NASA TECHNICAL
MEMORANDUM

NASA TM X-53818
March 13, 1969

NASA TM X-53818

THE TEMS APOLLO-SATURN IB TRACKING SYSTEM ERROR MODEL RESULTS THROUGH THE AS-205 FLIGHT TEST

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ABSTRACT

This is the fifth in a continuing series of reports summarizing the TEMS multiple regression analysis results from the current and previous Apollo-Saturn IB flight tests. The TEMS method for determining the tracker error models involves establishing the tracker errors and then determining functional expressions to describe the established errors. Guidelines used in obtaining truncated error models have resulted in generally acceptable models.

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RESEARCH AND DEVELOPMENT OPERATIONS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

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SUMMARY

This is the fifth in a continuing series of reports summarizing the TEMS multiple regression analysis results from the current and previous Apollo-Saturn IB flight tests. The TEMS method for determining the tracker error models involves establishing the tracker errors and then determining functional expressions to describe the established errors. Guidelines used in obtaining truncated error models have resulted in generally acceptable models.

INTRODUCTION

This report presents the TEMS multiple regression analysis results obtained from the evaluation of tracking system measurement errors on the Apollo-Saturn IB flight test data. It is the fifth in a continuing series of reports summarizing results from the current and previous flight tests.

The basic concept in the TEMS evaluation process involves establishing the tracker errors and then determining, in the least squares sense, error model expressions to describe the established errors [1]. The fundamental observational residual equations in the method are given by

$$\left.\begin{aligned} V_R &= \Delta R^0 - \Delta R \\ V_A &= \Delta A^0 - \Delta A \\ V_E &= \Delta E^0 - \Delta E \end{aligned}\right\}, \qquad (1)$$

Observational Residuals — Observed Deltas — Functional Deltas

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

$$\left.\begin{aligned}
V_{C_0} &= \delta C_0 + \tilde{C}_0 - C_0^\infty \\
V_{C_1} &= \delta C_1 + \tilde{C}_1 - C_1^\infty \\
&\vdots \\
V_{F_m} &= \delta F_m + \tilde{F}_m - F_m^\infty
\end{aligned}\right\}, \quad (3)$$

Parameter Residuals | Corrections | Coefficient Approximations | A Priori Coefficient Values

The corrections $\delta C_0, \delta C_1, \ldots, \delta F_m$ are determined in the least squares sense. The initial approximations $\tilde{C}_0, \tilde{C}_1, \ldots, \tilde{F}_m$ are then adjusted by these amounts.

Truncated tracker error models for representing the systematic errors are obtained using the TEMS method in conjunction with a stepwise regression procedure. The stepwise regression procedure involves examining at every step the variables incorporated into the error model in previous steps. Thus, the final regression model results in only the most significant variables being

retained in the model. The UNIVAC 1108, Executive VIII, computer program for application of the various procedures is currently in an operational production status.

SUMMARY OF APOLLO-SATURN IB RESULTS THROUGH THE AS-205 LAUNCH

The Apollo-Saturn AS-205 (Apollo 7) vehicle was launched at 10:02:45 (AM) Eastern Standard Time on October 11, 1968, from Kennedy Space Center, Launch Complex 34. Tracking data from seven C-band radars were utilized in the TEMS reduction. The post-flight reference trajectory used as the standard is presented in Reference 2. The vehicle ground track summary and location of the various tracking sites is shown in Figure 1. Location data for the launch site and the various tracking stations is given in Table I.

The AS-205 tracking data utilization is shown in Figure 2. These usable 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 $(\overline{\dot{W}})$ and approximation matrix $(\overline{C})$ equal to zero. A priori estimates of zero for the error model coefficients were also entered into the final TEMS computer runs.

The general approach for obtaining truncated error models to describe the AS-205 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 the first guideline) 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 the third guideline often involved selecting one of two variables that represented borderline cases in the order of entry in the stepwise regression, that is, the two variables had nearly equal partial correlation coefficient values. The approach given by these guidelines has generally resulted in acceptable error models for the AS-205 data.

The previous TEMS Apollo-Saturn IB summary report is given in Reference 3. An overall summary of the truncated error model results from [3] and from the AS-205 Flight Test is presented in Tables II through IX. It is observed in these tables that the coefficient standard deviations for the individual radars do not vary significantly from test to test. One exception to this observation is the AS-205 azimuth and elevation results for Radar 7.18. Table X shows that the least squares residual errors for the various radars are in close agreement with the input accuracy estimates of 5 meters in range and 0.006 degree in azimuth and elevation.

Table XI is a summary of the coefficient standard deviations obtained from the various tracking radars. The data in this table are grouped according to two categories:

(1) Category for all the radars combined.

(2) Category according to radar location.

From this table it is seen that the standard deviations for several of the coefficients do not vary significantly from radar to radar. The standard deviations appear to be fairly stable for the different radar locations considered in the second category. The summary in Table XII gives some idea of the size of the error model required to describe the tracking errors. No fewer than four and no more than nine terms, excluding constraints, have been retained in the truncated error models.

CONCLUSIONS

Results from the evaluation of tracking system measurement errors on the Apollo-Saturn IB flight test data (AS-201 through AS-205) are obtained using the TEMS Multiple Regression Analysis Method. Truncated tracker error models representing the systematic errors in the AS-204 and AS-205

data are obtained under guidelines using the TEMS Method in conjunction with a stepwise regression procedure. These guidelines show considerable usefulness for constructing tracker error models containing the most significant variables and represent an improvement in the area of model construction. An overall summary of results obtained on the AS-201 through AS-205 flight tests shows that the standard deviations for several of the error model coefficients do not vary significantly from test to test or from radar to radar. The average random errors remaining in the least squares residuals are in close agreement with the input accuracy estimates of 5 meters in range and 0.006 degree in azimuth and elevation.

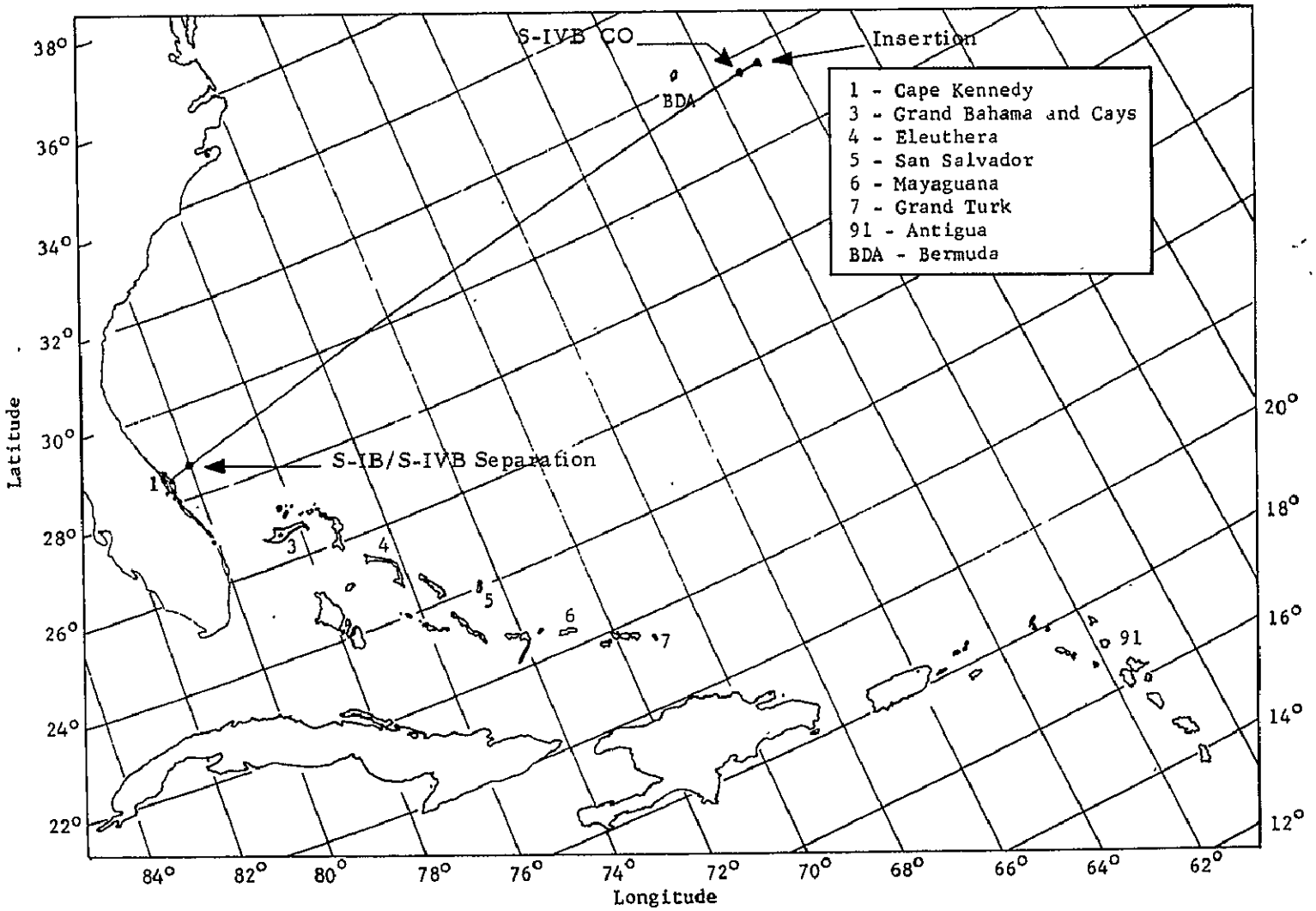

FIGURE 1. GEOMETRICAL RELATION BETWEEN THE AS-205 FLIGHT PATH AND THE TRACKING STATIONS

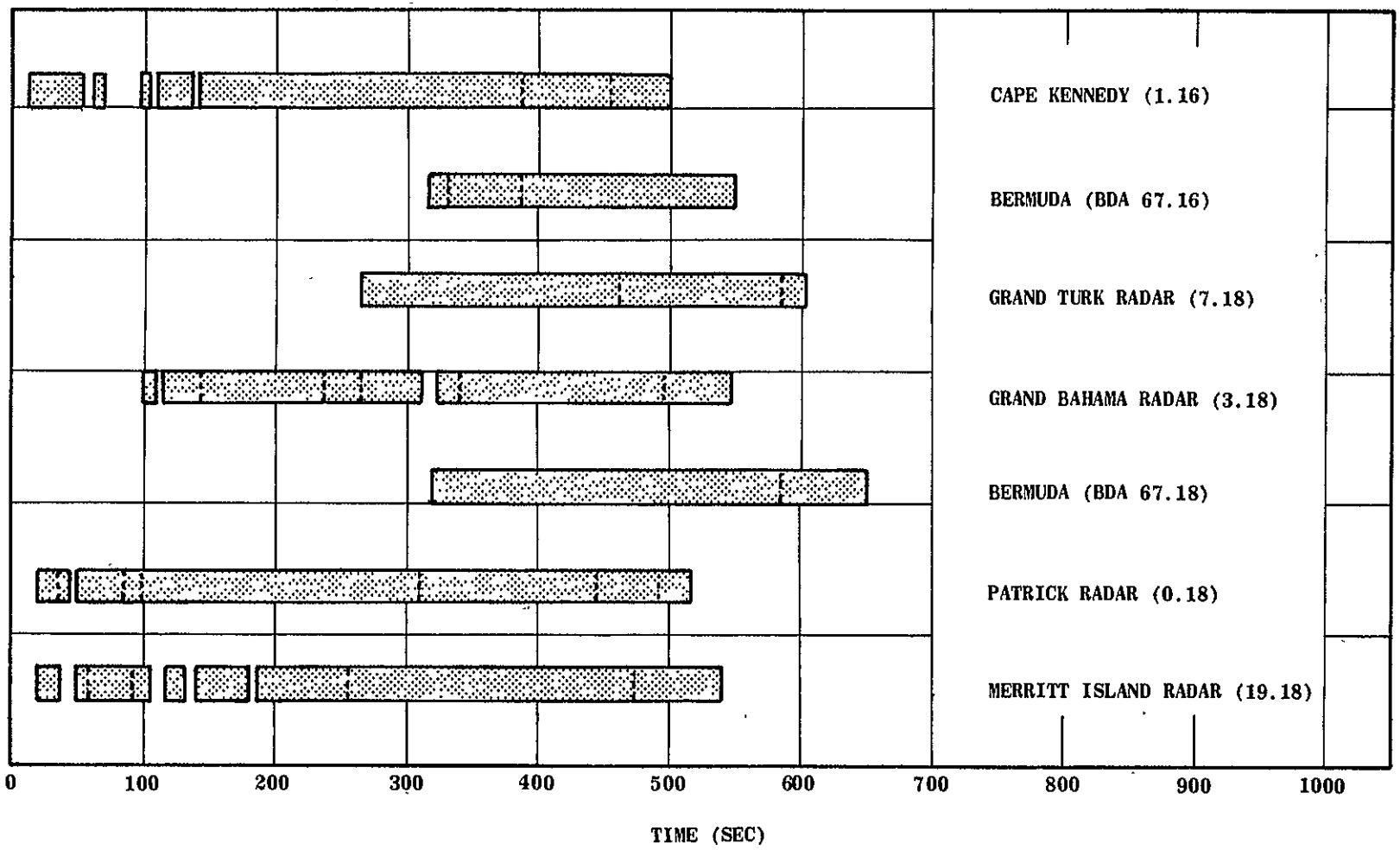

FIGURE 2. TEMS AS-205 TRACKING DATA UTILIZATION

TABLE I. LOCATION OF LAUNCH SITE AND C-BAND TRACKING RADARS USED IN TEMS AS-205 REDUCTION

Site	Latitude, degrees	Longitude, degrees	Height,[a] meters
Launch Complex 34	28.521963	80.561141	61.54[b]
Patrick (0.18)	28.226553	80.599293	19.92
Merritt Island (19.18)	28.424862	80.664404	16.39
Grand Bahama (3.18)	26.636350	78.267708	16.29
Grand Turk (7.18)	21.462890	71.132114	32.82
Bermuda (67.16)	32.348103	64.653801	17.81
Bermuda (67.18)	32.347964	64.653742	19.03
Cape Kennedy (1.16)	28.481766	80.576515	18.78

a. Elevation above the Fischer Spheroid

b. Elevation of the C-Band radar antenna above the Fischer Spheroid

TABLE II. TRUNCATED ERROR MODEL REGRESSION ANALYSIS RESULTS FOR RADAR 0.18

Coefficient Value and Standard Deviation	Flight Test No.				
	201	202	203	204	205
C_0	———	30.39	15.37	-56.69	11.12
σ		0.58	0.70	1.25	0.56
C_1	———	———	- 0.446E-4	———	-0.57E-4
σ			0.37E-5		0.19E-5
C_2	-0.0197	0.0055	———	0.0041	0.0100
σ	0.34E-3	0.20E-3		0.58E-3	0.49E-3
C_4	-172.32	-18.49	-271.06	-302.11	———
σ	9.69	4.50	20.22	11.22	
D_0	-0.0142	-0.0040	-0.00067	0.0148	-0.0016
σ	0.73E-3	0.28E-3	0.53E-3	0.0010	0.28E-3
D_3	———	0.0094	0.5220	———	0.6955
σ		0.036	0.151		0.059
D_5	0.0139	———	———	———	———
σ	0.0018				
D_7	———	———	———	-0.0622	———
σ				0.0042	
D_8	———	0.0172	———	0.0582	———
σ		1.1E-3		0.0042	
F_0	0.000115	0.0212	0.0112	0.0681	0.0109
σ	0.35E-3	1.1E-3	0.46E-3	0.0053	0.27E-3
F_3	———	1.084	-0.2633	-0.2701	-0.8753
σ		0.100	0.134	0.212	0.065
No. Data Pts.	323	377	259	356	471
σ_{VR}	3.30	3.65	2.33	15.02	3.96
σ_{VA}	0.0049	0.0050	0.0082	0.0081	0.0060
σ_{VE}	0.0086	0.0068	0.0086	0.0085	0.0067

TABLE III. TRUNCATED ERROR MODEL REGRESSION ANALYSIS RESULTS FOR RADAR 19.18

Coefficient Value and Standard Deviation	Flight Test No.				
	201	202	203	204	205
C_0 σ	———	57.57 0.62	51.61 0.36	6.90 0.89	7.26 0.40
C_1 σ	0.075E-4 0.14E-5	0.349E-4 0.14E-5	-0.50E-4 0.20E-5	———	-0.23E-4 0.78E-6
C_2 σ	-0.0105 0.26E-3	———	———	———	———
C_4 σ	———	-23.29 10.50	-275.03 11.07	-9.25 13.54	17.21 3.46
D_0 σ	-0.000101 0.24E-3	0.0016 0.75E-3	0.0020 0.25E-3	-0.88E-3 0.46E-3	-0.0051 0.42E-3
D_3 σ	———	-1.253 0.061	0.4070 0.126	3.57 0.143	1.68 0.128
D_5 σ	———	-0.0362 0.0017	———	———	———
D_7 σ	———	0.0143 0.0011	———	———	———
D_8 σ	———	———	———	———	0.0612 0.0019
F_0 σ	0.0036 0.23E-3	0.0368 0.35E-3	0.0398 0.23E-3	0.0027 0.45E-3	0.0696 0.0018
F_3 σ	0.3424 0.034	0.1828 0.049	-1.189 0.078	1.224 0.070	-0.6983 0.0540
No. Data Pts.	455	360	279	287	468
σ_{VR}	3.13	4.64	1.86	5.65	4.68
σ_{VA}	0.0049	0.0071	0.0039	0.0092	0.0057
σ_{VE}	0.0061	0.0070	0.0045	0.0066	0.0072

TABLE IV. TRUNCATED ERROR MODEL REGRESSION ANALYSIS RESULTS FOR RADAR 3.18

Coefficient Value and Standard Deviation	Flight Test No.				
	201	202	203	204	205
C_0 σ	-7.65 0.68	55.19 0.39	-72.32 1.21	-13.05 0.39	17.39 0.32
C_1 σ	-0.197E-4 0.15E-5	———	2.087E-4 0.46E-5	0.624E-4 0.93E-6	———
C_2 σ	0.0013 0.29E-3	0.0039 0.11E-3	-0.0273 0.50E-3	———	-0.0041 0.10E-3
C_4 σ	———	-77.15 4.00	———	139.55 4.16	46.14 2.76
D_0 σ	0.0143 0.46E-3	-0.00086 0.29E-3	———	0.0115 0.20E-3	-0.0038 0.20E-3
D_3 σ	0.0975 0.200	0.4300 0.056	0.3084 0.109	1.392 0.090	0.734 0.093
D_5 σ	———	———	0.0492 0.0016	———	———
D_7 σ	-0.0016 0.0011	———	———	———	———
D_8 σ	———	0.0043 0.38E-3	0.0038 0.77E-3	———	0.0117 0.34E-3
F_0 σ	0.0371 0.45E-3	0.0181 0.33E-3	0.0348 0.47E-3	-0.0196 0.212E-3	-0.0062 0.23E-3
F_3 σ	———	0.0846 0.094	0.0586 0.201	0.5901 0.126	1.695 0.147
No. Data Pts.	427	435	270	326	406
σ_{VR}	6.36	2.69	2.96	2.20	2.24
σ_{VA}	0.0044	0.0034	0.0068	0.0047	0.0036
σ_{VE}	0.0128	0.0085	0.0079	0.0032	0.0047

TABLE V. TRUNCATED ERROR MODEL REGRESSION ANALYSIS RESULTS FOR RADAR 7.18

Coefficient Value and Standard Deviation	Flight Test No.				
	201	202	203	204	205
C_0 σ	———	25.45 0.40	-85.14 2.95	12.20 1.59	-3.54 2.42
C_1 σ	-0.638E-4 0.30E-6	———	———	———	———
C_2 σ	0.0027 0.80E-4	0.0048 0.16E-3	0.0073 0.42E-3	———	-0.0063 0.41E-3
C_4 σ	———	29.78 2.00	-195.46 10.88	39.50 5.38	-69.71 10.48
D_0 σ	-0.0047 0.30E-3	0.0043 0.34E-3	0.000251 0.60E-3	-0.0082 0.56E-3	-0.0011 0.93E-3
D_3 σ	-1.667 0.122	0.2910 0.120	———	———	-1.35 1.50
D_5 σ	———	———	———	———	———
D_7 σ	———	———	———	———	———
D_8 σ	-0.0072 0.43E-3	0.0059 0.60E-3	———	———	-0.0607 0.0027
F_0 σ	0.0041 0.32E-3	-0.0092 0.30E-3	0.0113 0.60E-3	0.0394 0.56E-3	0.3020 0.0027
F_3 σ	1.049 0.359	———	———	———	433.65 9.03
No. Data Pts.	536	338	168	280	330
σ_{VR}	7.13	1.74	2.93	6.34	2.38
σ_{VA}	0.0060	0.0040	0.0055	0.0059	0.0056
σ_{VE}	0.0051	0.0074	0.0115	0.0130	0.0238

TABLE VI. TRUNCATED ERROR MODEL REGRESSION ANALYSIS RESULTS FOR RADAR 67.16

Coefficient Value and Standard Deviation	Flight Test No.				
	201	202	203	204	205
C_0	NA*	NA*	84.68	13.56	-69.76
σ			1.08	1.31	3.23
C_1			-0.58E-4	-0.636E-4	———
σ			0.14E-5	0.26E-5	
C_2			———	0.0079	-0.1186
σ				0.27E-3	0.86E-3
C_4			———	———	———
σ					
D_0			-0.0076	-0.0081	-0.0083
σ			0.41E-3	0.66E-3	0.64E-3
D_3			0.3350	0.2405	0.6104
σ			0.079	0.0126	0.0934
D_5			———	———	———
σ					
D_7			———	———	———
σ					
D_8			———	———	———
σ					
F_0			-0.0065	0.0106	0.0229
σ			0.44E-3	0.63E-3	0.73E-3
F_3			0.190	0.2604	-0.7614
σ			0.075	0.0236	0.1781
No. Data Pts.			139	180	227
σ_{VR}			1.44	11.16	10.01
σ_{VA}			0.0028	0.0037	0.0036
σ_{VE}			0.0063	0.0038	0.0078

* Not Available

TABLE VII. TRUNCATED ERROR MODEL REGRESSION ANALYSIS RESULTS FOR RADAR 67.18

Coefficient Value and Standard Deviation	Flight Test No.				
	201	202	203	204	205
C_0	NA*	NA*	NA*	30.62	27.32
σ				0.85	0.61
C_1				-0.585E-4	-0.526E-4
σ				0.11E-5	0.93E-6
C_2				0.0095	-0.0023
σ				0.18E-3	0.80E-4
C_4				———	———
σ					
D_0				-0.0019	-0.0075
σ				0.40E-3	0.32E-3
D_3				———	0.0090
σ					0.0085
D_5				———	———
σ					
D_7				———	———
σ					
D_8				-0.0032	0.0054
σ				0.70E-3	0.36E-3
F_0				-0.0041	-0.00013
σ				0.65E-3	0.36E-3
F_3				———	0.0049
σ					0.0191
No. Data Pts.				247	326
σ_{VR}				6.98	4.53
σ_{VA}				0.0036	0.0047
σ_{VE}				0.0040	0.0061

* Not Available

TABLE VIII. TRUNCATED ERROR MODEL REGRESSION ANALYSIS RESULTS FOR RADAR 91.18

Coefficient Value and Standard Deviation	Flight Test No.									
	201	202	203		204		205			
C_0	47.02	———	NA*		NA*		NA*			
σ	1.52									
C_1	-1.260E-4	———								
σ	0.18E-5									
C_2	0.0014	0.0024								
σ	0.10E-3	0.47E-3								
C_4	———	-7.67								
σ		7.30								
D_0	0.0038	-0.0092								
σ	0.44E-3	2.9E-3								
D_3	-1.639	———								
σ	0.110									
D_5	———	0.0975								
σ		0.032								
D_7	———	———								
σ										
D_8	-0.0125	———								
σ	0.68E-3									
F_0	0.0054	0.0191								
σ	0.42E-3	0.90E-3								
F_3	-2.204	———								
σ	0.233									
No. Data Pts.	342	73								
σ_{VR}	7.59	1.49								
σ_{VA}	0.0050	0.0070								
σ_{VE}	0.0076	0.0111								

* Not Available

TABLE IX. TRUNCATED ERROR MODEL REGRESSION ANALYSIS RESULTS FOR RADAR 1.16

Coefficient and σ_K	Flight Test No.									
	201		202		203		204		205	
C_0	NA*		NA*		NA*		NA*		-1.58	
σ									0.50	
C_1									-0.23E-4	
σ									0.10E-5	
C_2										
σ										
C_4									-1.41	
σ									5.1	
D_0									-0.0121	
σ									0.45E-3	
D_3									0.465	
σ									0.057	
D_5										
σ										
D_7										
σ										
D_8									0.0733	
σ									0.0014	
F_0									0.0767	
σ									0.0013	
F_3									-0.906	
σ									0.0389	
No. Data Pts.									428	
σ_{VR}									5.83	
σ_{VA}									0.0069	
σ_{VE}									0.0078	

* Not Available

TABLE X. RESIDUAL ERROR SUMMARY FOR TRACKING RADARS ON AS 201 - 205 FLIGHT TESTS

Radar ID	σ_{VR}, meters	σ_{VA}, degrees	σ_{VE}, degrees
0.18	5.65	0.0064	0.0078
19.18	3.99	0.0062	0.0063
3.18	3.29	0.0046	0.0074
7.18	4.10	0.0054	0.0092[a]
67.16[b]	7.53	0.0033	0.0059
67.18[c]	5.75	0.0041	0.0050
91.18[d]	7.59	0.0050	0.0076
1.16[e]	5.83	0.0069	0.0078

a. σ_{VE} data from AS-205 not included

b. Values based on data from three flights

c. Values based on data from two flights

d. Data from the AS-201 flight

e. Data from the AS-205 flight

TABLE XI. COEFFICIENT STANDARD DEVIATION SUMMARY FOR TRACKING RADARS ON AS 201 - 205 FLIGHT TESTS

Coefficient Standard Deviation	All Radars [a]	Cape Radars 19.18 0.18 1.16	Bermuda Radars 67.16 67.18	Grand Bahama Radar 3.18	Grand Turk Radar 7.18
σ_{C_0}	1.01	0.65	1.41	0.60	1.84
σ_{C_1} XE-5	0.17	0.17	0.15	0.23	—
σ_{C_2} XE-3	0.30	0.37	0.35	0.25	0.27
σ_{C_4}	8.06	9.92	—	3.64	7.18
σ_{D_0} XE-3	0.45	0.49	0.48	0.29	0.45
σ_{D_3}	0.093	0.095	0.048	0.109	0.121
σ_{D_5}	0.0017	0.0017	—	—	—
σ_{D_7}	0.0021	0.0026	—	—	—
σ_{D_8} XE-3	1.07	2.20	0.53	0.49	0.51
σ_{F_0} XE-3	0.71	1.08	0.56	0.34	0.44
σ_{F_3}	0.115	0.084	0.074	0.142	—

a. NOTE: (1) AS-205 7.18 Azimuth and Elevation results excluded

(2) AS-202 91.18 Range, Azimuth, and Elevation results excluded

(3) All other results combined

TABLE XII. TOTAL NUMBER OF TERMS IN TRUNCATED ERROR MODELS FOR AS 201 - 205 FLIGHT TESTS

Radar	Apollo-Saturn Flight Test				
	201	202	203	204	205
0.18	5	8	7	8	7
19.18	5	9	7	6	8
3.18	7	8	8	7	8
7.18	7	7	5	4	8
91.18	8	5	NA	NA	NA
67.16	NA	NA	6	7	6
67.18	NA	NA	NA	6	8
1.16	NA	NA	NA	NA	8

NA: Not Available

APPENDIX

RESULTS FROM THE APOLLO-SATURN 205 FLIGHT TEST

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

Range

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

Azimuth

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

Elevation

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

The specific physical interpretation of the terms appearing in equations (1), (2), and (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 computer program was thus developed so 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.

Results for the truncated versions of these error models on the AS-205 data are presented in this appendix. Coefficient correlations are given in Table A-I. The stepwise regression analysis results for the AS-205 data are given in Table A-II. Plots of the observed deltas, computed deltas, and the least squares residuals are presented in Figures A-1 through A-14. 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.

The least squares residuals for the truncated error models presented in this appendix can be thought of as being composed of (1) random errors and (2) 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 uncertainities in the standard used in establishing the tracking errors, unknown systematic errors not absorbed by those that are modeled, or geometry limitations, or both. The presence of a significant unmodeled systematic error may prevent an adquate description of the data from being obtained.

TABLE A-I. COEFFICIENT CORRELATIONS FOR THE TRUNCATED AS-205 RADAR ERROR MODELS

Radar 1.16

	C_0	C_1	C_4	D_0	D_3	D_8	F_0	F_3
C_0	1.0	-0 48	0.31	0 04	0.01	-0 06	-0 06	-0.14
C_1		1 0	0.52	0 07	0 02	-0 11	-0 11	-0 24
C_4			1.0	0.13	0 04	-0.21	-0.21	-0 47
D_0				1.0	0 08	-0 62	-0.60	0.08
D_3					1.0	-0 20	-0 19	0.03
D_8						1.0	0 96	-0.13
F_0							1.0	-0 16
F_3								1.0

	C_0	C_2	C_4	D_0	D_3	D_8	F_0	F_3
C_0	1 0	-0.33	0 64	0.03	0.0	0.01	0 03	0.01
C_2		1.0	0 35	-0.08	-0 01	-0 07	-0 02	0.0
C_4			1.0	-0 02	-0.01	-0 04	0 02	0 01
D_0				1 0	0 02	-0 39	-0 21	-0 05
D_3					1.0	0.08	0.04	0.01
D_8						1.0	0.53	0.14
F_0							1.0	0 36
F_3								1 0

Radar 0.18

	C_0	C_1	C_2	D_0	D_3	F_0	F_3
C_0	1.0	0 56	-0 76	0.18	-0.02	-0.0	0.0
C_1		1.0	-0.95	0.22	-0 02	-0.01	0 0
C_2			1.0	-0.23	0 02	0.01	0.0
D_0				1.0	0 04	0 0	0 0
D_3					1.0	0 0	0.0
F_0						1.0	0.10
F_3							1.0

Radar 19 18

	C_0	C_1	C_4	D_0	D_3	D_8	F_0	F_3
C_0	1 0	-0.45	0.21	0.03	0 0	-0 04	-0 04	-0.06
C_1		1 0	0 65	0 08	0 01	-0 11	-0 12	-0.18
C_4			1 0	0 12	0 01	-0 17	-0 18	-0 27
D_0				1 0	0 02	-0.72	-0.72	-0 07
D_3					1.0	-0.06	-0.06	-0.01
D_8						1 0	0.99	0 10
F_0							1.0	0.12
F_3								1.0

Radar 67.16

	C_0	C_2	D_0	D_3	F_0	F_3
C_0	1.0	0.99	0.04	-0 21	-0.06	-0 22
C_2		1.0	0 04	-0.22	-0 06	-0 22
D_0			1.0	0.44	0 0	-0.01
D_3				1.0	0 01	0.05
F_0					1.0	-0.60
F_3						1 0

Radar 67.18

	C_0	C_1	C_2	D_0	D_3	D_8	F_0	F_3
C_0	1 0	-0 88	-0.14	-0.01	0.0	0 02	-0.01	0 0
C_1		1.0	0 40	0.02	0.0	-0.07	0 03	0 01
C_2			1 0	0.06	0 0	-0.17	0.08	0.01
D_0				1 0	0.0	0 31	-0 17	-0.03
D_3					1 0	-0.15	0.08	0.01
D_8						1 0	-0 54	-0 08
F_0							1.0	0.07
F_3								1.0

Radar 7 18

	C_0	C_2	C_4	D_0	D_3	D_8	F_0	F_3
C_0	1.0	-0 01	0.95	0 0	0 0	-0 01	-0 05	-0.02
C_2		1.0	0 13	-0.09	0 01	-0.02	0.01	0.0
C_4			1.0	-0 01	0 0	-0 01	0.05	0 02
D_0				1.0	-0 47	-0.27	0.17	0 16
D_3					1 0	-0.02	0 01	0 01
D_8						1.0	-0 61	-0 58
F_0							1 0	0.95
F_3								1 0

TABLE A-II. STEPWISE REGRESSION ANALYSIS RESULTS FOR AS-205 DATA

Radar Equation	Variables in Regression	σ_Y	F Level
0.18			
ΔR	C_0, C_1, C_6, C_7, C_4, C_8, C_2	2.74	5.98
ΔA	D_0, C_2, D_3	0.0055	170.75
ΔE	F_0, C_2, C_5, D_7, C_4, F_3	0.0054	8.08
19.18			
ΔR	C_0, C_1, C_6, C_2, C_4, C_5, C_8	1.90	346.28
ΔA	D_0, C_2, D_3, C_5	0.0043	53.20
ΔE	F_0, C_5, F_3, C_4	0.0059	18.99
3.18			
ΔR	C_0, C_6, C_7, C_2, C_1	1.85	-0.03
ΔA	D_0, D_7, D_6, D_5, D_8, D_3, C_6, C_2	0.0031	4.03
ΔE	F_0, D_8, D_7, C_2, F_3	0.0043	15.65
1.16			
ΔR	C_0, C_6, C_2, C_7, C_5	2.93	-2.45
ΔA	D_0, C_2, D_3, C_5	0.0051	20.24
ΔE	F_0, C_5, C_2, C_7, C_6	0.0069	11.25
7.18			
ΔR	C_0, C_8, C_7, C_1, C_2, C_4	1.48	4.75
ΔA	D_0, C_2	0.0048	26.8
ΔE	F_0, C_4, D_8, C_2	0.0113	18.9
67.16			
ΔR	C_0, C_2, C_6	6.41	324.4
ΔA	D_0, C_2	0.0036	3219.3
ΔE	F_0, C_7, C_5, F_3, C_2	0.0060	3.7
67.18			
ΔR	C_0, C_1, C_6, C_5, C_4, C_8	1.88	7.25
ΔA	D_0, D_5, D_3, D_7, D_6, C_2, D_8	0.0041	6.13
ΔE	F_0, C_4, C_7, D_7, D_8	0.0050	6.84

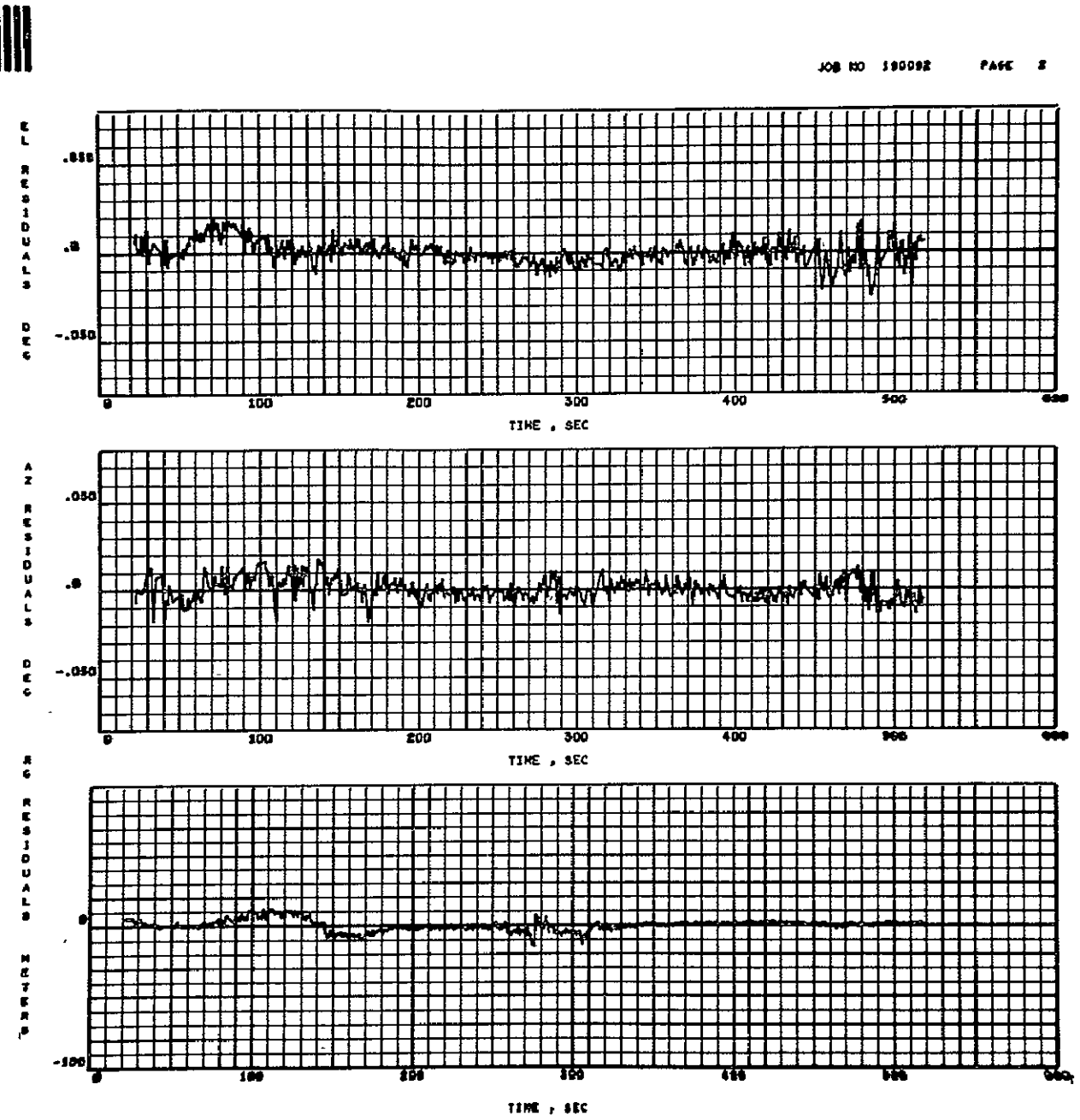

FIGURE A-1. RADAR 0.18 RESIDUALS ON AS-205

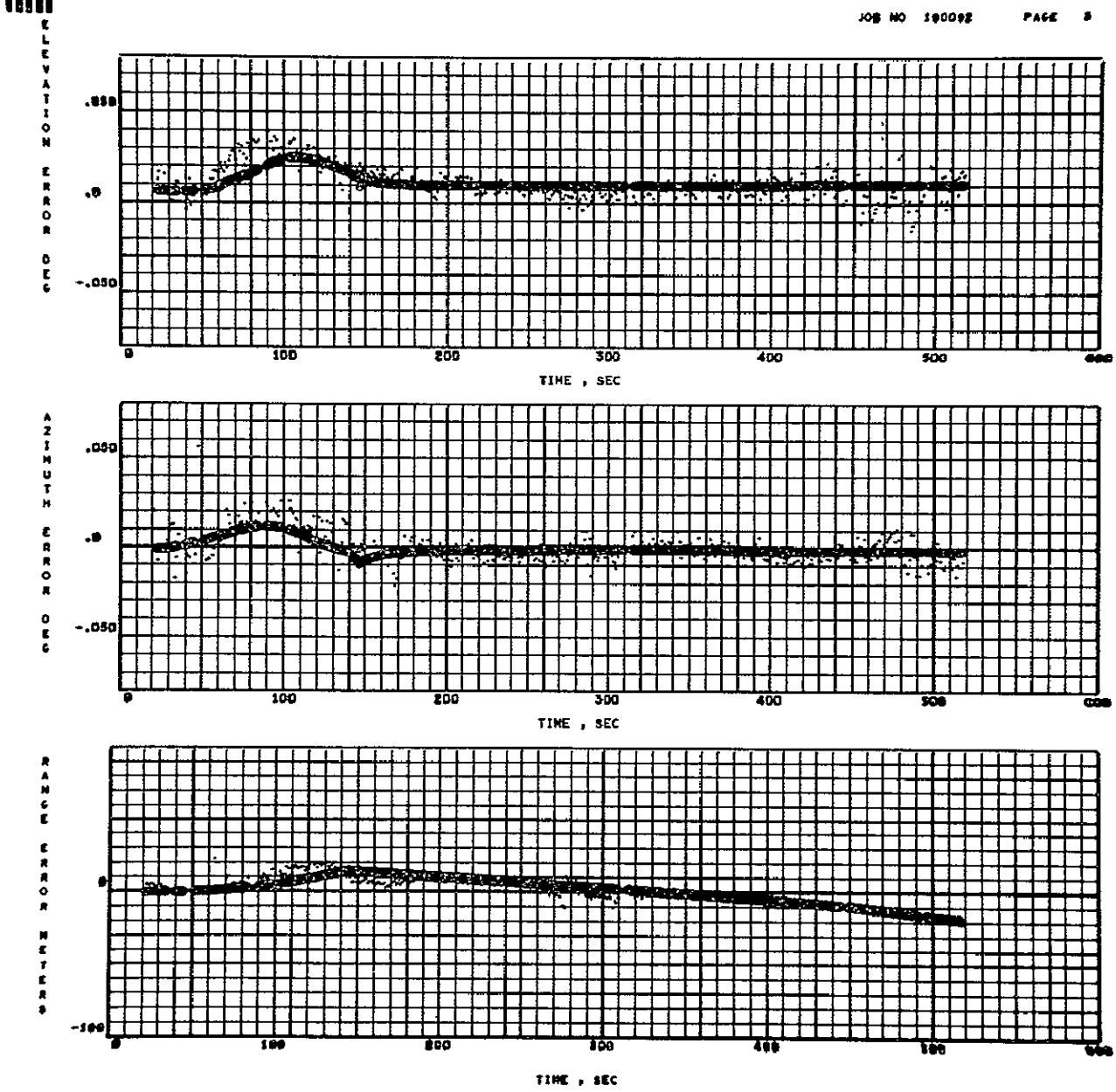

FIGURE A-2. RADAR 0.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-205

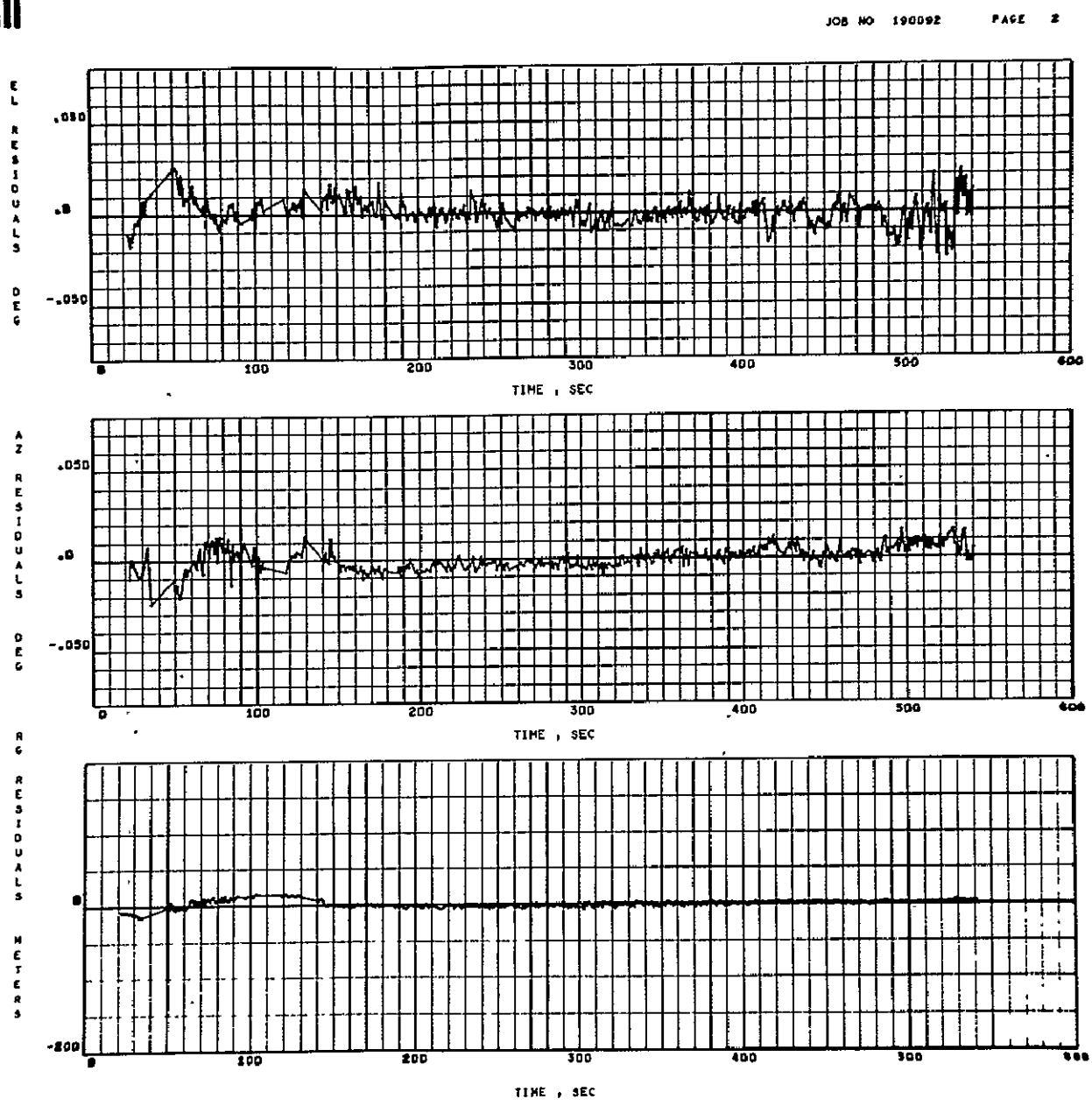

FIGURE A-3. RADAR 19.18 RESIDUALS ON AS-205

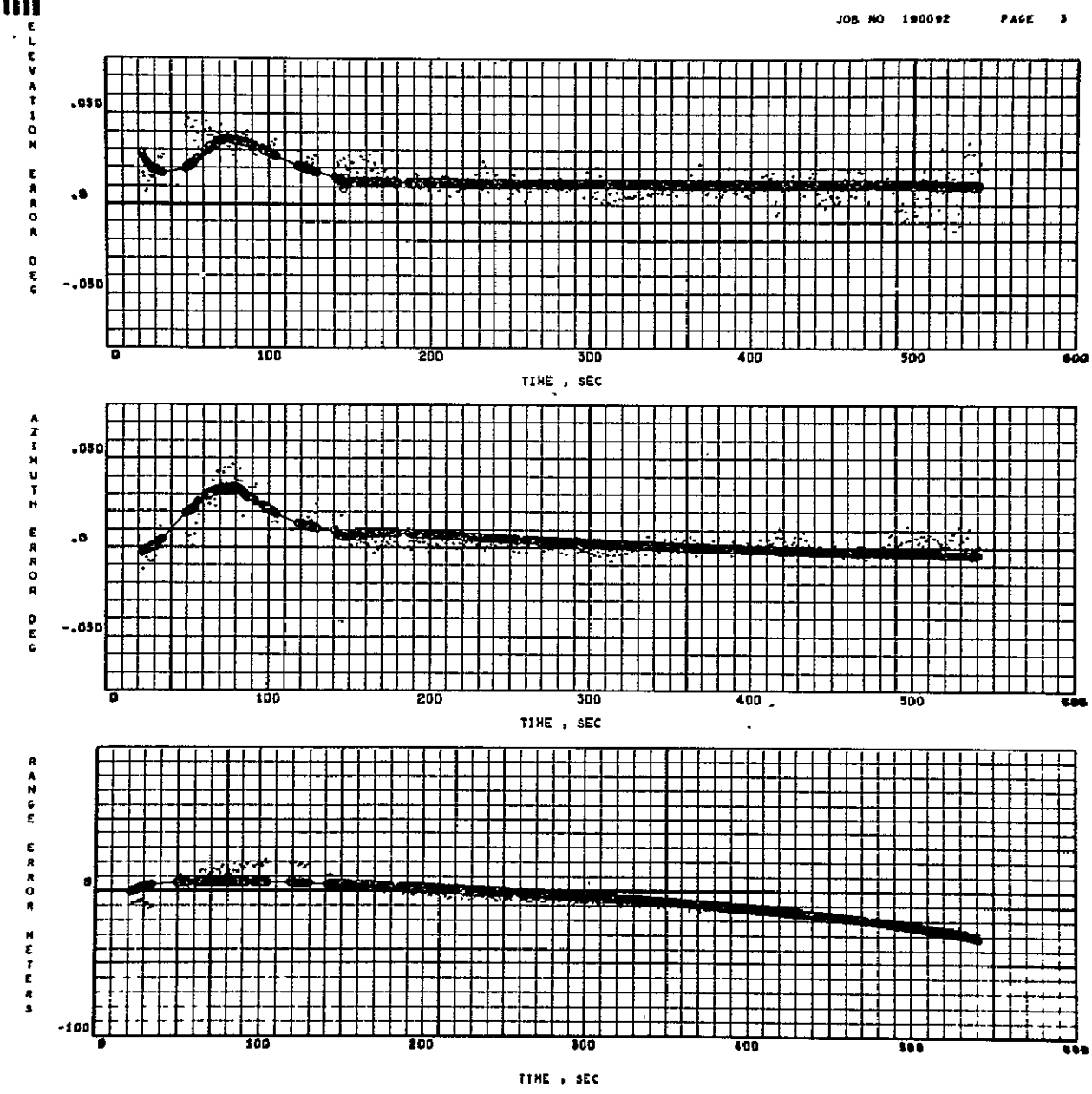

FIGURE A-4. RADAR 19.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-205

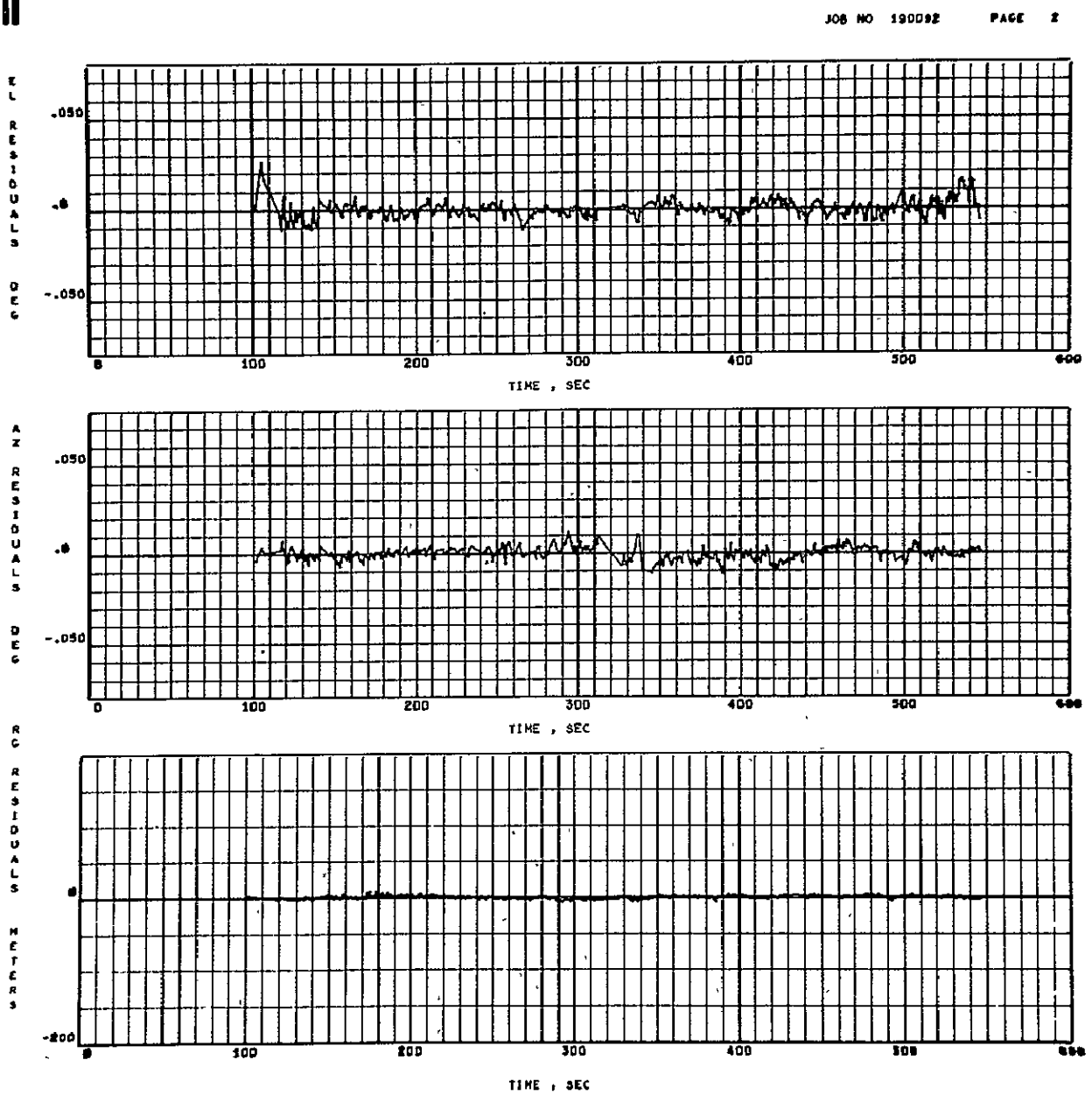

FIGURE A-5. RADAR 3.18 RESIDUALS ON AS-205

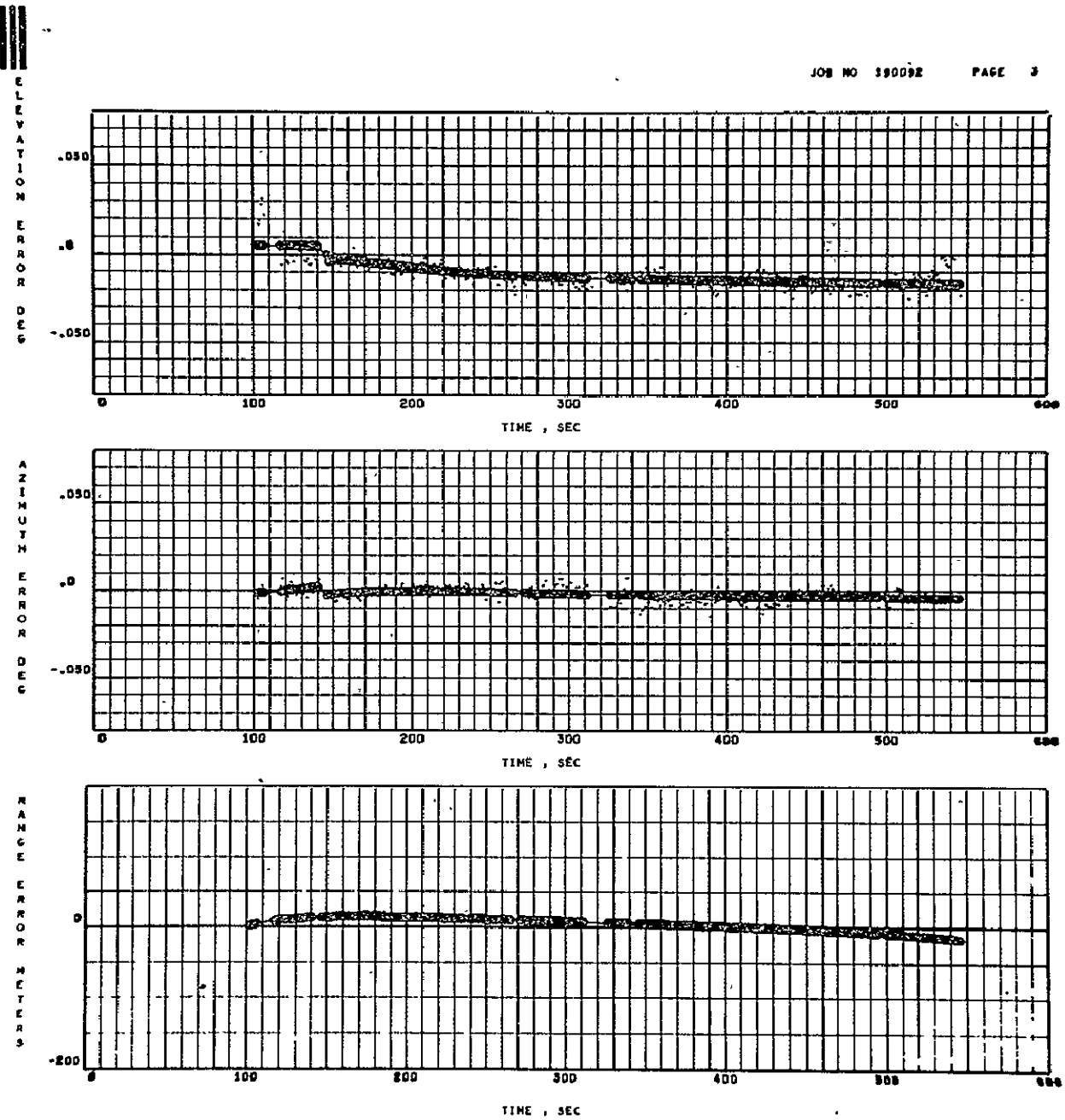

FIGURE A-6. RADAR 3.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-205

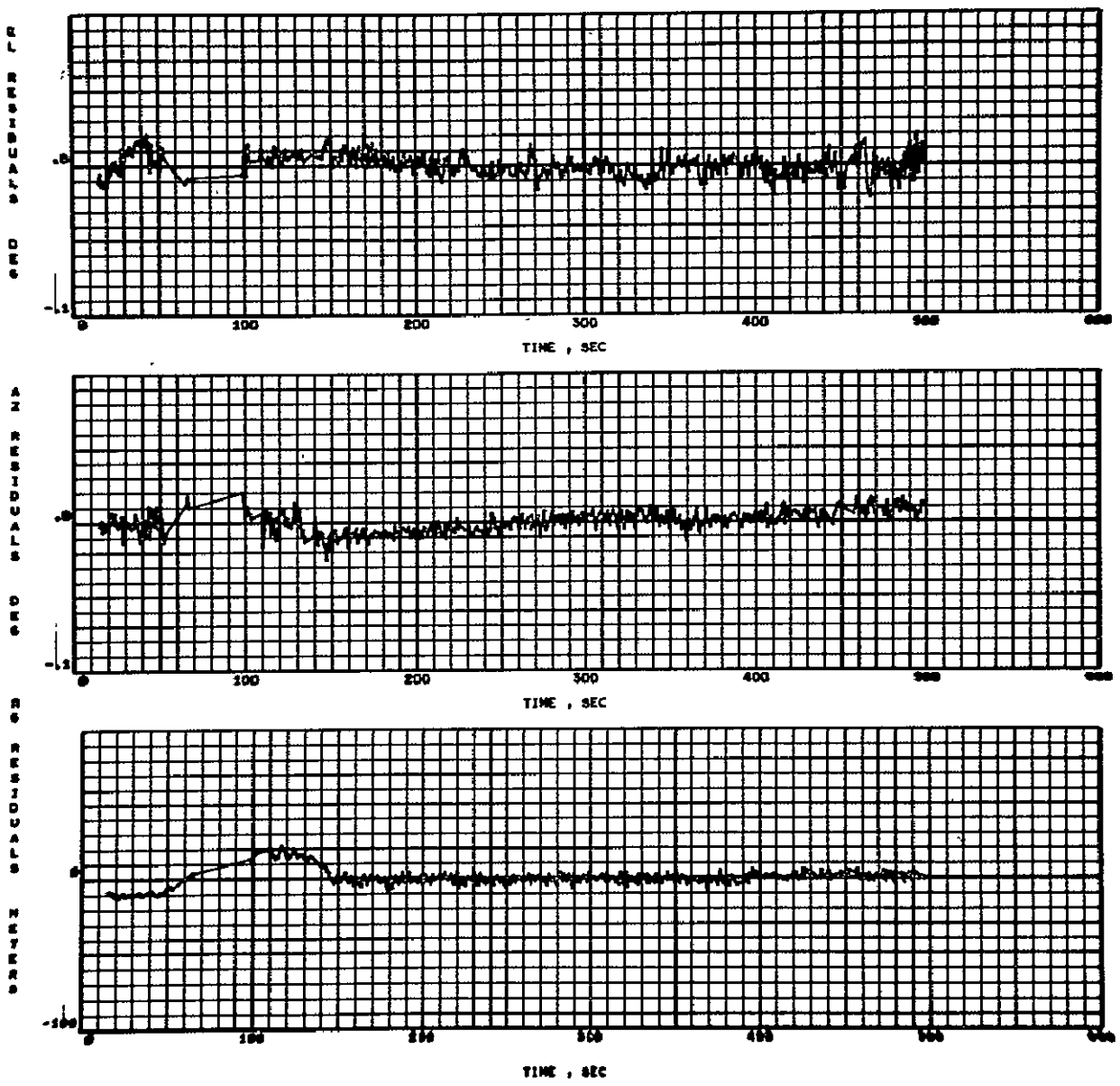

FIGURE A-7. RADAR 1.16 RESIDUALS ON AS-205

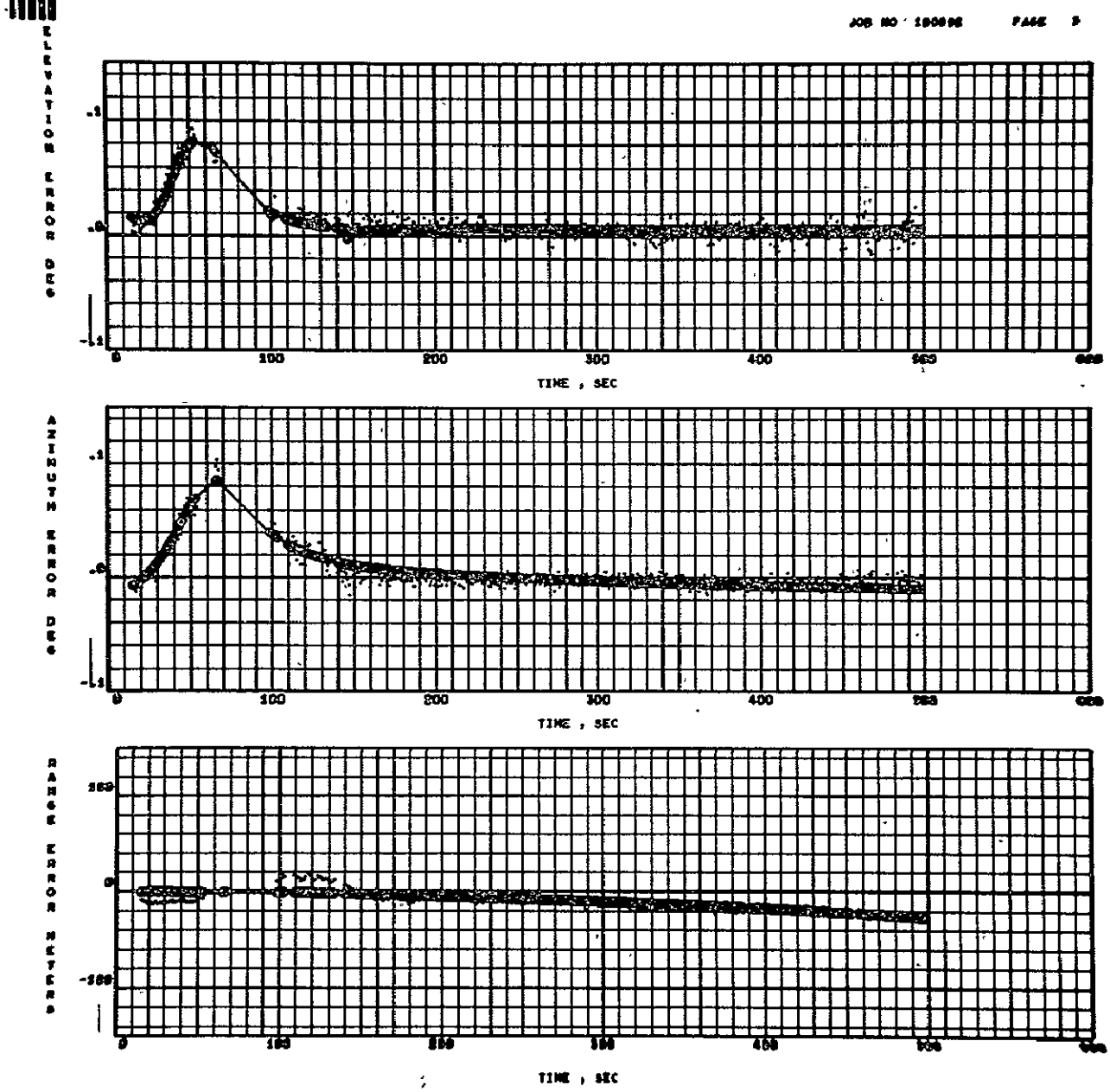

FIGURE A-8. RADAR 1.16 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-205

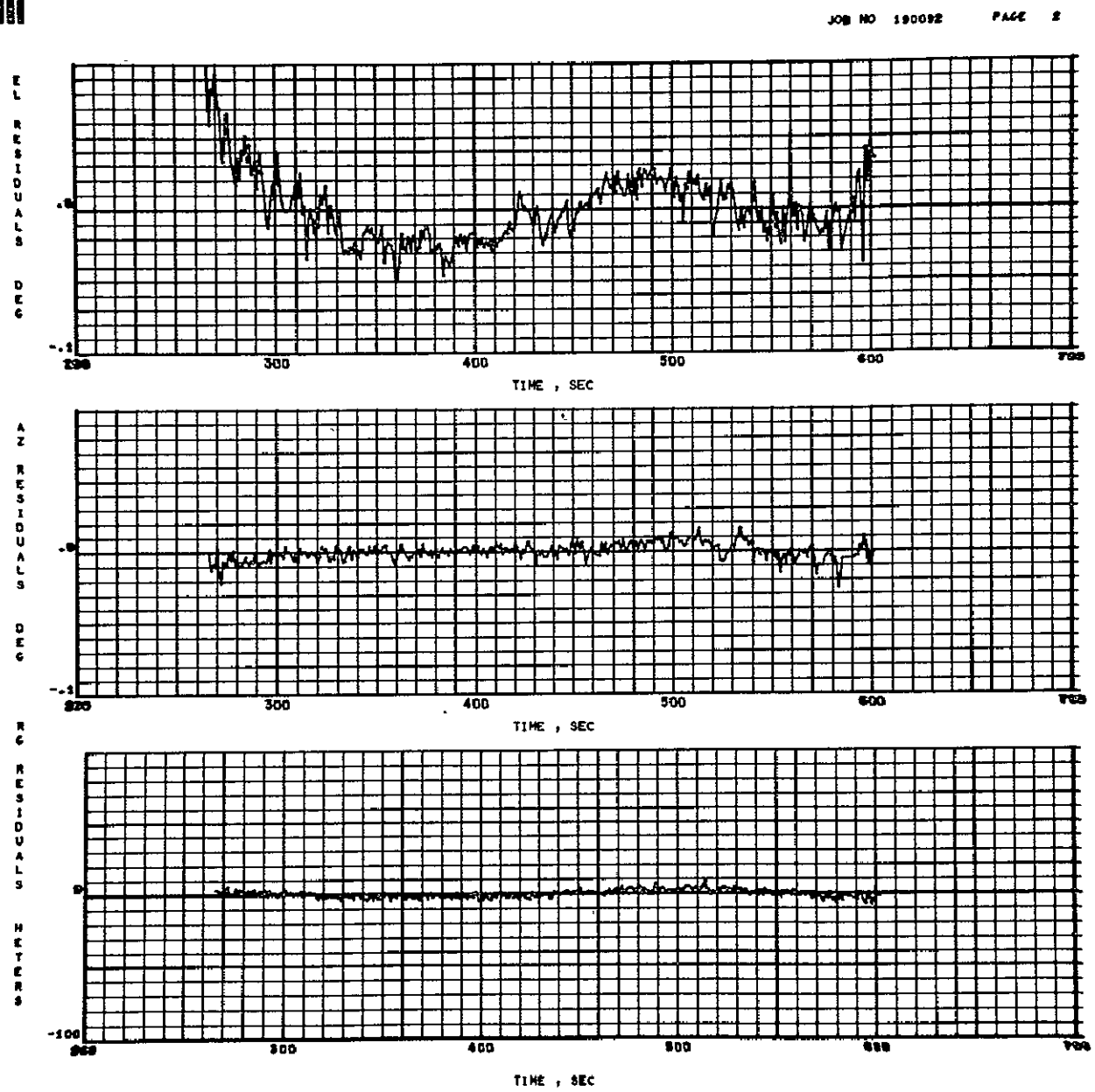

FIGURE A-9. RADAR 7.18 RESIDUALS ON AS-205

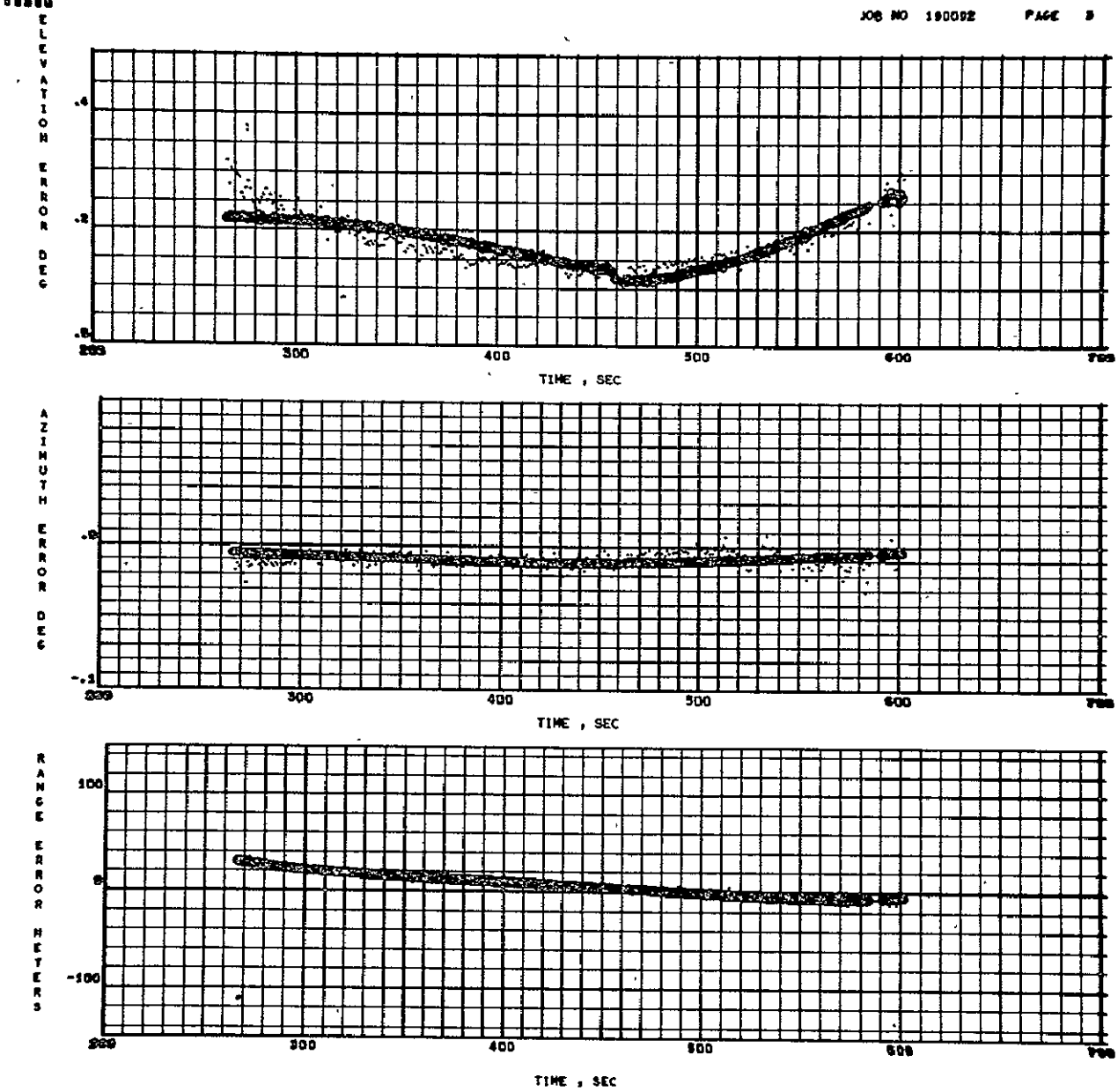

FIGURE A-10. RADAR 7.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-205

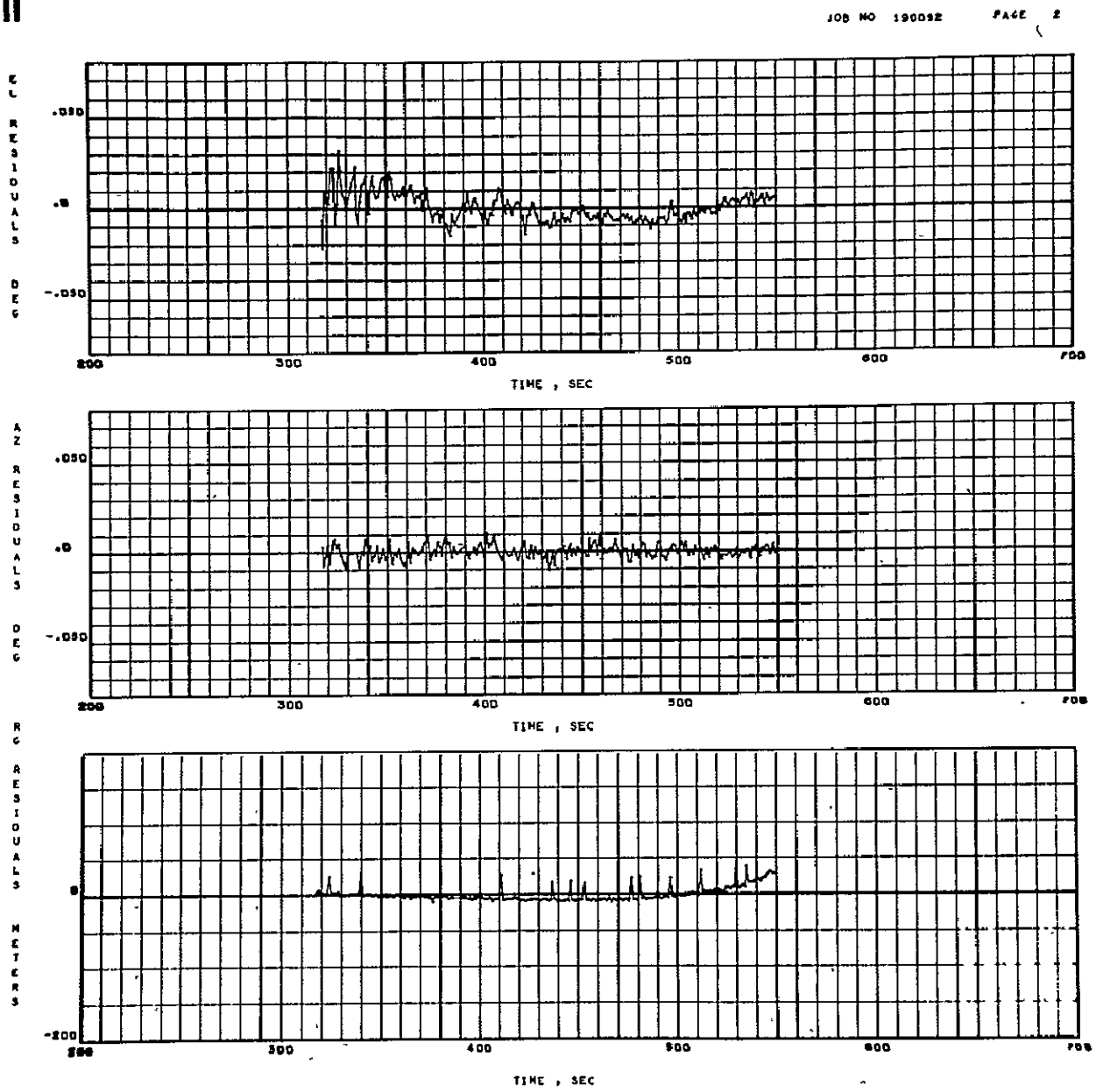

FIGURE A-11. RADAR 67.16 RESIDUALS ON AS-205

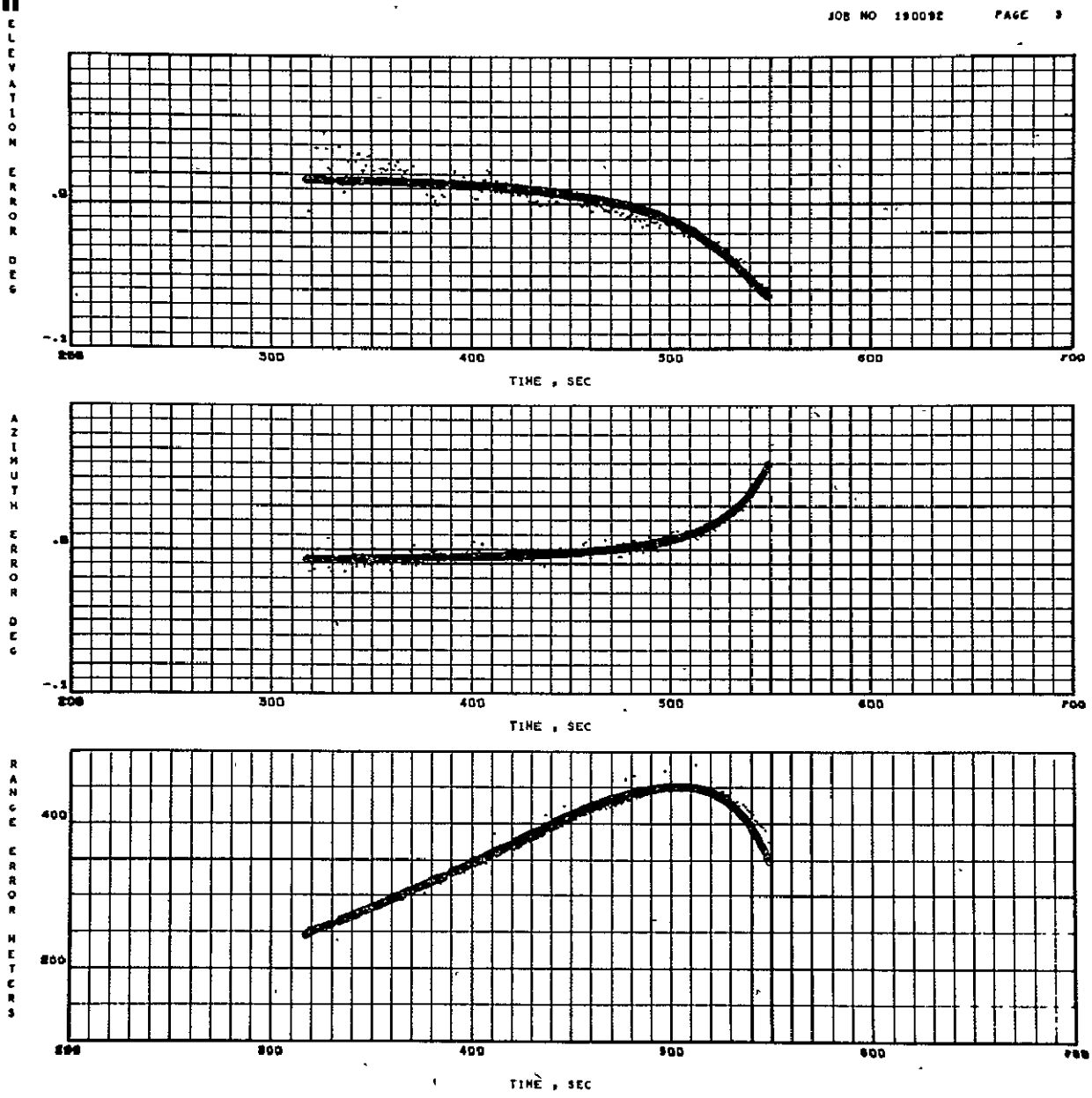

FIGURE A-12. RADAR 67.16 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-205

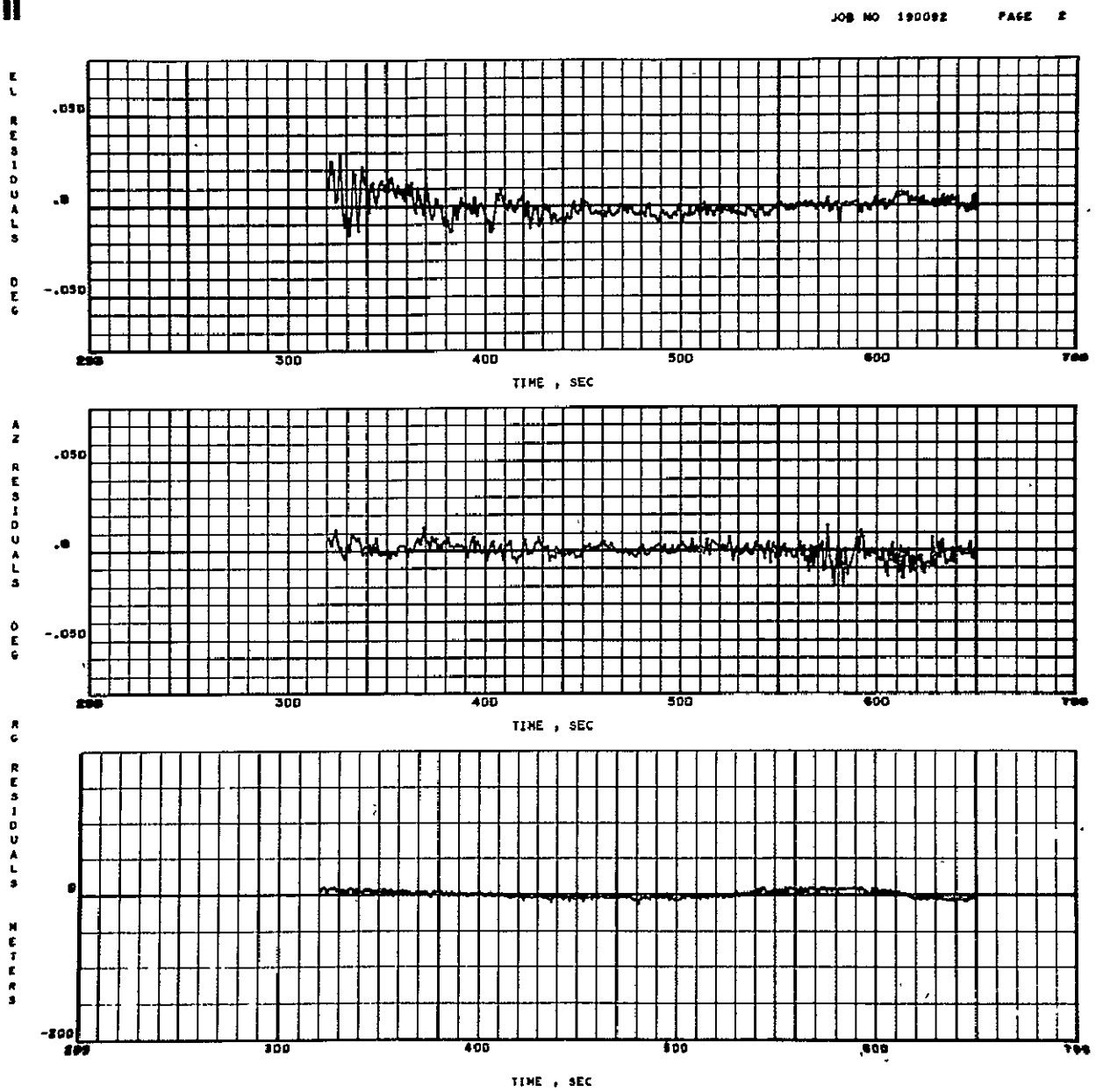

FIGURE A-13. RADAR 67.18 RESIDUALS ON AS-205

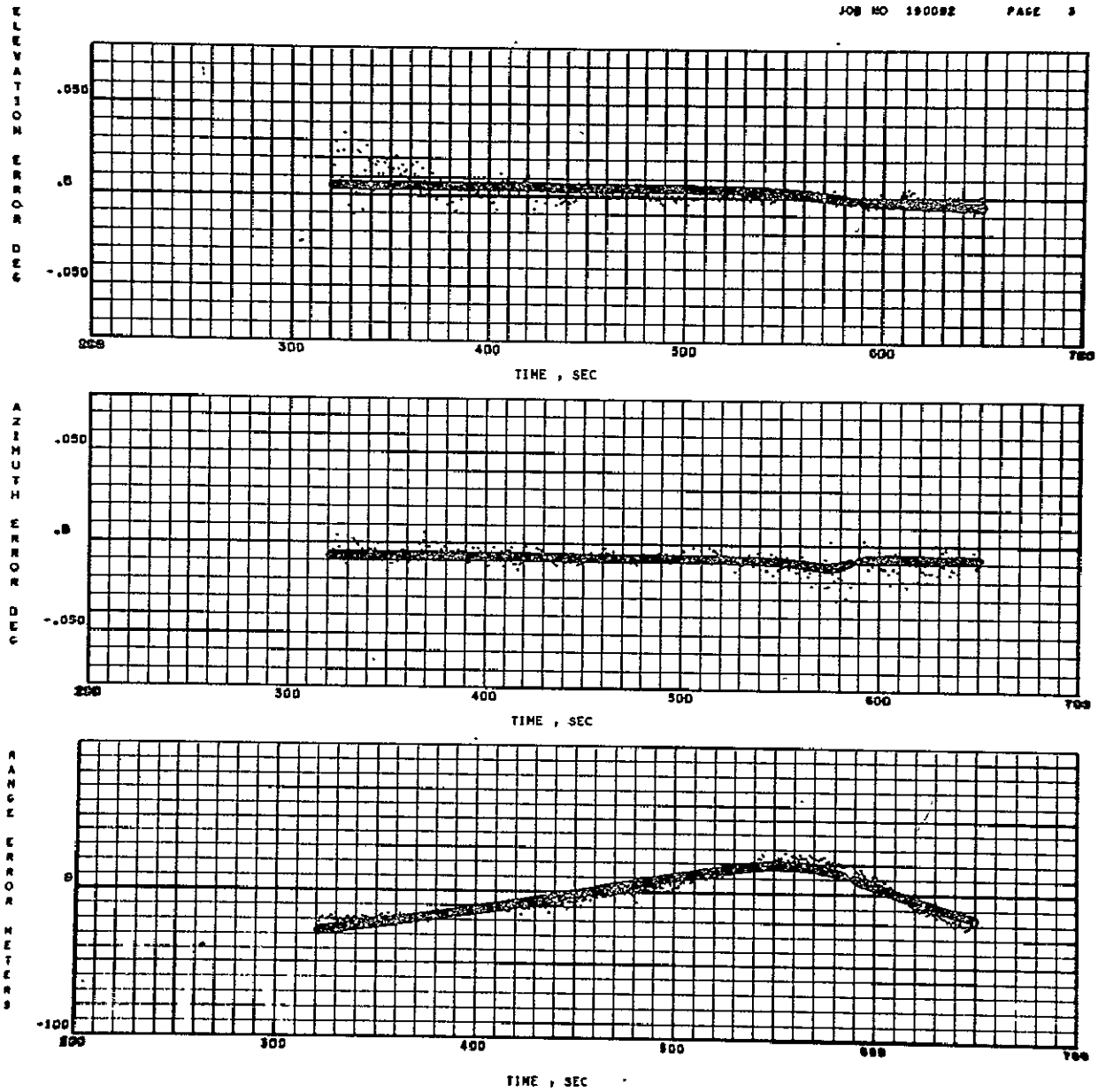

FIGURE A-14. RADAR 67.18 RANGE, AZIMUTH, AND ELEVATION ERRORS ON AS-205

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1. Junkin, Bobby G.: Regression Analysis Procedures for the Evaluation of Tracking System Measurement Errors. NASA TN D-4826, December 1968.

2. Saturn AS-205/CSM-101 Postflight Trajectory. Chrysler Corporation Space Division Report No. TN-AP-68-369, December 1968.

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APPROVAL

THE TEMS APOLLO-SATURN IB TRACKING SYSTEM ERROR MODEL RESULTS THROUGH THE AS-205 FLIGHT TEST

By Bobby G. Junkin

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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

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