TECHNICAL MEMORANDUM (NASA) 13

FLIGHT EVALUATION: OHIO UNIVERSITY OMEGA RECEIVER BASE

A description is given of the data-collection flight, round-trip from Athens, Ohio to Langley Field, Virginia, during which Omega data was collected on machine-readable media for use in the Tri-University Program in Air Transportation.

by

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I INTRODUCTION

The purpose of this Technical Memorandum is to document a flight evaluation of the Ohio University Omega Receiver Base, developed under the NASA Tri-University Program in Air Transportation, and to provide a vehicle for the transfer of flight-test data to NASA and to other participants in the Tri-University program.

Chart recordings of flight data are given, along with chronological listings of significant events which occurred during the flight. Digital data has been prepared in data-processing card form for distribution. Data include phase measurements from all eight Omega time-slots for the duration of the flight, plus event marks which serve to correlate the phase data with flight-path documentation.

It is anticipated that the data-collection and preparation techniques developed for this flight will be maintained and improved for future flight evaluation. We welcome comments on data form and content so that improvements in data usability may be made in the future.

II TEST FLIGHT-ROUND TRIP ATHENS, OHIO TO LANGLEY FIELD, VIRGINIA

A. General. A flight test of the Ohio University Omega Receiver Base developed under the NASA Tri-University Program in Air Transportation Systems was planned for October 17-18, 1974 to coincide with a meeting of the Tri-University participants at Langley Field, Virginia. In this manner we were able to use DC-3 aircraft flight time both for transportation of program personnel to the meeting and for flight data-collection activities. Details of receiver construction have been reported by the authors[1,2] and by Burhans[3].

B. Aircraft Instrumentation. For this test flight, the Ohio University DC-3 aircraft was equipped with a Sulzer 5-D 5 MHz frequency source, the Omega Receiver Base, and data-recording equipment. Six bits of Omega phase measurements with respect to the Sulzer reference were recorded on IBM-format digital magnetic tape once per Omega time-slot. The eighth bit was reserved for event marks (not used on this flight; events were manually added) and the seventh bit was used as a framing bit, "on" except for Omega time-slot D measurement intervals. Three two-channel chart recorders were installed. Omega signal amplitudes at both 10.2 and 13.6 KHz were charted on both the outward and return legs of the flight. Analog commutated phase from the receiver's phase register was recorded along with 10.2 amplitude (for timing purposes) on the second recorder. The third 2-channel unit was used to record two selected Omega LOP's for in-flight navigation activities. Oscilloscope monitoring of Omega signals and phase-locked replica signals was provided for real-time receiver observation and subjective evaluation.

All equipment was powered by 115-volt, 60 Hz inverters permanently installed in the DC-3. Arrangements were made for observation of cockpit instruments and manual recording of flight-path parameters. Manual observation of ground features with comparison to VFR sectional charts was used for in-flight navigation verification. In-flight Omega navigation from the chart-recorded LOP outputs was also compared with VOR/DME information supplied by the pilot at selected points during the flight.

Simultaneous event marks were provided for all three chart recorders to facilitate post-flight evaluation of Omega LOP data (at selected points during the flight).

C. Flight Path Documentation. A map of the flight path for the Langley flight evaluation is shown in Appendix A, together with a corresponding table of events. Pertinent facts concerning the flight are (all headings magnetic):

1. The aircraft was navigated by VOR.

2. An airspeed of approximately 150 knots was indicated for the level portion of flight.

3. Skies were clear and winds were light and variable.

4. An altitude of 9000 and 8000 feet was maintained to and from Langley AFB respectively.

Take-off was at 0600 hours (EDT) on October 17, 1974 from the Ohio University airport on a heading of 060°. A level altitude of 9000 feet was attained 12 minutes later. At 0636 hours the Elkins VOR was passed and the heading was changed to 127° (V38). In the interval from 0703 hours to 0714 hours, sunrise was observed. Gordonsville VOR was passed at 0714 hours, and the heading was changed to 120° in order to fly directly to the Harcum VOR. At 0733 hours the heading was changed to 160° and descent began at 0734 hours. At 0745 hours at an altitude of 2000 feet, the heading was changed to 060° and touchdown at Langley Field occurred at 0751 hours.

The return flight was on October 18, 1974 and take-off was at 1550 hours (EDT). The heading was 060° at take-off and was changed (via a wide arc) to 270° at 1550 hours. A heading of 310° to Hopewell VOR was assumed at 1601 hours, heading 323° was flown to Richmond VOR, and the flight proceeded on V38 to the Elkins VOR. From Elkins the flight path was direct to Ohio University airport. Touchdown occurred at 1814 hours on a heading of 060° after turning from a heading of 240°.

D. Omega Navigation During the Flight. The Ohio University Omega receiver base was evaluated in flight by navigating from Ohio University airport (I-81) to Langley Field, Virginia, using comparisons between raw Omega LOP data and preplotted Omega lanes. The 10.2 KHz B-D and A-B analog LOP outputs from the chart recorder are shown in the appendix foldout along with the flight path. Predicted lane crossings were plotted from Omega tables, H. O. Pub. No. 224 (III) B-D, A-B, superimposed on the Washington and Cincinnati sectionals. The 10.2 KHz B-D lanes are numbered 976 through 940 and 10.2 KHz A-B are numbered 987 through 1002 according to the standard Omega lane numbering format.

Discussion of Omega navigation enroute from Ohio University to Langley Field is provided on the outbound leg only, to exemplify the techniques used and various situations encountered; the return flight path is also plotted on the Appendix A chart. Analog Omega LOP's can be generated from the digital phase data utilizing the FORTRAN program in Appendix B.

The only Omega stations transmitting on October 17, 1974 were Norway, Trinidad, and North Dakota. In contrast to ground monitoring indications from the Tracor 599R Omega receiver and the Ohio University Omega receiver base, navigable signals from all three stations were received shortly after take-off.

Although placement of events on the LOP chart (Appendix A) was via parallel event marker circuitry aboard the test DC-3 aircraft and is correct with respect to time of day and event table (Appendix A), the placement of events 1 through 8 along the flight path was judgmental, based on visual ground references. These event marks are therefore not for accurate position-fixing. Events 9 through 14 were placed using the pilot's DME and are sufficiently accurate with respect to position on the flight path for comparison of received vs. true Omega LOP's. "Omega Propagation Correction Tables", H. O. Pub. No. 224 (M-C) A, B, D supply skywave corrections only for every 4° latitude and 4° longitude along our flight path and with resolution only to first and second halves of the month and integral hour of day. Our data collection took place near the limits of all three dimensions of correction. The resolution of these SWC tables is insufficient for aircraft use, which suggests a detailed look at the skywave correction algorithm and/or at possible differential Omega updating for future flight tests. Note, however, that post-flight skywave corrections may be applied to the digital data for more accurate Omega position fixes than were possible "on-the-fly", using only the tabled data.

The received B-D LOP value at the time of event 9 was 970.85 and the true value is 970.26, giving an error of .59 of a 10.2 KHz lane or about 4.63 nautical miles (see table, Appendix C). Similar results occur for position-finding at event 10, and a significantly smaller error occurs (2.75 nautical miles). Possible causes are sunrise at Trinidad and possible slight deviation from assumed flight path. It should be emphasized that these events were placed with respect to the pilot's DME and a small error in reading the miles-to-go indicator is also a possibility. Position approximations such as these suggest that future Omega data collection flights must incorporate an air-data-collection instrument package so that more accurate velocity, altitude, heading, DME readings, VOR indications, etc., can be correlated with received Omega LOP data to determine accuracy of the Omega navigational system.

Events 11, 12, and 13 give errors of less than one nautical mile on all occasions (table, Appendix C), well within the predicted accuracy limits of the Omega system (i.e., ±1 nautical mile daytime and ±2 nautical miles at night). Note also the large error at event 14 which occurs at the time of local sunrise at the plane also noticeable as an anomaly on both B-D and A-B LOP's. Event 23 (touchdown at Langley AFB) illustrates an accuracy of .47 mile with respect to a 10.2 KHz B-D LOP.

Referring to the 10.2 KHz LOP and table of events, it can be seen that climbing and descending (events 1 through 8 and 18 through 24) had no noticeable effects on the ability of the Ohio University Omega receiver to track the LOP's. Note also the change in length of the lane crossings as heading is changed. This is most noticeable on the wider 10.2 KHz A-B lanes. A constant heading from A-B lane number 907 to 989 yields a constant lane width. As the heading is changed at Elkins VOR to 127°, the flight path is more closely perpendicular to the A-B lanes. Their width is recorded as being shorter from A-B lane number 889 to number 995, and they grow shorter yet as the course is changed at Gordonsville VOR. At A-B lane number 997 the course is changed to more closely parallel the A-B lanes resulting in wider traces.

The final apprach to Langley Field is along a heading of 060° which is roughly 45° to both A-B and B-D lanes and the turn onto final approach and the final approach to touchdown can easily be followed on the recorded LOP's. As A-B lane number 1001 is crossed we begin up the ramp toward number 1002, but as the plane turns onto final, the ramp falls short of number 1002 and actually moves back toward A-B number 1001 until touchdown at A-B lane number 1001.6, indicating flight roughly parallel to and between A-B lanes 1001 and 1002. Reference to the flight path foldout, and true LOP's in Appendix C, shows that the turn from base to final approach actually does slightly "back-up" with respect to A-B lane 1002 and roughly parallel flight between A-B number 1001 and 1002 ensues until touchdown at A-B lane number 1001.6. A similar chain of events is evident on the B-D LOP's.

The return trip from Langley Field to Ohio University airport was utilized to flight test the 13.6 KHz capability of the Ohio University Omega receiver base. Observations were that 13.6 KHz reception was much poorer in the late afternoon than was 10.2 KHz in the early morning hours. However, it is impossible to draw conclusions as to which is the more navigable signal frequency until flight tests can be conducted on both 10.2 KHz and 13.6 KHz during both night and day.

E. Omega Data Description. Omega phase data is collected in machine-readable format for distribution to interested parties. For the flight evaluation reported here, data is available in 80-column card format as described below:

Columns 1-72 - On each card except the last, twenty-four integer numbers are punched, representing Omega time-slots D through C, covering three commutation sequences. The first number is for channel D, the second for time-slot E, etc. All numbers are in FORTRAN IV format, readable with I3 (integer with field length 3 columns) specifications.

- Each number represents an Omega phase measurement with reference to the local receiver clock (in this case the Sulzer 5-D). Each number will be a 2-digit integer within the range 0-63, representing phase difference in 64ths of an Omega cycle. If the number is negative, a manual event mark exists at the time represented by the measurement. Absolute values should be used when utilizing the phase data exclusive of event information.

- On the last card in a deck, any unused data fields are filled with integer number 99, to indicate the end of data. The number 99 is not to be used as an Omega phase measurement.

Columns 73-80 - On each card, a serial number is placed to aid in maintaining card deck sequence. In order for Omega data to be correct in time sequence, these numbers should be checked to insure proper order.

Two card decks are available; one from the outbound flight at 10.2 KHz, and the other from the return flight at 13.6 KHz.

Note that no explicit timing information is given. It is assumed that Omega data is self-timing, in that a complete sequence of eight measurements is always made in exactly ten seconds. All eight Omega channels are recorded, even though all stations may not be transmitting. For this flight, lane pairs A-B and B-D were used. To our knowledge, no other stations were transmitting. In Appendix B, a FORTRAN IV computer program is reproduced to show one method for summarizing the flight-test data. Card copies of the program and flight-test data reported here are available on request from the authors. Full documentation of the data reduction sequence appears in R. W. Lilley's, "Omega Flight-Test Data Reduction Sequence"[4].

III CONCLUSIONS AND RECOMMENDATIONS

As a result of this flight evaluation, several conclusions may be drawn as to the operation of the receiver base. Several recommendations concerning data-collection technique may be made.

A. Given sufficient signal levels, the receiver base phase-tracks two Omega LOP's simultaneously, providing the expected navigation-processor input signals. Chart recordings of Omega LOP's A-B and B-D could be interpreted manually, in near real-time, to verify approximate ground position and groundspeed.

In both straight/level flight and during normal maneuvers performed during take-off and landing, phase tracking was maintained. The reliable reception of the Norway (A) signal on the outbound flight was a pleasant surprise, as we have had difficulty receiving this signal in the laboratory. On the return flight, however, in the late afternoon, Norway was unusable.

B. The flight evaluation met its objective: that of obtaining commutated digital phase data for all eight Omega time slots during a test flight whose path was documented for correlation with the Omega data.

By means of this Technical Memorandum and data-processing card decks, the phase data will be made available to participants in the Tri-University Program for use in navigation-processor evaluation.

C. For future flight-evaluation activities, several changes should be made in the data-collection configuration:

1. Collected data on Omega characteristics would be made more meaningful and easier to use if flight parameters (heading, true airspeed, altitude) could be placed on magnetic tape in real time along with the Omega data. We recommend one flight-path data frame per 10 seconds of Omega data, in an appropriate digital format.

2. Future flights should be planned for data-collection specifically. The flight reported here was a dual-purpose transportation and data-collection flight. For minimal flight time transportation requirements, the flight path is generally not made directly over VOR checkpoints. For flight-evaluation purposes, the use of VOR checkpoints and a VOR/DME or Area Navigation system independent of the pilot's instruments allows near-real-time in-flight backup to the digital recording system, allowing meaningful event marks to be inserted manually.

3. An event marker circuit capable of placing on digital tape and chart recordings numbered (identifiable) event marks should be provided.

4. Data collection during various times of day (including flight through the transition "terminator") and at various altitudes over a variety of terrains.

5. Real-time skywave corrections based on on-board navigation-processor (if algorithms of sufficient resolution for aircraft are available) or possibly differential updating utilizing ground-based Ohio University Omega receiver bases. Ground monitoring and in-flight assistance by the other Tri-University participants is desirable and would be possible pending their acquisition of Ohio University receiver base prototypes.

D. Recommendations for the next flight evaluation are:

1. Station C (Hawaii) should be used. Since Hawaii was off the air during the flight test reported here, stations A, B, and D were used. It is probable that navigation using either A, C, and D or B, C, and D would be used in the Eastern U. S. under an operational Omega system. For this reason, we need live data on Hawaii for navigation-processor model evaluation.

2. The flight should be made in a small airplane, using the ADF sense antenna. The shared-antenna approach would lower the system cost since the user would not have to install added antennas. Careful attention should be given to possible interference between the ADF and Omega systems.

E. As soon as practicable, an on-board, generalized digital processor capability should be provided. Suggested hardware would be the Hewlett-Packard 9830 calculator/computer suitably interfaced to the receiver base. Work should proceed on inexpensive heading and true airspeed transducers for dead-reckoning aids to the navigation processor.

IV ACKNOWLEDGEMENTS

Omega Receiver flight tests are performed by the Omega project team under the Tri-University Program at Ohio University's Avionics Engineering Center. The Director of the Center is Dr. Richard H. McFarland, who acted as pilot in command during the test flight described here. Ralph Burhans is the Omega Project Engineer, and he served as an observer and consultant for in-flight navigation. John Abel, an undergraduate student intern in the Tri-University Program, prepared preflight charts and data, and carried out in-flight navigation tasks. Other Omega team members who aided in preparation of the flight test were graduate student Rick Palkovic and undergraduates Dan Moyer, Dan Ellis, Lee Wright and Dennis Zoulek.

The authors wish to thank each of these team members for their significant contributions to the success of this test flight.

V REFERENCES

[1] Chamberlin, Kent A., "Binary Phase Locked Loops for Omega Receivers," paper presented at the Second Omega Symposium, ION, Washington, D. C., November 7, 1974.

[2] Lilley, Robert W., "Binary Processing and Display Concepts for Low-Cost Omega Receivers," paper presented at the Second Omega Symposium, ION, Washington, D. C., November 7, 1974.

[3] Burhans, Ralph W., "Phase-Difference Method Offers Low-Cost Navigation Receivers," Electronics, Vol. 47, pp. 98-105, September 5, 1974.

[4] Lilley, Robert W., "Omega Flight-Test Data Reduction Sequence," Technical Memorandum (NASA) 12, Avionics Engineering Center, Department of Electrical Engineering, Ohio University, Athens, Ohio, November, 1974.

VI APPENDICES

APPENDIX A

FLIGHT PATH AND OMEGA LOP's

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TABLE OF EVENTS

OUTBOUND - 10.2 KHZ - OCTOBER 17, 1974		
Event No.	Time (EDT)	Remarks
1	0600:00	Take-off - Albany, Ohio - Magnetic Heading 060°
2	0601:15	Altitude 1000 Feet
3	0604:00	Altitude 2000 Feet
4	0606:00	Altitude 4000 Feet
5	0607:00	Altitude 5000 Feet
6	0608:20	Altitude 6000 Feet
7	0610:00	Altitude 7000 Feet
8	0612:00	Level at 9000
9	0619:00	50 Nautical Miles (DME) to EKN
10	0627:45	25 " "
11	0636:15	EKN Alter Heading to 127° (V38)
12	0655:20	50 Nautical Miles (DME) to GVE
13	0703:30	Period of Local Sunrise (at Plane): 25 Nautical Miles (DME) to GVE
14	0713:45	Period of Local Sunrise (at Plane): GVE Alter Heading to 133° (V38)
15	0724:00	Left Turn to 120° (Direct Harcum)
16	0733.15	Right Turn to 160°
17	0734:30	Begin Descent from 9000 Feet
18	0735:15	8000 Feet
19	0742:45	Level at 3000 Feet
20	0744:30	Begin Descent
21	0745:20	2000 Feet, Turn to 060°
22	0746:00	1500 Feet, Heading 060°
23	0751:00	Touchdown - Rollout, 180° Turn on Runway, Then Taxi Heading 240°

Continued

RETURN - 13.6 KHZ - OCTOBER 18, 1974		
Event No.	Time (EDT)	Remarks
24	1550:00	Take-off - Langley Field, Virginia - Magnetic Heading 060°
25	1552:00	Altitude 1000 Feet - Turning Left
26	1555:00	Heading 270° - Climbing
27	1601:00	Right Turn to 310° - Climbing
28	1602:00	Level at 8000 Feet - Heading 310°
		Flight Path at 8000 Feet - Direct Hopewell - Direct Richmond - V38 Gordonsville - V38 Elkins - Direct Albany
29	1758:00	Begin Descent
30	1805:00	Altitude 3000 Feet
31	1814:00	Touchdown - Heading 060° (Left Turn from 240°)

APPENDIX B

FORTRAN PROGRAM FDSUM –

OMEGA FLIGHT DATA SUMMARY

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C...OMEGA TEST DATA SUMMARY PROGRAM -- FDSUM
C...READS OMEGA DATA DECK FROM FDCON AND PRODUCES PLOTS OF SELECTED
C...PHASE MEASURES, SUMS OR DIFFERENCES; PRINTS MEAN, S. D., AND
C...SPECTRAL DATA FOR EACH OMEGA TIME SLOT.
C...
C...INPUT DECK FROM FDCON IS PRECEDED BY ONE CONTROL CARD. FORMAT:
C...
C... A-B,D+G   - GIVES TWO PLOTS ONE FOR DIFFERENCE OF A AND B PHASE,
C              AND ONE FOR SUM OF D AND G PHASE.
C...ONE PLOT MAY BE DONE BY ELIMINATING COMMA AND SECOND EXPRESSION
C...ONE-STATION PHASE PLOT MAY BE MADE BY USING THE DESIRED STATION
C        LETTER FOLLOWED BY TWO BLANKS.
C... BLANK CARD YIELDS NO PLOT AT ALL
C...
C... R. W. LILLEY, AVIONICS, NOVEMBER, 1974
C
      INTEGER SBUF(64,8)/512*0/
      INTEGER BK/' '/,STAR/'*'/,E/'E'/,LINE(132),LQ(9)
      DIMENSION IN(24),EN(8),SUM(8),SUMSQ(8),EM(8),ESD(8)
      INTEGER IBAR/'|'/
      INTEGER KL(4)
      INTEGER IP/'+'/,LA(3),LB(3),LT(9)/'D','E','F','G','H','A','B',
     * 'C',' '/
      IPS=1
      LQ(9)=0
      DO 20 I=1,8
      EN(I)=0.
      SUM(I)=0
   20 SUMSQ(I)=0.
C...READ CONTROL CARD AND PROCESS IT
      READ(1,2)LA,LB
    2 FORMAT(3A1,1X,3A1)
      DO 26 I=1,4
   26 KL(I)=0
      DO 16 I=1,9
      IF(LA(1).EQ.LT(I))KL(1)=I
      IF(LA(3).EQ.LT(I))KL(2)=I
      IF(LB(1).EQ.LT(I))KL(3)=I
      IF(LB(3).EQ.LT(I))KL(4)=I
   16 CONTINUE
      DO 128 I=1,4
      IF(KL(I).NE.9)GO TO 129
  128 CONTINUE
      IPS=2
  129 DO 17 I=1,4
      IF(KL(I).GT.0)GO TO 17
      PRINT 18
   18 FORMAT(' *** CONTROL CARD ERROR')
      STOP
   17 CONTINUE
      LAM=1
      IF(LA(2).EQ.IP)LAM=-1
      LBM=1
      IF(LB(2).EQ.IP)LBM=-1
      IF(IPS.EQ.2)GO TO 10
      PRINT 9,LA,LB
    9 FORMAT('1OMEGA PLOTS: ',3A1,64X,3A1/' 10 SECONDS PER LINE (DOWN',
     * '); 1/64 LANE PER CHARACTER (ACROSS).'/)
      PRINT 786
  786 FORMAT(/'   0',T65,'63',T68,'0',T130,'63')
      PRINT 787
  787 FORMAT(' ',130('_'))
C...READ INPUT DECK
 10    READ(1,1,END=50)IN
 1     FORMAT(24I3)
C...PROCESS EACH PHASE MEASUREMENT ON CARD
      DO 11 J=1,3
C...CLEAR PLOT BUFFER
      DO 13 I=1,132
 13    LINE(I)=BK
      LINE(3)=IBAR
      LINE(68)=IBAR
      LINE(66)=IBAR
      LINE(131)=IBAR
      DO 12 K=1,8
      LL=(IN((J-1)*8+K))
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```
C...CHECK FOR END OF DATA (99)
      IF(LL.GE.99)GO TO 50
      L=IABS(LL)
      SUM(K)=SUM(K)+L
      EN(K)=EN(K)+1.
      SUMSQ(K)=SUMSQ(K)+L*L
      LQ(K)=L
      SBUF(L+1,K)=SBUF(L+1,K)+1
      IF(LL.LT.0) LINE(2)=E
 12   CONTINUE
C PLOT
      IF(IPS.EQ.2)GO TO 10
      IF(KL(1).EQ.9.AND.KL(2).EQ.9)GO TO 456
      LOP1=LQ(KL(1))-LQ(KL(2))*LAM
      IF(LOP1.LT.0)LOP1=64+LOP1
      IF(LOP1.GE.64)LOP1=LOP1-64
      LINE(LOP1+3)=STAR
 456  IF(KL(3).EQ.9.AND.KL(4).EQ.9)GO TO 457
      LOP2=LQ(KL(3))-LQ(KL(4))*LBM
      IF(LOP2.LT.0)LOP2=64+LOP2
      IF(LOP2.GE.64)LOP2=LOP2-64
      LINE(LOP2+68)=STAR
 457  CONTINUE
      PRINT 112,LINE
 112  FORMAT(132A1)
 11   CONTINUE
      GO TO 10
C     PRINT STIX
 50   PRINT 101
 101  FORMAT('1STATISTICS FOR EACH TIME SLOT'/)
 200  FORMAT(10X'D     E     F     G     H     A     B     C'/)
      PRINT 200
      DO 102 I=1,8
      EM(I)=SUM(I)/EN(I)
 102  ESD(I)=SQRT ((SUMSQ(I)-((SUM(I)**2)/EN(I)))/EN(I))
      PRINT 103,EM,ESD
 103  FORMAT(' MEAN    ',8(F4.1,1X)//' S.D.    '8(F4.1,1X)/)
      PRINT 104
 104  FORMAT(' SPECTRUM DATA'/)
      PRINT 200
      DO 105 I=1,64
      K=I-1
      PRINT 106,K,(SBUF(I,L),L=1,8)
 106  FORMAT(1X,I2,5X,8(I4,1X))
 105  CONTINUE
      STOP
      END
```

STATISTICS FOR EACH TIME SLOT

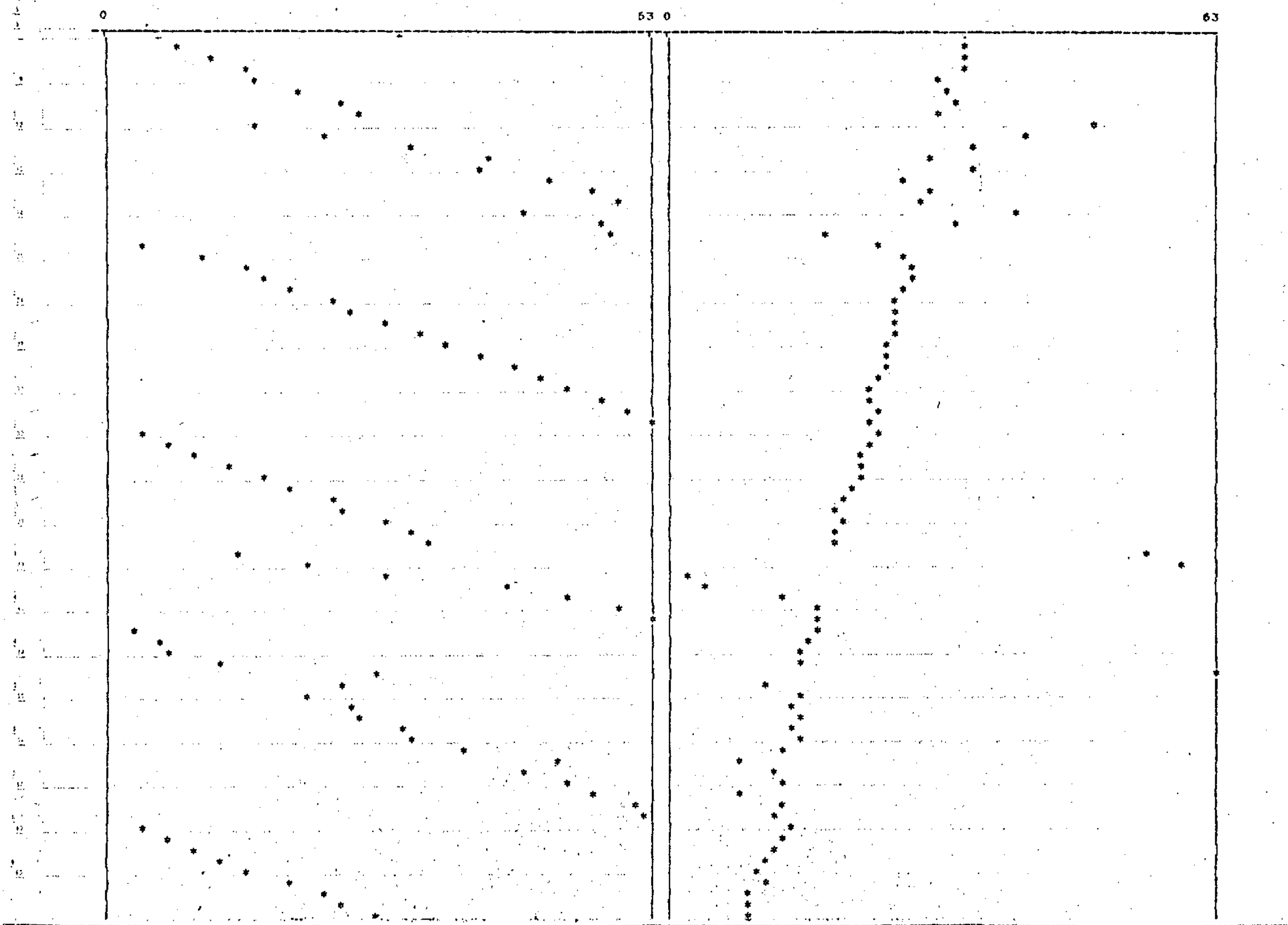
	D	E	F	G	H	A	B	C
MEAN	31.8	29.7	31.5	31.7	31.4	31.3	32.6	30.5
S.D.	18.3	18.4	18.6	18.4	18.4	18.5	17.5	17.8

SPECTRUM DATA

	D	E	F	G	H	A	B	C
0	13	17	13	12	14	11	11	12
1	13	17	12	18	15	10	9	11
2	16	12	23	14	12	20	13	13
3	12	15	18	14	17	21	14	14
4	13	17	15	7	13	19	13	12
5	14	15	11	12	16	12	14	16
6	20	16	14	21	13	9	13	9
7	12	14	12	17	19	19	19	12
8	9	16	9	13	11	14	8	13
9	15	15	13	14	9	12	5	14
10	13	13	13	15	16	13	8	12
11	11	19	14	8	11	16	14	24
12	10	17	13	18	13	14	13	25
13	17	11	13	10	18	12	15	18
14	9	18	13	13	20	11	12	14
15	14	13	14	9	8	14	8	18
16	12	16	18	16	14	10	9	11
17	18	20	17	12	9	16	12	15
18	10	14	11	15	17	17	19	13
19	15	18	11	17	12	19	15	12
20	15	16	20	20	15	10	11	15
21	20	34	14	18	22	14	7	11
22	13	26	11	12	9	20	11	15
23	21	18	21	7	13	9	17	24
24	13	8	17	18	14	12	20	19
25	12	14	13	11	15	16	15	22
26	13	12	12	6	16	18	8	12
27	16	15	13	14	18	18	13	13
28	13	9	15	17	15	10	17	17
29	14	9	9	20	10	10	13	14
30	15	8	16	11	12	17	20	15
31	19	9	13	12	14	16	17	14
32	12	14	15	9	10	10	20	21
33	15	11	17	19	20	16	15	16
34	13	9	8	17	13	16	18	9
35	13	13	12	14	15	13	20	15
36	15	18	14	18	17	7	19	14
37	11	17	20	16	17	16	18	13
38	17	12	16	11	20	13	26	12
39	14	13	13	19	12	17	13	19
40	16	13	10	14	12	13	17	12
41	15	10	10	20	13	12	10	11
42	16	13	15	15	12	16	17	13
43	8	15	17	11	18	22	16	19
44	17	16	10	15	17	11	12	8
45	12	15	23	16	8	13	13	15
46	18	8	13	10	11	7	15	12
47	14	8	11	10	12	17	10	17
48	14	8	13	9	10	18	17	15
49	13	13	19	14	20	9	14	13
50	16	15	7	20	15	13	17	12
51	14	19	13	16	13	17	19	11
52	13	17	17	18	17	16	19	13
53	14	20	22	9	15	11	19	12
54	19	13	9	18	10	9	19	17
55	11	9	15	10	16	18	19	6
56	14	14	15	13	13	20	13	16
57	11	10	11	10	16	5	8	9
58	17	11	12	20	10	19	12	14
59	16	9	18	16	14	13	8	11
60	13	17	15	16	10	15	5	13
61	17	15	15	10	14	12	18	11
62	14	8	12	9	14	15	10	11
63	11	9	15	20	19	14	13	13

OMEGA PLOTS: C-E
10 SECONDS PER LINE (DOWN); 1/64 LANE PER CHARACTER (ACROSS).

C+E



APPENDIX C

SELECTED POSITIONAL ERROR DATA

SELECTED POSITIONAL ERROR DATA				
Event No.	Received LOP (B-D)	True LOP	LOP Error	Miles Error
1	Outbound			
9	970.85	970.26	.59	4.63
10	968.09	967.74	.35	2.75
11	965.24	965.13	.11	0.86
12	958.38	958.40	.02	0.16
13	955.40	955.45	.05	0.40
14	951.82	952.50	.68	5.34
23	940.24	940.30	.06	0.47

Note: No skywave correction applied to this data.

SELECTED POSITIONAL ERROR DATA				
Event No.	Received LOP (A-B) Uncorrected	True LOP	LOP Error	Miles Error
9	987.52	987.91	.39	3.51
10	988.24	988.59	.35	3.15
11	989.18	989.34	.16	1.44
12	992.45	992.48	.03	0.27
13	993.70	994.00	.30	2.70
14	995.42	995.43	.01	0.09
23	1001.48	1001.76	.28	2.52

Note: No skywave correction applied to this data.