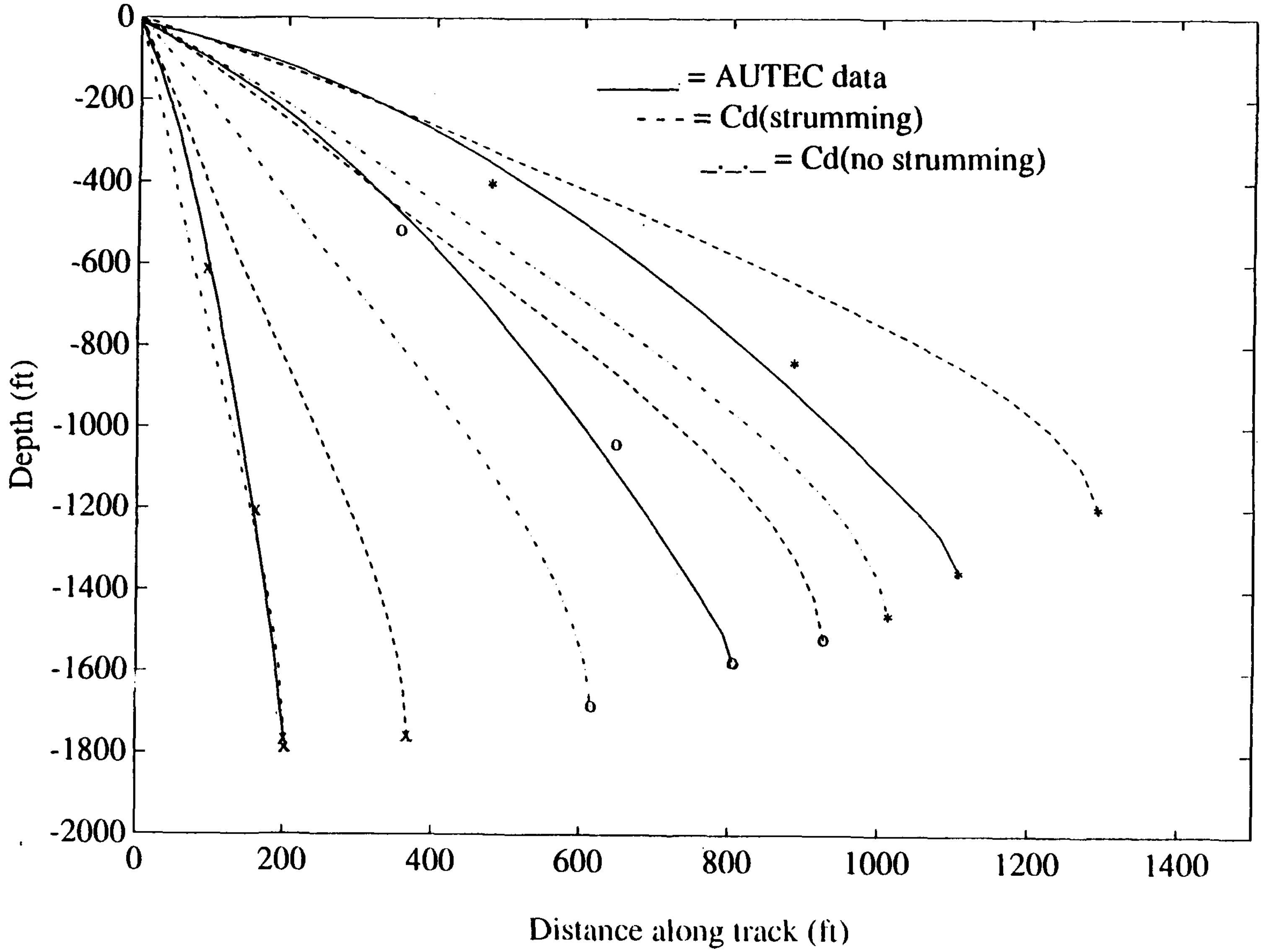

Figure 2. Profile view of tow test cable shapes.

Appendix A

SEADYN90 INPUT DATA - RUN 6

A SEADYN90 input file was developed from the data gathered at AUTEC. Minimal simplifications were made to the input variables. A representative input file is shown as Table A-1.

During each test, approximately 10 miles of cable were deployed, including the 1 mile of cable deployed vertically to set the anchor. The hardware dimensions are listed in Table A-2. Eleven acoustic tracking pingers were attached at various intervals on the cable (see Table A-3). A dummy hydrophone was spliced into the cable close to one of the pingers so the effects of this body could be monitored.

Other input entered into the SEADYN90 file include current profile, barge position, and cable payout rate, which are seen in the following graphs. The current profile was interpolated from the data gathered from the two Bounce Pingers deployed simultaneously, 1 mile apart. Figure A-1. shows the data gathered from both Bounce Pingers (descending and ascending) separated into Easting and Northing components. From this figure it can be seen that the four data sets match very well. Overlaid on the Bounce Pinger data is the SEADYN90 input data defined as the "probable" current profiles. The x and y velocities were entered into the SEADYN input file by dividing the current profile into 10 nonuniform sections. Figures A-2 and A-3 show other current profiles applied to the Run 6 data set for parametric analyses.

The barge track and pinger touchdown locations are illustrated in Figure A-4. It is clear even from the scale of this graph that the ship did not follow a straight line path. To model the ship's path without losing the cross-track movement, ship's position (recorded every 30 seconds) was entered into an ASCII file which was subsequently read by the SEADYN program. Figure A-5 illustrates the cable payout rate for Run 6. The dashed line represents the data gathered from the Phrognav SINCS system aboard the OCP SEACON. The solid line represents the data input into SEADYN90 as a user-defined subroutine. The trends were closely followed to accurately model the test conditions.

Table A-1. Sample SEADYN90 Input

```
              SEADYN-AUTEC VALIDATION EXPERIMENT
    RUN#6-h. 90 DEG TURN @ 1.5 KTS W/MTU reference simulation.
 -------------------------------------------------------------
1.  Drag coefficient was effectively doubled by instead doubling
    the cable diameter.  The "doubled Reynolds Number" is still in
    the same range so this is a valid modeling simplification.
2.  "Probable" current profile used for the lowest 1300 feet.
    Northing component of bottom layer current (+.15ft/sec).$
*  11% SLACK LAY, FLAT BOTTOM, CONSTANT (TEMPORAL) CURRENT PROFILE
PROBLEM
 170,169,-3,1
FLUID
 ,1
BODY
 1, ,65,1.176,4.458                * MTU
 2, ,25,0.333,4.375                * PINGER
MATE
 1, ,.110,.16W9,992146,1,.03       * CAGED ARMOR CABLE. Note doubled diameter.
NODE
   1, ,47924,-77929,-4900          * NODE 1 IS ANCHOR ON BOTTOM: FREE FIXITY
*                                    TO ALLOW FOR AUTOMATIC NODE GENERATION.
*                                    !!FIX NODE LATER IN DEAD!!
   9,1,49053,-77533,-1493.9        * NODE 9 PLACED TO FORCE CABLE INTO AN
*                                    INVERTED CATENARY (actually, "L") SHAPE.
  13,1,50008,-77197,    0,2,2,2    * NODE 13 IS THE INITIAL STERN POSITION
 170,1,50008,-77197,    0,2,2,2    * NODES TO BE PAYED-OUT ONBOARD VESSEL
PAYOUT
 1, 13, 12,380,156, 12,1,1         * BEGIN PAYOUT AT NODE 13, MITOSIS = 380 FT
ELEMENT
   1,  1,  2,,1
 169,169,170,,1
TENS
 2, 5,,,150                        * APPROXIMATE ONLY.
 6, 9,,,400
10,13,,,600
LIMIT
 1,-4900,,1.02,3
LLOC
 1,2,145,1
BLOC                       * CABLE PINGERS, node # with AUTEC pinger #:
 1,43                      * MTU, pinger #401
 2,27                      * 501
 2,36                      * 301
 2,45                      * 502
 2,49                      * 302
 2,55                      * 402
 2,61                      * 503
 2,75                      * 304
 2,89                      * 504
 2,109                     * 305
 2,130                     * 505
TFUN
 1,1,-703.5,    0,-480,3.2091
 2,6,   -480,18541,-480            * CALL NODMOV.DAT FOR SHIP PATH
 3,-1,6                            * call usrtfn, with tparm=test#=6.
 4,1,-703.5,    0,-480,1           * upward ramp used as curr multiplyer
 5,1,-703.5,    1,-480             * downward ramp used as curr multiplyer
```

Table A-1. Continued

```
FLOW
*  define current vector at 10 depths, constant versus time.
*    depth  Vx     Vy Vz depth  Vx     Vy Vz depth  Vx     Vy Vz depth    Vx  Vy Vz
 1,2 -4901,    0, .15,0,-3600,-.10, .30,0,-3010,-.35, .20,0,-2500, .05,-.10,0,
    -2000, .05,-.40,0,-1500,-.075,-.3,0,-1070,+.20,.075,0, -890,    0, .10,0,
     -490,    0, .80,0,      0, .10,-.25,0
 2,1,-1.5871,-.5776,0                  *1.0kts @ 250 deg (opposite of ship velocity)
TABL
 1,1,145W11,1
* --------------- initial static configuration ----------------------
LIVE
  FIX,3,11,12,13                * fix the anchor
  CURR,2                        * steady flow to get initial configuration.
* ---------- initial dynamics, ramped to avoid transients -----------
DYN
  MOVE,-1,2,4,3.0624,.9568      * ramp ship to 3.2 ft/sec
  CURR,2,1,5,1,1,4              * ramp steady current down to zero
*                                 and test current (varied w/ depth) up to full vel.
  OUTP,,223.5W15,1,60,1W20,1
  PAYO,1,3,1                    * tfun set #3 (which calls usrtfn)
  TIME,0.03,-480,-703.5,1
  SAVE,-1
*  -------------   "steady-state" dynamic deployment ----------------
DYN                             * 300 plot.dat entries.
  MOVE,-1,1,2,1                 * ship
  CURR,1,1                      * follow 10-point flow descrptn.
  OUTP,,600W15,1,179,1W20,2     * write plot.dat and limit.dat files @ 3 min.
  PAYO,1,3,1                    * tfun set #3 (which calls usrtfn)
  TIME,0.03,18541,,1            * net simulation time = 19021 seconds.
  SAVE,-6
END
```

Table A-2. Hardware Description

Cable Parameters		
diameter	=	0.66 inches
weight per foot	=	0.16 lb (submerged)
	=	0.304 lb (in-air)
EA	=	$9.925e^5$ lb
breaking strength	=	9,000 lb (minimum) (not used)
Hydrophone(MTU) Parameters		
length	=	54 inches
height	=	22 inches (used diameter = 14 inches
width	=	10 inches in SEADYN simulations)
weight	=	200 lb (in-air)
	=	65 lb (submerged)
Pinger Parameters		
length	=	52 inches
diameter	=	4 inches
weight	=	25 lb (submerged)
Anchor Parameters		
weight	=	275 lb (submerged)

Table A-3. Pinger Locations (from anchor)

Pinger No.	AUTEC Distance Along Cable (ft)	SEADYN90 Distance Along Cable (ft)
1	10,867	10,732
2	14,167	14,152
3*	16,782	16,812
4	17,582	17,572
5	19,182	19,092
6	21,432	21,372
7	23,682	23,652
8	28,907	28,972
9	34,127	34,292
10	41,962	41,892
11	49,787	49,872

*Hydrophone.

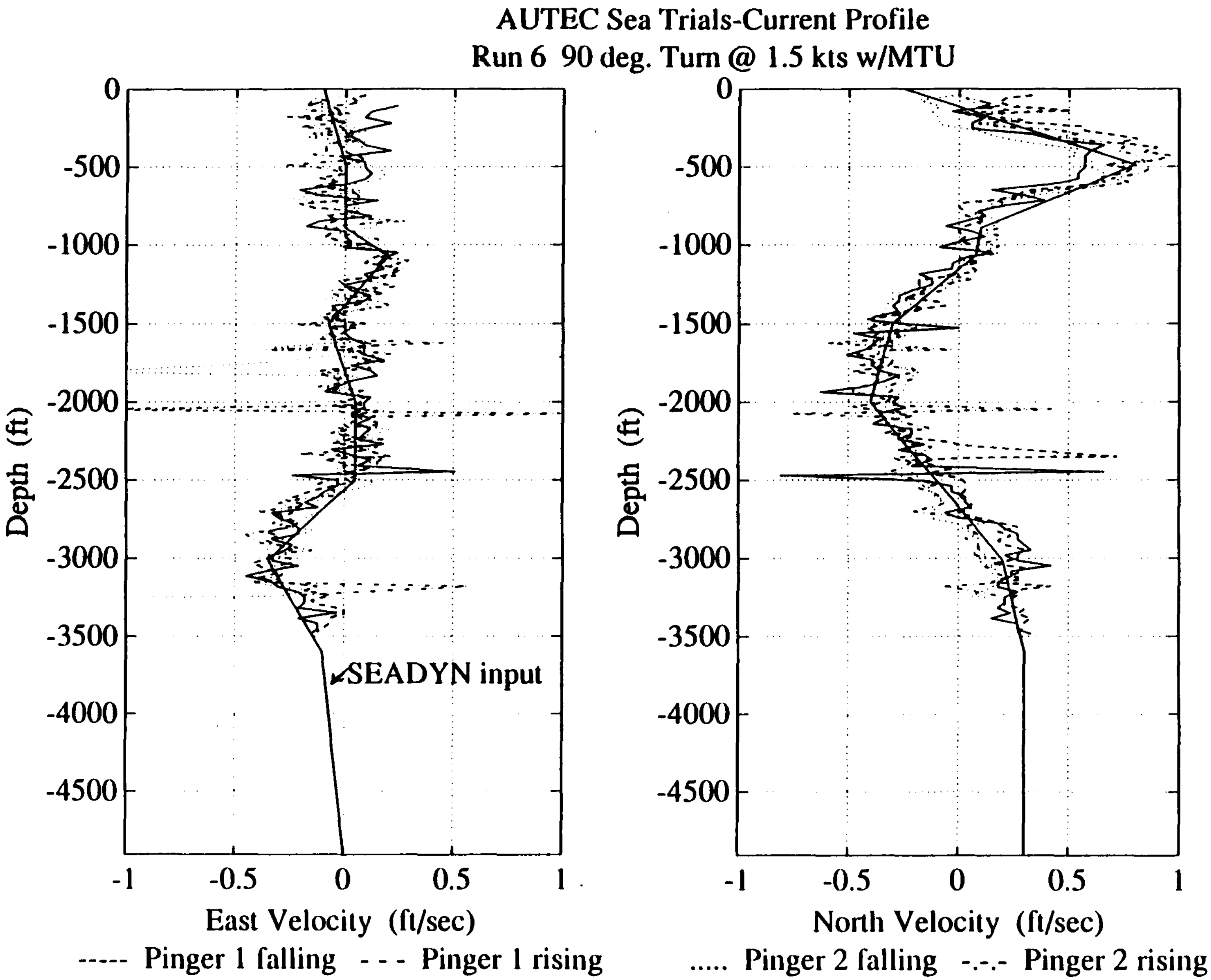

Figure A-1. AUTEC sea trials current profile - Run 6 90-degree turn at 1.5 knots w/MTU.

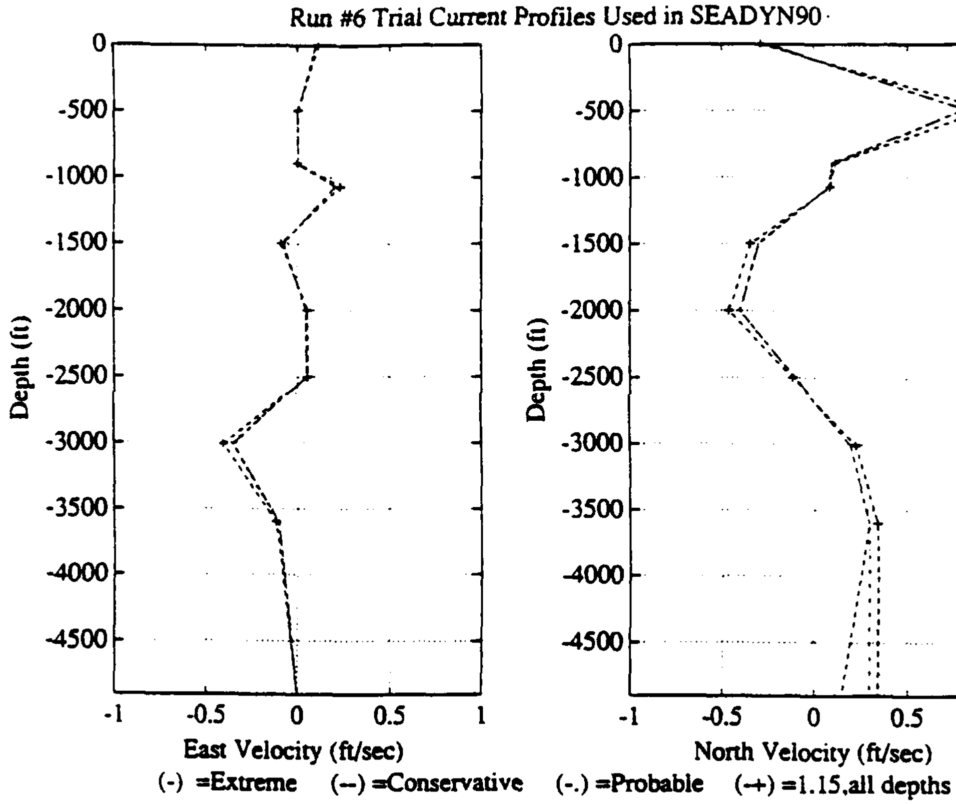

Figure A-2. Run 6 trial current profiles used in SEADYN90.

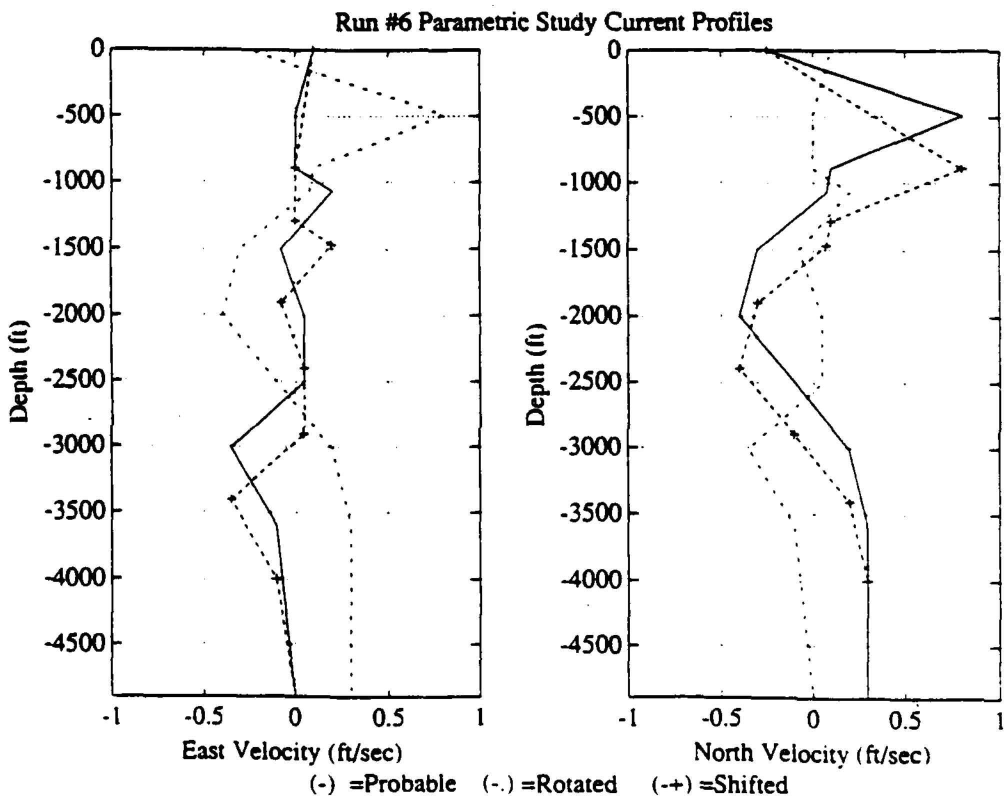

Figure A-3. Run 6 parametric study current profiles.

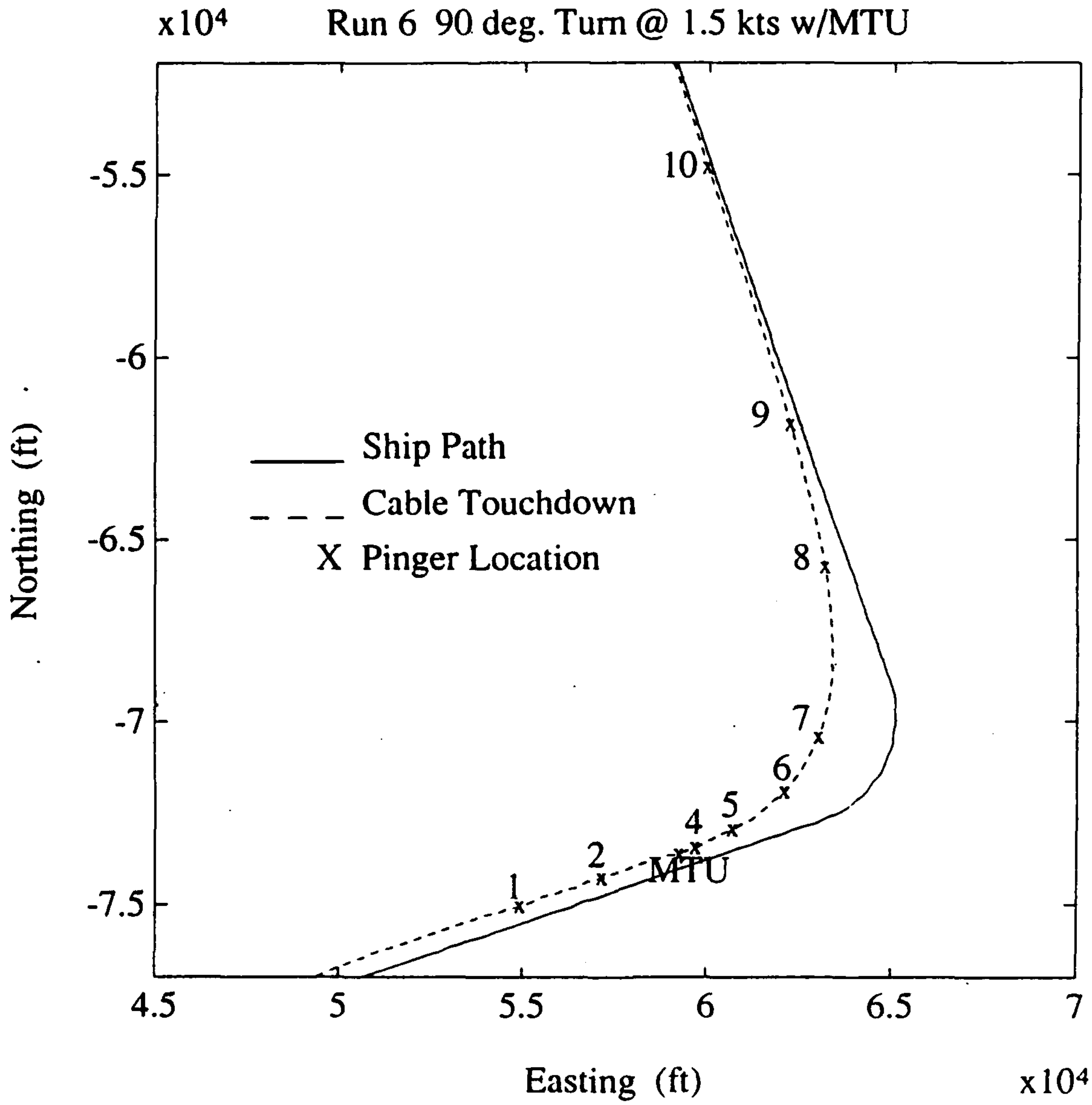

Figure A-4. Run 6 90-degree turn at 1.5 knots w/MTU.

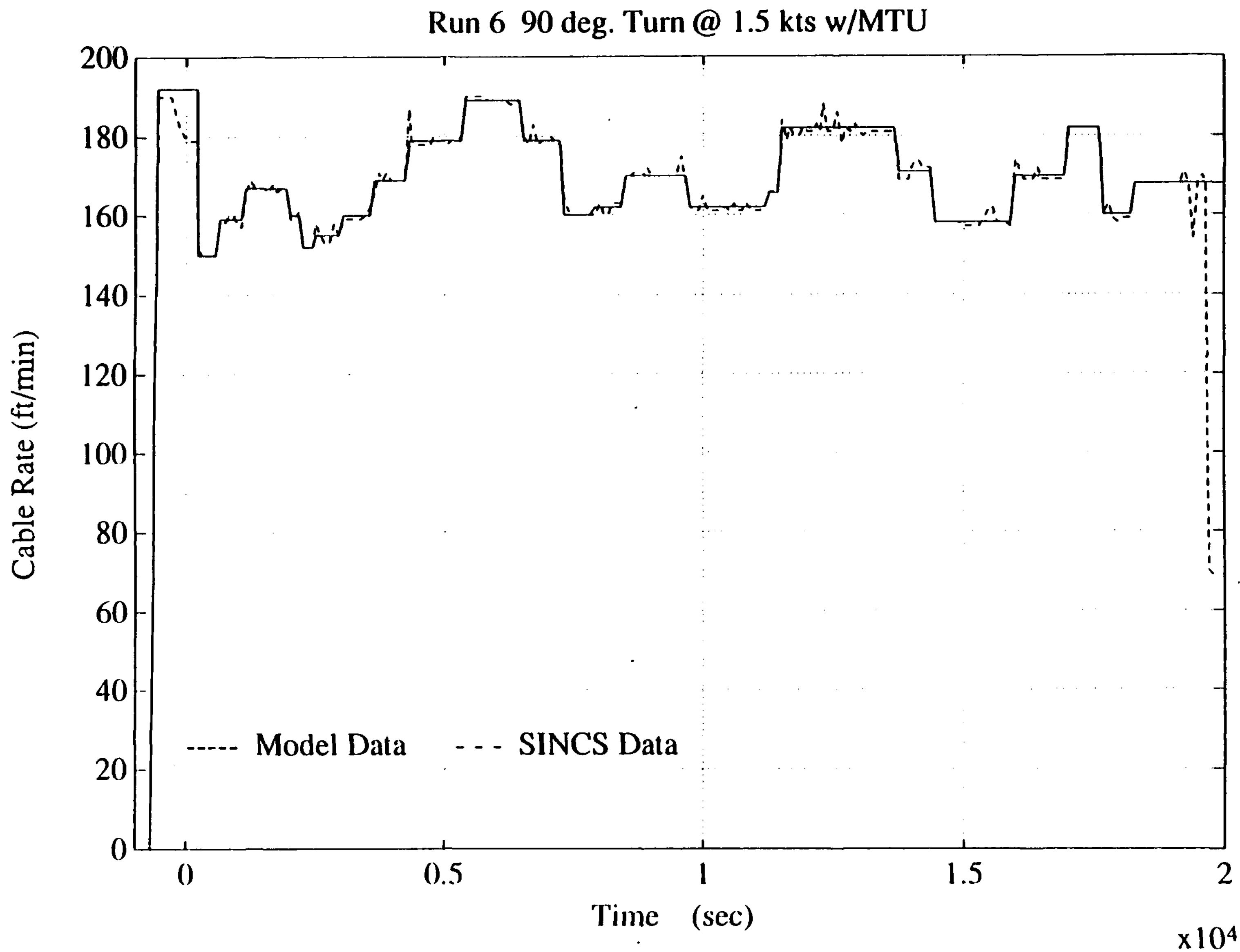

Figure A-5. Run 6 90-degree turn at 1.5 knots w/MTU.

Appendix B

SEADYN90 - SOAR COMPARISONS

This appendix graphically illustrates the quality of the results achieved by SEADYN90 for three of the SOAR experiments. Figure B-1 is a large-scale overview of nine of the measured and simulated cable trajectories superimposed on the (dotted) barge track. Figures B-2 through B-12 are the "best" comparisons for Run 6 using the probable current and the doubled normal drag coefficient (2.54). To assist in the inspection of these graphs, each of the cable trajectories is subjectively marked at three critical locations where the SOAR and SEADYN90 cable trajectories significantly alter course. Note that the measured pinger trajectories vary significantly, even for adjacent pingers.

There is a slight offset in surface locations between the SEADYN and SOAR data. This is due to the fact that the position of the simulated pinger was in some cases up to 150 feet away from the actual pinger location along the cable due to the required descretization of element lengths. Also, the SOAR pingers were pressure activated so no data was obtained until the pinger was 30 to 100 feet into the water column.

Figures B-13 through B-16 illustrate the cable trajectory comparisons for Run 2 and 7. These further illustrate that the normal drag coefficient of 2.54 is an accurate constant for these conditions and SEADYN90 is competent at simulating the SOAR conditions.

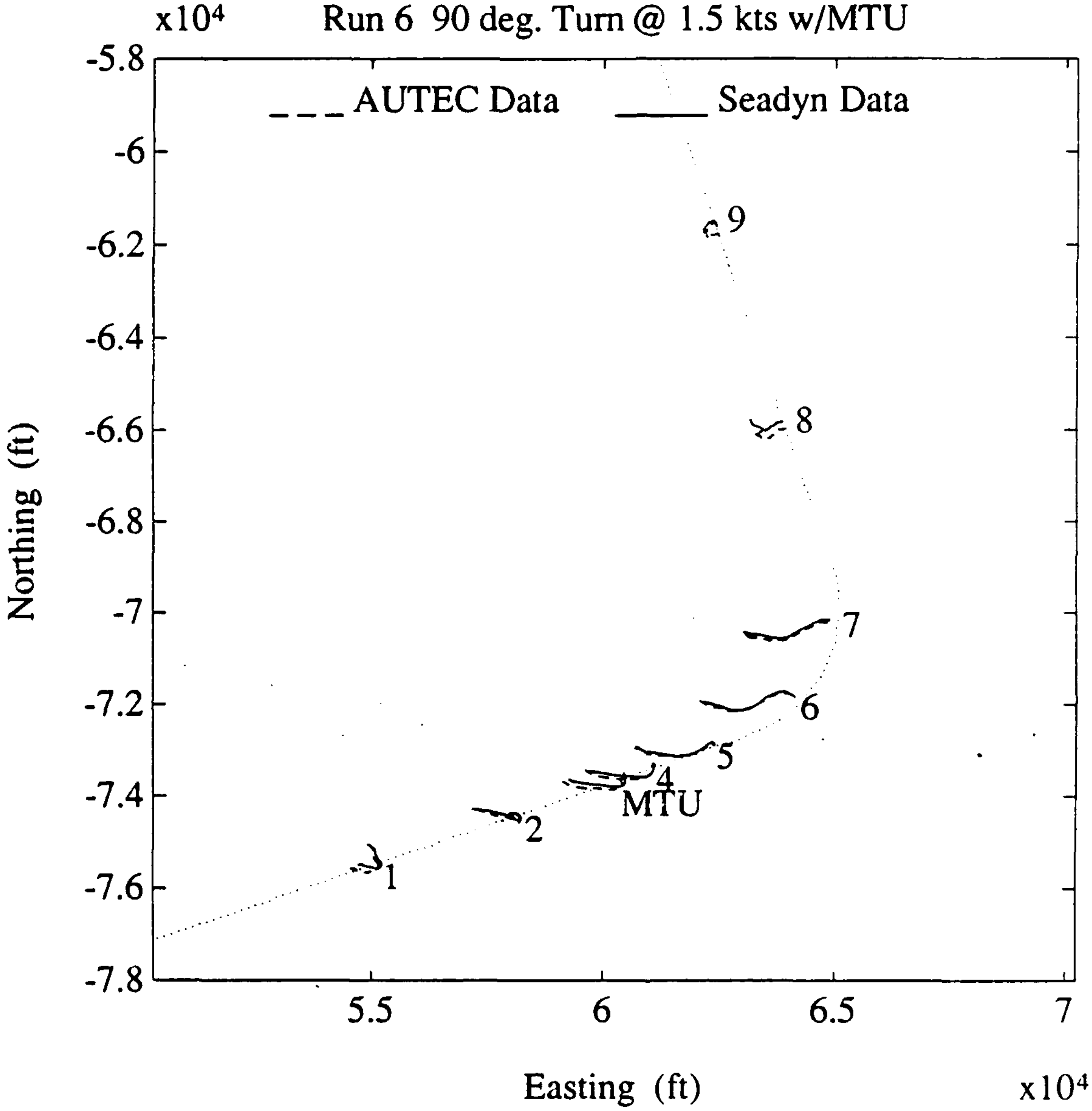

Figure B-1. Run 6 90-degree turn at 1.5 knots w/MTU.

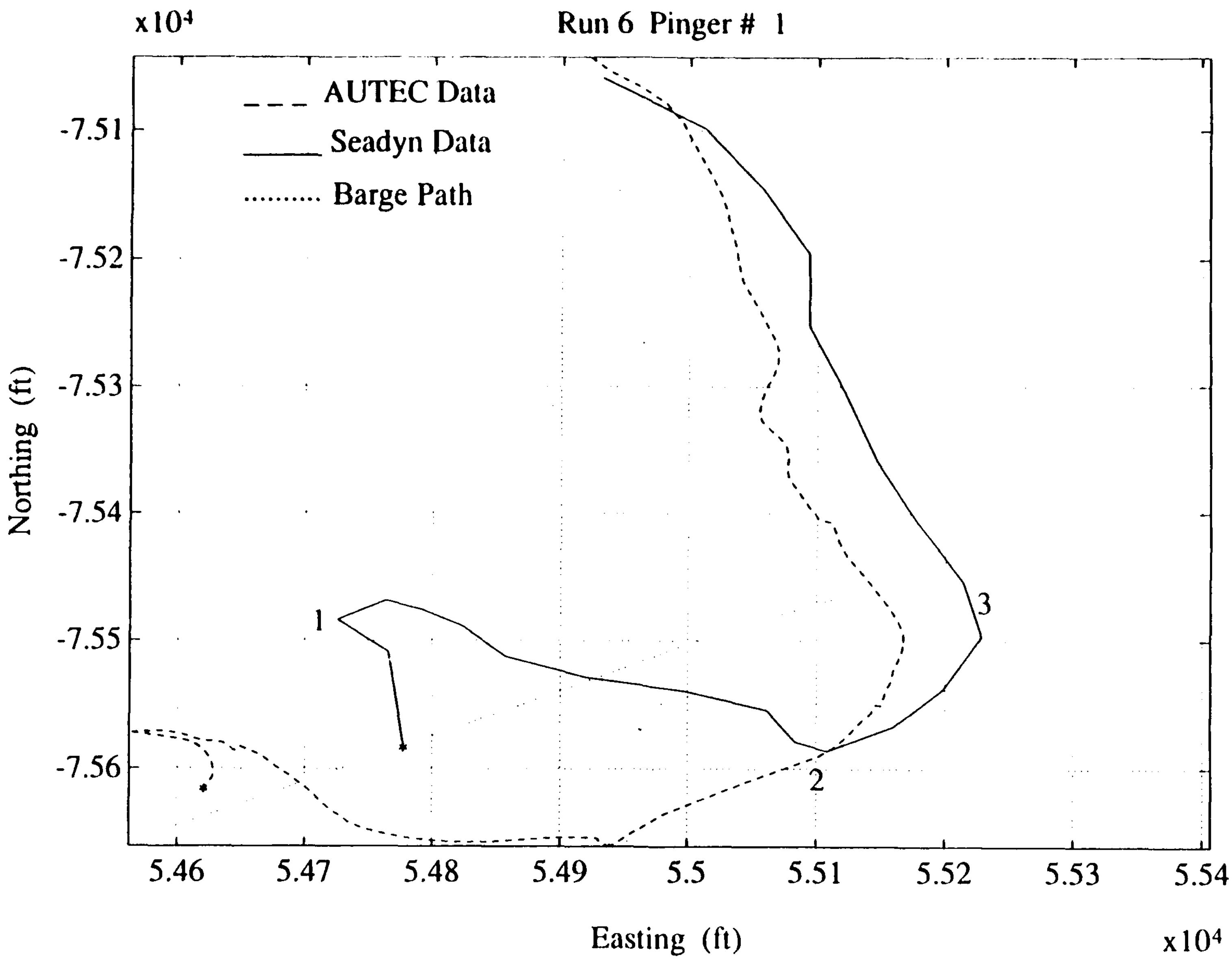

Figure B-2. Run 6 pinger #1.

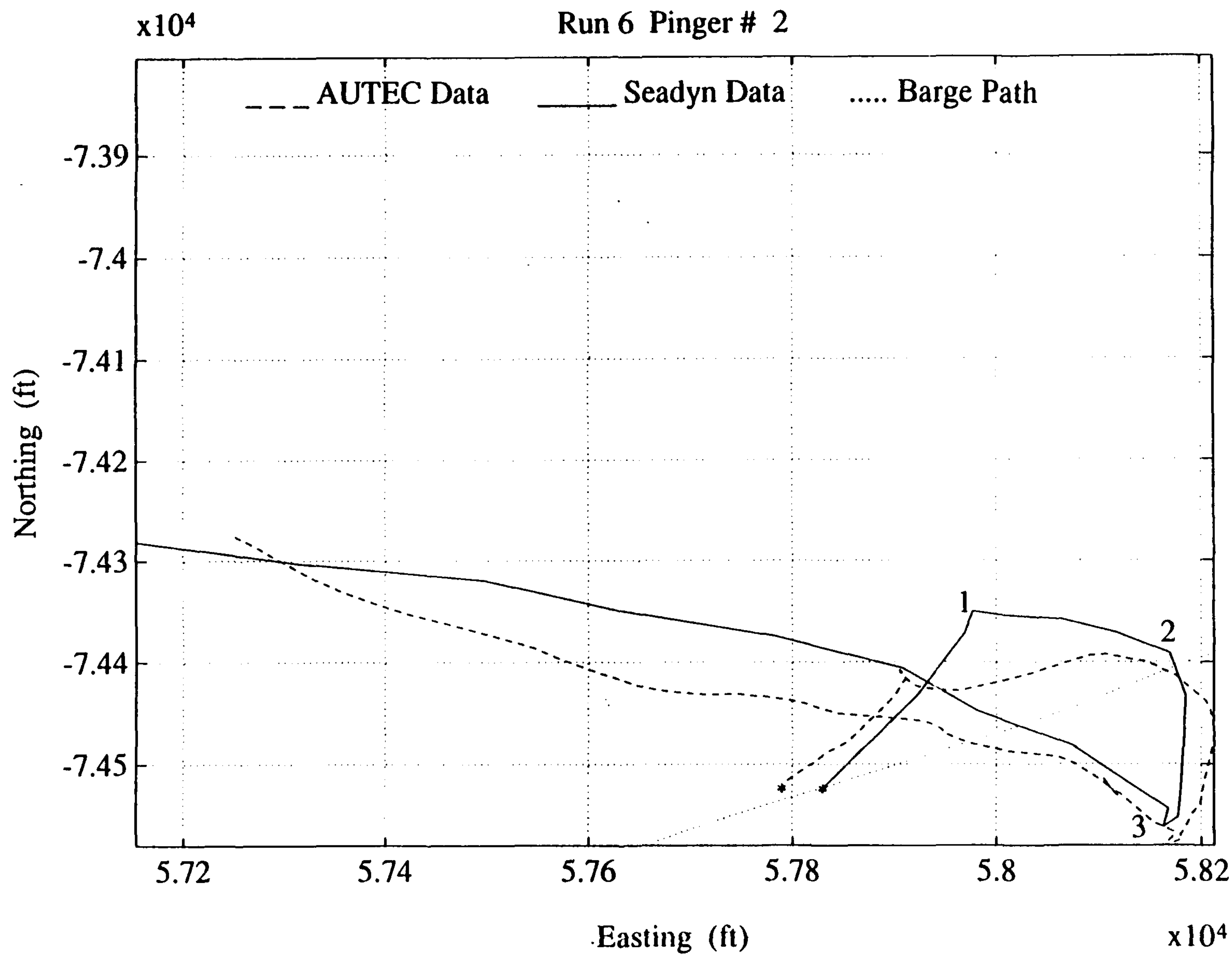

Figure B-3. Run 6 pinger #2.

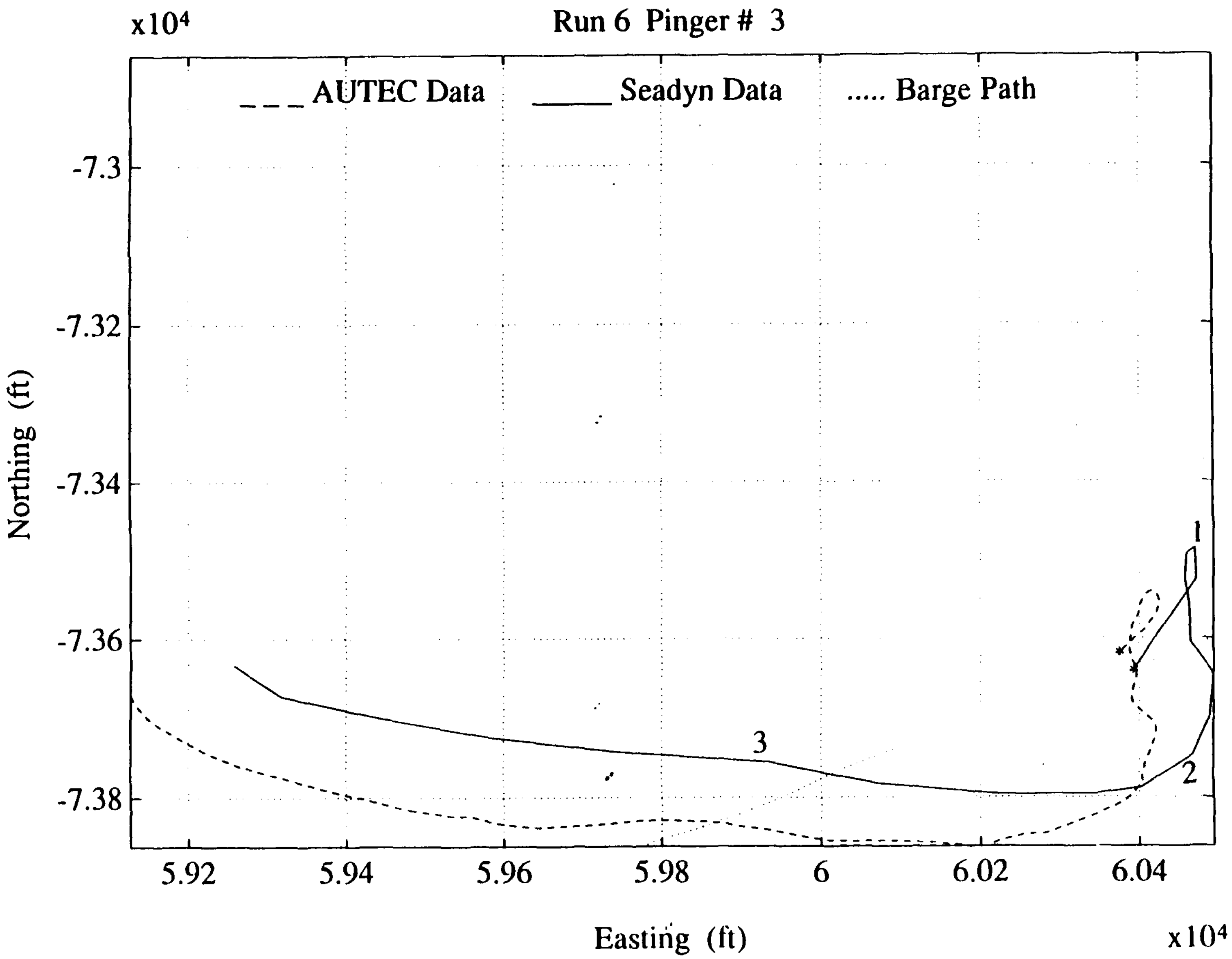

Figure B-4. Run 6 pinger #3.

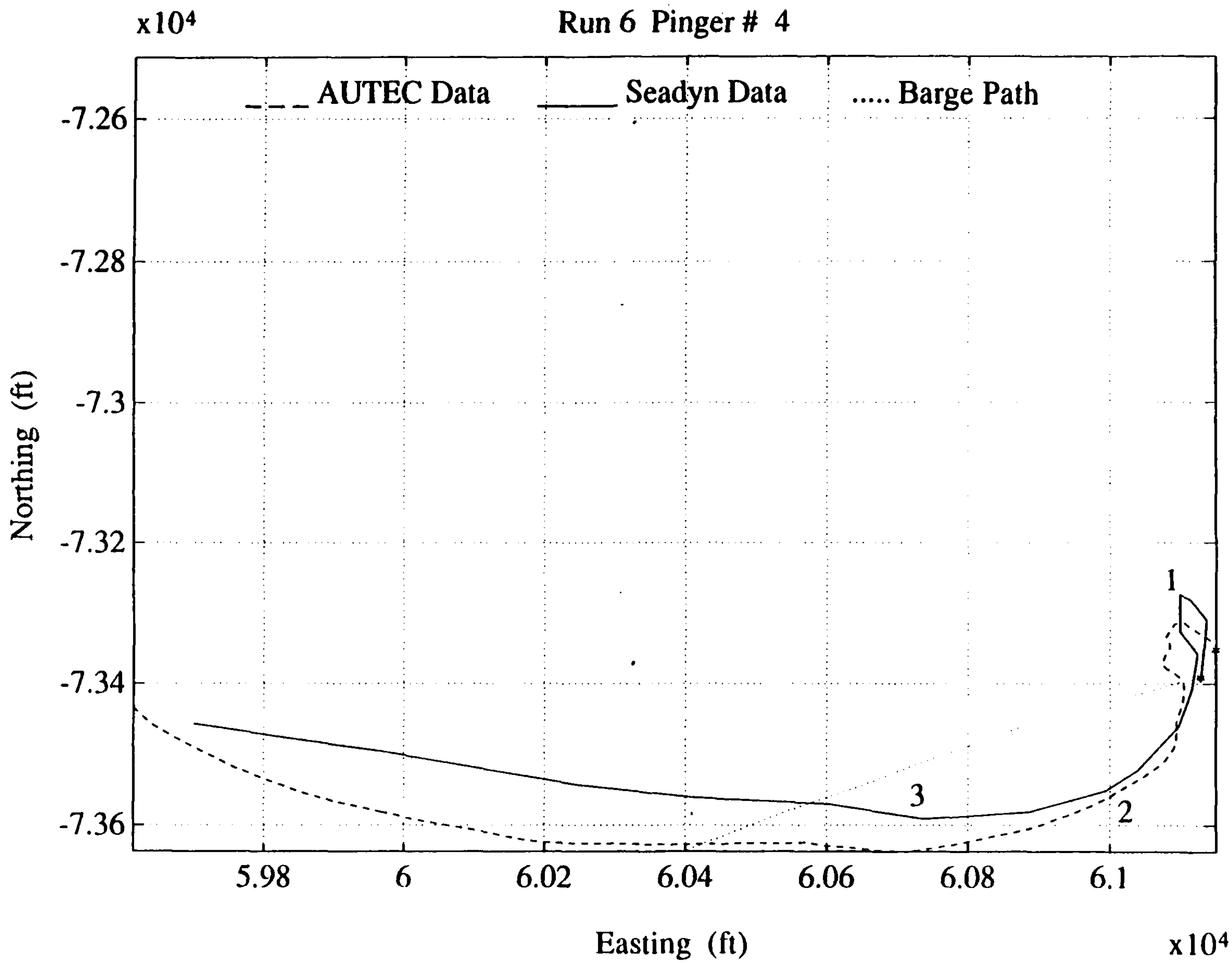

Figure B-5. Run 6 pinger #4.

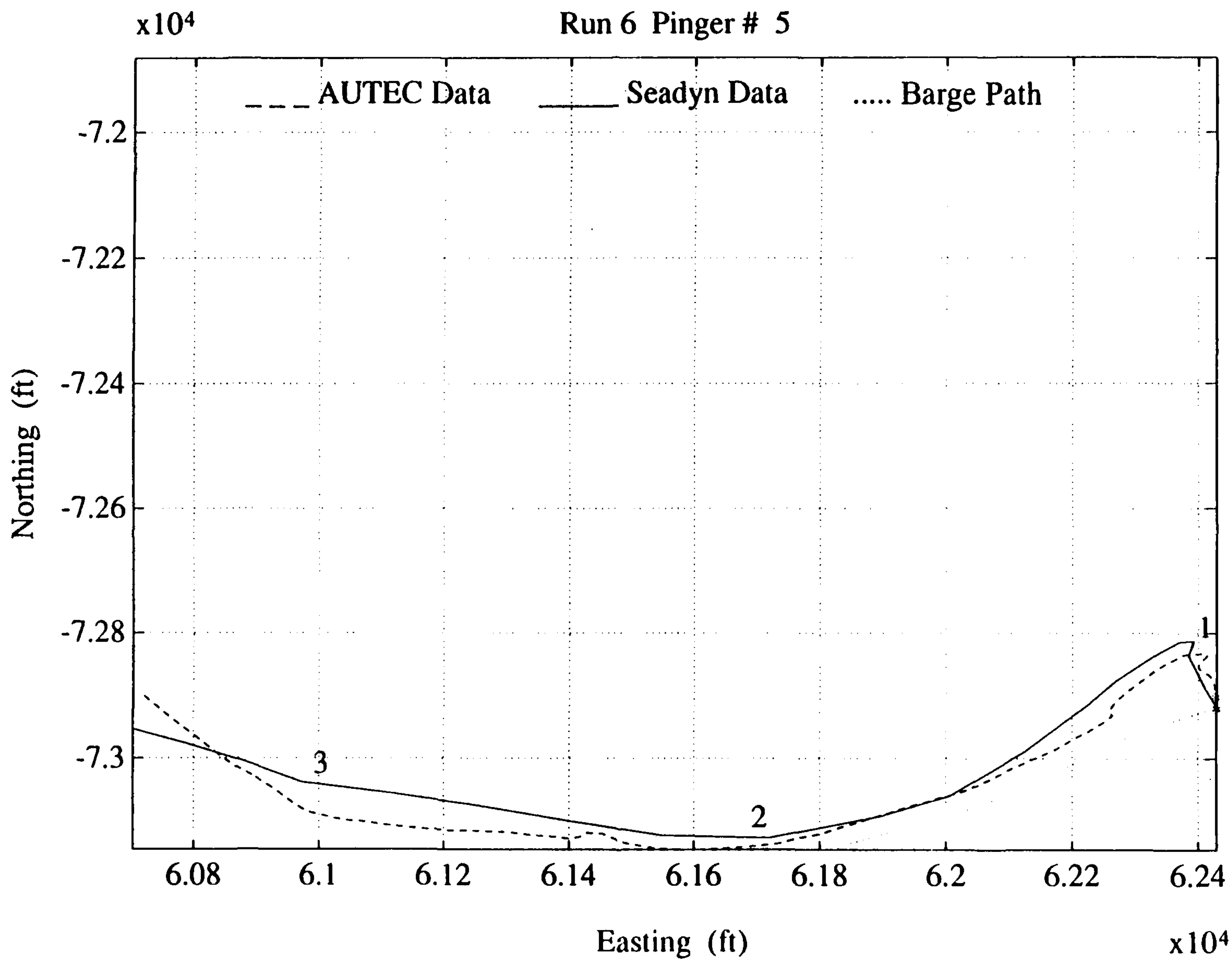

Figure B-6. Run 6 pinger #5.

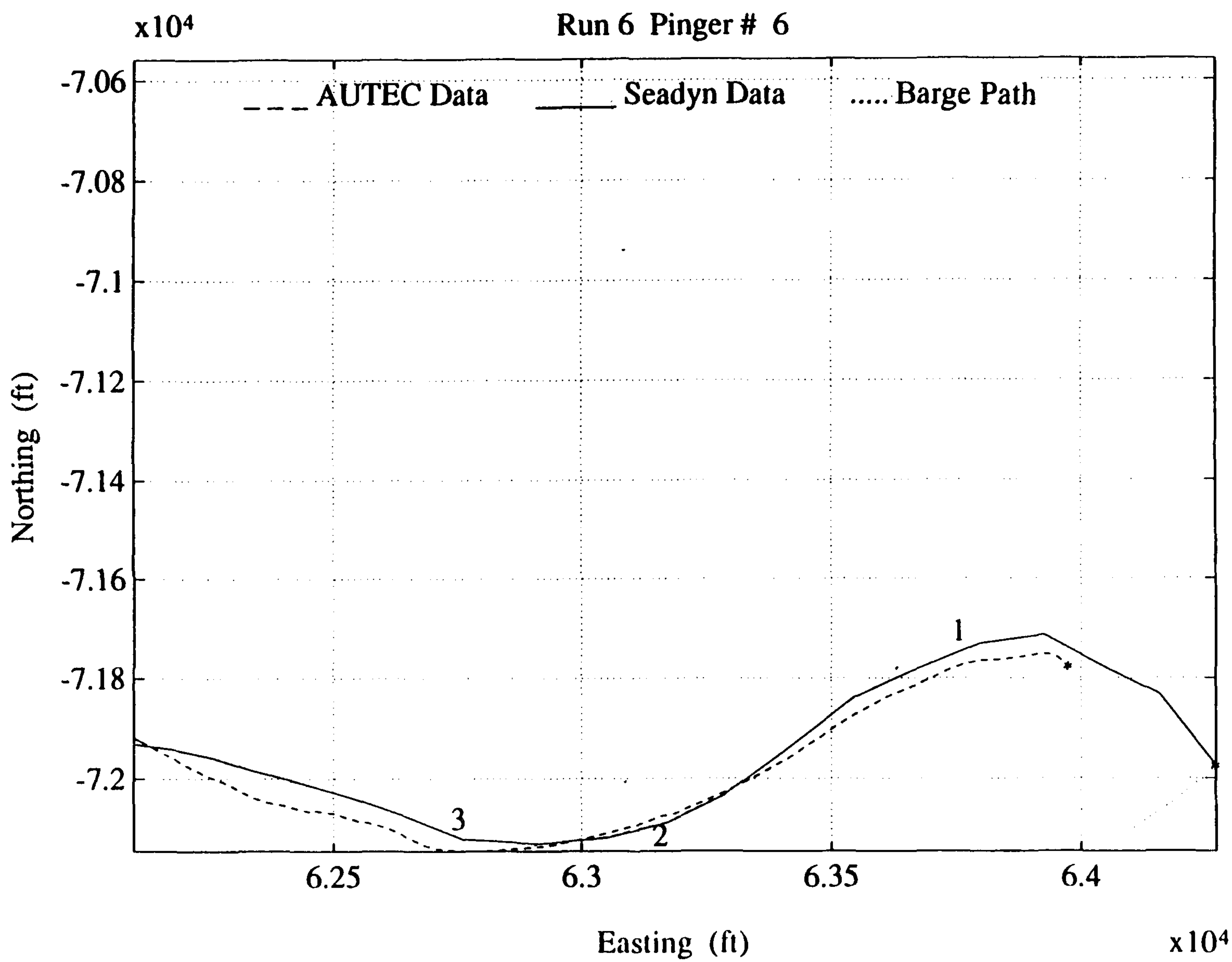

Figure B-7. Run 6 pinger #6.

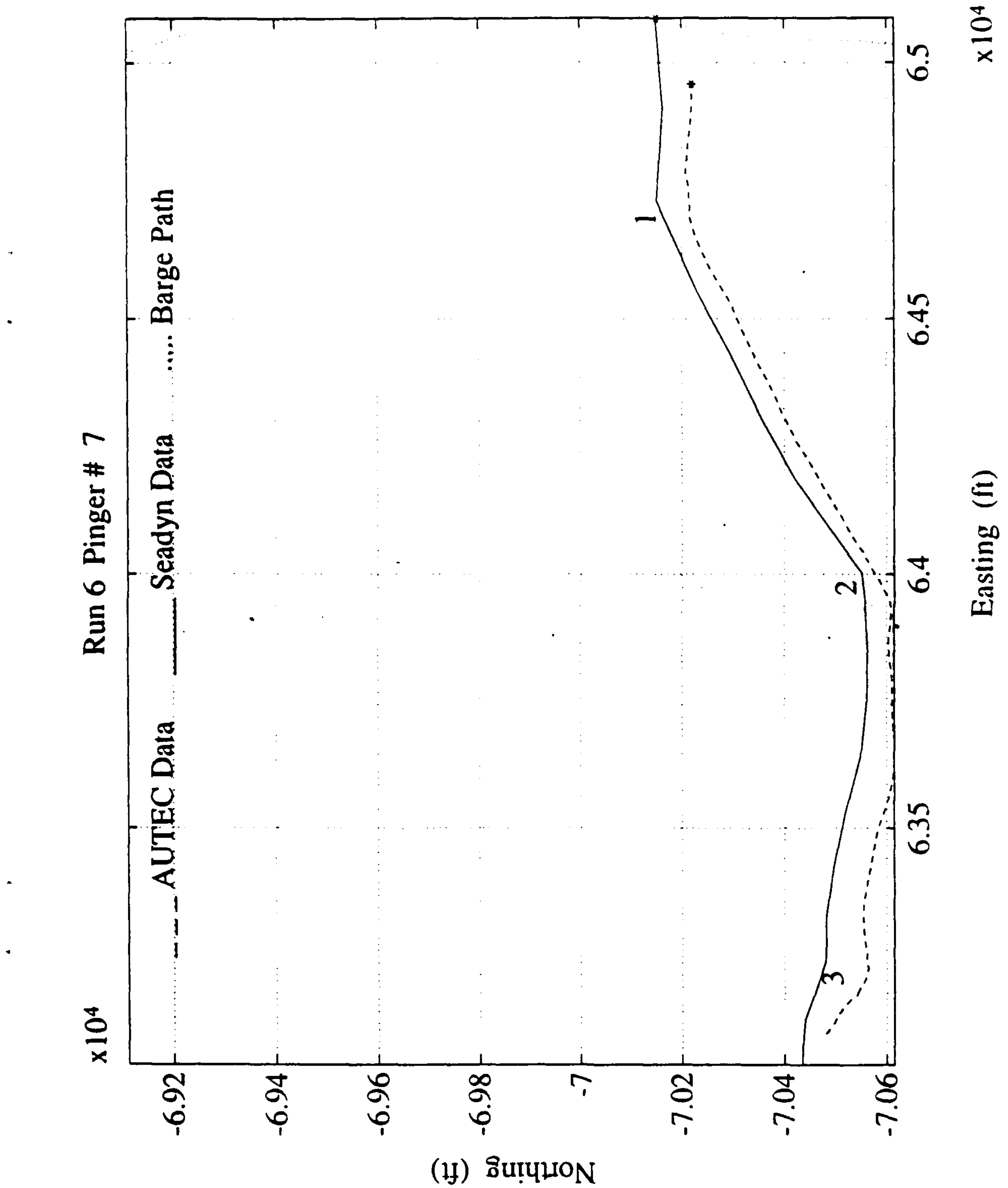

Figure B-8. Run 6 pinger #7.

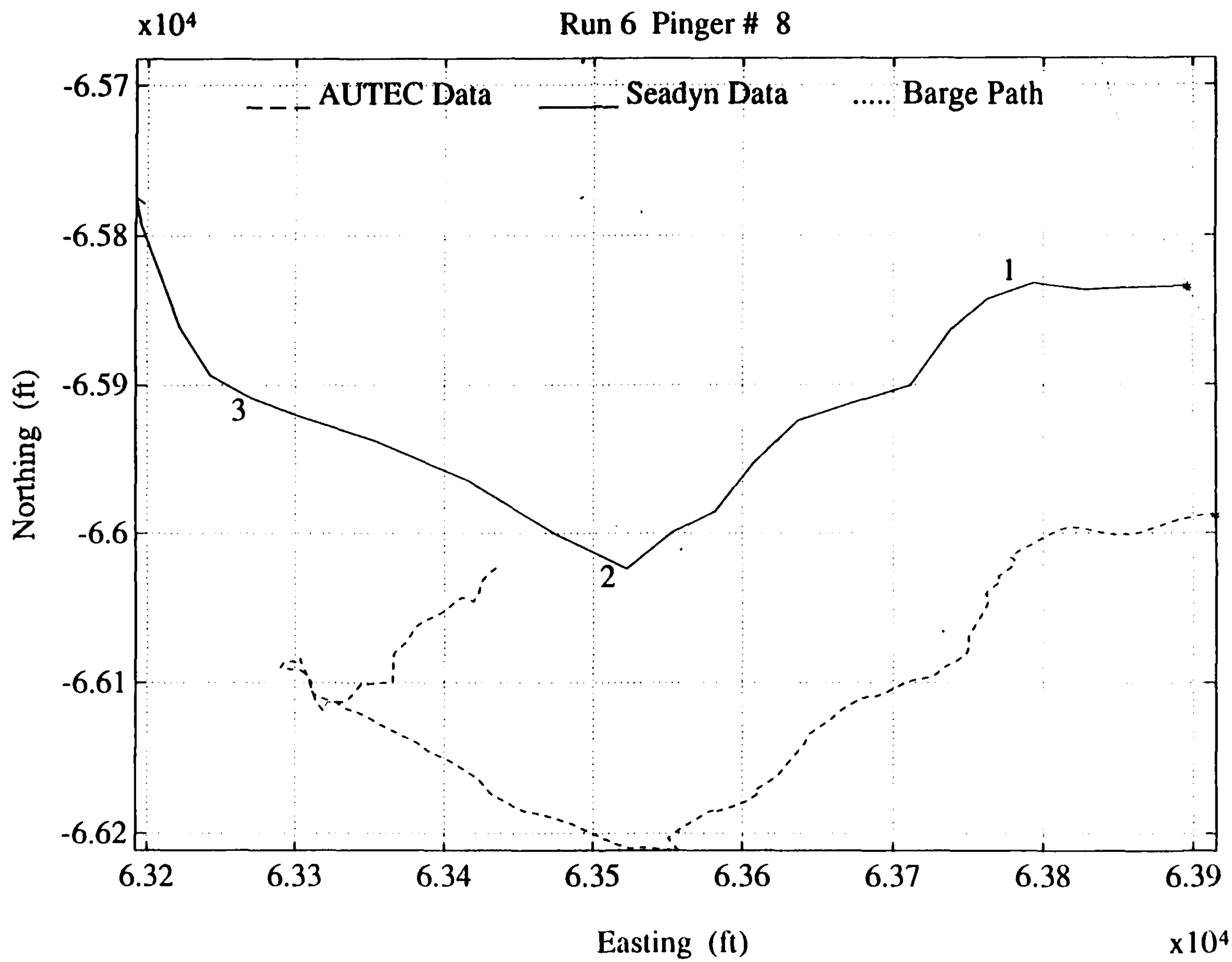

Figure B-9. Run 6 pinger #8.

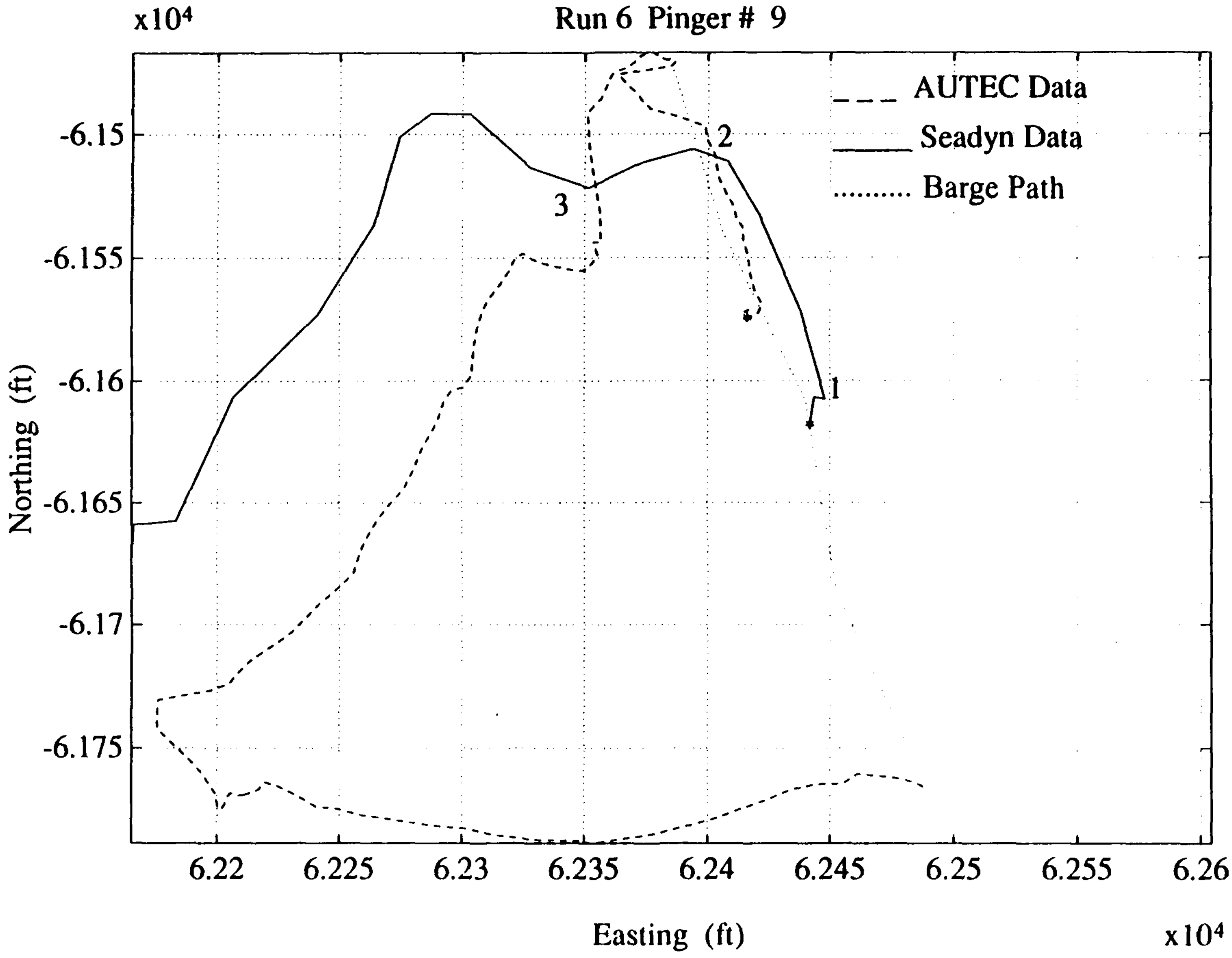

Figure B-10. Run 6 pinger #9.

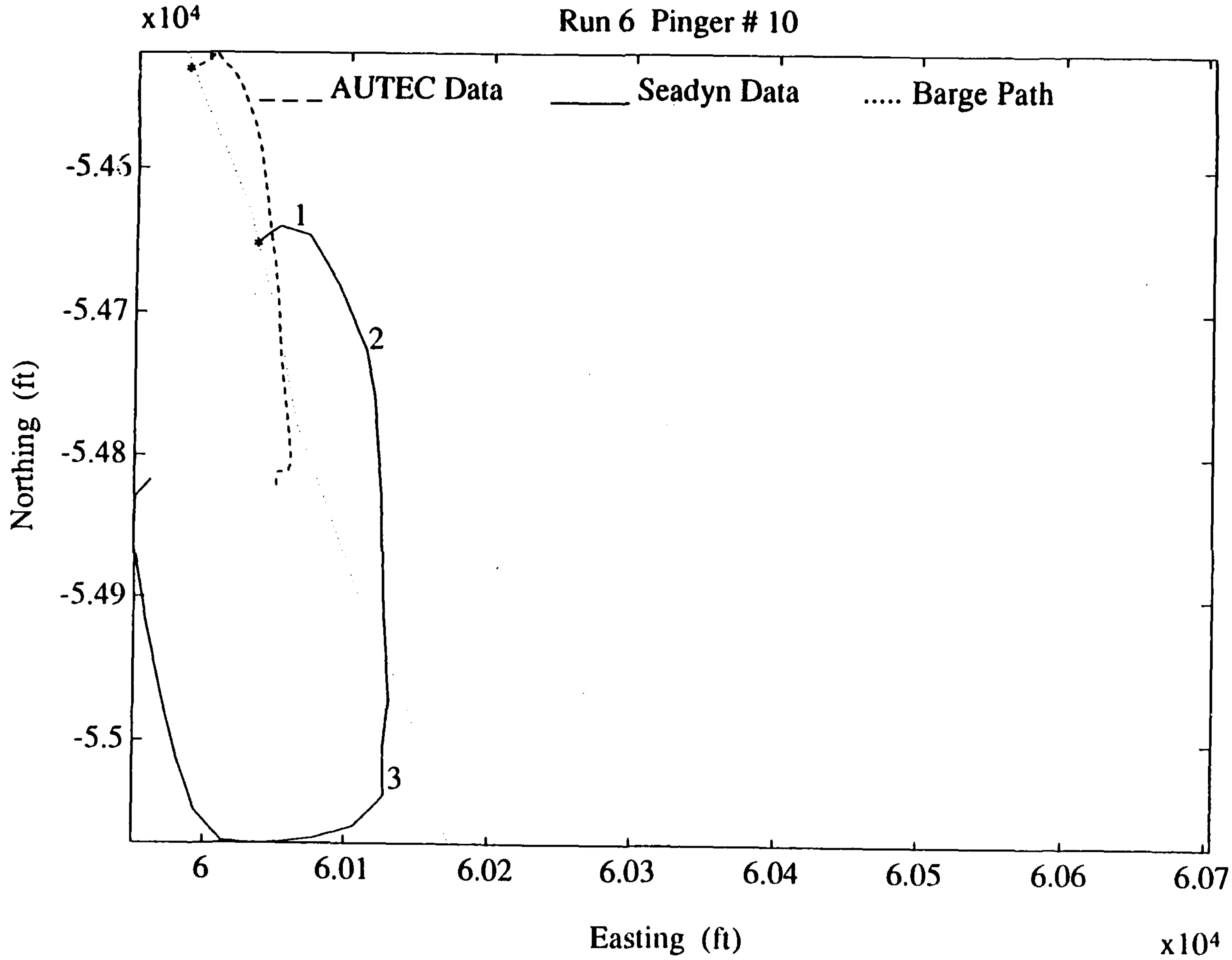

Figure B-11. Run 6 pinger #10.

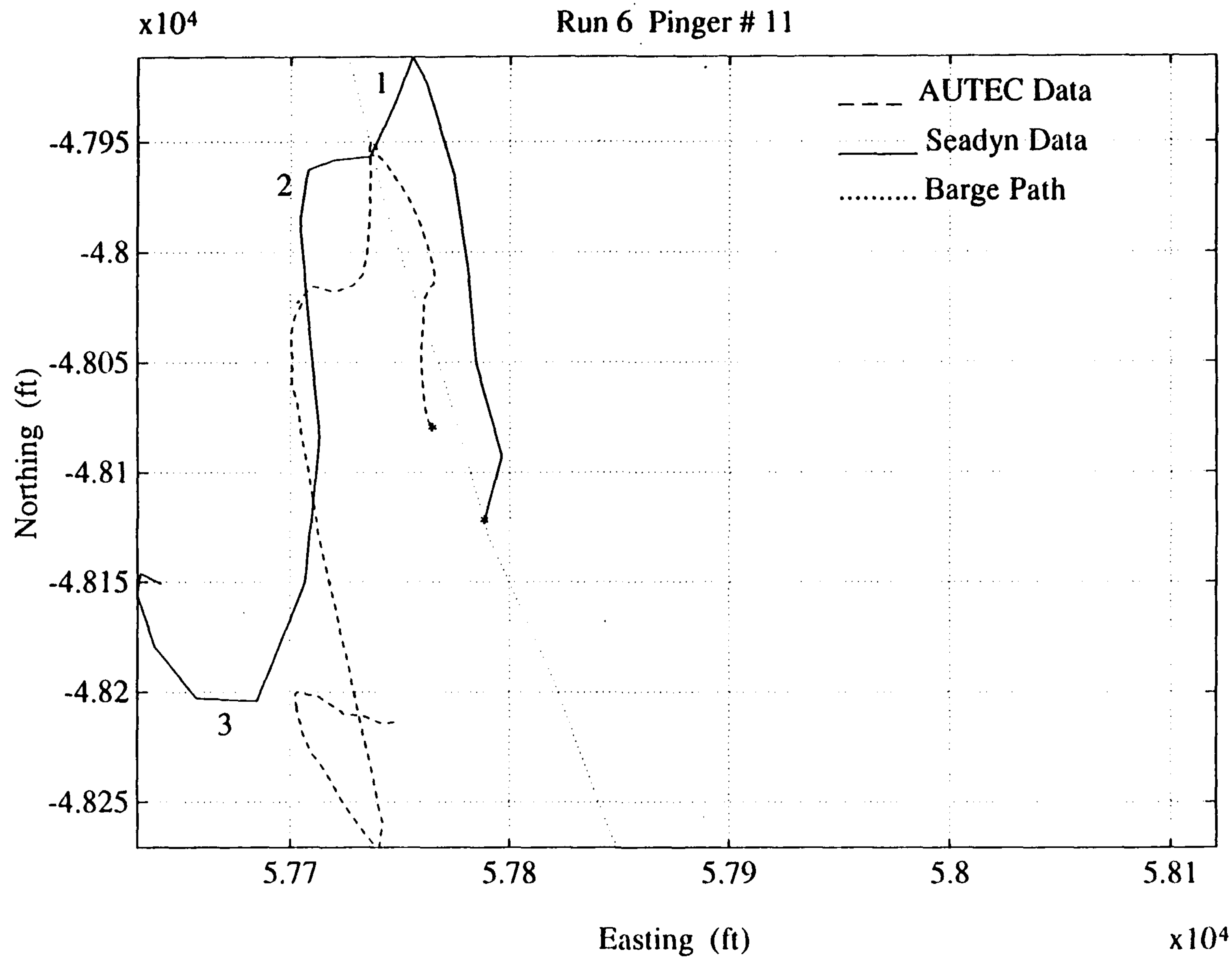

Figure B-12. Run 6 pinger #11.

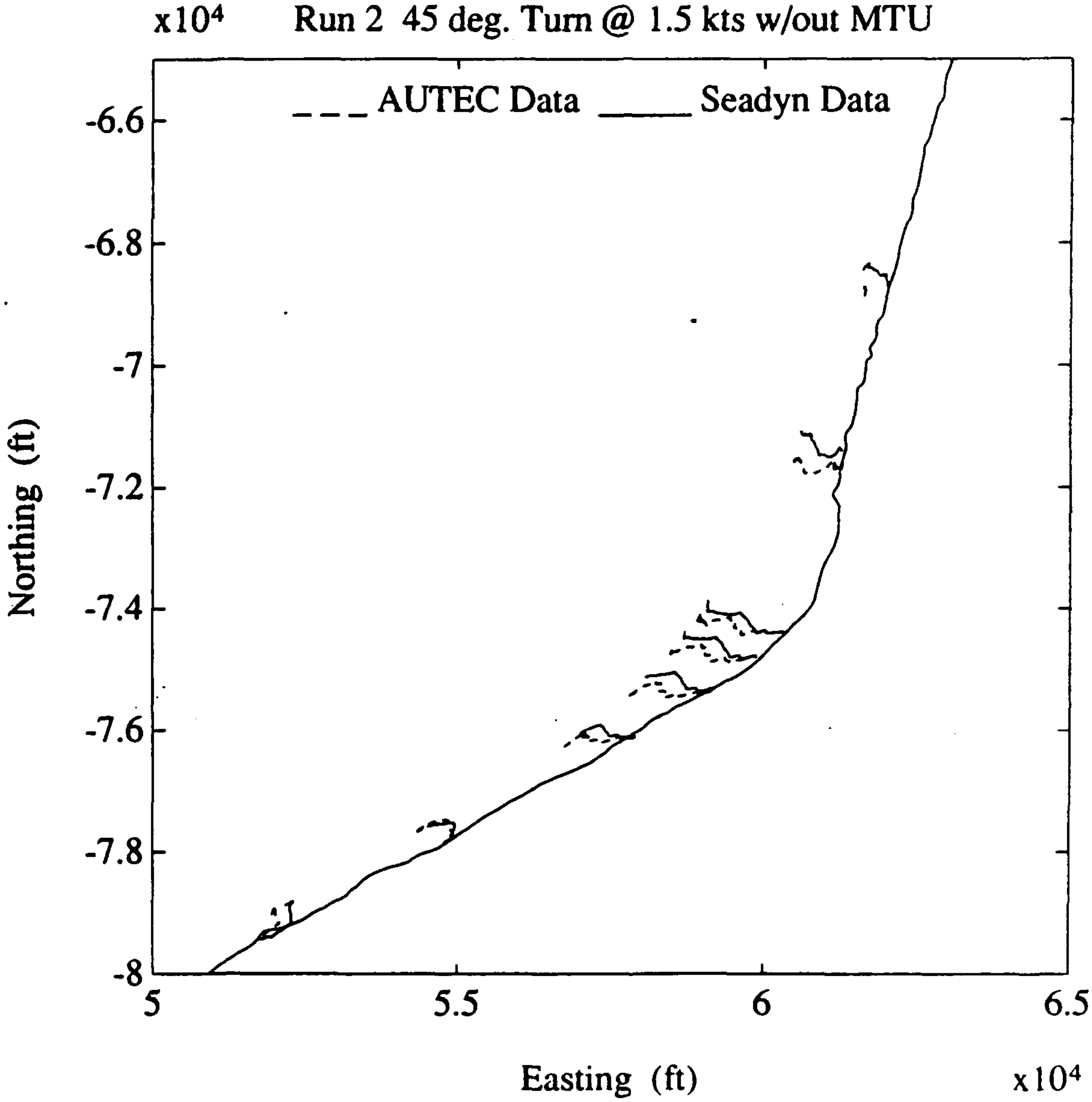

Figure B-13. Run 2 45-degree turn at 1.5 knots without MTU.

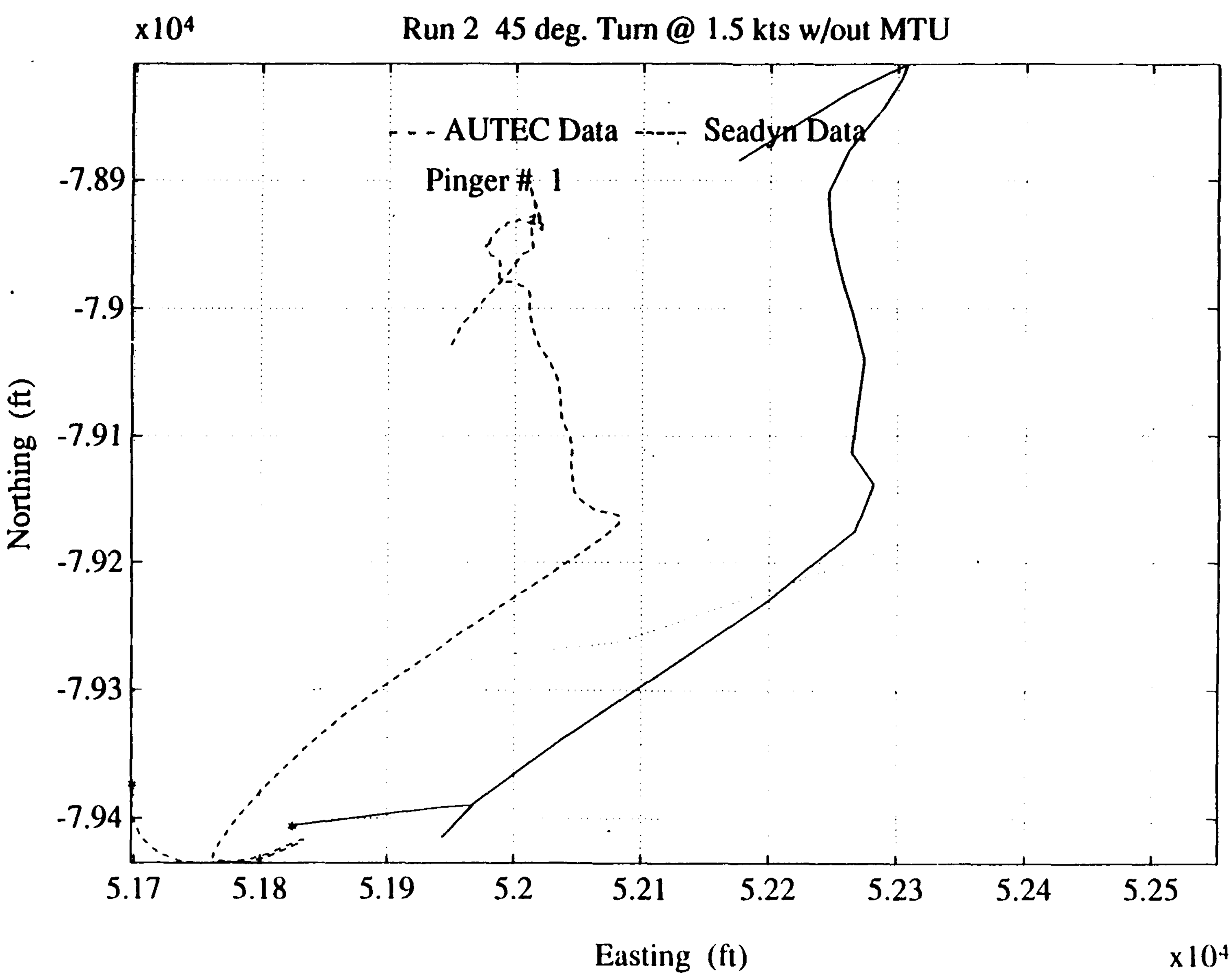

Figure B-14. Run 2 45-degree turn at 1.5 knots without MTU Surface Pinger #1.

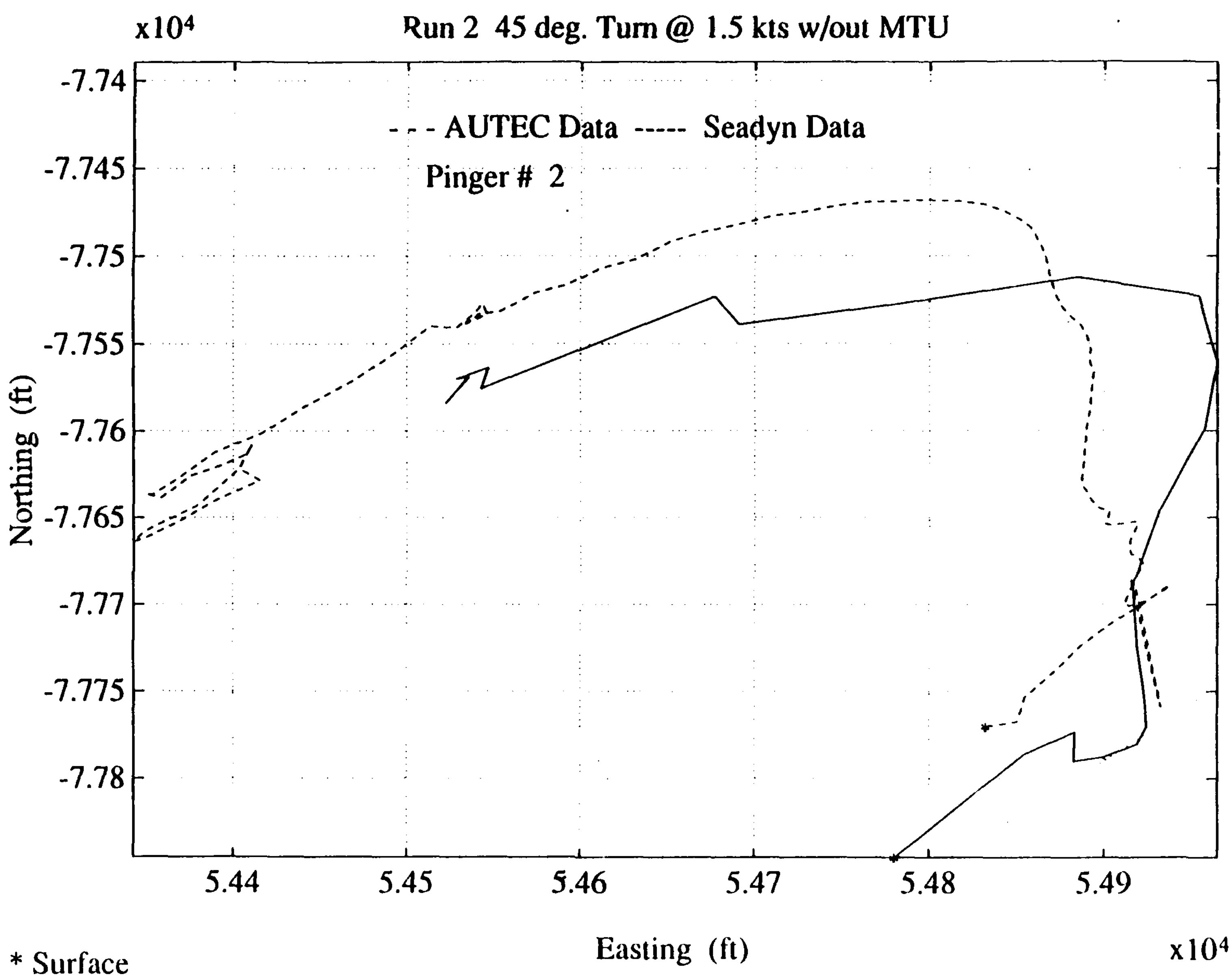

Figure B-15. Run 2 45-degree turn at 1.5 knots without MTU Surface Pinger #2.

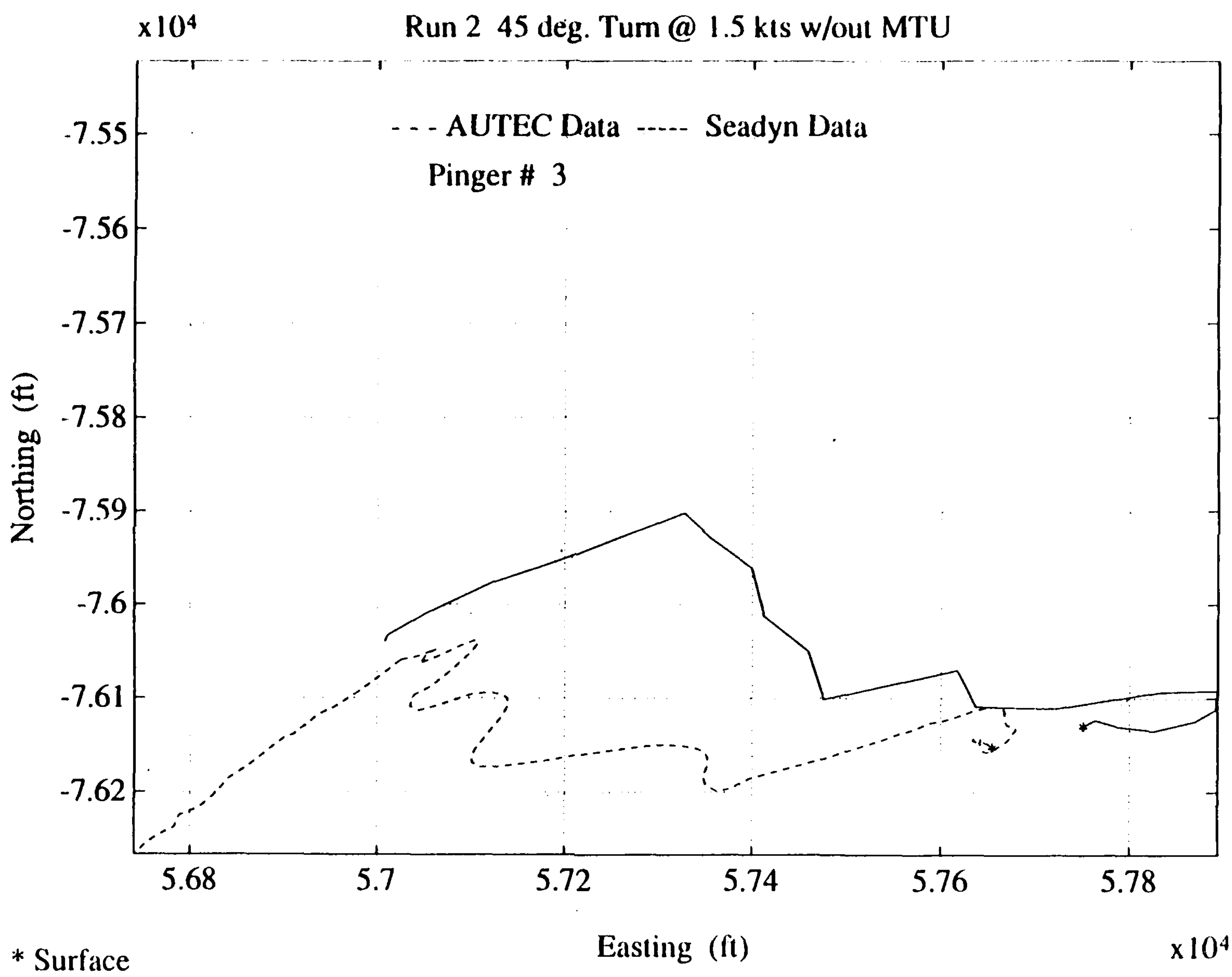

Figure B-16. Run 2 45-degree turn at 1.5 knots without MTU Surface Pinger #3.

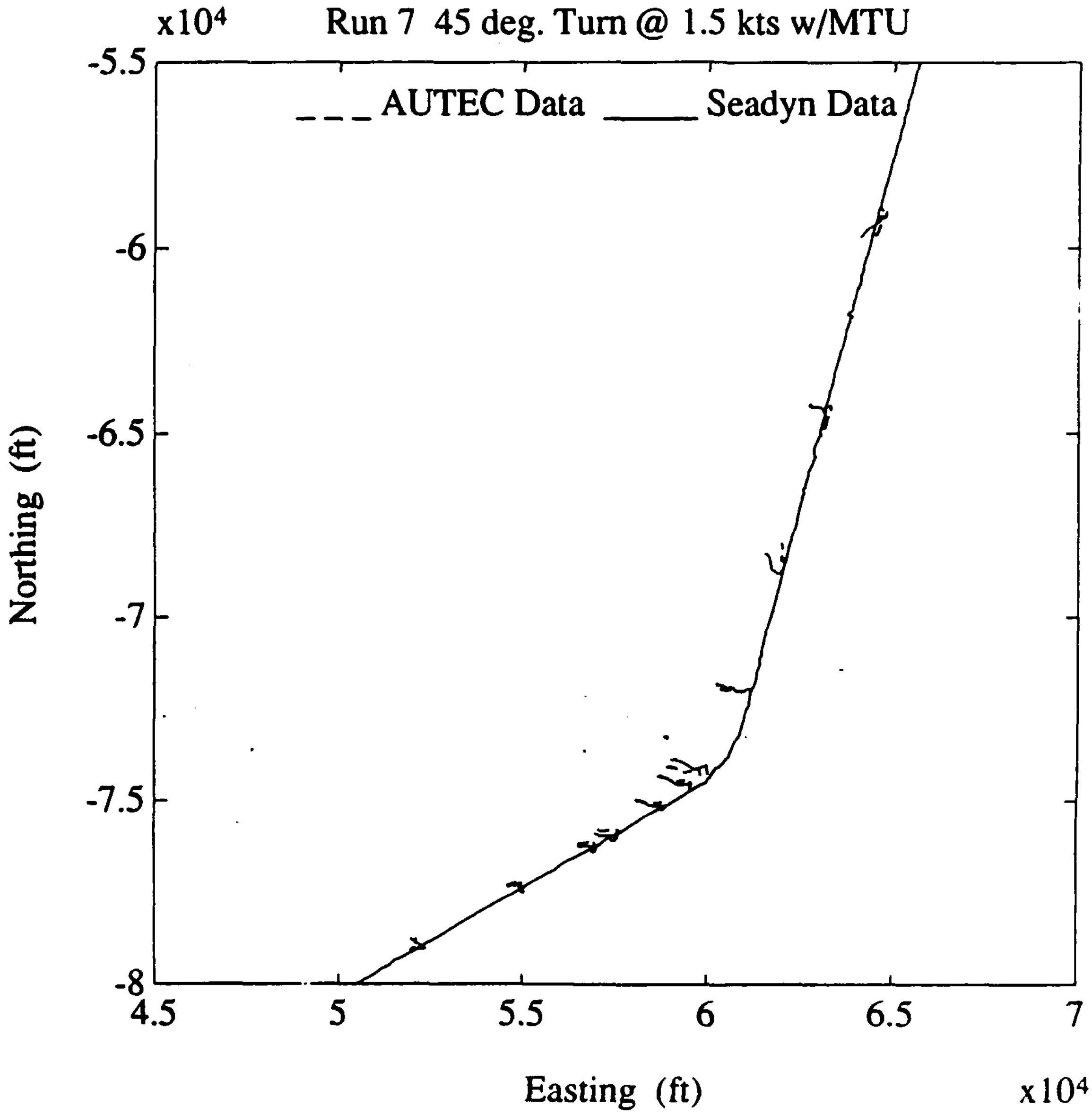

Figure B-17. Run 7 45-degree turn at 1.5 knots without MTU.

Appendix C

PARAMETRIC ANALYSES RESULTS

Parametric analyses were conducted to better understand the behavior of the SOAR cable and the modeling process (see Appendix B). Three separate sets of parametric runs were completed. The first set of parametric runs (Figures C-1a through C-7a) was a study of the effects that the drag coefficient produced on the cable trajectories. It can be seen from these graphs that a change in drag coefficient as little as 10 percent can change the final resting position of the node as much as 200 feet. This further confirms that the normal drag coefficient of 2.54 ± 0.1 is an accurate constant for these conditions.

The second parametric study (Figures C-1b through C-7b) looked at the effects of variations in the current profile with only changes to the bottom one-third of the water column. This illustrated the importance of knowing the current for this section of the water column. It also shows that current does not have as great an effect on the cable trajectories when the barge is altering course.

The final parametric study (Figures C-1c through C-7c) considered the effects of more extreme current changes, such as those caused by the failure of a data collection system in an on-site real-time simulation model. Again, the cable trajectories appeared to be affected less by the change in currents when the deploying vessel was altering course.

Current profiles of all the parametric analyses can be seen in Figures A-2 and A-3. Figure A-4 show that pingers 1 through 3 are before the change in barge path. Pingers 4 through 7 are affected by the 90-degree turn.

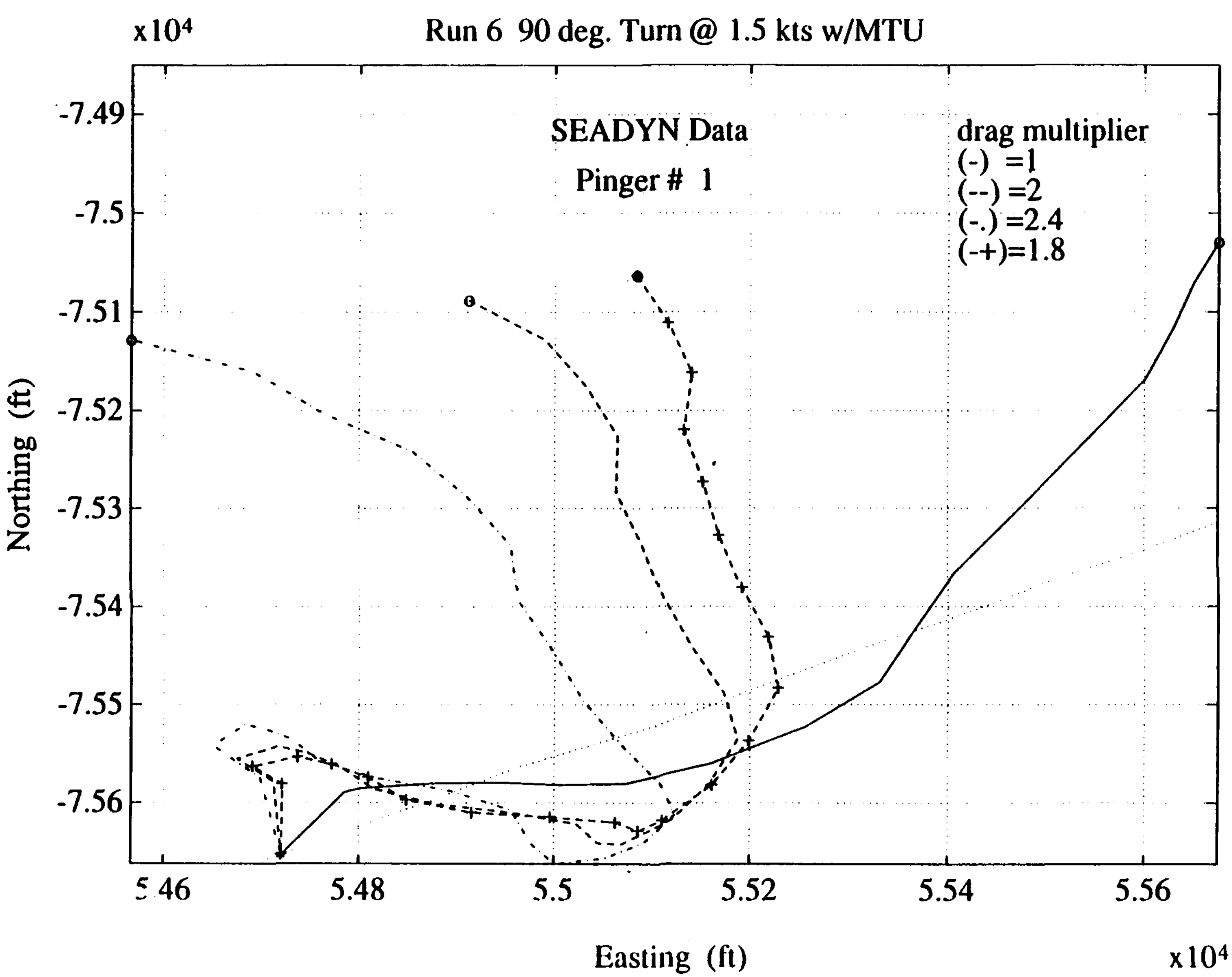

Figure C-1a. Pinger #1: effect of drag.

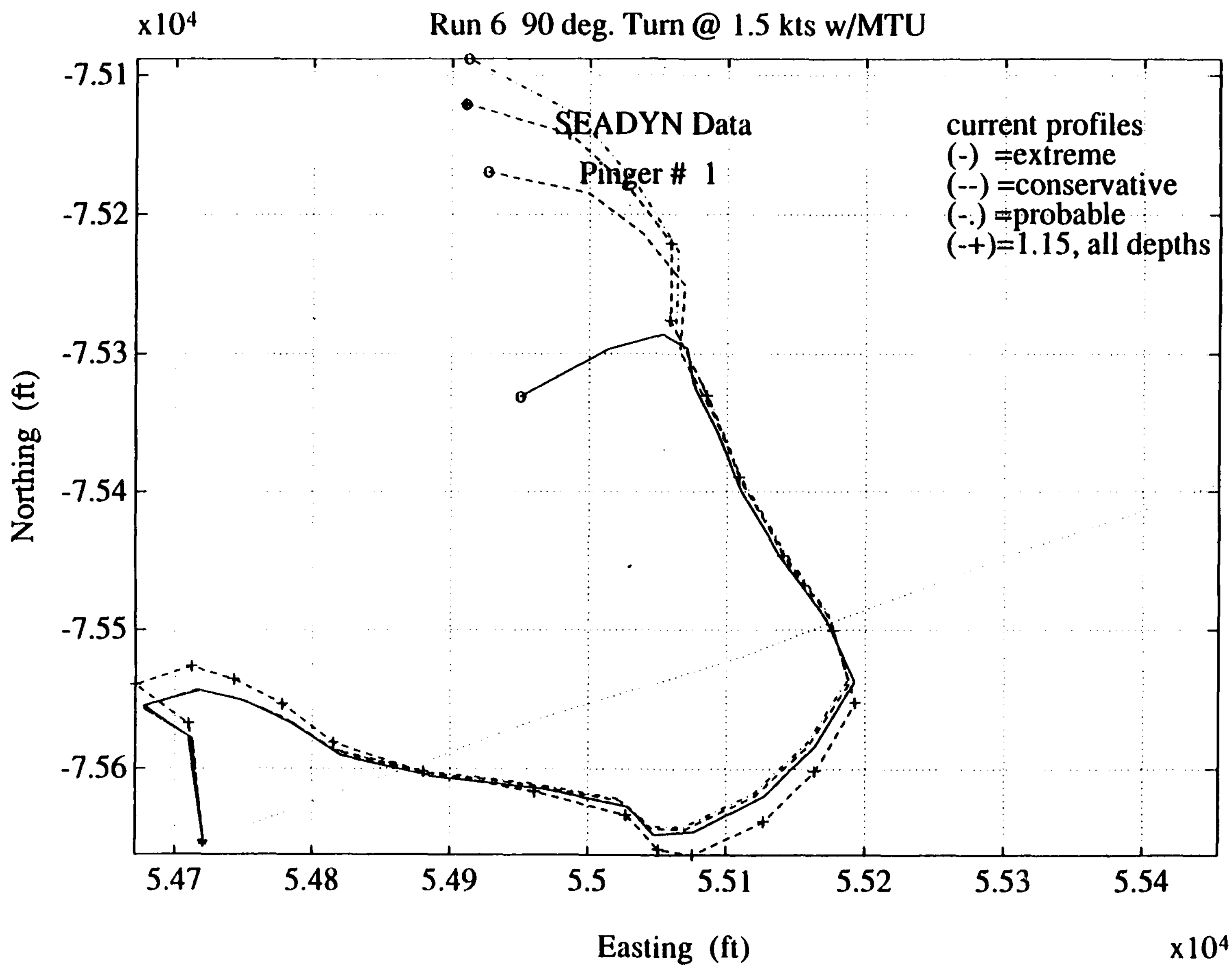

Figure C-1b. Pinger #1: effect of bottom current profile.

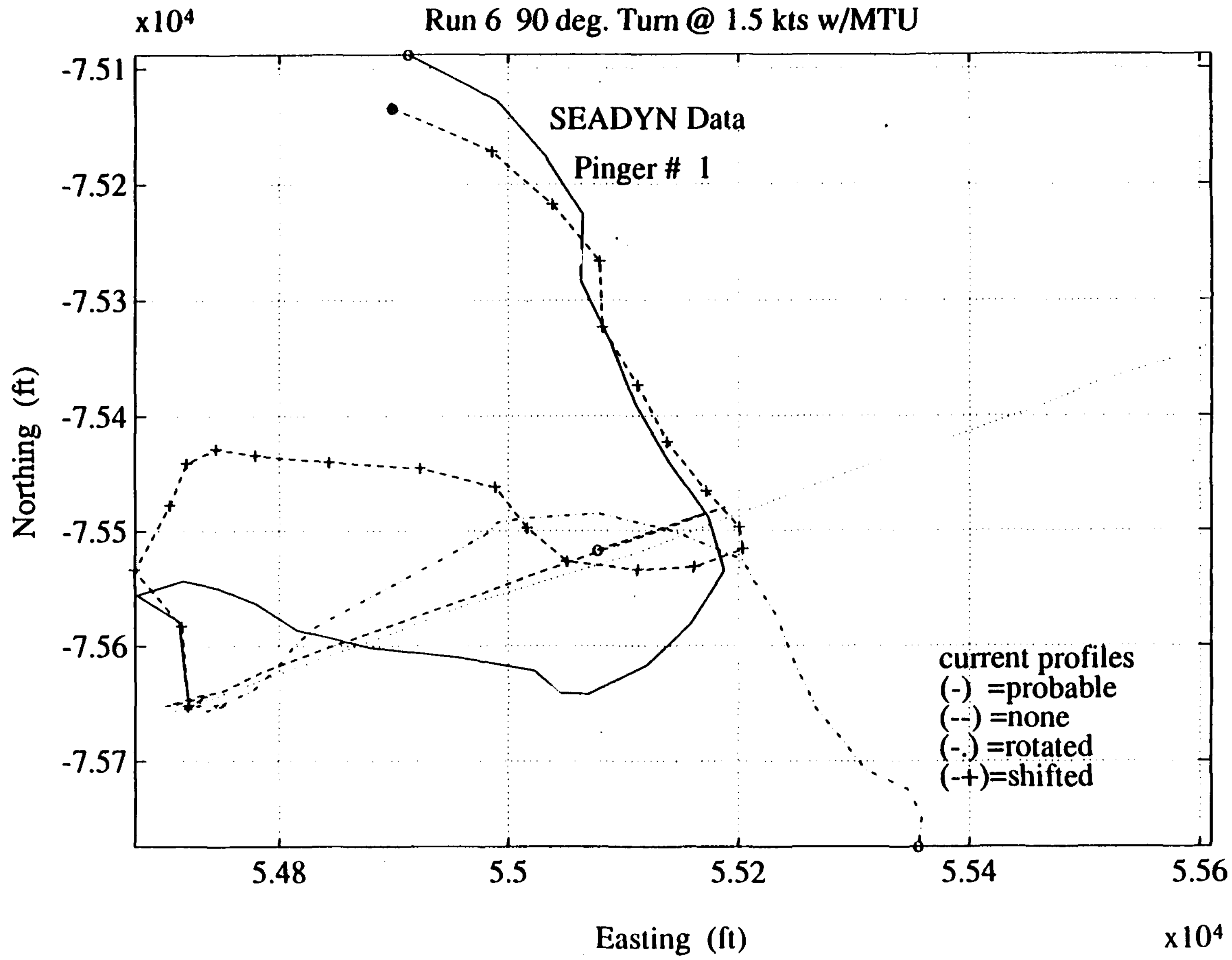

Figure C-1c. Pinger #1: effect of current profile.

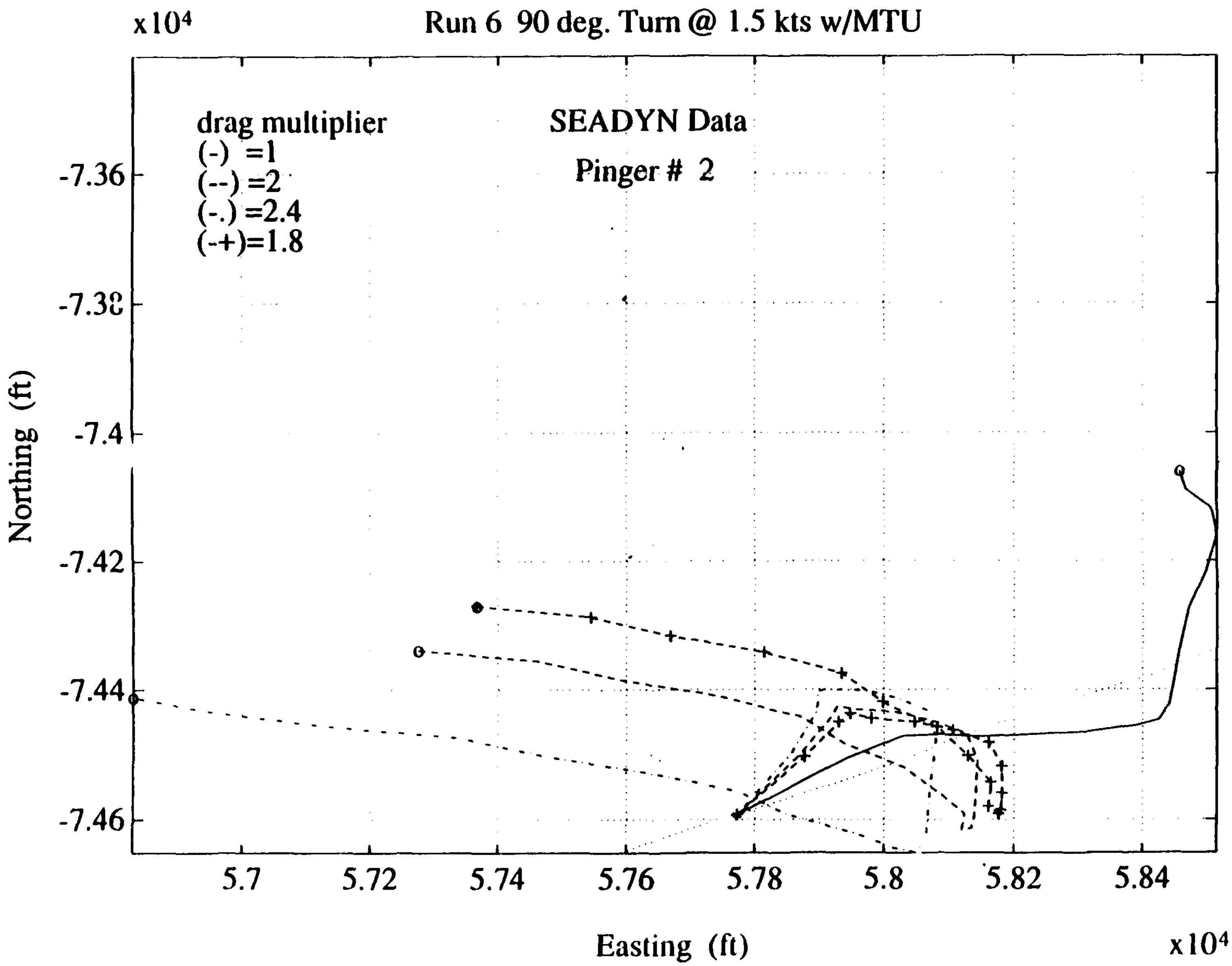

Figure C-2a. Pinger #2: effect of drag.

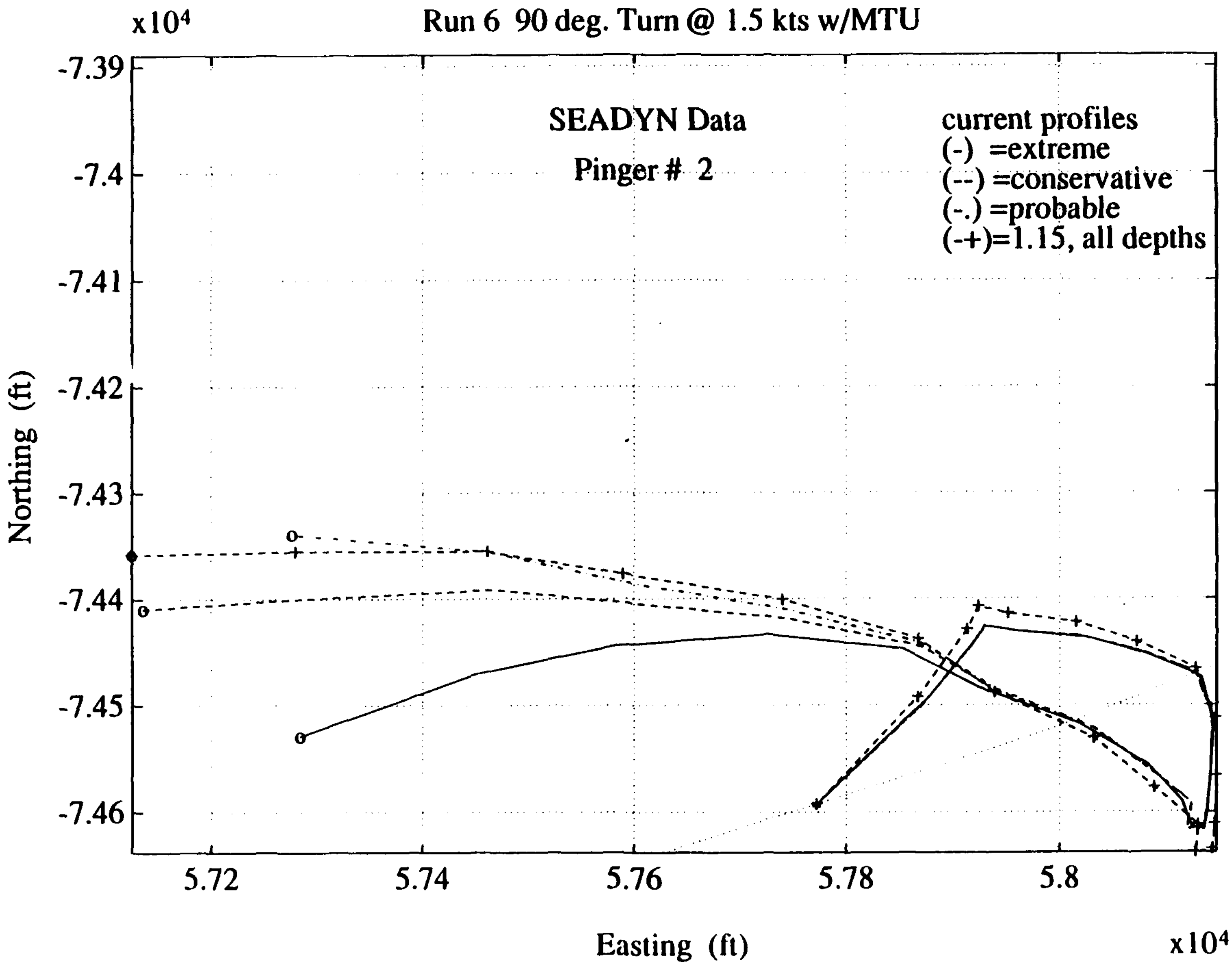

Figure C-2b. Pinger #2: effect of bottom current profile.

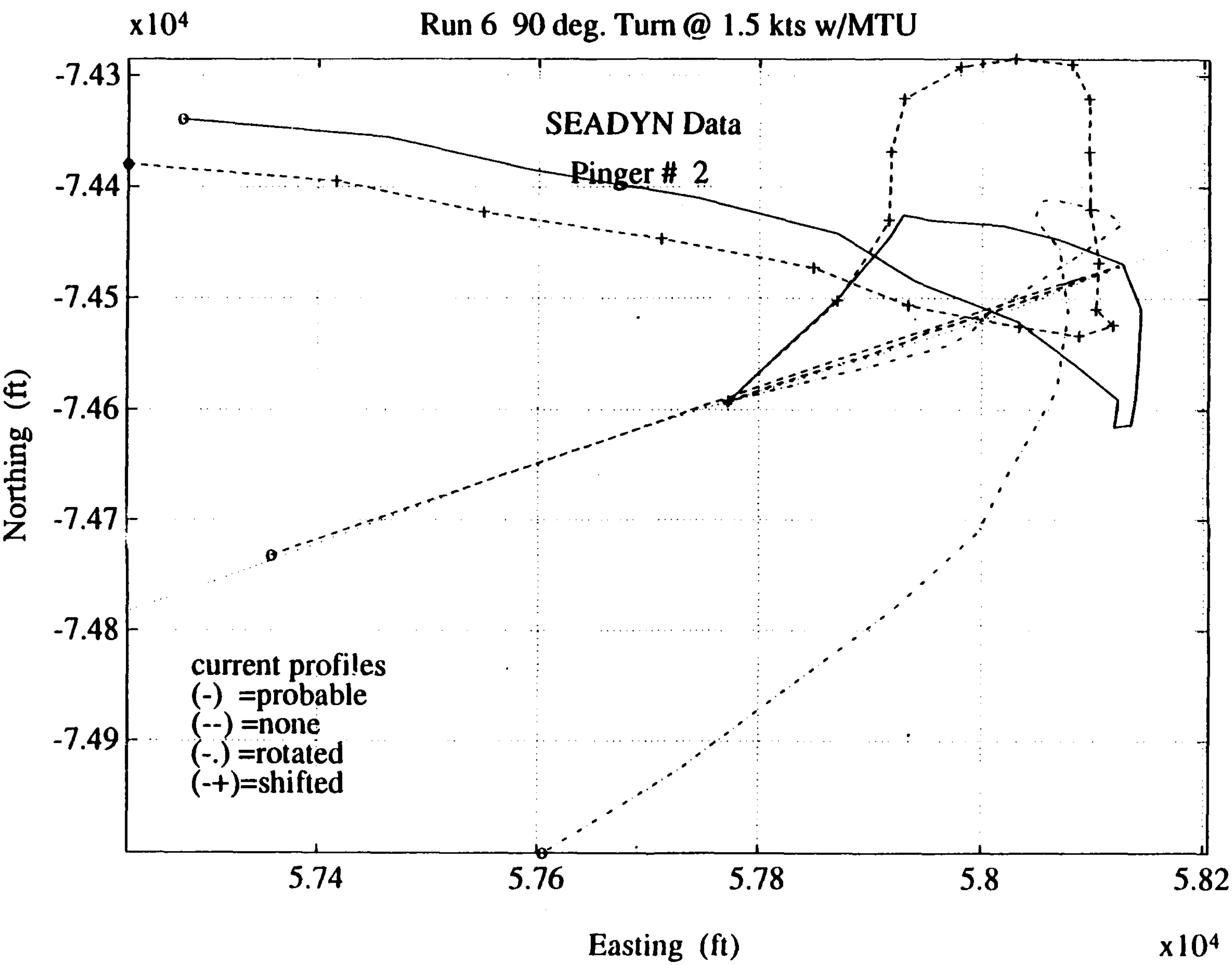

Figure C-2c. Pinger #2: effect of current profile.

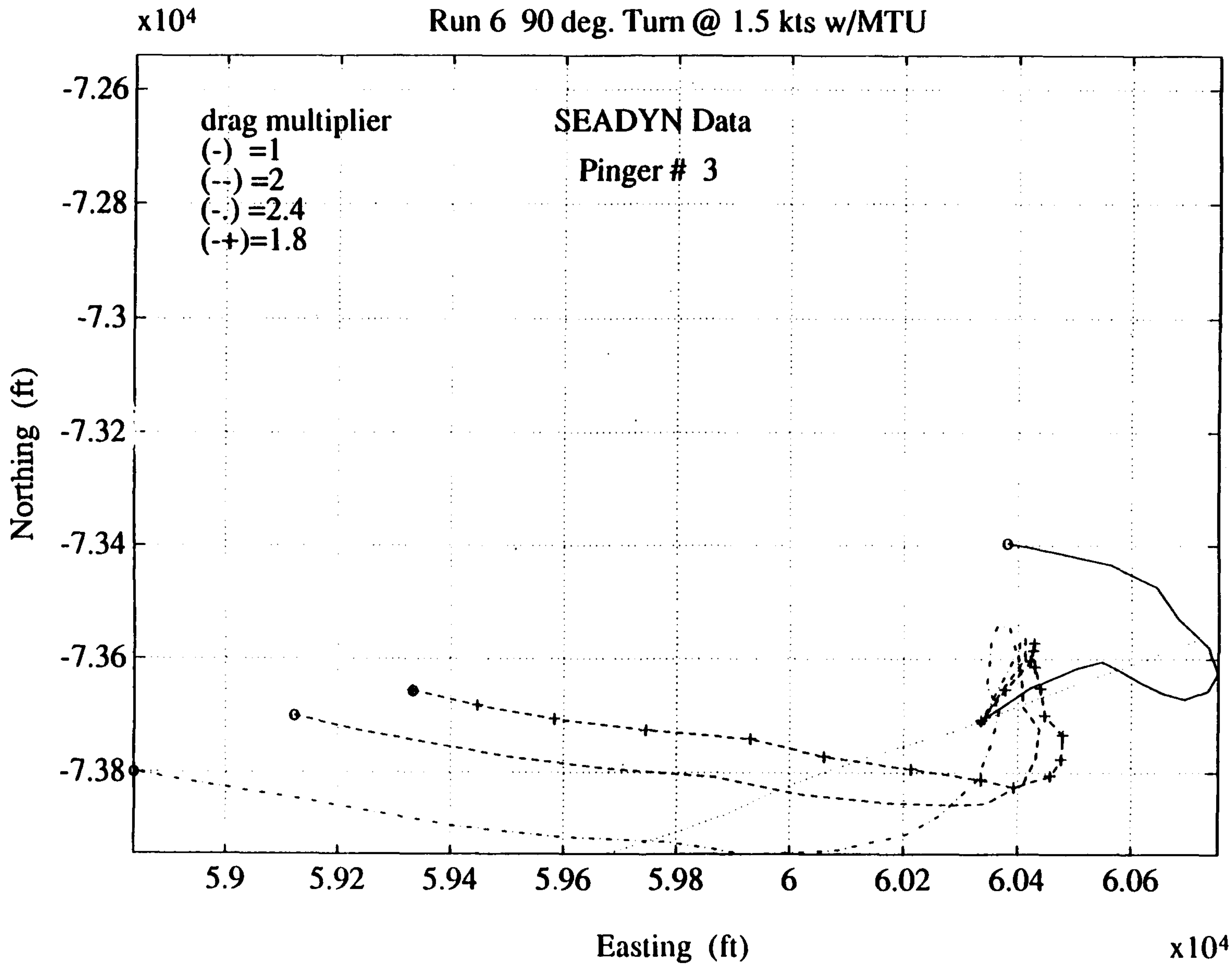

Figure C-3a. Pinger #3: effect of drag.

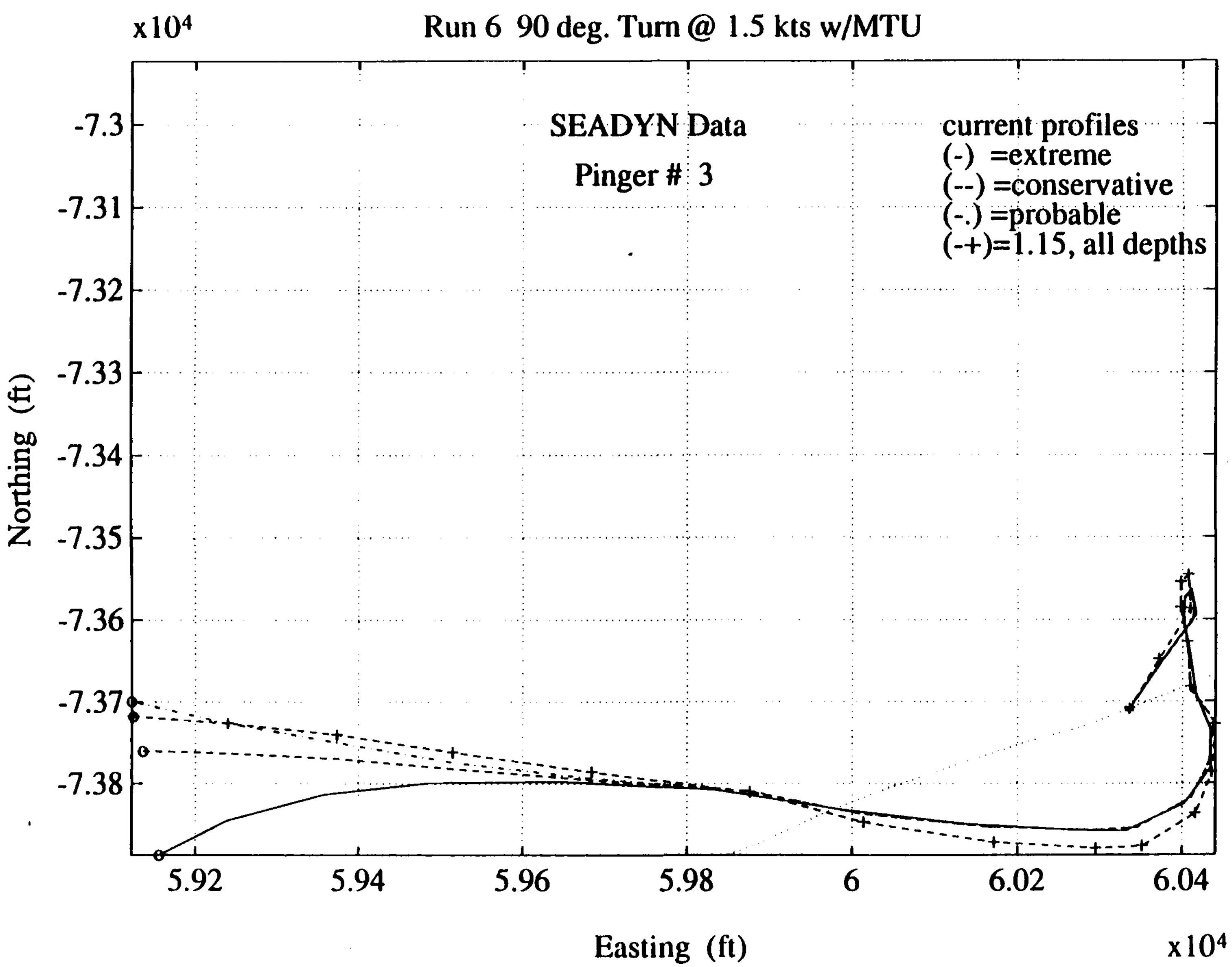

Figure C-3b. Pinger #3: effect of bottom current profile.

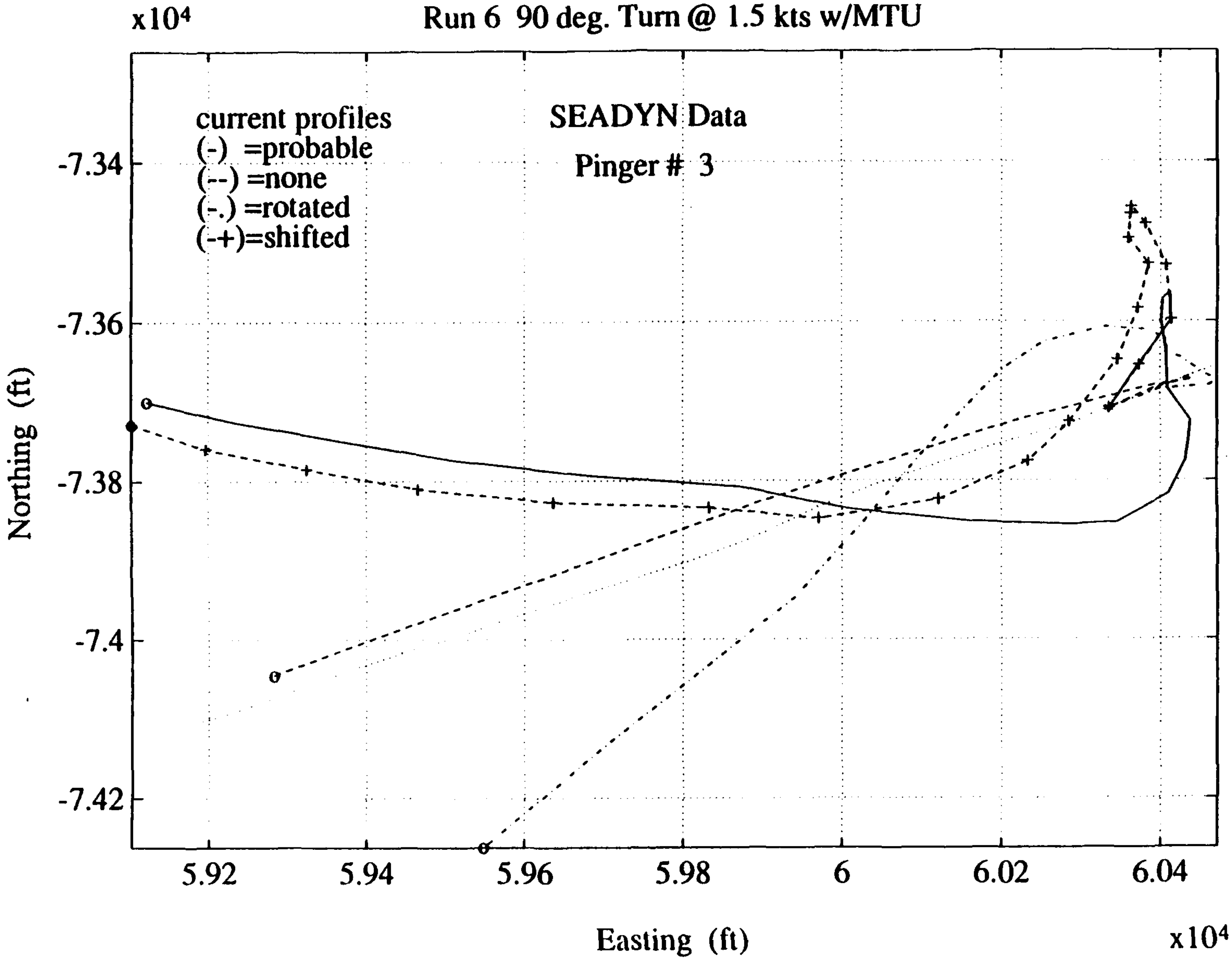

Figure C-3c. Pinger #3: effect of current profile.

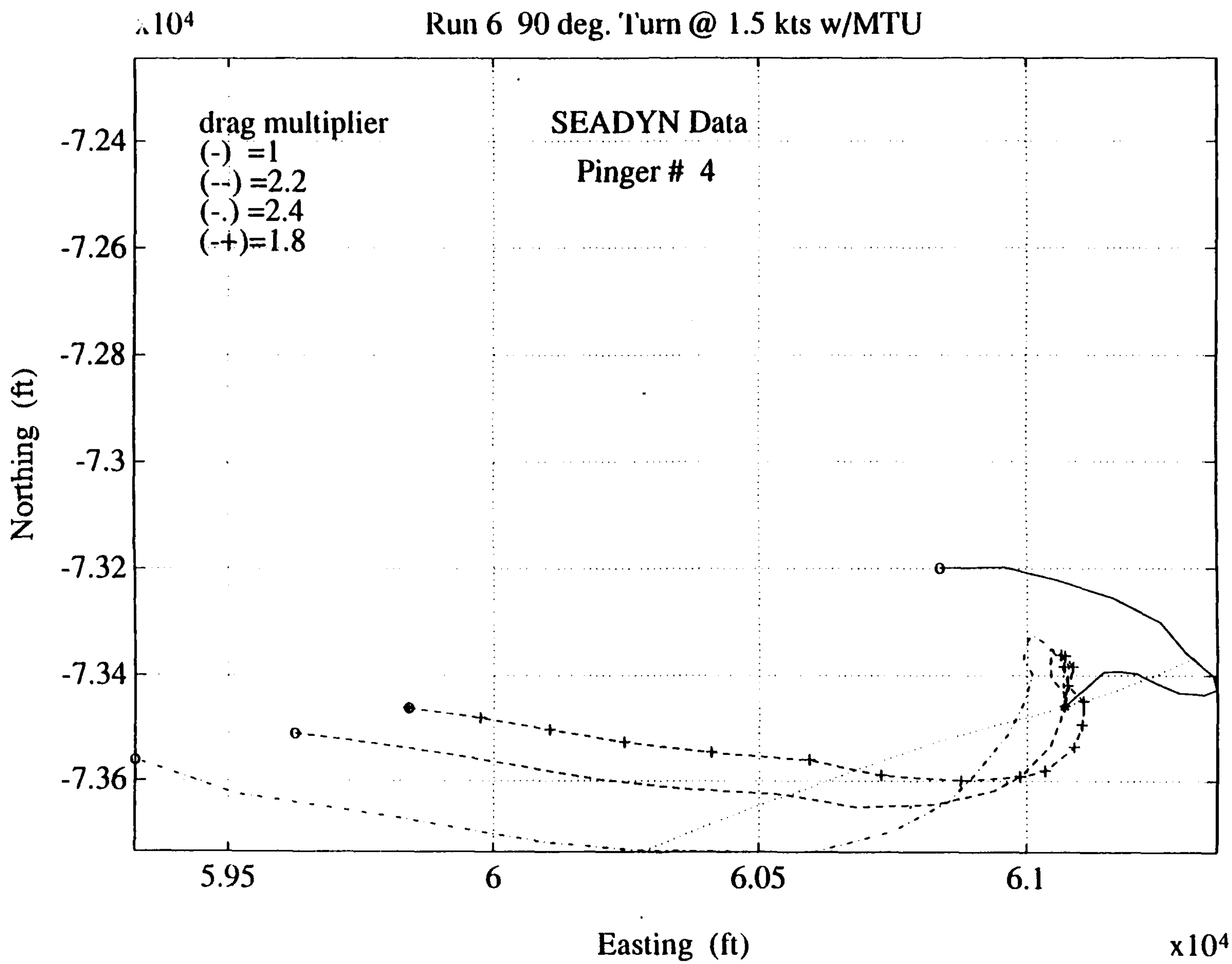

Figure C-4a. Pinger #4: effect of drag.

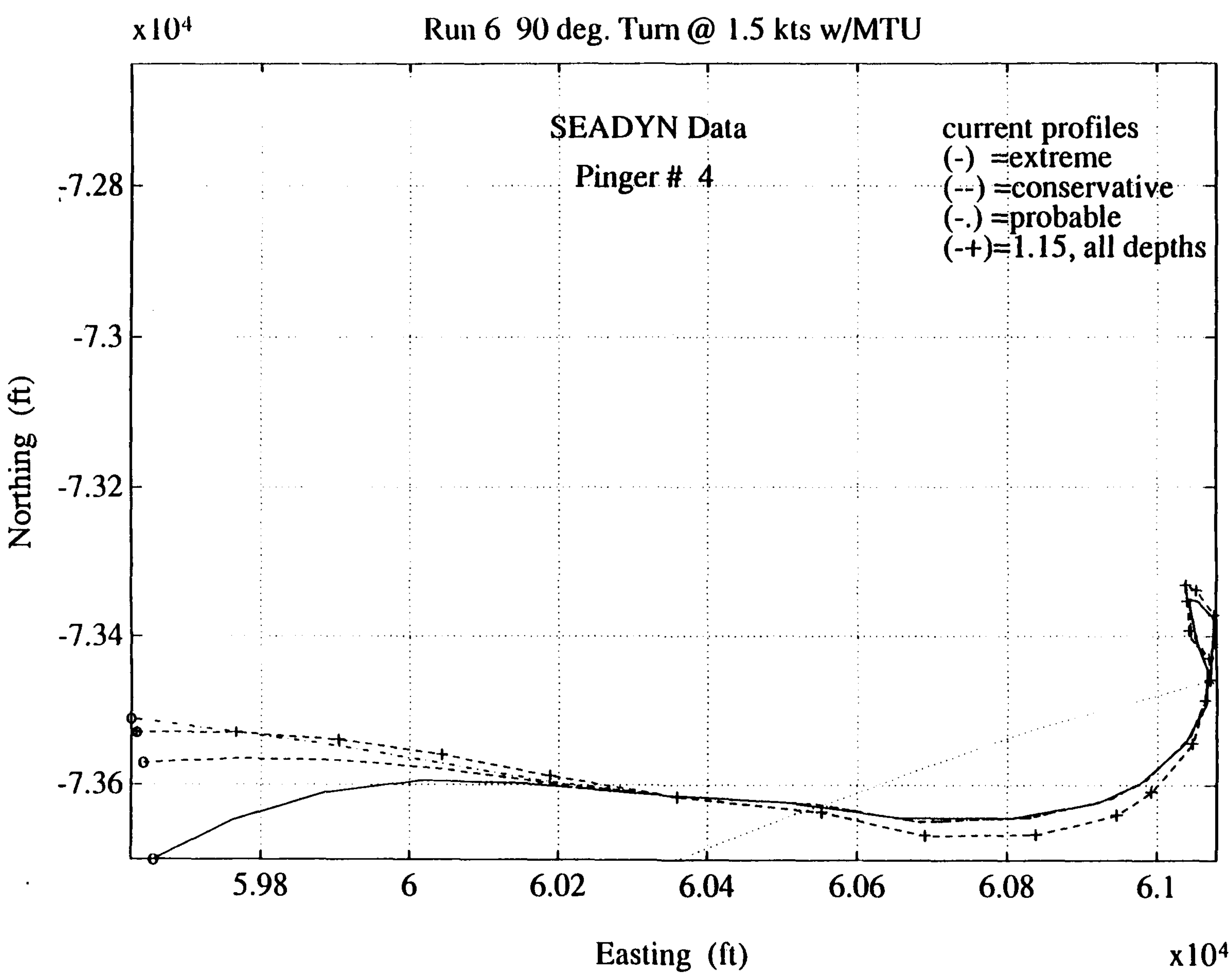

Figure C-4b. Pinger #4: effect of bottom current profile.

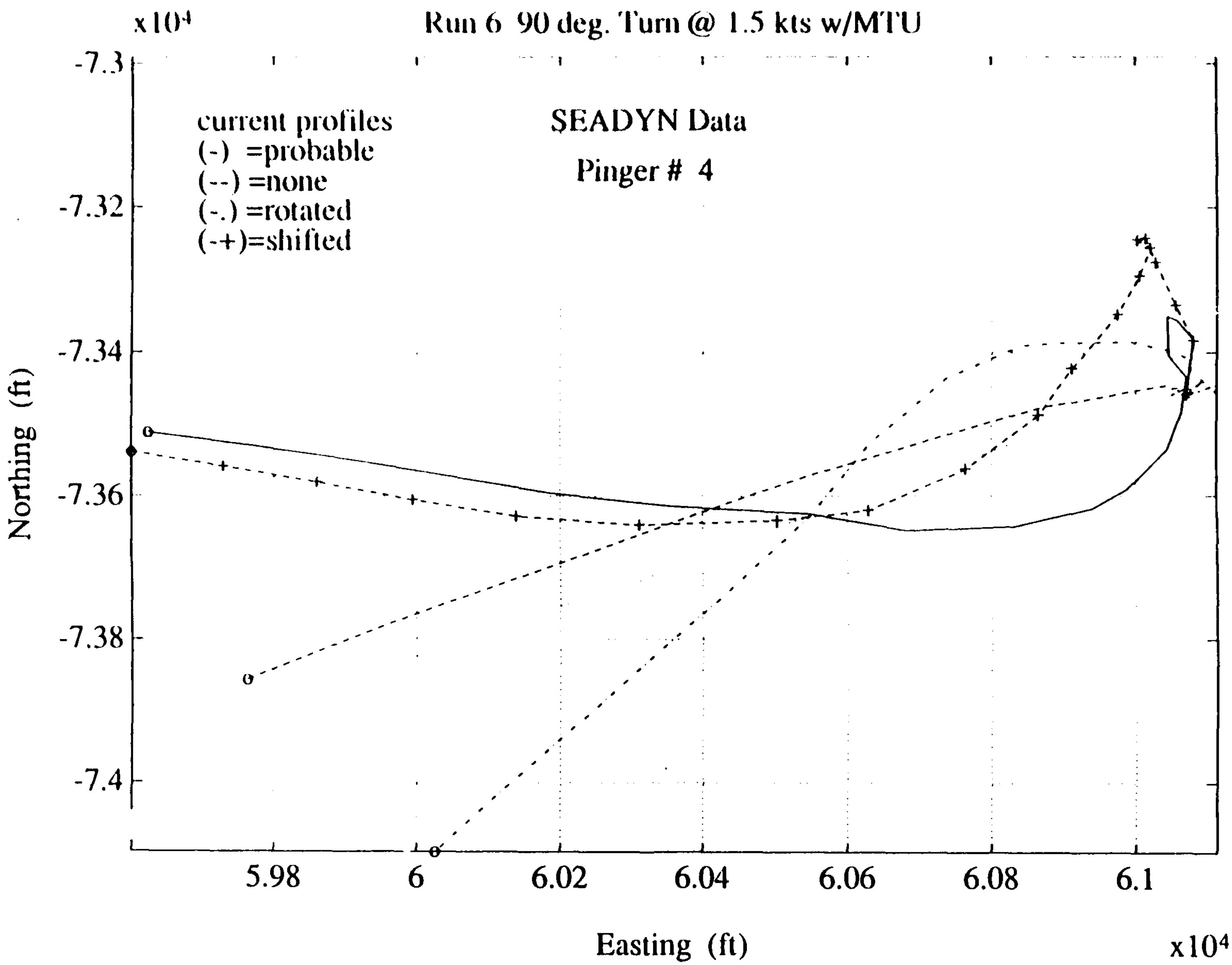

Figure C-4c. Pinger #4: effect of current profile.

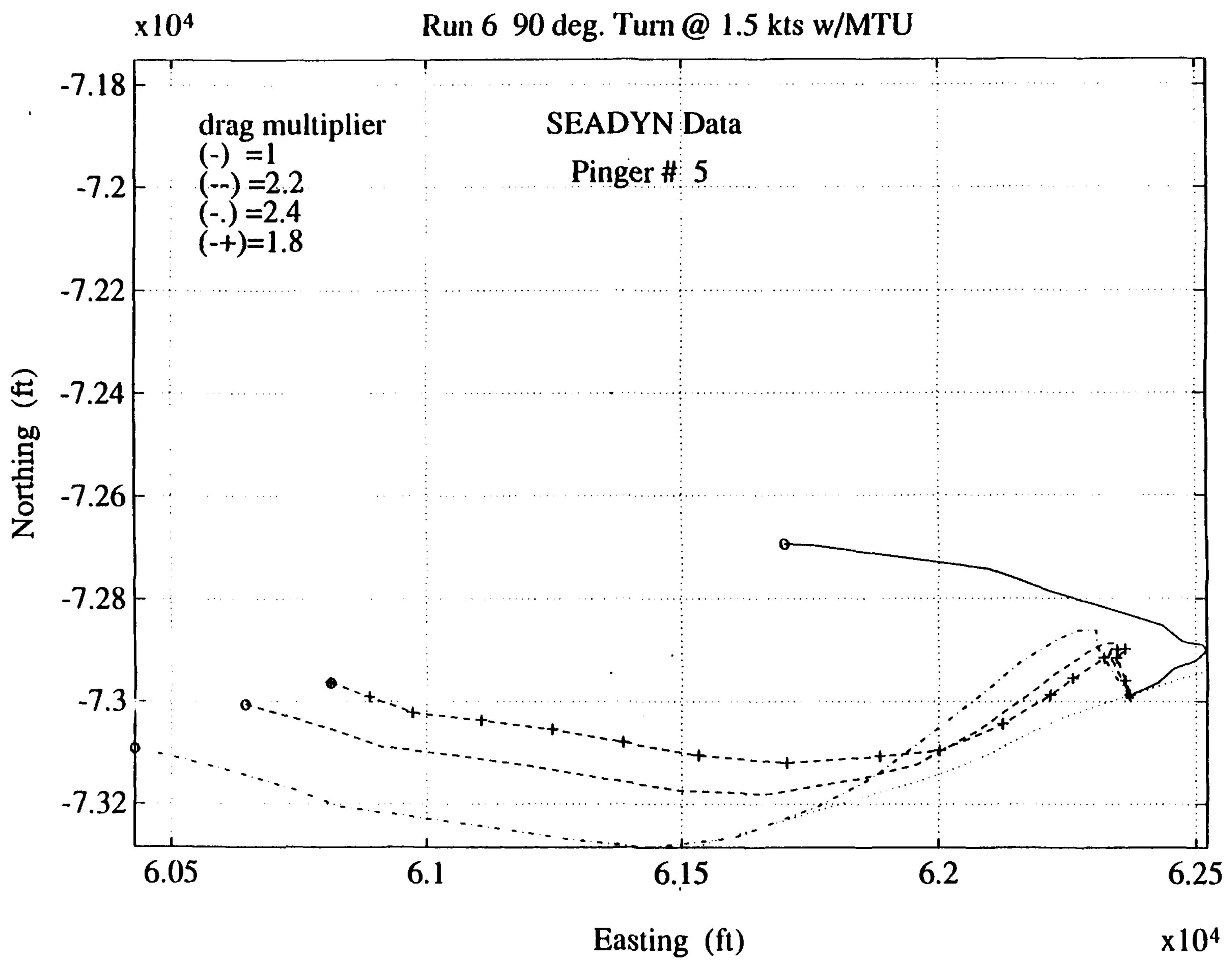

Figure C-5a. Pinger #5: effect of drag.

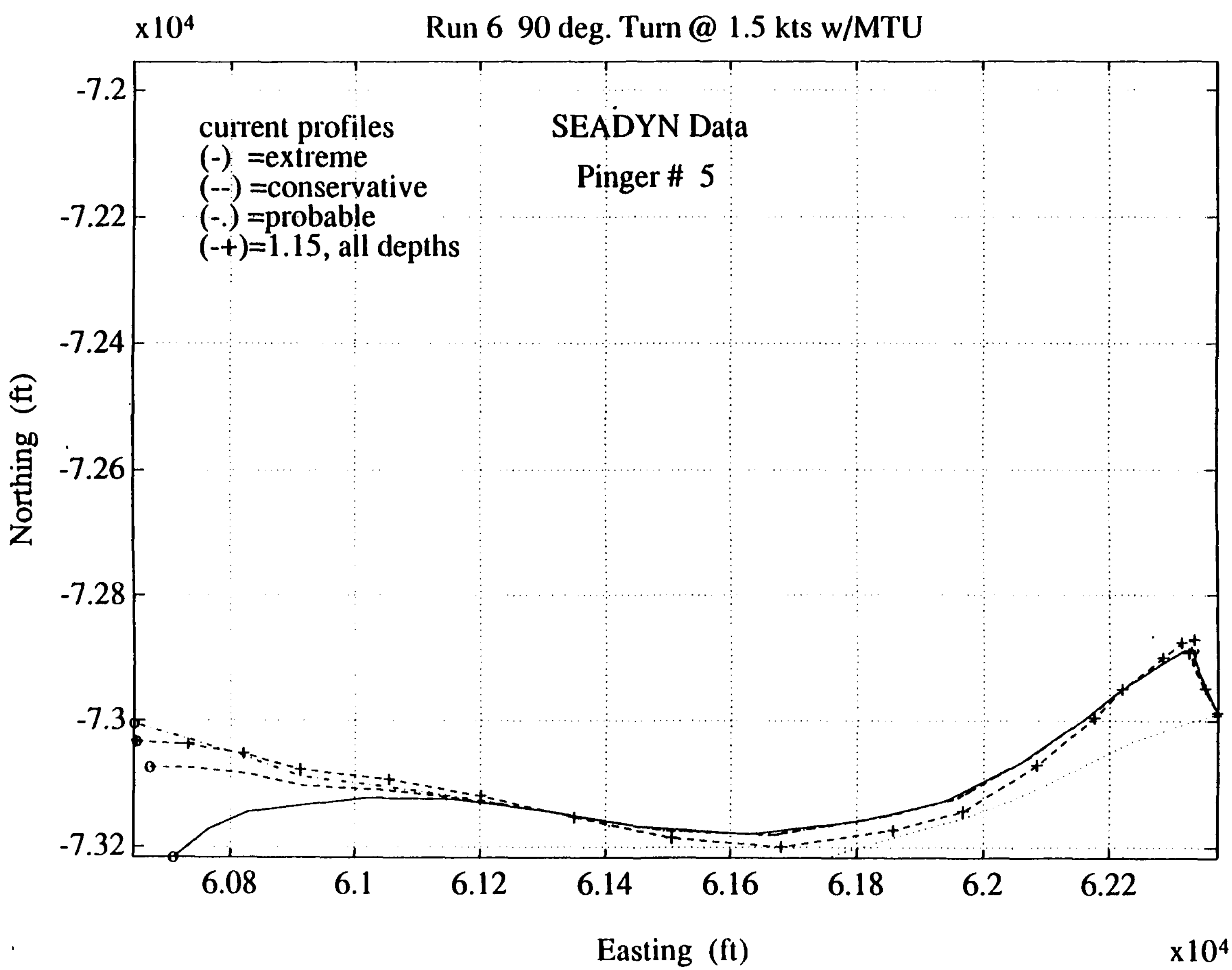

Figure C-5b. Pinger #5: effect of bottom current profile.

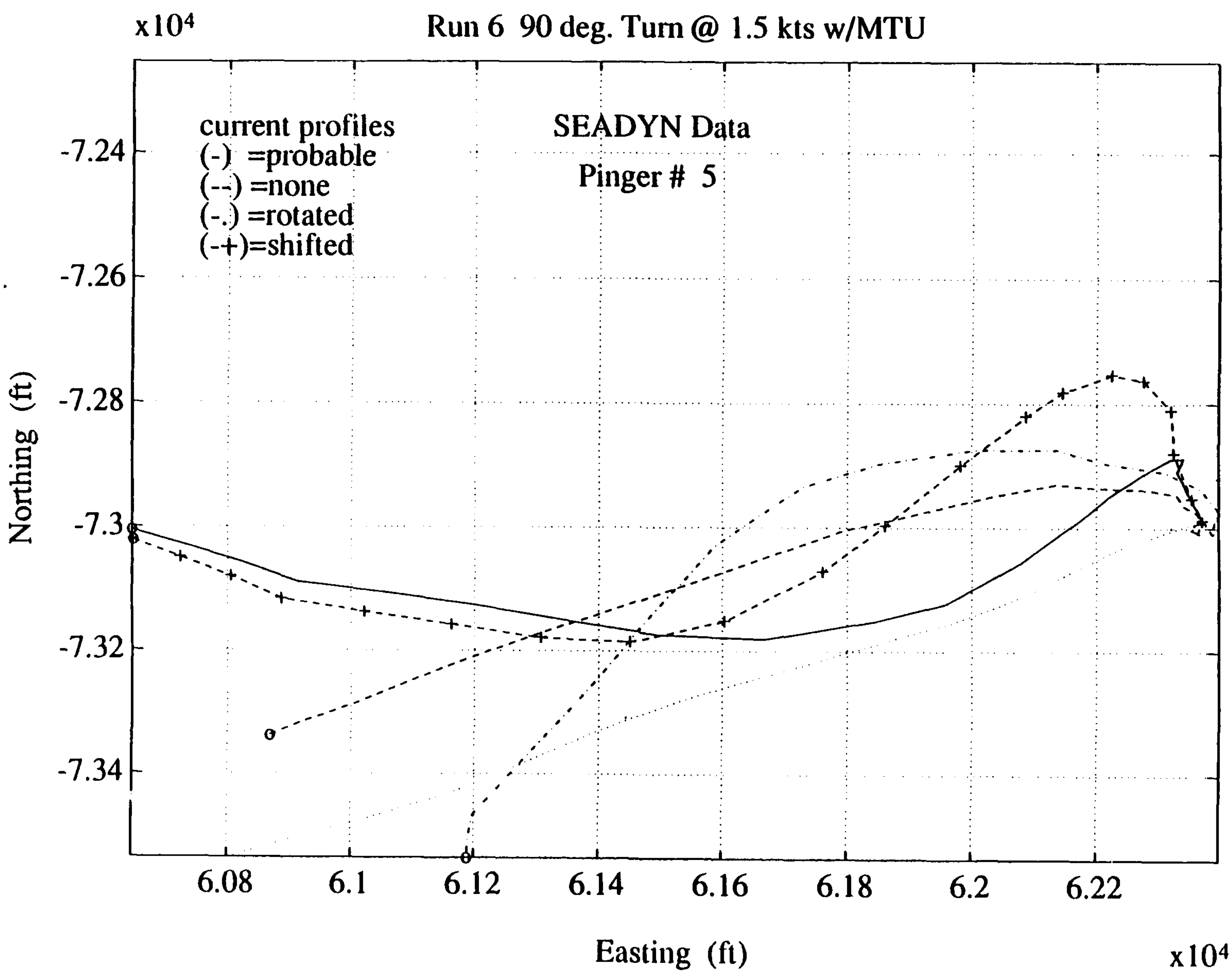

Figure C-5c. Pinger #5: effect of current profile.

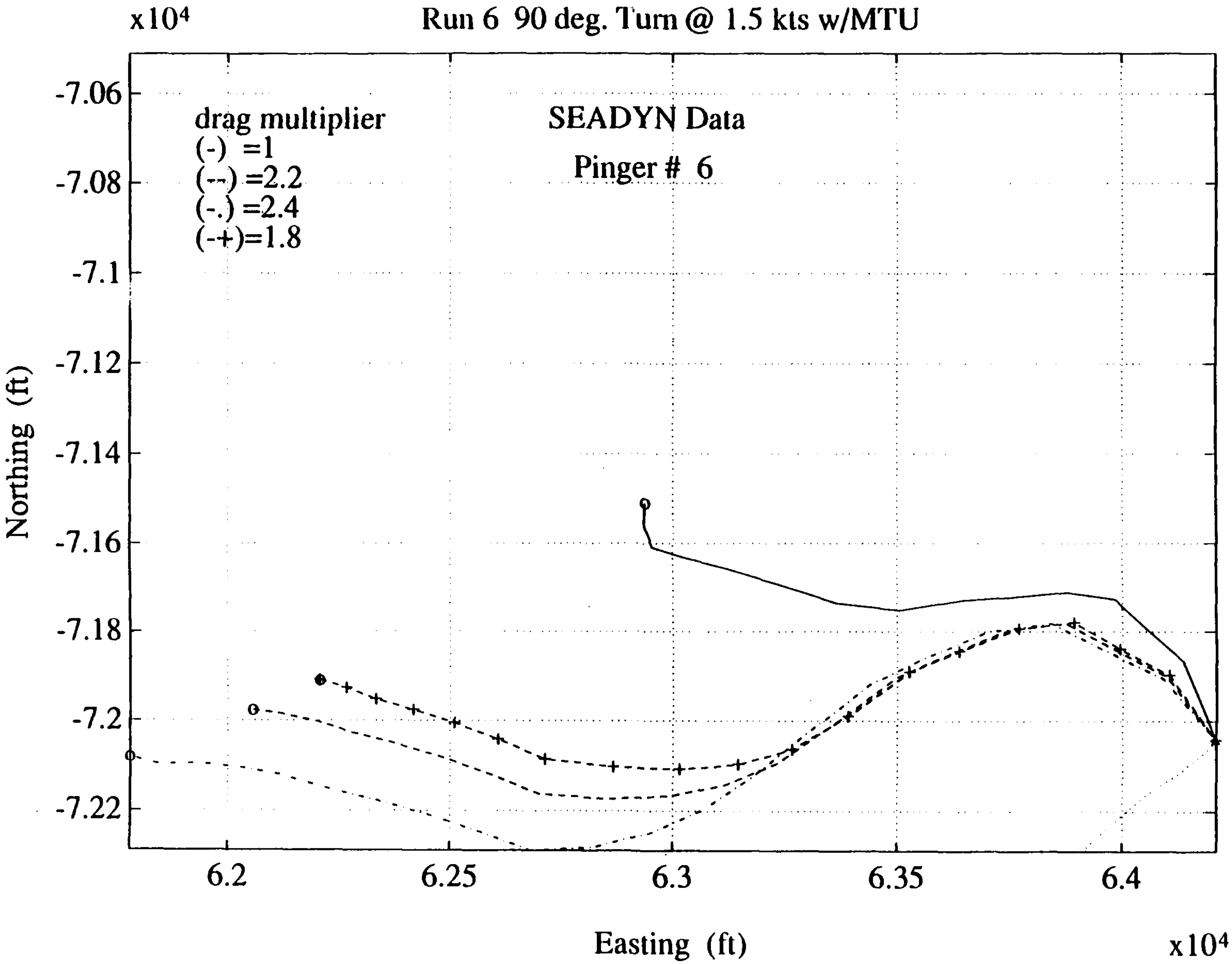

Figure C-6a. Pinger #6: effect of drag.

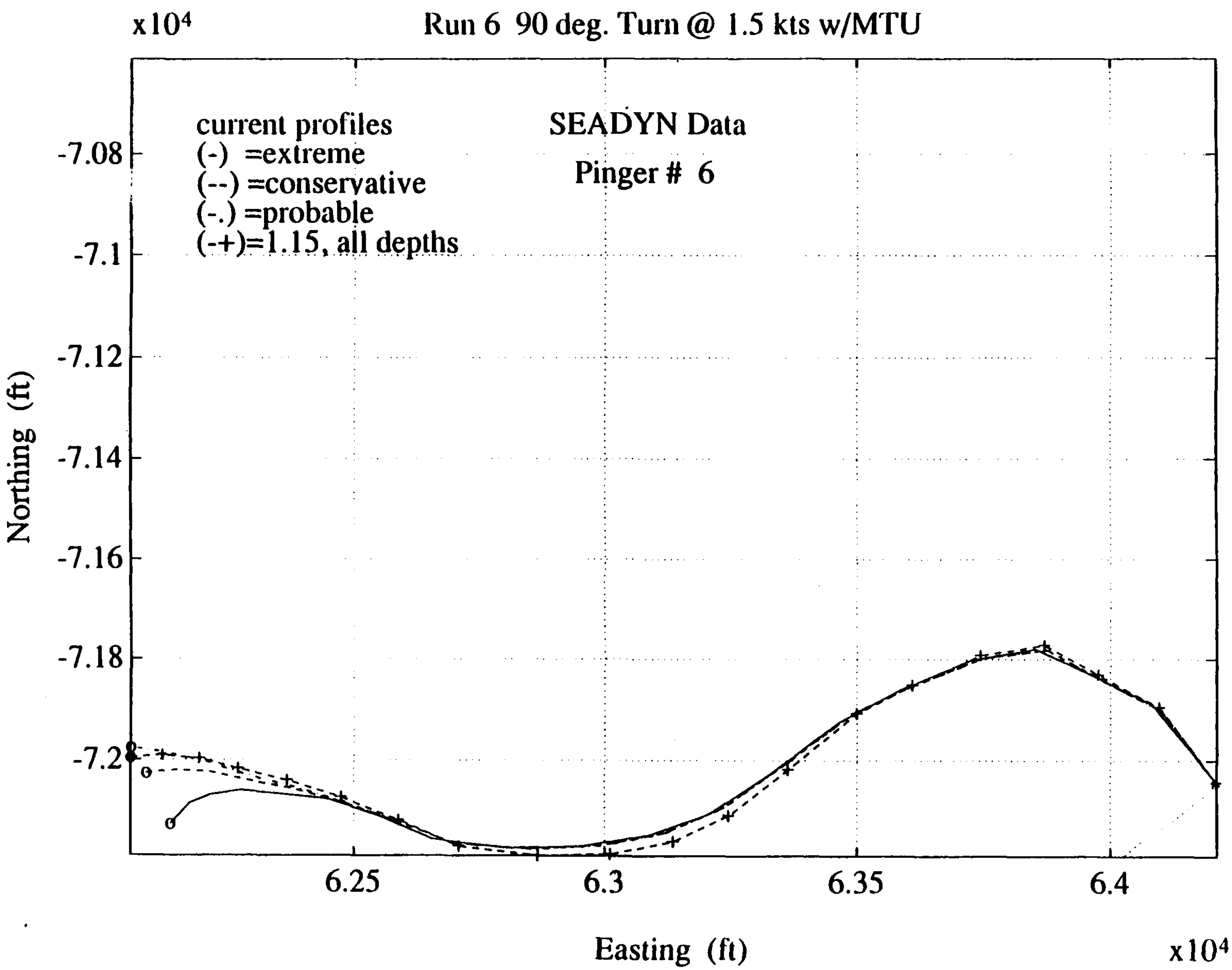

Figure C-6b. Pinger #6: effect of bottom current profile.

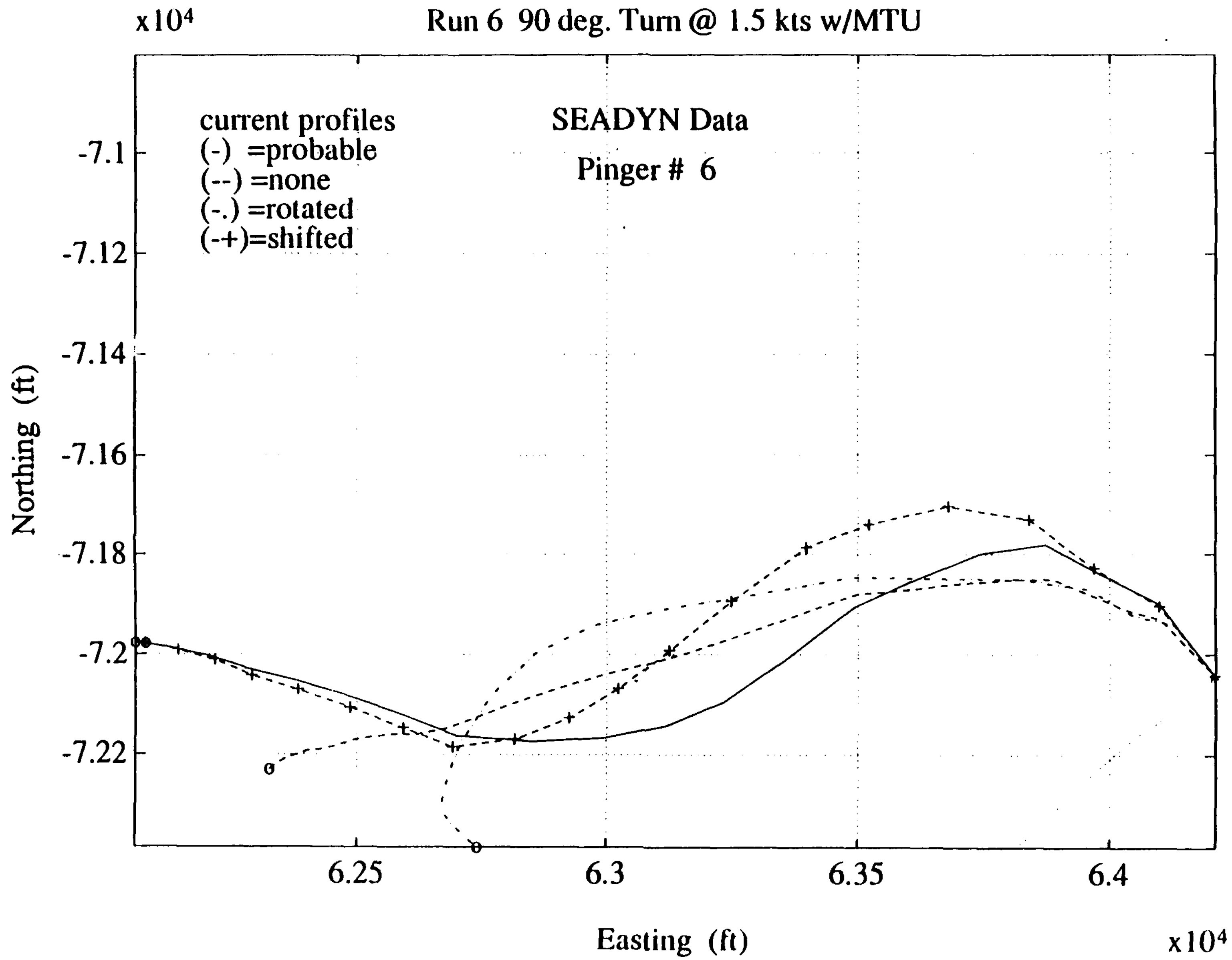

Figure C-6c. Pinger #6: effect of current profile.

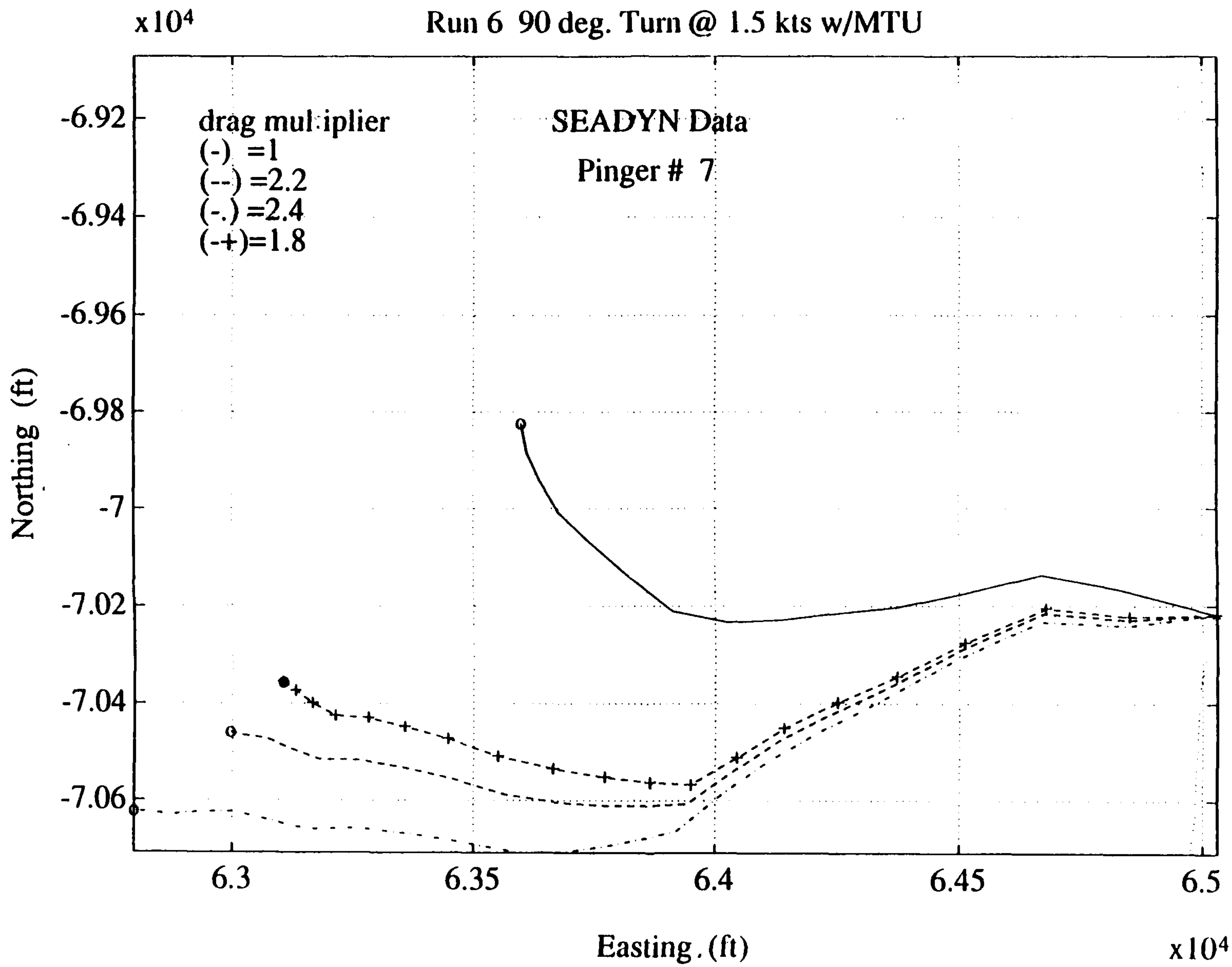

Figure C-7a. Pinger #7: effect of drag.

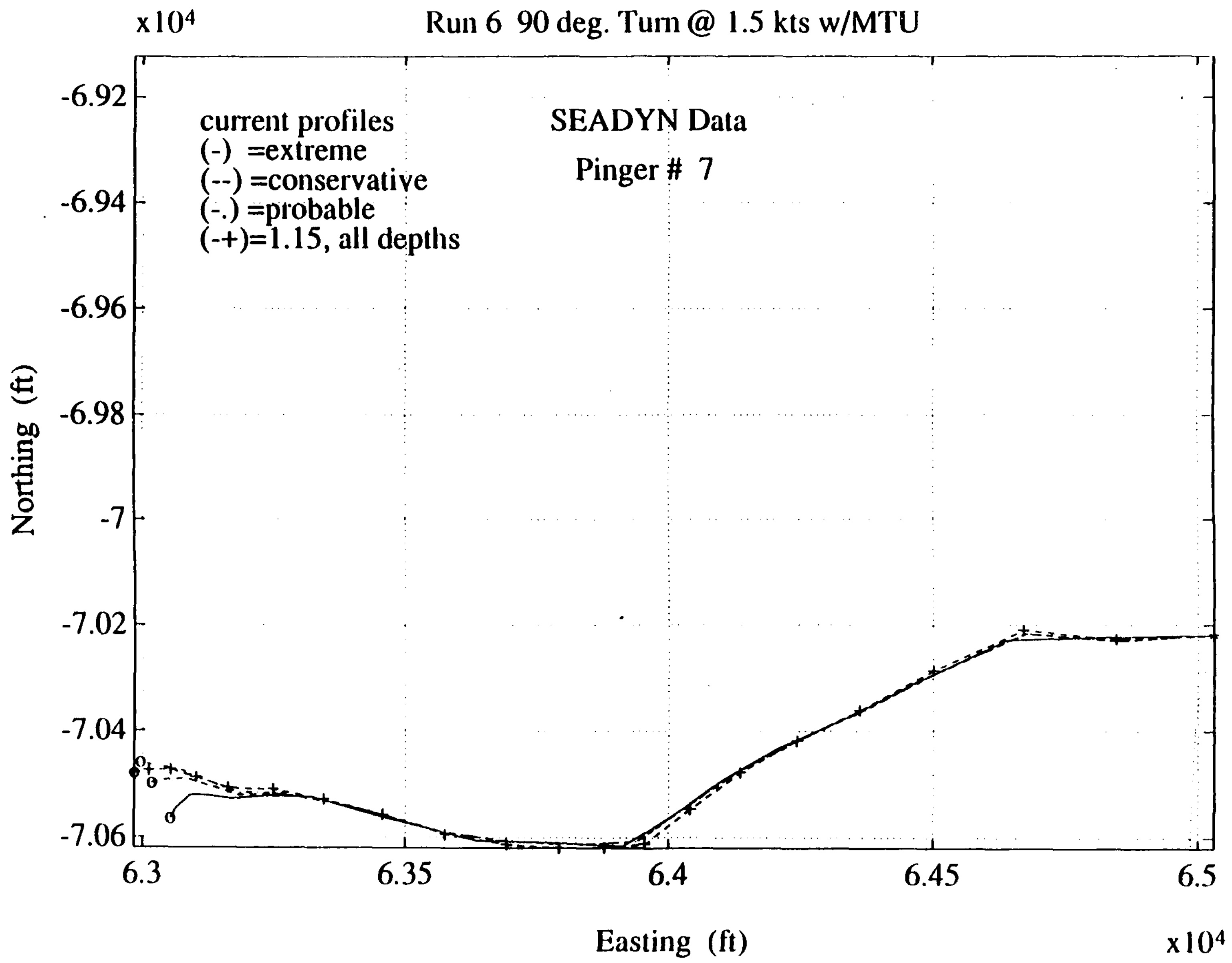

Figure C-7b. Pinger #7: effect of bottom current profile.

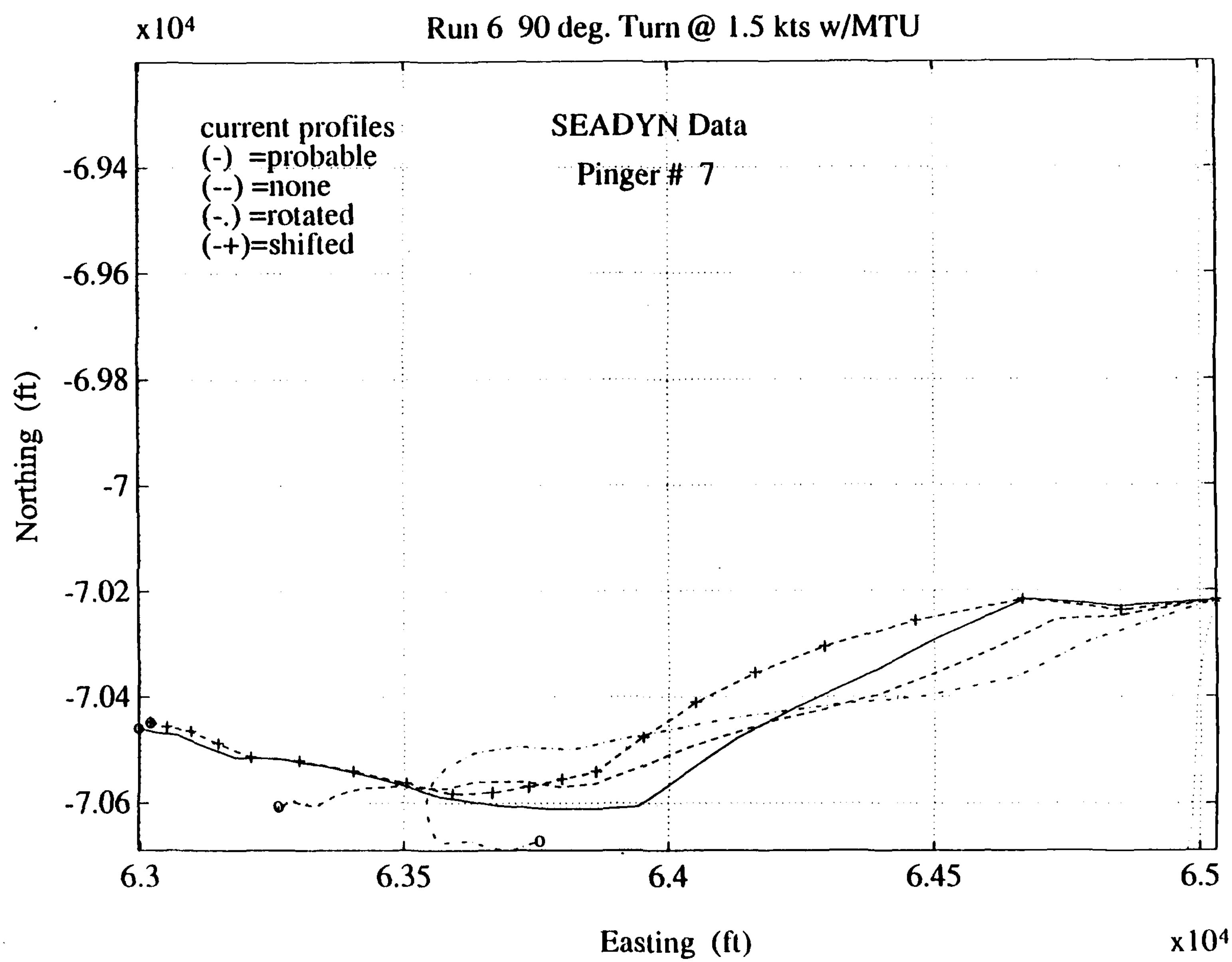

Figure C-7c. Pinger #7: effect of current profile.

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