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THE TEMS APOLLO-SATURN V RESULTS THROUGH THE AS-502 FLIGHT TEST

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ABSTRACT

Truncated tracker error models for representing the systematic errors on the Apollo-Saturn AS-501 and AS-502 flight tests are presented. The TEMS method for determining the models involves establishing the tracker errors and then determining, in the least squares sense, functional expressions to describe the established errors. Guidelines used in obtaining the truncated error models have resulted in generally acceptable models for the AS-501 and AS-502 data. Although C-band radar error models are used in the TEMS development, the method can be adapted to other types of tracking systems.

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COMPUTATION LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Concluded)

LIST OF TABLES

LIST OF TABLES (Concluded)

DEFINITION OF SYMBOLS

Symbol	Definition
TEMS	Acronym for Tracking System Error Model Studies
ΔR, ΔA, ΔE	Functional expressions for the systematic errors in range, azimuth, and elevation, respectively
ΔR^0, ΔA^0, ΔE^0	Observed tracking errors in range, azimuth, and elevation, respectively
V_R, V_A, V_E	Residuals in range, azimuth, and elevation, respectively
V_{C_0}, V_{C_1}, . . . , $V_{F_{12}}$	Coefficient observational residuals
C_0, C_1, . . .	Coefficients in range error model
D_0, D_1, . . .	Coefficients in azimuth error model
F_0, F_1, . . .	Coefficients in elevation error model
R, A, E	First derivatives of range, azimuth, and elevation, respectively, with respect to time
$\ddot{A}$, $\ddot{E}$	Second derivatives of azimuth and elevation, respectively, with respect to time
X, Y, Z	Reference position of vehicle in an earth-fixed ephemeris coordinate system with origin at the tracking site
σ^2_{VR}, σ^2_{VA}, σ^2_{VE}	Least square residual variances in range, azimuth, and elevation, respectively
$\tilde{C}_0$, $\tilde{C}_1$, . . .	Parameter approximation values
δC_0, δC_1, . . .	Parameter corrections
C_0^{∞}, C_1^{∞}, . . .	Parameter a priori values
r, a, e	Range, azimuth, and elevation error model factors, respectively

DEFINITION OF SYMBOLS (Concluded)

Symbol	Definition
F Level	Ratio for determining the statistical significance of a regression equation
σ_Y	Standard deviation of the response variable

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THE TEMS APOLLO-SATURN V RESULTS THROUGH THE AS-502 FLIGHT TEST

SUMMARY

Truncated tracker error models for representing the systematic errors on the Apollo-Saturn AS-501 and AS-502 flight tests are presented. Guidelines used in obtaining the truncated error models have resulted in generally acceptable models for the AS-501 and AS-502 data. The TEMS method for determining the models involves establishing the tracker errors and then determining, in the least squares sense, functional expressions to describe the established errors. Although C-band radar error models are used in the TEMS development, the method can be adapted to other types of tracking systems.

INTRODUCTION

This report is one in a continuing series summarizing results from the evaluation of tracking system measurement errors on the Apollo-Saturn V flight tests. The basic concept in the evaluation process is given in the TEMS Multiple Regression Analysis Method [1]. The method involves establishing the tracker errors and then determining, in the least squares sense, error model expressions to describe the established errors. The fundamental observational residual equations in the method are given by:

$$\left.\begin{array}{ccccc} V_R & = & \Delta R^0 & - & \Delta R \\ V_A & = & \Delta A^0 & - & \Delta A \\ V_E & = & \Delta E^0 & - & \Delta E \\ \underbrace{\qquad}_{\text{Observational Residuals}} & & \underbrace{\qquad}_{\text{Observed Deltas}} & & \underbrace{\qquad}_{\text{Functional Deltas}} \end{array}\right\} \qquad (1)$$

where:

$$\left.\begin{aligned}
\Delta R &= \tilde{C}_0 + \delta C_0 + (\tilde{C}_1 + \delta C_1)\, r_1 + (\tilde{C}_2 + \delta C_2)\, r_2 + \ldots + (\tilde{C}_k + \delta C_k)\, r_k \\
\Delta A &= \tilde{D}_0 + \delta D_0 + (\tilde{D}_1 + \delta D_1)\, a_1 + (\tilde{D}_2 + \delta D_2)\, a_2 + \ldots + (\tilde{D}_\ell + \delta D_\ell)\, a_\ell \\
\Delta E &= \tilde{F}_0 + \delta F_0 + (\tilde{F}_1 + \delta F_1)\, e_1 + (\tilde{F}_2 + \delta F_2)\, e_2 + \ldots + (\tilde{F}_m + \delta F_m)\, e_m
\end{aligned}\right\} \quad (2)$$

and r_k, a_ℓ, and e_m are functions of the basic range, azimuth, and elevation measurements. The parameter (or coefficient) residual equations are given by:

$$\left.\begin{array}{ccccccc}
V_{C_0} & = & \delta C_0 & + & \tilde{C}_0 & - & C_0^{\infty} \\
V_{C_1} & = & \delta C_1 & + & \tilde{C}_1 & - & C_1^{\infty} \\
\vdots & & & & & & \\
\underbrace{V_{F_m}}_{\substack{\text{Parameter}\\ \text{Residuals}}} & = & \underbrace{\delta F_m}_{\text{Corrections}} & + & \underbrace{\tilde{F}_m}_{\substack{\text{Coefficient}\\ \text{Approximations}}} & - & \underbrace{F_m^{\infty}}_{\substack{\text{A priori}\\ \text{Coefficient}\\ \text{Values}}}
\end{array}\right\} \quad (3)$$

We then determine the corrections δC_0, δC_1, ..., δF_m, in the least squares sense, and adjust our initial approximations $\tilde{C}_0$, $\tilde{C}_1$, ... $\tilde{F}_m$ by these amounts.

The above TEMS method is used in conjunction with a stepwise regression procedure to obtain truncated tracker error models for representing the systematic errors. The stepwise regression procedure involves examining at every step the variables incorporated into the error model in previous steps. The final regression model results in only the most significant variables being retained in the model. Detailed development information can be found in Reference 1.

The IBM 7094 and Univac 1108 computer programs for application of the TEMS method and the stepwise regression procedure are discussed in detail in Reference 1. The utilization of these two programs to obtain the final TEMS error models is summarized in Figure 1.

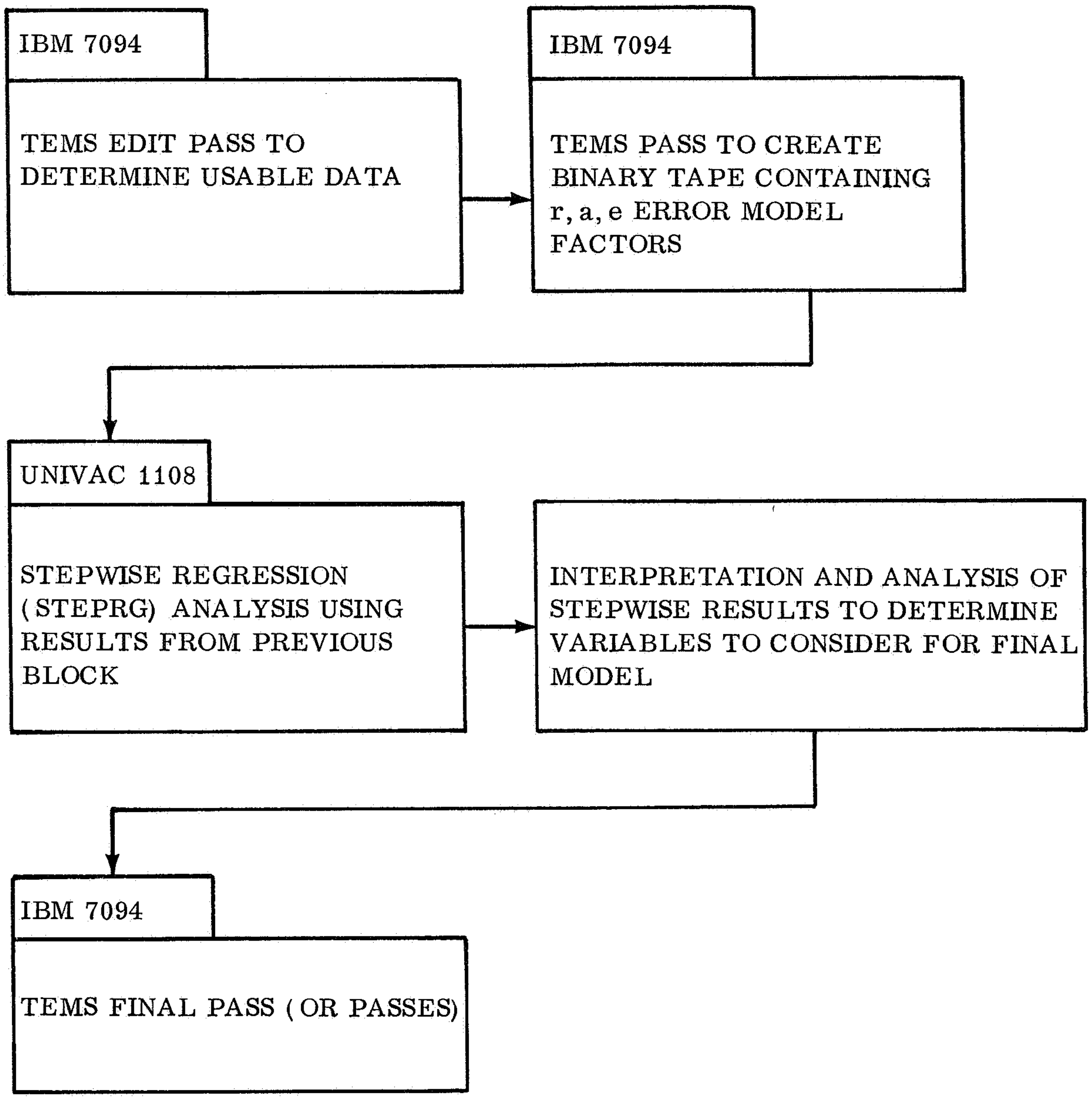


FIGURE 1. UTILIZATION OF THE TEMS AND STEPRG COMPUTER PROGRAMS

SUMMARY OF APOLLO-SATURN V RESULTS THROUGH THE AS-502 LAUNCH

The Apollo-Saturn AS-502 vehicle was launched at 07:00:01 (AM) Eastern Standard Time on April 4, 1968 from Kennedy Space Center, Launch Complex 39, Pad A. Tracking data from five C-band radars providing coverage on the launch to orbital insertion phase and three providing coverage on the orbital phase (revolution 1) were used in the reduction.

The post flight reference trajectory used as the standard in the reduction is presented in Reference 2. The relation between the vehicle trajectory for the first phase of the launch and the various C-band radar tracking sites is shown in Figure 2. A similar summary for the orbital phase is given in Figure 3. Table I contains location data for the launch site and the various tracking stations.

TABLE I. LOCATION OF LAUNCH SITE AND C-BAND TRACKING RADARS USED IN TEMS AS-502 REDUCTION

Site	Latitude, deg	Longitude, deg	Height,[a] m
Launch Complex 39, Pad A	28.608422	80.604133	116.04[b]
Patrick Radar (0.18)	28.226553	80.599293	19.92
Merritt Island Radar (19.18)	28.424862	80.664404	16.39
Grand Bahama Radar (3.18)	26.636350	78.267708	16.29
67.18 (FPQ-6)	32.347964	64.653742	19.03
Cape Kennedy (1.16)	28.481766	80.576515	18.78

a. Elevation above the Fischer Ellipsoid

b. Elevation of the C-band radar antenna above the Fischer Ellipsoid

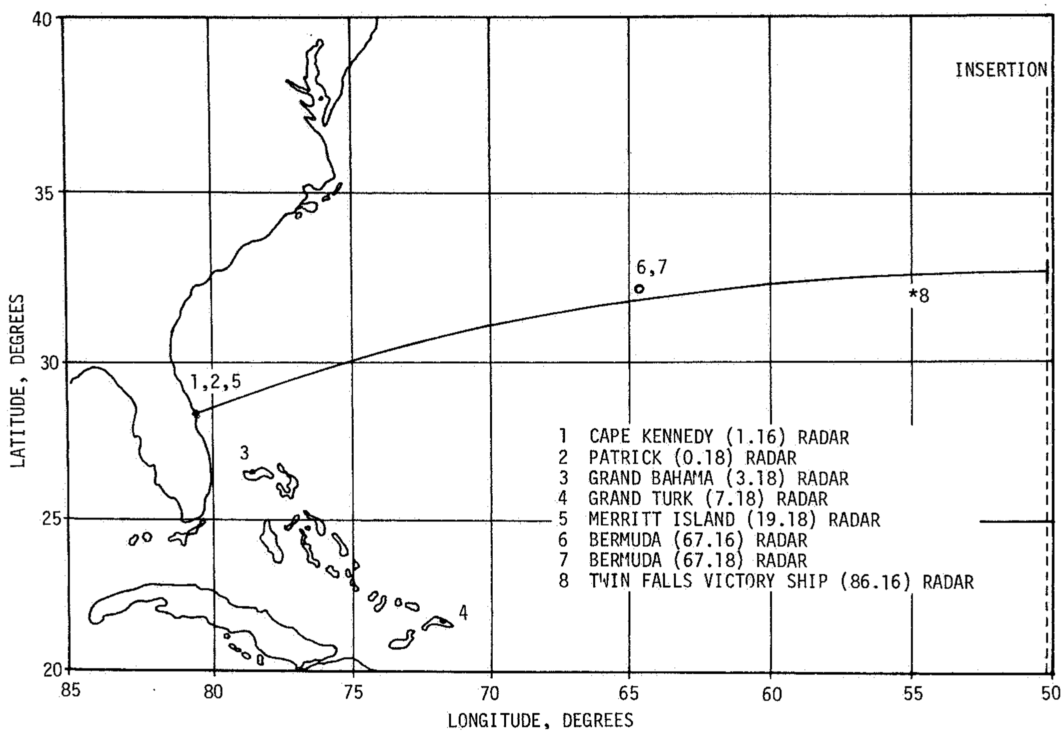


FIGURE 2. AS-502 LAUNCH PHASE GROUND TRACK

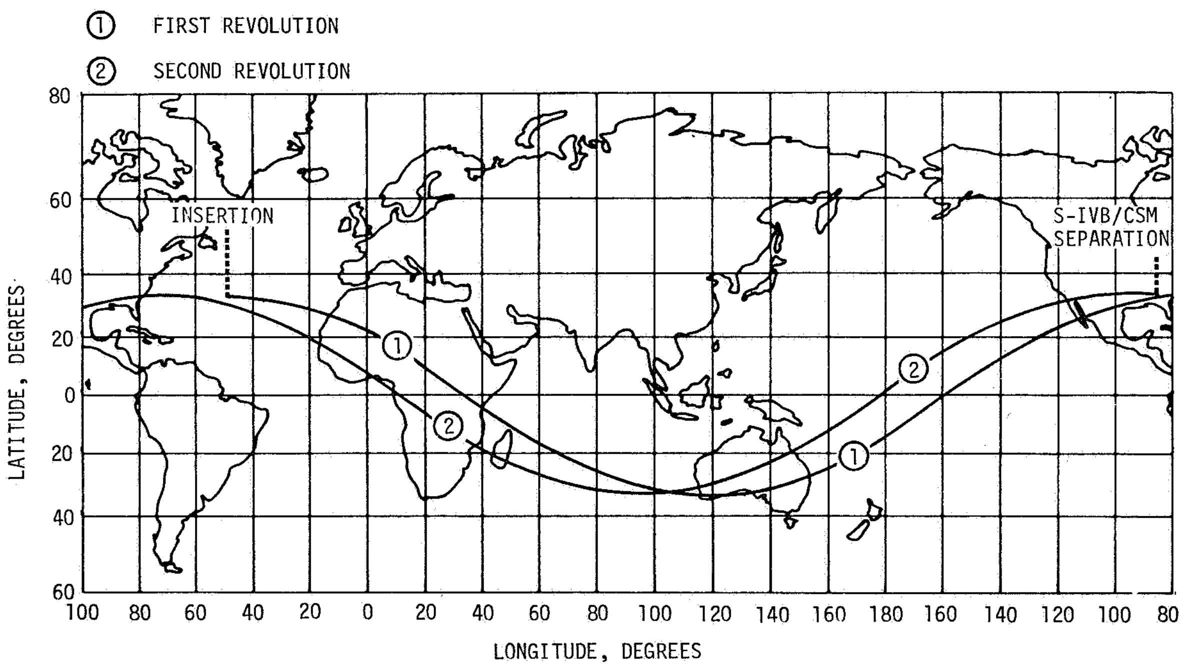


FIGURE 3. AS-502 ORBITAL PHASE GROUND TRACK

The specific tracking data utilization for the launch and orbital phases is shown in Figure 4. These data were determined from an edit pass through the TEMS program. The preliminary edited data for all the radars were processed with the parameter weight matrix ($\bar{W}$) and approximation matrix ($\bar{C}$) equal to zero. A priori estimates of zero for the error model coefficients were also entered into the final TEMS computer runs.

The general approach for obtaining truncated error models to describe the AS-501 and AS-502 range, azimuth, and elevation response variables is summarized in the following guidelines:

(1) It was assumed that the survey terms, rate bias term, and the azimuth and elevation velocity lag terms were not essential in obtaining truncated error models to describe the response variables.

(2) The first two variables entered in the stepwise regression (excluding those left out under the assumption in guideline 1) were selected for consideration in the final TEMS error model.

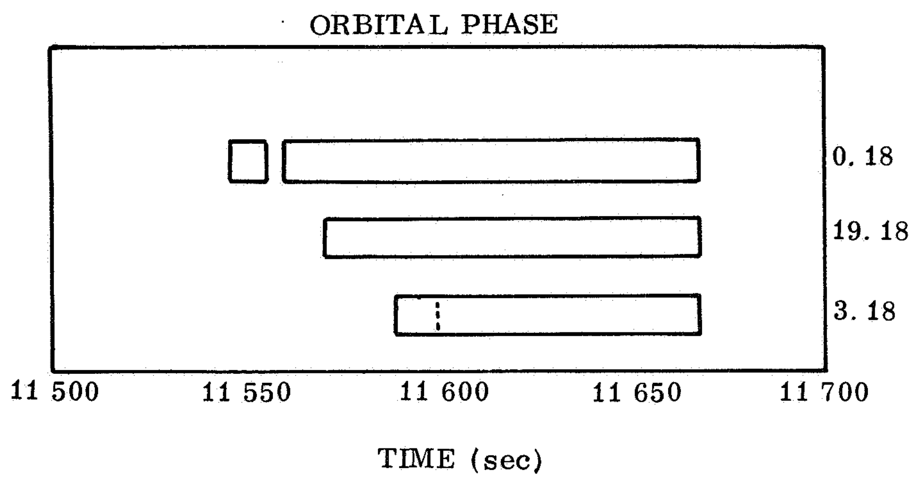
(3) A third variable was considered if an adequate description of the response variable was not obtained with the first two, or if a constraining condition required an additional variable in the model.

This approach actually results in entering the most significant variables into the error model. It should be pointed out that the third variable selected in guideline (3) often involved selecting one of two variables that represented borderline cases so far as the order of entry in the stepwise regression was concerned; i. e., the two variables had partial correlation coefficient values nearly equal.

The AS-501 and AS-502 truncated error model results obtained using guidelines (1) through (3) are presented in Tables II through V. Plots of the observed and computed response variables and the least squares residuals for the truncated models are given in Appendixes B and C. Coefficient correlations are also presented.

CONCLUSIONS

The TEMS Multiple Regression Analysis Method is used in conjunction with a stepwise regression procedure to obtain truncated tracker error models



NOTE:

THE DOTTED LINES INDICATE WHERE ONLY 1-3 DATA POINTS ARE LEFT OUT.

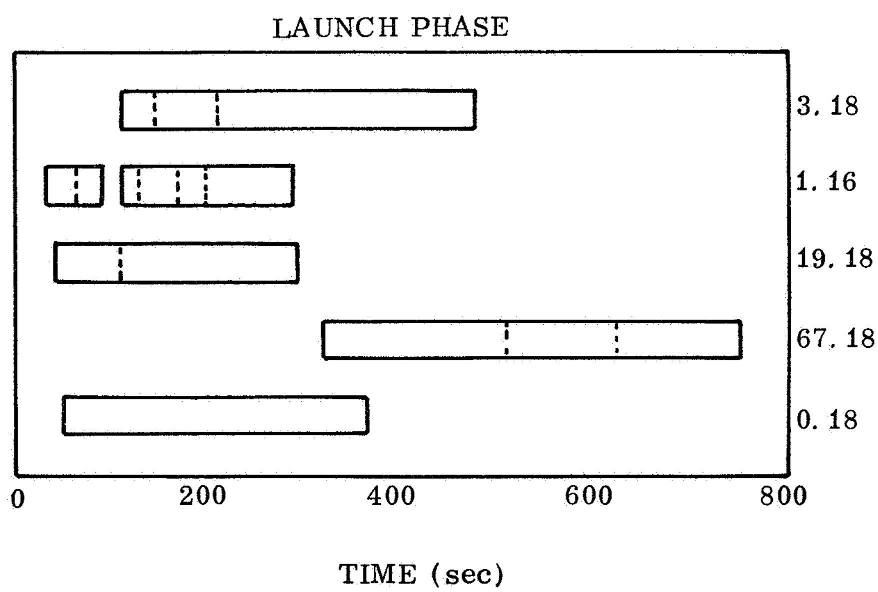


FIGURE 4. TEMS AS-502 TRACKING DATA UTILIZATION

for representing the systematic errors on the Apollo-Saturn AS-501 and AS-502 flight tests. Guidelines used in obtaining the truncated error models have resulted in generally acceptable models for the AS-501 and AS-502 data. Although C-band radar error models are used in the TEMS development, the method can be adapted to other types of tracking systems.

TABLE II. TRUNCATED RADAR ERROR MODEL MULTIPLE REGRESSION RESULTS FOR FIRST BURN DATA ON AS-501 AND AS-502 VEHICLE FLIGHT TESTS

Flight Test	Radar	Coefficient											σ_{VR} Met.	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				
501	0.18	-19.92	—	0.0091	23.71	0.0087	0.6915	—	-0.0202	—	0.0194	0.1791	3.96	0.0082	0.0072	335
502		- 4.76	-0.52E-4	0.0057	—	0.0044	0.0341	—	—	—	0.0170	-0.4858	4.64	0.0041	0.0055	311
501	19.18	-18.11	—	0.0055	-36.03	0.72E-3	—	0.0697	-0.0761	—	0.0330	-0.4390	5.23	0.0046	0.0062	219
502		-13.94	-0.25E-4	—	-37.69	-0.0093	-0.1339	0.0530	-0.0492	—	0.0523	—	3.54	0.0036	0.0050	247
501	3.18	5.21	—	0.0066	93.25	0.0054	0.5517	—	—	—	-0.84E-3	2.10	4.02	0.0027	0.0055	395
502		5.43	—	-0.0102	258.24	0.0032	1.0550	—	—	—	0.0010	—	5.39	0.0064	0.0058	354
501	7.18	-12.28	—	0.0024	36.20	-0.0176	-2.84	—	—	—	-0.0085	—	6.09	0.0038	0.0165	297
502-NA		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
501	67.16	58.47	-1.14E-4	-0.0022	—	0.34E-3	0.1632	—	—	0.0083	0.0073	0.2380	9.75	0.0097	0.0051	289
502-NA		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
501	67.18	84.34	-0.97E-4	-0.0049	—	0.0056	0.0192	—	—	0.0067	0.0021	-0.0027	9.16	0.0045	0.0057	297
502		216.63	-0.26E-3	-0.0272	—	-0.0081	—	—	—	0.0046	0.0228	—	29.21	0.0063	0.0110	431
501	1.16	-36.91	-0.59E-4	0.0171	—	0.0171	0.3386	—	-0.0177	—	0.0042	—	4.31	0.0121	0.0106	225
502		-23.65	-0.24E-4	—	177.78	0.0024	0.1526	—	—	—	0.0218	-0.5808	4.70	0.0100	0.0105	209
												Average σ	7.50	0.0063	0.0079	

NA: Not Available

TABLE III. COEFFICIENT STANDARD DEVIATIONS FOR TRUNCATED RADAR ERROR MODELS FOR FIRST BURN DATA ON AS-501 AND AS-502 VEHICLE FLIGHT TESTS

Flight Test	Radar	σ_K For Indicated Coefficient										
		C_0	C_1	C_2	C_4	D_0	D_3	D_5	D_7	D_8	F_0	F_3
501	0.18	0.84	—	0.25E-3	5.21	0.54E-3	0.074	—	0.0015	—	0.93E-3	0.100
502		0.57	0.23E-5	0.44E-3	—	0.30E-3	0.048	—	—	—	0.30E-3	0.071
501	19.18	0.72	—	0.33E-3	3.75	0.0010	—	0.0024	0.0016	—	0.0010	0.050
502		0.76	0.17E-5	—	13.97	0.0011	0.0580	0.0023	0.0013	—	0.0010	—
501	3.18	0.36	—	0.11E-3	2.27	0.23E-3	0.086	—	—	—	0.24E-3	0.173
502		0.63	—	0.17E-3	4.72	0.34E-3	0.124	—	—	—	0.33E-3	—
501	7.18	0.95	—	0.30E-3	1.97	0.64E-3	0.971	—	—	—	0.61E-3	—
502-NA		—	—	—	—	—	—	—	—	—	—	—
501	67.16	1.15	0.21E-5	0.09E-3	—	0.56E-3	0.005	—	—	0.48E-3	0.54E-3	0.014
502-NA		—	—	—	—	—	—	—	—	—	—	—
501	67.18	0.84	0.15E-5	0.10E-3	—	0.46E-3	0.004	—	—	0.43E-3	0.48E-3	0.012
502		1.99	0.27E-5	0.18E-3	—	0.0011	—	—	—	0.93E-3	0.0010	—
501	1.16	1.03	0.67E-5	0.89E-3	—	1.14E-3	0.073	—	0.0025	—	1.57E-3	—
502		1.54	0.37E-5	—	27.80	0.62E-3	0.055	—	—	—	0.62E-3	0.074

NA: Not Available

TABLE IV. TRUNCATED RADAR ERROR MODEL MULTIPLE REGRESSION RESULTS FOR SECOND BURN DATA ON AS-501 AND ORBITAL DATA ON AS-502 VEHICLE FLIGHT TESTS

Flight Test	Radar	Coefficient									σ_{VR} Met.	σ_{VA} Deg.	σ_{VE} Deg.	No. of Data Points
		C_0	C_1	C_2	D_0	D_3	D_7	D_8	F_0	F_3				
501		-25.89	-0.73E-5	-0.0059	-0.86E-3	-0.0117	-0.0223	—	0.0018	0.4277	7.30	0.0050	0.0073	492
502	19.18	350.17	—	0.0617	-0.0120	-4.94	—	—	0.0101	—	8.94	0.0031	0.0084	94
501		8.46	—	-0.0061	0.0091	0.2989	—	—	-0.0182	2.5233	7.16	0.0038	0.0055	322
502	3.18	701.95	—	0.1171	-0.0027	-13.14	—	—	-0.0098	—	8.57	0.0059	0.0116	73
501		34.84	-2.43E-5	-0.0043	0.0032	0.4009	—	—	-0.7E-4	-4.1971	2.22	0.0038	0.0059	684
502-NA	91.18	—	—	—	—	—	—	—	—	—	—	—	—	—
501		8.83	-2.87E-5	-0.0011	0.0055	—	—	0.0012	-0.0116	—	7.28	0.0053	0.0058	864
502-NA	67.18	—	—	—	—	—	—	—	—	—	—	—	—	—
501-NA		—	—	—	—	—	—	—	—	—	—	—	—	—
502	0.18	275.61	—	0.0482	-0.0067	-3.61	—	—	0.0001	—	9.24	0.0042	0.0122	113
									Average σ		7.23	0.0044	0.0081	

NA: Not Available

TABLE V. COEFFICIENT STANDARD DEVIATIONS FOR TRUNCATED RADAR ERROR MODELS FOR SECOND BURN DATA ON AS-501 AND ORBITAL DATA ON AS-502 VEHICLE FLIGHT TESTS

Flight Test	Radar	σ_K For Indicated Coefficients								
		C_0	C_1	C_2	D_0	D_3	D_7	D_8	F_0	F_3
501		0.60	0.05E-5	0.52E-4	0.33E-3	0.057	0.0012	—	0.58E-3	0.157
502	19.18	13.60	—	0.0021	0.0017	0.4755	—	—	0.86E-3	—
501		0.29	—	0.55E-4	0.35E-3	0.075	—	—	0.36E-3	0.256
502	3.18	27.91	—	0.0044	0.0035	1.78	—	—	0.0012	—
501		0.35	0.02E-5	0.61E-4	0.18E-3	0.201	—	—	0.18E-3	0.434
502-NA	91.18	—	—	—	—	—	—	—	—	—
501		0.36	0.01E-5	0.43E-4	0.24E-3	—	—	0.29E-3	0.27E-3	—
502-NA	67.18	—	—	—	—	—	—	—	—	—
501-NA		—	—	—	—	—	—	—	—	—
502	0.18	14.21	—	0.0022	0.0017	0.5440	—	—	0.95E-3	—

NA: Not Available

APPENDIX A

THE C-BAND 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

$$\Delta R = C_0 + C_1 R + C_2 \dot{R} + C_3 t + C_4(-0.022 \operatorname{cosec} E) + C_5\left(\frac{X}{R}\right) + C_6\left(\frac{Y}{R}\right) + C_7\left(\frac{Z}{R}\right) \qquad \text{(A-1)}$$

Azimuth

$$\Delta A = D_0 + D_1\dot{A} + D_3\ddot{A} + D_5 \tan E + D_6 \sec E + D_7 \tan E \sin A + D_8 \tan E \cos A + D_9\left(\frac{\sin A \cos A}{X}\right) + D_{10}\left(-\frac{\sin A \cos A}{Y}\right) + D_{11}\dot{A} \sec E \qquad \text{(A-2)}$$

Elevation

$$\Delta E = F_0 + F_1\dot{E} + F_3\ddot{E} + F_5(-\sin A) + F_6 \cos A + F_7\left[\left(\frac{0.022}{R \sin E} - 10^{-6}\right) \operatorname{cotan} E\right] + F_9\left(\frac{-X \tan E}{R^2}\right) + F_{10}\left(\frac{-Y \tan E}{R^2}\right) + F_{11}\left(\frac{\cos E}{R}\right) + F_{12}\dot{E} \cos E \qquad \text{(A-3)}$$

The specific physical interpretation of the terms appearing in equations (A-1), (A-2), and (A-3) are given in Reference 1. These equations require modifications, depending on the particular tracking system being considered and on the flight trajectory geometry. The IBM 7094 computer program was thus developed such that any combination of terms appearing in the error models can be retained in a given adjustment through the use of appropriate program control matrices.

APPENDIX B

RESULTS FROM THE APOLLO-SATURN 501 VEHICLE FLIGHT TEST

This appendix presents a summary of the results from the Apollo-Saturn 501 Vehicle Flight Test launched on November 9, 1967. The Stepwise Regression Analysis results for the first and second burn data are presented in Tables B-I and B-II, respectively. Coefficient correlations for the truncated error models for the first and second burn data are given in Tables B-III and B-IV, respectively.

In the figures (B-1 through B-22), the tracking errors for the various radars are represented by dots. The description of these errors as obtained from the TEMS least squares adjustment program is represented by the solid computed curves.

The least squares residuals for the truncated error models presented in this appendix and in Appendix C can be thought of as being composed of random errors and unmodeled systematic errors. A high random error content in the data may prevent a systematic error of comparable magnitude from being determined. The latter errors are those that can be attributed to uncertainties in the standard used in establishing the tracking errors, unknown systematic errors not absorbed by those that are modeled, or to geometry limitations. The presence of a significant unmodeled systematic error may prevent an adequate description of the data from being obtained.

TABLE B-I. STEPWISE REGRESSION ANALYSIS RESULTS FOR AS-501 FIRST BURN DATA

Equation	Variables in Regression	σ_Y	F Level
0.18			
ΔR	C_0, C_5, C_8, C_4, C_6	1.71	-0.10
ΔA	D_0, C_2, D_7, D_8, C_6	0.0058	6.6
ΔE	F_0, C_6, C_2, D_7, D_8	0.0060	-1.0
19.18			
ΔR	C_0, C_1, C_6, C_5, C_7	2.39	76.9
ΔA	D_0, C_2, D_7	0.0042	234.9
ΔE	F_0, C_7, C_2, F_3	0.0048	9.5
7.18			
ΔR	$C_0, C_7, C_6, C_1, C_8, C_2$	1.13	15.0
ΔA	D_0, D_7	0.0037	76.6
ΔE	F_0, D_7	0.0158	22.9
3.18			
ΔR	$C_0, C_5, C_1, C_7, C_8, C_2, C_6$	1.82	22.8
ΔA	D_0, C_2, D_3, D_6, D_7	0.0024	35.0
ΔE	$F_0, C_6, C_5, D_7, C_4, F_3$	0.0043	16.8
67.16			
ΔR	C_0, C_6, C_7, C_8, C_1	2.73	7.5
ΔA	D_0, D_3, D_7, D_5, C_6	0.0072	3.8
ΔE	F_0, F_3, D_8, C_7, D_7	0.0044	10.1
67.18			
ΔR	C_0, C_1, C_7, C_4, C_2	1.95	-0.80
ΔA	D_0, D_3, D_5, D_7	0.0042	5.6
ΔE	$F_0, C_2, D_7, F_3, C_5, C_7, C_4$	0.0034	7.9
1.16			
ΔR	C_0, C_5, C_8, C_2	4.05	-0.06
ΔA	D_0, C_2, D_7, D_8, C_6	0.0102	5.9
ΔE	F_0	0.0101	<3.5

TABLE B-II. STEPWISE REGRESSION ANALYSIS RESULTS FOR AS-501 SECOND BURN DATA

Equation	Variables in Regression	σ_Y	F Level
91.18			
ΔR	C_0, C_8, C_7, C_2, C_4, C_1	1.77	105.8
ΔA	D_0, C_2, D_6, D_7, D_3	0.0035	36.7
ΔE	F_0, C_2, F_3	0.0054	11.8
3.18			
ΔR	C_0, C_2, C_6, C_5, C_1, C_7	3.37	22.3
ΔA	D_0, D_3, D_5, D_6	0.0035	-0.90
ΔE	F_0, C_7	0.0048	267.6
19.18			
ΔR	C_0, C_2, C_8, C_7	4.12	153.8
ΔA	D_0, D_3, D_7, D_8, D_6	0.0039	-1.5
ΔE	F_0, C_4, F_3, D_8	0.0062	-0.20
67.18			
ΔR	C_0, C_6, C_4, C_2, C_5, C_8, C_7, C_1	3.85	28.4
ΔA	D_0, C_2, D_8, D_7, D_5, D_6, D_3	0.0040	26.9
ΔE	F_0, D_8, C_2, C_4	0.0053	43.0

TABLE B-III. COEFFICIENT CORRELATIONS FOR THE TRUNCATED AS-501 FIRST BURN RADAR ERROR MODELS

	C_0	C_1	C_2	D_0	D_3	D_8	F_0	F_3
C_0	1.00	-0.92	0.12	0.01	0.0	-0.02	0.0	0.0
C_1		1.00	-0.16	-0.01	0.0	0.03	0.0	0.0
C_2			1.00	0.05	0.01	-0.18	0.01	0.0
D_0				1.00	-0.03	0.25	-0.01	-0.01
D_3					1.00	-0.12	0.01	0.01
D_8						1.00	-0.04	-0.05
F_0							1.00	0.03
F_3								1.00

Radar 67.16

	C_0	C_2	C_4	D_0	D_3	F_0	F_3
C_0	1.00	-0.37	0.56	0.04	0.0	0.02	0.0
C_2		1.00	0.41	-0.12	0.01	0.02	0.01
C_4			1.00	-0.05	0.0	0.04	0.01
D_0				1.00	0.04	0.0	0.0
D_3					1.00	0.0	0.0
F_0						1.00	0.30
F_3							1.00

Radar 3.18

	C_0	C_2	C_4	D_0	D_3	F_0
C_0	1.00	-0.15	0.77	0.01	0.0	0.02
C_2		1.00	0.25	-0.10	0.01	0.01
C_4			1.00	-0.03	0.0	0.03
D_0				1.00	-0.24	0.0
D_3					1.00	0.0
F_0						1.00

Radar 7.18

	C_0	C_1	C_2	D_0	D_3	D_7	F_0
C_0	1.00	0.19	-0.61	-0.11	0.21	0.27	-0.23
C_1		1.00	0.84	-0.15	0.29	0.37	-0.31
C_2			1.00	0.18	-0.35	-0.44	0.37
D_0				1.00	-0.56	-0.80	0.73
D_3					1.00	0.68	-0.62
D_7						1.00	-0.91
F_0							1.00

Radar 1.16

	C_0	C_1	C_2	D_0	D_3	D_8	F_0	F_3
C_0	1.00	-0.88	-0.18	-0.01	0.0	0.05	-0.02	0.0
C_1		1.00	0.41	0.02	0.01	-0.10	0.04	0.01
C_2			1.00	0.05	0.02	-0.25	0.09	0.01
D_0				1.00	-0.03	0.26	-0.10	-0.02
D_3					1.00	-0.13	0.05	0.01
D_8						1.00	-0.39	-0.07
F_0							1.00	0.06
F_3								1.00

Radar 67.18

	C_0	C_2	C_4	D_0	D_5	D_7	F_0	F_3
C_0	1.00	-0.82	0.63	-0.03	0.09	-0.02	-0.01	-0.17
C_2		1.00	-0.37	0.03	-0.05	-0.07	0.07	0.10
C_4			1.00	-0.02	0.13	-0.18	0.10	-0.26
D_0				1.00	-0.80	0.06	-0.06	0.0
D_5					1.00	-0.56	0.52	-0.01
D_7						1.00	-0.92	0.0
F_0							1.00	0.07
F_3								1.00

Radar 19.18

	C_0	C_2	C_4	D_0	D_3	D_7	F_0	F_3
C_0	1.00	-0.75	0.58	0.06	0.0	0.0	-0.01	-0.06
C_2		1.00	-0.05	-0.01	-0.04	-0.10	0.09	0.0
C_4			1.00	0.10	-0.06	-0.13	0.10	-0.12
D_0				1.00	-0.27	-0.72	0.66	-0.06
D_3					1.00	0.43	-0.39	0.03
D_7						1.00	-0.91	0.08
F_0							1.00	-0.03
F_3								1.00

Radar 0.18

TABLE B-IV. COEFFICIENT CORRELATIONS FOR THE TRUNCATED AS-501 SECOND BURN RADAR ERROR MODELS

	C_0	C_1	C_2	D_0	D_3	D_7	F_0	F_3
C_0	1.00	-0.87	0.33	-0.01	0.0	0.0	0.0	0.0
C_1		1.00	-0.56	0.03	0.0	0.01	0.0	0.0
C_2			1.00	-0.05	-0.01	-0.01	0.01	0.0
D_0				1.00	-0.07	-0.20	0.17	-0.10
D_3					1.00	0.45	-0.37	0.21
D_7						1.00	-0.83	0.48
F_0							1.00	-0.38
F_3								1.00

Radar 19.18

	C_0	C_1	C_2	D_0	D_8	F_0
C_0	1.00	-0.69	-0.02	0.0	0.0	0.0
C_1		1.00	-0.55	-0.01	0.02	0.01
C_2			1.00	0.03	-0.04	-0.02
D_0				1.00	0.22	0.12
D_8					1.00	0.53
F_0						1.00

Radar 67.18

	C_0	C_1	C_2	D_0	D_3	F_0	F_3
C_0	1.00	-0.67	0.01	0.0	0.0	0.0	0.0
C_1		-1.00	-0.69	0.04	0.0	0.0	0.0
C_2			1.00	-0.05	0.0	0.0	0.01
D_0				1.00	0.35	0.0	0.0
D_3					1.00	0.0	0.0
F_0						1.00	0.44
F_3							1.00

Radar 91.18

	C_0	C_2	D_0	D_3	F_0	F_3
C_0	1.00	0.01	0.0	0.0	0.0	0.0
C_2		1.00	-0.06	0.0	0.0	0.0
D_0			1.00	0.0	0.0	0.0
D_3				1.00	0.0	0.0
F_0					1.00	0.25
F_3						1.00

Radar 3.18

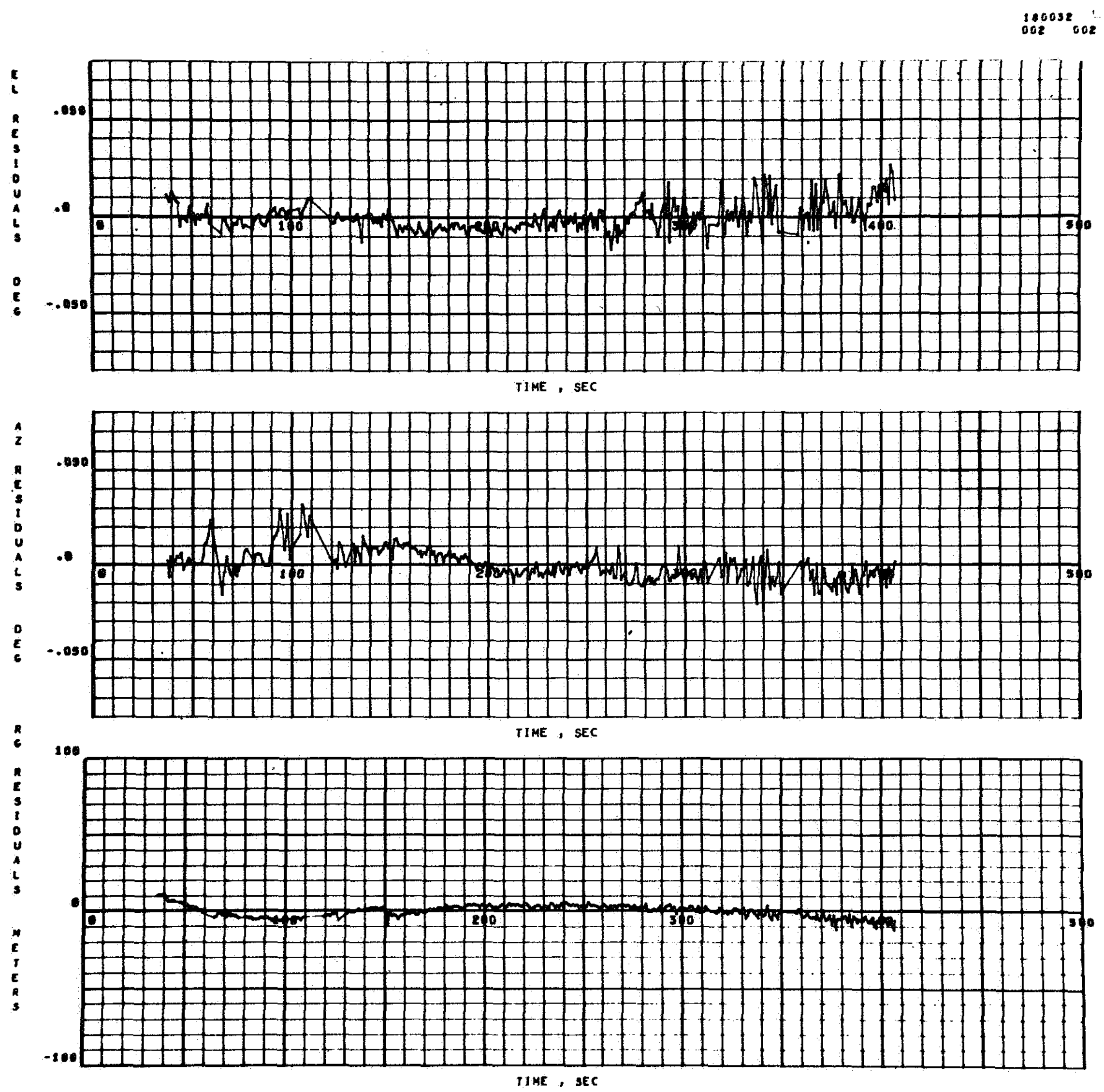


FIGURE B-1. RADAR 0.18 RESIDUALS ON AS-501
FIRST BURN DATA

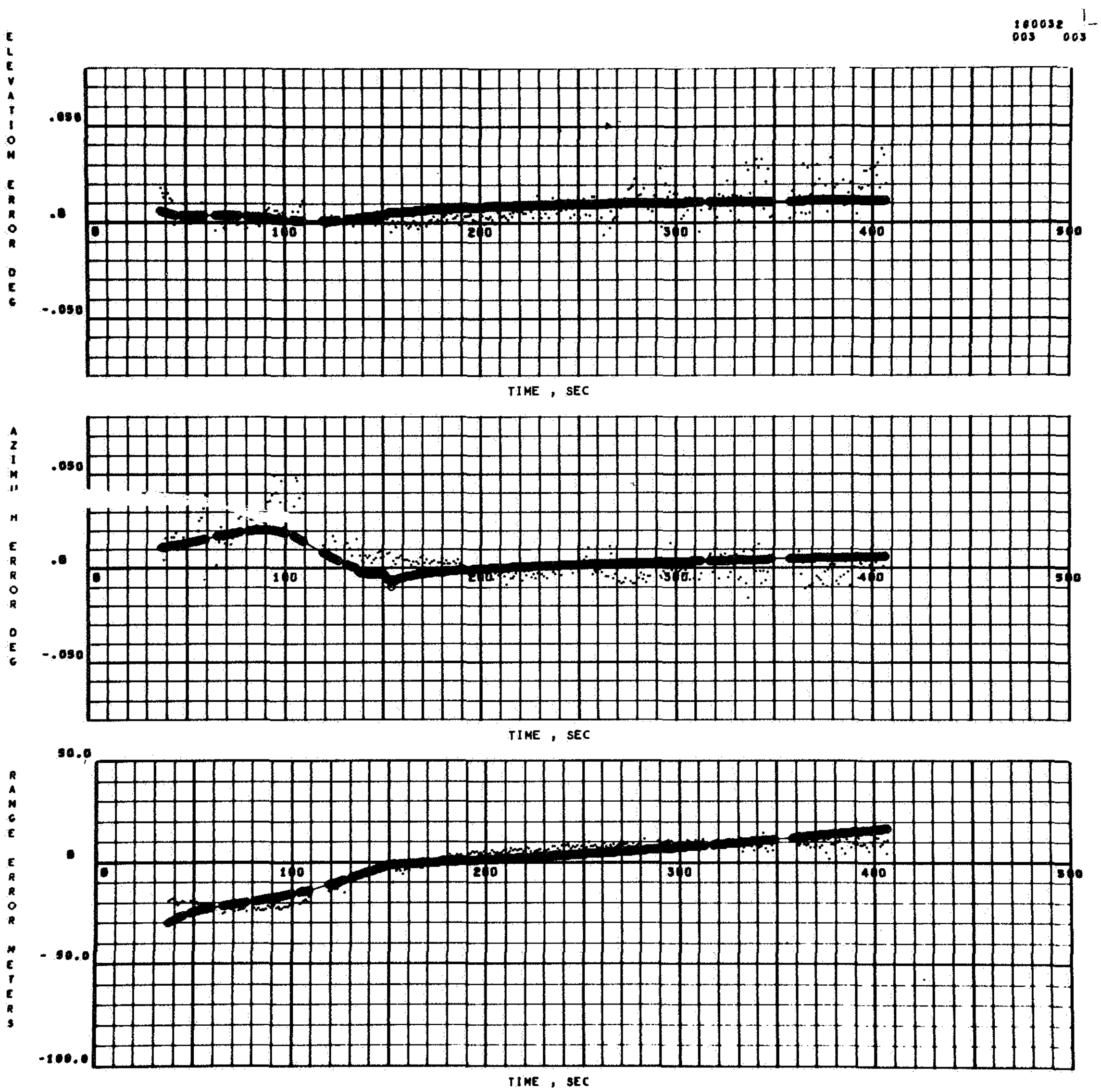


FIGURE B-2. RADAR 0.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-501 FIRST BURN DATA

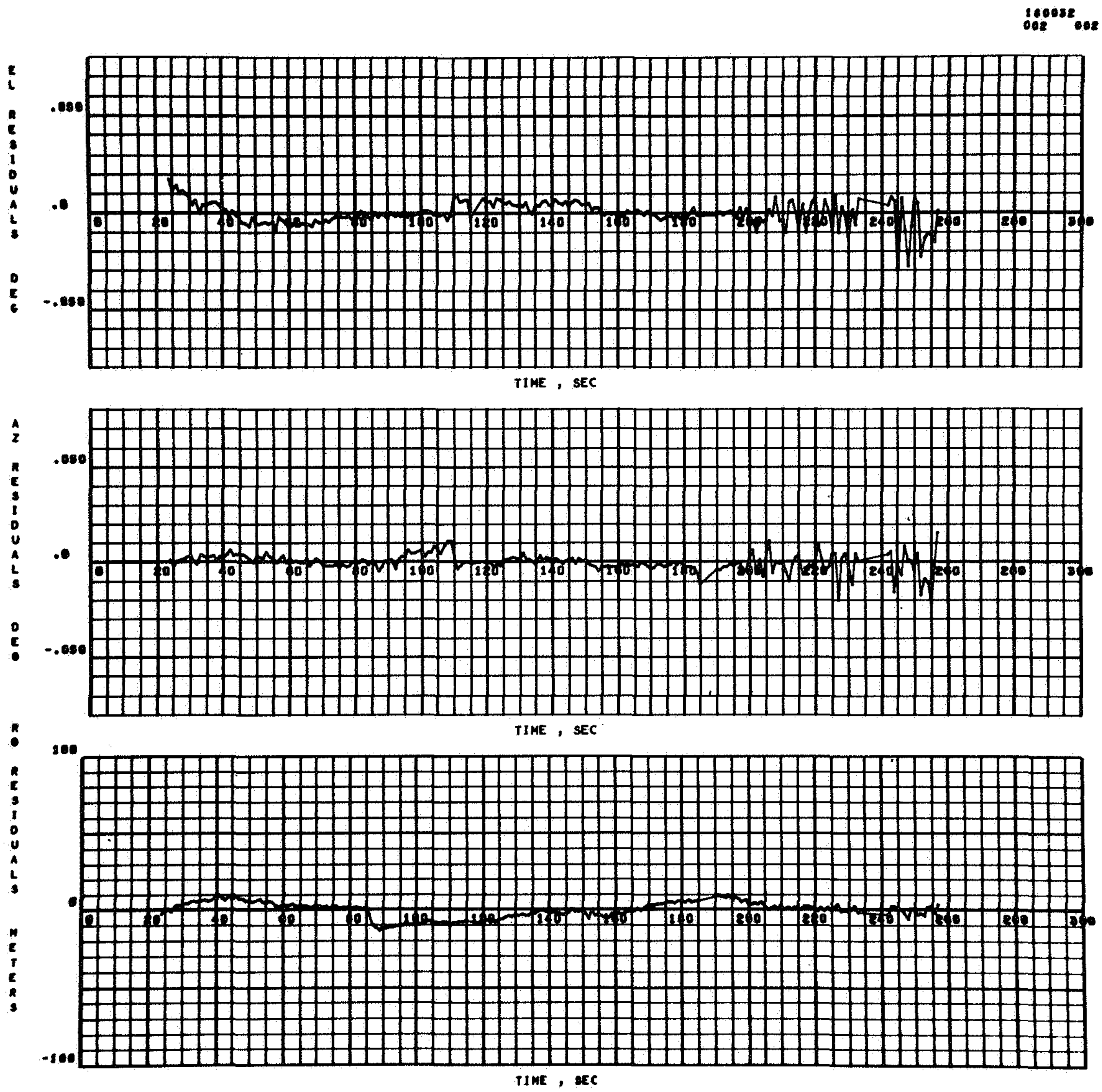


FIGURE B-3. RADAR 19.18 RESIDUALS ON AS-501
FIRST BURN DATA

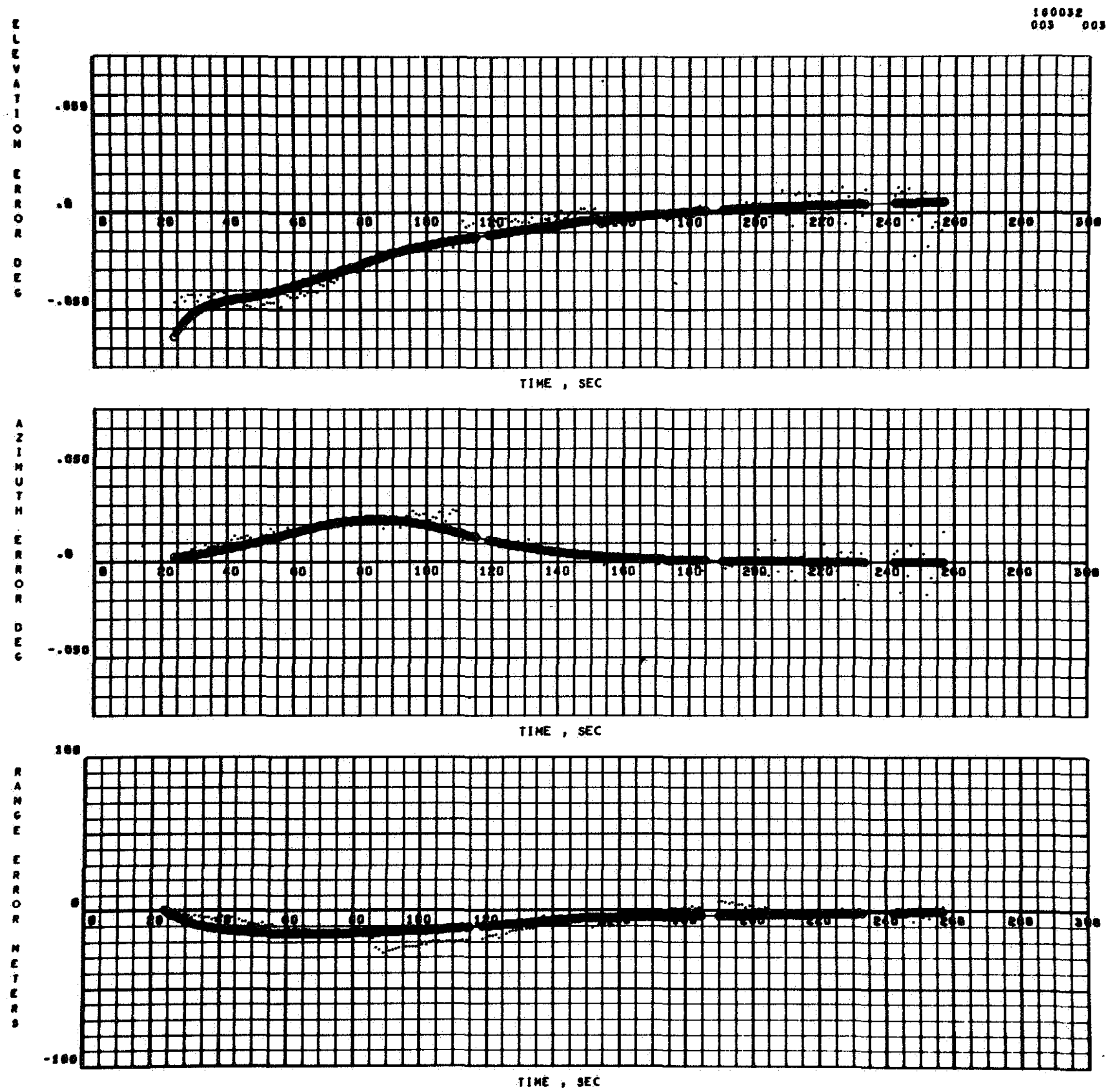


FIGURE B-4. RADAR 19.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-501 FIRST BURN DATA

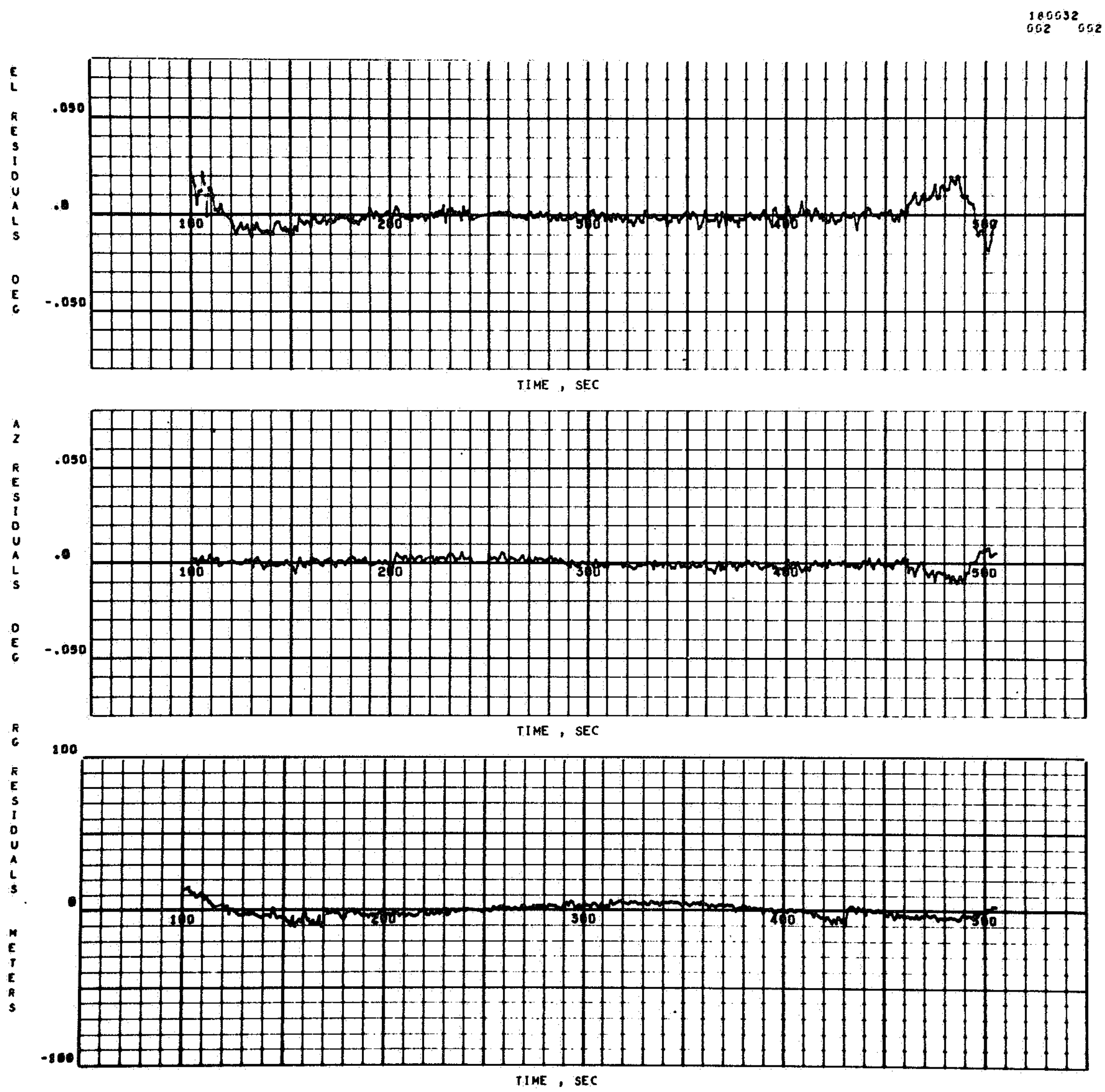


FIGURE B-5. RADAR 3.18 RESIDUALS ON AS-501
FIRST BURN DATA

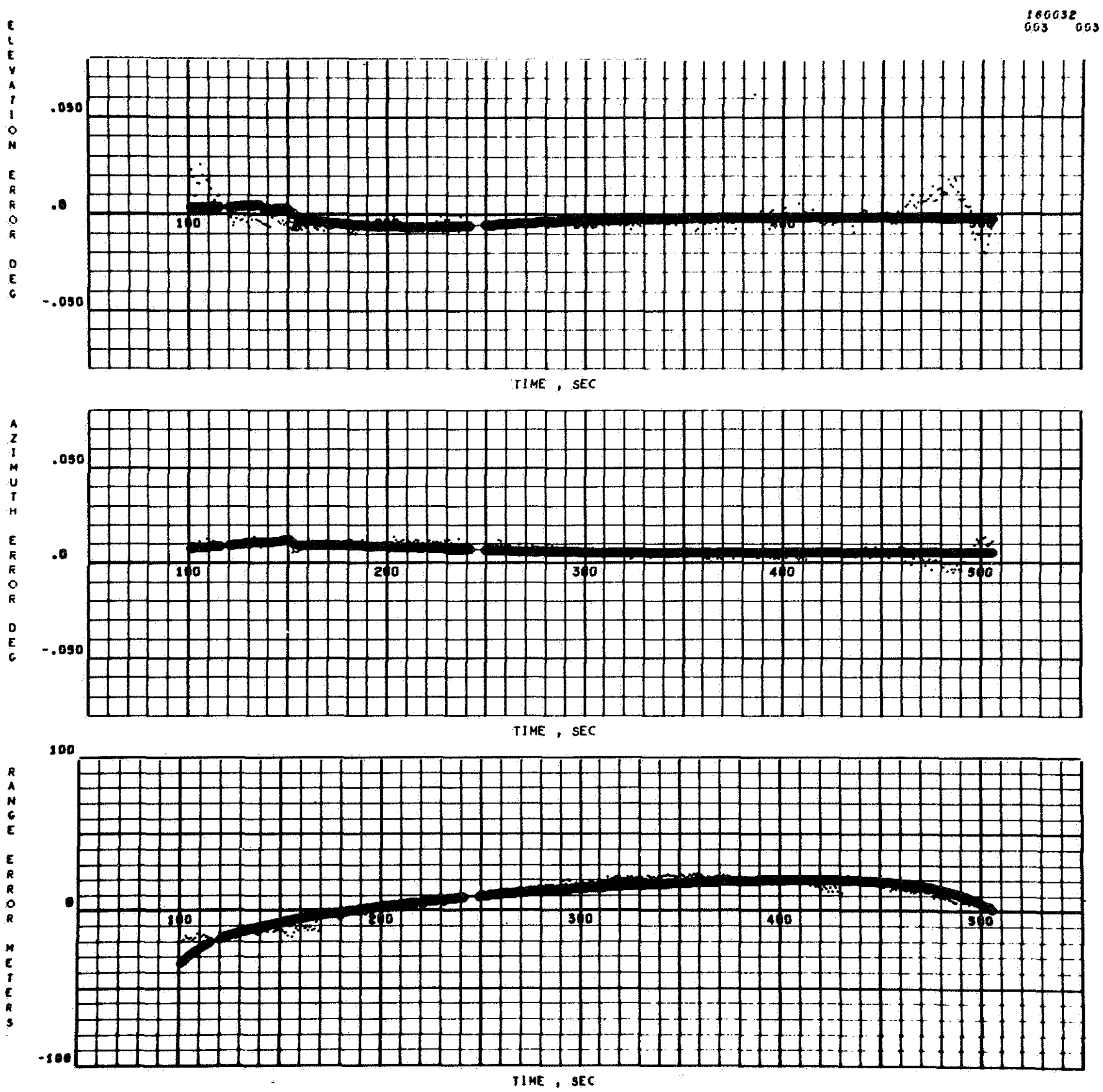


FIGURE B-6. RADAR 3.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-501 FIRST BURN DATA

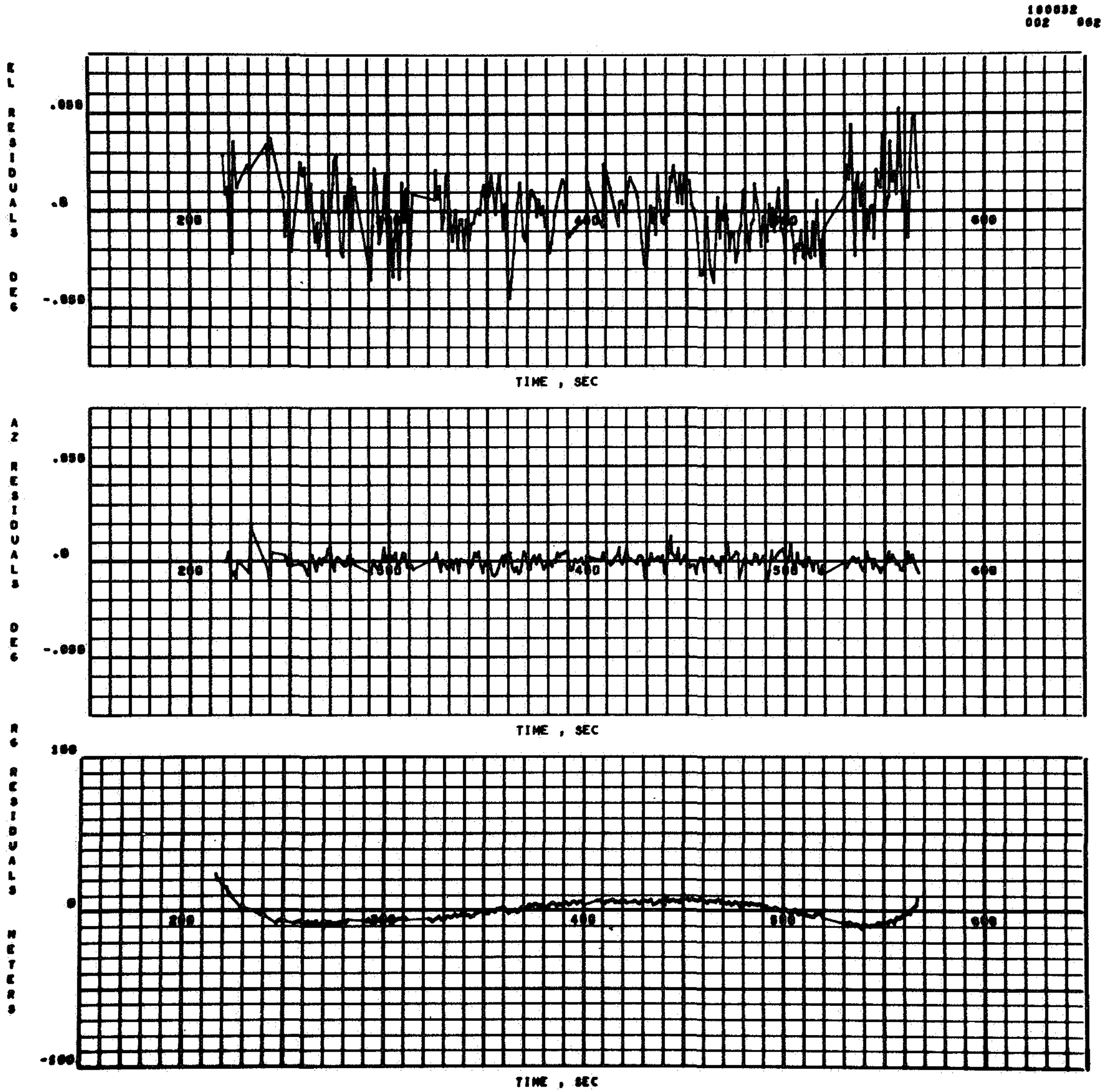


FIGURE B-7. RADAR 7.18 RESIDUALS ON AS-501 FIRST BURN DATA

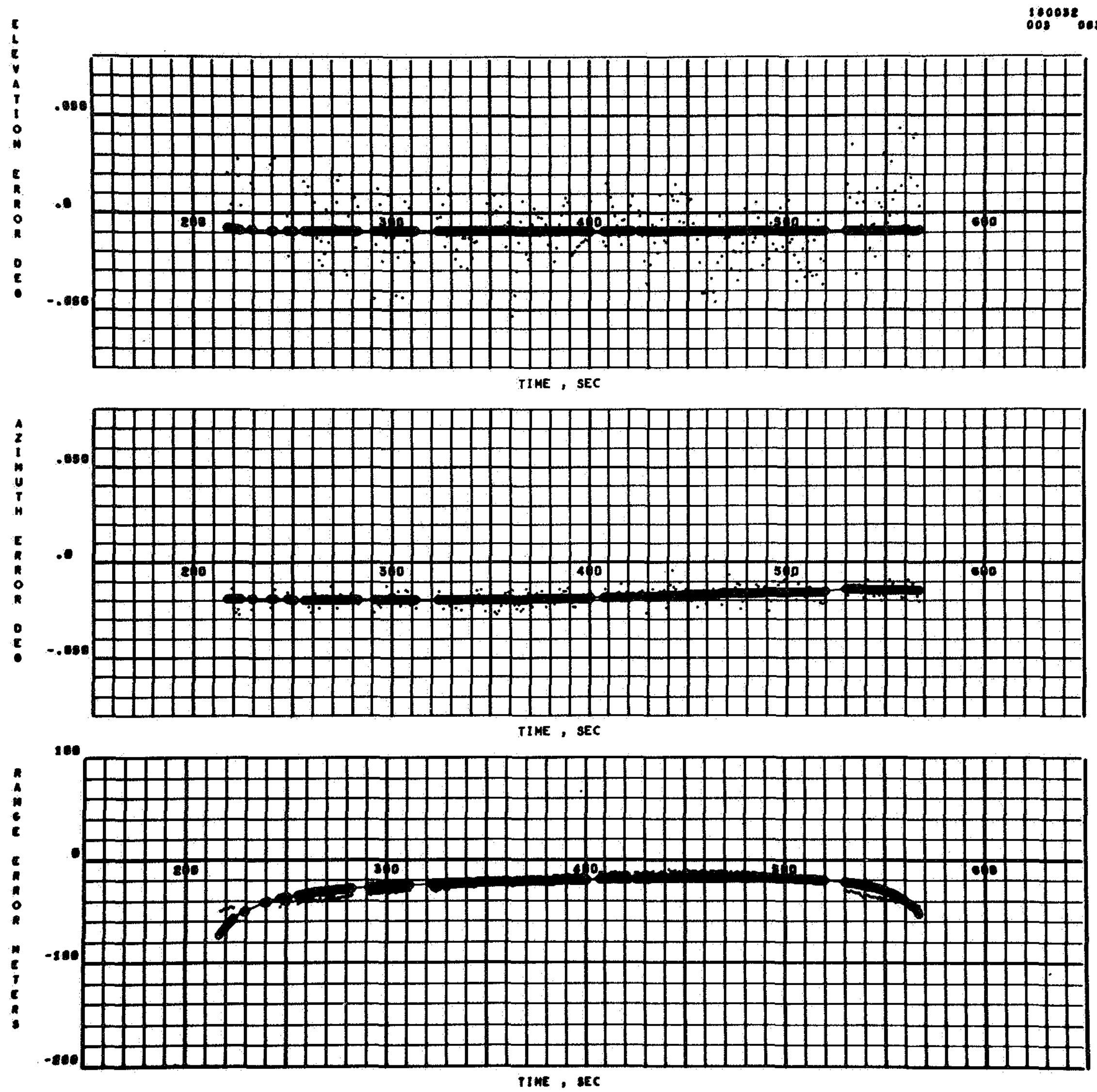


FIGURE B-8. RADAR 7.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-501 FIRST BURN DATA

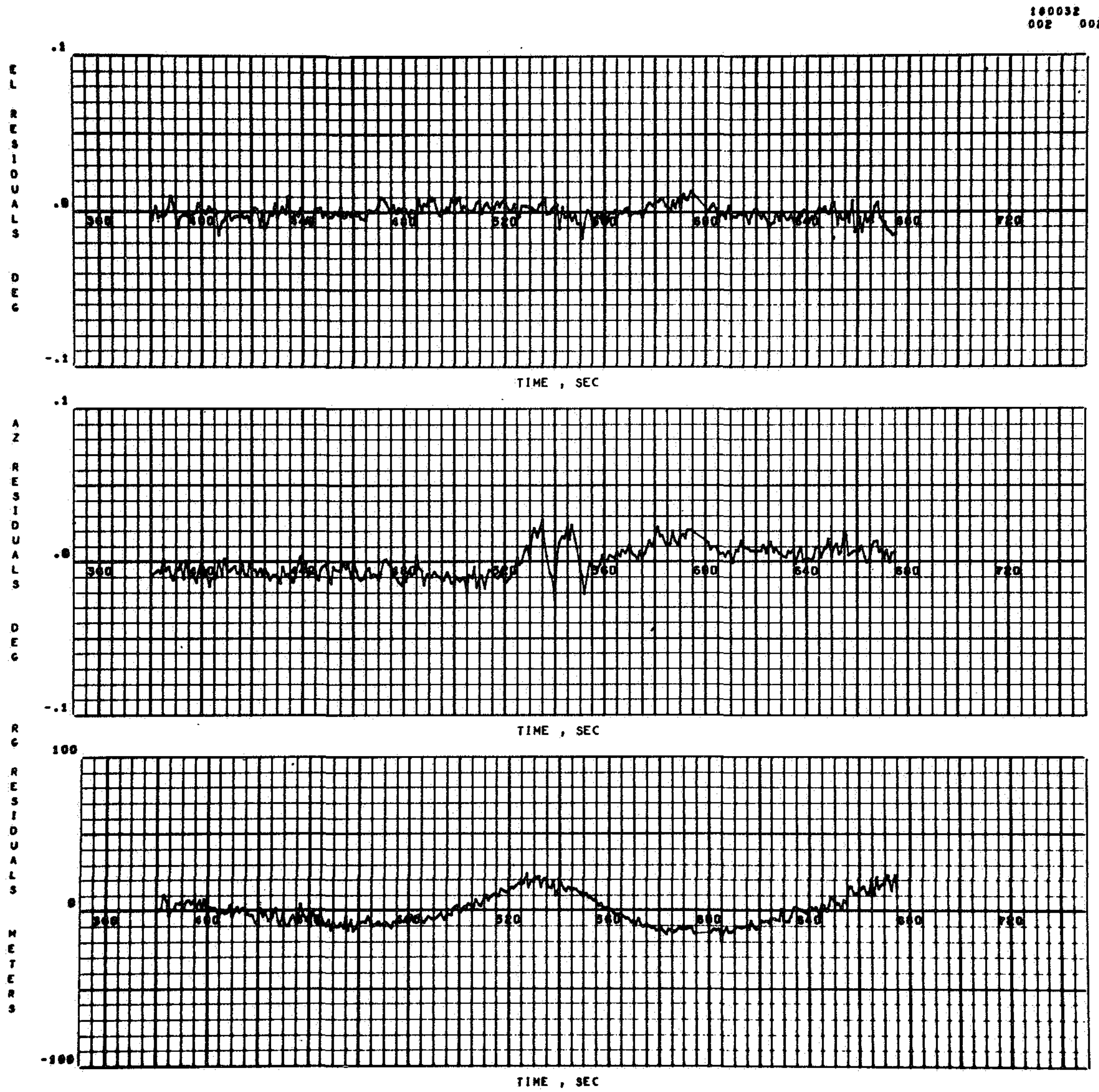


FIGURE B-9. RADAR 67.16 RESIDUALS ON AS-501
FIRST BURN DATA

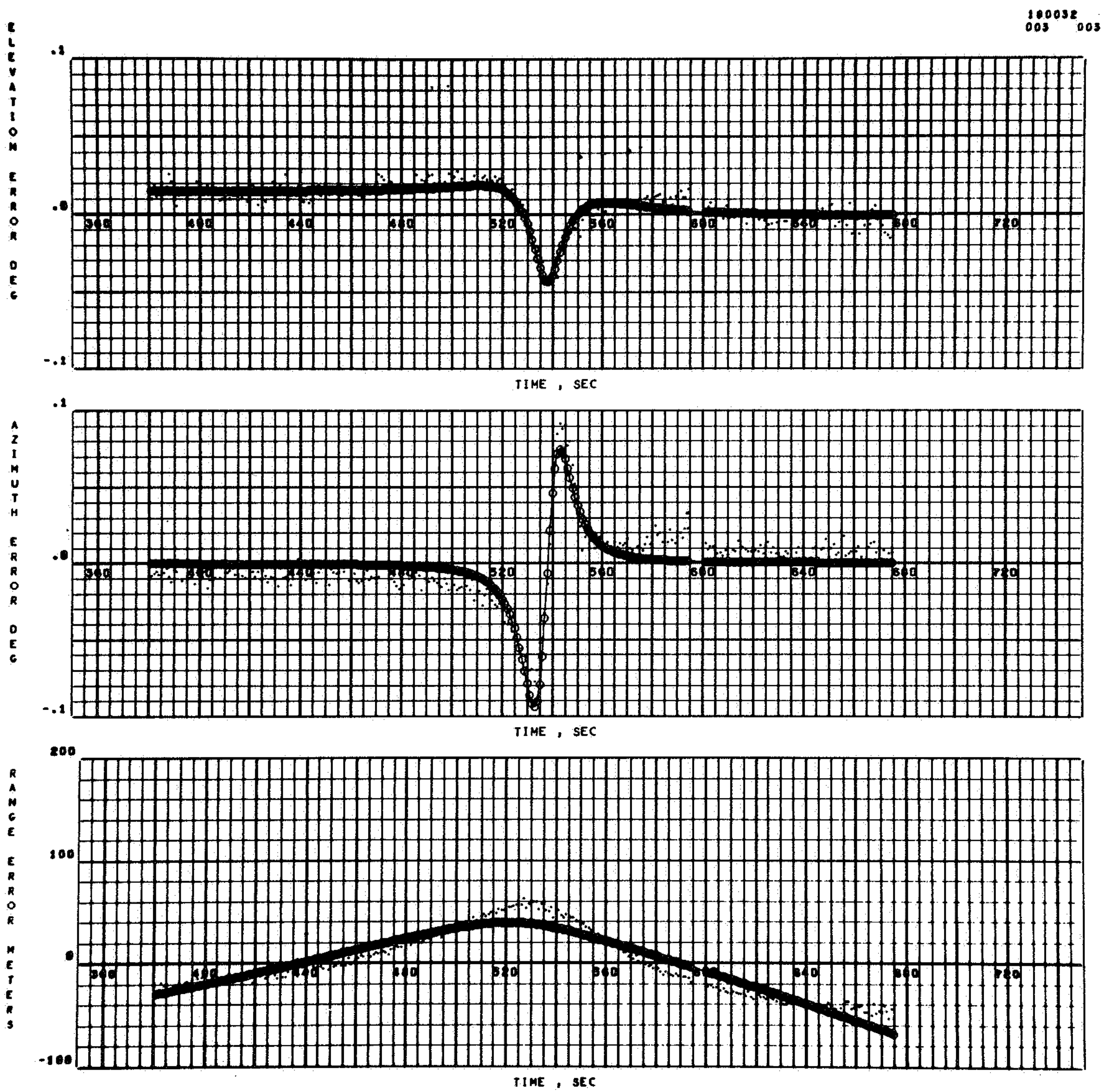


FIGURE B-10. RADAR 67.16 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-501 FIRST BURN DATA

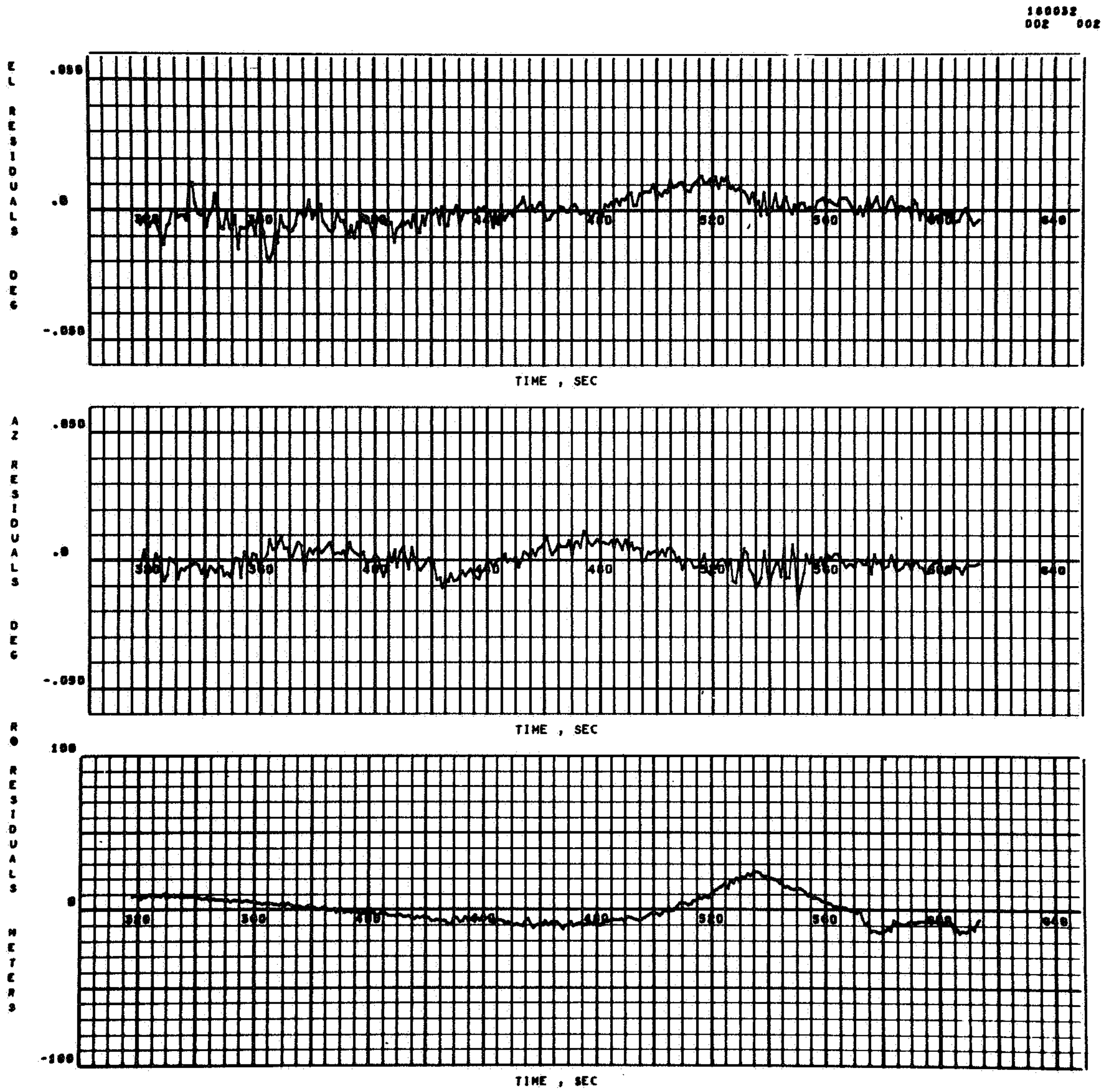


FIGURE B-11. RADAR 67.18 RESIDUALS ON AS-501 FIRST BURN DATA

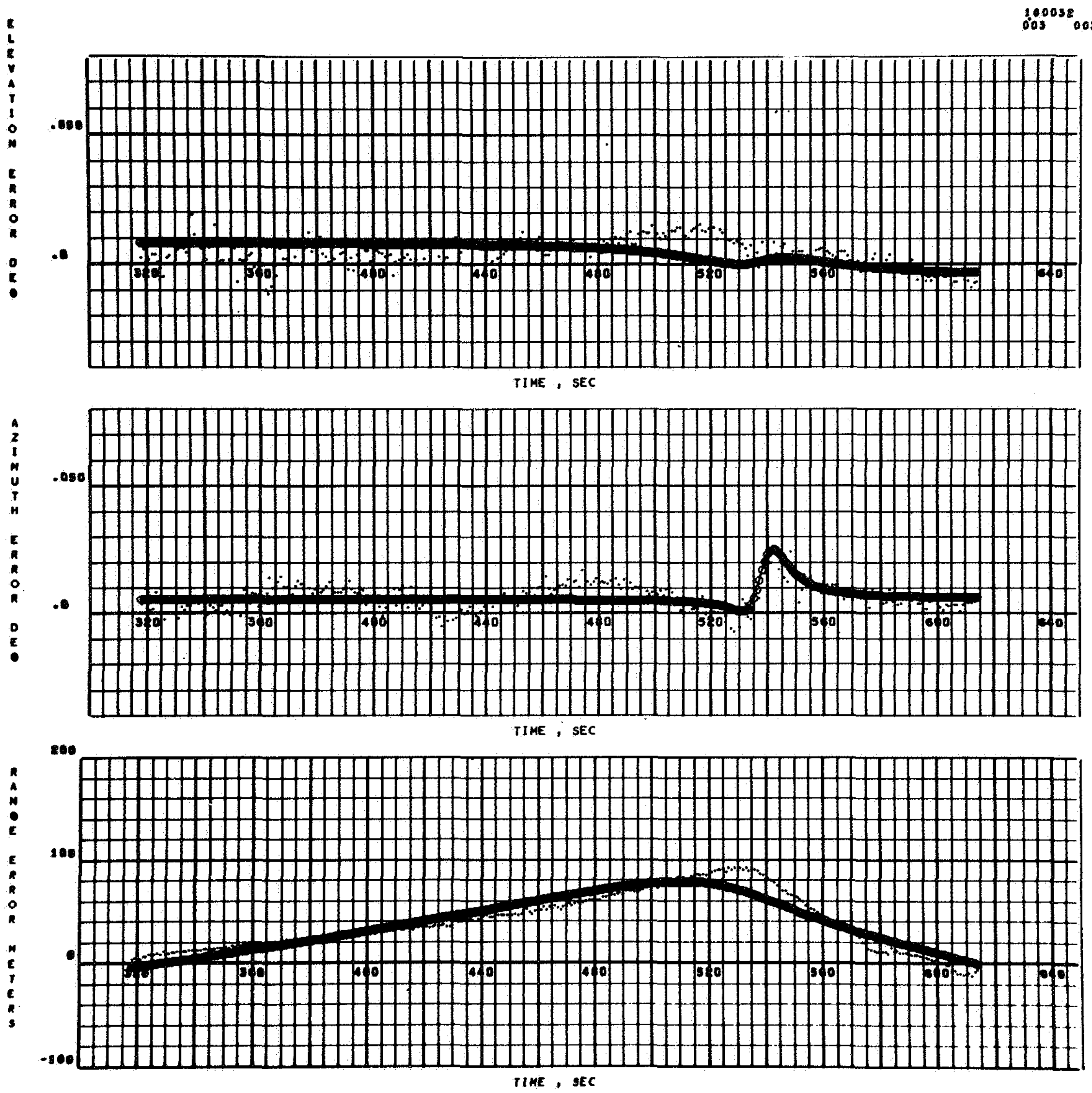


FIGURE B-12. RADAR 67.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-501 FIRST BURN DATA

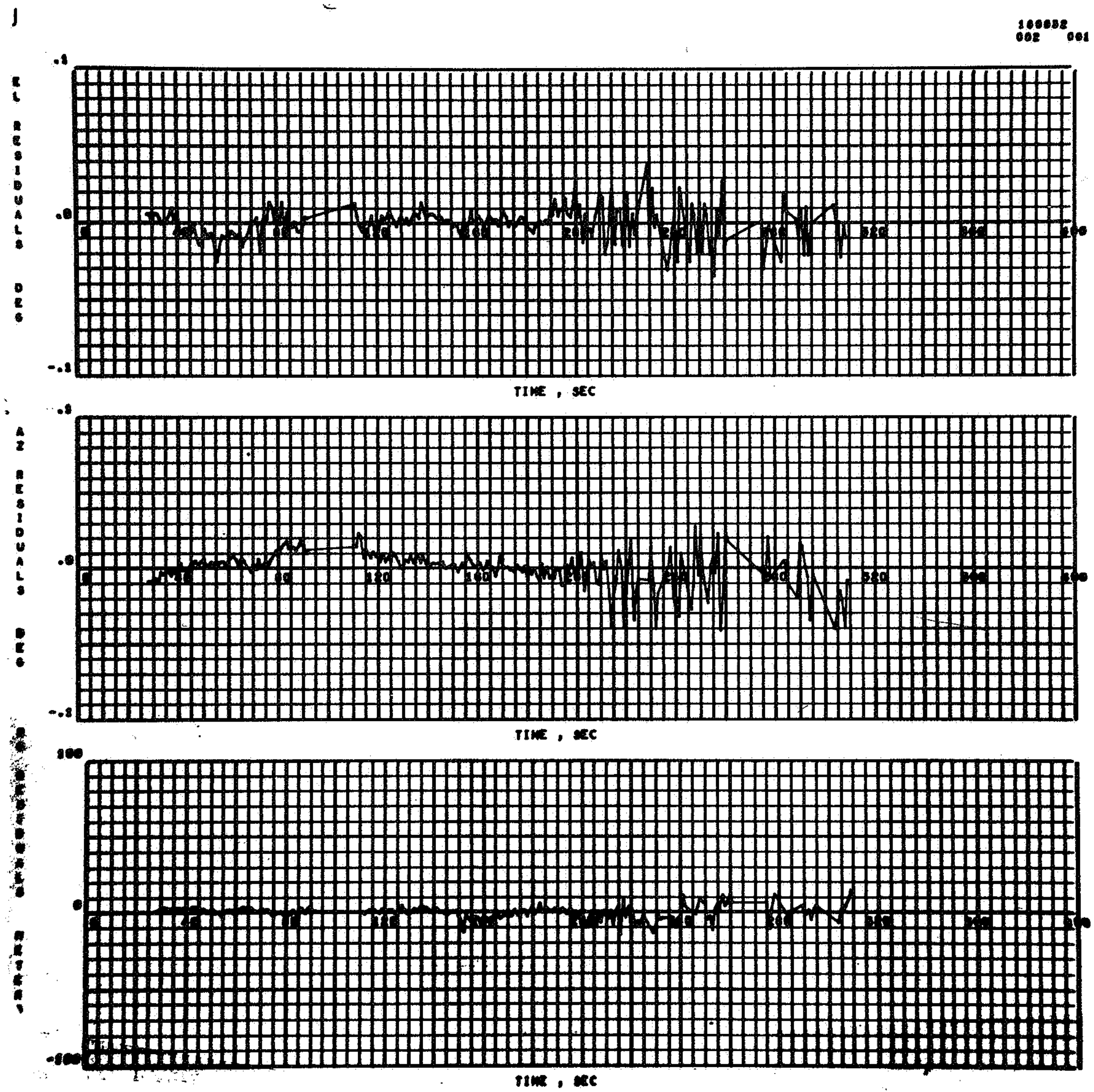


FIGURE B-13. RADAR 1.16 RESIDUALS ON AS-501
FIRST BURN DATA

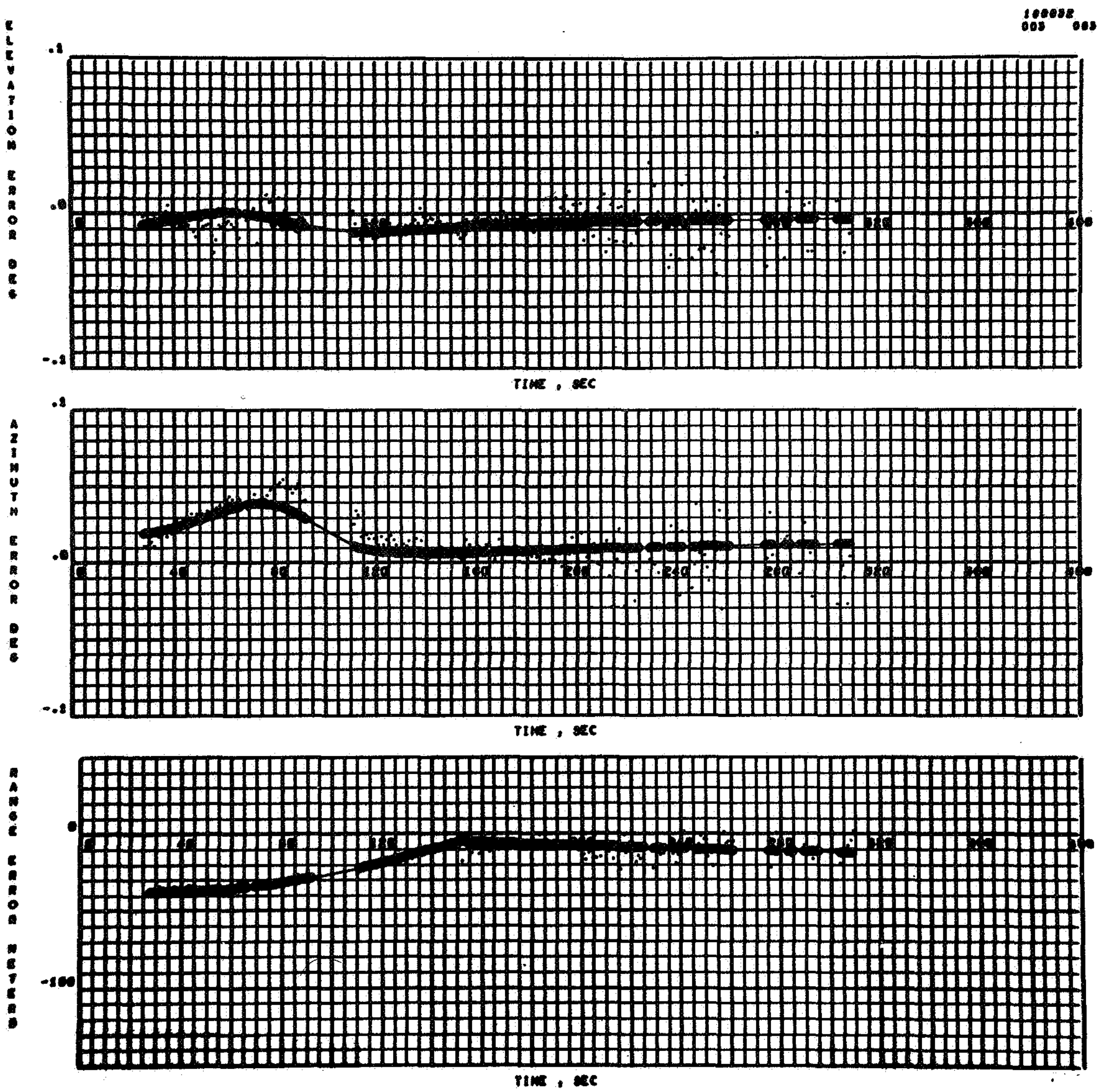


FIGURE B-14. RADAR 1.16 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-501 FIRST BURN DATA

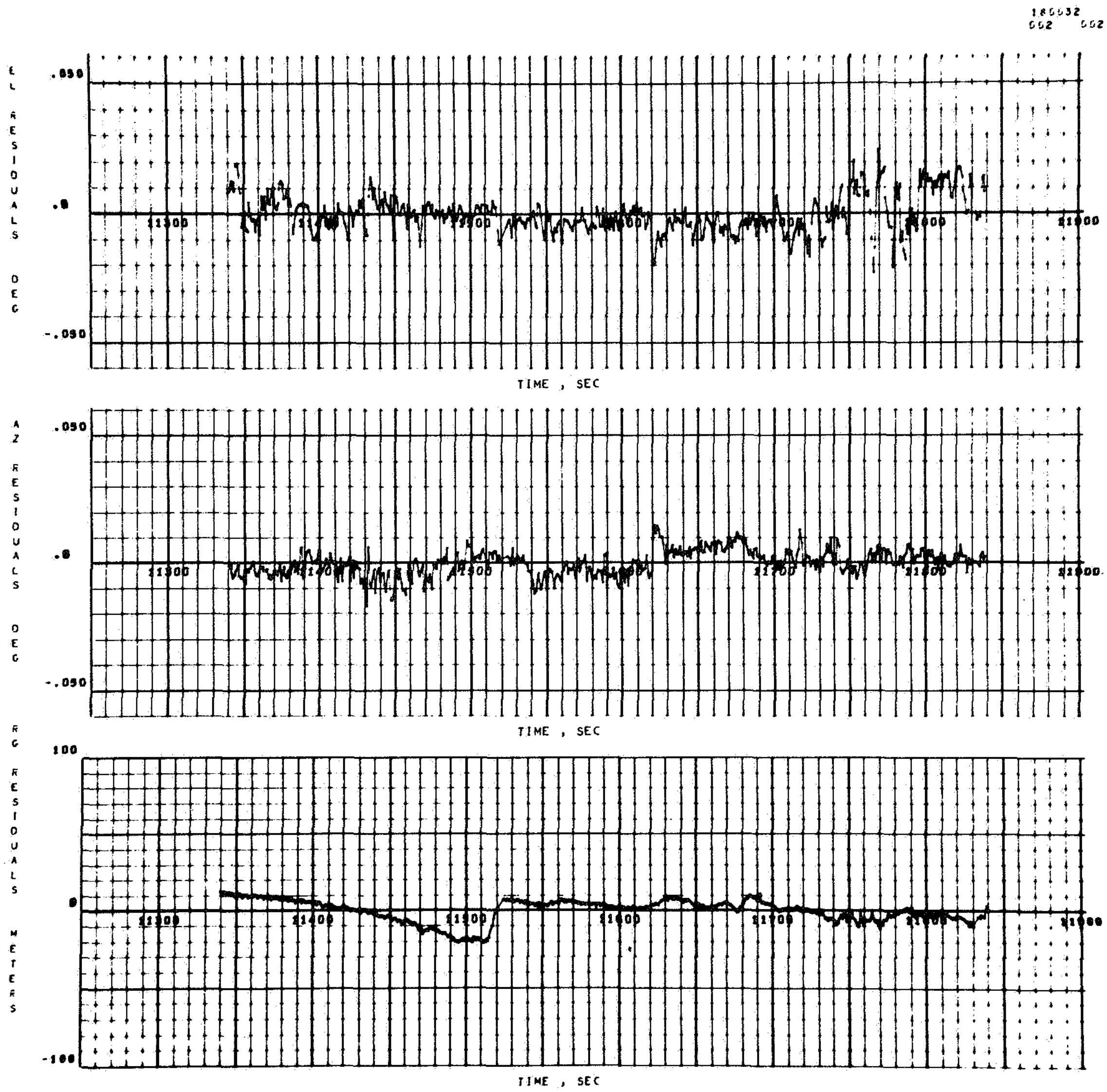


FIGURE B-15. RADAR 19.18 RESIDUALS ON AS-501
SECOND BURN DATA

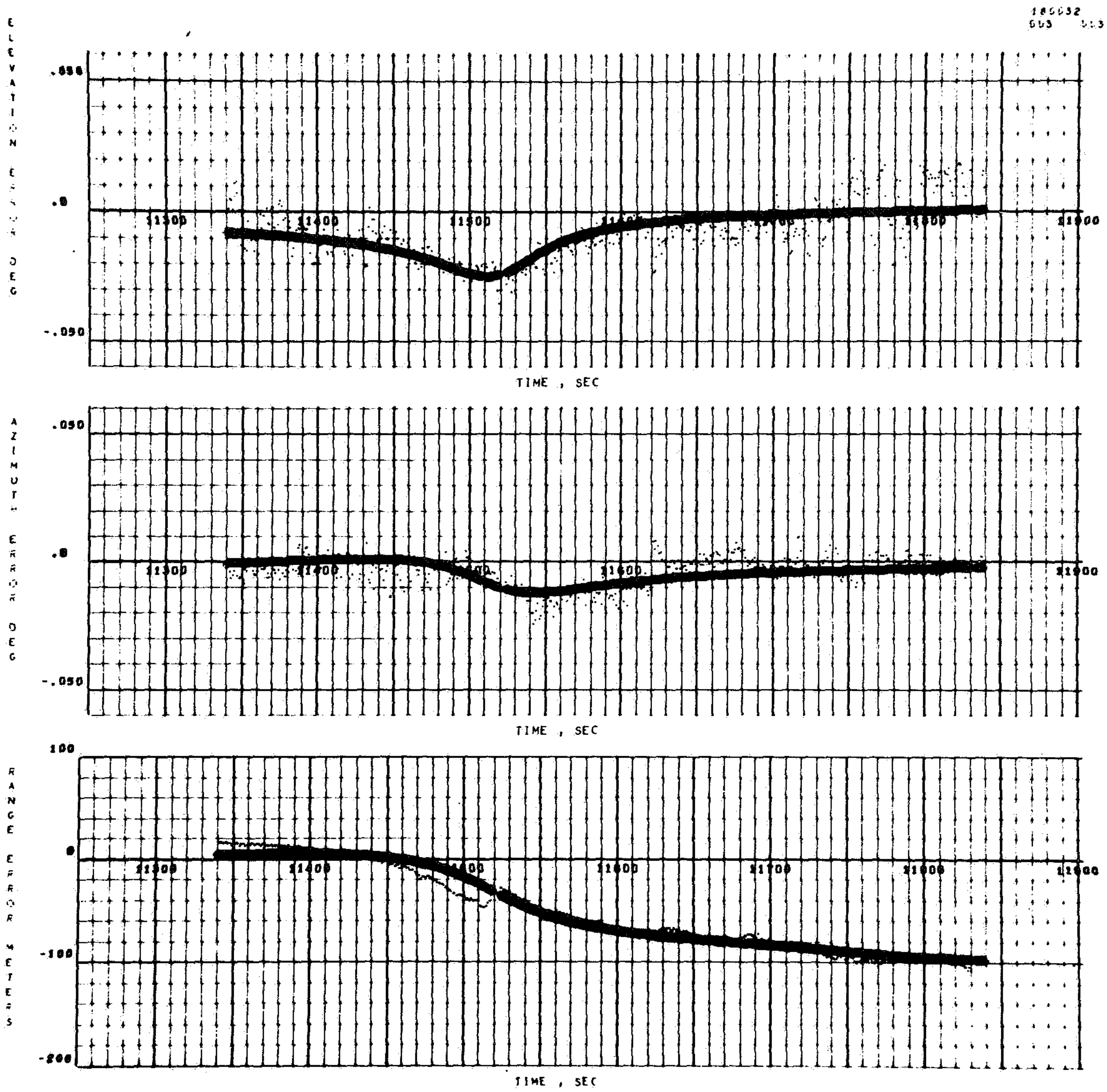


FIGURE B-16. RADAR 19.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-501 SECOND BURN DATA

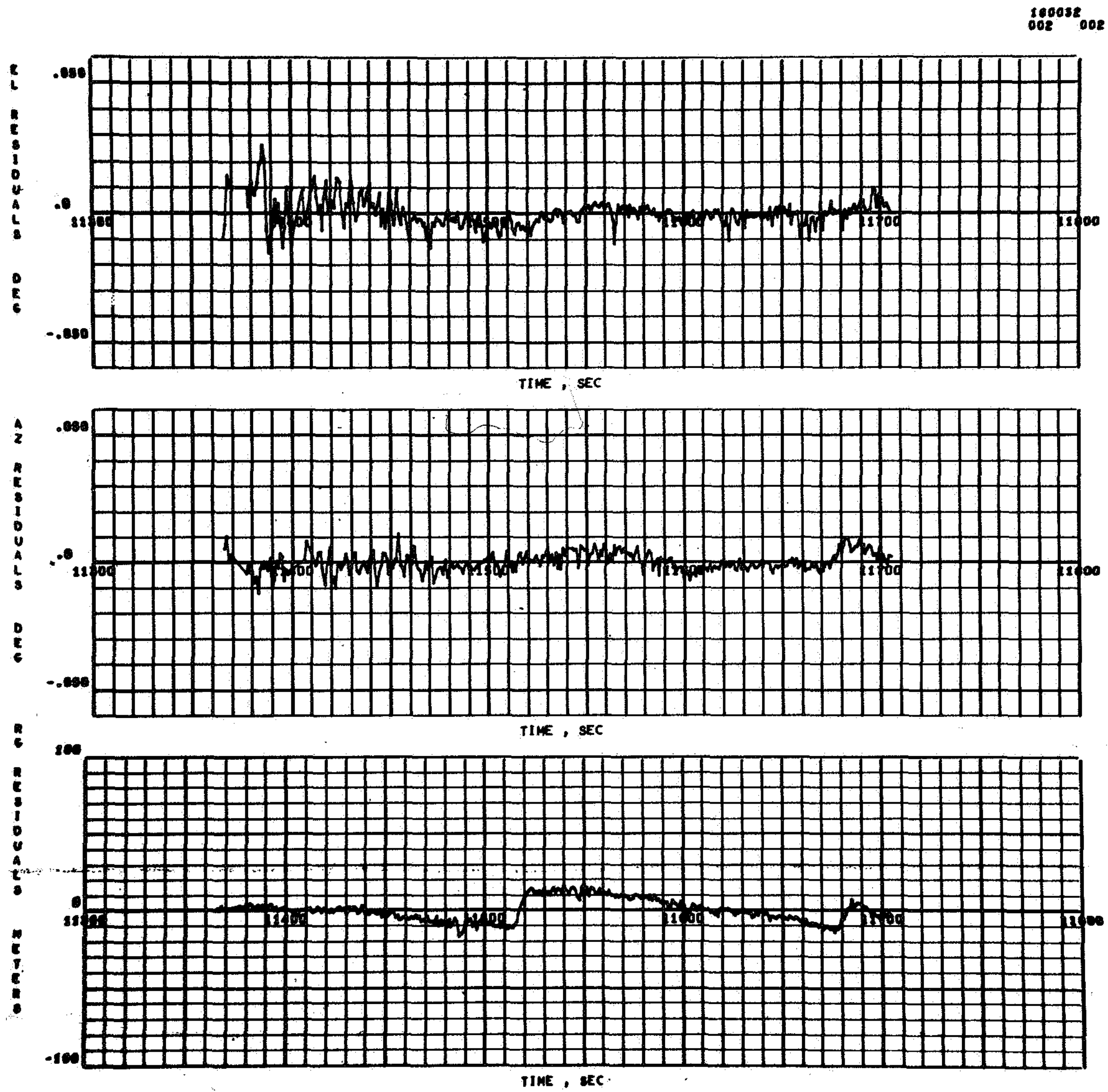


FIGURE B-17. RADAR 3.18 RESIDUALS ON AS-501
SECOND BURN DATA

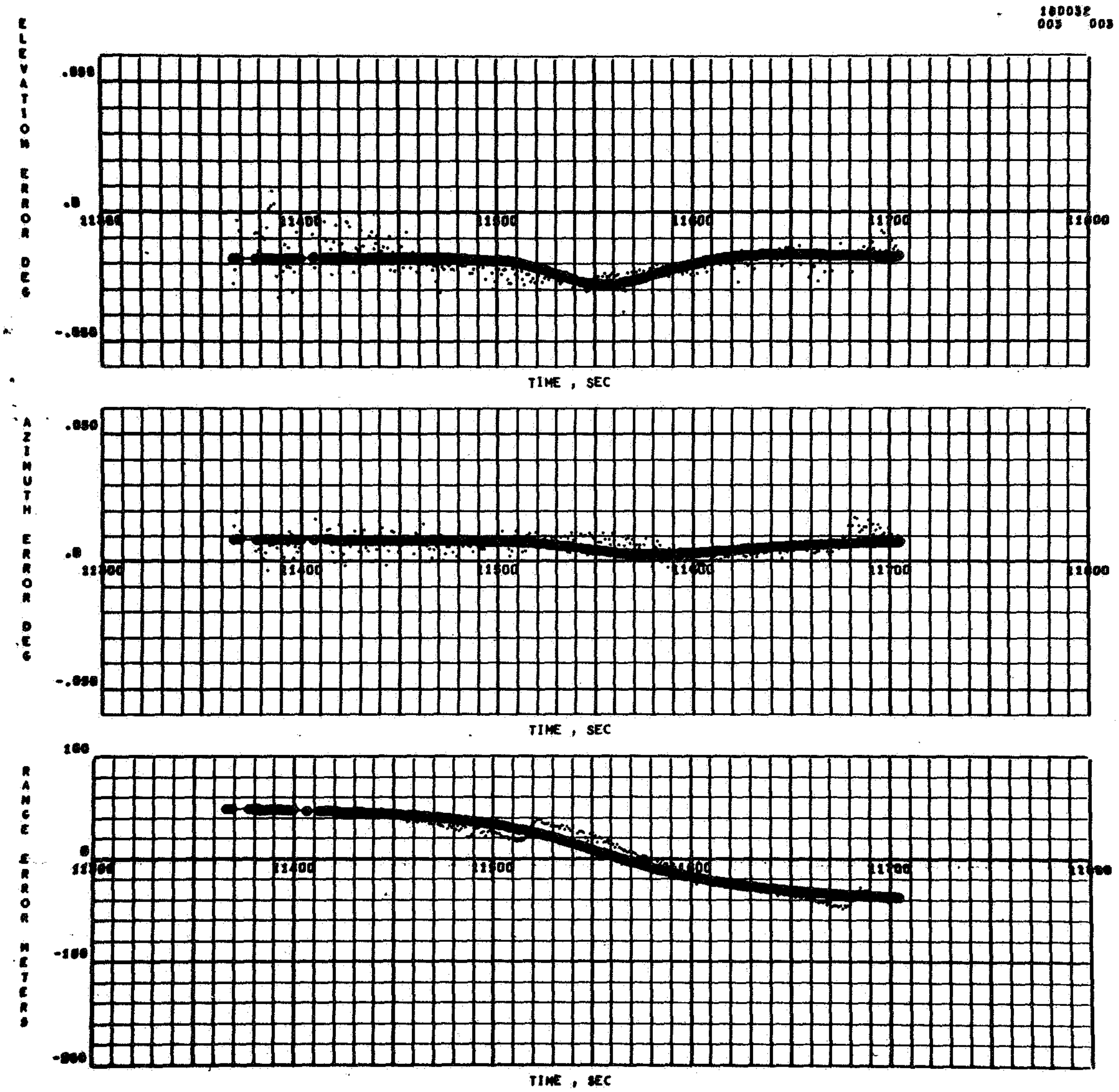


FIGURE B-18. RADAR 3.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-501 SECOND BURN DATA

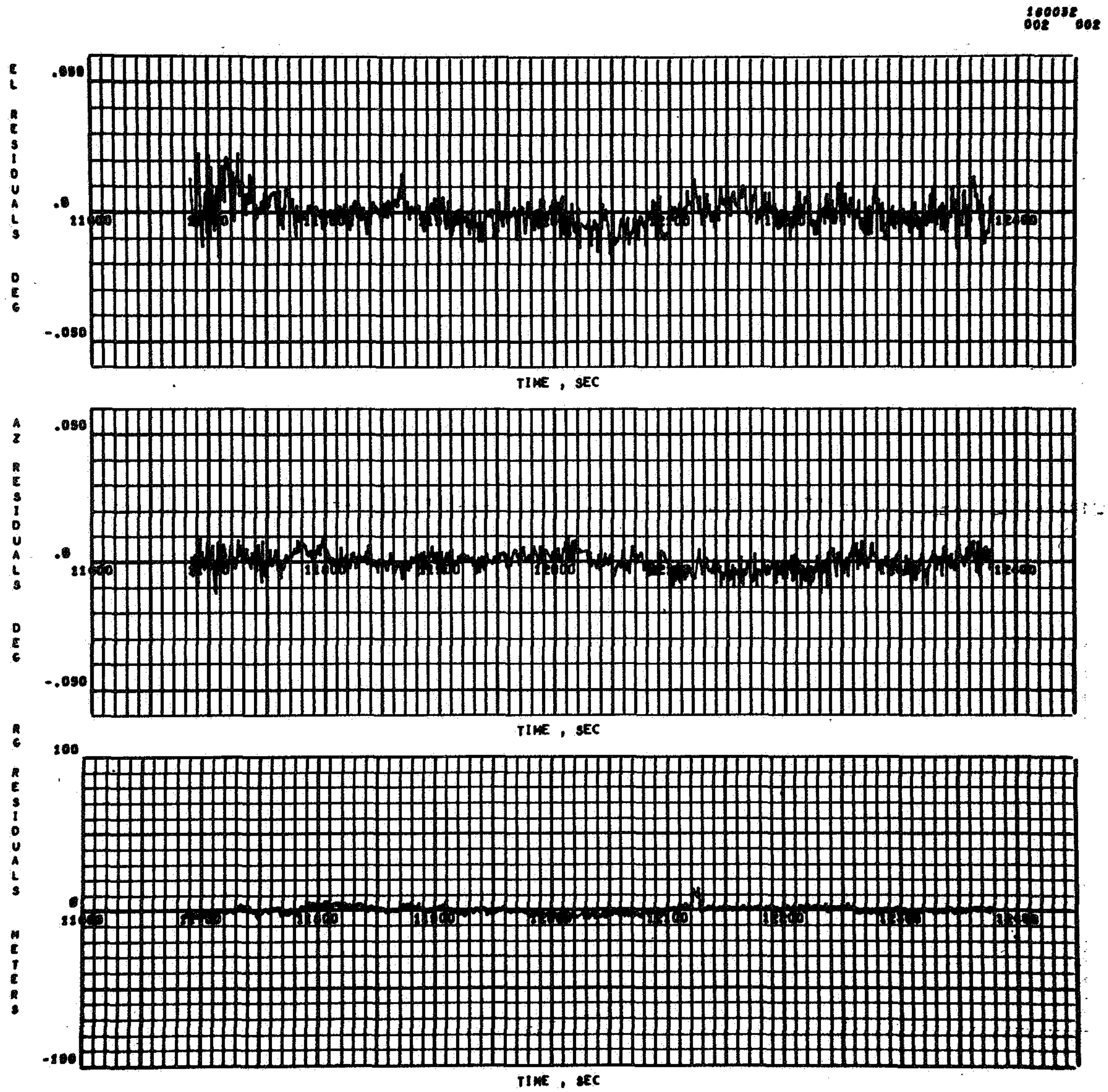


FIGURE B-19. RADAR 91.18 RESIDUALS ON AS-501
SECOND BURN DATA

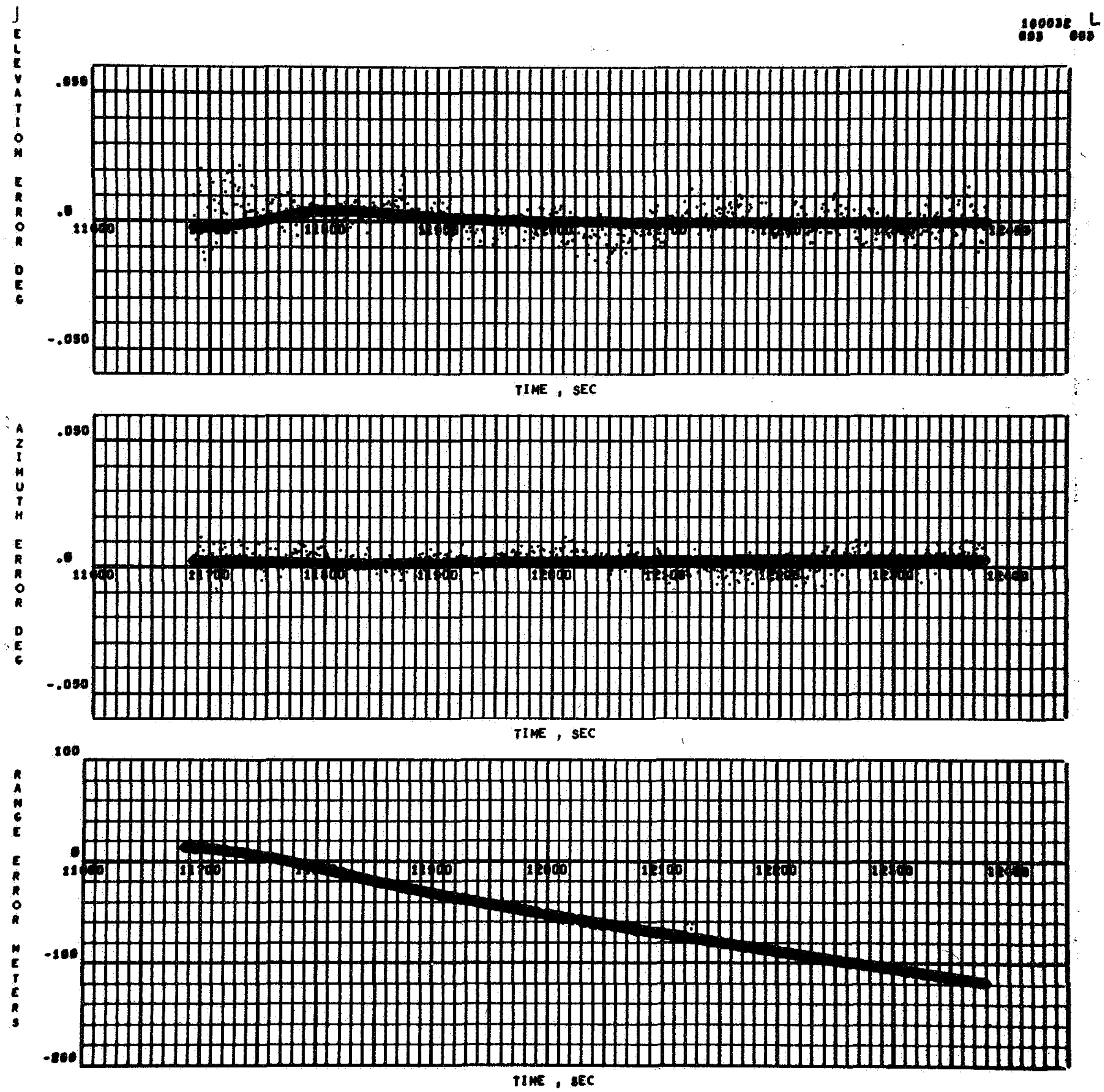


FIGURE B-20. RADAR 91.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-501 SECOND BURN DATA

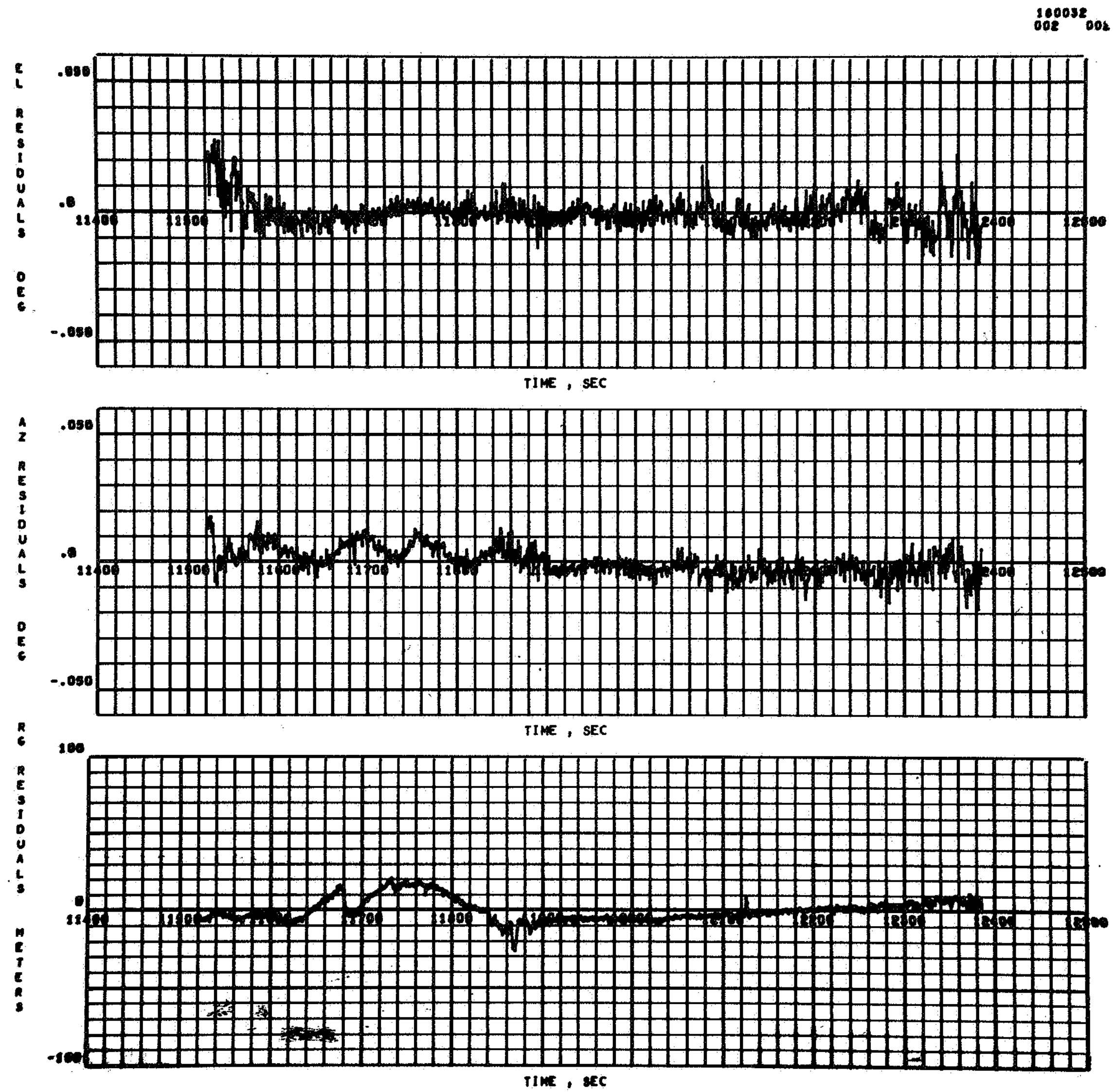


FIGURE B-21. RADAR 67.18 RESIDUALS ON AS-501 SECOND BURN DATA

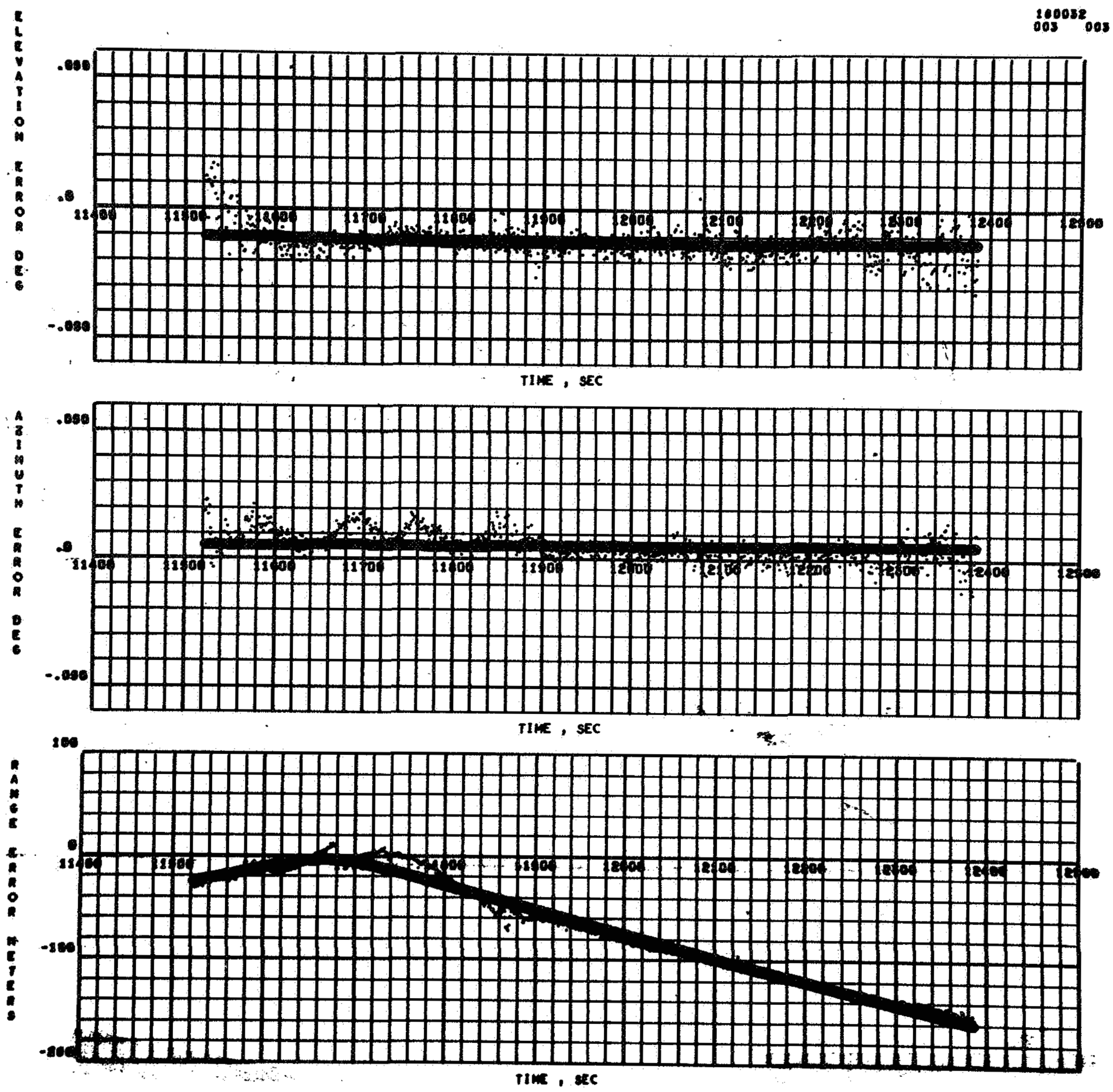


FIGURE B-22. RADAR 67.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-501 SECOND BURN DATA

APPENDIX C

RESULTS FROM THE APOLLO-SATURN 502 VEHICLE FLIGHT TEST

This appendix presents a summary of the results from the Apollo-Saturn 502 Vehicle Flight Test launched on April 4, 1968. The Stepwise Regression Analysis results for the AS-502 data are given in Tables C-I and C-II. Coefficient correlations are given in Tables C-III and C-IV. Plots of the observed deltas, computed deltas, and the least squares residuals are presented in Figures C-1 through C-16. The tracking errors for the various radars are represented by dots in these figures. The description of these errors as obtained from the TEMS least squares adjustment program is represented by the solid computed curves.

TABLE C-I. STEPWISE REGRESSION ANALYSIS RESULTS FOR AS-502 LAUNCH PHASE DATA

Equation	Variables in Regression	σ_Y	F Level
19.18			
ΔR	$C_0, C_1, C_7, C_4, C_8, C_5, C_6$	1.45	111.8
ΔA	D_0, D_8, D_3, D_5	0.0027	-0.08
ΔE	$F_0, C_7, F_3, D_8, D_7, C_5, C_4, C_2, C_6$	0.0022	14.0
3.18			
ΔR	$C_0, C_1\ C_8, C_2, C_4, C_5$	1.19	-0.03
ΔA	D_0, D_7, D_5, D_3	0.0053	13.6
ΔE	F_0, C_2, C_4	0.0053	-1.8
67.18			
ΔR	$C_0, C_6, C_1, C_8, C_2, C_7, C_4$	2.48	9.1
ΔA	D_0, C_2, D_7, D_6	0.0035	5.5
ΔE	$F_0, C_7, D_8, C_4, C_5, D_7$	0.0061	-2.02
0.18			
ΔR	$C_0, C_1, C_7, C_8, C_4, C_5, C_6$	2.16	4.7
ΔA	D_0, D_8, D_7	0.0035	7.6
ΔE	F_0, C_4, C_5, C_7	0.0032	-1.8
1.16			
ΔR	C_0, C_1, C_8, C_2, C_4	4.20	3.7
ΔA	D_0, D_8	0.0093	41.3
ΔE	F_0, F_3, D_7	0.0102	16.7

TABLE C-II. STEPWISE REGRESSION ANALYSIS RESULTS FOR AS-502 ORBITAL PHASE (REV. 1) DATA

Equation	Variables in Regression	σ_Y	F Level
19.18			
ΔR	C_0, C_2, C_6, C_5	4.21	21.58
ΔA	D_0, D_3, C_6, D_5	0.0028	6.28
ΔE	F_0	0.0082	0.15
0.18			
ΔR	C_0, C_2, C_5, C_4, C_8	3.84	44.10
ΔA	D_0, D_6, C_2	0.0039	26.0
ΔE	F_0, C_6	0.0121	4.8
3.18			
ΔR	C_0, C_6, C_7, C_8, C_4	1.52	254.20
ΔA	D_0, D_7	0.0058	31.1
ΔE	F_0, C_4	0.0100	17.0

TABLE C-III. COEFFICIENT CORRELATIONS FOR THE TRUNCATED AS-502 LAUNCH PHASE ERROR MODELS

	C_0	C_1	C_4	D_0	D_3	D_5	D_7	F_0
C_0	1.0	0.06	0.87	0.03	-0.05	0.03	-0.15	0.14
C_1		1.0	0.46	0.02	-0.03	0.02	-0.08	0.07
C_4			1.0	0.04	-0.06	0.04	-0.17	0.16
D_0				1.0	-0.54	-0.87	-0.21	0.20
D_3					1.0	0.42	0.33	-0.30
D_5						1.0	-0.23	0.22
D_7							1.0	-0.93
F_0								1.0

19.18

	C_0	C_1	C_2	D_0	D_3	F_0	F_3
C_0	1.0	0.34	-0.69	0.22	0.01	0.0	-0.03
C_1		1.0	-0.88	0.28	0.02	0.0	-0.04
C_2			1.0	-0.31	-0.02	0.0	0.04
D_0				1.0	0.06	0.0	-0.01
D_3					1.0	0.0	0.0
F_0						1.0	0.28
F_3							1.0

0.18

	C_0	C_1	C_4	D_0	D_3	F_0	F_3
C_0	1.0	-0.08	0.94	0.0	0.0	-0.04	-0.14
C_1		1.0	0.38	0.10	0.0	-0.02	-0.06
C_4			1.0	0.0	0.0	-0.05	-0.16
D_0				1.0	-0.13	0.0	0.0
D_3					1.0	0.0	0.0
F_0						1.0	0.03
F_3							1.0

1.16

	C_0	C_2	C_4	D_0	D_3	F_0
C_0	1.0	-0.31	0.66	0.04	0.0	0.04
C_2		1.0	0.39	-0.14	0.0	0.03
C_4			1.0	-0.05	0.0	0.06
D_0				1.0	0.15	0.0
D_3					1.0	0.0
F_0						1.0

3.18

	C_0	C_1	C_2	D_0	D_8	F_0
C_0	1.0	-0.90	0.20	0.01	-0.03	0.0
C_1		1.0	-0.31	-0.01	0.04	0.0
C_2			1.0	0.04	-0.14	0.0
D_0				1.0	0.18	0.0
D_8					1.0	0.01
F_0						1.0

67.18

TABLE C-IV. COEFFICIENT CORRELATIONS FOR THE TRUNCATED AS-502 ORBITAL PHASE (REV. 1) ERROR MODELS

	C_0	C_2	D_0	D_3	F_0
C_0	1.0	1.0	-0.06	-0.16	-0.30
C_2		1.0	-0.06	-0.16	-0.30
D_0			1.0	-0.93	0.02
D_3				1.0	0.05
F_0					1.0

3.18

	C_0	C_2	D_0	D_3	F_0
C_0	1.0	1.0	-0.07	-0.20	-0.29
C_2		1.0	-0.07	-0.20	-0.29
D_0			1.0	-0.83	0.02
D_3				1.0	0.06
F_0					1.0

19.18

	C_0	C_2	D_0	D_3	F_0
C_0	1.0	1.0	-0.07	-0.20	-0.25
C_2		1.0	-0.07	-0.20	-0.25
D_0			1.0	-0.81	0.02
D_3				1.0	0.05
F_0					1.0

0.18

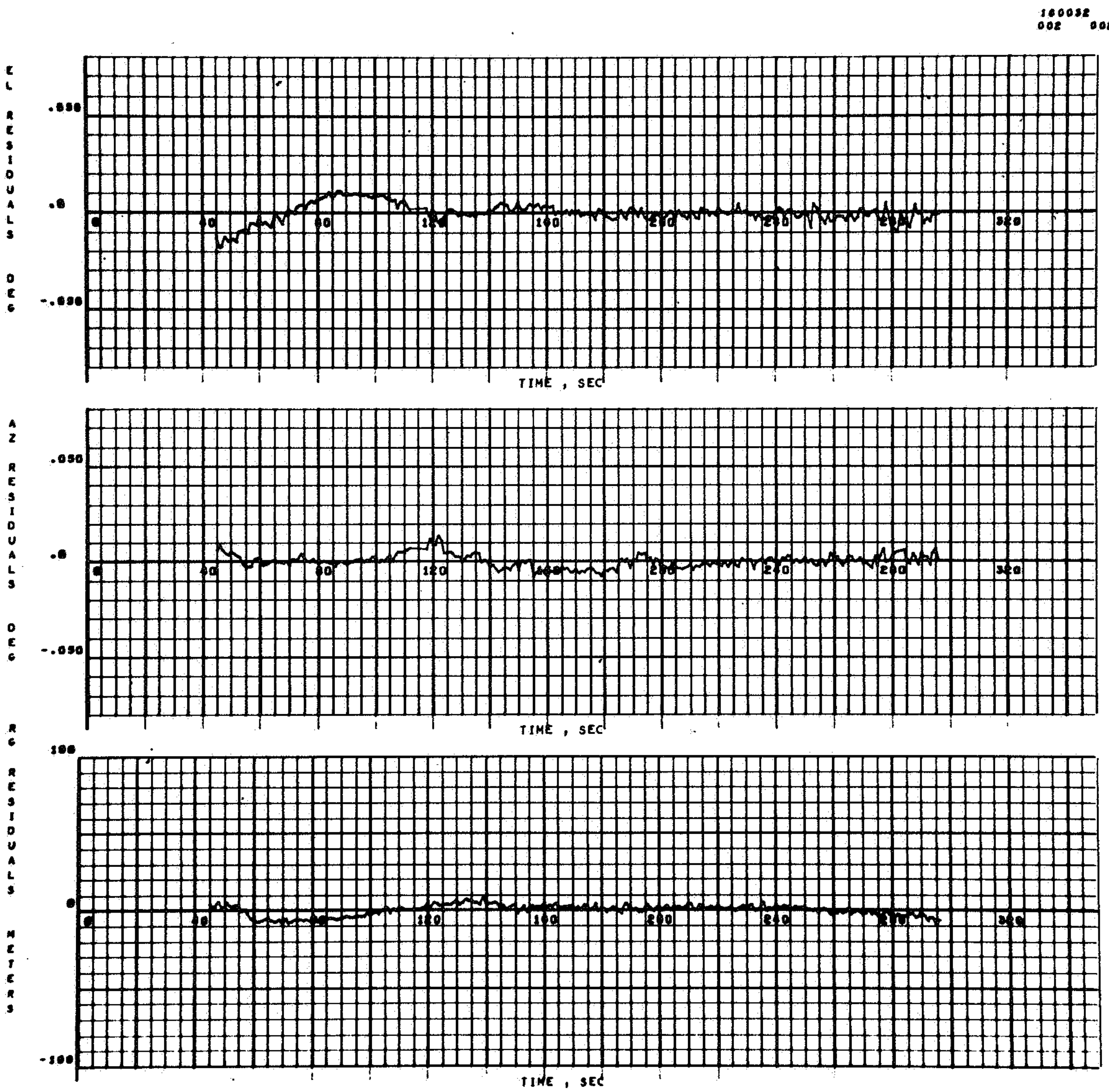


FIGURE C-1. RADAR 19.18 RESIDUALS ON AS-502 LAUNCH PHASE DATA

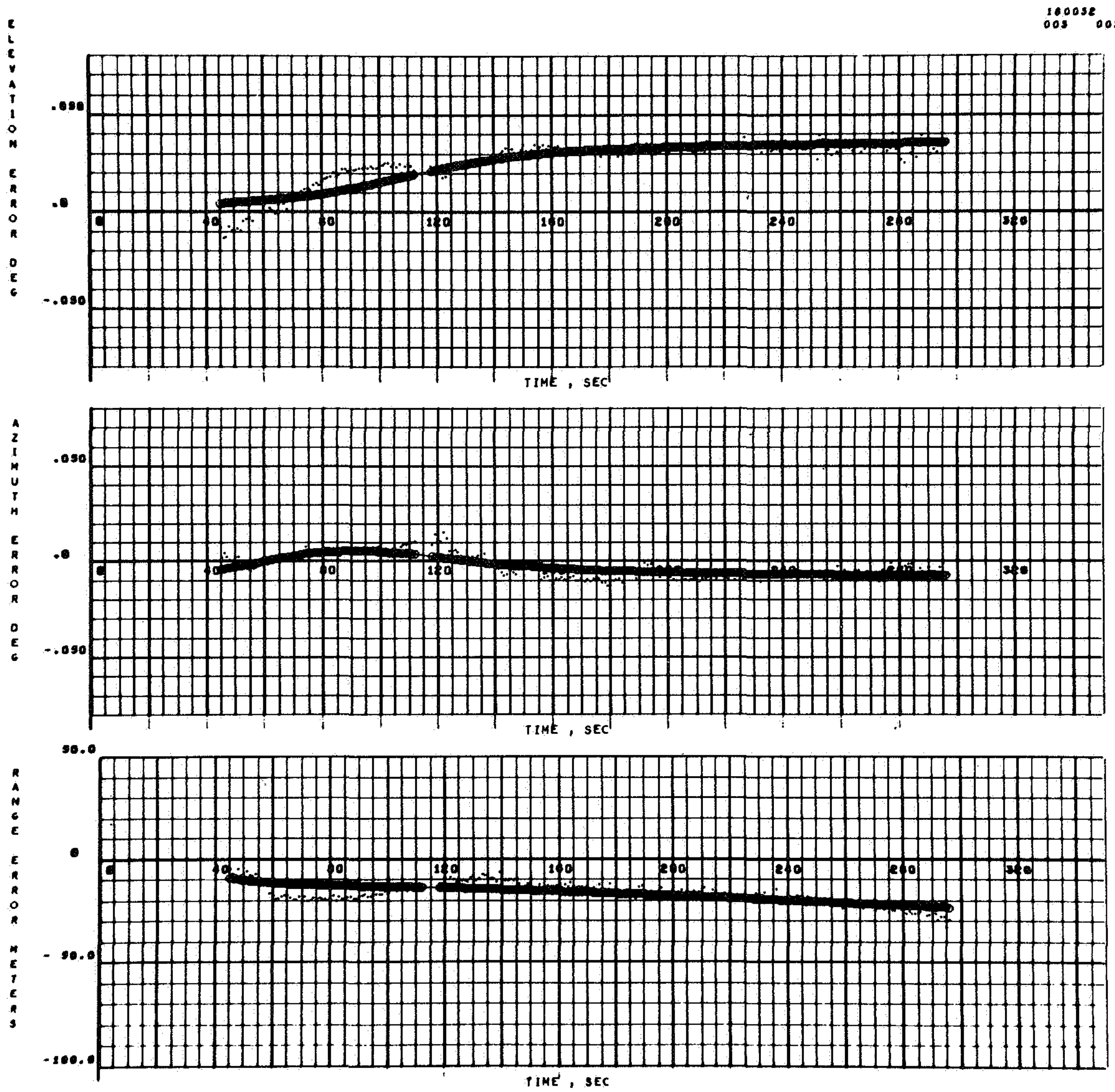


FIGURE C-2. RADAR 19.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-502 LAUNCH PHASE DATA

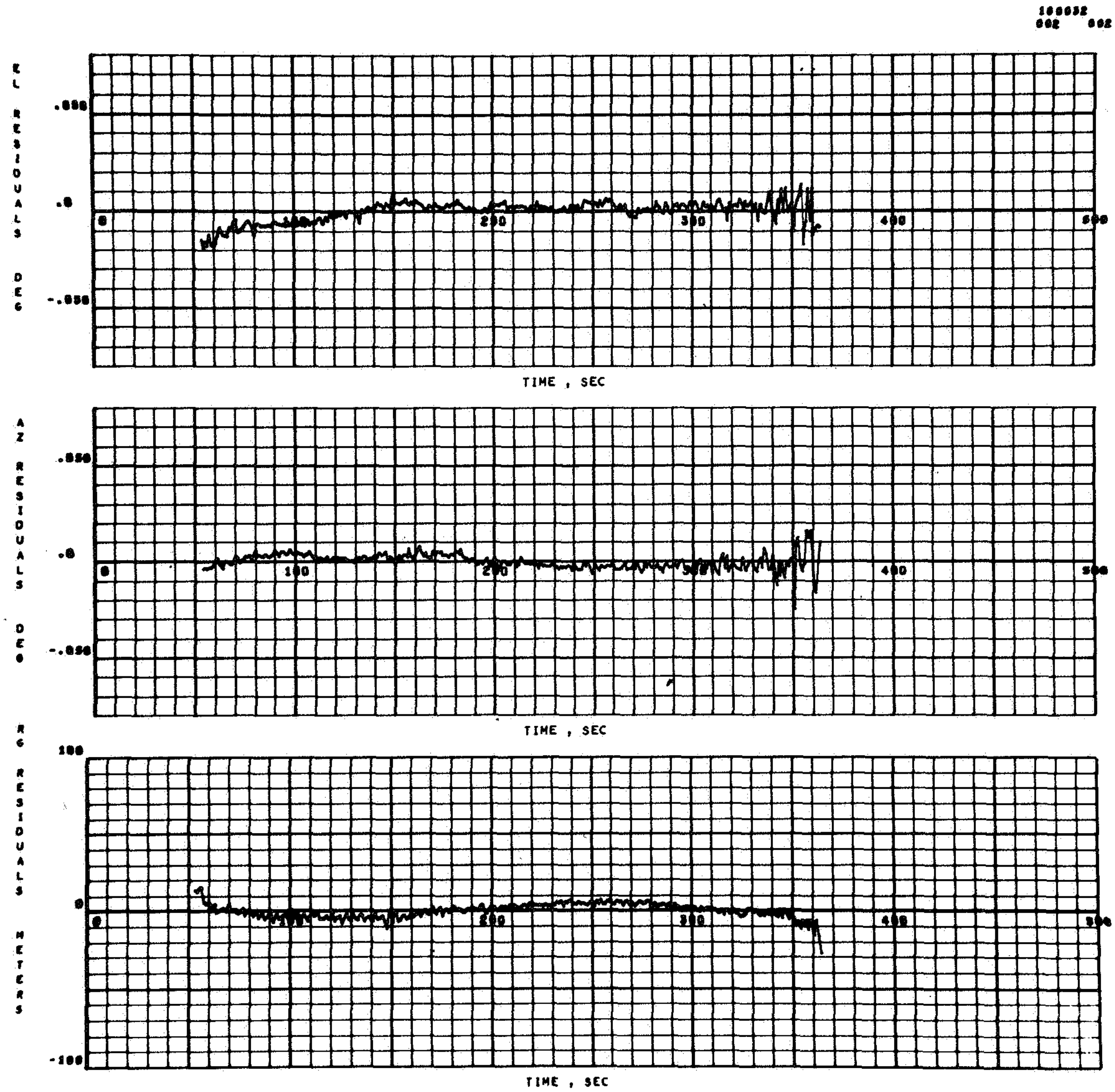


FIGURE C-3. RADAR 0.18 RESIDUALS ON AS-502
LAUNCH PHASE DATA

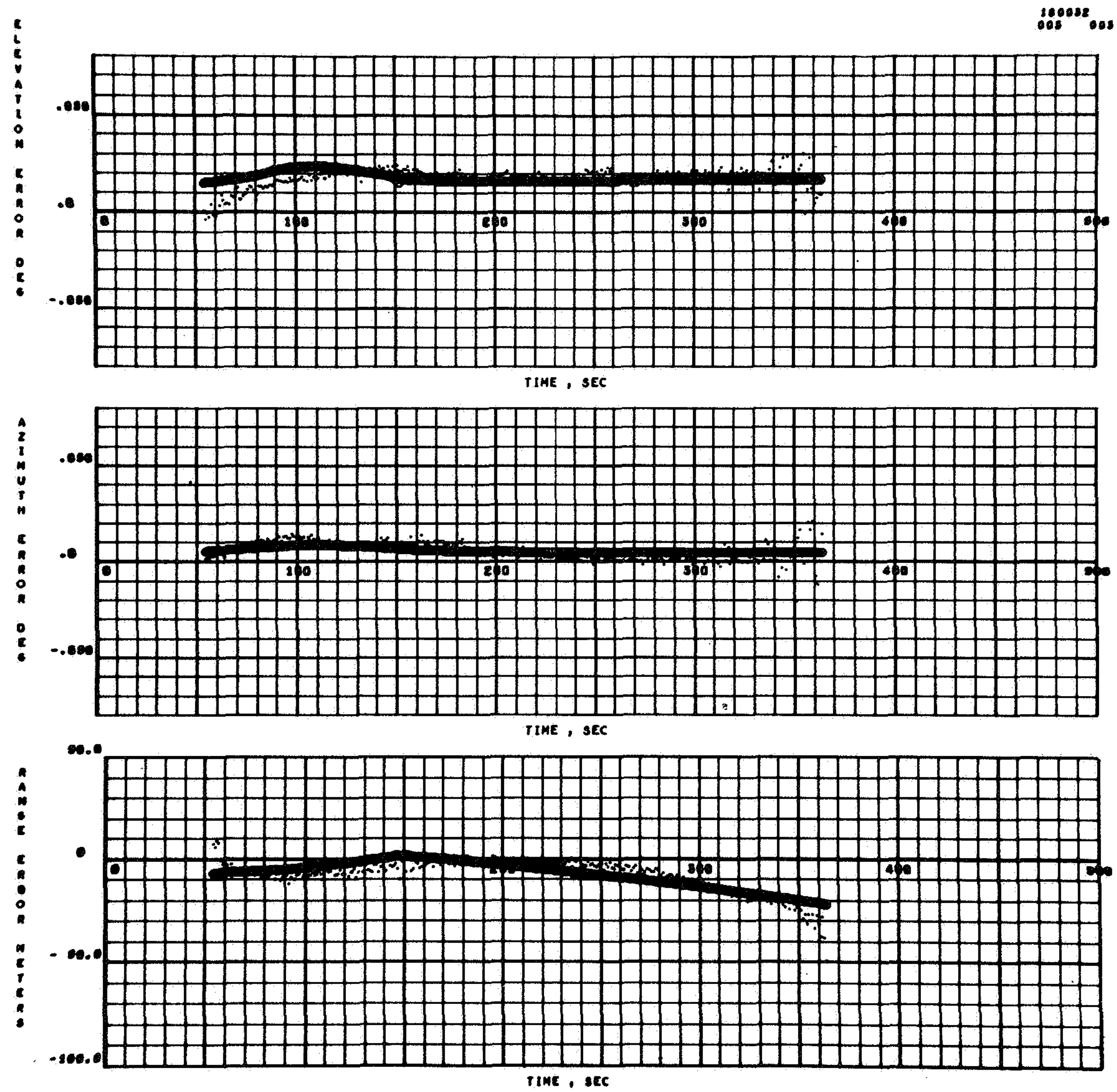


FIGURE C-4. RADAR 0.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-502 LAUNCH PHASE DATA

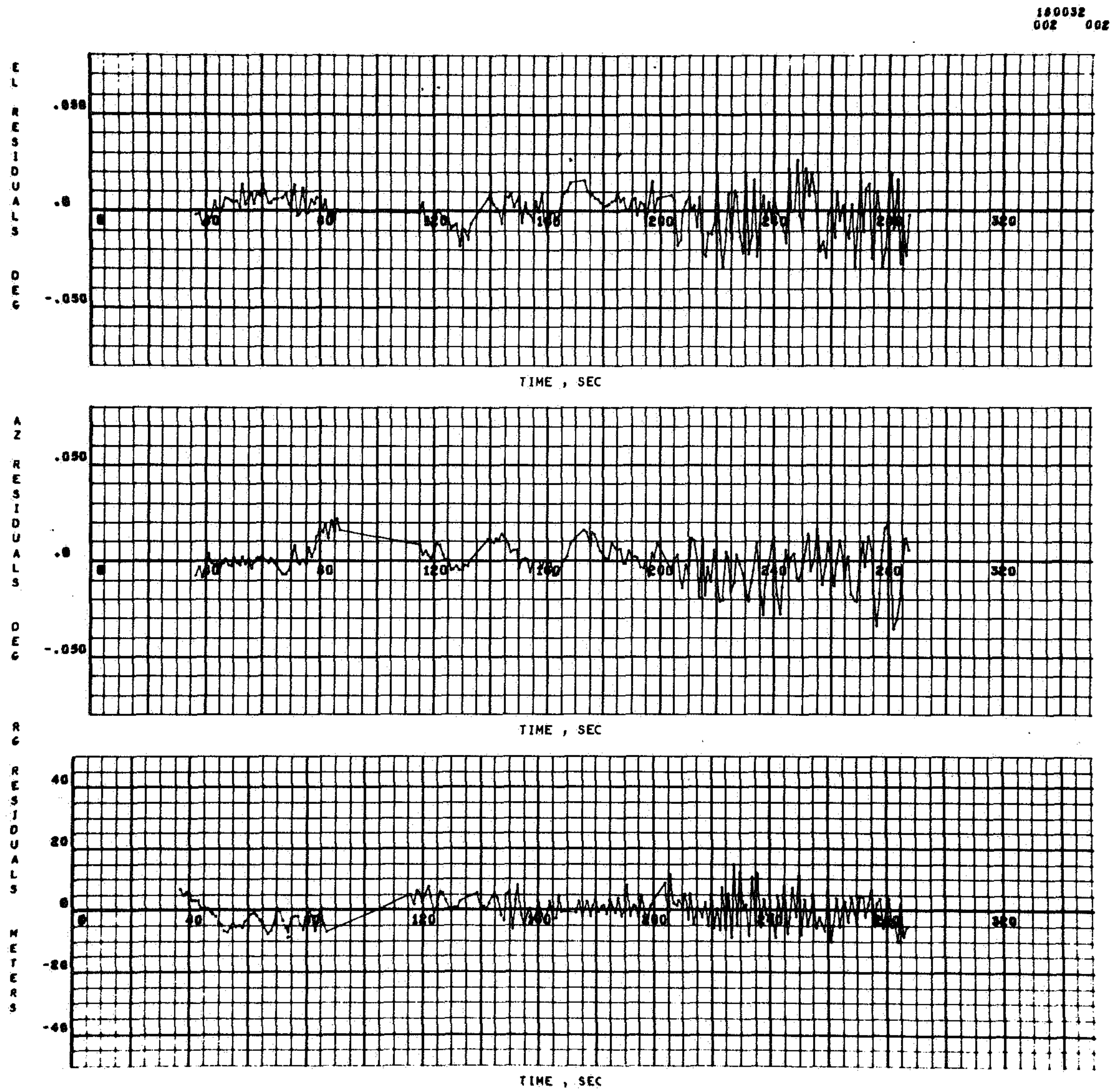


FIGURE C-5. RADAR 1.16 RESIDUALS ON AS-502 LAUNCH PHASE DATA

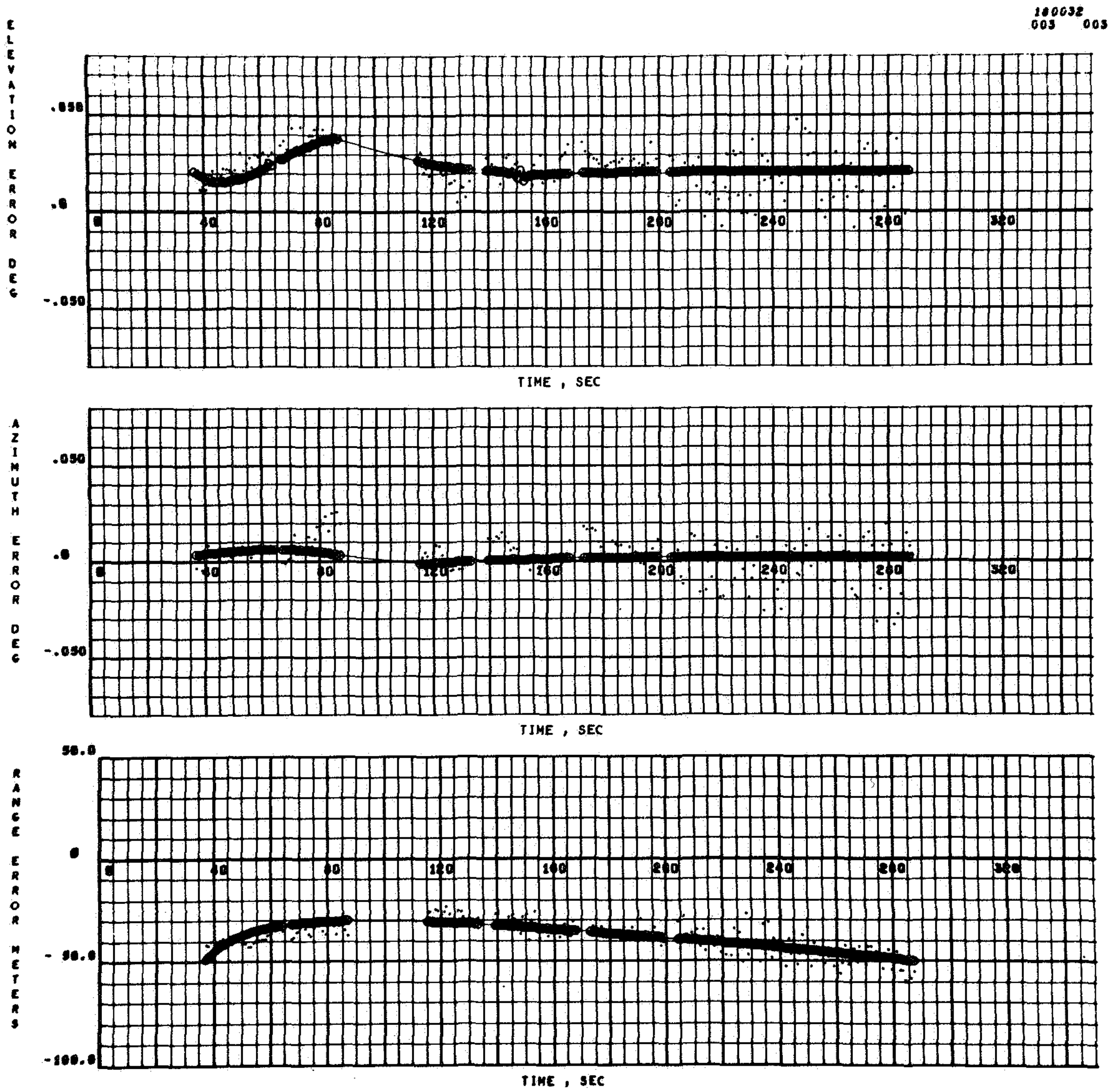


FIGURE C-6. RADAR 1.16 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-502 LAUNCH PHASE DATA

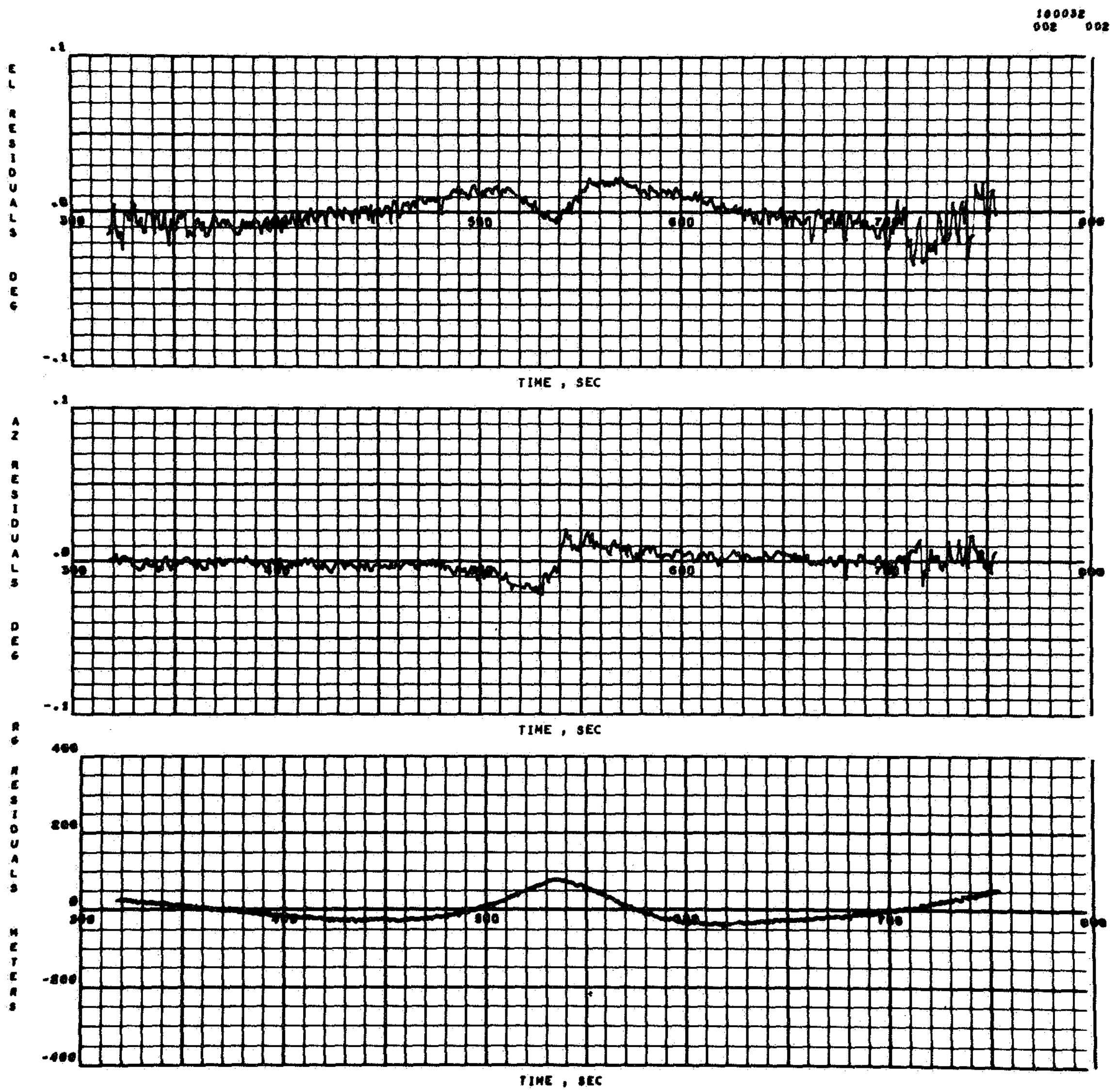


FIGURE C-7. RADAR 67.18 RESIDUALS ON AS-502
LAUNCH PHASE DATA

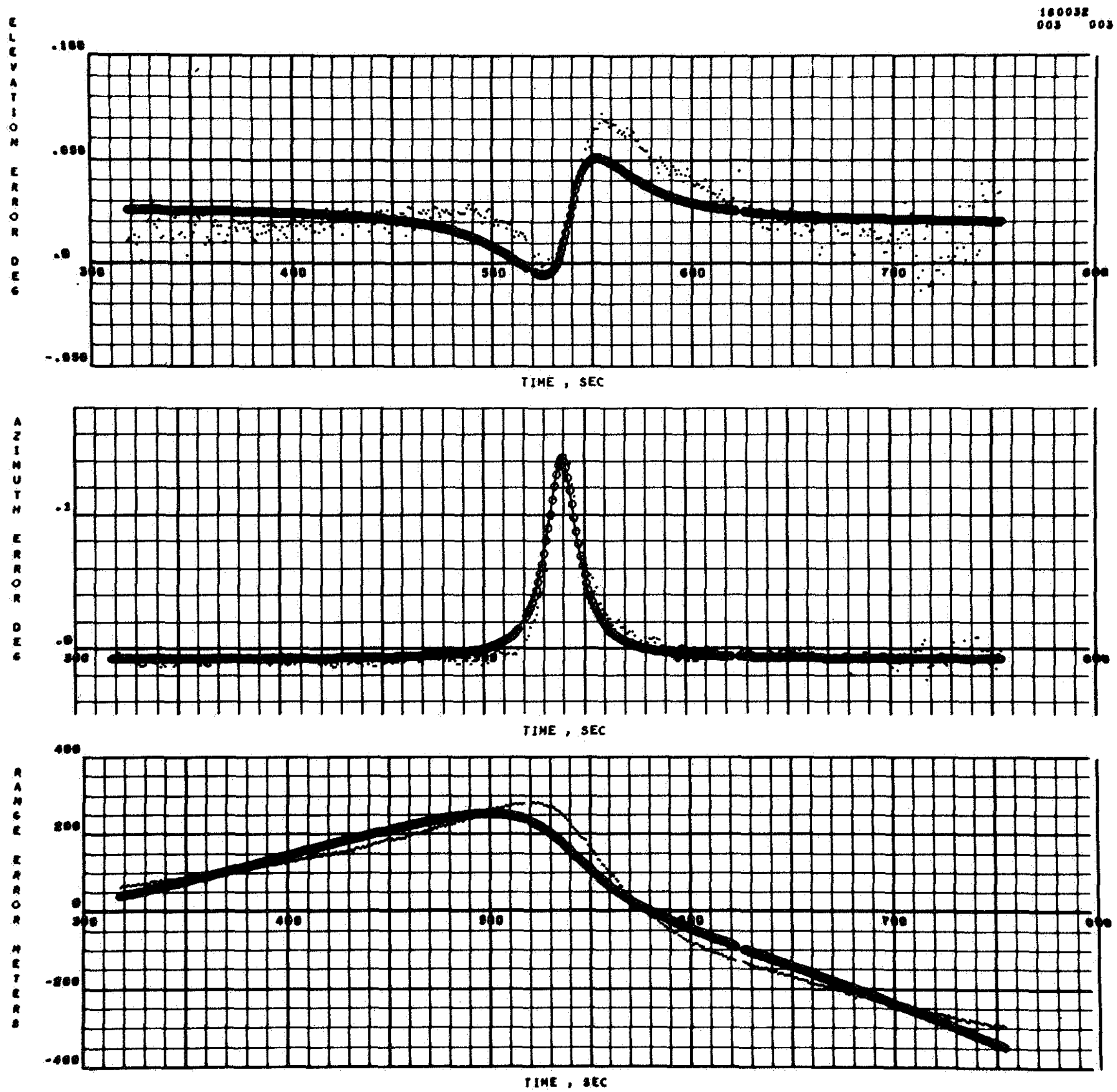


FIGURE C-8. RADAR 67.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-502 LAUNCH PHASE DATA

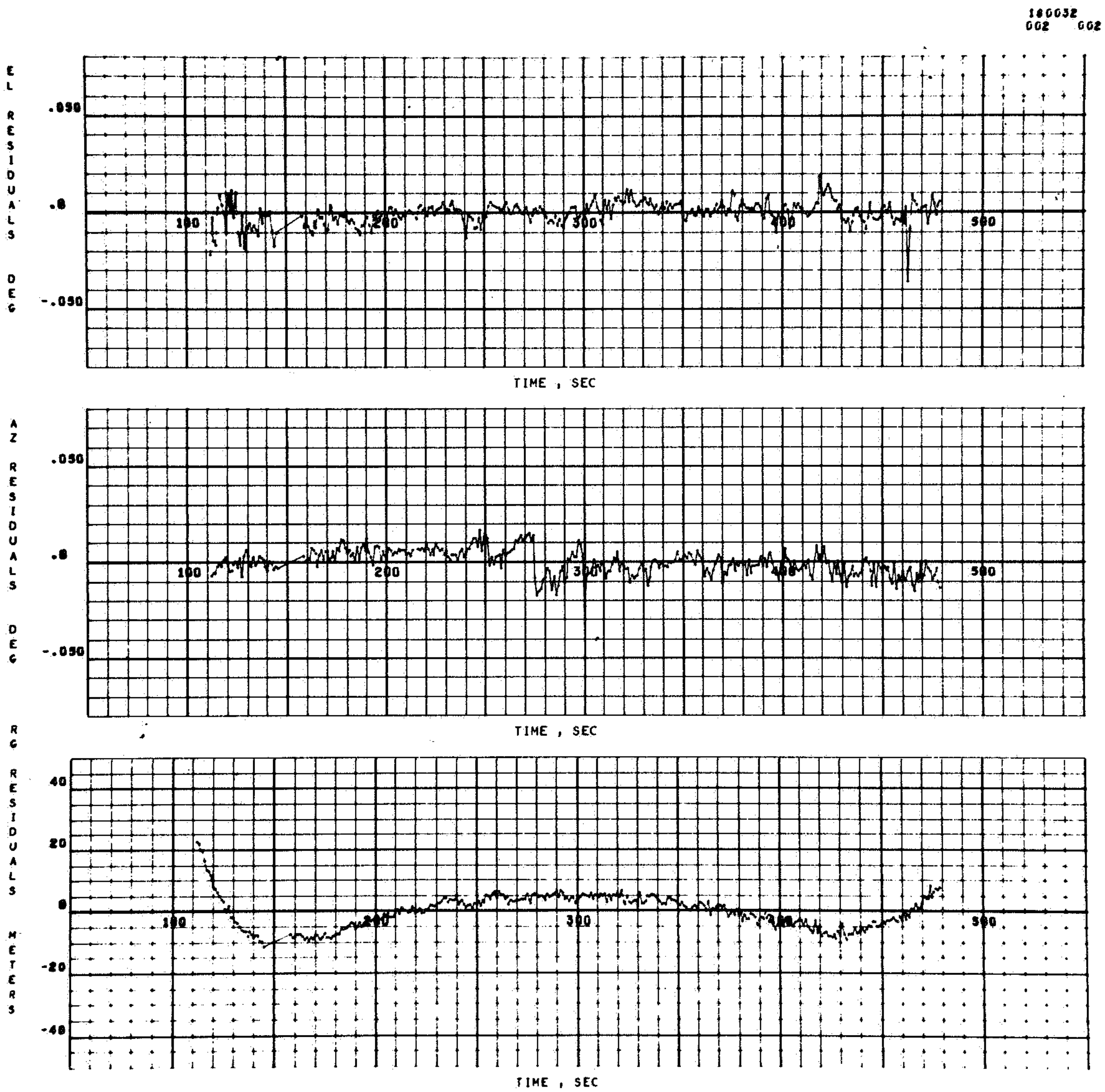


FIGURE C-9. RADAR 3.18 RESIDUALS ON AS-502 LAUNCH PHASE DATA

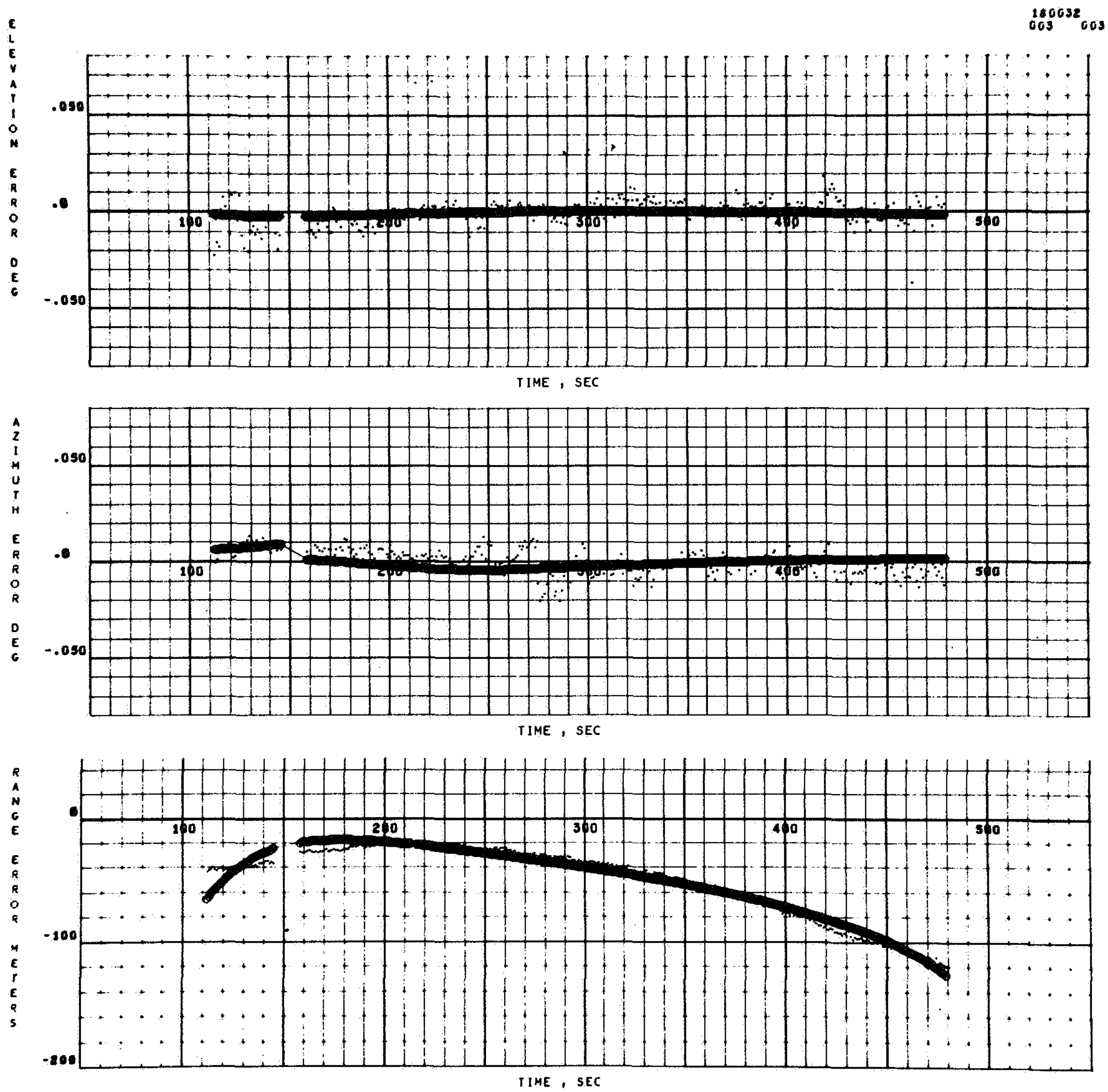


FIGURE C-10. RADAR 3.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-502 LAUNCH PHASE DATA

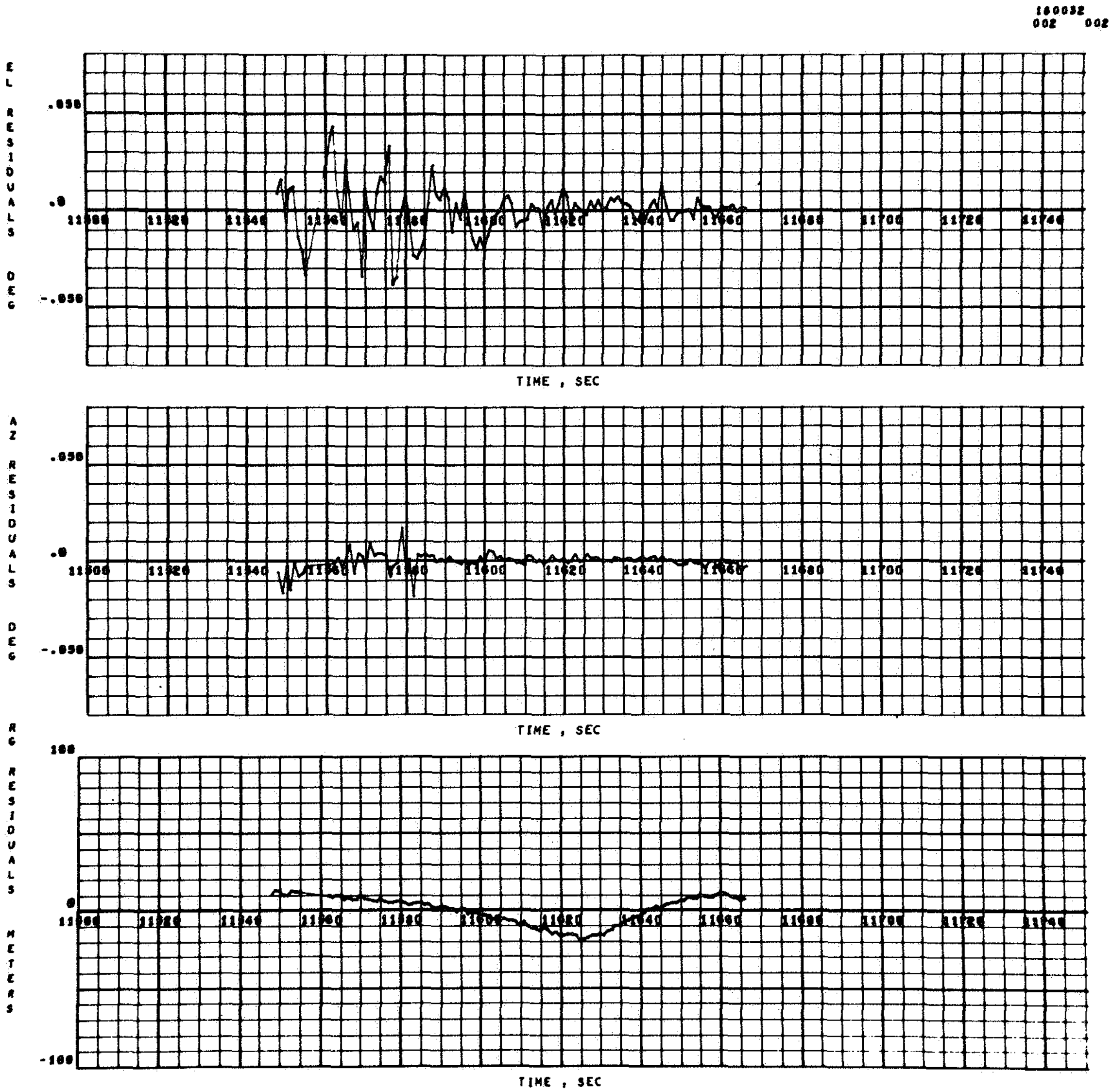


FIGURE C-11. RADAR 0.18 RESIDUALS ON AS-502 ORBITAL PHASE (REV. 1) DATA

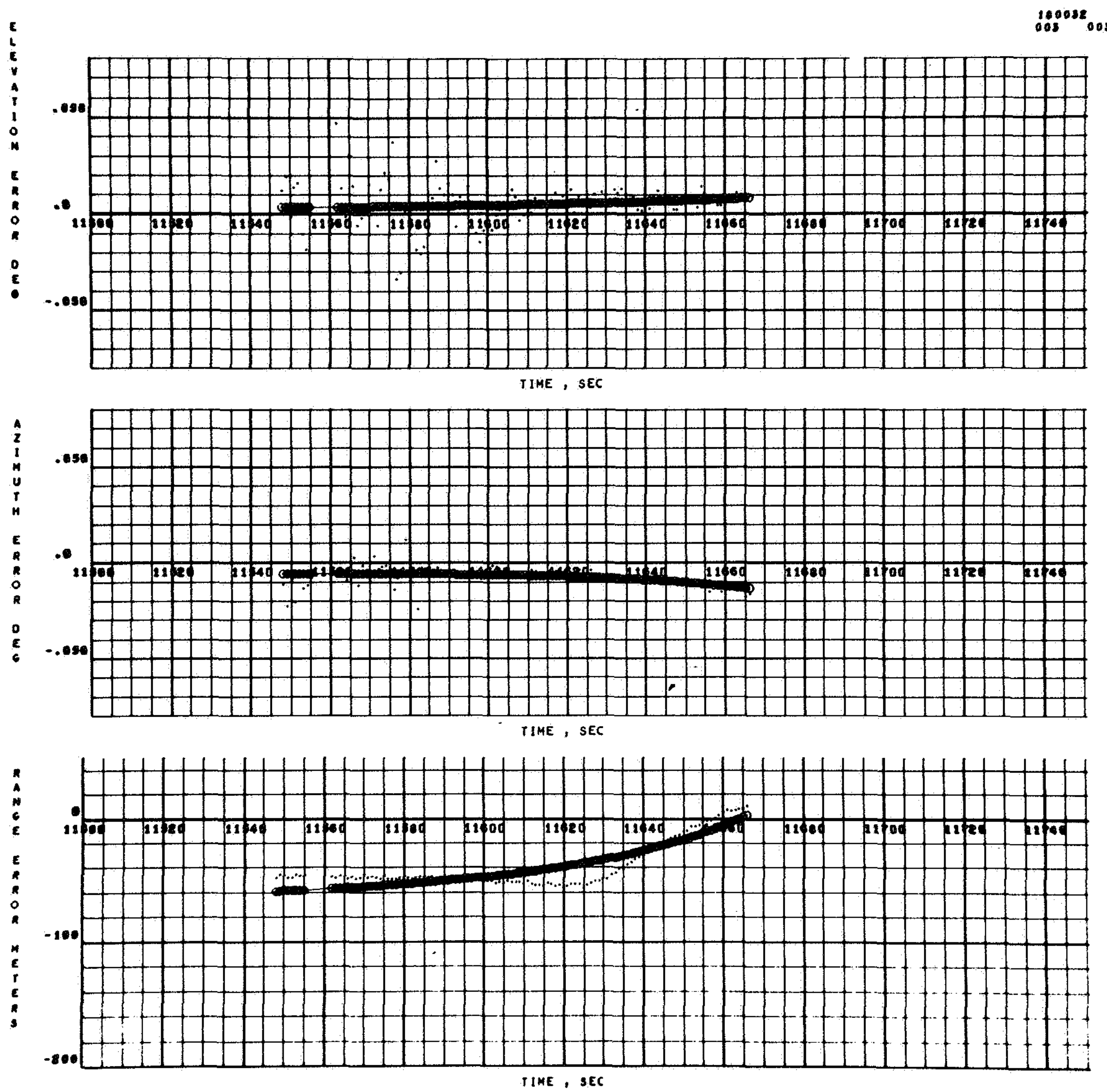


FIGURE C-12. RADAR 0.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-502 ORBITAL PHASE (REV. 1) DATA

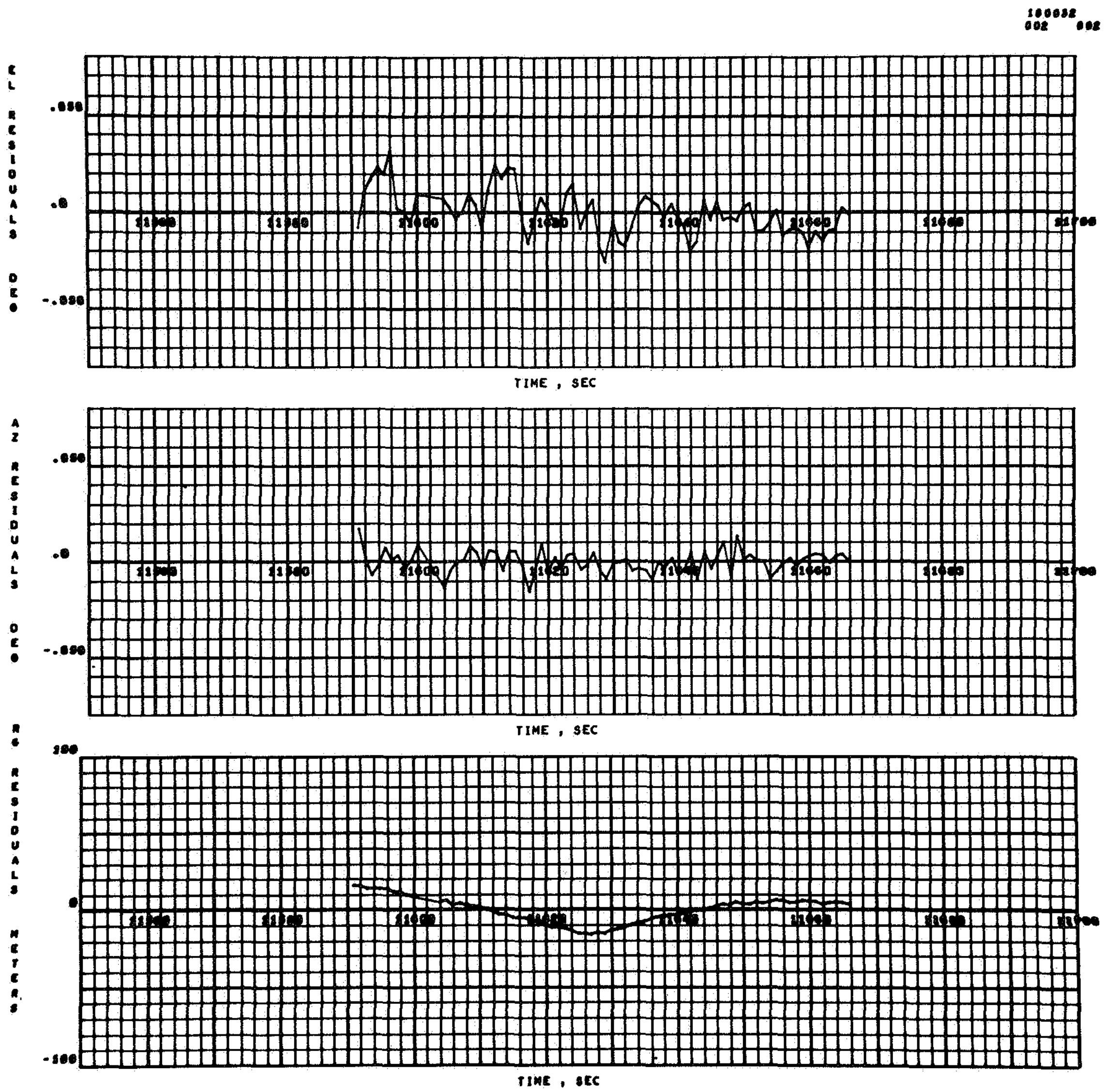


FIGURE C-13. RADAR 3.18 RESIDUALS ON AS-502
ORBITAL PHASE (REV. 1) DATA

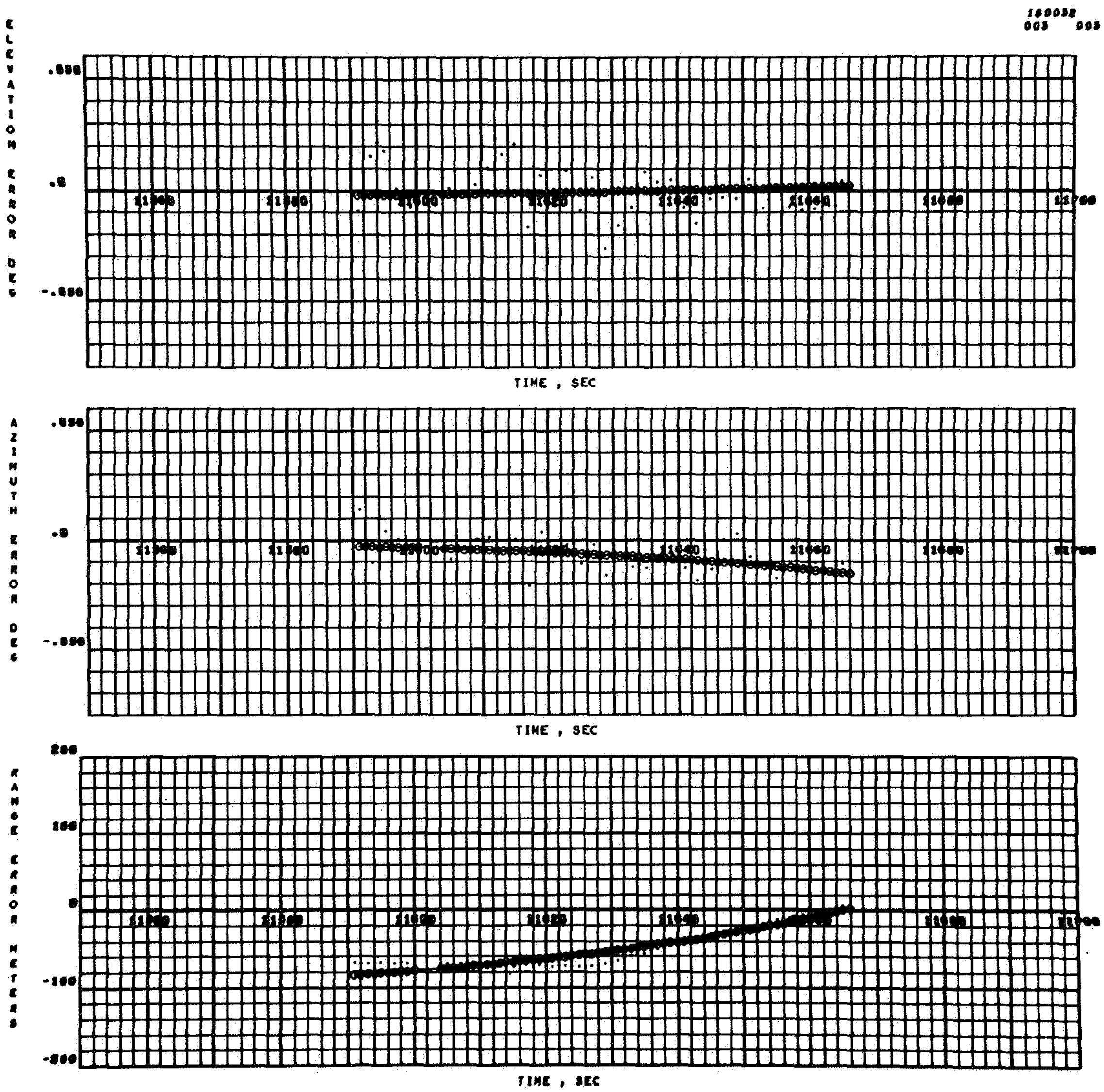


FIGURE C-14. RADAR 3.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-502 ORBITAL PHASE (REV. 1) DATA

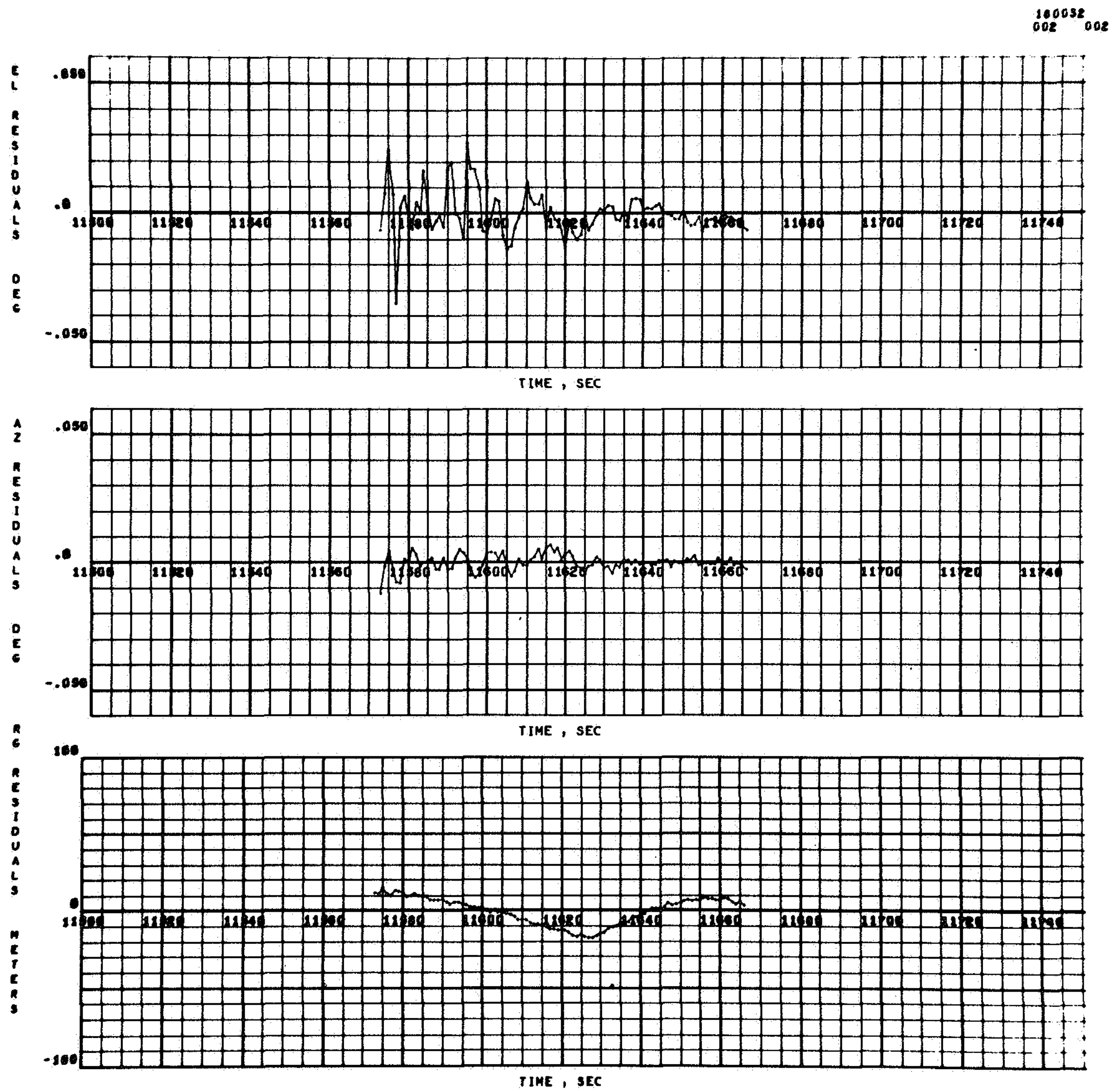


FIGURE C-15. RADAR 19.18 RESIDUALS ON AS-502 ORBITAL PHASE (REV. 1) DATA

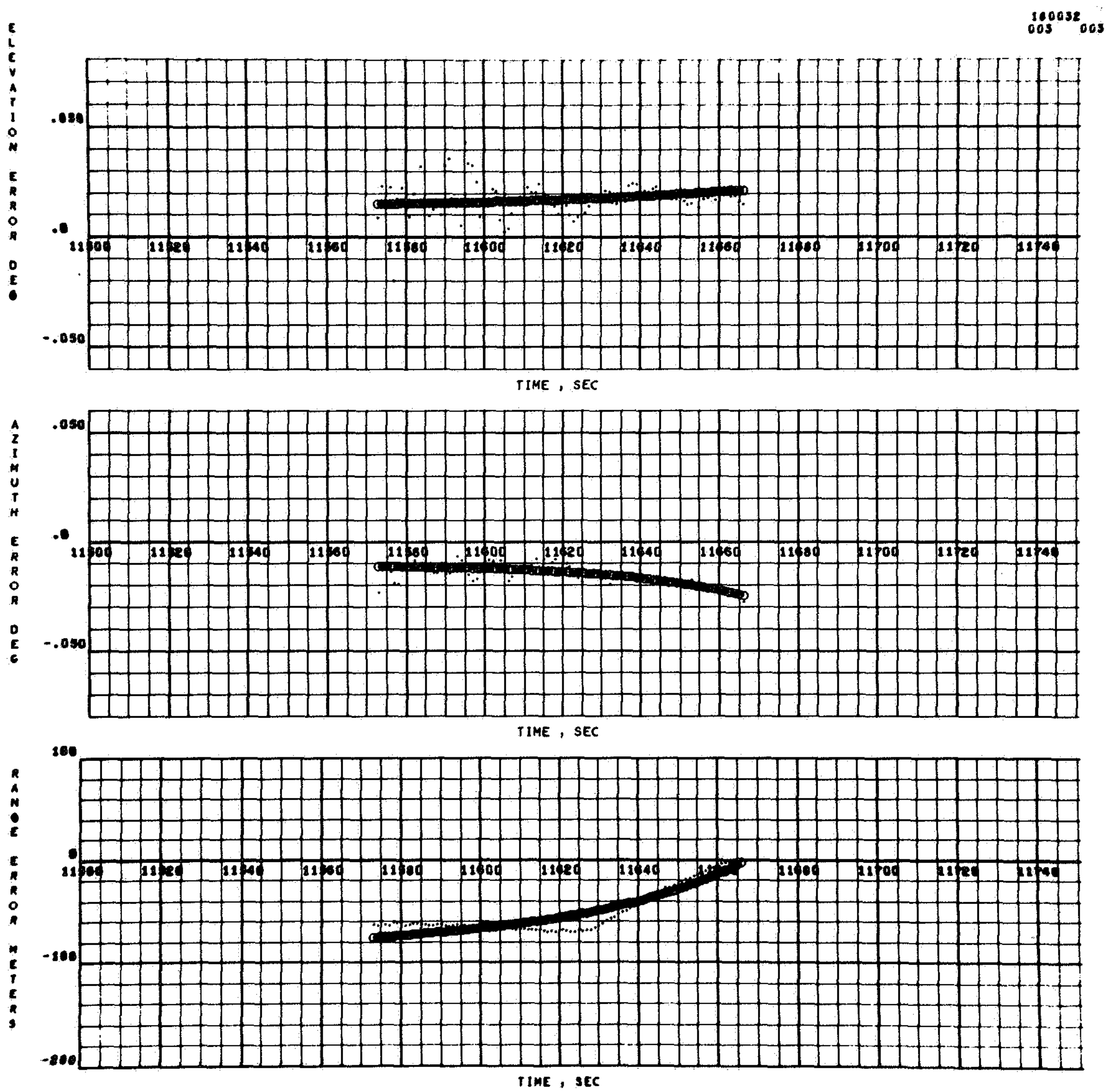


FIGURE C-16. RADAR 19.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-502 ORBITAL PHASE (REV. 1) DATA

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APPROVAL TM-X 53804

THE TEMS APOLLO-SATURN V RESULTS THROUGH THE AS-502 FLIGHT TEST

By Bobby G. Junkin

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This document has also been reviewed and approved for technical accuracy.

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