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LEAST SQUARES ANALYSIS OF UNIFIED S-BAND SYSTEM DATA FROM AS-202

BY

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ABSTRACT

Results are presented of a preliminary analysis of Unified S-Band System high speed range rate and X-Y angular data acquired from the Merritt Island and the Bermuda ground stations during the AS-202 mission. The data analyzed were acquired under powered flight conditions. The procedure used in the analysis consisted of fitting polynomials in the least squares sense to tracking data over short time intervals. The resulting standard deviations of fit were used as measures of the noise characteristics of the data.

CONCLUSIONS

From the preliminary analysis presented here of Unified S-Band System high speed (10 samples/second) range rate and X-Y angular data acquired during the powered flight portion of AS-202, the following may be concluded:

(a) The standard deviation of the noise component of data acquired in the two-way mode at the Merritt Island ground station is 2.5 to 6.8 cm/sec. for range rate data, and 0.0019° (0.033 m rad) to 0.022° (0.38 m rad) for X- and Y-angular data. The specifications (ref. 1) call for an angular noise error no greater than 0.0086° (0.15 m rad).

(b) For data from the Bermuda ground station the standard deviation of the noise component is 3.1 to 3.4 cm/sec. for range rate data acquired in the two-way mode, 6.3 to 7.3 cm/sec. for data acquired in the multiple non-coherent mode; for X- and Y-angular data, 0.0036° (0.063 m rad) to 0.042° (0.73 m rad).

LEAST SQUARES ANALYSIS OF UNIFIED S-BAND SYSTEM DATA FROM AS-202

INTRODUCTION

The AS-202 mission involved active tracking by the ground stations at Merritt Island, Bermuda and Carnarvon. AS-202 provided the first opportunity for these stations to participate in a coherent or two-way tracking mode. Information regarding their performance during the flight was taken from ref. 2.

Launch time T was August 25, 1966 17^h 15^m 32.844^s. A total of about 23 minutes of tracking data was acquired. For a variety of reasons much was unusable; for example, high-speed data from Carnarvon were unusable because the proper start of frame sequence in the data recording could not be determined. Preliminary analysis (ref. 2) revealed no major ground equipment malfunctions at the Merritt Island and Bermuda ground stations.

The purpose of the analysis reported here is the determination of the noise characteristics of high-speed (10 samples/second) range rate and X-Y angular data acquired from Merritt Island and Bermuda. The analysis consisted of fitting polynomials in the least squares sense to tracking data over short time intervals (about 20 seconds of data). Polynomials of degree 2 to 8 were used on the range rate data and polynomials of degree 2 to 5 on the angular data. The data consists of "true" signals perturbed by noise. Least squares polynomials are approximations of the signal so that the residuals, data minus polynomial, approximate the noise. The criterion of goodness of fit used is that the polynomial best describing the signal in the data is the one that minimizes the standard deviation of the polynomial fit; that is, if the standard deviation from a polynomial of degree k + 1 is greater than or equal to that from a polynomial of degree k, then the polynomial of degree k best describes the signal in the data. The corresponding standard deviation is thus a measure of the noise component of the data.

Analysis using least squares polynomials is reported in ref. 3 for Unified S-Band System high speed range rate and X-Y angular data acquired during "fly-by" tests at the Merritt Island, Bermuda, and Carnarvon ground Stations in March and April, 1966.

RESULTS

Merritt Island Data

For seven minutes, from T + 3 to T + 460 seconds, Merritt Island maintained two-way lock with the spacecraft. Data in this interval were acquired under powered flight conditions. After editing, these data were generally equispaced at 10 samples per second. The least squares procedure was applied to 14 groups of 201 equispaced data points; these cover a time interval of 4.5 minutes. Tables 1 - 3 contain the standard deviations for the range rate, X-angle, and Y-angle residuals. The unusually large standard deviation for range rate noise in interval number 6 is attributable to second stage burn that occurred during this interval (at about T + 144 seconds). In general, the standard deviation of the range rate noise is 2.5 to 6.8 cm/sec. However, the standard deviation of the range rate noise is as high as 60 cm/sec. (Table 1, interval number 4). The standard deviation of the X-angle noise is 0.0019° (0.033 m rad) to 0.022° (0.38 m rad), and that for the Y-angle is 0.0024° (0.042 m rad) to 0.017° (0.30 m rad).

Typical range rate, X-angle, and Y-angle residuals are shown in Figures 1 - 3; they are from data in interval number 8 ($17^h\ 18^m\ 26.7^s$ to $17^h\ 18^m 46.7^s$).

Variations in the standard deviation of the residuals as a function of the degree of the least squares polynomial are illustrated in Figures 4-6 for several groups of range rate, X-angle, and Y-angle data from Merritt Island. These variations, due in part to numerical roundoff, are typical of those resulting from the least squares data analysis reported here.

From T + 460 seconds to T + 482 seconds, when the reference receiver dropped lock because of weak signals, Merritt Island maintained one-way lock with the spacecraft. Data from this period were not analyzed.

Bermuda Data

Until T + 412 seconds Bermuda was in autotrack in a multiple non-coherent mode. At this time the Bermuda receiver loop lock was lost and was not regained until T + 478 seconds. From T + 520 seconds to T + 604 seconds, when the spacecraft entered the antenna keyhole, the tracking mode was two-way. After the spacecraft emerged from the keyhole, 14 seconds of autotrack data were acquired before the signal was lost at T + 724 seconds. Data acquired in both the multiple non-coherent and two-way modes were analyzed; these data were acquired under powered flight conditions. After editing, the data generally were not equispaced. They were broken into groups of 101 points. There were four groups of data acquired in one-way mode (covering a time interval of 71

seconds), and 3 groups of data acquired in two-way mode (covering a time interval of 46 seconds). The least squares procedure was then applied. Tables 4-6 contain the standard deviations for the Bermuda range rate, X-angle, and Y-angle residuals. In general the standard deviation of the range rate noise is 6.3 to 7.3 cm/sec. for data acquired in the multiple non-coherent mode, and 3.1 to 3.4 cm/sec. for two-way mode. The standard deviation of the X-angle noise is 0.0098° (0.17 m rad) to 0.042° (0.73 m rad), and that for the Y-angle is 0.0036° (0.063 m rad) to 0.025° (0.44 m rad).

REFERENCES

1. GSFC-TDS-RFS-220; "Performance Specifications on Acquisition Tracking Receiver," July 8, 1964, page 8, paragraph 3.3.3.10.

2. "Performance Evaluation of the Unified S-Band Ground System for AS-202," Report No. X-506-66-585, Goddard Space Flight Center, Greenbelt, Maryland, November 1, 1966.

3. Kahn, W. D., "Apollo-USB Flyby Tests, A Preliminary Quick Look Noise Analysis," Report No. X-507-66-464, Goddard Space Flight Center, Greenbelt, Maryland, September 1966.

Table 1
Summary of Noise Characteristics of Range Rate Data Acquired from the Merritt Island USB Station During AS-202, August 25, 1966

Interval No.	Date 1966	Initial Time	Final Time	No. of Points*	Degree of Polynomial	Standard Deviation of Residuals (cm/sec)
		Hr-Min-Sec	Hr-Min-Sec			
1	8/25	17-16- 6.0	17-16-26.0	201	8	4.82
2	8/25	17-16-26.1	17-16-46.1	201	8	6.77
3	8/25	17-16-42.2	17-17- 6.2	201	7	3.89
4	8/25	17-17- 6.3	17-17-26.3	201	8	59.8
5	8/25	17-17-26.4	17-17-46.4	201	5	31.5
6	8/25	17-17-46.5	17-18- 6.5	201	8	204.0
7	8/25	17-18- 6.6	17-18-26.6	201	6	6.51
8	8/25	17-18-26.7	17-18-46.7	201	6	2.88
9	8/25	17-18-46.8	17-19- 6.8	201	6	2.49
10	8/25	17-19- 6.9	17-19-26.9	201	4	2.70
11	8/25	17-19-27.0	17-19-47.0	201	3	2.90
12	8/25	17-19-47.1	17-20- 7.1	201	5	2.97
13	8/25	17-20- 7.2	17-20-27.2	201	6	3.19
14	8/25	17-22- 7.2	17-22-27.2	201	4	6.31

*10 samples per second

Table 2
Summary of Noise Characteristics of X-angle Data Acquired from the Merritt Island USB Station During AS-202, August 25, 1966

Interval No.	Date 1966	Initial Time	Final Time	No. of Points*	Degree of Polynomial	Standard Deviation of Residuals	
		Hr-Min-Sec	Hr-Min-Sec			deg	m rad
1	8/25	17-16- 6.0	17-16-26.0	201	3	0.014	0.24
2	8/25	17-16-26.1	17-16-46.1	201	4	0.022	0.38
3	8/25	17-16-42.2	17-17- 6.2	201	3	0.0082	0.14
4	8/25	17-17- 6.3	17-17-26.3	201	5	0.0042	0.073
5	8/25	17-17-26.4	17-17-46.4	201	5	0.0088	0.15
6	8/25	17-17-46.5	17-18- 6.5	201	4	0.0022	0.038
7	8/25	17-18- 6.6	17-18-26.6	201	5	0.0019	0.033
8	8/25	17-18-26.7	17-18-46.7	201	4	0.0081	0.14
9	8/25	17-18-46.8	17-19- 6.8	201	3	0.0041	0.072
10	8/25	17-19- 6.9	17-19-26.9	201	5	0.0028	0.049
11	8/25	17-19-27.0	17-19-47.0	201	5	0.0038	0.066
12	8/25	17-19-47.1	17-20- 7.1	201	5	0.0062	0.11
13	8/25	17-20- 7.2	17-20-27.2	201	4	0.012	0.21
14	8/25	17-22- 7.2	17-22-27.2	201	2	0.014	0.24

*10 samples per second

Table 3
Summary of Noise Characteristics of Y-Angle Data Acquired from the Merritt Island USB Station During AS-202, August 25, 1966

Interval No.	Date 1966	Initial Time	Final Time	No. of Points*	Degree of Polynomial	Standard Deviation of Residuals	
		Hr-Min-Sec	Hr-Min-Sec			deg	m rad
1	8/25	17-16- 6.0	17-16-26.0	201	4	0.016	0.28
2	8/25	17-16-26.1	17-16-46.1	201	5	0.017	0.30
3	8/25	17-16-42.2	17-17- 6.2	201	3	0.011	0.19
4	8/25	17-17- 6.3	17-17-26.3	201	4	0.0087	0.15
5	8/25	17-17-26.4	17-17-46.4	201	5	0.0054	0.094
6	8/25	17-17-46.5	17-18- 6.5	201	5	0.0024	0.042
7	8/25	17-18- 6.6	17-18-26.6	201	5	0.0024	0.042
8	8/25	17-18-26.7	17-18-46.7	201	5	0.0083	0.14
9	8/25	17-18-46.8	17-19- 6.8	201	4	0.0034	0.059
10	8/25	17-19- 6.9	17-19-26.9	201	4	0.0031	0.054
11	8/25	17-19-27.0	17-19-47.0	201	3	0.0047	0.082
12	8/25	17-19-47.1	17-20- 7.1	201	4	0.0077	0.13
13	8/25	17-20- 7.2	17-20-27.2	201	4	0.011	0.19
14	8/25	17-22- 7.2	17-22-27.2	201	3	0.011	0.19

*10 samples per second

Table 4
Summary of Noise Characteristics of Range Rate Data Acquired from the Bermuda USB Station During AS-202, August 25, 1966

Interval No.	Date 1966	Initial Time	Final Time	No. of Points	Degree of Polynomial	Standard Deviation of Residuals (cm/sec)
		Hr-Min-Sec	Hr-Min-Sec			
1*	8/25	17-20-52.4	17-21- 9.1	101	7	6.25
2*	8/25	17-21- 9.2	17-21-27.9	101	8	7.33
3*	8/25	17-21-28.0	17-21-45.0	101	7	6.89
4*	8/25	17-21-45.1	17-22- 2.9	101	7	6.36
5**	8/25	17-24-18.4	17-24-38.2	101	7	3.18
6**	8/25	17-24-38.3	17-24-48.3	101	6	3.37
7**	8/25	17-24-48.4	17-25- 4.7	101	8	3.13

*Multiple Non-Coherent Mode
**Two-Way Mode

Table 5
Summary of Noise Characteristics of X-angle Data Acquired from the Bermuda USB Station During AS-202, August 25, 1966

Interval No.	Date 1966	Initial Time	Final Time	No. of Points	Degree of Polynomial	Standard Deviation of Residuals	
		Hr-Min-Sec	Hr-Min-Sec			deg	m rad
1*	8/25	17-20-52.4	17-21- 9.1	101	2	0.030	0.52
2*	8/25	17-21- 9.2	17-21-27.9	101	5	0.028	0.49
3*	8/25	17-21-28.0	17-21-45.0	101	5	0.042	0.73
4*	8/25	17-21-45.1	17-22- 2.9	101	5	0.027	0.47
5**	8/25	17-24-18.4	17-24-38.2	101	5	0.0098	0.17
6**	8/25	17-24-38.3	17-24-48.3	101	5	0.013	0.23
7**	8/25	17-24-48.4	17-25- 4.7	101	5	0.013	0.23

*Multiple Non-Coherent Mode
**Two-Way Mode

Table 6
Summary of Noise Characteristics of Y-angle Data Acquired from the Bermuda USB Station During AS-202, August 25, 1966

Interval No.	Date 1966	Initial Time	Final Time	No. of Points	Degree of Polynomial	Standard Deviation of Residuals	
		Hr-Min-Sec	Hr-Min-Sec			deg	m rad
1*	8/25	17-20-52.4	17-21- 9.1	101	4	0.0097	0.17
2*	8/25	17-21- 9.2	17-21-27.9	101	5	0.016	0.28
3*	8/25	17-21-28.0	17-21-45.0	101	4	0.016	0.28
4*	8/25	17-21-45.1	17-22- 2.9	101	4	0.025	0.44
5**	8/25	17-24-18.4	17-24-38.2	101	5	0.0036	0.063
6**	8/25	17-24-38.3	17-24-48.3	101	5	0.0045	0.079
7**	8/25	17-24-48.4	17-25- 4.7	101	5	0.0045	0.079

*Multiple Non-Coherent Mode
**Two-Way Mode

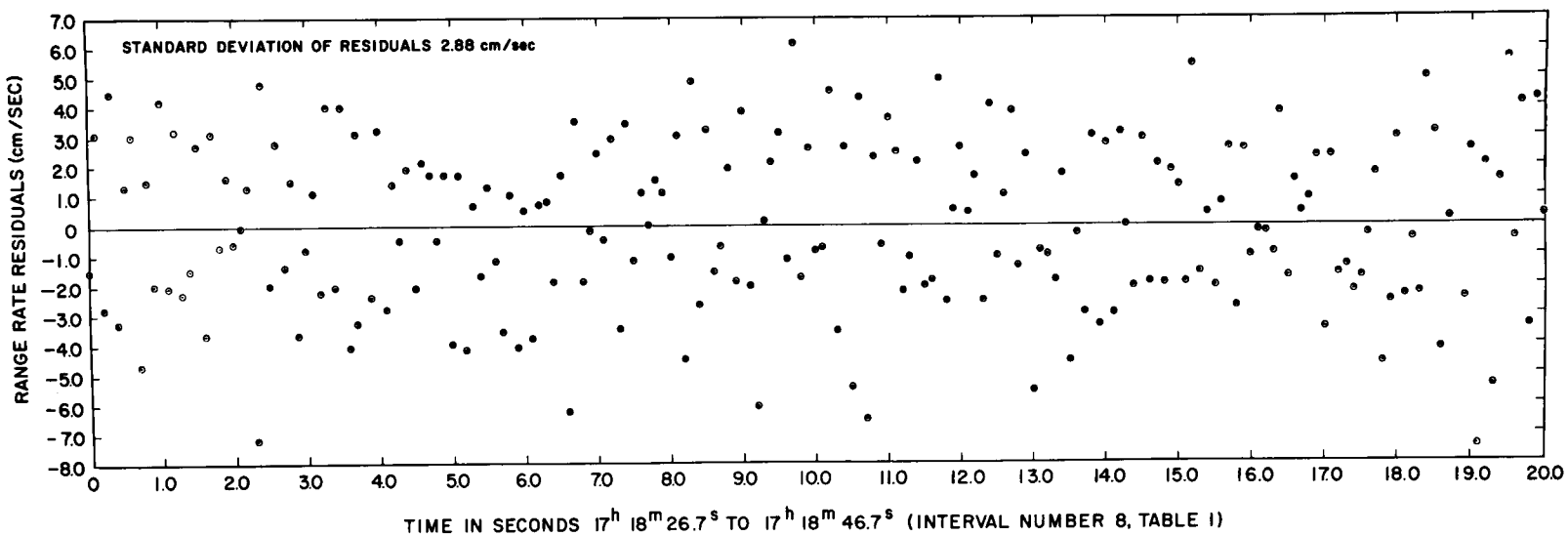


Figure 1–Merritt Island Range Rate Residuals from Least Squares Polynomial of Degree 6, AS-202, August 25, 1966.

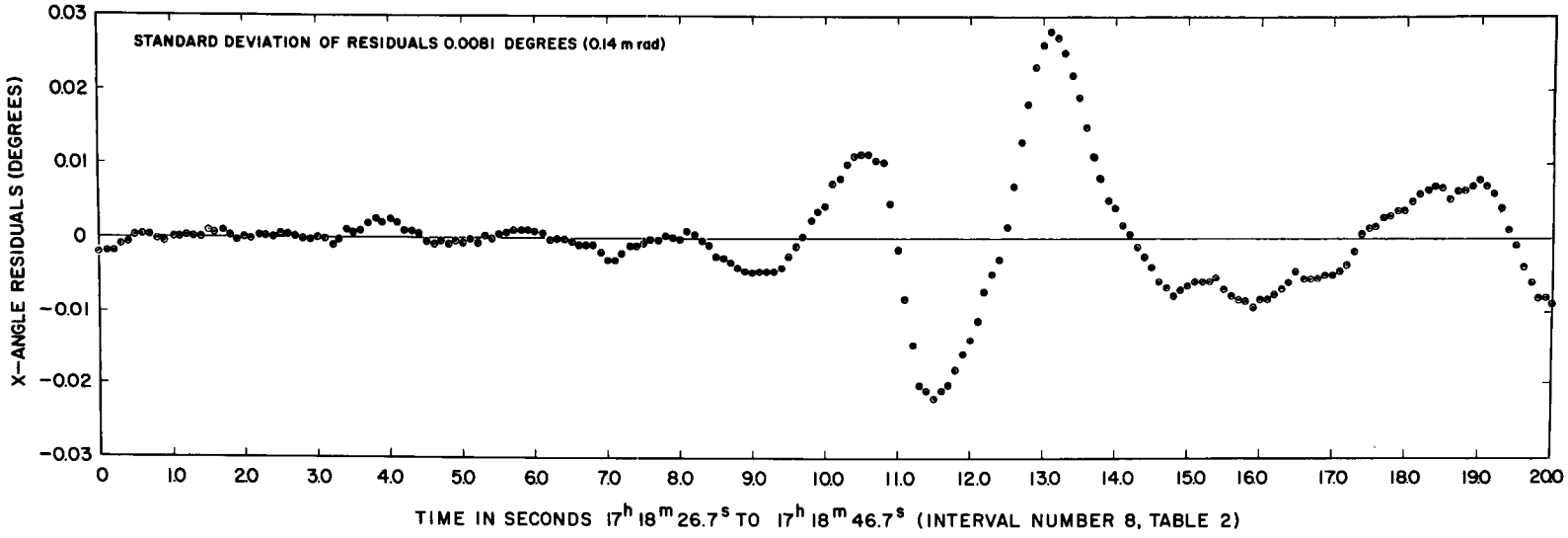


Figure 2–Merritt Island X-Angle Residuals from Least Squares Polynomial of Degree 4, AS-202, August 25, 1966.

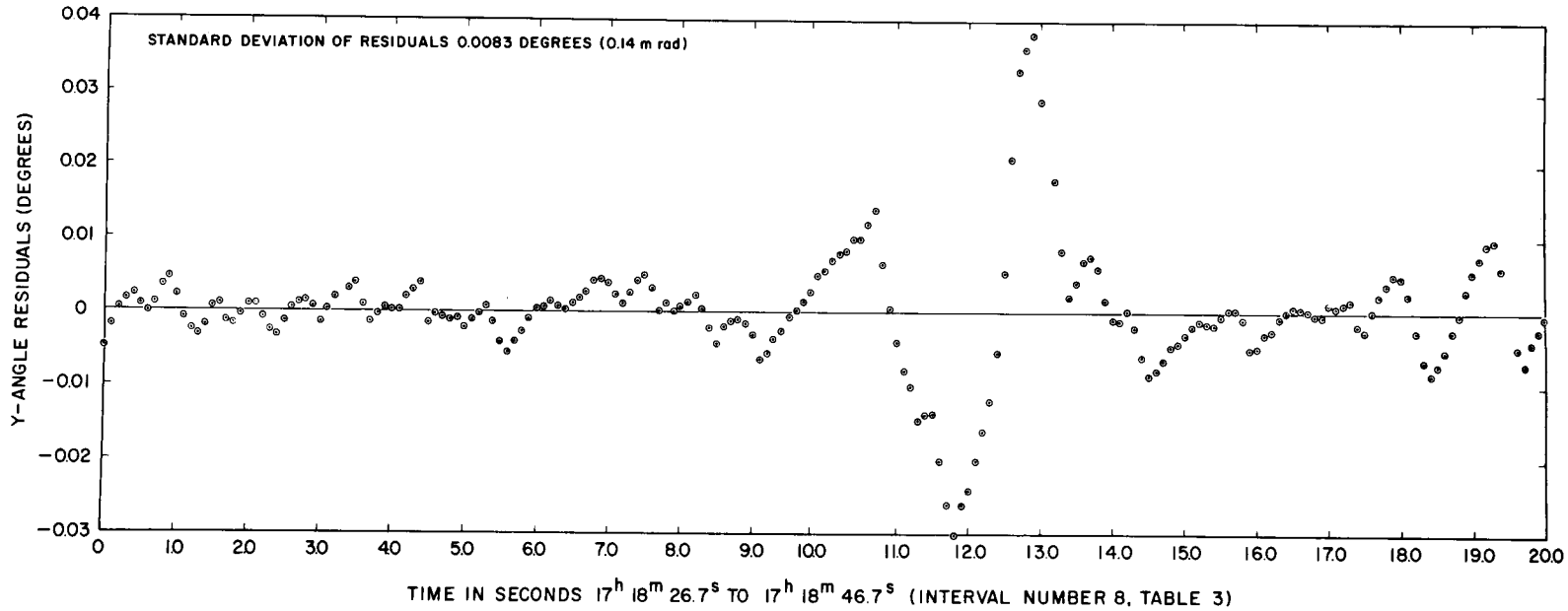
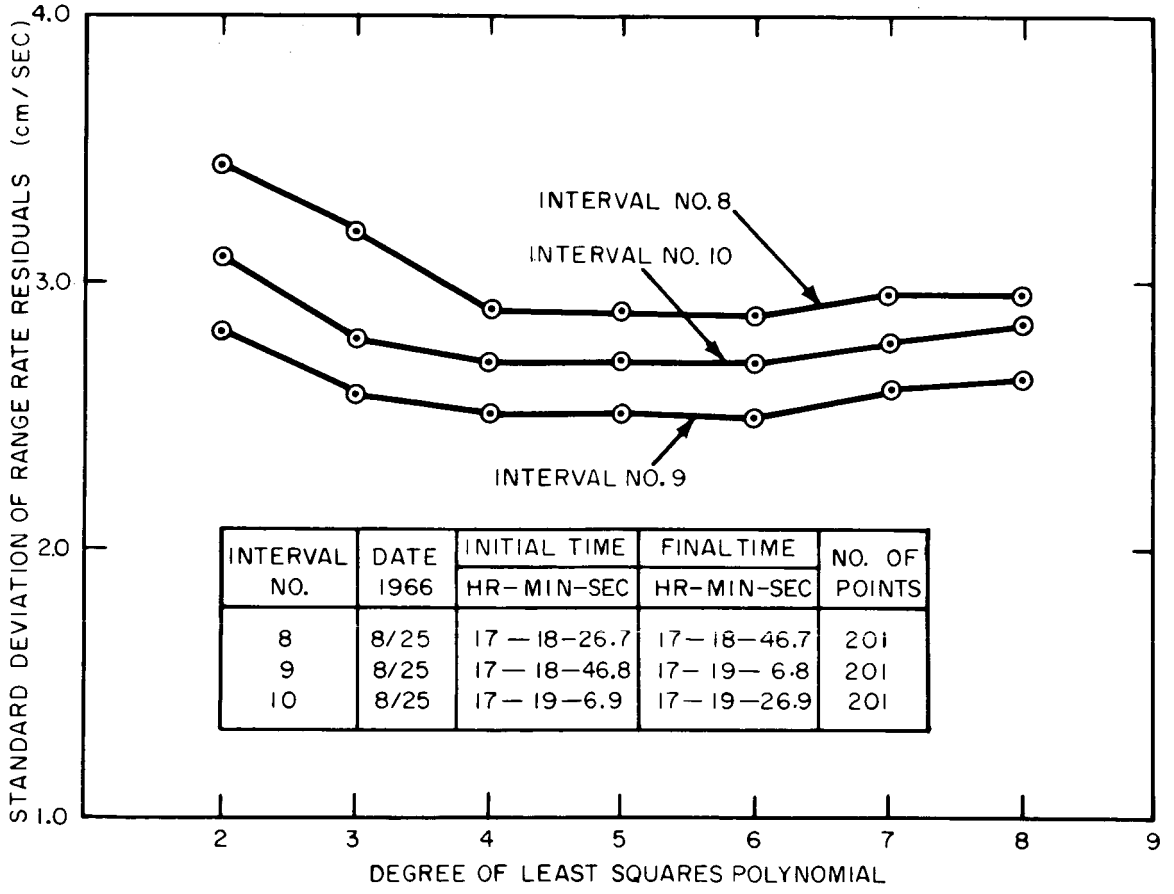
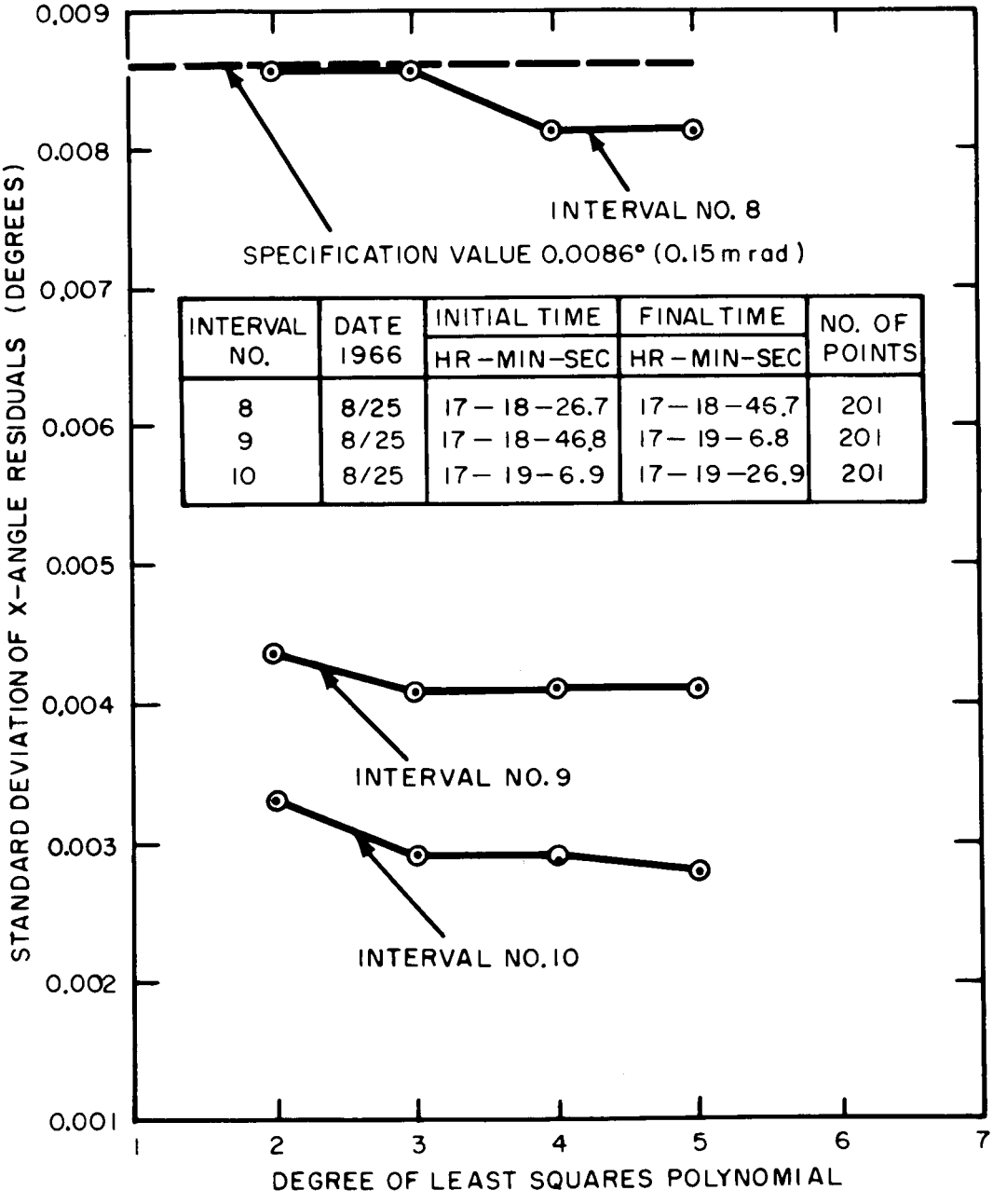


Figure 3–Merritt Island Y-Angle Residuals from Least Squares Polynomial of Degree 5, AS-202, August 25, 1966.



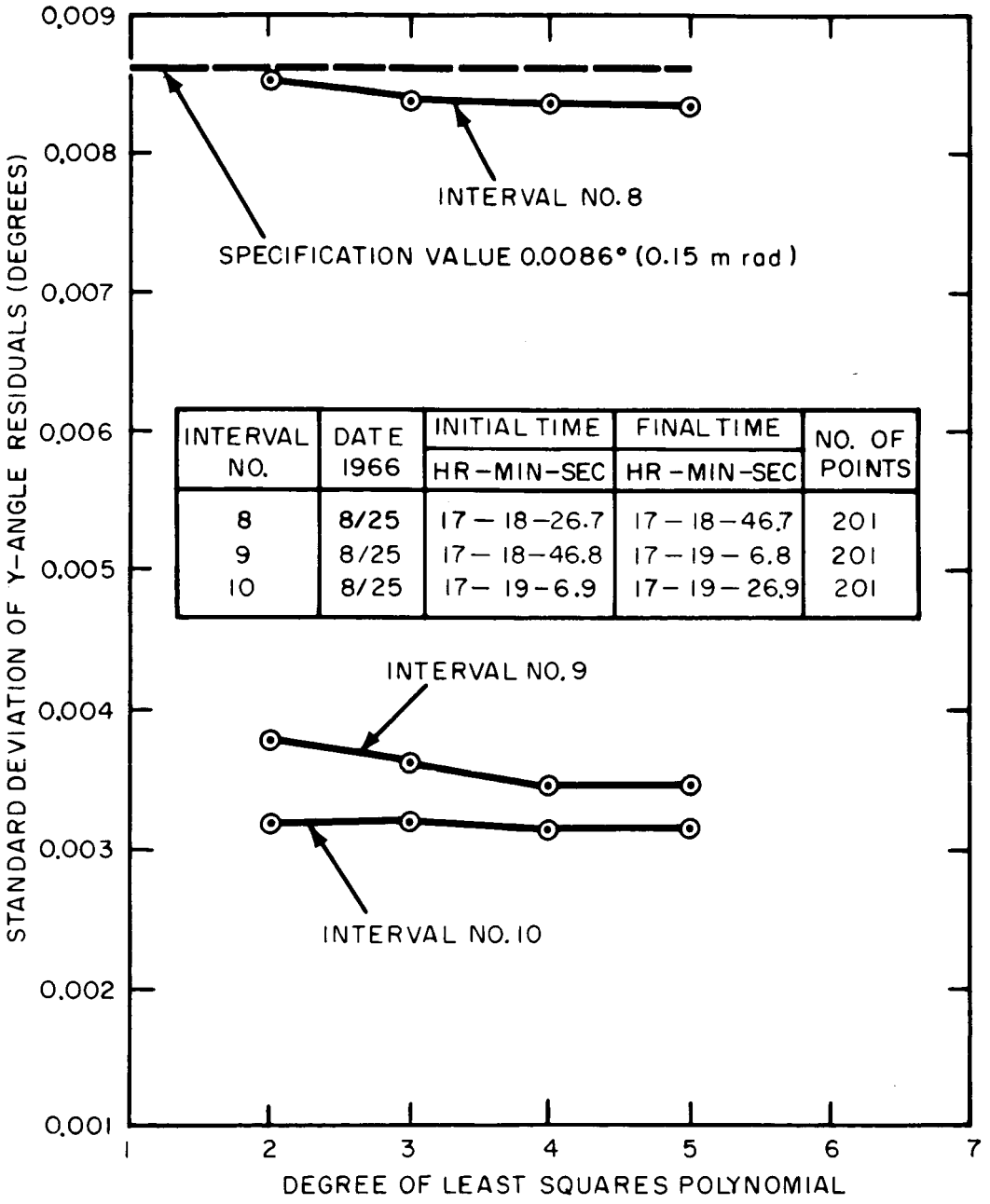
INTERVAL NO.	DATE 1966	INITIAL TIME HR-MIN-SEC	FINAL TIME HR-MIN-SEC	NO. OF POINTS
8	8/25	17 — 18–26.7	17 — 18—46.7	201
9	8/25	17 — 18—46.8	17 — 19— 6.8	201
10	8/25	17 — 19—6.9	17 — 19—26.9	201

Figure 4–Noise Characteristics of Merritt Island Range Rate Data from AS-202, August 25, 1966.



INTERVAL NO.	DATE 1966	INITIAL TIME HR-MIN-SEC	FINAL TIME HR-MIN-SEC	NO. OF POINTS
8	8/25	17-18-26.7	17-18-46.7	201
9	8/25	17-18-46.8	17-19-6.8	201
10	8/25	17-19-6.9	17-19-26.9	201

Figure 5–Noise Characteristics of Merritt Island X-Angle Data from AS-202, August 25, 1966.



INTERVAL NO.	DATE 1966	INITIAL TIME HR-MIN-SEC	FINAL TIME HR-MIN-SEC	NO. OF POINTS
8	8/25	17 – 18 – 26.7	17 – 18 – 46.7	201
9	8/25	17 – 18 – 46.8	17 – 19 – 6.8	201
10	8/25	17 – 19 – 6.9	17 – 19 – 26.9	201

Figure 6–Noise Characteristics of Merritt Island Y-Angle Data from AS-202, August 25, 1966.