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THE INFLUENCE OF TRACKING STATION LOCATION UNCERTAINTIES ON SATELLITE ORBIT ERRORS

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D. W. KOCH

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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By
D. W. Koch

April 5, 1967

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

ABSTRACT

Results of a study to investigate the effect of varying station location uncertainties upon RMS errors in spacecraft position and velocity are presented. RMS errors in the state vector are evaluated for four different sets of earth orbits using five different station location uncertainties. A comparison of the RMS errors in the state vector with and without station location uncertainties is then made. In addition, the effect of different orbital eccentricity, perigee height, and inclination upon RMS errors is studied.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

THE INFLUENCE OF TRACKING STATION LOCATION UNCERTAINTIES ON SATELLITE ORBIT ERRORS

INTRODUCTION

A study is made of the influence of station location uncertainties on RMS errors in the state vector for a representative sample of earth orbits, varying in eccentricity, perigee height, and inclination. It was initiated to estimate how well tracking systems of the GSFC Satellite Tracking and Data Acquisition Network (STADAN) can determine the orbit of a spacecraft. In this study, the RMS errors in the state vector are evaluated at an arbitrarily selected point five hours after epoch. Only measurement noise, measurement bias errors, and station location uncertainties are considered as error sources. The influence of the uncertainty in the earth's gravitational constant μ and the effects of time synchronization errors are neglected. Bias errors are considered but not solved for, resulting in a conservative estimate of the RMS errors in the state vector. Solving for the bias errors would result in an optimistic estimate of the RMS errors in the state vector. Thus, by not solving for the bias errors, a margin of safety is introduced into the results obtained in this study. Values for measurement noise and bias errors are consistent with those found in ANWG Technical Report No. AN-1.1 (Reference 3). A linear error analysis computer program employing a patched conic nominal trajectory and a weighted least squares filter is used.

TEXT

Error analysis studies are made for the following four sets of geocentric orbits. Each set consists of three trajectories with the same eccentricity and perigee height but different inclinations.

SET 1

eccentricity : 0.2
perigee height: 600 km
inclination : 30°, 60°, 90°

SET 2

eccentricity : 0.2
perigee height: 1000 km
inclination : 30°, 60°, 90°

SET 3

eccentricity : 0.8
perigee height: 600 km
inclination : 30°, 60°, 90°

SET 4

eccentricity : 0.8
perigee height: 1000 km
inclination : 30°, 60°, 90°

For each set, a study of RMS errors in the state vector versus station location uncertainties for various inclinations is made. Thus, the mutual influence of station location uncertainties and inclination upon RMS errors in the state vector is evaluated. Comparison between sets indicates the effect upon RMS errors in the state vector of eccentricity, perigee height, and inclination which are varied over the entire range of different station location uncertainties.

The RMS errors in the state vector are evaluated for five different values of total station location uncertainties ranging from 0 to 160 meters. The RMS error in the state vector not incorporating the effect of station location uncertainties is considered the standard for comparison.

Tracking is simulated by five tracking systems of the STADAN network, each system measuring range and range rate. Tracker-vehicle geometry prevents simultaneous tracking by all stations and during a given tracking period usually only one station can track. Tracking coverage for the three trajectories of Set 1 is given in Figure 1. Data from 3 to 3-1/4 hours of tracking are processed during each trajectory. Figures 2 through 9 show the distribution of RMS errors in spacecraft position and velocity versus total station location uncertainties for the trajectories of Sets 1 through 4. Each of the three curves includes the effect of measurement noise and measurement bias errors. No prior knowledge of the state vector at epoch is assumed. The RMS errors in the state vector steadily increase with increasing station location uncertainties regardless of how orbital eccentricity, perigee height, and inclination are varied. This indicates that station location uncertainties are the dominant influence upon RMS errors in the state vector. Tables 1 through 4 present RMS errors in position and velocity versus total station location uncertainties for the first trajectory of Sets 1 through 4.

Inspection of Tables 1 and 2 reveals that RMS errors in spacecraft position and velocity evaluated at a total station location uncertainty of 160 meters are increased by as much as a factor of 26 from the standard.* Comparison of Tables 1 with 2 and 3 with 4 indicates that perigee height has an insignificant effect upon RMS errors in spacecraft position and velocity. It is known (see Reference 2, Chapter 3.0, for the influence of station location uncertainties and bias errors in tracking by the Atlantic Ship) that station location uncertainties and bias errors have a significant effect upon RMS errors in spacecraft position and velocity. An additional investigation (Reference 5) shows the former to have the greater effect after several stations have tracked. Thus, results obtained in this study are consistent with previous investigations.

*The RMS errors in the state vector not incorporating the effect of station location uncertainties.

It is evident that eccentricity has a great effect upon RMS errors in spacecraft position and velocity by comparing Tables 1 with 3 and 2 with 4. Indeed, increases in RMS errors in spacecraft position by a factor of 7 occur for certain values of station location uncertainties. Figures 10 and 11 show RMS errors in spacecraft position and velocity for Trajectory 1 of Sets 1 and 3.

Table 1

RMS Errors vs Total Station Location Uncertainties
for the First Trajectory of Set 1

Total Station Location Uncertainty (m)	RMS Error in Position (m)	RMS Error in Velocity (cm/s)
0	8.94*	0.60*
40	41.1	4.00
80	80.7	8.00
120	120.6	12.00
160	160.6	15.90

Table 2

RMS Errors vs Total Station Location Uncertainties
for the First Trajectory of Set 2

Total Station Location Uncertainty (m)	RMS Error in Position (m)	RMS Error in Velocity (cm/s)
0	8.59*	1.6*
40	56.6	5.5
80	112.3	10.6
120	168.1	15.9
160	224.1	21.1

*Standard for comparison

Table 3

RMS Errors vs Total Station Location Uncertainties
for the First Trajectory of Set 3

Total Station Location Uncertainty (m)	RMS Error in Position (m)	RMS Error in Velocity (cm/s)
0	208.2*	1.00*
40	356.6	2.40
80	619.9	4.50
120	900.2	6.60
160	1,186.2	8.80

Table 4

RMS Errors vs Total Station Location Uncertainties
for the First Trajectory of Set 4

Total Station Location Uncertainty (m)	RMS Error in Position (m)	RMS Error in Velocity (cm/s)
0	213.4*	1.1*
40	377.6	2.6
80	658.7	5.0
120	958.7	7.4
160	1,264.0	9.8

*Standard for comparison

CONCLUSION

Station location uncertainties are the dominant influence upon RMS errors in the state vector regardless of variation in orbital eccentricity, perigee height or inclination during earth orbits. The largest value of total station location uncertainty considered (160 m) increases RMS errors in spacecraft position and velocity by a factor of 26 from the standard* in some instances. The influence of station location uncertainties is especially great during orbits of low eccentricity ($e = 0.2$). Orbital eccentricity increases RMS errors in spacecraft position by factors of 5 to 7 while decreasing RMS errors in spacecraft velocity by a factor of 2. Perigee height and orbital inclination have a negligible effect upon RMS errors in the state vector at low (0.2) or high (0.8) eccentricity.

ACKNOWLEDGMENTS

The author expresses his appreciation to Mrs. A. Marlow, J. L. Cooley, and W. D. Kahn for their assistance in reviewing this report.

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4. Kahn, W. D., "Tracking Studies for Project Apollo," Proceedings of the Apollo Unified S-Band Technical Conference (NASA SP-87), GSFC, July 14-15, 1965, pp. 13-20.

5. Cooley, J. L., "Comparison of the Effects of Station Location Uncertainty and Measurement Bias During One Earth Parking Orbit," GSFC Report (to be published).

*The RMS errors in the state vector not incorporating the effect of station location uncertainties.

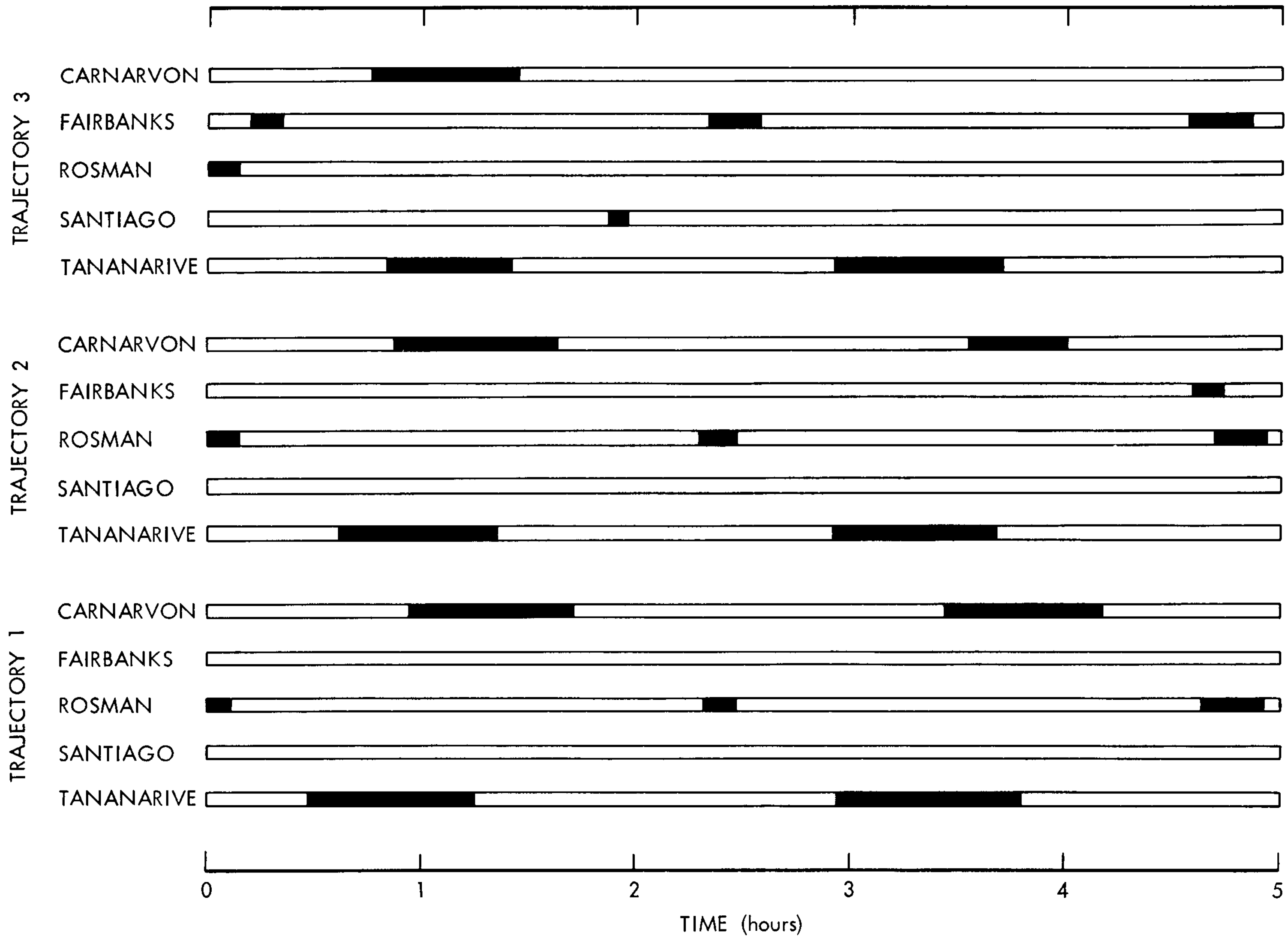

Figure 1. Tracking Coverage for the Three Trajectories of Set 1

ORBITAL PARAMETERS

T = MAY 26, 1966 0^H

	TRAJECTORY 1	TRAJECTORY 2	TRAJECTORY 3	
a	8722.7063	8722.7063	8722.7063	KM.
e	0.2	0.2	0.2	
i	30.0	60.0	90.0	DEG.
Ω	93.15656	145.0111	163.2799	DEG.
ω	72.61479	33.43395	28.5000	DEG.
M	0.0	0.0	0.0	DEG.

HORIZON

$\epsilon \geq 5^{\circ}$

SAMPLING RATE

1 MEAS/6 SEC

TRACKER LOCATIONS

	LATITUDE	LONGITUDE	HT(m)
CARNARVON	-24.897356°	113.716066°	64
FAIRBANKS	64.871830°	-147.836840°	187
ROSMAN	35.200000°	-82.883339°	882
SANTIAGO	-33.149473°	289.330910°	680
TANANARIVE	-19.020152°	47.269833°	1390

TRACKER UNCERTAINTIES

NOISE	BIAS
δ_r = 30 FT	Δ_r = 60 FT
$\delta_{\dot{r}}$ = .02 FT/S	$\Delta_{\dot{r}}$ = .03 FT/S

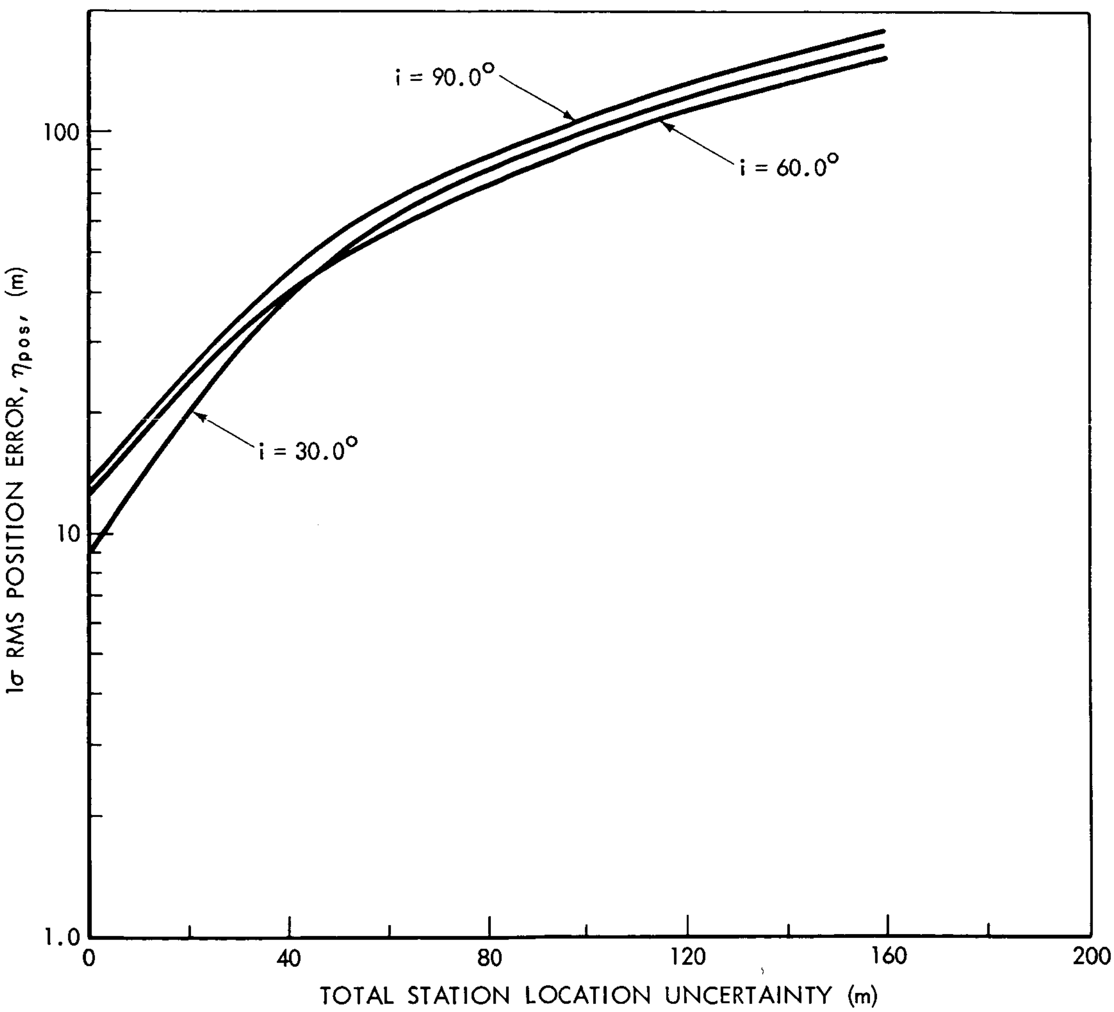

Figure 2. RMS Errors in Position for the Trajectories of Set 1

ORBITAL PARAMETERS

T = MAY 26, 1966 0^H

	TRAJECTORY 1	TRAJECTORY 2	TRAJECTORY 3	
a	8722.7063	8722.7063	8722.7063	KM.
e	0.2	0.2	0.2	
i	30.0	60.0	90.0	DEG.
Ω	93.15656	145.0111	163.2799	DEG.
ω	72.61479	33.43395	28.5000	DEG.
M	0.0	0.0	0.0	DEG.

HORIZON

$\epsilon \geq 5^\circ$

SAMPLING RATE

1 MEAS/6 SEC

TRACKER LOCATIONS

	LATITUDE	LONGITUDE	HT(m)
CARNARVON	-24.897356°	113.716066°	64
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ROSMAN	35.200000°	- 82.883339°	882
SANTIAGO	-33.149473°	289.330910°	680
TANANARIVE	-19.020152°	47.269833°	1390

TRACKER UNCERTAINTIES

NOISE	BIAS
δ_r = 30 FT	Δ_r = 60 FT
$\delta_{\dot{r}}$ = .02 FT/S	$\Delta_{\dot{r}}$ = .03 FT/S

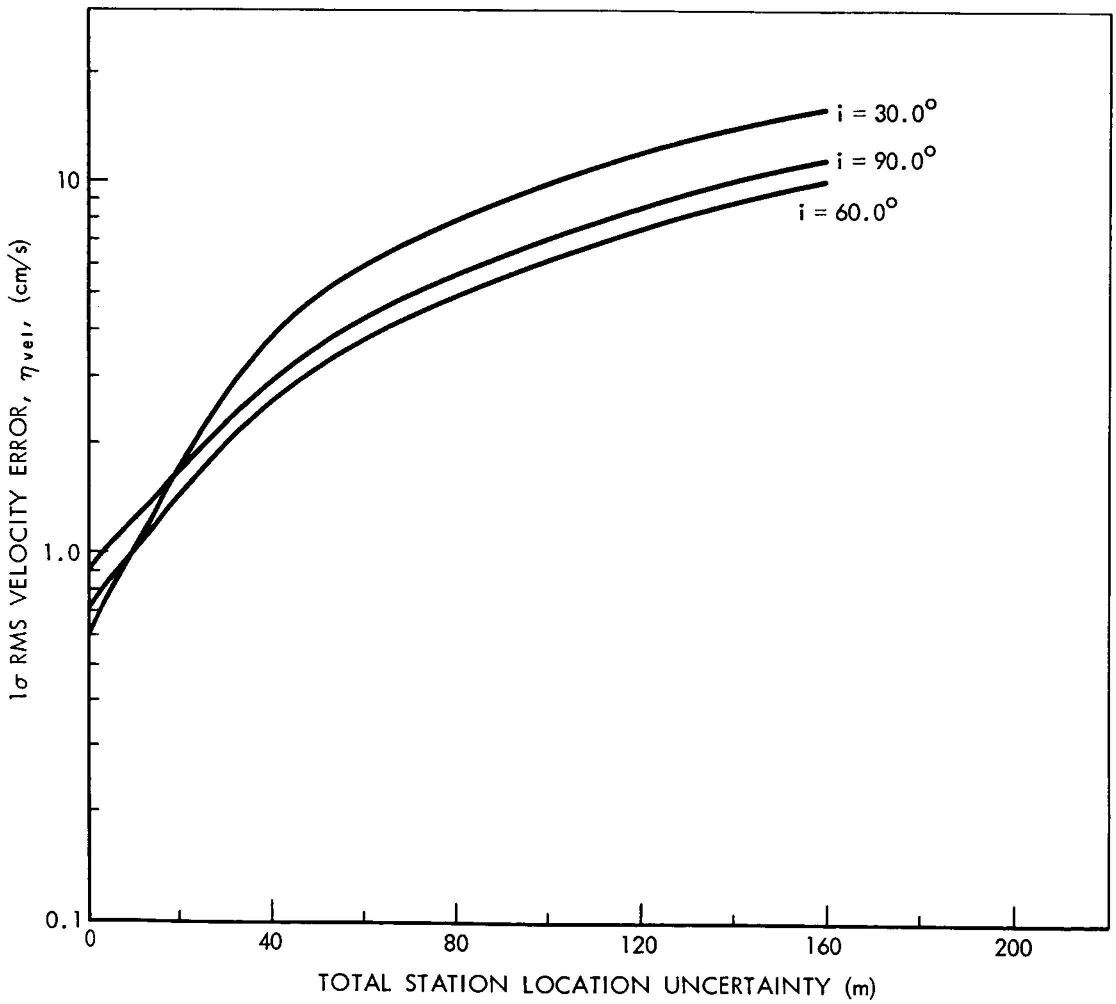

Figure 3. RMS Errors in Velocity for the Trajectories of Set 1

ORBITAL PARAMETERS

T = MAY 26, 1966 0^H

	TRAJECTORY 1	TRAJECTORY 2	TRAJECTORY 3	
a	9222.7063	9222.7063	9222.7063	KM.
e	0.2	0.2	0.2	
i	30.0	60.0	90.0	DEG.
Ω	93.15656	145.0111	163.2799	DEG.
ω	72.61479	33.43395	28.5000	DEG.
M	0.0	0.0	0.0	DEG.

HORIZON

$\epsilon \geq 5^\circ$

SAMPLING RATE

1 MEAS/6 SEC

TRACKER LOCATIONS

	LATITUDE	LONGITUDE	HT(m)
CARNARVON	-24.897356°	113.716066°	64
FAIRBANKS	64.871830°	-147.836840°	187
ROSMAN	35.200000°	-82.883339°	882
SANTIAGO	-33.149473°	289.330910°	680
TANANARIVE	-19.020152°	47.269833°	1390

TRACKER UNCERTAINTIES

NOISE	BIAS
δ_r = 30 FT	Δ_r = 60 FT
$\delta_{\dot{r}}$ = .02 FT/S	$\Delta_{\dot{r}}$ = .03 FT/S

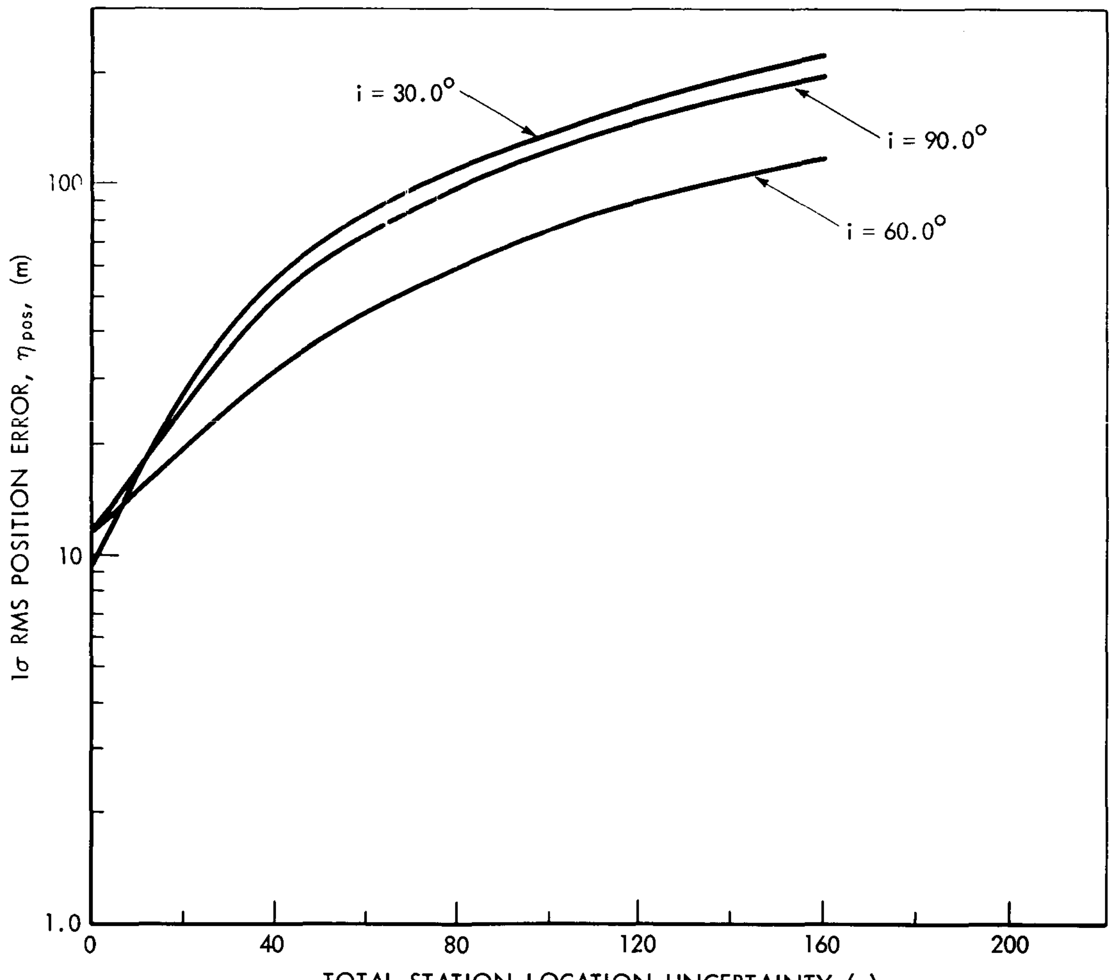

Figure 4. RMS Errors in Position for the Trajectories of Set 2

ORBITAL PARAMETERS

T = MAY 26, 1966 0^H

	TRAJECTORY 1	TRAJECTORY 2	TRAJECTORY 3	
a	9222.7063	9222.7063	9222.7063	KM.
e	0.2	0.2	0.2	
i	30.0	60.0	90.0	DEG.
Ω	93.15656	145.0111	163.2799	DEG.
ω	72.61479	33.43395	28.5000	DEG.
M	0.0	0.0	0.0	DEG.

HORIZON

$\epsilon \geq 5^\circ$

SAMPLING RATE

1 MEAS/6 SEC

TRACKER LOCATIONS

	LATITUDE	LONGITUDE	HT(m)
CARNARVON	-24.897356°	113.716066°	64
FAIRBANKS	64.871830°	-147.836840°	187
ROSMAN	35.200000°	- 82.883339°	882
SANTIAGO	-33.149473°	289.330910°	680
TANANARIVE	-19.020152°	47.269833°	1390

TRACKER UNCERTAINTIES

NOISE	BIAS
δ_r = 30 FT	Δ_r = 60 FT
$\delta_{\dot{r}}$ = .02 FT/S	$\Delta_{\dot{r}}$ = .03 FT/S

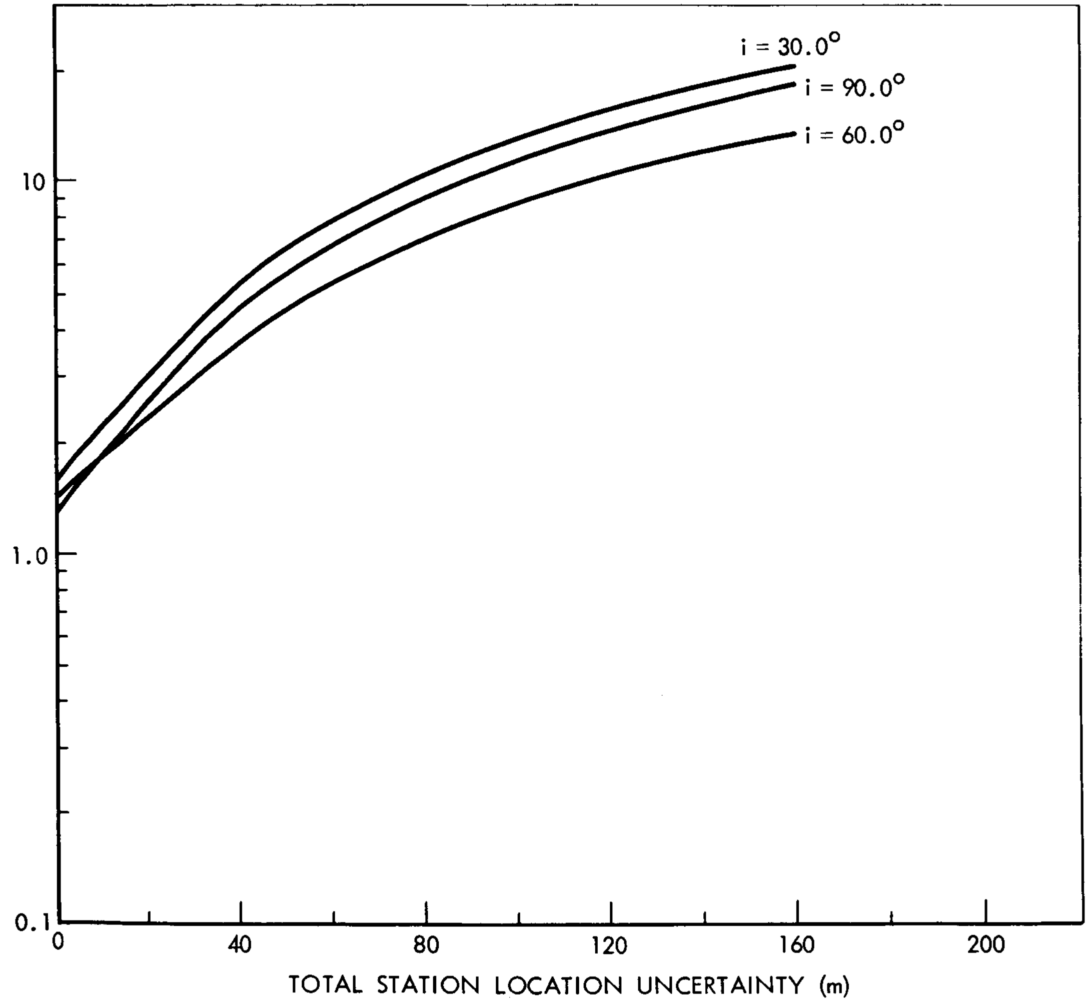

Figure 5. RMS Errors in Velocity for the Trajectories of Set 2

ORBITAL PARAMETERS

T = MAY 26, 1966 0^H

	TRAJECTORY 1	TRAJECTORY 2	TRAJECTORY 3	
a	34890.825	34890.825	34890.825	KM.
e	0.8	0.8	0.8	
i	30.0	60.0	90.0	DEG.
Ω	93.15656	145.0111	163.2799	DEG.
ω	72.61479	33.43395	28.5000	DEG.
M	0.0	0.0	0.0	DEG.

HORIZON

$\epsilon \geq 5^\circ$

SAMPLING RATE

1 MEAS/6 SEC

TRACKER LOCATIONS

	LATITUDE	LONGITUDE	HT(m)
CARNARVON	-24.897356°	113.716066°	64
FAIRBANKS	64.871830°	-147.836840°	187
ROSMAN	35.200000°	- 82.883339°	882
SANTIAGO	-33.149473°	289.330910°	680
TANANARIVE	-19.020152°	47.269833°	1390

TRACKER UNCERTAINTIES

NOISE	BIAS
δ_r = 30 FT	Δ_r = 60 FT
$\delta_{\dot{r}}$ = .02 FT/S	$\Delta_{\dot{r}}$ = .03 FT/S

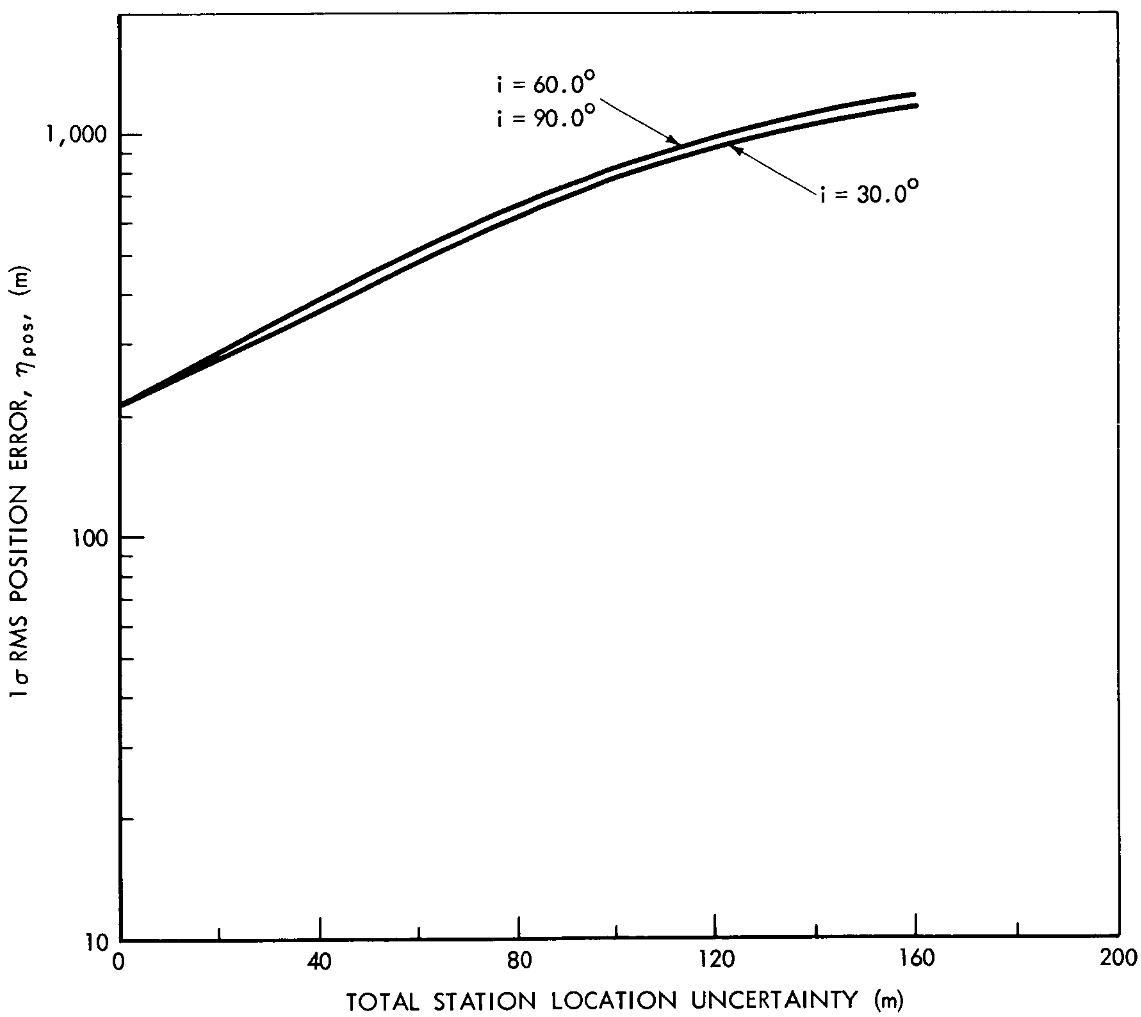

Figure 6. RMS Errors in Position for the Trajectories of Set 3

ORBITAL PARAMETERS

T = MAY 26, 1966 0^H

	TRAJECTORY 1	TRAJECTORY 2	TRAJECTORY 3	
a	34890.825	34890.825	34890.825	KM.
e	0.8	0.8	0.8	
i	30.0	60.0	90.0	DEG.
Ω	93.15656	145.0111	163.2799	DEG.
ω	72.61479	33.43395	28.5000	DEG.
M	0.0	0.0	0.0	DEG.

HORIZON

$\epsilon \geq 5^\circ$

SAMPLING RATE

1 MEAS/6 SEC

TRACKER LOCATIONS

	LATITUDE	LONGITUDE	HT(m)
CARNARVON	-24.897356°	113.716066°	64
FAIRBANKS	64.871830°	-147.836840°	187
ROSMAN	35.200000°	- 82.883339°	882
SANTIAGO	-33.149473°	289.330910°	680
TANANARIVE	-19.020152°	47.269833°	1390

TRACKER UNCERTAINTIES

NOISE	BIAS
δ_r = 30 FT	Δ_r = 60 FT
$\delta_{\dot{r}}$ = .02 FT/S	$\Delta_{\dot{r}}$ = .03 FT/S

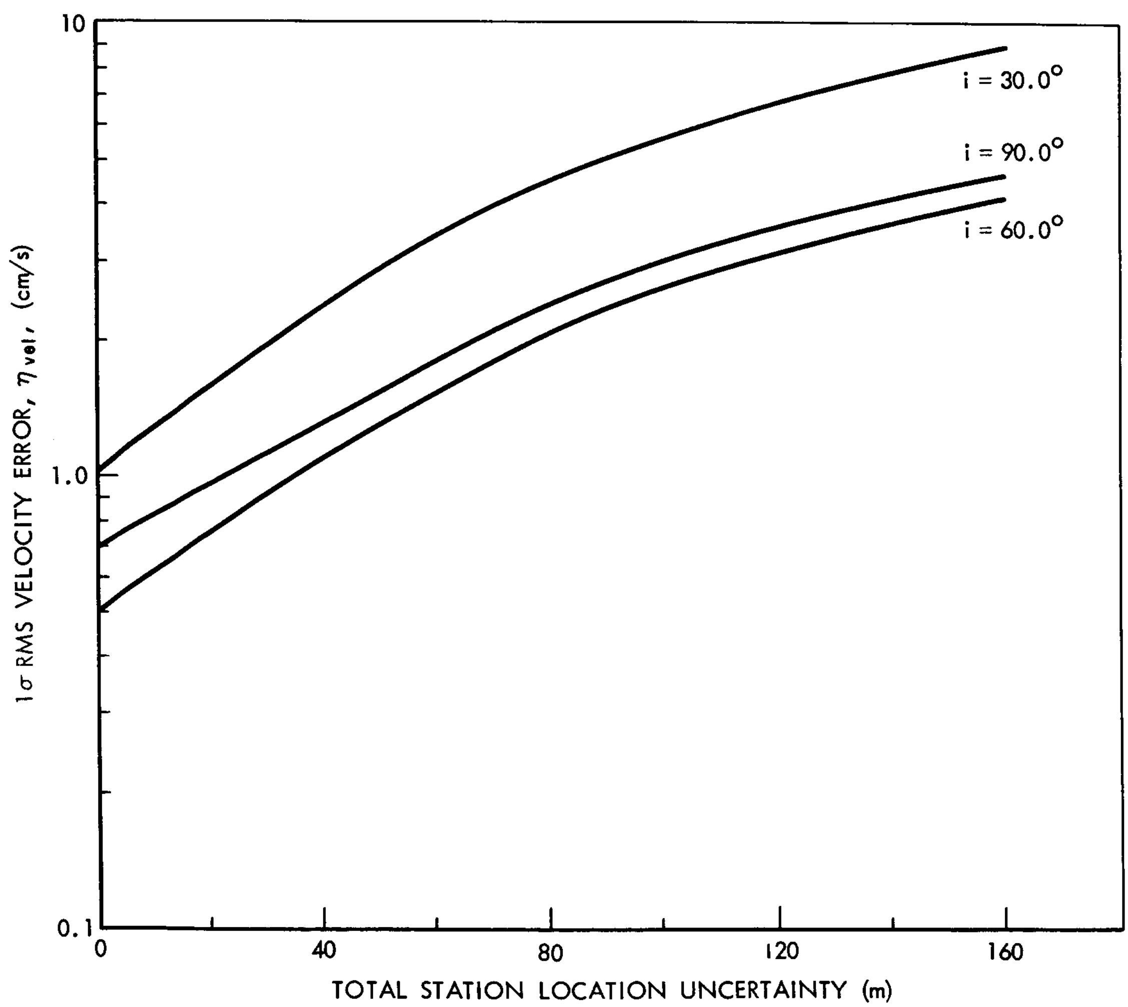

Figure 7. RMS Errors in Velocity for the Trajectories of Set 3

ORBITAL PARAMETERS

T = MAY 26, 1966 0^H

	TRAJECTORY 1	TRAJECTORY 2	TRAJECTORY 3	
a	36890.82	36890.82	36890.82	KM.
e	0.8	0.8	0.8	
i	30.0	60.0	90.0	DEG.
Ω	93.15656	145.0111	163.2799	DEG.
ω	72.61479	33.43395	28.5000	DEG.
M	0.0	0.0	0.0	DEG.

HORIZON

$\epsilon \geq 5^\circ$

SAMPLING RATE

1 MEAS/6 SEC

TRACKER LOCATIONS

	LATITUDE	LONGITUDE	HT(m)
CARNARVON	-24.897356°	113.716066°	64
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ROSMAN	35.200000°	- 82.883339°	882
SANTIAGO	-33.149473°	289.330910°	680
TANANARIVE	-19.020152°	47.269833°	1390

TRACKER UNCERTAINTIES

NOISE	BIAS
δ_r = 30 FT	Δ_r = 60 FT
$\delta_{\dot{r}}$ = .02 FT/S	$\Delta_{\dot{r}}$ = .03 FT/S

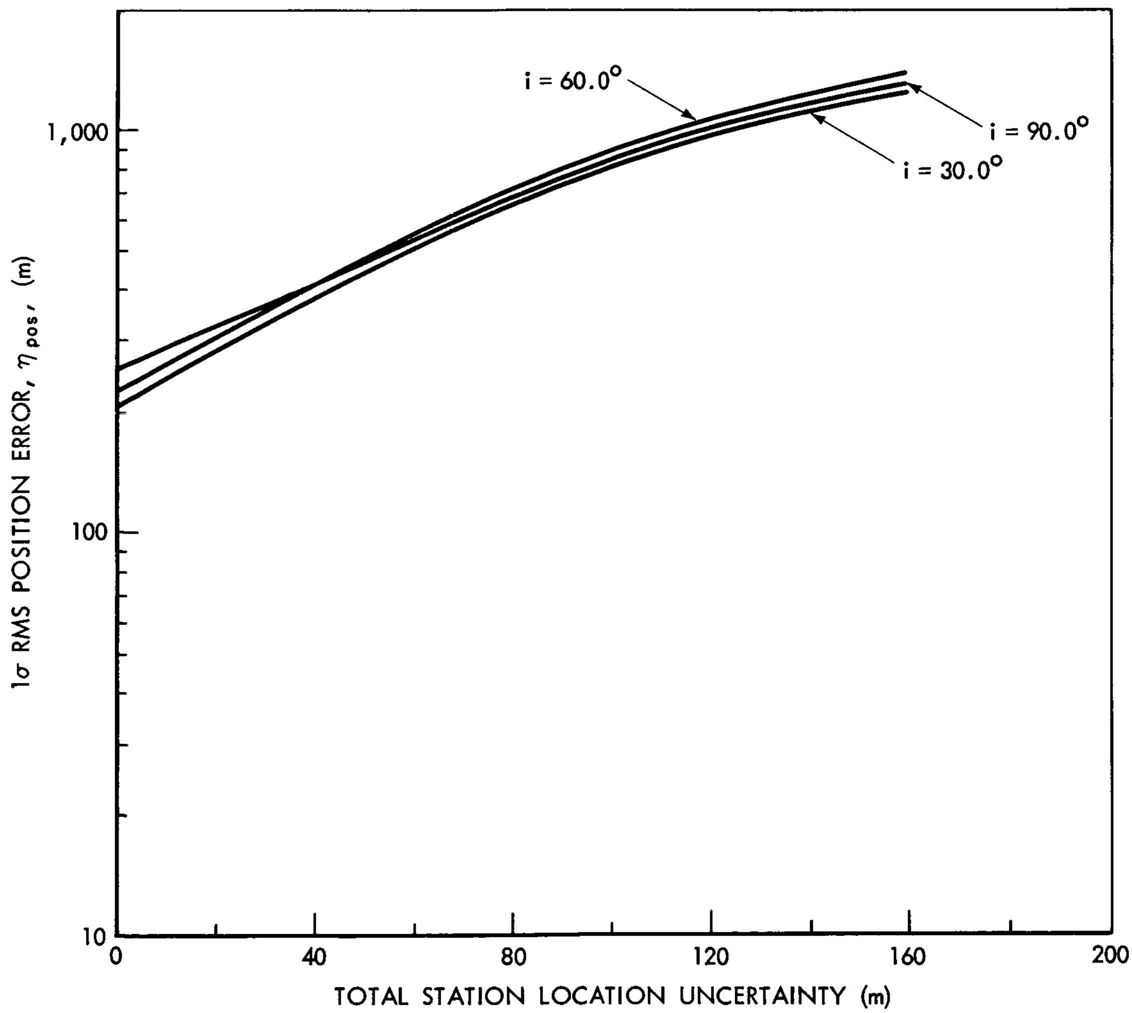

Figure 8. RMS Errors in Position for the Trajectories of Set 4

ORBITAL PARAMETERS

T = MAY 26, 1966 0^H

	TRAJECTORY 1	TRAJECTORY 2	TRAJECTORY 3	
a	36890.82	36890.82	36890.82	KM.
e	0.8	0.8	0.8	
i	30.0	60.0	90.0	DEG.
Ω	93.15656	145.0111	163.2799	DEG.
ω	72.61479	33.43395	28.5000	DEG.
M	0.0	0.0	0.0	DEG.

HORIZON

$\epsilon \geq 5^{\circ}$

SAMPLING RATE

1 MEAS/6 SEC

TRACKER LOCATIONS

	LATITUDE	LONGITUDE	HT(m)
CARNARVON	-24.897356°	113.716066°	64
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TANANARIVE	-19.020152°	47.269833°	1390

TRACKER UNCERTAINTIES

NOISE	BIAS
δ_r = 30 FT	Δ_r = 60 FT
$\delta_{\dot{r}}$ = .02 FT/S	$\Delta_{\dot{r}}$ = .03 FT/S

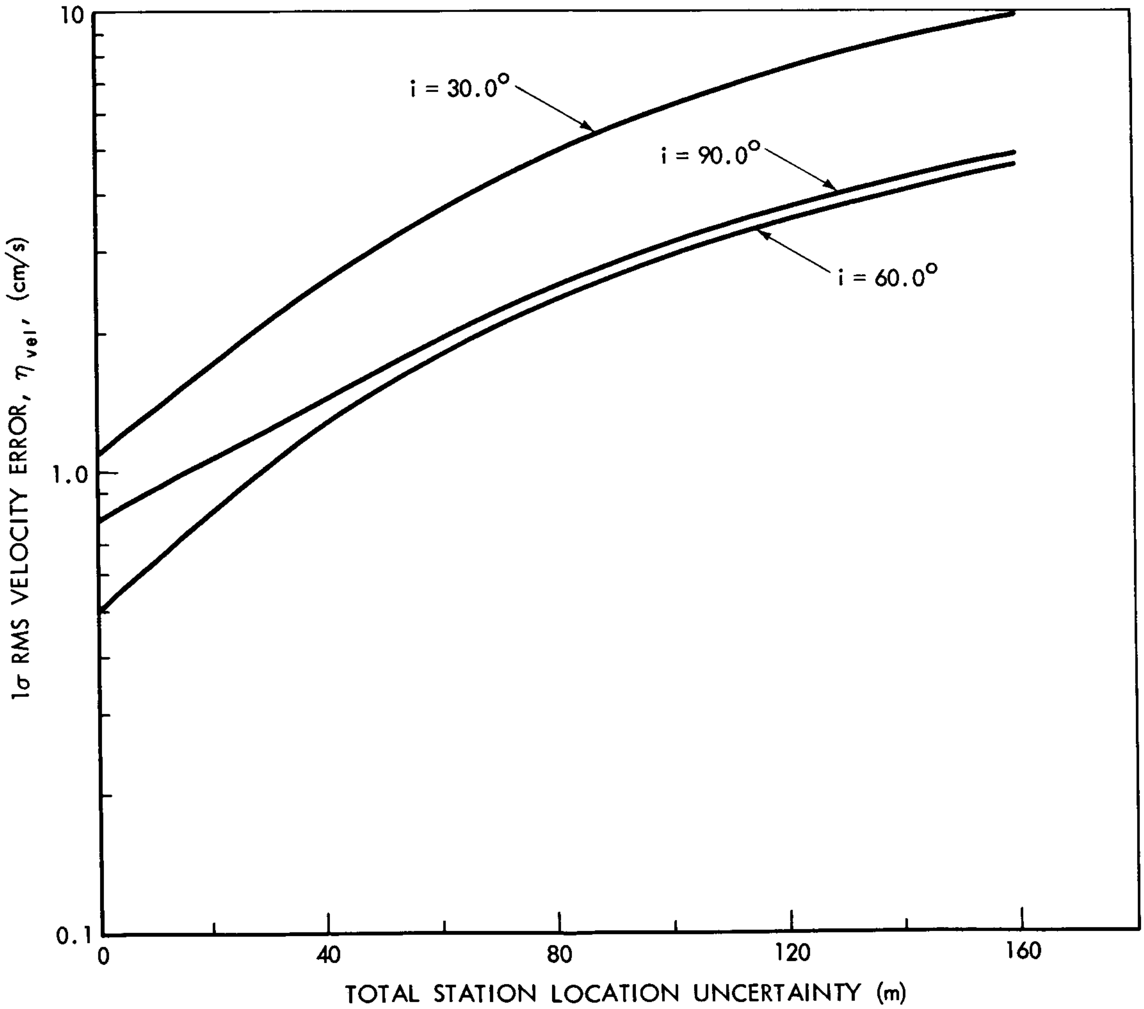

Figure 9. RMS Errors in Velocity for the Trajectories of Set 4

ORBITAL PARAMETERS

T = MAY 26, 1966 0^H

	TRAJECTORY 1 OF SET 1	TRAJECTORY 1 OF SET 3	
a	8722.7063	34890.825	KM.
e	0.2	0.8	
i	30.0	30.0	DEG.
Ω	93.15656	93.15656	DEG.
ω	72.61479	72.61479	DEG.
M	0.0	0.0	DEG.

HORIZON

$\epsilon \geq 5^\circ$

SAMPLING RATE

1 MEAS/6 SEC

TRACKER LOCATIONS

	LATITUDE	LONGITUDE	HT(m)
CARNARVON	-24.897356°	113.716066°	64
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SANTIAGO	-33.149473°	289.330910°	680
TANANARIVE	-19.020152°	47.269833°	1390

TRACKER UNCERTAINTIES

NOISE	BIAS
δ_r = 30 FT	Δ_r = 60 FT
$\delta_{\dot r}$ = .02 FT/S	$\Delta_{\dot r}$ = .03 FT/S

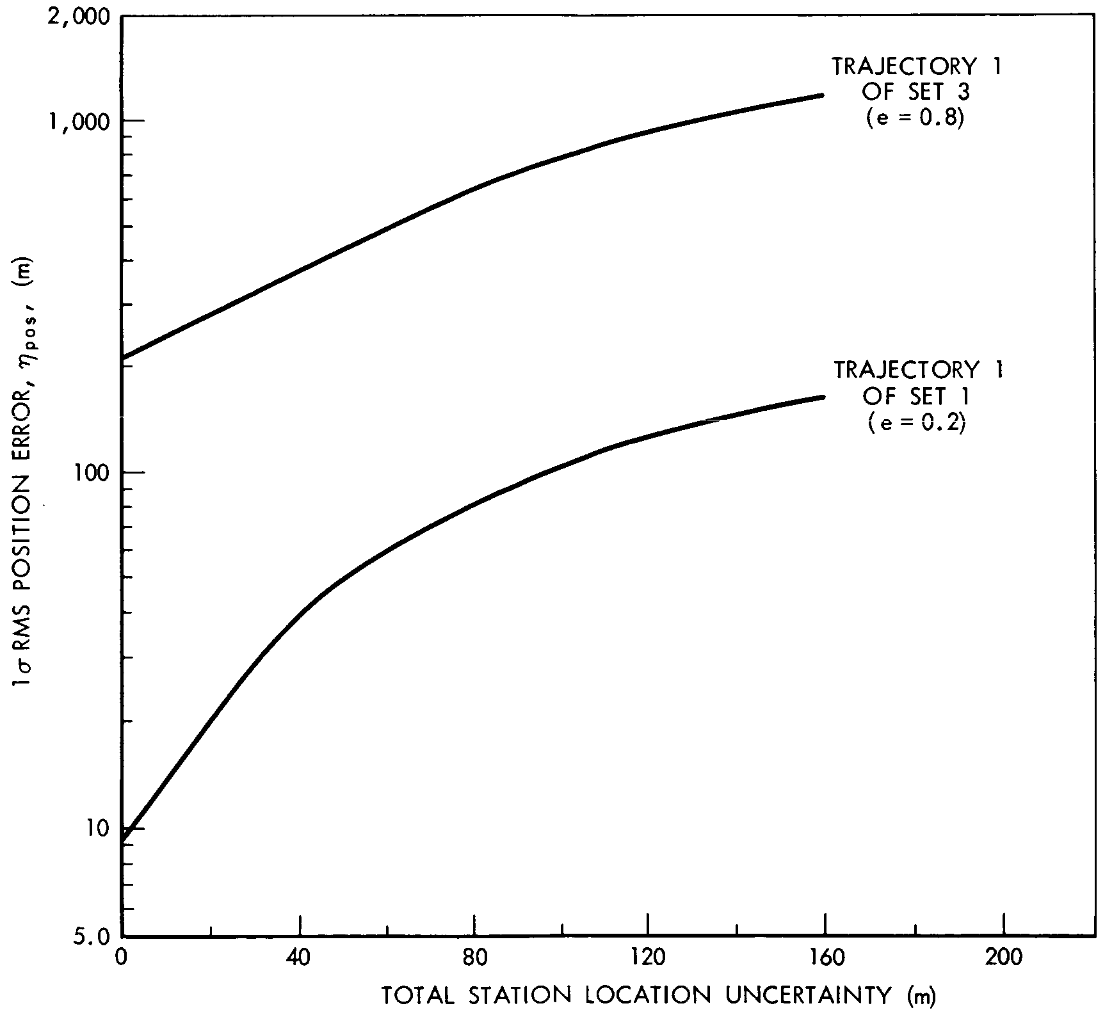

Figure 10. RMS Errors in Position for Trajectory 1 of Sets 1 and 3

ORBITAL PARAMETERS

T = MAY 26, 1966 0^H

	TRAJECTORY 1 OF SET 1	TRAJECTORY 1 OF SET 3	
a	8722.7063	34890.825	KM.
e	0.2	0.8	
i	30.0	30.0	DEG.
Ω	93.15656	93.15656	DEG.
ω	72.61479	72.61479	DEG.
M	0.0	0.0	DEG.

HORIZON

$\epsilon \geq 5^{\circ}$

SAMPLING RATE

1 MEAS/6 SEC

TRACKER LOCATIONS

	LATITUDE	LONGITUDE	HT(m)
CARNARVON	-24.897356°	113.716066°	64
FAIRBANKS	64.871830°	-147.836840°	187
ROSMAN	35.200000°	- 82.883339°	882
SANTIAGO	-33.149473°	289.330910°	680
TANANARIVE	-19.020152°	47.269833°	1390

TRACKER UNCERTAINTIES

NOISE	BIAS
δ_r = 30 FT	Δ_r = 60 FT
$\delta_{\dot r}$ = .02 FT/S	$\Delta_{\dot r}$ = .03 FT/S

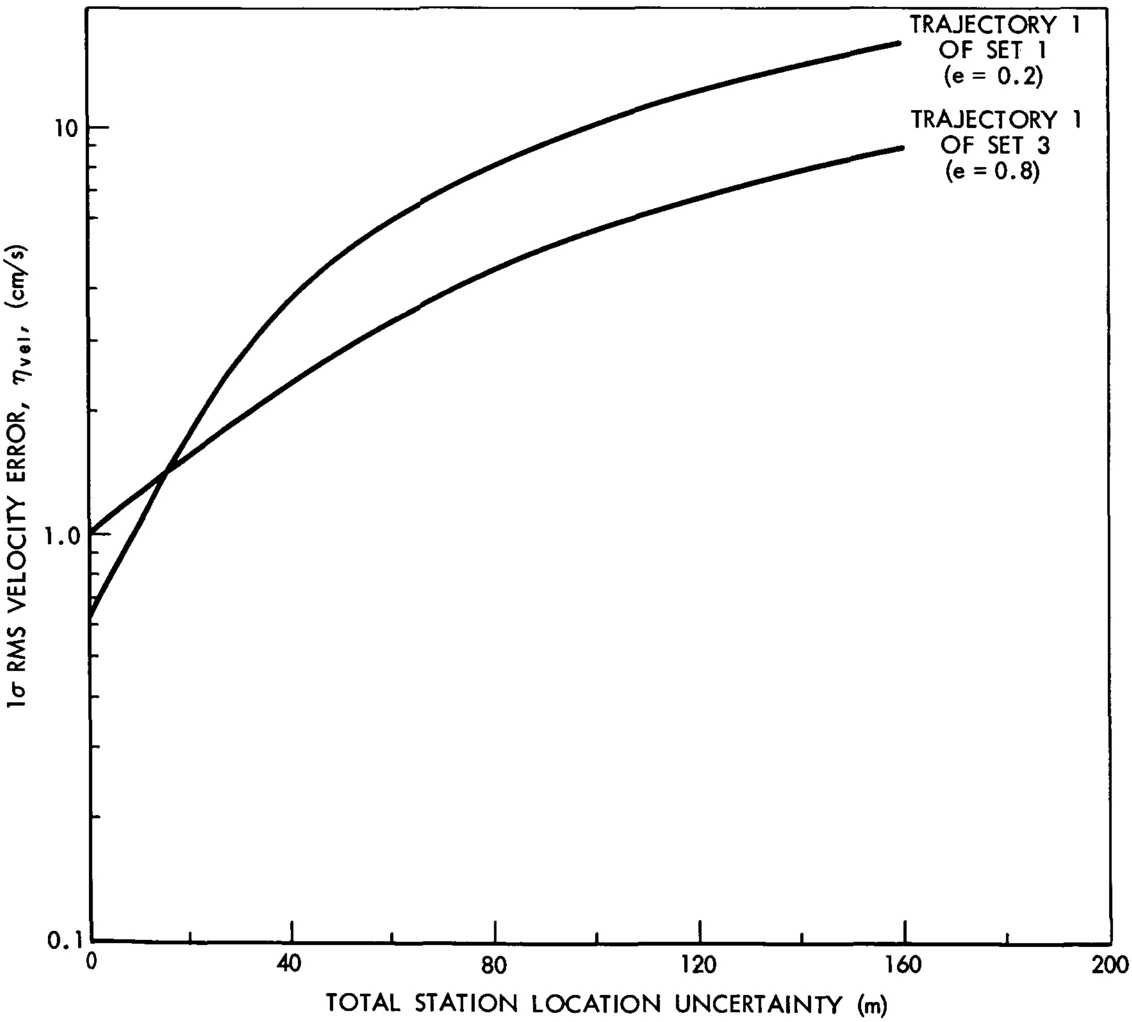

Figure 11. RMS Errors in Velocity for Trajectory 1 of Sets 1 and 3