NASA CONTRACTOR REPORT

NASA CR-612

NAVY SATELLITE NAVIGATION SYSTEM

by Frederick G. Paulsen

Prepared by
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
Washington, D. C.

Sponsored by DEPARTMENT OF DEFENSE *and*
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • SEPTEMBER 1966

NASA CR-612

NAVY SATELLITE NAVIGATION SYSTEM

By Frederick G. Paulsen

Prepared by
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
Washington, D.C.

Sponsored by

DEPARTMENT OF DEFENSE

and

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – Price $2.50

FOREWORD

By an agreement between the Department of Defense and the National Aeronautics and Space Administration concerning the nonmilitary applications of the Transit (presently called Navy Satellite Navigation System), the NASA shall have full responsibility for governmental determination of the suitability of Transit navigational equipment to meet nonmilitary navigation requirements. In order for NASA to conduct its evaluation, and because of the lack of a suitable vessel to house the navigational equipment, arrangements were made for the U.S. Coast and Geodetic Survey of the Environmental Science Services Administration to perform the required tests.

This report contains the results of the use of the Navy's Navigational Satellite as a navigation aid to a nonmilitary ship operator.

INTRODUCTION

The Navy Satellite Navigation System was developed by the Applied Physics Laboratory of Johns Hopkins University for the United States Navy. The specific purpose of the system is to provide a navigation position fix of a ship from data received from a satellite in orbit.

The United States Coast and Geodetic Survey purchased one set of shipboard gear from the Navy in order to evaluate the accuracy of the system for possible use in oceanographic survey work. The shipboard gear consists basically of a radio receiver and a computer, plus supporting hardware. The satellite navigation system was to be placed aboard the USC&GSS PIONEER for use and evaluation.

Accordingly, Ensign Frederick G. Paulsen and Chief Electronics Technician Lyle C. Work of the PIONEER were assigned to the Applied Physics Laboratory of Johns Hopkins University for a one-and-one-half week course in operation and maintenance of the system. Following this the system was installed aboard USC&GSS PIONEER on 4 to 6 May 1965.

The PIONEER was assigned a special project, OPR-457, the specific purpose being to evaluate the Navy Satellite Navigation System for possible use in survey work. This project lasted until the PIONEER's return to home port, Oakland, California, on 6 July 1965.

This report gives a brief description of the system and a detailed analysis of the accuracies obtained. The report describes the requirements for operation of the system and the problems encountered. Evaluation of its usefulness in survey work is also made, along with recommendations for future use.

DESCRIPTION OF NAVY SATELLITE NAVIGATION SYSTEM

The Navy Satellite Navigation System was installed aboard USC&GSS PIONEER in Oakland, California from 4 May 1965 to 6 May 1965. The first position fixes were taken on 6 May 1965, and the system was declared operational. The gear was used alongside Clay Street Pier in Oakland from 6 May 1965 to 18 May 1965 to take fixes and train officers in using the system for navigation. Underway fixes were first taken on PIONEER's Oceanographic Equipment Evaluation Range from 18 to 21 May 1965. Upon the PIONEER'S return to Oakland, fixes were again taken while alongside, for use in establishing probable accuracy to be expected using the system.

On 1 June 1965, PIONEER departed Oakland, California on Project OPR-457, a series of tracklines including Kodiak, Adak, and Attu, Midway Island, Johnston Island, and Honolulu, Hawaii as ports of call, and returning to Oakland on 6 July 1965. Two orbiting Satellites, # 63041 and # 03164, were used during the entire period of evaluation.

Description of Equipment

The Navy Satellite Navigation System shipboard installation consists of a receiver unit and attendant antenna and amplifiers, a computer for processing data received, and a printer-control head unit.

The system receives and interprets signals on two frequencies transmitted by the satellite. The main frequency, 400 megacycles, is the frequency upon which Doppler counts and orbital parameters are received from the satellite. The Doppler counts are obtained by counting the pulse differences between a very precise crystal oscillator in the receiver, and the 400-megacycle signal transmitted by a precise crystal oscillator in the satellite. Over a two-minute interval, which is timed by a tonal signal from the satellite, the computer sums the frequency difference it measures.

Superimposed on the 400-megacycle signal by phase-modulation are the orbital parameters required for the computer to determine the exact position of the satellite at the beginning and ending of the two-minute periods.

A secondary signal, 150 megacycles, is used as an atmospheric refraction correction to the 400-megacycle Doppler counts. The 150-megacycle signal is put through multiplying and dividing circuits to be comparable to the 400-megacycle signal. In this comparison the differences between the two signals are measured, and pulses are either added to or subtracted from the Doppler counts, compensating for atmospheric refraction variations in the Doppler counts.

The printer-control head unit prints out digitally information received through the receiver and the computer. It is also used to control and monitor operations of the receiver unit.

The computer stores the data received from the receiver, accepts and stores information entered manually, and computes the position fix. It also computes "alerts", which are future times when the satellite will be above the horizon again and usable for a position fix. The computer is controlled in its operations by a punched tape program which is read into the computer during every fix.

Operation of the System

A brief description of the steps involved in obtaining a position fix with the Navy Satellite Navigation System is helpful in evaluating the usefulness of the system.

With the computer program tape used during OPR-457, the operator was required to:

1. "Lock onto" the satellite. This involves knowing approximately what time the satellite will come up above the horizon and searching the frequency range using the control head until the continuous tone of the satellite is heard in the attached earphones. The tone descends in frequency as the receiver is tuned more exactly on the satellite, descending to a "null" as exact turning is achieved. The receiver is locked on this "null" by a switch on the control head and then tracks the satellite automatically.

2. Start the computer program tape at the beginning. This enables the computer to receive data from the receiver, which is then stored in the computer memory and simultaneously printed out by the printer.

3. When the satellite goes below the horizon, push two buttons on the computer, "Reset" and "Start". This feeds more punched tape program into the computer, allowing it to evaluate the orbital data received and reject any errors it detects. The information received has all been repeated at least three times, and the computer is able to detect and reject individual errors, which gives it correct data with which to compute the fix.

4. Enter data manually. To compute a fix, the computer must have an estimate of ship's latitude; ship's longitude; the height of the antenna above or below the ellipsoid upon which the computer solves the fix; Greenwich time during the pass of the satellite; east component of ship's velocity; north component of ship's velocity; and a one-digit entry which tells whether or not the ship was on constant course and speed during the satellite pass. The computer then computes the navigational fix, giving one fix per satellite pass.

5. After transferring the fix to paper, apply the necessary corrections to convert the latitude and longitude of the solution from the "APL Ellipsoid" on which the computer solution is based, to the North American Datum on which C&GS charts for the Continental United States and Alaska are based. This involves a visual scaling and interpolation between point corrections on a small-scale chart for both latitude and longitude.

   A copy of the chart used in these corrections is included in this report for inspection. The values were supplied by the Applied Physics Laboratory of Johns Hopkins University for the points plotted.

6. Plot the fix on the chart. This involves only a plot by latitude and longitude.

System Data Inputs and Outputs

The Navy Satellite Navigation System requires that the receiver be "locked on" to the satellite for at least three two-minute intervals during a pass. This establishes a minimum time, six minutes, that the satellite must be above the horizon and the signal strong enough to receive. However, in practice the satellite usually must be readable for about eight minutes, unless by lucky coincidence one of the two-minute "beeps" comes immediately after locking on, and one of the "beeps" comes immediately before losing the signal. The satellite sometimes is above the horizon but too low to be readable for the required time, and the required data for a fix is not obtained.

The three two-minute intervals do not need to be consecutive during the pass. That is, during a pass of the satellite, lock may be lost and regained one or even two times, and the computer will still receive enough data to compute a fix if three complete intervals can be received.

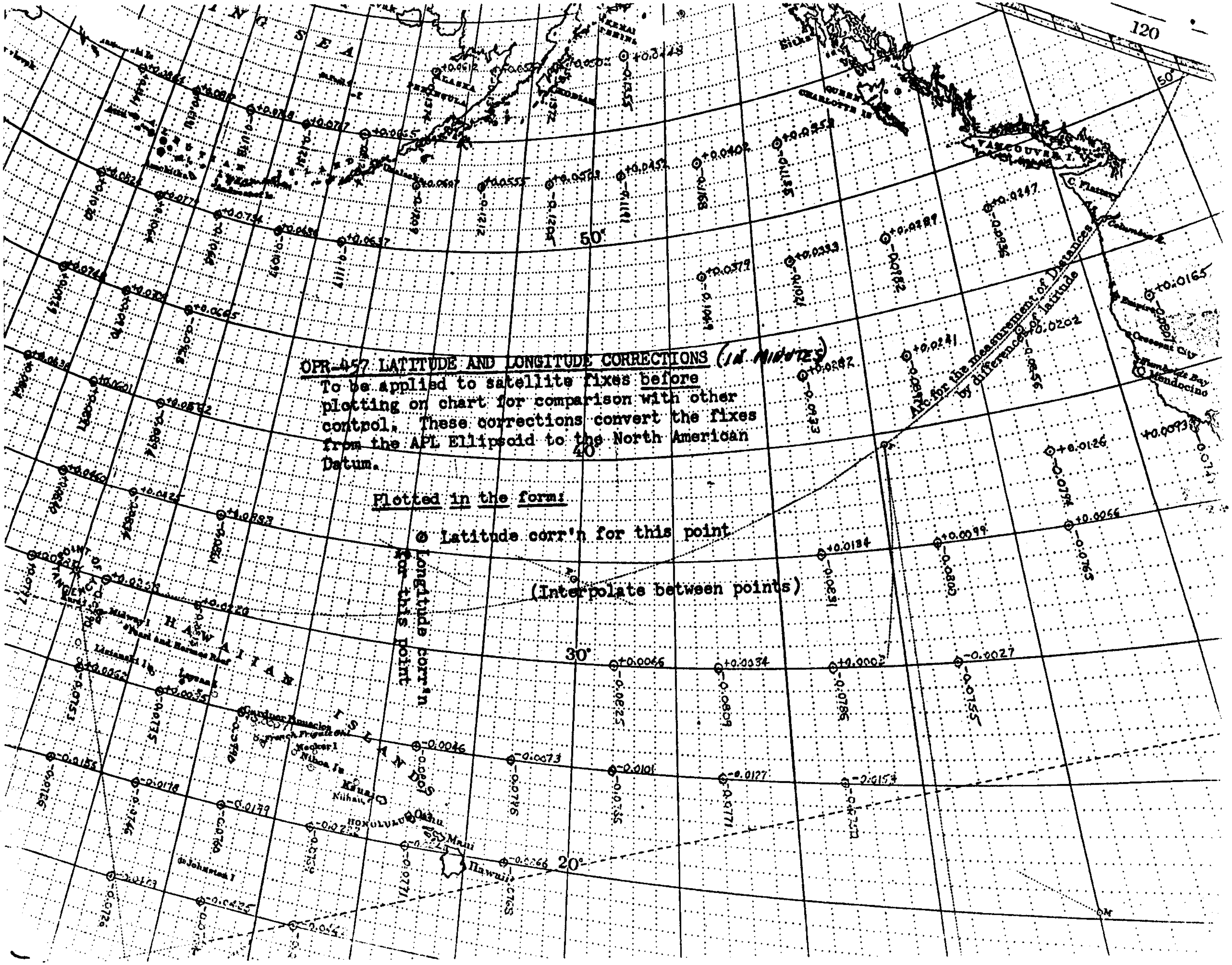
The computer must solve for latitude of the fix, longitude of the fix, and the actual difference in frequencies of the crystal oscillators in the satellite and receiver—"offset frequency". Three complete two-minute intervals are required to furnish the three equations necessary to solve for the three unknowns.

Each two-minute interval furnishes a Doppler count plus the position of the satellite at the "beeps" which form the ends of the interval. The Doppler count plus the satellite positions define a hyperboloid fixed in three-dimensional space. This is the mathematical shape upon which the ship must have been to have received said Doppler counts. The Doppler counts define relative motion of the satellite and the ship. The computer must form at least three of these hyperboloids and intersect them at the height of the antenna above the earth's surface as represented by the APL Ellipsoid. This is the reason for the manual data entry of antenna height.

The result of this is a single point fix for the pass of the satellite. The computer is programmed to solve this navigational fix as of four minutes after the first "beep" starting the first complete two-minute interval. This solution time remains the same even if lock is lost on the satellite during the pass, and allows the operator to obtain a simultaneous fix with other means of control for comparison with the satellite fix.

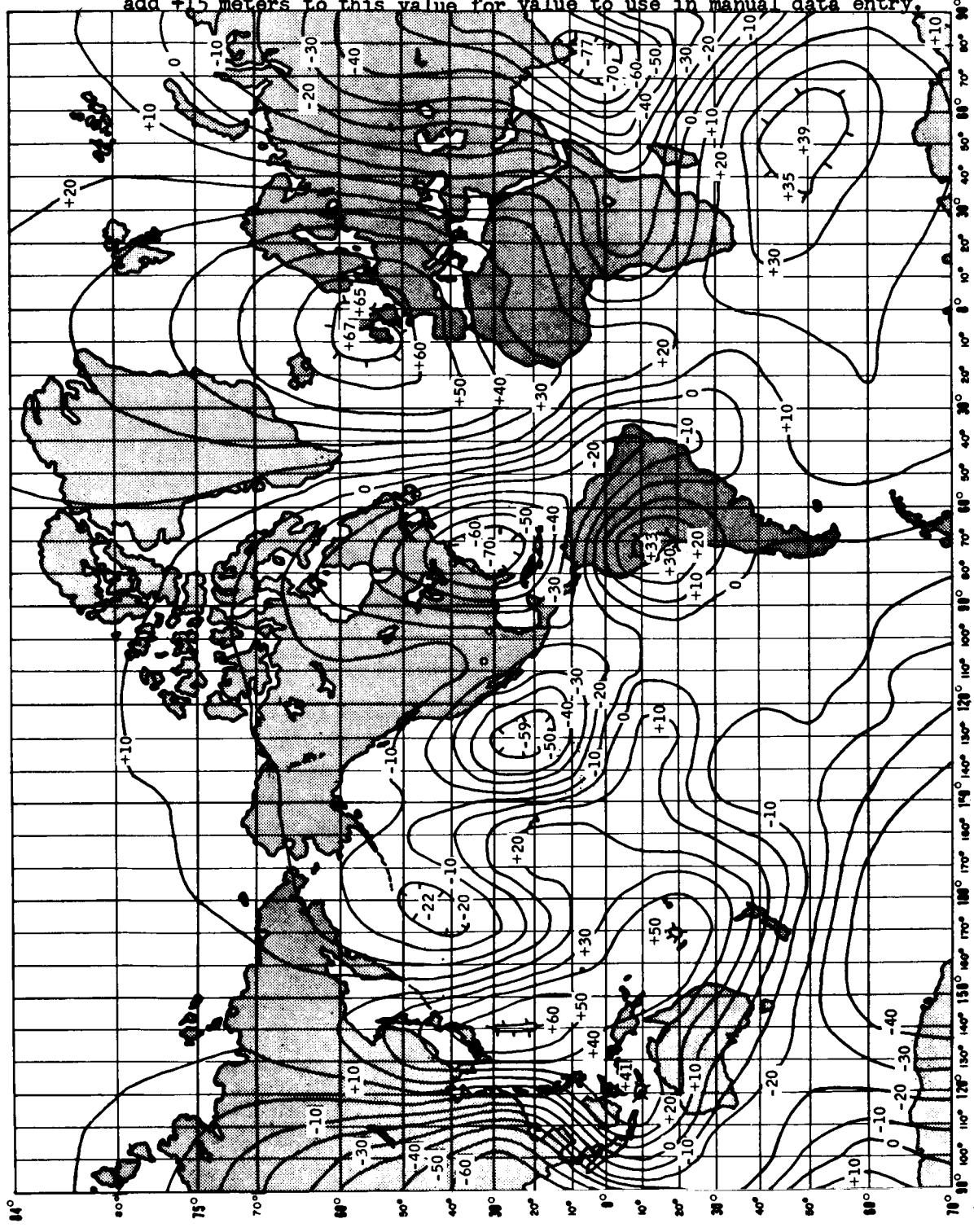
The data received from the satellite must be accurate for use by the computer, so there is programmed into the computer a "majority vote" procedure. Since the information is repeated by the satellite every two minutes, the computer, by this "majority vote" procedure, can reject incorrect digits which may have been received because of weak signal strength or other reasons.

The information entered manually into the computer must also be accurate within certain limits in order that the computer may arrive at an accurate fix. The latitude and longitude estimate is not too critical and can be in error by as much as one hundred miles. A one-meter error in the antenna height produces approximately four meters error in the position fix. The time entry must only be within 12 minutes of the time of fix, and has no effect on fix accuracy within this limitation. The east component of ship's velocity is not as critical as the north component of ship's velocity, which produces an error in the fix of 0.2 miles for every knot it is in error. These figures were supplied by APL of Johns Hopkins University, and no attempt has been made to verify them. No accurate evaluation of these is possible with the shipboard gear because of the masking effect of random error in the system.


OPR-457 LATITUDE AND LONGITUDE CORRECTIONS (in Minutes)
To be applied to satellite fixes before plotting on chart for comparison with other control. These corrections convert the fixes from the APL Ellipsoid to the North American Datum.
Plotted in the form:
⊙ Latitude corr'n for this point
⊙ Longitude corr'n for this point
(Interpolate between points)
Arc for the measurement of Distances by differences of latitude
HAWAIIAN ISLANDS
ALASKA PENINSULA
VANCOUVER I.
QUEEN CHARLOTTE IS.
Honolulu
Hawaii
Maui
Oahu
Kauai
Niihau
Midway I.
Johnston I.
Mendocino
Crescent City
Sitka
50°
40°
30°
20°
120

ANTENNA HEIGHT CORRECTIONS

Instructions for Use: Find ship's position, interpolate on this chart for actual earth's surface correction. Then, for PIONEER, add +15 meters to this value for value to use in manual data entry.



EVALUATION OF ACCURACIES OBTAINED WITH THE NAVY SATELLITE NAVIGATION SYSTEM

Clay Street Pier, Oakland, California:

A comparatively large number of fixes using the satellite system was obtained from the period 6 May 1965 to 1 June 1965, before departing on OPR-457. These were obtained both for operator instruction and to keep the "alerts" up to date. These fixes were analyzed for evaluating the range of accuracies to be expected of the system for in-port fixes.

The well-established location with respect to geodetic triangulation and the large number of fixes obtained make this evaluation especially valuable for comparison with fixes obtained in other ports.

Attempts were made to obtain sixty-three fixes, and fifty eight fixes were actually obtained, for a success percentage of 92%. Of the five failures, two were due to apparent computer malfunctions, one to operator error, and two to the pass angle being too low. (See "Tabulation of Satellite Data").

The minimum error of the fifty-eight fixes obtained was 0.01 miles, or 60 feet. This magnitude of error was achieved on two fixes out of the fifty-eight obtained. The maximum error observed was 1.07 miles on one fix. However, this is not at all a typical error of the system, as the next greatest error observed was 0.53 miles. (See Graph Number 1)

The average error for the entire fifty-eight fixes was 0.16 miles. 31% of the fixes observed had errors of less than 0.10 miles, 74% had errors of less than 0.20 miles, and 88% of the fixes had errors of less than 0.25 miles.

The accuracy was not related to pass angle (the maximum altitude of the satellite above the horizon during a pass) until a critical value of approximately 70° was reached. Below a pass angle of 70°, no fix was in error more than 0.30 miles. Above 70° pass angle, half of the fixes observed were over 0.30 miles in error and half were as accurate as those fixes having less than 70° pass angle. (See Graph Number 2).

The geometry involved in the solution produces the large errors for high pass angles. A high pass angle places the vertices of the hyperboloids of solution very near the position of the ship, thus making the hyperboloids intersect at very shallow angles to one another to form the fix. This causes the same type of error which is likely to occur when intersecting lines of position cross at shallow angles with other means of control. A small error in the lines will move the fix a relatively great distance.

The magnitude of error did not seem to correlate appreciably with the azimuth of the error. (See Graph Number 3) That is, the error was no greater in any one direction than in any other.

The Oakland errors varied in all directions, with a slight preference for 200° to 320° in azimuth. (See Graph Number 4) There was a slight trend within this range, indicating perhaps some systematic errors within the system or that the APL Ellipsoid is not correctly referenced to the North American Datum. This slight trend should be investigated to determine its cause.

This trend in azimuth is not related to the satellite observed or to the pass angle. It may be related to the direction of the satellite pass, North-to-South or South-to-North, although many South-to North passes were observed in proportion to the North-to-South passes observed. The preponderance of South-to-North passes observed was merely due to the coincidence of the passes coming when more people were awake. The North-to-South passes during this period happened to come during the small hours of the morning.

Neither satellite of the two used was more accurate than the other. They gave approximately the same errors both in magnitude of error and azimuth of error.

However, on certain consecutive passes of the same satellite, a trend in both azimuth and magnitude of errors was noticed. (See "Tabulation of Satellite Data", Fixes Number 21-22, 28-29, 30-31, 34-35, 42-43, 46-47, 53-54, and 57-58). This may possibly be due to errors in the predictions of the satellites orbit for that period of time. If this is so, it may indicate a need for recomputing fixes from orbital figures, published later, in order to improve accuracy of fixes.

The Oakland dockside series of fixes was used in assessing whether or not later fixes in other ports looked "good" or not. This series established the approximate limits of variability due to the system itself, and the quality of data to be expected.

TABULATION OF SATELLITE DATA

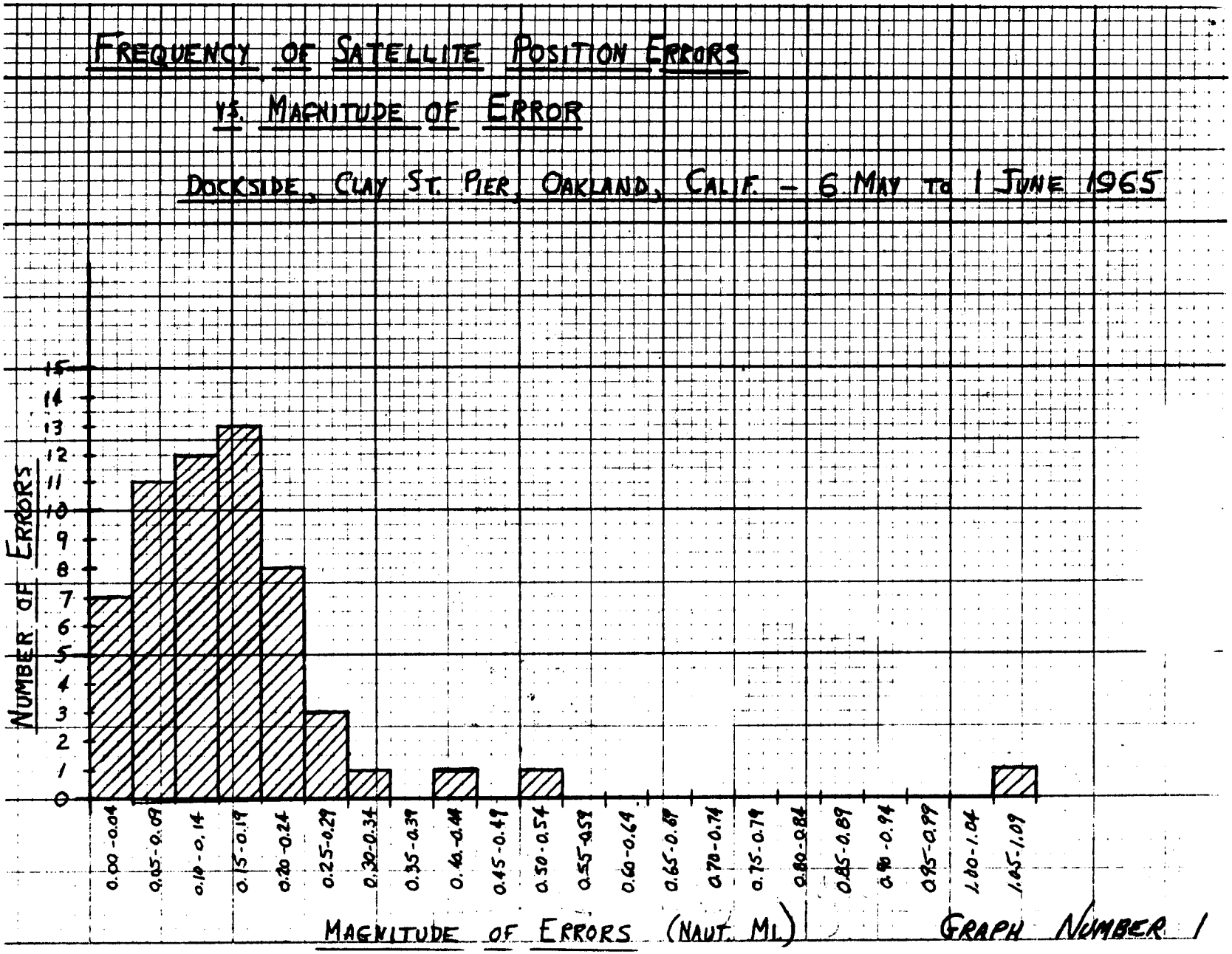
Fixes alongside Clay Street Pier, Oakland, California
6 May 1965 to 1 June 1965

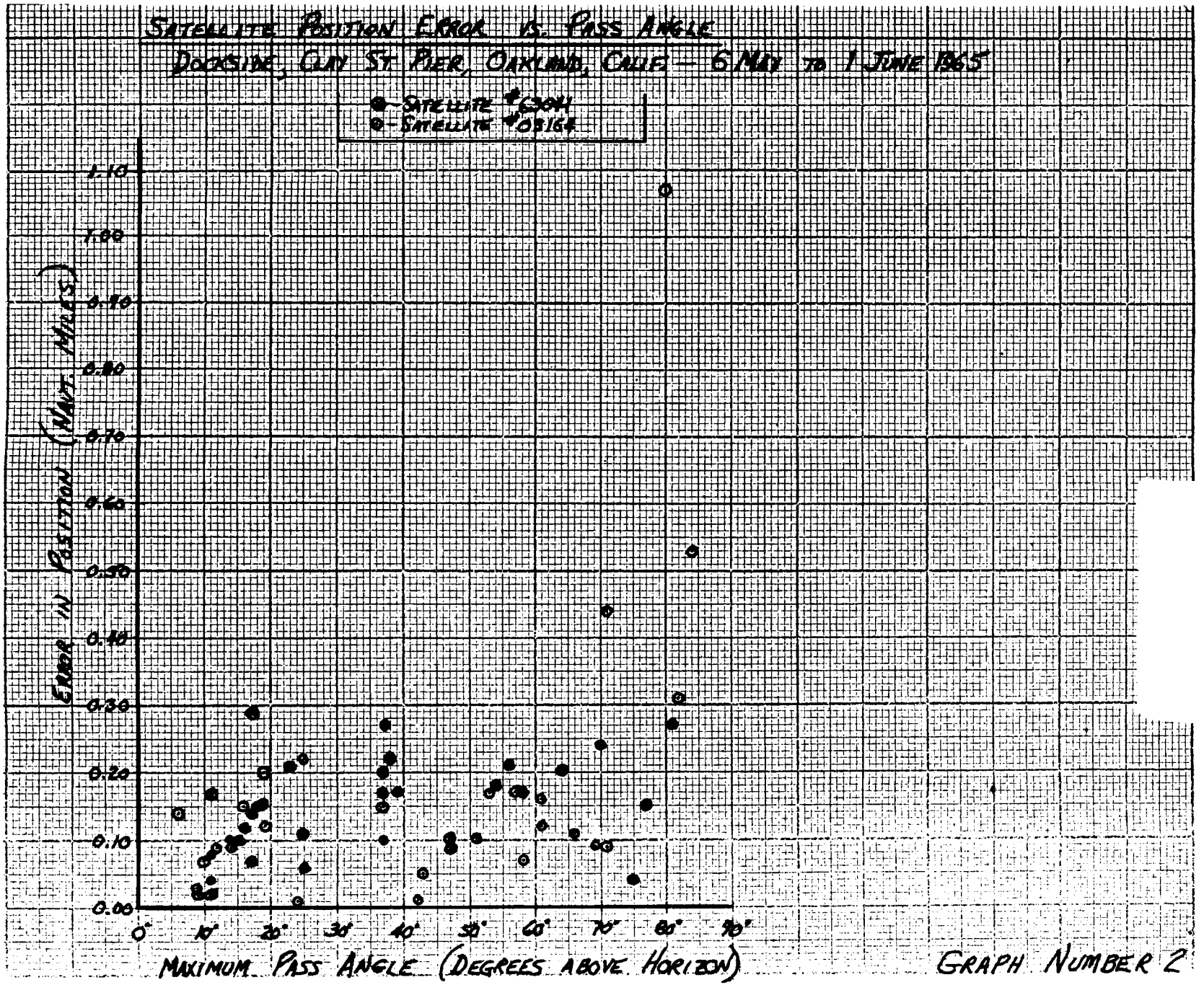
Julian Date	GMT Time	Fix No.	Satellite Number	Direct. of Pass	Pass Angle	Az. of Error	Error (naut.mi.)
126	1820	1	03164	S-N	37°	238°	0.10
126	2254	2	63041	S-N	37°	222°	0.20
127	0514	3	03164	N-S	06°	323°	0.14
127	0654	4	03164	N-S	66°	085°	0.11
127	1826	5	03164	S-N	42°	270°	0.01
127	2003	-	Computer malfunction--did not settle on fix				
127	2212	6	63041	S-N	17°	306°	0.14
127	2348	-	Computer malfunction--did not settle on fix				
128	0516	-	Operator error--entered local time				
128	0658	7	03164	N-S	82°	088°	0.31
128	2014	8	03164	S-N	19°	268°	0.12
129	0058	9	63041	S-N	23°	206°	0.21
129	1827	10	03164	S-N	58°	048°	0.07
129	2216	11	63041	S-N	25°	261°	0.11
130	1838	12	03164	S-N	69°	065°	0.09
130	2022	13	03164	S-N	14°	247°	0.10
130	2132	14	63041	S-N	11°	210°	0.02
130	2315	15	63041	S-N	75°	117°	0.04
131	0106	-	Low pass angle--weak signal				
131	0703	16	03164	N-S	61°	353°	0.12
131	1655	17	03164	S-N	09°	150°	0.03
131	1835	18	03164	S-N	80°	083°	1.07
131	2020	-	Low pass angle--not enough intervals				
131	2230	19	63041	S-N	37°	193°	0.27
132	0707	20	03164	N-S	51°	017°	0.10
132	1658	21	03164	S-N	11°	228°	0.04
132	1840	22	03164	S-N	84°	259°	0.53
132	2146	23	63041	S-N	17°	322°	0.07
133	1703	24	03164	S-N	14°	246°	0.09
133	2243	25	63041	S-N	54°	212°	0.18
134	2056	26	03164	S-N	61°	239°	0.16
134	2158	27	63041	S-N	25°	270°	0.06
135	1710	28	03164	S-N	19°	211°	0.20
135	1850	29	03164	S-N	53°	228°	0.17
135	2116	30	63041	S-N	11°	317°	0.17

TABULATION OF SATELLITE DATA

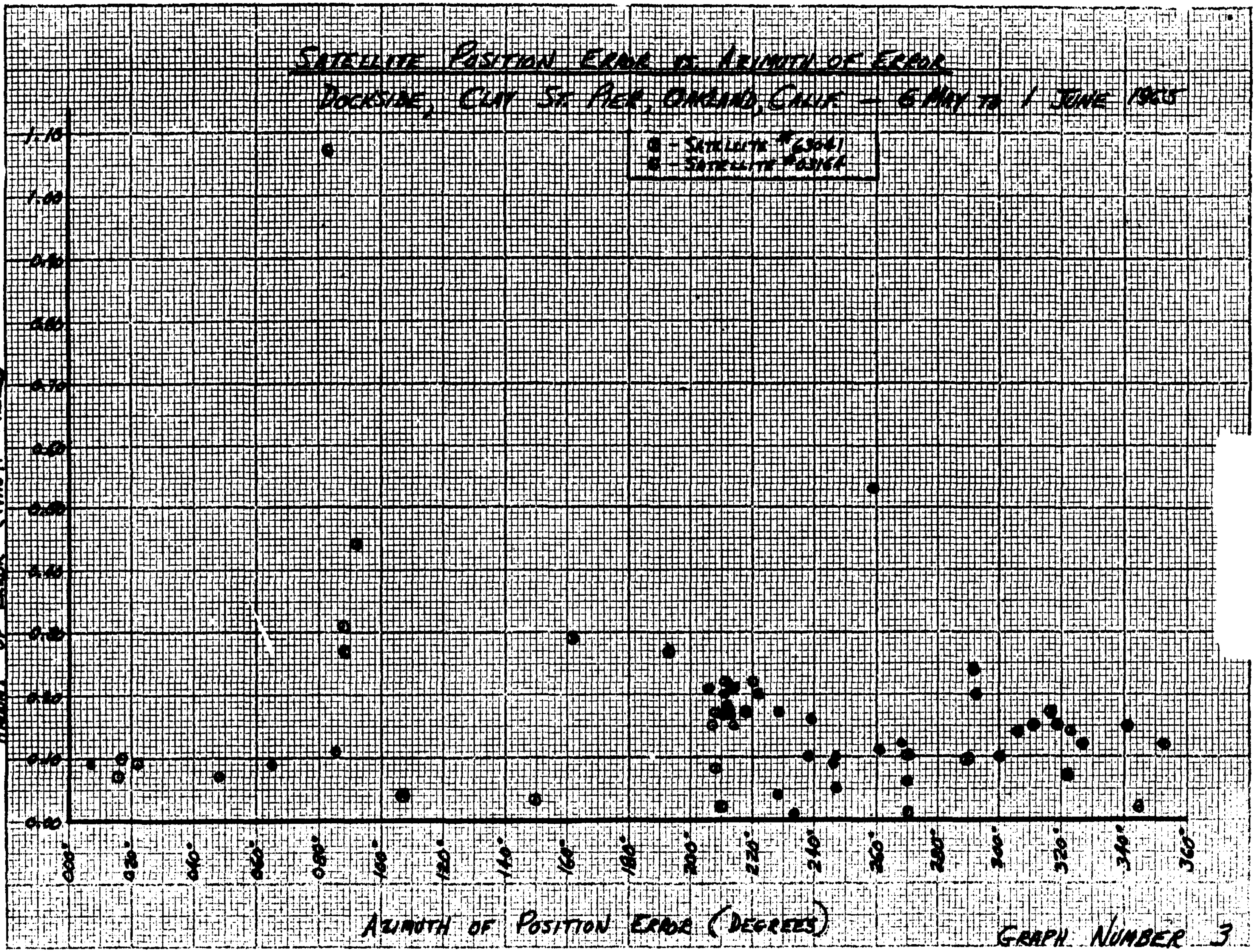
Fixes alongside Clay Street Pier, Oakland, California
6 May 1965 to 1 June 1965 -- (continued)

Julian Date	GMT Time	Fix No.	Satellite Number	Direct. of Pass	Pass Angle	Az. of Error	Error (naut. mi.)
135	2304	31	63041	S-N	77°	341°	0.15
136	0046	32	63041	S-N	15°	300°	0.10
136	2212	33	63041	S-N	37°	210°	0.17
137	1716	34	03164	S-N	25°	220°	0.22
137	1858	35	03164	S-N	37°	214°	0.15
137	2126	36	63041	S-N	17°	162°	0.29
137	2310	37	63041	S-N	64°	293°	0.20
141	1732	38	03164	S-N	43°	247°	0.05
141	2152	39	63041	S-N	38°	212°	0.22
142	0420	40	03164	N-S	10°	016°	0.07
142	2108	41	63041	S-N	18°	311°	0.15
143	0424	42	03164	N-S	12°	007°	0.09
143	0606	43	03164	N-S	71°	092°	0.44
143	2206	44	63041	S-N	56°	214°	0.21
144	2306	45	63041	S-N	47°	270°	0.10
145	1614	46	03164	S-N	09°	345°	0.02
145	1742	47	03164	S-N	71°	022°	0.09
145	2220	48	63041	S-N	81°	088°	0.27
146	1610	49	03164	S-N	11°	208°	0.08
147	2049	50	63041	S-N	18°	319°	0.15
147	2134	51	63041	S-N	39°	213°	0.17
148	0440	52	03164	N-S	24°	234°	0.01
148	1614	53	03164	S-N	16°	207°	0.15
148	1758	54	03164	S-N	57°	208°	0.17
148	2148	55	63041	S-N	57°	218°	0.17
149	2248	56	63041	S-N	47°	290°	0.09
152	2032	57	63041	S-N	16°	327°	0.12
152	2216	58	63041	S-N	70°	292°	0.24

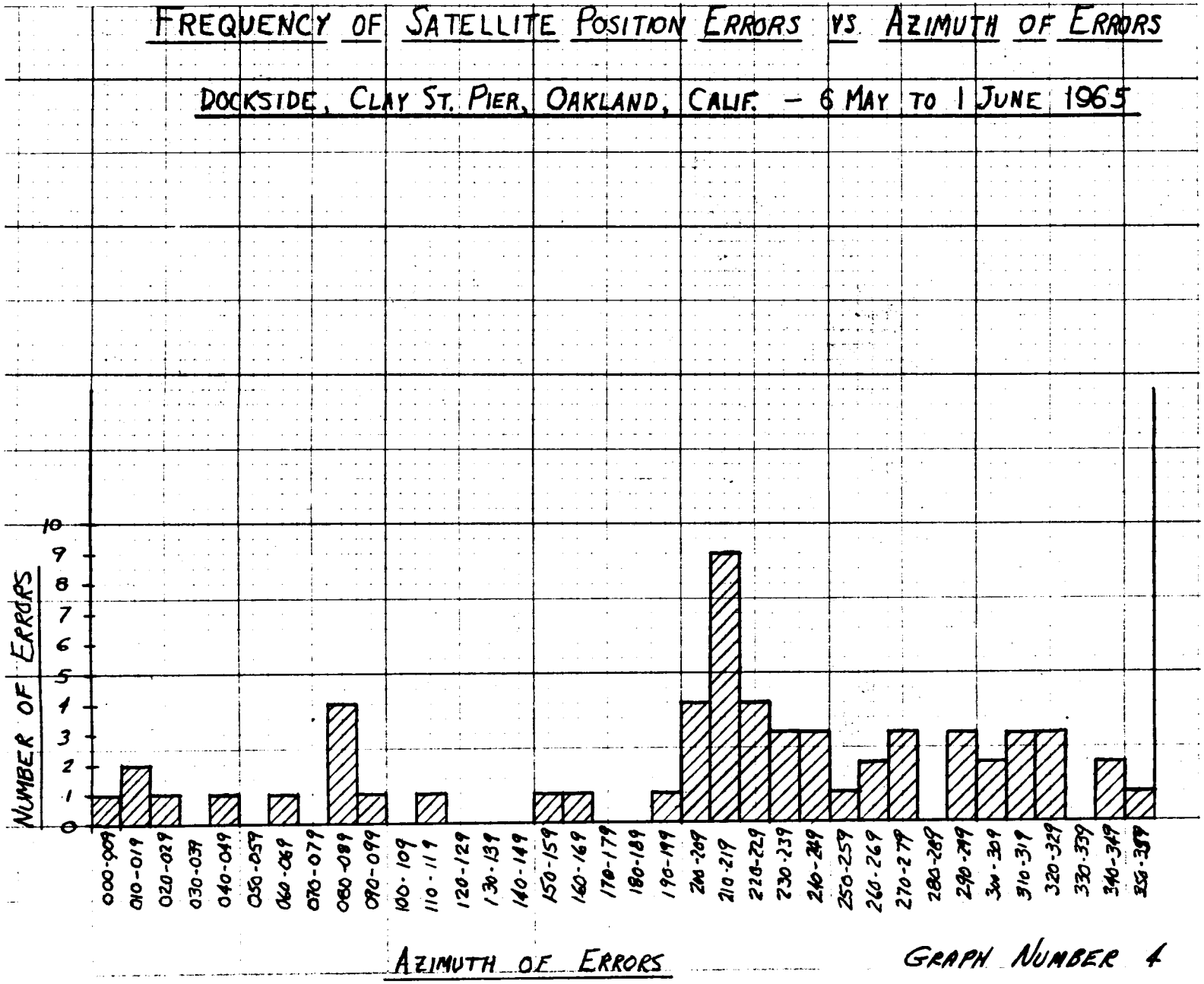

FREQUENCY OF SATELLITE POSITION ERRORS
VS. MAGNITUDE OF ERROR
DOCKSIDE, CLAY ST. PIER, OAKLAND, CALIF. – 6 MAY TO 1 JUNE 1965
NUMBER OF ERRORS
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0.00-0.04
0.05-0.09
0.10-0.14
0.15-0.19
0.20-0.24
0.25-0.29
0.30-0.34
0.35-0.39
0.40-0.44
0.45-0.49
0.50-0.54
0.55-0.59
0.60-0.64
0.65-0.69
0.70-0.74
0.75-0.79
0.80-0.84
0.85-0.89
0.90-0.94
0.95-0.99
1.00-1.04
1.05-1.09
MAGNITUDE OF ERRORS (NAUT. MI.)
GRAPH NUMBER 1



GRAPH NUMBER 2



SATELLITE POSITION ERROR vs. AZIMUTH OF ERROR
DOCKSIDE, CLAY ST. PIER, OAKLAND, CALIF. — 6 MAY TO 1 JUNE 1965
AMOUNT OF ERROR (NAUT. MILES)
1.10
1.00
0.00
0.10
0.20
000°
020°
040°
060°
080°
100°
120°
140°
160°
180°
200°
220°
240°
260°
280°
300°
320°
340°
360°
AZIMUTH OF POSITION ERROR (DEGREES)
GRAPH NUMBER 3



GRAPH NUMBER 4

Pacific Oceanographic Equipment Evaluation Range:

The first underway fixes aboard the PIONEER were obtained from 18 to 21 May 1965 while running the gravity range with Shoran Control, and while underway to and from the range with visual or Radar Control.

The fixes obtained and the following analysis of them formed the basis for a later level of confidence in underway fix-taking using the satellite gear.

Nineteen fixes were attempted on this run and seventeen fixes obtained, for a success percentage of 90%. The reasons for failure to obtain fixes were operator error in failing to note a course change during a satellite pass, and computer or receiver malfunction thought to be due to Shoran interference. Three more fixes are unavailable for analysis due to failure of simultaneous control. Therefore only fourteen fixes are included in the underway evaluation on this run.

The Shoran transmitter thought to be interfering on the one pass was later found faulty and removed from service. Another transmitter was substituted, no interference was noted, and no malfunctions were caused.

Of the fourteen fixes evaluated, the mean error was 0.22 miles; eleven fixes, or 79%, were less than 0.30 miles in error. (See Graph Number 5). The minimum error observed was 0.04 miles, achieved three times out of the fourteen fixes.

It is to be noted that the smaller errors were observed mainly when making comparison with Shoran Control, and most of the larger errors were observed with Radar Control as comparison. This may be shown by the average error upon comparison with Shoran Control, 0.17 miles, and the average error upon comparison with Radar, 0.30 miles. It is seen that the average error upon comparison with Shoran, which is very accurate, agrees very well with the average error observed alongside Clay Street Pier, Oakland. It also indicates that Radar fixes are not comparable in accuracy, and some of the error in comparison may be placed in the Radar fixes.

The accuracy again was not directly related to pass angle. (See Graph Number 6) Three pass angles greater than 70° were observed, and none of these produced any greater error than those below 70°.

The magnitude of the error correlated to a very slight degree with the azimuth of the error. (See Graph Number 7) The larger errors all were in a southerly direction, but the number of observations is not sufficiently large to make any conclusion.

The direction of pass of the satellite, north-to-south or south-to-north, had no observable effect on either magnitude or azimuth of error. (See Graph Number 7) Neither satellite was more accurate than the other.

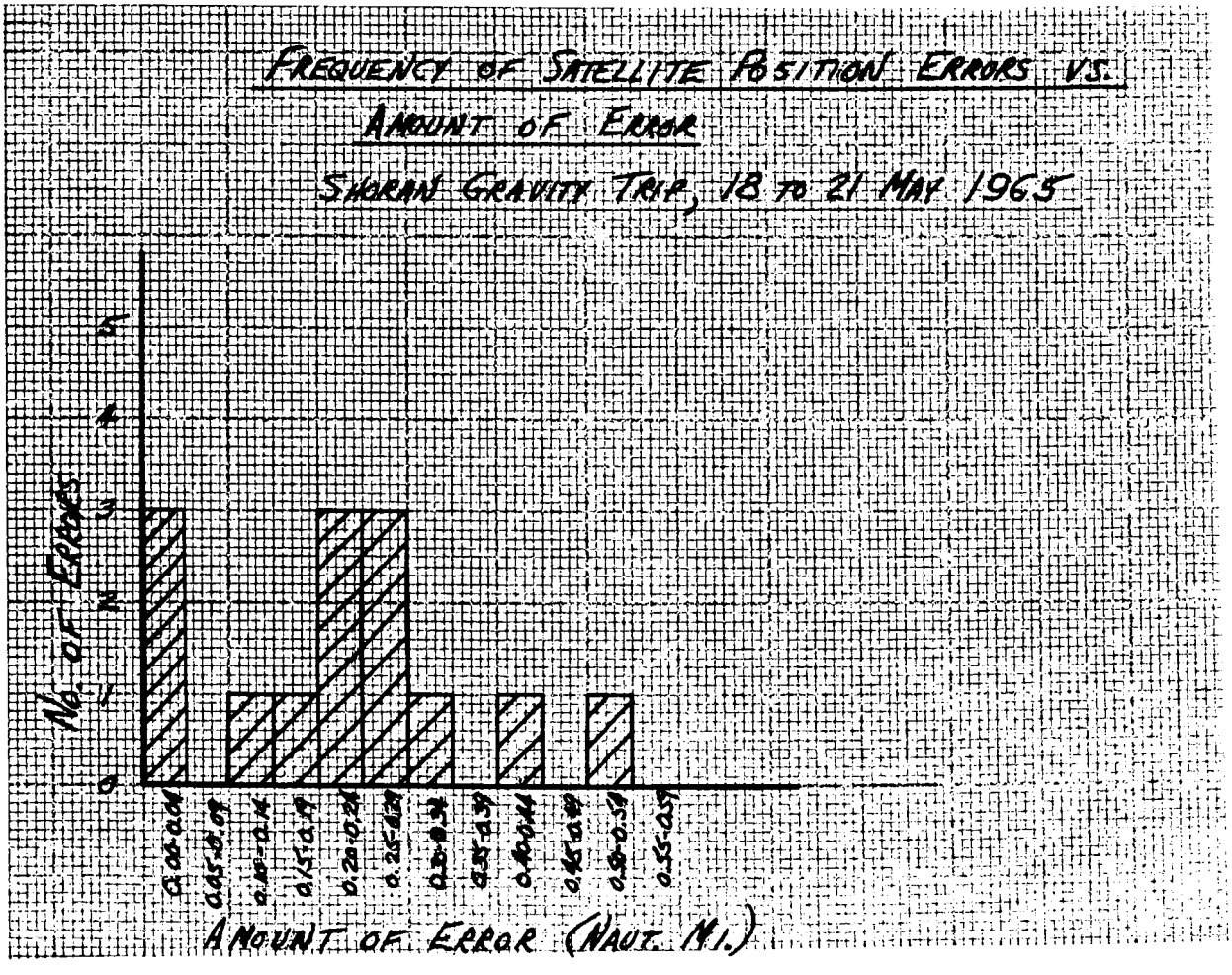
Course and speed of the ship had no noticeable effect on the quality of the fix obtained, as long as the components of ship's velocity were correctly entered by the operator.

Azimuth of the errors is randomly distributed, no direction having a great preponderance of the errors. (See Graph Number 8)

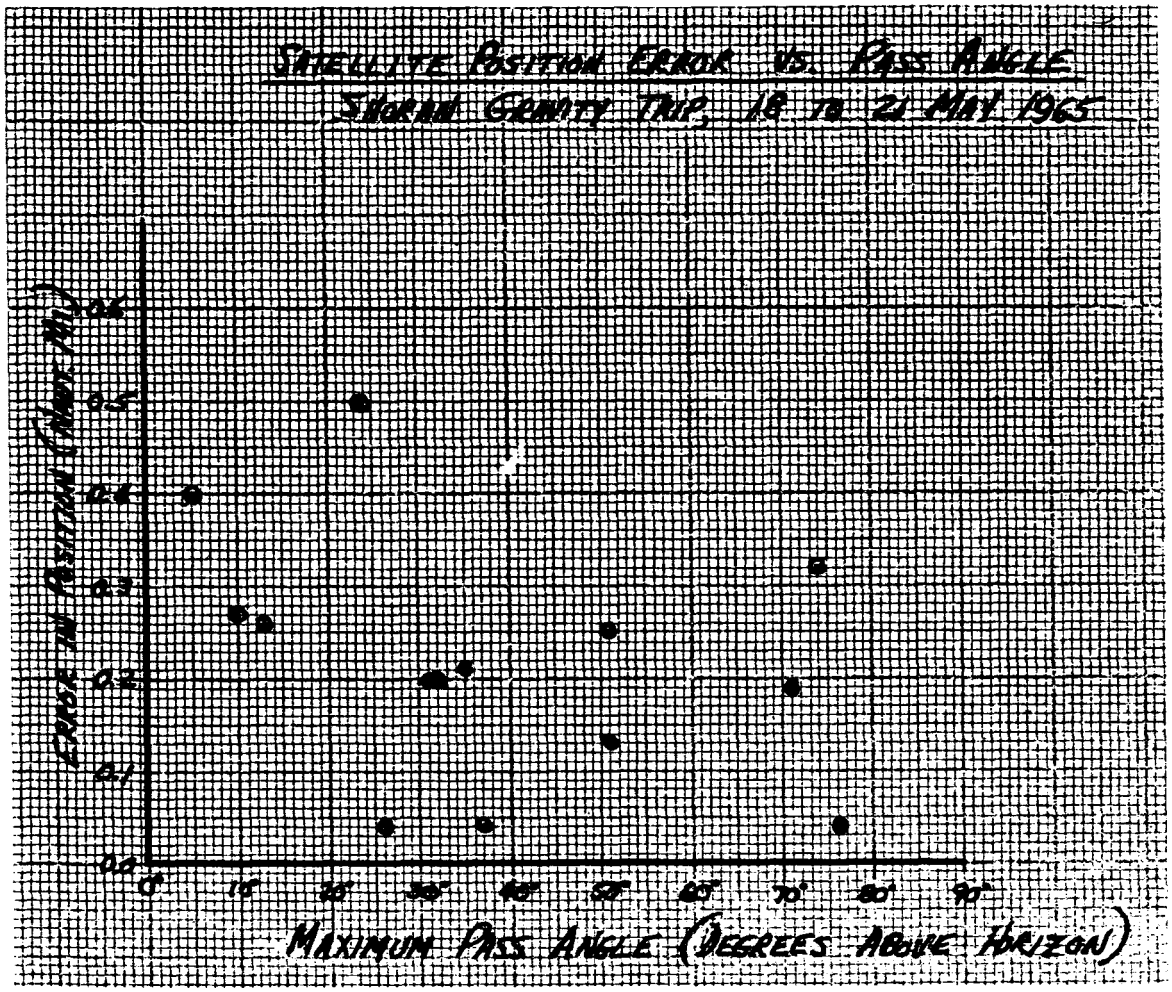
TABULATION OF SATELLITE DATA

Pacific Oceanographic Equipment Evaluation Range -- 18 to 21 May 1965

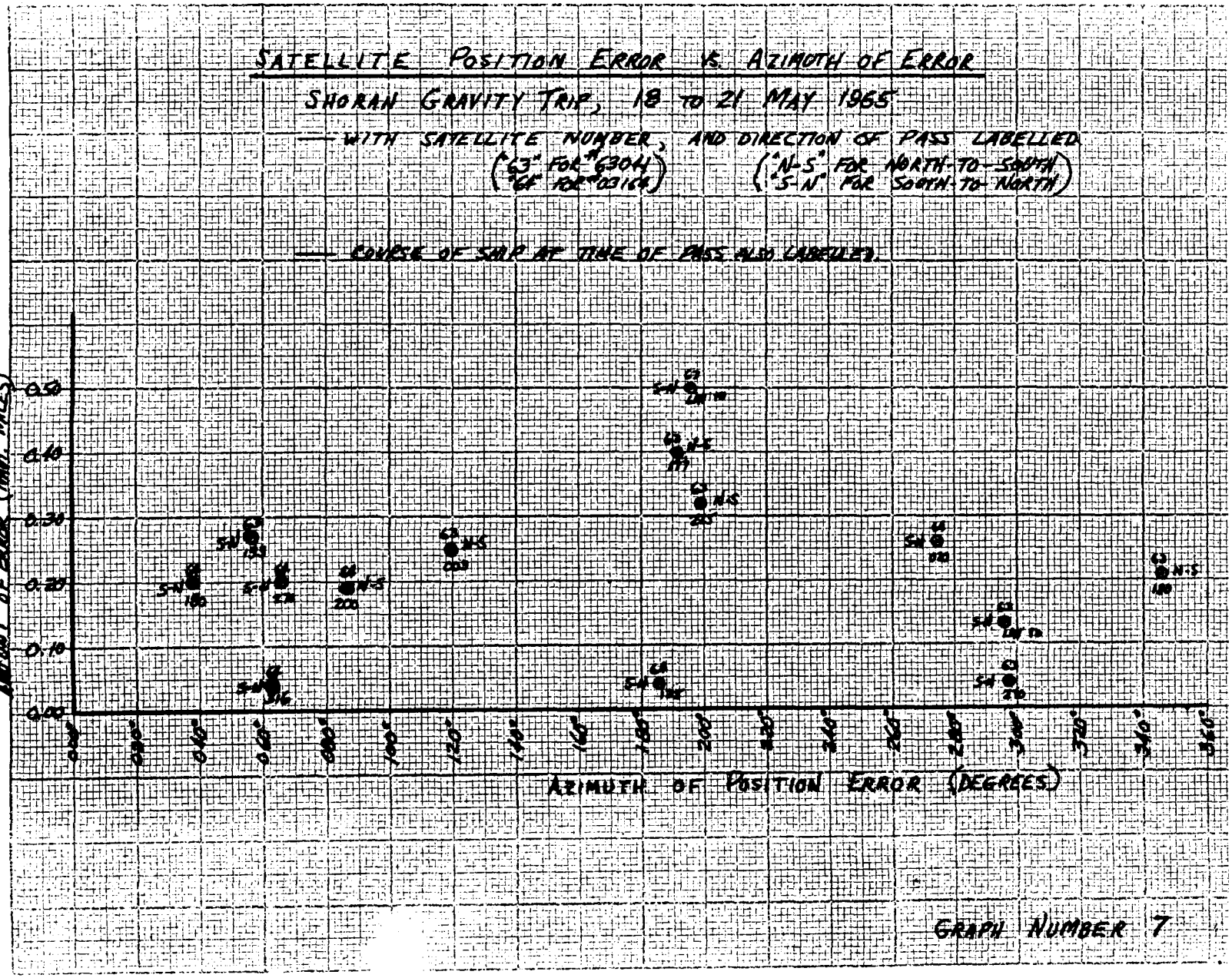
Satellite Number	Julian Date	GMT Time	Position of Satellite Fix	Compar. Control	Dir. of Pass	Ship's Course	Pass Angle	Az. of Error	Error (n. mi.)
63041	138	2226	Operator error--did not allow for course change during fix						
63041	139	0014	Shoran transmitter thought to be interfering with reception						
03164	139	0558	38° 21.7595'N, 123° 06.9779'W	None	--	--	54°	--	--
03164	139	0742	38° 13.3130'N, 123° 08.9057'W	None	--	--	19°	--	--
63041	139	1132	38° 14.0887'N, 123° 06.1615'W	Rad&Vis	N-S	004°	51°	120°	0.25
63041	139	1324	38° 07.4832'N, 123° 05.4247'W	Rad&Vis	N-S	177°	05°	192°	0.40
03164	139	1730	38° 16.1894'N, 123° 07.1503'W	Visual	S-N	180°	32°	038°	0.20
03164	139	1918	38° 13.1613'N, 123° 06.7348'W	Radar	S-N	270°	31°	066°	0.20
63041	139	2146	38° 01.2460'N, 123° 07.3170'W	Radar	S-N	Lay to	24°	196°	0.50
63041	139	2334	38° 01.3065'N, 123° 06.7016'W	Radar	S-N	Lay to	51°	296°	0.13
03164	140	0612	38° 05.0530'N, 123° 11.8662'W	Shoran	N-S	200°	71°	087°	0.19
63041	140	1044	38° 11.1835'N, 123° 05.1861'W	Shoran	N-S	225°	74°	199°	0.32
63041	140	1236	38° 09.0100'N, 123° 17.2636'W	None	--	--	16°	--	--
03164	140	1734	38° 14.3250'N, 123° 13.5613'W	Shoran	S-N	135°	37°	186°	0.04
03164	140	1918	38° 13.5441'N, 123° 10.7593'W	Shoran	S-N	316°	26°	063°	0.04
63041	140	2104	38° 08.7402'N, 123° 05.0800'W	Shoran	S-N	134°	10°	057°	0.27
63041	140	2248	38° 07.7913'N, 123° 00.4802'W	Shoran	S-N	270°	76°	297°	0.04
03164	141	0748	38° 09.0220'N, 123° 11.5700'W	Shoran	S-N	020°	13°	275°	0.26
63041	141	1000	38° 05.2040'N, 123° 06.3710'W	Shoran	N-S	180°	35°	346°	0.21



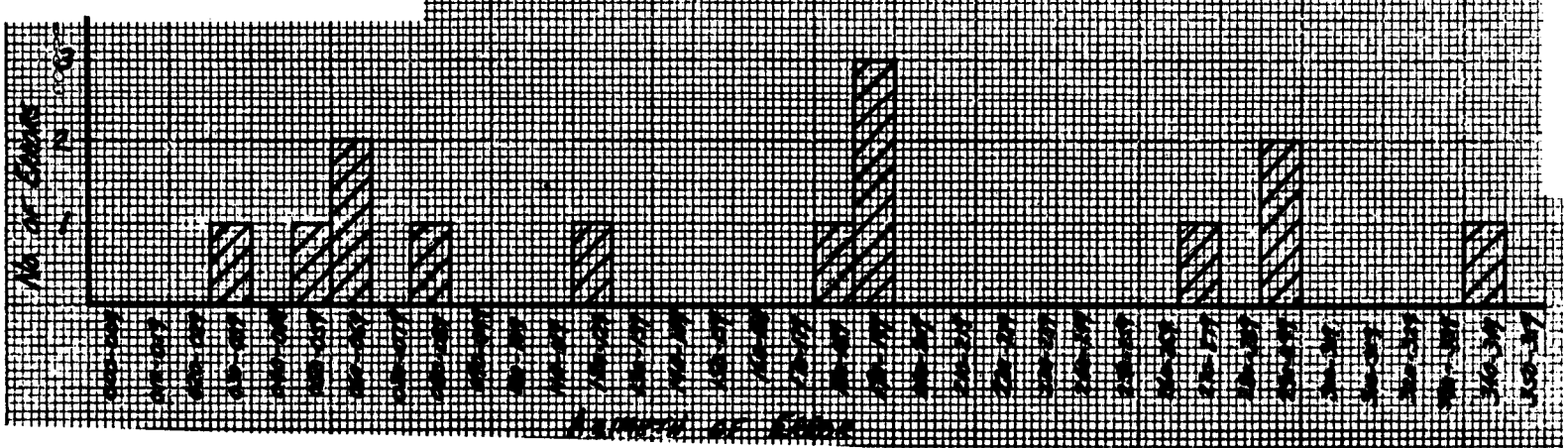
GRAPH NUMBER 5



GRAPH NUMBER 6


SATELLITE POSITION ERROR VS. AZIMUTH OF ERROR
SHORAN GRAVITY TRIP, 18 TO 21 MAY 1965
— WITH SATELLITE NUMBER, AND DIRECTION OF PASS LABELLED
("63" FOR "63044", "65" FOR "03165") ("N-S" FOR NORTH-TO-SOUTH, "S-N" FOR SOUTH-TO-NORTH)
— COURSE OF SAR AT TIME OF PASS ALSO LABELLED.
AMOUNT OF ERROR (NAUT. MILES)
0.50
0.40
0.30
0.20
0.10
0.00
AZIMUTH OF POSITION ERROR (DEGREES)
GRAPH NUMBER 7

FREQUENCY OF SATELLITE POSITION ERRORS VS.
AZIMUTH OF ERROR
SIORAN GRAVITY TRIP, 18 TO 21 MAY 1965



GRAPH NUMBER 8

San Francisco, California to Kodiak, Alaska:

The PIONEER, on its run from San Francisco to Kodiak from 2 June 1965 to 7 June 1965, attempted sixty-seven fixes and obtained fifty-two, for a completion percentage of 78%.

Of the fifteen fixes missed, five were caused by computer malfunctions, probably due to either sudden voltage changes in the power, or due to tape reader head malfunction. Three missed fixes were caused by operator error in entering data, and one was caused by operator error in mounting the program tape on the computer. Three misses were caused by low pass angles, and one caused by losing lock on the satellite, probably due to shading by the ship's mast. The other two missed fixes were due to two satellites being above the horizon at the same time, one satellite useful and the other faulty but still broadcasting the audible signal. The operator erroneously locked on the faulty satellite in these cases, receiving scrambled data.

As operators received more instruction and became more familiar with the gear, the number of operator-caused failures was substantially reduced. The operators became more skilled in mounting the tape, performing proper data entry, and recognizing scrambled data received from a satellite, in order to search again and lock onto an operative satellite.

Comparison of the satellite fixes for observable error was made with Loran A on this leg of the cruise. (See "Tabulation of Satellite Data") It was noted that the Loran A, while usually in the general area of the satellite fix, was not consistent in its differences with the satellite fixes. At the same time, it was noted that the satellite fixes agreed very well among themselves on both a speed and corse basis. For these reasons, and because of the level of accuracy previously achieved by the satellite gear in the trial run on the Pacific Oceanographic Equipment Evaluation Range, it was decided that the most accurate smooth-plot of the trackline could be made by using the satellite fixes.

Therefore the satellite fixes were used as the primary basis of control for this trackline. Comparison was made continually with the Loran A in this plot to be certain it stayed in general agreement. However, the fluctuation in agreement of satellite and Loran A fixes is believed to be due to the variance of the Loran A much more than the error of the satellite fixes.

The "Tabulation of Satellite Data", however, is arranged on the basis of where the satellite fix was in relation to conventional control, or smooth-plotted positions which differ from the satellite fixes. This format is followed throughout the tabulations in this report, for this trackline and all others, notwithstanding that on the open ocean, the satellite fix was felt to be the best estimate of actual ship's position.

Six satellite fixes were not used the final smooth-plot on this leg of the cruise. These were far enough in error in relation to the remainder of the fixes that they were detectably erroneous. Of these, four are either very high passes, or very low passes where reception is weak and the Doppler count subject to errors. The six fixes not used in the smooth-plot had an average error of 1.21 miles. The largest error observed on these was 1.91 miles, on a pass having a pass angle of 81°.

The forty-two fixes which were compared with Loran A had an average error of 0.45 miles in relation to the position indicated by the Loran A. The azimuths of the errors were not systematic, and as previously mentioned, are believed due largely to variance of the Loran A. The error figure therefore is not considered serious, but reflects more the quality of Loran A.

The satellite system checked very well within itself for a large number of fixes. It is believed that a much more accurate, and certainly more easily plottable, trackline was made possible by the satellite navigation system.

Dockside, Kodiak, Alaska:

The PIONEER attempted four satellite fixes on 7 June 1965 while moored at Kodiak, Alaska. Three satellite fixes were obtained, the fourth not obtained because the pass angle was too low.

The ship's position was established with three-point sextant fixes and the satellite fixes compared with this. Comparison was very good with the charted position of the ship, having an average error of 0.10 miles. (See section of chart and "Tabulation of Satellite Data".) The largest error observed was 0.13 miles. Although the errors were not random in azimuth, the small quantity of fixes and low distance errors make this fact insignificant.

The accuracy of the satellite system in Kodiak is evaluated to be entirely satisfactory.

TABULATION OF SATELLITE DATA

San Francisco, California to Kodiak, Alaska -- 2 June 1965 to 7 June 1965

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
-	153	0322	--	--	Operator error--entered local time			
No #	153	0508	Radar brngs.	Not on OS sheet	38° 30.3536'N, 123° 22.5049'W	61°	?	0.30
-	153	0646	--	--	Computer malfunction--power pulse?			
-	153	0746	--	--	Computer malfunction--power pulse?			
-	153	0930	--	--	Operator error--program tape on wrong			
5A	153	1124	Loran A	Only one rate plots	39° 35.3610'N, 124° 30.7293'W	23°	-	0.00
12A	153	1642	Loran A	Only one rate plots	40° 33.0525'N, 125° 21.2439'W	30°	168°	0.05
15A	153	1824	Loran A	40° 47.8'N, 125° 37.8'W	40° 48.3242'N, 125° 37.5697'W	33°	014°	0.75
-	153	2007	--	--	Low pass angle--not enough intervals			
-	153	2130	--	--	Locked on bad satellite--data scrambled			
-	153	2318	--	--	Locked on bad satellite--data scrambled			

TABULATION OF SATELLITE DATA

San Francisco to Kodiak -- (continued, page 2)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)	
-	154	0324	--	--	Operator error--entered wrong velocity				
31A	154	0512	Loran A	42° 28.3'N, 126° 57.5'W	42° 28.7739'N, 126° 57.0118'W	48°	085°	0.62	
40A	154	1224	Loran A	43° 37.3'N, 128° 05.8'W	43° 37.7924'N, 128° 05.7938'W	12°	010°	0.32	
45A	154	1640	Loran A	44° 27.8'N, 128° 52.3'W	44° 27.5129'N, 128° 52.0460'W	31°	127°	0.25	
48A	154	1832	Loran A	44° 48.1'N, 129° 09.6'W	44° 47.9337'N, 129° 09.7395'W	43°	187°	0.15	
51A	154	2056	Smooth plot	45° 14.0'N, 129° 34.2'W	45° 14.7238'N, 129° 35.7242'W	21°	195°	0.65	(*)
56A	155	0028	Loran A	45° 55.1'N, 130° 16.9'W	45° 55.0127'N, 130° 17.1146'W	12°	222°	0.10	
62A	155	0514	Loran A	46° 49.4'N, 131° 10.7'W	46° 49.4612'N, 131° 11.7764'W	48°	276°	0.85	
65A	155	0802	Loran A	Only one rate plots	47° 19.6508'N, 131° 47.0598'W	07°	337°	0.10	

(*) -- Satellite fix not used in final smooth plot of trackline.

TABULATION OF SATELLITE DATA

San Francisco to Kodiak -- (continued, page 3)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
67A	155	0948	Loran A	Only one rate plots	47° 39.6710'N, 132° 11.1195'W	52°	162°	0.09
69A	155	1134	Loran A	Only one rate plots	48° 00.8689'N, 132° 33.7707'W	29°	-	0.00
72A	155	1322	Loran A	Only one rate plots	48° 21.8031'N, 132° 55.2612'W	05°	025°	0.15
76A	155	1656	Loran A	49° 02.4'N, 133° 42.8'W	49° 02.5187'N, 133° 42.8508'W	32°	331°	0.28
78A	155	1836	Loran A	49° 20.0'N, 134° 05.2'W	49° 20.6528'N, 134° 06.6864'W	55°	286°	0.75
81A	155	2022	Loran A	49° 39.3'N, 134° 31.5'W	49° 39.8487'N, 134° 32.8515'W	09°	296°	0.96
83A	155	2154	Loran A	No point fix pass.	49° 56.5165'N, 134° 55.1037'W	49°	007°	0.60
87A	155	2342	Loran A	50° 06.0'N, 135° 06.6'W	50° 06.5485'N, 135° 06.4279'W	33°	005°	0.55
89A	156	0134	Loran A	Only one rate plots	50° 20.7624'N, 135° 24.2539'W	07°	030°	0.65

TABULATION OF SATELLITE DATA

San Francisco to Kodiak -- (continued, page 4)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
92A	156	0336	--	--	Too many losses of lock--shading by mast			
95A	156	0516	Loran A	51° 00.7'N, 136° 16.8'W	51° 00.9570'N, 136° 17.2779'W	40°	331°	0.42
97A	156	0658	Loran A	Only one rate plots	51° 19.3905'N, 136° 42.6880'W	35°	268°	0.10
-	156	0838	--	--	Computer malfunction--power pulse?			
101A	156	1048	Loran A	No rate plots	52° 03.4492'N, 137° 37.7456'W	71°	-	-
103A	156	1234	Loran A	Only one rate plots	52° 22.6345'N, 138° 05.9384'W	14°	-	0.00
106A	156	1422	Loran A	No point fix poss.	52° 40.7151'N, 138° 34.9037'W	05°	-	0.20
109A	156	1658	Loran A	Only one rate plots	53° 08.2045'N, 139° 15.1305'W	29°	213°	0.11
111A	156	1840	Loran A	No rate plots	53° 15.7824'N, 139° 24.3591'W	75°	-	-

TABULATION OF SATELLITE DATA

San Francisco to Kodiak -- (continued, page 5)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)	
114A	156	2026	Loran A	53° 25.1'N, 139° 37.7'W	53° 26.0259'N, 139° 37.6232'W	18°	305°	1.28	
-	156	2103	--	--	Computer malfunction--recorded bad Doppler count				
117A	156	2254	Loran A, Sun line	No point fix poss.	53° 52.6536'N, 140° 14.8708'W	79°	047°	0.88	
120A	157	0050	Loran A	54° 09.3'N, 140° 44.2'W	54° 09.2523'N, 140° 44.1572'W	23°	-	0.00	
123A	157	0238	Smooth plot	54° 24.8'N, 141° 11.9'W	54° 24.7960'N, 141° 13.8628'W	02°	269°	1.25	(*)
125A	157	0338	Loran A	54° 34.8'N, 141° 26.7'W	54° 34.0248'N, 141° 26.4955'W	05°	176°	1.45	
-	157	0656	--	--	Operator error--incorrect data entry				
130A	157	0702	Loran A	55° 05.8'N, 142° 17.1'W	55° 04.8258'N, 142° 17.6492'W	56°	204°	0.95	
131A	157	0812	Loran A	55° 15.3'N, 142° 34.0'W	55° 15.2691'N, 142° 34.0029'W	09°	-	0.00	
132A	157	0844	Loran A	55° 19.2'N, 142° 42.7'W	55° 20.2254'N, 142° 42.6894'W	10°	181°	0.98	

(*) -- Satellite fix not used in final smooth plot.

TABULATION OF SATELLITE DATA

San Francisco to Kodiak -- (continued, page 6)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)	
133A	157	1000	Smooth plot	55° 30.7'N, 143° 02.7'W	55° 30.4377'N, 143° 01.6933'W	41°	132°	0.70	(*)
135A	157	1146	Loran A	Only one rate plots	55° 44.8814'N, 143° 31.0918'W	47°	252°	1.05	
137A	157	1334	Loran A	56° 00.0'N, 143° 56.8'W	55° 59.5333'N, 143° 57.1102'W	11°	199°	0.49	
-	157	1522	--	--	Low pass angle--not enough intervals				
142A	157	1702	Loran A	56° 17.1'N, 144° 59.2'W	56° 16.7723'N, 144° 58.7172'W	25°	117°	0.38	
144A	157	1844	Smooth plot	56° 18.5'N, 145° 34.7'W	56° 18.1573'N, 145° 37.7444'W	70°	258°	1.80	(*)
148A	157	2028	Loran A	Only one rate plots	56° 22.5312'N, 146° 11.7753'W	10°	262°	0.20	
150A	157	2212	Loran A	Only one rate plots	56° 28.8101'N, 146° 47.6367'W	39°	262°	0.12	
152A	157	2356	Loran A	56° 35.3'N, 147° 25.3'W	56° 34.9337'N, 147° 24.6394'W	60°	133°	0.55	

(*) -- Satellite fix not used in final smooth plot.

TABULATION OF SATELLITE DATA

San Francisco to Kodiak -- (continued, page 7)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)	
-	158	0144	--	--	Computer malfunction--would not settle on fix				
-	158	0334	--	--	Low pass angle--not enough intervals				
159A	158	0522	Loran A	56° 50.8'N, 149° 05.0'W	56° 50.5060'N, 149° 05.5461'W	35°	220°	0.45	
161A	158	0704	Smooth plot	56° 57.3'N, 149° 33.3'W	56° 59.2124'N, 149° 33.3670'W	81°	000°	1.91	(*)
163A	158	0850	Loran A	Only one rate plots	57° 05.0193'N, 150° 01.1235'W	19°	090°	0.59	
165A	158	0916	Loran A	57° 07.1'N, 150° 08.9'W	57° 06.8449'N, 150° 08.2987'W	18°	124°	0.28	
167A	158	1032	Smooth plot	57° 12.9'N, 150° 27.8'W	57° 13.5175'N, 150° 28.4814'W	02°	332°	0.92	(*)
168A	158	1058	Loran A	57° 15.0'N, 150° 34.3'W	57° 15.0113'N, 150° 34.8782'W	68°	270°	0.27	
170A	158	1246	Loran A	57° 21.7'N, 151° 03.9'W	57° 22.7043'N, 151° 03.5932'W	32°	012°	1.03	
173A	158	1432	Radar	57° 31.3'N, 151° 29.3'W	57° 30.8098'N, 151° 31.1931'W	11°	062°	1.07	

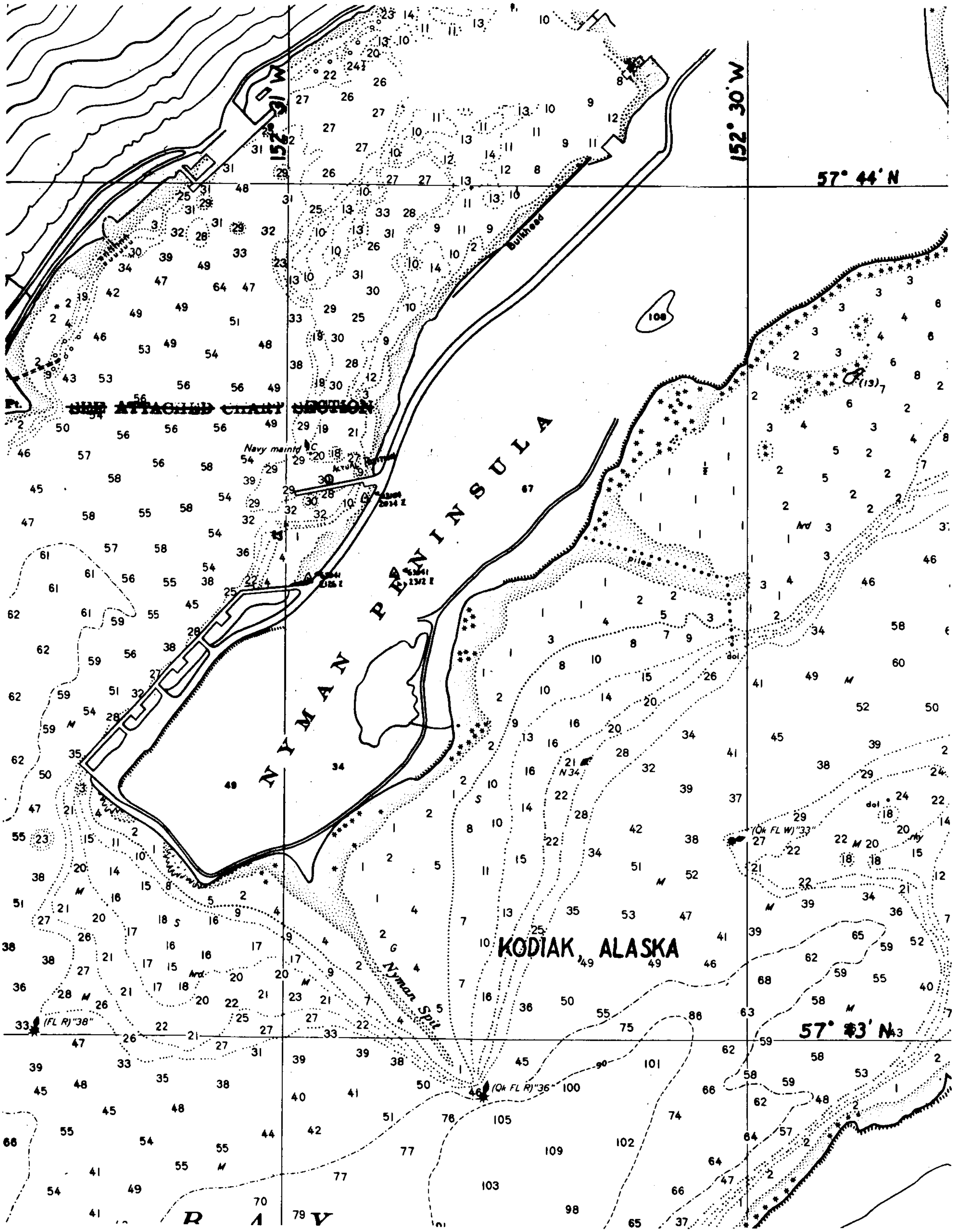
(*) -- Satellite fix not used in final smooth plot.

TABULATION OF SATELLITE DATA

Dockside, Kodiak, Alaska -- 7 June 1965

Charted Position of PIONEER -- 57° 43.655'N, 152° 30.905'W

Satellite Number	Julian Date	GMT Time	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
63041	158	1938	Low pass angle--not enough intervals			
03164	158	2034	57° 43.6334'N, 152° 30.8256'W	28°	117°	0.05
63041	158	2126	57° 43.5359'N, 152° 30.9499'W	18°	192°	0.12
63041	158	2312	57° 43.5448'N, 152° 30.7647'W	62°	145°	0.13


152° 31' W
152° 30' W
57° 44' N
57° 43' N
SEE ATTACHED CHART SECTION
NYMAN PENINSULA
Bulkhead
Piles
Navy maint'd
(Qk FL W) "33"
(FL R) "38"
(Qk FL R) "36"
Nyman Spit
KODIAK, ALASKA

Kodiak, Alaska to Adak, Alaska:

The PIONEER ran from Kodiak to Adak from 8 June 1965 to 11 June 1965. During this leg of the trip thirty-eight fixes were attempted with the satellite gear and twenty-seven were actually obtained, for a success percentage of 71%.

Five of the eleven failures were due to low pass angle. This is a feature of the system over which there is no control, being merely a function of ship's position and the orbital characteristics of the satellite. Two fixes were missed because of computer malfunctions, probably in the tape reader head. Two fixes were lost due to operator error in data entry. One fix was missed due to two satellites being audible at the same time, one non-functional and being locked onto instead of the functioning satellite. This happened more often in higher latitudes because the convergence of the satellites' polar orbits made the satellites usable more times a day than in lower latitudes. For this reason there is a tendency for more than one satellite being above the horizon at the same time. Fixes were obtained more often than in lower latitudes, though. One fix was missed due to losing lock too many times during the pass, probably due to shading by the ship's mast.

Comparison of accuracy on this leg of the trip was made with smooth-plotted positions plotted by conventional means of control only. The satellite fixes were not considered for this smooth-plot, but were plotted after the trackline was inked. Comparison was then made with the inked positions. The "Tabulation of Satellite Data" was again made up assuming the satellite fix to be always in error.

The average error for the entire twenty-seven fixes compared is 0.38 miles, which does not compare very well with previous accurate comparisons. It is believed that a breakdown into comparisons by different types of control will give a more accurate evaluation.

Eighteen fixes were compared with positions determined by Radar Control, either alone or in combination with visual bearings. These comparisons have an average error of 0.46 miles.

Five fixes were compared with positions determined by three-point sextant fixes, and these have an average of 0.19 miles. Two fixes were compared with positions determined by visual bearings, these having an average error of 0.13 miles. Averaging these seven fix comparisons together produces an average error of 0.17 miles for comparisons with totally visually determined positions. This figure is very comparable to previous accurate determinations, and is believed to be the best estimate of underway accuracy available on the entire cruise. The largest error observed upon comparison with the visual fixes was 0.40 miles.

A conclusion is also forced: namely , that Radar positions are not as accurate as visual positions. This is possible because long-range Radar readings cannot be made on the actual shoreline, and because of individual differences, in operators of Radar.

No celestial positions were possible because of continual fog and clouds.

Azimuth of errors for both visual and radar fixes was not random as before. Errors were in a generally easterly direction for the majority of fixes. The ship was on westerly courses during this leg, but any causal relation remains unknown. No relation of this type has been observed at any other time with this system.

Dockside, Adak, Alaska:

While the PIONEER was mored to Dock No. 3, Adak, on 11 June 1965 and 12 June 1965, eleven satellite fixes were attempted. Nine were obtained, low pass angle responsible for one miss and a computer malfunction, probably the tape reader head, for the other.

The ship's position was established with three-point sextant fixes, and the satellite fixes compared very well with this. (See "Tabulation of Satellite Data") The average error was 0.15 miles, and the azimuth of the errors was random. The largest error observed was 0.31 miles.

Within the limits of error of the satellite system, the position comparison was favorable at Adak.

TABULATION OF SATELLITE DATA

Kodiak, Alaska to Adak, Alaska -- 8 June 1965 to 11 June 1965

Fix No.	Julian Date	GMT Time	Comparison Control	Smooth Plot Position	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
178A	159	0526	Radar	57° 48.89'N, 152° 04.34'W	57° 48.7499'N, 152° 04.0737'W	23°	133°	0.19
183A	159	0712	--	--	Computer malfunction--did not settle on fix			
185A	159	0824	Radar	58° 28.51'N, 151° 57.91'W	58° 28.8501'N, 151° 57.5123'W	09°	031°	0.40
186A	159	0852	Radar	58° 34.74'N, 152° 02.50'W	58° 34.5311'N, 152° 02.1324'W	23°	137°	0.26
189A	159	1012	Radar	58° 43.78'N, 152° 27.07'W	58° 43.7900'N, 152° 26.7433'W	32°	089°	0.18
195A	159	1200	Visual & radar	58° 28.09'N, 153° 03.91'W	58° 28.7006'N, 153° 03.4454'W	70°	022°	0.66
200A	159	1346	Visual	58° 08.67'N, 153° 35.90'W	58° 08.7441'N, 153° 35.8824'W	22°	008°	0.10
-	159	1528	--	--	Low pass angle--not enough intervals			
205A	159	1854	Radar	57° 16.82'N, 155° 16.50'W	57° 17.3008'N, 155° 16.5959'W	60°	354°	0.38
208A	159	2040	Radar	56° 58.40'N, 155° 49.59'W	56° 59.5035'N, 155° 49.6045'W	29°	359°	0.70

TABULATION OF SATELLITE DATA

Kodiak to Adak -- (continued, page 2)

Fix No.	Julian Date	GMT Time	Comparison Control	Smooth Plot Position	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
211A	159	2228	Radar	56° 41.15'N, 156° 25.00'W	56° 41.1463'N, 156° 24.9838'W	30°	225°	0.05
215A	160	0010	Radar	56° 23.25'N, 157° 03.30'W	56° 24.6586'N, 156° 59.0938'W	72°	062°	2.70
-	160	0348	--	--	Low pass angle--not enough intervals			
231A	160	0530	--	--	Operator error--entered wrong velocity			
238A	160	0714	Three-point sextant fix	55° 31.15'N, 159° 36.90'W	55° 31.1157'N, 159° 36.4865'W	68°	103°	0.20
245A	160	0856	Visual & radar	55° 21.94'N, 160° 14.83'W	55° 22.1367'N, 160° 15.3925'W	28°	301°	0.37
247A	160	0926	Radar	55° 23.70'N, 160° 26.92'W	55° 23.4278'N, 160° 26.9470'W	11°	180°	0.26
-	160	1254	--	--	Low pass angle--not enough intervals			
268A	160	1450	Three-point sextant fix	55° 00.58'N, 162° 18.93'W	55° 00.1910'N, 162° 18.5571'W	12°	146°	0.40
278A	160	1716	--	--	Operator error--entered wrong D.R. latitude			
292A	160	2038	Three-point sextant fix	54° 22.85'N, 164° 27.24'W	54° 22.7653'N, 164° 27.2196'W	37°	193°	0.06

TABULATION OF SATELLITE DATA

Kodiak to Adak -- (continued, page 3)

Fix No.	Julian Date	GMT Time	Comparison Control	Smooth Plot Position	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
304A	160	2326	Three-point sextant fix	54° 19.12'N, 165° 40.06'W	54° 19.2334'N, 165° 39.9758'W	40°	055°	0.20
311A	161	0112	Radar	54° 11.60'N, 166° 19.75'W	54° 11.8688'N, 166° 20.4548'W	52°	275°	0.30
319A	161	0300	Visual & radar	54° 01.10'N, 166° 58.45'W	54° 01.08'N, 166° 58.12'W	10°	097°	0.18
337A	161	0720	Visual & radar	53° 30.52'N, 168° 32.25'W	53° 30.9365'N, 168° 31.4061'W	44°	053°	0.65
-	161	0834	--	--	Low pass angle--not enough intervals			
344A	161		Radar & D. R.	53° 21.01'N, 169° 07.03'W	53° 21.0160'N, 169° 07.0337'W	38°	none	0.00
350A	161	1028	Radar	53° 10.80'N, 169° 36.80'W	53° 10.9617'N, 169° 36.9255'W	15°	326°	0.20
357A	161	1216	Radar	52° 59.39'N, 170° 10.43'W	52° 59.8662'N, 170° 09.6820'W	63°	045°	0.66
365A	161	1404	Radar & D. R.	52° 48.65'N, 170° 46.50'W	52° 48.6096'N, 170° 46.2056'W	31°	109°	0.20

TABULATION OF SATELLITE DATA

Kodiak to Adak -- (continued, page 4)

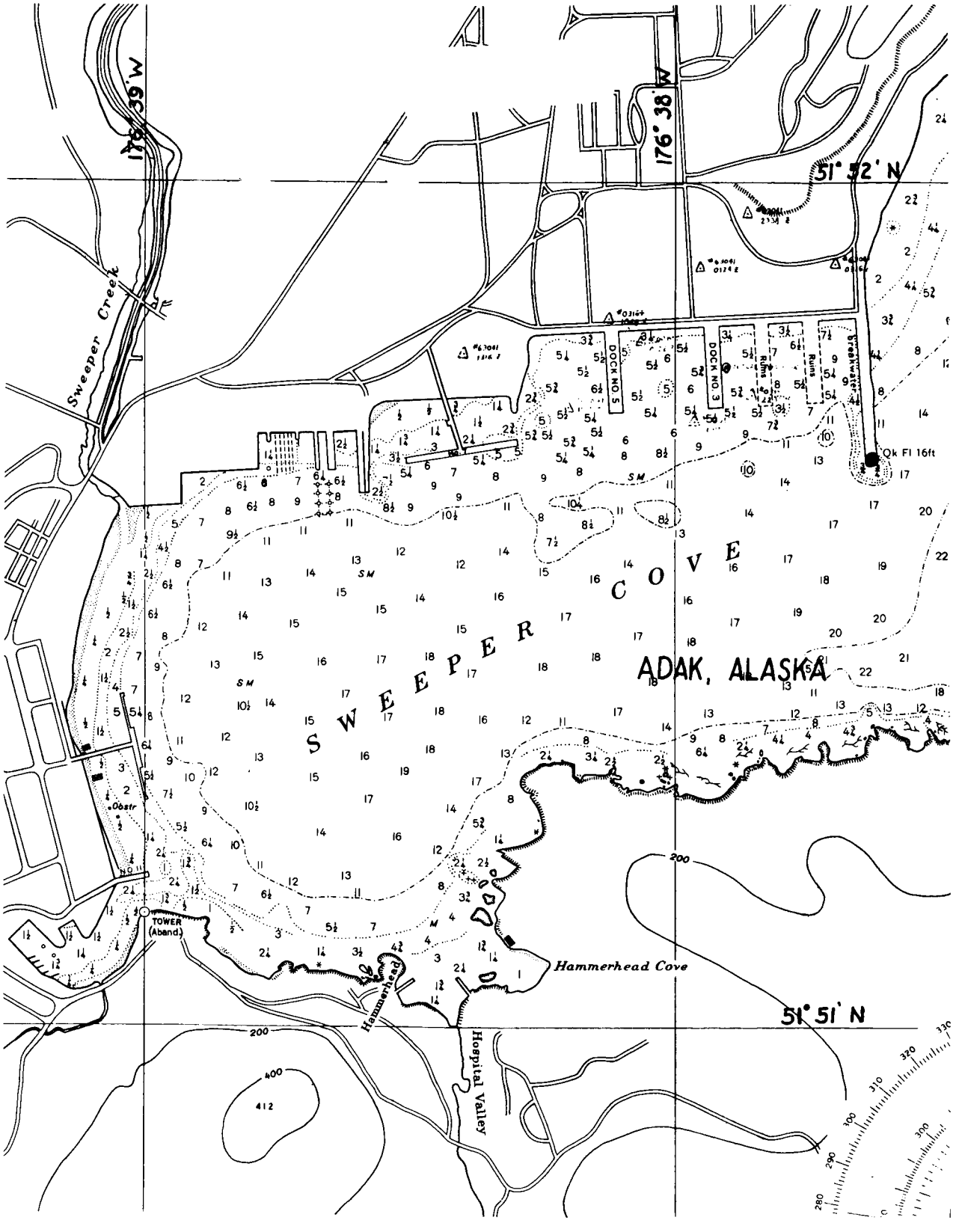
Fix No.	Julian Date	GMT Time	Comparison Control	Smooth Plot Position	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
-	161	1542	---	---	Locked on bad satellite			
-	161	1715	---	--	Low pass angle--not enough intervals			
385A	161	1900	Visual	52° 27.35'N, 172° 41.15'W	52° 27.4498'N, 172° 41.0118'W	27°	052°	0.15
392A	161	2042	Dead reckoning	52° 27.50'N, 173° 21.05'W	52° 27.7826'N, 173° 20.6544'W	60°	043°	0.32
398A	161	2228	Dead reckoning	52° 28.55'N, 174° 02.90'W	52° 28.2681'N, 174° 02.9937'W	12°	196°	0.28
-	162	0016	---	--	Computer malfunction--tape reader head			
-	162	0200	---	--	Lost lock on satellite--not enough intervals			
422A	162	0404	Three-point sextant fix	52° 08.65'N, 176° 11.93'W	52° 08.6703'N, 176° 11.7933'W	07°	085°	0.11

TABULATION OF SATELLITE DATA

Dockside, Adak, Alaska -- 11, 12 June 1965

Charted Position of PIONEER -- 51° 51.780'N, 176° 37.906'W

Satellite Number	Julian Date	GMT Time	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
03164	162	0722	51° 51.8098'N, 176° 38.0624'W	46°	287°	0.10
03164	162	1048	51° 51.8386'N, 176° 38.1259'W	09°	293°	0.15
63041	162	1136	51° 51.7316'N, 176° 38.2010'W	30°	255°	0.19
63041	162	1316	51° 51.7964'N, 176° 38.3991'W	76°	273°	0.31
63041	162	1458	Computer malfunction--only recorded one Doppler count			
03164	162	1904	51° 51.7154'N, 176° 37.9652'W	23°	209°	0.07
63041	162	2150	Low pass angle--not enough intervals			
03164	162	2232	51° 51.7464'N, 176° 37.8571'W	13°	138°	0.05
63041	162	2338	51° 51.9632'N, 176° 37.8660'W	28°	008°	0.19
63041	163	0124	51° 51.8990'N, 176° 37.9540'W	66°	346°	0.12
63041	163	0316	51° 51.9029'N, 176° 37.7001'W	14°	046°	0.18


176° 39' W
176° 38' W
51° 52' N
51° 51' N
Sweeper Creek
DOCK NO. 5
DOCK NO. 3
Ruins
Ruins
Breakwater
Qk Fl 16ft
SM
SWEEPER COVE
ADAK, ALASKA
Obstr
TOWER
(Aband)
Hammerhead
Hammerhead Cove
Hospital Valley
200
400
412
280
290
300
310
320
330

Adak, Alaska to Attu, Alaska:

The PIONEER ran from Adak to Attu on 12 and 13 June 1965, attempting thirteen satellite fixes on this leg of the cruise. Eleven of the thirteen were successful, resulting in fixes, for a percentage of 85%. One missed fix was due to low pass angle, and the other was due to operator error in data entry.

On this leg, as from Kodiak to Adak, the smooth plot was accomplished before considering the satellite data. The satellite fixes were then plotted fro comparison with the inked positions.

The average error for all fixes observed was 0.42 miles. A breakdown into averages by types of comparison control gives much the same results, though, as the Kodiak to Adak leg.

Seven fixes were compared with radar fixes, and these had an average error of 0.53 miles. Three fixes were compared with three-point sextant or visual bearing fixes, and these had an average error of only 0.19 miles. The largest error on comparison with visual fixes was 0.21 miles.

The figure of 0.19 miles average error compares very well with previous accurate underway comparisons and is believed to be the best value available on this leg.

The large errors when compared with radar control again point out that the radar fixes may not be very accurate.

No celestial observations could be made on this leg because of fog.

The azimuths of the errors were random on this leg of the trip.

At Anchor, Massacre Bay, Attu, Alaska:

While anchored in Massacre Bay, Attu, on 13 and 14 June 1965, PIONEER attempted ten satellite fixes. Successful fixes were obtained on all ten attempts, and these were compared with simultaneous three-point sextant fixes. (See section of chart and "Tabulation of Satellite Data".)

The average error of satellite positions was 0.14 miles, while the smallest error observed was 0.02 miles, and the largest was 0.29 miles. The errors were random in azimuth, and the satellite system was judged to give satisfactory results in Attu.

TABULATION OF SATELLITE DATA

Adak, Alaska to Attu, Alaska -- 12 June 1965 to 13 June 1965

Fix No.	Julian Date	GMT Time	Comparison Control	Smooth Plot Position	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
434A	163	0726	Three-point sextant fix	52° 04.60'N, 177° 01.28'W	52° 04.6137'N, 177° 01.6941'W	33°	267°	0.21
441A	163	0908	Radar	52° 05.65'N, 177° 42.60'W	52° 06.1285'N, 177° 41.8926'W	50°	045°	0.70
447A	163	1042	Radar	52° 06.42'N, 178° 20.10'W	52° 07.0096'N, 178° 18.7746'W	12°	053°	0.98
454A	163	1228	Radar	52° 07.56'N, 179° 01.30'W	52° 08.0638'N, 179° 01.0306'W	52°	018°	0.55
461A	163	1416	Radar	52° 10.07'N, 179° 44.70'W	52° 09.6731'N, 179° 45.1317'W	36°	206°	0.48
468A	163	1606	Visual & Radar	52° 07.23'N, 179° 29.89'E	52° 07.0905'N, 179° 30.6674'E	08°	104°	0.55
481A	163	1908	Visual	52° 07.74'N, 178° 18.38'E	52° 07.6499'N, 178° 18.1235'E	20°	248°	0.15
-	163	2100	---	--	Operator error--entered "W" instead of "E" longitude			
496A	163	2236	Visual & Radar	52° 19.74'N, 176° 58.20'E	52° 19.4896'N, 176° 58.3107'E	17°	171°	0.32

TABULATION OF SATELLITE DATA

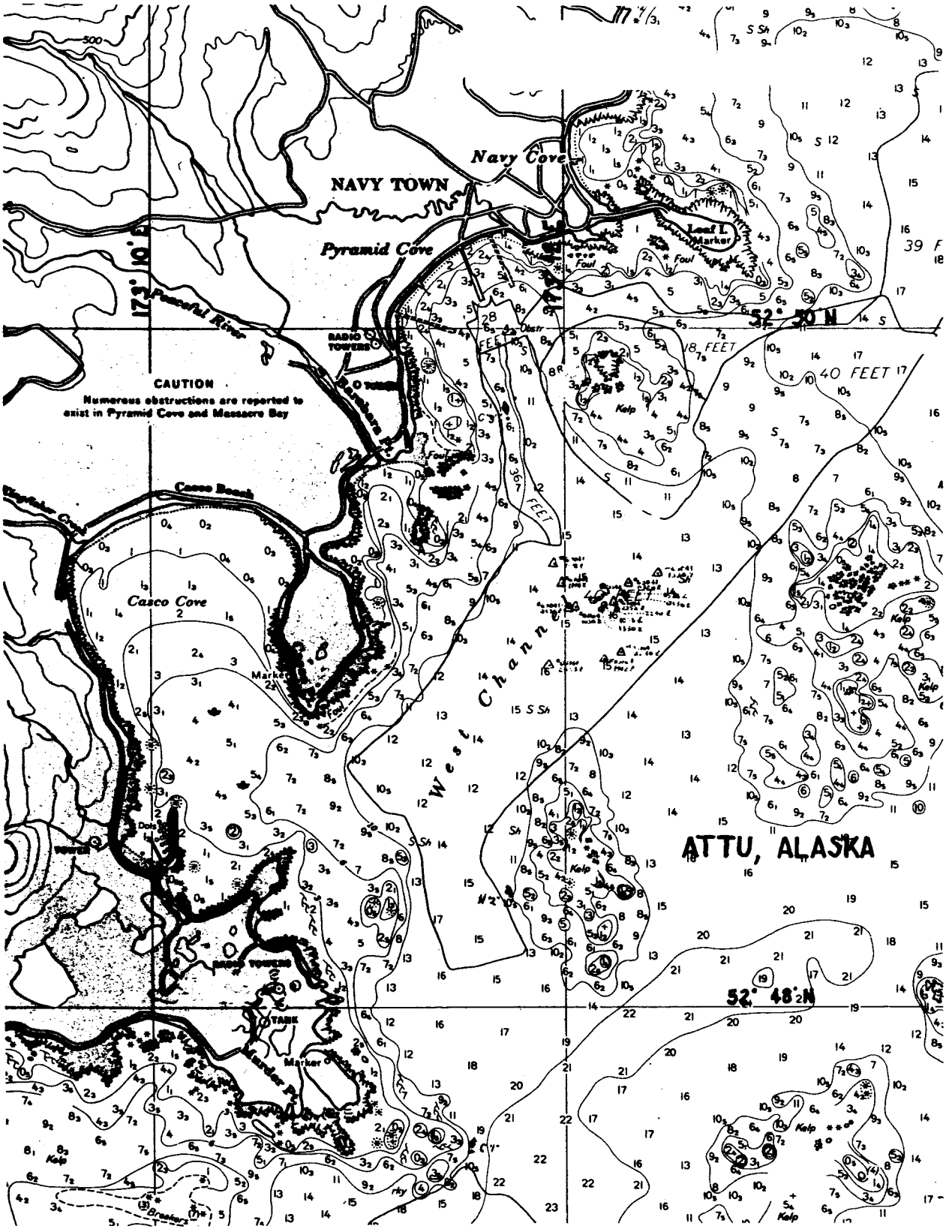
Adak to Attu -- (continued, page 2)

Fix No.	Julian Date	GMT Time	Comparison Control	Smooth Plot Position	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
504A	164	0040	Three-point Sextant fix	52° 28.05'N, 176° 10.76'E	52° 27.8573'N, 176° 10.7745'E	46°	181°	0.20
511A	164	0226	Radar	52° 34.00'N, 175° 29.30'E	52° 33.9640'N, 175° 29.4896'E	43°	287°	0.10
518A	164	0416	Dead reckoning	52° 41.15'N, 174° 47.70'E	52° 41.0538'N, 174° 47.0984'E	09°	261°	0.40
-	164	0541	--	--	Low pass angle--not enough intervals			

TABULATION OF SATELLITE DATA

At Anchor, Massacre Bay, Attu, Alaska -- 13, 14 June 1965

Satellite Number	Julian Date	Time GMT	Charted Position of PIONEER	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
03164	164	1056	52° 49.19'N, 173° 12.19'E	52° 49.1822'N, 173° 12.0586'E	09°	265°	0.08
63041	164	1144	52° 49.19'N, 173° 12.14'E	52° 49.2476'N, 173° 11.9865'E	26°	300°	0.11
63041	164	1330	52° 49.17'N, 173° 12.18'E	52° 49.2772'N, 173° 12.4462'E	71°	057°	0.19
63041	164	1518	52° 49.17'N, 173° 12.18'E	52° 49.3048'N, 173° 11.9483'E	16°	315°	0.19
03164	164	1912	52° 49.17'N, 173° 12.18'E	52° 49.0260'N, 173° 12.1908'E	25°	177°	0.15
03164	164	2054	52° 49.24'N, 173° 12.19'E	52° 49.0048'N, 173° 11.9212'E	65°	213°	0.29
03164	164	2240	52° 49.17'N, 173° 12.26'E	52° 49.0472'N, 173° 12.2682'E	12°	174°	0.13
63041	164	2352	52° 49.17'N, 173° 12.26'E	52° 49.1950'N, 173° 12.2366'E	22°	334°	0.02
63041	165	0136	52° 49.21'N, 173° 12.29'E	52° 49.1769'N 173° 12.0201'E	79°	258°	0.17
63041	165	0328	52° 49.22'N, 173° 12.28'E	52° 49.2495'N, 173° 12.3028'E	20°	022°	0.03


Navy Cove
NAVY TOWN
Pyramid Cove
Peaceful River
RADIO TOWERS
CAUTION
Numerous obstructions are reported to exist in Pyramid Cove and Massacre Bay
Casco Beach
Casco Cove
West Channel
Leaf L. Marker
Foul
Kelp
36 FEET
18 FEET
40 FEET
52° 50'N
52° 48'2N
ATTU, ALASKA
TANK
Marker

Attu, Alaska to Midway Island:

The PIONEER departed Attu, Alaska on 14 June 1965 and arrived at Midway Island on 20 June 1965, having completed a trackline and several coring stations enroute. Seventy-one satellite fixes were attempted on this leg and fifty-eight were obtained successfully; 82% of the fixes attempted were successful.

Of the thirteen fixes not obtained, five were due to computer malfunctions; three of thse due probably to tape reader head problems, and two of these due probably to sudden voltage fluctuations in the power supply, which was caused by the heavy winch used on coring stations. Four fixes were missed due to operator errors in entering data and manipulating the computer. Two were due to locking onto a faulty satellite and not having enough intervals left on the good satellite after relocking. One missed fix was due to a low pass angle, and one was due to unknown causes--the printout tape was not saved and no explanation was made on the computation form.

On this leg of the trip, as on all the remaining legs, the satellite fixes were used in smooth-plotting, because it is felt that trackline accuracy was gained. The satellite fixes had proved to be very accurate up to this point, and the standard means of control were not available with great accuracy. This is particularly true since both Loran C sets had been out of service since the beginning of the cruise and therefore unavailable for comparative purposes. Generally cloudy weather also precluded many astronomical sights. The Loran A was again quite variable, while nonetheless comparing in a general way with the satellite fixes.

Twenty-seven of the fifty-eight fixes obtained were not used in the smooth-plot, being eliminated by small errors in the speed and course analysis of fixes over a long distance. The average amount by which these were rejected, or error relative to the smooth-plotted position, is 0.27 miles, and the azimuth of these errors was random. The largest amount by which any were rejected was 1.05 miles, on a pass angle of 78°.

One sun line was obtained for direct comparison, and the satellite fix had an error of 0.05 miles when compared with this line.

The satellite fixes which were used in the smooth plot were compared to what Loran A was available, and the average of these comparisons is 0.51 miles. However, as mentioned before, this is not believed to be a valid expression of satellite fix accuracy, but more so of Loran A accuracy.

The satellite system compared very well with all means of checking on this leg of the cruise.

Dockside, Midway Island:

While moored at Midway Island on 20 June 1965 and 21 June 1965, PIONEER attempted eight satellite fixes and obtained seven. One

was missed due to operator error in entering data.

The accuracy obtained (See attached section of chart and "Tabulation of Satellite Data") is somewhat different than previous results. While the fixes group about a single point as closely as before, the point at Midway does not appear to be the charted position of the ship. The average error is larger than any previously obtained, and the azimuths of the errors are not random.

The average of the errors is 0.24 miles; the smallest error is 0.06 miles, but the largest error is 0.38 miles. The azimuths of the errors are all in a northerly direction, no satellite fix being south of the ship's charted position. These results are quite different than any obtained previously, and several hypotheses may be advanced in attempts to explain these results.

The first hypothesis is that the Navy Satellite Navigation System is subject to special errors in this part of the earth. This is not known aboard the PIONEER, but does not seem to be a tenable theory in view of the nature of the system itself.

The second hypothesis is that PIONEER's gear was performing improperly at the time. This is not believed to be true, because of the extremely typical grouping of the satellite fixes. They group about a single point as closely as the in-port fixes previously taken in any port, even if this point is not the charted position of the ship.

The third hypothesis is that the satellites had been programmed with slightly erroneous orbital data during this period. This is entirely unknown at present, but if the fixes were to be recomputed at a later date using actual orbital parameters rather than predicted, the effect of these errors might be determined.

The fourth hypothesis is that the charted position of Midway Island is not its true position. This is felt to be possible due to the island's isolated location and consequent lack of interconnecting geodetic triangulation. Isolated geodetic astronomical positions may also be in error due to lack of adequate gravity development in an area. There was, however, no information aboard to indicate the controlling datum for the charts, and this was consequently assumed to be the North American Datum.

By averaging all satellite position determinations it is found that the position of the ship, as determined by the satellite system is 28° 13.084' N., 177° 22.123' W. This is a difference of 0.204' north in latitude, and 0.046' west in longitude. This is an approximate estimation of the possible error in position of the island, if this error is indeed found to exist.

The Navy Satellite Navigation System was accurate in that it settled as closely about a single point as could be expected from past results. Therefore the evaluation is favorable at Midway Island, even though the system did not settle on the ship's charted position. Further analysis of results and reconciliation of this difference should be attempted.

TABULATION OF SATELLITE DATA

Attu, Alaska to Midway Island -- 14 June 1965 to 20 June 1965

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
537A	165	0918	None	--	51° 56.2130'N, 173° 29.3300'E	65°	--	0.00
541A	165	1242	None	---	51° 46.5300'N, 173° 39.4500'E	45°	--	0.00
-	165	1424	--	--	Operator error--pushed "Reset" and "Start" at wrong time			
-	165	1618	--	--	Computer malfunction--power surge from deep-sea winch on oceo station			
-	165	1922	--	--	Computer malfunction--would not settle on fix			
-	165	2058	--	--	Computer malfunction--power surge from deep-sea winch on oceo station			
549A	165	2244	None	--	51° 55.2074'N, 173° 55.6127'E	16°	--	0.00
553A	166	0050	Loran A	51° 28.1'N, 174° 08.0'E	51° 29.1827'N, 174° 08.0319'E	55°	030°	1.10
558A	166	0238	Loran A	Only one rate plots	51° 11.1779'N, 174° 12.0815'E	33°	120°	0.40
561A	166	0430	Loran A	Only one rate plots	50° 52.4801'N, 174° 11.6800'E	05°	--	0.00

TABULATION OF SATELLITE DATA

Attu to Midway -- (continued, page 2)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)	
565A	166	0740	Loran A	Only one rate plots	50° 14.4768'N, 174° 14.4304'E	26°	120°	0.70	
-	166	0914	--	--	Computer malfunction--no explanation on tape				
-	166	1058	--	--	Operator error--entered wrong time				
570A	166	1158	Loran A	Only one rate plots	49° 25.6709'N, 174° 41.2449'E	26°	115°	0.45	
573A	166	1346	Smooth plot	49° 04.9'N, 174° 50.3'E	49° 04.6631'N, 174° 49.9603'E	65°	241°	0.20	(*)
-	166	1526	--	--	Locked on bad satellite--then not enough intervals on good satellite				
581A	166	1918	Smooth plot	47° 48.0'N, 175° 20.2'E	47° 48.1020'N, 175° 19.9310'E	20°	292°	0.20	(*)
583A	166	2100	Loran A	Only one rate plots	47° 24.8410'N, 175° 30.3750'E	68°	105°	0.10	
587A	167	0004	Loran A	Only one rate plots	46° 42.2433'N, 175° 50.6347'E	30°	105°	0.10	

(*) -- Satellite fix not used in final smooth plot of trackline.

TABULATION OF SATELLITE DATA

Attu to Midway -- (continued, page 3)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)	
590A	167	0150	Smooth plot	46° 20.2'N, 175° 59.5'E	46° 19.9804'N, 175° 59.2745'E	50°	202°	0.25	(*)
591A	167	0342	Smooth plot	46° 19.3'N, 176° 00.9'E	46° 19.2590'N, 176° 01.5108'E	08°	107°	0.40	(*)
594A	167	0744	Loran A	Only one rate plots	46° 17.1300'N, 176° 04.1490'E	32°	-	0.00	
597A	167	0928	Smooth plot	45° 59.5'N, 176° 10.4'E	45° 59.3540'N, 176° 10.4830'E	41°	169°	0.15	(*)
600A	167	1112	Smooth plot	45° 41.1'N, 176° 17.3'E	45° 41.2140'N, 176° 17.3360'E	13°	350°	0.15	(*)
602A	167	1258	Smooth plot	45° 24.1'N, 176° 24.8'E	45° 24.1306'N, 176° 24.5568'E	73°	291°	0.10	(*)
604A	167	1446	None	--	45° 06.6893'N, 176° 32.7873'E	20°	-	0.00	
609A	167	1922	Loran A	Only one rate plots	44° 38.4322'N, 176° 45.4665'E	22°	097°	1.00	

(*) -- Satellite fix not used in final smooth plot of trackline.

TABULATION OF SATELLITE DATA

Attu to Midway -- (continued, page 4)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)	
610A	167	2102	Smooth plot	44° 36.5'N, 176° 45.2'E	44° 36.2507'N, 176° 45.1113'E	49°	201°	0.23	(*)
611A	167	2250	Smooth plot	44° 34.6'N, 176° 45.8'E	44° 34.4321'N, 176° 45.9023'E	06°	152°	0.18	(•)
612A	167	2318	Smooth plot	44° 34.2'N, 176° 45.7'E	44° 34.2317'N, 176° 45.8646'E	15°	090°	0.08	(•)
614A	168	0102	Loran A	Only one rate plots	44° 33.1617'N, 176° 45.1125'E	83°	096°	0.12	
615A	168	0254	Loran A	Only one rate plots	44° 30.8599'N, 176° 45.2276'E	18°	276°	0.60	
-	168	0602	--	--	Low pass angle--not enough intervals				
622A	168	0748	Loran A	Only one rate plots	43° 15.2228'N, 177° 08.3460'E	38°	095°	0.95	
628A	168	0930	Smooth plot	42° 59.4'N, 177° 20.2'E	42° 59.2600'N, 177° 20.2900'E	32°	160°	0.20	(•)
629A	168	1028	Smooth plot	42° 58.8'N, 177° 20.0'E	42° 58.6280'N, 177° 20.1280'E	03°	156°	0.15	(*)

(*) -- Satellite fix not used in final smooth plot of trackline.

TABULATION OF SATELLITE DATA

Attu to Midway -- (continued, page 5)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az.of Error	Error (naut. mi.)	
631A	168	1212	None	--	42° 57.9476'N, 177° 19.7506'E	39°	-	0.00	
632A	168	1400	None	--	42° 57.1443'N, 177° 19.2178'E	35°	-	0.00	
638A	168	1926	Smooth plot	41° 59.2'N, 177° 47.6'E	41° 59.4510'N, 177° 47.0250'E	26°	332°	0.28	(*)
641A	168	2108	Smooth plot	41° 36.4'N, 177° 57.0'E	41° 36.6330'N, 177° 57.0780'E	41°	005°	0.20	(*)
644A	168	2254	Smooth plot	41° 14.0'N, 178° 04.4'E	41° 14.0627'N, 178° 04.0918'E	02°	289°	0.30	(*)
646A	169	0014	Smooth plot	40° 55.3'N, 178° 10.4'E	40° 55.0051'N, 178° 10.5353'E	43°	170°	0.30	(*)
648A	169	0202	Smooth plot	40° 30.3'N, 178° 19.8'E	40° 30.1607'N, 178° 19.7146'E	30°	185°	0.12	(*)
-	169	0604	--	---	Locked on bad satellite instead of good				

(*) -- Satellite fix not used in final smooth plot of trackline.

TABULATION OF SATELLITE DATA

Attu to Midway -- (continued, page 6)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)	
652A	169	0752	Loran A	Only one rate plots	40° 08.3760'N, 178° 24.4460'E	45°	270°	0.90	
-	169	0930	--	---	No fix--no explanation and tape not saved				
658A	169	1128	None	--	39° 40.8652'N, 178° 35.7117'E	19°	-	0.00	
659A	169	1316	Loran A	Only one rate plots	39° 39.1763'N, 178° 34.5871'E	65°	112°	0.60	
661A	169	1504	Loran A	Only one rate plots	39° 38.3026'N, 178° 32.9597'E	08°	090°	0.65	
666A	169	1928	Smooth plot	39° 05.6'N, 178° 45.9'E	39° 05.5286'N, 178° 45.5998'E	30°	256°	0.15	(*)
669A	169	2108	None	--	38° 44.6286'N, 178° 55.0411'E	31°	-	0.00	
672A	169	2330	None	--	38° 14.9804'N, 179° 07.8716'E	21°	-	0.00	
675A	170	0114	None	--	37° 52.7371'N, 179° 16.8744'E	59°	-	0.00	

(*) -- Satellite fix not used in final smooth plot of trackline.

TABULATION OF SATELLITE DATA

Attu to Midway -- (continued, page 7)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)	
678A	170	0306	Smooth plot	37° 29.1'N, 179° 26.2'E	37° 28.4711'N, 179° 25.6902'E	06°	213°	0.70	(*)
-	170	0610	--	--	Computer malfunction--stopped in computations				
-	170	0800	--	--	Operator error--entered wrong data				
685A	170	0942	Smooth plot	36° 01.1'N, 179° 59.0'E	36° 01.5810'N, 179° 59.2860'E	16°	015°	0.40	(*)
687A	170	1046	Smooth plot	35° 46.8'N, 179° 56.8'W	35° 46.8440'N, 179° 56.9156'W	07°	290°	0.10	(*)
689A	170	1230	Smooth plot	35° 22.9'N, 179° 49.6'W	35° 23.0267'N, 179° 49.6696'W	63°	315°	0.08	(*)
692A	170	1418	None	--	34° 58.1168'N, 179° 42.2133'W	15°	-	0.00	
698A	170	1930	None	--	33° 46.4053'N, 179° 17.7955'W	35°	-	0.00	
701A	170	2112	Smooth plot	33° 23.3'N, 179° 10.2'W	33° 23.6169'N, 179° 10.2649'W	22°	346°	0.27	(*)

(*) -- Satellite fix not used in final smooth plot of trackline.

TABULATION OF SATELLITE DATA

Attu to Midway -- (continued, page 8)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)	
703A	170	2244	Sun line	One line only	33° 02.3163'N, 179° 03.9783'W	07°	117°	0.05	
-	171	0026	---	--	Operator error--entered wrong data				
709A	171	0214	None	--	32° 16.4381'N, 178° 48.5812'W	14°	-	0.00	
714A	171	0622	Smooth plot	31° 21.7'N, 178° 29.6'W	31° 21.7650'N, 178° 29.4960'W	08°	072°	0.06	(*)
716A	171	0802	Smooth plot	30° 58.7'N, 178° 22.1'W	30° 59.0316'N, 178° 23.2553'W	78°	289°	1.05	(*
718A	171	0946	Smooth plot	30° 34.7'N, 178° 13.9'W	30° 34.6933'N, 178° 13.4446'W	09°	088°	0.30	(*)
721A	171	1144	Loran A	One rate only	30° 07.7184'N, 178° 05.7453'W	34°	042°	0.35	
724A	171	1336	Loran A	One rate only	29° 40.5399'N, 177° 58.0834'W	29°	221°	0.60	
731A	171	1932	Smooth plot	28° 20.9'N, 177° 35.1'W	28° 21.4764'N, 177° 34.9495'W	43°	015°	0.58	(*)

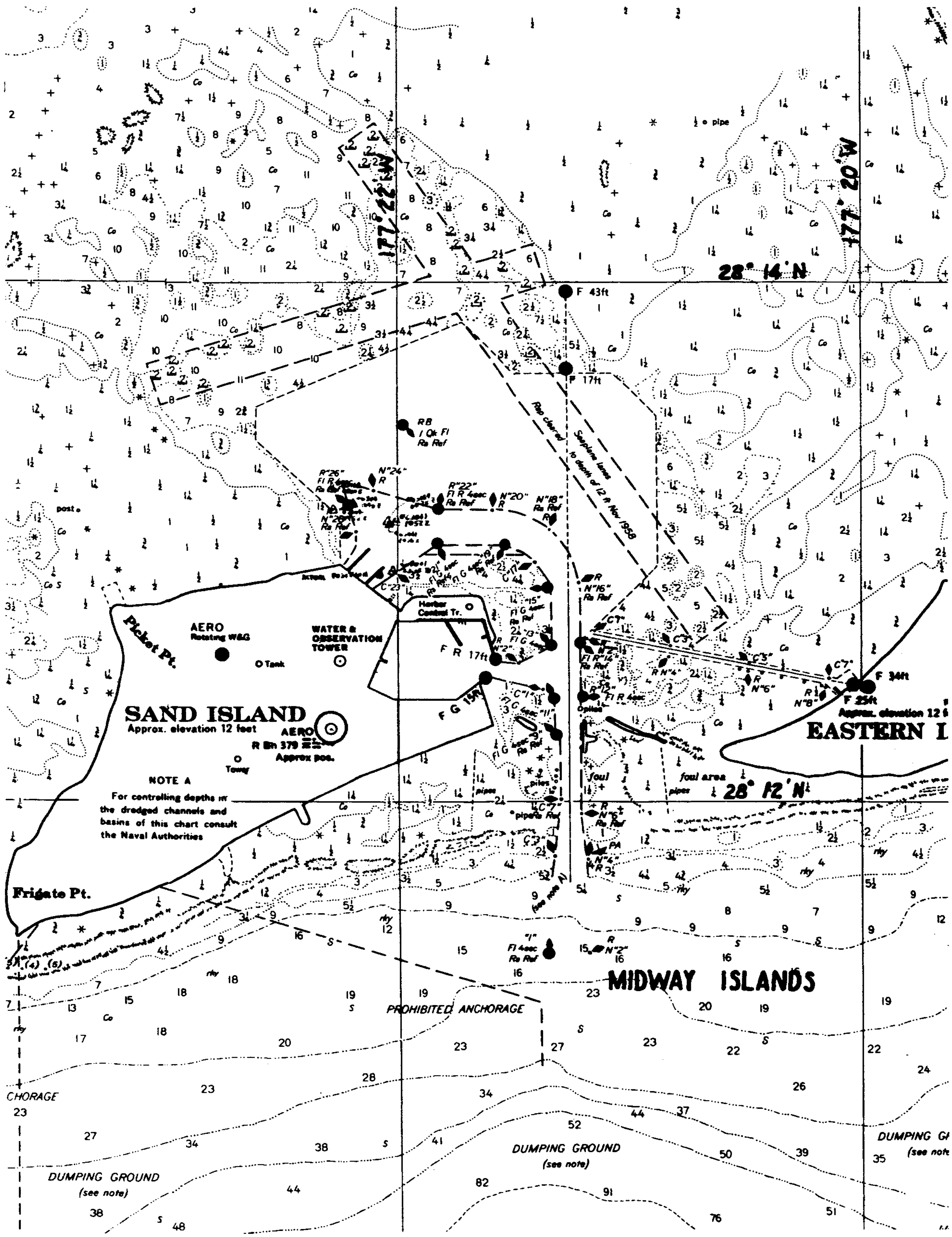
(*) -- Satellite fix not used in final smooth plot of trackline.

TABULATION OF SATELLITE DATA

Dockside, Midway Islands -- 20, 21 June 1965

Charted Position of PIONEER -- 28° 12.880'N, 177° 22.077'W

Satellite Number	Julian Date	GMT Time	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
63041	171	2338	28° 12.8874'N, 177° 22.0129'W	33°	075°	0.06
63041	172	0120	Operator error--time entered incorrectly			
03164	172	0628	28° 13.0766'N, 177° 22.0408'W	08°	010°	0.21
03164	172	0808	28° 13.2113'N, 177° 22.2856'W	72°	332°	0.38
03164	172	0952	28° 13.1288'N, 177° 22.2828'W	13°	325°	0.31
63041	172	1052	28° 13.0741'N, 177° 22.0053'W	14°	018°	0.22
63041	172	1246	28° 13.1453'N, 177° 22.1945'W	61°	340°	0.29
63041	172	1436	28° 13.0626'N, 177° 22.0386'W	04°	012°	0.19


SAND ISLAND
Approx. elevation 12 feet
EASTERN I
MIDWAY ISLANDS
Picket Pt.
Frigate Pt.
AERO
Rotating W&G
WATER & OBSERVATION TOWER
Tank
Harbor Control Tr.
NOTE A
For controlling depths in the dredged channels and basins of this chart consult the Naval Authorities
28° 14' N
28° 12' N
177° 22' W
177° 20' W
F 43ft
F 17ft
F 34ft
F 25ft
F R 17ft
F G 15ft
foul area
PROHIBITED ANCHORAGE
DUMPING GROUND
(see note)
CHORAGE

Midway Island to Johnston Island:

The PIONEER ran from Midway Island to Johnston Island from 21 June 1965 to 24 June 1965, with coring stations enroute. During this time, twenty-six satellite fixes were attempted and twenty-five actually obtained. One was not obtained because the satellite's pass angle was too low. This is a percentage successful of 96%.

Accuracy comparison was made with Loran C, Loran A, and a sun line. Eleven satellite fixes were obtained for comparison with Loran C, and these had an average error of 0.33 miles. The largest error observed was 1.05 miles, this in comparison with a sun line also. Twelve satellite fixes were compared with Loran A or a combination of Loran A and Loran C, and these had an average error of 0.49 miles. The largest error observed was 1.30 miles, but this is believed due to the variations in the Loran A system. The Loran C had a possible variance and inaccuracy also, due to the set having just been repaired. The Electronics Department had been working on the Loran C ever since the beginning of the cruise, and had just been successful in making repairs to it.

The azimuths of these errors had no observable trend and are considered random for both means of comparison control.

The satellite system is therefore judged to have performed satisfactorily on this leg of the cruise.

Dockside, Johnston Island:

On 24 and 25 June 1965, the PIONEER obtained three satellite fixes while moored at Johnston Island, using sextant angles for comparison control.

The average error of these fixes was 0.20 miles, and as at Midway the azimuths were not random. At Johnston Island, however, the errors were all in a southeasterly direction.

It is realized that three satellite fixes are not enough of a sampling to make conclusions. Perhaps, though, the fixes at Johnston Island were subject to similar influences as those at Midway.

The satellite fixes grouped as closely as could be expected, but in a different location than the ship's charted position, and the system is judged to have performed satisfactorily at Johnston Island also.

TABULATION OF SATELLITE DATA

Midway Island to Johnston Island -- 21 June 1965 to 24 June 1965

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
-	172	1754	--	--	Low pass angle--not enough intervals			
741A	172	1936	None	--	27° 53.4615'N, 177° 05.6333'W	54°	-	0.00
745A	172	2120	None	--	27° 34.7087'N, 176° 49.6668'W	11°	-	0.00
748A	172	2256	Loran A	One rate only	27° 17.0459'N, 176° 34.9482'W	14°	036°	0.48
751A	173	0038	Loran A	One rate only	27° 00.9319'N, 176° 21.4157'W	64°	217°	0.09
759A	173	0630	Loran C	26° 00.3'N, 175° 41.9'W	26° 00.7522'N, 175° 41.3679'W	15°	045°	0.50
764A	173	0812	Loran A + C	25° 42.5'N, 175° 26.9'W	25° 42.6629'N, 175° 26.4822'W	48°	051°	0.42
772A	173	1200	Loran C	One rate only	24° 56.4388'N, 174° 54.8563'W	64°	322°	0.40
776A	173	1348	Loran A + C	24° 36.5'N, 174° 37.3'W	24° 36.5176'N, 174° 37.8915'W	12°	269°	0.55

TABULATION OF SATELLITE DATA

Midway to Johnston -- (continued, page 2)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
783A	173	1800	Loran C	23° 51.9'N, 173° 57.5'W	23° 51.9242'N, 173° 57.4527'W	06°	-	0.00
786A	173	1936	Loran C	23° 35.2'N, 173° 42.5'W	23° 35.1584'N, 173° 42.9216'W	68°	264°	0.40
790A	173	2124	Loran C	23° 11.9'N, 173° 25.6'W	23° 11.6468'N, 173° 25.5099'W	04°	165°	0.35
795A	173	2352	Loran C	22° 40.4'N, 173° 01.7'W	22° 40.2235'N, 173° 01.5759'W	69°	157°	0.26
799A	174	0140	Loran C, Sun line	22° 17.2'N, 172° 45.6'W	22° 16.6888'N, 172° 46.4596'W	11°	229°	1.05
802A	174	0634	Loran C	One rate only	22° 17.1681'N, 172° 50.1614'W	24°	145°	0.06
807A	174	0816	Loran C	One rate only	22° 04.5852'N, 172° 40.4295'W	31°	325°	0.05
814A	174	1114	Loran A	One rate only	21° 30.6944'N, 172° 14.3210'W	35°	-	0.00

TABULATION OF SATELLITE DATA

Midway to Johnston -- (continued, pg. 3)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
818A	174	1302	Loran A	One rate only	21° 10.7787'N, 171° 59.9402'W	23°	198°	0.08
828A	174	1800	Loran A + C	20° 14.5'N, 171° 07.9'W	20° 14.6293'N, 171° 07.7564'W	10°	065°	0.13
830A	174	1940	Loran C	19° 51.8'N, 170° 51.4'W	19° 52.1079'N, 170° 51.5092'W	56°	332°	0.48
833A	174	2306	Loran C	One rate only	19° 48.5504'N, 170° 52.8399'W	32°	149°	0.10
836A	175	0050	Loran A + C	19° 38.3'N, 170° 49.2'W	19° 38.8483'N, 170° 48.4411'W	26°	050°	0.75
846A	175	0640	Loran A	18° 35.4'N, 170° 19.6'W	18° 35.4400'N, 170° 20.4763'W	36°	275°	0.94
850A	175	0822	Loran A	18° 16.5'N, 170° 13.5'W	18° 16.4184'N, 170° 12.6914'W	20°	091°	0.80
854A	175	1030	Loran A	17° 52.6'N, 170° 02.6'W	17° 52.6318'N, 170° 02.9773'W	17°	270°	0.35
857A	175	1216	Loran A	17° 33.2'N, 169° 56.7'W	17° 33.2328'N, 169° 55.3219'W	45°	092°	1.30

TABULATION OF SATELLITE DATA

Dockside, Johnston Island -- 24, 25 June 1965

Charted Position of PIONEER -- 16° 44.22'N, 169° 31.96'W

Satellite Number	Julian Date	GMT Time	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
03164	175	1942	16° 43.9914'N, 169° 31.8262'W	59°	149°	0.26
63041	175	2218	16° 44.2040'N, 169° 31.7368'W	13°	095°	0.23
63041	176	0002	16° 44.1456'N, 169° 31.8799'W	56°	133°	0.11

Johnston Island to Honolulu, Hawaii:

The PIONEER ran from Johnston Island to Honolulu on 25 and 26 June 1965 and attempted fourteen satellite fixes on the way. Twelve of these were successful, for a percentage of 86%.

Two fixes were missed, one because of a computer malfunction and the other because of low pass angle.

Of the twelve fixes obtained, three were obviously very bad, having errors of 4.75 miles, 2.50 miles, and 2.03 miles. The cause of these erroneous fixes is not known, but is perhaps due to the computer program deficiency called "scaling".

"Scaling" is a program deficiency only, and has been corrected on a later computer program tape. As explained by APL, "scaling" happens only between the latitudes of 30° N. and 30° S., and does not apply to all fixes in these latitudes. For a few satellite passes, however, it may cause the computer to compute an erroneous fix. This was not detected even as a possibility very often on OPR-457, but is believed to have applied to a few fixes.

The remaining nine of the twelve fixes were compared with Loran A and Loran C, and had an average error of 0.42 miles. The errors do not seem to be random in azimuth, but fall in a generally easterly direction.

It is not known with certainty what the cause of this is, but the hypothesis advanced in the section of this report on accuracy on in-port fixes in Honolulu, Hawaii may be related to this effect.

The errors, although not random with respect to the Loran, were such that they could not be detected in the smooth plot. Therefore the satellite fixes were utilized on the smooth-plot on this leg of the cruise, and the system performance was rated very good.

Dockside, Honolulu, Hawaii:

The PIONEER was moored in Honolulu, Hawaii from 27 June 1965 to 30 June 1965, first at Pier 40, Army Transportation Terminal and then she was moved to Pier 39, Army Transportation Terminal on 29 June 1965, remaining there until departing. In both locations her position was determined by visual means and by sextant angles.

During this time the ship attempted sixteen satellite fixes and obtained fourteen, a successful percentage of 88%. Two fixes were missed, one due to computer malfunction and the other to low pass angle.

The fourteen fixes obtained were subject to very unusual errors with respect to the charted positions of the ship, both in magnitude of errors and azimuths of errors. The errors had an average magnitude of 0.31 miles, and ranged from a low of 0.17 miles to a high of 0.38 miles. This alone would be quite unusual with respect to previous in-port results, but the fact that the azimuths on all fourteen fixes are nearly constant is even more unusual. The number of fixes obtained is believed in this instance to be large enough to lend serious credence to these results.

The same four hypotheses which were considered in the fixes taken at Midway Island are also to be considered at Honolulu, Hawaii.

The first, that the system itself is subject to special errors in this part of the earth, is again not considered plausible because of the nature of the system.

The second, that the PIONEER's gear may have been malfunctioning, does not seem possible in view of the consistency of the results.

The third, that the satellites may have been injected with erroneous data, is possible, but does not seem probable in view of the period of time over which these results were obtained. The satellites are re-injected with data approximately every twelve hours, and it is not probable that they would be injected with equally erroneous data for four consecutive days. However, the fixes should be recomputed using actual orbital data for this period, in order to eliminate this possibility.

The fourth hypothesis, that the Hawaiian Islands are not actually charted in their correct location on the earth may be the one which is not easily rejected. This is as possible as it was at Midway Island for the same reasons: Lack of interconnecting geodetic triangulation, and geodetic astronomical positions being affected by deflection of the vertical.

There are two supporting pieces of evidence for this hypothesis. The first is the series of fixes obtained in Honolulu. The second piece of evidence is in the trackline run from Honolulu to San Francisco using satellite control. The Loran C on this trackline was received until approximately 500 miles out of Hawaii on the trackline, and the SH4X rate was noticed to be plotting rather consistently north of the trackline as plotted using satellite fixes. Rate SH4X has its master station on Johnston Island and its slave station on the island of Hawaii. The lines of position are roughly parallel to the trackline, and were observed to be slightly north of the satellite trackline near Oahu. This distance increased as the distance from the Hawaiian Islands became greater, finally becoming consistently approximately a mile north of the trackline in the vicinity of 28° N. latitude, and 148° W. longitude.

This is viewed as supporting evidence because of the consistency of the Loran C readings; and because of the fact that if the Hawaii end of the Johnston-Hawaii SH4X baseline were moved as shown by the satellite fixes in Honolulu, it would have the effect of moving the lines of position of SH4X so that they would coincide very closely with the satellite trackline, on the North American Datum.

These two pieces of evidence, viewed together, make further investigation of this discrepancy necessary.

By averaging the satellite fixes taken in Honolulu at Pier 40, the position of the ship would be 21° 19.098' N., 157° 52.898' W., on the North American Datum. This is a difference in position of minus 0.266' N., and minus 0.190' W.

It must be realized that the Hawaiian Islands are charted on the Old Hawaiian Datum, while the satellite fixes were reduced to the North American Datum. Therefore, as such, the islandsare not actually charted in an incorrect location as the latitudes and longitudes are on a local datum. They may be charted in a different location than they would be if the North American Datum were extended to the Hawaiian Islands. This extension maybe desireable, since both datums are based on the same reference spheroid, Clarke's Spheroid of 1866. This may be the first time such an extension has been possible, even approximately, but final precise interconnection will have to be done by other means, such as satellite trangulation. These results may provide an approximate tie between the Old Hawaiian Datum and the North American Datum. This may be of some help in furthering the estimate of the earth's actual shape.

The satellite system performed well in its consistency of position with regard to a point, even though this point was not the charted position of the PIONEER. The evaluation is therefore favorable for the system in Honolulu.

TABULATION OF SATELLITE DATA

Johnston Island to Honolulu, Hawaii -- 25 June 1965 to 26 June 1965

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)	
887A	176	0826	Loran A	17° 20.7'N, 167° 51.7'W	17° 21.3372'N, 167° 51.5978'W	12°	012°	0.75	
892A	176	1128	Smooth plot, Loran A	17° 41.0'N, 167° 04.4'W	17° 41.3098'N, 166° 59.9523'W	73°	087°	4.75	(*)
905A	176	1804	Loran A	18° 23.7'N, 165° 23.2'W	18° 24.0272'N, 165° 22.9962'W	27°	029°	0.30	
-	176	1942	--	--	Computer malfunction--would not settle on fix				
914A	176	2136	D. R. between Loran A	18° 46.0'N, 164° 26.9'W	18° 46.0422'N, 164° 26.9438'W	07°	-	0.00	
918A	176	2316	Loran A	18° 56.1'N, 163° 59.3'W	18° 55.9532'N, 163° 58.8298'W	77°	108°	0.55	
929A	177	0506	Loran A & C	19° 35.8'N, 162° 23.0'W	19° 35.8409'N, 162° 22.9514'W	08°	-	0.00	
934A	177	0646	Loran A	19° 47.0'N, 161° 56.4'W	19° 46.9855'N, 161° 55.7012'W	63°	090°	0.70	
-	177	0826	--	--	Low pass angle--not enough intervals				

(*) -- Satellite fix not used in final smooth plot.

TABULATION OF SATELLITE DATA

Johnston to Honolulu -- (continued, page 2)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)	
943A	177	1042	Smooth plot	20° 10.1'N, 160° 49.4'W	20° 09.5948'N, 160° 51.9834'W	59°	256°	2.50	(*)
947A	177	1230	Smooth plot, Loran A & C	20° 21.2'N, 160° 19.8'W	20° 21.6167'N, 160° 17.5992'W	12°	078°	2.03	(*)
959A	177	1816	Loran A + C	20° 57.2'N, 158° 53.6'W	20° 57.2341'N, 158° 53.6143'W	52°	-	0.00	
963A	177	1956	Loran A & C	21° 05.4'N, 158° 37.3'W	21° 05.3700'N, 158° 37.0240'W	08°	089°	0.20	
969A	177	2232	Visual, Loran C	21° 15.6'N, 158° 08.9'W	21° 15.2406'N, 158° 07.5986'W	60°	107°	1.25	

(*) -- Satellite fix not used in final smooth plot.

TABULATION OF SATELLITE DATA

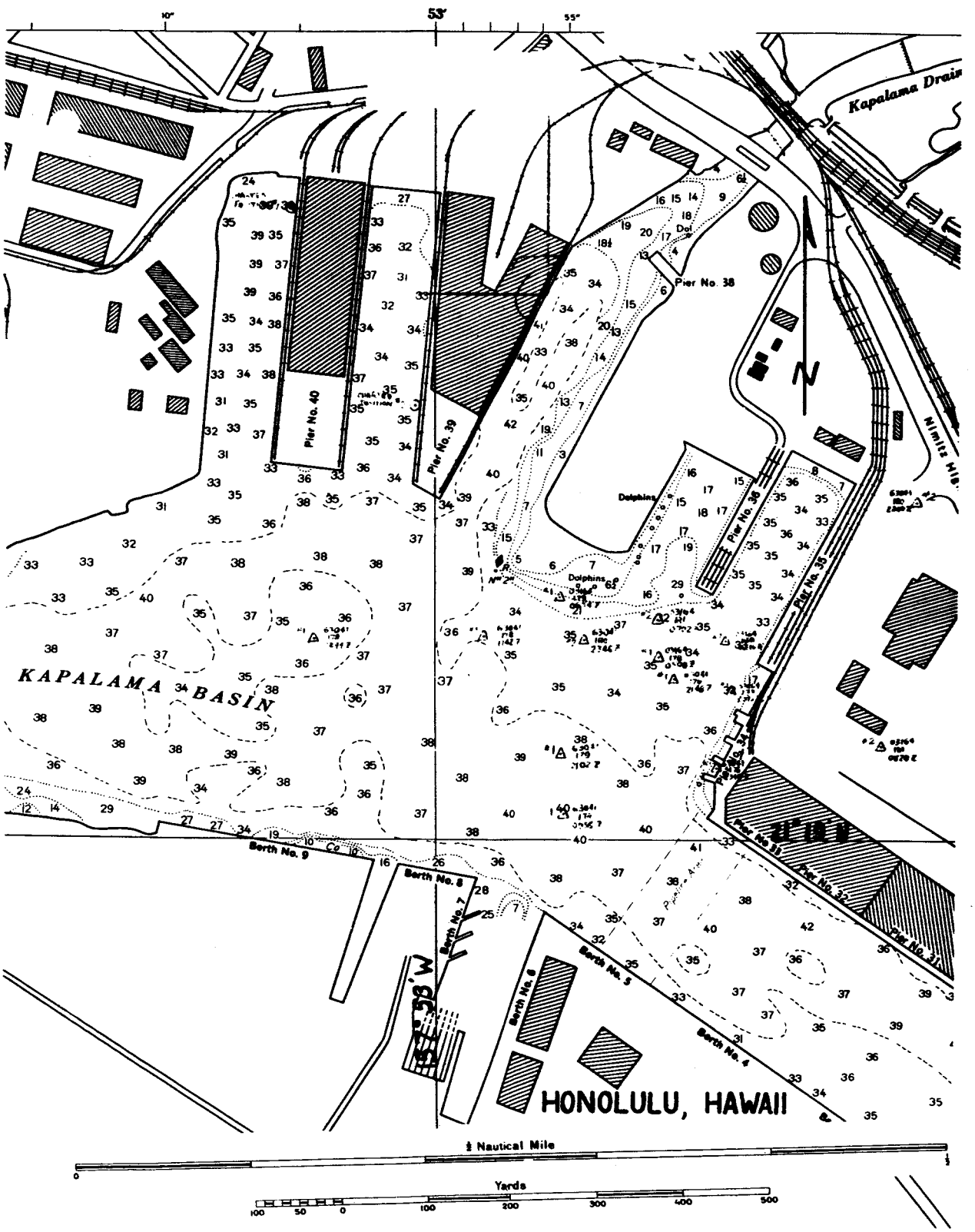
Dockside, Honolulu, Hawaii -- 27 - 30 June 1965

Pier 40, Charted Position of PIONEER -- 21° 19.364'N, 157° 53.088'W

Satellite Number	Julian Date	GMT Time	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)
03164	178	0508	21° 19.1055'N, 157° 52.8610'W	17°	141°	0.33
63041	178	0956	21° 19.0147'N, 157° 52.9205'W	31°	156°	0.38
63041	178	1142	21° 19.1175'N, 157° 52.9694'W	27°	156°	0.27
63041	178	2148	21° 19.0930'N, 157° 52.8512'W	26°	141°	0.35
63041	178	2340	21° 19.0418'N, 157° 52.8277'W	32°	143°	0.41
03164	179	0512	21° 19.0857'N, 157° 52.8168'W	20°	138°	0.38
03164	179	0654	21° 19.1410'N, 157° 52.9221'W	36°	145°	0.27
03164	179	1958	Low pass angle--not enough intervals			
63041	179	2102	21° 19.1500'N, 157° 52.9219'W	09°	154°	0.35
63041	179	2244	21° 19.1159'N, 157° 53.0753'W	73°	177°	0.25
63041	180	0038	Computer malfunction--would not settle on fix			
03164	180	0516	21° 19.1156'N, 157° 52.8182'W	24°	135°	0.35

Pier 39, Charted Position of PIONEER -- 21° 19.252'N, 157° 53.013'W

63041	180	2200	21° 19.1955'N, 157° 52.7023'W	42°	101°	0.29
63041	180	2346	21° 19.1170'N, 157° 52.9068'W	20°	144°	0.17
03164	181	0520	21° 19.0536'N, 157° 52.7260'W	29°	126°	0.33
03164	181	0702	21° 19.1287'N, 157° 52.8610'W	25°	131°	0.19


10"
53'
55"
Kapalama Drain
Pier No. 38
Pier No. 40
Pier No. 39
Pier No. 36
Pier No. 35
Pier No. 34
Pier No. 33
Pier No. 32
Pier No. 31
Nimitz Hwy
Dolphins
Dolphins
KAPALAMA BASIN
Berth No. 9
Berth No. 8
Berth No. 7
Berth No. 6
Berth No. 5
Berth No. 4
21° 18' N
157° 52' 38" W
HONOLULU, HAWAII
½ Nautical Mile
Yards
100 50 0 100 200 300 400 500

Honolulu, Hawaii to San Francisco, California:

The PIONEER sailed from Honolulu to San Francisco from 1 July 1965 until 6 July 1965. Enroute she attempted to obtain fifty-five satellite fixes. An average of 75% were obtained, amounting to forty-one fixes taken successfully.

Fourteen fixes were not obtained, and computer malfunctions, probably in the program tape reader head, were responsible for nine of these. Operator error in data entry was responsible for three missed fixes, and low pass angles of satellites responsible for the remaining two.

The satellite fixes were again used whenever possible in smooth-plotting the trackline, because at most times these were believed to be the most accurate estimate of position. However, twenty-four of the forty-one fixes were not used in the smooth-plot. Most of these twenty-one were rejected by small amounts, the average of these amounts being 0.39 miles. The fixes which were used in the smooth-plot were compared with any available conventional control, which was mainly Loran A, but included some Loran C and some celestial fixes. The average of the errors when compared with Loran A was 0.95 miles, but of this is believed due to the variance of the Loran A. One fix was compared directly with Loran C, the error being 0.22 miles. Only one rate of the Loran C was functional at the time, however. Two fixes were compared with sun lines, the average error being 0.38 miles.

One satellite fix was compared directly with a celestial fix, and other satellite fixes were indirectly compared with celestial fixes by means of the positions dead reckoned between them. These comparisons were all extremely good, and provided additional justification for belief in the accuracy of the satellite trackline.

As mentioned in the Honolulu, Hawaii in-port accuracy section of this report, the SH4X Loran C rate had a consistent difference with the line of satellite fixes. It consistently plotted north of the satellite fixes, the distance north increasing as the ship went further from the islands. This was used as evidence in support of the hypothesis about Hawaii's mislocation.

The azimuths of the errors in satellite fix comparisons appeared again to be random, with the exception of the Loran C SH4X rate mentioned above.

The accuracy of the satellite gear is therefore considered very good on this leg of the cruise. The only detraction from the value of the system on this leg was the large number of computer failures, probably due to the tape reader head malfunctioning.

TABULATION OF SATELLITE DATA

Honolulu, Hawaii to San Francisco, California -- 1 July 1965 to 6 July 1965

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)	
973A	182	0522	Visual	21° 37.1'N, 158° 21.9'W	21° 37.1957'N, 158° 21.8653'W	33°	062°	0.04	
980A	182	0706	Visual & Radar	21° 53.6'N, 158° 00.3'W	21° 53.5373'N, 158° 00.3623'W	21°	225°	0.10	
-	182	0838	--	--	Operator error--wrong data entry				
988A	182	1022	Smooth plot	22° 23.7'N, 157° 17.8'W	22° 23.2729'N, 157° 17.5646'W	82°	161°	0.40	(•)
992A	182	1212	Smooth plot	22° 38.9'N, 156° 56.4'W	22° 39.2407'N, 156° 56.7437'W	09°	326°	0.32	(•)
1001A	182	1646	Loran A	23° 17.9'N, 156° 01.4'W	23° 17.4900'N, 156° 01.0406'W	18°	135°	0.45	
1005A	182	1828	Smooth plot	23° 31.6'N, 155° 39.0'W	23° 31.3999'N, 155° 39.6840'W	34°	251°	0.70	(*)
1009A	182	2032	Smooth plot	23° 50.0'N, 155° 08.8'W	23° 49.5071'N, 155° 08.9766'W	07°	216°	0.60	(*)
-	182	2214	--	--	Operator error--wrong data entry				

(•) _ Satellite fix not used in final smooth plot.

TABULATION OF SATELLITE DATA

Honolulu to San Francisco -- (continued, page 2)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)	
1018A	183	0002	Loran C	Only one rate plots	24° 19.4209'N, 154° 19.7445'W	54°	358°	0.22	
1029A	183	0524	Smooth plot, Celestial	25° 03.1'N, 153° 10.0'W	25° 03.6203'N, 153° 10.3822'W	41°	329°	0.58	(*)
-	183	0712	--	--	Low pass angle--not enough intervals				
1040A	183	1122	Smooth plot	25° 58.2'N, 151° 43.0'W	25° 58.9688'N, 151° 41.3625'W	17°	057°	1.65	(*)
1046A	183	1650	Smooth plot	26° 49.1'N, 150° 18.0'W	26° 49.1994'N, 150° 17.9295'W	39°	236°	0.09	(*)
1048A	183	1834	Smooth plot	27° 05.3'N, 149° 51.2'W	27° 05.1180'N, 149° 51.1740'W	18°	150°	0.13	(*)
1053A	183	2128	Smooth plot	27° 33.1'N, 149° 06.4'W	27° 33.0632'N, 149° 06.8379'W	58°	257°	0.44	(*)
1057A	183	2310	Smooth plot	27° 49.2'N, 148° 39.1'W	27° 49.3838'N, 148° 39.0939'W	36°	004°	0.11	(*)
-	184	0528	--	--	Computer malfunction--would not settle on fix				

(*) -- Satellite fix not used in final smooth plot.

TABULATION OF SATELLITE DATA

Honolulu to San Francisco -- (continued, page 3)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)	
1071A	184	0714	Smooth plot	29° 02.0'N, 146° 29.6'W	29° 02.0654'N, 146° 29.2766'W	04°	052°	0.23	(*)
1073A	184	0850	Loran A	Only one rate plots	29° 16.7538'N, 146° 03.0496'W	35°	320°	0.55	
1075A	184	1036	--	--	Computer malfunction--bad fix--computer program "scaling?"				
1081A	184	1516	None	--	30° 09.2900'N, 144° 18.8305'W	07°	-	0.00	
-	184	1654	--	--	Computer malfunction--never did settle on fix				
1084A	184	1842	Sun line	Only one line	30° 38.8518'N, 143° 23.3095'W	07°	271°	0.10	
1087A	184	2042	Sun line	Only one line	30° 55.1142'N, 142° 49.8199'W	44°	302°	0.65	
1090A	184	2226	None	--	31° 08.5297'N, 142° 19.9639'W	25°	-	0.00	
1093A	185	0006	Smooth plot	31° 21.8'N, 141° 51.0'W	31° 22.2888'N, 141° 51.0499'W	40°	345°	0.46	(*)

(*) -- Satellite fix not used in final smooth plot.

TABULATION OF SATELLITE DATA

Honolulu to San Francisco -- (continued, page 4)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)	
1097A	185	0348	None	---	31° 50.8066'N, 140° 45.8820'W	28°	-	0.00	
1100A	185	0530	Smooth plot	32° 03.6'N, 140° 16.0'W	32° 03.5748'N, 140° 16.1357'W	31°	248°	0.08	(*)
1106A	185	1014	Smooth plot	32° 40.5'N, 138° 53.7'W	32° 40.2252'N, 138° 53.5142'W	31°	153°	0.18	(•)
1108A	185	1200	Loran A	Only one rate plots	32° 54.4257'N, 138° 23.0994'W	35°	308°	1.15	
1112A	185	1518	Smooth plot	33° 20.6'N, 137° 25.5'W	33° 20.8952'N, 137° 25.5853'W	21°	354°	0.20	(*)
1114A	185	1700	Smooth plot	33° 34.0'N, 136° 55.5'W	33° 33.7726'N, 136° 55.4646'W	42°	161°	0.15	(•)
-	185	1842	--	--	Low pass angle--not enough intervals				
1119A	185	2128	Smooth plot	34° 05.5'N, 135° 34.3'W	34° 05.4749'N, 135° 34.2917'W	18°	145°	0.04	(•)
1122A	185	2314	Smooth plot	34° 18.0'N, 135° 02.0'W	34° 17.9551'N, 135° 01.9852'W	56°	180°	0.05	(•)

(*) -- Satellite fix not used in final smooth plot.

TABULATION OF SATELLITE DATA

Honolulu to San Francisco -- (continued, page 5)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut. mi.)	
-	186	0102	--	--	Computer malfunction--recorded bad Doppler count				
-	186	0350	--	--	Operator error--wrong data entry				
1129A	186	0534	Loran A	No rate is close	35° 02.6388'N, 133° 07.6476'W	16°	-	0.00	
1134A	186	0926	Loran A	Only one rate plots	35° 29.33'N, 131° 56.37'W	24°	107°	0.90	
1136A	186	1110	Smooth plot	35° 40.0'N, 131° 24.1'W	35° 39.9214'N, 131° 23.6909'W	46°	102°	0.40	(•)
1138A	186	1304	Smooth plot	35° 51.4'N, 130° 49.9'W	35° 52.0447'N, 130° 48.4393'W	03°	066°	1.35	(*)
1140A	186	1522	Smooth plot	36° 06.0'N, 130° 06.2'W	36° 06.0941'N, 130° 06.2160'W	47°	046°	0.06	(•)
1143A	186	1706	Loran A	36° 15.7'N, 129° 35.2'W	36° 15.9926'N, 129° 36.1998'W	19°	298°	0.92	
-	186	2044	--	--	Computer malfunction--tape reader head				
-	186	2220	--	--	Computer malfunction--recorded bad Doppler count				

(*) -- Satellite fix not used in final smooth plot.

TABULATION OF SATELLITE DATA

Honolulu to San Francisco -- (continued, page 6)

Fix No.	Julian Date	GMT Time	Comparison Control	Position by Comparison Control	Position of Satellite Fix	Pass Angle	Az. of Error	Error (naut.mi.)	
-	187	0008	--	--	Computer malfunction--would not settle on fix				
1155A	187	0212	Smooth plot	37° 03.4'N, 127° 13.1'W	37° 03.4423'N, 127° 12.9121'W	14°	088°	0.18	(*)
1157A	187	0354	Loran A	Only one rate plots	37° 13.1126'N, 126° 46.5955'W	69°	175°	0.80	
1159A	187	0538	Loran A	Only one rate plots	37° 21.14'N, 126° 18.87'W	08°	177°	0.95	
-	187	1024	--	--	Computer malfunction--would not compute fix				
1167A	187	1216	Loran A	Only one rate plots	37° 47.6657'N, 124° 29.2041'W	08°	250°	1.90	
1169A	187	1346	Smooth plot	37° 55.7'N, 124° 04.1'W	37° 55.8234'N, 124° 04.4350'W	11°	276°	0.34	(*)
1172A	187	1526	Smooth plot	38° 05.2'N, 123° 37.4'W	38° 05.1809'N, 123° 38.0689'W	86°	270°	0.55	(*)
-	187	1712	--	--	Computer malfunction--would not settle on fix				

(*) -- Satellite fix not used in final smooth plot.

REQUIREMENTS, RECOMMENDATIONS, AND PROBLEMS ENCOUNTERED

The satellite navigation system must be readily accessible to the Hydrographer, as he uses the fixes and has all the information necessary in manual data entry. The equipment was mounted on the forward chart table in the charthouse of the PIONEER in order to satisfy this requirement. In this location it is possible for the Hydrographer to monitor all passes of the satellites and also to obtain simultaneous control for comparison with satellite fixes.

Thirty to forty minutes are required to obtain a satellite fix. However, only about ten minutes' time is actually required of the Hydrographer, leaving him relatively free for his other duties. This ten minutes, though, is scattered over the thirty to forty minutes required in obtaining a fix. Most of the time required in obtaining fixes is time spent in tracking the satellite automatically, and waiting for the computer to process the information and compute the fix.

Only two satellites were available during the cruise, and satellite fixes were available very hour and forty-five minutes for a period of seven or eight hours. Then after this period they were not available at all for about six hours. Therefore, some type of continuous control, such as Loran A or Loran C, is desireable between satellite fixes when trying to maintain a course on a line or series of lines. This may be used during the periods of no satellite fixes to give some indication of whether or not the ship is maintaining the line which it is trying to follow.

Space required for the equipment was a problem aboard the PIONEER. While it was necessary to mount the satellite gear in the chart room, very little space was available due to other equipment already in place. The satellite gear requires a base area of approximately four feet by six feet for the receiver, computer, and control head. The computer requires a vertical clearance of approximately three feet, the other units slightly less. The PIONEER does not have the computer test device, but this would require additional base area of two feet by three feet, and two and one-half feet of vertical clearance.

The only location which would fit these requirements aboard the PIONEER was the forward chart table in the chart room. This chart table was overlaid with a piece of 5/8" plywood, upon which the gear was installed. The location has proved quite satisfactory and convenient, though completely filling the former chart table.

The power source gave some problems at certain times, but this is believed to have been largely overcome. Normal changing of generators while underway under no extreme power demand, is not known to have caused any computer failures. On the first coring station on the Attu to Midway leg of the cruise, the computer did malfunction because of power fluctuations. The heavy winches, when started or stopped, caused sudden line voltage changes which at times completely stopped the computer in mid-operation, also changing the memory content of the computer. This made the fix irretrievable at the time, because the memory is essential to the computer. At some other times, mainly on tape reader head malfunctions, the fix was retrievable at certain steps

in the program, by restarting the section of program tape which had been misread. This was possible only if the memory content had not been changed during the operation.

The slight power fluctuations of normal ship operations had little or no effect and apparently electrical noises and power spikes were successfully overcome by use of isolation transformers in the power feeds to the receiver and computer. The failures on coring stations could be eliminated, it was found, by running the heavy coring machinery with power from the ship's emergency generator. This was done on all subsequent core stations, and the computer showed a much lower failure rate.

The antenna system is connected to the receiver by a 200-foot long cable supplied with the gear. This allows relative freedom in choosing an antenna location aboard ship, since the antenna can be placed anywhere the 200-foot cable will reach. The antenna itself is small but heavy. It is approximately four feet in diameter horizontally, measures about three and one-half feet vertically, and weighs about forty pounds. The antenna must have as clear a view of the entire sky as possible, masthead mounting being optimum. This was impractical aboard PIONEER due to an existing radar installation at the top of the mast. The location finally chosen was atop a ten-foot stanchion built of four-inch iron pipe at the extreme forward edge of the PIONEER's flying bridge. This location gave a completely clear horizon from forward back to both quarters of the ship, but there was some shading aft due to the mainmast, its two radar dishes, and mast rigging. This caused only two fixes to be missed during the entire two-month cruise, however, and its effect is judged to be of little importance. Lock was lost on a few other passes due to this cause also, but was quickly regained with enough two-minute intervals remaining to compute a fix.

Heat was no problem in the equipment during the entire cruise, and no extra cooling equipment had to be provided. However, it is stated in the computer instructions that the "Run-Load" switch on the program tape reader must be left in the "Run" position when the computer is on. This is necessary because of a cooling fan in the tape reader which is on only in the "Run" position. The tape reader uses some germanium transistors which, being next to the computer power supply, could overheat and be damaged otherwise.

Observations were not affected by weather conditions and were made successfully in all weathers. However, heavy rolling of the ship in rough water did cause premature loss of lock on satellites in some instances.

There was no trouble with the satellite gear itself other than with the light bulb in the program tape reader head. This bulb is used to send a focussed band of light through punched holes in the program tape as it moves through the tape reader head. The light which passes through the holes must be strong enough to be "seen" by photo-voltaic cells immediately below the tape. These photo-voltaic cells then

convert the light which hits them into electrical impulses which form istructions to the computer. Every impulse must be correct or the computer will not compute a proper navigational fix.

The focussing of this beam is quite critical, as the photo-voltaic cells will not respond to a weak beam of light. This has been a major problem with the equipment thus far. Due to variability in the manufacturing process, the light bulbs are not the same from one to the next. Some bulbs are quite difficult to focus properly, and some require changes in their adjustment after a period of use. This latter is perhaps due in some measure to the motion and vibration of the ship at sea, as very little trouble has been experienced with the light bulb while in port.

This has been at most times the only adjustment necessary to rid the system of the "computer malfunctions" listed in the tabulations of data. It is viewed as a fairly serious and continuing problem. Steps are being taken to minimize its effect even if it cannot be entirely eliminated. The focussing of the beam is being checked at least daily in order to keep it within proper tolerances. An additional program tape has been promised by the Applied Physics Laboratory of Johns Hopkins University which will permit recomputation of missed fixes if adequate data was received from the satellite. It will permit manual re-entry of all data received from the satellite, and recomputation of the navigational fix, which is not possible at present.

These steps should help to greatly increase the percentage of successful fixes.

The only other known cause of equipment failure was dust collecting on the tape reader head. This required only a quick, simple removal of the dust with asmall nylon brush.

The intellectual requirement for operating the system is not great. The system requires only a correct sequence of button-pushing and proper data entry, which are both very simple. Although a facility for rejection of incorrect data which as been mistakenly entered is provided in the system, incorrect data entry is a major source of failure to obtain fixes. The remedy for this is a closer attention to detail by the operator, familiarity with the system, and a system of two people checking the data to be entered. The first two of these are gradually coming about, and the extra checking procedure has been initiated. The recomputation program tape mentioned above should enable these fixes to be recomputed if necessary.

Only routine minor maintenance has been necessary to date. The PIONEER's Electronics Technicians are quite capable of this. However, should anything major ever go wrong with the computer, it is doubtful if anybody at all could repair the gear without the computer test device, which we do not have.

The satellite navigation system has the capability of being moved to another ship very easily. There are virtually no problems in installation of the gear other than physically locating and securing the gear. The initial installation aboard the PIONEER took four men only about three days; it was only necessary to plug in the equipment, warm it up, and start using it. Much of the equipment has since been replaced with new gear, and there were no new problems associated with removal and replacement. It required three men slightly less than one day to accomplish this; the new gear also worked immediately after warm-up.

SUMMARY AND CONCLUSIONS

During the two months covered by this report the Navy Satellite Navigation System has proven to be accurate and reliable. It is recommended as an efficient means of controlling deep-sea survey work.

The underway accuracy of the system as established by the best types of comparison control aboard the PIONEER, sextant angles, visual bearings, and shoran, is approximately 0.17 miles average error. Approximately 90% of underway fixes are less than 0.35 miles in error. With other types of underway comparison control, the accuracy appears somewhat worse, but this is believed due more to the variability of the standard control rather than to decreased accuracy of the satellite system.

Dockside accuracy is of the same order, with an average error of approximately 0.16 miles.

Reliability of the system is established by the fact that of 418 attempts made to obtain fixes, 347 were successfully obtained, or a percentage of 83%. If low pass angles, over which there is no control, are eliminated, 399 fixes were attempted and 347 were obtained. This is 87% successful, which is a highly reliable system.

The percentages, though, are made more meaningful by separating in-port fixes from underway fixes. Again eliminating low pass angles, the over-all success percentage for in-port fixes was 94%. Operator error was responsible for 2% of the attempts being missed, and the computer malfunctioned 4% of the time.

For underway attempts, eliminating low pass angles, the system was successful only 84% of the time. Operators made errors on 5% of the attempts, and miscellaneous reasons were responsible 3% of the time. The important percentage here is that the computer malfunctioned on almost 8% of the underway fixes attempted.

This relatively large percentage of malfunctions is believed due to one primary cause, the light bulb in the tape reader head. The focussing of this bulb depends on a straight horizontally suspended filament which appears to be sensitive to vibrations of the ship underway. This, however, is the only complaint about the system components. The remainder of the system has been extremely reliable.

Due to the relative infrequency of the fixes obtained, it is believed that some type of continuous control should be used to augment the satellite system. The two systems, used in this way, provide an excellent check on each other, and allow the position of the ship to be known quite accurately at any desired moment. This is invaluable in maintaining course on a preset system of lines to be surveyed.

The overall evaluation of the Navy Satellite Navigation System is very favorable for use by the Coast and Geodetic Survey in deep-sea trackline survey work.