NASA TECHNICAL MEMORANDUM

NASA TM X-53585

March 3, 1967

NASA TM X-53585

TEMS RADAR ERROR MODEL REGRESSION ANALYSIS RESULTS FROM THE SATURN AS-201, AS-202, AND SA-203 FLIGHT TESTS

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ABSTRACT

The TEMS method for evaluating systematic errors in radar tracking system measurements is illustrated with data from the 201 and 202 Apollo-Saturn tests and the 203 Saturn test. On the basis of results from these three tests, it appears that error model coefficient values are not repeatable from test to test. It is also noted that the standard deviations for several of the coefficients do not vary significantly from radar to radar on the three flights. The average random errors remaining in the residuals for the three flights are .0053 degrees and .0080 degrees in azimuth and elevation, respectively, and 3.55 meters in range. The occurrence of the various terms on each test and for each radar indicates that no less than five and no more than nine terms are required in the truncated error models.

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COMPUTATION LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

DEFINITION OF SYMBOLS

Symbol	Definition
$\Delta R, \Delta A, \Delta E$	functional expressions for the systematic errors in range, azimuth, and elevation, respectively
$\Delta R^{\circ}, \Delta A^{\circ}, \Delta E^{\circ}$	observed tracking errors in range, azimuth, and elevation, respectively
$V_R, V_A, V_E,$	residuals in range, azimuth and elevation, respectively
TEMS	acronym for Tracking System Error Model Studies
$C_0, C_1, \ldots$	coefficients in range error model
$D_0, D_1, \ldots$	coefficients in azimuth error model
$F_0, F_1, \ldots$	coefficients in elevation error model
$R^{\circ}, A^{\circ}, E^{\circ}$	measured tracking parameters in range, azimuth, and elevation, respectively
R^r, A^r, E^r	reference tracking parameters in range, azimuth, and elevation, respectively
X_e, Y_e, Z_e	reference position of vehicle in an earth-fixed plumbline coordinate system with origin at the launch site
X_{es}, Y_{es}, Z_{es}	reference position of vehicle in an earth-fixed plumbline coordinate system with origin at the tracking site
X, Y, Z	reference position of vehicle in an earth-fixed ephemeris coordinate system with origin at the tracking site
h_L, h_T	height of launch site and tracking site, respectively, above reference ellipsoid
Φ_L, λ_L	geodetic latitude and geocentric longitude, respectively, of launch site

Symbol	Definition
Φ_T, λ_T	geodetic latitude and geocentric longitude, respectively, of tracking site
K_L	firing azimuth of vehicle
$\hat{a}$, $\hat{b}$	semi-major and semi-minor axes, respectively, of reference ellipsoid
σ^2_{VR}, σ^2_{VA}, σ^2_{VE}	least squares residual variances in range, azimuth, and elevation, respectively
σ_0^2	unit variance
ρ_{ij}	correlation coefficient for i-th and j-th error model coefficients
$\bar{\dot{W}}$	parameter weight matrix
$\bar{C}$	parameter approximation matrix
$\bar{C}^{\infty}$	parameter a priori matrix
$\bar{\delta}$	parameter correction matrix
$\sigma^2_{C_0}$, $\sigma^2_{C_1}$, ...	parameter variances
$\bar{\bar{W}}$	observational weight matrix
$\sigma_0^2 (\bar{B}^T \bar{\bar{W}} \bar{B} + \bar{\dot{W}})^{-1}$	variance-covariance matrix of the regression parameters

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SUMMARY

The TEMS method for evaluating systematic errors in radar tracking system measurements is illustrated with data from the 201 and 202 Apollo-Saturn tests and the 203 Saturn test. On the basis of results from these three tests, it appears that error model coefficient values are not repeatable from test to test. It is also noted that the standard deviations for several of the coefficients do not vary significantly from radar to radar on the three flights. The average random errors remaining in the residuals for the three flights are .0053 degrees and .0080 degrees in azimuth and elevation, respectively, and 3.55 meters in range. The occurrence of the various terms on each test and for each radar indicates that no less than five and no more than nine terms are required in the truncated error models.

TEMS RADAR ERROR MODEL REGRESSION ANALYSIS RESULTS FROM THE SATURN AS-201, AS-202, AND SA-203 FLIGHT TESTS

SECTION I. INTRODUCTION

The problem of evaluating systematic errors in tracking system measurements is of primary concern with regard to determining an accurate flight trajectory from the basic tracking measurements. A method for accomplishing this evaluation is provided in TEMS, an acronym for Tracking System Error Model Studies. Basically, the evaluation involves establishing the tracker errors and then determining error model expressions to describe these established errors. The detailed development of TEMS for radar tracking systems is documented in [1] and [2]. Reference [3] contains a similar development of TEMS for the AZUSA (Glotrac Station I) tracking system. Optimal values for the coefficients of each error model can be estimated from the regression analysis presented in [1]. The explicit mathematical development for a rigorous least squares adjustment of radar error model parameters with constraints is presented in [2]. The method in [2] is a modification and an improvement of the procedures presented in [1] to include provisions for the utilization of a priori values for the error model parameters and their variances. A difficulty involved in the regression analysis used to evaluate the tracking system errors is the intercorrelation of various terms in the error models. The results can be misleading if two or more correlated terms or coordinate functions are similar. A high random error (noise) content in the data may prevent a systematic error of comparable magnitude from being determined. The unmodeled systematic errors remaining in the residuals, if significant, can be attributed to uncertainties in the assumed standard, unknown systematic errors not absorbed by those that are modeled, and/or geometry limitations. The presence of a significant unmodeled systematic error may prevent an adequate description of the tracking errors from being obtained.

Application of the TEMS method to radar tracking systems is illustrated in [1] and [2] using data from the Apollo-Saturn (AS) 201 and 202 Flight Tests, respectively. A summary of the AS-201 results is included in [2]. This report presents the TEMS radar results obtained from the regression analysis on the Saturn (SA) 203 Flight Test. Included is a summary of the AS-201 and AS-202 results presented in [1] and [2]. On the basis of results from these three flights, it appears that error model coefficient values are not repeatable from test to test or from radar to radar. It is also noted that the standard deviations for several of the coefficients do not vary significantly from test to test or from radar to radar. The frequency of occurrence of the various terms on each of the three flights and for each radar indicates that no less than five and no more than nine terms are required in the truncated error models.

The work herein and in [1], [2], and [3] has been performed under the sponsorship of Messrs. Max Horst and J. B. Haussler of the Flight Evaluation Branch in the Aero-Astrodynamics Laboratory.

SECTION II. DISCUSSION

A. THE BASIC RADAR TRACKING SYSTEM ERROR MODELS

The basic radar error models for describing the systematic errors in the range, azimuth, and elevation measurements are given by the following equations:

Range

$$\Delta R = C_0 + C_1 R + C_2 \dot{R} + C_3 t + C_4 (-.022 \operatorname{cosec} E) + C_5 \left(\frac{X}{R} \right) + C_6 \left(\frac{Y}{R} \right) + C_7 \left(\frac{Z}{R} \right) \quad (2.1)$$

Azimuth

$$\Delta A = D_0 + D_1 \dot{A} + D_3 \ddot{A} + D_5 \tan E + D_6 \sec E + D_7 \tan E \sin A + D_8 \tan E \cos A + D_9 \left(\frac{\sin A \cos A}{X} \right) + D_{10} \left(\frac{-\sin A \cos A}{Y} \right) + D_{11} \dot{A} \sec E \quad (2.2)$$

Elevation

$$\Delta E = F_0 + F_1 \dot{E} + F_3 \ddot{E} + F_5 (-\sin A) + F_6 \cos A + F_7 \left[\left(\frac{.022}{R \sin E} - 10^{-6} \right) \operatorname{cotan} E \right] + F_9 \left(\frac{-X \tan E}{R^2} \right) + F_{10} \left(\frac{-Y \tan E}{R^2} \right) + F_{11} \left(\frac{\cos E}{R} \right) + F_{12} \dot{E} \cos E \quad (2.3)$$

These equations are repeated here to assist in interpreting the results. The specific physical interpretation of the various terms in each model is given in [1]. Constraints in the form of functional relations between the coefficients in equations (2.1), (2.2), and (2.3) are given by:

$$\left.\begin{aligned} C_2 &= D_1 = F_1 \\ C_4 &= F_7 \\ C_5 &= D_9 = F_9 \\ C_6 &= D_{10} = F_{10} \\ C_7 &= F_{11} \\ D_8 &= F_5 \\ D_7 &= F_6 \end{aligned}\right\} \qquad (2.4)$$

B. TEMS/ RADAR COMPUTER PROGRAM

The IBM 7094 FORTRAN IV Computer Program has been developed such that any combination of terms appearing in the basic error models can be retained in a given adjustment by the use of appropriate program control matrices. The setup of these matrices is discussed in [1]. A diagram of the flow of computations through the program is summarized in Figure 1.

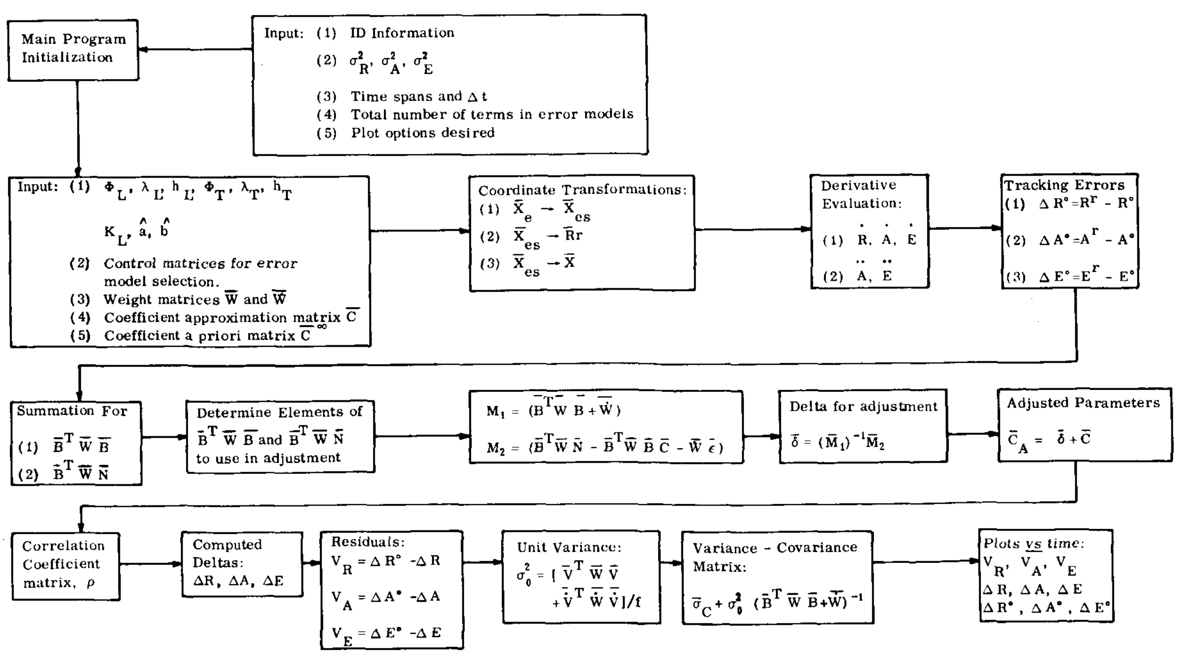

FIGURE 1. TEMS/ RADAR LEAST SQUARES ADJUSTMENT PROGRAM FLOW

The approach to modifying the total error models has, generally, resulted in acceptable truncated error models. It is, however, time consuming and has required an average of about 10-12 runs per radar on each test.

SECTION III. RESULTS FROM SATURN 203 VEHICLE FLIGHT TEST

A. GENERAL INFORMATION

The Saturn 203 Vehicle was launched from Cape Kennedy on July 5, 1966 at $9^H\ 53^M\ 17^S$ Eastern Standard Time. The relation between the SA-203 flight path and the various radar tracking sites is shown in Figure 2. The postflight reference trajectory used as the standard and detailed discussions of the various data sources are presented in [4]. Event times that are important for the TEMS reduction are the S-IB/ S-IVB separation (143.44 sec.) and S-IVB CO (433.348 sec.). Preliminary data from Radars 0.18, 19.18, 3.18, 7.18, and BDA were corrected for refraction prior to processing. The geographic coordinates and elevations

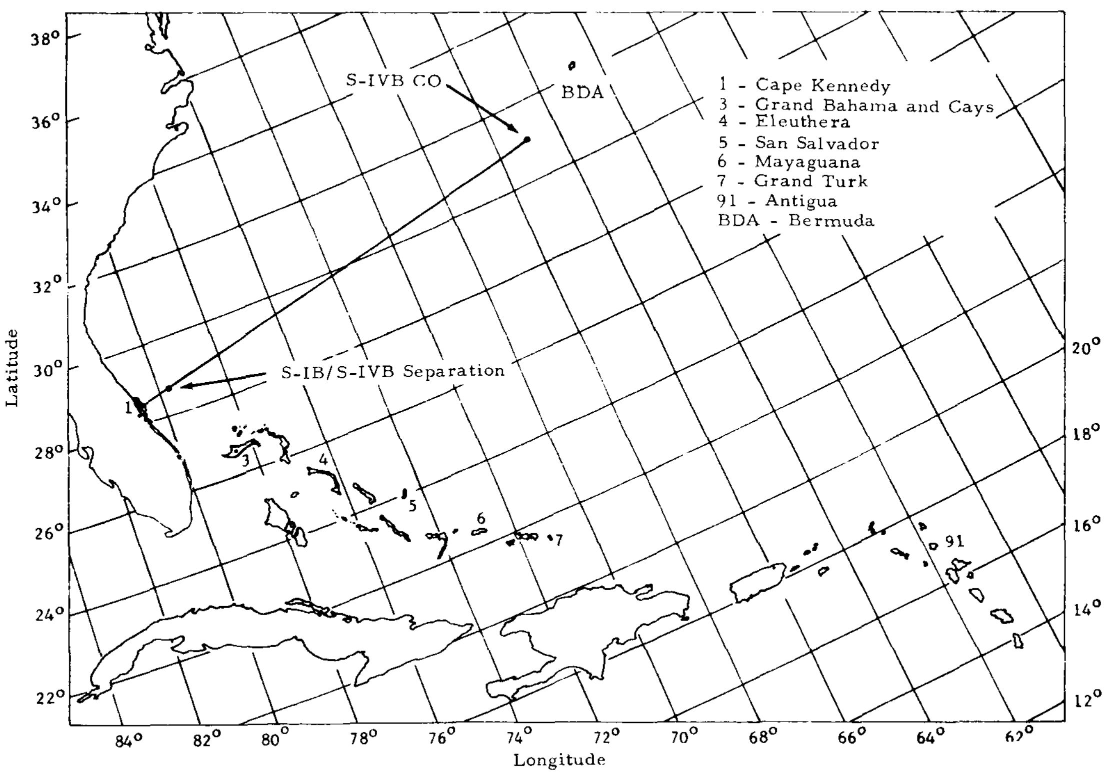

FIGURE 2. GEOMETRICAL RELATION BETWEEN SA-203 FLIGHT PATH AND THE TRACKING STATIONS

above the Fischer Ellipsoid for Launch Pad 37B and the various tracking radar sites are given in Table 1.

The time spans of preliminary SA-203 radar IU beacon track data used in the TEMS reduction are shown in Figure 3. These usable data were determined by making a first edit pass through the computer program. This provided a comparison of the reference tracking measurements and the radar tracking measurements whereby the tracking errors could be established.

B. RADAR MULTIPLE REGRESSION RESULTS

The preliminary edited data for all the radars were processed with the parameter weight matrix ($\overline{\dot{W}}$) and approximation matrix ($\overline{C}$) equal to zero. A priori estimates of zero for the error model coefficients were also entered into the adjustment.

Fifteen error model coefficients on Radars 3.18, 7.18, and BDA, and 12 coefficients on Radars 0.18 and 19.18 were solved for in the total error model regressions. As on the AS-201 and AS-202 flight tests, results for the first run total error models showed extremely high correlation between certain of the coefficients. The SA-203 truncated error model results are summarized in Tables 2 and 3. Additional information is given in Appendix C and includes plots of the observed and computed deltas, and the least squares residuals.

It was determined that the tracking errors in the range measurements from Radar 0.18 could be sufficiently described by the bias (C_o), scale factor (C_1) and refraction (C_4) errors. Regression runs were made with and without the correlated terms C_1 and C_4. It was found that both of these terms were required. Various runs also indicated retaining only D_0 and D_3 in azimuth and F_0 and F_3 in elevation.

The same terms used to describe the tracking errors on Radar 0.18 were obtained in the truncated error models for Radar 19.18. It was found that both of the correlated terms C_1 and C_4 were required to describe the range variation. The noise content in the 19.18 data appears to be below the input estimates of 5 meters in R and .006 degrees in A and E.

Three highly correlated terms were retained in the truncated range error model on Radar 3.18 - the bias (C_o), scale factor (C_1), and timing (C_2) terms.

TABLE 1. LOCATION OF LAUNCH SITE AND TRACKING RADARS USED IN TEMS SA-203 REDUCTION

Site	Latitude, deg.	Longitude, deg.	Height* , m.
Launch Pad 37B	28.531857	80.564953	57.00**
Patrick Radar (0.18)	28.226553	80.599293	15.51
Merritt Island Radar (19.18)	28.424862	80.664404	12.02
Grand Bahama Radar (3.18)	26.636350	78.267708	12.05
Grand Turk Radar (7.18)	21.462890	71.132114	28.45
Bermuda Radar (BDA)	32.348103	64.653801	24.31

* Elevation above the Fischer Ellipsoid

** Elevation of the radar antenna above the Fischer Ellipsoid

TABLE 2. TRUNCATED RADAR ERROR MODEL MULTIPLE REGRESSION RESULTS ON AS-201, AS-202, AND SA-203 VEHICLE FLIGHT TESTS

Radar	Test No.	COEFFICIENT											σ_{VR} m.	σ_{VA} Deg.	σ_{VE} Deg.	No. of Data Points
		C_0	C_1	C_2	C_4	D_0	D_3	D_5	D_7	D_8	F_0	F_3				
0.18	201	-	-	-.0197	-172.32	-.0142	-	.0139	-	-	.000115	-	3.30	.0049	.0086	323
	202	30.39	-	.0055	- 18.49	-.0040	.0094	-	-	.0172	.0212	1.084	3.65	.0050	.0068	377
	203	15.37	-.446E-4	-	-271.06	-.00067	.5220	-	-	-	.0112	-.2633	2.33	.0082	.0086	259
19.18	201	-	.075 E-4	-.0105	-	-.000101	-	-	-	-	.0036	.3424	3.13	.0049	.0061	455
	202	57.57	.349E-4	-	-23.29	.0016	-1.253	-.0362	.0143	-	.0368	.1828	4.64	.0071	.0070	360
	203	51.61	-.500E-4	-	-275.03	.0020	.4070	-	-	-	.0398	-1.189	1.86	.0039	.0045	279
3.18	201	-7.65	-.197E-4	.0013	-	.0143	.0975	-	-.0016	-	.0371	-	6.36	.0044	.0128	427
	202	55.19	-	.0039	-77.15	-.00086	.430	-	-	.0043	.0181	.0846	2.69	.0034	.0085	435
	203	-72.32	2.087E-4	-.0273	-	-	.3084	.0492	-	.0038	.0348	.0586	2.96	.0068	.0079	270
7.18	201	-	-.638E-4	.0027	-	-.0047	-1.667	-	-	-.0072	.0041	1.049	7.13	.0060	.0051	536
	202	25.54	-	.0048	29.78	.0043	.2910	-	-	.0059	-.0092	-	1.74	.0040	.0074	338
	203	-85.14	-	.0073	-195.46	.000251	-	-	-	-	.0113	-	2.93	.0055	.0115	168
91.18	201	47.02	-1.260E-4	.0014	-	.0038	-1.639	-	-	-.0125	.0054	-2.204	7.59	.0050	.0076	342
	202	-	-	.0024	-7.67	-.0092	-	.0975	-	-	.0191	-	1.49	.0070	.0111	73
	203	NA														
BDA	201	NA														
	202	NA														
	203	84.68	-.58 E-4	-	-	-.0076	.3350	-	-	-	-.0065	.190	1.44	.0028	.0063	139
												Average σ	3.55	.0053	.0080	

NA: Not available

TABLE 3. COEFFICIENT STANDARD DEVIATIONS FOR TRUNCATED RADAR ERROR MODELS ON AS-201, AS-202, AND SA-203 VEHICLE FLIGHT TESTS

Radar	Test Number	σ_K For Indicated Coefficient											Terms
		C_0	C_1	C_2	C_4	D_0	D_3	D_5	D_7	D_8	F_0	F_3	
0.18	201	—	—	.34E-3	9.69	.73E-3	—	.0018	—	—	.35E-3	—	5
	202	.58	—	.20E-3	4.50	.28E-3	.036	—	—	1.1E-3	1.1E-3	.100	8
	203	.70	.37E-5	—	20.22	.53E-3	.151	—	—	—	.46E-3	.134	7
19.18	201	—	.14E-5	.26E-3	—	.24E-3	—	—	—	—	.23E-3	.034	5
	202	.62	.14E-5	—	10.50	.75E-3	.061	.0017	.0011	—	.35E-3	.049	9
	203	.36	.20E-5	—	11.07	.25E-3	.126	—	—	—	.23E-3	.078	7
3.18	201	.68	.15E-5	.29E-3	—	.46E-3	.200	—	.0011	—	.45E-3	—	7
	202	.39	—	.11E-3	4.00	.29E-3	.056	—	—	.38E-3	.33E-3	.094	8
	203	1.21	.46E-5	.50E-3	—	—	.109	.0016	—	.77E-3	.47E-3	.201	8
7.18	201	—	.30E-6	.80E-4	—	.30E-3	.122	—	—	.43E-3	.32E-3	.359	7
	202	.40	—	.16E-3	2.00	.34E-3	.120	—	—	.60E-3	.30E-3	—	7
	203	2.95	—	.42E-3	10.88	.60E-3	—	—	—	—	.60E-3	—	5
91.18	201	1.52	.18E-5	.10E-3	—	.44E-3	.110	—	—	.68E-3	.42E-3	.233	8
	202	—	—	.47E-3	7.30	2.9E-3	—	.032	—	—	.90E-3	—	5
	NA/203												
BDA	NA/201												
	NA/202												
	203	1.08	.14E-5	—	—	.41E-3	.079	—	—	—	.44E-3	.075	6
No. Occurrences		11	9	11	9	14	11	4	2	6	15	10	

NA: Not available

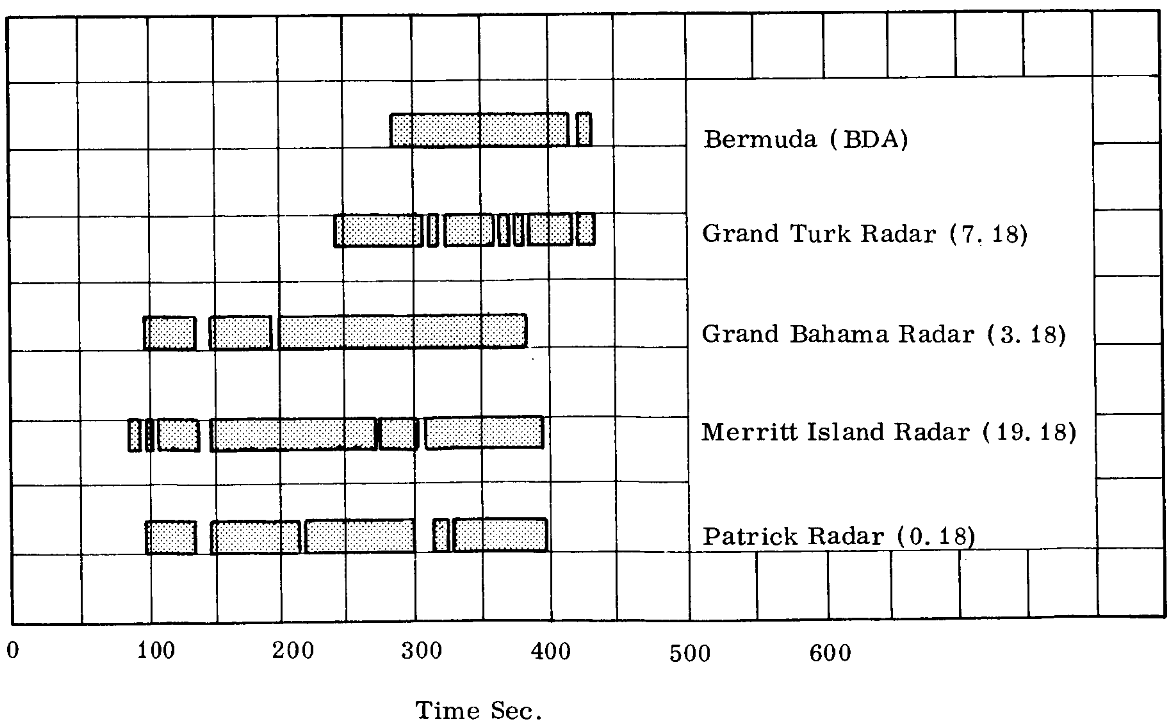

FIGURE 3. TEMS SA-203 RADAR TRACKING DATA UTILIZATION

The range fit was significantly degraded with any one of the three terms left out. The azimuth model obtained is one of the few where the coefficients D_5 and D_8 were retained in the truncated model.

Regression runs made with and without the correlated coefficients C_o and C_4 indicated that both were required in the range model for Radar 7.18. The timing error was also retained. The results indicate a higher noise content in the elevation data than the input estimate of .006 degrees.

It was determined on the Bermuda Radar that the correlated bias and scale factor terms were required in the range error model. The high angular correlation in the total error models was reduced significantly by using the coefficients D_o, D_3, F_o, and F_3. These were determined to be the most significant contributors in the azimuth and elevation error models.

The standard deviations of the least squares residuals for the SA-203 models in Table 2 indicate close agreement with the accuracy estimates of 5 meters in R and .006 degrees in A and E. The noted exception is the elevation data from Radar 7.18.

C. SUMMARY

An overall summary of the truncated error model results on the AS-201, AS-202, and SA-203 flight tests is included in Tables 2 and 3. Coefficient correlations and plots of the observed deltas, computed deltas, and the least squares residuals are given in Appendixes A, B, and C for the 201, 202, and 203 tests, respectively. The firing azimuth on the AS-201 and AS-202 tests was 105° and 72° on the SA-203 test. From the results presented in Table 2, it would appear that coefficient values are not repeatable from test to test or from radar to radar. The average random errors remaining in the azimuth and elevation residuals for the three flights are .0053 degrees and .0080 degrees, respectively. The average azimuth value compares favorably with the input estimate of .006 degrees. A value of .006 degrees was used as the input estimate of the random error in the elevation data. The average random error in the range data of 3.55 meters is slightly less than the input estimate of 5 meters.

It is interesting to note in Table 3 that the standard deviations for several of the coefficients do not vary significantly from test to test or from radar to radar. Another point worth noting in Table 3 is that no less than five and no more than nine terms, excluding constraints, have been retained in the truncated error models. Only in one case, Radar 19.18 on AS-202, was a nine term error model required. The bias (C_0) and timing (C_2) errors in range and the bias (D_0, F_0) and servo lag (D_3, F_3) errors in azimuth and elevation have occurred more frequently than the other terms.

SECTION IV. CONCLUSIONS

Results from the application of the TEMS method to radar tracking data on the Saturn 203 Flight Test are presented. A summary of the AS-201 and AS-202 results is included. On the basis of results from these three flights, it appears that error model coefficient values are not repeatable from test to test or from radar to radar. It is also noted that the standard deviations for several of the coefficients do not vary significantly from test to test or from radar to radar. The average random errors remaining in the residuals for the three flights are .0053 degrees and .0080 degress in azimuth and elevation, respectively, and 3.55 meters in range.

The frequency of occurrence of the various terms on each of the three flights and for each radar indicates that no less than five and no more than nine terms are required in the truncated error models. This information will be updated on each flight test and any significant changes will be noted. A current investigation is concerned with the utilization of the coefficient standard deviations as a priori inputs in the adjustment.

APPENDIX A

RESULTS FROM APOLLO-SATURN 201 VEHICLE FLIGHT TEST

This appendix presents a summary of the results from the Apollo-Saturn 201 Vehicle Flight Test launched on February 26, 1966. The tracking errors in range, azimuth, and elevation for the various radars are represented by dots. The description of these tracking errors as obtained from the TEMS/ Radar Least Squares Adjustment Program is represented by the solid computed curves. As pointed out in [1], goodness of fit is only one of the criteria for determining the adequacy of a specific error model. The process of determining a valid error model to represent the tracking errors involves a detailed examination of all coefficients that are correlated by more than .70. The goodness of fit is often degraded in attempting to minimize correlation between coefficients.

Table A1

COEFFICIENT CORRELATIONS FOR THE TRUNCATED AS-201 RADAR ERROR MODELS

RADAR 3.18

	C_0	C_1	C_2	D_0	D_3	D_7	F_0
C_0	1.00	-.49	.11	0.	0.	0.	0.
C_1		1.00	-.88	0.	0.	.01	0.
C_2			1.00	0.	0.	-.01	0.
D_0				1.00	-.22	-.34	.08
D_3					1.00	.41	-.10
D_7						1.00	-.25
F_0							1.00

RADAR 91.18

	C_0	C_1	C_2	D_0	D_3	D_8	F_0	F_3
C_0	1.00	-.97	-.30	0.	0.	0.	0.	0.
C_1		1.00	.35	0.	0.	0.	0.	0.
C_2			1.00	-.01	0.	0.	0.	0.
D_0				1.00	-.05	-.41	-.03	.19
D_3					1.00	-.06	0.	0.3
D_8						1.00	.08	-.46
F_0							1.00	.18
F_3								1.00

RADAR 7.18

	C_1	C_2	D_0	D_3	D_8	F_0	F_3
C_1	1.00	-.62	0.	0.	0.	0.	0.
C_2		1.00	-.01	0.	0.	0.	0.
D_0			1.00	-.03	-.20	-.07	.03
D_3				1.00	-.10	-.04	.01
D_8					1.00	.38	-.14
F_0						1.00	.15
F_3							1.00

RADAR 19.18

	C_1	C_2	D_0	F_0	F_3
C_1	1.00	-.96	.01	0.	0.
C_2		1.00	-.01	0.	0.
D_0			1.00	0.	0.
F_0				1.00	.07
F_3					1.00

RADAR 0.18

	C_2	C_4	D_0	D_5	F_0
C_2	1.00	.96	0.	-.01	.02
C_4		1.00	0.	-.01	.02
D_0			1.00	-.88	0.
D_5				1.00	0.
F_0					1.00

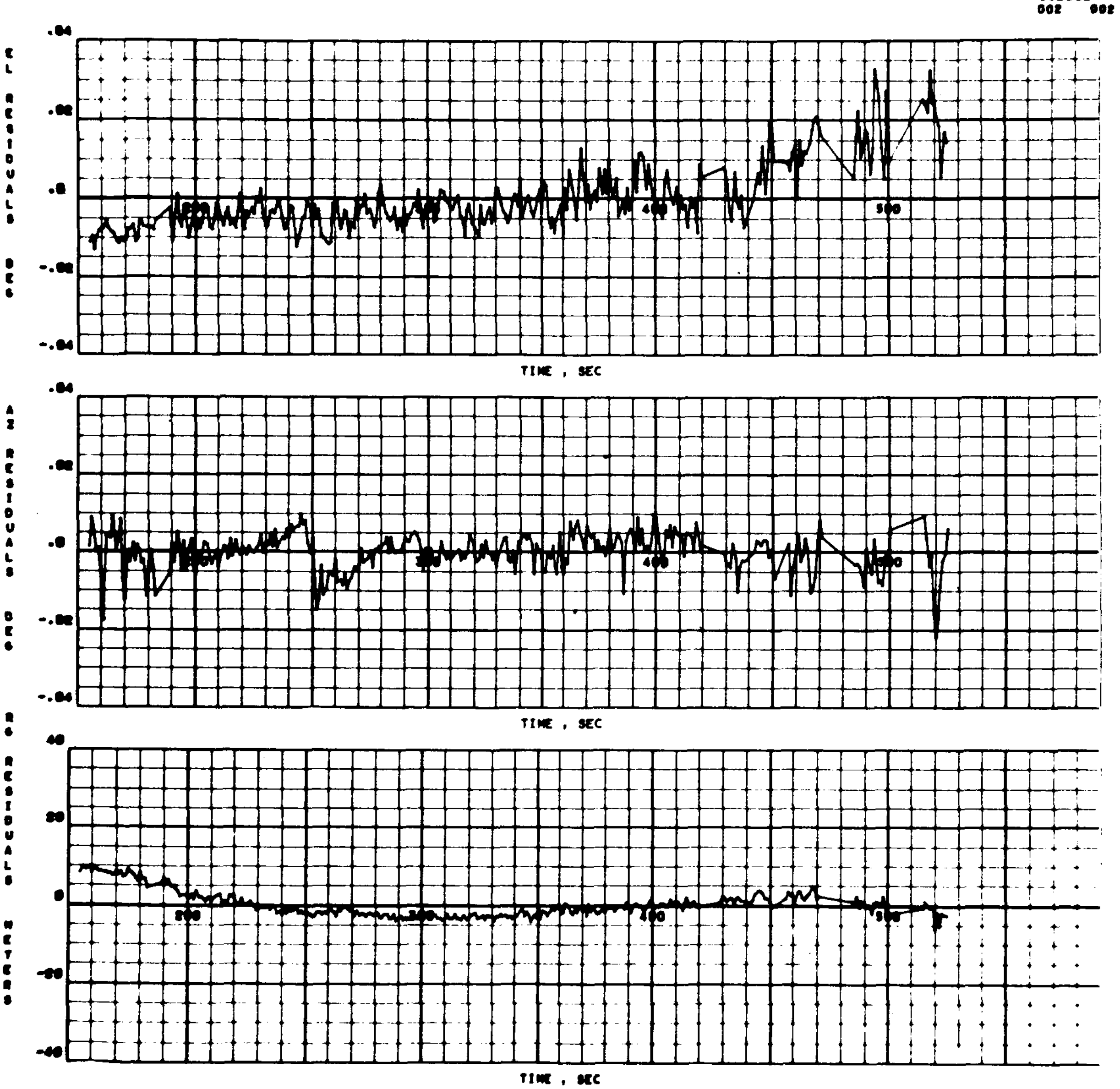

FIGURE A1. RADAR 0.18 RESIDUALS ON AS-201

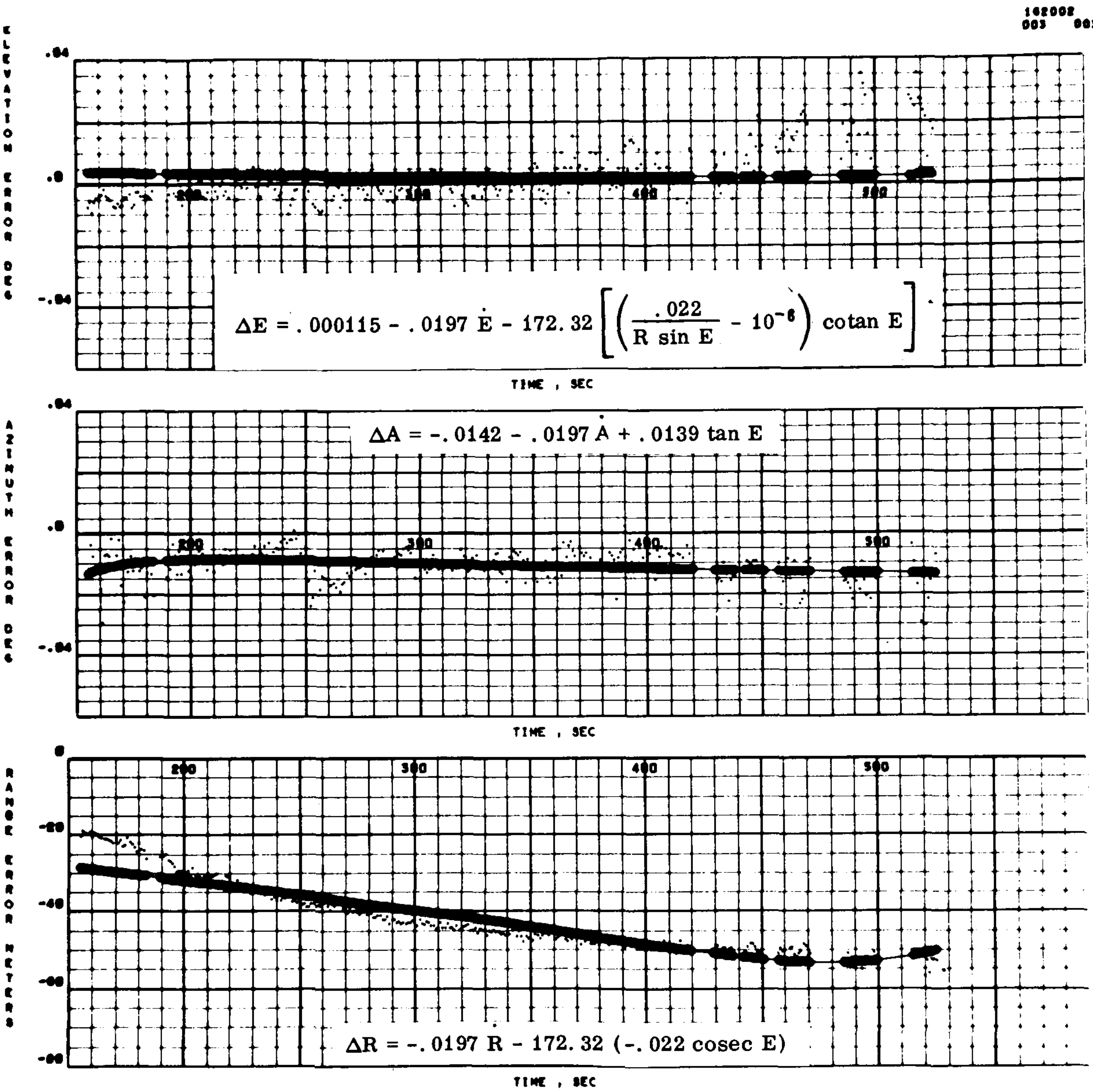

FIGURE A2. RADAR 0.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-201

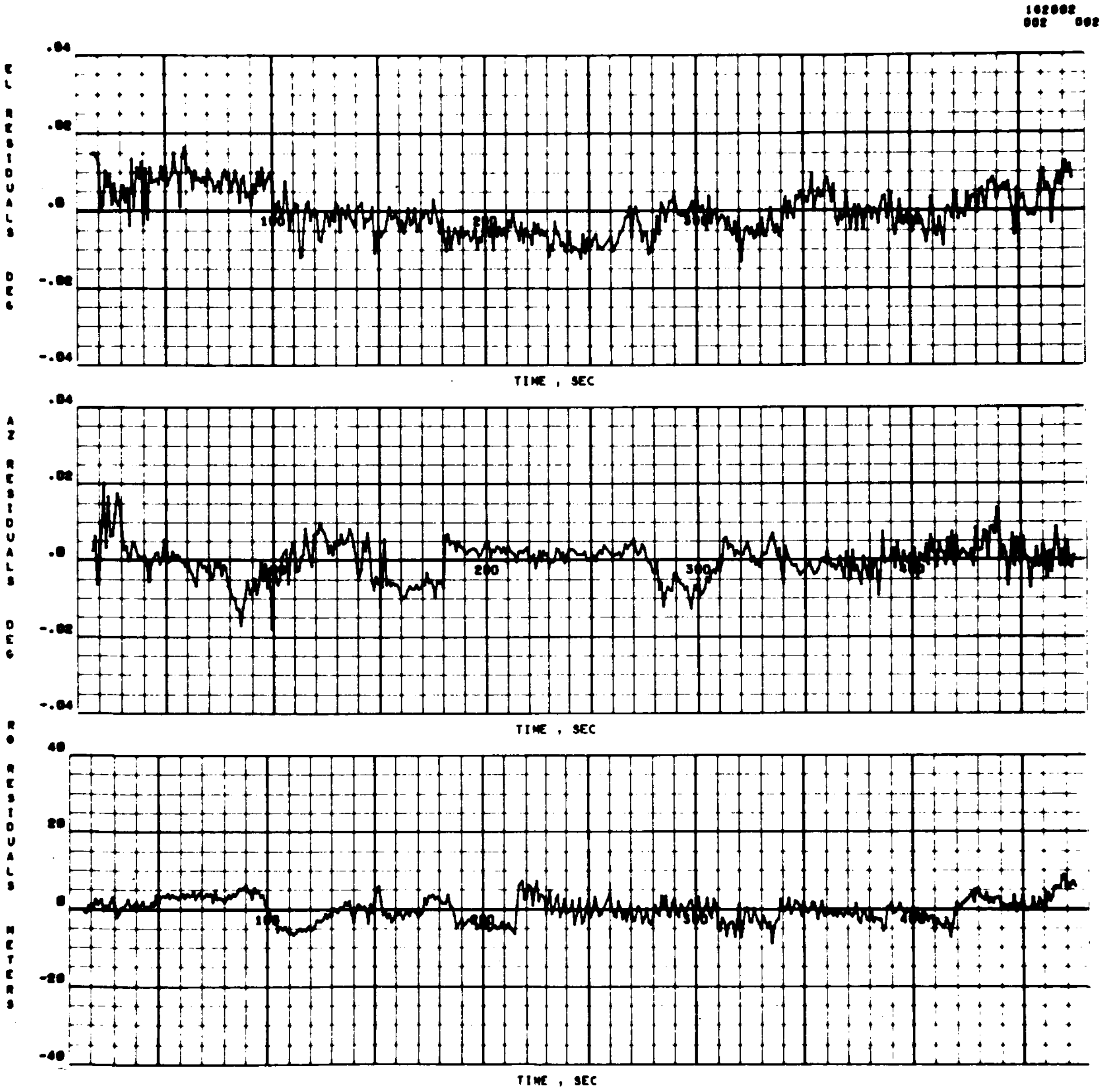

FIGURE A3. RADAR 19.18 RESIDUALS ON AS-201

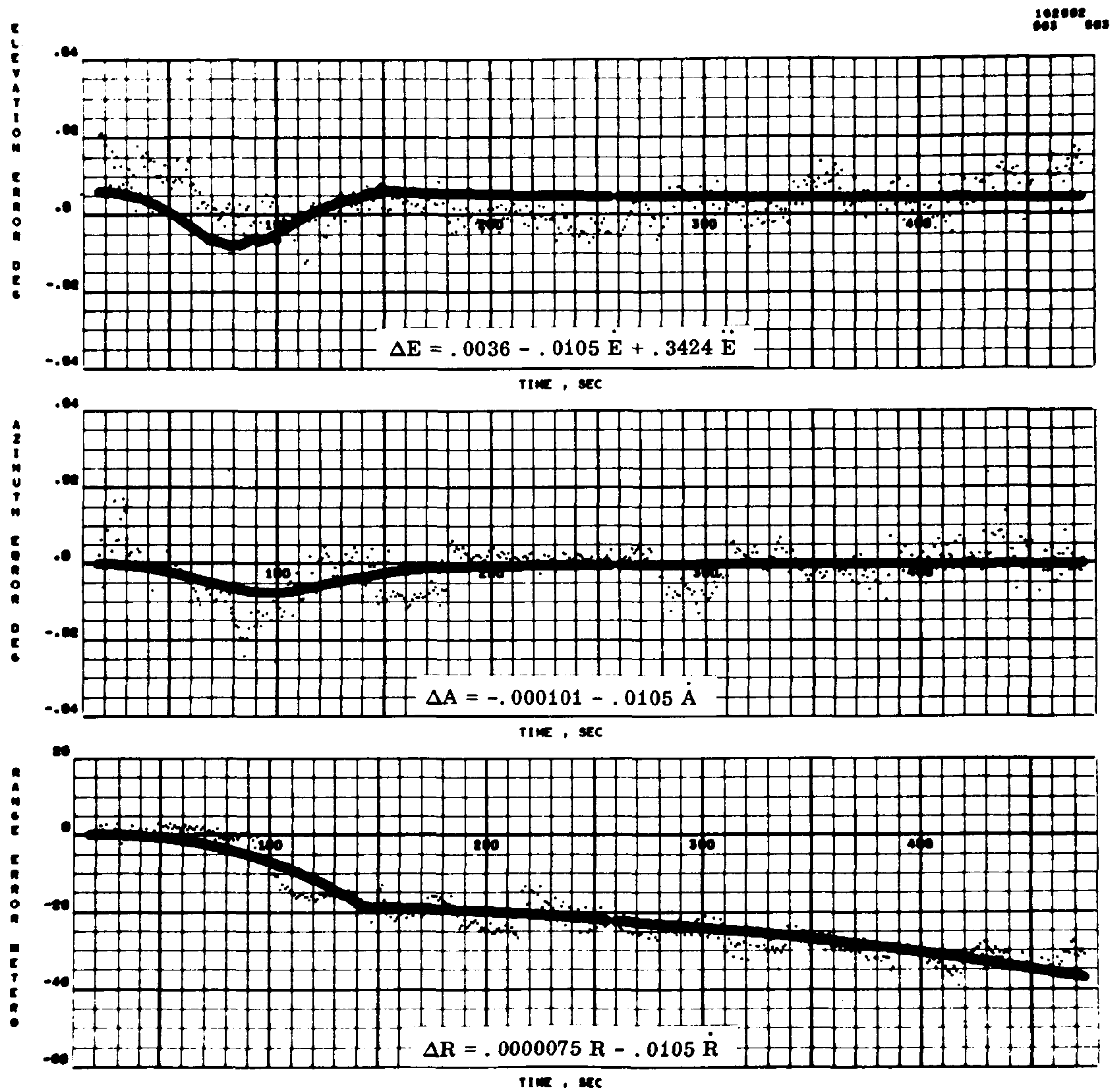

FIGURE A4. RADAR 19.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-201

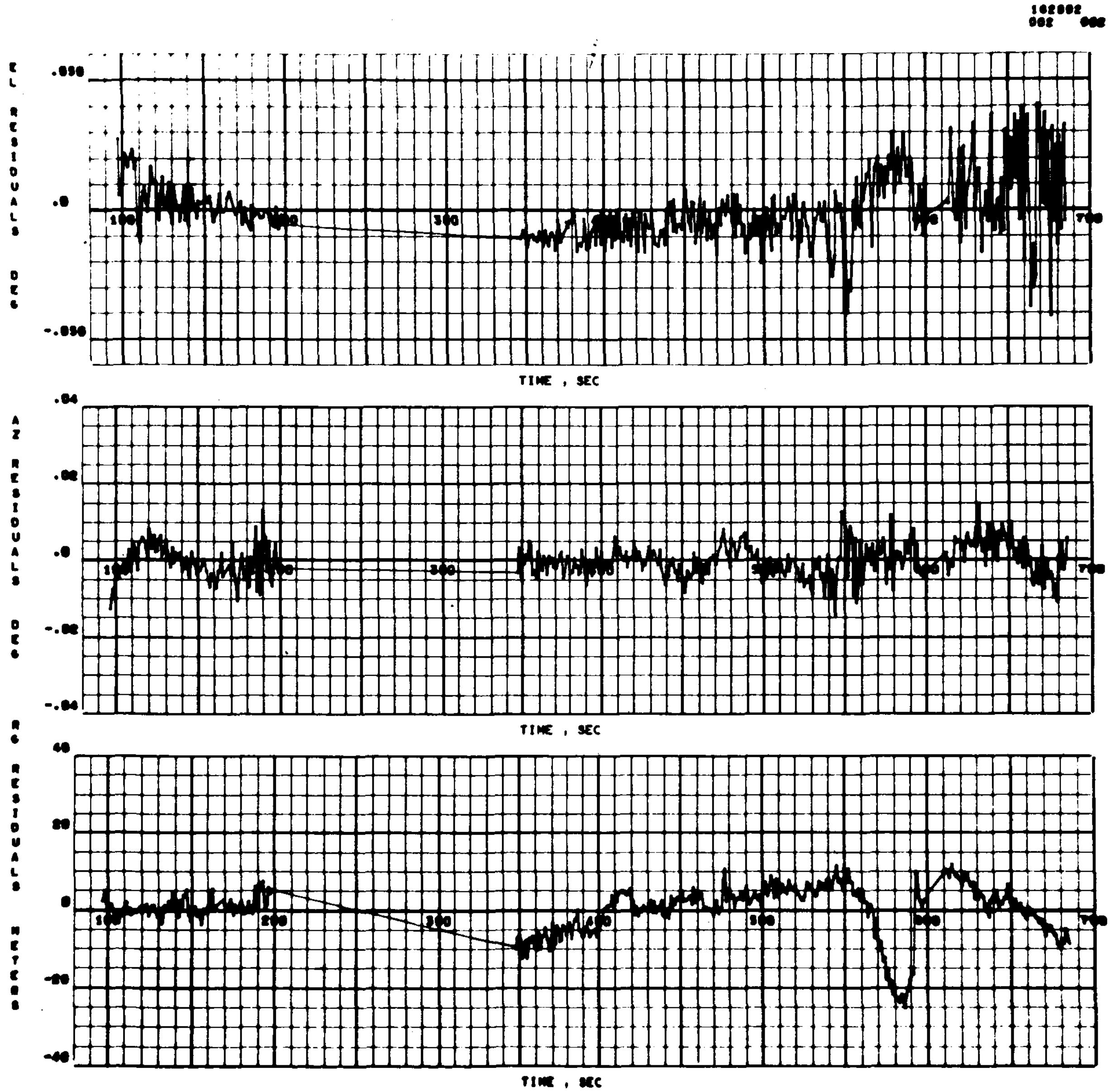

FIGURE A5. RADAR 3.18 RESIDUALS ON AS-201

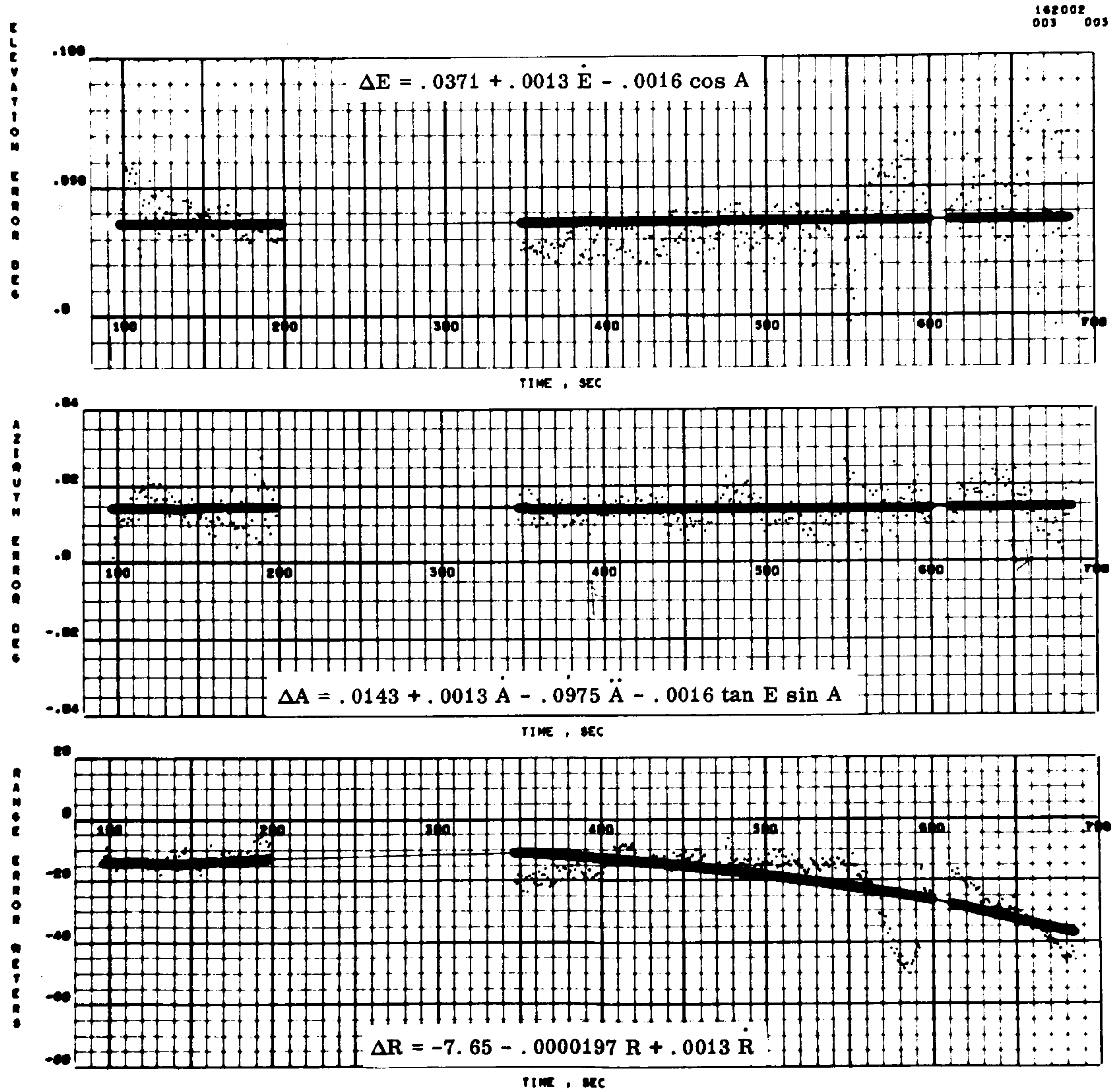

FIGURE A6. RADAR 3.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-201

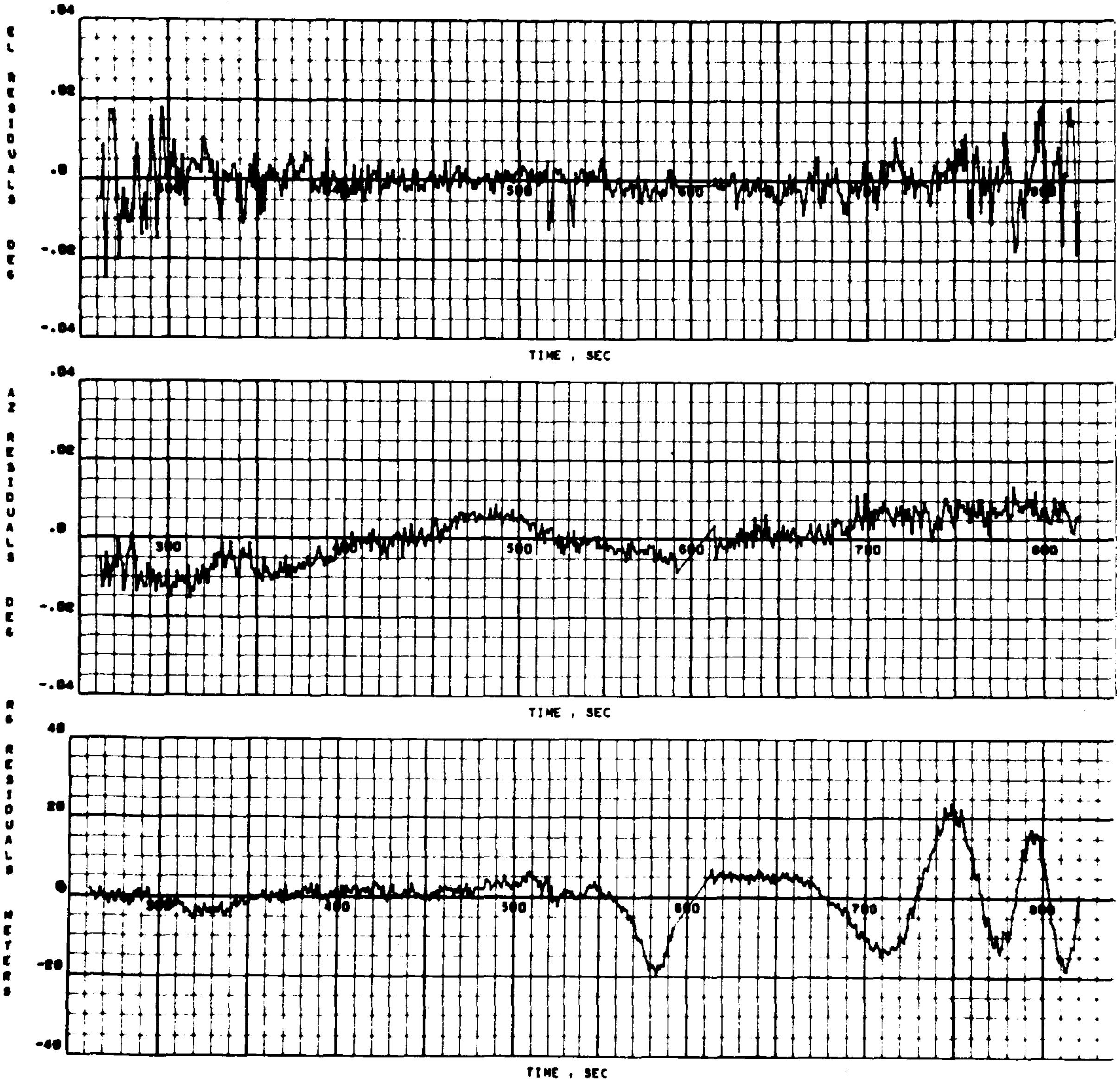

FIGURE A7. RADAR 7.18 RESIDUALS ON AS-201

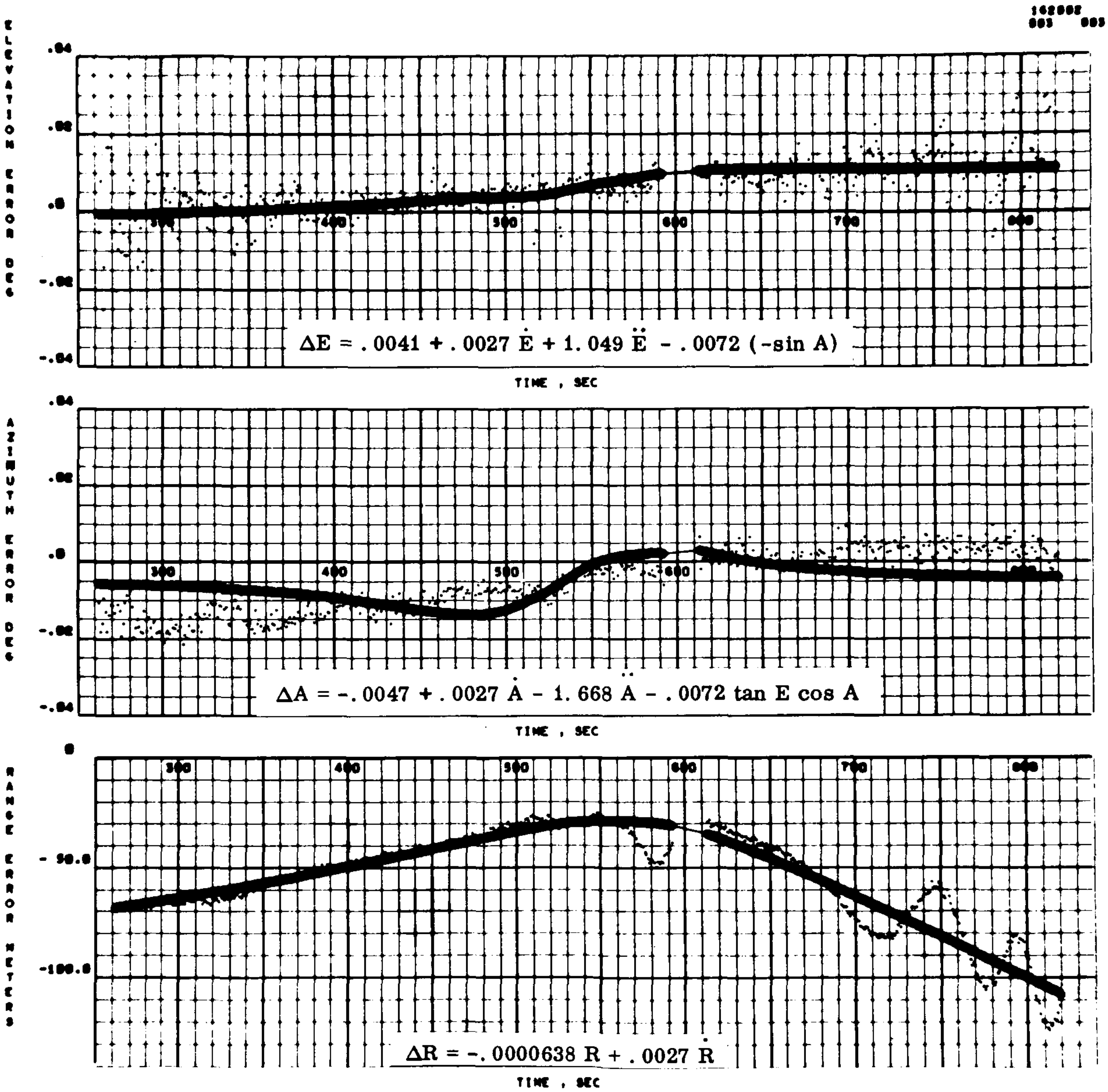

FIGURE A8. RADAR 7.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-201

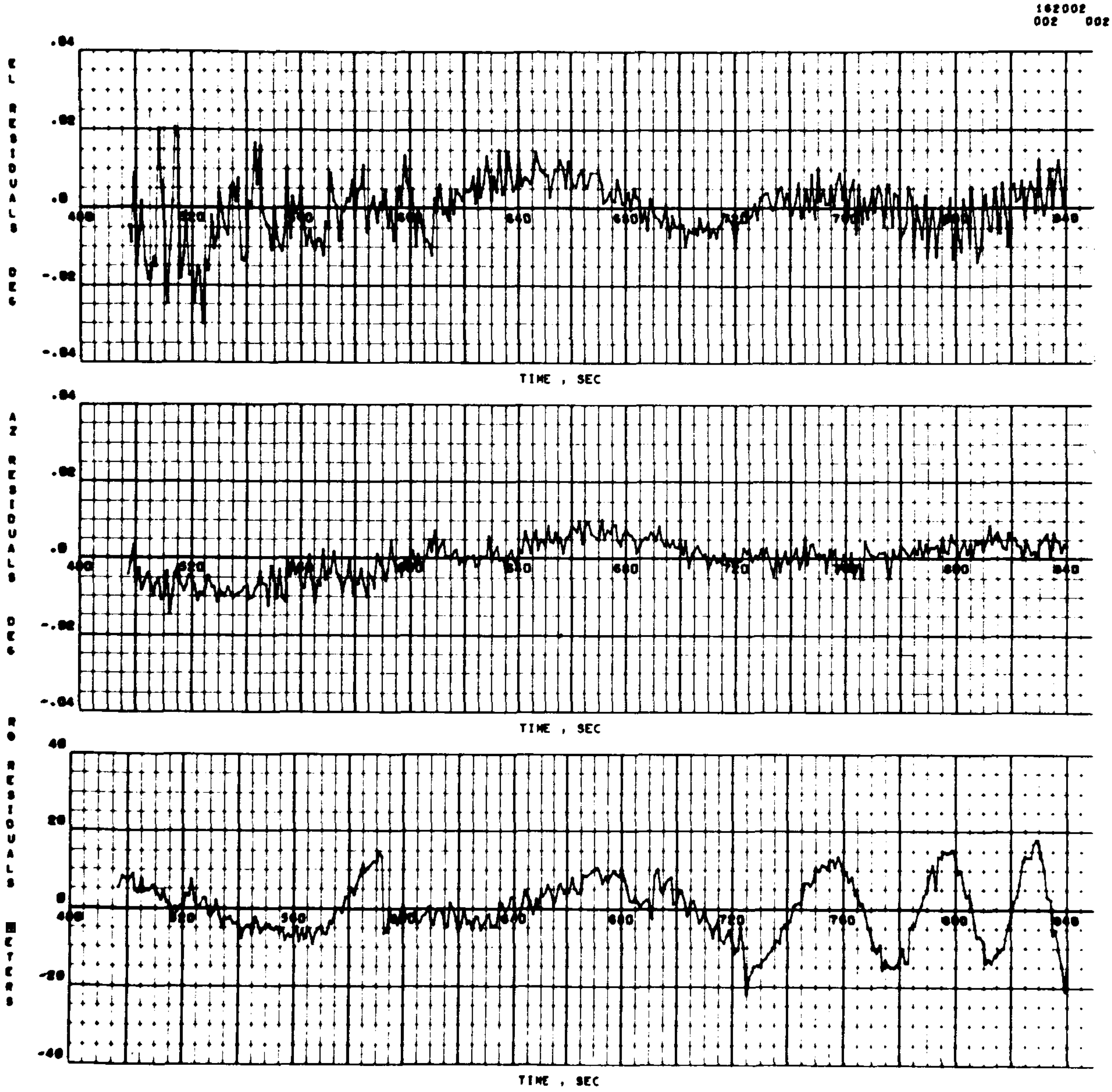

FIGURE A9. RADAR 91.18 RESIDUALS ON AS-201

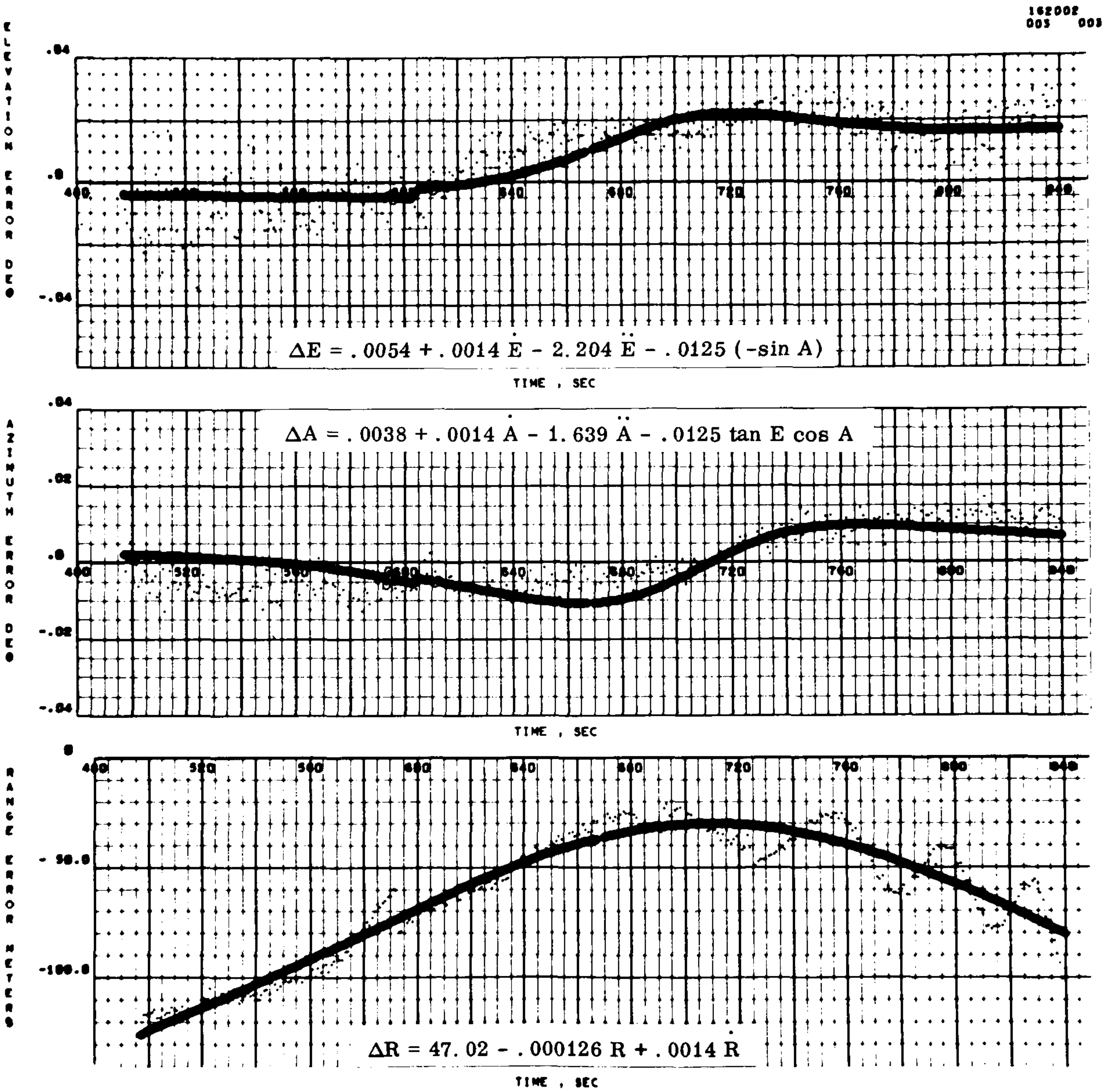

FIGURE A10. RADAR 91.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-201

APPENDIX B

RESULTS FROM APOLLO-SATURN 202 VEHICLE FLIGHT TEST

This appendix presents a summary of the results from the Apollo-Saturn 202 Vehicle Flight Test launched on August 25, 1966. The tracking errors in range, azimuth, and elevation for the various radars are represented by dots. The description of these tracking errors as obtained from the TEMS/ Radar Least Squares Adjustment Program is represented by the solid computed curves. See Appendix A for comments concerning goodness of fit.

Table B1

COEFFICIENT CORRELATIONS FOR THE TRUNCATED AS-202 RADAR ERROR MODELS

RADAR 0.18

	C_0	C_2	C_4	D_0	D_3	D_8	F_0	F_3
C_0	1.	-.67	.50	.06	-.02	.09	.09	-.08
C_2		1.	.16	-.08	.05	-.20	-.18	.04
C_4			1.	-.01	.03	-.10	-.09	-.07
D_0				1.	0	-.08	-.08	.06
D_3					1.	-.30	-.29	.18
D_8						1.	.96	-.59
F_0							1.	-.63
F_3								1.

RADAR 19.18

	C_0	C_1	C_4	D_0	D_3	D_5	D_7	F_0	F_3
C_0	1.	-.04	.66	0	-.02	.10	-.17	-.06	-.14
C_1		1.	.64	0	-.02	.10	-.16	-.05	-.14
C_4			1.	0	-.03	.15	-.25	-.08	-.21
D_0				1.	-.23	-.71	-.02	0	0
D_3					1.	.07	.11	.01	.02
D_5						1.	-.58	-.07	-.10
D_7							1.	.13	.18
F_0								1.	.16
F_3									1.

RADAR 3.18

	C_0	C_2	C_4	D_0	D_3	D_8	F_0	F_3
C_0	1.	-.18	.63	.02	0	.01	.03	.01
C_2		1.	.46	-.08	.01	-.12	-.05	.01
C_4			1.	-.04	.01	-.06	0	.02
D_0				1.	.07	-.30	-.17	.02
D_3					1.	-.10	-.06	.01
D_8						1.	.57	-.06
F_0							1.	.07
F_3								1.

RADAR 7.18

	C_0	C_2	C_4	D_0	D_3	D_8	F_0
C_0	1.	.36	.59	-.05	0	-.01	.01
C_2		1.	-.30	-.12	0	-.05	-.01
C_4			1.	.03	0	.03	.03
D_0				1.	-.47	-.29	.14
D_3					1.	-.09	.04
D_8						1.	-.47
F_0							1.

RADAR 91.18

	C_2	C_4	D_0	D_5	F_0
C_2	1.	-.94	0	-.02	-.11
C_4		1.	0	.01	.11
D_0			1.	-.95	0
D_5				1.	0
F_0					1.

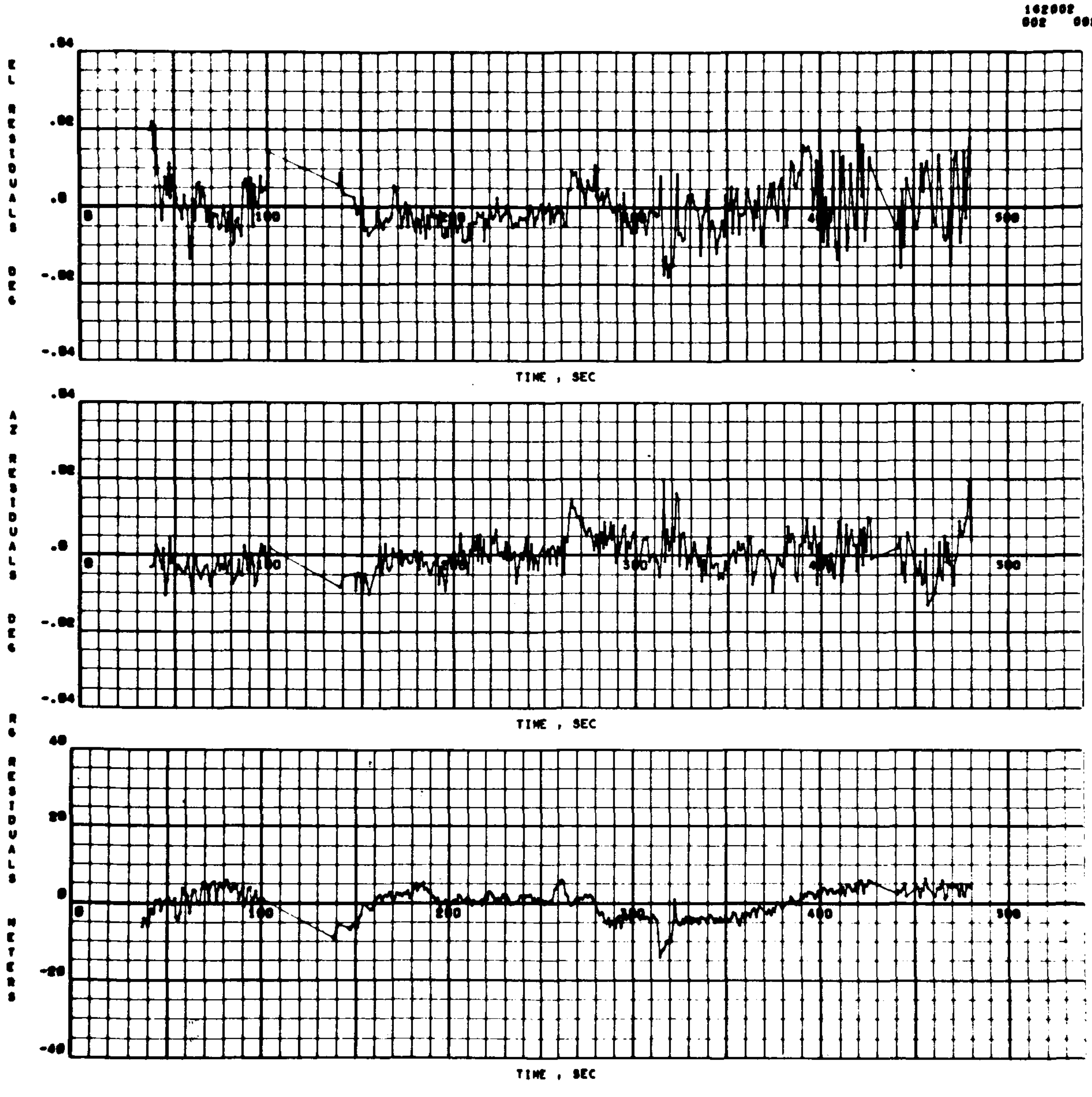

FIGURE B1. RADAR 0.18 RESIDUALS ON AS-202

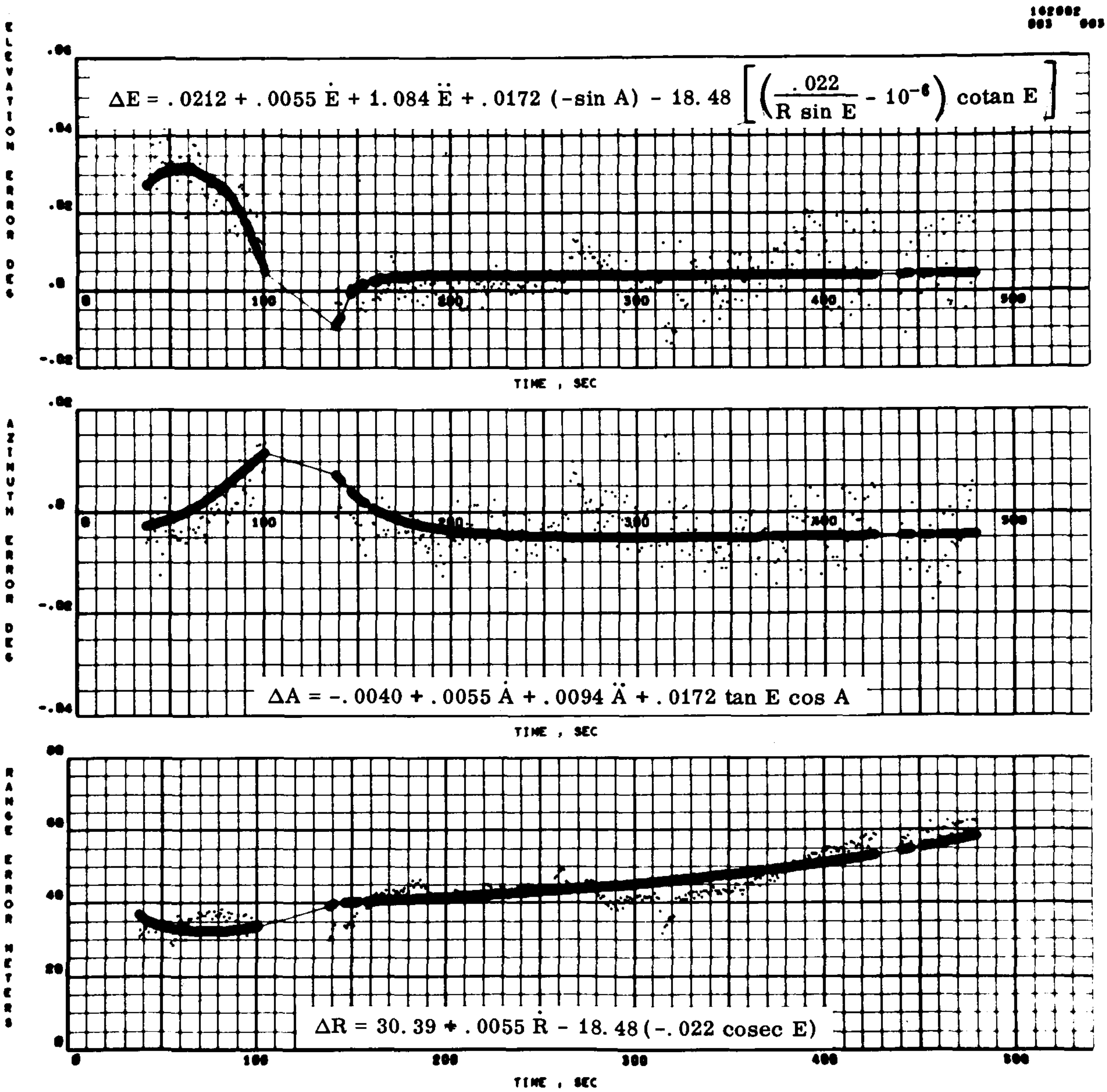

FIGURE B2. RADAR 0.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-202

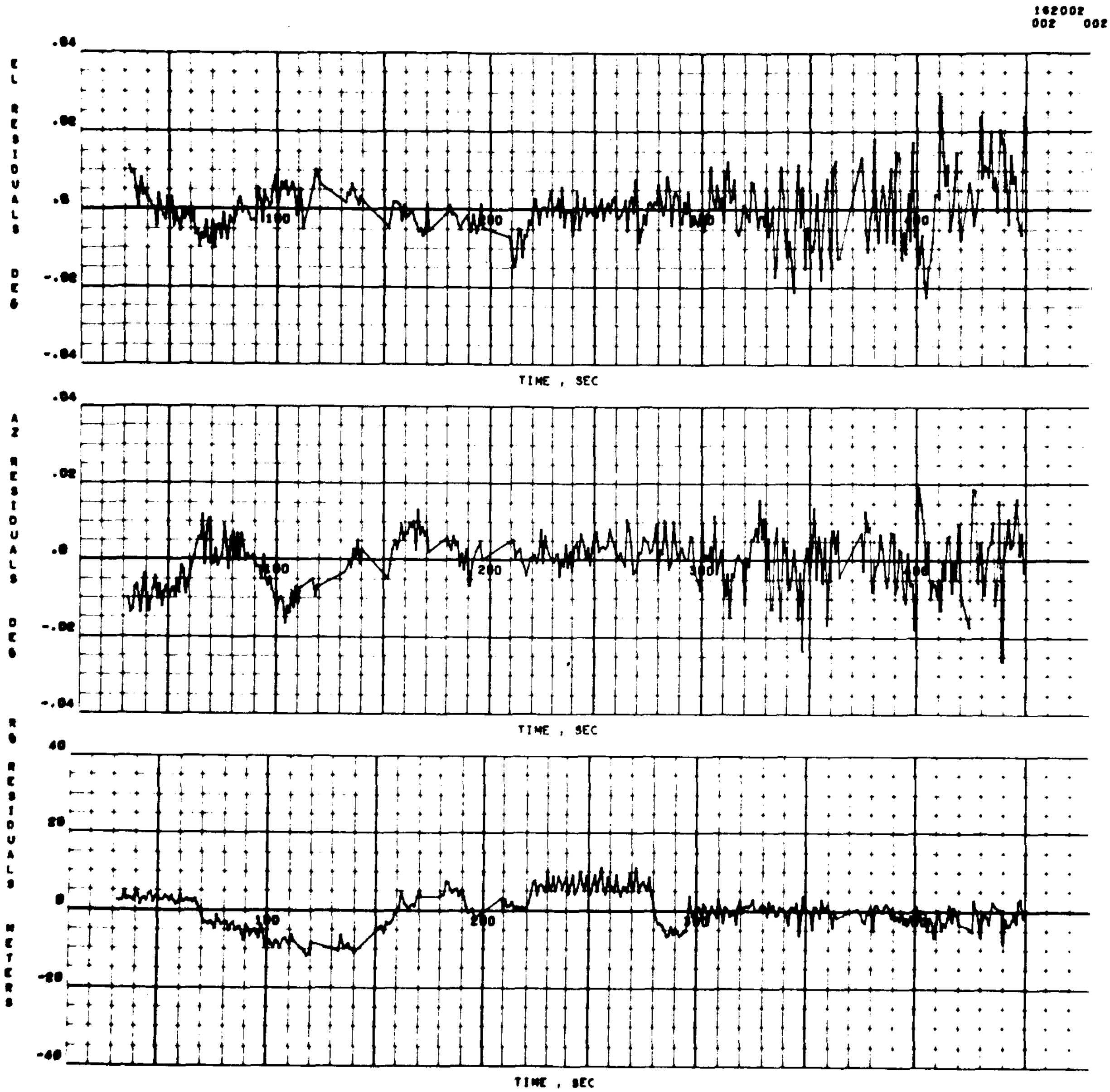

FIGURE B3. RADAR 19.18 RESIDUALS ON AS-202

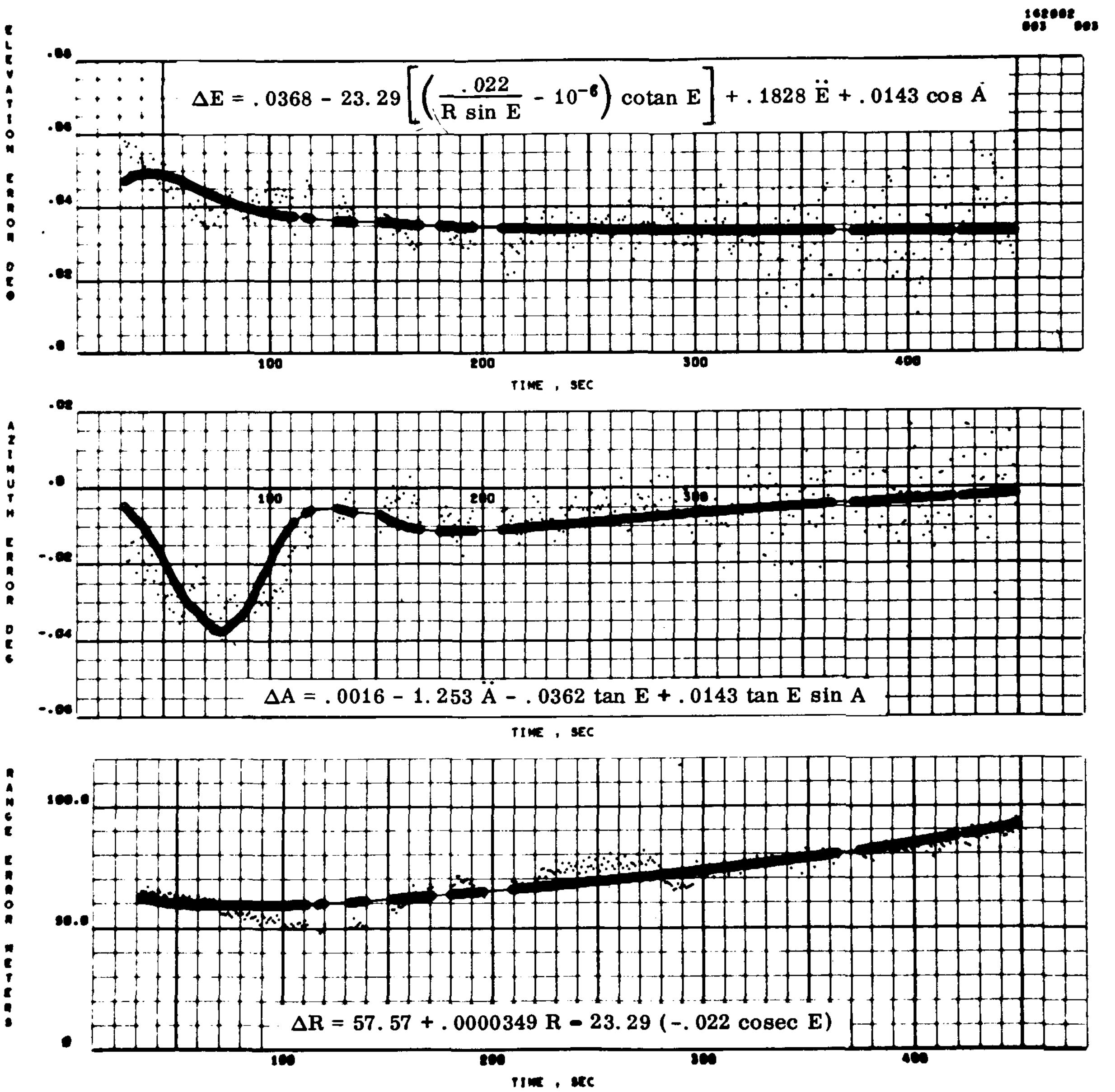

FIGURE B4. RADAR 19.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-202

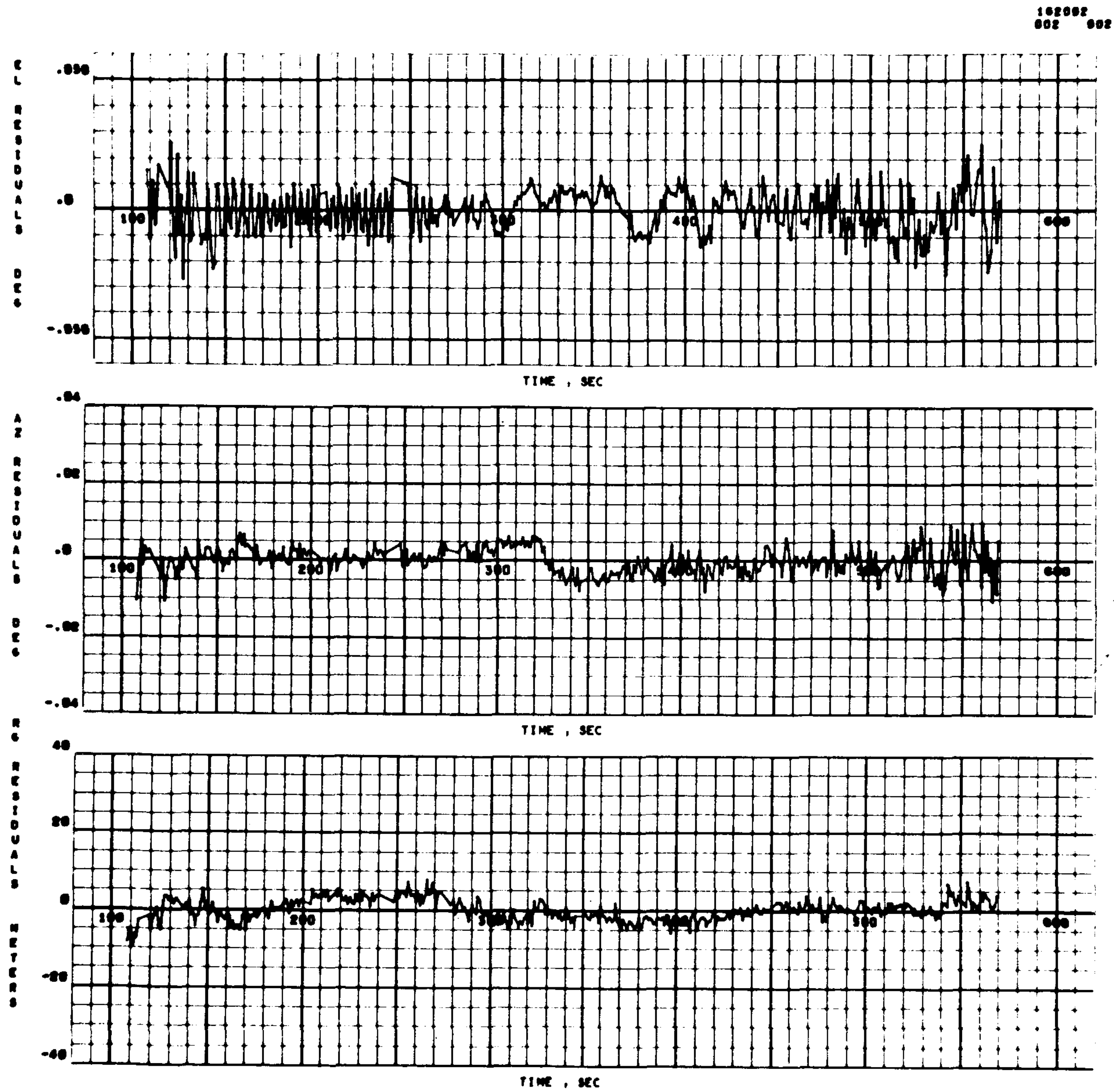

FIGURE B5. RADAR 3.18 RESIDUALS ON AS-202

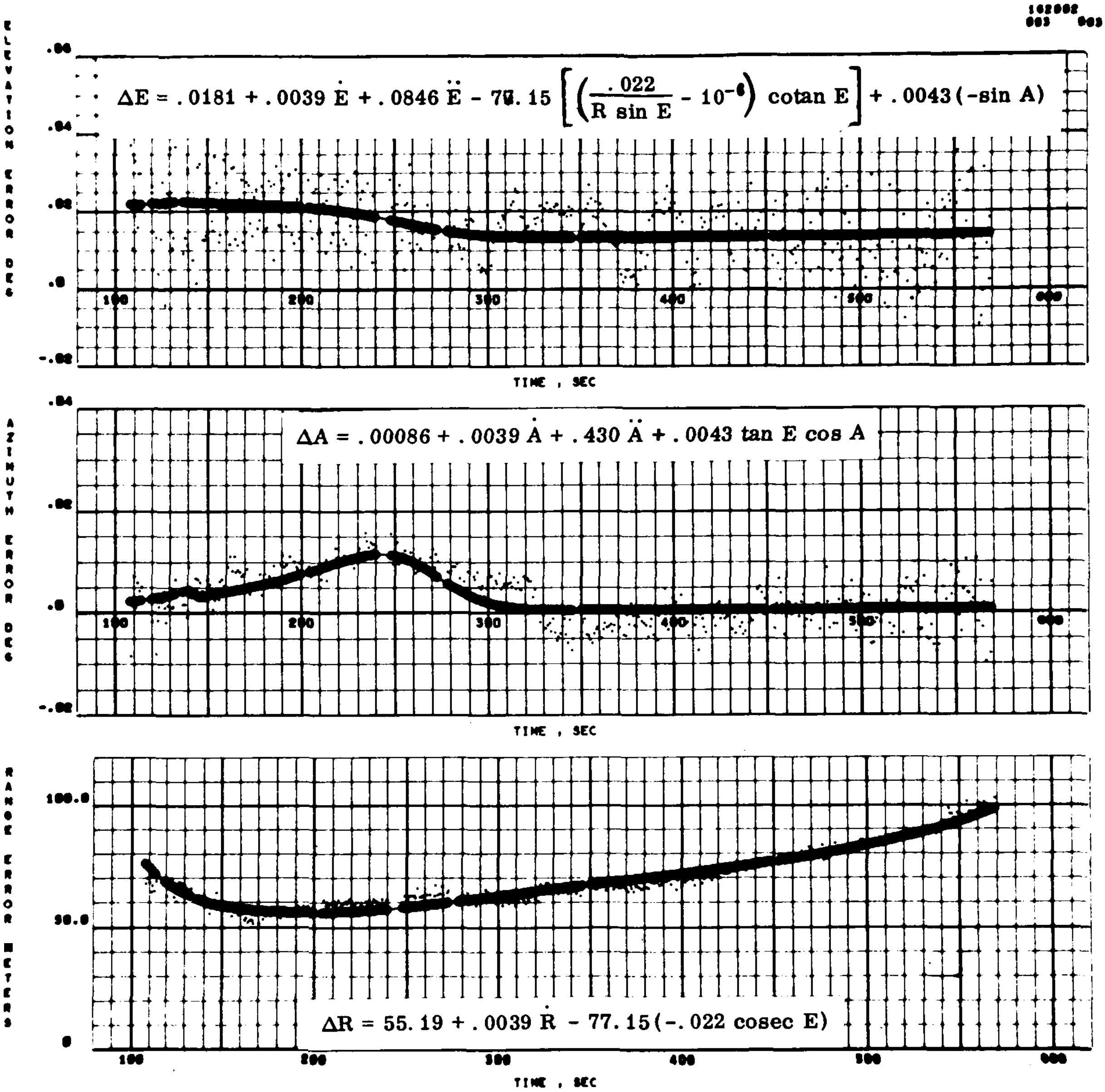

FIGURE B6. RADAR 3.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-202

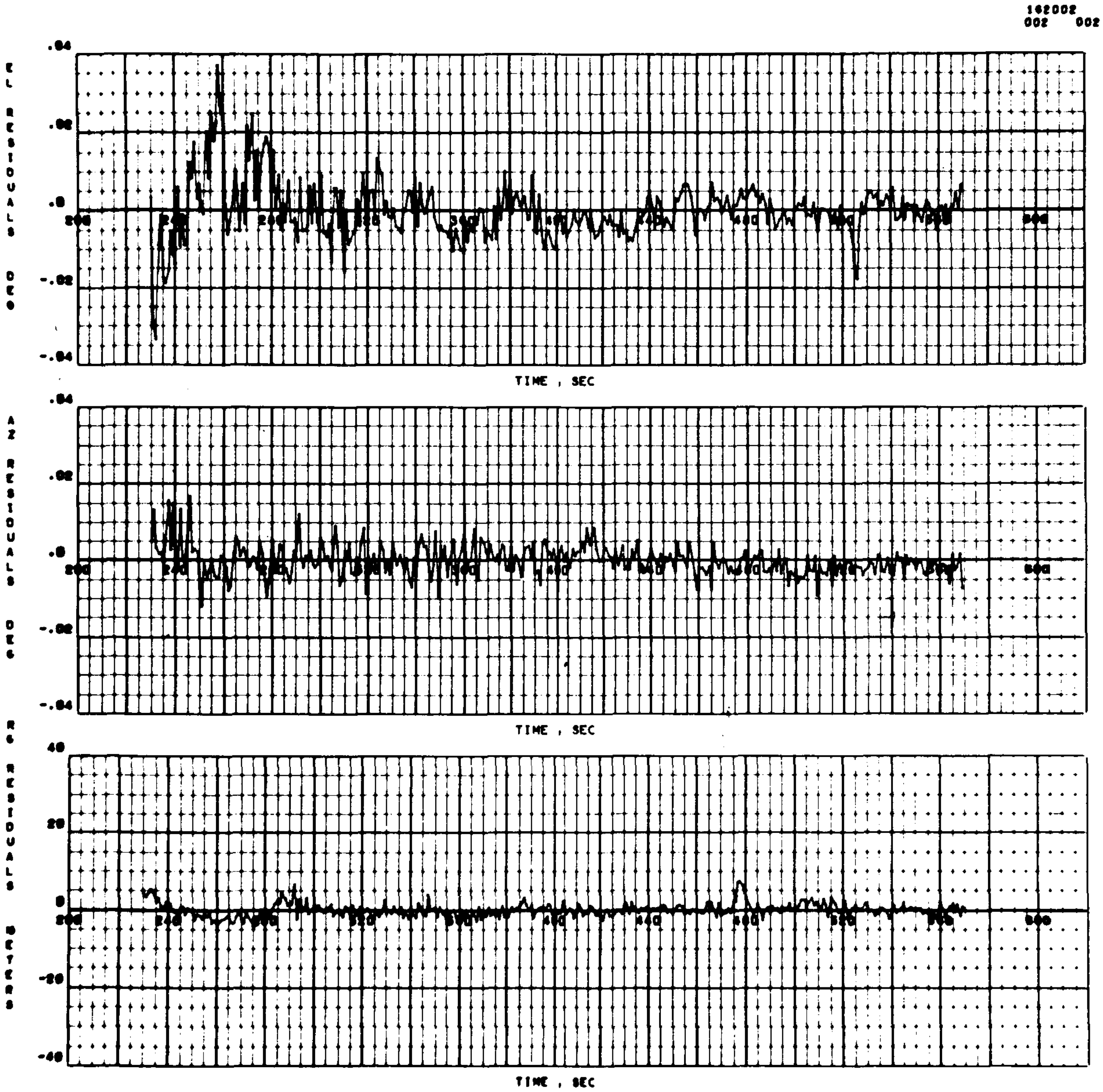

FIGURE B7. RADAR 7.18 RESIDUALS ON AS-202

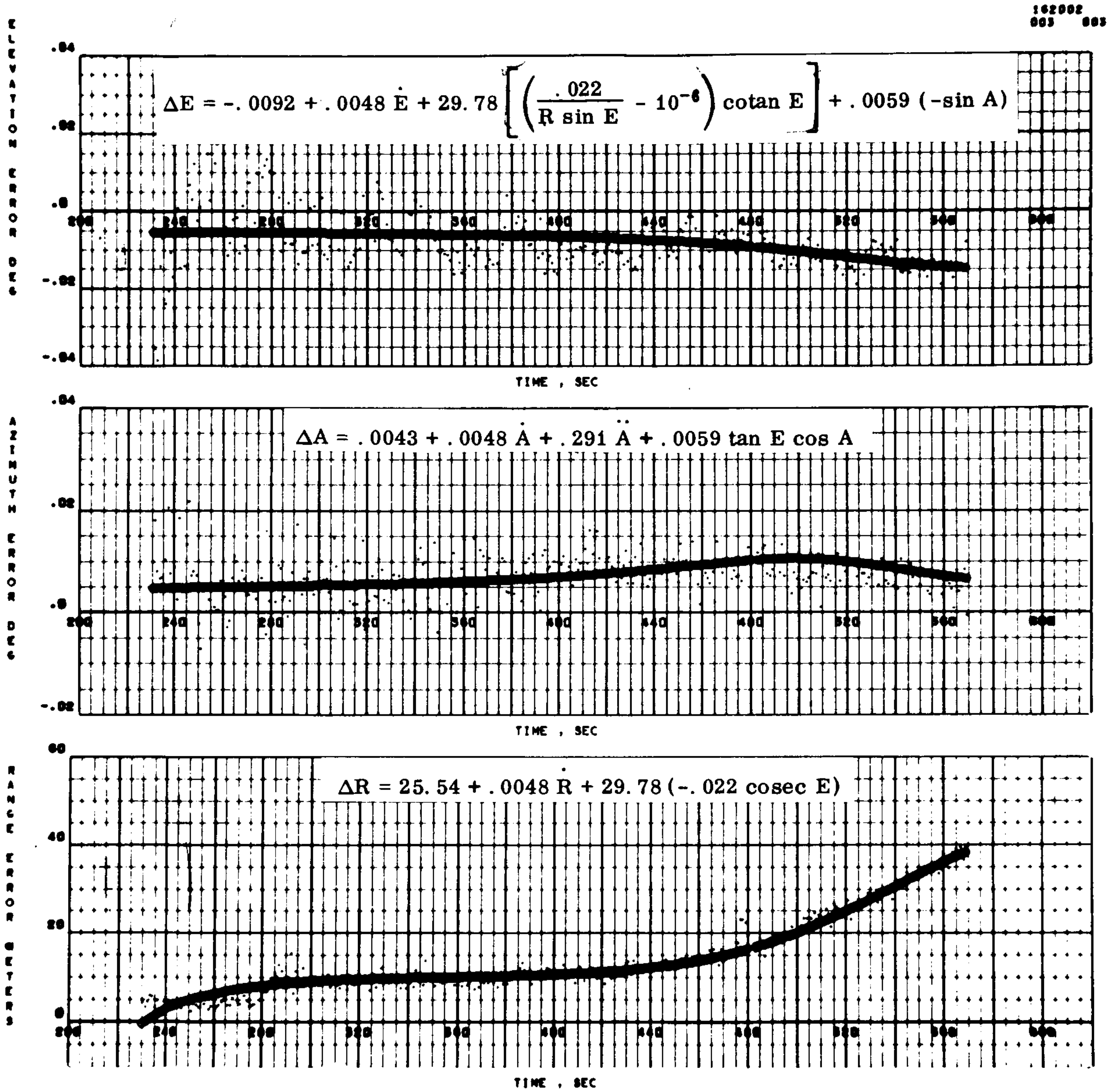

FIGURE B8. RADAR 7. 18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-202

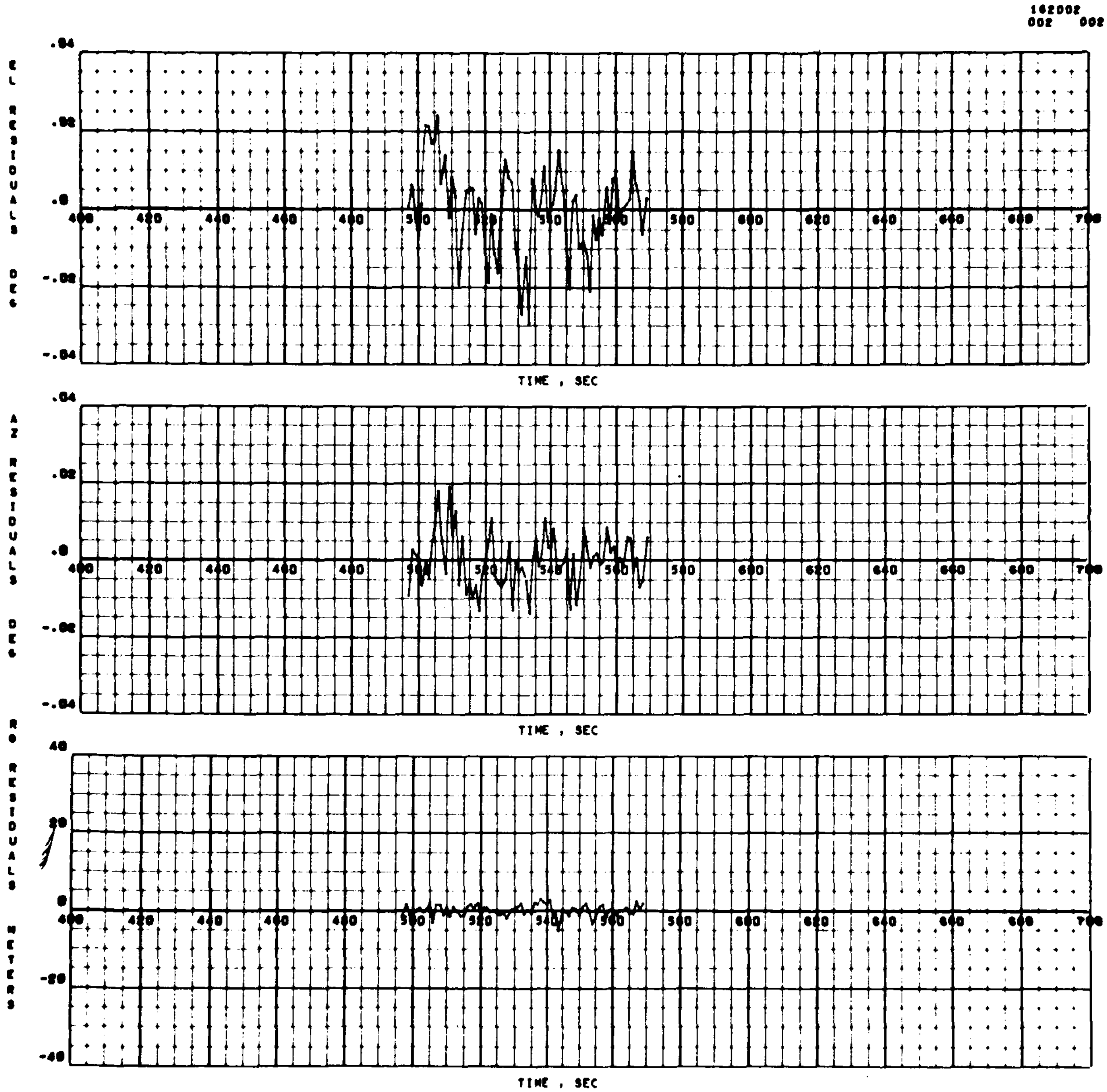

FIGURE B9. RADAR 91.18 RESIDUALS ON AS-202

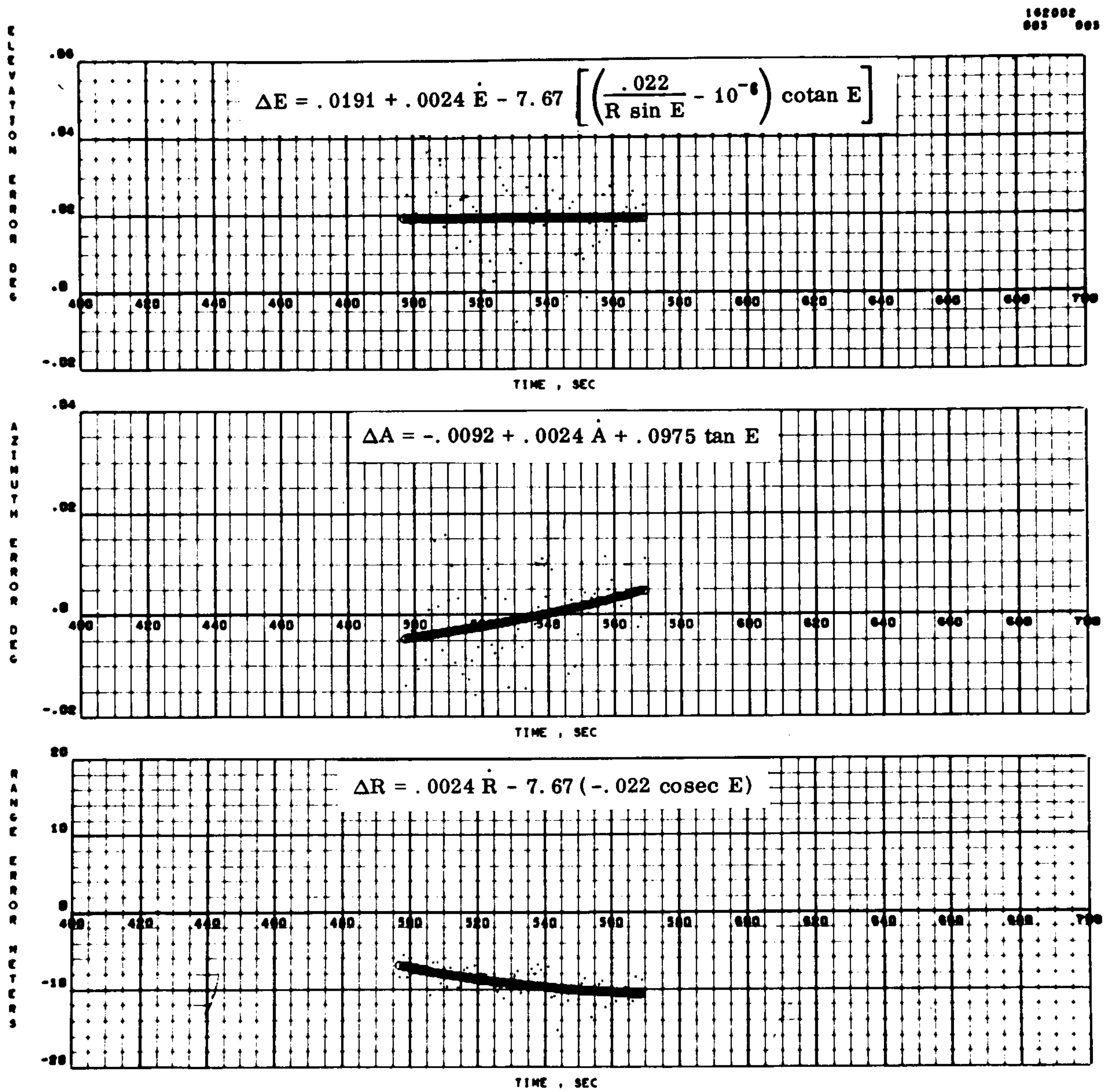

FIGURE B10. RADAR 91.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-202

APPENDIX C

RESULTS FROM SATURN 203 VEHICLE FLIGHT TEST

This appendix presents a summary of the results from the Saturn 203 Vehicle Flight Test launched on July 5, 1966. The tracking errors in range, azimuth, and elevation for the various radars are represented by dots. The description of these tracking errors as obtained from the TEMS/ Radar Least Squares Adjustment Program is represented by the solid computed curves. See Appendix A for comments concerning goodness of fit.

TABLE C1. COEFFICIENT CORRELATIONS FOR THE TRUNCATED SA-203 RADAR ERROR MODELS

RADAR 0.18

	C_0	C_1	C_4	D_0	D_3	F_0	F_3
C_0	1.00	-.04	.23	0	0	.04	.01
C_1		1.00	.95	0	0	.15	.04
C_4			1.00	0	0	.16	.04
D_0				1.00	.57	0	0
D_3					1.00	0	0
F_0						1.00	.30
F_3							1.00

RADAR 19.18

	C_0	C_1	C_4	D_0	D_3	F_0	F_3
C_0	1.00	.06	.32	0	0	.05	.01
C_1		1.00	.95	0	0	.16	.04
C_4			1.00	0	0	.16	.04
D_0				1.00	.49	0	0
D_3					1.00	0	0
F_0						1.00	.21
F_3							1.00

RADAR 3.18

	C_0	C_1	C_2	D_3	D_5	D_8	F_0	F_3
C_0	1.00	-.90	.73	-.07	-.25	-.11	-.05	.01
C_1		1.00	-.94	.09	.32	.14	.06	-.01
C_2			1.00	-.10	-.34	-.15	-.07	.01
D_3				1.00	.30	.01	0	0
D_5					1.00	-.35	-.16	.01
D_8						1.00	.46	-.05
F_0							1.00	.31
F_3								1.00

RADAR 7.18

	C_0	C_2	C_4	D_0	F_0
C_0	1.00	-.41	.98	.07	.16
C_2		1.00	-.36	-.18	-.06
C_4			1.00	.07	.16
D_0				1.00	.01
F_0					1.00

BERMUDA RADAR

	C_0	C_1	D_0	D_3	F_0	F_3
C_0	1.00	-.96	0	0	0	0
C_1		1.00	0	0	0	0
D_0			1.00	.53	0	0
D_3				1.00	0	0
F_0					1.00	-.62
F_3						1.00

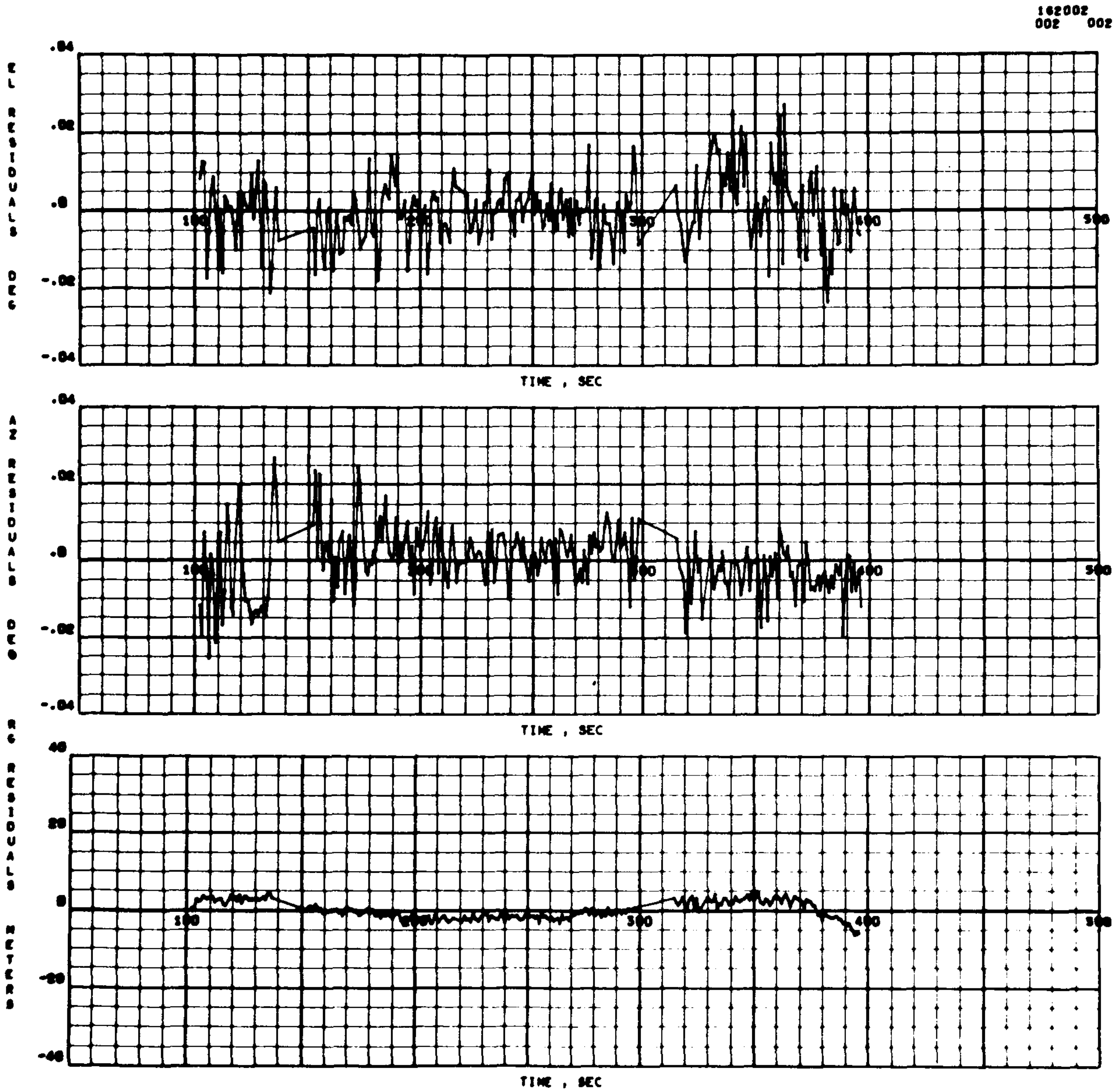

FIGURE C1. RADAR 0.18 RESIDUALS ON SA-203

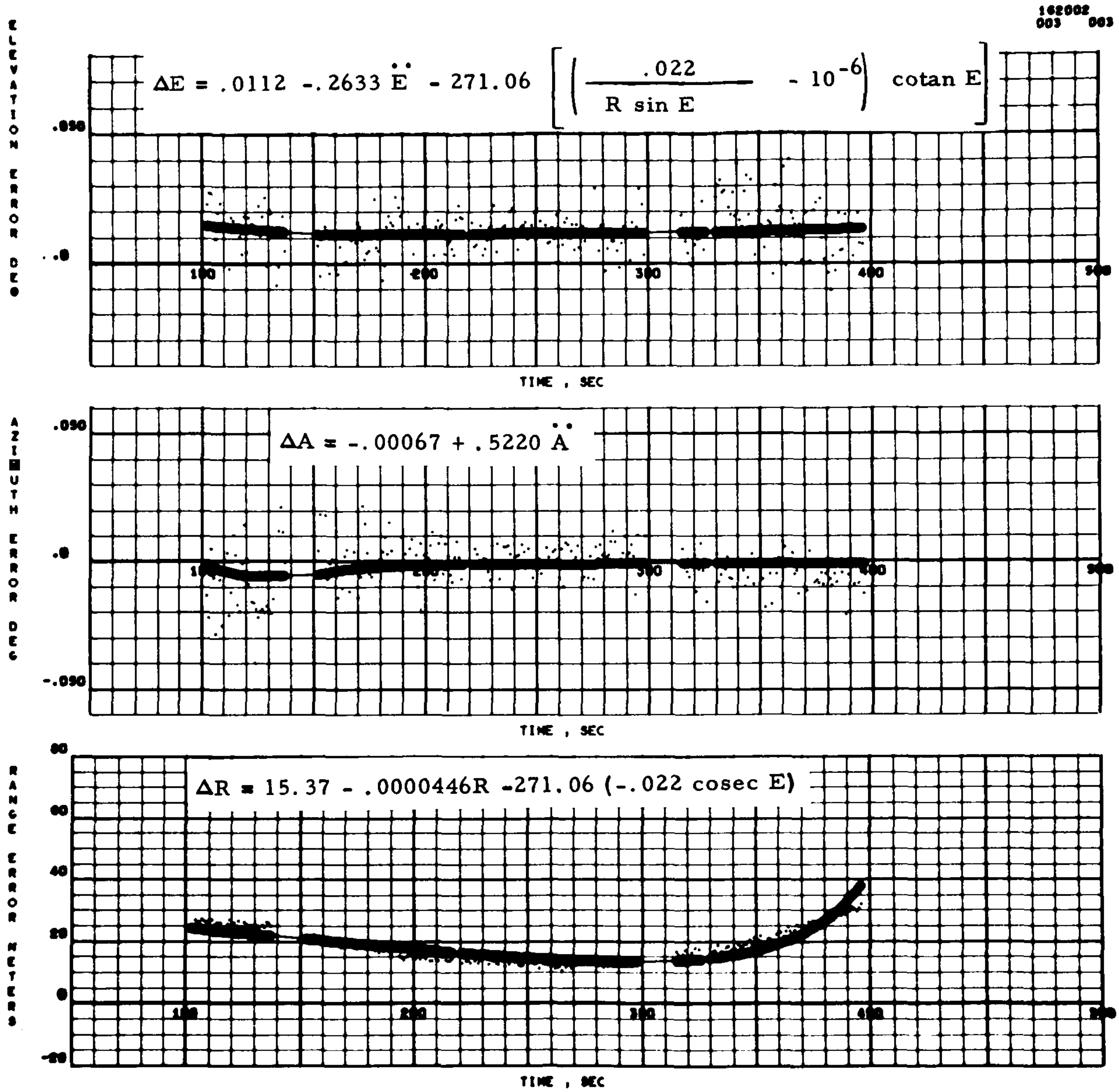

FIGURE C2. RADAR 0.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON SA-203

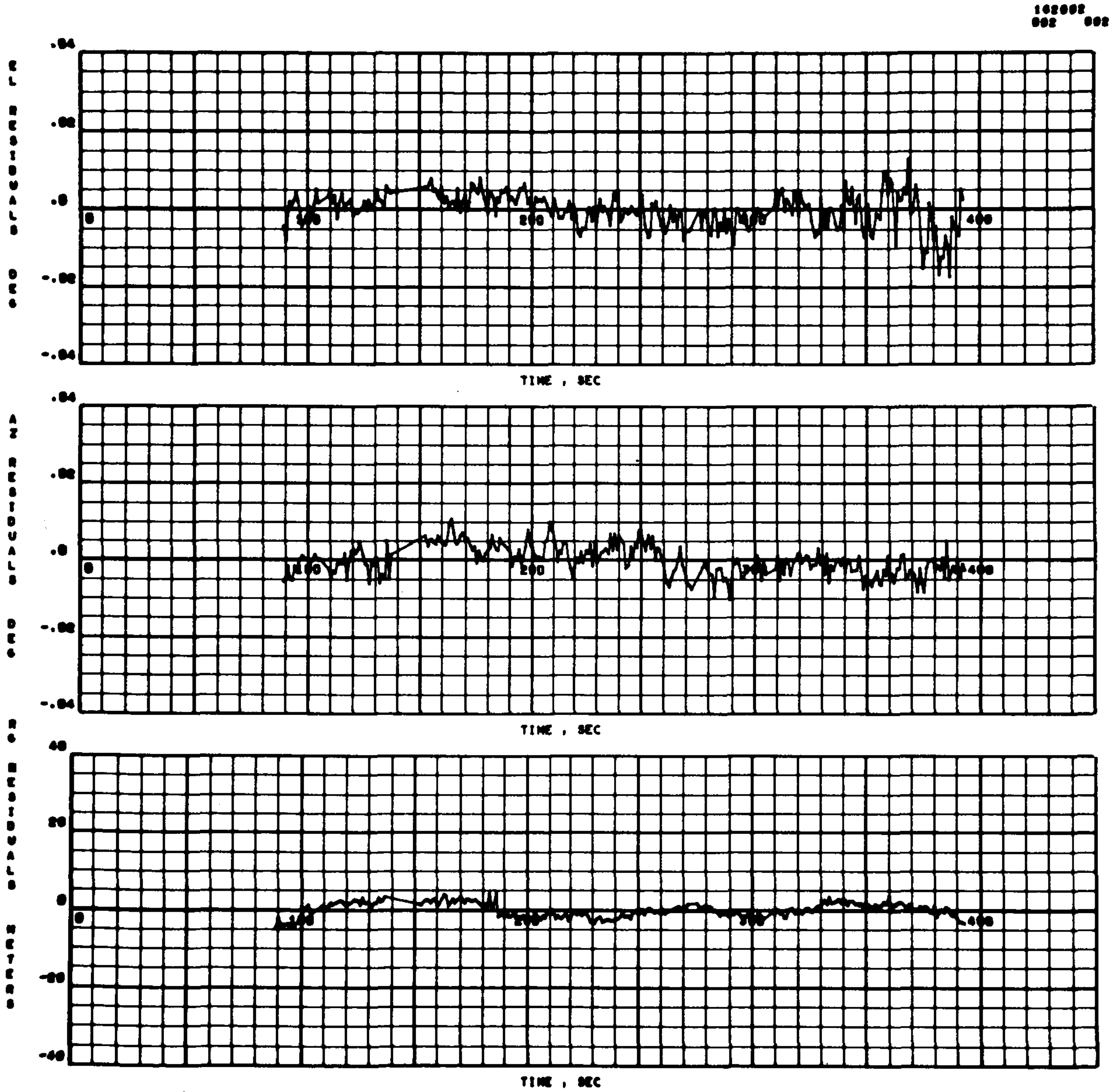

FIGURE C3. RADAR 19.18 RESIDUALS ON SA-203

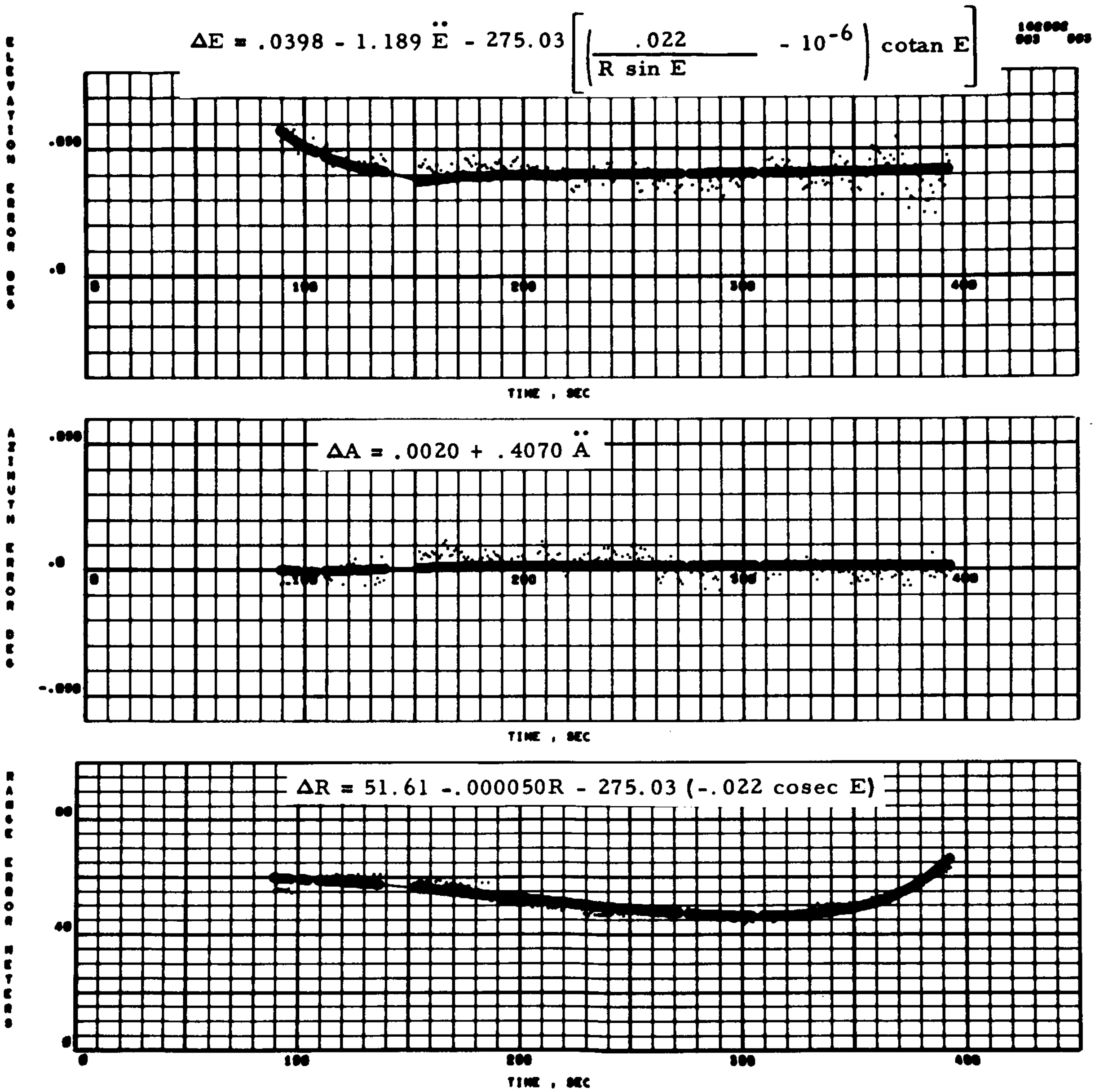

FIGURE C4. RADAR 19.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON SA-203

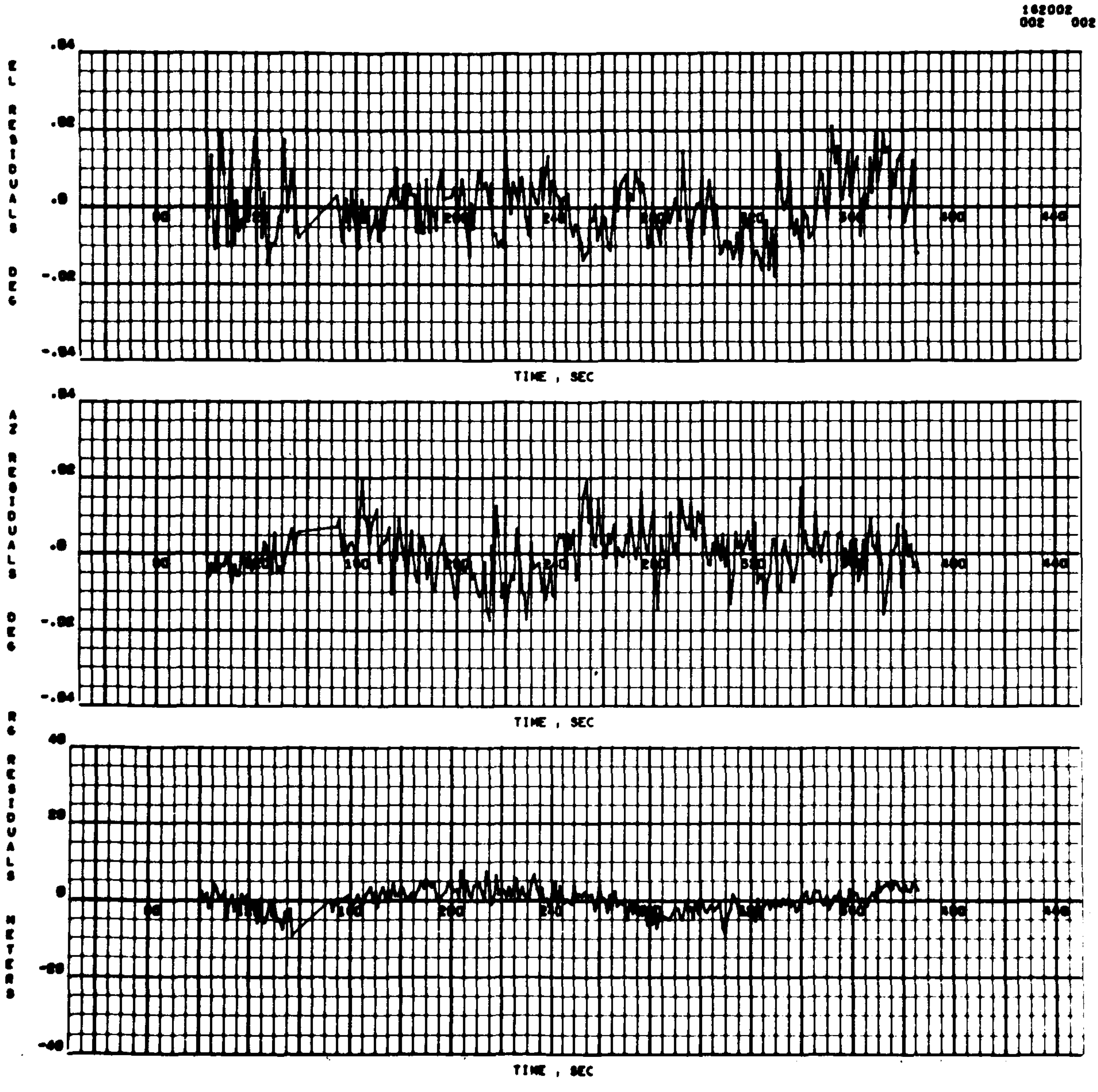

FIGURE C5. RADAR 3.18 RESIDUALS ON SA-203

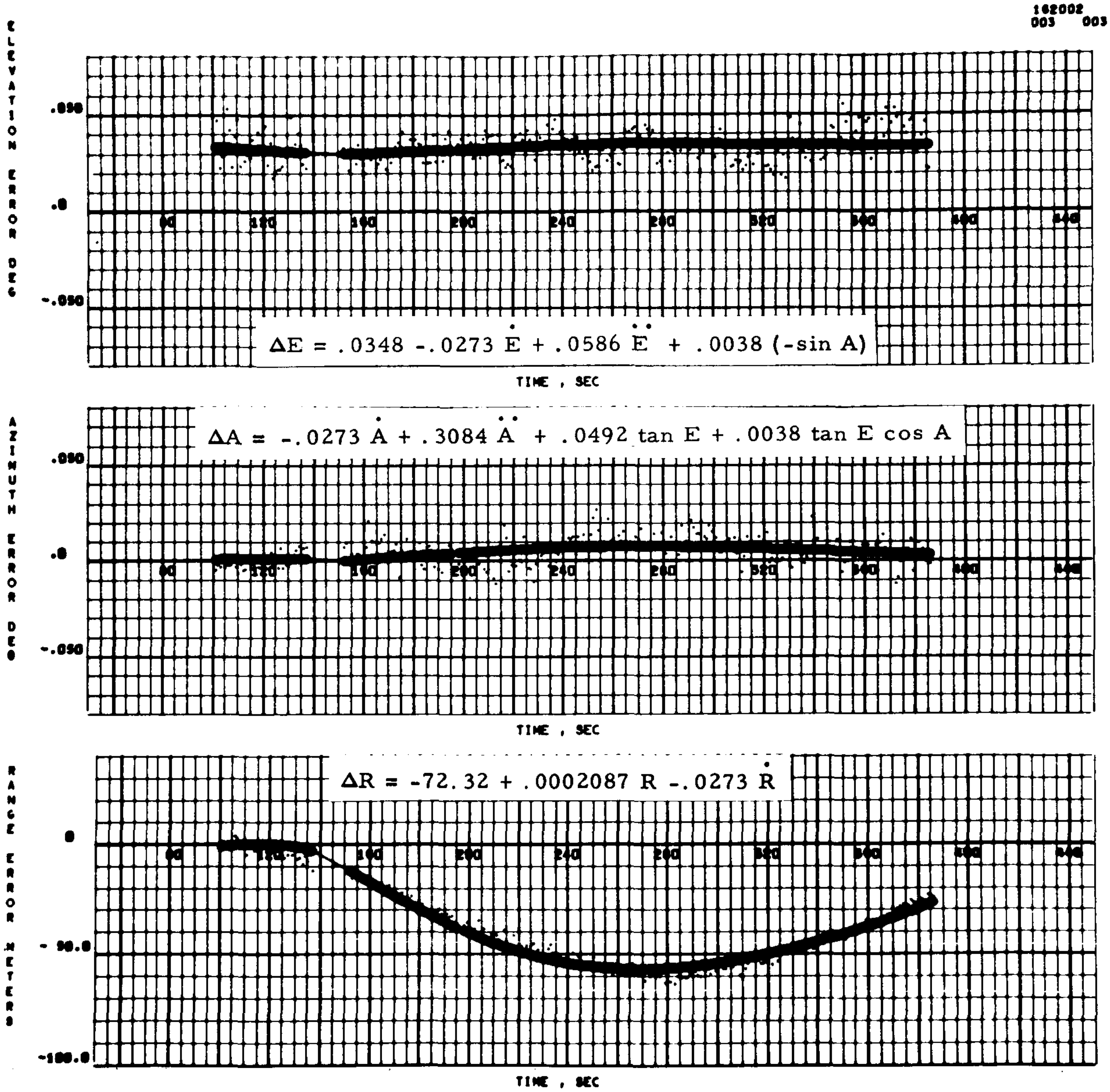

FIGURE C6. RADAR 3.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON SA-203

FIGURE C7. RADAR 7.18 RESIDUALS ON SA-203

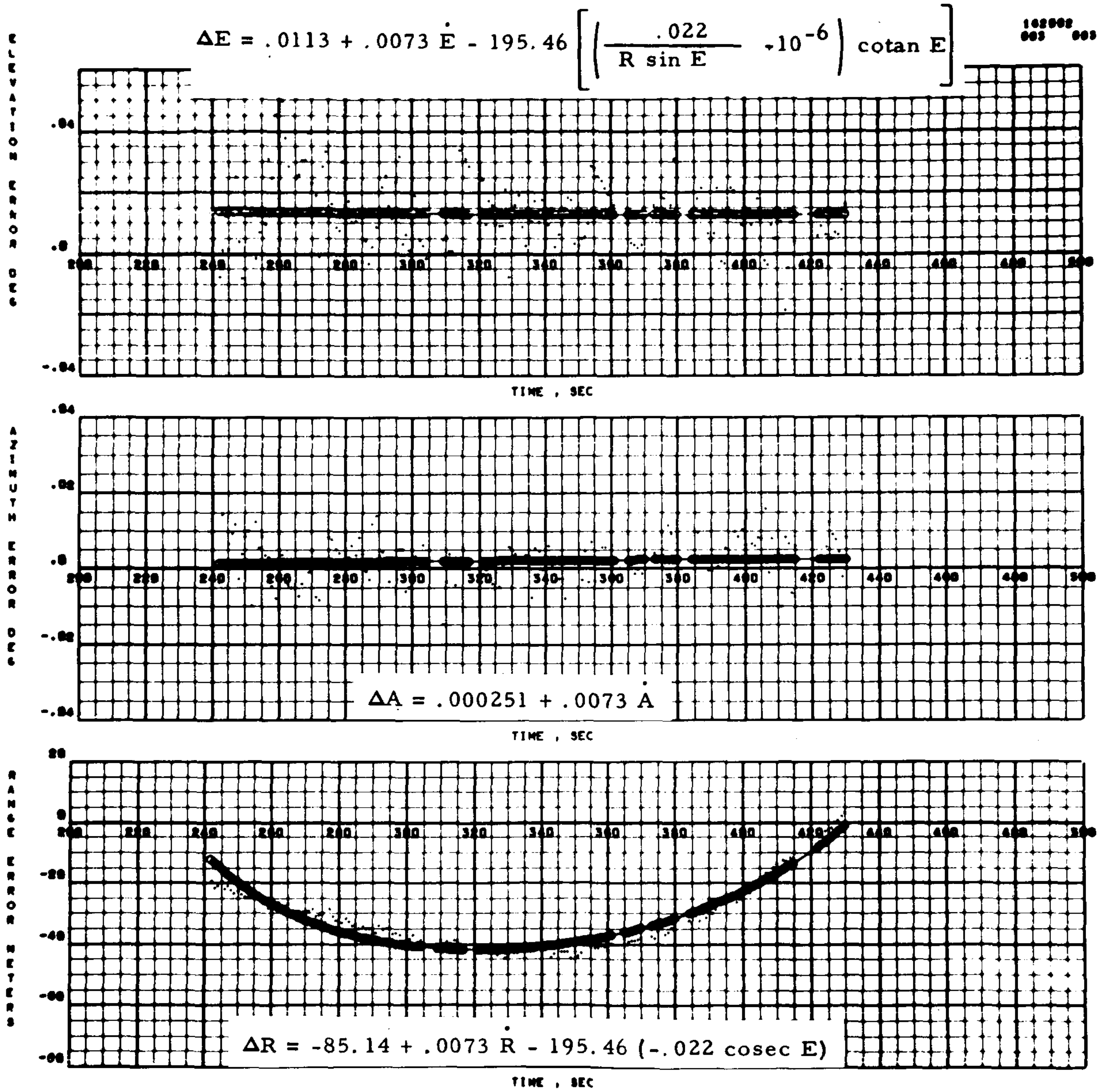

FIGURE C8. RADAR 7.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON SA-203

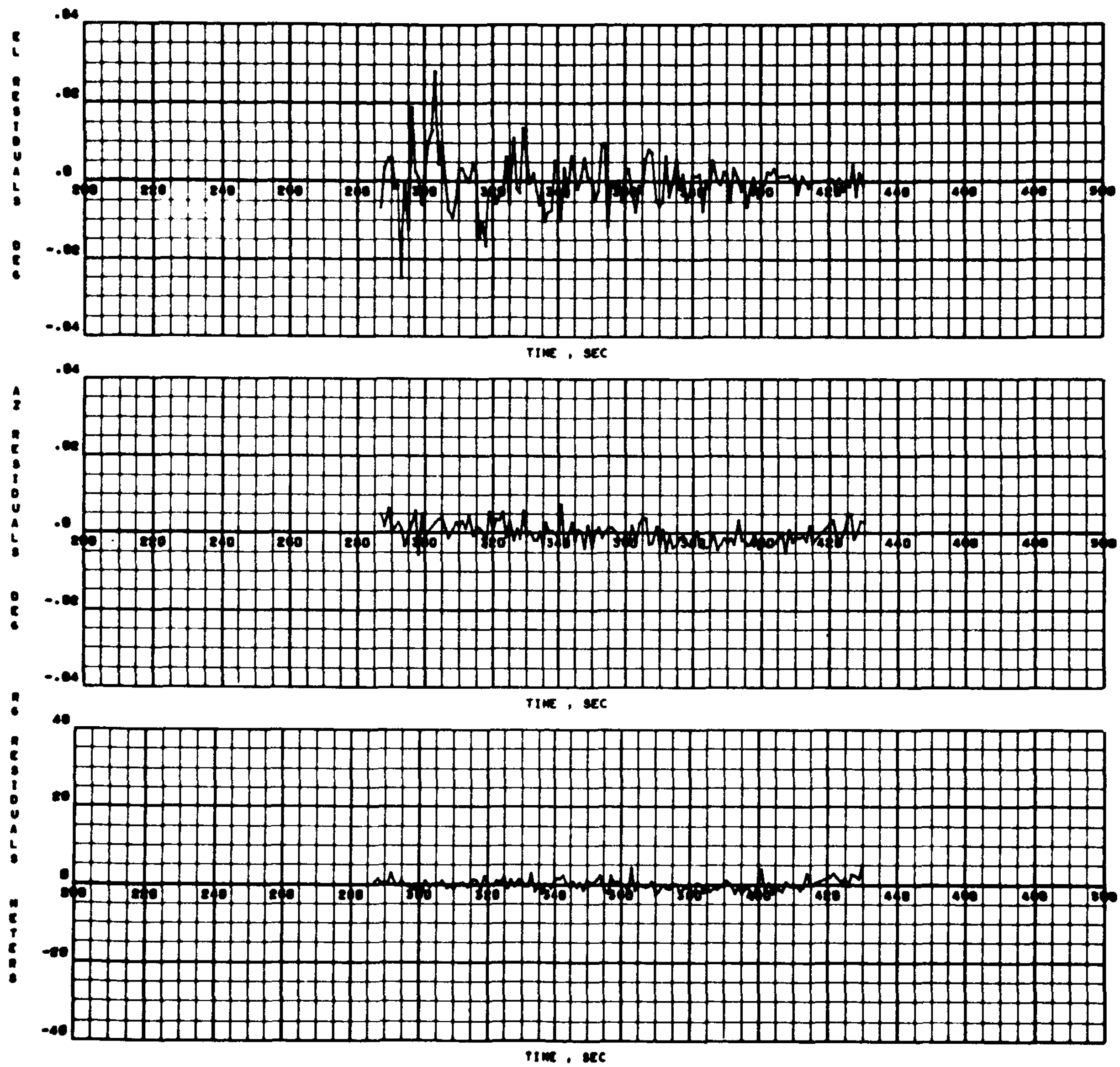

FIGURE C9. RADAR BDA RESIDUALS ON SA-203

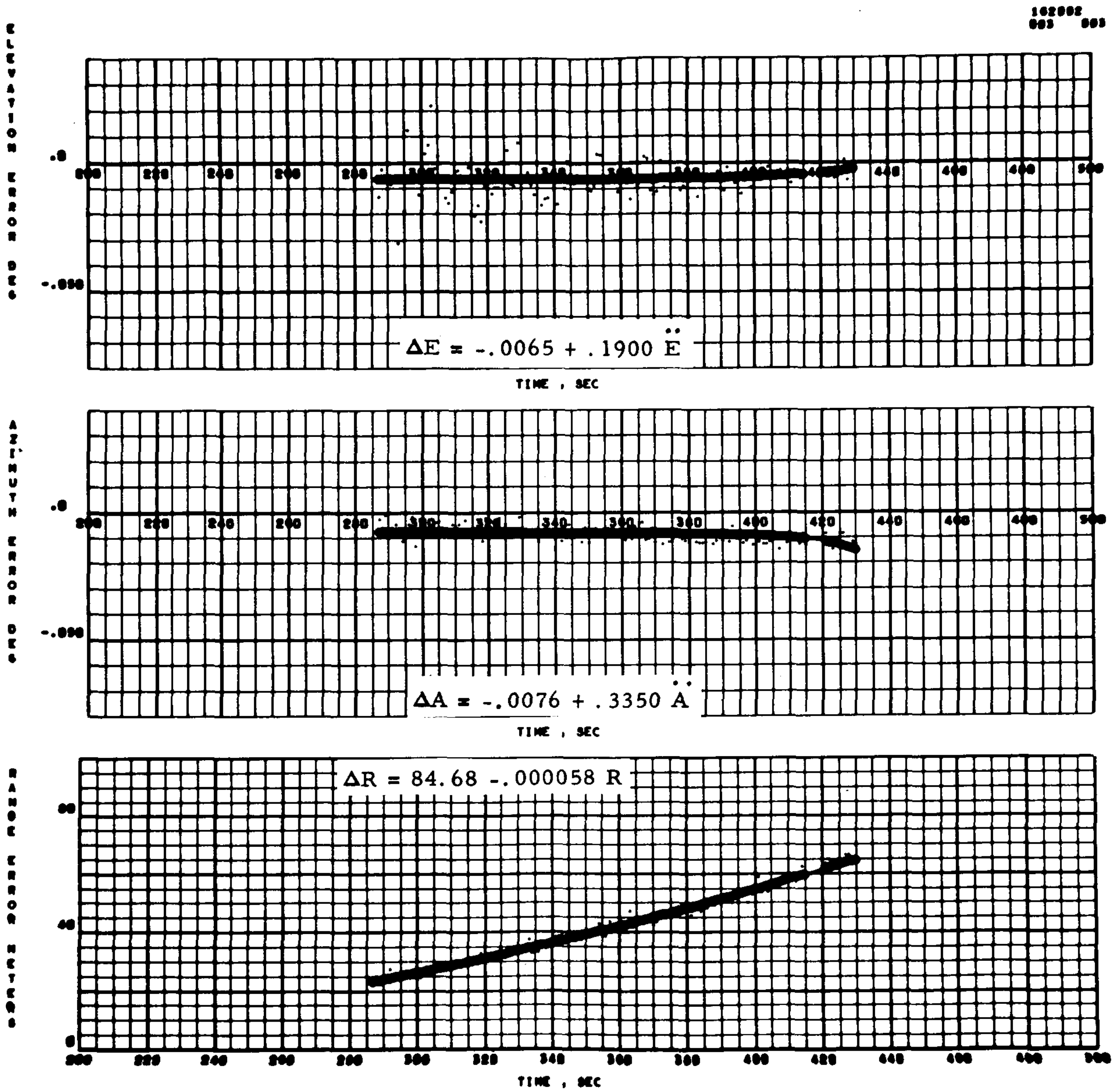

FIGURE C10. RADAR BDA RANGE, AZIMUTH, AND ELEVATION ERRORS ON SA-203

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TEMS RADAR ERROR MODEL REGRESSION ANALYSIS RESULTS FROM THE SATURN AS-201, AS-202, AND SA-203 FLIGHT TESTS

By

Bobby G. Junkin

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