Range Commanders Council
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DOCUMENT 403-92

SYSTEM TRACKING ACCURACY AND OPERATIONAL ACCEPTANCE TESTING OF THE AUTEC SONOBUOY TRACKING SYSTEM (STS)

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	July 1992	

4. TITLE AND SUBTITLE
System Tracking Accuracy and Operational Acceptance Testing of the AUTEC Sonobuoy Tracking System (STS)

5. FUNDING NUMBERS

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Underwater Systems Group
Range Commanders Council
White Sands Missile Range, NM 88002-5110

8. PERFORMING ORGANIZATION REPORT NUMBER
RCC Document 403-92

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Range Commanders Council
STEWS-SA-R
White Sands Missile Range, NM 88002-5110

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
same as block 8

11. SUPPLEMENTARY NOTES
New document

12a. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION UNLIMITED: APPROVED FOR PUBLIC RELEASE

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report presents the results of the data collected during operational acceptance testing of the Atlantic Undersea Test and Evaluation Center's (AUTEC) Sonobuoy Tracking System (STS). The STS is a passive, phase-measuring, interferometer type system designed to track up to 40 transmitters on the weapons range.

14. SUBJECT TERMS
STS, sonobuoy

15. NUMBER OF PAGES
125

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASS	UNCLASS	UNCLASS	NONE

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)

DOCUMENT 403-92

SYSTEM TRACKING ACCURACY AND OPERATIONAL ACCEPTANCE TESTING OF THE AUTEC SONOBUOY TRACKING SYSTEM (STS)

JULY 1992

Prepared by

UNDERWATER SYSTEMS GROUP
RANGE COMMANDERS COUNCIL

Published by

Secretariat
Range Commanders Council
White Sands Missile Range,
New Mexico 88002-5110

PREFACE

This document is published in response to an Underwater Systems Group (USG) task established in April 1991 and entitled "Tracking Accuracies of the AUTEC Sonobuoy Tracking System (STS)." The scope and objective of the task were to produce a report on the accuracy capability of the AUTEC STS for tracking sonobuoys and properly-equipped range vessels. The resulting report provides an update of STS performance and accuracy postulated in RCC Document 402-86, *Sonobuoy Tracking System Concepts for ASW Test Ranges* published in March 1986.

The material presented in this document is taken from portions of AUTEC's extensive STS acceptance testing conducted at Andros Island in the Bahamas during the period from May 1990 through February 1991. Subjects related to STS accuracy and to the integration of STS into AUTEC real-time operations are believed to be of interest to other underwater ranges.

It is intended that this report provide the USG community with reference documentation on the capabilities of a significant range tracking asset.

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SYSTEM TRACKING ACCURACY AND OPERATIONAL ACCEPTANCE TESTING OF THE AUTEC SONOBUOY TRACKING SYSTEM (STS)

1.0 OBJECTIVE

This report presents the results of the data collected during operation acceptance testing of Atlantic Undersea Test and Evaluation Center's (AUTEC) Sonobuoy Tracking System (STS).

2.0 INTRODUCTION

The STS is a passive, phase-measuring, interferometer type system designed to simultaneously track up to 40 transmitters on the Weapons Range (WR) with each transmitting an FM signal on 1 of 99 sonobuoy VHF frequencies. At AUTEC, STS antenna arrays and associated equipment are installed at sites 2, 3, and 4. The STS site receiver/converters interface via AUTEC communications with the site 1 STS computer equipment which, in turn, interfaces with AUTEC's real-time computer system. The STS is described in detail in reference 1. Figure 1 depicts STS geometry for AUTEC's WR.

The AUTEC's STS was installed during February-September 1980. System calibration was unsuccessfully attempted in October 1989 and successfully accomplished in the January-February 1990 time period.

The Site Acceptance Test (SAT) was conducted in May 1990, post-SAT testing was conducted in July 1990, the Operational Acceptance Test (OAT) was conducted in October 1990, and post-OAT testing was conducted in February 1991.

3.0 SUMMARY

The SAT was designed to be extensive enough to thoroughly address acceptance of the system from the vendor. In so doing, the SAT also provided much of the data required to satisfy OAT of the system, thus permitted the OAT testing to be somewhat abbreviated and rather focused in its objectives.

This report, therefore, includes SAT results pertaining to OAT objectives as well as those from the OAT tests themselves. And because they are of related interest, a summary of SAT results pertaining to SAT objectives is also provided in this document. Acceptance testing is described in paragraph 6, SAT testing in paragraph 6.1, and OAT testing in paragraph 6.2.

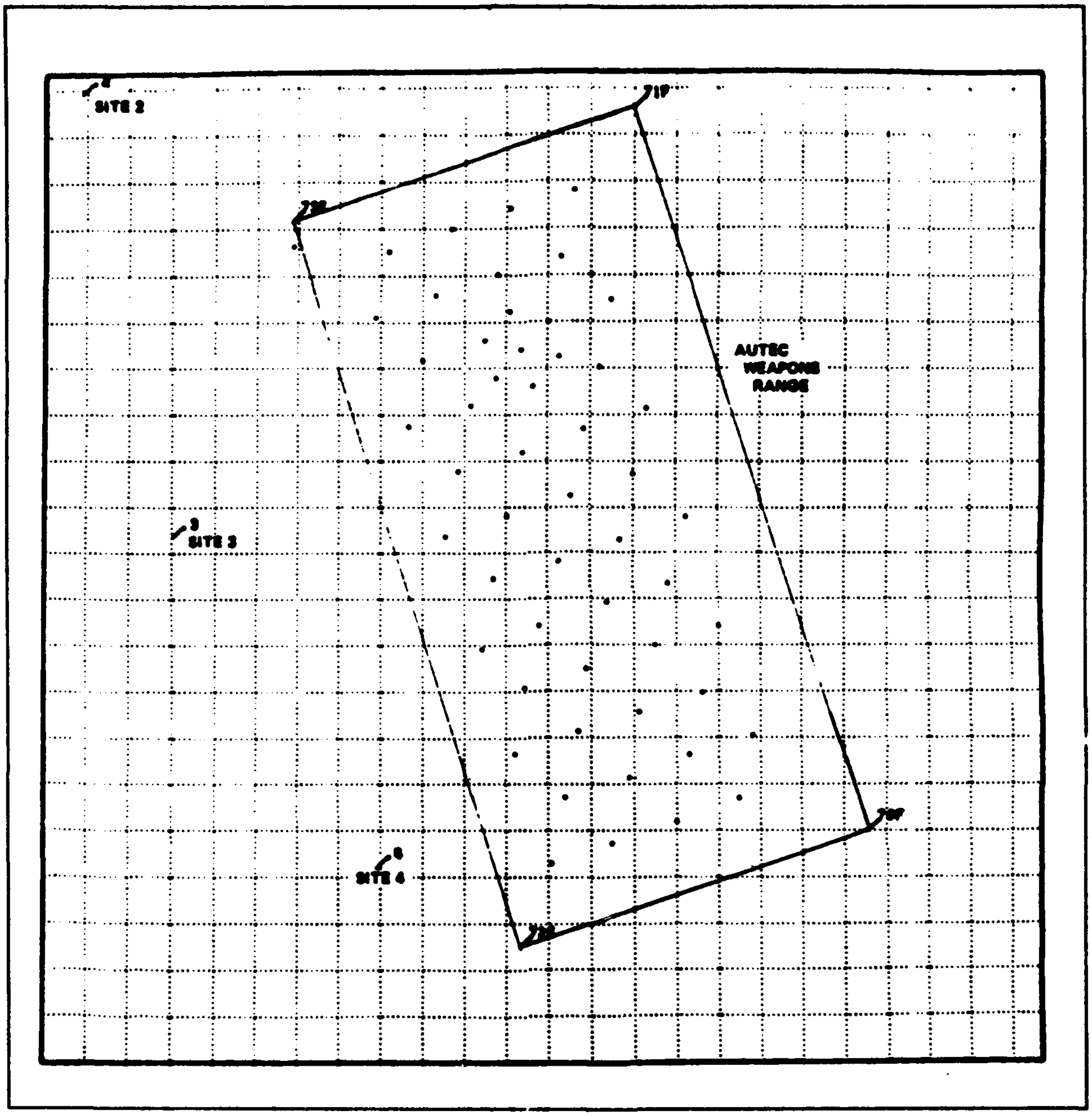

Figure 1. AUTEC STS system geometry.

Results of testing and analyses are presented in paragraph 7, which is organized by subject rather than by specific test. Paragraph 7.1 deals with STS accuracy in tracking sonobuoys and properly equipped range vessels and proceeds chronologically. Paragraphs 7.3 through 7.13 cover various topics resulting from the tests and analyses; they are based on or applicable to more than a single test.

4.0 CONCLUSIONS

As previously reported, the STS satisfied all SAT requirements. System accuracy estimates proved significantly better than specified accuracy requirements. Based on SAT testing, post-test tracking accuracy for sonobuoys is estimated at 9 yards (1 sigma). And, during the SAT, on average, and excluding channels with radio frequency interference (RFI), more than 90 percent of the differences, post-test, between STS and the WR In-Water (I/W) system were less than 25 yards; at least 68 percent were required to be less than 25 yards. Real-time accuracy for sonobuoys is degraded by the real-time computer update rate of STS positions; update aging can impose an additional error of up to 32 yards (on a 1 knot sonobuoy) in real-time displays.

Real-time relative position computations for a pair of targets avoid the update aging problem by time-correlating the data from the two targets. Time-correlating is accomplished through extrapolation and is, therefore, subject to extrapolation errors. Such errors were not evaluated for this report.

The STS was designed for tracking sonobuoys. There were no SAT requirements for tracking targets with higher dynamics, nor have any requirements for such tracking been placed on the system since the SAT. However, because of considerable interest in this latter area for several reasons, acceptance testing since the SAT included several experiments in tracking range vessels with the STS.

Based on these experiments, it is estimated that post-test tracking accuracy for properly equipped range craft can be as good as 11 yards (1 sigma) under certain specific conditions. Real-time accuracy for boats is degraded by the real-time computer update rate of STS positions, which can impose an additional error of up to 410 yards (on a-13 knot boat) in real-time displays because of the aging of position updates. Errors highly correlated with boat speed and acting as a time bias between STS and I/W were shown (by OAT and post-OAT test results) to be caused by velocity clipping within the STS Kalman filter subroutine. Temporarily relaxing this clipping for the post-OAT test led to the 11-yard accuracy.

There appears to be a relatively small position bias (3-5 yards) between STS and I/W (based on SAT and post-OAT tests); this bias is included in the above accuracy estimates. (This bias was somewhat larger 7 yards, for Sonobuoy Simulator Vehicle (SSV) tracking during the SAT.)

The site 4 PARGOS transmitter (100 W on 142 MHz) should be secured during any operations requiring STS support. The STS channels having RFI during pretest clear-channel checks should be avoided during operations. During the SAT, the STS was shown to be unaffected by the AUTEC acquisition and track radars.

It is possible that any significant changes in large natural features or man-made facilities in the vicinity of the STS site antennas or within their RF propagation paths could degrade the existing system calibration. Recalibration will involve

(a) a repeat of the extensive exercise conducted on the WR in early 1990, and

(b) extensive calibration data processing (performed in 1990 by the STS vendor) with vendor-delivered software which has not yet been used by AUTEC personnel.

If the velocity clipping is properly set (whether automatically or manually) for a target, the 0.2° rejection criterion for root sum square (rss) of azimuth residuals is applicable (at least for now) to range boats as well as sonobuoys. If velocity clipping is left at 2.0 m/s, then boat tracking errors will be excessive and real-time editing, tailored for sonobuoys, will reject most boat track above about 4 knots.

The STS should not be committed to track beyond 14-nmi (without additional on-range testing). This excludes a 6-nmi triangular area just outside the 427 hydrophone array in the southeast corner of the rectangular region specified for accurate STS track. The STS also has azimuth limits on its system calibration.

Track initialization can only occur within certain limits, but these limitations are outside the WR. Tracking can proceed beyond these limits under certain circumstances, but if track is lost, it cannot be reinitialized there.

5.0 RECOMMENDATIONS

The SEL program used to receive and archive STS playback data from the STS computer should be modified to include the same STS data-editing algorithm as used in the SEL in the real-time. Conditional operational acceptance of AUTEC's STS is recommended, following installation and checkout of a data-editing algorithm for STS playbacks.

Operational acceptance should be conditional pending receipt from the vendor of all documentation. Operational acceptance may need to be conditional, based on one or more of the following

(a) spares availability,
(b) hardware maintainability,
(c) operational efficiency,
(d) diagnostics effectiveness, and
(e) software maintainability.

These areas are left to other members of the STS OAT Committee such as Range Engineering, Operations Control, and Software Engineering.

The following enhancements should be considered

(1) The real-time STS data-editing algorithm in the SEL should be improved for sonobuoy tracking as well as for tracking range vessels (see paragraph 7.2).

(2) Range vessel tracking requires different velocity clipping (and perhaps other parameters such as prefilter editing) in the STS computer than is required for sonobuoys. With some software modification, proper selection of these parameters could be made automatically from a parameter file using the target "type" designation (see paragraph 7.3).

(3) A more "permanent" portable sonobuoy simulator (to overcome certain limitations of the SRT-22) is needed if the system is to be routinely used to track range vessels (see paragraph 7.8).

(4) The AUTEC real-time post-test processing software continues to move away from the need for periodic data. (Apparently, the only software, real-time or post-test, requiring periodic data is the post-test processing program RTOUT.) When the need for periodic data no longer exists, the 30-second STS "B" data should be discontinued in favor of the exclusive use of the aperiodic "b" data (see paragraph 7.9).

(5) Faster playback rates into the host computer are needed. Based on the STAT, the limiting factor is not the STS (see paragraph 7.10).

(6) Position sigmas produced by the STS probably should be revised (see paragraph 7.11).

(7) The quantity "VAL," currently in the STS data packet sent to the SEL, should be read and archived (see paragraph 7.12).

(8) A receptacle should be permanently located in the observation area of both operation rooms where an STS monitor can be temporarily connected for certain special tests. (For such special tests in one of the operation rooms, the monitor, if not in use, would come from the other operation rooms.)

6.0 TESTS CONDUCTED

This paragraph briefly identifies the various tests from which data were collected to satisfy OAT objectives. As discussed in paragraph 2.0, these tests include those conducted under the SAT as well as those conducted under the OAT. Paragraph 7.0 provides results of the tests and the associated analyses.

6.1 SAT Tests

Some of the on-range portions of the SAT required the use of a Sonobuoy Simulator Vehicle (SSV) to provide adequate spatial coverage of the WR as well as adequate coverage of the sonobuoy VHF frequencies. The SSV is discussed in paragraph 7.13.

The SAT tests were conducted during 21-30 May 1990. They are described in more detail in the reference 2 SAT Plan. The OAT tests are described in paragraph 6.2. Test results are discussed in paragraph 7.

6.1.1 SSV Tracking Test

This test demonstrates STS performance and tracking accuracy over the WR (up to 14 nmi from the STS sites) for all 99 sonobuoy VHF frequencies. The SSV was tracked by the STS and the I/W acoustic system while being towed by AUTEC's LCU-1647 along three straight parallel legs running the length of the WR (see figure 2). During each track, a different set of 40 sonobuoy channels was to be tracked, and the channels selected so that the three legs would cover all 99 channels. Test objectives and the operational plan are given in detail in paragraph 7.1 of reference 2.

Results of this test are reported in subparagraph 7.1.1.1 and paragraph 7.4.

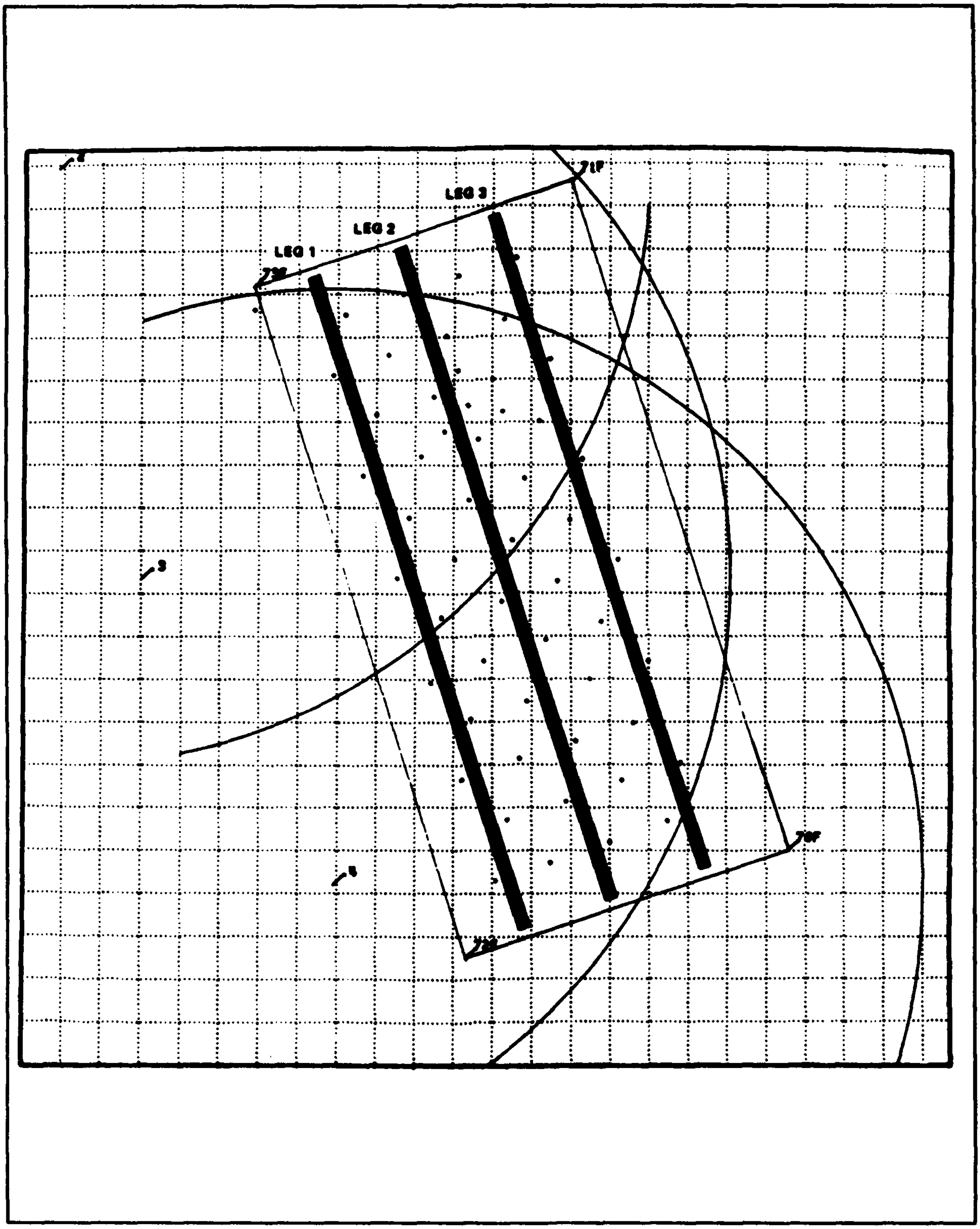

Figure 2. Track for the SSV tracking test.

6.1.2 Sonobuoy Test

This test demonstrates STS performance and accuracy under a maximum STS tracking load of 40 actual sonobuoys all 4 required types: AN/SSQ-53, -57, -62, and -77.

The 44 sonobuoys (40 plus 4 in-water spares) were to be deployed within range of all 3 STS receiving sites (see figure 3) to provide a maximum tracking load. Six of the sonobuoys were to be tethered to a JETTS (an MK-72 acoustic pinger with its own flotation and battery-pack) to provide a tracking reference from the WR I/W system. Tether length selection as a tradeoff between minimizing buoy/pinger separation and minimizing short-term effects on the way the sonobuoy and its antenna rode in the water.

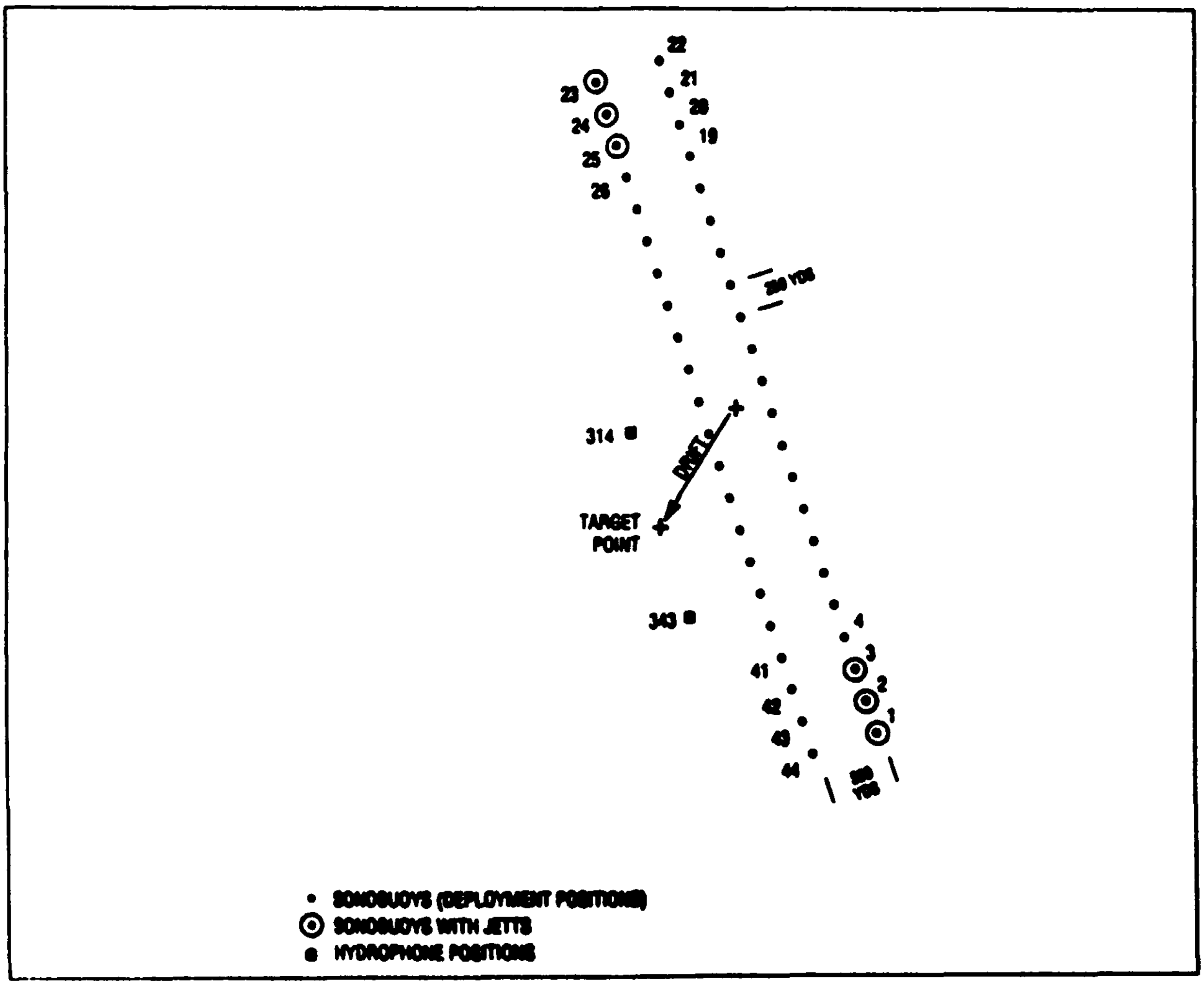

Figure 3. Sonobuoy deployment for the 40 sonobuoy test.

Test objectives and the operational plan are given in detail in paragraph 7.2 of reference 2. Results of this test are discussed in subparagraph 7.1.1.2 and paragraph 7.4.

6.1.3 Playback Tests

This test verifies that data archived by the STS can be played back and that the resulting playback TX files on the SEL computer are virtually identical to the real-time TX files.

The test involved playing back two selected data spans, each with the STS computer set for RECOMPUTE ON (solution recomputed from archived raw data) and RECOMPUTE OFF (archived real-time solutions played back). One of the data spans started at the beginning of the data tape; the other started well into the same tape.

Test objectives and the operational plan are given in detail in paragraph 7.3 of reference 2. Results of these tests are reported in paragraphs 7.4 and 7.10.

6.1.4 Sonobuoy Maximum Range and Accuracy Test

This test demonstrates STS capability to track sonobuoys at least 14 nmi from each STS site and evaluates STS performance and accuracy with sonobuoys at the best and worst STS geometries.

From 6 to 7 sonobuoys were to be deployed at each of 4 zones within the WR (see figure 4). Zones 1 and 3 were arranged to evaluate the 14 nmi requirement; zones 2 and 4 were chosen to evaluate accuracies at the best and worst system geometries. In zones 2 and 4, 4 of the 6 sonobuoys were tethered to JETTS pingers to provide a tracking reference from the WR I/W system. The other two sonobuoys in each of these zones were tethered together.

Test objectives and the operational plan are given in detail in paragraph 7.4 of reference 2. Results of this test are provided in subparagraph 7.1.1.2 and paragraph 7.4.

6.1.5 Calibration Data Test

This test demonstrates that STS calibration tables can be printed, that selected cells in the tables can be listed, and that selected data in the tables can be modified. The test consisted of making the appropriate listings and temporary modifications. Some additional detail is provided in paragraph 8.0 of reference 2. Test results are reported in paragraph 7.4.

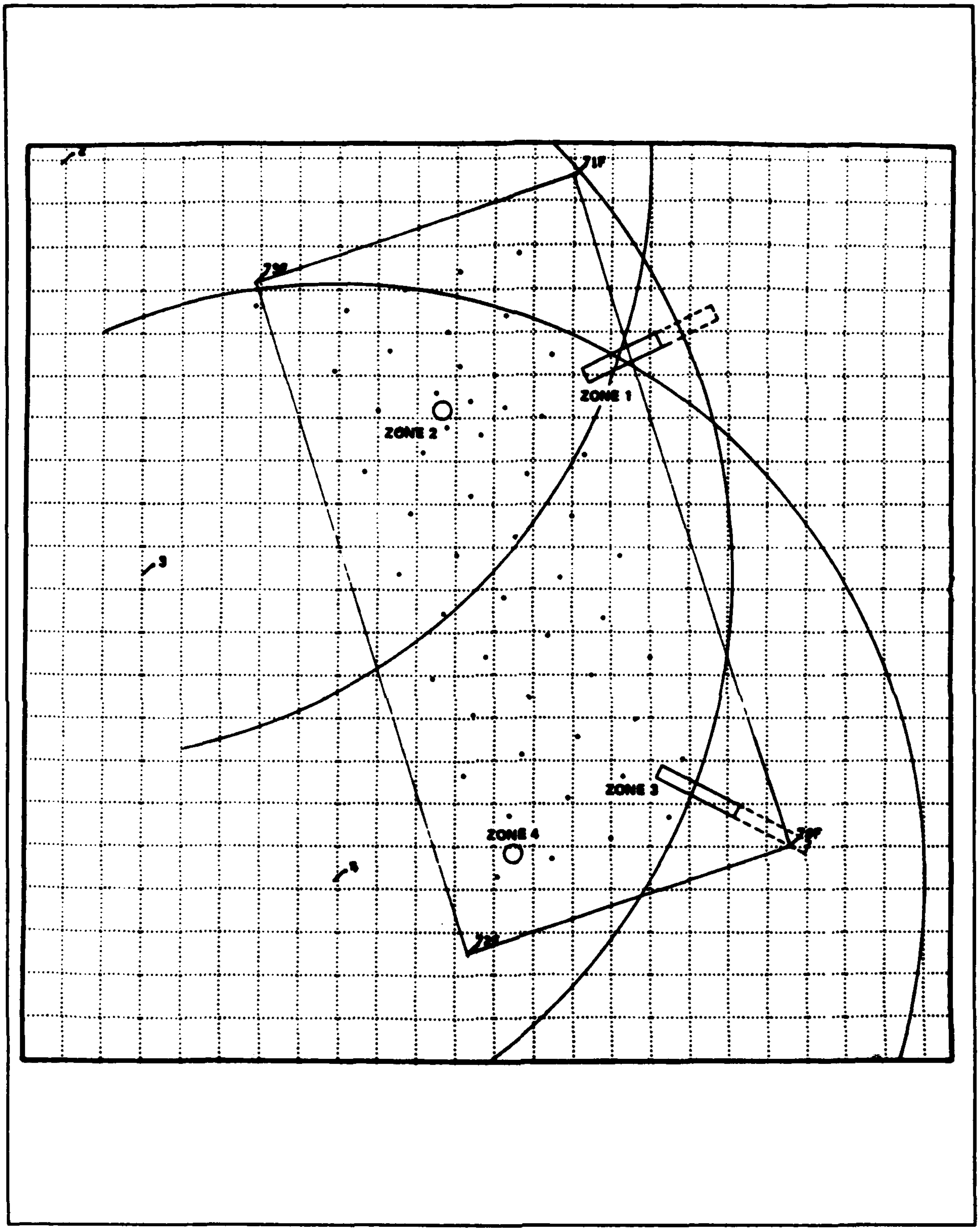

Figure 4. Sonobuoy deployment for maximum range/accuracy test.

6.1.6 Radar Interference Test

This brief test was conducted to determine what effects, if any, AUTEC's acquisition and tracking radars would have on the STS equipment or its tracking capability.

The test consisted of rotating ACQ radars at sites 2 and 3, then turning on and aiming the 2A track radar directly at the nearest STS antenna and at the STS equipment hut at site 2, while the STS was tracking 5 SSV channels. Some additional test details are provided in appendix 1 of the reference 2 plan. Results of this test are reported in paragraph 7.6.

6.1.7 Initialization Limits Tests

Three separate demonstrations were conducted during the SAT to evaluate the effects of limits in the STS software on track initialization. They are described in detail in appendix 2 of the reference 2 plan. Results of these tests are reported in paragraph 7.7.

6.1.8 Post-SAT Tests

On 26 July 1990, AUTEC conducted a brief post-SAT test, following "final" software installation by the STS vendor. The test objective was to obtain a quick-look check that the STS could perform at least as well as during the May 1990 SAT. The test consisted of the STS tracking two sonobuoys, with JETTS attached, in the site 3 hydrophone area of the Weapons Range (W3) for approximately 1 hour as well as a check of a playback anomaly noted during the SAT (see paragraph 7.4). Results of this test are reported in paragraph 7.5.

On 31 July 1990, a brief on-range test was conducted to checkout STS data handling by the SEL computer following a SEL software modification (Build 2.4.B.10). The test consisted of the STS tracking a portable sonobuoy simulator (model SRT-22-AT12900) aboard the TR-825. The TR-825 maneuvered on the Weapons Range at various speeds and headings for approximately 1.5 hours. Results of this test are discussed in paragraph 7.1.2.

6.2 OAT Tests

As discussed in paragraph 2.0, tests conducted under both the SAT and the OAT provided data to satisfy OAT objectives. This paragraph identifies those tests conducted under the OAT itself. Because of the extensive nature of the SAT tests, it was possible to design the OAT tests to address only certain specific factors, as discussed in the following subparagraphs.

6.2.1 On-Range Test

Objectives of the on-range OAT test, conducted on 22 October 1990, investigated system biases which had been observed during the SAT and during the 31 July 1990 boat test (post-SAT test) with a portable sonobuoy simulator (SRT-22), and it further evaluated STS system accuracy in tracking targets with higher dynamics than sonobuoys.

This test consisted of the STS tracking four portable sonobuoy simulators on the TR-825 which ran a variety of boat dynamics around a square pattern in W3, while also tracking various numbers of sonobuoys deployed in the site 4 hydrophone area of the Weapons Range (W4).

Test objectives and the operational plan are given in detail in the reference 3 of the OAT Plan.

Results of this test are reported in subparagraph 7.1.2.2. A discussion of the Portable Sonobuoy Simulator, SRT-22 is provided in paragraph 7.8.

6.2.2 Replay Tests

As part of the OAT, systems analysis defined a number of replays of SAT and post-SAT data to study several items of interest related to the OAT. These included investigation of velocity clipping in the Kalman Filter subroutine in the STS tracking software, investigation of two distinct biases noted during the SAT and post-SAT tests, and evaluation/optimization of STS data edit criteria for the SEL computer.

As discussed in paragraph 7.10, most of these replays were not or could not be made.

6.2.3 Post-OAT Test

Because of several STS raw data tapes being inadvertently erased, an additional test was conducted to repeat the last cycle of the square boat track pattern of the OAT test. The test objective was to further investigate STS errors which were highly correlated with speed. The test consisted of the STS tracking two SRT-22s on the RANGEMASTER (R/M) (TR-501) while twice repeating the last cycle of the OAT in W3. Test objectives and the operational plan are given in reference 4 on the post-OAT plan. Results from this test are discussed in subparagraph 7.1.2.3.

7.0 RESULTS

7.1 STS Tracking Accuracies

7.1.1 Sonobuoy Tracking Accuracy

It may be helpful to recall that sonobuoy frequencies range from 136 to 173.5 MHz (VHF). Sonobuoy channels 32 through 99 are the lower frequencies; channels 1 through 16 and 17 through 31 are interleaved and are the higher frequencies. Channel 32 is the lowest; channel 16 is highest.

It also may be helpful to recall the SAT accuracy requirement: 68 percent of the horizontal position differences between STS and I/W were required to be less than 25 yards. The STS not only satisfied this requirement, it proved to be considerably better.

During the SAT (defined in paragraph 6.1), the STS tracked the SSV (see paragraph 7.13) as well as actual sonobuoys. The STS accuracies tracking the SSV and sonobuoys are discussed in subparagraphs 7.1.1.1 and 7.1.1.2.

7.1.1.1 Accuracy Tracking the SSV

The Sonobuoy Simulator Vehicle was towed along three straight parallel courses (legs) which ran the length of the WR (*see figure 2*).

It was planned to have the SSV transmit on 40 channels selected for each leg of the test in such a way that all 99 sonobuoy frequencies would be used at least once. Leg 1 ran for approximately 8 hours and all 40 of its channels were used. The two segments of leg 2, run on two different days, lasted a total of approximately 5 hours. Because of a problem with the SSV, leg 3 was not run in automatic mode. As a result, 16 channels were selected for running individually in the manual mode for 10 minutes at a time. (The 16 channels chosen were those not used during legs 1 and 2, minus those with RFI.) All of these 16 channels were repeated for a second 10 minutes each, and 6 were repeated for a third 10 minutes each. The result was that 95 of the 99 frequencies were used during the SAT SSV tracking test. As reported in paragraph 7.4, four channels were not used because of RFI.

Typical for SSV tracking, figures 5 through 7 are plots of position differences between STS and I/W as a function of time for three channels used during leg 1. Figures 5a through 5d show the differences for channel 16 the highest sonobuoy frequency, and are typical of good clean track with virtually no RF interference (RFI). Statistics on horizontal position differences for this channel are mean = 7.9 yards, circular standard error = 6.6 yards, and total RMS radial error = 10.3 yards.

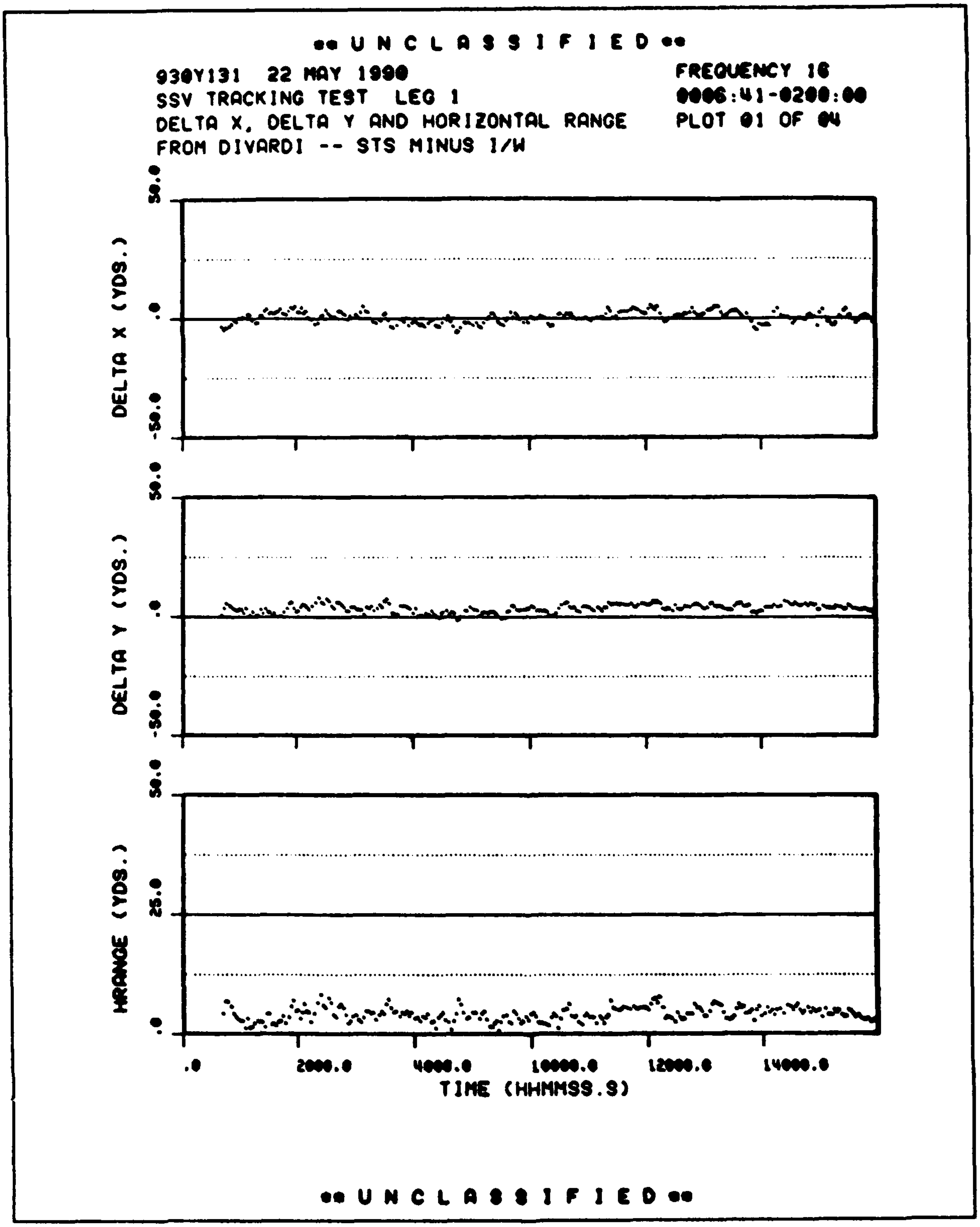

Figure 5a. SAT SSV tracking test, STS minus I/W, channel 16.

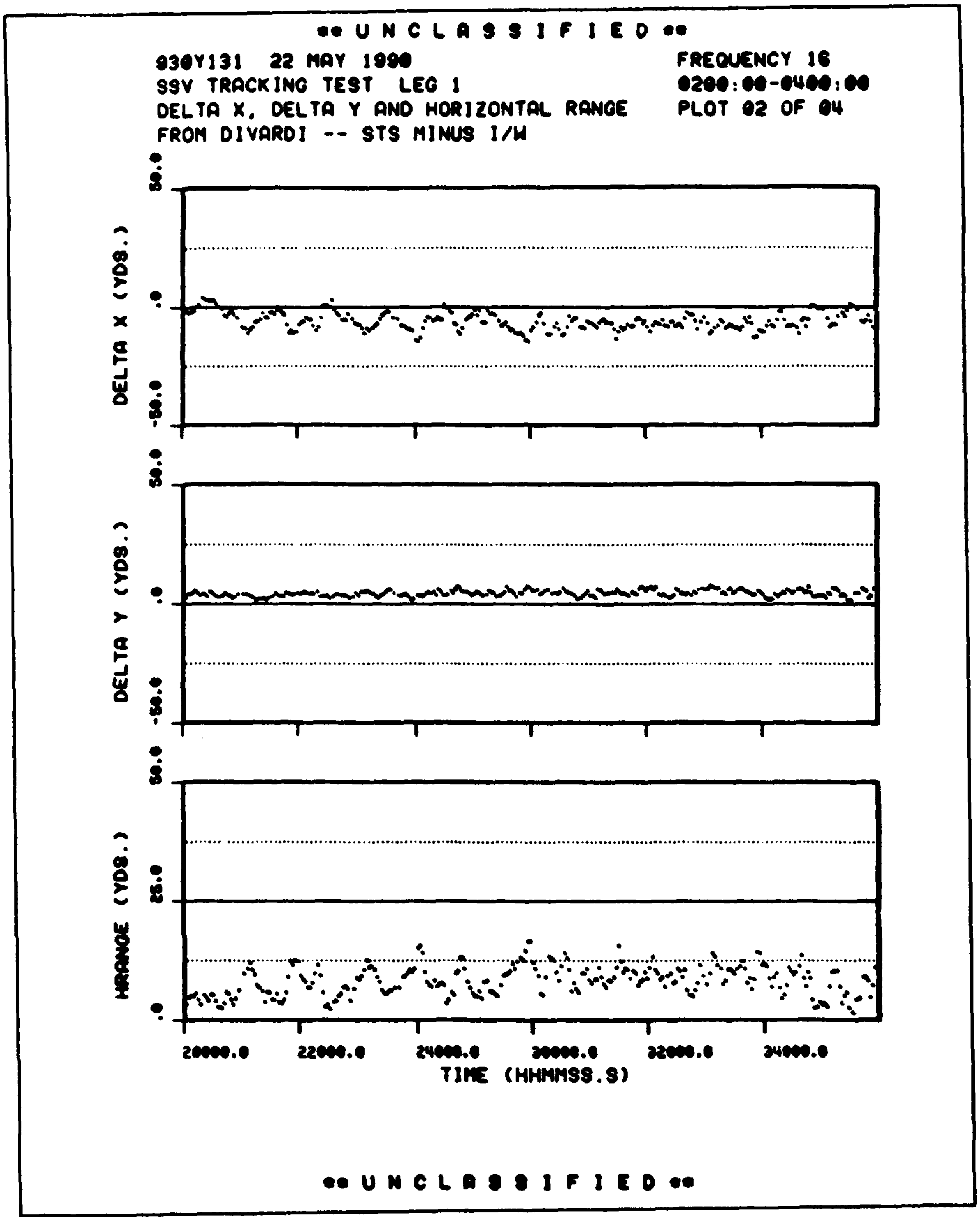

Figure 5b. SAT SSV tracking test, STS minus I/W, channnel 16.

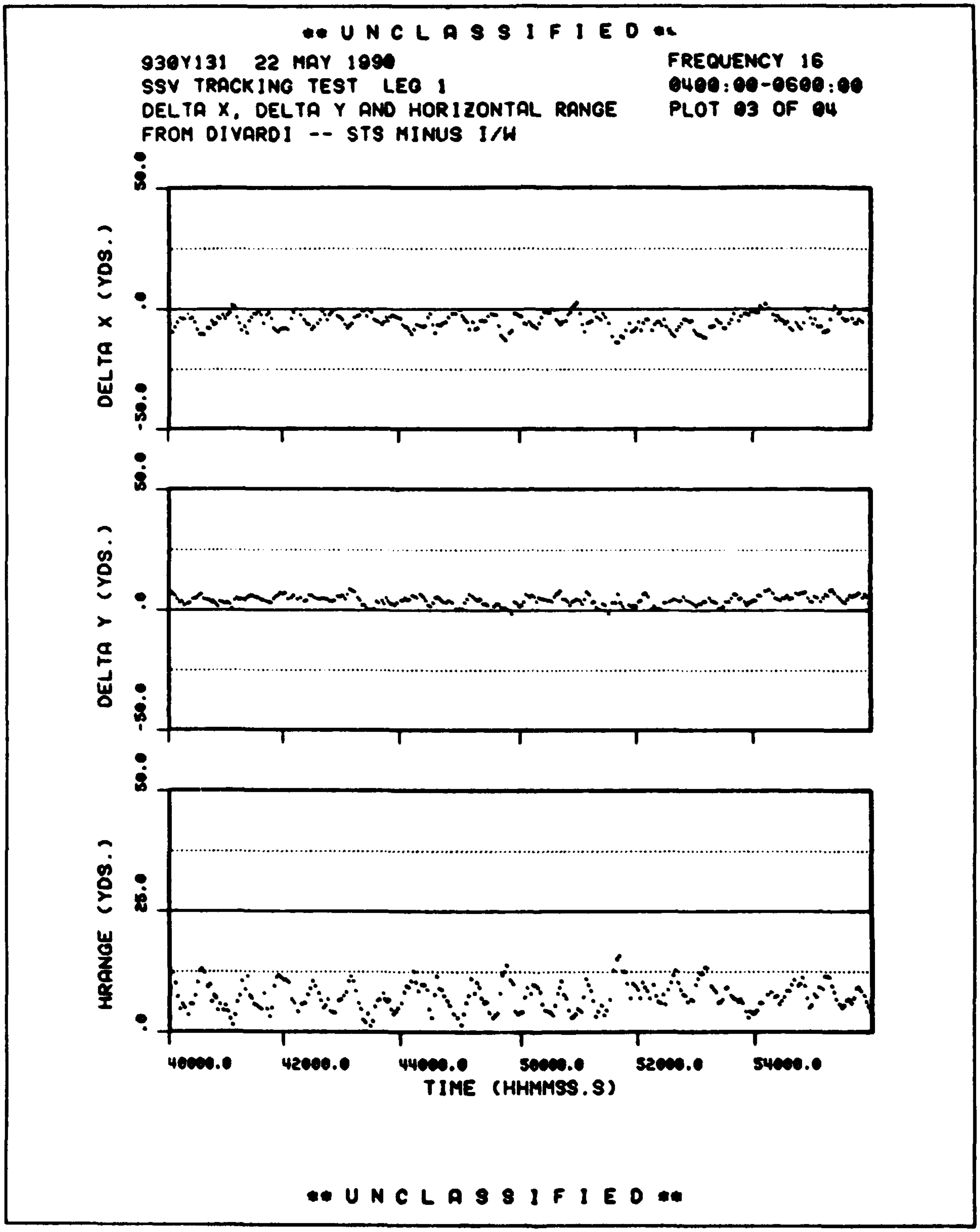

Figure 5c. SAT SSV tracking test, STS minus I/W, channel 16.

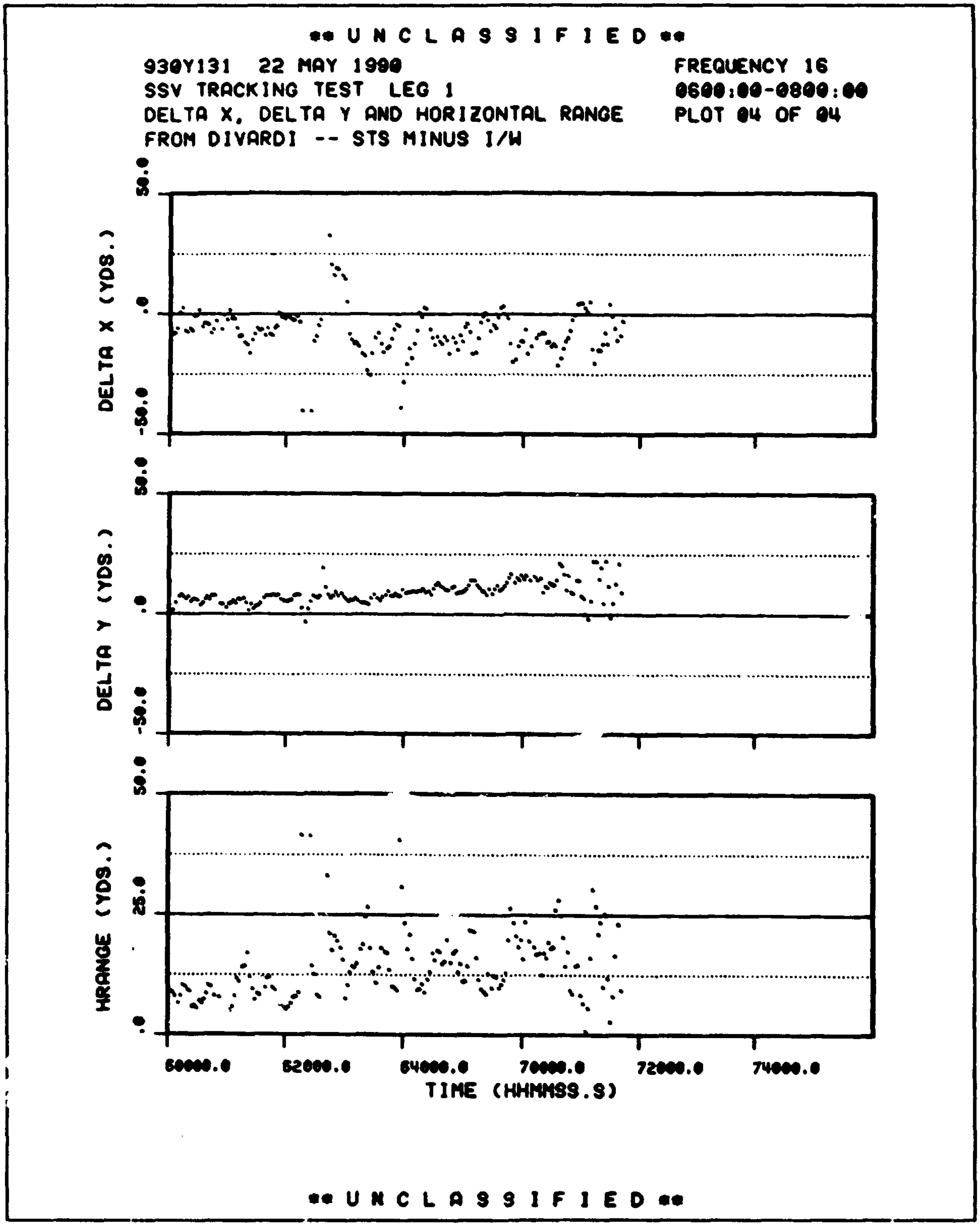

Figure 5d. SAT SSV tracking test, STS minus I/W, channel 16.

Figures 6a through 6d for channel 39, a low-sonobuoy frequency, also illustrate good track but with occasional spikes because of STS rather than I/W. While this spiking did not jeopardize meeting the STS accuracy requirement, the vendor was asked to examine whether this spiking could be reduced by additional or refined prefilter data editing/rejection. As noted in paragraph 7.4, the vendor reported that he could not make any improvement. Figures 7a through 7d for channel 77, a mid-range frequency, show the effects of severe RFI.

Table I lists the percentage of STS-I/W differences which are less than the 25 yard accuracy requirement for each segment of the SSV test. As can be seen, the system performed significantly better than the 68 percent requirement. Deleting several channels because of RFI per test-segment as shown, 96 percent of the differences were within 25 yards. Even with no data deleted, 93 percent of the differences were within the requirement.

Accuracy estimates based on the STS tracking the SSV are listed in table II. Estimates of bias (mean), variation about the mean (circular standard error of CSE), and total RMS radial error are shown for each of the three legs and for all three combined (pooled estimates).

The error estimates in this table and several following tables are defined next. Bias vector components (magnitude and direction) are computed from the mean errors in X and Y (WR coordinates) in the usual manner. Circular-standard error (CSE) is a 1 sigma circular region, computed here as the mean of the linear standard errors in X and Y. Total RMS radial error is computed at the RMS of the radial errors in the X, Y plane.

Estimates in the upper portion of table II labeled "Cursory Editing Only" are based on post-test rejection of differences between STS and I/W exceeding 200 yards. This usually involved rejecting obviously wild points with differences of thousands of yards, but there were occurrences of differences of several hundred yards. Approximately 2 percent of the data were rejected for the upper portion of table II.

The SAT was conducted in May 1990, prior to incorporating any automatic STS data editing algorithms. (An algorithm now in use for automatic data editing is discussed in paragraph 7.2). Therefore, estimates in the lower portion of table II labeled "Automatic Editing (Predicted)" are based on the projected or predicted effect than an automatic editing algorithm might have had. This very brief, subjective prediction consisted of omitting those tracking channels that appeared to contain a significant number of data points which might be excluded by an automatic data-editing algorithm (rather than the prohibitively laborious task of manually rejecting specific data points). This harsher editing hardly changed the system bias estimate of 7.3 yards but it gave a marked reduction in variation about the mean, resulting in an estimated total RMS radial error of only 13 yards.

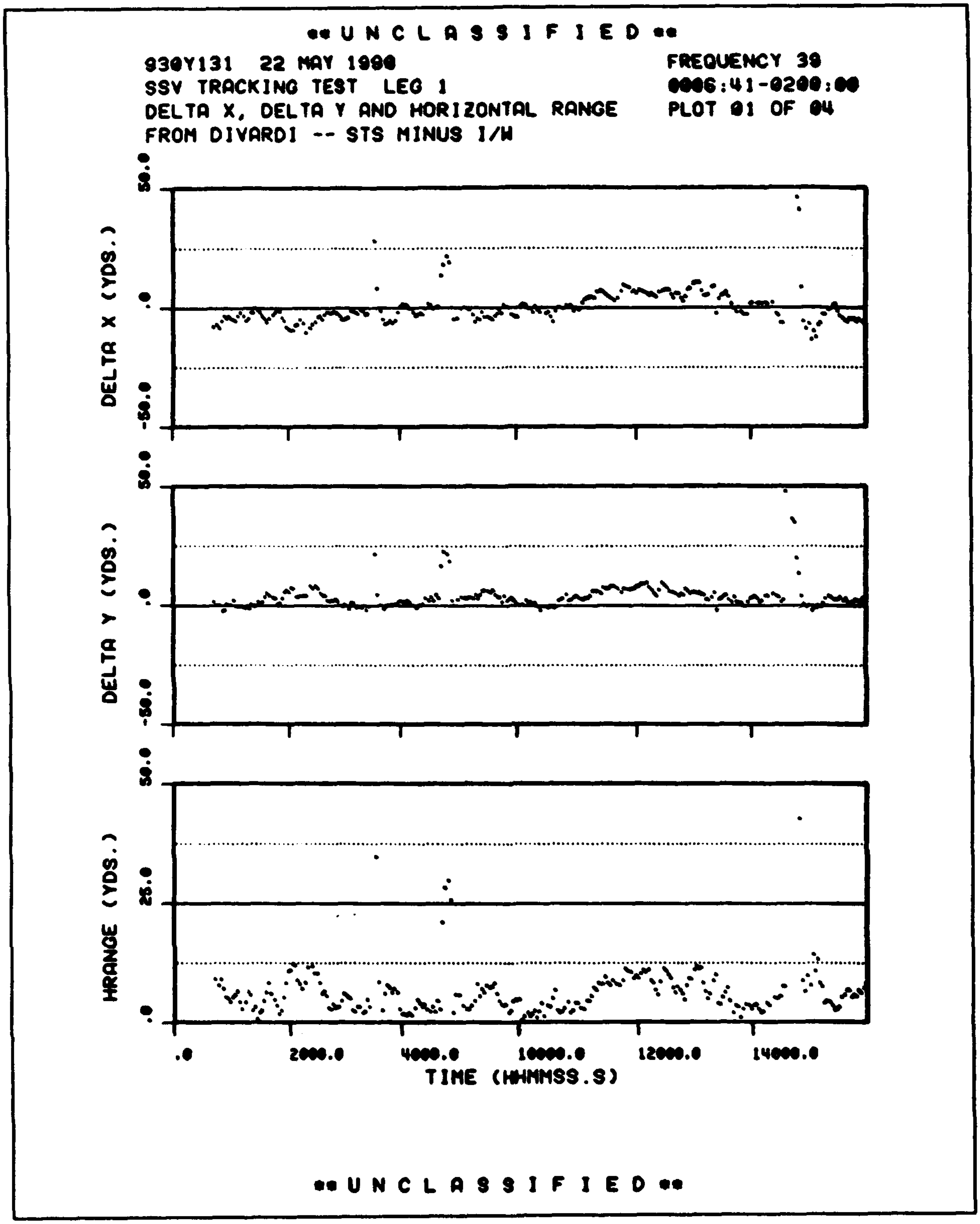

Figure 6a. SAT SSV tracking test, STS minus I/W, channel 39.

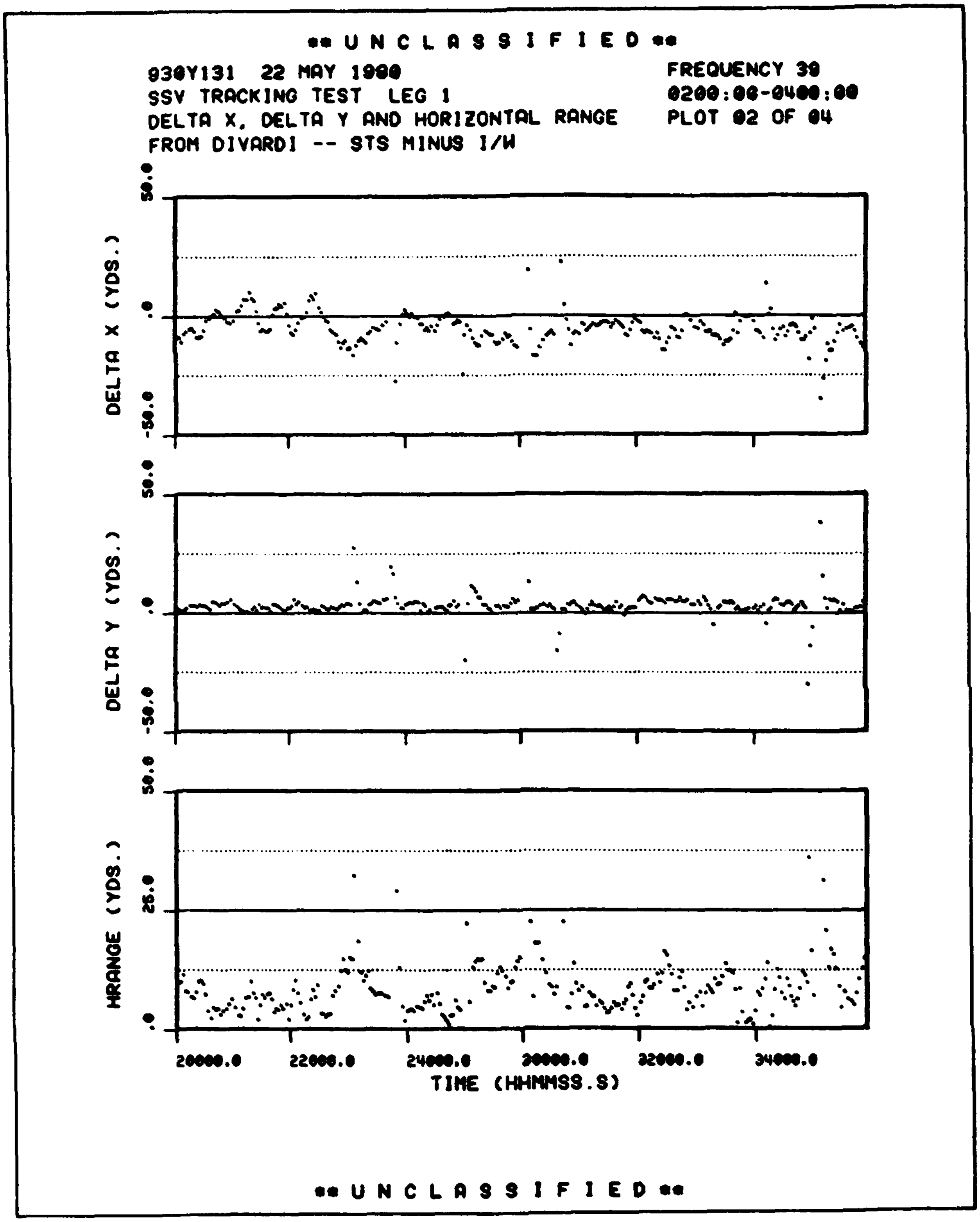

Figure 6b. SAT SSV tracking test, STS minus I/W, channel 39.

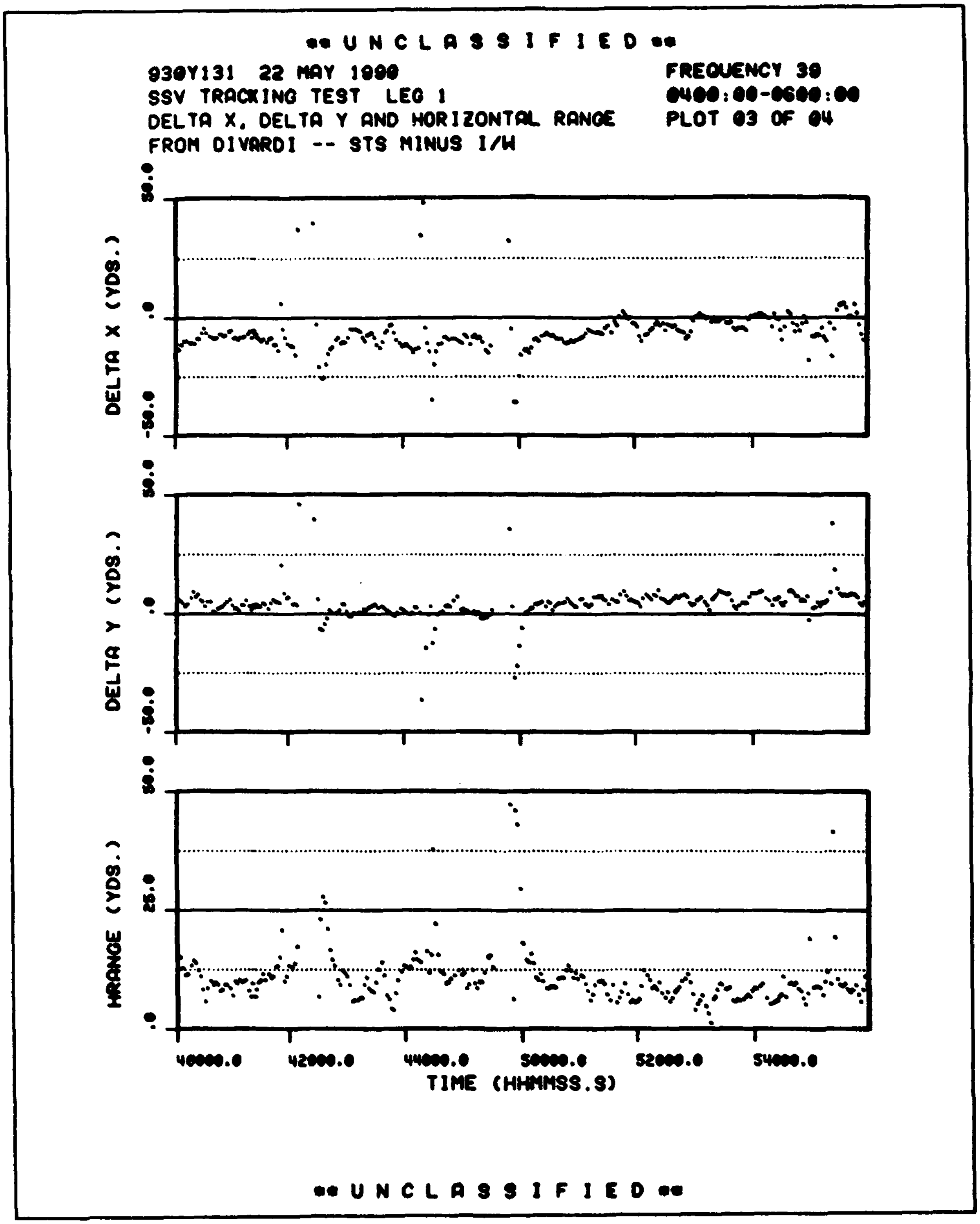

Figure 6c. SAT SSV tracking test, STS minus I/W, channel 39.

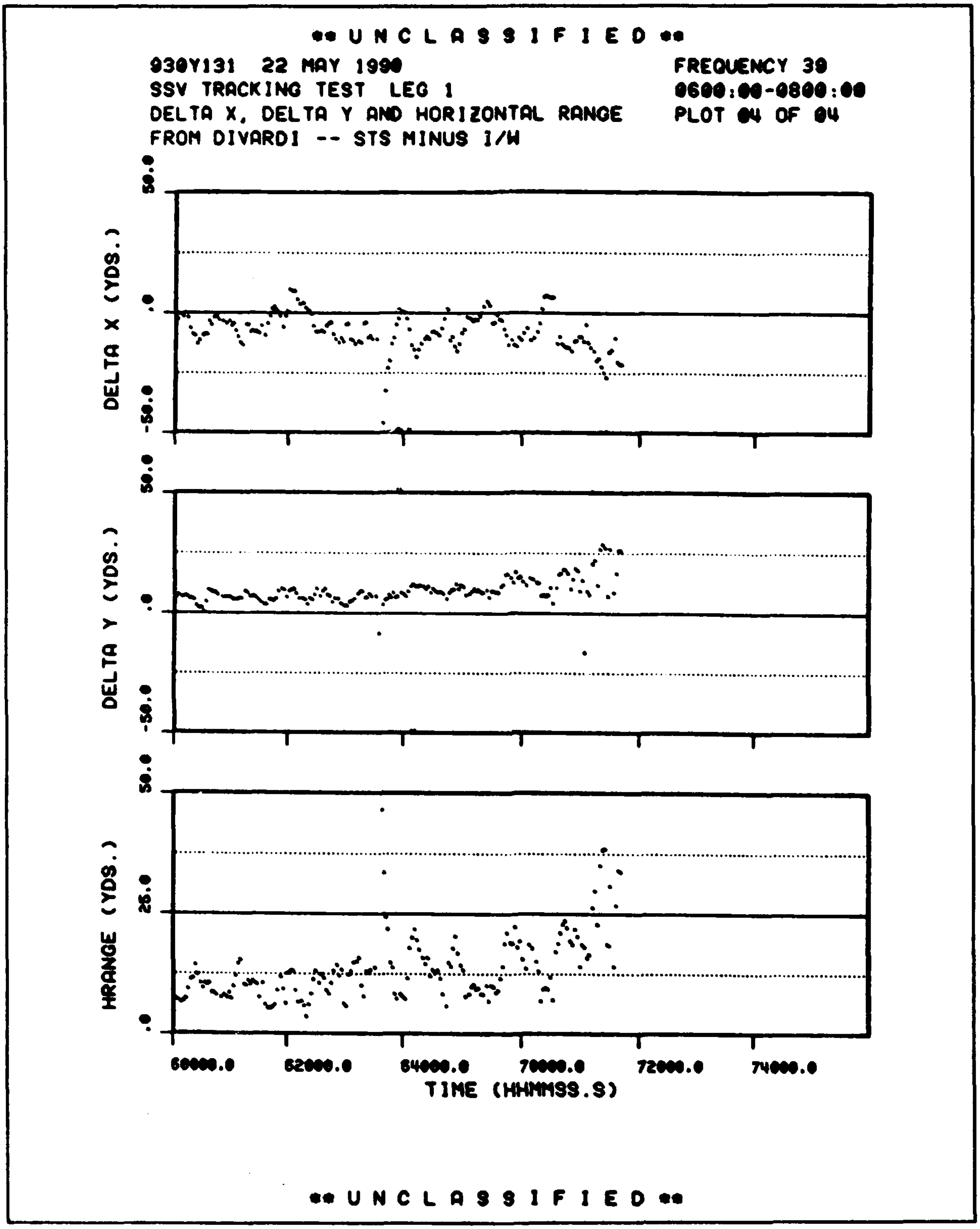

Figure 6d. SAT SSV tracking test, STS minus I/W, channel 39.

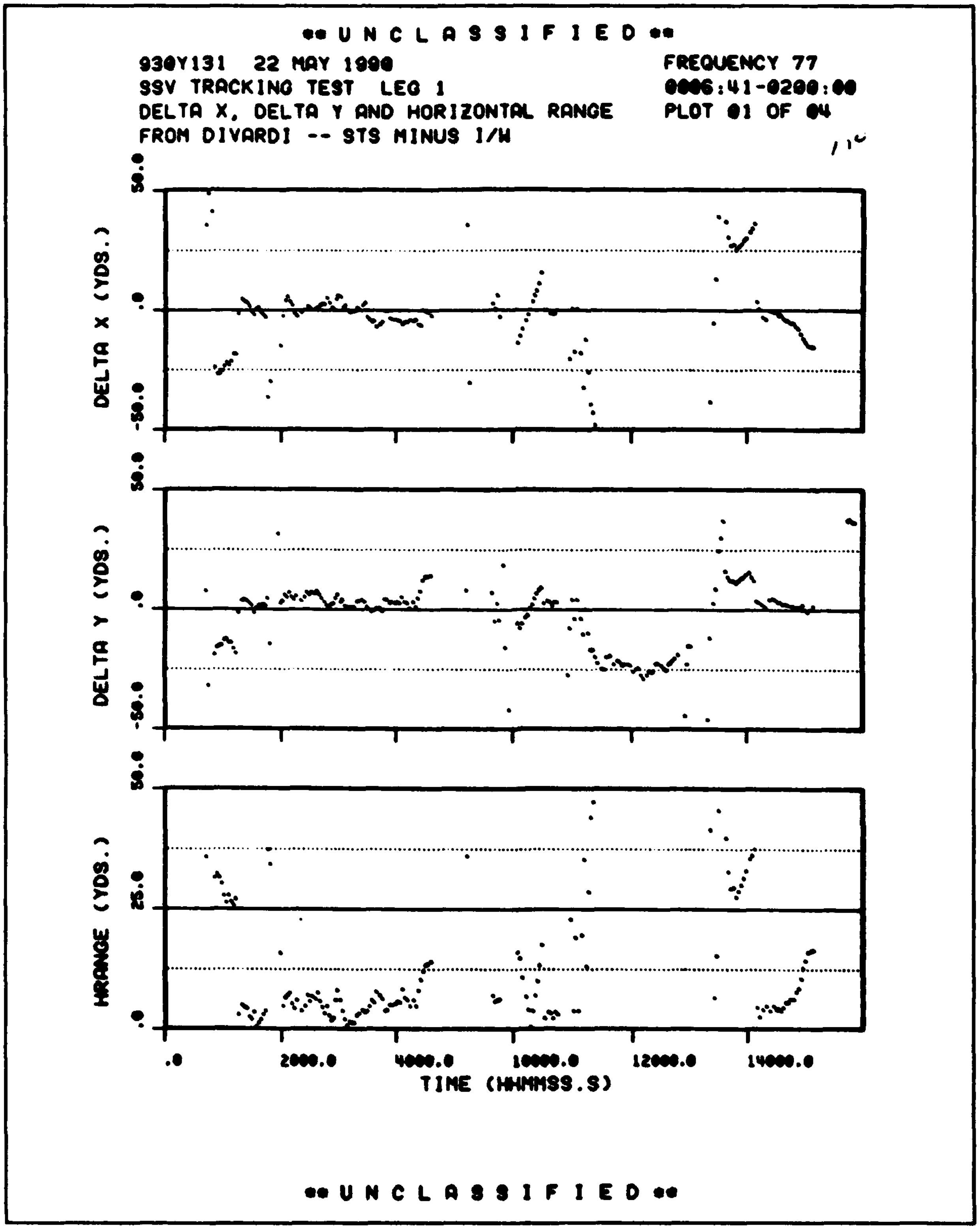

Figure 7a. SAT SSV tracking test, STS minus I/W, channel 77.

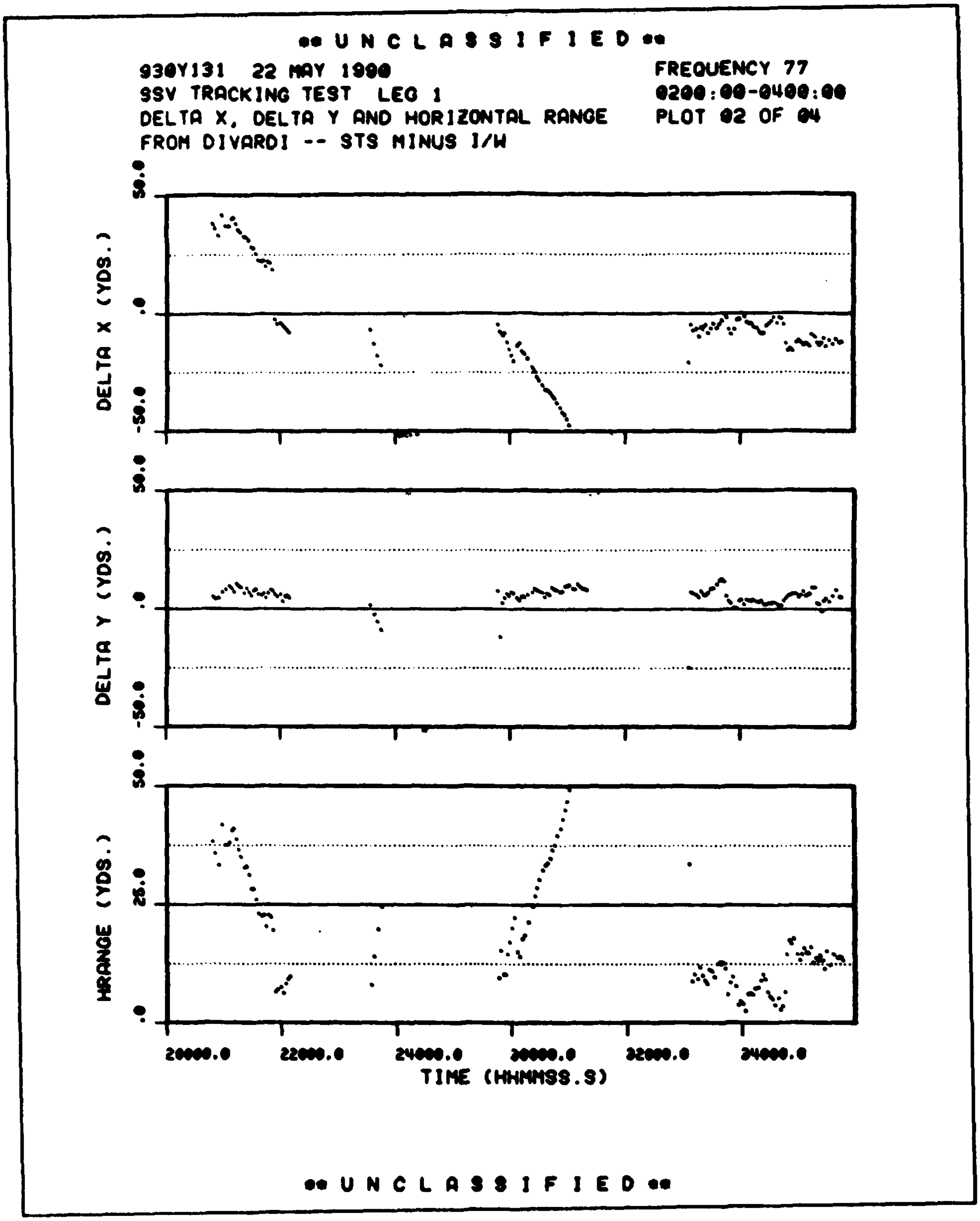

Figure 7b. SAT SSV tracking test, STS minus I/W, channel 77.

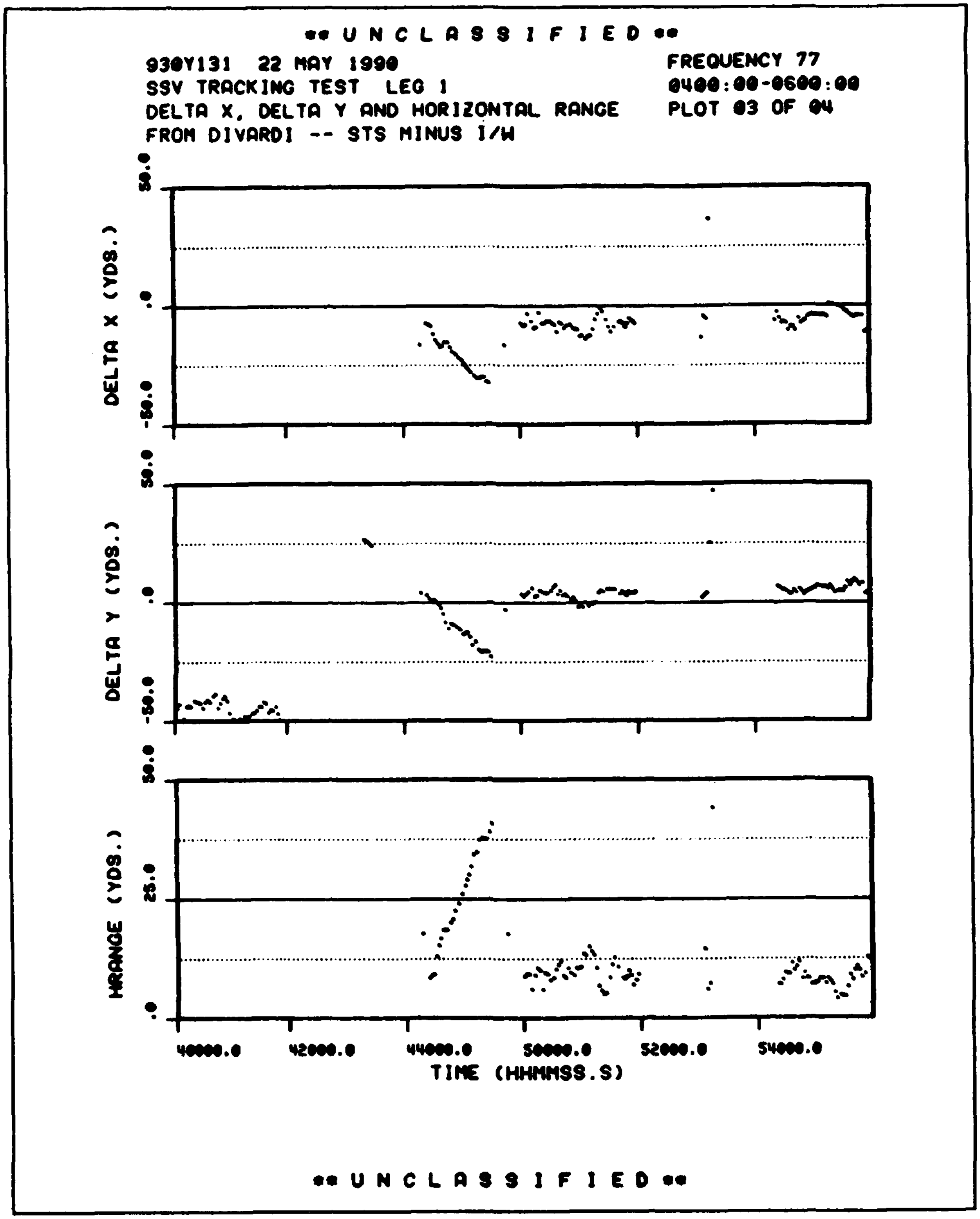

Figure 7c. SAT SSV tracking test, STS minus I/W, channel 77.

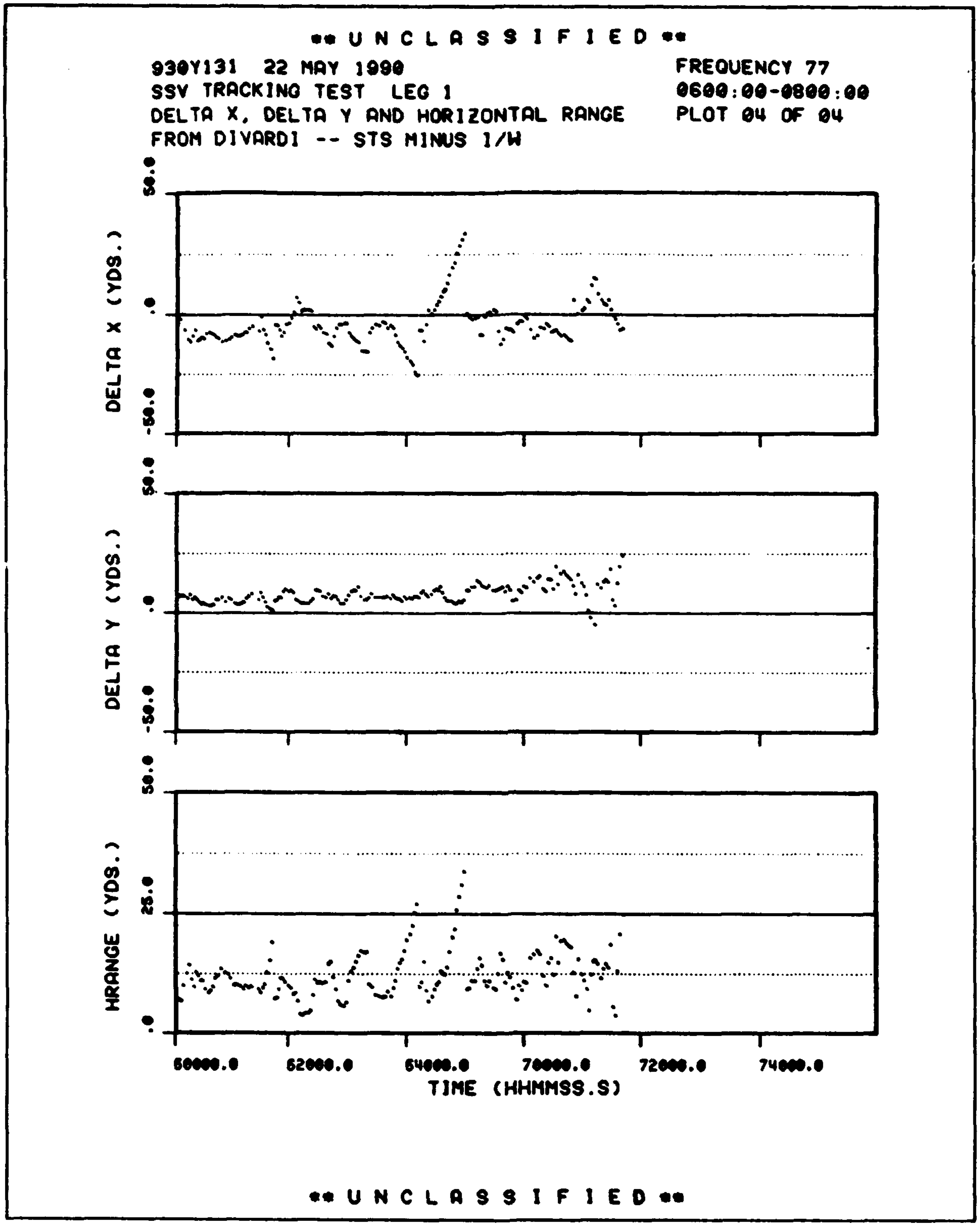

Figure 7d. SAT SSV tracking test, STs minus I/W, channel 77.

TABLE I. STS-I/W VERSUS ACCURACY REQUIREMENT, SSV				
	ALL DATA		CHANNELS OMITTED BECAUSE OF RFI	
TEST SEGMENT	WITHIN 25 YARDS	NUMBER OF CHANs USED	WITHIN 25 YARDS	NUMBER OF CHANs USED
LEG 1	94.7%	40	96.4%	38
LEG 2, PART 1	94.3%	40	97.5%	37
LEG 2, PART 2	92.5%	40	97.5%	36
LEG 3	90.6%	16	94.2%	14
ALL 3 LEGS	93.0%	--	96%	--

TABLE II. STS SITE ACCEPTANCE TEST ACCURACY RESULTS (Using the Sonobuoy Simulator Vehicle (SSV) Units: Yards, except as noted.

CURSORY EDITING ONLY (points exceeding 200 yards rejected)	LEG 1	LEG 2	LEG 3	ALL 3
Resultant Bias (Mean)	6.5	7.9	8.0	7.5
Variation About the Mean	12.0	12.3	15.2	13.3
Total RMS Radial Error	18.5	16.4	21.9	19.1
Bias Direction (Az, deg)	321	320	315	318
Number of Data Points	34,235	28,150	31,769	94,154
AUTOMATIC EDITING (Predicted) (as discussed in text)	**LEG 1**	**LEG 2**	**LEG 3**	**ALL 3**
Resultant Bias (Mean)	6.8	8.0	7.2	7.3
Variation About the Mean	8.8	9.9	6.3	8.7
Total RMS Radial Error	14.3	13.2	11.6	13.2
Bias Direction (Az, deg)	315	320	315	317
Number of Data Points	26,216	25,072	22,411	73,699

The accuracy estimates in table II are based on post-test STS data rather than real-time STS data. The differences between these two data sets are discussed in paragraph 7.9. In table II, observe how similar the bias magnitudes and bias directions (bias azimuths) leg 2, the middle leg, was run northward and legs 1 and 3 were run southward, this bias could not be due to a time bias between STS and I/W. Although the on-range calibration was intended to calibrate STS to I/W, it left STS with a 7-yard bias on the results of the SAT SSV tracking test. In spite of this, the STS proved significantly better than the SAT accuracy requirement during this test.

7.1.1.2 Accuracy Tracking Sonobuoys

Although the SSV simulates sonobuoys well, while providing required spatial and frequency coverage not practical with sonobuoys, there are differences between SSV and sonobuoy tracking: transmitter antenna height, antenna motion, and in the case of AN/SSQ-53s, -57s, -62s, and -77s. Therefore, the SAT also involved tracking actual sonobuoys including

(a) simultaneously tracking 40 sonobuoys, including all 4 sonobuoy types, within the STS 3-site coverage area (for maximum tracking load on the STS) (see figure 3);

(b) tracking 6 sonobuoys within each of zones 2 and 4, selected as the best and worst areas for STS geometrical strength (see figure 4);

(c) tracking 7 sonobuoys within each of zones 1 and 3 across the 14 nmi range limits for the 3 STS sites (see figure 4). Maximum ranges and STS coverage area are discussed in paragraph 7.7.

Fifteen of the sonobuoys in subparagraphs (a) and (b) were each tethered to a JETTS (an MK-72 acoustic pinger with its own flotation and battery-pack) to permit a comparison of STS and I/W track for these sonobuoys. A tether length of 3 yards was selected as a tradeoff between minimizing the effect of tethering on short-term buoy-antenna motion in the water and minimizing the horizontal separation between pinger and buoy antenna. Assuming this horizontal separation was uniformly distributed between ± 3 yards, the standard deviation of this separation is 1.73 yards. RSSing this with an STS standard error as small as 10 yards yields a total standard error of only 10.1 yards; even the full length of 3 yards RSSed with a 10 yard STS error yields only 10.4 yards. Thus, the effect of tether length on accuracy was, and is, considered negligible.

Figures 8 through 21 are typical real-time plots of sonobuoy tracks from STS data. Figures 8 through 13 are plots of several AN/SSQ-53s, while figures 14 through 19 are plots of SSQ-77 tracks. Real-time plots of SSQ-62s are shown in figure 20, and figure 21 shows an SSQ-57. Differences in drift rates between the -77s and the other buoys are evident in these figures, probably because of differences in their hydrophone depths. All sonobuoys were set for shallowest hydrophone depths: all less than 100 feet except the -77s at 1000 feet.

Table III refers to figures 8-12 to give a qualitative evaluation of possible effects of the JETTS pinger packages on course and speed of the sonobuoys tethered to them. In the figures, sonobuoys of interest are identified in the titles by their channel numbers; in the plots themselves, the channel numbers have an uppercase "B" suffix. As shown in table III, little or no effect on three AN/SSQ-53s was observed, but moderate to considerable effect on SSQ-77s' course and speed may have been due to the pinger packages.

Typical for sonobuoy tracking, figures 22a through 23c are plots of position differences (Delta-X, Delta-Y, and horizontal range) between STS and I/W as a function of time, for two sonobuoy channels. Figures 22a and b for channel 81, a mid-range frequency, show good, clean STS track; (statistics on horizontal position differences for this channel: mean = 6.6 yards, circular standard error = 2.5 yards, total RMS radial error = 7.0 yards). Figures 23a through 23c for channel 29, a high sonobuoy frequency, also shows good track but with some of the spiking experienced with SSV tracking, as mentioned previously and in subparagraph 7.4(a).

Table IV lists the percentage of STS-I/W differences which are less than the 25 yard accuracy requirement for each test with sonobuoys. As can be seen, the system performed significantly better than the 68 percent requirement. Deleting one channel because of RFI as shown, 97 percent of the differences were within 25 yards. Even with no data deleted, 94 percent of the differences were within the requirement.

Pooling horizontal position difference data for the sonobuoys with JETTS yields the accuracy estimates in table V. (How the various estimates in this and other tables are computed is discussed in subparagraph 7.1.1.1). Points whose differences exceeded 200 yards (3.4 percent of the data) were rejected (referred to in table V as "Cursory Editing Only"). One channel was omitted because of RFI. As in the previous paragraph on SSV tracking accuracy, a prediction of automatic editing was considered here for sonobuoy tracking, but no additional data rejection was required.

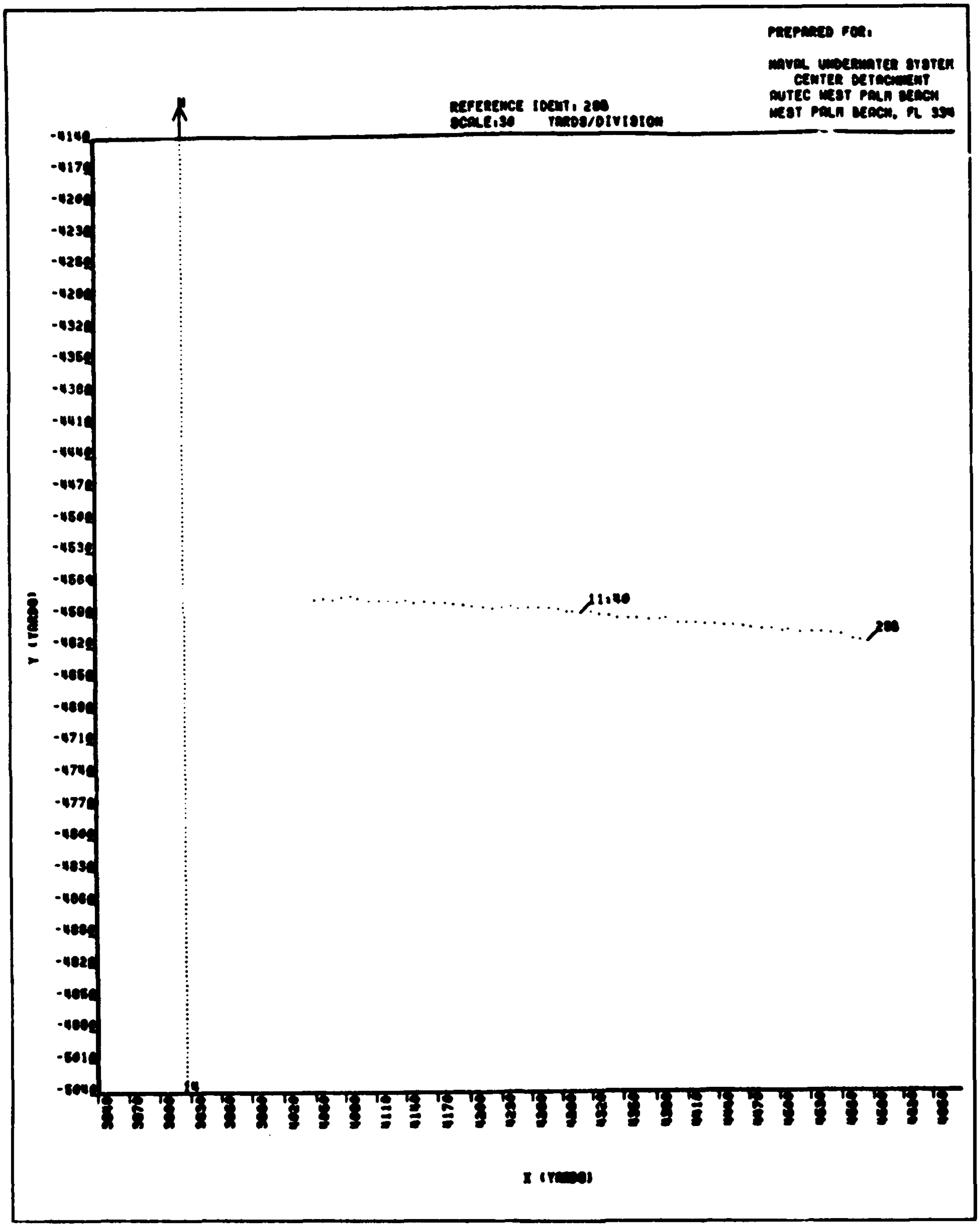

Figure 8. SAT 40 S/B test, AN/SSQ-53 track, 29.

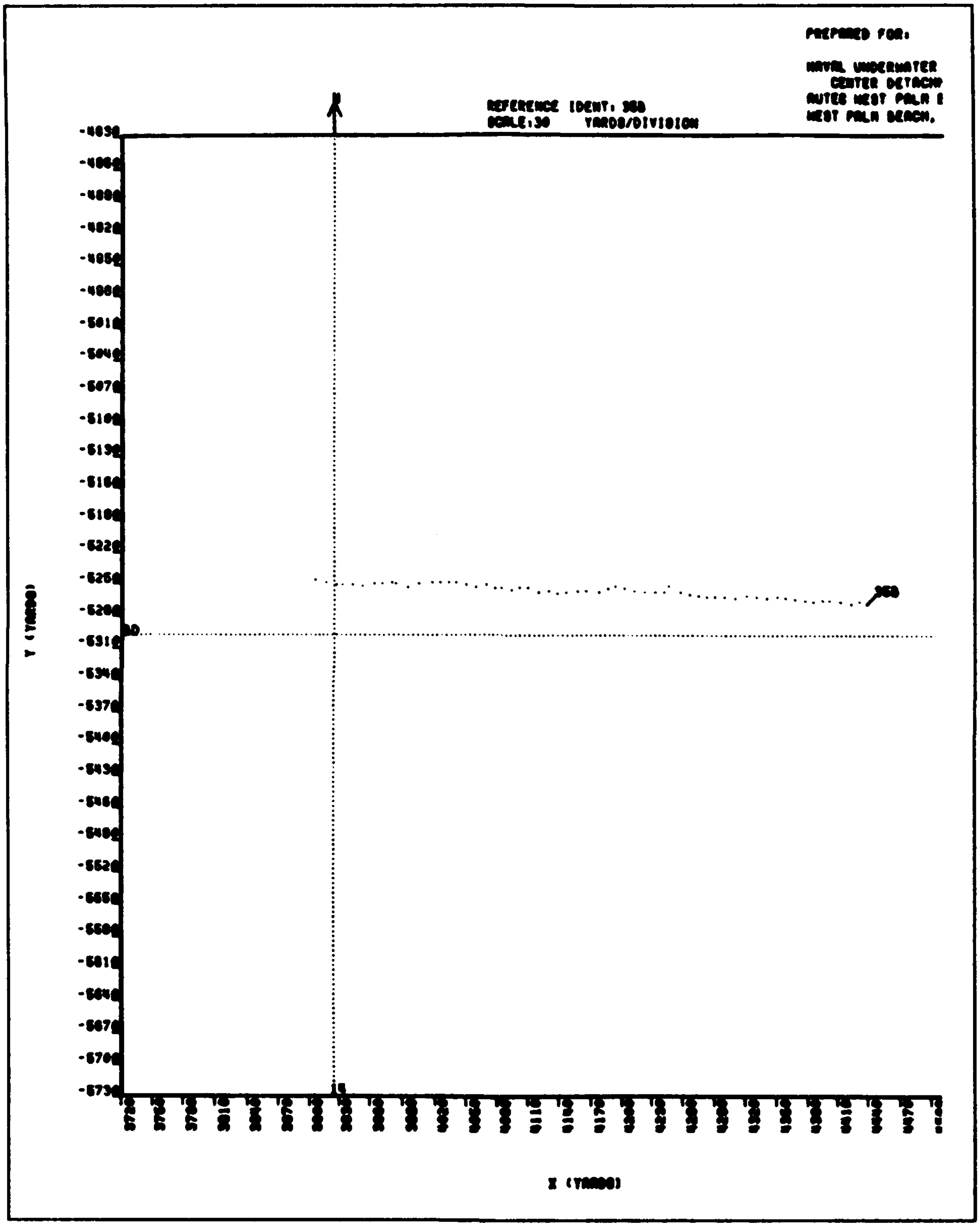

Figure 9. SAT 40 S/B test, AN/SSQ-53 track, 35.

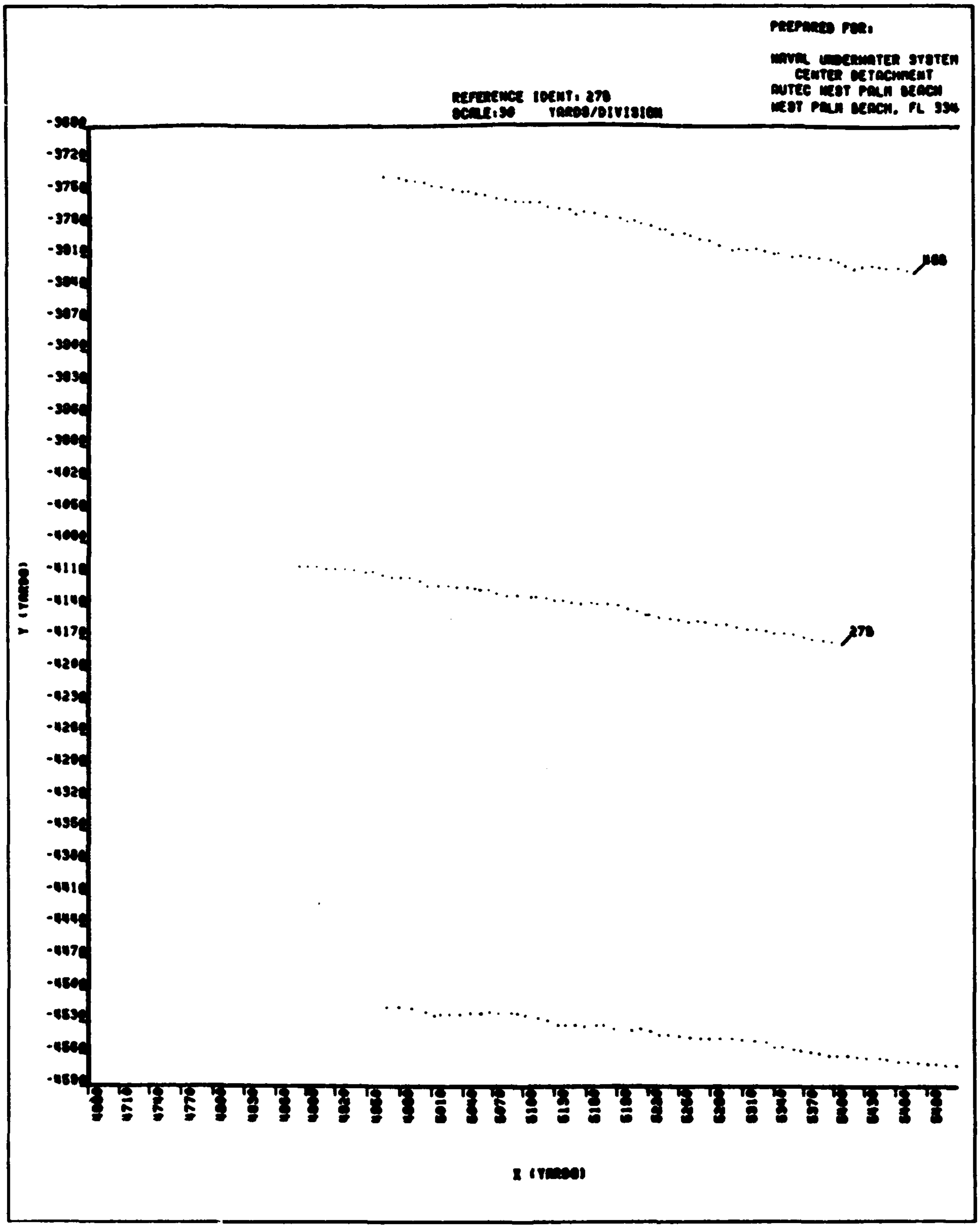

Figure 10. SAT 40 S/B test, AN/SSQ-53 tracks, 46, 27, 37.

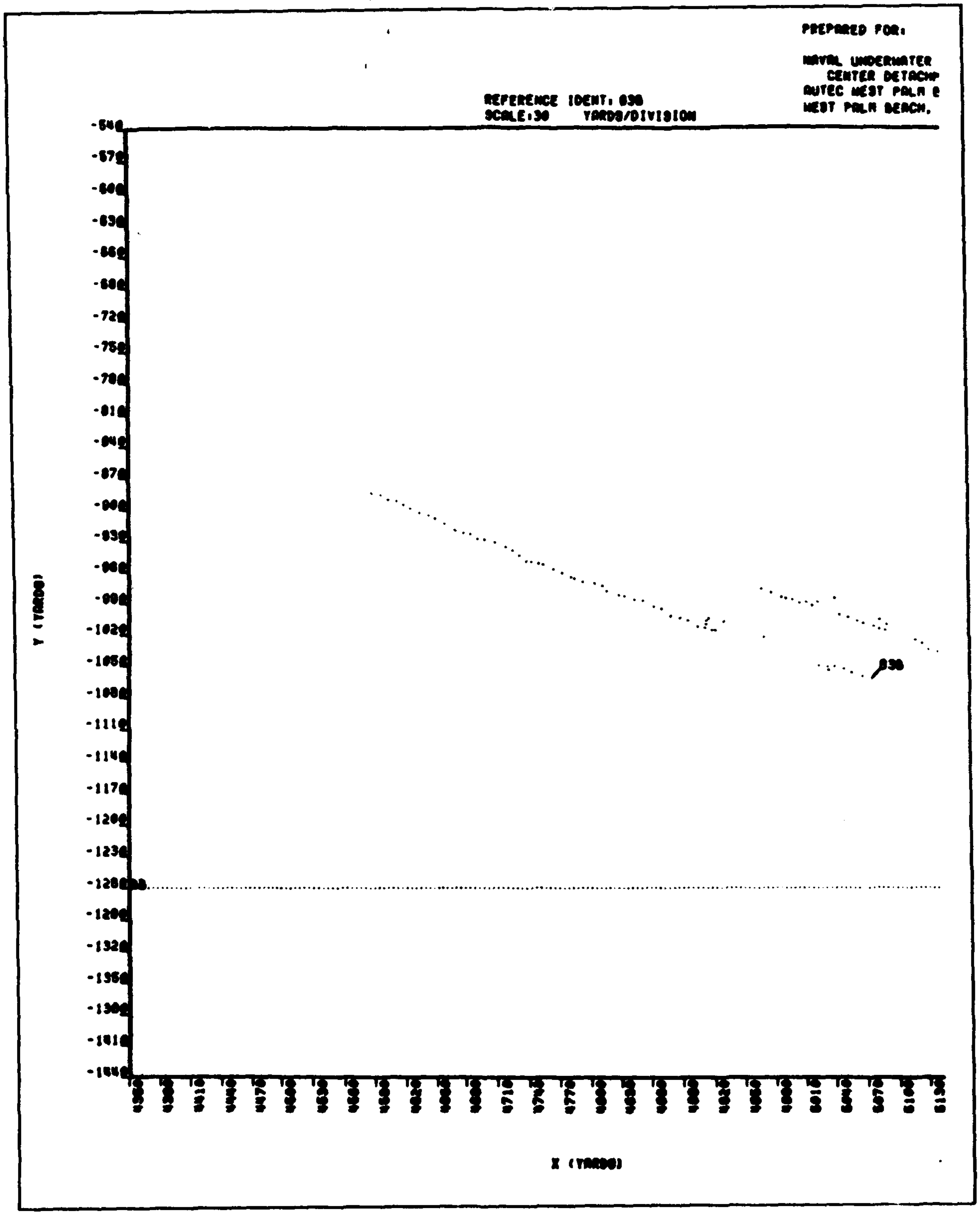

Figure 11. SAT 40 S/B test, AN/SSQ-53 track, 83.

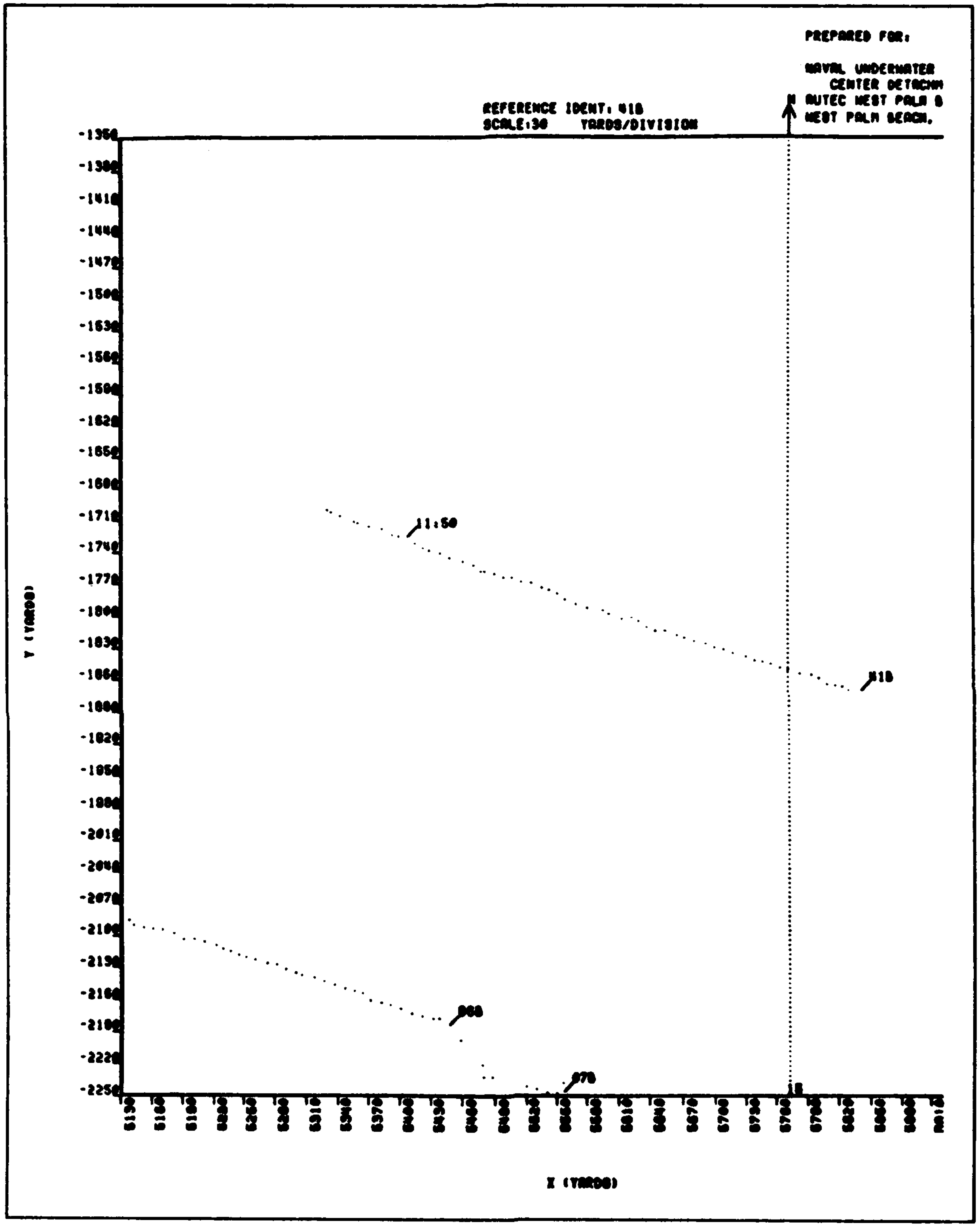

Figure 12. SAT 40 S/B test, AN/SSQ-53 track, 41.

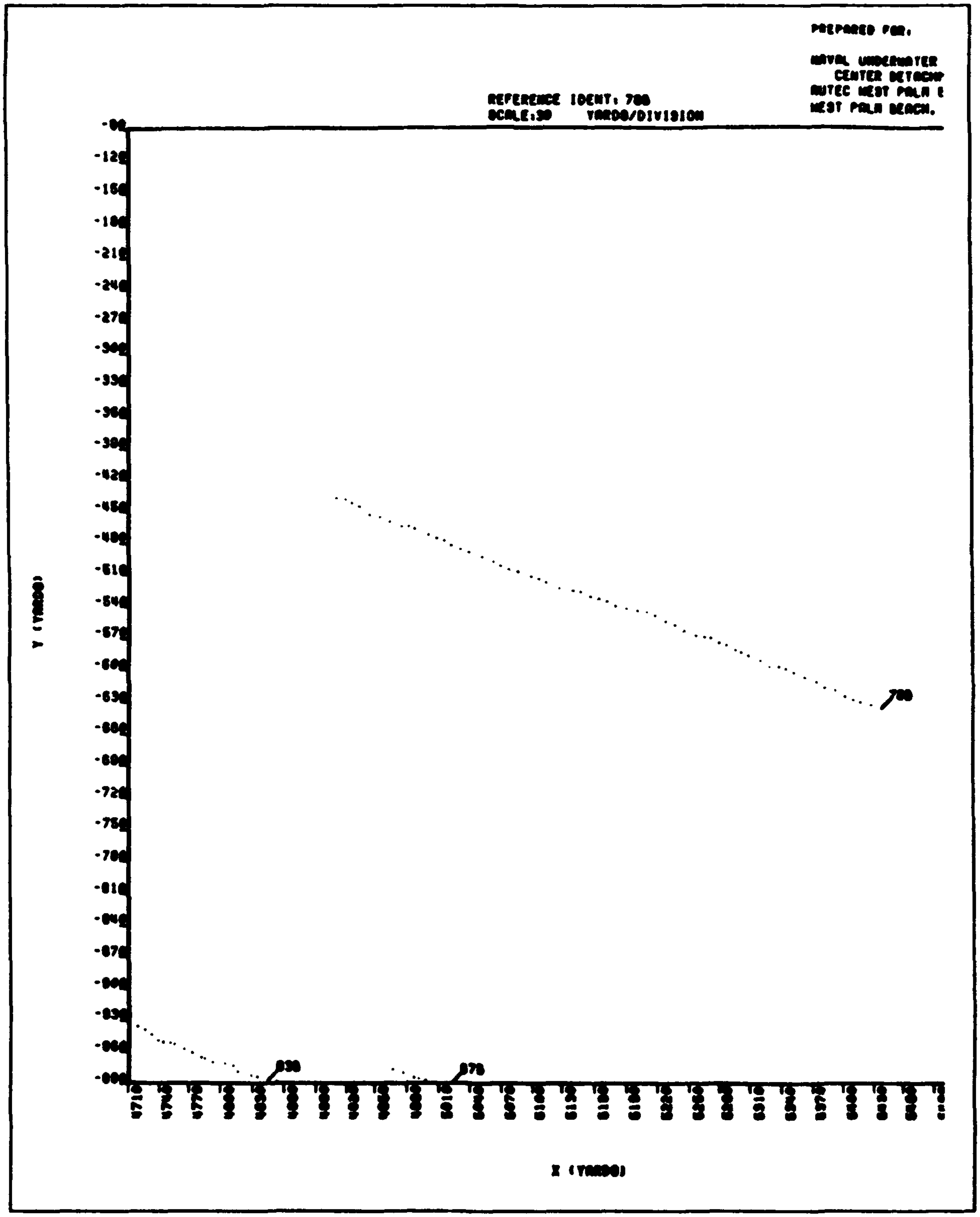

Figure 13. SAT 40 S/B test, AN/SSQ-53 track, 78.

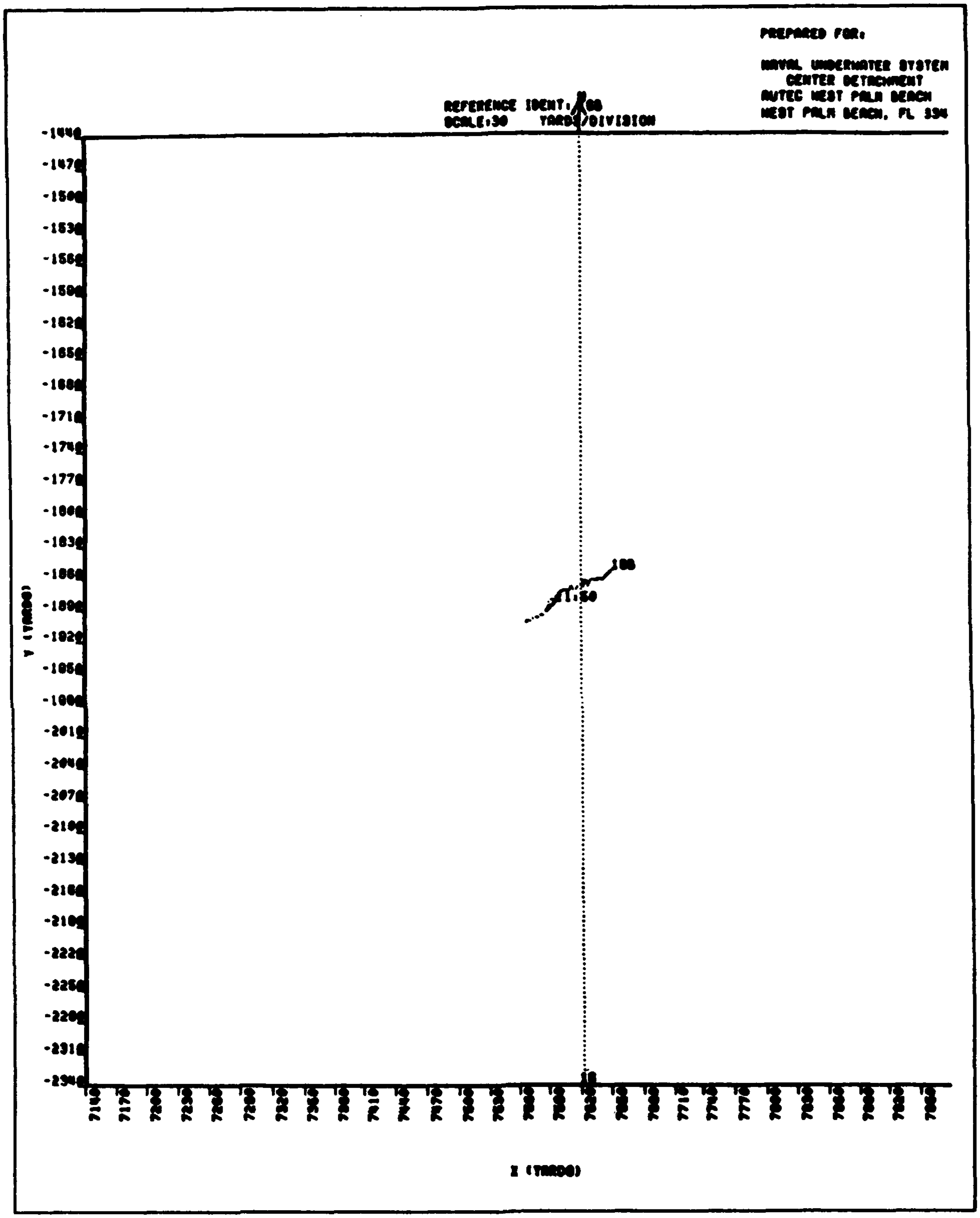

Figure 14. SAT 40 S/B test, AN/SSQ-77 track, 16.

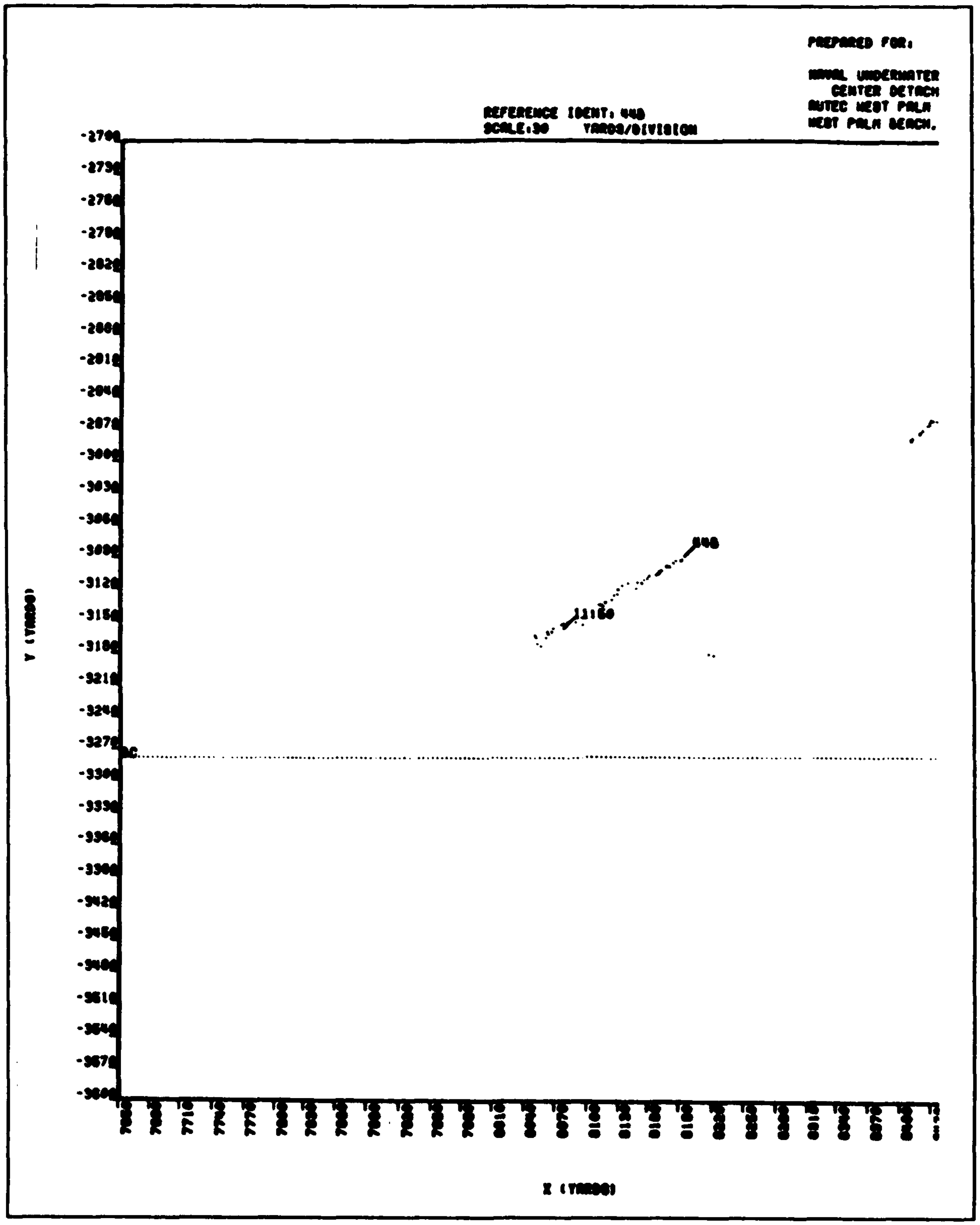

Figure 15. SAT 40 S/B test, AN/SSQ-77 track, 44.

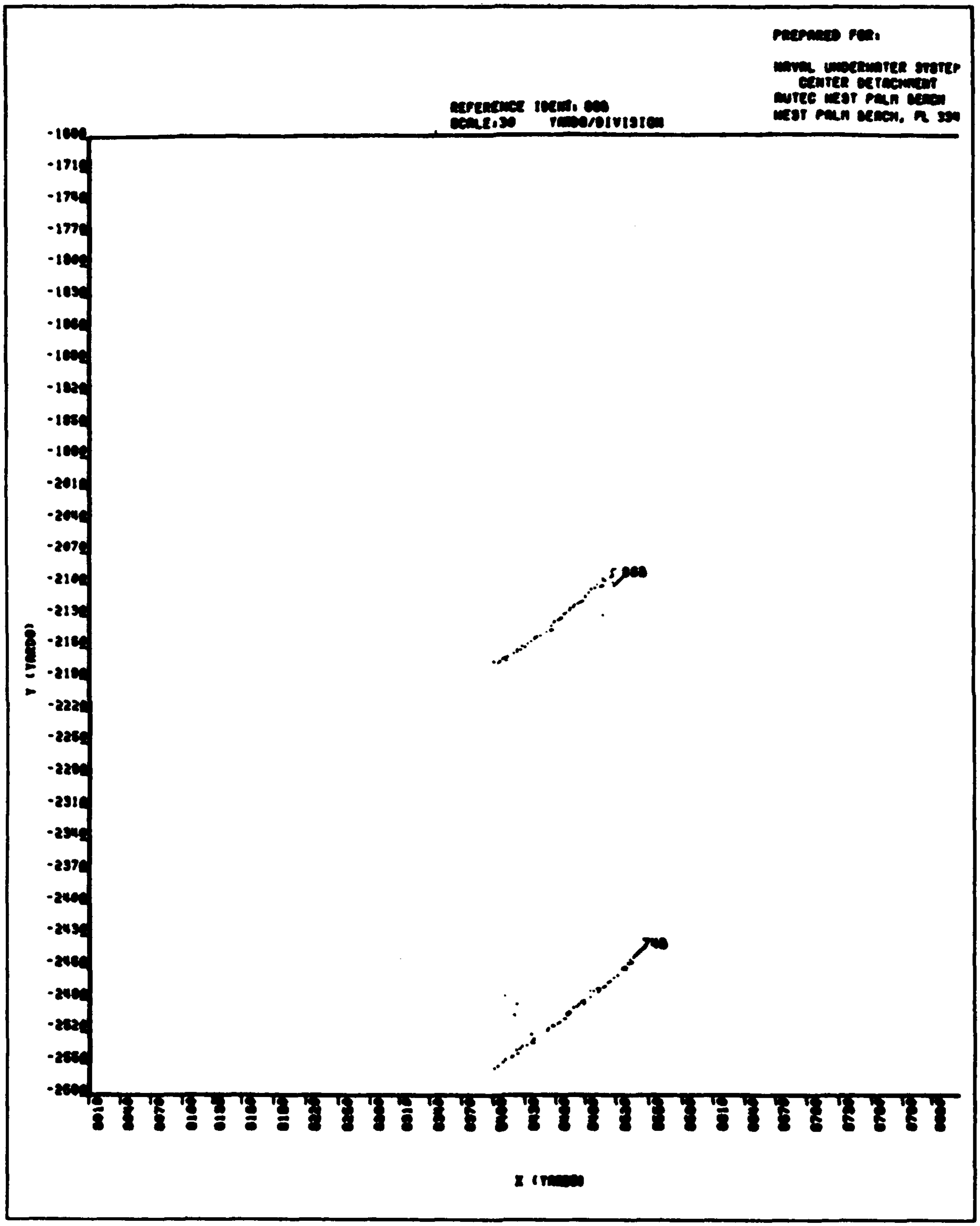

Figure 16. SAT 40 S/B test, AN/SSQ-77 tracks, 86, 74.

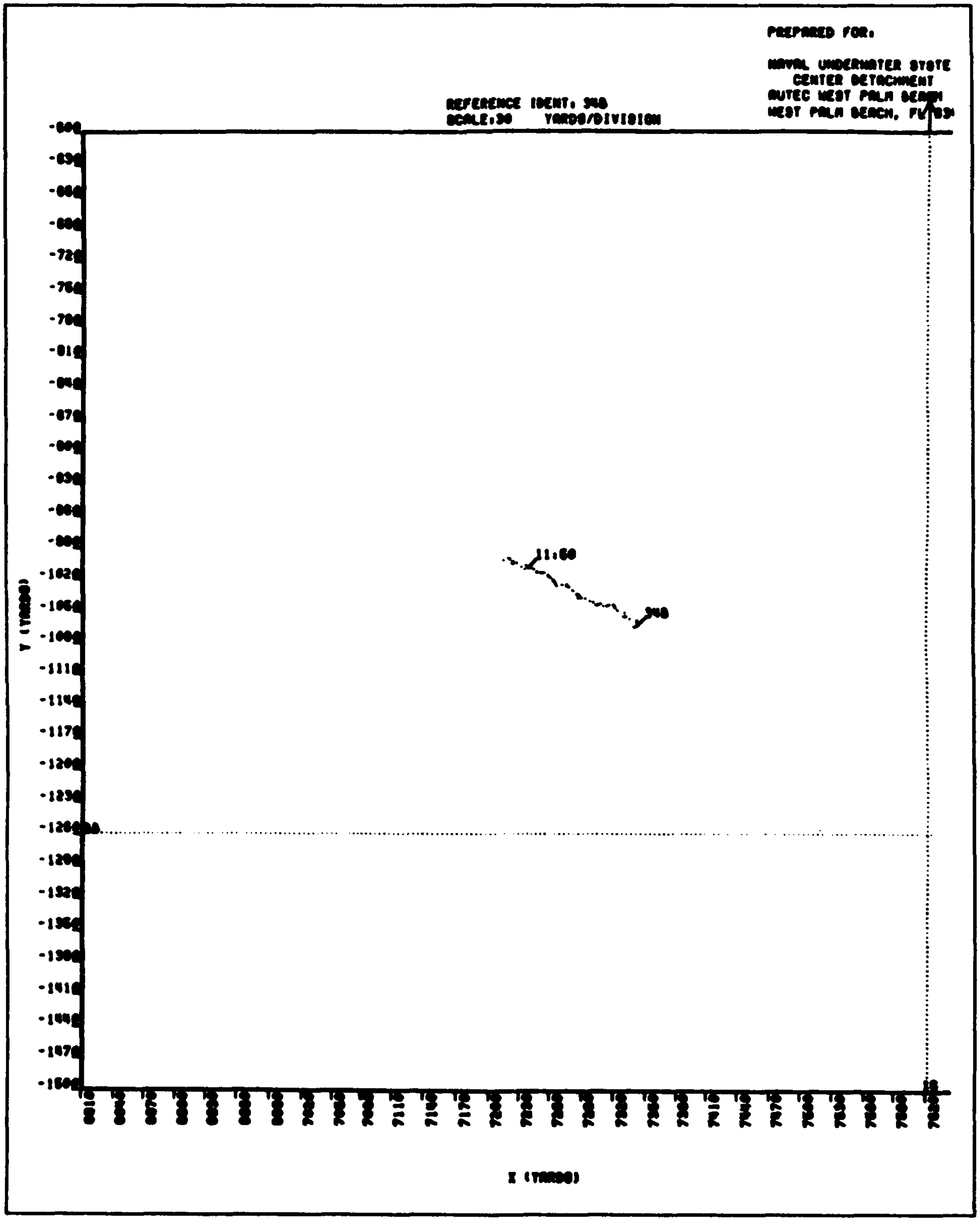

Figure 17. SAT 40 S/B test, AN/SSQ-77 track, 34.

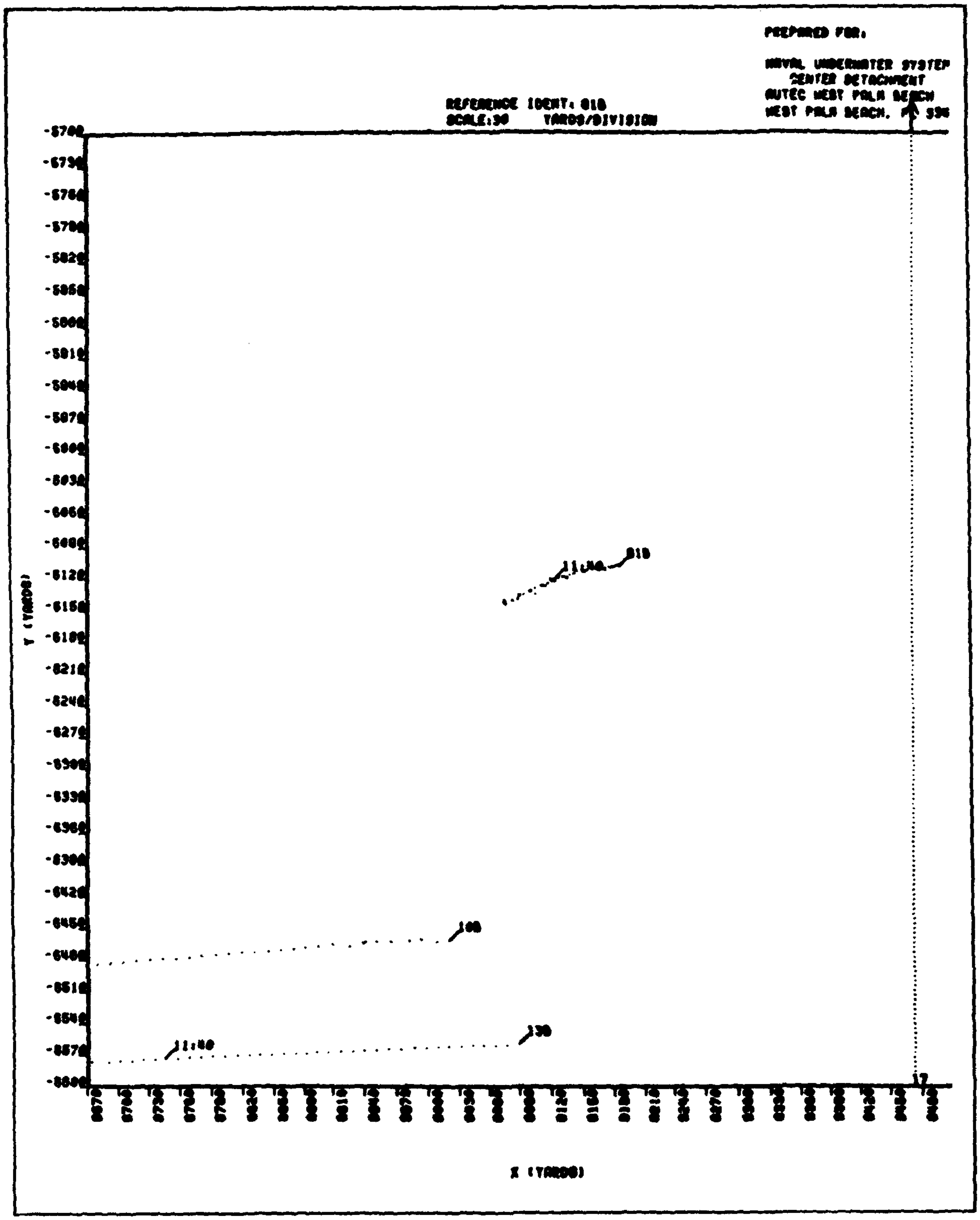

Figure 18. SAT 40 S/B test, AN/SSQ-77 track, 81.

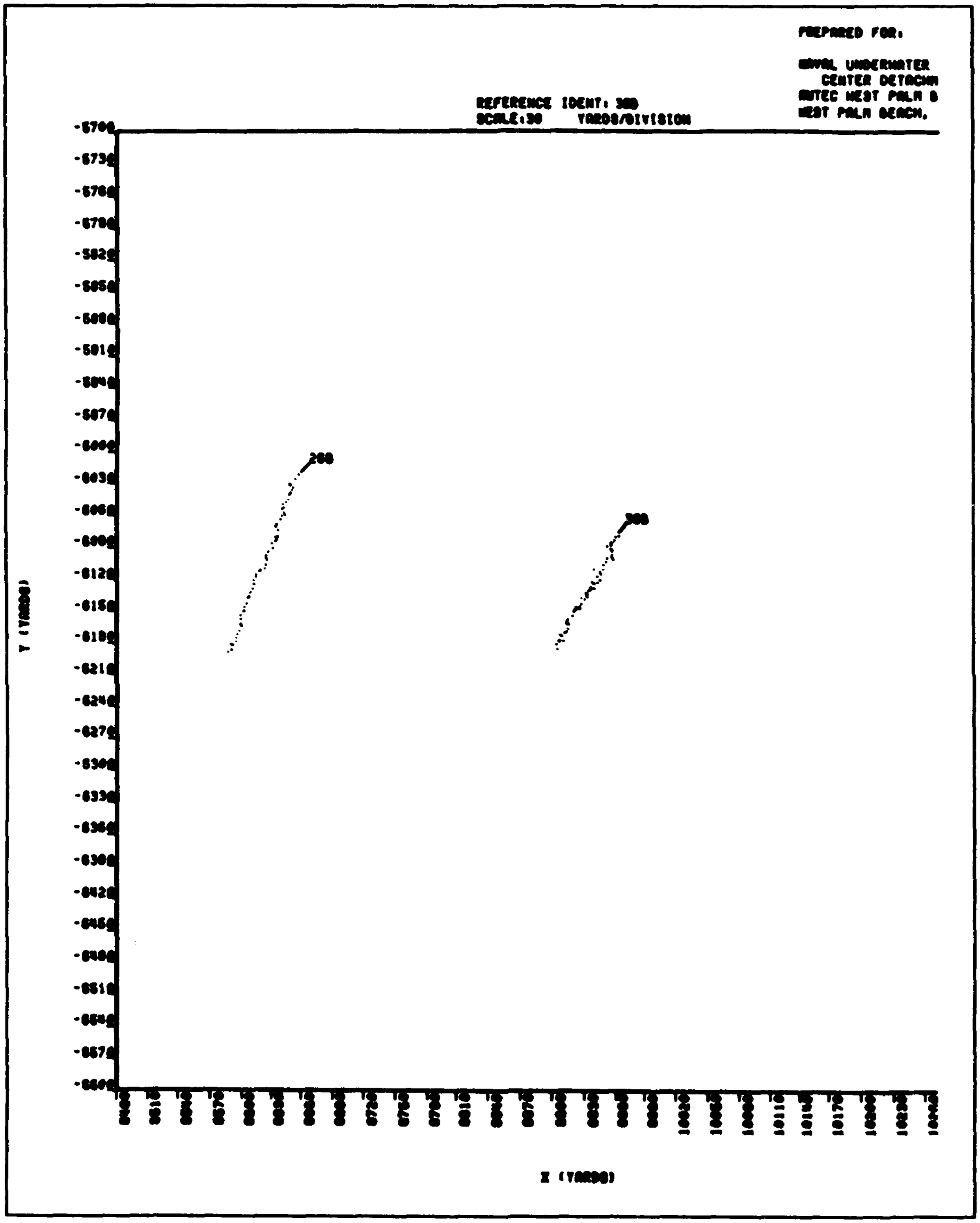

Figure 19. SAT 40 S/B test, AN/SSQ-77 tracks, 26, 38.

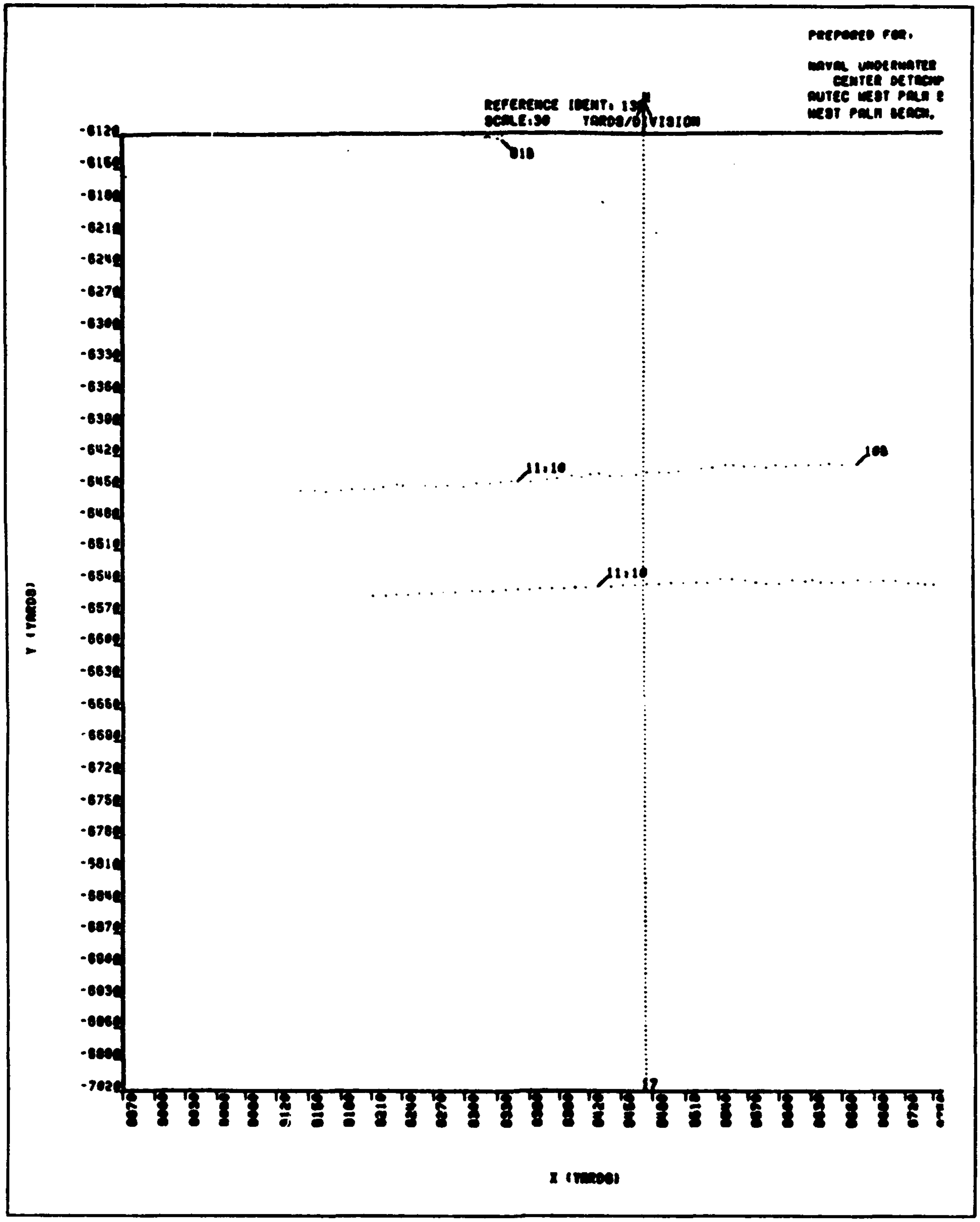

Figure 20. SAT 40 S/B test, AN/SSQ-62 tracks, 10, 13.

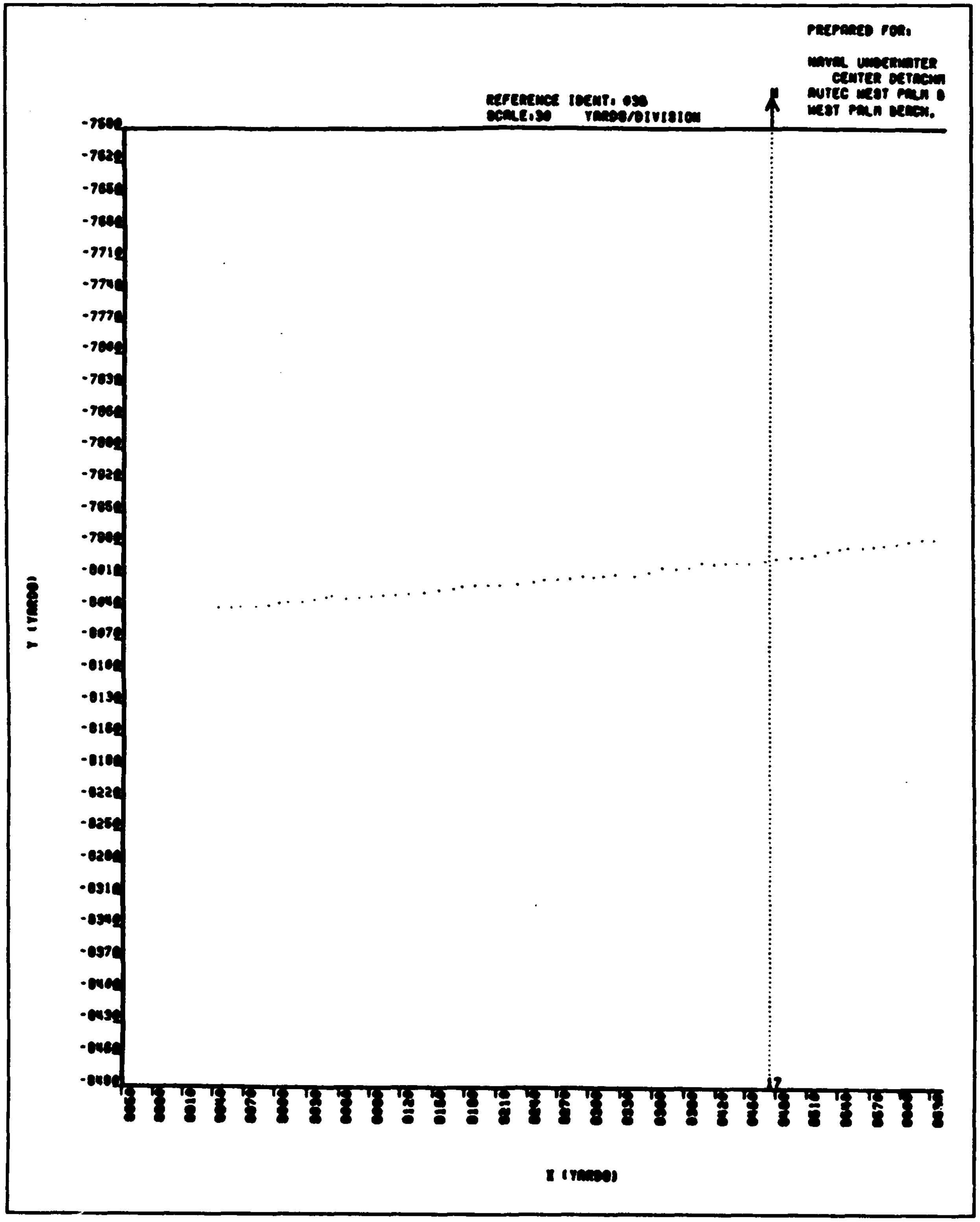

Figure 21. SAT 40 S/B test, AN/SSQ-57 track, 03.

TABLE III. EFFECTS OF TETHERED PINGER ON SONOBUOY TRACK					
S/BS with JETTS		S/Bs without JETTS		TYPE	EFFECTS POSSIBLY BECAUSE OF JETTS
CHANNELS	FIGURES	CHANNELS	FIGURES	AN/SSQ-	
29,35	8,9	46,27,37	10	53	Slight to none
83	11	41,78	12,13	53	Slight to none
16	14	44,86	15,16	77	Moderate (speed)
34	17	44,86	15,16	77	Considerable (course)
81	18	26,38	19	77	Moderate (course)

N O T E S

1. In the figures referred to above, sonobuoys are identified by their channel numbers followed by an uppercase letter B.

2. All figures referred to above are real-time plots with 40 sonobuoys in track. All are to the same scale: 30 yards/division.

3. The figures referred to above cover the same 30-minute time interval.

Again, the STS's demonstrated accuracy was superior to the SAT accuracy requirement, and the total RMS radial error from these tests is less than 9 yards and less than SSV tracking accuracy by one-third. Notice that the bias, though smaller, is in a NW direction as in the case of SSV tracking. These accuracy estimates are based on post-test data. Real-time accuracy is degraded by the real-time computer update rate of STS positions as discussed in paragraph 7.9.

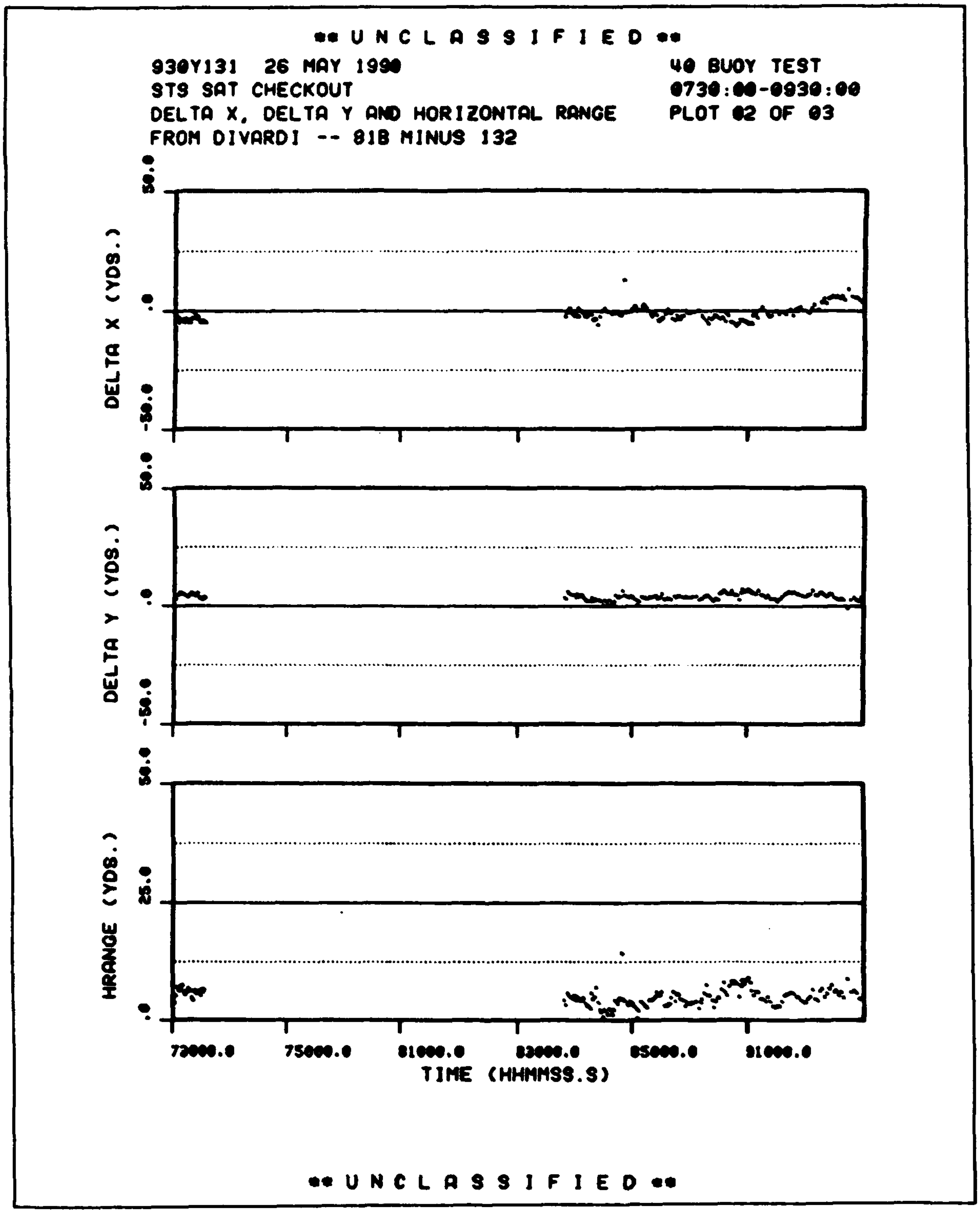

Figure 22a. SAT 40 S/B test, STS minus I/W, channel 81.

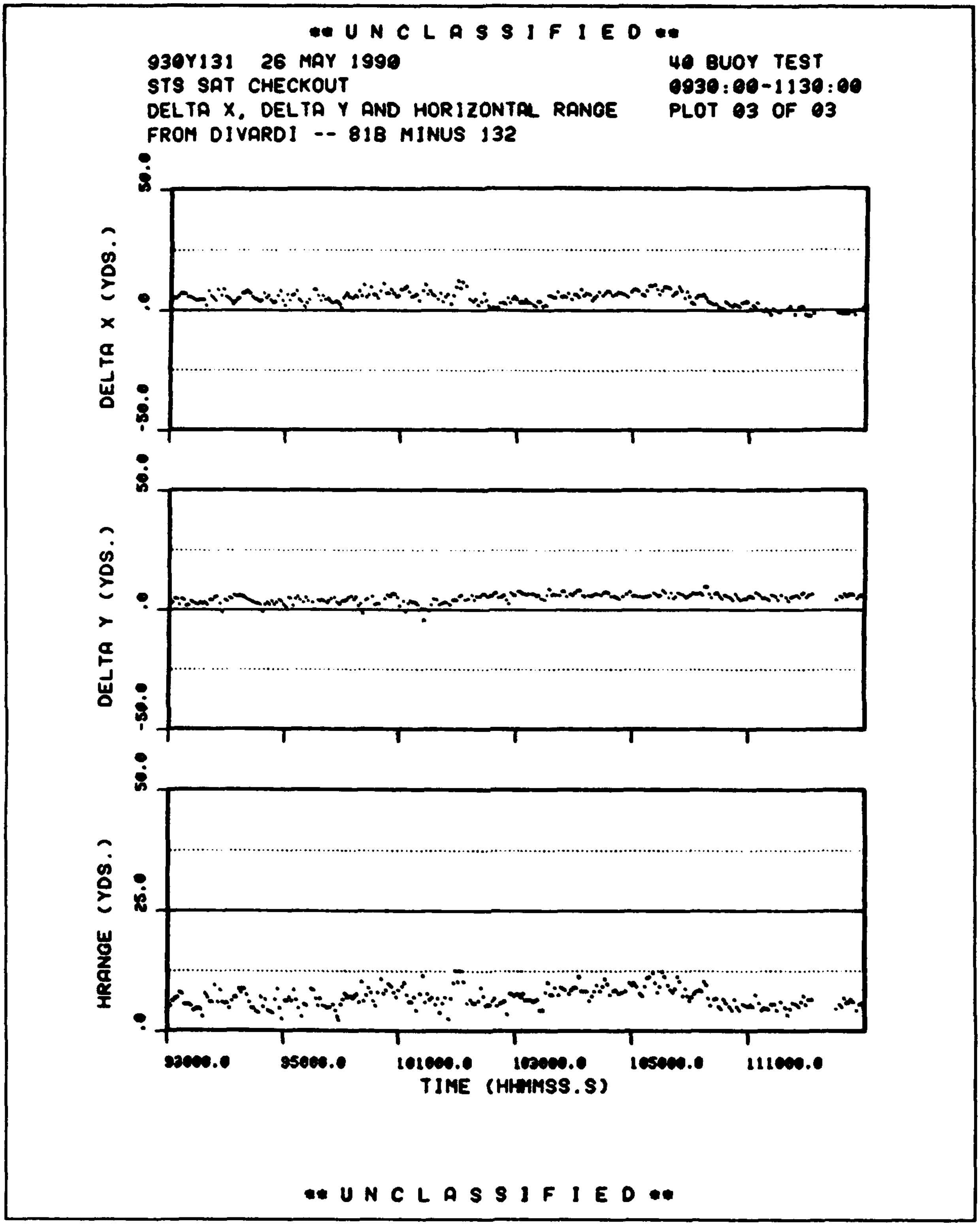

Figure 22b. SAT 40 S/B test, STS minus I/W, channel 81.

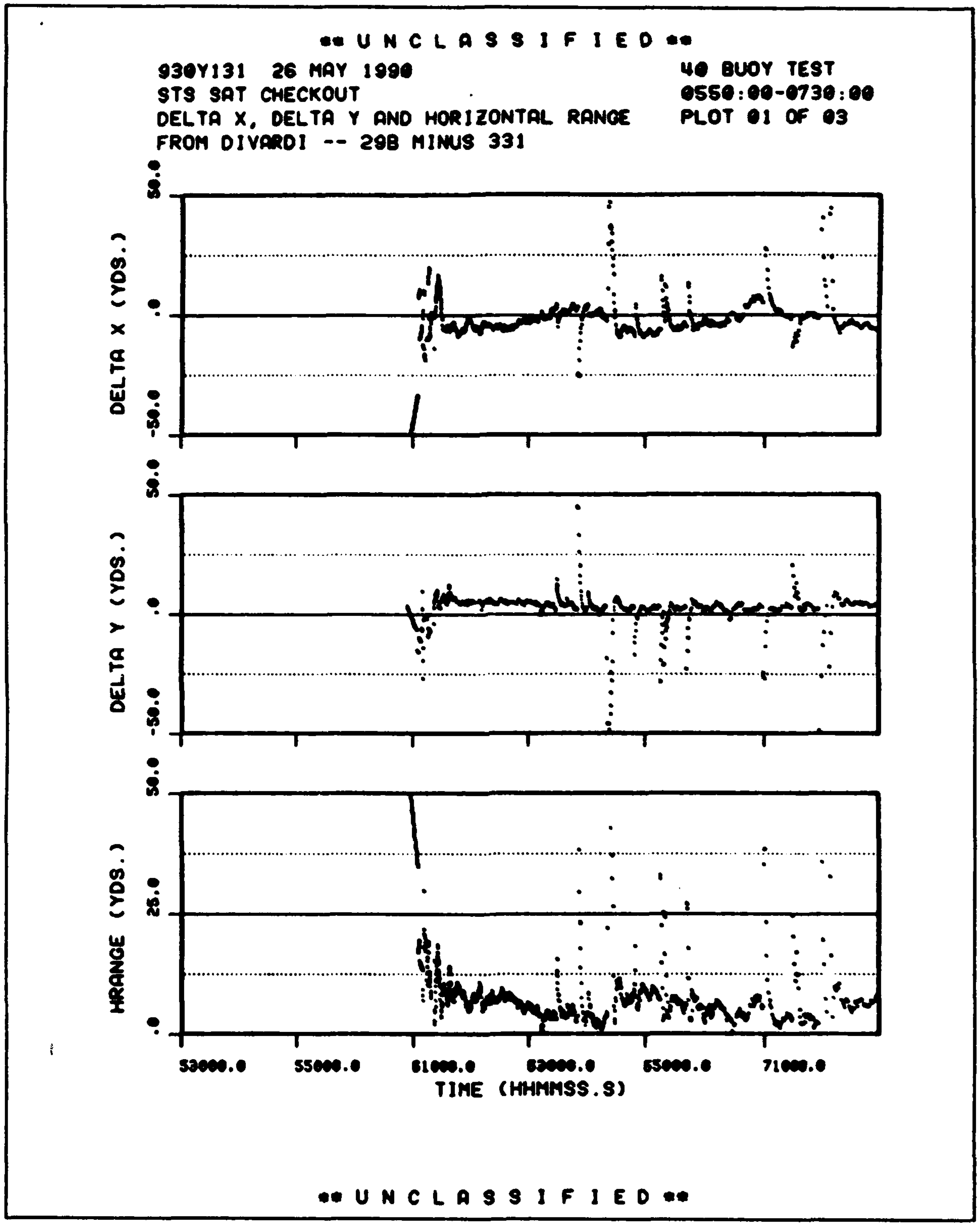

Figure 23a. SAT 40 S/B test, STS minus I/W, channel 29.

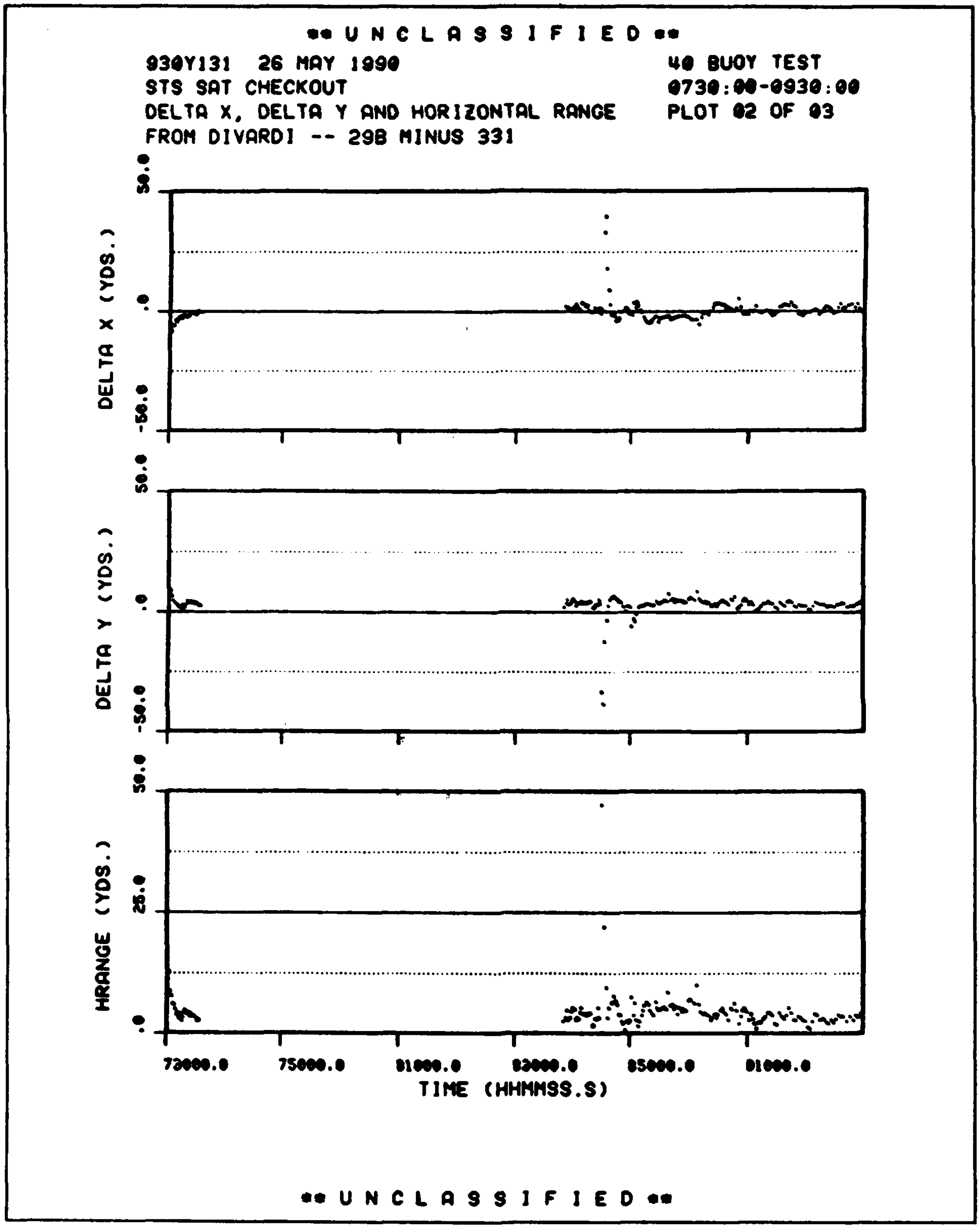

Figure 23b. SAT 40 S/B test, STS minus I/W, channel 29.

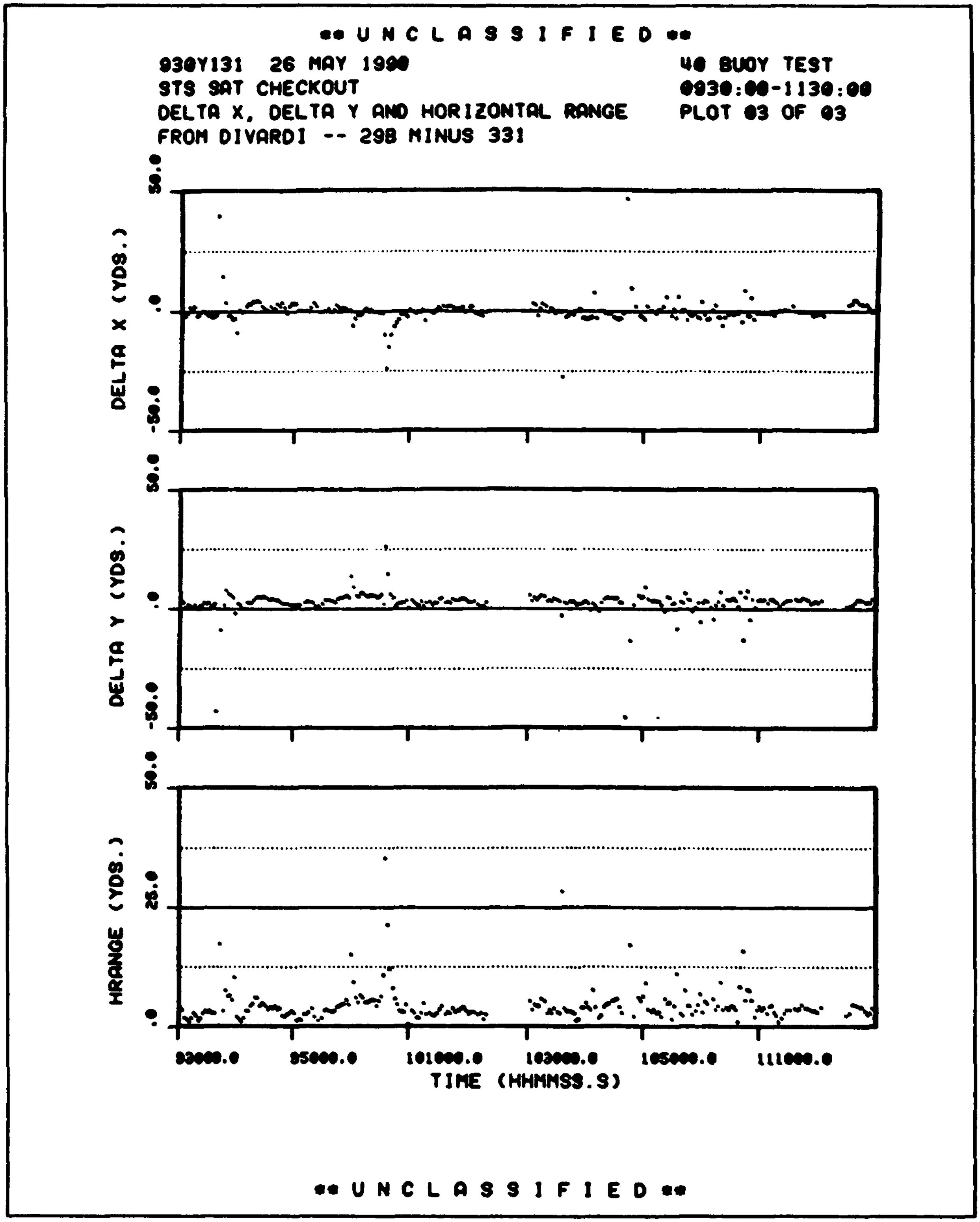

Figure 23c. SAT 40 S/B test, STS minus I/W, channel 29.

An evaluation of STS tracking three pairs of sonobuoys (the sonobuoys in each pair tethered together with a 9-foot tether), is given in table VI. (There were no SAT requirements on this experiment.) These sonobuoys were deployed in zones 2 and 4 of the Maximum Range/Accuracy Test. Only one pair in each zone was planned, but a second was deployed in zone 2 when it appeared that there might have been a problem with the first. Note that the bias estimated here is not in STS relative to I/W. It is possible that most of the 4.3 yard bias estimate is due to the 3-yard tether. As expected, the variation about the mean (CSE) is not far from the square root of two times the variation in table V for individual sonobuoys.

TABLE IV. STS-1/W VERSUS ACCURACY REQUIREMENT, SONOBUOYS. Includes only those sonobuoys tethered to their own acoustic pinger (JETTS).

TEST	ALL DATA		CHANNELS OMITTED BECAUSE OF RFI	
	WITHIN 25 YARDS	NUMBER OF CHANs USED	WITHIN 25 YARDS	NUMBER OF CHANs USED
ZONE 2	99.5%	4	99.5%	4
ZONE 4	99.8%	4	99.8%	4
40 SONOBUOY	83.2%	7	90.0%	6
ALL 3 TESTS	94.0%	--	97.1%	--

TABLE V. STS SITE ACCEPTANCE TEST ACCURACY RESULTS (Using Sonobuoys: AN/SSQ-53Bs and 77s)

CURSORY EDITING ONLY (Points Exceeding 200 yards Rejected)	
Resultant Bias (Mean)	4.2 yards
Variation About the Mean	5.3 yards
Total RMS Radial Error	8.6 yards
Bias Direction (Azimuth)	326°
Number of Data Points	13,838
Number of Points Rejected	488

TABLE VI. STS TRACKING PAIRED SONOBUOYS DURING THE SAT (Sonobuoys Tethered Together) In Zone 2: (06 and 46) and (7 and 41) In Zone 4: (2 and 37)	
CURSORY EDITING ONLY (Points Exceeding 200 yards Rejected)	
Resultant Bias (Mean) Variation About the Mean Total RMS Radial Error	4.3 yards 8.7 yards 9.1 yards
Bias Direction (Azimuth)	198°
Number of Data Points	4,292

N O T E

The bias estimated here is **NOT** relative to I/W, since STS positioned both buoys in each pair.

7.1.2 Boat Tracking Accuracy

The following subparagraphs are prefaced here by stating that there were no SAT requirements on the STS for tracking range vessels. The STS was not designed to track boats; it was designed to track only sonobuoys. As such, it is understandable that certain parameters in the STS software, set to optimize sonobuoy track, would not necessarily be optimum for tracking range craft.

On the other hand, there was and is considerable interest in using STS to monitor the position of range vessels standing off during operations, thereby freeing target channels in the I/W and I/A systems. It is a short distance from such interest to desiring to track vessels as they maneuver on the range. It was for these reasons that AUTEC designed and constructed four portable sonobuoy simulators (model SRT-22-AT12900, discussed in paragraph 7.8) for use aboard range vessels. These simulators were available for the following test.

7.1.2.1 Post-SAT Test

On 31 July 1990, a brief test was conducted to checkout STS data handling by the SEL computer following a SEL software modification. The primary objective of the test was accomplished, but the test provided the first opportunity at AUTEC to have STS track a target moving at speeds considerably faster than sonobuoys. The results of the test spurred interest in the STS tracking vehicles, and raised some questions concerning system biases which were not fully answered until further testing and analyses were completed.

The test consisted of the STS tracking an SRT-22 portable sonobuoy simulator aboard the TR-825, (plus two sonobuoys in the water). The TR-825 maneuvered at various speeds and headings for approximately 1.5 hours. Figures 24 and 25 show the TR-825's track during the test as determined by I/W and by the STS.

Figures 26a and b are plots versus time of the TR-825's course and speed (by I/W) and the horizontal range between STS and I/W for the duration of the test. The first hour of the test is plotted in figure 26a and the remaining half-hour in figure 26b; similarly, with several of the plots to follow. High correlation between speed and STS error is immediately evident by comparing the lower two plots in the figures: small error with small speed and increased error with increased speed. The TR-825's maximum speed is 13.7 knots.

This high correlation between speed and error is confirmed by the upper portions of figures 27a and b, where horizontal range between STS and I/W is plotted versus speed (upper) and versus course (lower).

> **N O T E**
>
> The abscissa and its scale are above each plot, not below.

At this point, there were at least two possibilities:

(1) such an error might be caused by the clipping or limiting of the velocity components to a maximum magnitude of 2.0 meters/second (paragraph 7.3) in the STS's Kalman filter subroutine and

(2) such an error, which is systematic with boat speed, could be due to a time bias between the two systems.

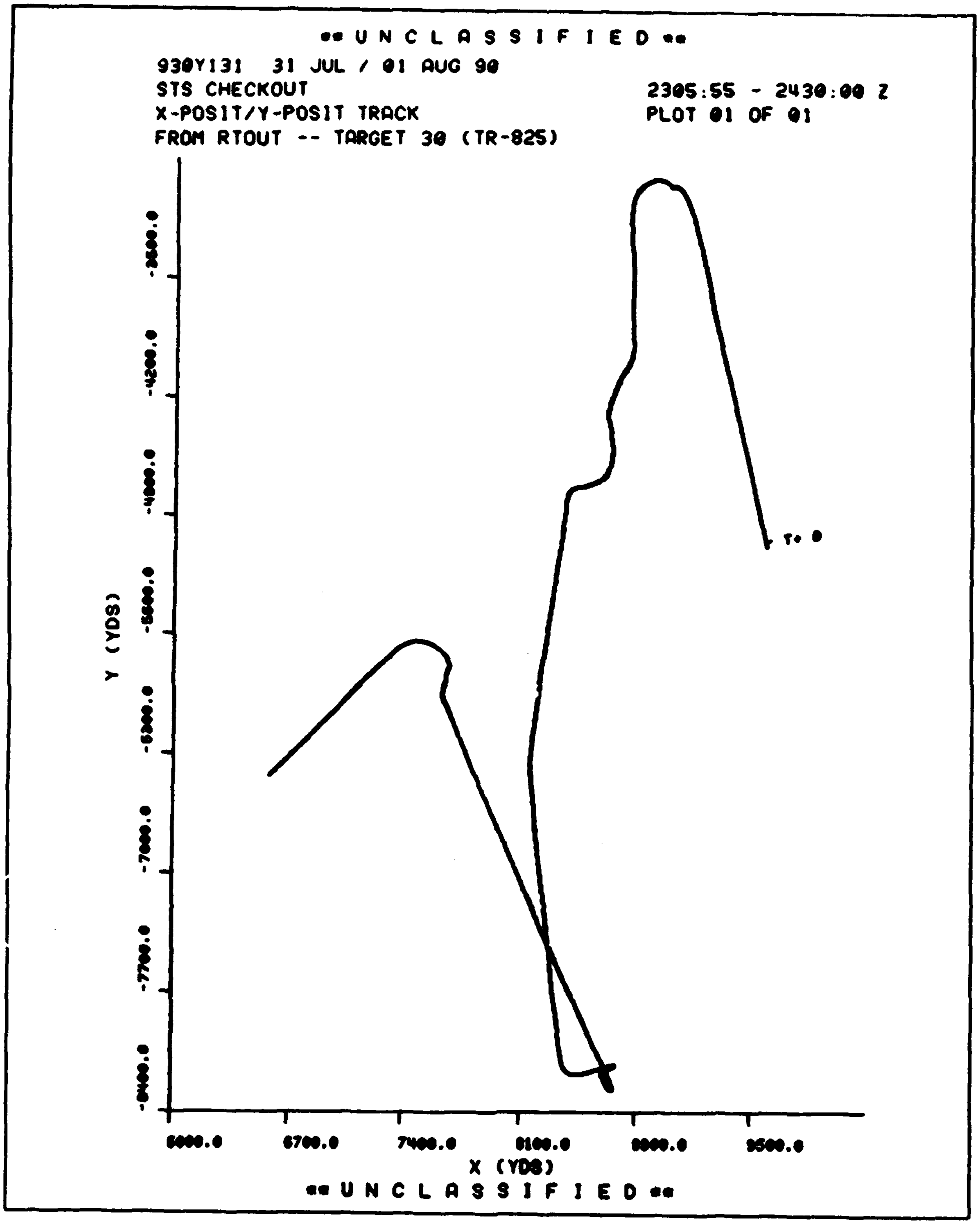

Figure 24. Post-SAT, boat track from I/W.

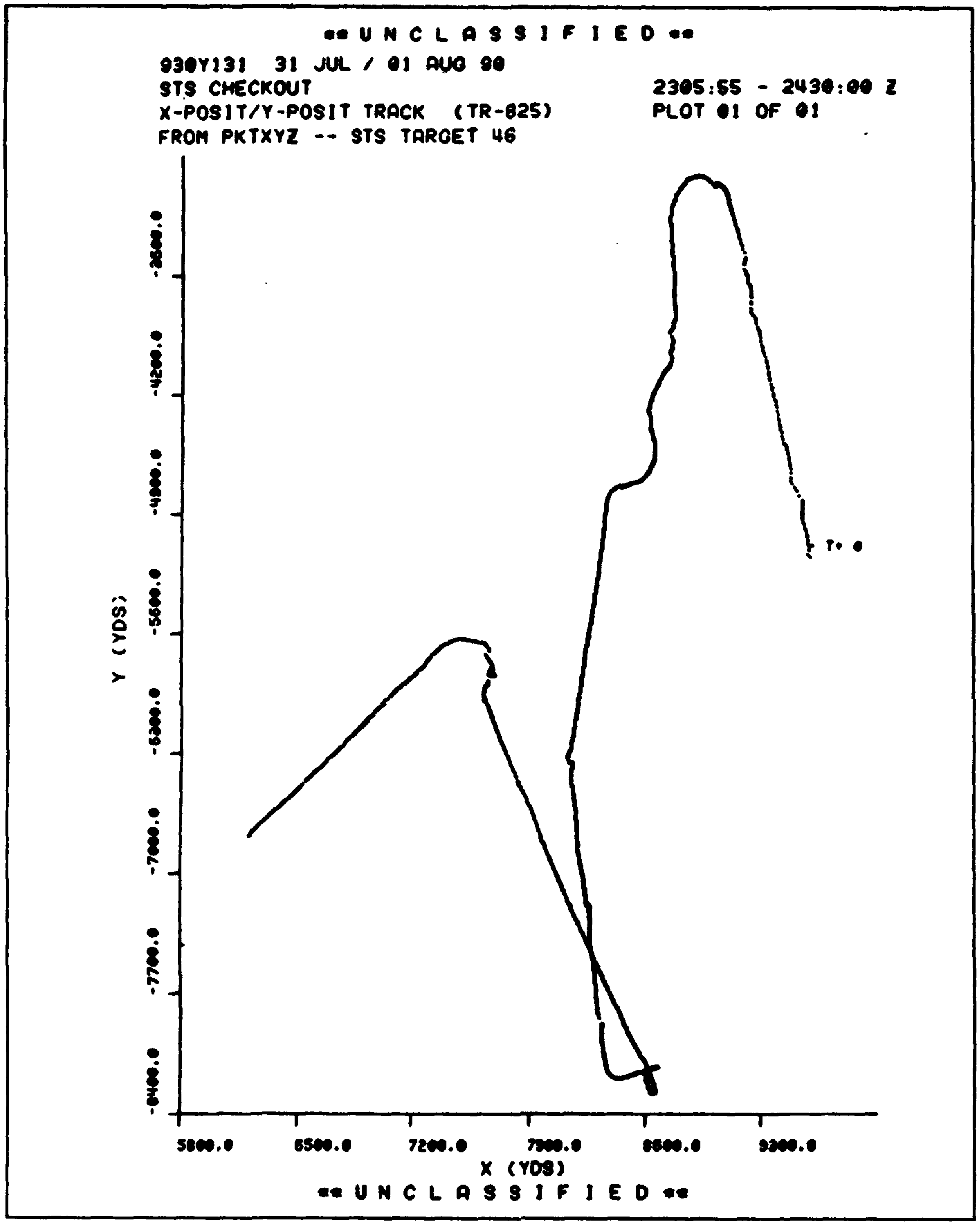

Figure 25. Post-SAT, boat track from STS.

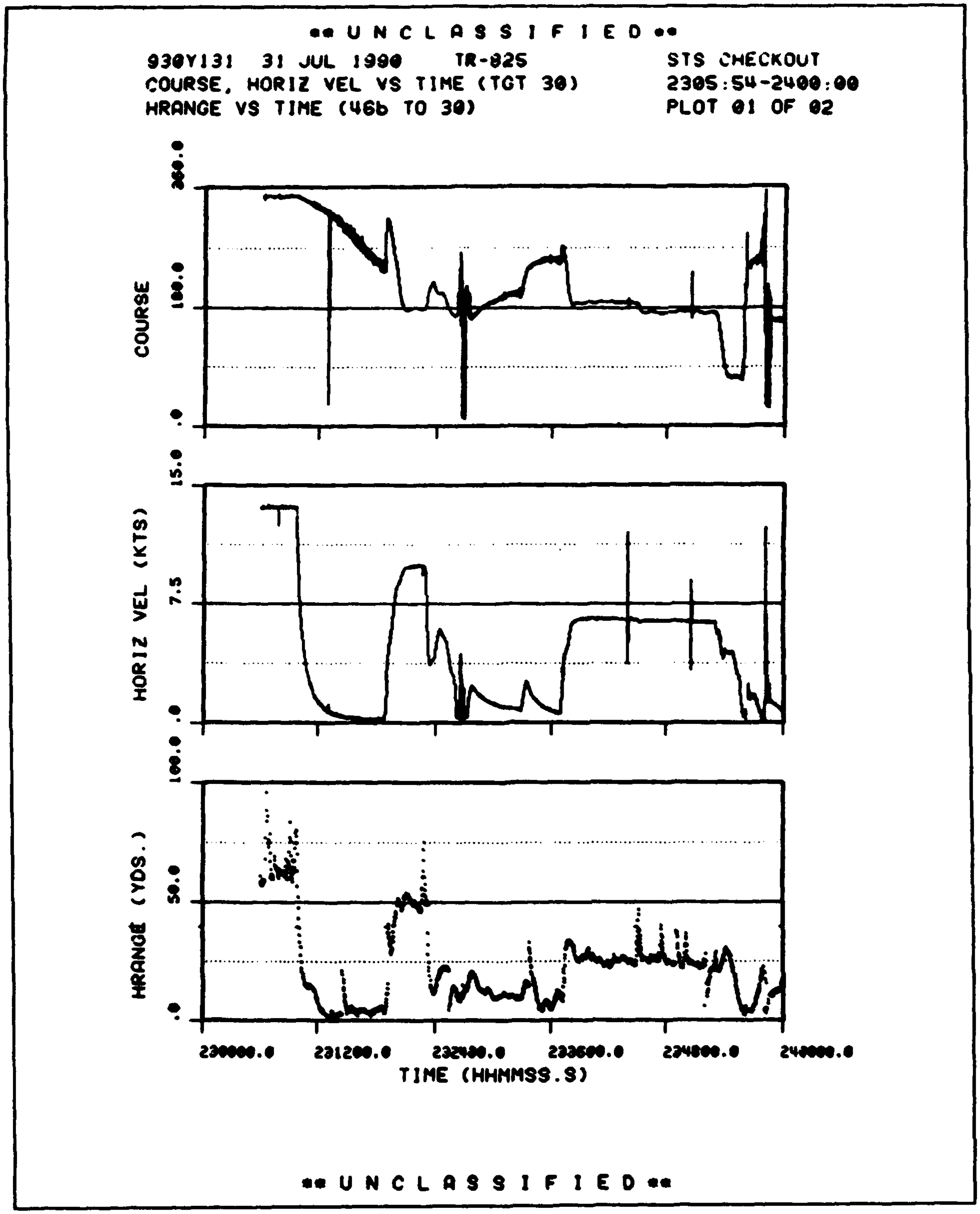

Figure 26a. Post-SAT, STS-I/W versus time.

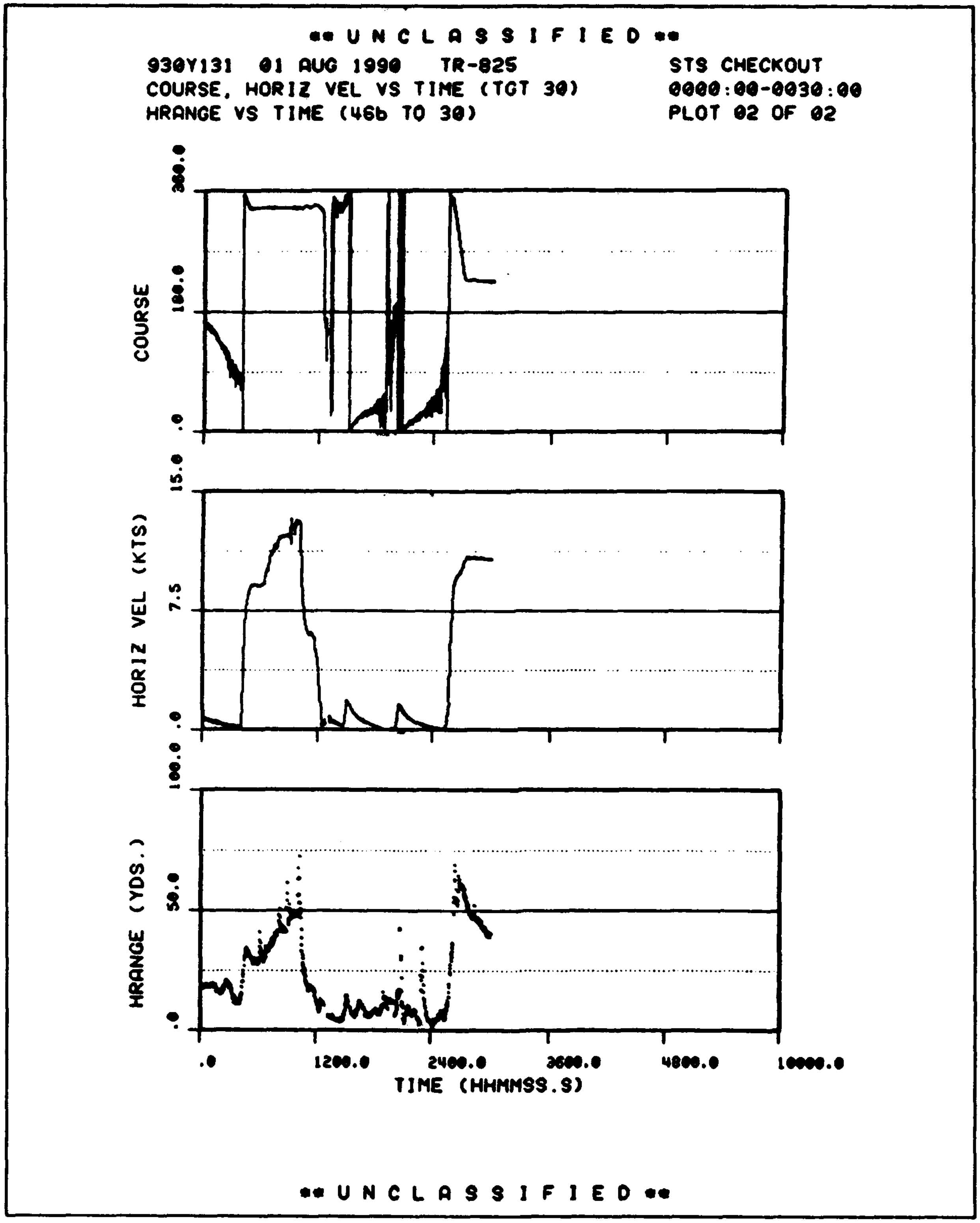

Figure 26b. Post-SAT, STS-I/W versus time.

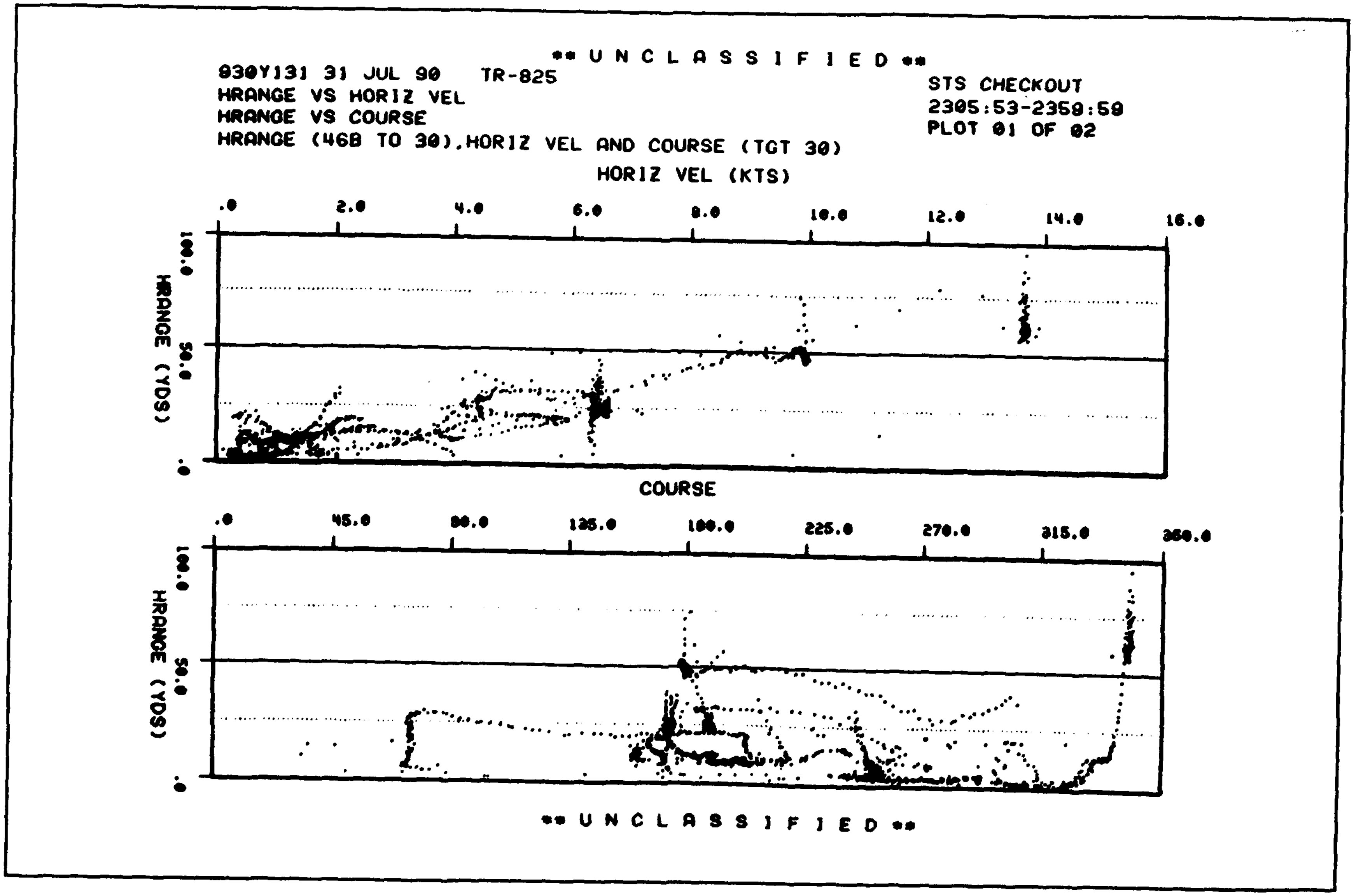

Figure 27a. Post-SAT, STS-I/W versus velocity and course.

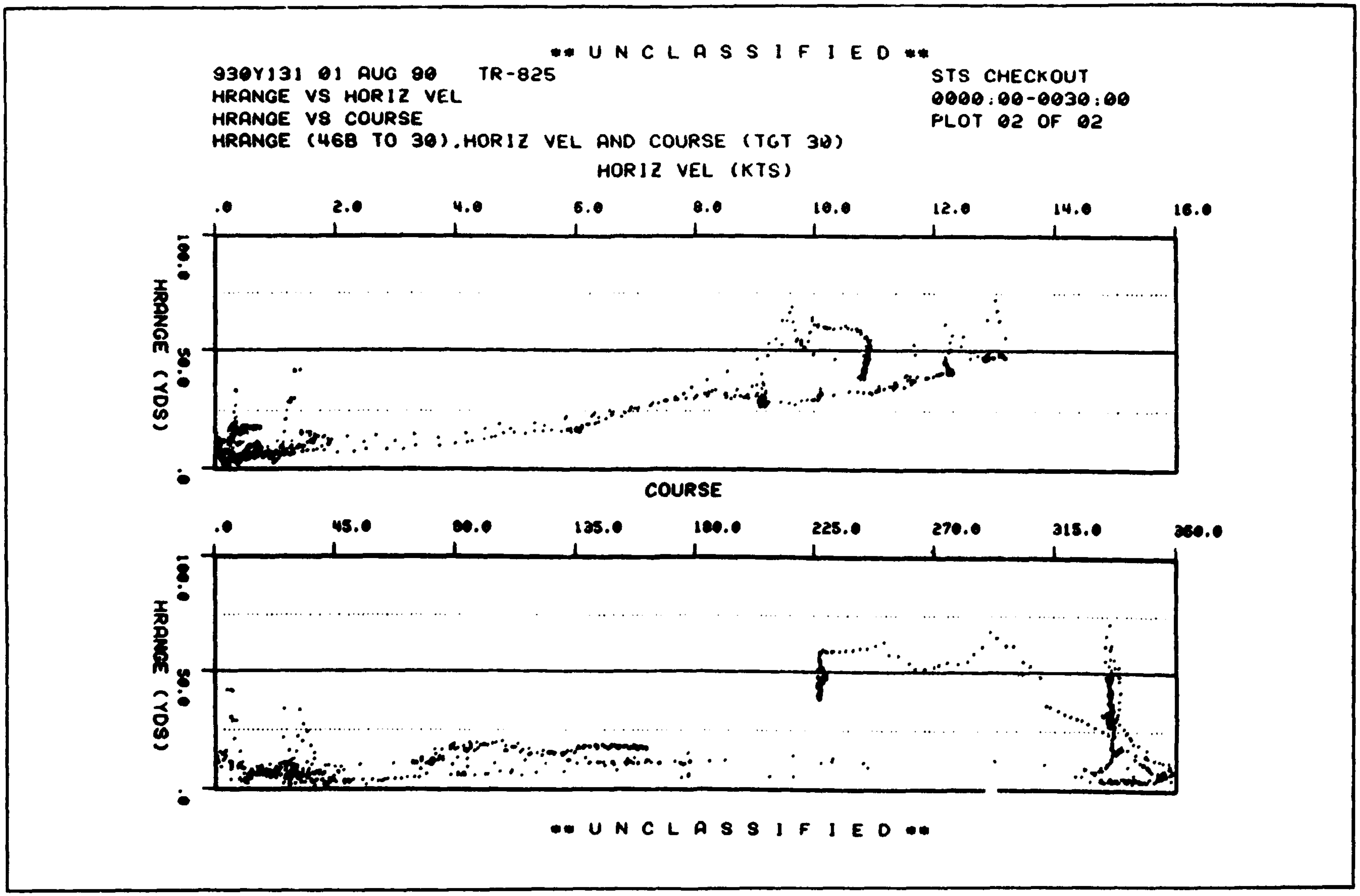

Figure 27b. Post-SAT, STS-I/W versus velocity and course.

An analysis of correlation between coordinate components of position error and speed is diagrammed in figure 28. The two diagrams on the left depict in-track errors, both a delay, diagrams on the right show the relationships with cross-track errors.

The upper-left diagram shows a velocity vector, V, and its X and Y components. Also shown are a position error vector, e, and its X and Y components. The e vector, representing a delay, is in line with the V vector but in the opposite direction. As can be seen, the X components of e and V are opposite and could be expected to be highly negatively correlated. In other words, the coefficient, ρ, (see figure 28) of pair-wise correlation between the X components of e and V in this case would not only be negative but close to -1. The same is true of the correlation coefficient of the Y components of e and V. This holds no matter which quadrant the V vector is in. The other diagrams in figure 28 show different sign relationships for the correlation coefficients.

To apply this analysis to the 31 July 1990 test, the X and Y components of the differences between STS and I/W were plotted against the X and Y components of the velocity vector. The results are shown in figures 29a and b. Nearly perfect negative correlations are evident, indicating an error acting as an in-track delay, that is, acting as a time bias between STS and I/W with STS delayed relative to I/W. The straight lines in the figures were visually fit to the data; the slopes (yards/[yards/seconds] = seconds) of these straight lines provide estimates of the delay. The estimates ranged from 8.2 to 9.2 seconds. Note in figures 29a and b, that there is no obvious evidence of the errors action differently for velocities between ± 2.2 yards/second (that is, ± 2.0 meters/seconds) versus velocities outside this interval.

Time-shifting STS data by several of these delay estimates, and reprocessing the STS-I/W difference data showed that an 8.2 second time bias correction gave the best results, and virtually eliminated the correlated error, as shown in figures 30a and b (compare with figures 29a and b) and in figures 31a and b (compare with figures 27a and b). Plots versus time of the STS-I/W differences, after time-delay correction, are shown in figures 32a and b (compare with figures 26a and b).

A careful examination of how the SEL was handling STS data was conducted (by Software Engineering); nothing was found on the SEL side that could cause a time bias between STS and I/W.

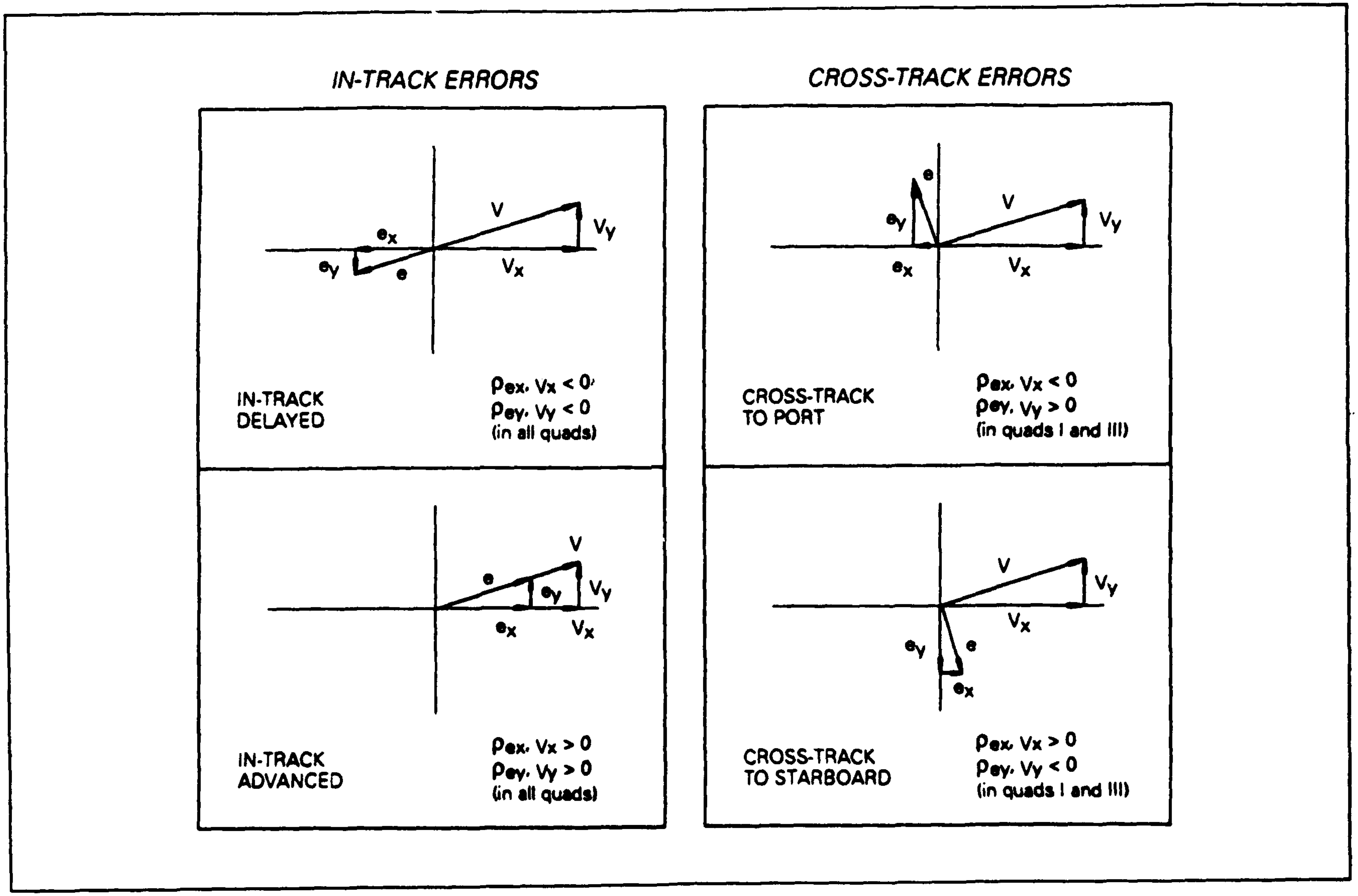

Figure 28. Correlation of position errors with velocity.

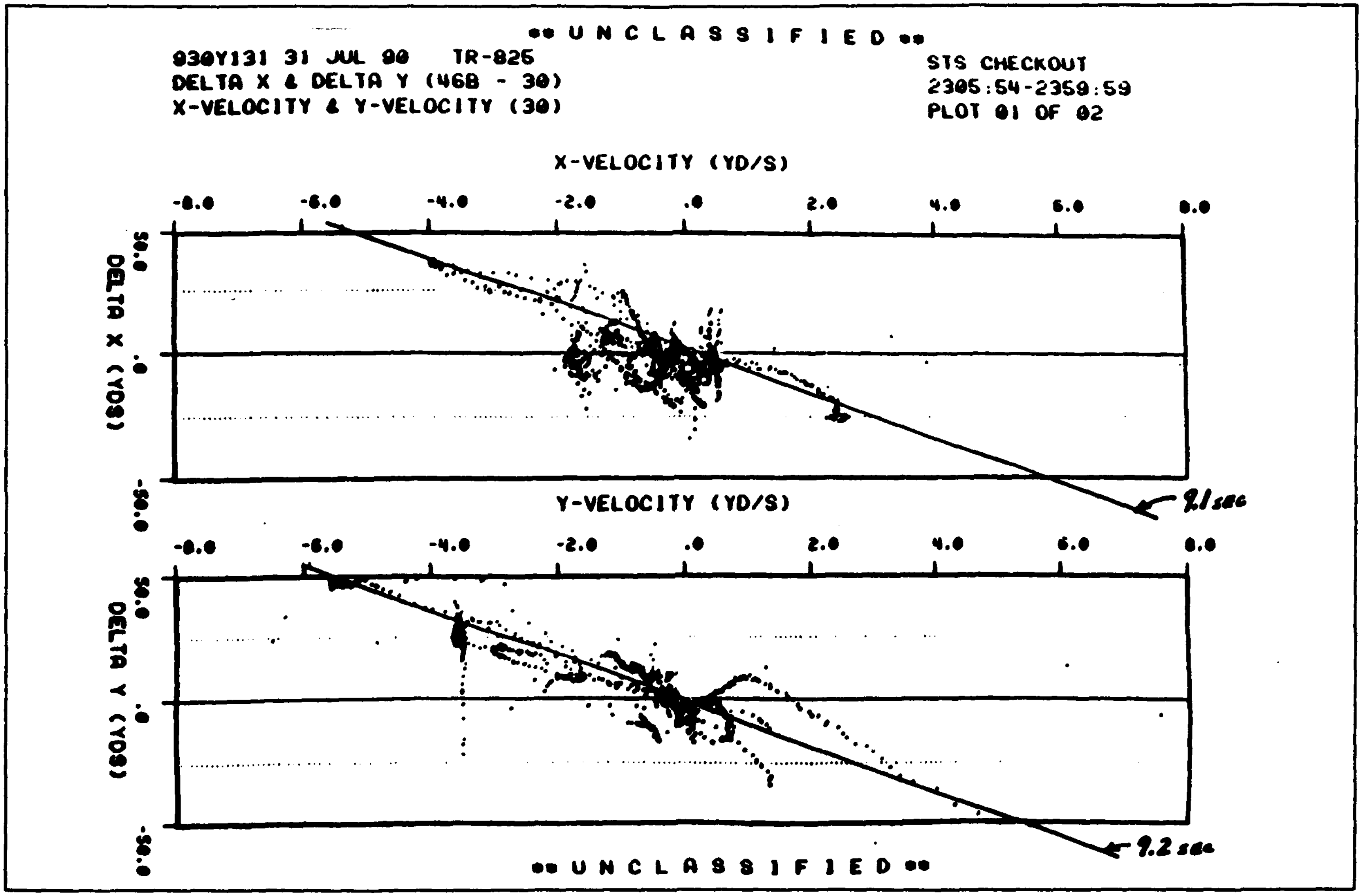

Figure 29a. Post-SAT, X, Y-errors versus X, Y-velocities.

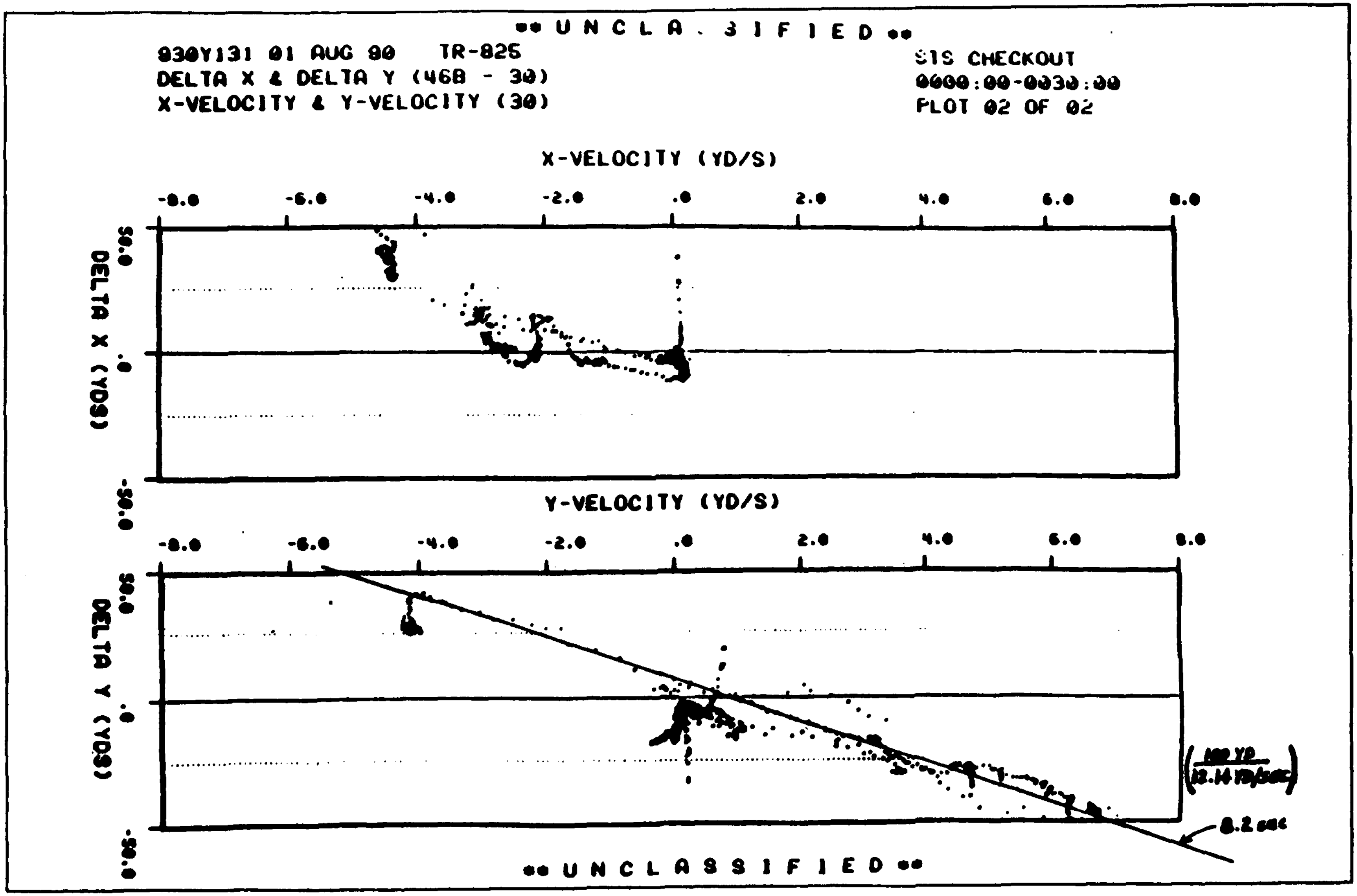

Figure 29b. Post-SAT, X, Y-errors versus X, Y-velocities.

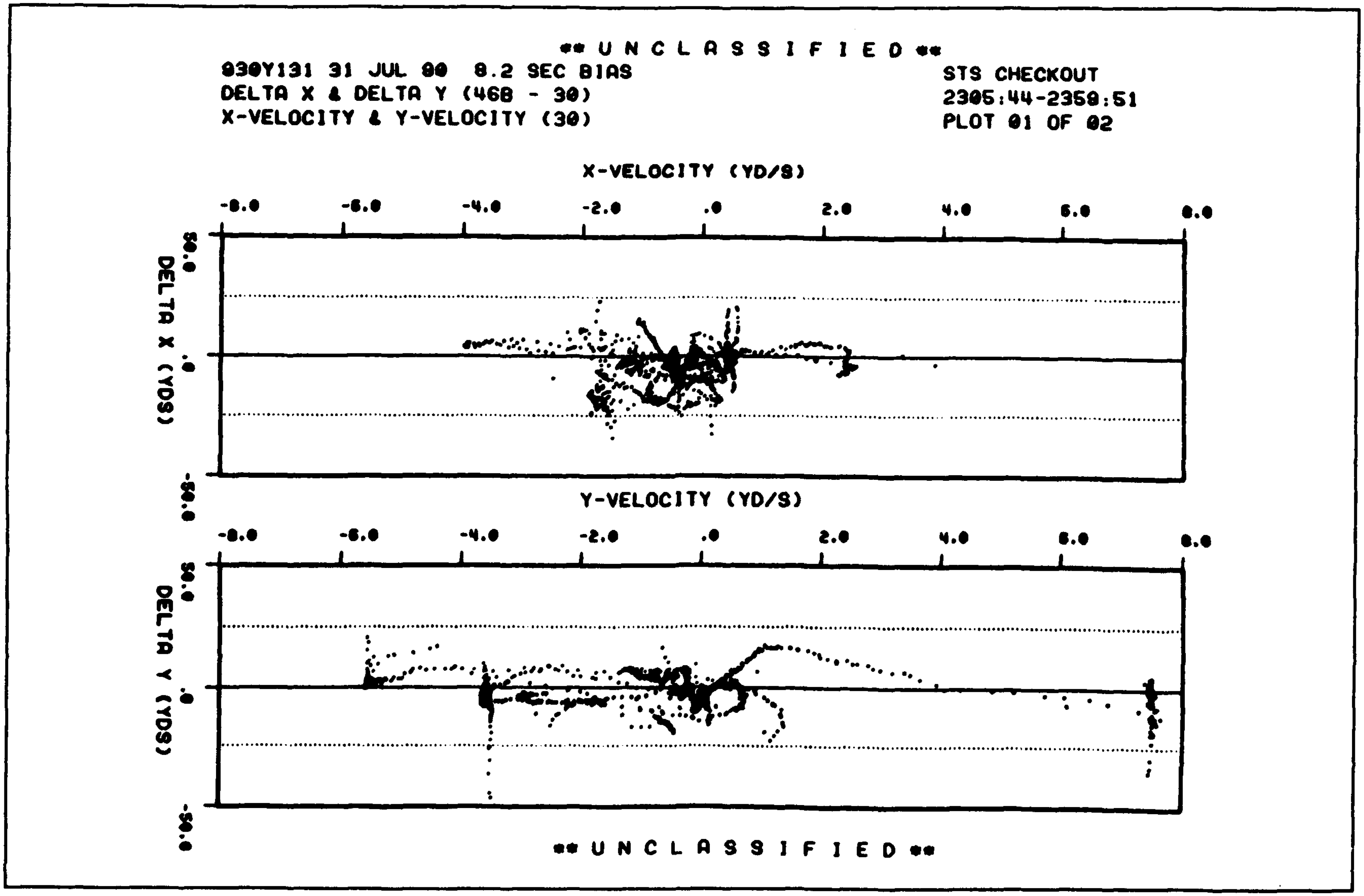

Figure 30a. X, Y-errors versus X, Y-velocities, bias removed.

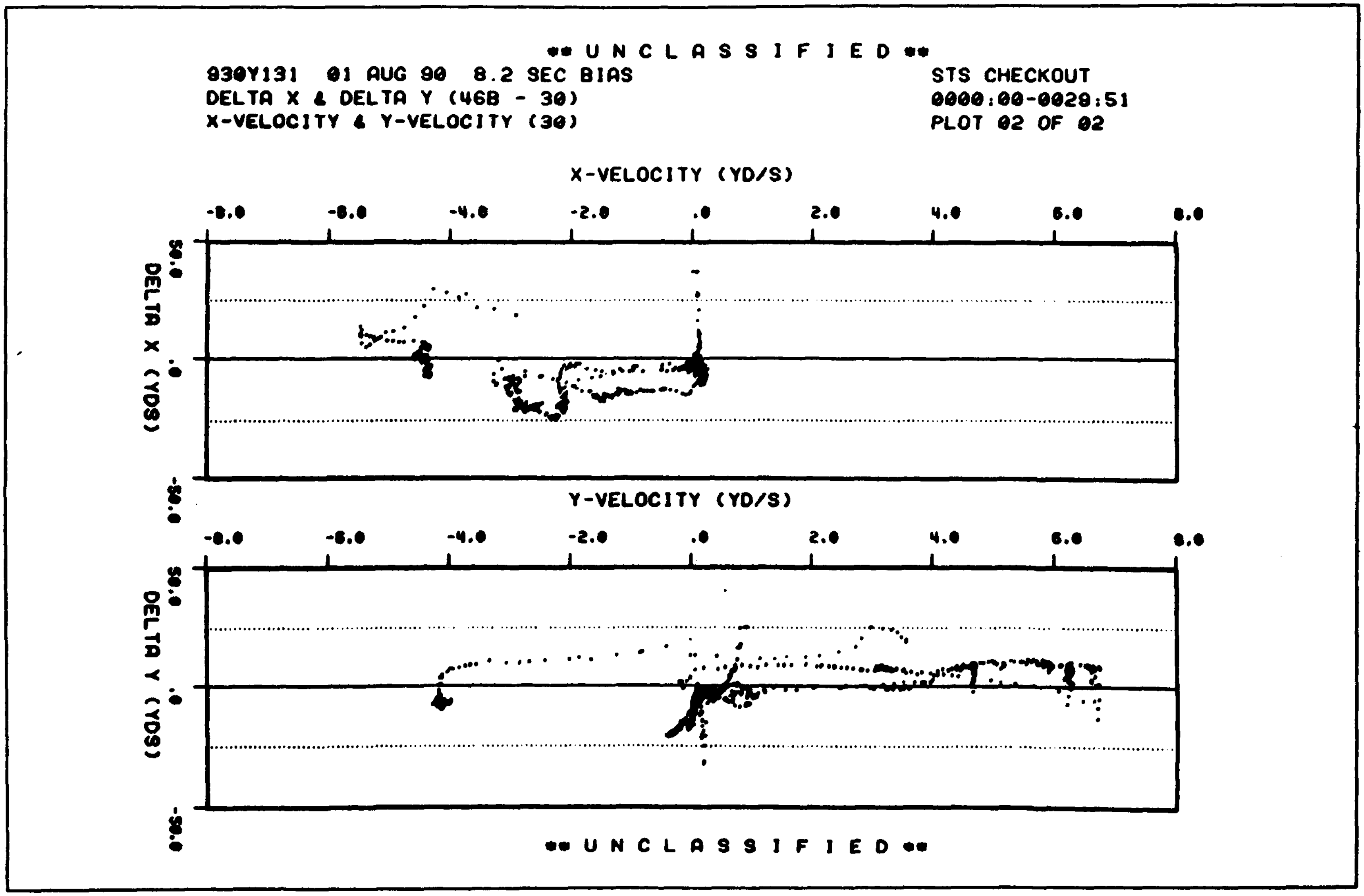

Figure 30b. X, Y-errors versus X, Y-velocities, bias removed.

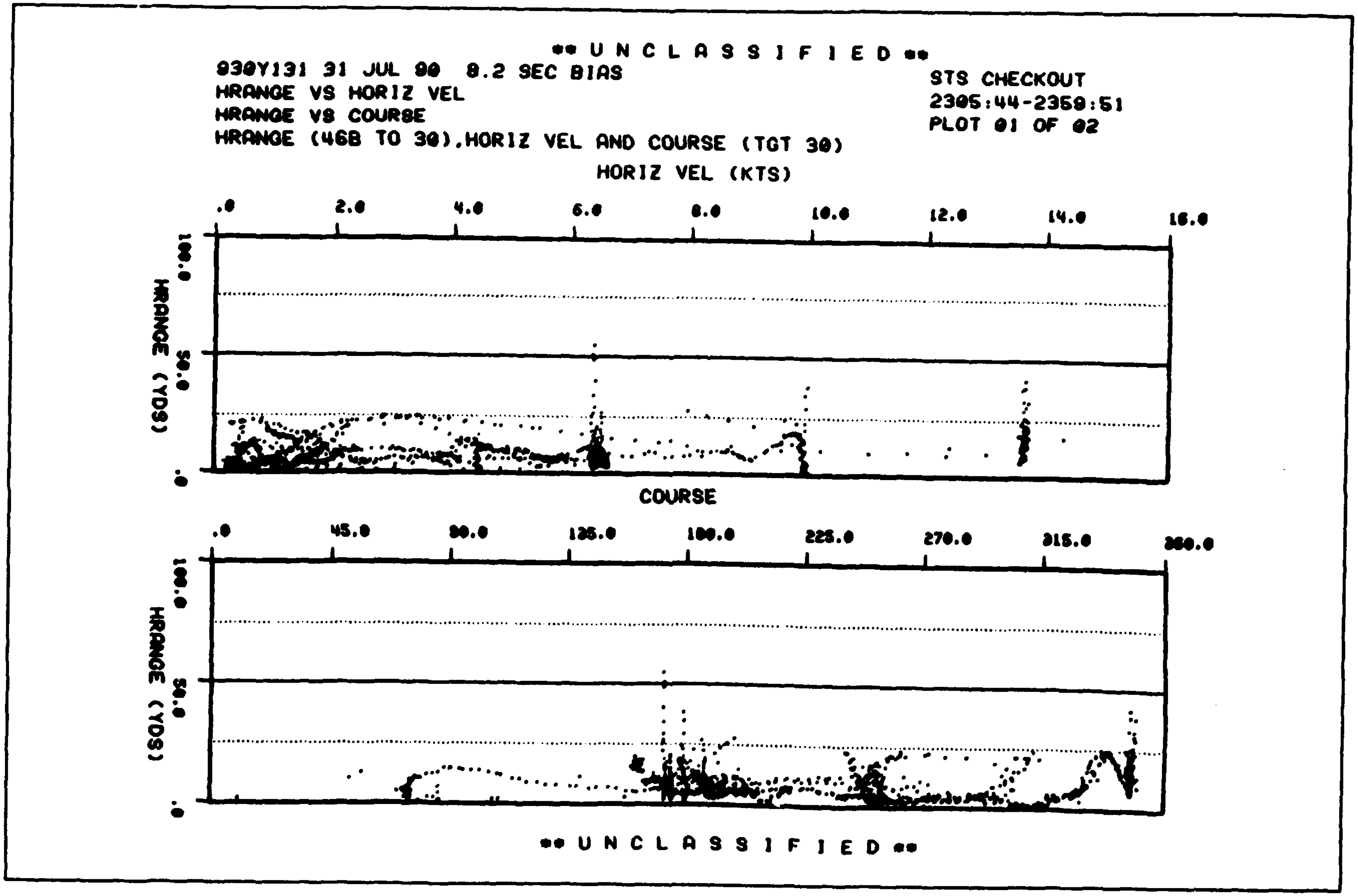

Figure 31a. STS-I/W versus velocity and course, bias removed.

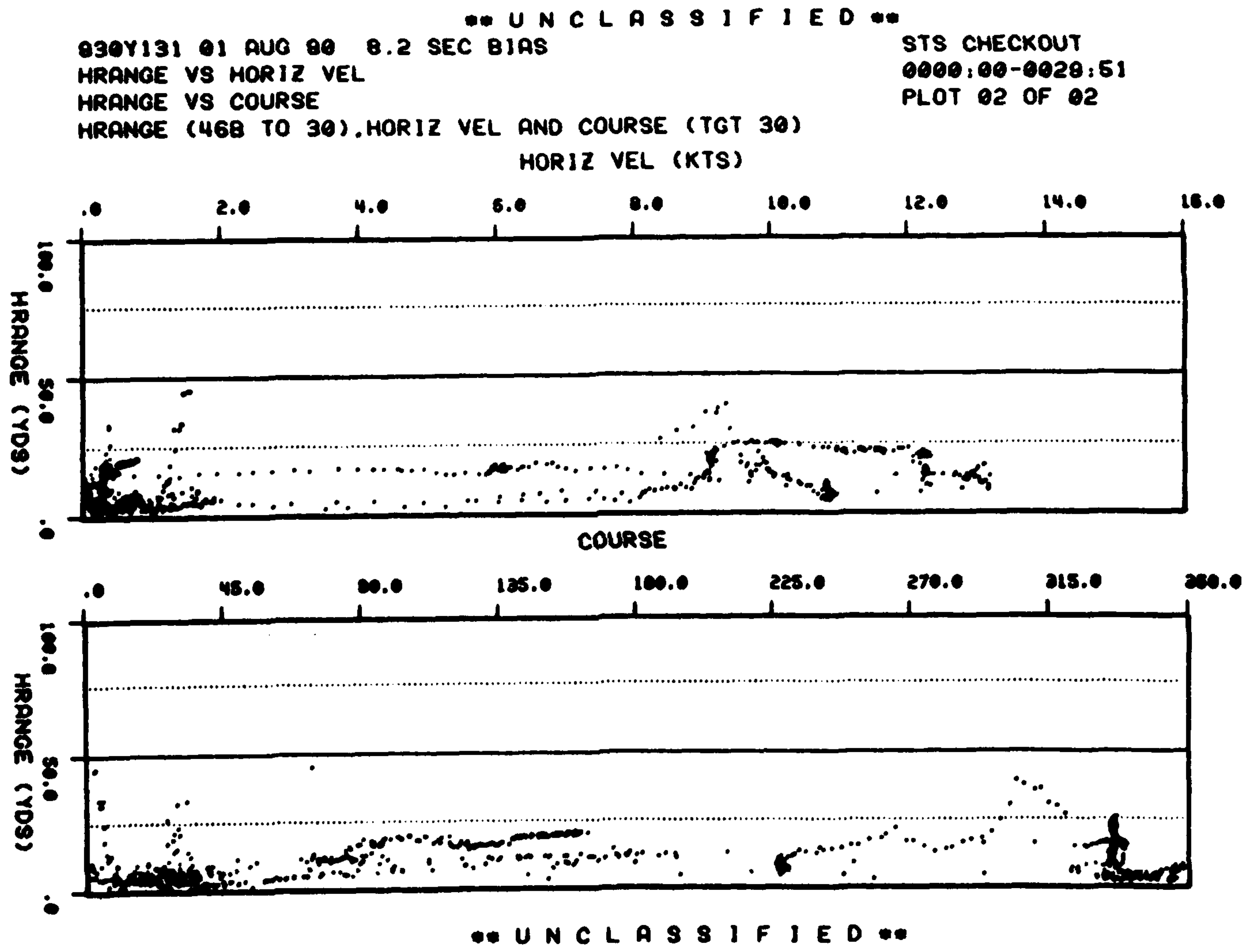

Figure 31b. STS-I/W versus velocity and course, bias removed.

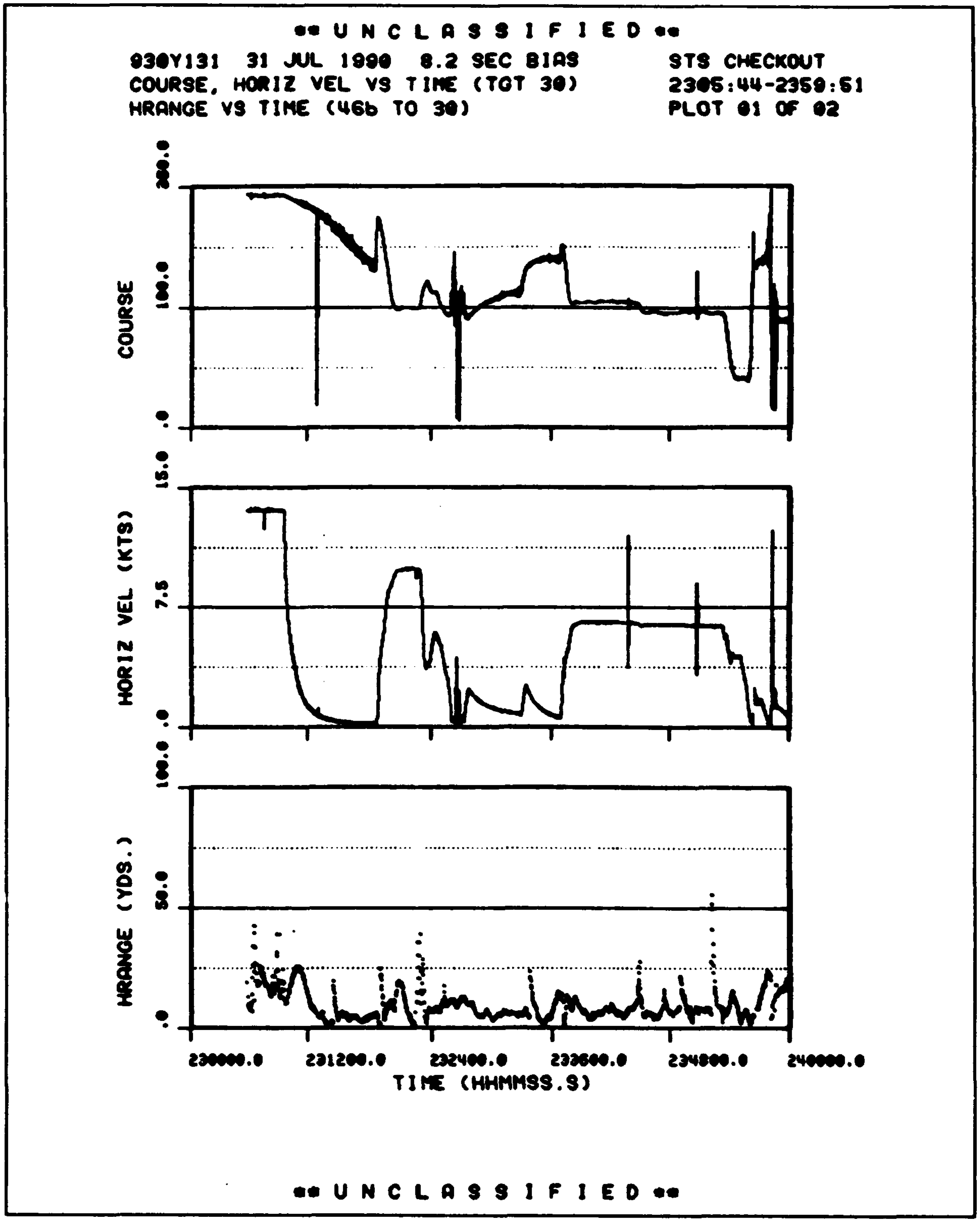

Figure 32a. Post-SAT, STS-I/W versus time, bias removed.

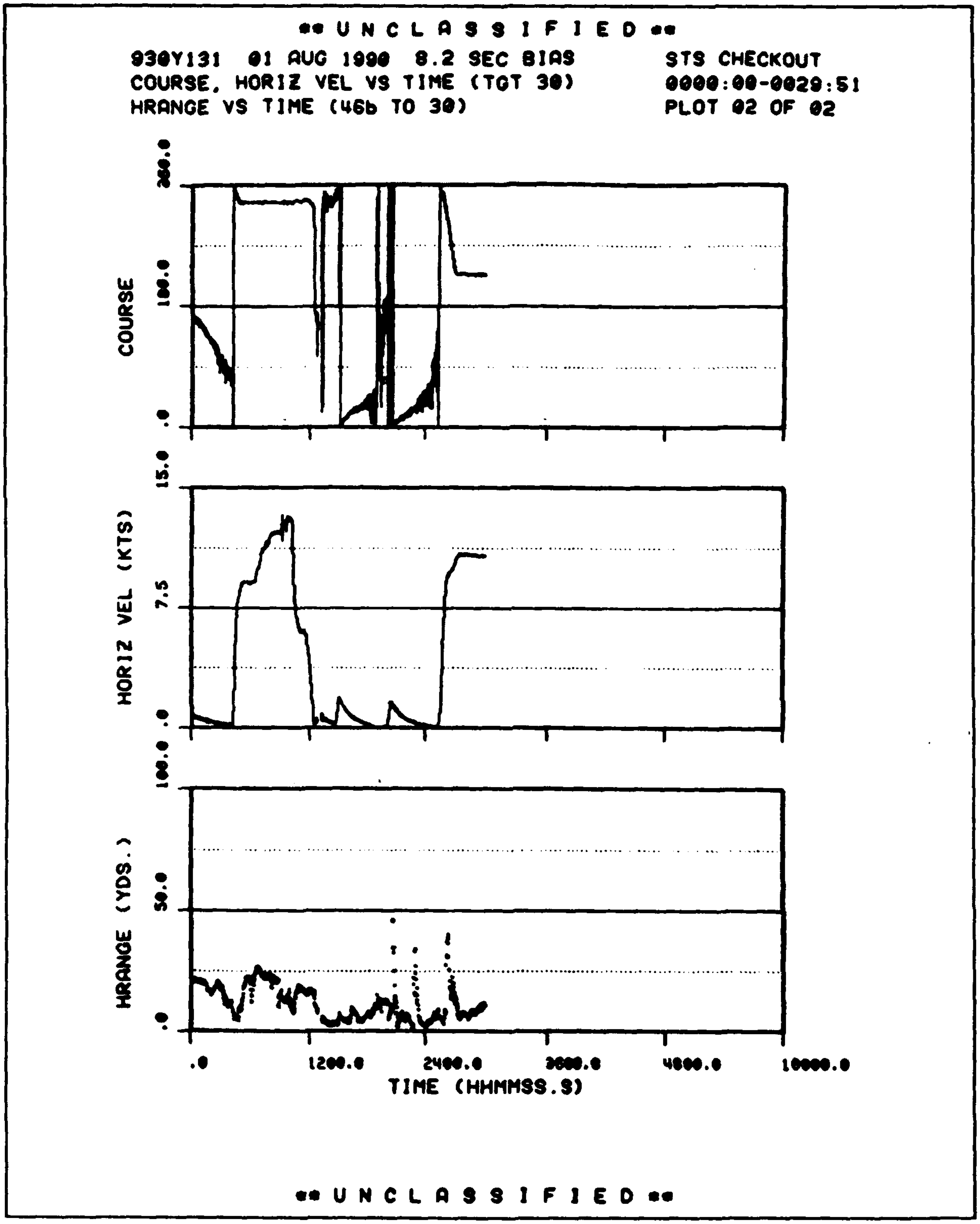

Figure 32b. Post-SAT, STS-I/W versus time, bias removed.

Accuracy estimates for STS resulting from this test are listed in table VII. The upper part of the table are estimates of resultant position bias (mean), variation about the mean (circular standard error), and total RMS radial error based on STS-I/W differences prior to a time-bias correction. (A discussion of how these accuracy estimates were computed can be found in subparagraph 7.1.1.1.). The lower portion of table VII gives similar estimates after an 8.2 second bias correction was applies. (No STS data rejection was needed for ths test.)

TABLE VII. SPECIAL POST-SAT TEST ACCURACY RESULTS (31 July 1990; SRT-22 Aboard TR-825)	
(Maximum Speed: 13.7 knots; 3 Targets in Track)	
NO-TIME BIAS CORRECTION	
Resultant Bias (Mean)	1.5 yards
Variation About the Mean	18.3 yards
Total RMS Radial Error	27.3 yards
Bias Direction (Azimuth)	37°
Number of Data Points	2,743
TIME-BIAS CORRECTION APPLIED (8.2 seconds subtracted from STS times)	
Resultant Bias (Mean)	4.3 yards
Variation About the Mean	7.8 yards
Total RMS Radial Error	11.8 yards
Bias Direction (Azimuth)	244°
Number of Data Points	2,737*

* The difference in number of data points before and after time-bias correction is due to the 8.2 second time shift of STS relative to I/W.

Compare the total RMS radial error of 27 yards prior to time bias correction with 12 yards after such correction. The 12-yard estimate from tracking a boat up to 13.7 knots is very close to the 13-yard estimate from SSV tracking, and the 9-yard estimate from sonobuoy tracking. Also note that the bias direction (bias azimuth) in the lower part of table VII is 70-80° less than during the SAT. (These accuracy estimates are based on post-test data. Real-time accuracy is degraded by the real-time computer update rate of STS positions, as discussed in paragraph 7.9.)

Thus, this special boat test on 31 July 1990 revealed an error which appeared to act as a time bias between STS and I/W systems. The SSV Tracking Test of the May 1990 SAT exhibited a fixed position bias, (although not large enough to fail the SAT, as discussed in subparagraph 7.1.1). Such biases are distinctly different. (Also, the position bias appeared to change direction between the two tests). The only known change between the May and July tests which might have related to this dichotomy was that the vendor replaced the STS applications software, although no software change known to AUTEC personnel would have caused such bias changes.

To further investigate, it was planned to replay several STS raw data tapes from the SAT with the STS computer (containing the latest software) in the RECOMPUTE mode to see if the biases changed and to observe the effect on biases of relaxing the velocity clipping in the Kalman subroutine. Range schedules prevented these replays prior to the Operational Acceptance Test (OAT).

Further investigation of system biases, boat tracking accuracies, and velocity clipping were addressed during the OAT, discussed in the following section.

7.1.2.2 OAT Accuracy Results

Operational Acceptance Testing focused primarily on two objectives: collect additional data to investigate system biases and further evaluate STS accuracy in tracking range vessels.

The second objective was to be accomplished by the TR-825 executing various dynamics (maximum turn rates, and slow and maximum accelerations and decelerations) along the four courses of a square pattern within W3. The first objective (bias investigation) was to be achieved by real-time data collection with the then-existing velocity clipping (2.0 meters/second) in the STS Kalman filter subroutine, followed by processing with any time biases removed, and playbacks with the velocity clipping relaxed. (Also, it was planned to momentarily cease transmission at a known time on one of the SRT-22s to verify the STS's data time tagging.)

The OAT was conducted on 22 October 1990 according to the reference 3 OAT Plan. The AUTEC's TR-825 served as the test vessel with four portable sonobuoy simulators (SRT-22s) aboard. Two SRT-22s used their own whip antennas and were mounted atop the fiberglass launch control hut on the port side, aft of the wheelhouse. These two units, numbered P2 and P3, were assigned Channels 93 (158.875 MHz) and 64 (148.000 MHz). The other two SRT-22s were connected to permanently mounted VHF trombone antennas (cut for approximately 144 MHz): one on the wheelhouse (uni` P1) and the other on the fiberglass hut (unit P4). These two antennas were assigned Channels 32 (136.000 MHz) and 53 (143.875 MHz). All antennas were above the wheelhouse roof. Prior to departure from site 1, a transmission test of all four SRT-22s was conducted dockside, with site 1 communications monitoring receptions on their Watkins-Johnson surveillance receiver.

Prior to OAT data collection, the TR-825 deployed 20 sonobuoys in W4 to provide a grater tracking load on the STS. As planned, the TR-825 made four cycles around the box pattern, executing the planned dynamics. The tracking load on the STS during each cycle was as follows (slightly different than the planned loading).

CYCLE	Number of SRT-22s in Track	Number of Sonobuoys in Track	Total Number of Targets in Track
1	4	20	24
2	4	20	24
3	4	10	14
4	2	0	2

During the first leg of cycle 1, the real-time STS data editing algorithm in the SEL had to be altered to avoid rejecting most of the test data. Specifically, the criterion on the RSS of azimuth residuals had to be increased from 0.2 to 1.0°. The change was made and the test continued. (Editing is discussed in paragraphs 7.2.)

During cycle 4, with only two SRT-22s in use (P1 and P4, the two connected to the trombone antennas), transmissions on P4 (channel 53) were interrupted for 12 seconds during leg 2 and for 14 seconds during leg 3. These momentary interruptions were accomplished by switching P4s RF output into a dummy load. With two channels in track, the STS cycle time (between visits to a given channel) was a nominal 1.3 seconds. (The STS data referred to here are the fast-rate "b" data coming across the STS-SEL interface as discussed in paragraph 7.9.) There is no evident in the results shown here of any bias in STS time tagging.

	LEG 2, 2239Z		LEG 3, 2255Z	
	CEASE (secs)	RESUME (secs)	CEASE (secs)	RESUME (secs)
P4 XMSN	00.0	12.0	00.0	14.0
STS DATA	00.5	13.7	01.0	15.7

Results from all 4 cycles are similar except that with greater target loads cycles 1-3 have less data density (fewer STS solutions in a given time period) than cycle 4. During the first three cycles, data from P1 and P4 were slightly better than from P2 and P3.

For cycle 4, with only two tracking channels assigned, horizontal position differences between the STS and I/W systems along with boat course and speed, are plotted versus time in figures 33 and 34 (for P1 on channel 32 and P4 on channel 53. As expected with velocity components clipped at ± 2.0 m/s, position errors in STS are highly correlated with speed as they were in the post-SAT test, figures 26a and b. Horizontal position differences between STS-I/W plotted versus speed and course are shown in figures 35 and 36 (for P1 and P4), and are similar to figures 27a and b for the post-SAT test.

The striking difference between the OAT test results and those from the post-SAT test is shown in figures 37 and 38 (for P1 and P4) versus figures 29a and b. Note that the OAT data reveals a distinct difference in X and Y position errors for speeds between ±2.2 yards/seconds (~2.0 m/s) as opposed to those outside this interval; the post-SAT test did not. (Why the post-SAT data did not reveal this discrepancy, as noted in subparagraph 7.1.2.1, is not known at this time.) Thus, velocity clipping became the likely cause of position errors correlated with time.

This velocity clipping increased the importance of playing back STS raw data tapes from the OAT (and post-SAT) with the STS computer in the RECOMPUTE mode and with velocity clipping in the Kalman filter subroutine relaxed. However, delays because of range schedules, coupled with the replay difficulties discussed in paragraph 7.10, (and several tapes discovered to have been inadvertently erased), prevented acquiring this additional data for analysis. For these reasons, the following post-OAT test was conducted.

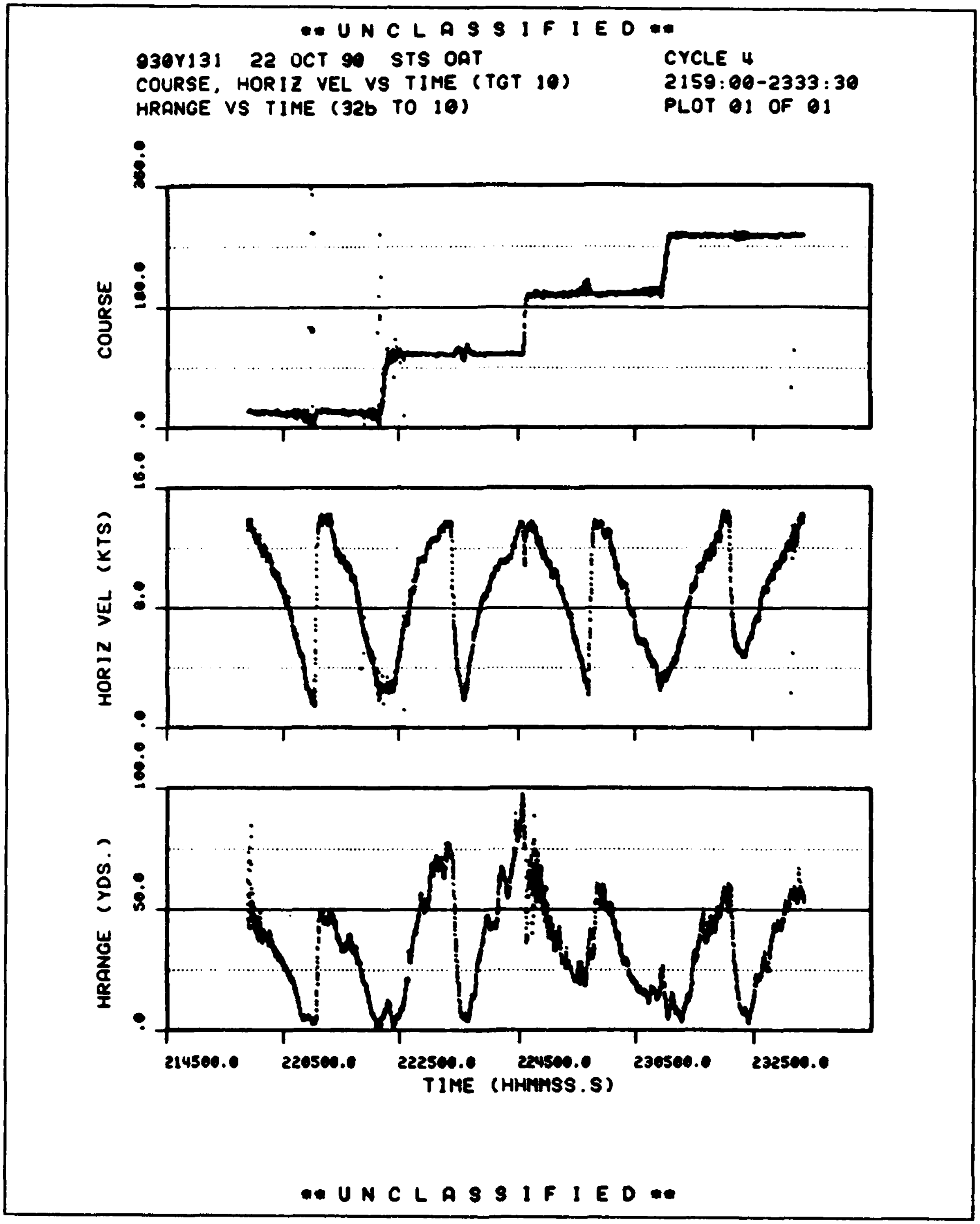

Figure 33. OAT, horizontal range versus time, 32, cycle 4.

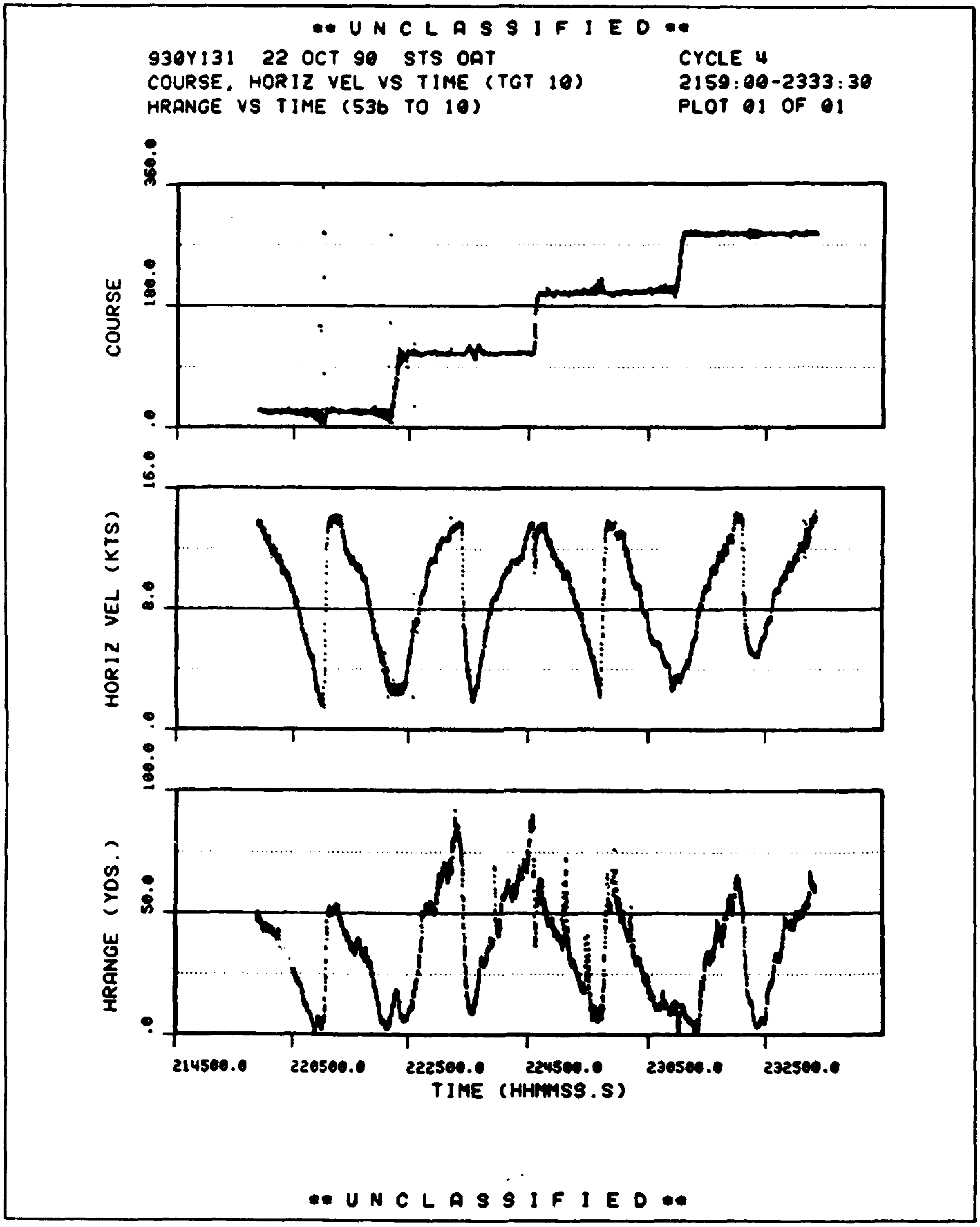

Figure 34. OAT, horizontal range versus time, 53, cycle 4.

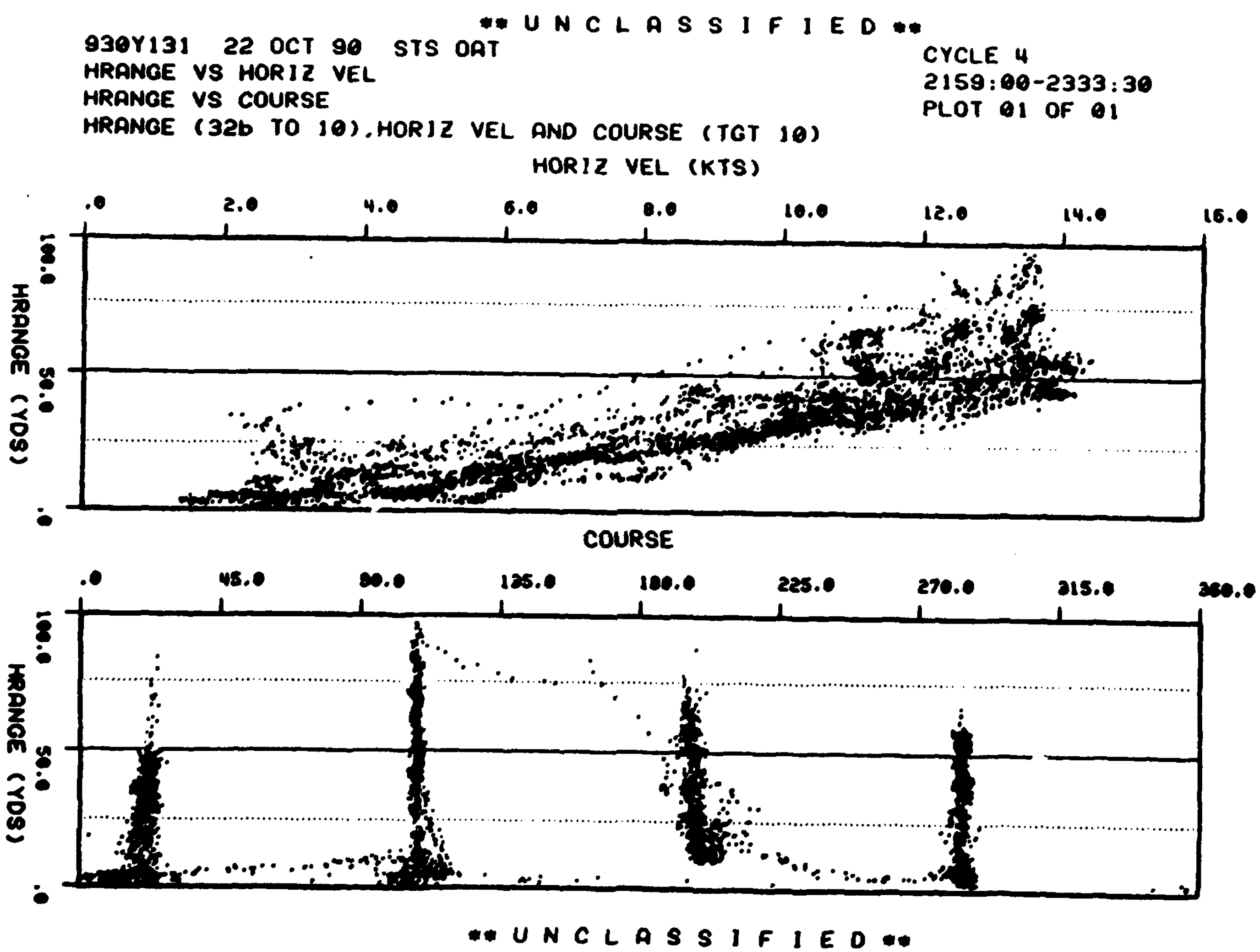

Figure 35. OAT, horizontal range versus velocity and course, 32, cycle 4.

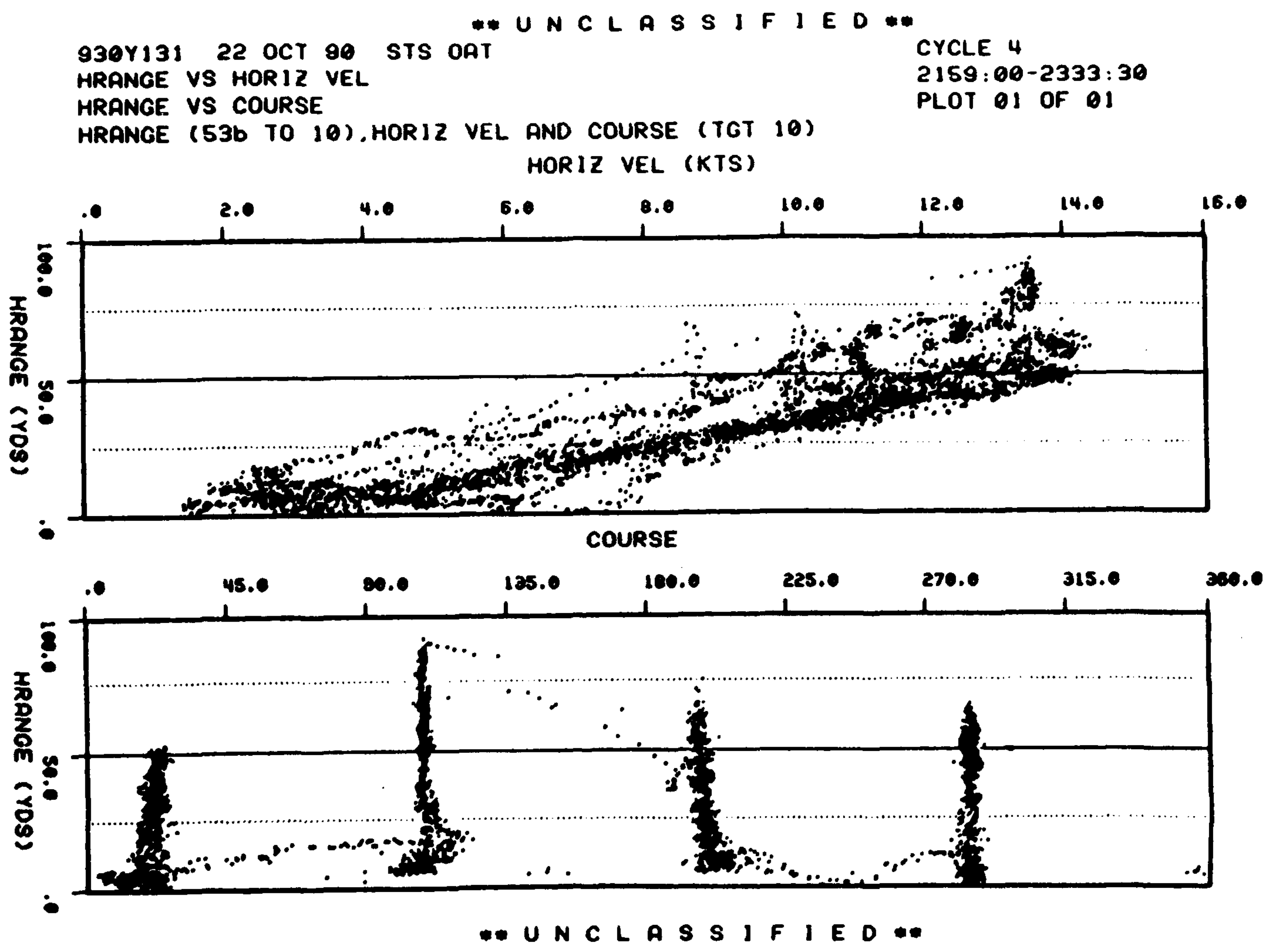

Figure 36. OAT, horizontal range versus velocity and course, 53, cycle 4.

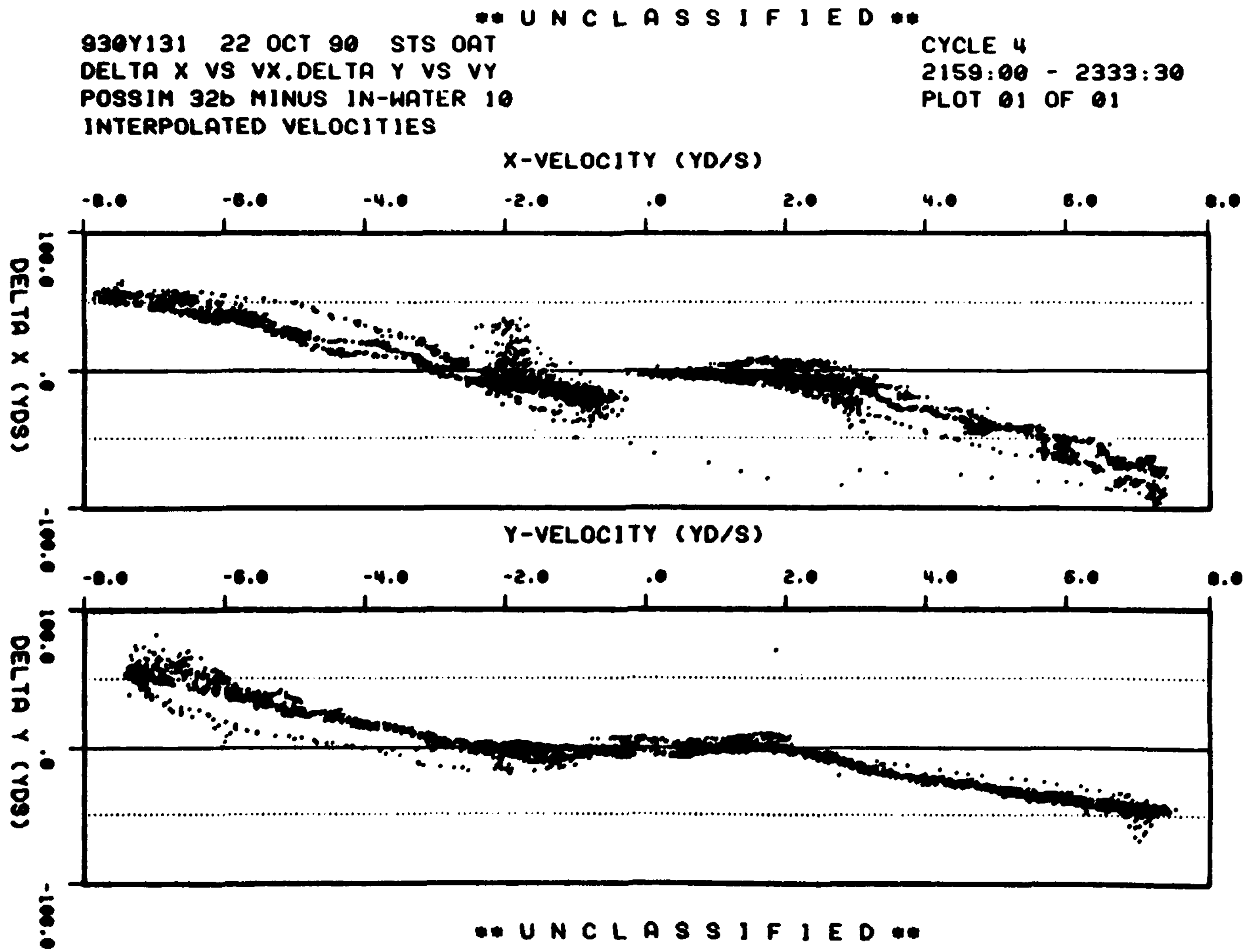

Figure 37. OAT, X, Y-errors versus X, Y-velocities, 32, cycle 4.

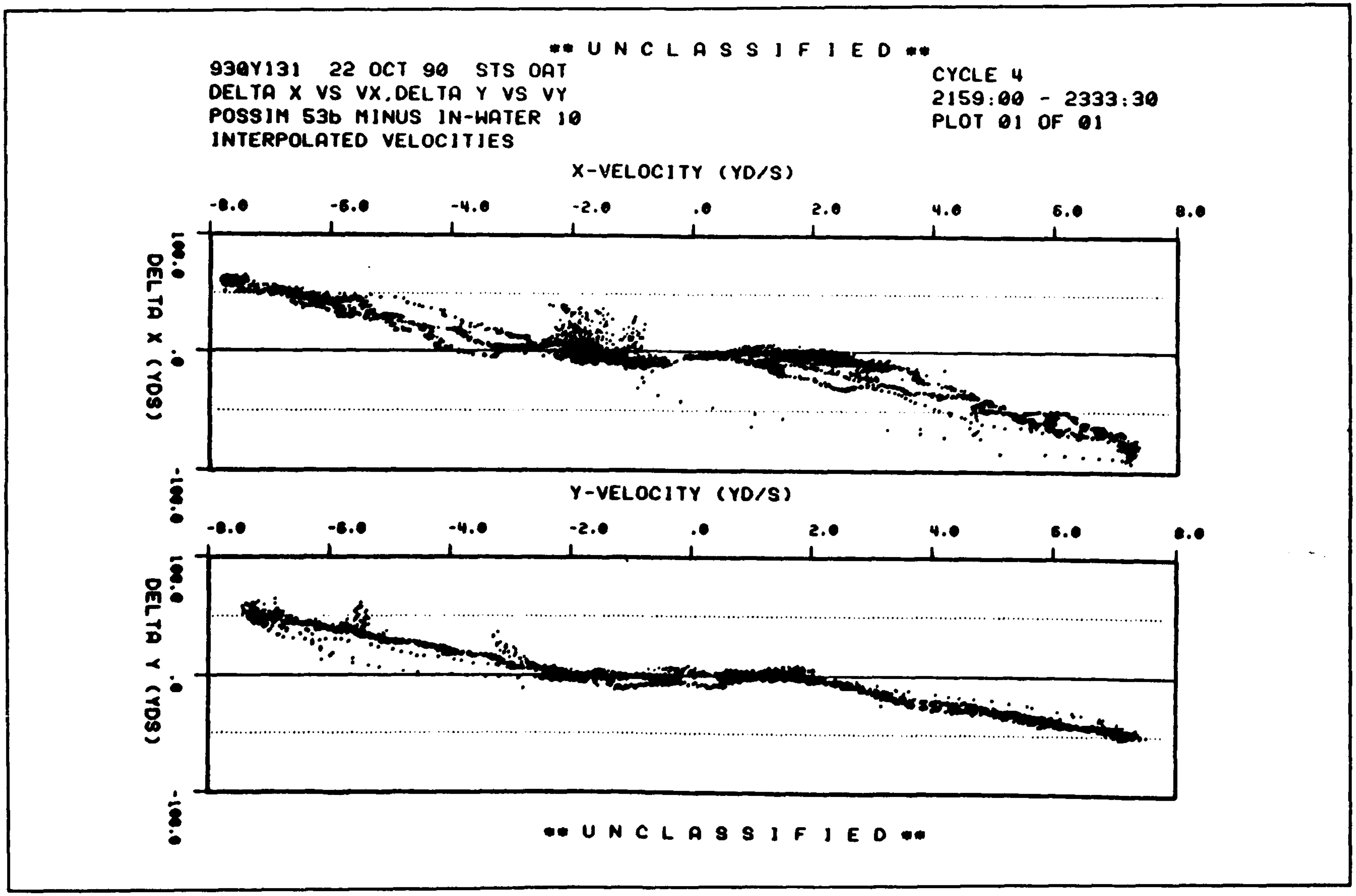

Figure 38. OAT, X, Y-errors versus X, Y-velocities, 53, cycle 4.

7.1.2.3 Post-OAT Test

This test was designed to repeat cycle 4 of the OAT, but this time velocity clipping was relaxed for the test so that data collected in real-time would not experience such clipping. It was requested that the limits on velocity components be increased from 2.0 to 10.0 meters/second (19.4 knots) which is adequate for range vessels. The change was made to 20.0 meters/second (38.9 knots).

It was also requested that the STS data edit algorithm in the SEL be modified temporarily for this test, namely, that the criterion on RSS of azimuth residuals be increased from 0.2 to 1.0° (as was required for the OAT and discussed in the previous section). The change was made to 20°, but post-test analysis showed that the larger value caused no problem. As a matter of fact, it turned out this criterion could have remained at 0.2°.

Although the test vessel for the OAT was the TR-825, she was unavailable to support this post-OAT test when scheduled. Therefore, the RANGEMASTER (R/M) (TR-51) was used. The R/M has an 11.5 knot cruising speed (versus the TR-825's nearly 14 knots), and a single permanently mounted VHF trombone antenna mounted approximately 3 feet starboard and 1 foot aft of the mast, and above the wheelhouse. For this test, a second trombone was lashed to a halyard at approximately the same height and relationship to the mast but on the port side.

The SRT-22s were connected to these antennas and were set for sonobuoy channels 32 and 53, and in the OAT, channel 32 used the starboard trombone, while channel 53 used the port one. Pretest checkout of the SRT-22s was conducted using site 1 communication's Watkins-Johnson surveillance receiver.

This post-OAT test was conducted on 26 February 1991. It turned out that the range schedule permitted cycle 4 of the OAT to be repeated twice, and these are referred to be here as cycles 1 and 2. The resulting data, shown in figures 39 through 46, confirmed that the velocity clipping at 2.0 m/s (3.9 knots), which is adequate for sonobuoy tracking, was the cause of boat positions being highly correlated with speed.

Figures 39 through 42 are plots versus time of course, speed, and horizontal position difference between the STS and I/W systems for both channels 32 and 53 for both cycles. There appears to be no correlation with speed.

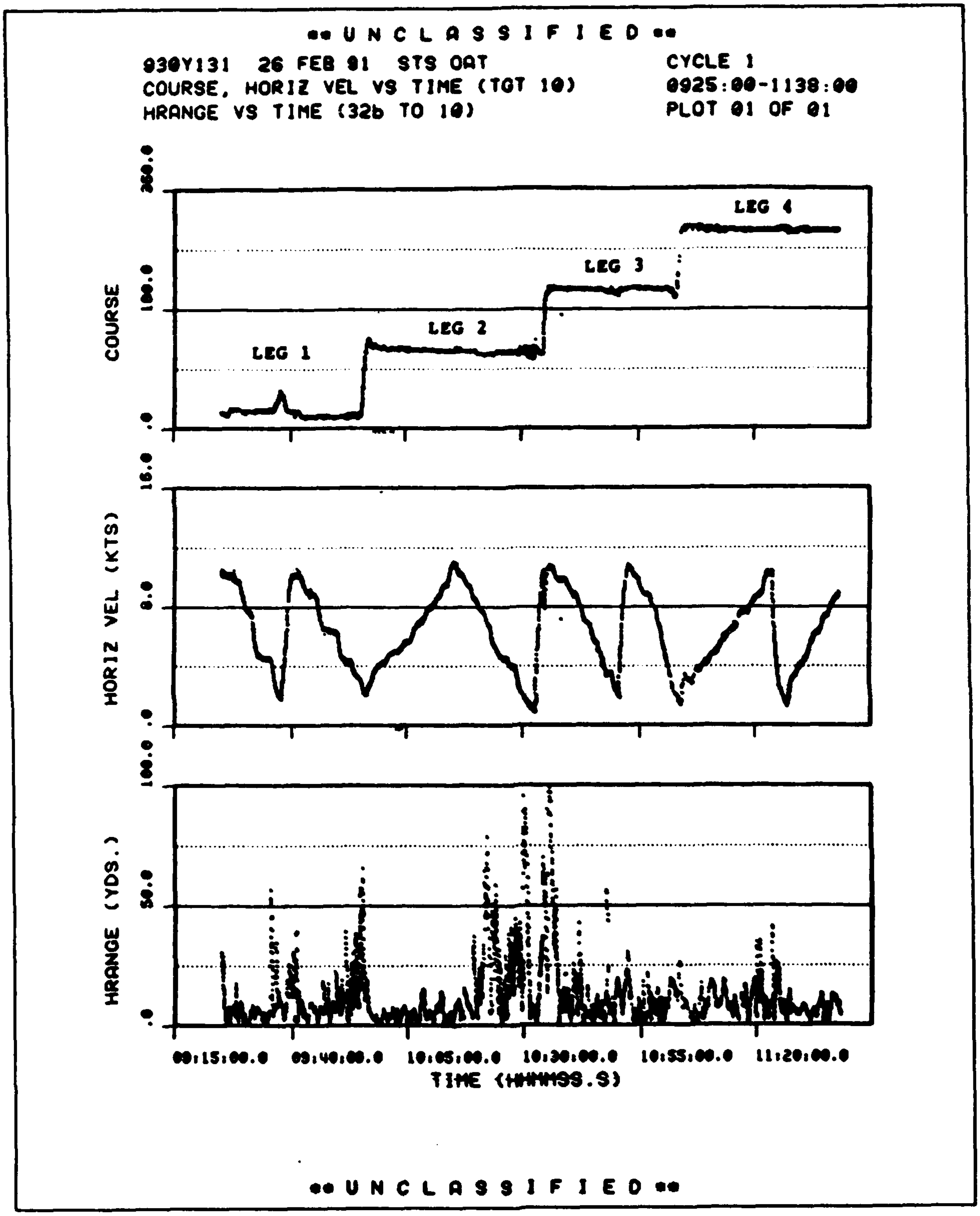

Figure 39. Post-OAT, horizontal range versus time, 32, cycle 1.

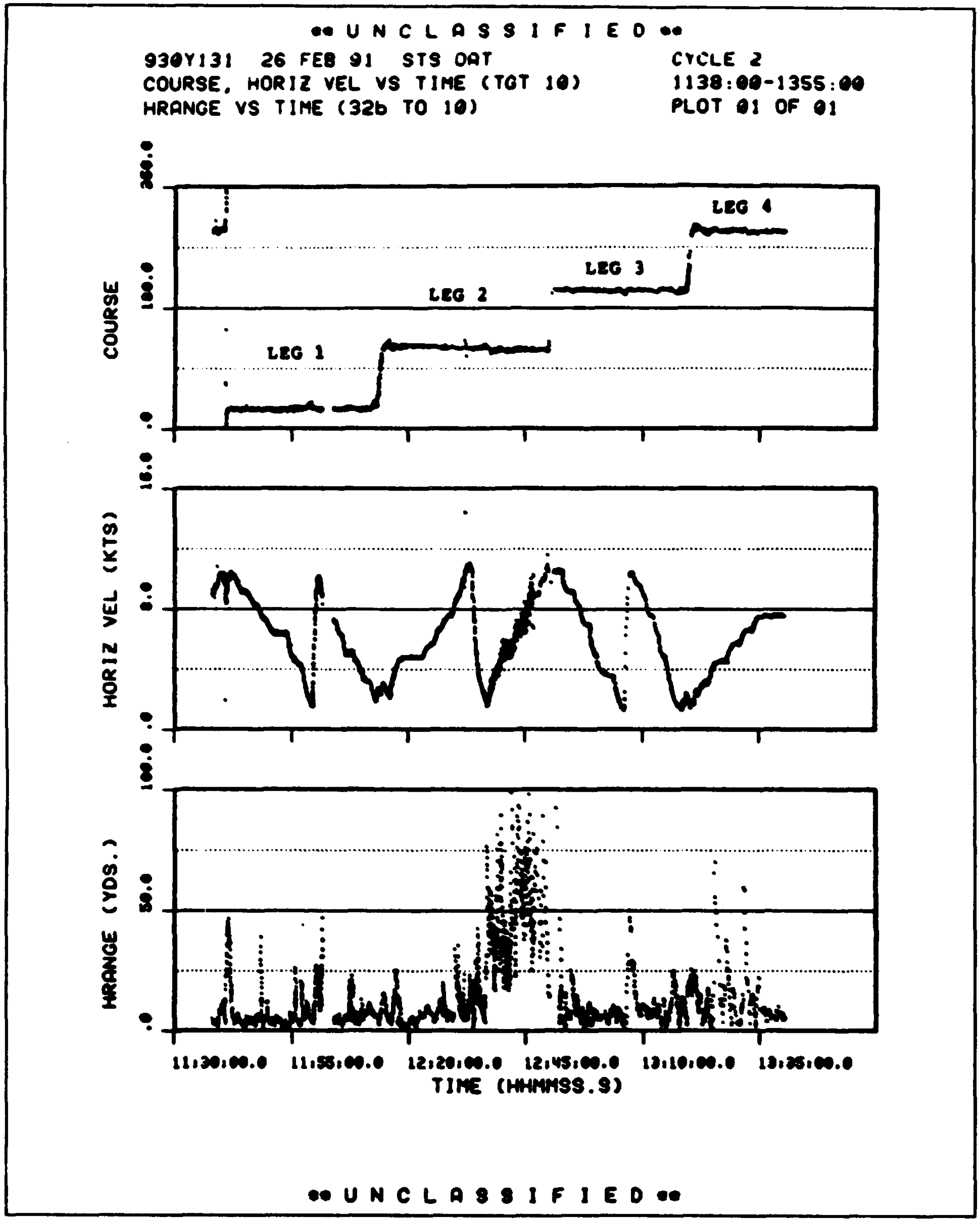

Figure 40. Post-OAT, horizontal range versus time, 32, cycle 2.

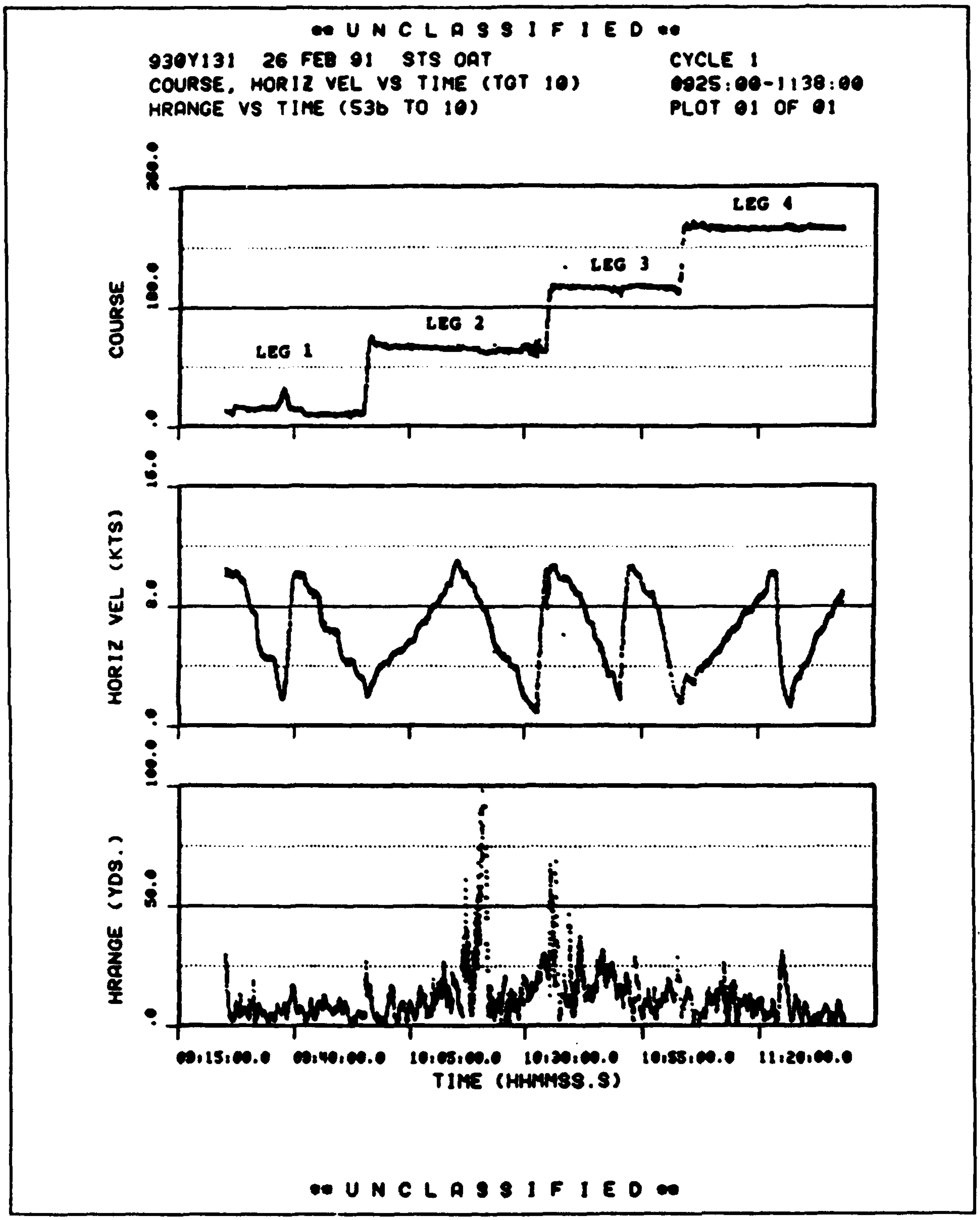

Figure 41. Post-OAT, horizontal range versus time, 53, cycle 1.

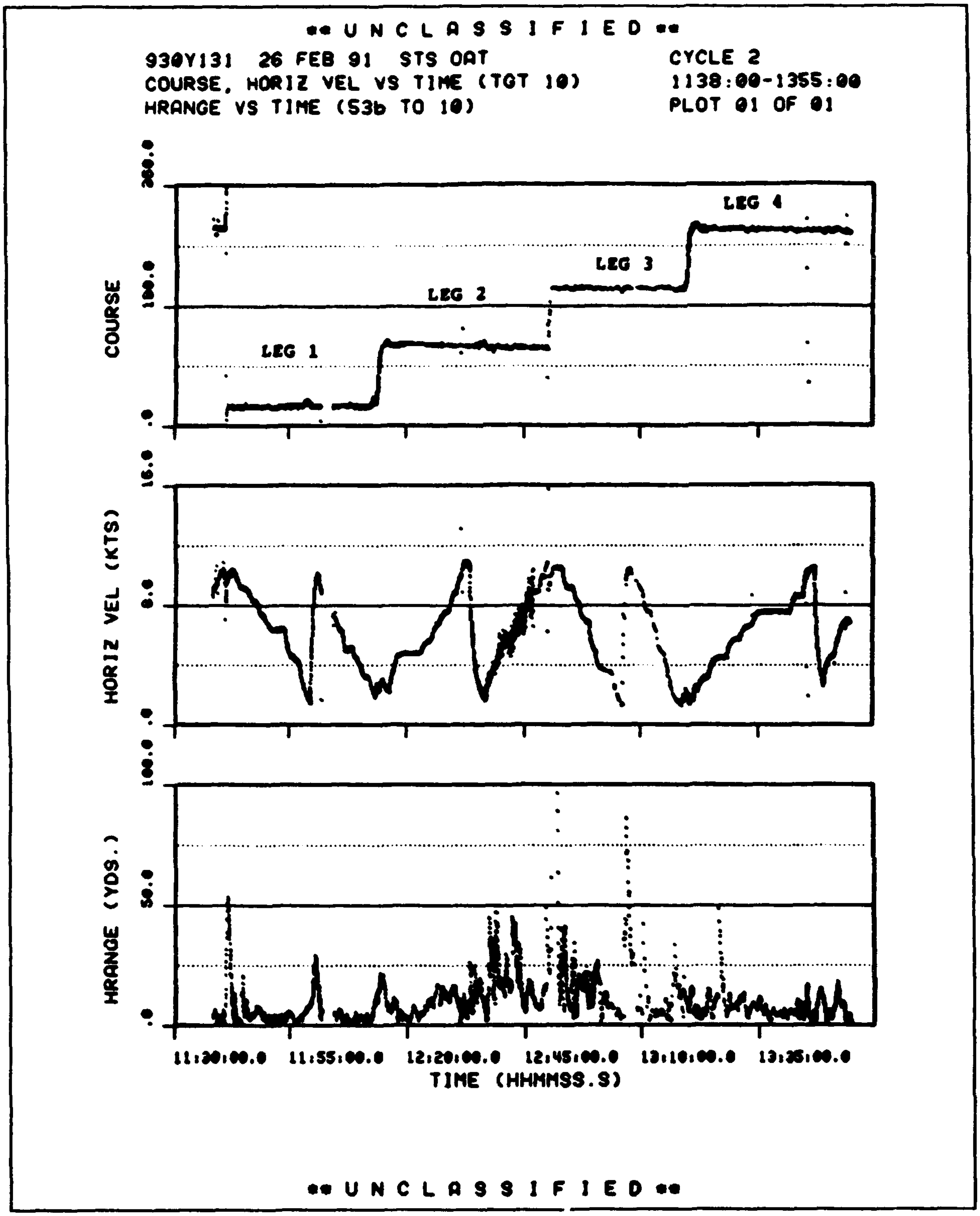

Figure 42. Post-OAT, horizontal range versus time, 53, cycle 2.

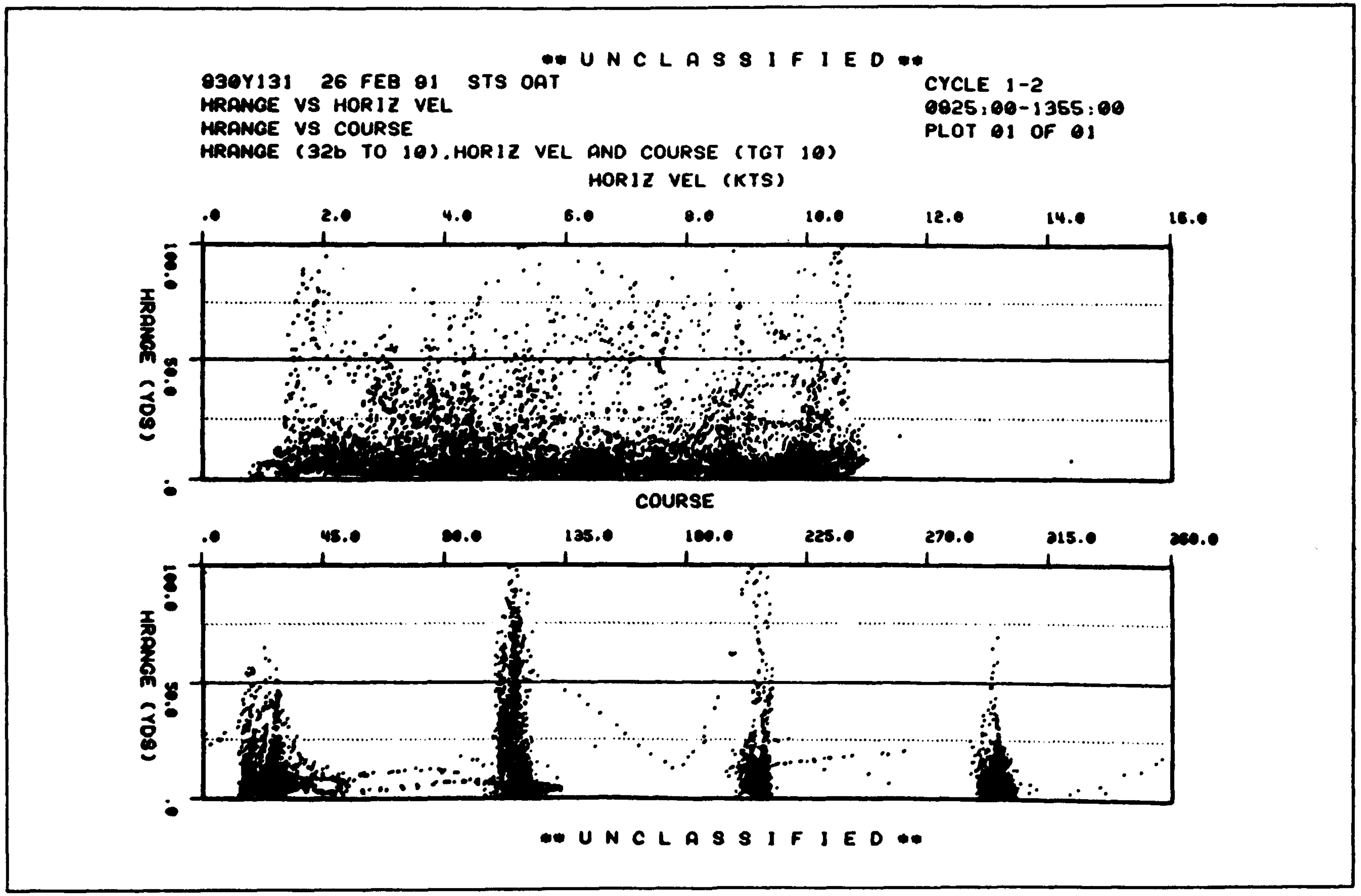

Figure 43. Post-OAT, horizontal range versus velocity and course, 32.

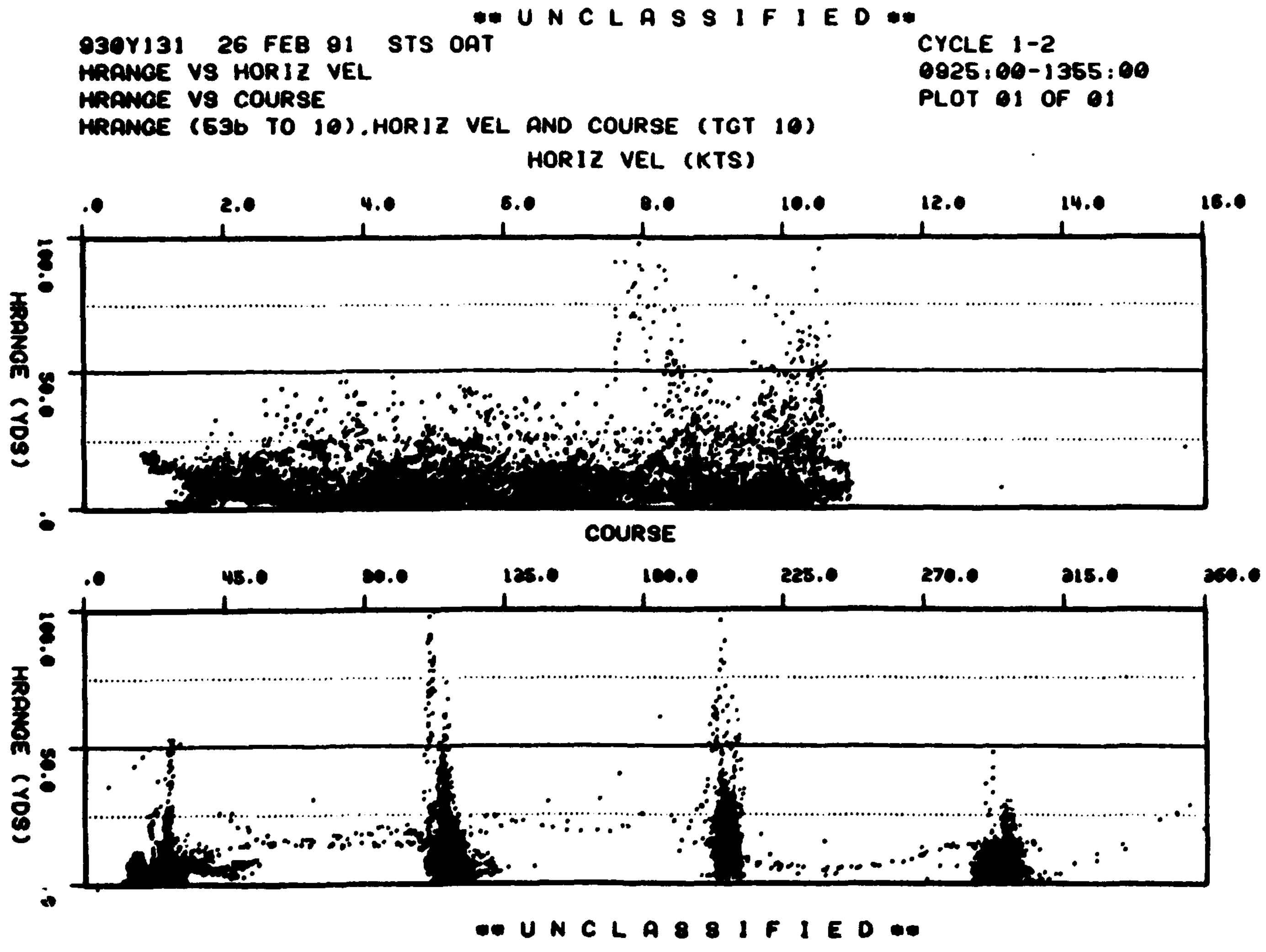

Figure 44. Post-OAT, horizontal range versus velocity and course, 53.

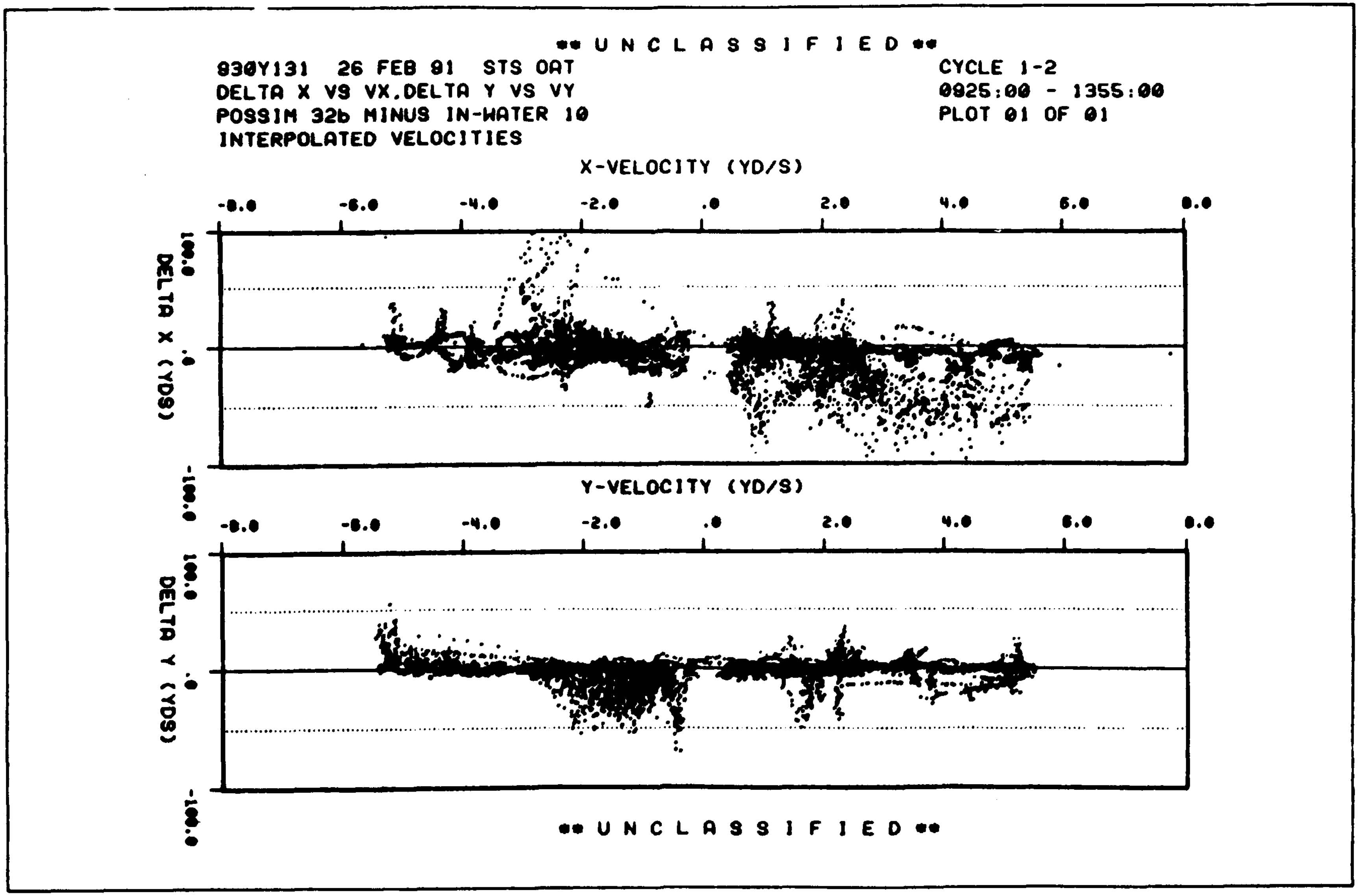

Figure 45. Post-OAT, X, Y-errors versus X, Y-velocities, 32.

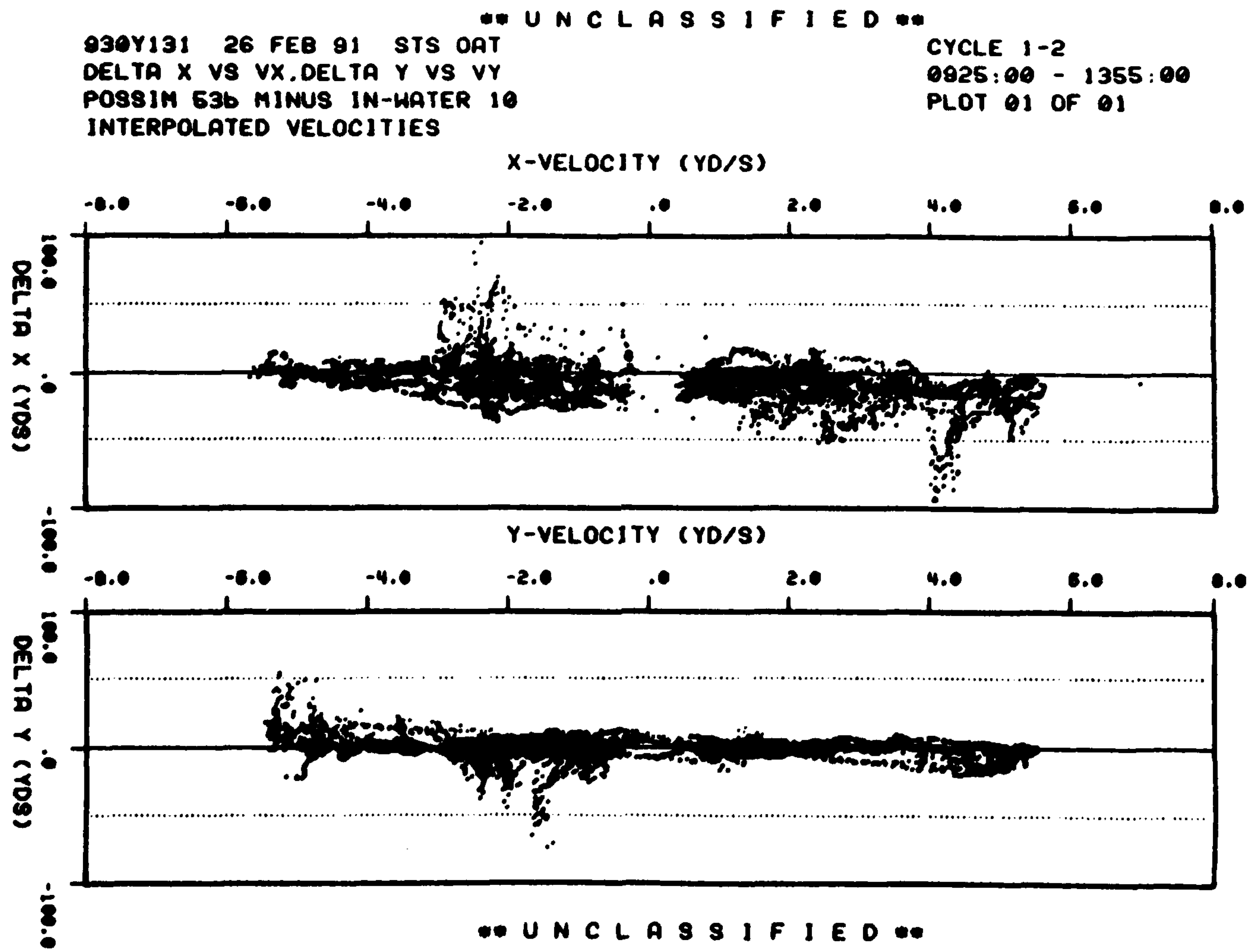

Figure 46. Post-OAT, X, Y-errors versus X, Y-velocities, 53.

Figures 43 and 44 are plots of horizontal position differences between STS and I/W versus speed and course, and figures 45 and 46 are plots of X and Y position differences versus X and Y components of velocity. These plots confirm no correlation with speed. To aid in comparisons with the previous tests, the following cross-reference of figure numbers is provided.

Figure Number Cross-Reference		
Velocity Clipping: 2.0 m/s		20.0 m/s
Post-SAT	OAT	Post-OAT
26a & b	33, 34	39-42
27a & b	35, 36	43, 44
29a & b	37, 38	45, 46

There are some large noise bursts in figures 39 through 46. In general, these noise bursts are not surprising, but in figure 39 for channel 32, for example, there appears to be an abnormal amount of noise during the last half of leg 2 on a nominal course of 113° during cycle 1. (The legs are identified by course in the upper plot of this and following figures.)

Curiously, a large noise burst occurs again during the last half of leg 2 during cycle 2 (see figure 40). Noise during similar time periods occurs for channel 53 in figures 41 and 42, though not to the same extent. (Because of the boat dynamics during the last half of the two leg 2s, the noise on channel 32 during these periods is spread over the full range of speeds in the upper portion of figure 43 which includes both cycles; similar effects are seen in figures 44 through 46.)

If this period of noise had occurred over the entire leg 2 (that is, same heading all the way and little change in aspect angle to the STS sites), it might have been attributed to RF shadowing of the antennas aboard the R/M. That is occurred for both channels seems to eliminate the individual SRT-22s themselves as the cause. The fact that the noise bursts are as different as they are between channels, and because they occurred at the same place in both cycles, seems to rule out anything common between both the two SRT-22s such as power.

Coincidentally, this noise phenomenon happened to be the one segment of this test which deviated from the plan. The last half of leg 2 on both cycles was planned to be a gradual acceleration from minimum to maximum speed; it turned out to be a deceleration during cycle 1, so boat dynamics were different between cycles for this segment of leg 2. There are also some similarities and some differences in the Site Data Use Codes for the two RF channels, but none which explain the noise phenomenon noted here. At this time, the cause of the noise bursts on both cycles during the last half of leg 2 is unknown. It is noted that a tighter criterion on RSS of azimuth residuals and perhaps some additional criteria (on first differences of the X and Y coordinates) in the STS data edit algorithm on the SEL might have automatically rejected a good portion of this noise. (Editing is discussed in paragraph 7.2.)

Table VIII lists STS boat tracking accuracy estimates based on this test's data. Estimates in the upper portion of the table are based on a modified real-time editing (that is, with the criterion on the RSS of azimuth residuals increased from 0.2 to 2.0° as discussed previously) with a slight amount of "cursory editing" (STS-I/W differences greater than 200 yards as discussed in earlier sections). All data from the last half of both leg 2s were rejected to yield the estimates in the lower portion of the table.

Accuracy estimates in the lower portion of table VIII (with the last half of leg 2 in both cycles excluded) represent the best case for STS boat tracking and assume

(a) an improved editing algorithm, that is, one that will reject much of the noise of the type experienced in this test (see paragraph 7.2);

(b) proper installation of SRT-22 antennas (see paragraph 7.8);

(c) no RFI on the tracking channel (see paragraph 7.6);

(d) proper constants in the software for the channels used to track the boats; at least velocity clipping opened up to 10.0 m/s (as discussed in paragraph 7.3);

(e) less than about five channels in track (without further evaluation); this test used only two; and

(f) within range of at least two STS sites and within the azimuth limits of the system calibration (see paragraph 7.7).

TABLE VIII. STS BOAT TRACKING ACCURACY ESTIMATES FROM THE POST-OAT TEST

MODIFIED REAL-TIME DATA EDITING (defined in text)	SRT-22 CHANNELS		
	32	53	Both
Resultant Bias (Mean)	4.7	5.0	4.8
Variation About the Mean	12.3	9.5	10.9
Total RMS Radial Error	18.7	15.0	16.8
Bias Direction (Az, deg)	258	279	269
Number of Data Points	9,513	10,691	20,204

MODIFIED REAL-TIME EDIT PLUS LAST HALF OF LEG 2 REJECTED, BOTH CYCLES*	SRT-22 CHANNELS		
	32	53	Both
Resultant Bias (Mean)	1.9	4.3	3.1
Variation About the Mean	7.4	6.7	7.1
Total RMS Radial Error	10.9	10.8	10.9
Bias Direction (Az, deg)	288	281	283
Number of Data Points	8,067	9,061	17,128

Units: yards except as noted.

* As discussed in subparagraph 7.1.2.3.

The STS boat tracking accuracy capability addressed here is currently a <u>post-test</u> capability. The <u>real-time</u> capability is degraded because of the STS data update rate for real-time display as discussed in paragraph 7.9.

Note that the total RMS radial error of 10.9 yards in table VIII for this post-OAT boat test is in excellent agreement with the 11.8 yards in table VII for the post-SAT boat test. Compare the bias estimates in table VIII of 3.1 yards at an azimuth of 283° with similar estimates of 4.2 yards at 326° in table V for the SAT sonobuoy tests.

It was desired to have the same boat test data processed by the STS two ways: with velocity clipping at ± 2.0 m/s and at ± 20.0 m/s. The larger value was in place for the real-time data, so a playback of the STS raw data in the RECOMPUTE mode with the smaller value was requested. The result was virtually useless: every data point showed Site Data Use Codes set for all three sites and much noise in the data. The cause is unknown but may have been an incorrect configuration for playback. In any case, time constraints prevented follow-up analysis. Unlike the OAT, the post-OAT test did not address the effects of larger target loads (fewer STS measurements and fewer solutions per unit time) on boat tracking accuracy.

7.2 Data Editing

The STS data output to the SEL (host) computer is currently uninhibited; all data, good or bad, are sent to the SEL. Since software in the STS HP computer contains a Kalman filter and certain prefilter data rejection algorithms, the most efficient place to identify bad STS track data may be in the STS software. This will, however, require adequate familiarization with existing STS software. Meanwhile, STS data edit/rejection is being accomplished in the SEL.

The first STS data editing algorithm was added to ISPROC in the SEL computer on 8 August 1990 based on a recommendation by Systems Analysis and is documented in table I of reference 5. This recommendation was based upon data collected during the SAT and post-SAT tests. It turned out that the recommended algorithm was not fully implemented.

On 29 November 1990, the editing algorithm was revised per a memo to Software Engineering from Systems Analysis dated 19 October 1990. That revision is the current algorithm for STS data editing in the SEL and is given in table IX. This revision also included a modification to make the Site Data Use Code for an inactive site a dash (-) in the SEL computer, rather than leave it blank as in the STS HP computer.

If a range vessel is to be tracked at more than 3.9 knots, and if the Velocity Clipping Values in the STS Kalman Filter Subroutine are not increased as discussed in paragraph 7.3, then the criterion of 0.2 on the root sum square of azimuth residuals must be increased to 1.0 in ISPROC. The criterion on the RSS of residuals does not have to be increased for these speeds if the Velocity Clipping Levels are increased.

At present, STS data editing in the SEL is probably satisfactory for tracking sonobuoys, but probably should be updated for tracking higher dynamic targets (range vessels). (For example, editing based on first and second differences in positions and perhaps on STS velocities, and possibly altering the criterion on the RSS of azimuth residuals as discussed in subparagraph 7.1.2.3.) Systems Analysis has software in place for further evaluation and revision of STS data editing in the SEL, but there are no current plans to pursue further evaluation in the near future. The RSS values of azimuth residuals slightly more/less than 180° have been observed on occasion. In these cases, subtracting 180° (manually) yields values which are reasonable for good track.

TABLE IX. STS DATA EDITING CRITERIA CURRENTLY IN THE SEL

CRITERION NUMBER	PARAMETER	FOR N ACTIVE SITES, REJECT DATA POINT IF VALUE OF PARAMETER IS
1	RSS of Residuals	> 0.2°
2	Site Data Use Codes	> (N-2) of any combination of capital letters, blanks, or lower case a's
3	Site Data Use Codes	> 0 lower case i's
4	Site Data Use Codes	< 1 "." (dot)

7.3 Velocity Clipping

The STS Kalman filter estimates a four-element state vector containing X, X-dot, Y, and Y-dot, that is, position and velocity in a two-dimensional X, Y-coordinate system. (The Z-coordinate is computed from the resulting X, Y-coordinates and zero height.) Before RETURNing from this subroutine, and before predicting the next state vector (which is done in a separate subroutine), the velocity vector is clipped by post-filter limiting to within ±2.0 meters/second (±2.2 yards/second or ±3.9 knots).

The 2.0 meters/second limit was intended by the STS vendor to prevent wild velocities from being used to predict the next state vector when tracking sonobuoys at considerably less than 2.0 meters/second. Valid sonobuoy speeds are unaffected, and of course, sonobuoy tracking is what the system was designed to accomplish. On the other hand, in attempting to extend the system's capability, the 2.0 meters/second clipping strongly affects STS track of SRT-22s aboard range vessels at speeds up to 14 knots (7.2 meters/second), since in this case valid velocity components with magnitudes above 2.0 meters/second are clipped and state vector prediction is degraded; the greater the actual velocity, the greater the degradation, resulting in STS track position errors which are highly correlated with speed (see subparagraph 7.1.2.1).

The post-OAT test provided preliminary verification that range vessels equipped with SRT-22s can be tracked nearly as accurately as sonobuoys if the velocity clipping the Kalman subroutine is relaxed sufficiently. For AUTEC vessel track, both the VEL-X-MAX and VEL-Y-MAX values should be increased from 2.0 to 10.0 meters/second (19.4 knots).

For the post-OAT, such changes were made manually in the source code. With appropriate STS software modifications, correct velocity clipping values could be automatically selected from a parameter file depending upon the type of "sonobuoy" being tracked, where the type code could identify a target as a boat versus a sonobuoy.

Further analysis may reveal that other parameter values such as parameters in prefilter data editing algorithms need to be changed to optimize vessel tracking. If the velocity clipping is properly set (whether automatically or manually) for a target, the 0.2 rejection criterion for RSS of azimuth residuals is applicable (at least for now) to range boats as well as sonobuoys. If velocity clipping is left at 2.0 meters/second, then boat racking errors will be excessive and real-time editing, tailored for sonobuoys, will reject most boat track above about 4 knots.

7.4 SAT Summary

Results of the comprehensive Site Acceptance Test were documented on 11 July 1990, and a copy of that report is provided in table X. That report lists 19 objectives or requirements on the system (based on contractual agreements with the STS vendor), and states which phase of the SAT addressed each objective, the number of RF channels used in that phase, and whether each objective was met. All SAT objectives were met. Specific comments (see notes in table X) were provided regarding a number of the objectives and are self-explanatory; however, several of these comments indicated action pending at the time of that report. The results of such action (by the vendor after returning to San Diego) are as follows:

(a) Objective number 4 (note 2): The vendor investigated the numerous spikes in STS position output data but were unable to provide any improvement. These spikes did not prevent the STS meeting contracted accuracy requirements, namely 68 percent of the STS-I/W differences had to be less than 25 yards. (The STS tracking accuracies are addressed in paragraph 7.1.)

(b) Objective number 6 (note 3): The vendor corrected the RSS of azimuth residuals to include in the sum only residuals from sites in solution. They also added the parameter "VAL" to the data packet. ("VAL" is discussed further in paragraph 7.12.)

TABLE X. SAT RESULTS SUMMARY				
STATUS OF ACHIEVING STS SAT OBJECTIVES				
OBJ #	OBJECTIVE	TEST PHASE	NUMBER OF CHANNELS EXAMINED	OBJECTIVE SATISFIED
1	Operational on all 99 frequencies.	SSV	98 (all)	Note 1
2	Supports all four fleet S/B types.	40 S/B	5 (all)	Yes
3	Meets accuracy requirements tracking S/Bs.	ACCY & 40 S/B	14 (all) (15 buoys)	Yes
4	Meets specified accuracy over 100 percent of coverage area for all 99 frequencies.	SSV	95 (all)	Note 2
5	Tracks up to 40 different frequencies simultaneously within accuracy requirements.	40 S/B	40 (all) (7 w/JETTS)	Yes
6	Correctly passes all specified data to the SEL.	ALL	Most	Note 3
7	Meets 14 nmi range requirement.	MAX RANGE	17 (all)	Note 4
8	Is immune to AUTEC's existing tracking and surveillance radars.	RFI	5 (all)	Yes
9	Meets accuracy requirements anytime of day or night, sunrise or sunset.	MOST	MOST	Yes
10	Meets accuracy requirements during rain or shine.	SSV	5 (all)	Yes
11	Calibrated as far north as a LOB from site 2 of 80° (CCW from N).	DEMO 1&2	3 (all)	Note 5
12	Tracks sonobuoys outside calibrated area.	---	---	Note 6
13	Can be calibrated by used outside calibrated area.	---	---	Note 7
14	Playback virtually identical to real-time.	PLAYBACK	5 (all)	Note 8

TABLE X. SAT RESULTS SUMMARY (cont'd)				
STATUS OF ACHIEVING STS SAT OBJECTIVES				
OBJ #	OBJECTIVE	TEST PHASE	NUMBER OF CHANNELS EXAMINED	OBJECTIVE SATISFIED
15	Meets accuracy requirements with wave heights to 5 feet and winds to 40 knots.	SSV-S/B	20 (all)	Note 9
16	Can support from two to six sites.	---	---	Note 10
17	Adequate system diagnostics and fault location.	ALL	---	Note 11
18	Accurately executes all required system functions and options.	ALL	---	Note 11
19	Provides required output content in required formats for all required screens, tapes, and printouts.	ALL	---	Note 11

Notes on next page.

TABLE X. SAT RESULTS SUMMARY (cont'd)	
NOTE NUMBER	**N O T E**
1	Channel 85 unused during SAT (omitted from Leg 3 of SSV Test and from 40 S/B Test because of RFI).
2	Verified 95 channels with SSV through most azimuths except 16 of these were manually selected one at a time for 10 minutes each (2500 feet each). Because of RFI, four channels not used with SSV: 03, 46, 83, 85.) Cubic accepted action item to investigate numerous spikes in STS position output data.
3	Square root of sum of squares of residuals not correct during SAT. Cubic accepted actions items to include in the sum only residuals from sites in solution and to add the parameter "VAL" to the data packet.
4	A 14 nmi range was demonstrated with S/Bs (15 nmi in one case), but even 15 nmi leaves a triangle of about 5 square nmi uncovered in the SE corner of the required accuracy area. (The SSV has approximately 17 nmi range, which can reach the SE corner, but out of I/W range.
5	Demonstrations 1 and 2 showed the STS can track some north of the required accuracy area and even within accuracy requirements. Parameter file printouts verified that azimuth limits on calibration table data include up to an 80° LOB from site 2. Demos 1 and 2 also verified ability to track across initialization limits and to initiate and track north of the normal initialization limits when these limits were temporarily extended.
6	Maximum range test verified that STS can track sonobuoys outside the required accuracy area but within azimuth limits on the calibration tables. Sonobuoy (or SSV) track outside the calibrated area (that is, outside the azimuth limits) was not attempted during the SAT.
7	The ability to change calibration data table elements was verified by several examples during the SAT. Extending the calibrated area (or conducting a new calibration) is an involved process which could not be verified during the SAT.
8	Playback to real-time comparisons were successful with the exception of one case of playback beginning (30 minutes after start of the data file): the playback Kalman settled and the differences were zero for 17 minutes, at which time the differences diverged. (This is an action item cubic agreed to investigate.
9	Maximum wave heights and winds of 6 feet and 26 knots, were experienced during the SAT with no noticeable degradation in accuracy.
10	AUTEC has three STS sites which were active during the SAT. Parameter files allow for up to six sites. Program limitations, memory limitations or cycle-time limitations, with respect to a six-site capability are unknown.
11	Seem to have been demonstrated during SAT operations and during formal and informal training. Judged acceptable by all cognizant groups immediately after SAT. No change in this is known as of this date.

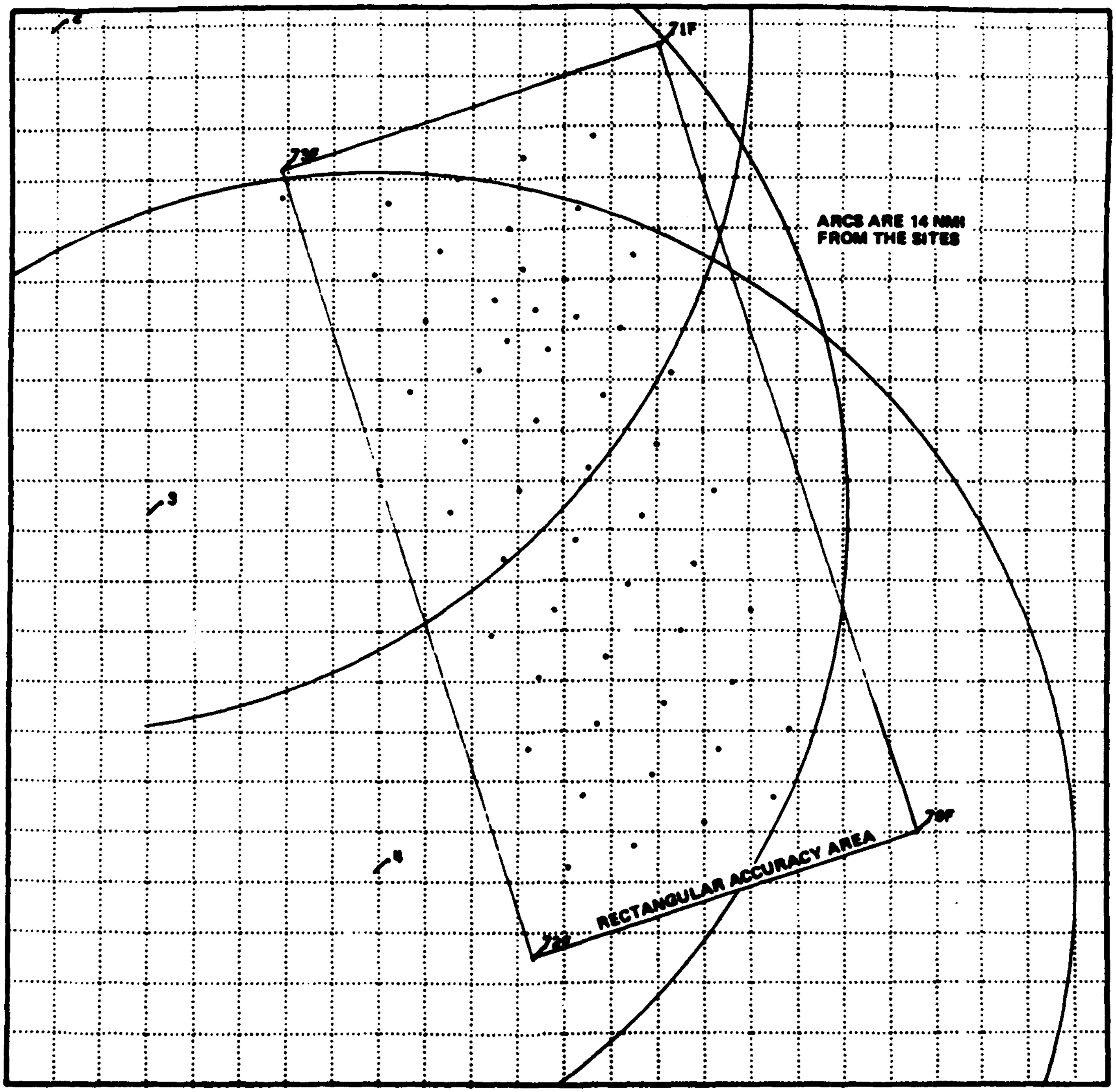

Figure 47. Rectangular accuracy area.

(c) Objective number 14 (note 8): Playback-to-real-time comparisons were successful with the exception of one case of playback with RECOMPUTE ON (beginning 30 minutes after start of the data file). The playback Kalman settled, and the differences were zero for 17 minutes, at which time the differences diverged. In this case, the vendor found that the cause was the way the software was handling communication time outs during real time. A software correction was made. For more details, see pages 13 and 124 of reference 6.

The STS vendor published its own detailed SAT report (see reference 6).

7.5 Post-SAT Testing

The vendor installed modified STS software in July 1990 following the May 1990 SAT. On 25-26 July 1990, following software installation, tests were conducted to verify that the STS performed at least as well as during the SAT and to verify correction of the playback anomaly observed during the SAT. The vendor made a software change to correct the playback anomaly discussed in subparagraph 7.4(c). During this test, the correction was verified by repeating the playbacks made during the SAT and observing that the anomaly did not recur.

The on-range test, conducted on 26 July 1990, consisted of the STS tracking two sonobuoys, each tethered to a JETTS, for 1 hour in W3. Following real-time evaluation of STS performance, Systems Analysis published reference 7 confirming satisfactory performance of the system during the SAT. On 31 July 1990, an additional post-SAT test, with an entirely different objective, was conducted with STS tracking a boat. This test is discussed in subparagraph 7.1.2.1.

7.6 RFI Effects

The RFI in a given sonobuoy channel can affect phase measurements at one or more of the STS sites causing degraded or lost track. The STS clear channel check prior to sonobuoy deployment is, therefore, an important part of STS pretest preparation. Channels found to contain RFI during these checks should be avoided for test operations. Reference 8 identifies VHF sources at AUTEC (known at the time of that publication) and their relationship to sonobuoy channels.

During the STS on-range calibration in October 1989, it was found that the lower third of the sonobuoy channels (that is, channels 32 to 64 from 136 to 148 MHz) were completely unusable for STS with the 200 W site 4 PARGOS transmitter up (on 142 MHz).

Since then there have been indications that STS tracking and PARGOS are incompatible, regardless of the STS channels used. Until further evaluation is done, the PARGOS transmitter should be secured during any operations requiring STS support.

During the May 1990 SAT, AUTEC's acquisition radars at sites 2 and 3, and the 2A track radar were shown to have no effect on STS while tracking five SSV channels. These Radar Interference Tests included pointing 2A at the nearest STS site 2 antenna (E6) and at the STS Equipment Hut at site 2 for a full 2 minutes with no effect on STS.

7.7 STS Area Coverage

Figure 47 depicts AUTEC's WR and STS geometry. The rectangular area shows the area over which STS tracking accuracy requirements were applicable during the SAT. The STS downrange sites are located at AUTEC sites 2, 3, and 4. Range limits of 14 nmi from each of the sites are shown in figure 47. The STS's ability to track out to the required 14 nmi from each site was demonstrated during the Maximum Range Test (MRT) of the SAT. The system should not be committed to track beyond 14 nmi without additional on-range testing. Insufficient data were collected during the SAT to relate maximum range to sea state, but a 14 nmi maximum range for seas up to 3 feet is believed to be a safe commitment.

During the SAT's MRT (on 23 May 1990), three sonobuoys were deployed in each of zones 1 and 3, at 14 nmi from sites 2 and 4 (zone 1) and at 14 nmi from site 3 (zone 3) (see figure 4). In each of these zones, single buoys also were deployed 0.5 and 1.0 nmi closer in and 0.5 and 1.0 nmi farther out. In zone 1, reasonably consistent track with three sites was obtained on the sonobuoys out to 15 nmi, although site 2 was intermittent beyond 14 nmi. In zone 3 (two site maximum), good track was only sporadic beyond 13.5 nmi. For this reason, zone 3 was repeated on 27 May 1990, with reasonably consistent track on three buoys at 14 nmi.

On 29 May 1990, the vendor altered by 3 dB, the minimum allowable received signal strength for processing track data. This change was due to a 3 dB difference inn received signal strengths between the SSV and sonobuoys. After the SAT, data collected during the MRTs in zones 1 and 3 on 23 May 1990 were replayed with RECOMPUTE ON by the vendor who later reported reasonably consistent track out to 15 nmi in both zones 1 and 3 (see pages 124 through 142 reference 6). Incidentally, it was found that the SSV can be tracked out to a range of about 17 nmi from each site. Nominal transmit power levels for the SSV, sonobuoys and the STAR calibration transmitters are given in table XI.

TABLE XI. TRANSMIT POWER FOR VHF SOURCES RELATED TO STS		
TRANSMITTER	TRANSMIT POWER	
AN/SSQ-53s	1.0 W	30 dBm
AN/SSQ-57s	1.0 W	30 dBm
AN/SSQ-77s	1.0 W	30 dBm
SSV	1.0 W	30 dBm
AN/SSQ-62s	0.25 W	24 dBm
STAR Xmitters	0.1 mW	-10 dBm

As can be seen in figure 47, about 35 percent of the rectangular accuracy region is within the STSs three-site coverage area, as defined by the 14 nmi arcs. Most of this three-site coverage is in W3. Note that the 14 nmi range limit leaves a triangular area (of about 6 square nmi) in the southeast corner of the rectangular accuracy area where the STS cannot track sonobuoys. This region is just outside the 427 array, the WR's most southeasterly hydrophone array.

In addition to range limits, there are azimuth limits for each site, because the system has been calibrated over only a limited sector of azimuths from each site.

STS CALIBRATION AZIMUTH LIMITS (Degrees)		
SITE	FROM	TO
2	80	153
3	22	140
4	352	117

For the most part, these azimuth limits bound angles subtended at each site by the accuracy rectangle shown in figure 47. In the case of site 2, its smaller azimuth limit was decreased from 92 to 80° to satisfy a requirement originally imposed with the idea of extending tracking north of the WR a few miles.

Site 2 calibration data are sparse in the sector between the 80° limit and the 92° azimuth to the NE corner of the accuracy rectangle. In spite of this, demonstrations 1 and 2 of the SAT showed that STS can track the SSV some distance north of the required accuracy area and within accuracy requirements (with one tracking channel assigned at a time). Channel 45 was tracked to approximately X = 11,800 yards, Y - 7,200 yards.

Certain buildings, towers, trees, and foliage existed within the calibration azimuth limits or in the vicinity of each site's STS antennas at the time of the on-range calibration early in 1990. The effects of these objects on RF propagation were essentially calibrated out. It is possible that significant changes in these masses (removal or installation of buildings or towers, significant growth of trees) could degrade the existing calibration. Recalibration will involve

(a) a repeat of the extensive exercise conducted on the WR in early 1990, and

(b) extensive calibration data processing (performed in 1990 by the STS vendor with software which has not yet been used by AUTEC personnel.

The system has not been calibrated outside the limits tabulated previously, but tracking is theoretically possible outside these limits, if the necessary propagation paths are sufficiently clear. However, tracking accuracy is degraded since only a mean phase difference correction (over all calibrated azimuth cells) for each site/antenna-pair/frequency is used outside the calibration azimuth limits.

The MRS of the SAT verified that the STS can track sonobuoys outside the required accuracy area but within the azimuth limits on the calibration tables. Demonstrations 1 and 2 of the SAT verified that the STS can track the SSV outside the required accuracy area but within the azimuth limits. Sonobuoy (or SSV) track outside the calibrated area (that is, outside the azimuth limits) was not attempted during the SAT.

In addition to the limits on tracking already mentioned, limits were also placed by vendor on tracking initialization. Tracking initialization is accomplished through a series of iterative least squares adjustments whose results must pass certain criteria before the track is handed to the Kalmar filter. Solution limits during initialization are in the form of minimum and maximum X and Y coordinates which establish a rectangle, the sides of which run N-S and E-W. The STS vendor arranged this initialization limit box to circumscribe the rectangular accuracy area as shown in figure 48.

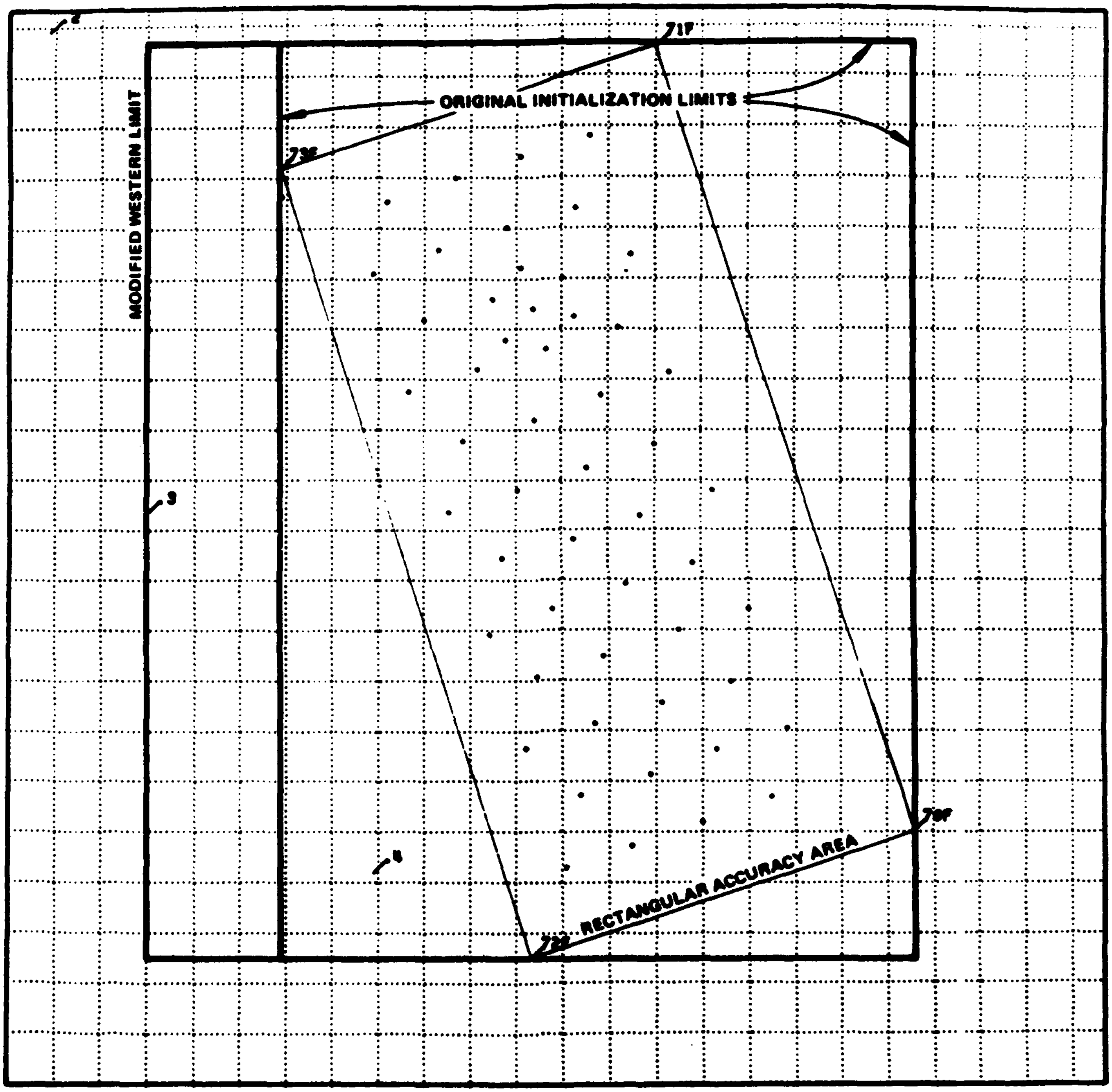

Figure 48. Tracking initialization limits.

Once track has been initialized and handed over to the Kalman, the initialization limits no longer apply. Therefore, tracking which originated within the initialization limit box can continue beyond its boundaries (to the extent of the other limits already discussed), and this tracking was verified (500 yards across the northern limit) during the SAT (demonstration 1). However, if loss of track occurs while the transmitter is beyond this limit box, reinitialization cannot occur (beyond the limit).

That the initialization limit box could be opened up without deleterious effect on initialization or tracking was verified during the SAT (demonstration 3) by temporarily expanding the box by 20,000 meters (10.8 nmi) on all sides. In October 1990, well after the SAT, the western boundary of the rectangle (minimum value of WR coordinate X) was moved west from -80 meters to -5,000 meters to permit initialization track further west (see figure 48). It is understood that the western boundary remains at this location; it has caused no tracking difficulty.

7.8 Portable Sonobuoy Simulators

Based on the 31 July 1990 post-SAT test, the 22 October 1990 OAT and the 26 February 1991 post-OAT test, the AUTEC-produced portable sonobuoy simulators (SRT-22s) (see figures 49a and b), have performed well aboard AUTEC TRs when their antennas were properly located as high and as unobstructed as possible and definitely above the wheelhouse roof and above other broad metallic structures.

When the SRT-22 has its own antenna connected to the coaxial connector on its lid, the entire SRT-22 container must be placed in the best antenna location which is generally not a satisfactory location for operating the controls inside the container. It was found that a more convenient arrangement is to place each SRT-22 inside the wheelhouse, for example, and run a coaxial cable to a permanently (or temporarily) installed VHF "trombone" antenna.

The electronic portion of the SRT-22 is actually a repackaged AN/SSQ-53 sonobuoy. Since the 53Bs are designed to operate up to 8 hours and then scuttle, the SRT-22, as part of a boat tracking system, has several potential limitations:

(1) The SRT-22s reliability for long-term use is questionable.

(2) Reliability is certainly not enhanced when the antenna is not tuned to the selected transmit frequency. (Reflected power has been observed to be as high as 25 percent of transmitted power.)

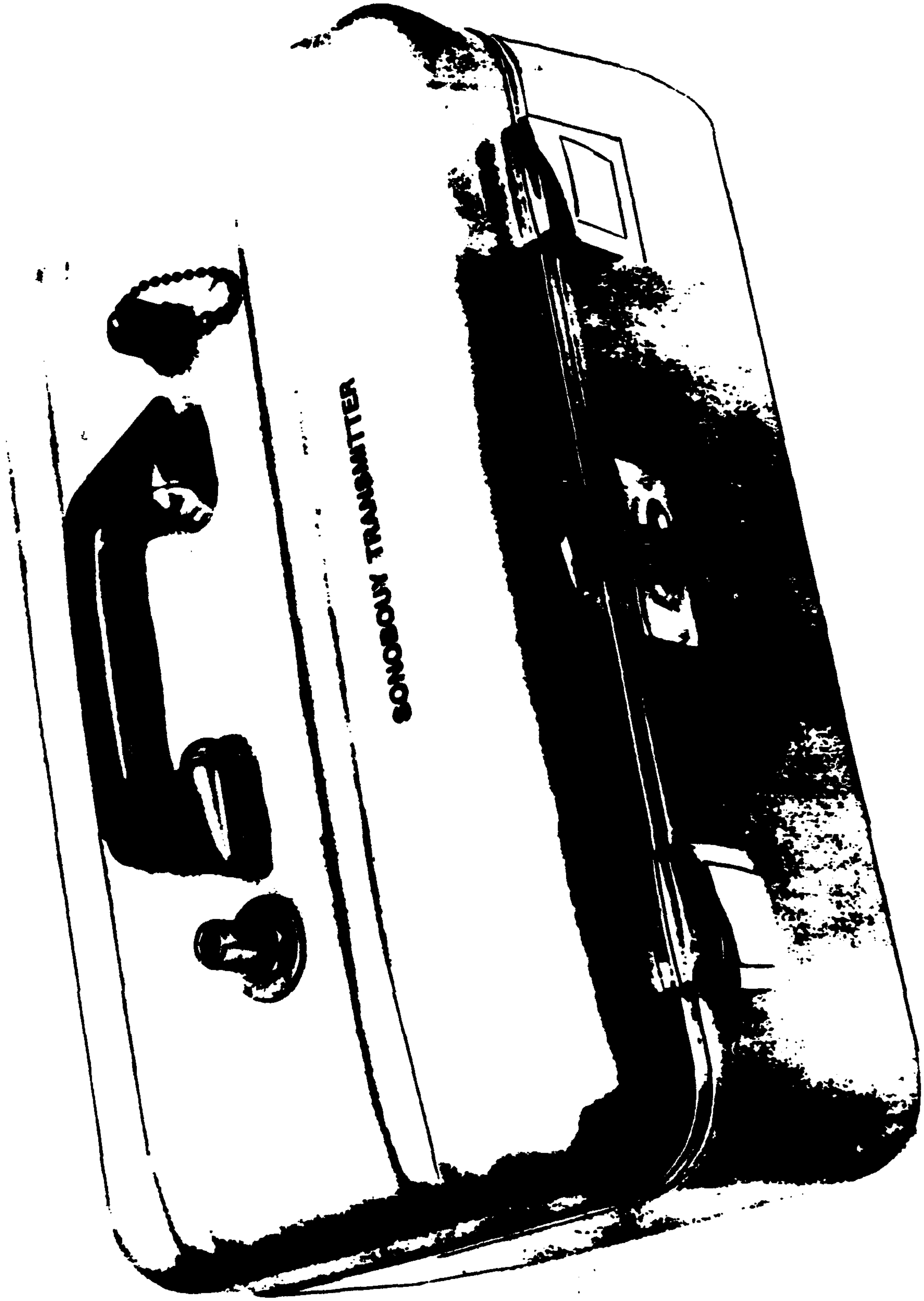

Figure 49a. Sonobuoy Simulator (SRT-22-AT12900).

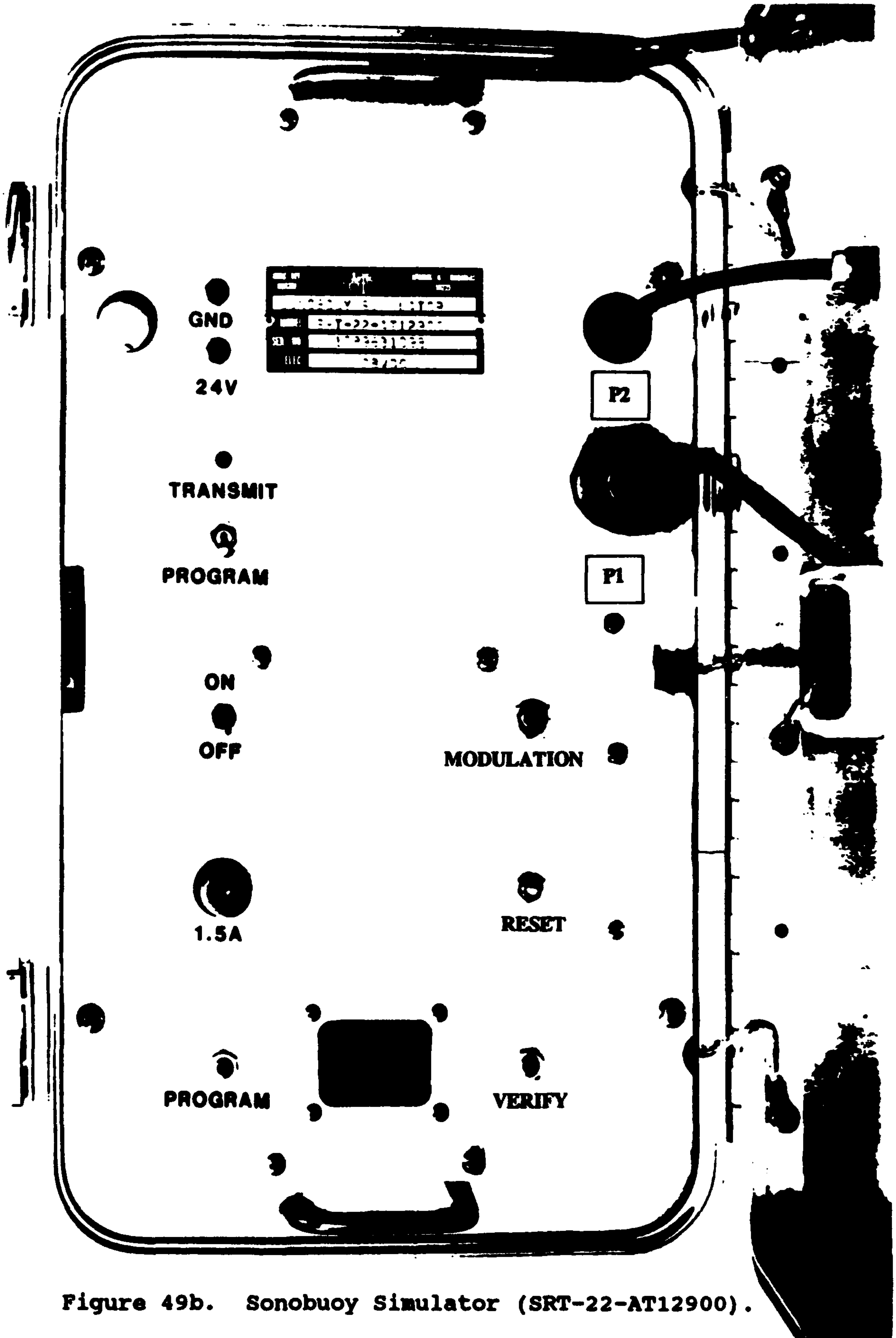

Figure 49b. Sonobuoy Simulator (SRT-22-AT12900).

(3) If run until scuttle time, the scuttle sequence can destroy the unit. If turned off before this time and restarted, there is at least a 17-second delay before transmission can resume.

If the STS is to be routinely used to track boats on the WR, a more permanent sonobuoy simulator transmitter should be considered. Further, a more permanent installation aboard the TRs would seem warranted, perhaps including a coaxial switch for less wear and tear on coaxial connectors when the trombones are switched from one use to another (voice-communication versus STS).

7.9 Real-Time STS Data

STS data are passed to the SEL computer in data packets, one packet per position-fix per target, and archived in an RD file. All STS-produced positions (good or bad) are passed. In the SEL, these data are identified by sonobuoy channel number followed by a lower-case "b" as in "32b." If a "b" data point fails the editing criteria in the SEL (paragraph 7.2), a lower-case "x" is appended to the target identification, as in "32bx," allowing rejected data to be readily excluded during post-test processing.

The interval between visits to a given channel is approximately 0.65 seconds times the number of channels assigned. If a full 40 channels are assigned, each channel is serviced approximately once every 26 seconds. Thus, "b" data for a given channel can occur at various rates, depending upon the number of channels assigned and upon the number of points edited.

The STS displayed in real time for a given STS target are generated by the SEL for time points which are 30 seconds apart and identified by an uppercase "B" suffix as in "32B." These 30-second "B" data are generated by extrapolating backward from the target's "b" data points which is nearest in time but no earlier than the 30-second time point, using the STS velocity from the "b" data point.

All STS data "b," "B," and "bx," are archived in the TX file. The 30-second "B" data are used for real-time display and for most post-test processing applications, including products issued to range users (primarily because program RTOUT requires periodic input data). The faster rate, "b" data (the data which survived editing) can provide the best accuracy for post-test processing purposes which do not require equally spaced data. The accuracy analyses reported in this document made use of "b" data. And, these data were compared to 2 pps I/W data interpolated to STS times.

If a "B" data point occurs at the same time as a "b" data point, and if there are 40 channels assigned (26-second interval, approximately), then the next "b" data point past the next 30-second point will be 2 x 26 - 52 seconds, meaning that there is a 52-second wait for the next "B" data point, and then it is 22 seconds old when it occurs. If, in this case, the "b" data points were just under 4 seconds later (with respect to the "B" data), then the last "B" data point would be 56 seconds old at the next update, and the update would be 26 seconds old when it occurs.

During the May 1990 SAT, the real-time software did not time-match STS data with radar or I/W data for real-time display of individual STS target positions. So a comparison of STS and I/W data in real time (as during the SAT and OAT operations) was between the latest STS "B" data point and the latest I/W data point, the latter being updated once every second. As a result, aside from tracking errors in the two systems, real-time display of horizontal range between the two systems plotted against time had a sawtooth pattern. Conceptually, this pattern could have had maximum peaks corresponding to a nominal 56 second time disparity between STS and I/W and maximum valleys corresponding to a nominal 26 second time disparity.

For a sonobuoy speed of 1 knot, 56 seconds equates to 32 yards and 26 seconds to 15 yards. For a boat speed of 13 knots, 56 seconds equates to 410 yards (0.2 nmi) and 26 seconds to 190 yards. The discrepancy in real time for sonobuoys might be acceptable; for boats, probably not. It is noted, however, that this is a worst-case scenario in which all 40 STS tracking channels are assigned. Table XII (upper portion) gives the effects on STS positions in real time because of the age of SEL updates (the "B" data) for the number of channels assigned. Only as a comparison, the lower portion of table XII shows the effects of update aging if the real-time update rate were identical to the update rate in the STS (the lower-case "b" data rate). The lower portion of table XII shows a marked improvement, but it is still not entirely satisfactory for tracking range vessels when a large number of channels are assigned. In other words, target dynamics and desired tracking accuracy dictate a minimum data rate and, therefore, a maximum number of channels that can be assigned. It should be noted that the values in both portions of table XII are based on a nominal STS time of 0.65 seconds per assigned channel; actual tracking will vary.

Currently, SGI workstation software time correlates data for a pair of targets when computing relative target data. For the latest position of each of a pair of targets, the older of the two positions is extrapolated forward in time, using its velocity and acceleration vectors, to the time of the other target's position. This extrapolation avoids the update aging problem for

TABLE XII. EFFECTS BECAUSE OF UPDATE AGING BASED ON EXISTING SEL UPDATE RATE FOR REAL-TIME DISPLAY.					
NUMBER OF CHANNELS ASSIGNED	APPROX CYCLE TIME* (secs)	MAX ERROR (yards) BEFORE NEXT UPDATE BECAUSE OF AGE OF LAST UPDATE		MAX ERROR (yards) IN THE UPDATE BECAUSE OF ITS AGE WHEN IT OCCURS	
		1 KNOT	13 KNOTS	1 KNOT	13 KNOTS
1	0.65	17	224	0	5
10	6.5	21	267	4	48
20	13.0	24	314	7	95
30	19.5	28	362	11	143
40	26.0	32	410	15	190

TABLE XII. EFFECTS BECAUSE OF UPDATE AGING IF THE SEL UPDATE RATE WERE IDENTICAL TO THE STS UPDATE RATE. (Only for comparison with above values)					
NUMBER OF CHANNELS ASSIGNED	APPROX CYCLE TIME* (secs)	MAX ERROR (yards) BEFORE NEXT UPDATE BECAUSE OF AGE OF LAST UPDATE		MAX ERROR (yards) IN THE UPDATE BECAUSE OF ITS AGE WHEN IT OCCURS	
		1 KNOT	13 KNOTS	1 KNOT	13 KNOTS
1	0.65	0	5	0	0
10	6.5	4	48	0	0
20	13.0	7	95	0	0
30	19.5	11	143	0	0
40	26.0	15	190	0	0

*Actual tracking will vary.

relative computations, although extrapolation errors, of course, remain. In the case of STS data, there is the interesting situation of extrapolating backward from "b" data to obtain the 30-second "B" data, and then extrapolating forward from the "B" data for relative target computations.

At present, forward extrapolation is not done for individual target positions in real time, so the previously discussed effects of aging of position updates are applicable to individual real-time positions. For real-time graphics displays, such effects would be unnoticed for sonobuoys because of plot scale. The same is probably true for boats for most scales if the number of STS channels assigned is small.

AUTEC real-time and post-test processing software continues to move away from the need for periodic data. (Now, apparently, the only software, real time or post test, requiring periodic data is the post-test processing program RTOUT.) When the need for periodic data no longer exists, the 30-second STS "B" data should be discontinued in favor of the exclusive use of the aperiodic "b" data.

7.10 STS Playbacks

In real time, STS data are stored in an RD file as well as a TX file. (The FR.END is bypassed.) These STS data will, therefore, be included in an RD file simulation (RD file playback) and in a "Hot Wash-up" from the TX file. (The real-time editing algorithm in paragraph 7.2, is applicable to the RD file simulation.) The STS has the capability to play back STS-generated magnetic tapes from the STS tape drives under control of the HP and to place these playback data on the STS-SEL interface. However, there is no existing capability to time synchronize these data with I/W and I/A data from a FR.END playback.

Prior to the SAT, a SEL program, TESTSTS, was written to help evaluate the STS-SEL interface protocol and was not intended to serve STS data playbacks. This program, however, is the only existing means to allow STS playbacks into the SEL, and it was used for this purpose during (and since) the SAT. Program TESTSTS places STS playback data into a stand-alone file in the format of a TX file, that is, with no other systems' data (and it generates no RD file). (It should be possible to merge this stand-alone TX file with a real-time generated TX file containing I/W and I/A data, but this has not been verified with such an STS file.) Program TESTSTS does not contain an STS data editing algorithm, so that STS data in a resulting stand-alone TX file will not have been edited.

During the replay test of the SAT, a replay rate of approximately twice real time was initially used but was too fast for the real-time computer system. The STS vendor had to increase the "task suspend time" to provide a replay rate nearly as slow as real-time. The STS playback rate to the SEL is currently only slightly faster than real time. This rate, along with the fact that playbacks from the STS HP tie up a SEL, are major deterrences to accomplishing STS playbacks.

Some enhancements to consider are

(a) STS playback data editing with the same algorithm used for real-time STS data editing, and

(b) faster STS playback rates into the host computer, although this enhancement might have to wait on a new host and front end.

7.11 STS-Produced Position Error Estimates

The STS-produced standard deviations in X and Y displayed on the "Selected Channel Data Display" screen (under "sigma") and passed to the SEL, are not based on the state vector covariance matrix or on any measure of data fit. They are essentially Geometric Dilution of Precision (GDOPs) obtained as if the estimated state vector was the result of an unfiltered, unweighted, single-point, least-squares solution with an a priori estimate of measurement noise. In other words, these estimates could be computed (for any given positions on the WR) without any tracking data actually being collected. A more desirable output would be an a posteriori estimate of position error, at least one that takes data closure into account when more than two sites are solution.

7.12 Parameter VAL

One of the quantities computed by the STS software and displayed on the Track Status Screen is VAL. The VAL is a measure, in percent, of how much data are being used in the STS solutions. As the data usage fluctuates, VAL rises and falls accordingly. If all data from all active STS sites are being used in the solutions, then VAL can rise to 100 percent. If all data from two of three active sites are being used, then VAL can rise to 67 percent.

The VAL is displayed on the operator's screen but was not originally in the STS data packet sent to the SEL. This might be a useful quantity to archive for post-test analysis (for example, its value to STS data editing on the SEL cannot be evaluated unless VAL is archived for analysis). Therefore, at Systems Analysis' request, the STS vendor added VAL to the data packet.

The VAL now needs to be read and archived by the SEL, and added to the STS PKTXYZ output. In the data packet, VAL is located in byte 44, which was a filler byte and, therefore, is currently ignored by the SEL software.

7.13 Sonobuoy Simulator Vehicle (SSV)

As supplied by the STS vendor, the SSV is a 12-foot towed, V-bottom, covered fiberglass hull with a VHF transmitter, antenna and associated electronics, a zero-parallax acoustic pinger mounting on an extension below the keel, and a 3-foot V-fin cabled to a connector under the keel for stability. The SSV system includes a receiver/controller on the towing vessel, connected to the SSV by a 300-foot multi-conductor electro-mechanical tow table.

The SSV was designed to rapidly cycle through up to 40 selected channels (approximately 3 per second) under control of the STS HP computer at site 1 (via a transmitter at site 4 and the receiver/controller on the towing vessel). By maintaining a slow towing speed, a dense enough pattern of position fixes in each azimuth cell at each site for all the selected channels could be acquired.

During the unsuccessful STS calibration attempt in October 1989 (see reference 9), the SSV required modification to improve acoustic tracking. The AUTEC replaced the 3-foot V-fin with a 4-foot V-fin having its own pinger mounting (see figure 50). It was cabled in such a way as to place its pinger approximately 15 feet below the keel (see figure 51). Reference 10 report acoustic system tracking test which demonstrated that the V-fin pinger provided superior quality tracking data relative to the keel-mounted pinger. Zero horizontal parallax with the keel-mounted pinger was also demonstrated. The V-fin pinger was used for the successful STS calibration exercise conducted in early 1990 (see reference 11) as well as for the SAT.

The SSV tow-cable faults experienced during the calibration exercises have been repaired. Range engineering have no schematics for the SSV electronics at this time, but this information has been requested through channels.

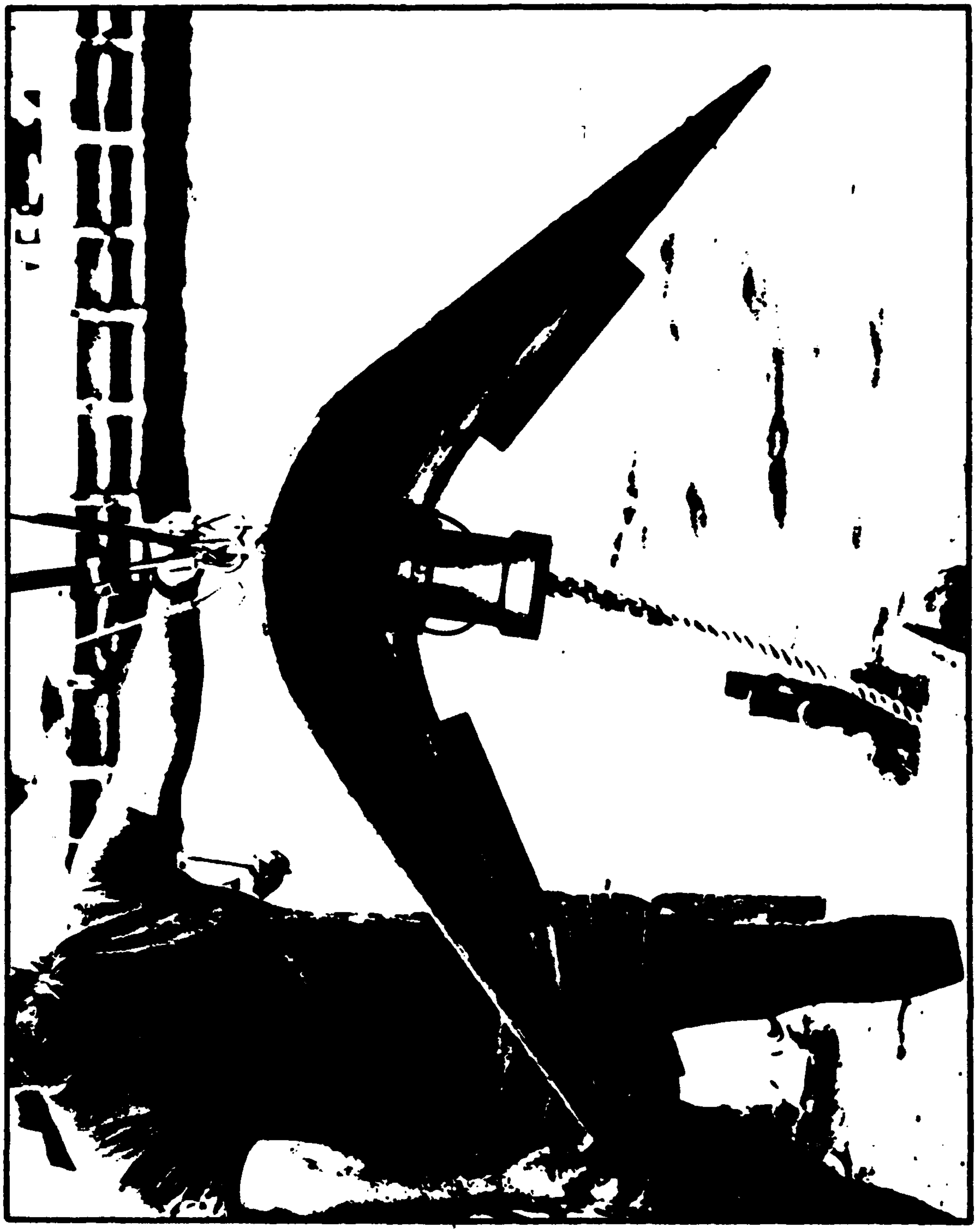

Figure 50. AUTEC's 4-feet V-fin with MK-72 pinger.

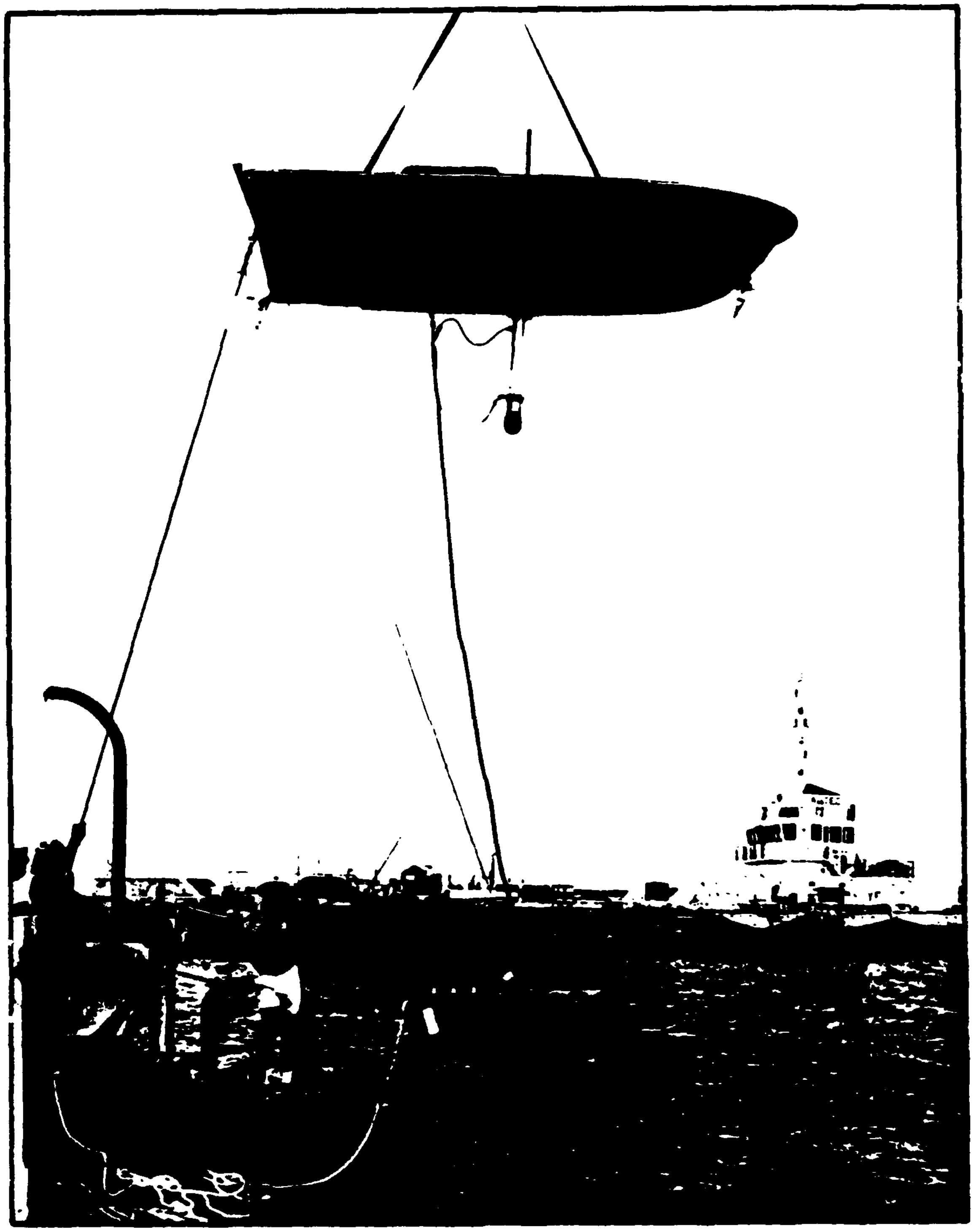

Figure 51. Sonobuoy simulator vehicle as modified by AUTEC.

8.0 STS Antenna Survey

Table XIII provides a chronology of events related to the official surveys to date of AUTEC's STS receiving antennas.

Det 4/GSG of the Defense Mapping Agency conducted the official surveys of the STS antenna positions at AUTEC sites 2, 3, and 4. Final positions relative to World Geodetic System 1972 (WGS-72) and to World Geodetic System 1984 (WGS-84) (as well as to the Cape Canaveral Datum) are listed in their report (see reference 12), along with relative antenna position data and survey accuracy estimates.

Survey accuracy estimates for all three sites are stated in reference 12 as

Horizontal Positions:	0.015 m, CSE
Elevations:	0.025 m, SE
Distances [between antennas]:	0.015 m, SE

where SE is (linear) standard error and CSE is circular standard error.

Det 4/GSG also reported "The results indicate all antennas are within the required alignment of ±0.025m except antennas S2-E2, S3-E3, and S4-E2. These antennas are off-line by 44 mm, 26 mm, and 29 mm respectively..." relative to a line through antennas E1 and E6 at each site.

A comparison by Systems Analysis of measured distances between antennas versus the designed separations shows all are within ±25 mm except for

Site 2	Site 3	Site 4
E2-E3 35 mm		E2-E3 61 mm
E4-E5 43 mm	E4-E5 32 MM	
E5-E6 28 mm		

TABLE XIII. AUTEC STS RECEIVING ANTENNA SURVEY HISTORY	
DATE	**ACTION**
Jun 89	DMA Survey - Sites 2, 3, and 4.
20 Jul 89	DMA Letter Report - Sites 2, 3, and 4.
Aug 89	AUTEC Moved Site 3 Antennas (survey showed several were too far from planned positions; virtually all were moved).
Aug 89	DMA Resurvey - Site 3.
Aug 89	DMS Preliminary Data - Site 3.
16 Aug 89	Systems Analysis Tables with "Final" Site 2, "Preliminary" Site 3, and "Final" Site 4. These tables were provided to Cubic.
22 Sep 89	DMS Letter Report - Site 3.
22 Sep 89	Systems Analysis Table with "Final" Site 3. This table was provided to Cubic. (No value differed from the "Preliminary" values by more than 3mm.)
[Jan 90	STS System Calibration Exercise.]
Feb 90	Beach Erosion Near Pole E6 at Site 4. (A Systems Analysis rep's on-site assessment: "E6 is still firmly anchored -- do not believe it has actually move.")
[May 90	STS Site Acceptance Test.]
Jun 90	DMA Resurvey - Sites 2, 3, and 4.
31 Jul 90	DMA Letter Report - sites 2, 3, and 4. (The largest differences between these values and the previous "final" values are 43 mm in latitude, 34 mm in longitude and 10 mm in elevation; these are probably due to pole warping. Note that the differences for Pole E6 at Site 4 were 3 mm, 11 mm and 10 mm in latitude, longitude and elevation, respectively. See paragraph 8.0 of text for how the 31 July 1990 values compare with the planned positions.)
[Oct 90	STS Operational Acceptance Test.]

REFERENCES

1. Cubic Defense Systems Report No. SP562-1, Configuration Item Product Function Specification for AUTEC Sonobuoy Tracking System, dated 13 April 1990, with Revision SP 562-1A, dated 27 June 1990.

2. GE Systems Analysis Document, Site Acceptance Test (SAT) Plan for AUTEC Sonobuoy Tracking System (STS), Version 1.1, dated 11 October 1990.

3. GE Systems Analysis Document, Operational Acceptance Test Plan for the AUTEC Sonobuoy Tracking System (STS), Version 1.1, dated 11 October 1990.

4. GE Systems Analysis Document, STS Post-OAT Test Plan, dated 19 February 1991.

5. Letter to the STS OAT Committee from Systems Analysis, subject: "STS Data Rejection Algorithm for the SEL," dated 14 August 1990.

6. Cubic Defense Systems Document Number TR 562-3, Site Acceptance Test Report for AUTEC Sonobuoy Tracking System, dated 27 July 1990.

7. Letter to Range Engineering from Systems Analysis, subject: "STS Site Acceptance," dated 26 July 1990.

8. GE Systems Analysis Report, VHF Environment for AUTEC's Sonobuoy Tracking Systems (STS), dated 10 April 1990.

9. Letter to Range Engineering from Systems Analysis, subject: "STS Calibration," dated 18 October 1989.

10. GE Systems Analysis Report, Sonobuoy Simulator Vehicle (SSV) In-Water Tracking Evaluation, dated 10 January 1990.

11. GE Systems Analysis Internal Memo, subject: "Jan/Feb 1990 STS CALEX," dated 9 February 1990.

12. Letter to NUSC/AUTEC from Det 4/GSG (DMA/HTC), subject: "Results of Sonobuoy Antenna Surveys at Sites 2, 3, and 4 on Andros Island," dated 31 July 1990.