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INTERPLANETARY NAVIGATION AND GUIDANCE STUDY VOLUME III: ILLUSTRATIONS AND TABLES

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INTERPLANETARY NAVIGATION AND GUIDANCE STUDY

VOLUME III: ILLUSTRATIONS AND TABLES

(Report Dated-October 30, 1965)

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Astrionics Laboratory

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NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

FOREWORD

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SECTION 1

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SECTION 2

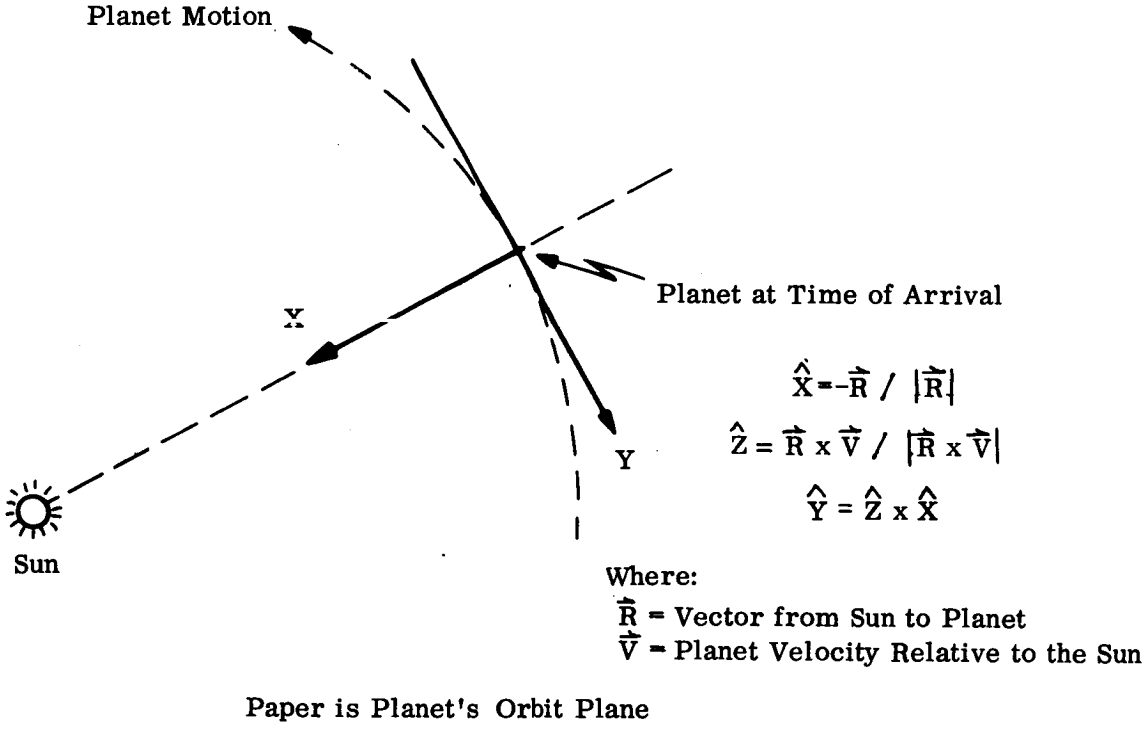


Figure 2-1 Target Coordinates

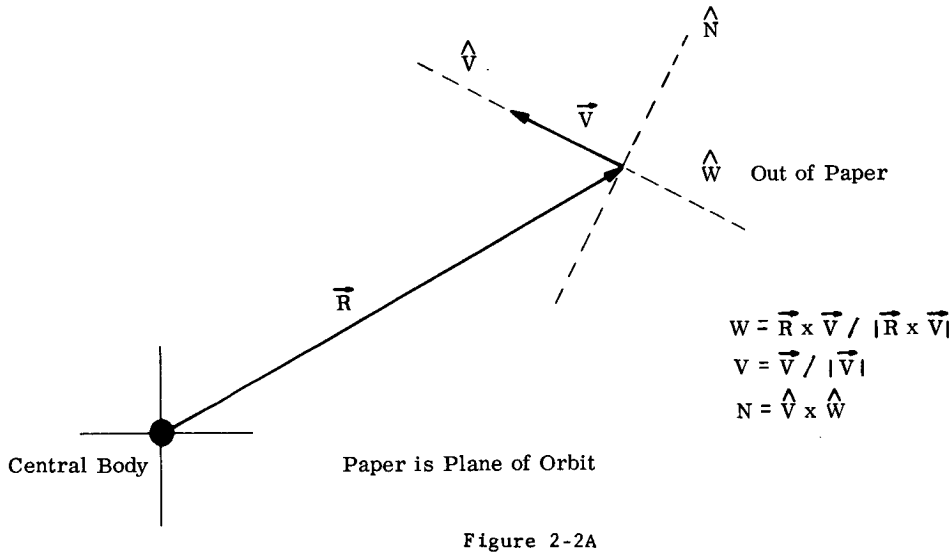


Figure 2-2A

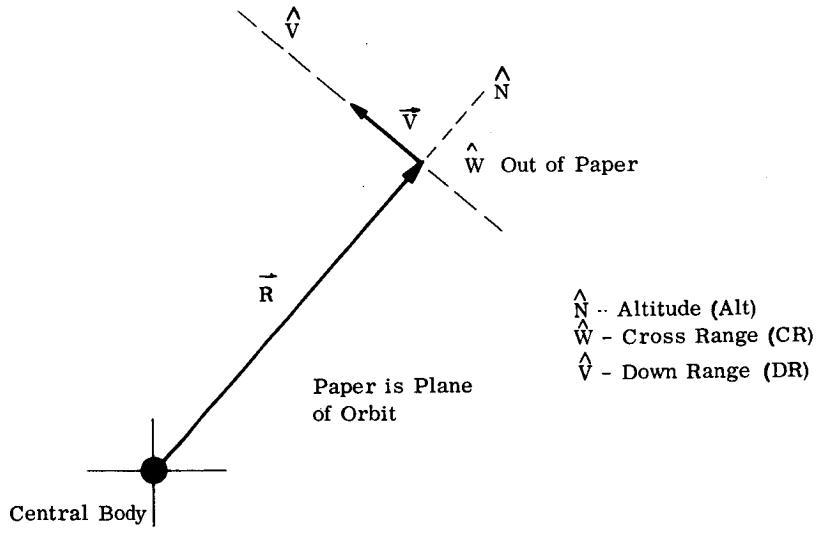


Figure 2-2B

Figure 2-2 General N,V,W Coordinates

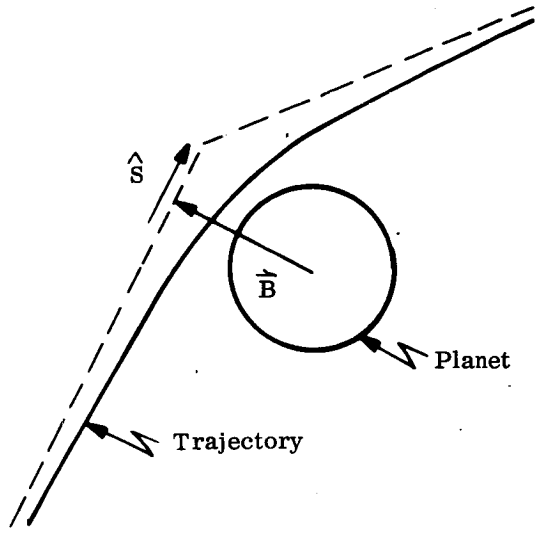


Figure 2-3A

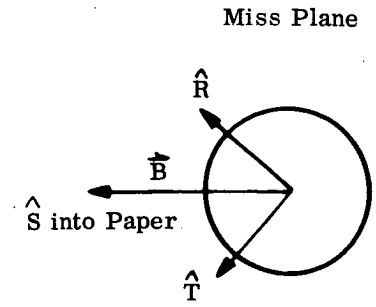


Figure 2-3B

Figure 2-3 B Vector Coordinates

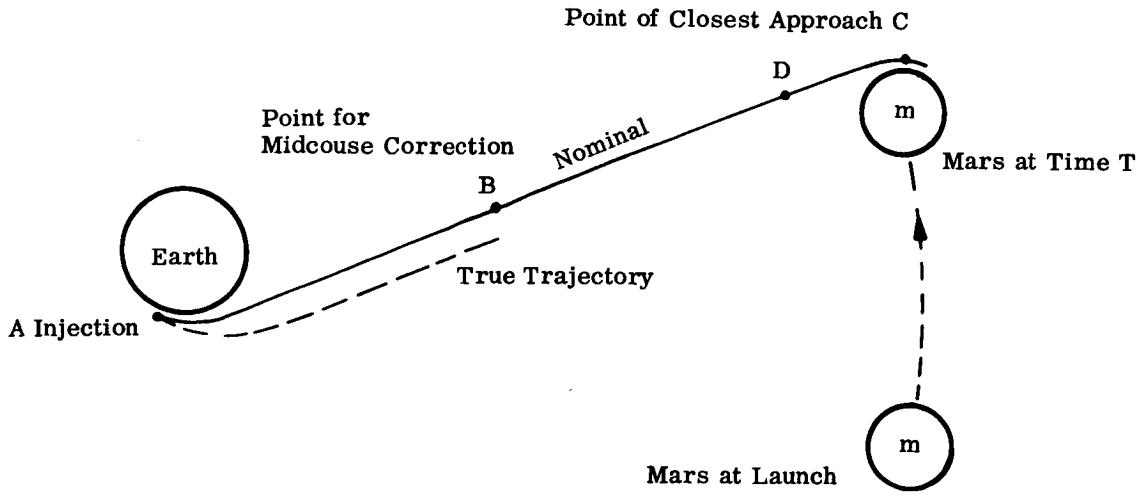
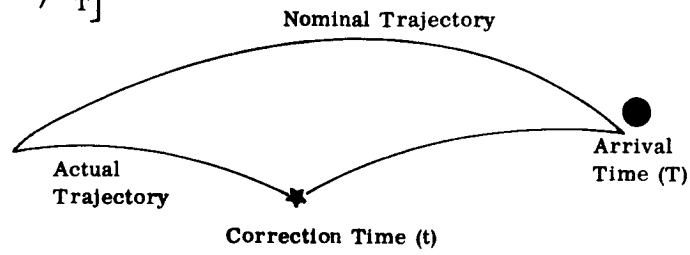


Figure 2-4

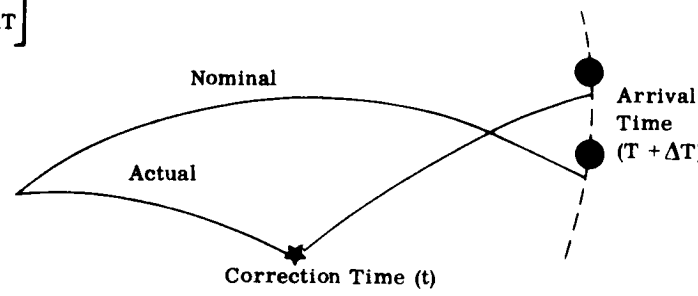
Fixed Time of Arrival (FTA)

$$\left[\dot{X}g\,(t) = -D_2^{-1}\begin{pmatrix}\Delta x\\ \Delta y\\ \Delta z\end{pmatrix}_T\right]$$



Variable Time of Arrival (VTA)
Velocity Relative to Target Constraint

$$\left[\dot{X}g\,(t) = -D_2^{-1}\begin{pmatrix}\Delta B\bullet T\\ \Delta B\bullet R\\ \Delta V_\infty\end{pmatrix}_{T+\Delta T}\right]$$



Variable Time of Arrival (VTA)
Minimize ΔV Constraint

$$\left[\dot{X}g\,(t) = -D_2^{-1}\begin{pmatrix}\Delta B\bullet T\\ \Delta B\bullet R\\ \Delta M\end{pmatrix}_{T+\Delta T}\right]$$

ΔM Selected to Minimize ΔV Required

$\dot{X}g$ = Guidance Correction

D_2 = Matrix of Sensitivities Relating Constraints at (T) to Velocity Changes at (t).

Figure 2-5 Guidance Laws

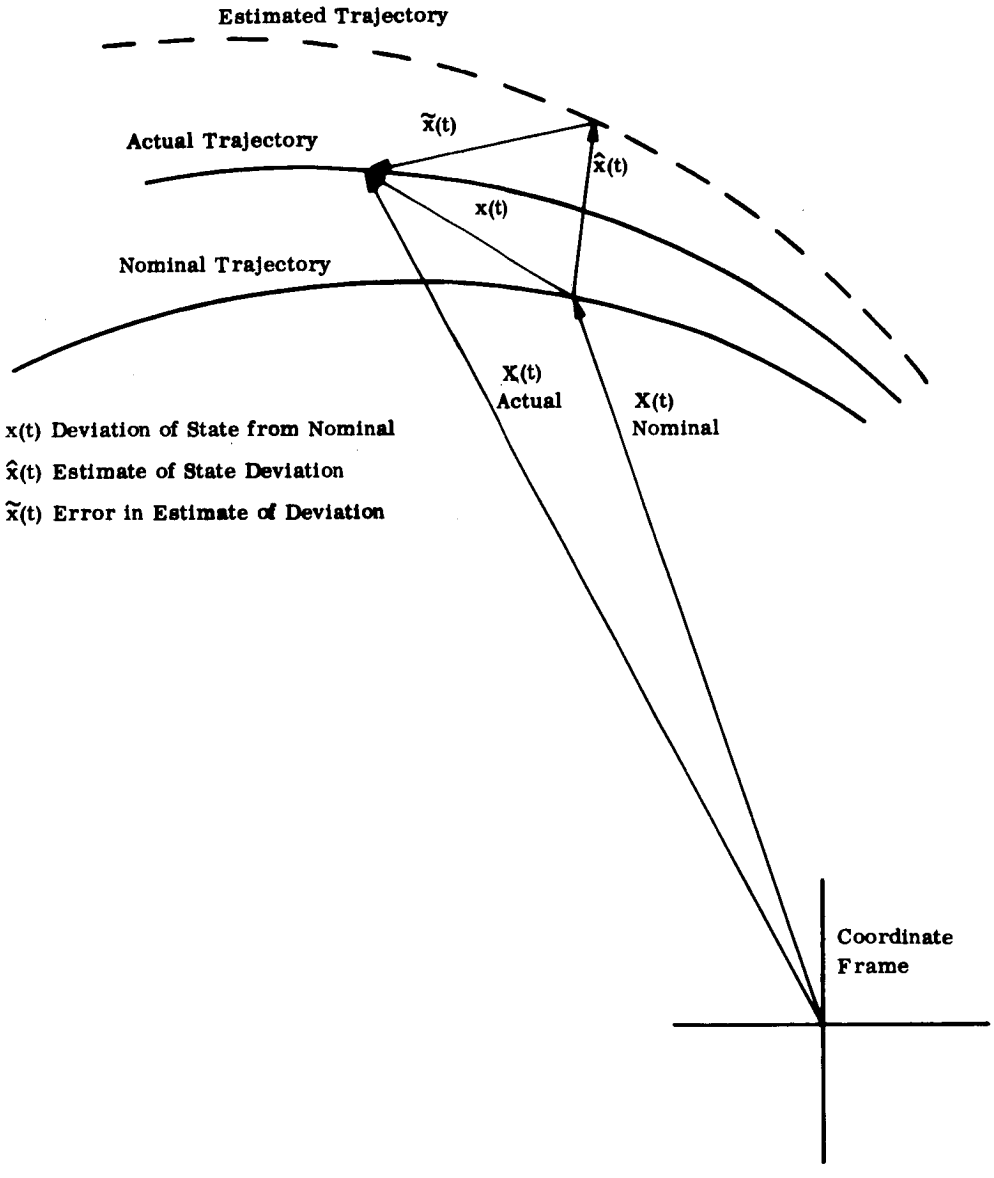


Figure 2-6 State Deviations

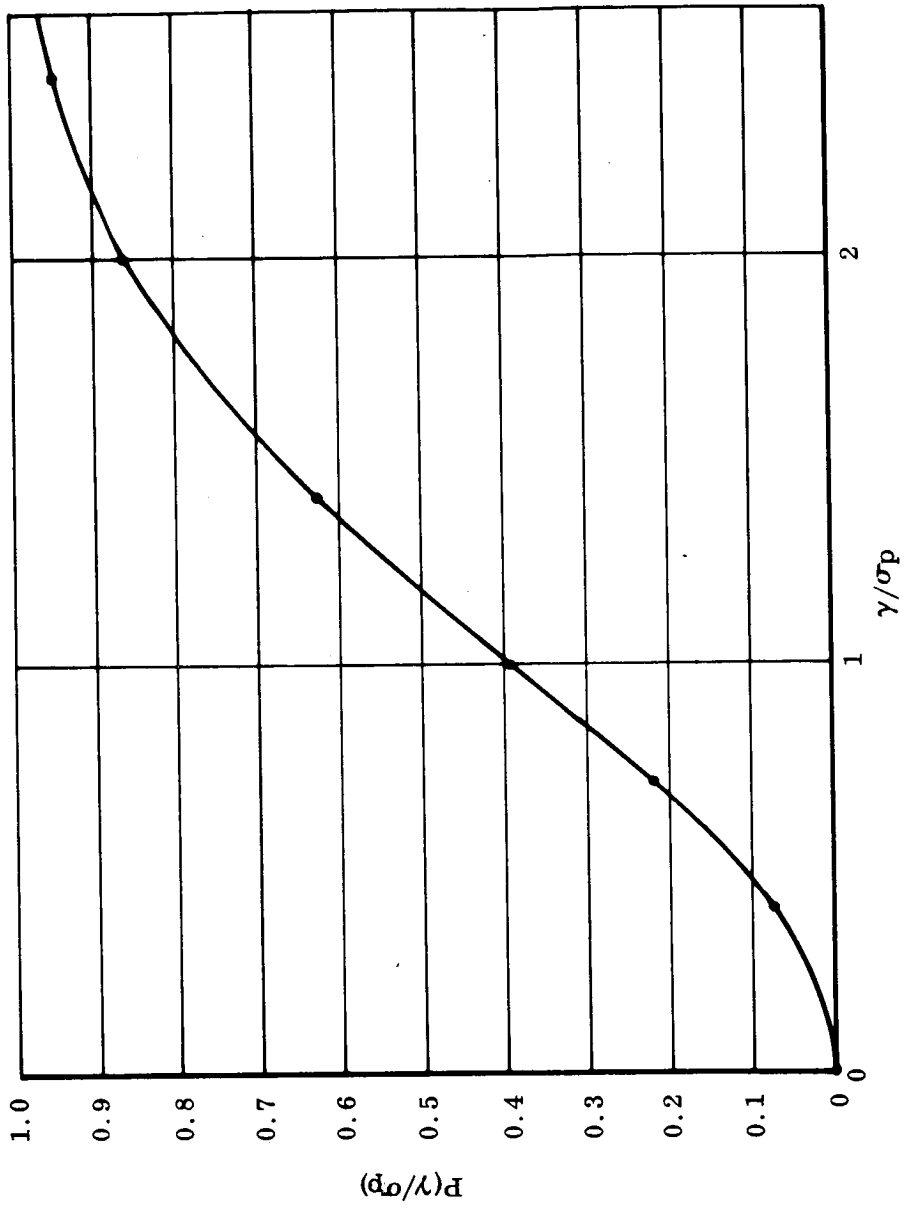


Figure 2-7 Probability Distribution Function for the Half-Cone Angle

SECTION 3

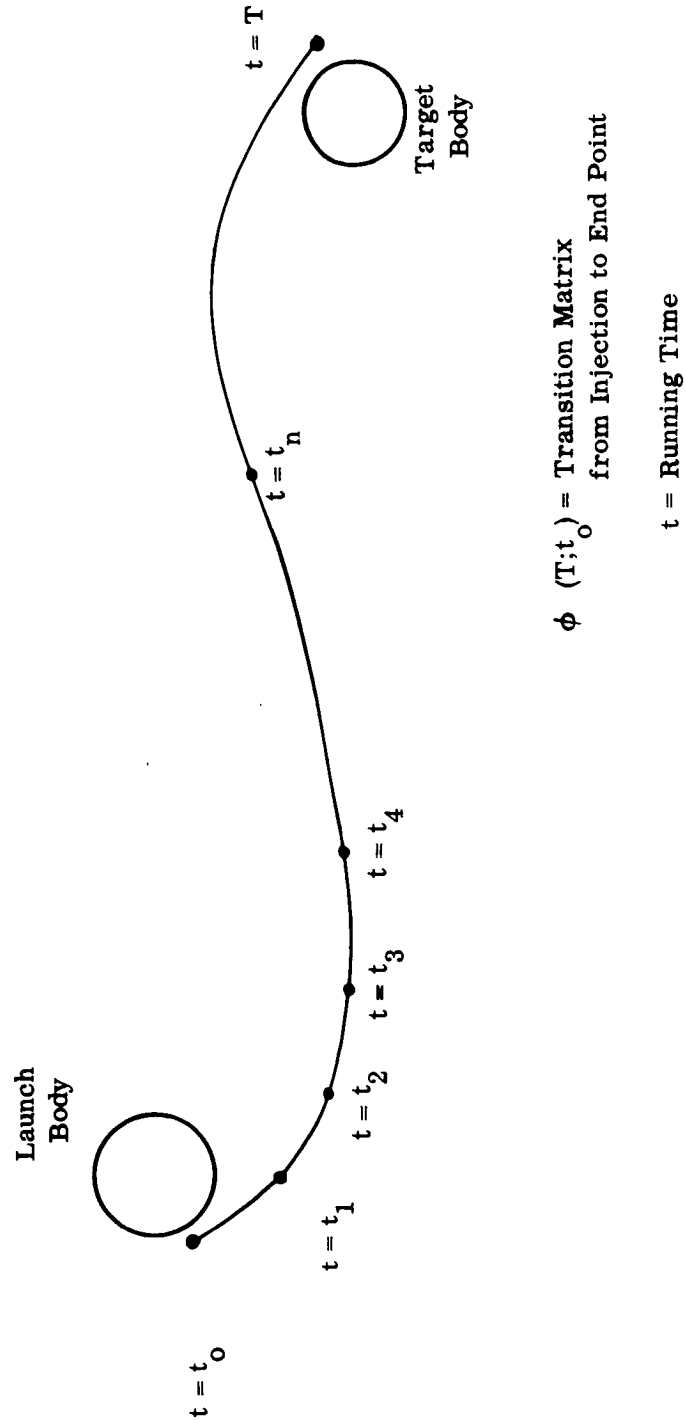


Figure 3-1 Typical Trajectory

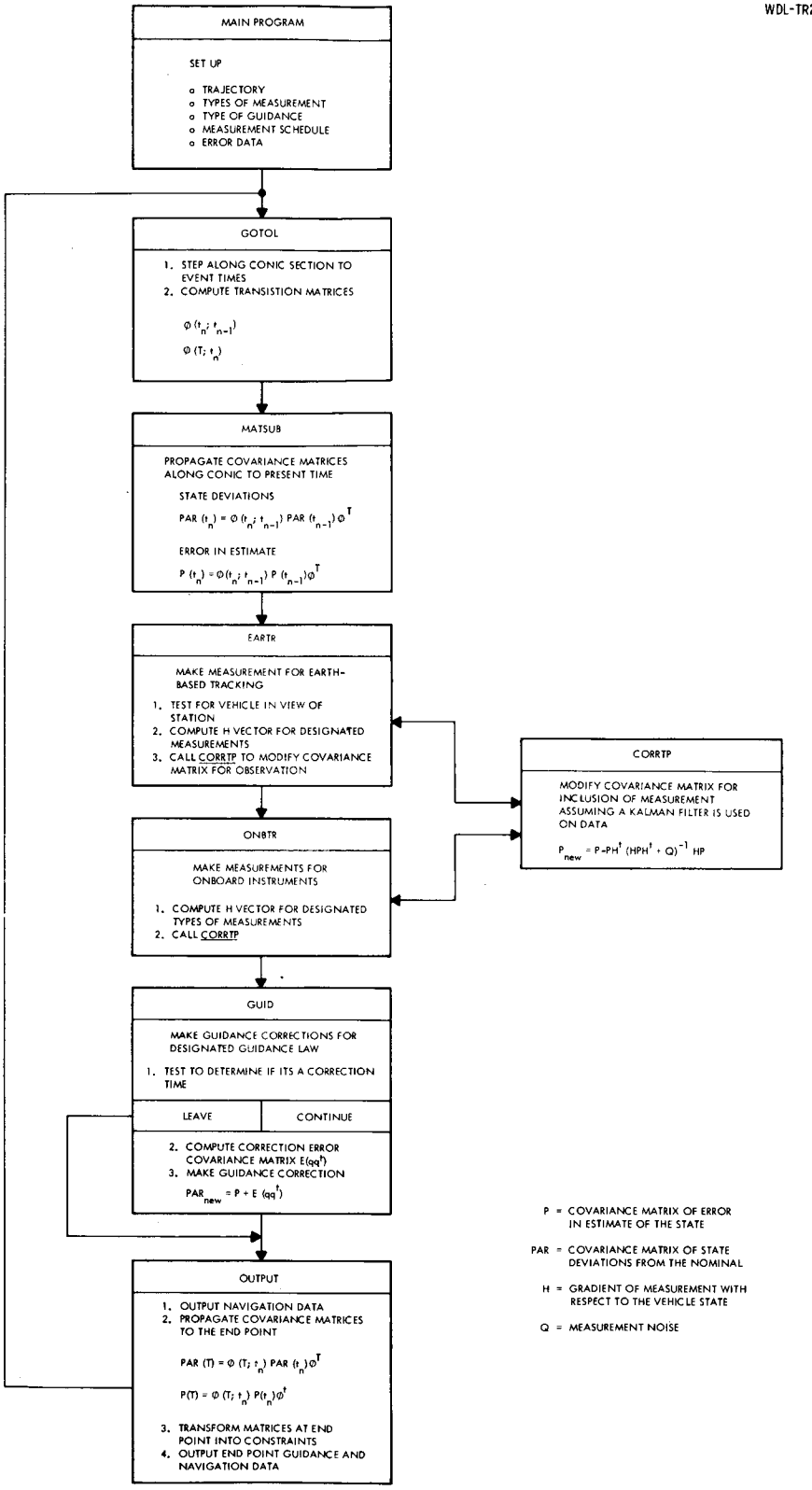


Figure 3-2 Flow Diagram for Conic Error Propagation Program

SECTION 4

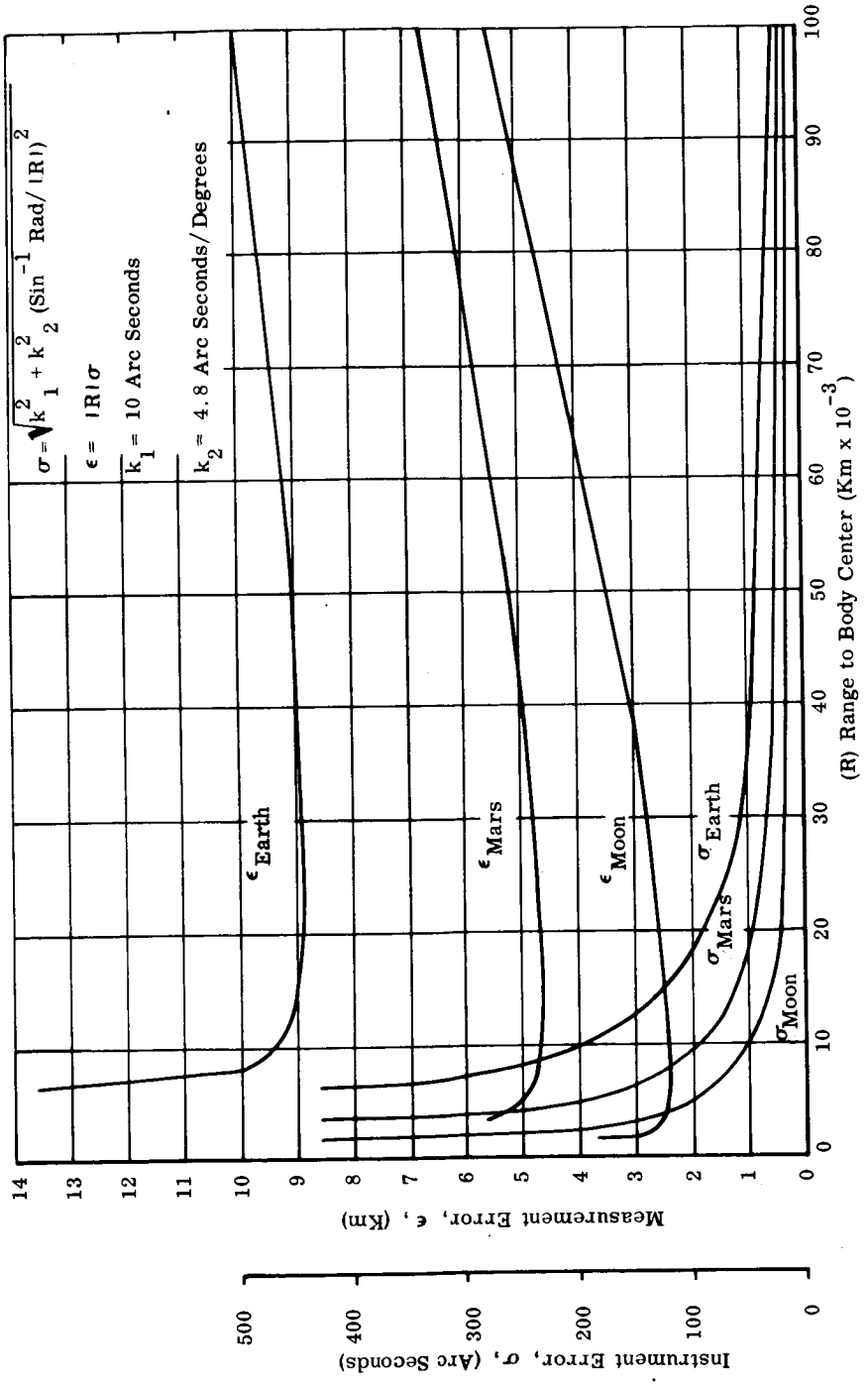


Figure 4-1 Optical Instrument Error Model

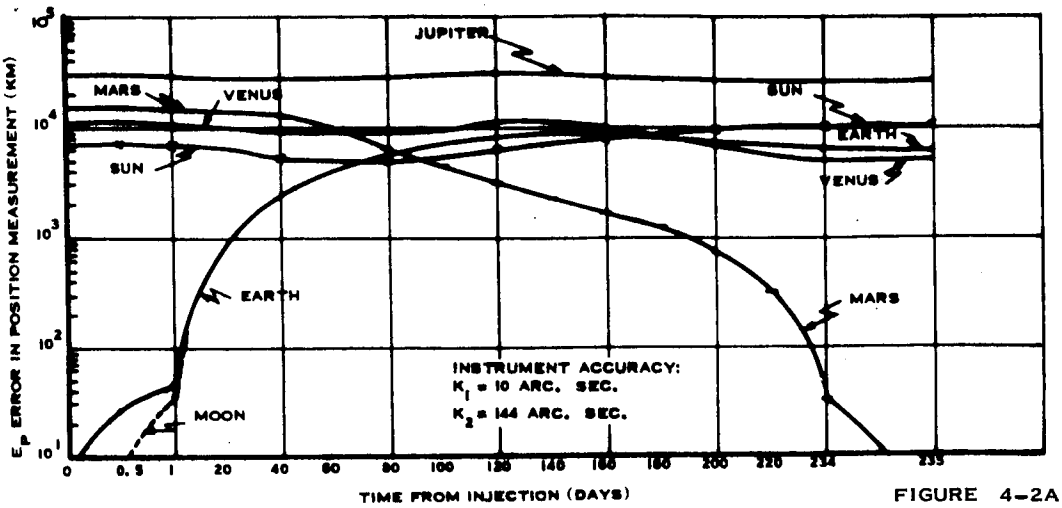


FIGURE 4-2A

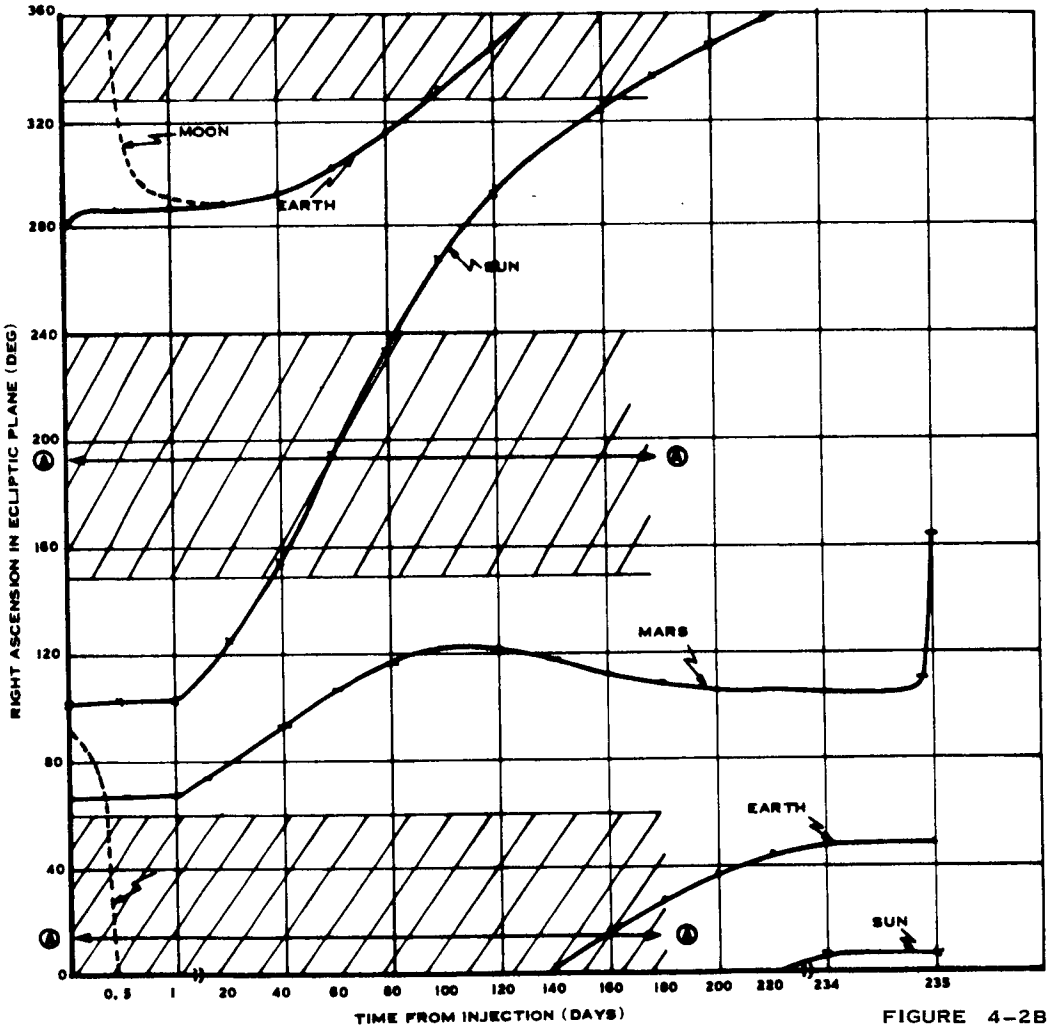


FIGURE 4-2B

Figure 4-2 Schedule Data for Earth-Mars Trajectory

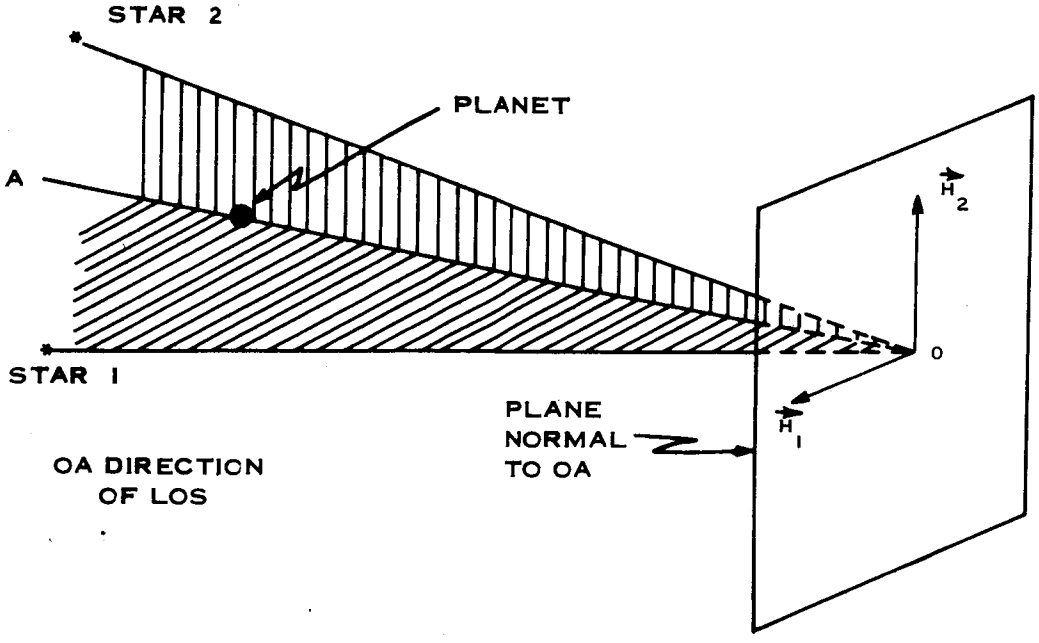


Figure 4-3 Relationship Between the Direction of the LOS to a Body and the $\vec{h}$ Vectors Associated with the Measurements Used to Determine the Direction of the LOS

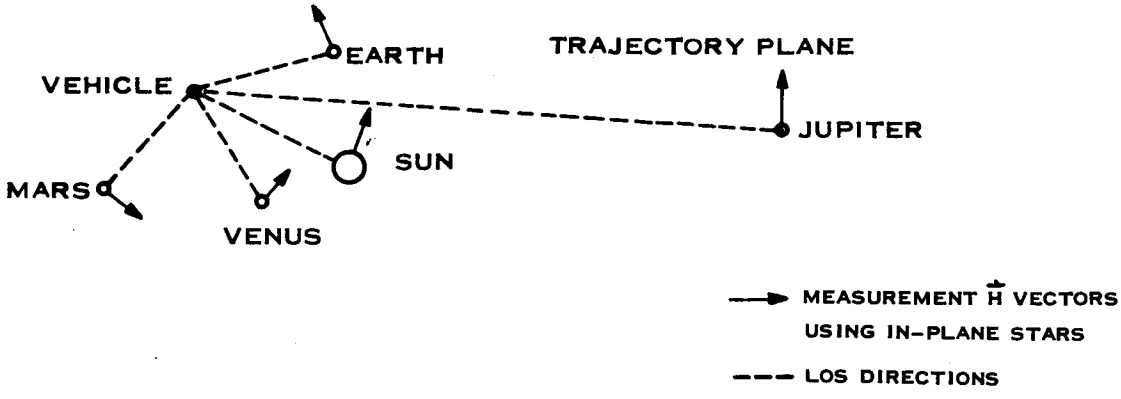


Figure 4-4 Problem of Determining the Two-Dimensional Position in the Trajectory Plane

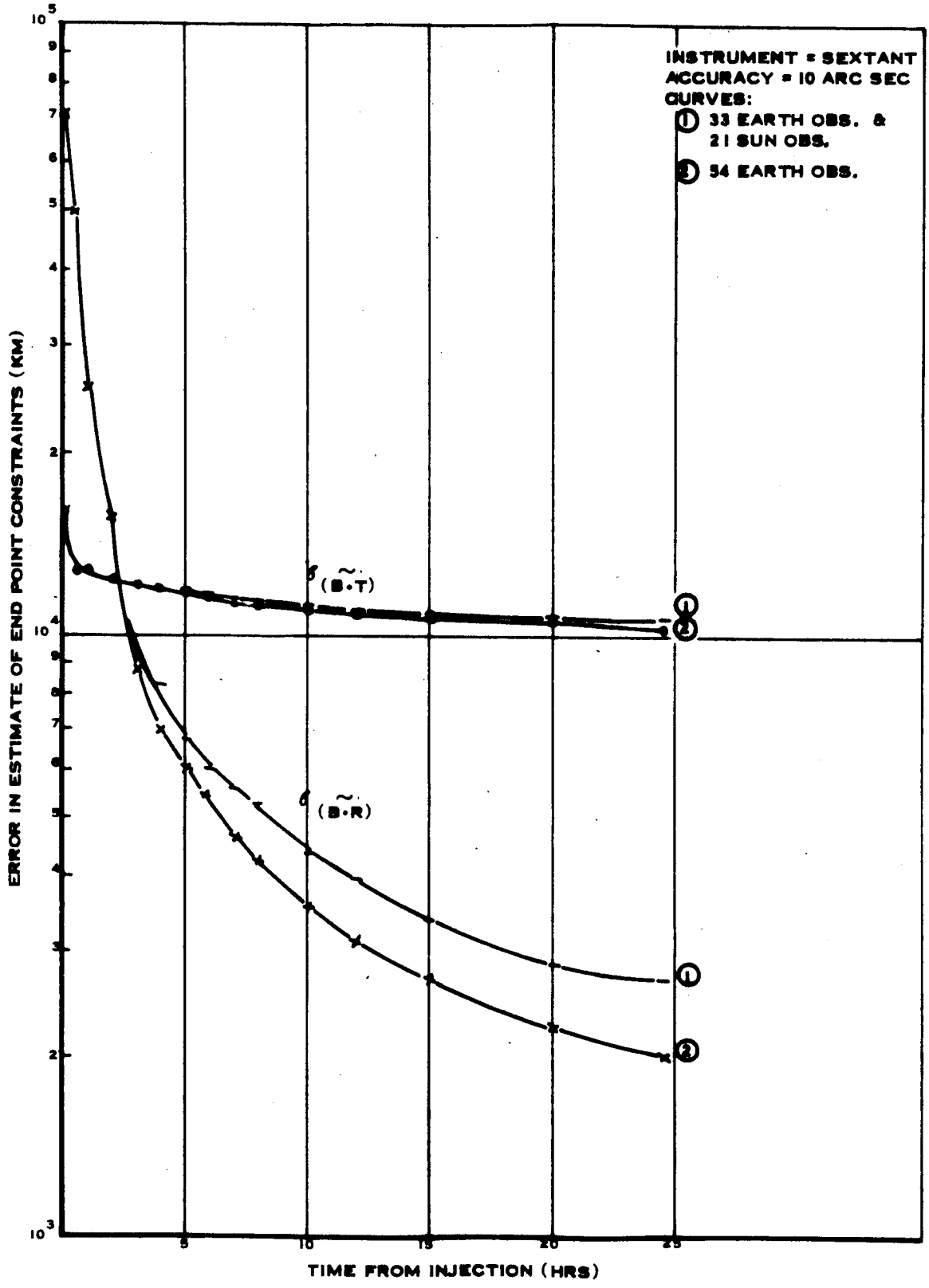


Figure 4-5 Influence of Using Sun Observations Early on the Earth-Mars Trajectory

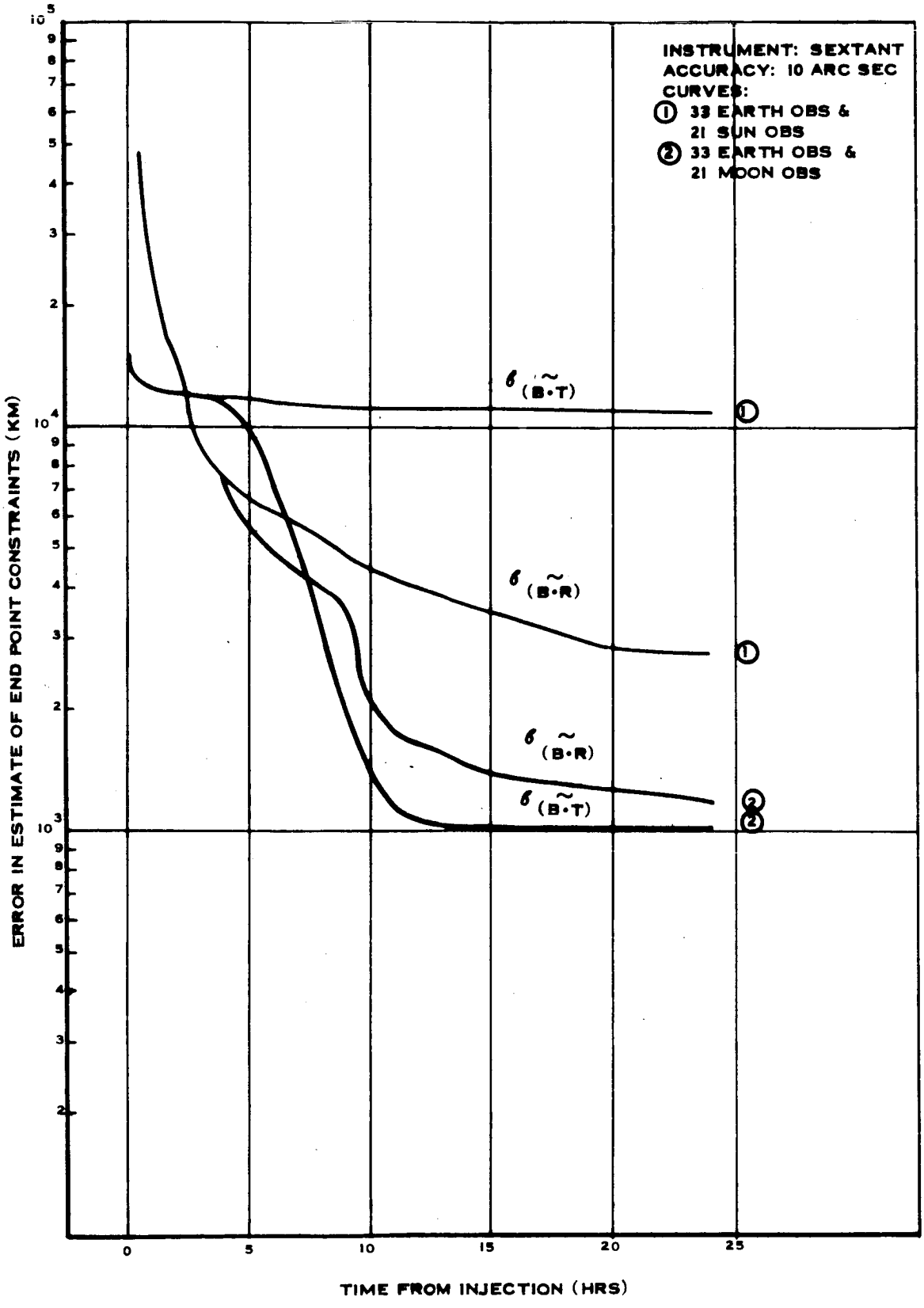


Figure 4-6 Influence of Using Moon Observations on the Earth-Mars Trajectory

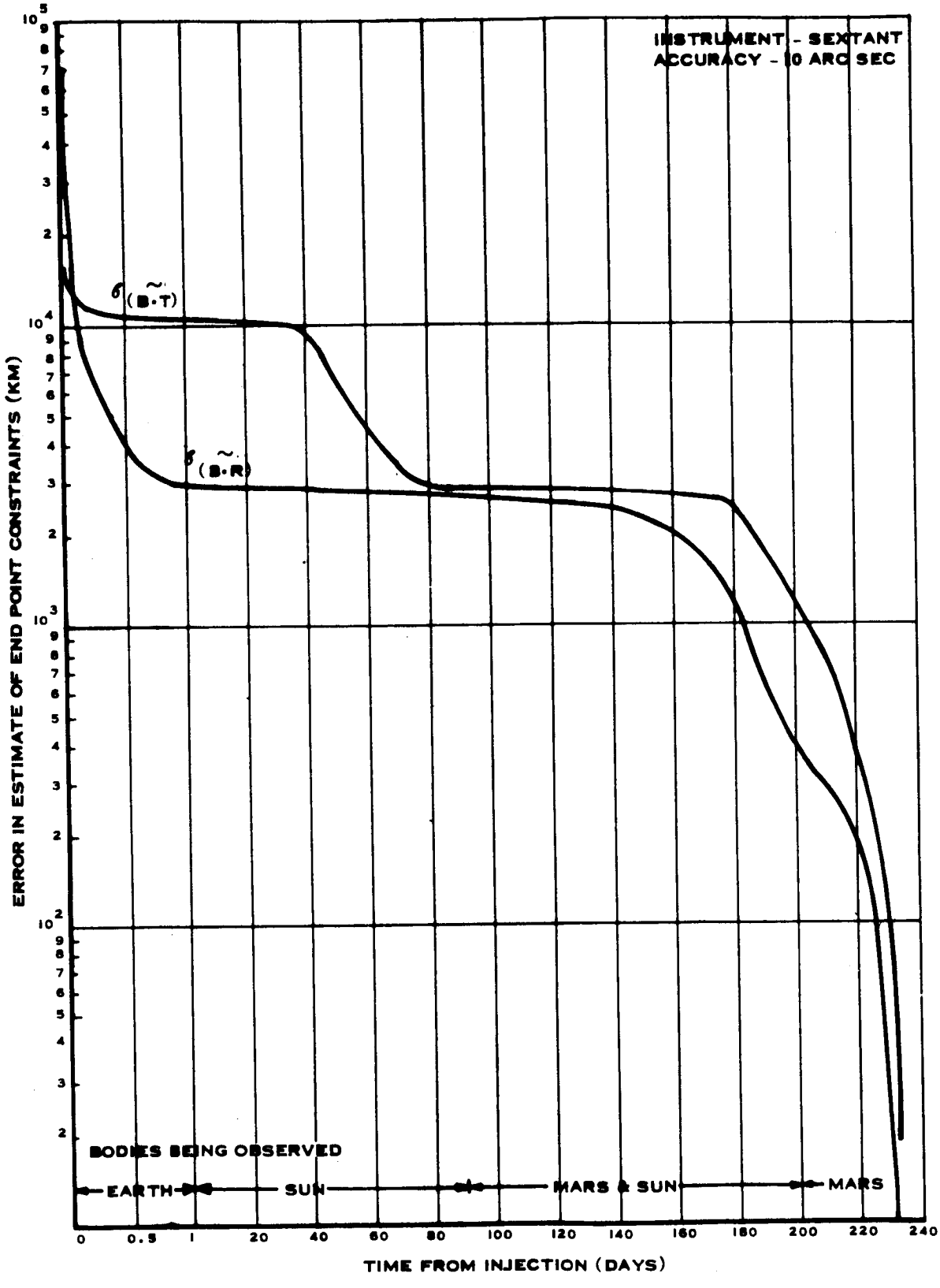


Figure 4-7 Tracking Data for Earth-Mars Trajectory

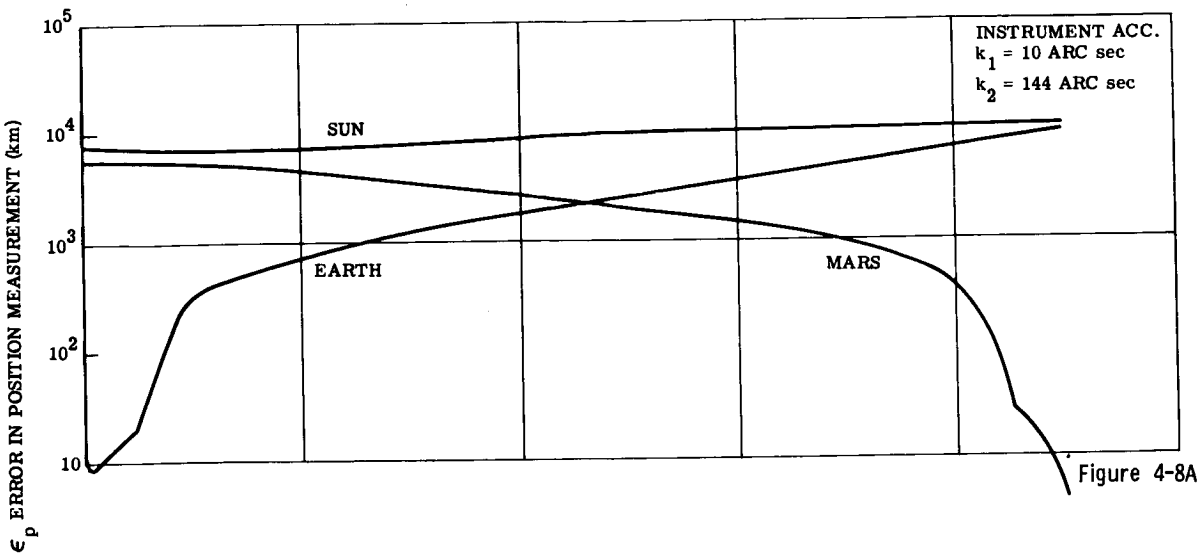


Figure 4-8A

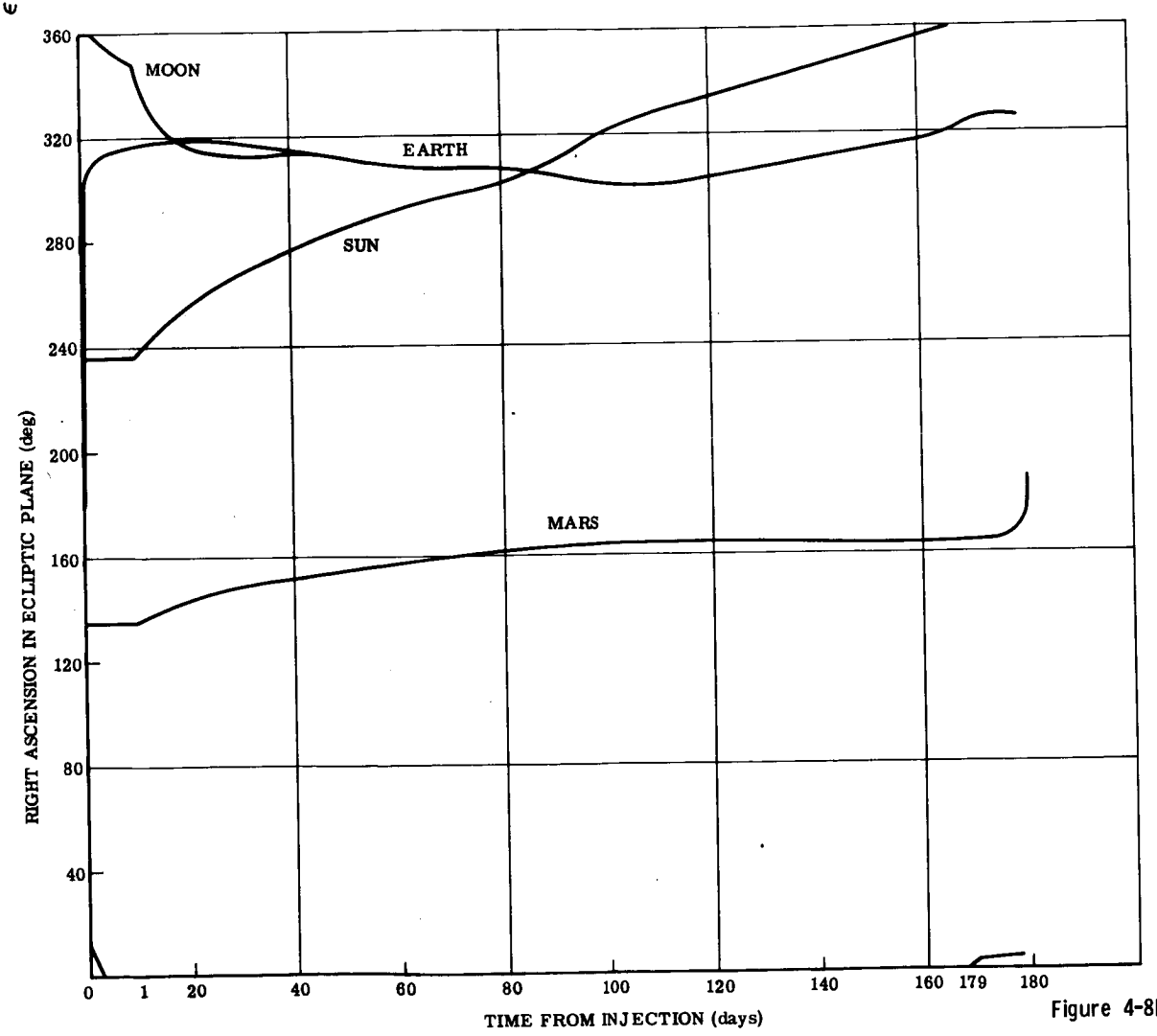


Figure 4-8B

Figure 4-8 Earth-Mars Low-Energy Trajectory

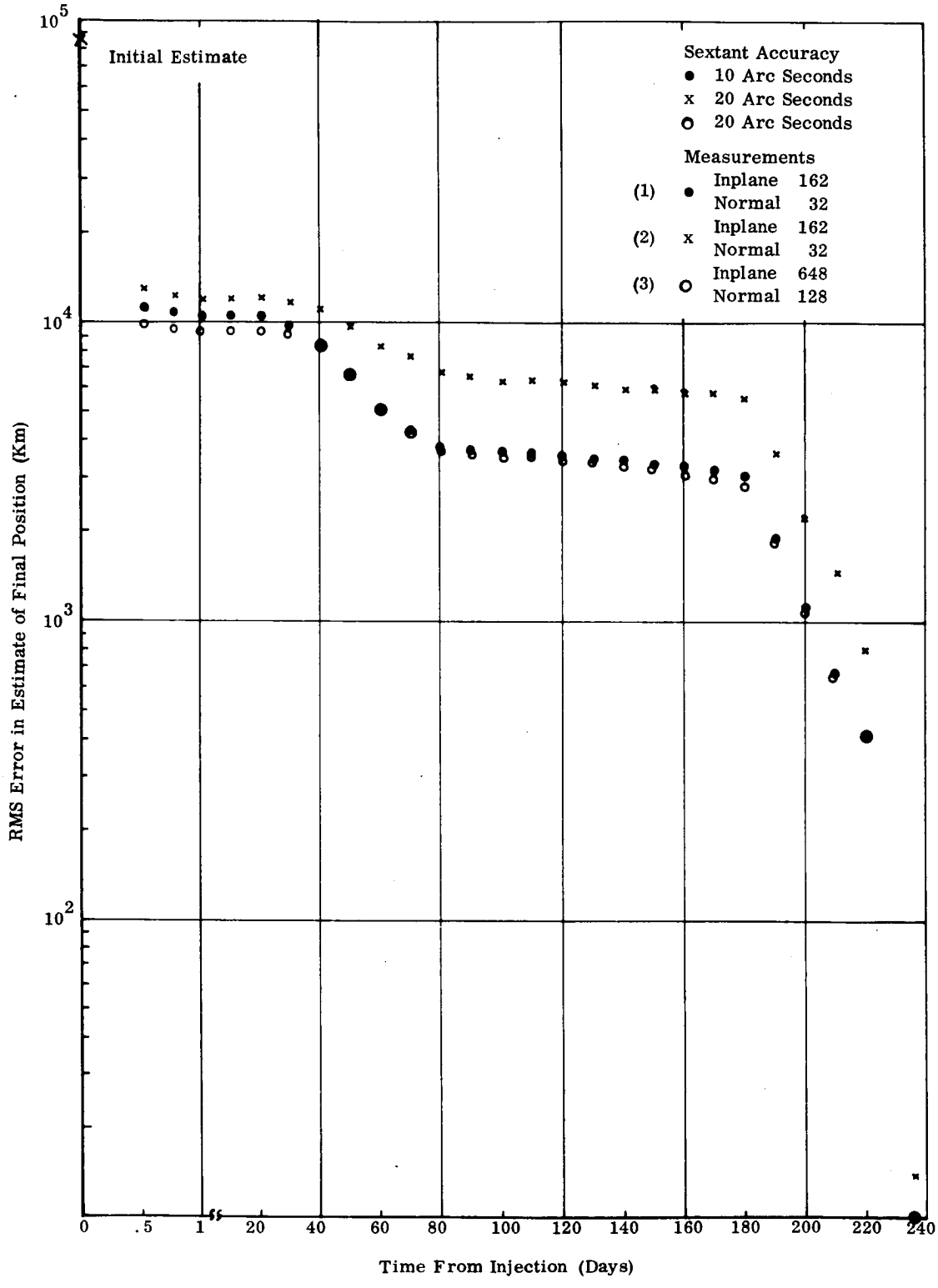


Figure 4-9 Tradeoff Between Instrument Accuracy and Number of Observations

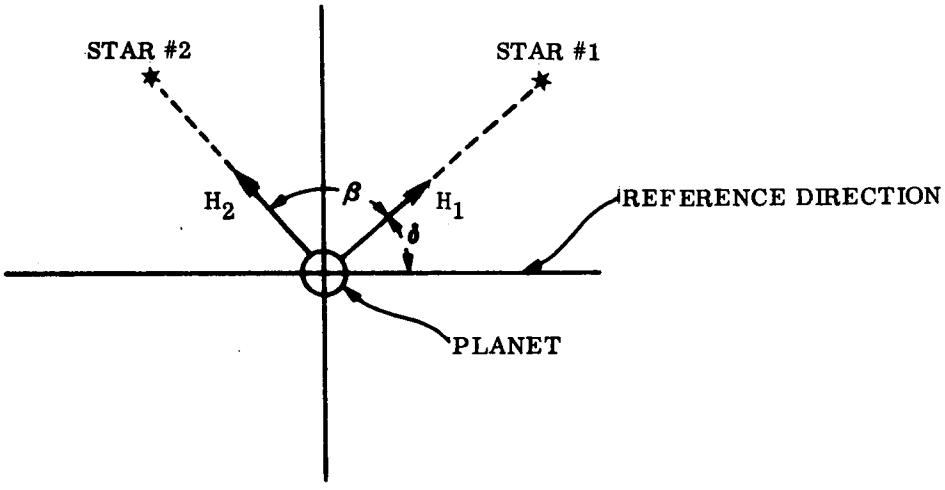


Figure 4-10

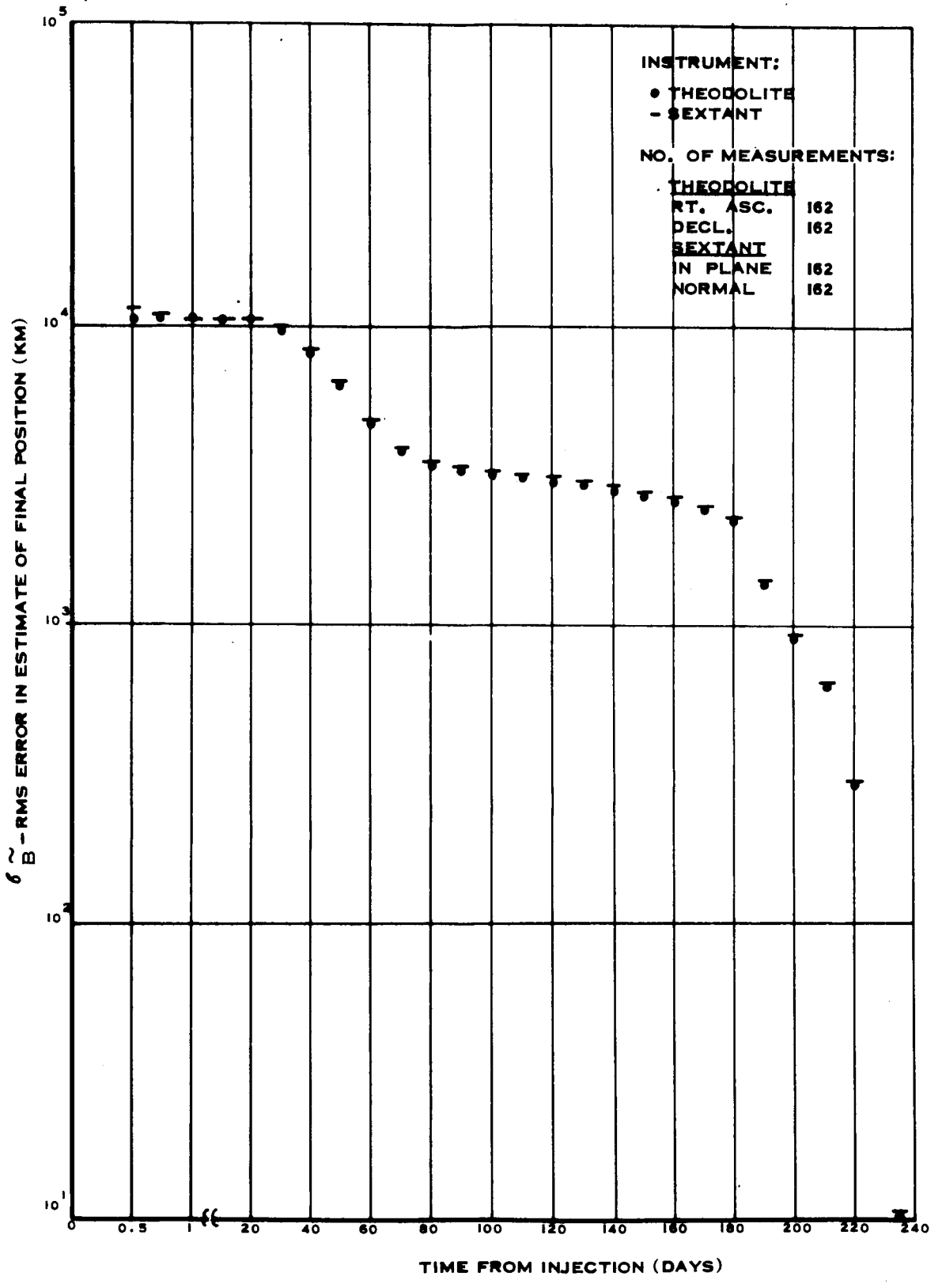


Figure 4-11 Comparison of Orbit Determination with a Theodolite and a Sextant

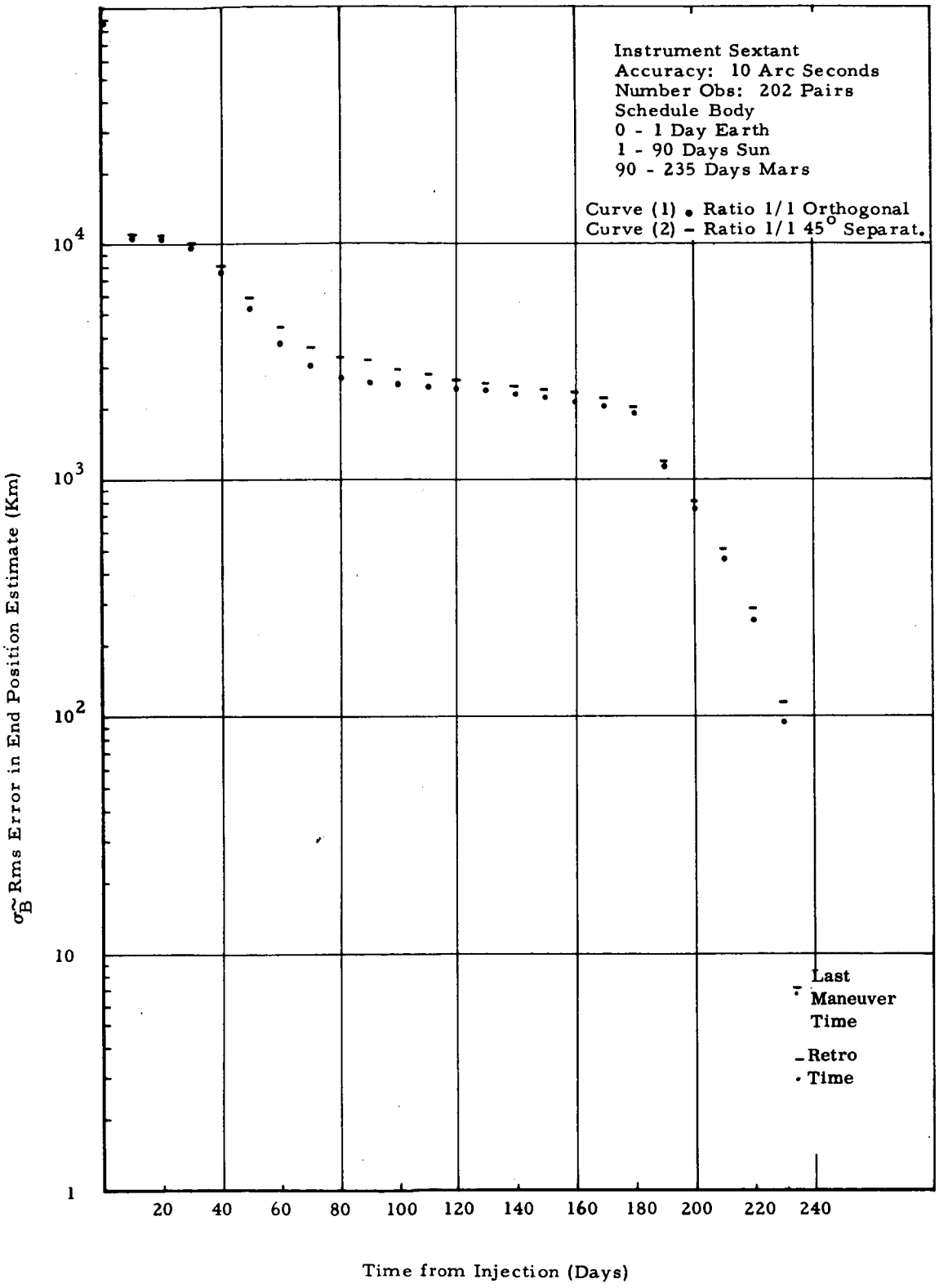


Figure 4-12 Influence of Non-Orthogonal Measurements

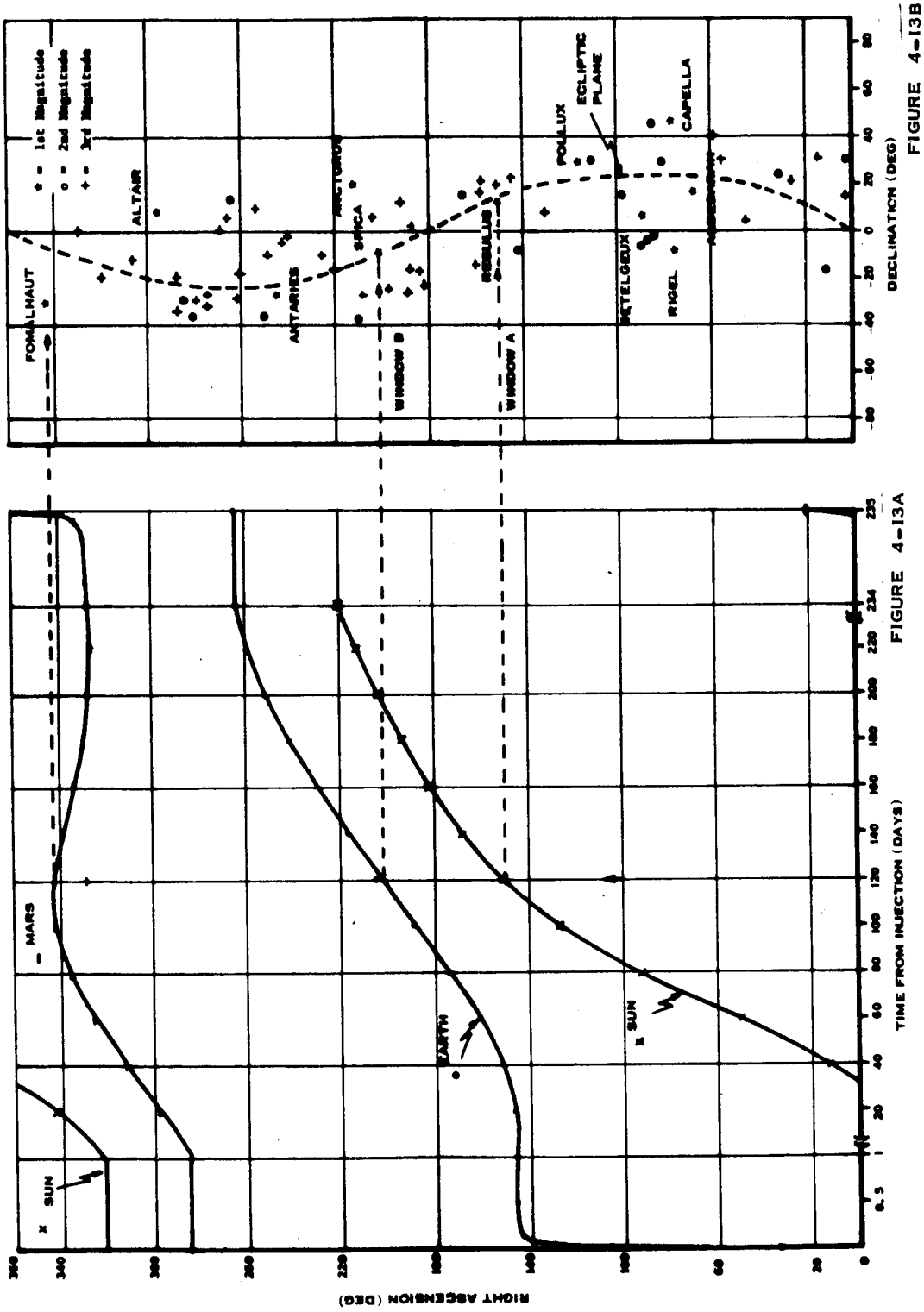
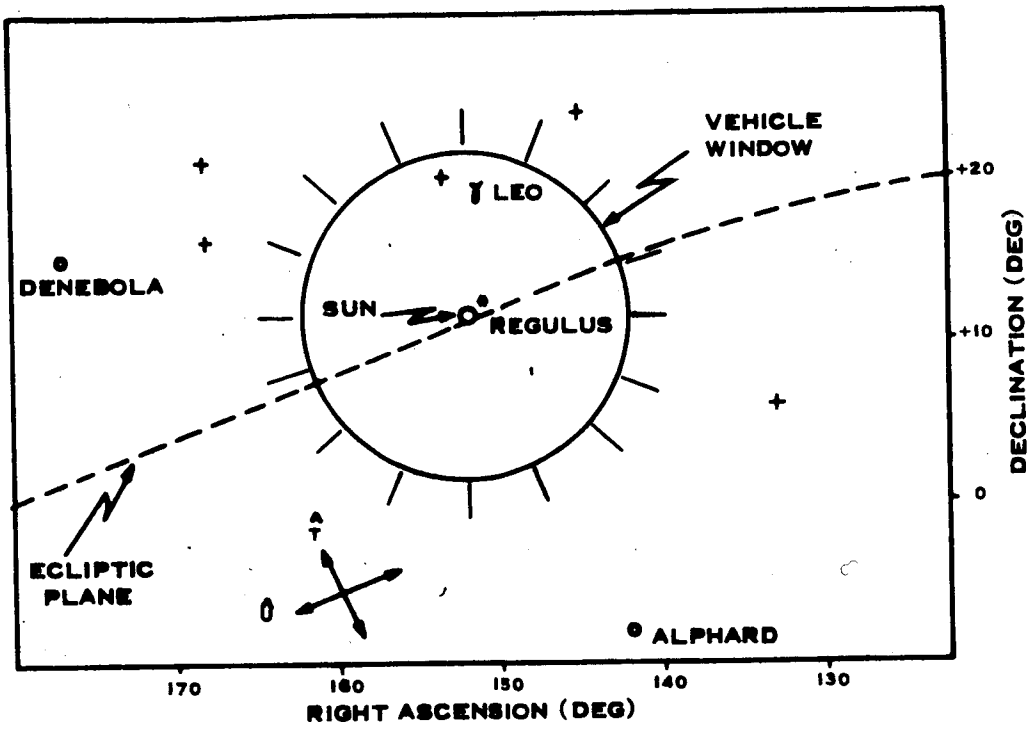


Figure 4-13 Star Selection Data



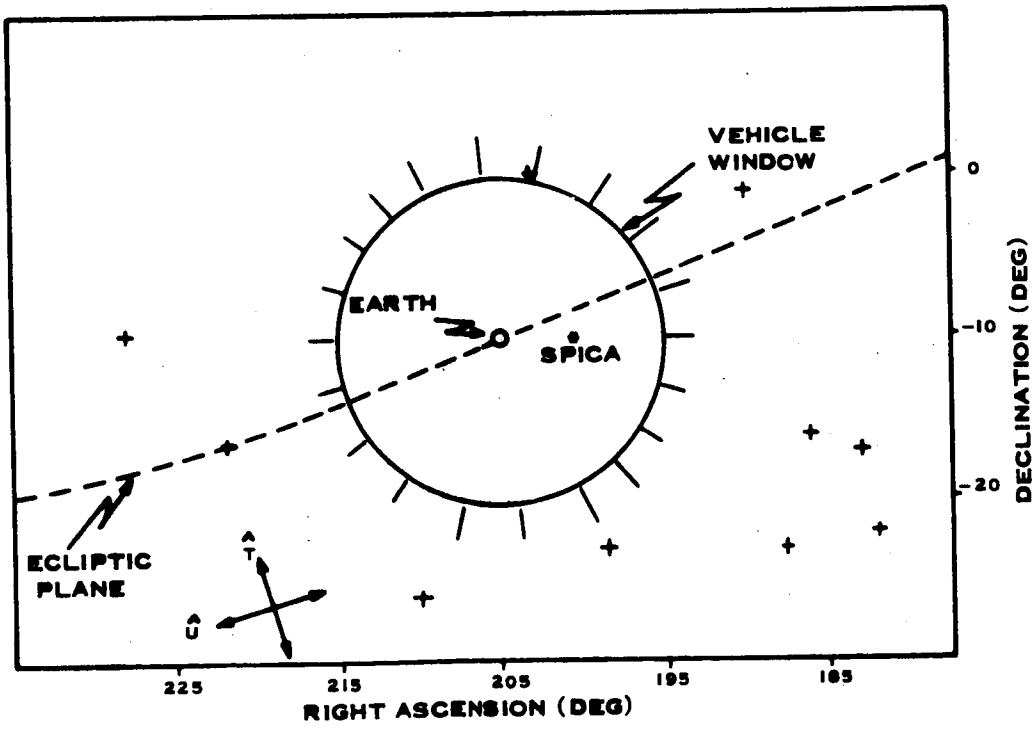


Figure 4-14 Vehicle Observation Windows

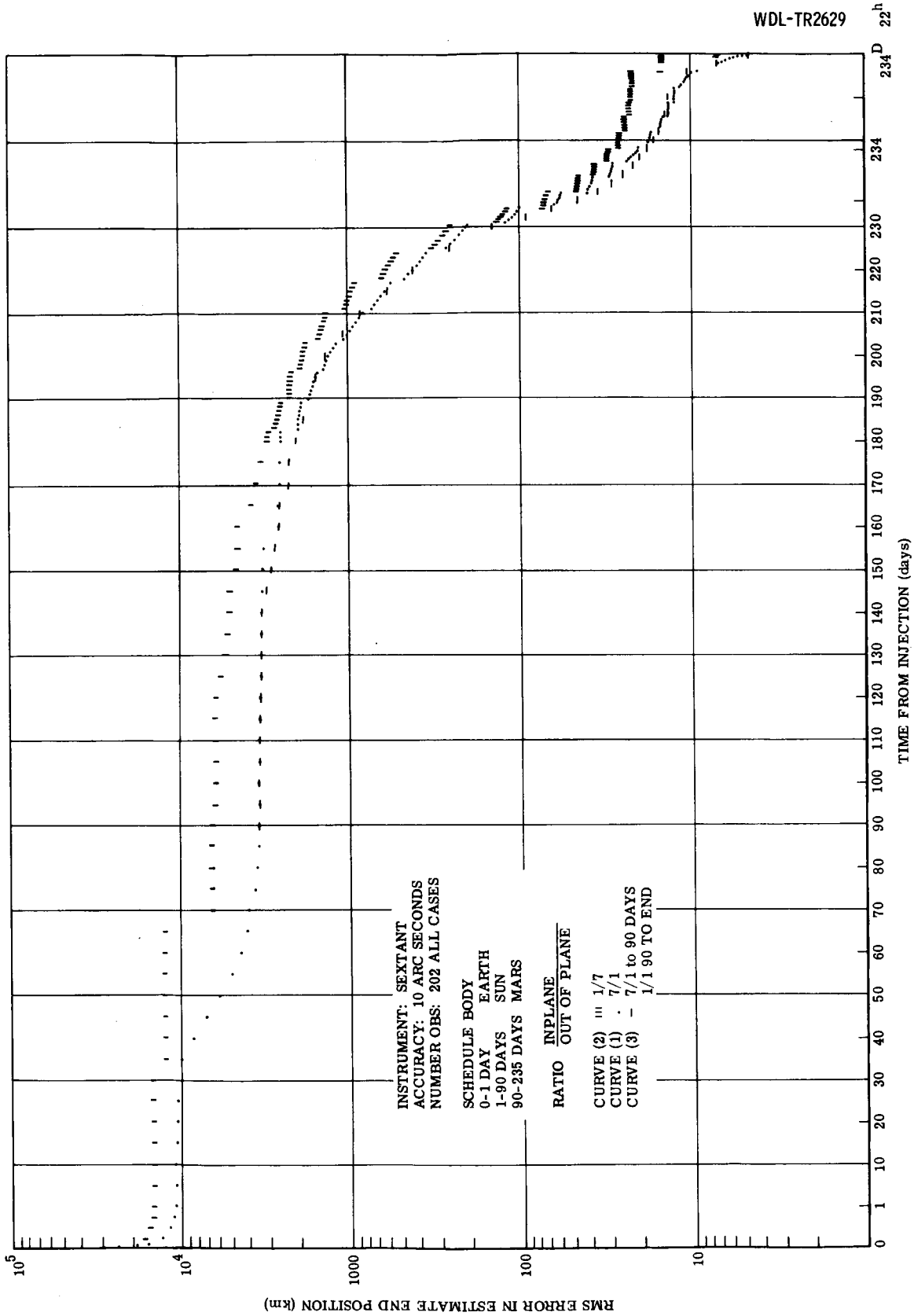

INSTRUMENT: SEXTANT
ACCURACY: 10 ARC SECONDS
NUMBER OBS: 202 ALL CASES
SCHEDULE BODY
0-1 DAY EARTH
1-90 DAYS SUN
90-235 DAYS MARS
RATIO INPLANE / OUT OF PLANE
CURVE (2) ''' 1/7
CURVE (1) · 7/1
CURVE (3) – 7/1 to 90 DAYS
1/1 90 TO END
RMS ERROR IN ESTIMATE END POSITION (km)
TIME FROM INJECTION (days)
10^5
10^4
1000
100
10
0
1
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
234
234D 22h

Figure 4-15

TABLE 4-1

GRADIENTS OF MEASUREMENTS*

MEASUREMENT	GRADIENT	COMMENTS
Range	$(\hat{R}^T \; ; \; 0)$	(Along $\vec{R}$; 0)
Range Rate	$\left(\frac{\hat{X}^T}{\lvert\vec{R}\rvert}\left\{I-\hat{R}\hat{R}^T\right\} \; ; \; \hat{R}^T\right)$	(Normal $\vec{R}$; Along $\vec{R}$)
AZ-EL Angles	$\left[\frac{1}{\lvert\vec{R}\rvert}\left(\frac{\hat{R} \times \hat{R}'}{\lvert\hat{R} \times \hat{R}'\rvert} \times \hat{R}\right);0\right]$	(Normal $\vec{R}$; 0)
Subtended Angle	$\left(-\frac{2 \operatorname{Tan} \alpha}{\lvert R\rvert} \hat{R}^T \; ; \; 0\right)$	(Along $\vec{R}$; 0)
Sextant	$\left[\frac{1}{\lvert\vec{P}\rvert}\left(\frac{\hat{P} \times \hat{S}}{\lvert\hat{P} \times \hat{S}\rvert} \times \hat{P}\right); \; 0\right]$	(Normal $\hat{P}$; 0)

* Derived in Appendix B

TABLE 4-2

NOMINAL TRAJECTORY

CELESTIAL BODY SELECTION

Time	Body	Measurement Accuracy	Comments
0-80 Days	Earth	10-5000 km	Primary Body
0-1 Day	Moon	10-100 km	Normal to Earth's Direction
40-80 Days	Sun	5000 km	Normal to Earth's Direction
90-235 Days	Mars	4000-8 km	Primary Body
160-235 Days	Earth	8000-6000 km	Normal to Mars Direction

TABLE 4-3

MINIMUM ENERGY TRAJECTORY

CELESTIAL BODY SELECTION

Time	Body	Measurement Accuracy	Comments
0-90 Days	Earth	10-3000 km	Primary Body
0-90 Days	Mars	7000-3000 km	Secondary Body
90-180 Days	Mars	3000-8 km	Primary Body
90-180 Days	Earth	3000-10000 km	Secondary Body

SECTION 5

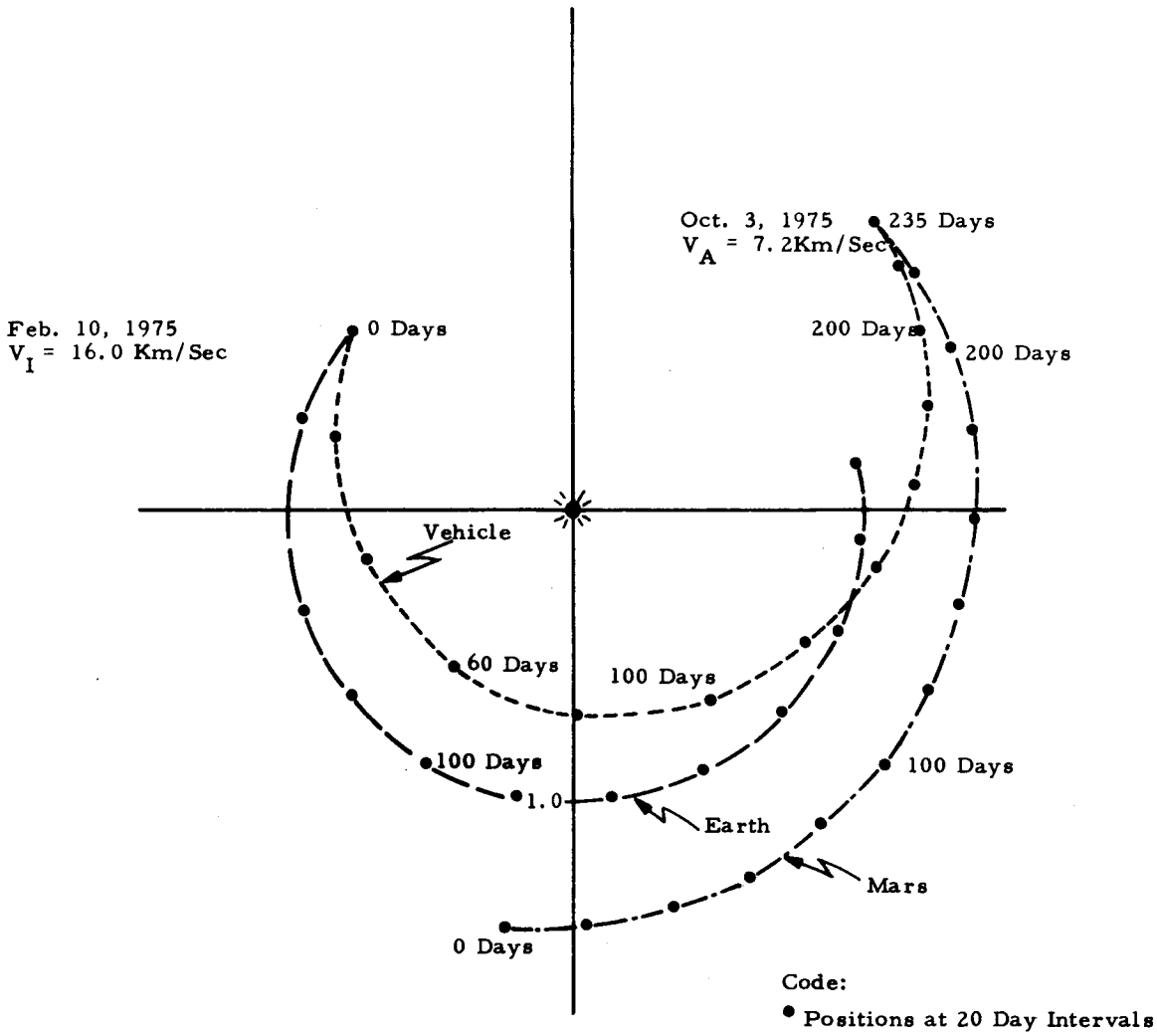


Figure 5-1 Ecliptic of Date Coordinates - Earth-Mars Trajectory, 235 Days

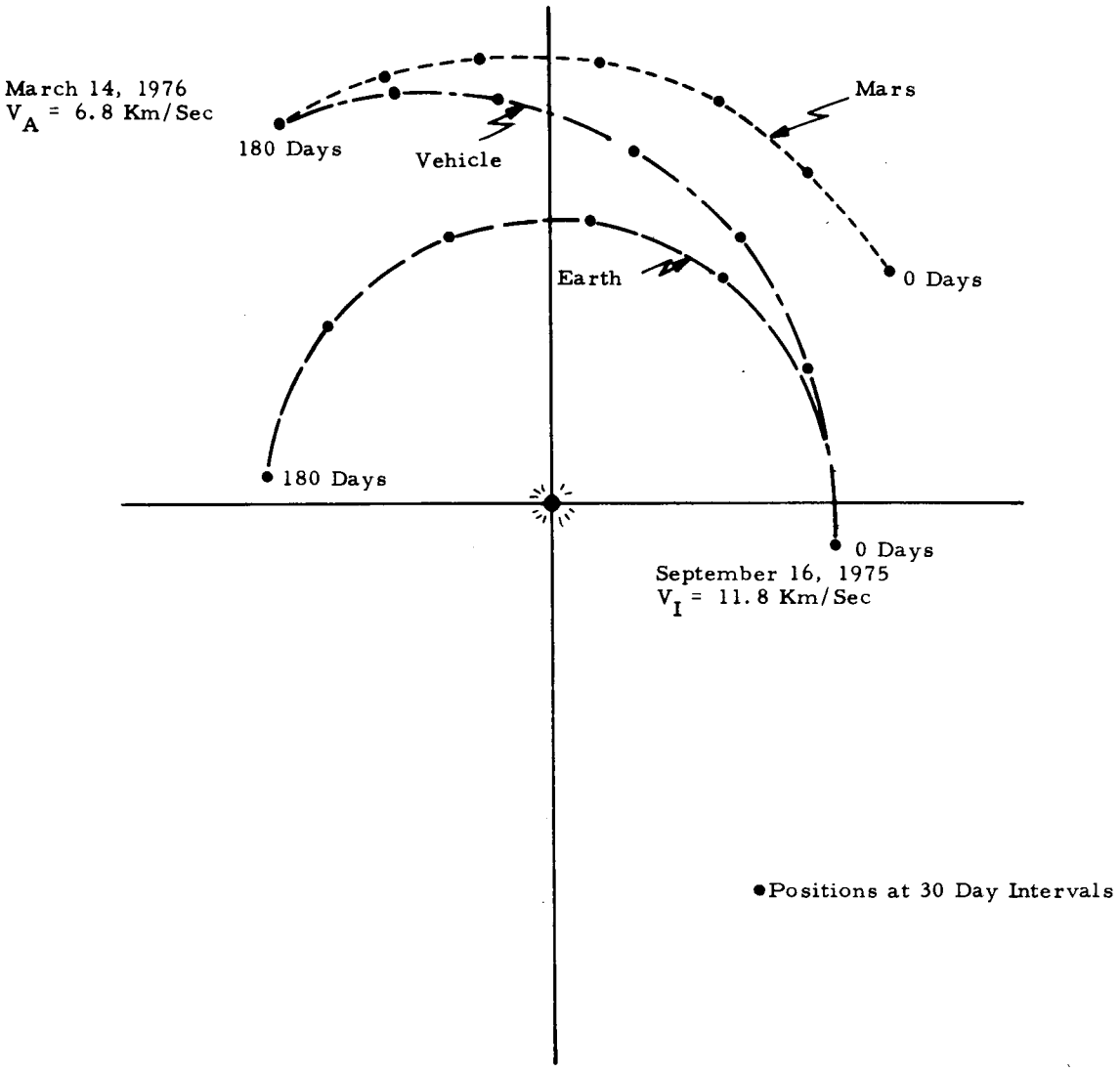
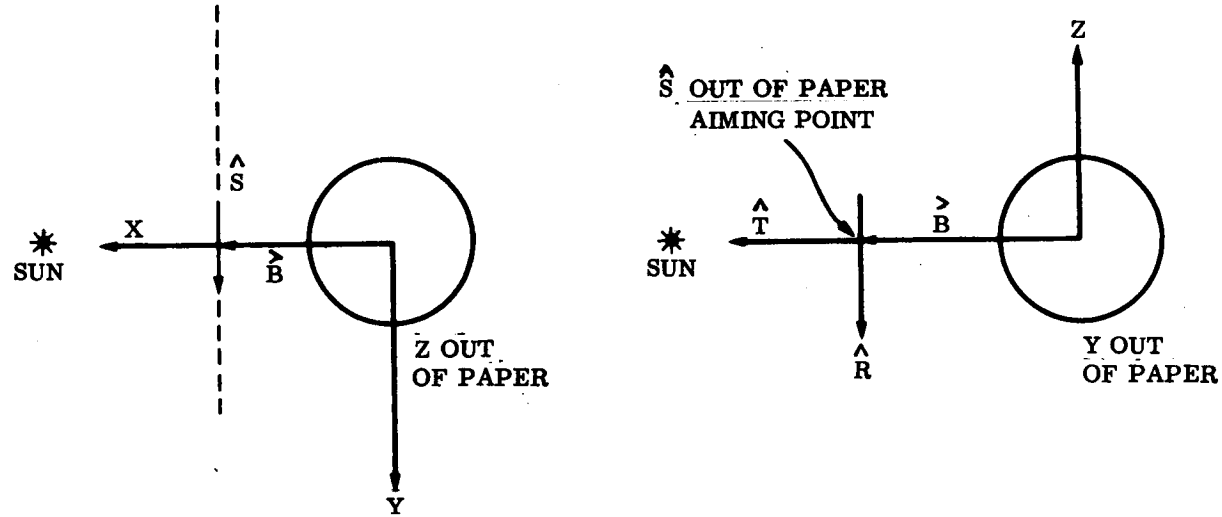


Figure 5-2 Ecliptic of Date Coordinates - Earth-Mars Trajectory, 180 Days



(X, Y, Z) TARGET COORDINATES
---- INCOMING ASYMPTOTE

NOMINAL VALUES OF B VECTOR DATA

$$\hat{B} = \begin{pmatrix} 5031. \\ 828.5 \\ -112.4 \end{pmatrix} \quad \hat{S} = \begin{pmatrix} -.1639 \\ .9794 \\ -.1172 \end{pmatrix} \quad \hat{T} = \begin{pmatrix} .9862 \\ .1650 \\ 0 \end{pmatrix} \quad \hat{R} = \begin{pmatrix} .0193 \\ -.1156 \\ -.9931 \end{pmatrix}$$

Figure 5-3. Nominal Trajectory Approach Geometry

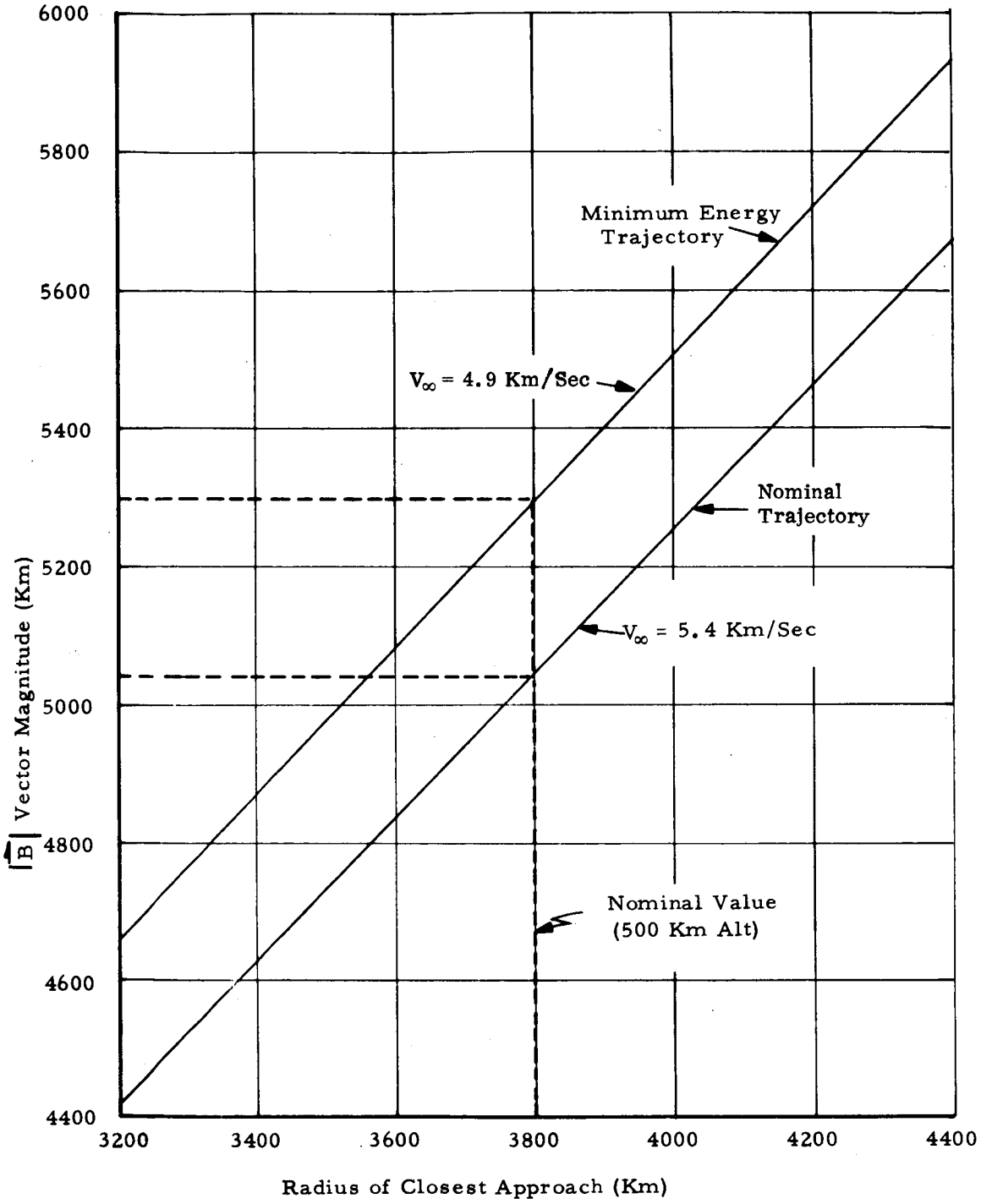


Figure 5-4 Relationship Between $|\vec{B}|$ Magnitude and Radius of Closest Approach

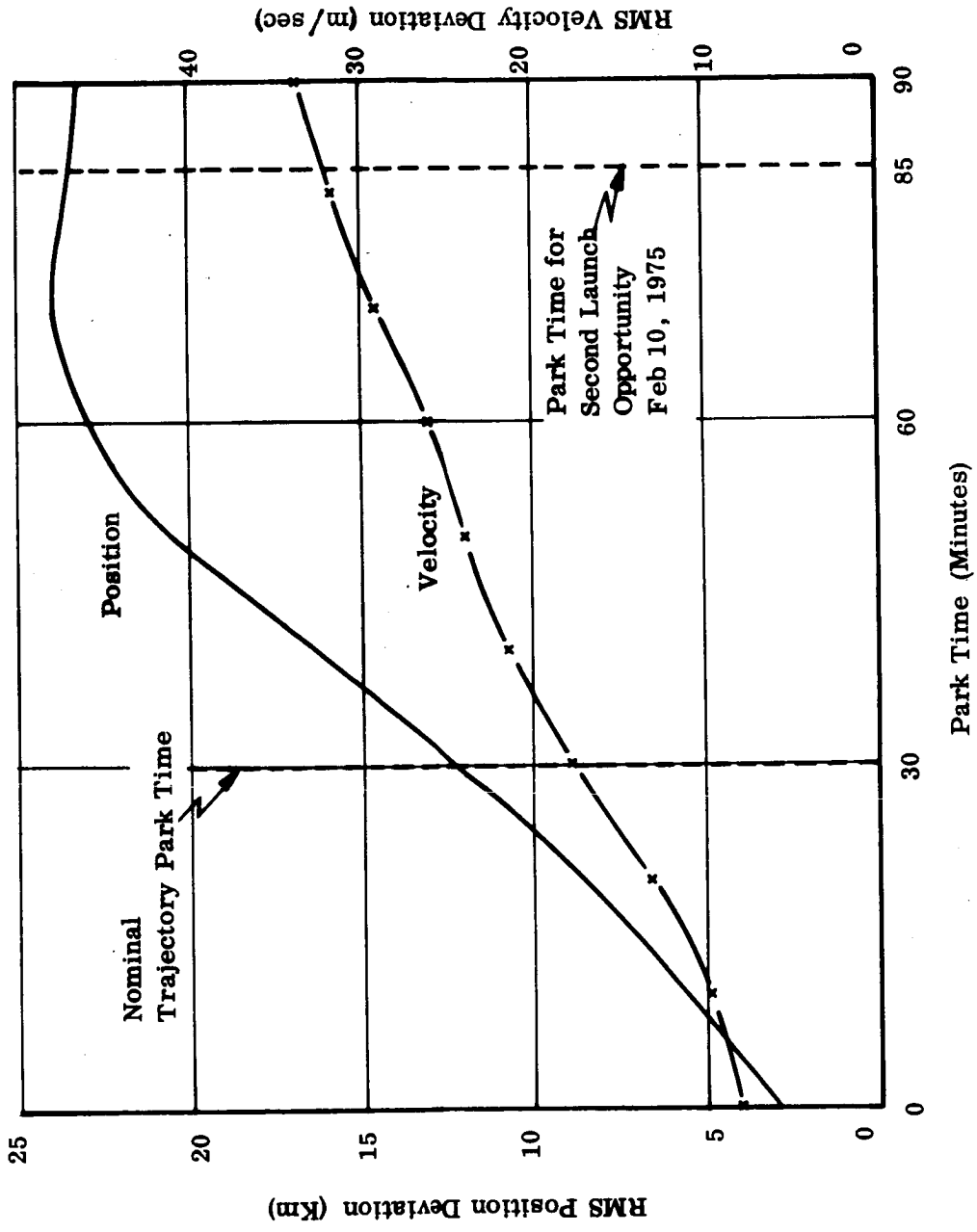


Figure 5-5 State Deviations vs. Park Time

$\sigma_N = 3.89$ Km $\sigma_V = 11.7$ Km $\sigma_W = .841$ Km $\sigma_{\dot{N}} = 14.5$ m/Sec $\sigma_{\dot{V}} = 5.02$ m/Sec $\sigma_{\dot{W}} = 9.03$ m/Sec

Normalized Covariance Matrix

	N	V	W	$\dot{N}$	$\dot{V}$	$\dot{W}$
N	1.0	-.723	0	.641	-.915	0
V		1.0	0	-.942	.901	0
W			1.0	0	0	-.011
$\dot{N}$				1.0	-875	0
$\dot{V}$		Symmetric Matrix			1.0	0
$\dot{W}$						1.0

Figure 5-6 Covariance Matrix in NVW Coordinates of State Deviations from Nominal at Injection (30 Minutes Park Time)

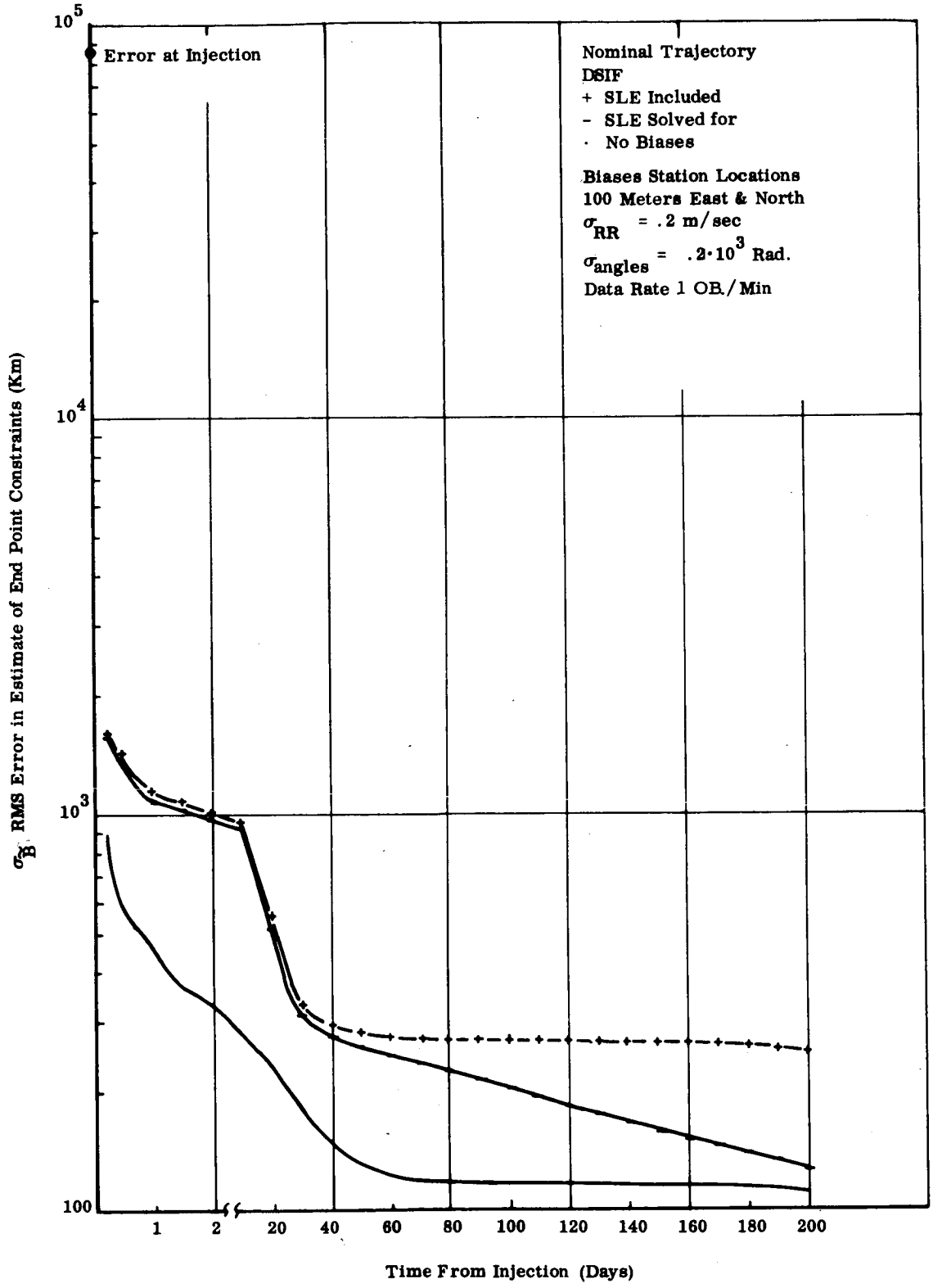


Figure 5-7 DSIF Tracking Data

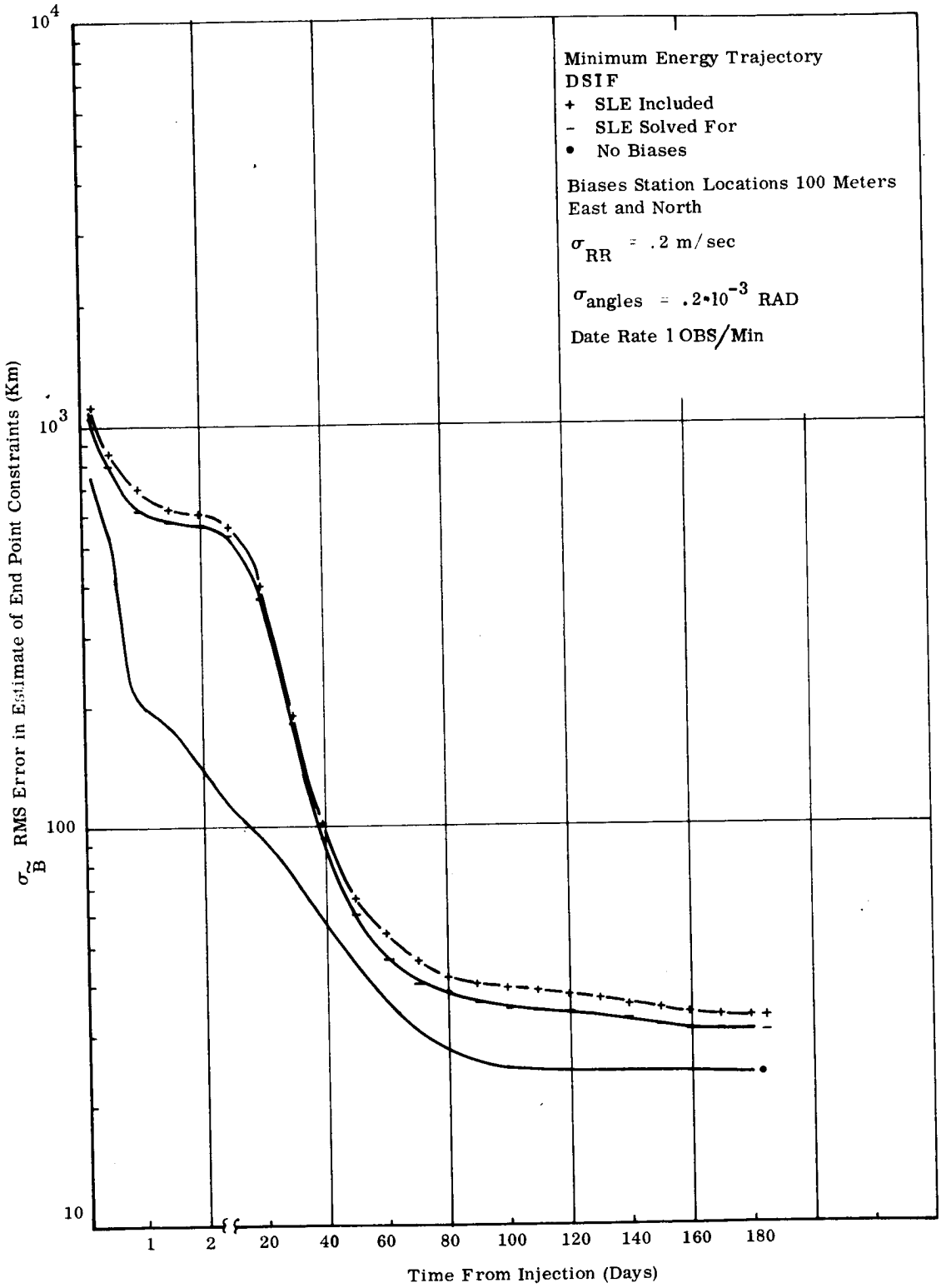
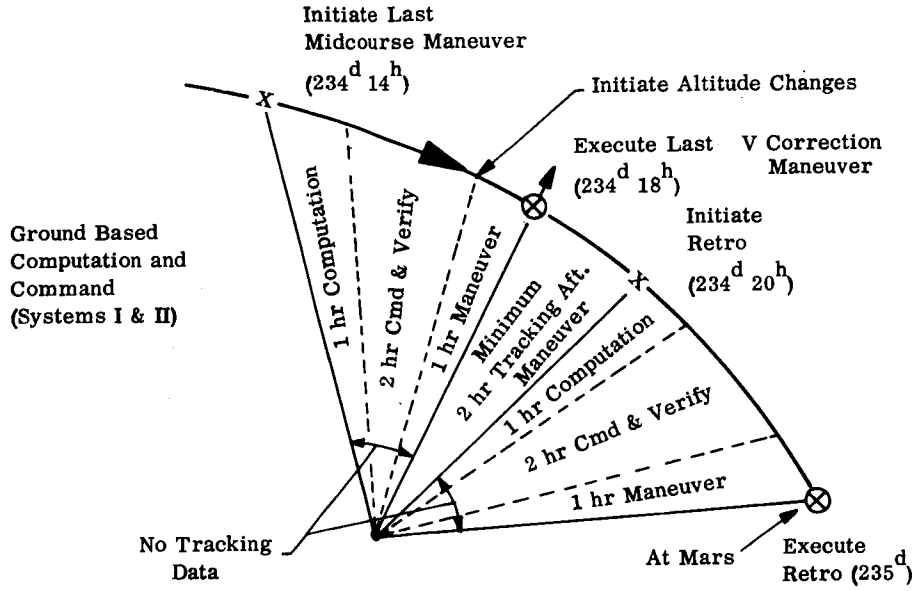
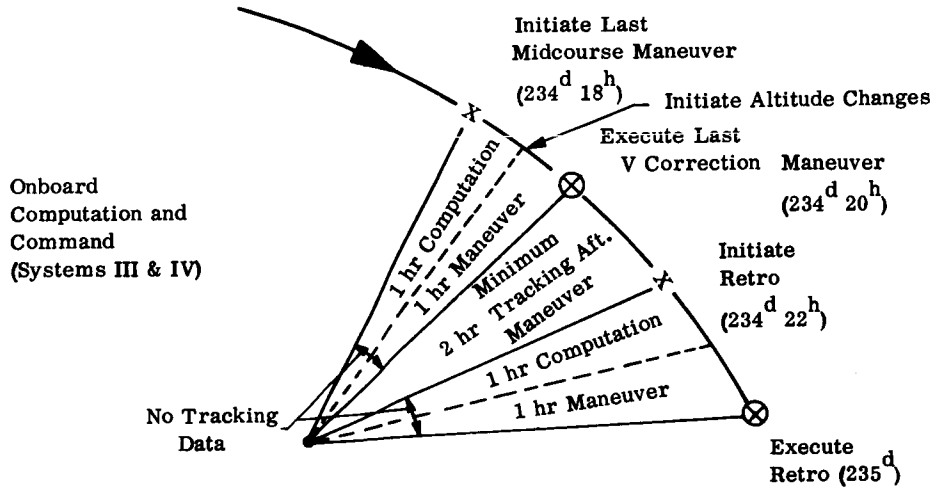


Figure 5-8 DSIF Tracking Data





Note: These maneuver constraints which are illustrated for the last midcourse maneuver also apply to the other maneuvers as well.

Figure 5-9 Maneuver Constraints

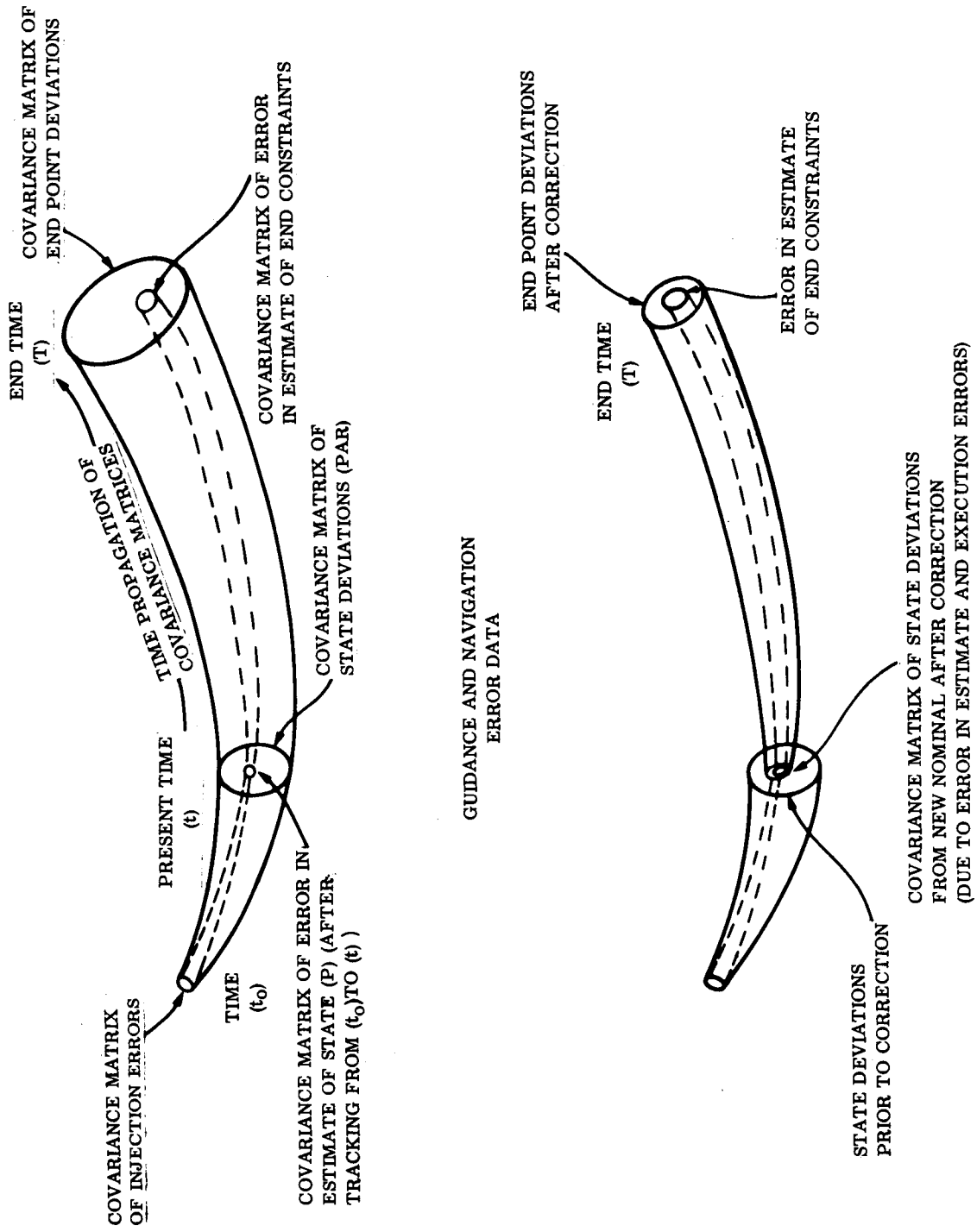


Figure 5-10 Guidance Data After a Correction

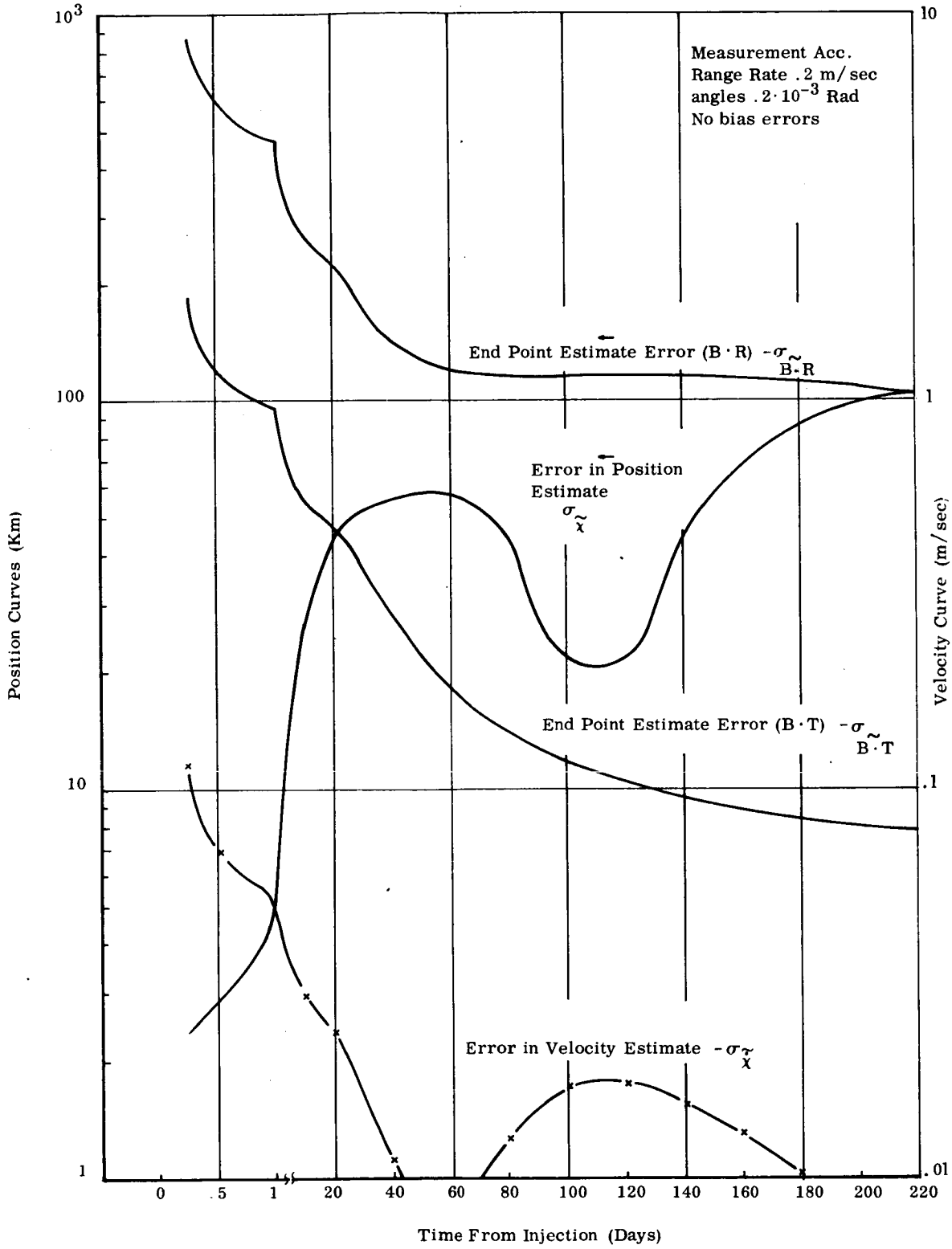


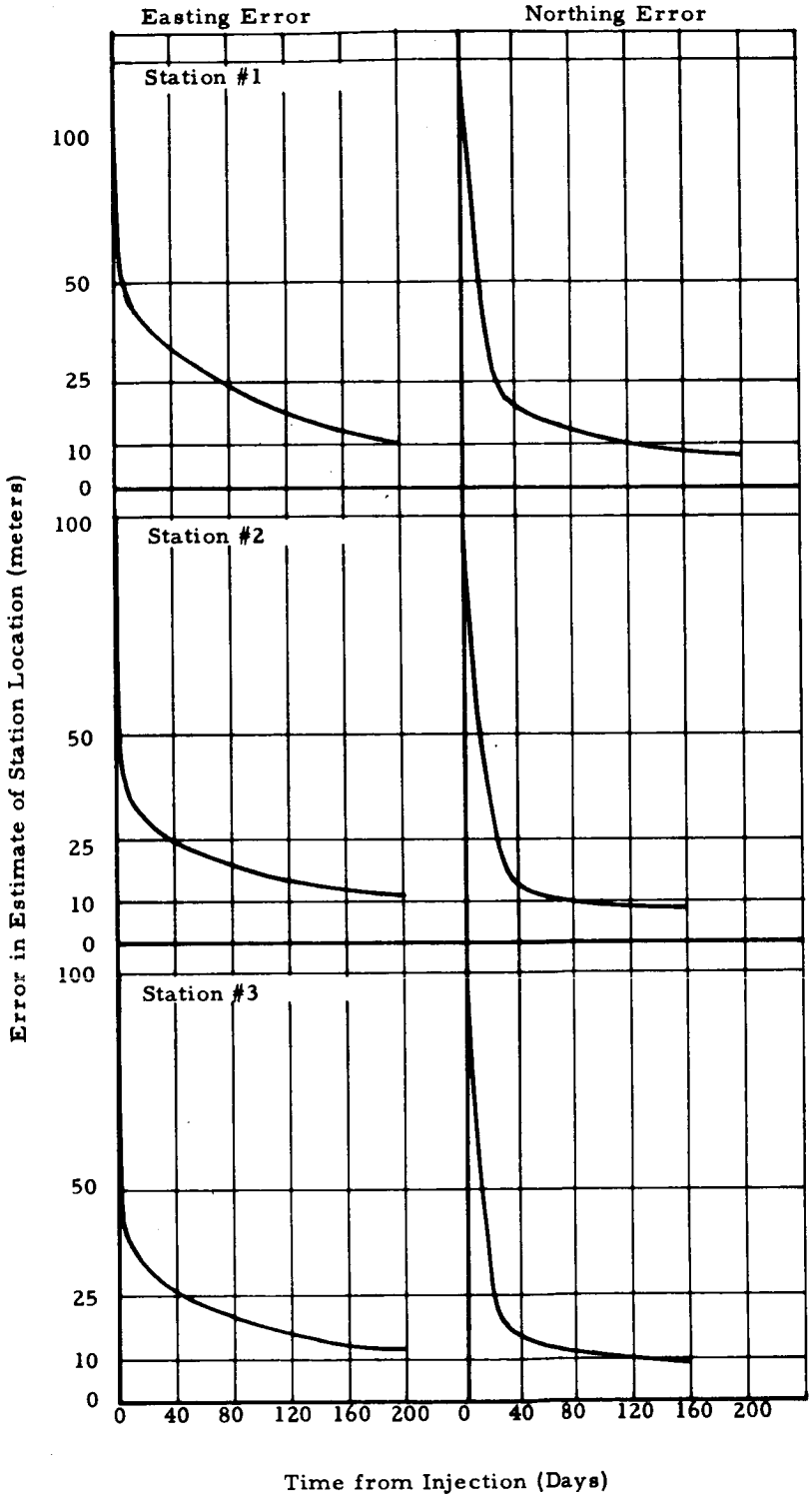
Figure 5-11 DSIF Tracking Data

$\sigma_N = 15.4$ Km $\sigma_V = 20.2$ Km $\sigma_W = 84.0$ Km $\sigma_{\dot{N}} = .37$ cm/sec $\sigma_{\dot{V}} = .07$ cm/sec $\sigma_{\dot{W}} = 1.2$ cm/sec

Normalized Covariance Matrix

	N	V	W	$\dot{N}$	$\dot{V}$	$\dot{W}$
N	1.0	-0.775	0.046	0.963	-0.626	0.046
V		1.0	-0.007	-0.907	0.323	-0.007
W			-1.0	0.031	-0.067	0.999
$\dot{N}$	Symmetric Matrix			1.0	-0.396	0.031
$\dot{V}$					1.0	-0.067
$\dot{W}$						1.0

Figure 5-12 Covariance Matrix in NVW Coordinates of Error in Estimate of the State After 200 Days of DSIF Tracking



Nominal Trajectory
DSIF Tracking
$\sigma_{RR} = .2$ m/sec
$\sigma_{Angles} = .2 \cdot 10^{-3}$ rad

Stations

1. Goldstone
2. Johannesburg
3. Womera

Initial Station
Location Errors
100 meters East.
100 meters Nort.

Figure 5-13 Error in Estimate of Station Locations

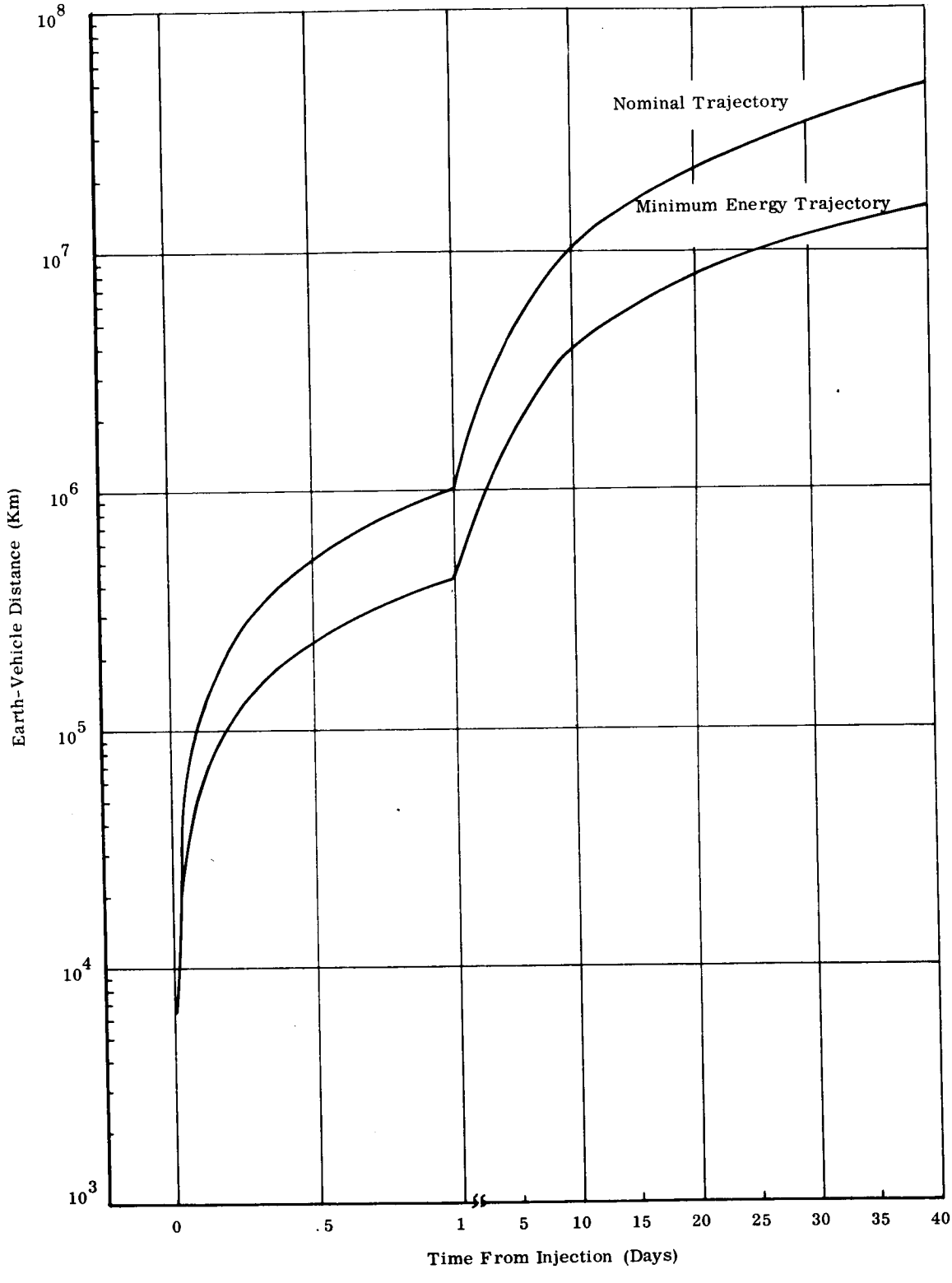


Figure 5-14 Earth-Vehicle Distance

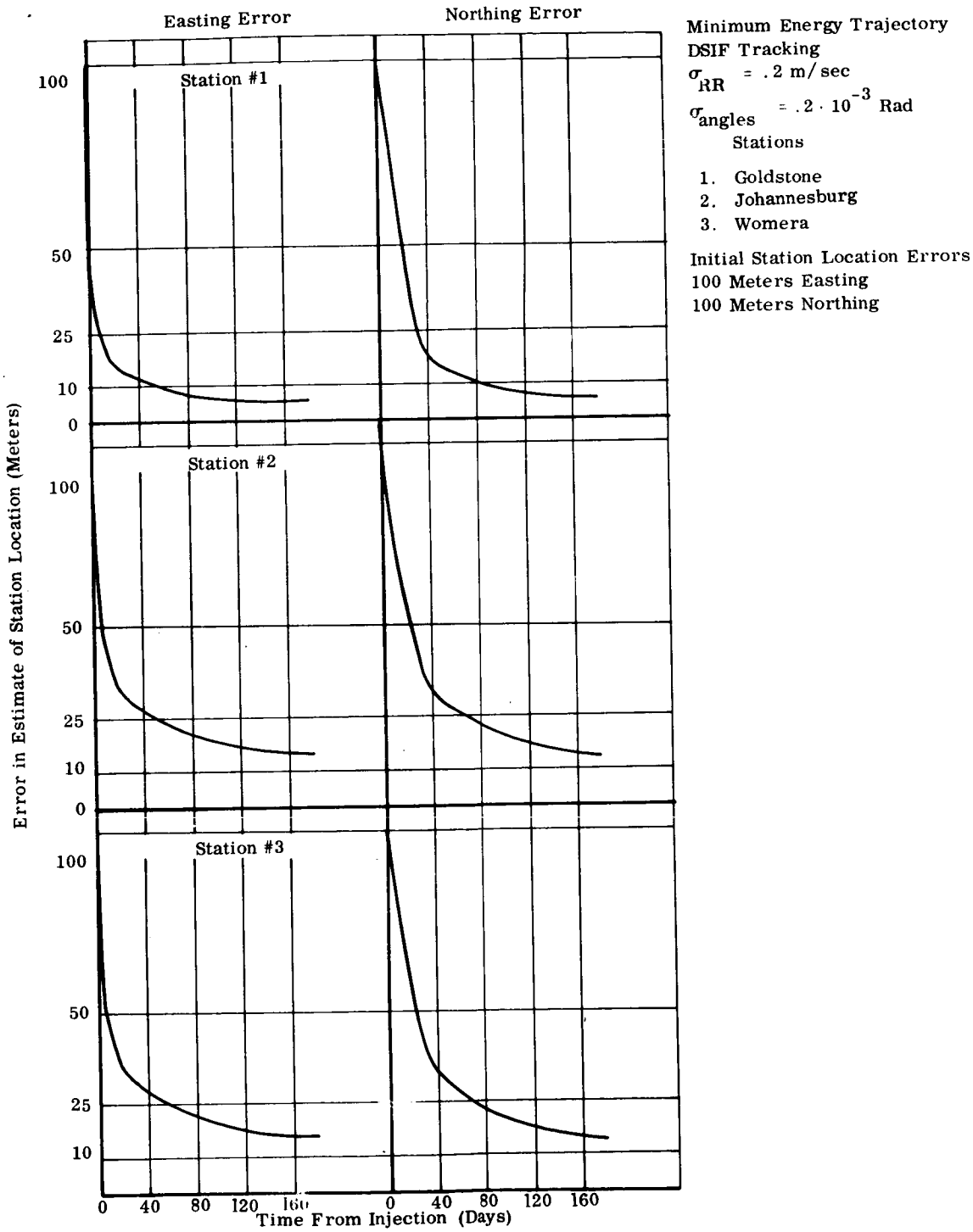


Figure 5-15 Error in Estimate of Station Locations

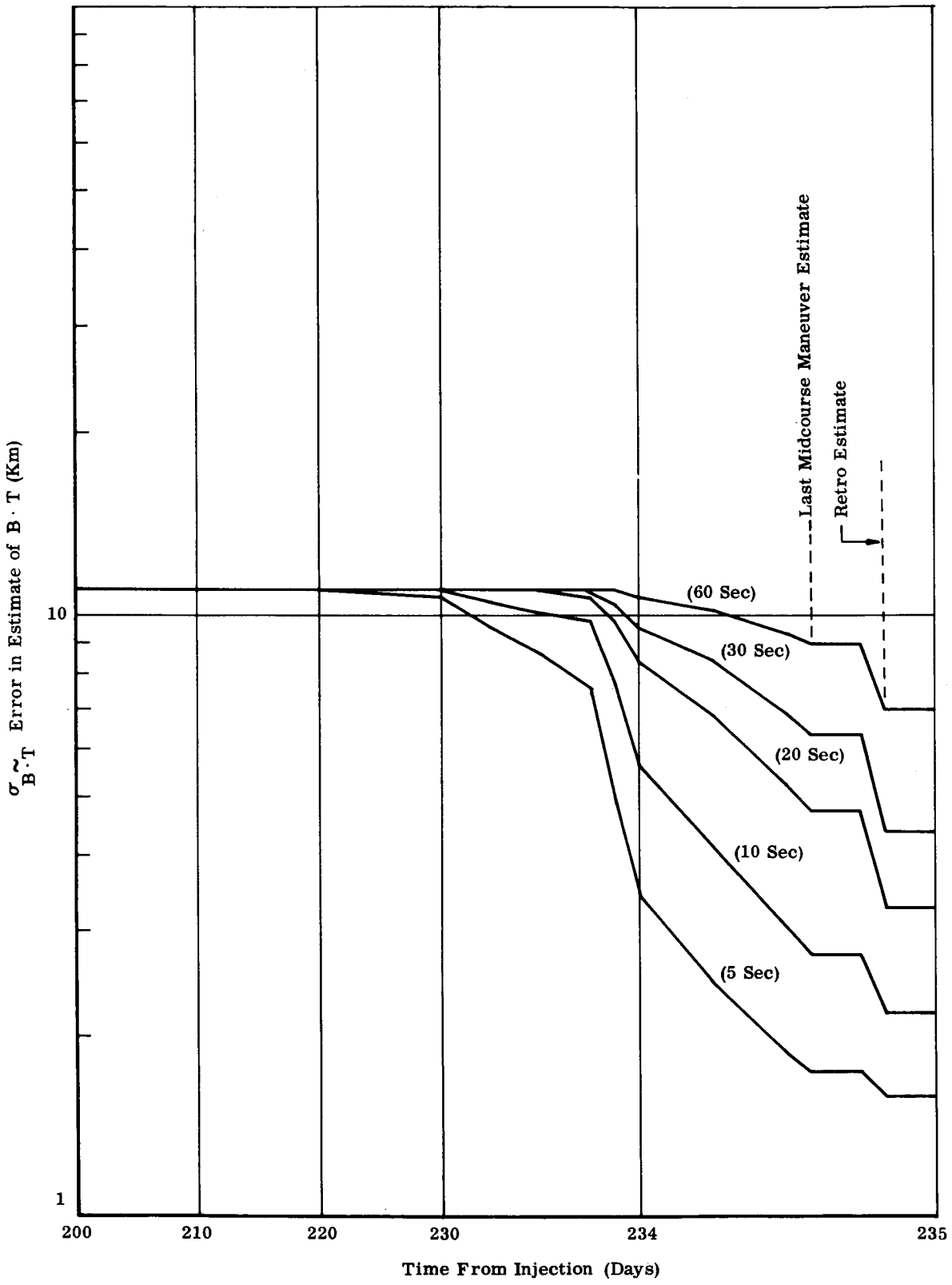


Figure 5-16A System II - DSIF and Onboard Tracking (B · T)

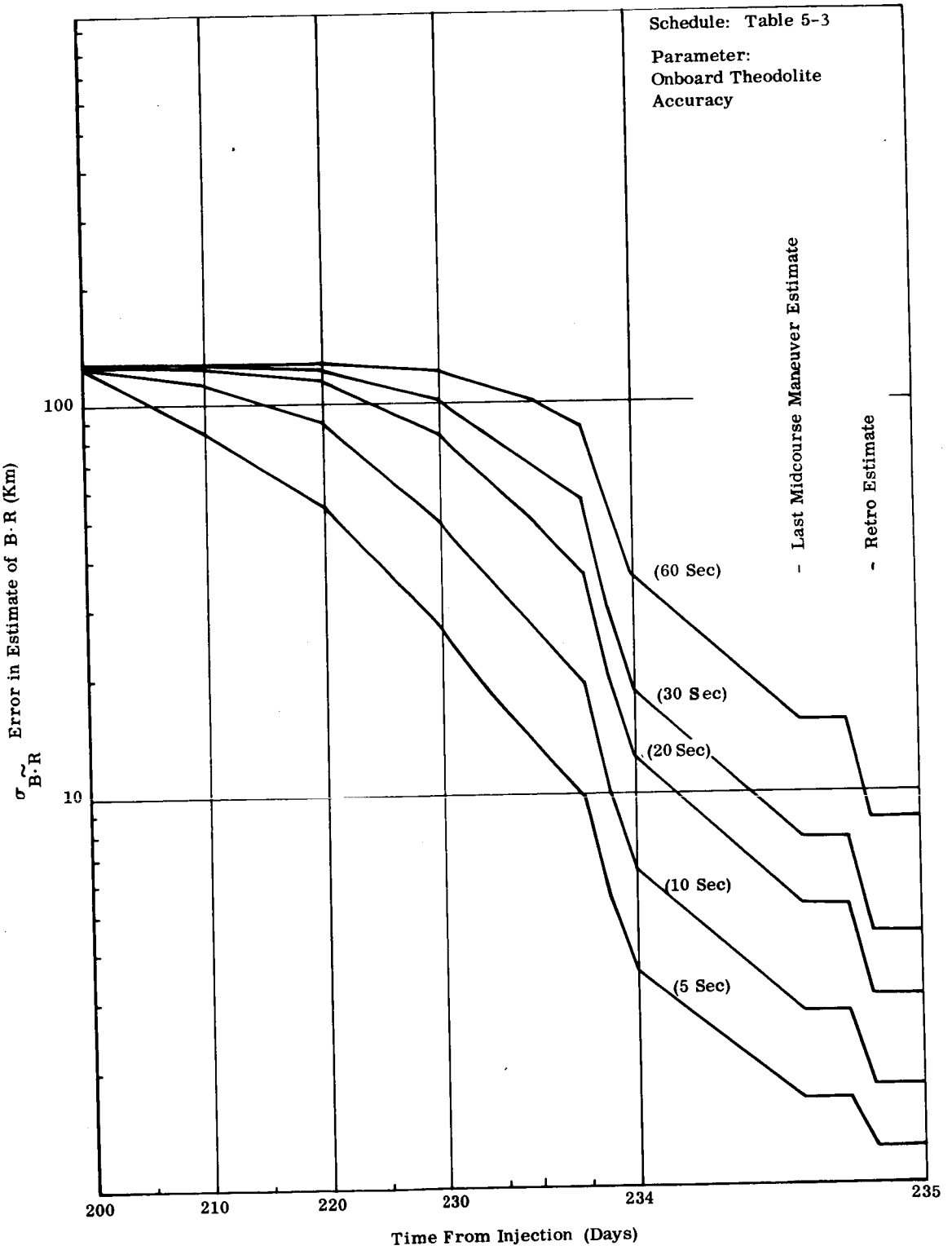


Figure 5-16B System II - DSIF and Onboard Tracking (B · R)

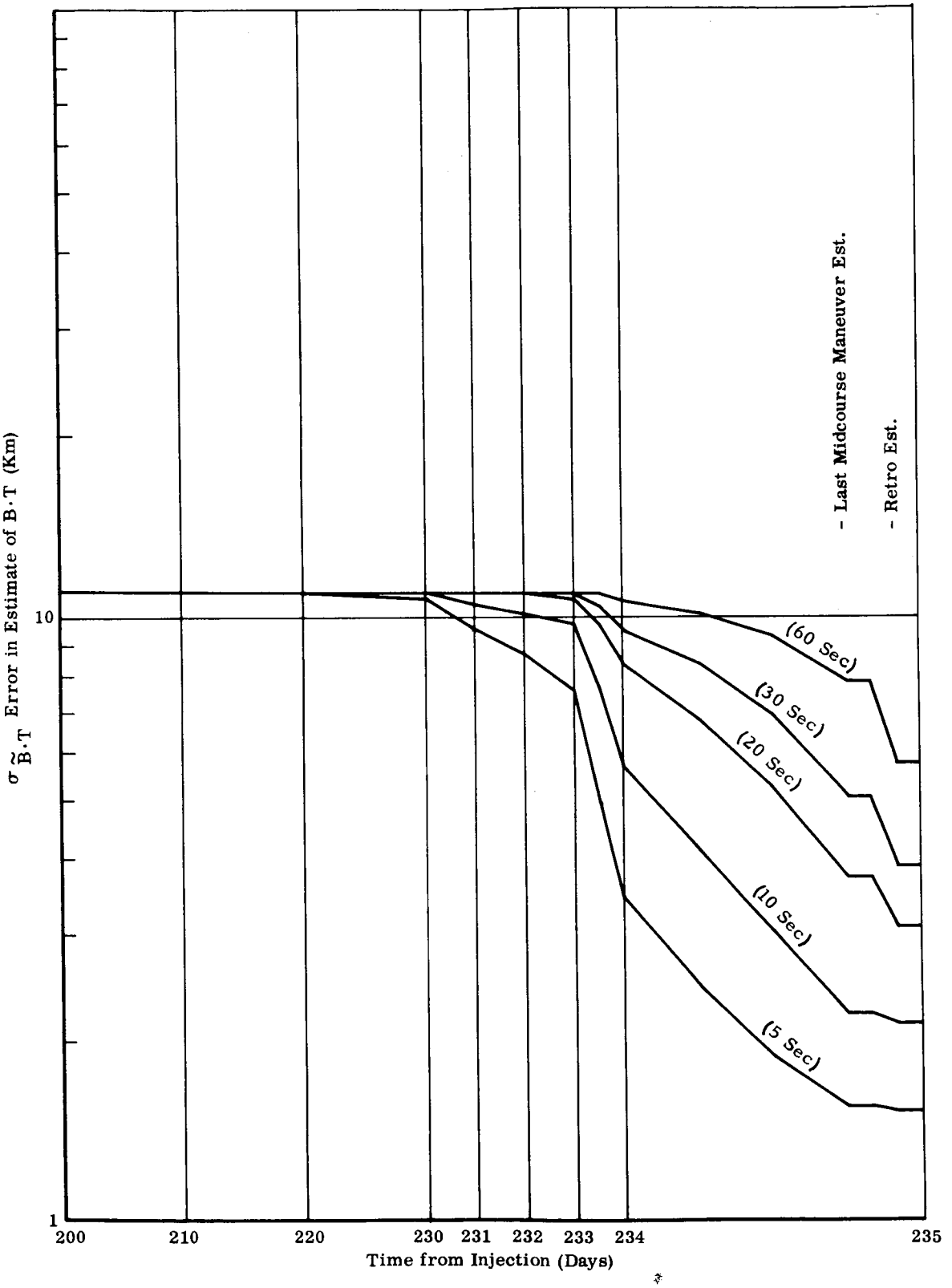


Figure 5-17A System III - DSIF and Onboard Tracking (B · T)

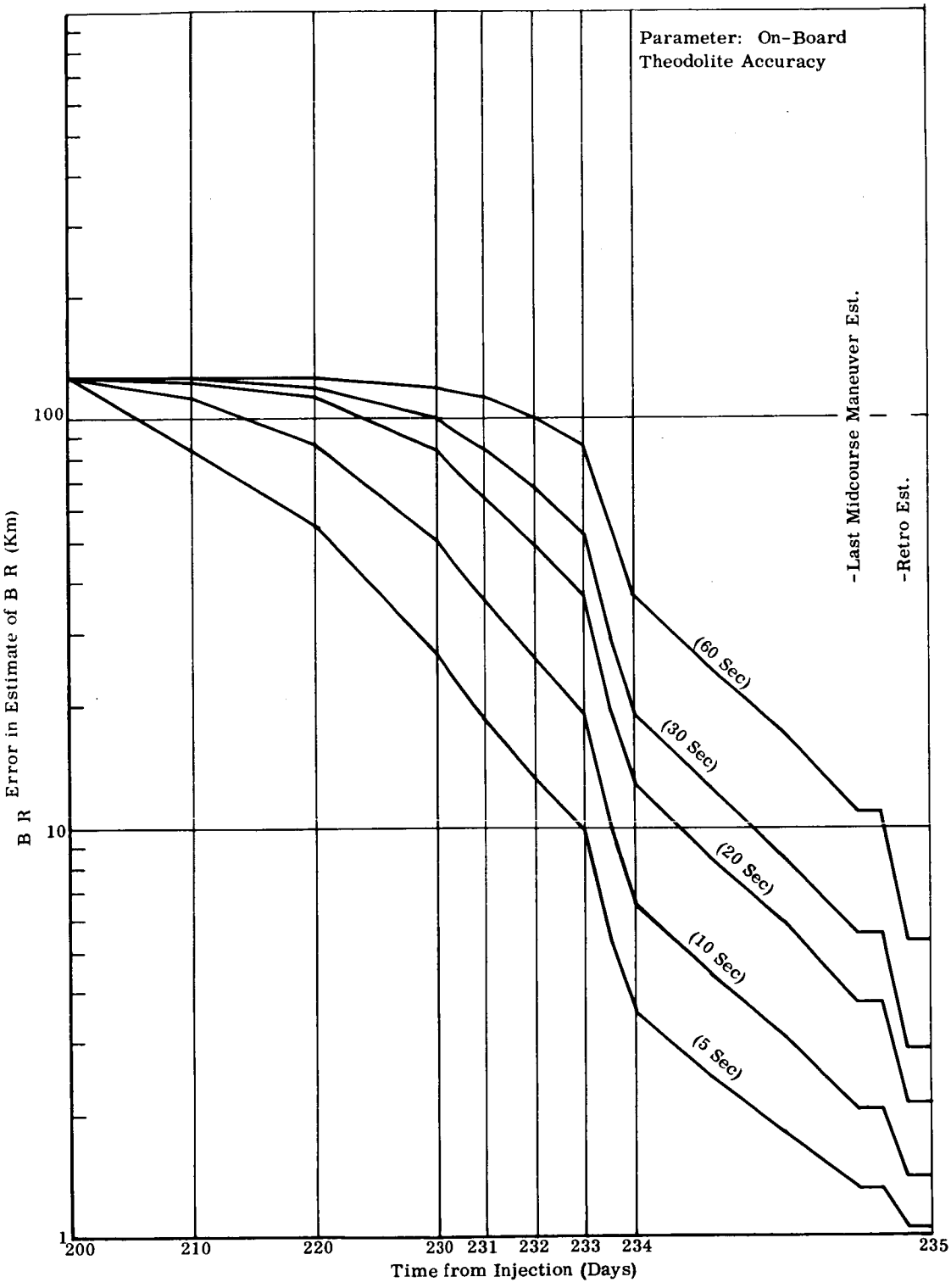


Figure 5-17D System III - DSIF and Onboard Tracking (B • R)

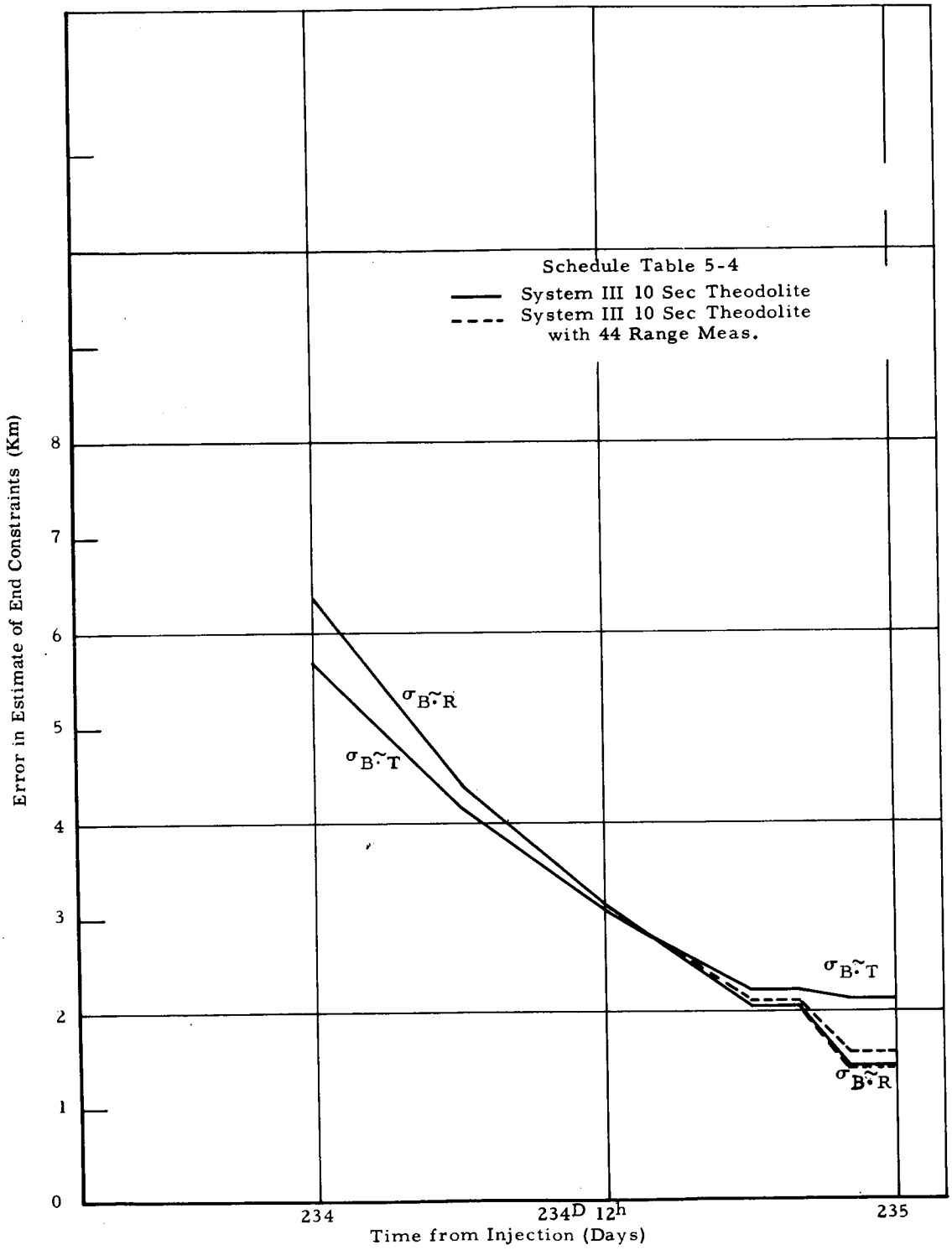


Figure 5-18 System III with Range Measurement

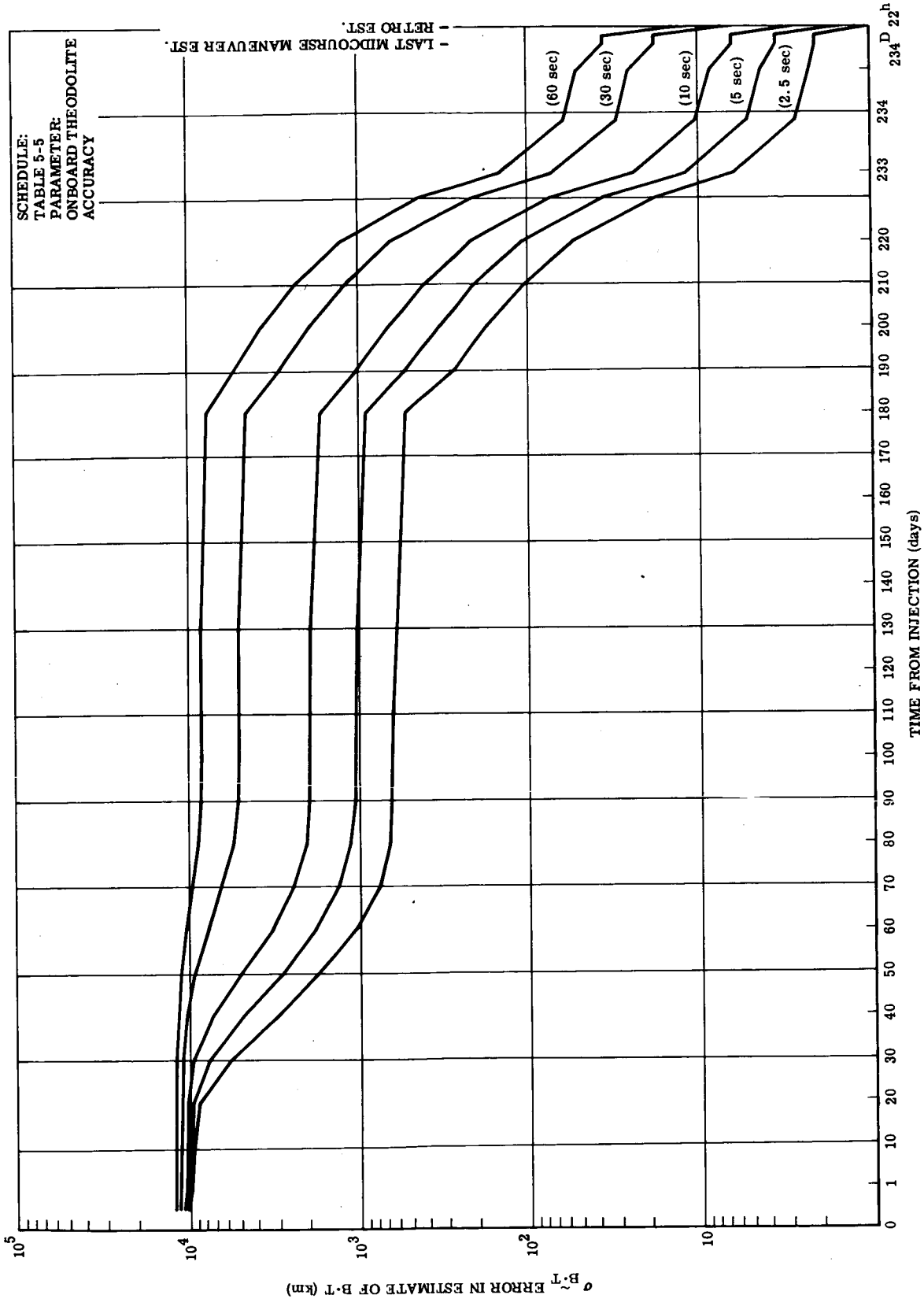


Figure 5-19A System IV, Onboard Only (B · T)

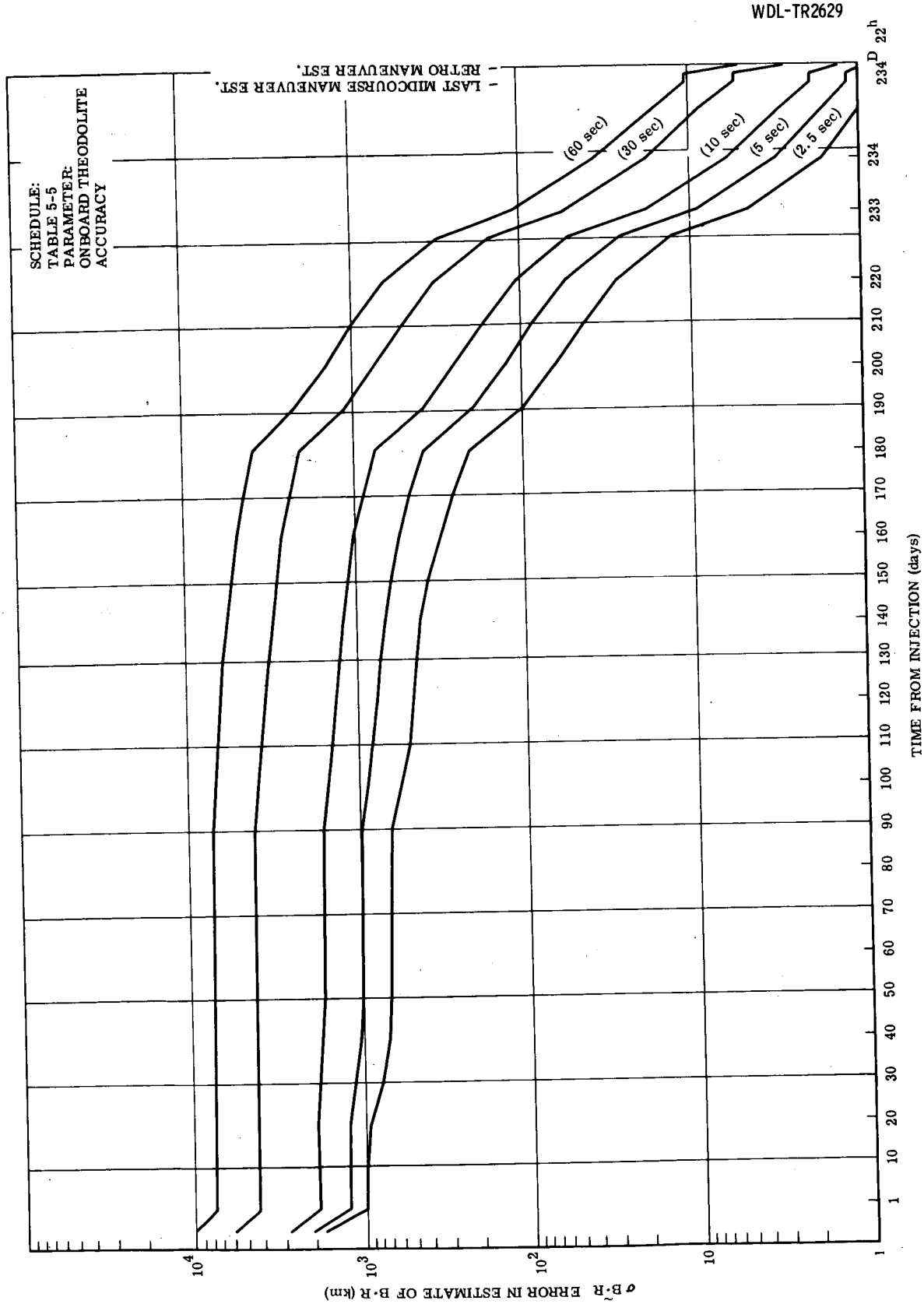


Figure 5-19B System IV, Onboard Only (B · R)

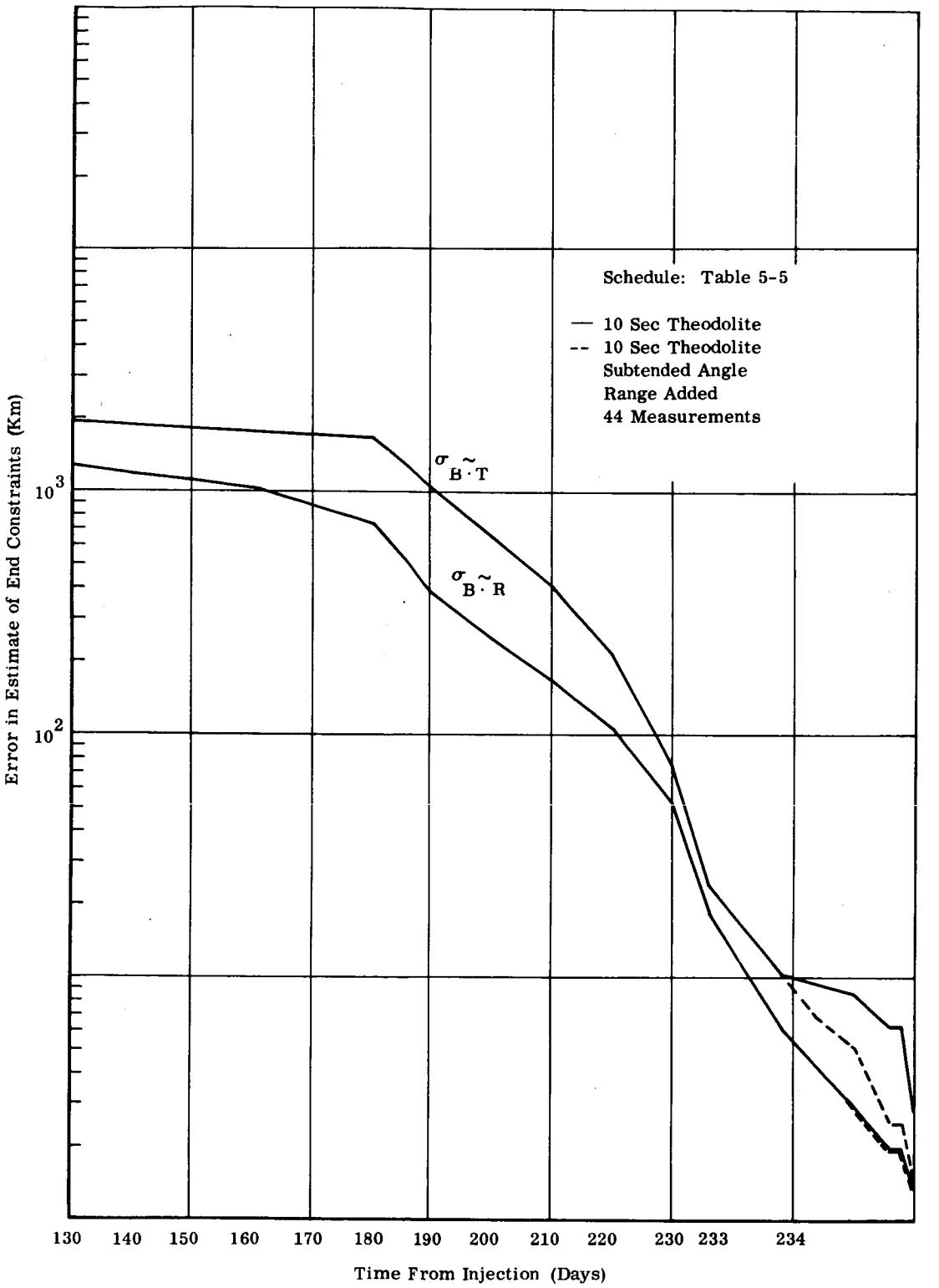


Figure 5-20 System IV with Range Measurements

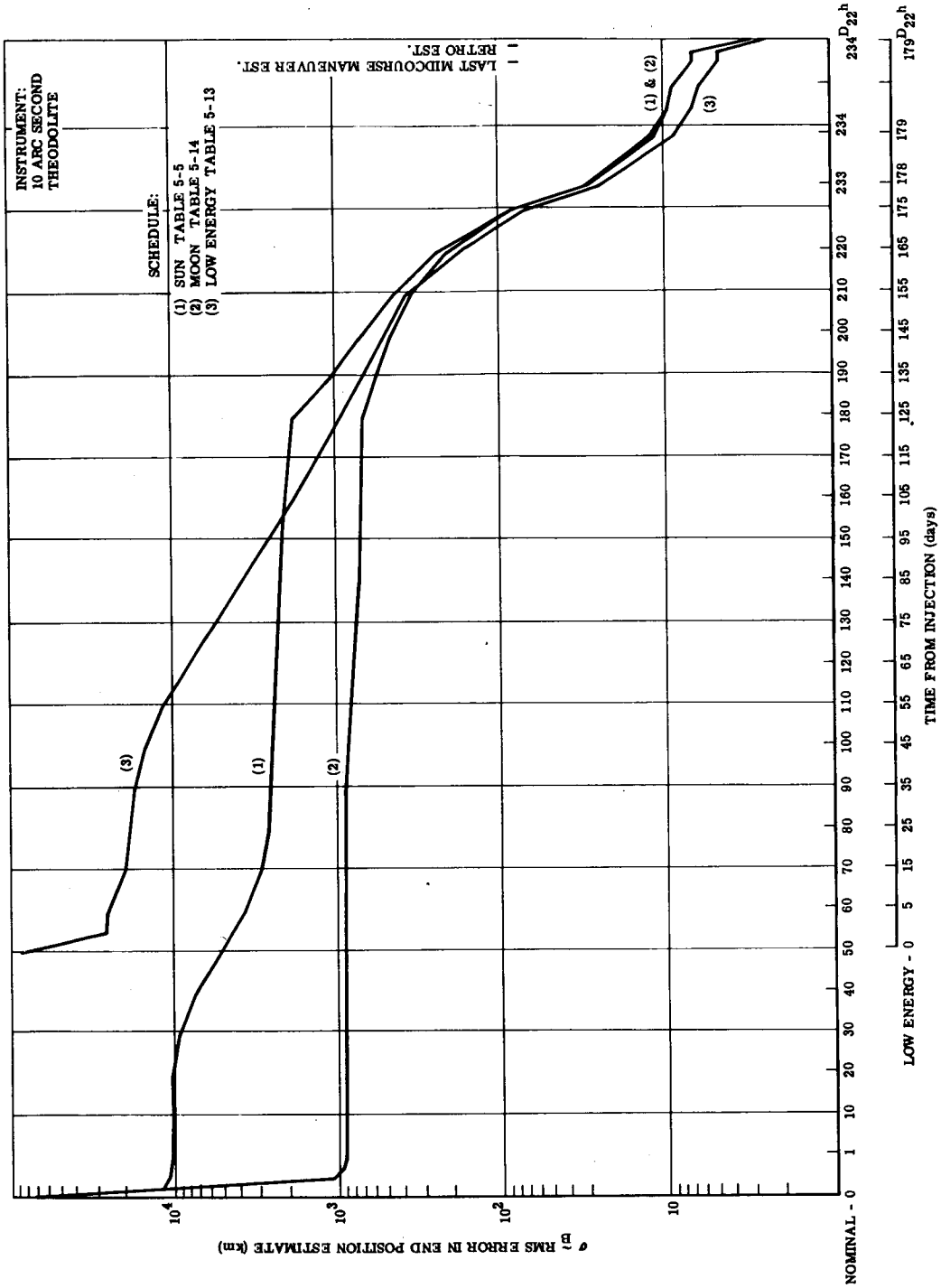


Figure 5-21 Special Cases, System IV

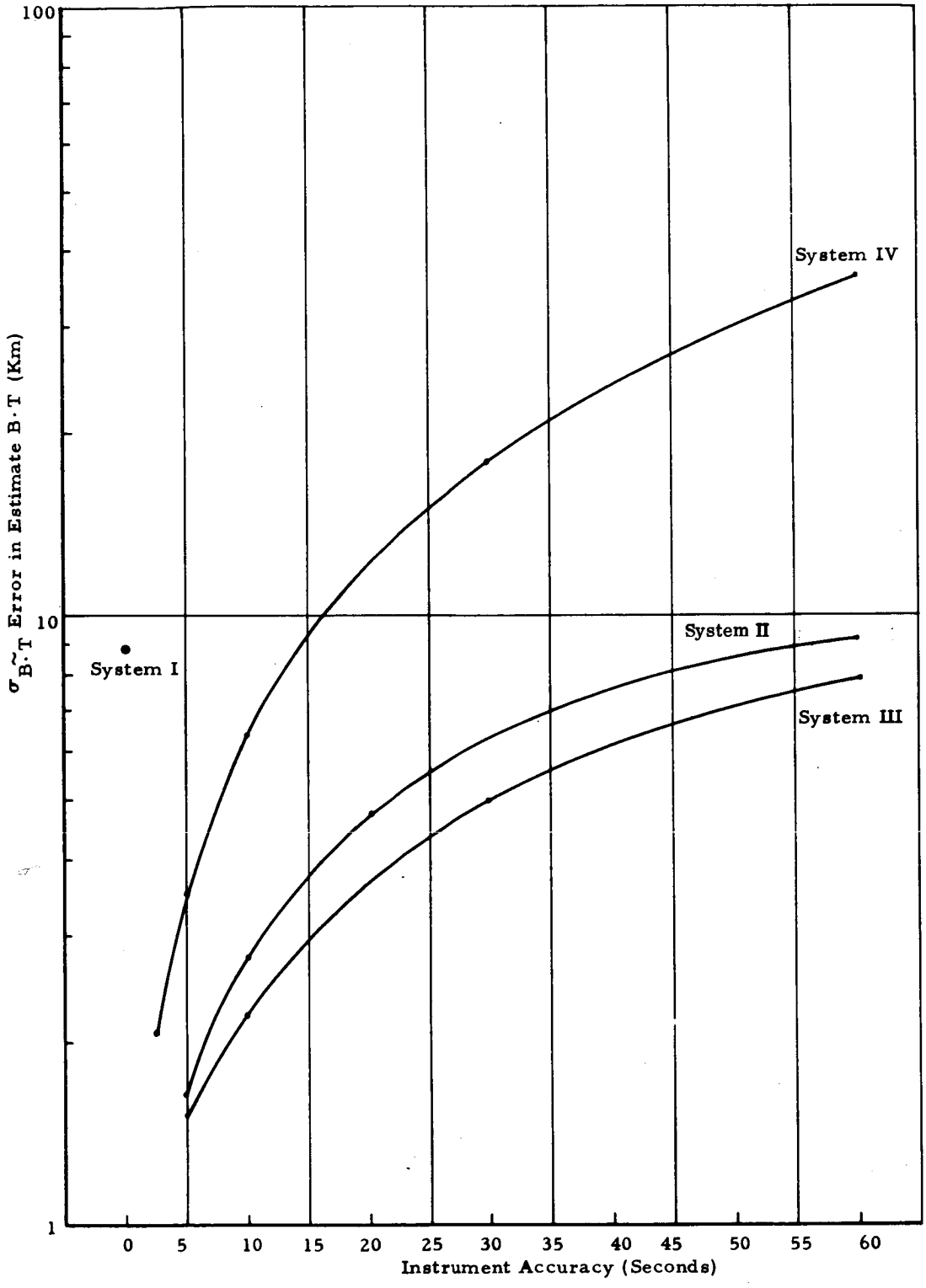


Figure 5-22A Summary of Navigation Performance, Time of Last Maneuver (B • T)

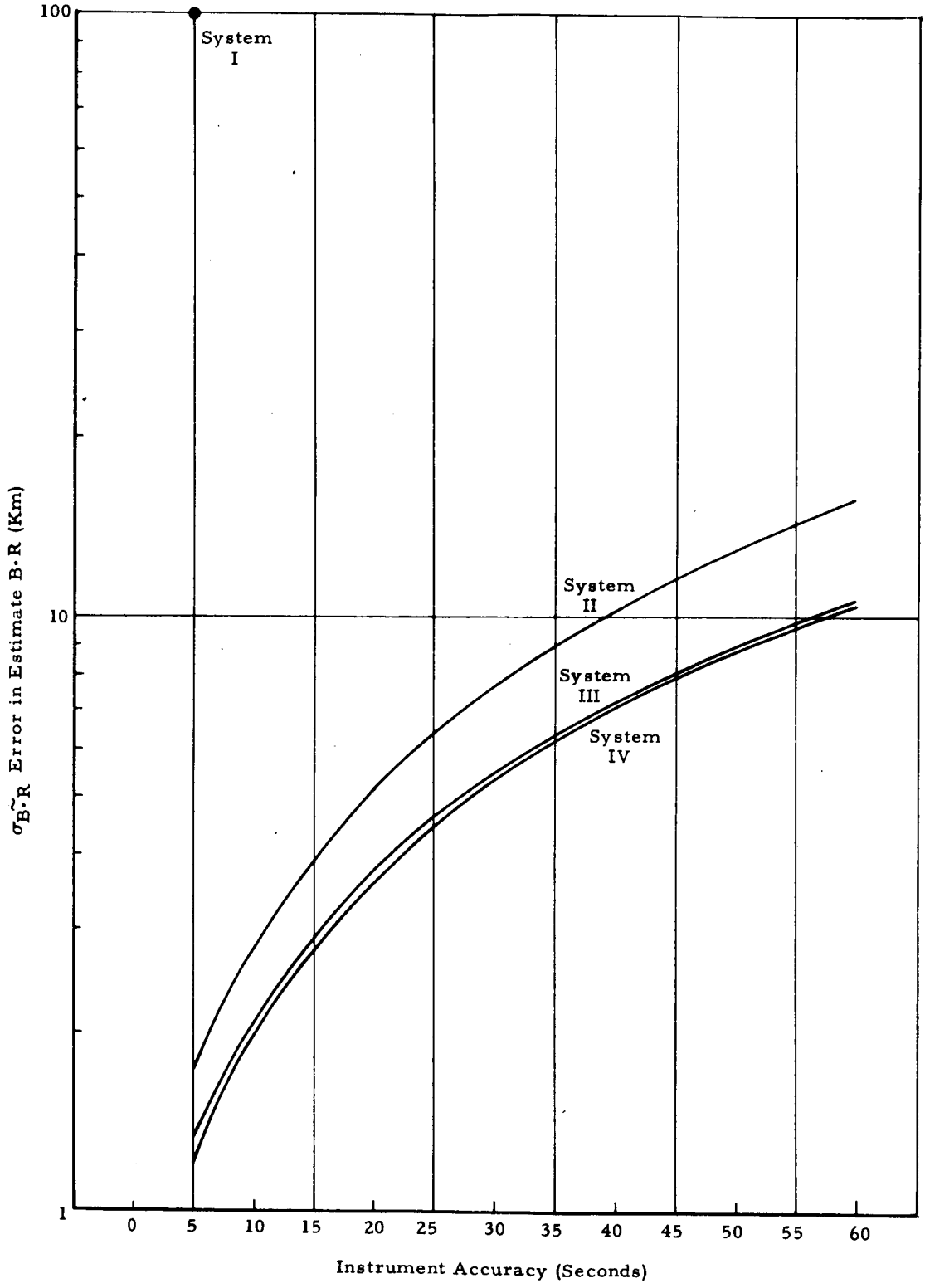


Figure 5-22B Summary of Navigation Performance, Time of Last Maneuver (B · R)

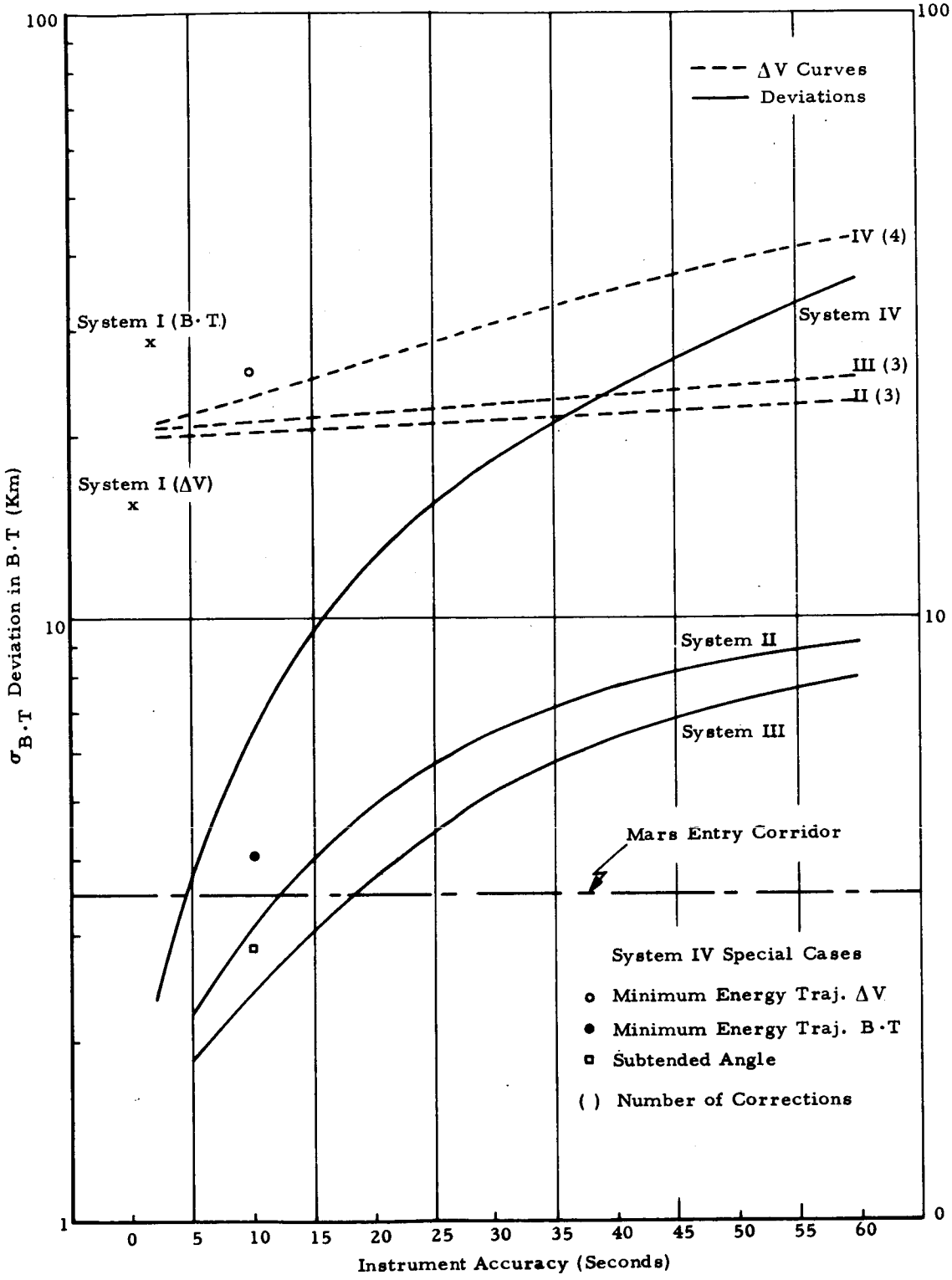


Figure 5-23A Summary of Systems Guidance Performance (B · T)

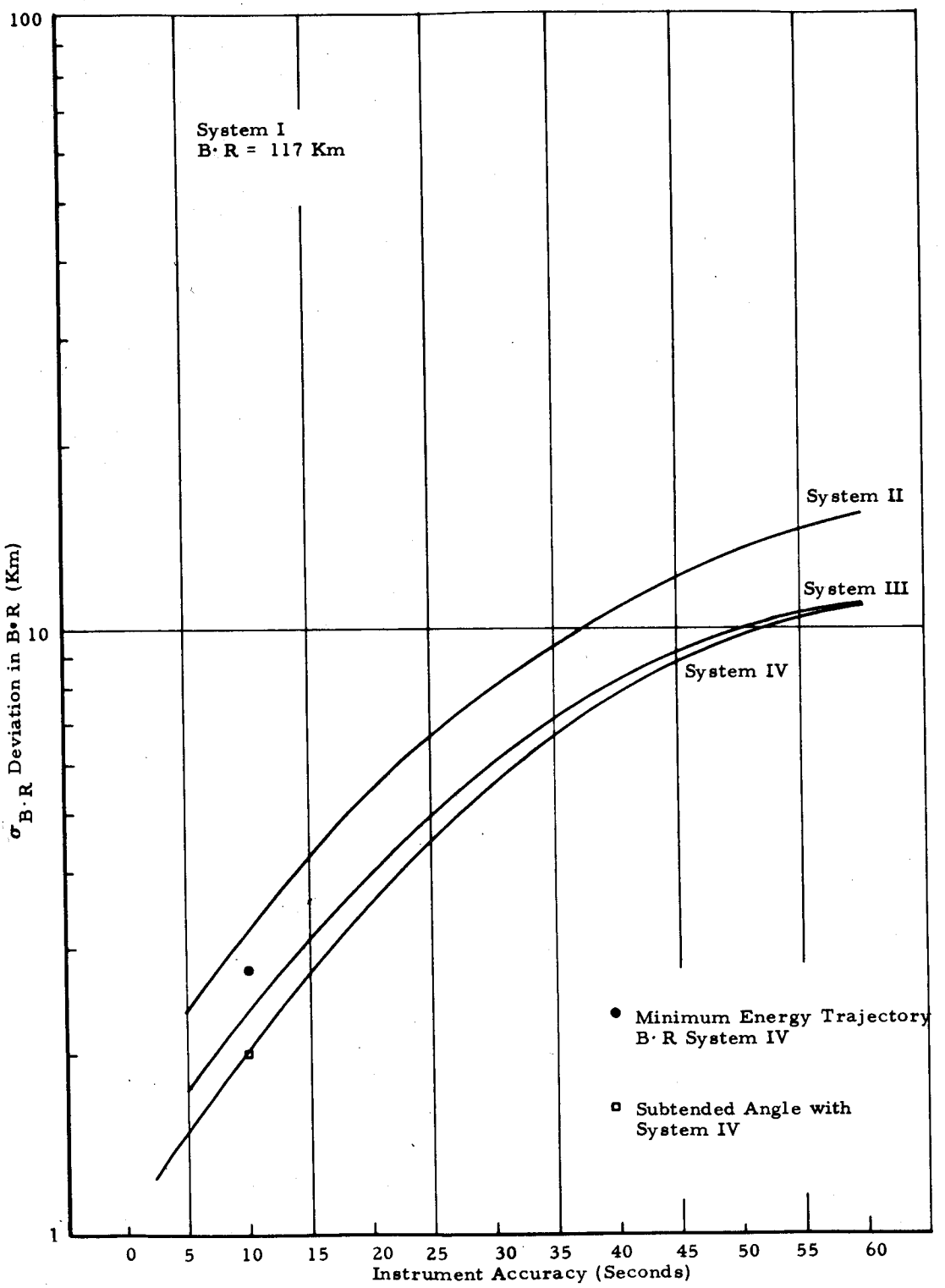


Figure 5-23B Summary of Systems Guidance Performance (B • R)

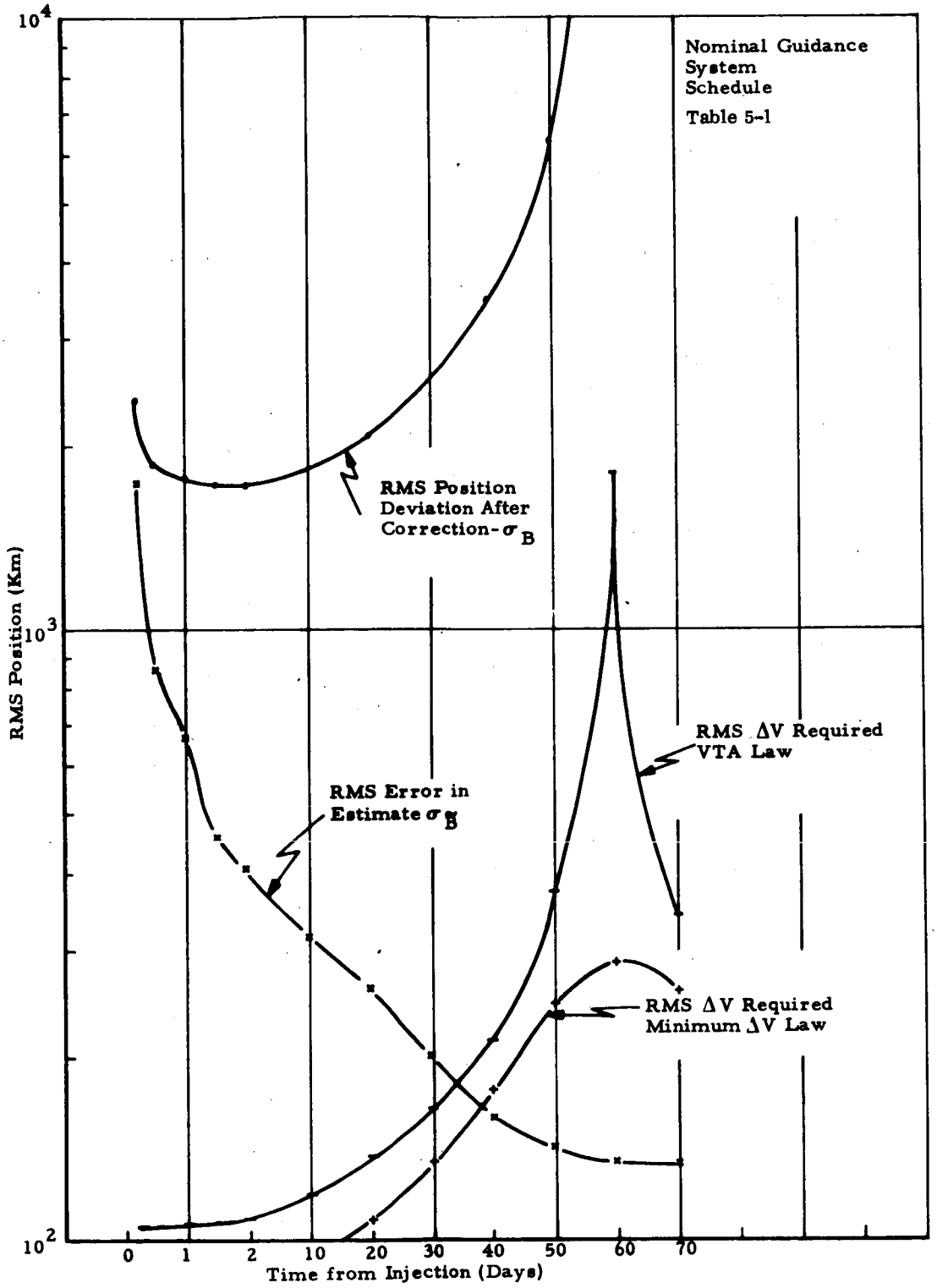


Figure 5-24 System I, First Correction Guidance Data

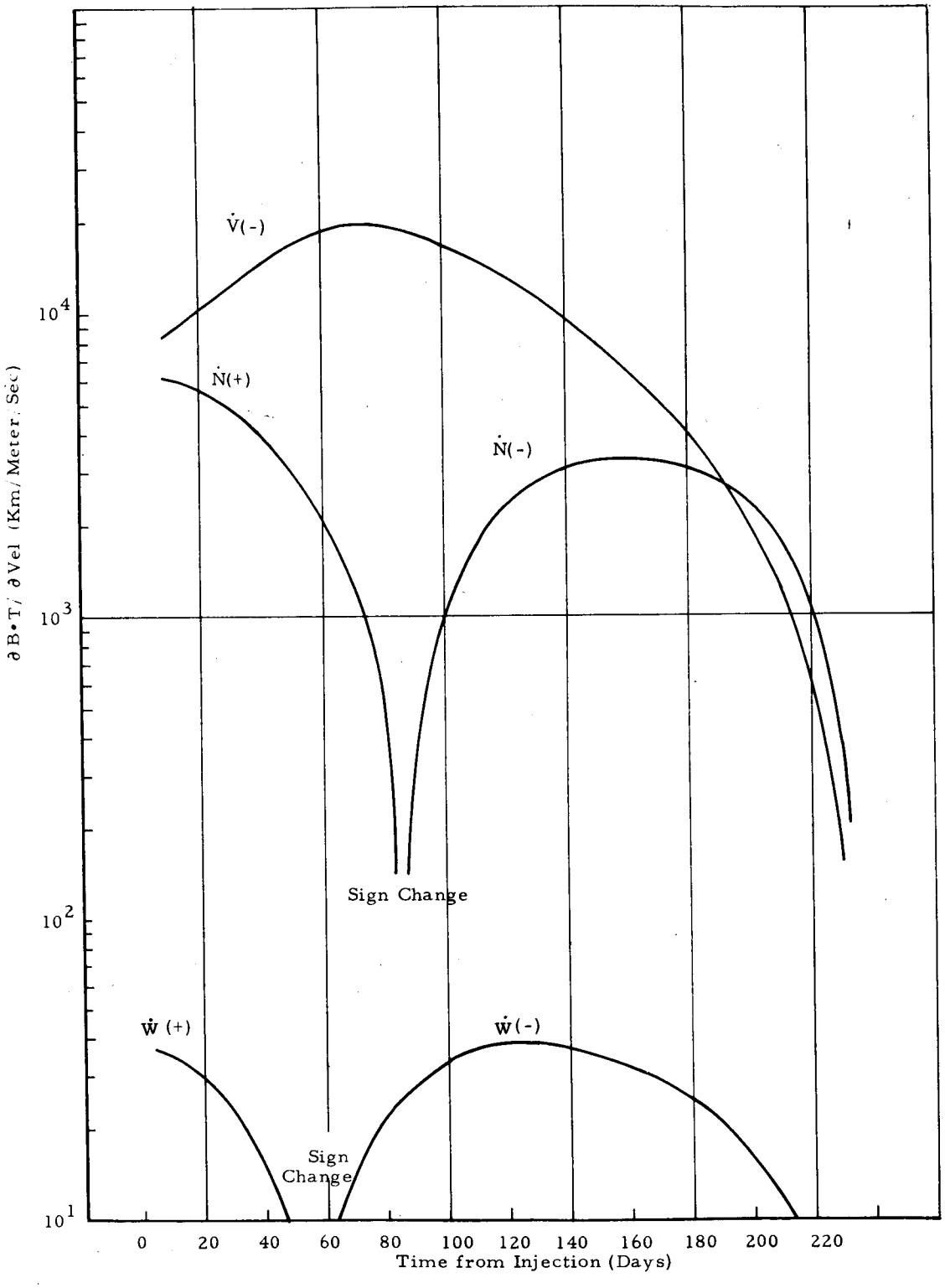


Figure 5-25 B • T Sensitivities to Velocity Changes in the NVW Directions

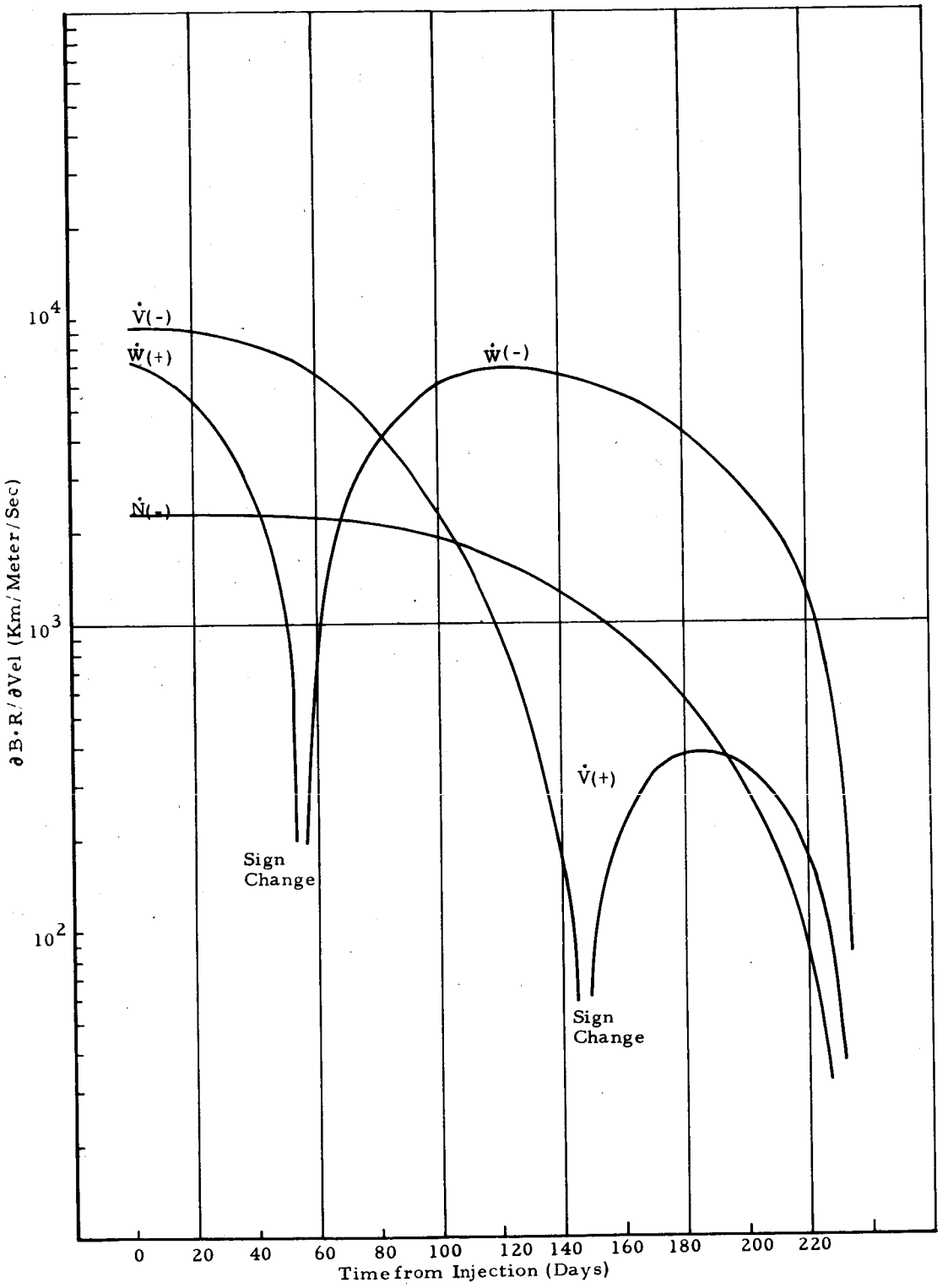


Figure 5-26 B • R Sensitivities to Velocity Changes in the NVW Directions

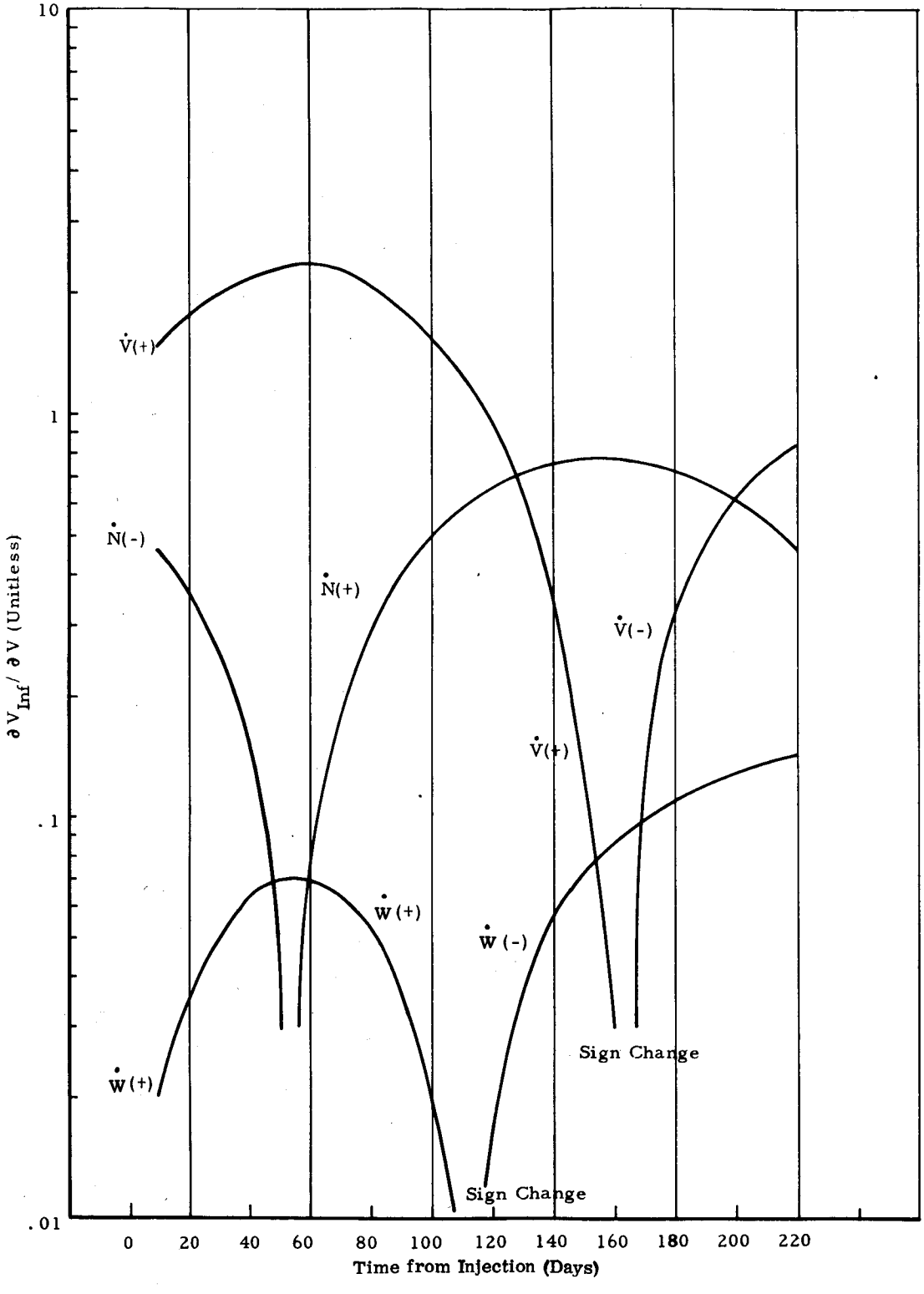


Figure 5-27 V_{INF} Sensitivities to Velocity Changes - NVW Directions

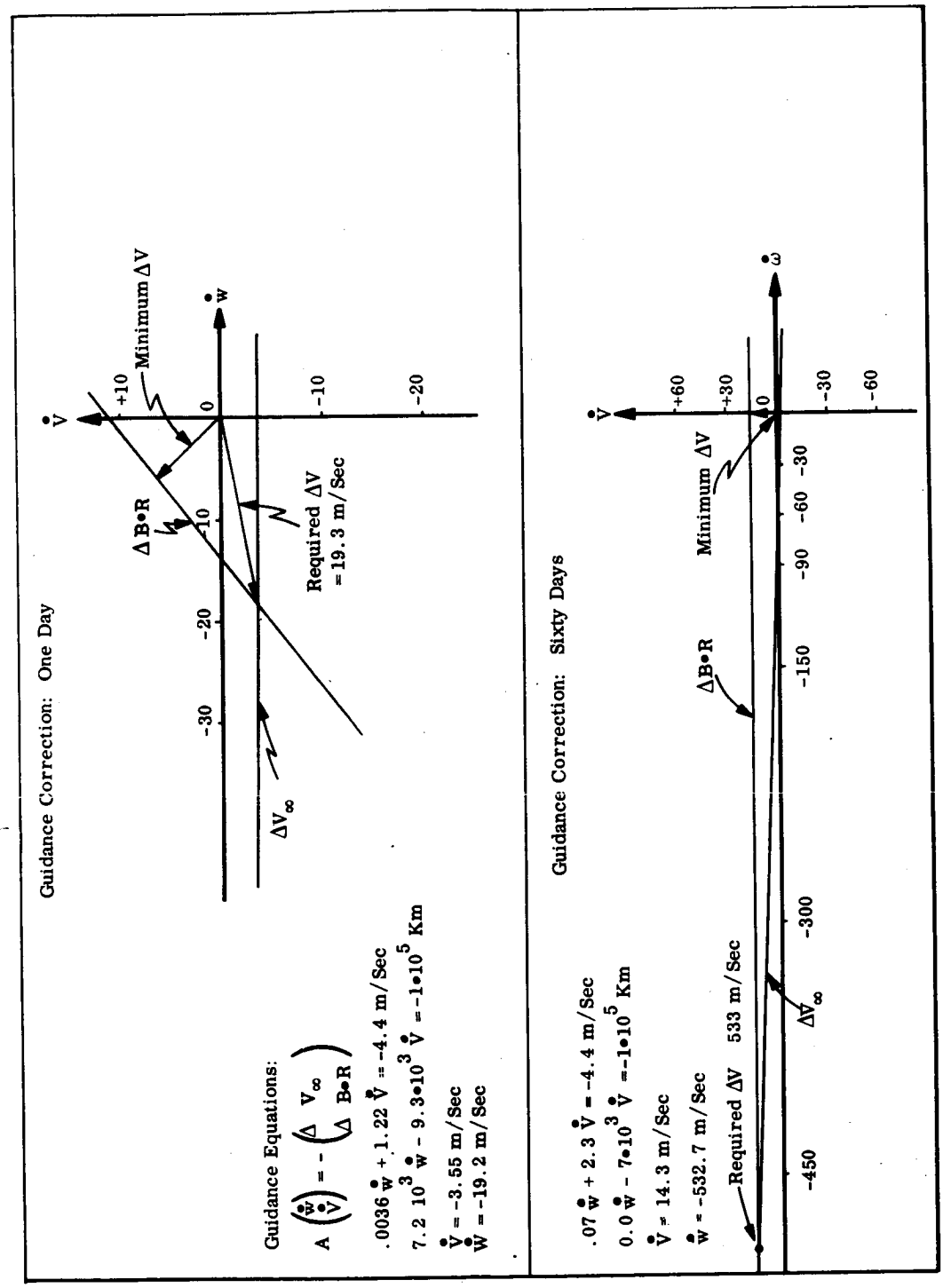


Figure 5-28 Two-Dimensional Illustrations of Required Δv Corrections at One Day and 60 Days

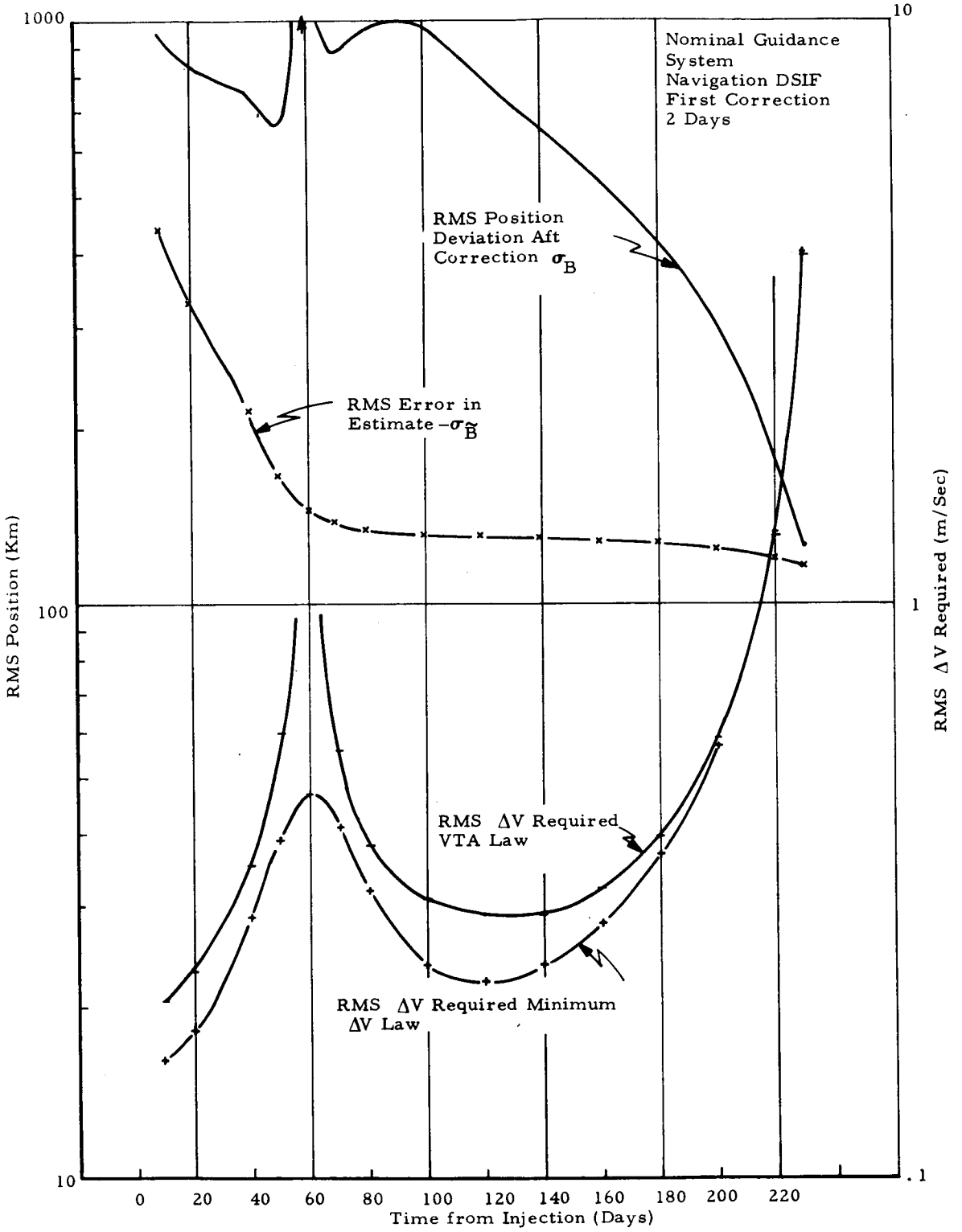


Figure 5-29 System I - Second Correction Guidance Data

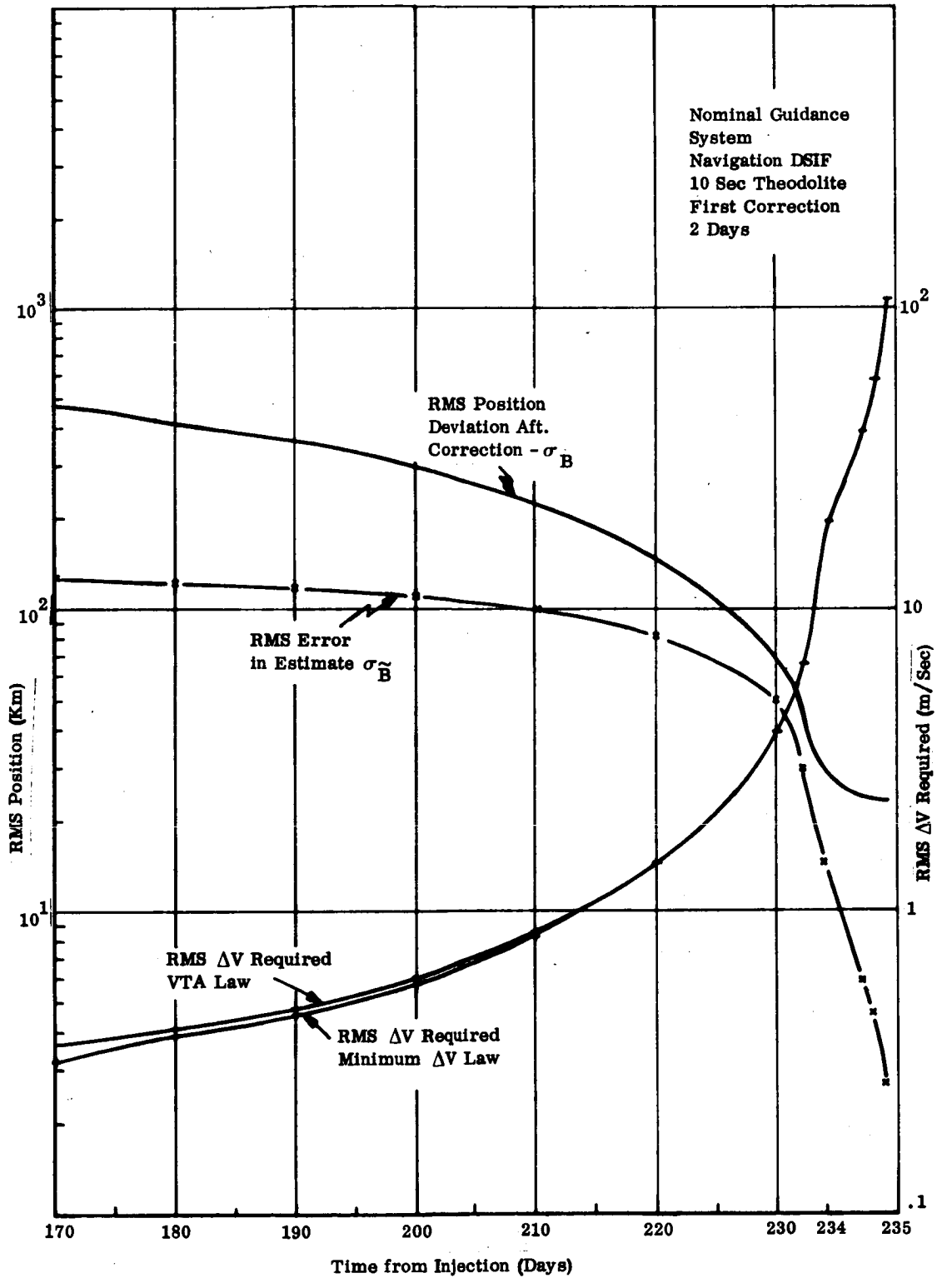


Figure 5-30 Systems II and III, Second Correction Guidance Data

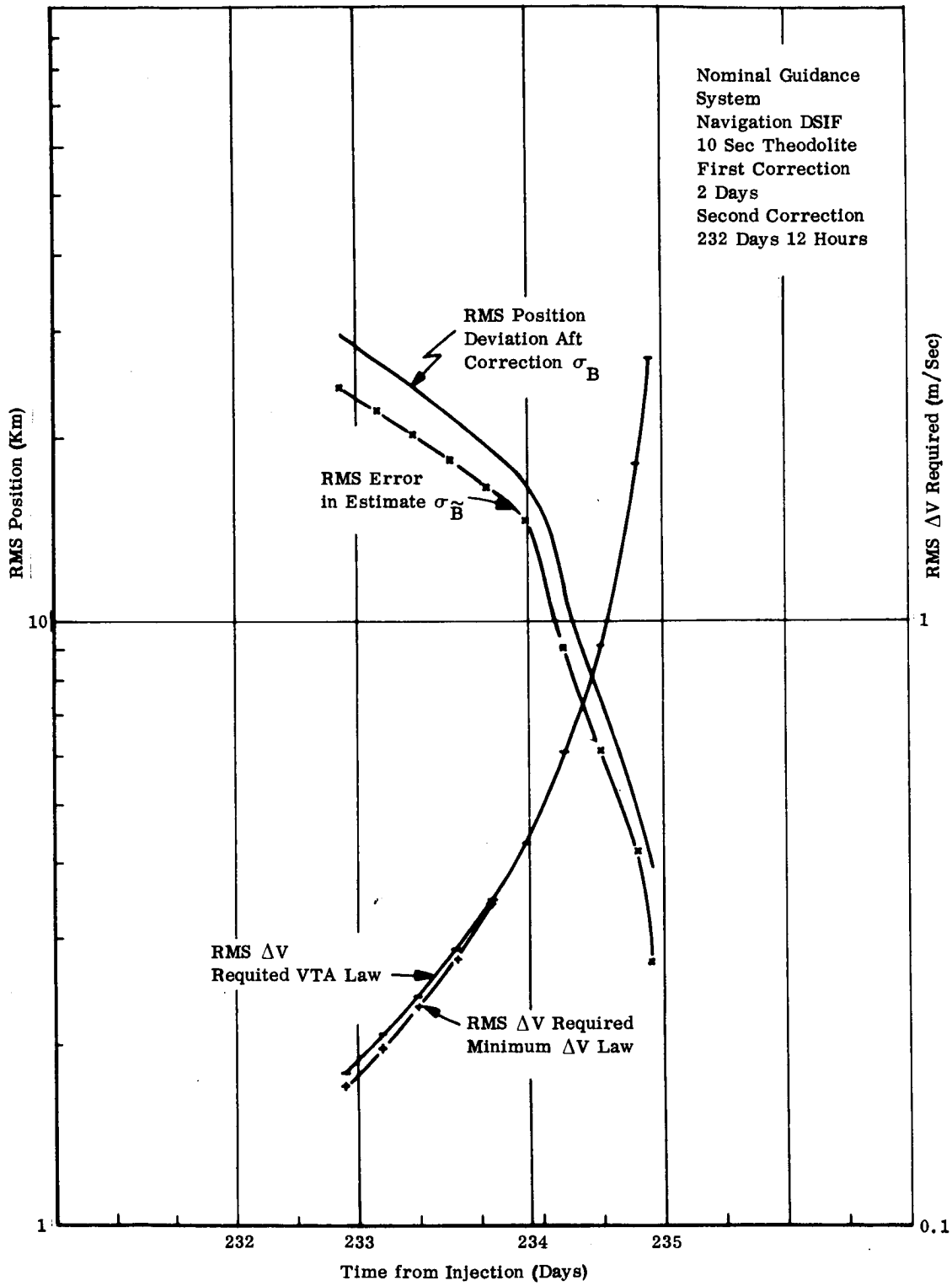


Figure 5-31 Systems II and III, Third Correction Guidance Data

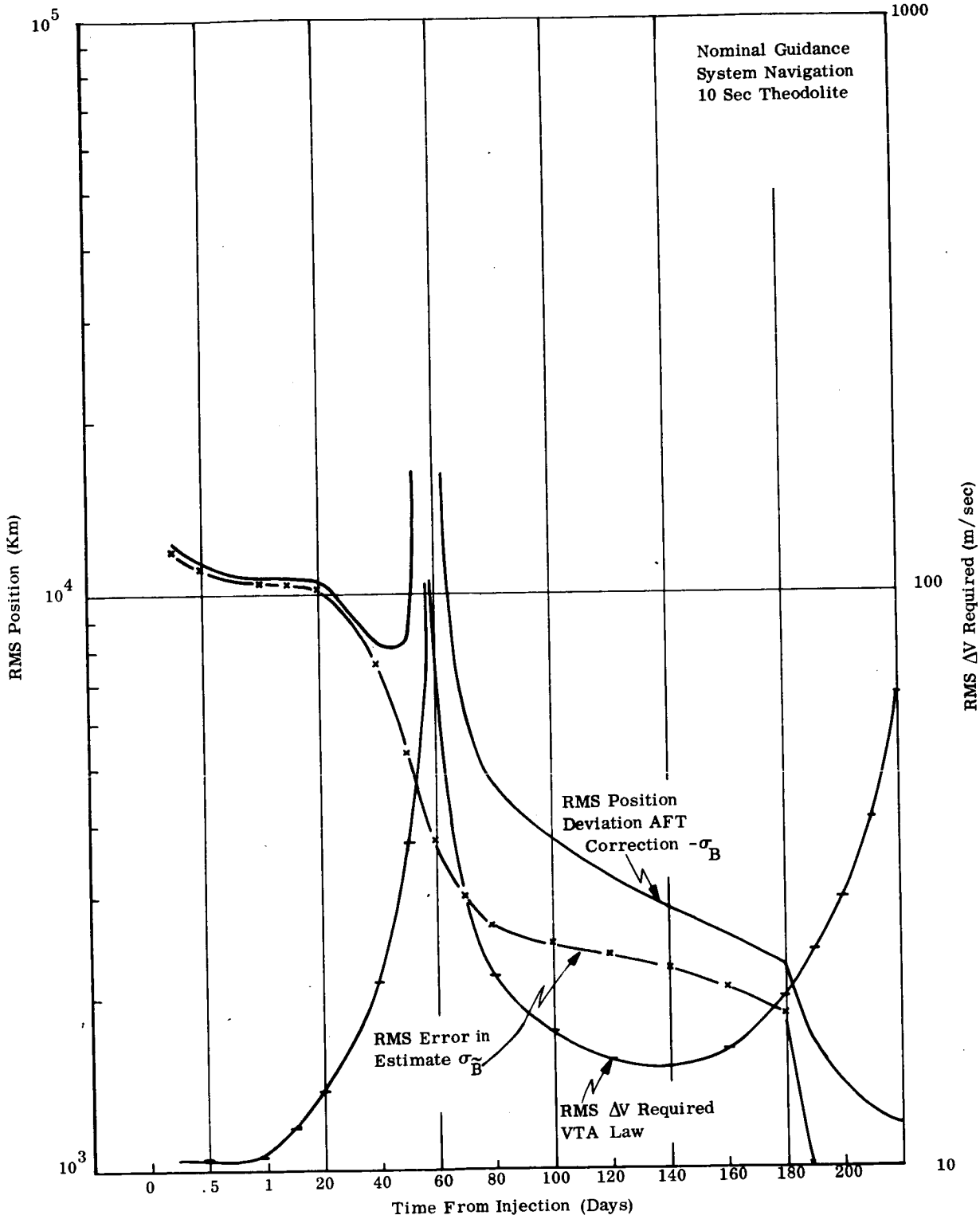


Figure 5-32 System IV, First Correction Guidance Data

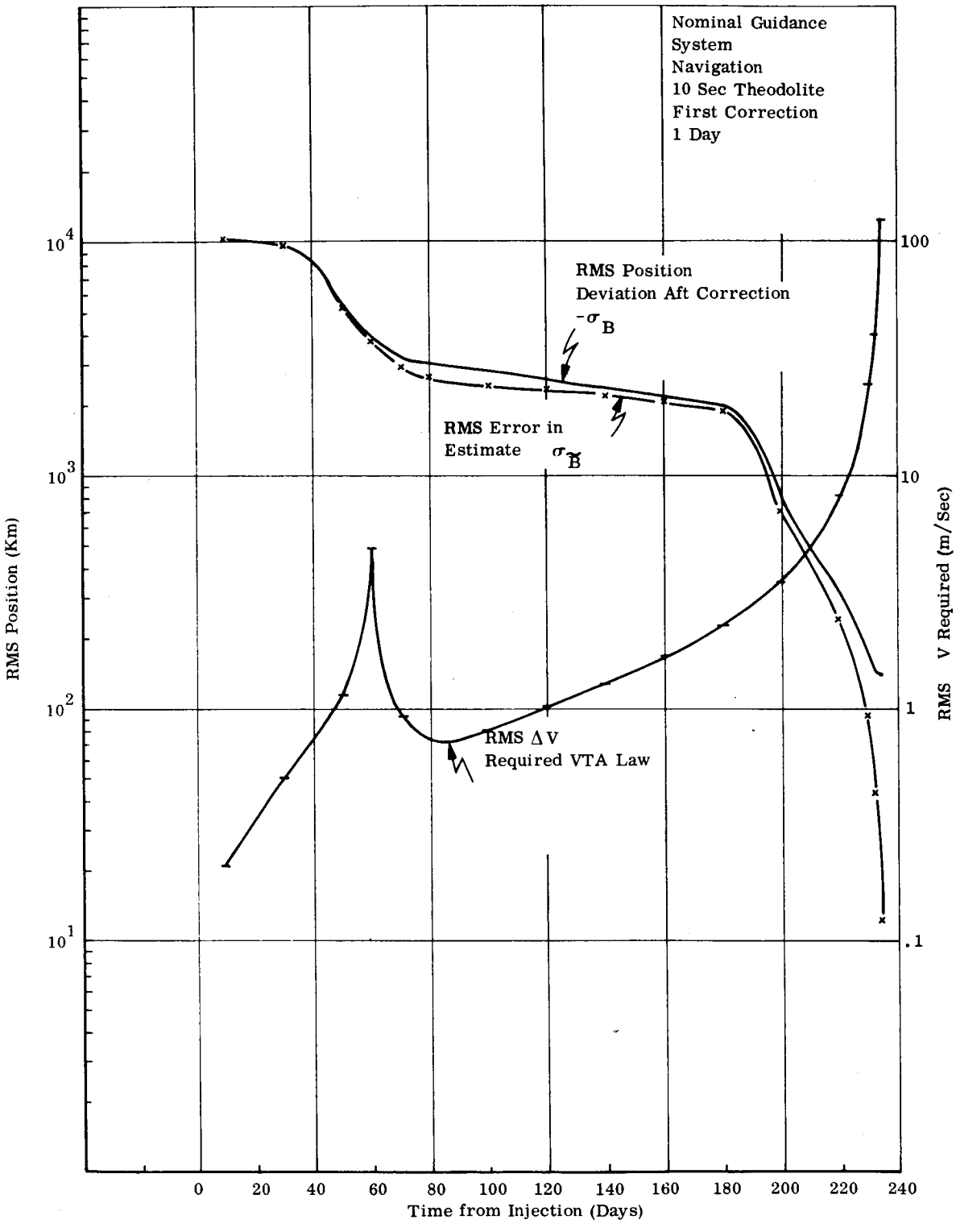


Figure 5-33 System IV - Second Correction Guidance Data

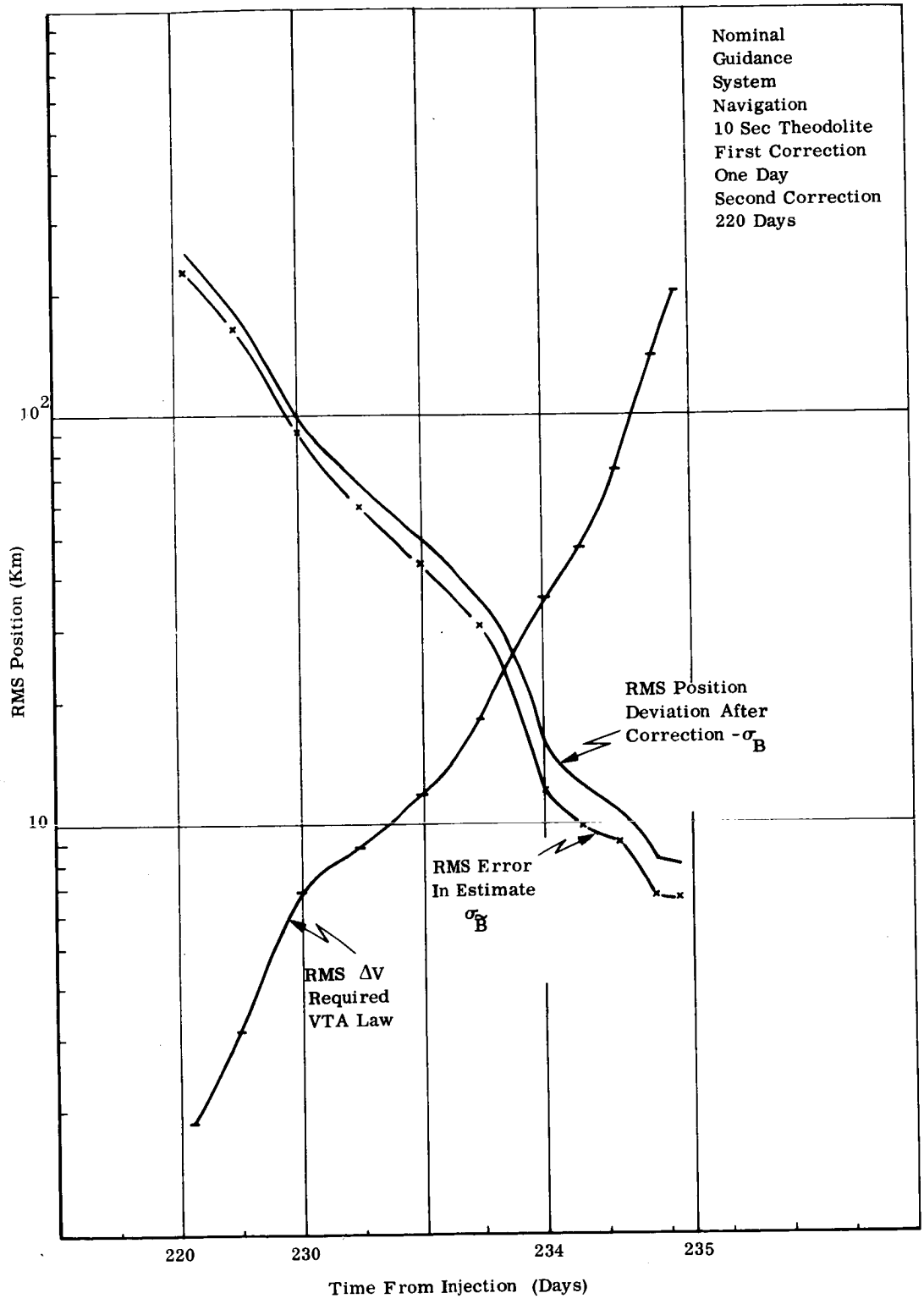


Figure 5-34 System IV - Third Correction Guidance Data

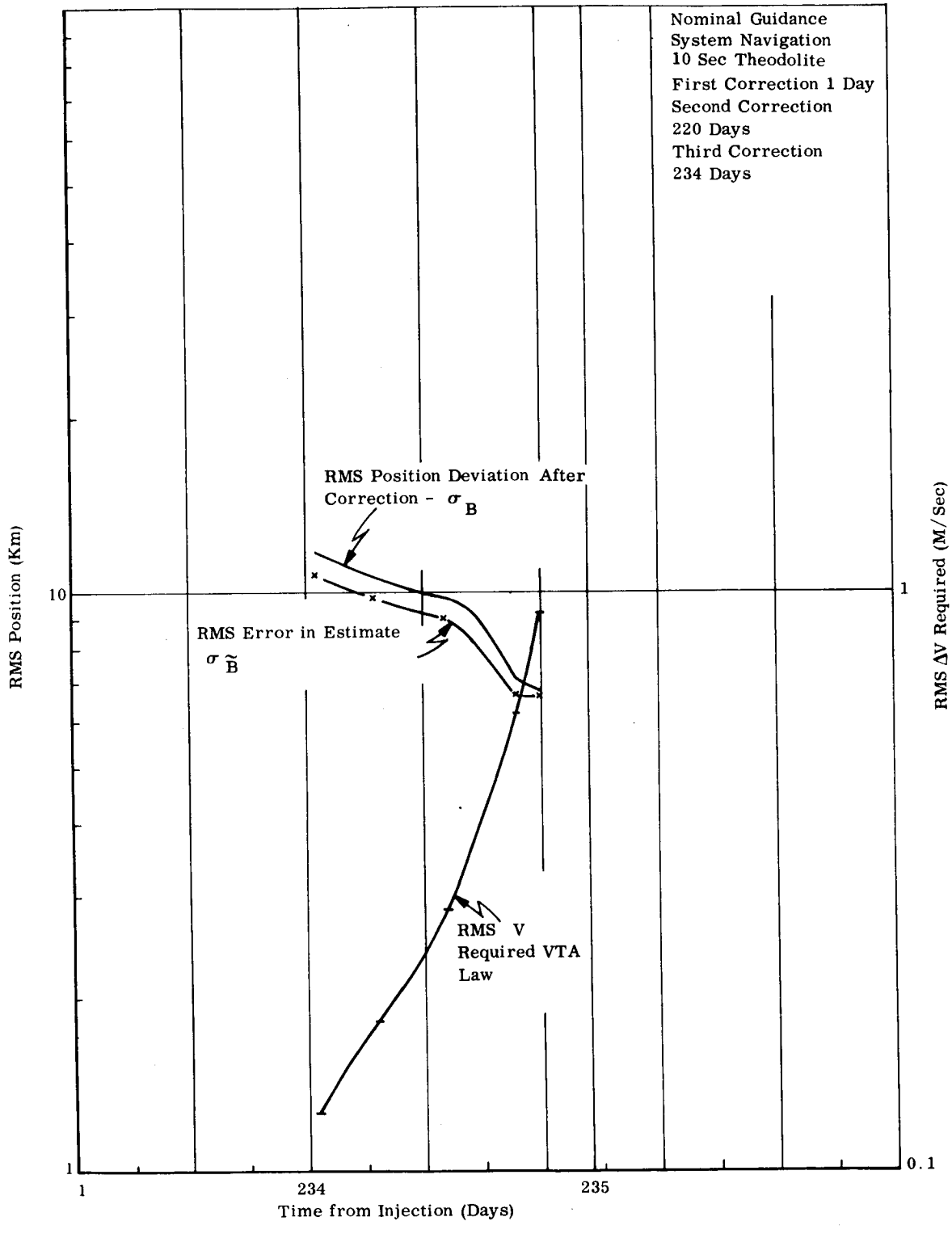


Figure 5-35 System IV - Fourth Correction Guidance Data

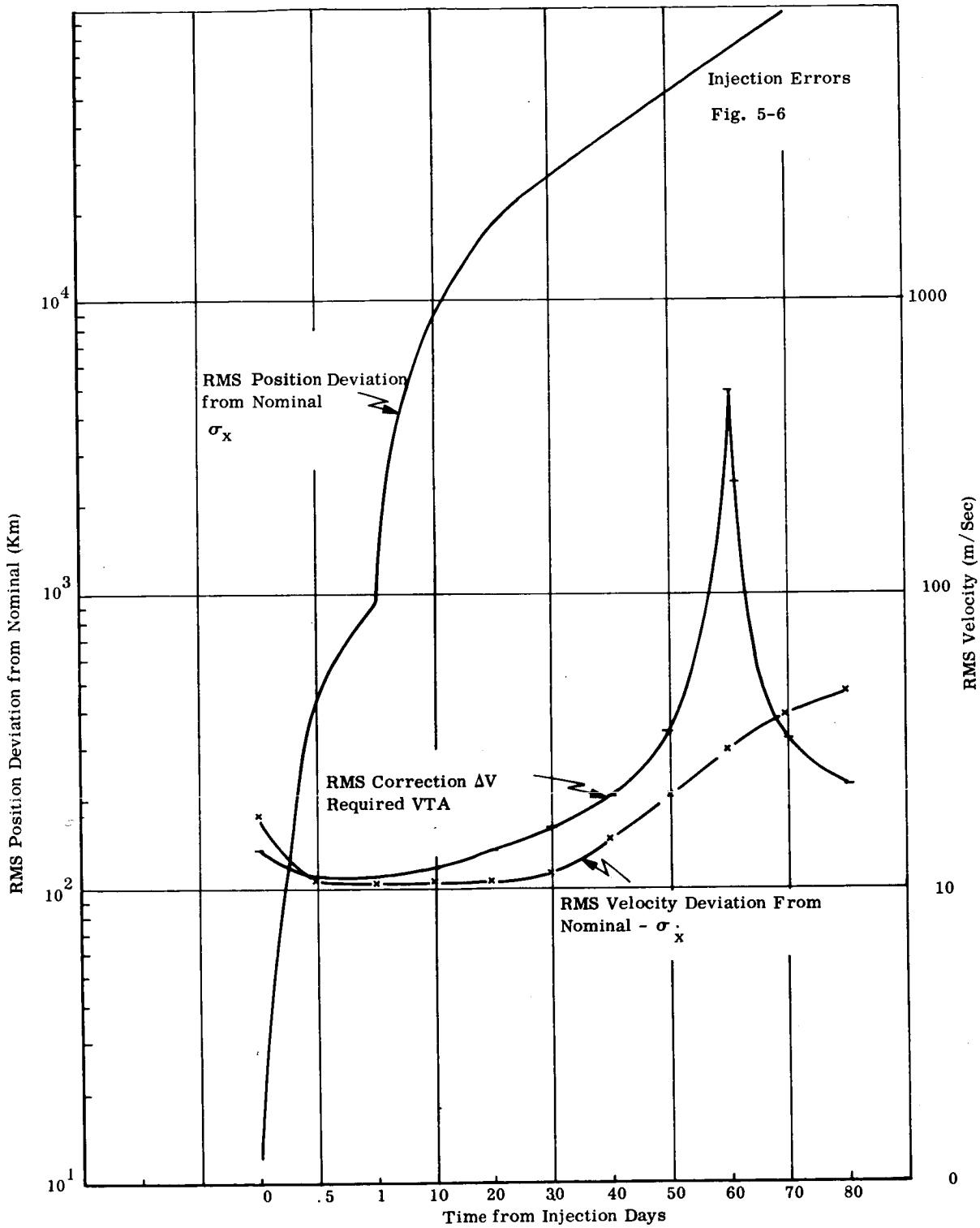


Figure 5-36 Effect of Nominal Injection Errors

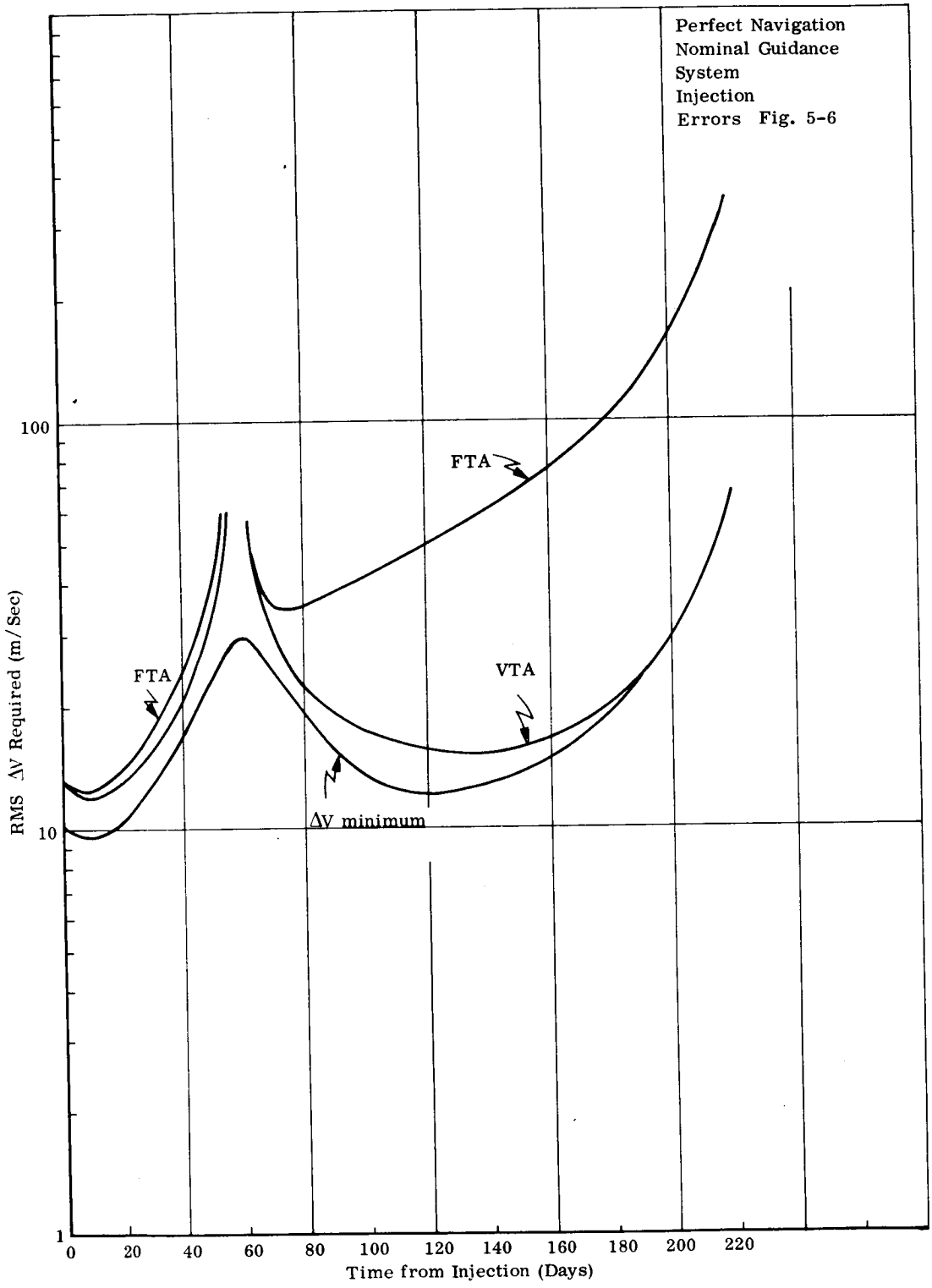


Figure 5-37 First Correction - Δv Requirements for Various Guidance Laws

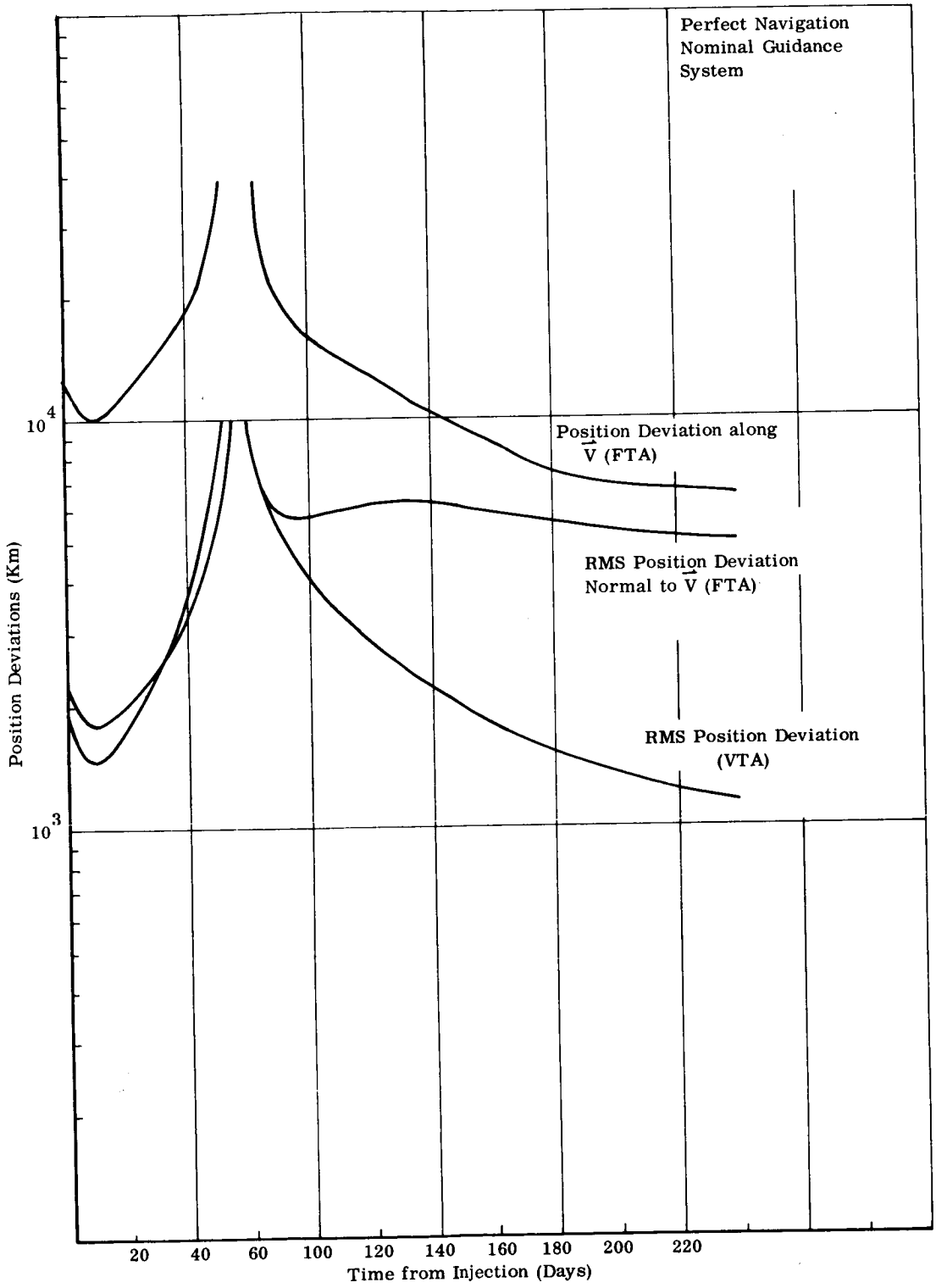


Figure 5-38 Position Deviations After First Correction

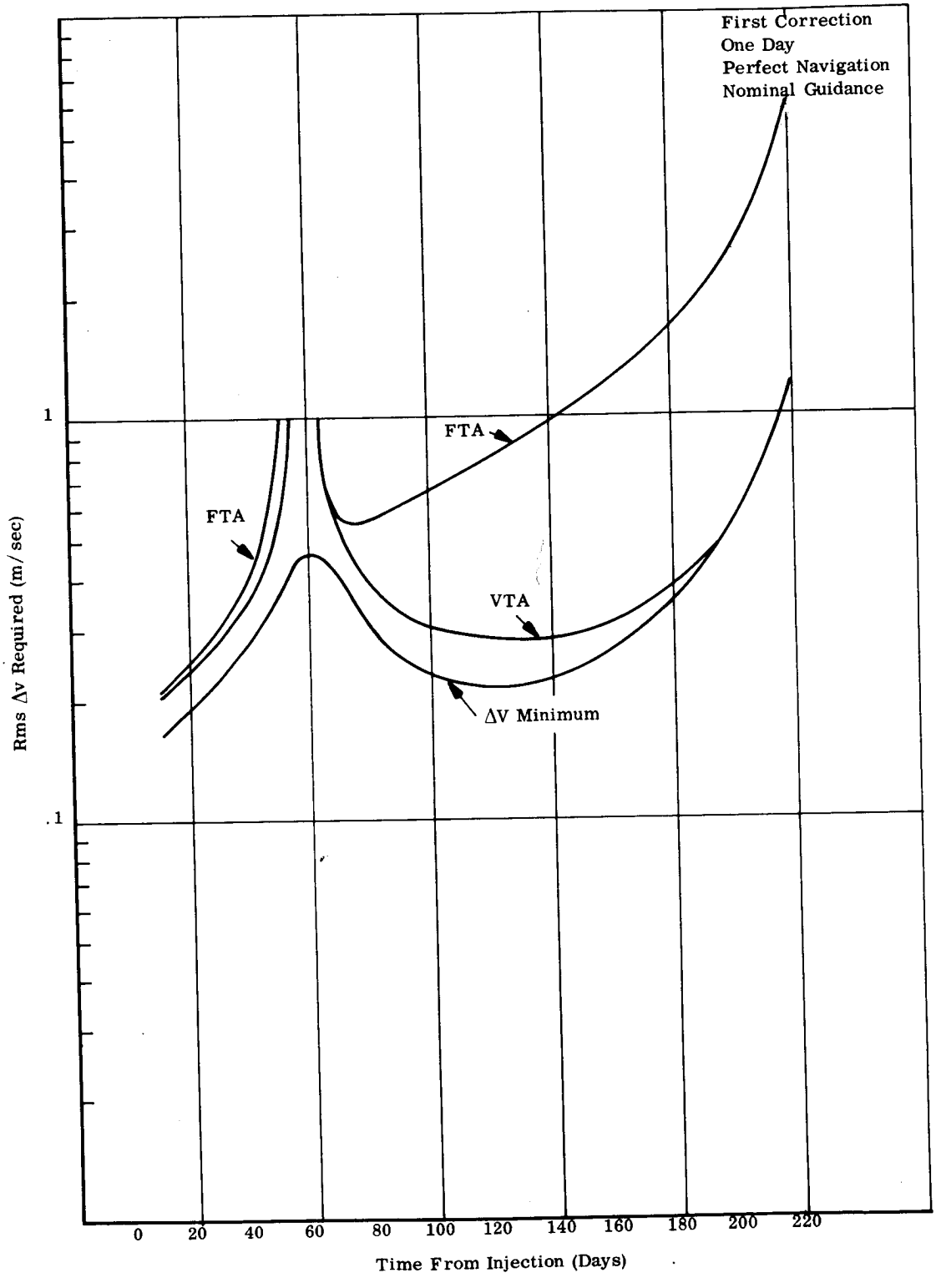


Figure 5-39 Second Correction Δv Requirements for Various Guidance Laws

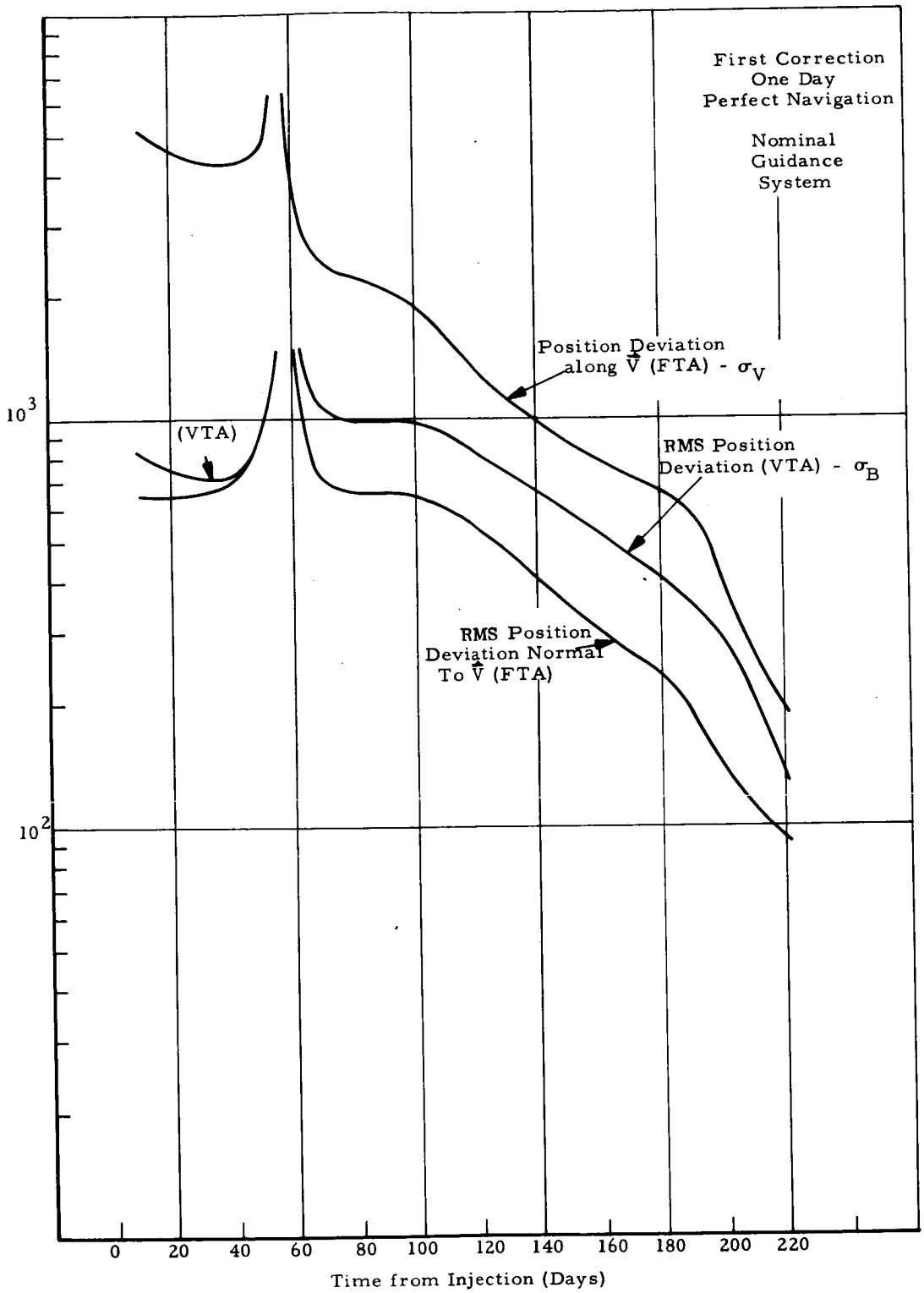


Figure 5-40 Position Deviations After Second Correction

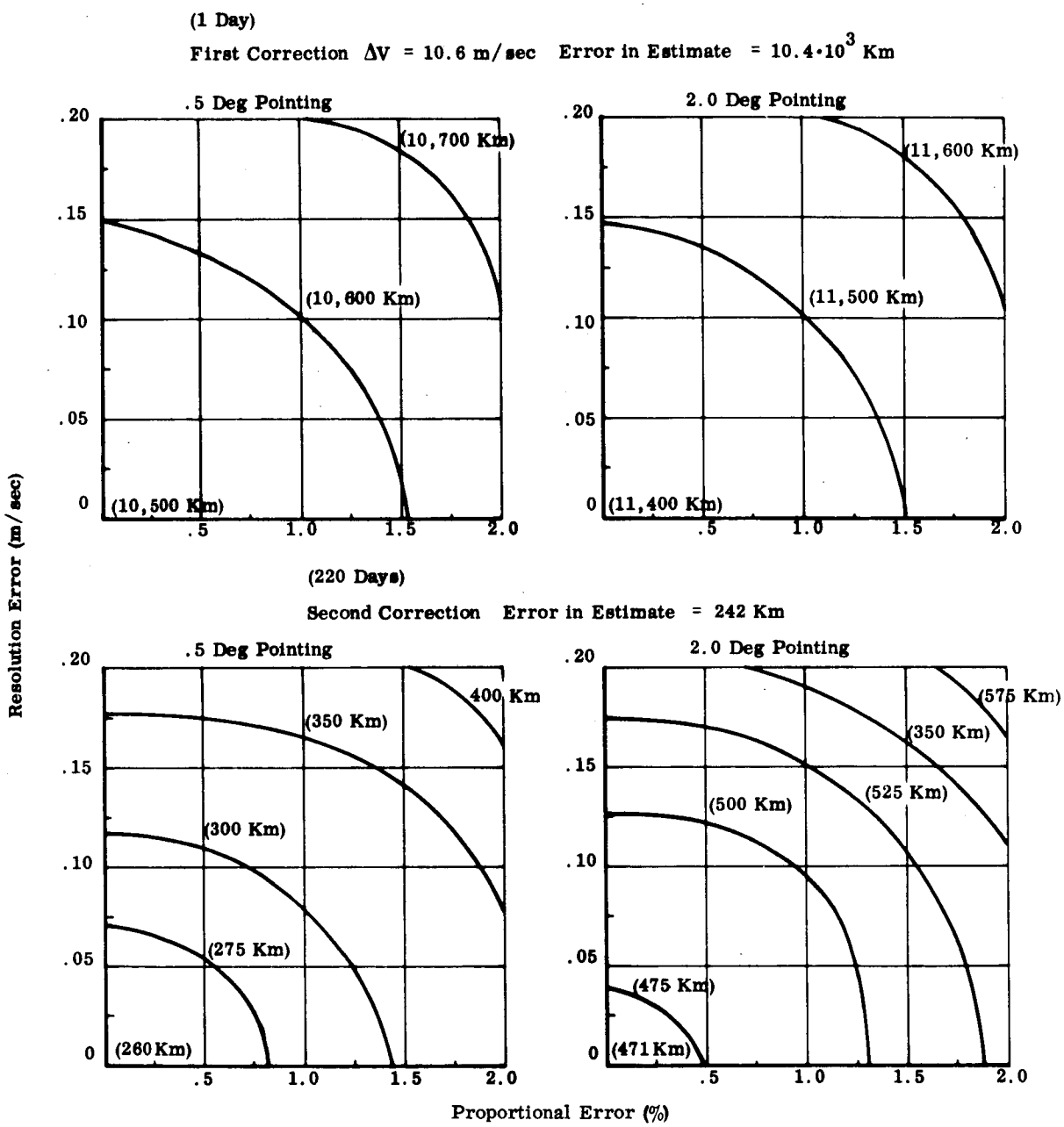


Figure 5-41A End-Point Deviations vs. Guidance System Errors - First and Second Corrections

Navigation
System IV
10 Sec Theodolite
and Subtended
Angle Range
VTA Guidance

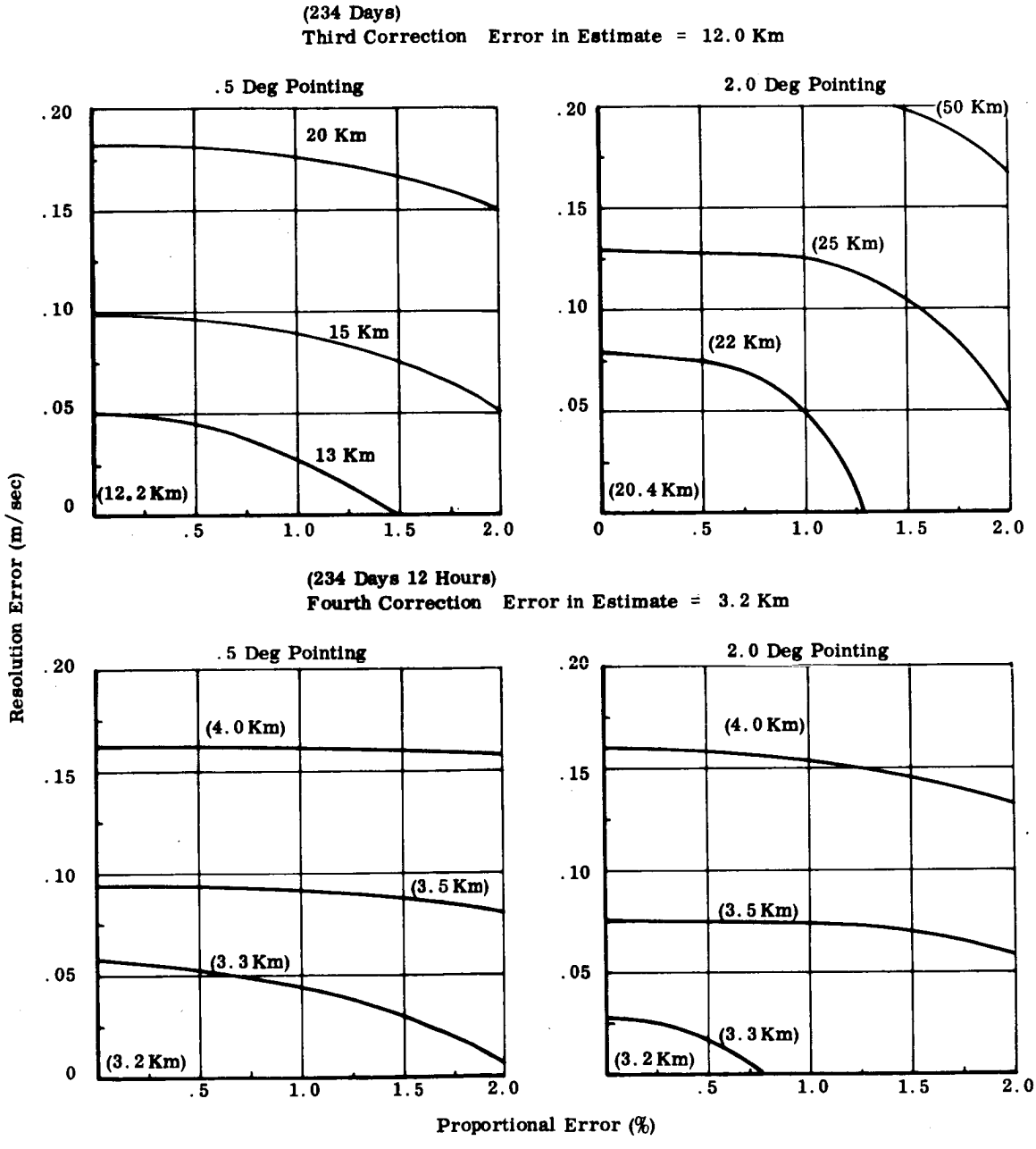


Figure 5-41B End-Point Deviations vs. Guidance System Errors - Third and Fourth Corrections

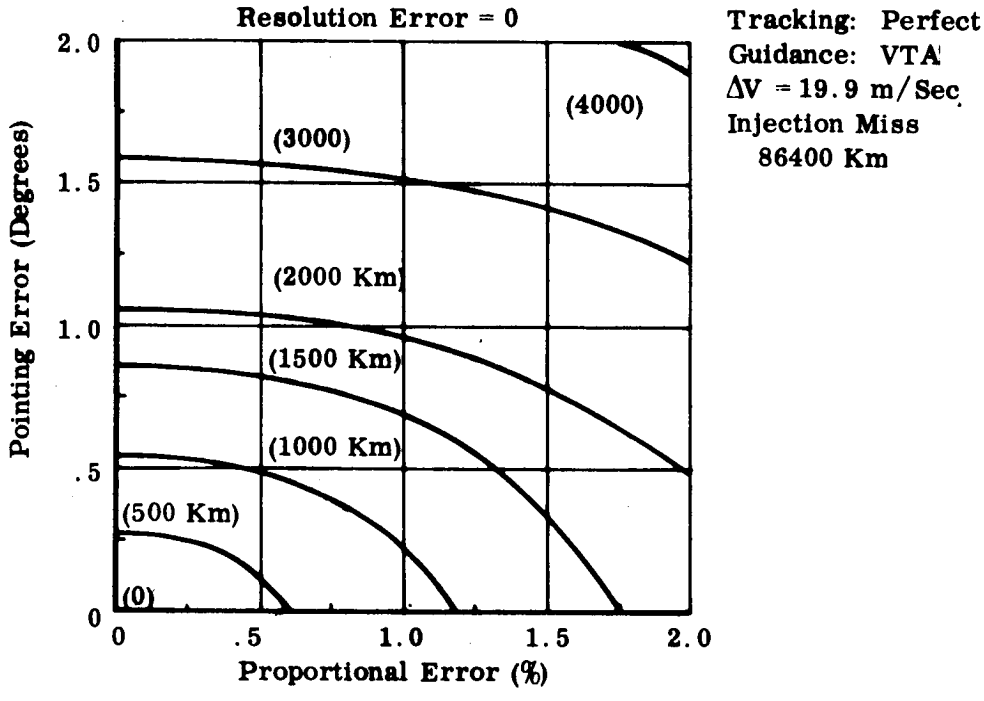
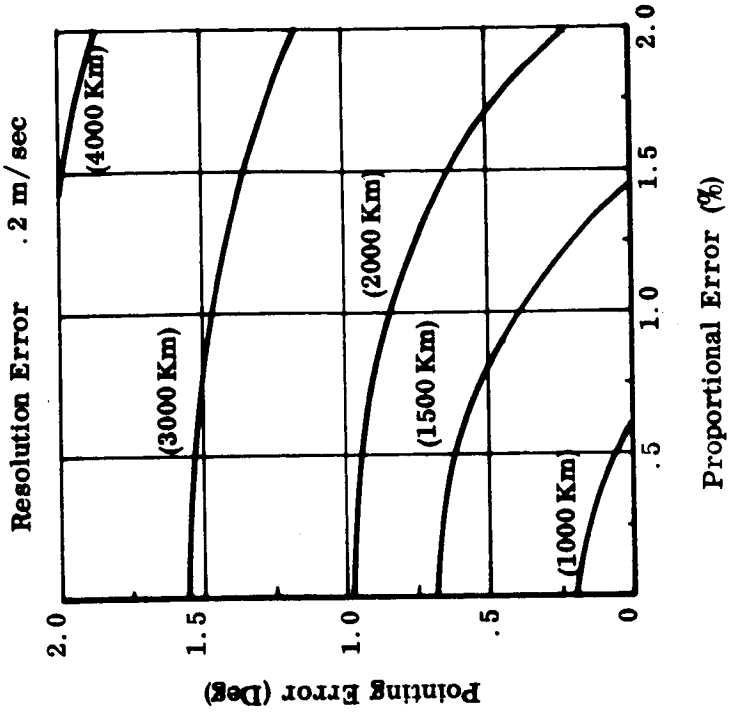


Figure 5-42A Single Correction Data - 180 Days



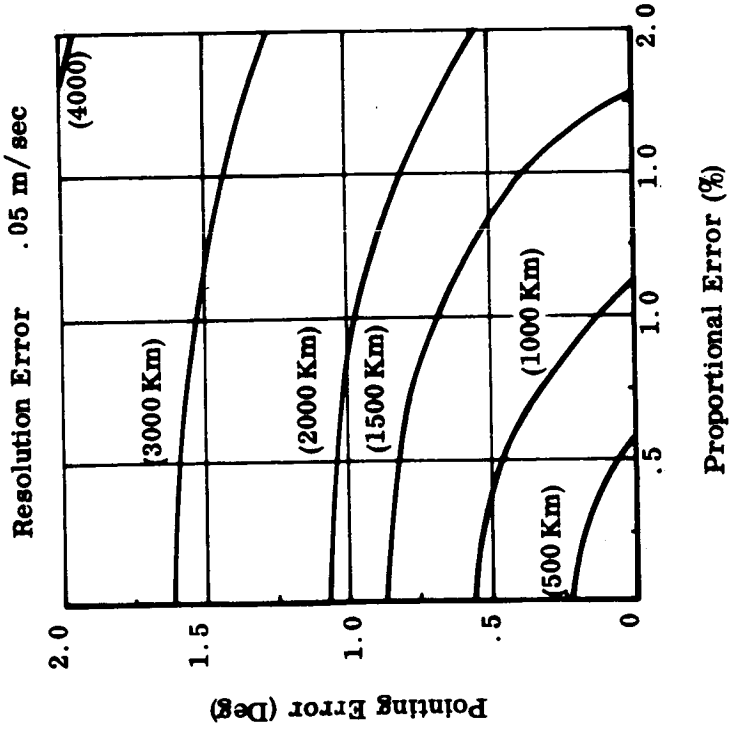


Figure 5-42B Single Correction Data - 180 Days

TABLE 5-1

DSIF TRACKING SCHEDULE

TIME	TRACKING BEING USED (3 STATIONS)
0-2 Days	(Rng Rate, Az,El) Tracking when in view
2-10 Days	None
10-230 Days	Tracking when in view for a day every tenth day
234 Day	Tracking when in view

TABLE 5-2

DSIF

TRACKING SYSTEM, ERROR DATA

TRACKER	RNG. RATE	AZ & EL	DATA RATE	TRACKING
Goldstone	0.2 M/Sec	$0.2\ 10^{-3}$ RAD	1 OBS./MIN	Above Horizon
Womera	0.2 M/Sec	$0.2\ 10^{-3}$ RAD	1 OBS./MIN	Above Horizon
Johannesburg	0.2 M/Sec	$0.2\ 10^{-3}$ RAD	1 OBS./MIN	Above Horizon

TABLE 5-3

SYSTEM II SCHEDULE

TIME*	BODY OBSERVER	INTERVAL OF OBS.	TOTAL NUMBER OF OBS.
200-230 Days	Mars	1 Day	30
230-233 Days	Mars	6 Hours	12
233-234 Days	Mars	1 Hour	24
$234-234^{D}14^{h}$	Mars	30 Minutes	28
$234^{D}14^{h}-234^{D}18^{h}$	None	---	--
$234^{D}18^{h}-234^{D}20^{h}$	Mars	15 Minutes	8
$234^{D}20^{h}-234^{D}$	None	---	--
		Onboard Observations	102

TABLE 5-4

SYSTEM II SCHEDULE

TIME*	BODY OBSERVER	INTERVAL OF OBS.	TOTAL NUMBER OF OBS.
200-230 Days	Mars	1 Day	30
230-233	Mars	6 Hours	12
233-234	Mars	1 Hour	24
$234-234^{D}18^{h}$	Mars	30 Minutes	36
$234^{D}10^{h}-234^{D}20^{h}$	None	---	--
$234^{D}20^{h}-234^{D}22^{h}$	Mars	15 Minutes	8
$234^{D}22^{h}-235$	None	---	--
		Onboard Observations	110

*0-200 Days DSIF Schedule in Table 5-1 was used

TABLE 5-5

SYSTEM IV ONBOARD
SCHEDULE WITH SUN

TIME	BODY OBSERVED	INTERVAL OF OBS.	TOTAL NUMBER OF OBS.
$0\text{-}3^h$	Earth	15 Minutes	12
$3^h\text{-}1^D$	Earth	1 Hour	21
$1^D\text{-}90^D$	Sun	5 Days	18
$90^D\text{-}180^D$	Mars	5 Days	18
$180^D\text{-}230^D$	Mars	1 Day	50
$230^D\text{-}233^D$	Mars	6 Hours	12
$233^D\text{-}234^D$	Mars	1 Hour	24
$234^D\text{-}234^D18^h$	Mars	30 Minutes	36
$234^D18^h\text{-}234^D20^h$	None	---	--
$234^D20^h\text{-}234^D22^h$	Mars	15 Minutes	8
$234^D22^h\text{-}235^D$	None	---	--
		TOTAL	199

TABLE 5-6

GUIDANCE
CORRECTION TIMES

SYSTEM	CORRECTIONS			
	FIRST	SECOND	THIRD	FOURTH
I	2 Days	231 Days	---	---
II	2 Days	232 Days 12 Hr.	234 Days 18 Hr.	---
III	2 Days	232 Days 12 Hr.	234 Days 20 Hr.	---
IV	1 Day	220 Days	234 Days	234 Days 20 Hr.

TABLE 5-7

SYSTEM I

GUIDANCE PERFORMANCE

	FIRST CORRECTION (2 Days)	SECOND CORRECTION (231 Days)
Error in Estimate	$\sigma_{\tilde{B}\cdot T}$ = 81.1 KM $\sigma_{\tilde{B}\cdot R}$ = 399.9 KM	$\sigma_{\tilde{B}\cdot T}$ = 10.0 KM $\sigma_{\tilde{B}\cdot T}$ = 113.3 KM
Deviation Aft. Corr.	$\sigma_{B\cdot T}$ = 882. KM $\sigma_{B\cdot R}$ =1478. KM	$\sigma_{B\cdot T}$ = 28.1 KM $\sigma_{B\cdot R}$ = 119.0 KM
AV Required	10.74 M/Sec	4.94 M/Sec

TABLE 5-8

SYSTEM II
GUIDANCE PERFORMANCE

INSTRUMENT ACCURACY (SECONDS)	SECOND CORRECTION* ($232^D 12^h$)			THIRD CORRECTION ($234^D 18^h$)		
	DEVIATIONS		AV	DEVIATIONS		AV
	B·T (KM)	B·R(KM)	(M/SEC)	B·T(KM)	B·R (KM)	(M/SEC)
5	21.9	26.4	7.91	2.23	2.38	1.53
10	22.7	32.5	7.91	3.10	3.25	1.77
20	23.0	48.7	7.91	4.93	5.51	2.39
30	23.1	64.2	7.91	6.48	7.92	3.02
60	23.2	90.3	7.91	9.13	15.2	4.32

*First correction data is the same as shown in Table 5-7

TABLE 5-9

TERMINAL NAVIGATION
DATA SYSTEMS II AND III

INSTRUMENT ACCURACY (SECONDS)	SYSTEM	ERROR IN ESTIMATE AT LAST MANEUVER TIME	% DIFF.	ERROR IN ESTIMATE AT RETRO TIME	% DIFF.
5	II III	2.40 2.04	15.0	2.04 1.85	9.3
10	II III	3.88 3.04	21.6	2.83 2.54	10.2
20	II III	7.01 5.27	24.8	4.48 3.73	16.7
30	II III	9.94 7.48	24.7	6.18 4.78	22.6
60	II III	17.5 13.3	24.0	10.9 7.79	28.5

TABLE 5-10

SYSTEM III

GUIDANCE PERFORMANCE

INSTURMENT ACCURACY (SECONDS)	SECOND CORRECTION (232^D12^h)			THIRD CORRECTION (234^D20^h)		
				DEVIATIONS		AV
				B•T (KM)	B•R (KM)	(M/SEC)
5	SAME AS TABLE 4-7			1.87	1.75	2.28
10				2.45	2.39	2.63
20				3.86	3.98	3.56
30				5.17	5.79	4.51
60				7.95	10.9	6.46

TABLE 5-11

SYSTEM III

SPECIAL CASE PERFORMANCE

SPECIAL CASE	ERROR IN ESTIMATE AT TIME OF LAST MIDCOURSE MANEUVER		END POINT DEVIATIONS	
	B·T (KM)	B·R (KM)	B·T (KM)	B·R (KM)
Nominal Trajectory	2.2	2.1	2.45	2.39
Minimum Energy Trajectory	1.9	1.9	2.29	2.23
Covariance Matrix Perturbed	6.8	2.1	6.12	2.46

TABLE 5-12

SYSTEM IV

GUIDANCE PERFORMANCE

INSTRUMENT ACCURACY (SECONDS)	FIRST CORRECTION (1 DAY)			SECOND CORRECTION (220^D)		
	DEVIATIONS		AV	DEVIAITONS		AV
	B·T (KM)	B·R (KM)	(M/SEC)	B·T (KM)	B·R (KM)	(M/SEC)
2.5	9500	1732	10.57	166	104	7.74
5	10000	1920	10.57	191	116	7.88
10	10300	2390	10.56	269	153	8.18
30	11250	4590	10.54	668	349	9.35
60	12050	7880	10.51	1300	670	11.0

INSTRUMENT ACCURACY (SECONDS)	THIRD CORRECTION (234^D)			FOURTH CORRECTION ($234^D 20^h$)		
	DEVIATIONS		AV	DEVIATIONS		AV
	B·T (KM)	B·R (KM)	(M/SEC)	B·T (KM)	B·R (KM)	(M/SEC)
2.5	7.5	5.9	2.24	2.36	1.27	.62
5	8.8	6.5	2.56	3.72	1.50	.68
10	12.8	8.6	3.53	6.54	2.01	.92
30	32.4	20.3	8.61	18.2	5.59	2.21
60	63.5	39.5	16.7	36.1	10.9	4.29

TABLE 5-13

SYSTEM IV ONBOARD
SCHEDULE FOR
MINIMUM ENERGY
TRAJECTORY

TIME	BODY OBSERVED	INTERVAL OF OBS.	TOTAL NUMBER OF OBS.
$0\text{-}1^h$	Earth	15 Minutes	4
$1^h\text{-}1^D$	Earth	1 Hour	23
$1^D\text{-}30^D$	Earth	1 Day	29
$30^D\text{-}160^D$	Earth and Mars	5 Days	52
$160^D\text{-}175^D$	Mars	1 Day	15
$175^D\text{-}178^D$	Mars	6 Hours	12
$178^D\text{-}179^D$	Mars	1 Hour	24
$179^D\text{-}179^D18^h$	Mars	30 Minutes	36
$179^D18^h\text{-}179^D20^h$	None	---	--
$179^D20^h\text{-}179^D22^h$	Mars	15 Minutes	8
$179^D22^h\text{-}180^D$	None	---	--
		TOTAL	203

TABLE 5-14

SYSTEM IV ONBOARD
SCHEDULE WITH MOON

$0\text{-}6^h$	Earth	15 Minutes	24
$6^h\text{-}1^D$	Moon	30 Minutes	42
$90\text{-}235^D$	None	---	--
	Same as Above (4-11A)		148
		TOTAL	214

TABLE 5-15

GUIDANCE REQUIREMENTS

Correction	30-Minute Park Orbit	85-Minute Park Orbit
Injection Velocity Deviation	17.90 m/sec	32.10 m/sec
	RMS ΔV Required	RMS ΔV Required
1st Correction	10.56 m/sec	19.69 m/sec
2nd Correction	8.18 m/sec	7.21 m/sec
3rd Correction	3.53 m/sec	3.45 m/sec
4th Correction	.92 m/sec	.92 m/sec

TABLE 5-16

GUIDANCE DATA FOR FTA AND VTA GUIDANCE LAWS

Guidance Law	Deviations at End: VTA (B·T) FTA (Normal to $\bar{V}$) (km)		Deviations at End: VTA (B·R) FTA (Along $\bar{V}$) (km)	Total ΔV Required (m/sec)	Time Deviation (Minutes)
#1 Nominal Trajectory FTA	7.12		270.	56.8	.62
VTA	6.54	RMS=6.79	2.01	23.2	38.6
#2 Subtended Angle Added FTA	5.10		74.3	61.3	.17
VTA	2.87	RMS=3.53	2.06	23.2	38.6
#3 Minimum Energy Trajectory FTA	6.30		199.	64.5	.49
VTA	4.07	RMS=4.93	2.79	25.9	81.5

Ecliptic of Date
Coordinates

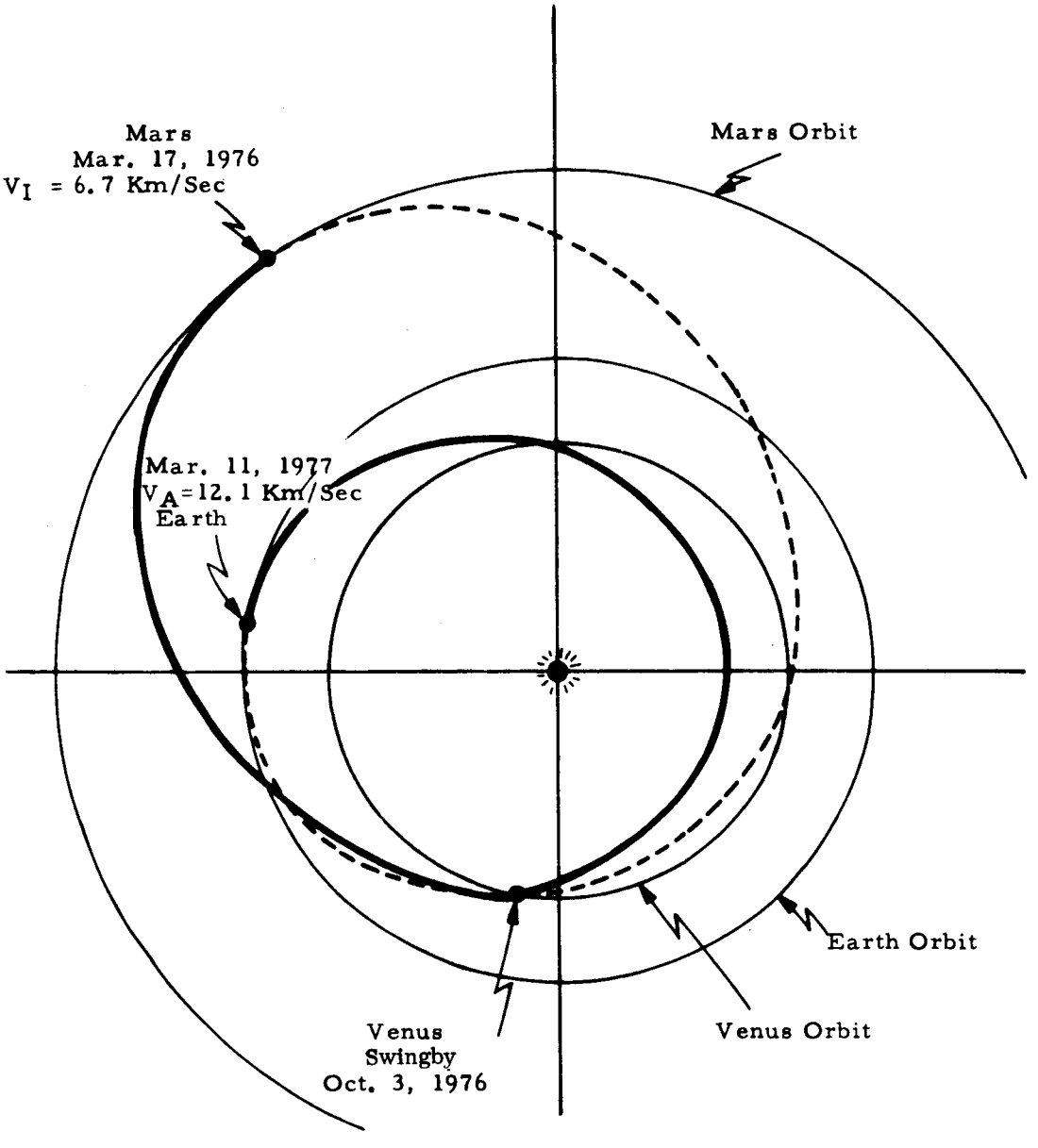
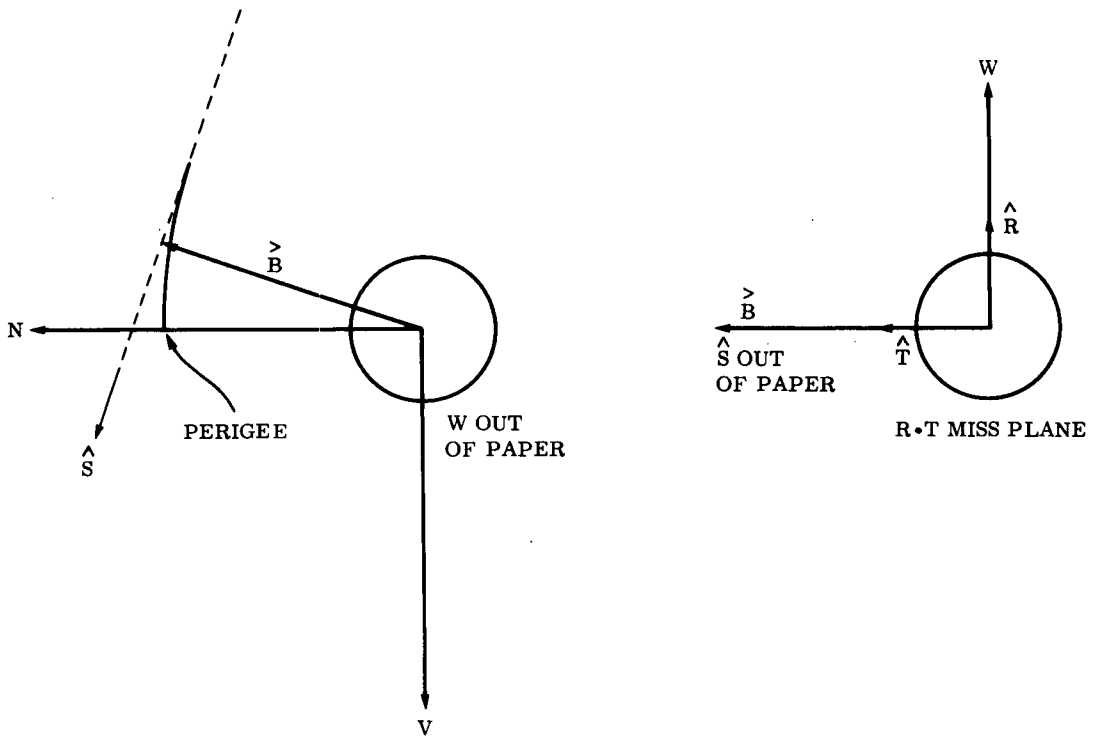


Figure 6-2 Mars-Venus-Earth Trajectory, 360 Days



--- INCOMING ASYMPTOTE
N, V, W, COORDINATES
AT PERIGEE

NOMINAL VALUES OF $\vec{B}$ VECTOR DATA

$$B = \begin{pmatrix} 8786. \\ -3416. \\ 0 \end{pmatrix} \quad \hat{S} = \begin{pmatrix} .362 \\ .932 \\ 0 \end{pmatrix} \quad \hat{T} = \begin{pmatrix} .932 \\ -.362 \\ 0 \end{pmatrix} \quad R = \begin{pmatrix} 0 \\ 0 \\ 1.0 \end{pmatrix}$$

Figure 6-3 Target Constraints

$\sigma_n = 17.3$ Km, $\sigma_v = 17.3$ Km, $\sigma_w = 17.3$ Km,

$\sigma_{\dot{n}} = 17.3$ m/sec, $\sigma_{\dot{v}} = 17.3$ m/sec, $\sigma_{\dot{w}} = 17.3$ m/sec

$$
\begin{array}{c}
 \\ n \\ v \\ w \\ \dot{n} \\ \dot{v} \\ \dot{w}
\end{array}
\begin{array}{c}
\begin{array}{cccccc} n & v & w & \dot{n} & \dot{v} & \dot{w} \end{array} \\
\left[\begin{array}{cccccc}
1 & 0 & 0 & 0 & 0 & 0 \\
 & 1 & 0 & 0 & 0 & 0 \\
 & & 1 & 0 & 0 & 0 \\
 & & & 1 & 0 & 0 \\
 & \text{Symmetric} & & & 1 & 0 \\
 & \text{Matrix} & & & & 1
\end{array}\right]
\end{array}
$$

Figure 6-4 Injection Covariance Matrix of State Deviations from Nominal

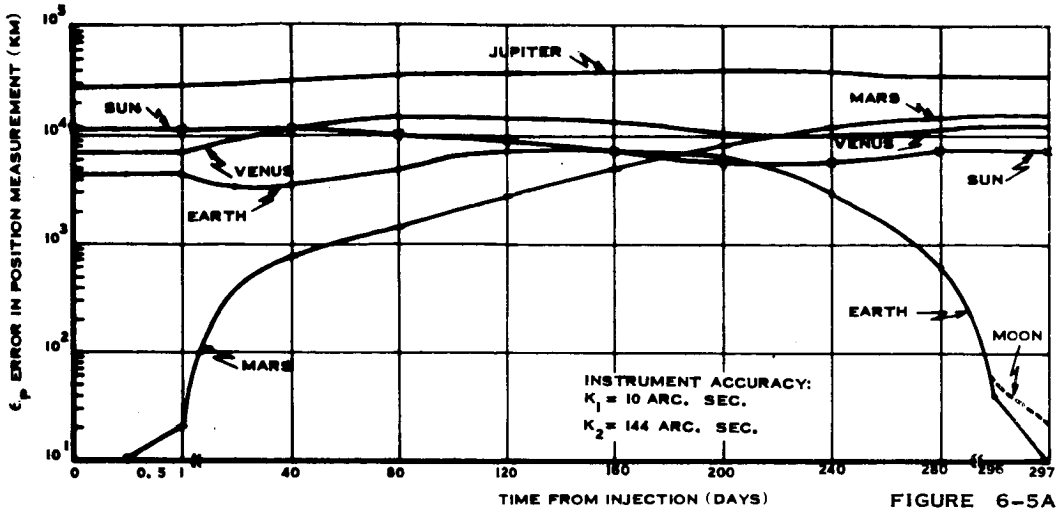


FIGURE 6-5A

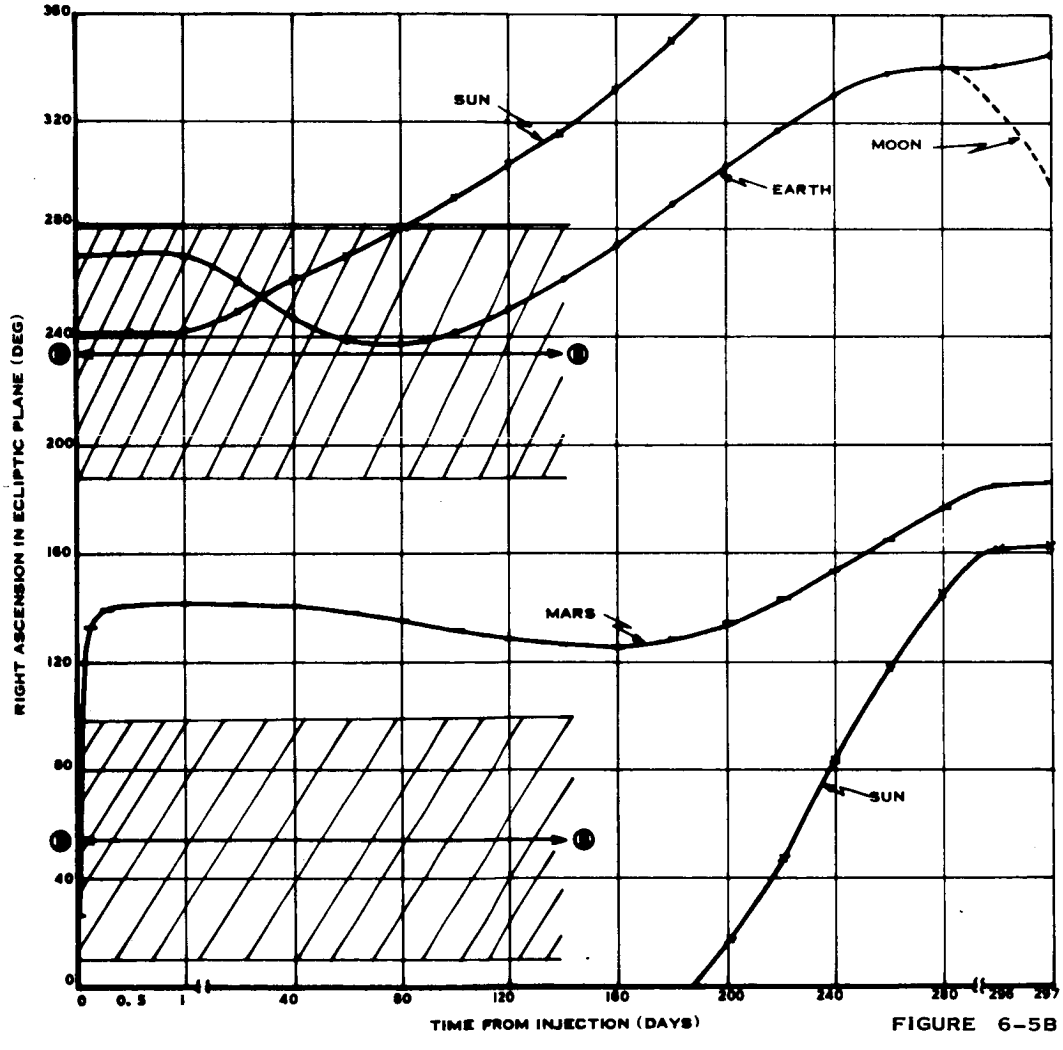


FIGURE 6-5B

Figure 6-5 Schedule Data for Mars-Earth Trajectory

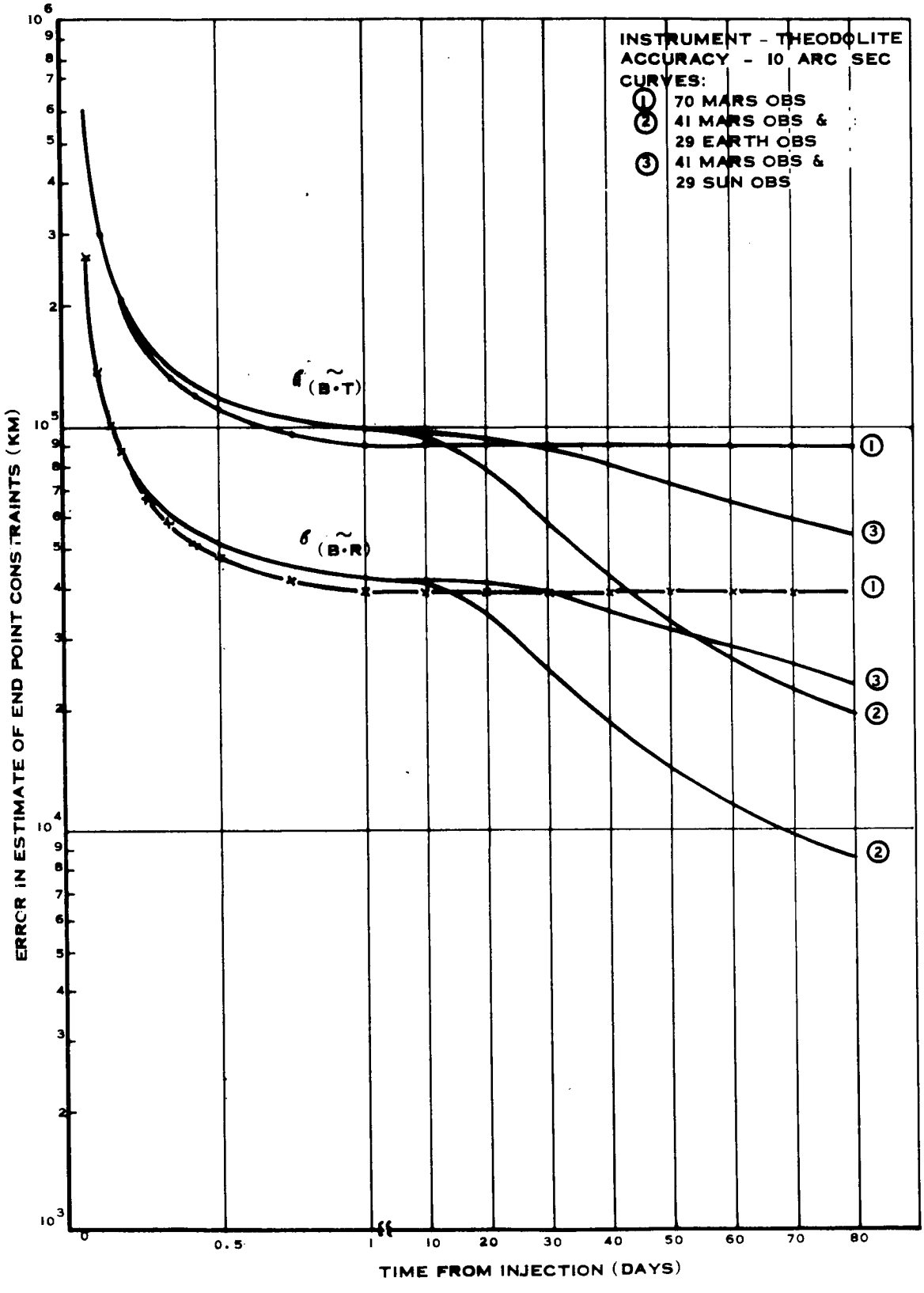


Figure 6-6 Tracking Data Early on the Mars-Earth Trajectory

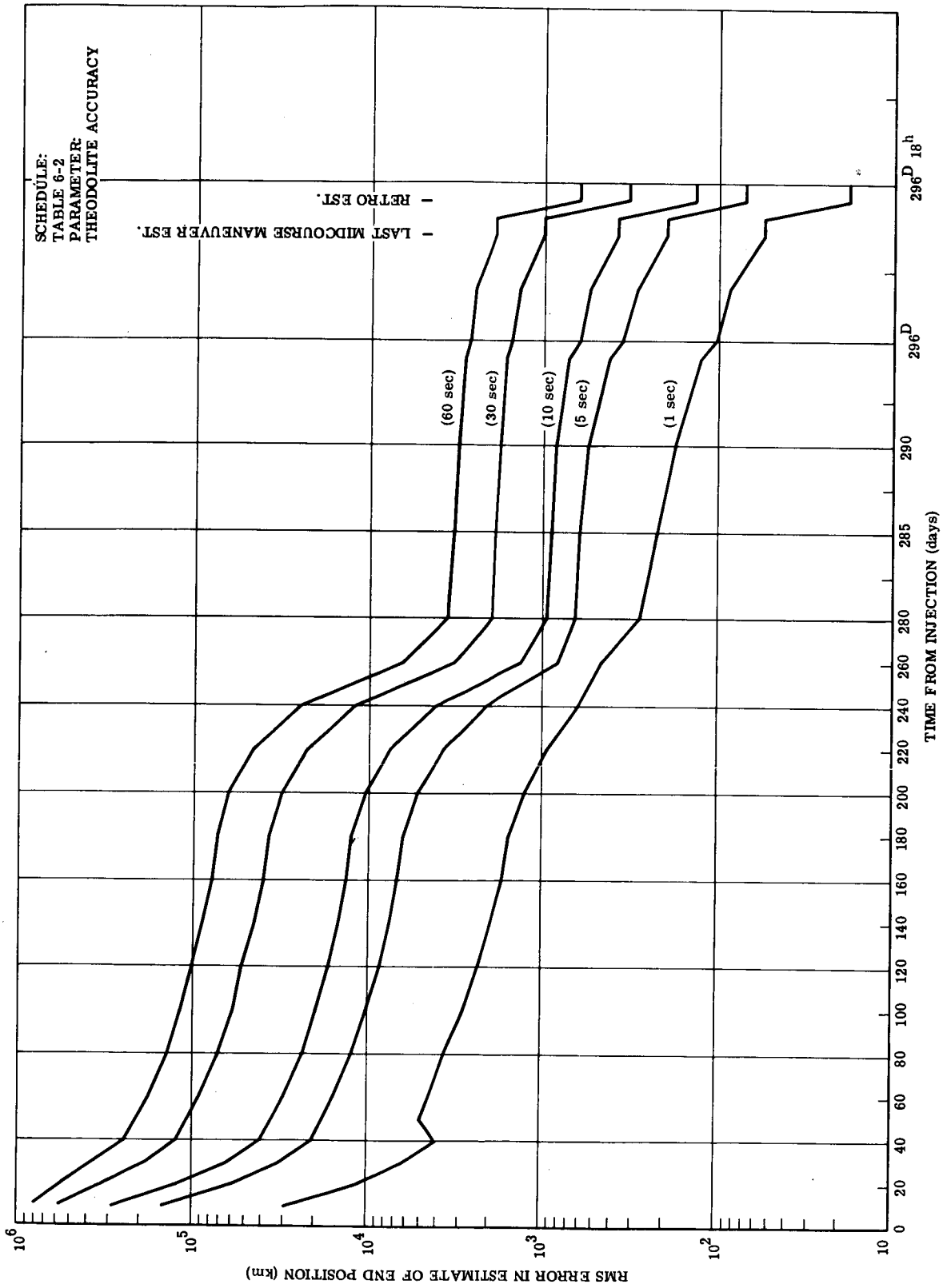


Figure 6-8 Mars-Earth Trajectory, System IV

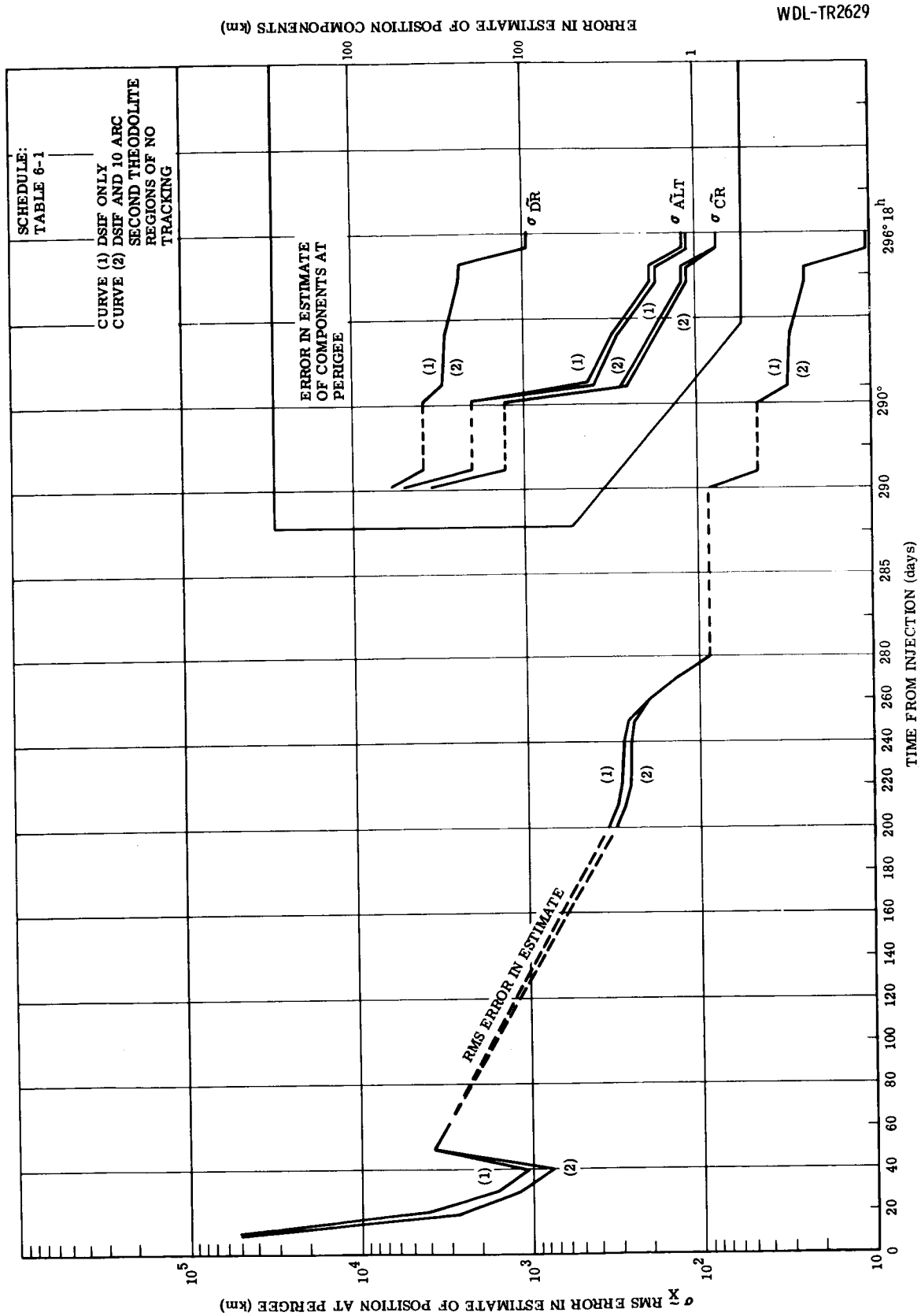


Figure 6-7 Mars-Earth Trajectory - System III Navigation Data

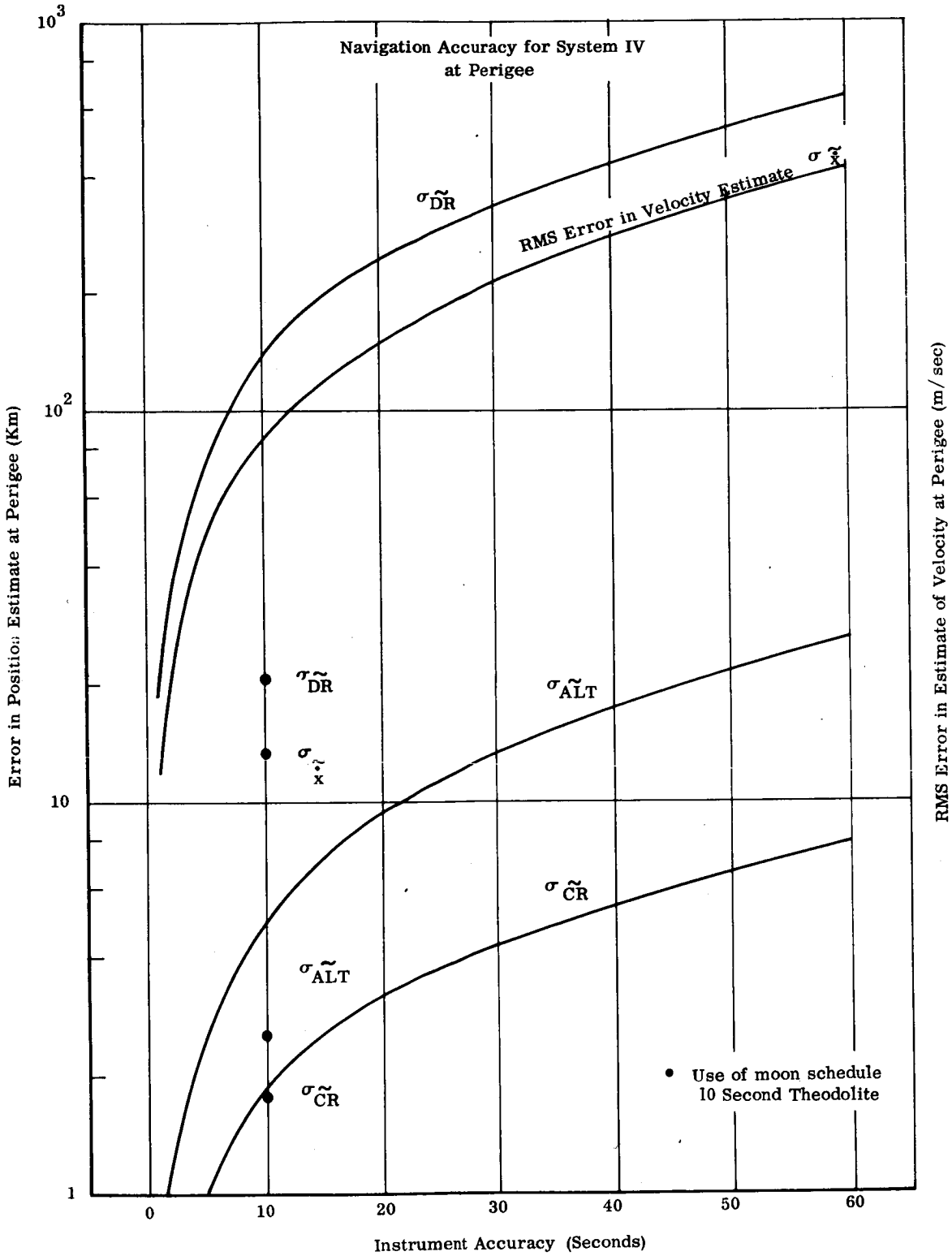


Figure 6-9 Navigation Accuracy for System IV at Perigee

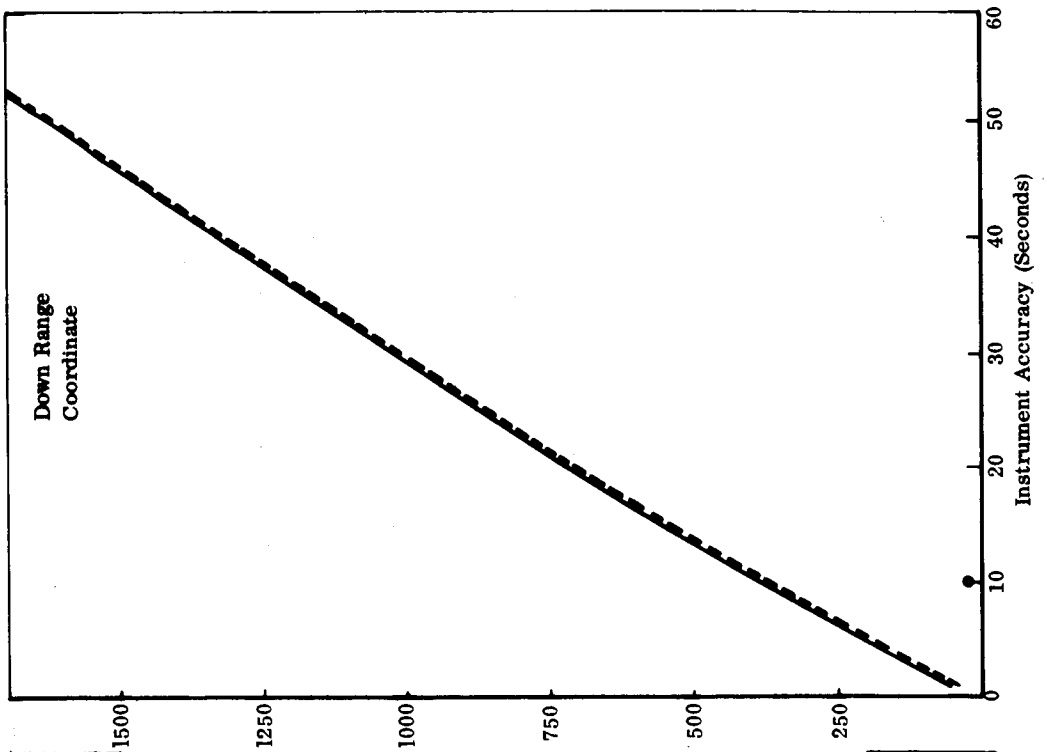


Figure 6-10B

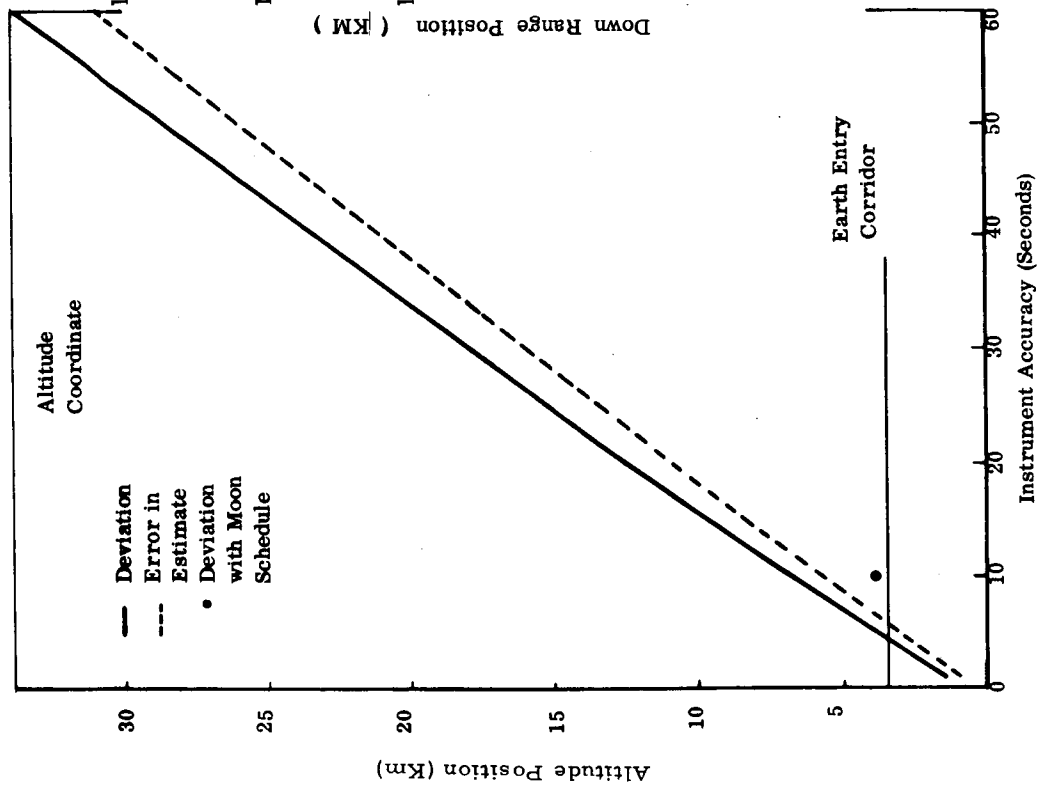


Figure 6-10A

Figure 6-10 System IV Guidance Performance

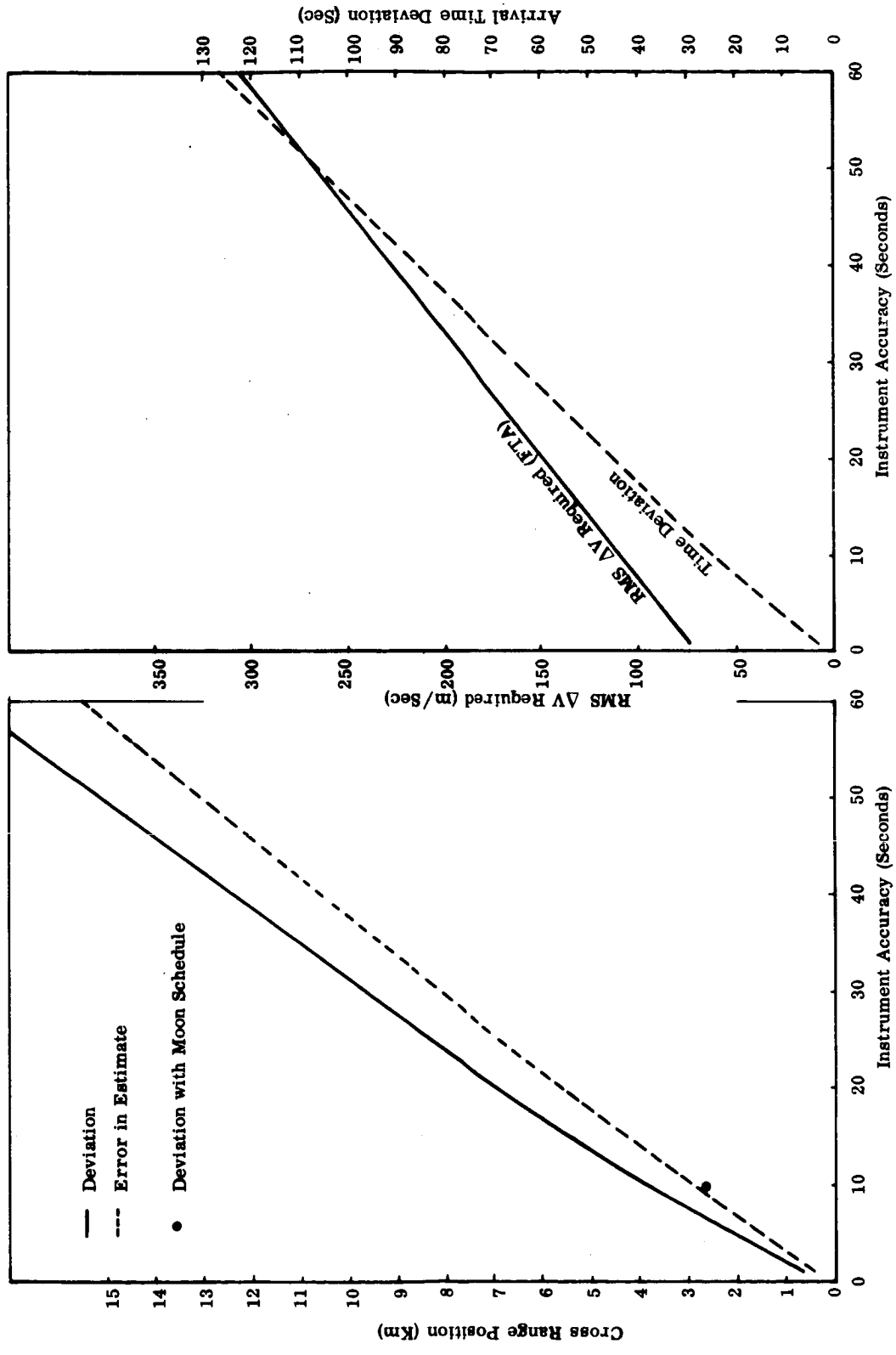


Figure 610C

Figure 6-10D

Figure 6-10 System IV Guidance Performance (Cont'd)

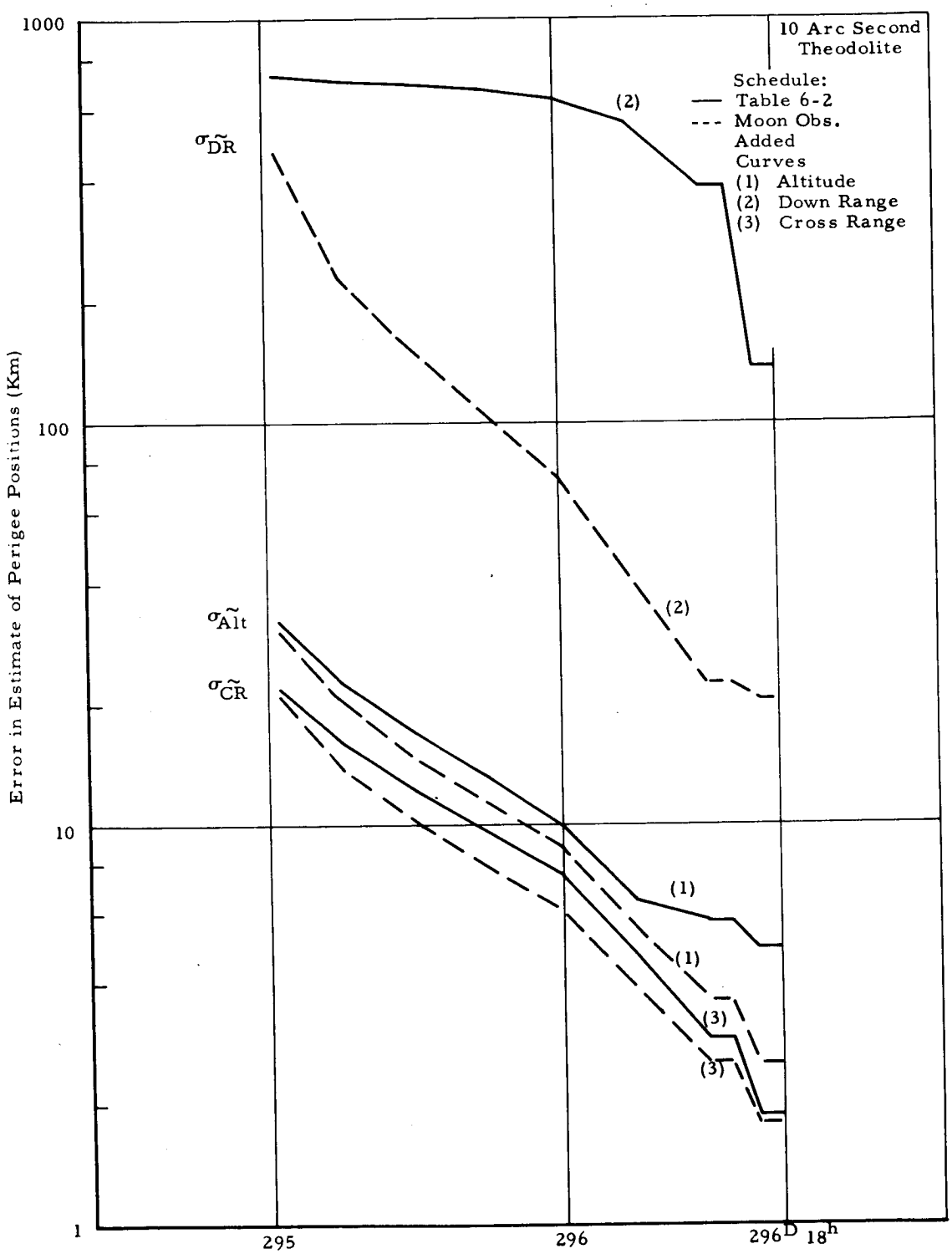


Figure 6-11 System IV Moon Observations

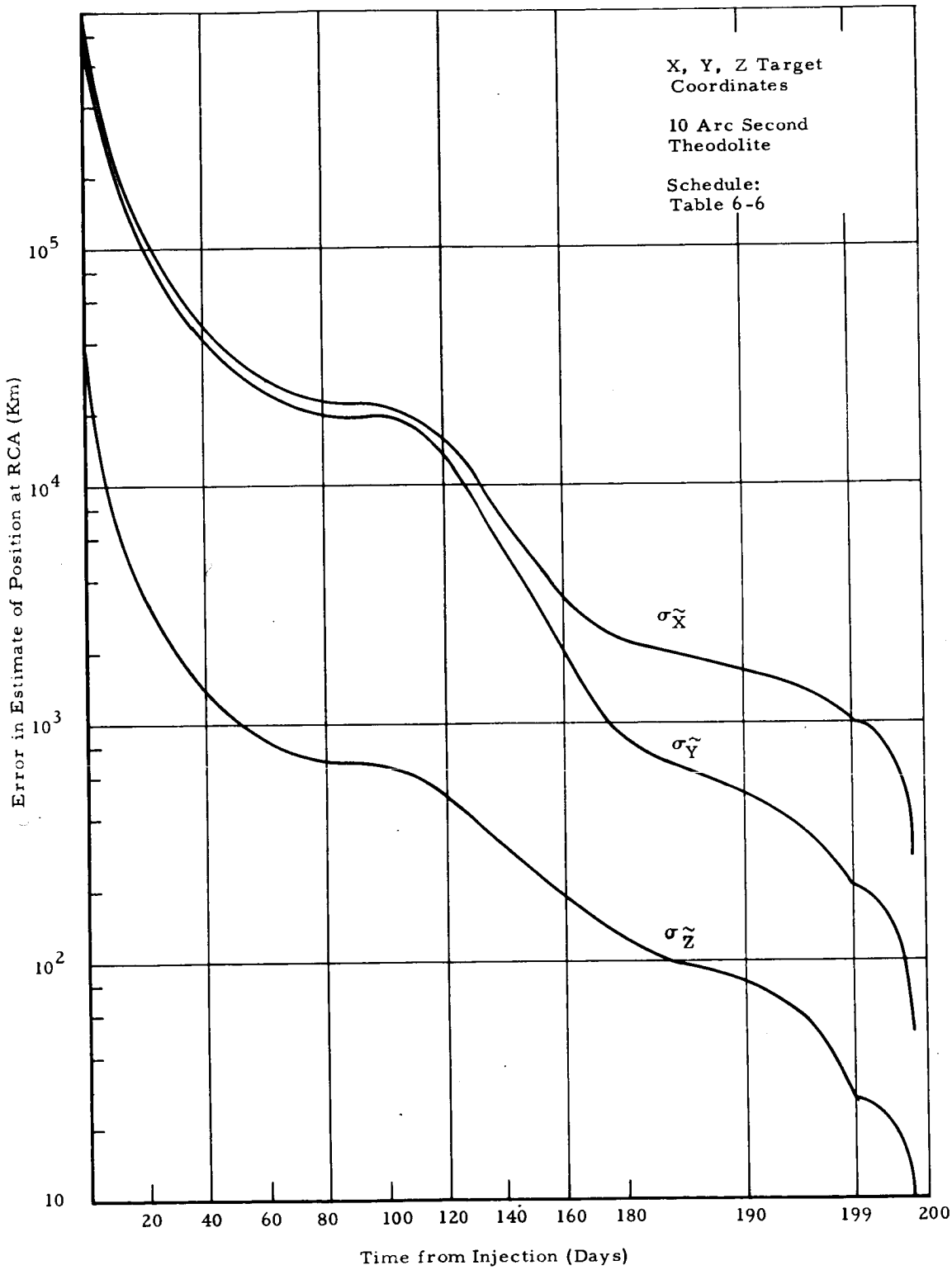


Figure 6-12A Mars-Venus Trajectory

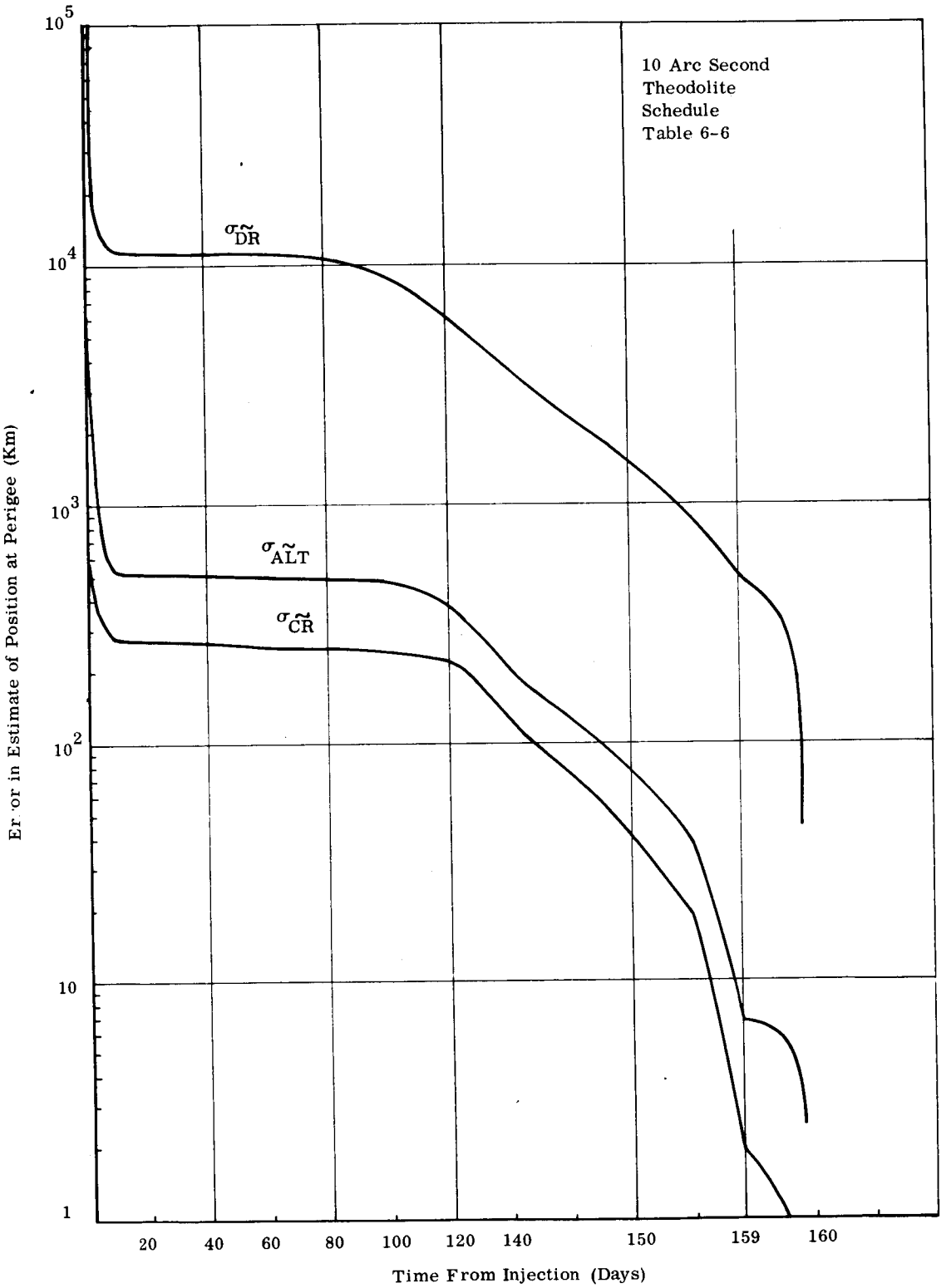


Figure 6-12B Venus-Earth Trajectory

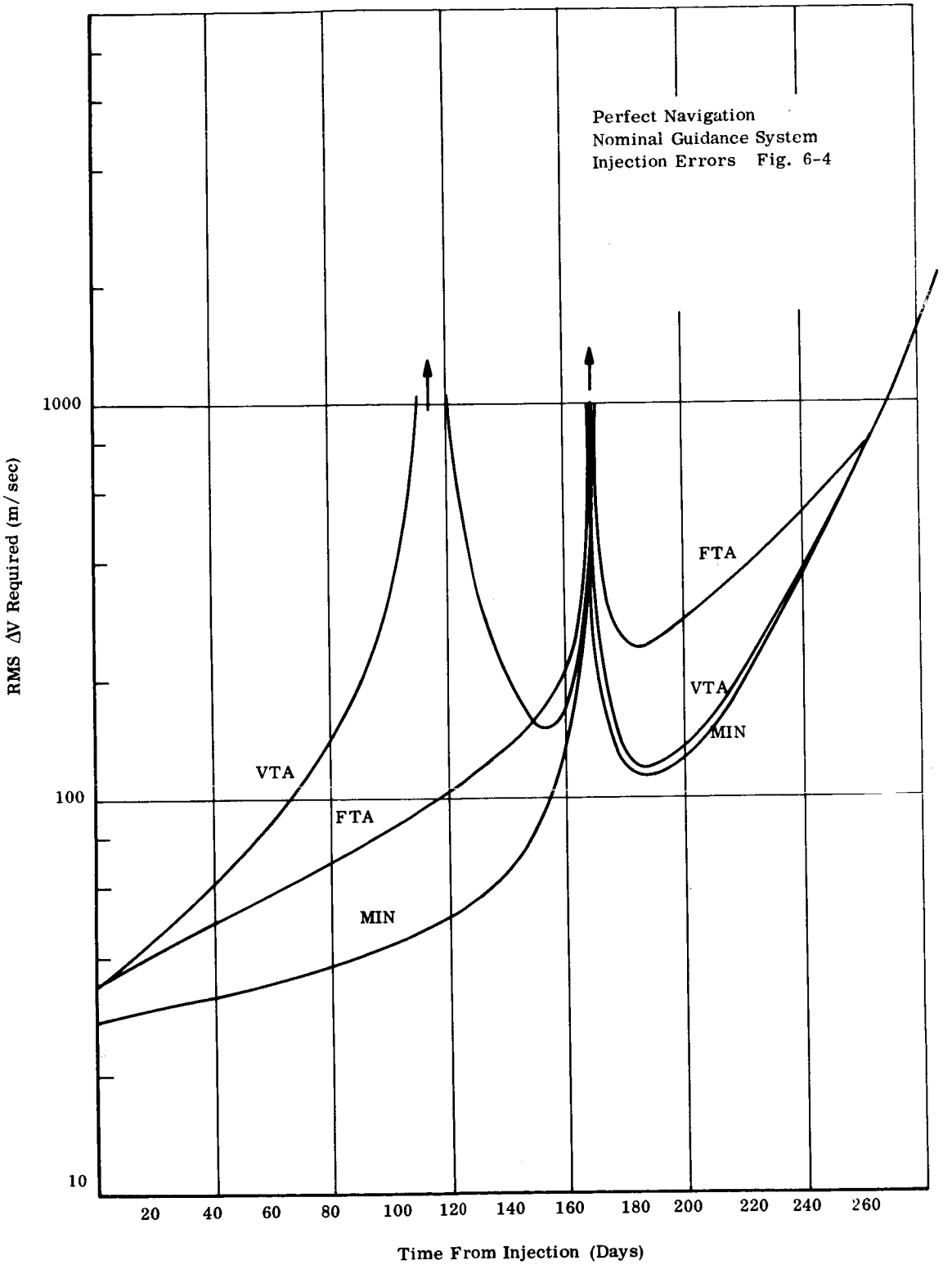


Figure 6-13 First Correction, Δv Requirements for Various Guidance Laws

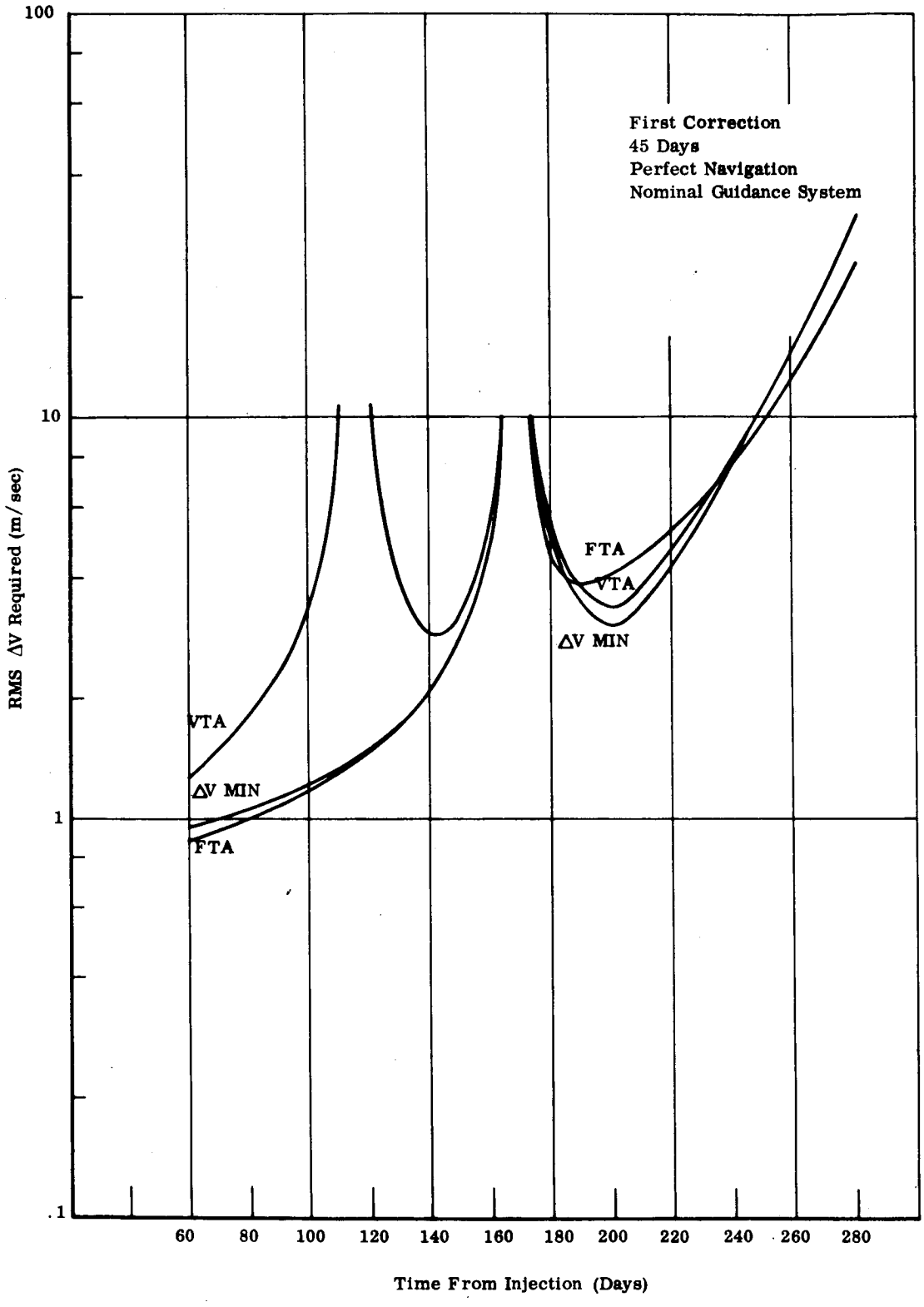


Figure 6-14 Second Correction Δu Requirements for Various Guidance Laws

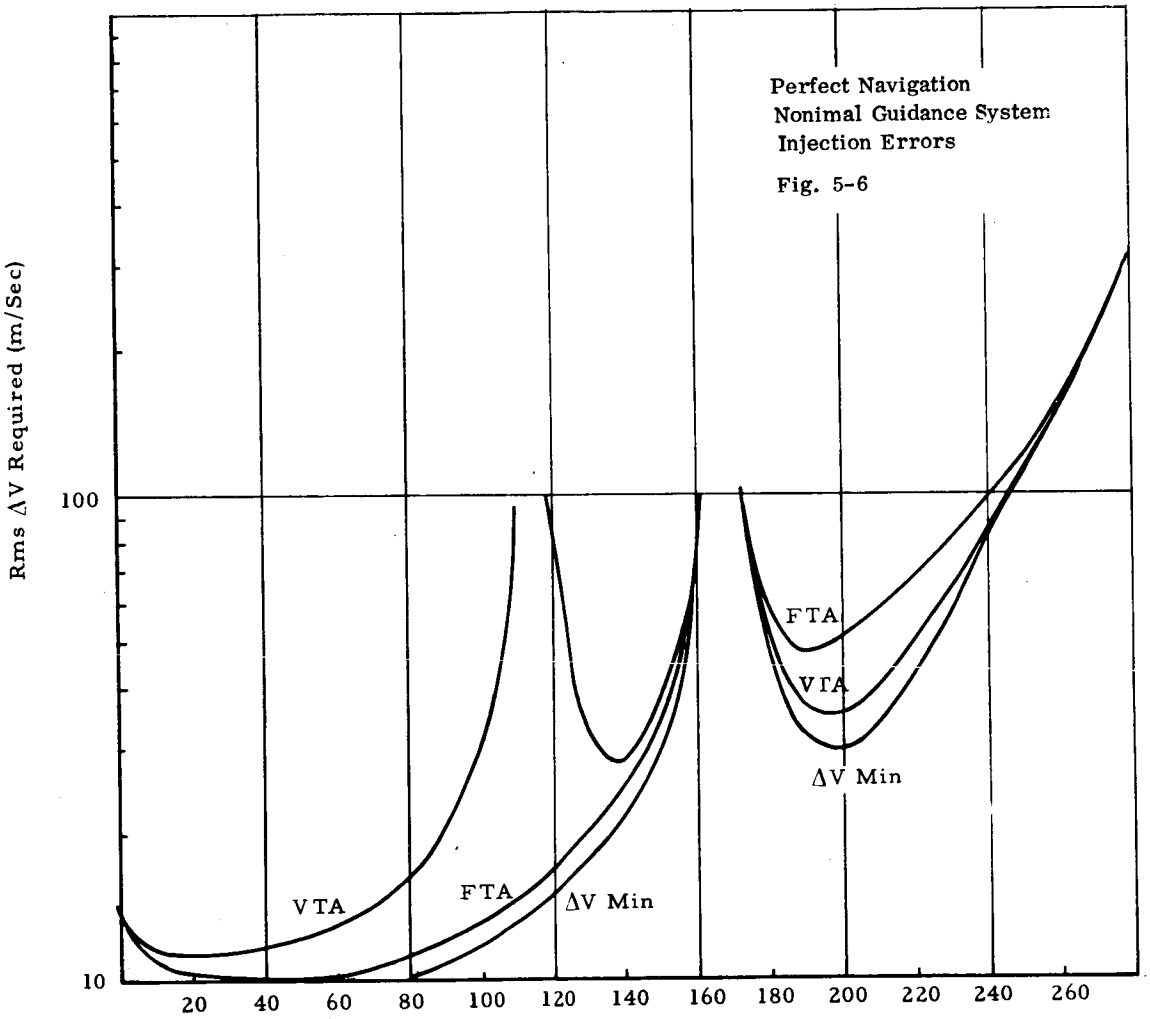


Figure 6-15 First Correction, Δv Requirements with Special Injection Errors

TABLE 6-1

SYSTEM III SCHEDULE

Time	Body	Observation * Interval	Number of OBS
$0-2^d$	Mars	1 Hour	48
2^d-10^d	None	------	---
10^d-60^d	Earth	2 Hour Interval all day every tenth day	72
60-200	None	------	---
200-290	Earth	3 Hour Interval all day every tenth day	80
$295-296^d12^h$	Earth	1 Hour	36
$296^d12^h-296^d14^h$	None	------	---
$296^d14^h-296^d16^h$	Earth	1 Hour	2
$296^d16^h-296^d18^h$	None	------	---
		Onboard OBS	238

*During Tracking Periods the DSIF Tracking Network was used Continuously.

TABLE 6-2

SYSTEM IV SCHEDULE

Time	Body	OBS Interval	Number Of OBS
$0\text{-}6^h$	Mars	15 Minutes	24
$6^h\text{-}1^d$	Mars	1 Hour	18
$1^d\text{-}40^d$	Earth	2 Days	20
$40^d\text{-}242^d$	Earth	5 Days	40
$242^d\text{-}292^d$	Earth	1 Day	50
$292^d\text{-}295^d$	Earth	6 Hours	12
$295^d\text{-}296^d$	Earth	1 Hour	24
$296^d\text{-}296^d12^h$	Earth	30 Minutes	24
$296^d12^h\text{-}296^d14^h$	None	-------	--
$296^d14^h\text{-}296^d16^h$	Earth	15 Minutes	
$296^d16^h\text{-}296^d18^h$	None	-------	--
		Total Number of OBS	220

TABLE 6-3

GUIDANCE TIMES FOR SYSTEMS III & IV

1st Correction	2nd Correction	3rd Correction	4th Correction
45 days	250 days	295^d18^h	296^d14^h

TABLE 6-4

SYSTEM III GUIDANCE DATA

DSIF & 10-Second Theodolite				DSIF Only		
Correction ΔV (m/sec)	Coord.	Error in Estimate (km)	Deviation Aft. Corr. (km)	Correction ΔV(m/sec)	Error in Estimate (km)	Deviation Aft. Corr. (km)
1st	ALT	385	24300	1st	475	24300
	DR	412	25600		497	25600
ΔV=52.8	CR	254	14400	ΔV=52.8	343	14400
2nd	ALT	160	434	2nd	176	441
	DR	141	672		155	675
ΔV=9.49	CR	137	290	ΔV=9.49	151	297
3rd	ALT	5.72	10.1	3rd	6.15	10.5
	DR	31.8	34.7		32.2	35.1
ΔV=8.78	CR	3.68	6.76	ΔV=8.89	3.92	6.95
4th	ALT	1.84	2.09	4th	1.96	2.17
	DR	25.0	25.0		25.1	25.2
ΔV=1.36	CR	1.20	1.28	ΔV=1.38	1.27	1.37
TOTAL ΔV=72.43				TOTAL ΔV=72.56		

TABLE 6-5

SYSTEM IV GUIDANCE PERFORMANCE WITH MOON OBSERVATIONS IN SCHEDULE

Schedule		ALT* (km)	DR (km)	CR (km)	ΔT (min)	ΔV (m/sec)
Table 6-2	Est.	5.76	383	2.91	.42	110.34
	Dev.	6.80	383	3.86		
Moon Obs. Added	Est.	3.65	22.7	2.58	.12	90.66
	Dev.	3.79	22.8	2.66		

*Corridor Coordinate

TABLE 6-6

VENUS TRACKING SCHEDULE

Mars-Venus			
Time	Interval	Number	Body
0-1	1 Hour	24	Mars
1-75	2 Days	37	Sun
75-150	2 Days	37	Venus
150-198	1 Day	48	Venus
198-200	1 Hour	48	Venus
	TOTAL	194	

Venus-Earth			
0-1	1 Hour	24	Venus
1-110	5 Days	22	Sun
110-158	1 Day	48	Earth
158-160	1 Hour	48	Earth
	TOTAL	142	

TABLE 6-10

GUIDANCE PERFORMANCE FOR VARIOUS INJECTION CONDITIONS (FTA)

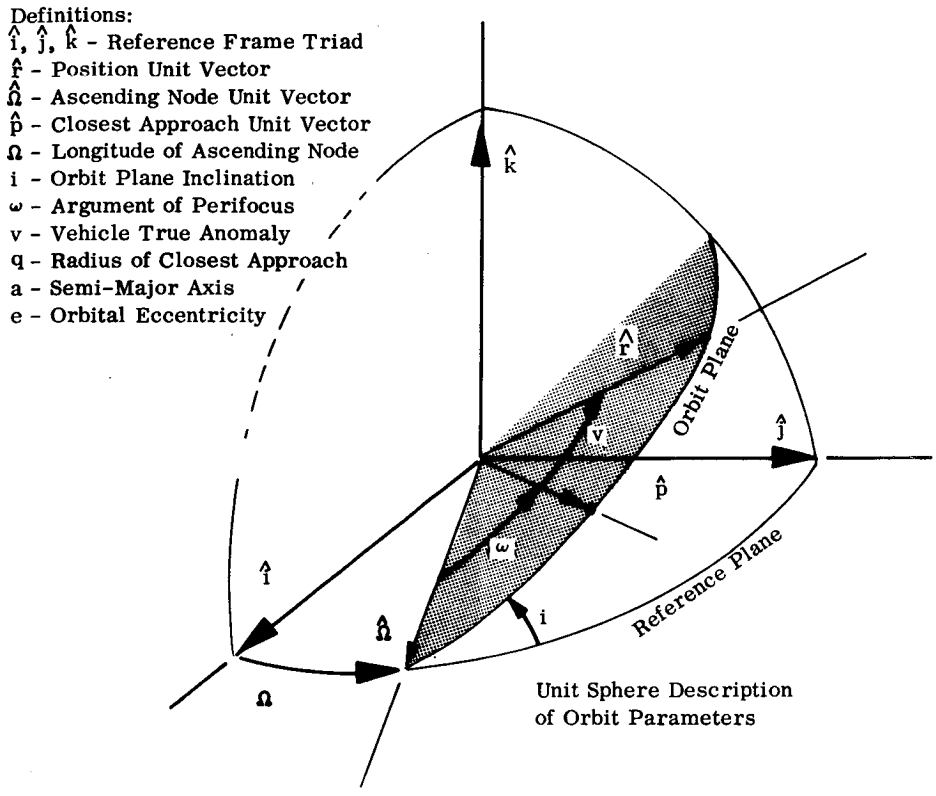
Case	Initial Error in Est.	Initial Deviation State	ΔV Requirements (m/sec)				Perigee Deviations (km)
			1st	2nd	3rd	4th	
1	Fig. 6-4	Fig. 6-4	50.68	12.98	20.98	25.7	ALT 6.73 DR 380 CR 3.82
2	Fig. 6-4 With RMS VEL=3m/sec	Fig.6-4	50.68	12.92	20.80	25.0	ALT 6.40 DR 350 CR 3.59
3	Same as Case 2	Fig.6-4 With RMS VEL=3m/sec	22.93	9.89	19.0	21.7	ALT 6.23 DR 361 CR 3.48

TABLE 6-11

COMPARISON OF ΔV REQUIRED ON OUTBOUND AND RETURN TRAJECTORIES (FTA)

Trajectory	Injection Covariance Matrix	ΔV Requirements (m/sec)				
		1st	2nd	3rd	4th	TOTAL
Outbound	Figure 5-6	10.59	13.23	10.73	22.34	56.89
Return	Figure 5-6	9.87	8.48	18.3	20.2	56.85

SECTION 7



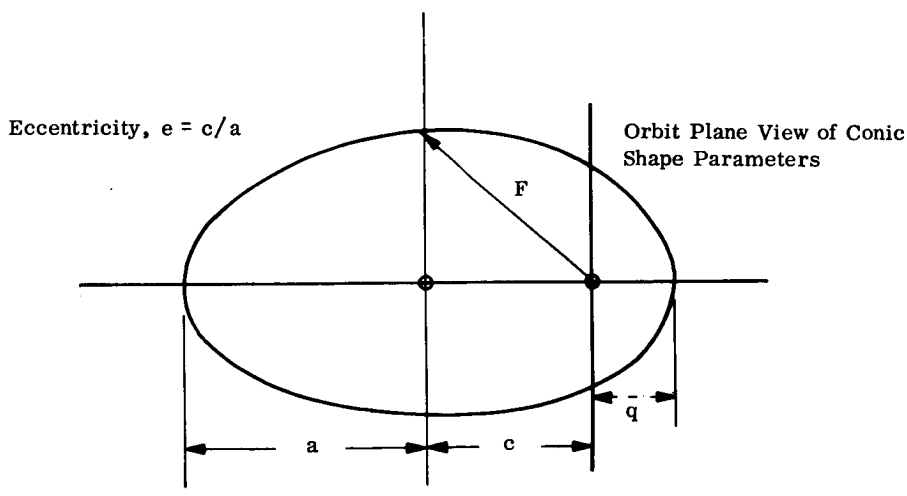


Figure 7-1 Orbital Element Definitions

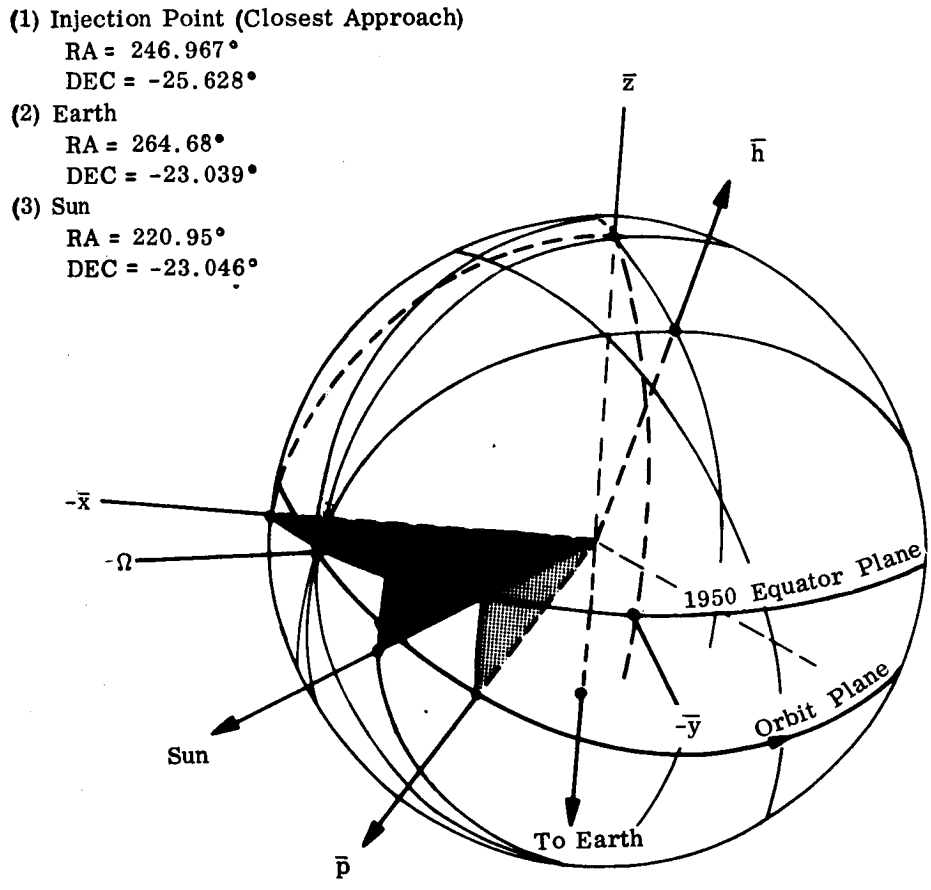


Figure 7-2 Orbit-Planetary Body Configuration at Park Orbit Injection

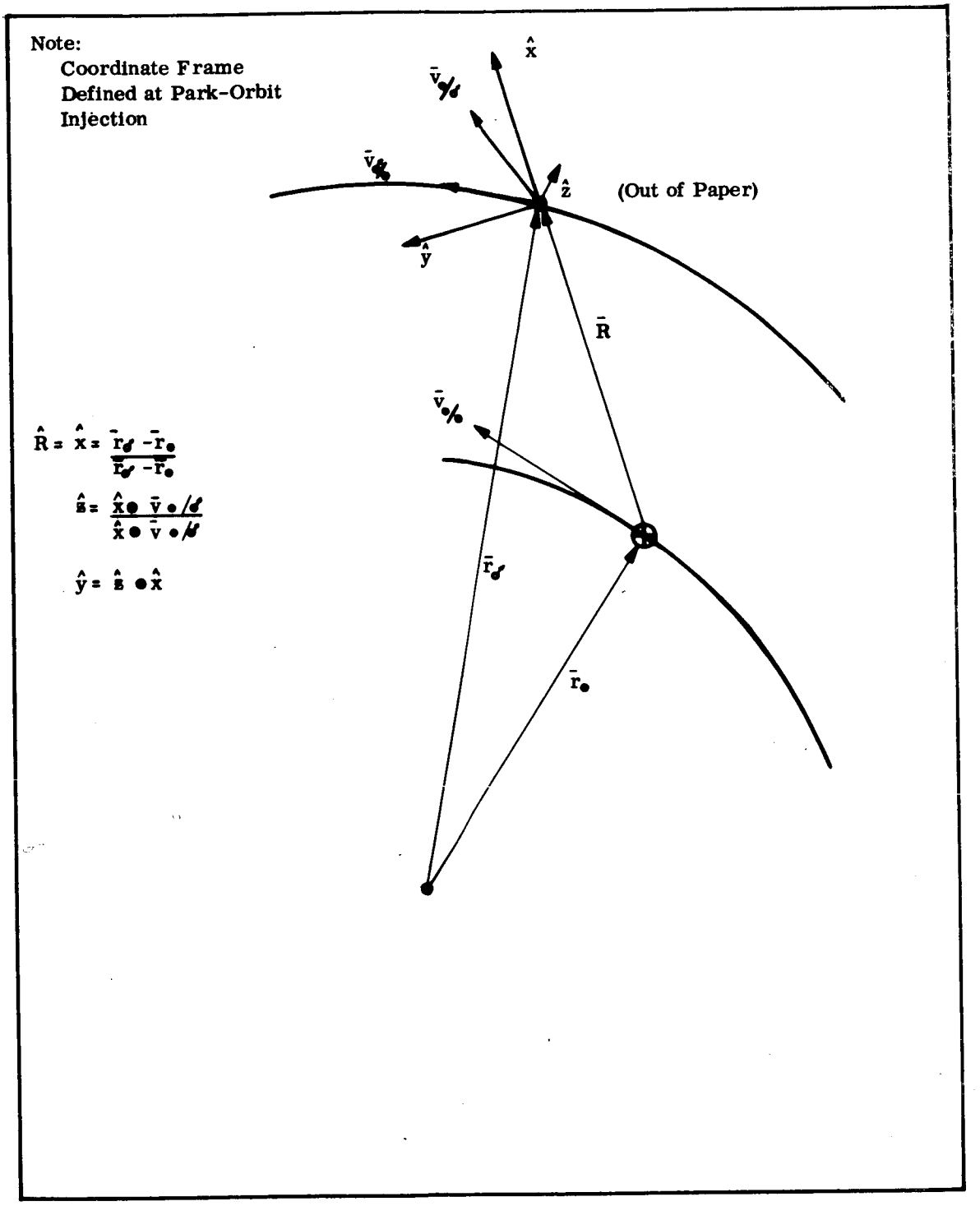


Figure 7-3 Earth-Based Tracker Coordinate System

Configuration I

$\hat{R} \bullet \hat{x} = 1$

$\hat{R} \bullet \hat{y} = 0$

$\hat{R} \bullet \hat{z} = 0$

$\hat{R} \bullet \hat{w} = 0$

Configuration II

$\hat{R} \bullet \hat{x} = 1$

$R \bullet \hat{y} = 0$

$\hat{R} \bullet \hat{z} = 0$

$\hat{R} \bullet \hat{w} = -1$

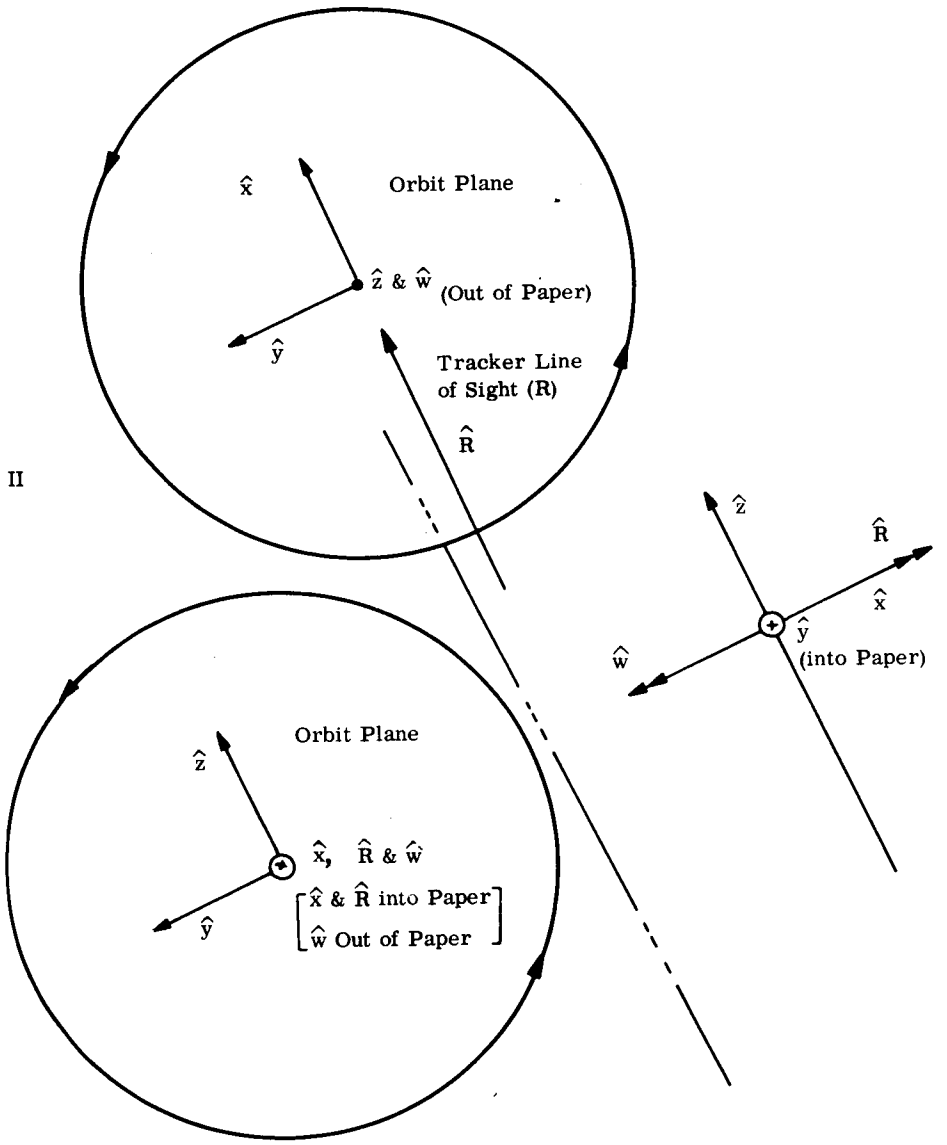


Figure 7-4 Initial Orbit Plane - DSIF Tracker Configurations

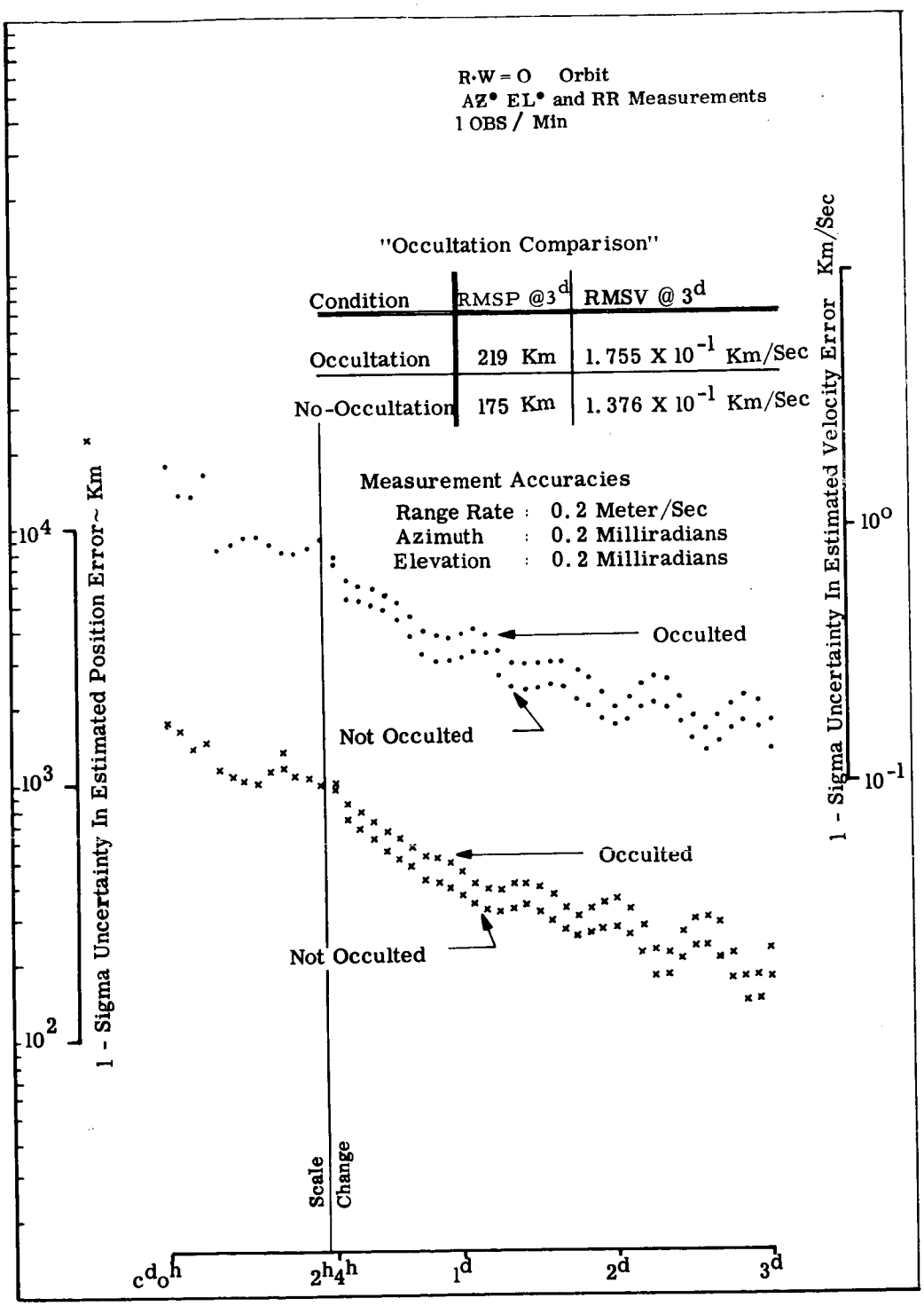


Figure 7-5 System I (DSIF Tracking) Park Orbit

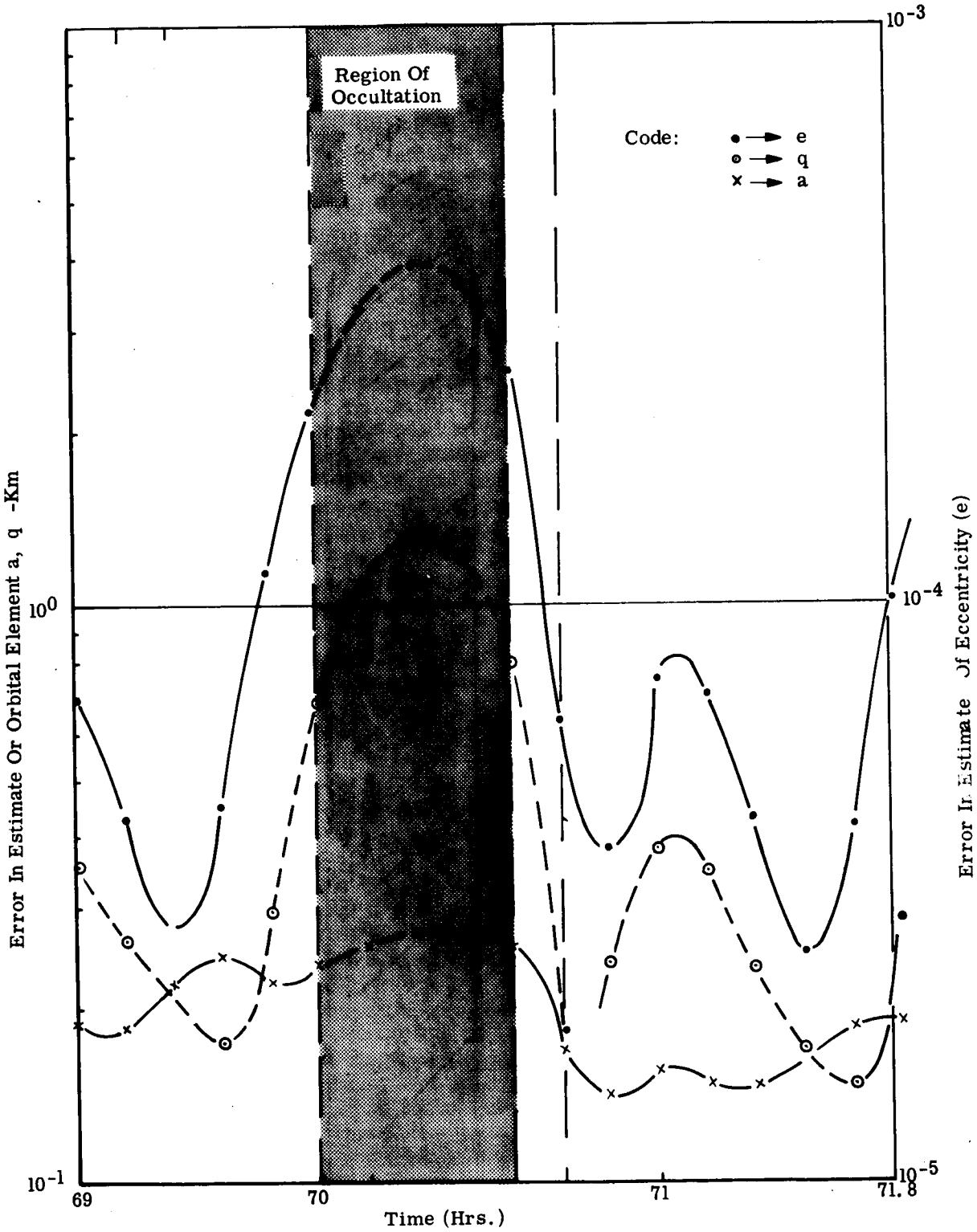


Figure 7-6 1-Sigma Uncertainties in Orbital Elements, Configuration $(\hat{R} \cdot \hat{W}) = 0$

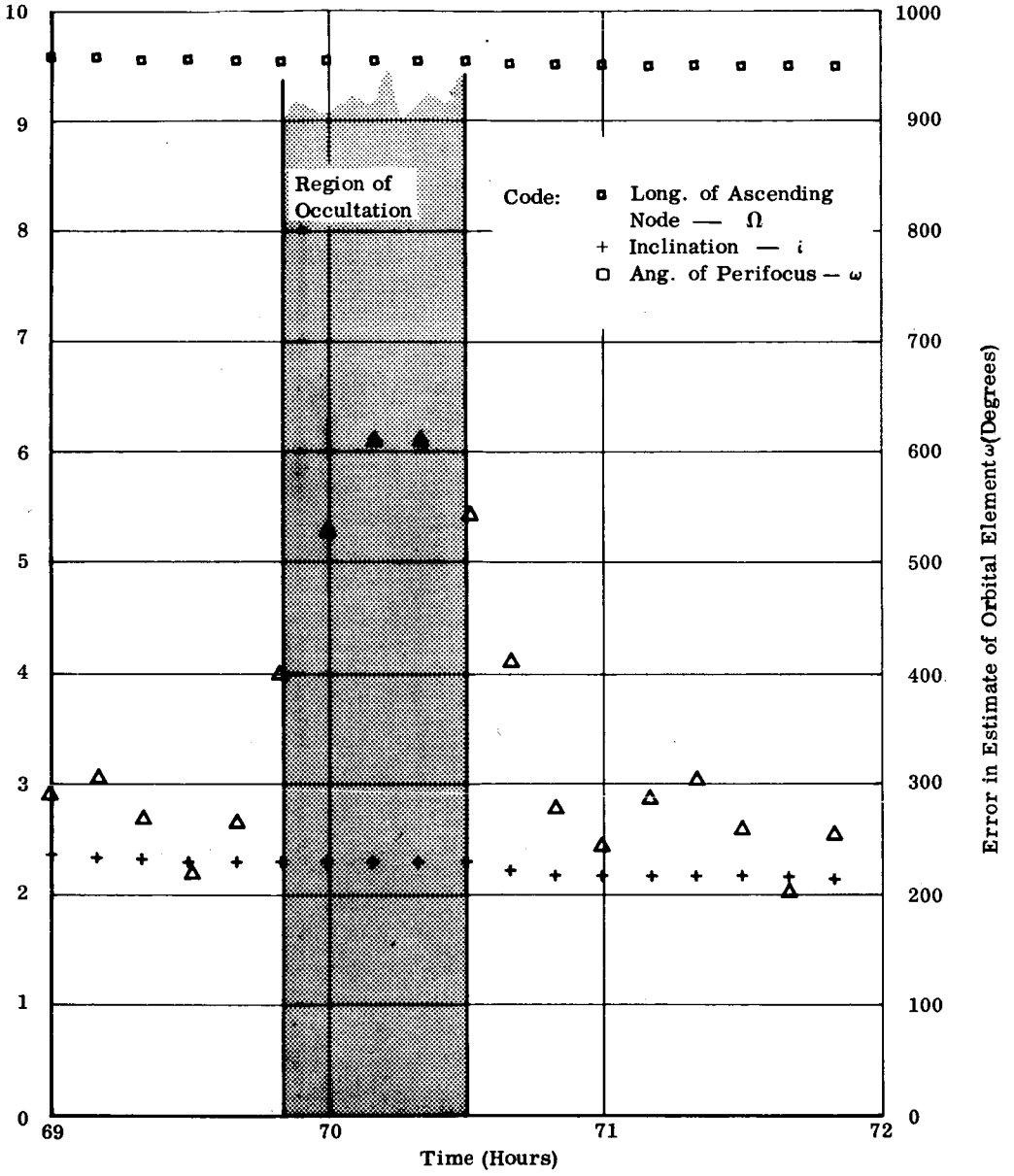


Figure 7-7 1-Sigma Uncertainties in Orbital Elements, Configuration (R · W) = 0

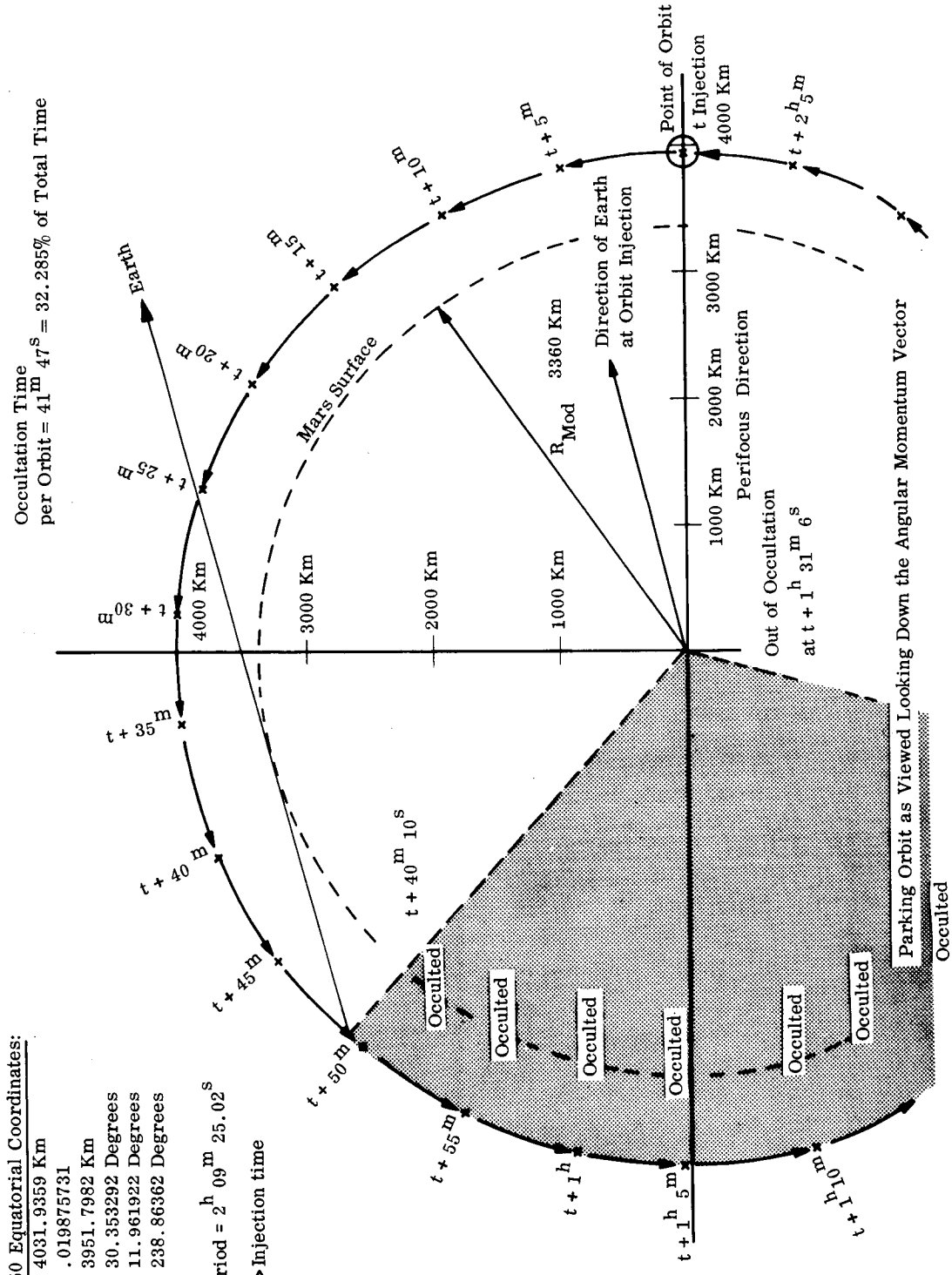


Figure 7-8 Nominal Orbit - Occultation

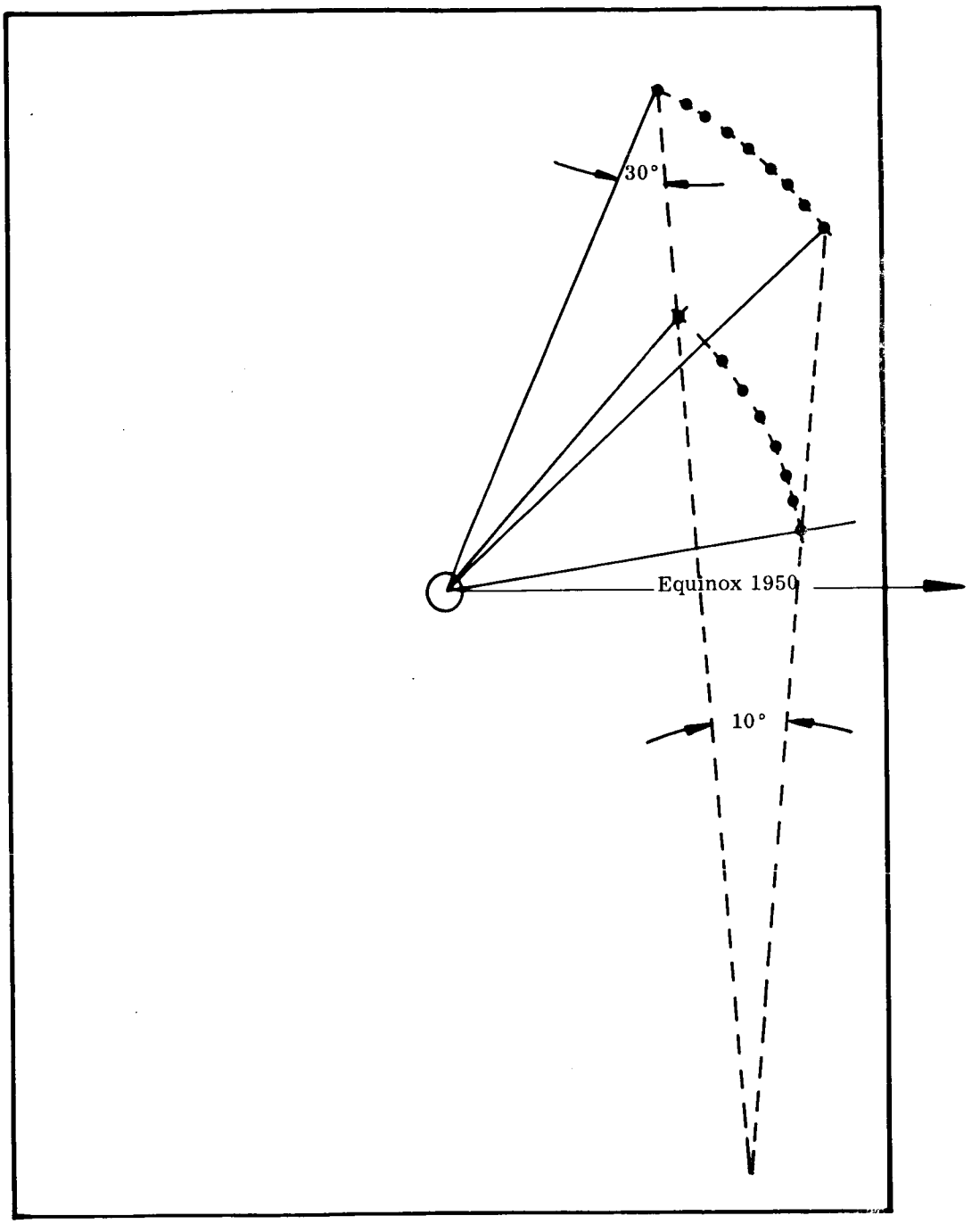


Figure 7-9 1950-Ecliptic Projections of the Positions of Earth and Mars During the 40 Days Spent in Martian Parking Orbit

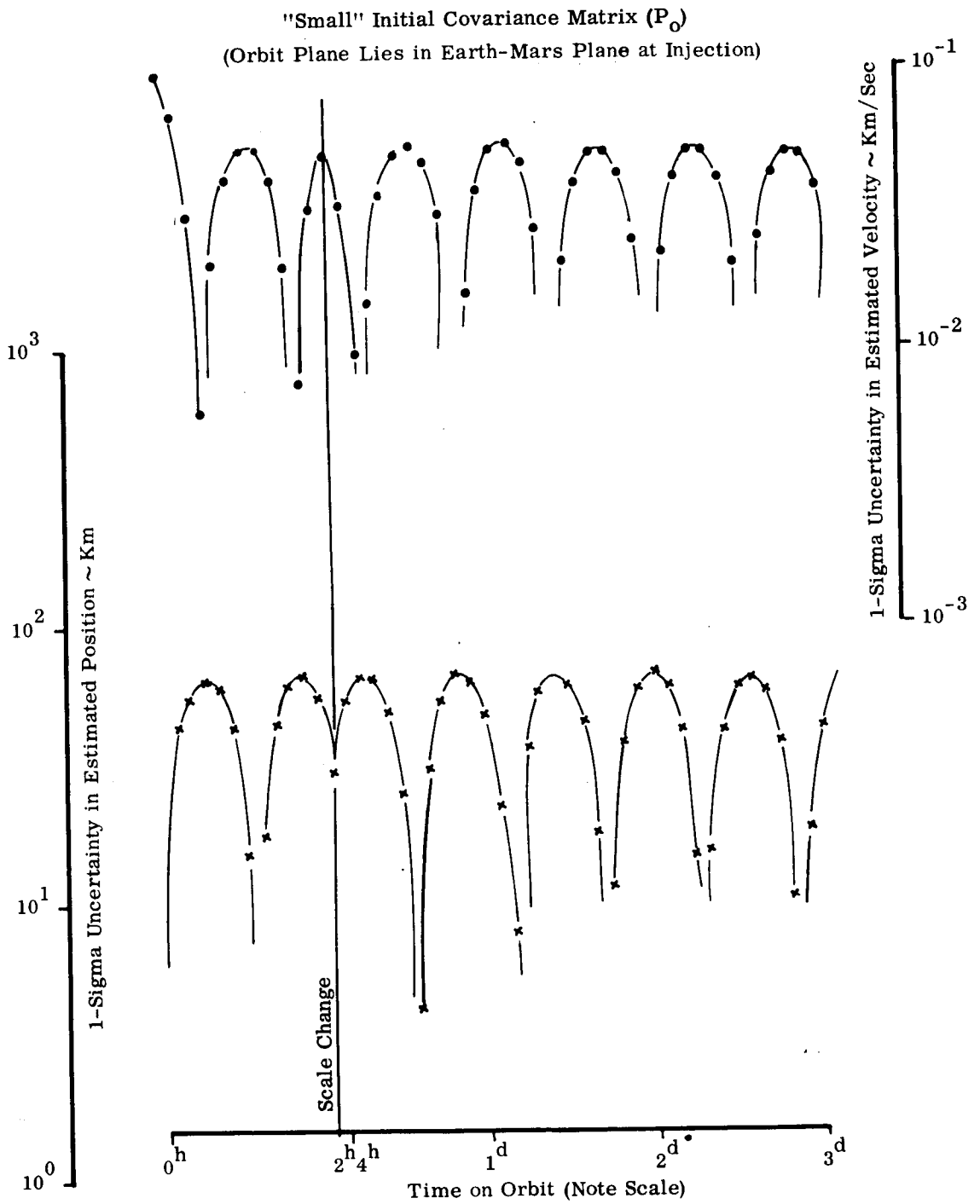


Figure 7-10 DSIF Special Orbit - $\hat{R} \cdot \hat{W} = 0$, $\hat{R} \cdot \hat{P} = 0$
(Range Rate ~ Azimuth ~ Elevation)

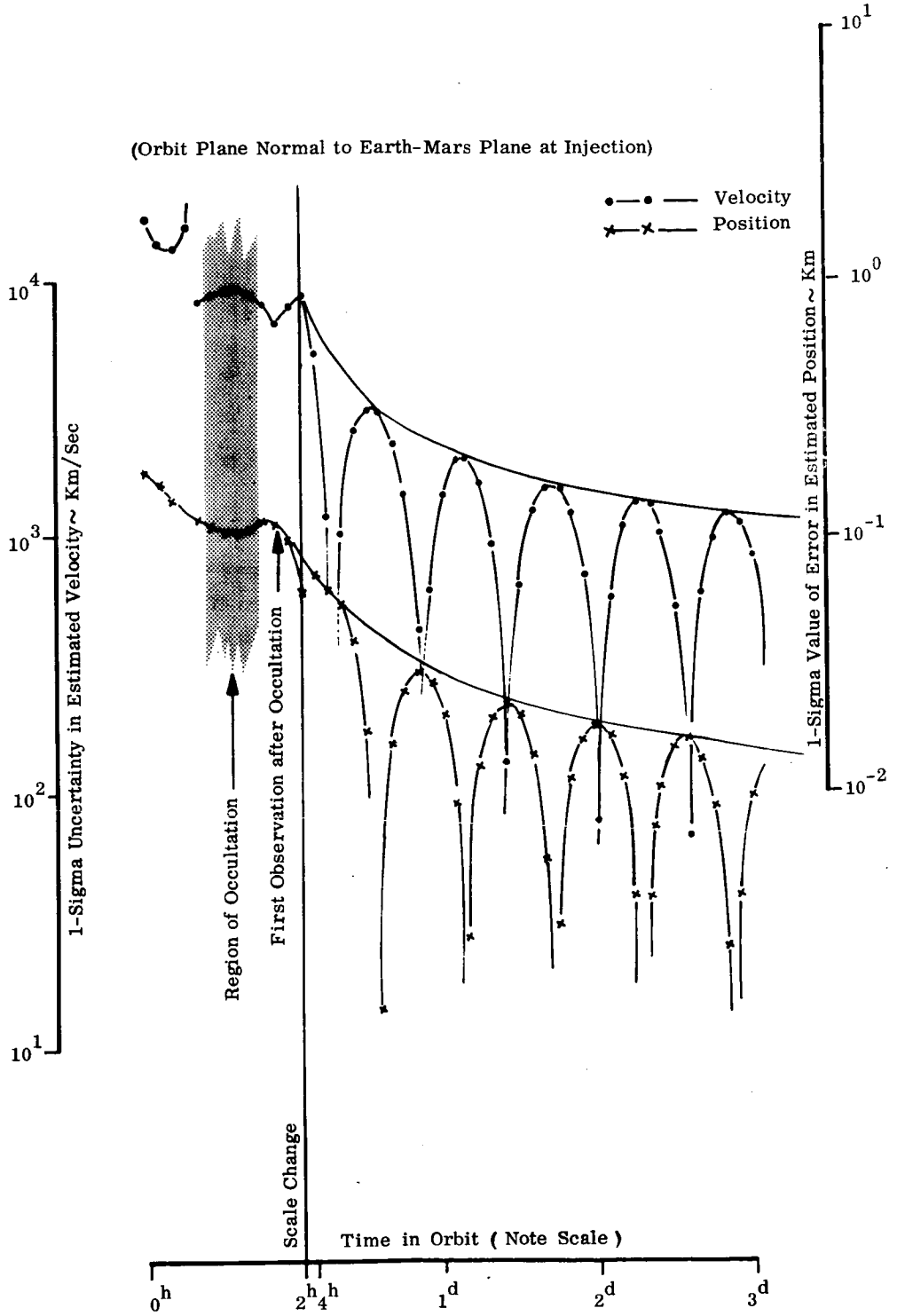


Figure 7-11 RMS Uncertainties in Position and Velocity - DSIF - Special Orbit ~ $\hat{R} \cdot \hat{W} = 0$, $\hat{R} \cdot \hat{P} = -1$

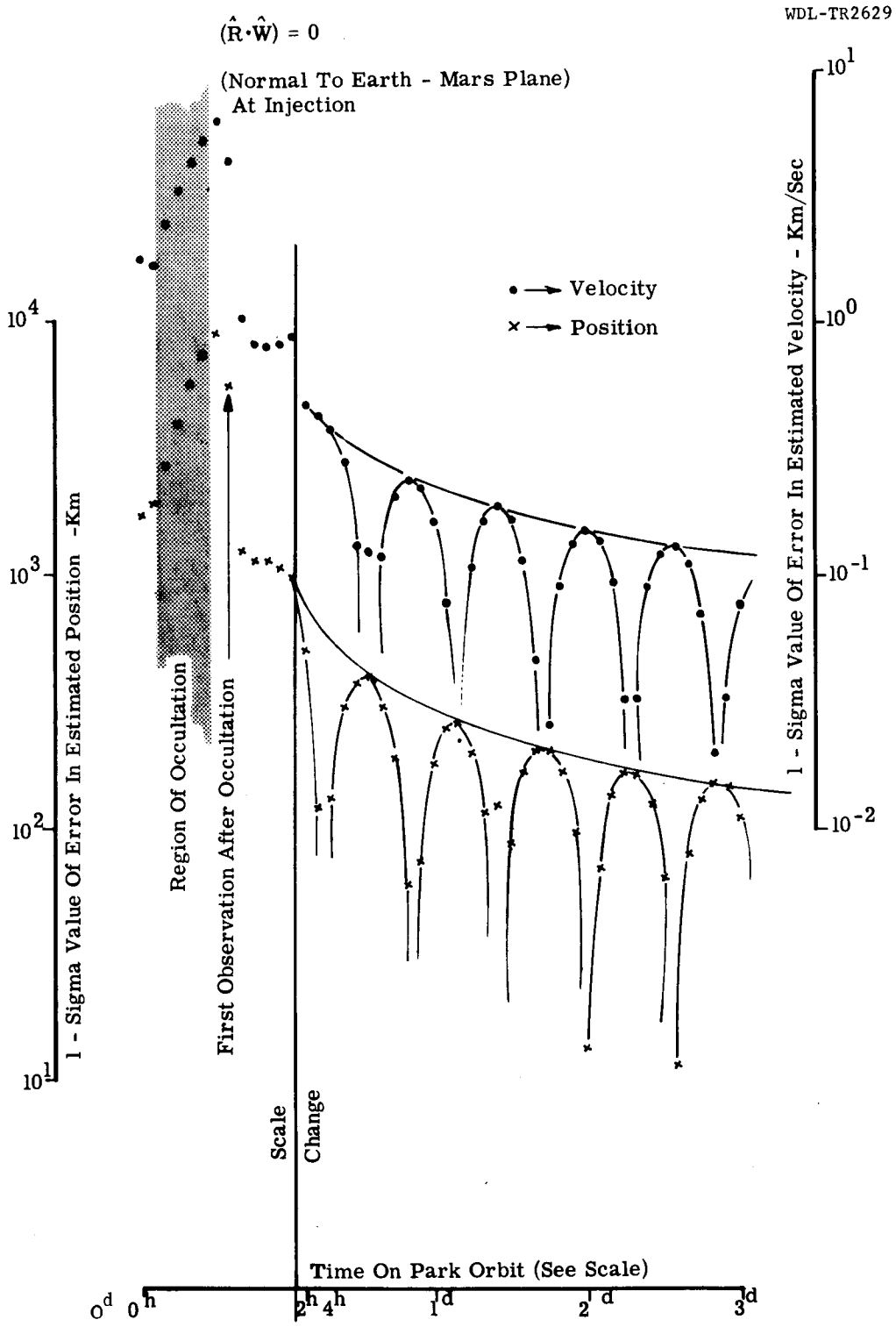


Figure 7-12 RMS Position and Velocity Uncertainties, $(\hat{R} \cdot \hat{W}) = 0$

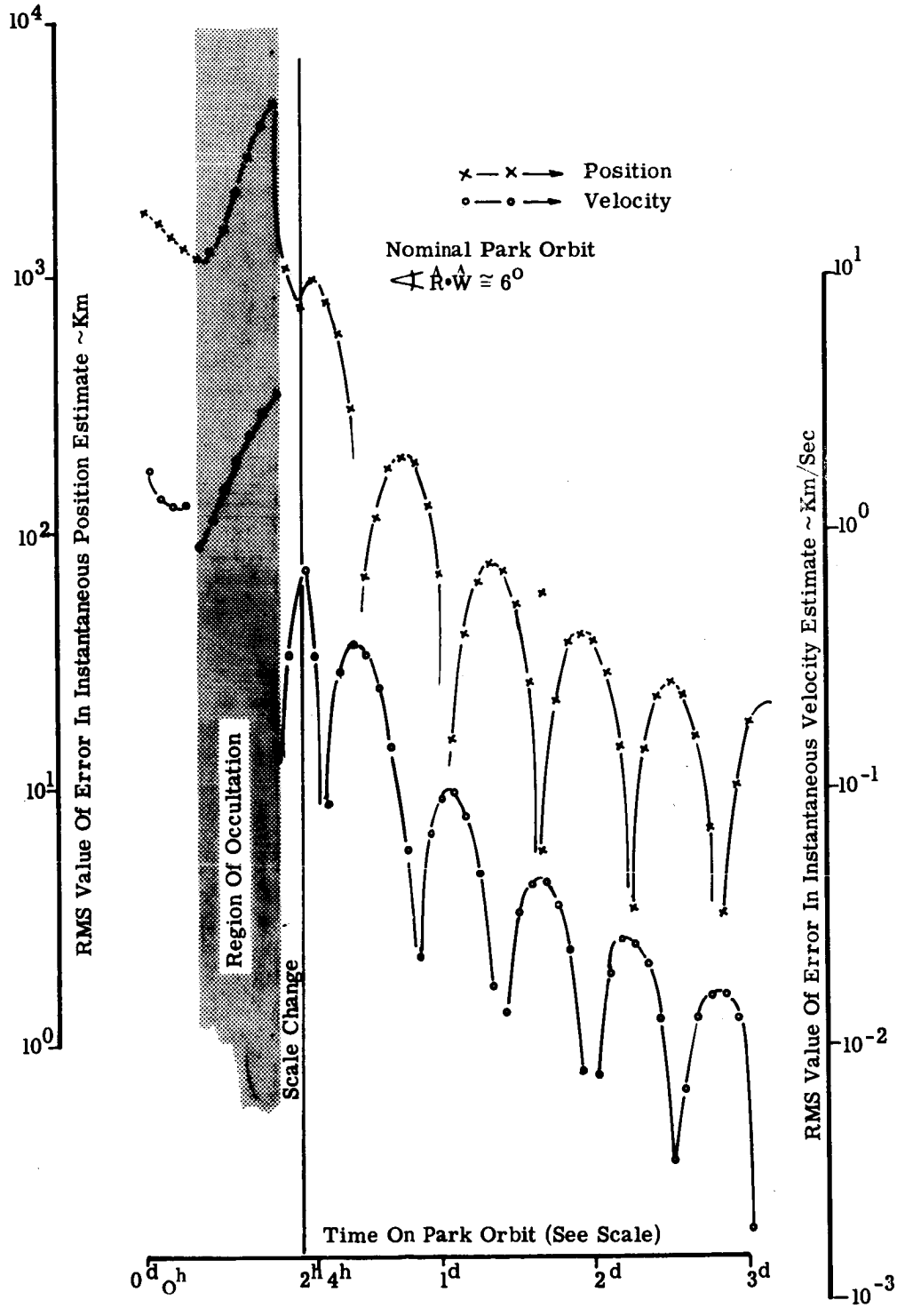


Figure 7-13 DSIF Nominal Orbit RMS Position and Velocity Uncertainties

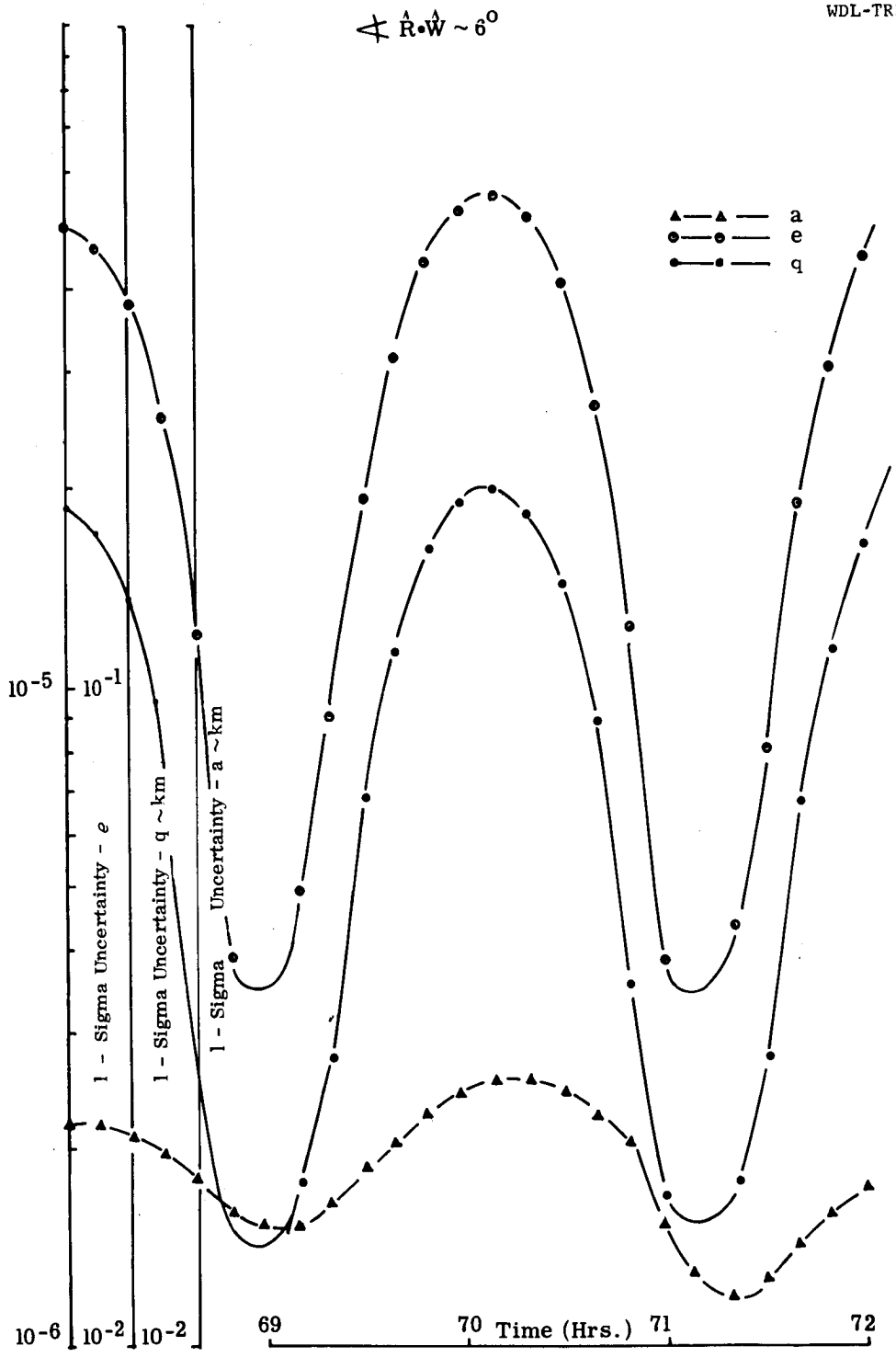


Figure 7-14 DSIF Uncertainties in Orbital Elements, Nominal Park Orbit - $\measuredangle \hat{R} \cdot \hat{W}$ = 6 Degrees

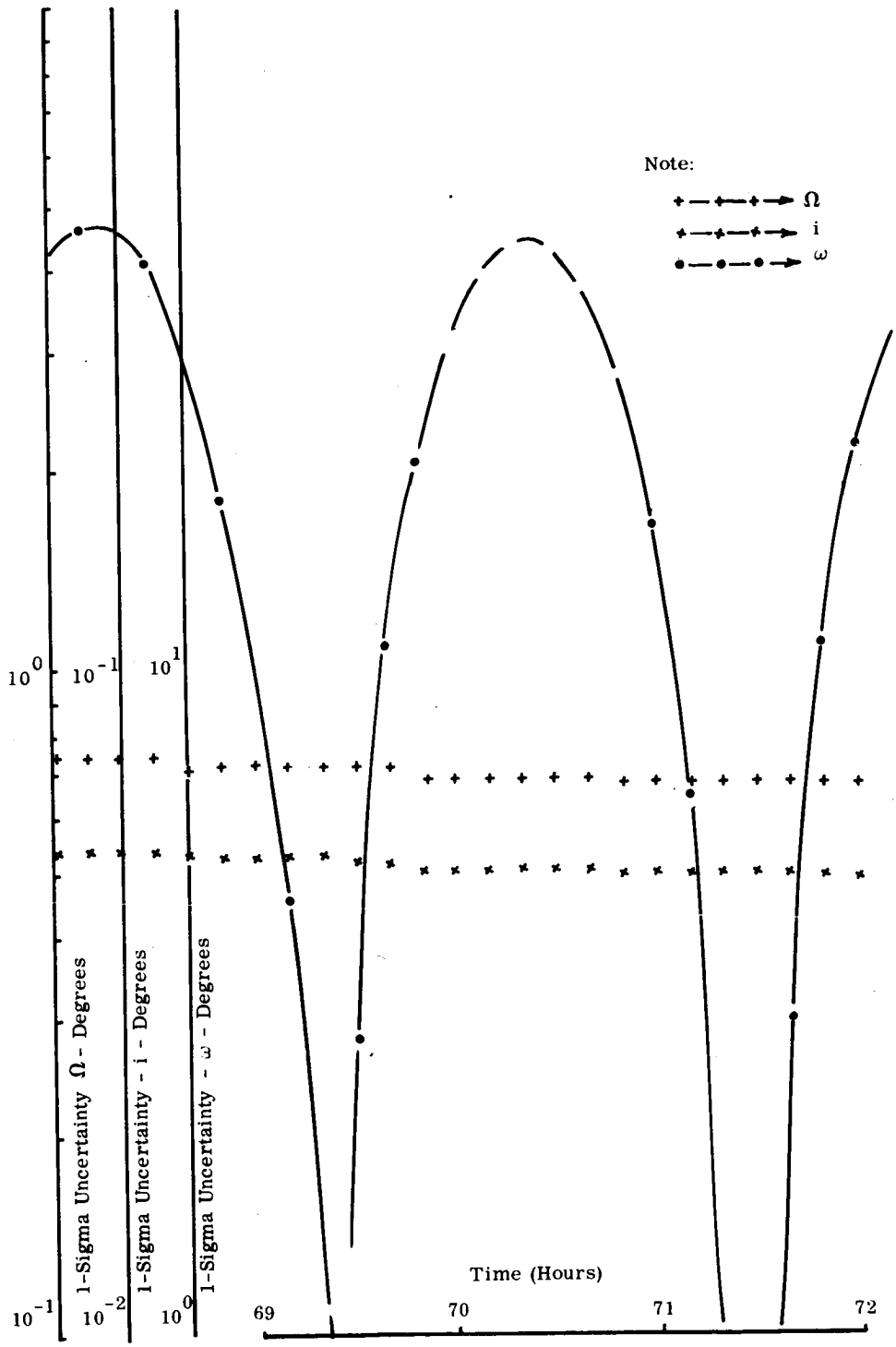


Figure 7-15 Uncertainties in Orbital Elements - DSIF - Nominal Park Orbit - $\measuredangle \hat{R} \cdot \hat{W}$ = 6 Degrees

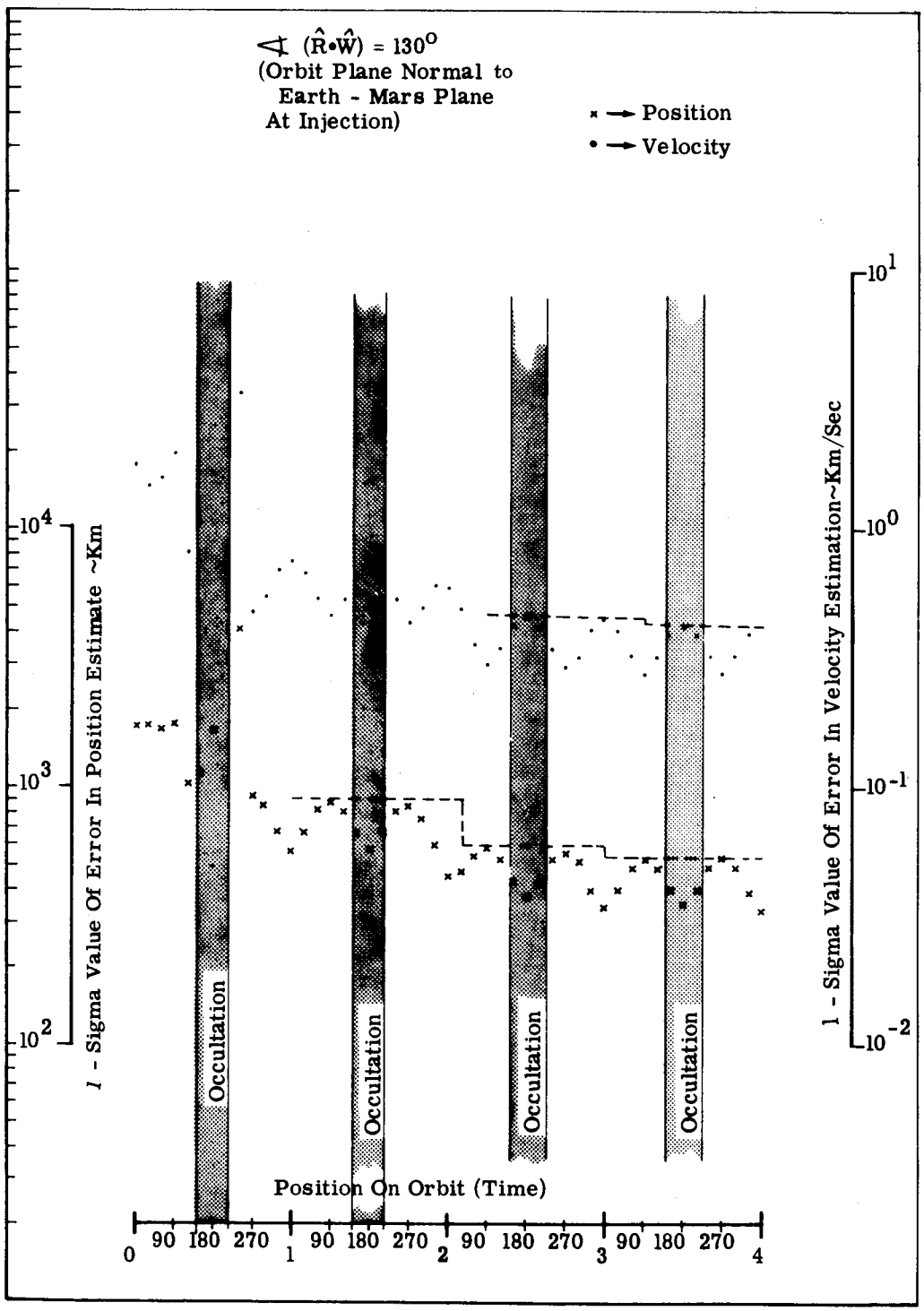


Figure 7-16 RMS Uncertainties in Position and Velocity - DSIF - ∢ (R̂ · Ŵ) = 130 Degrees

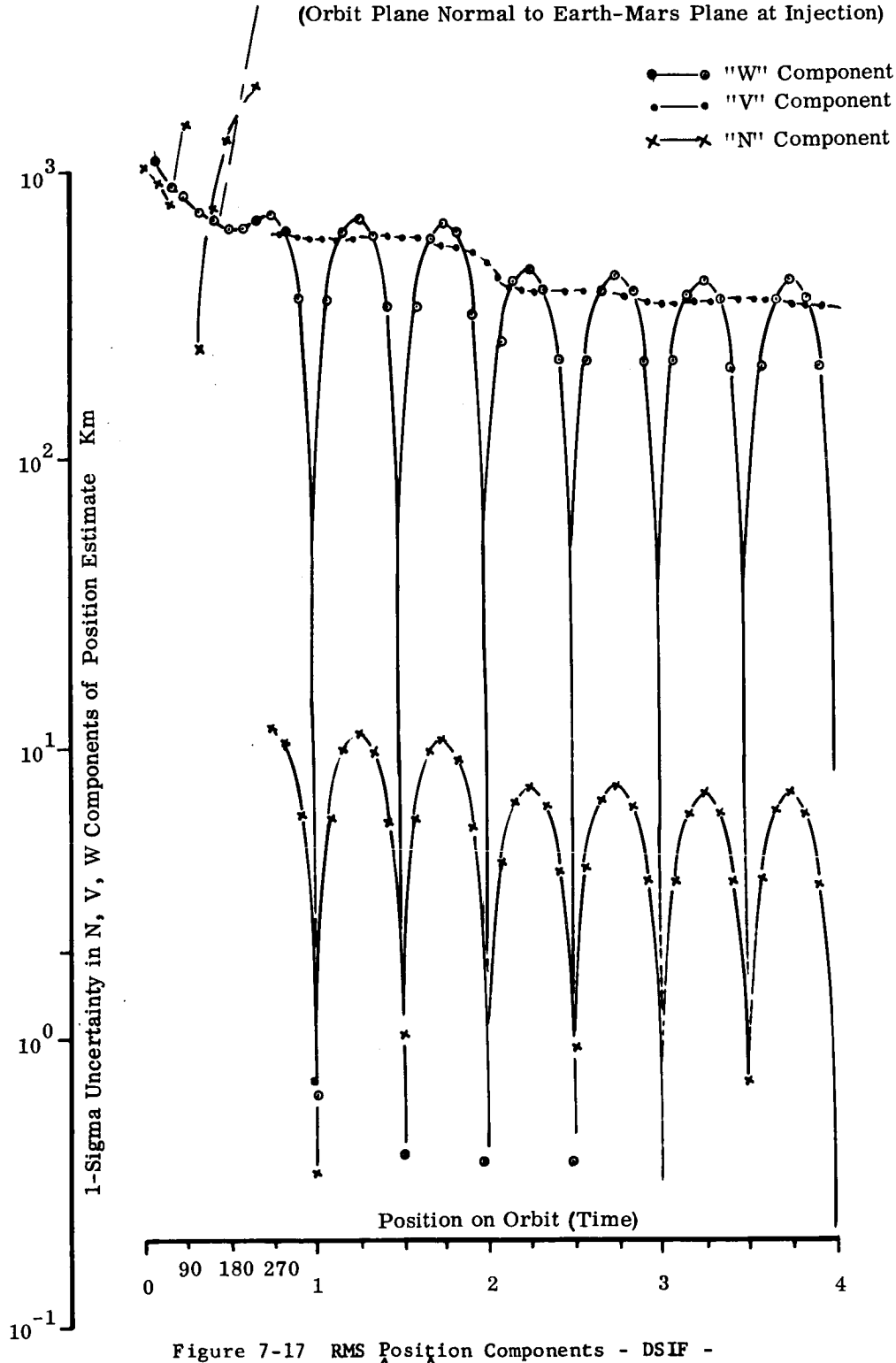


Figure 7-17 RMS Position Components - DSIF - $\measuredangle(\hat{R} \cdot \hat{W})$ = 130 Degrees

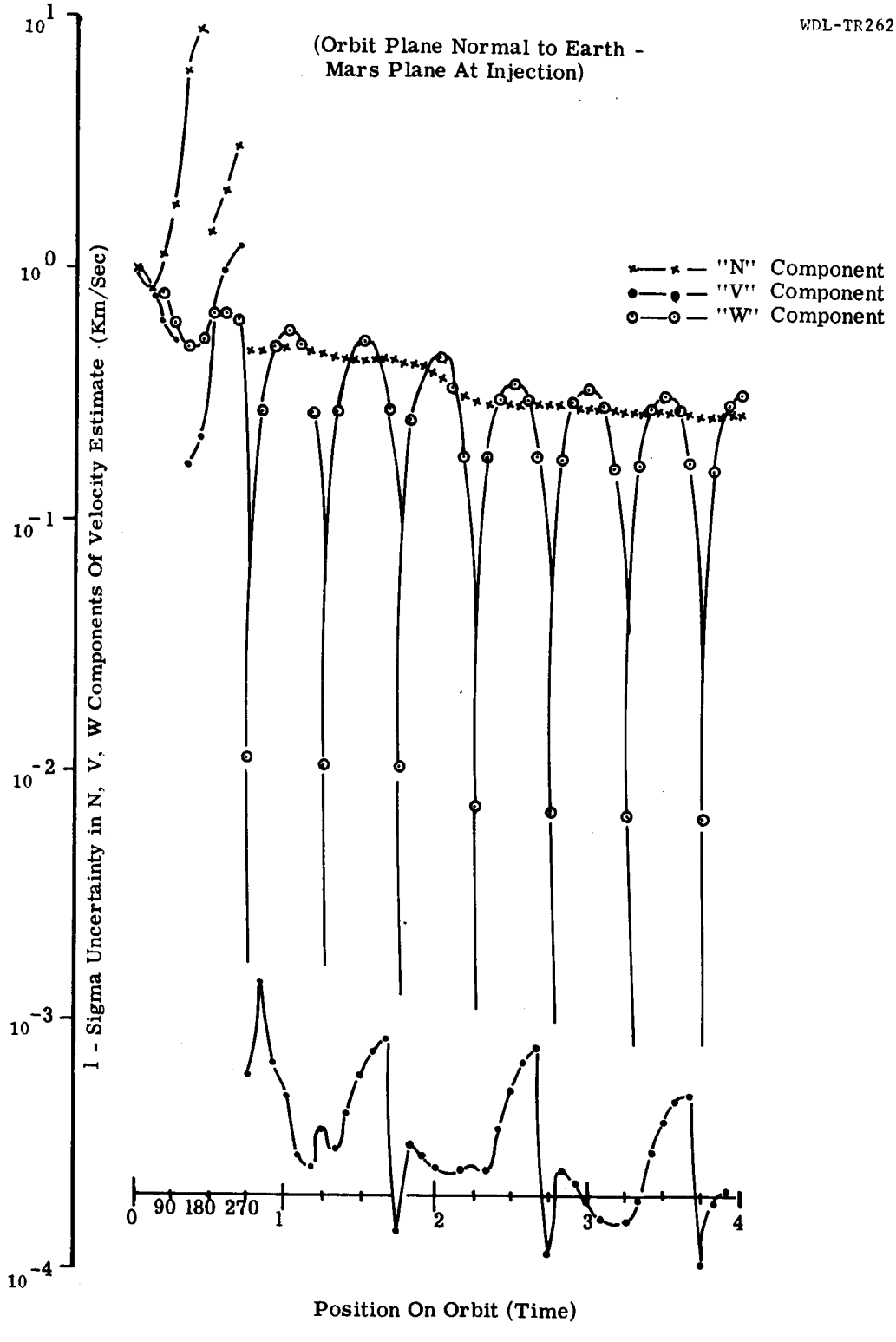


Figure 7-18 RMS Velocity Components - DSIF - $\measuredangle(\hat{R} \cdot \hat{W})$ = 130 Degrees

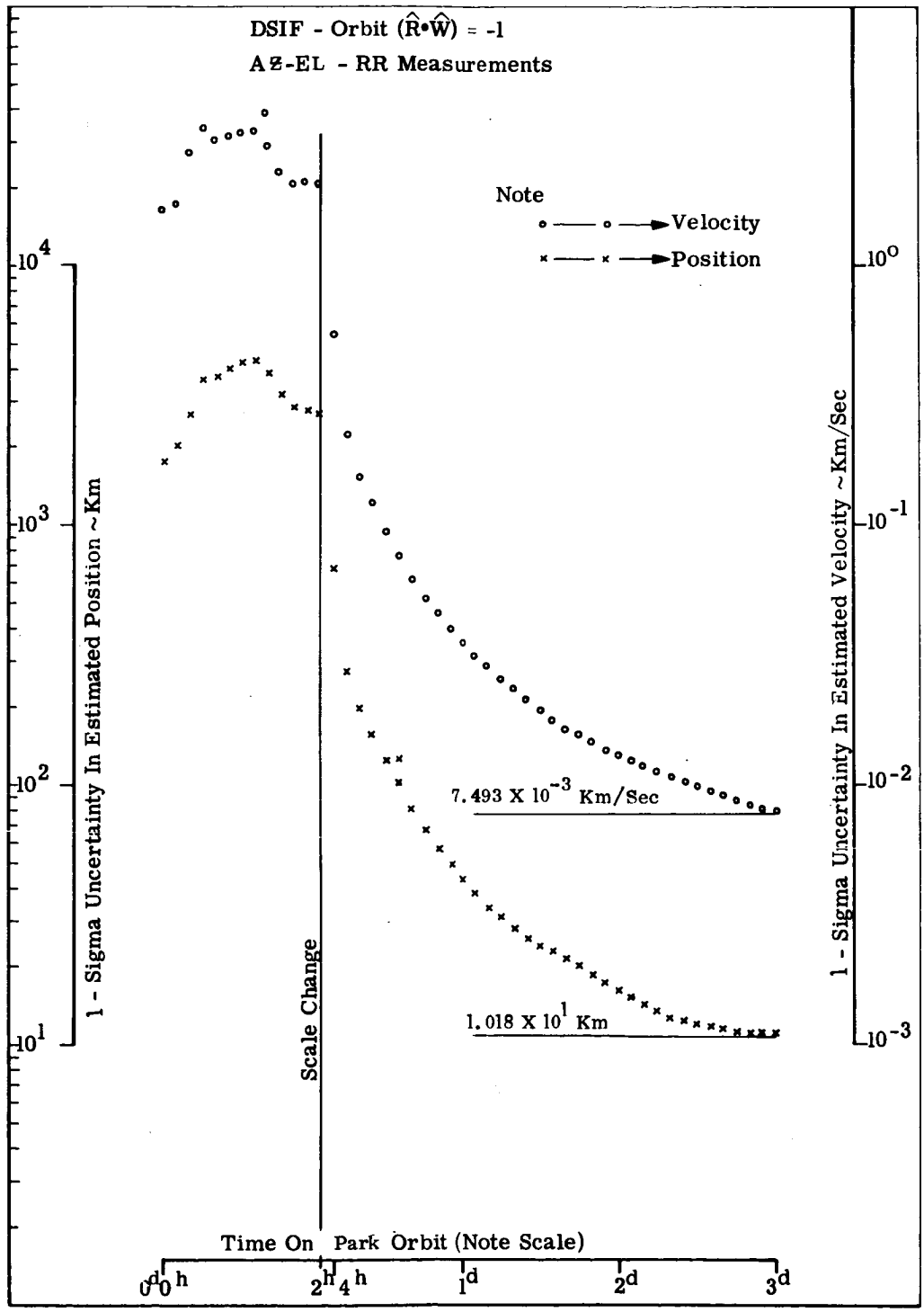


Figure 7-19 RMS Position and Velocity Uncertainties - DSIF - Orbit $(\hat{R} \cdot \hat{W}) = -1$

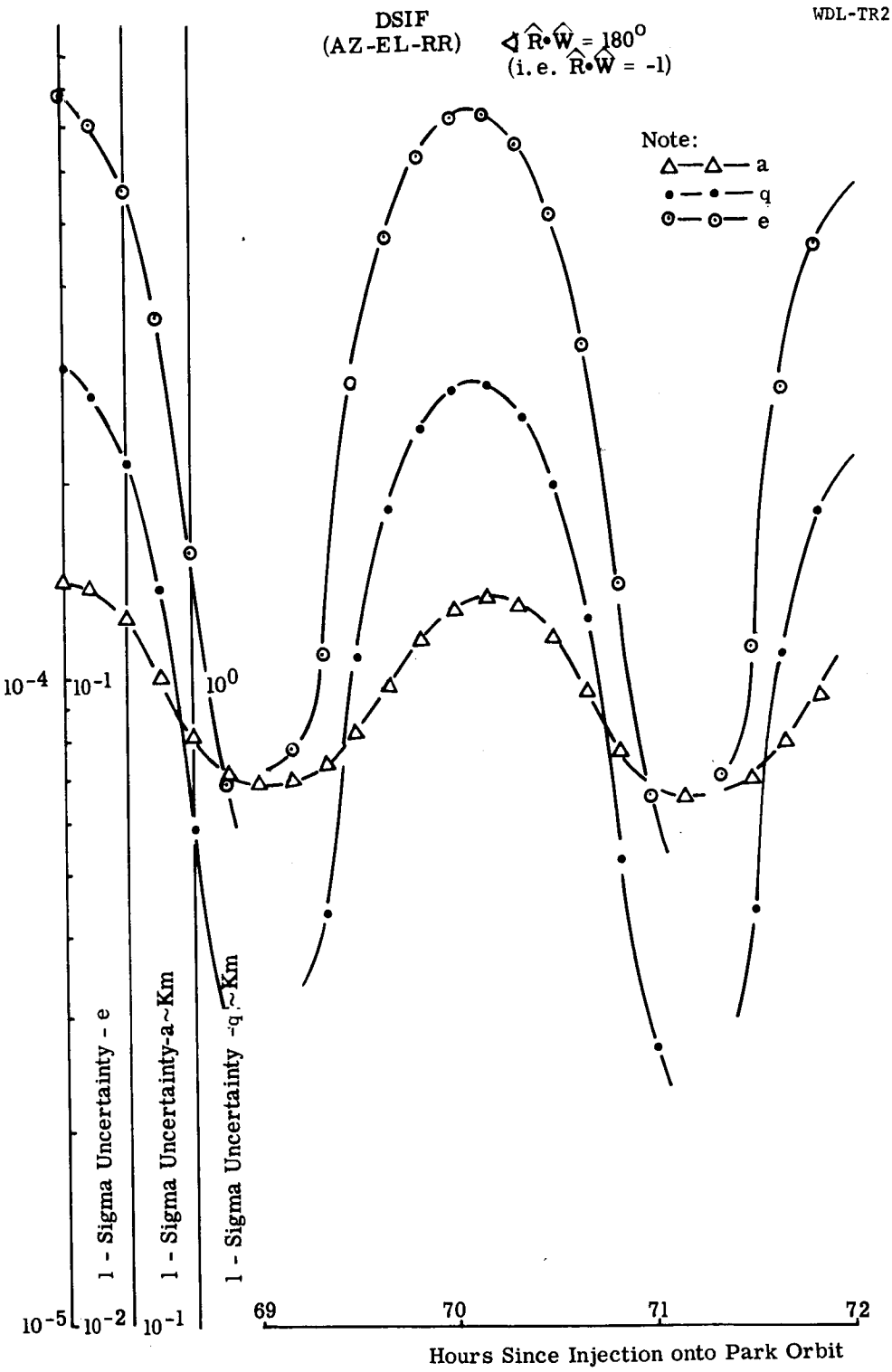


Figure 7-20 Uncertainties in Orbital Elements - DSIF - $\measuredangle \hat{R} \cdot \hat{W}$ = 180 Degrees

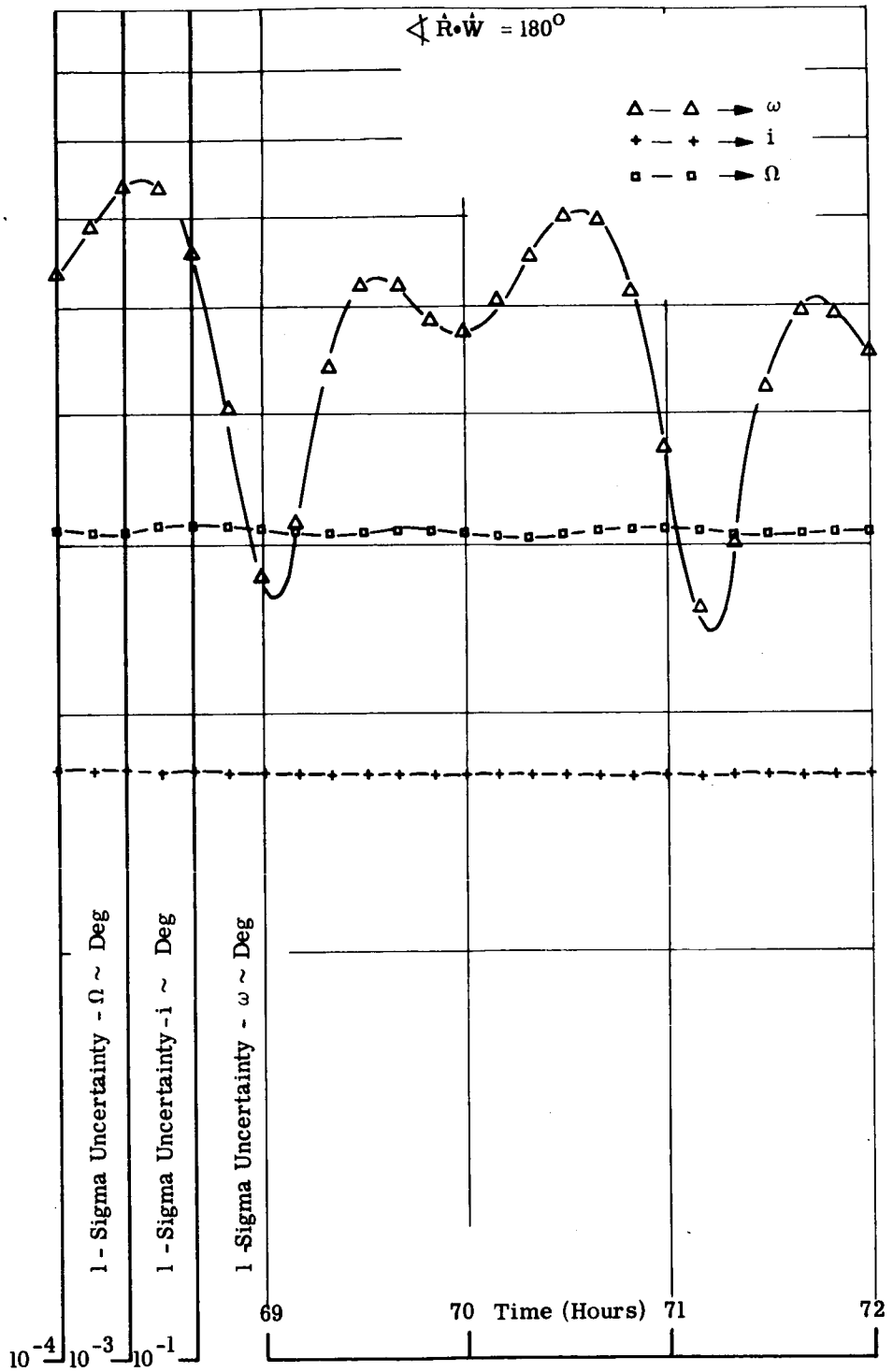


Figure 7-21 Uncertainties in Orbital Elements - ∢ $\hat{R} \cdot \hat{W}$ = 180 Degrees

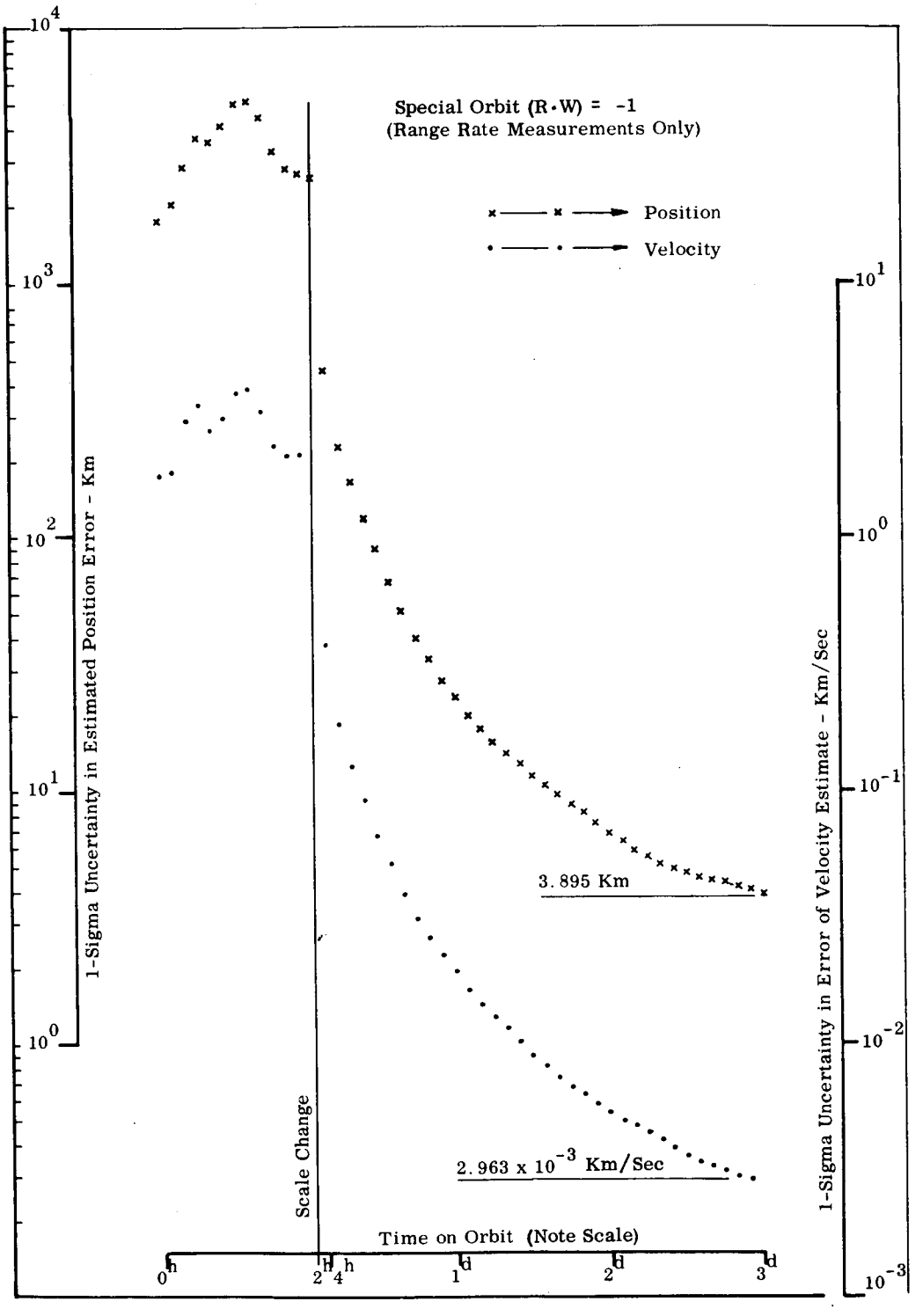


Figure 7-22 RMS Position and Velocity Uncertainties - DSIF - ∢(R · W) = 180 Degrees

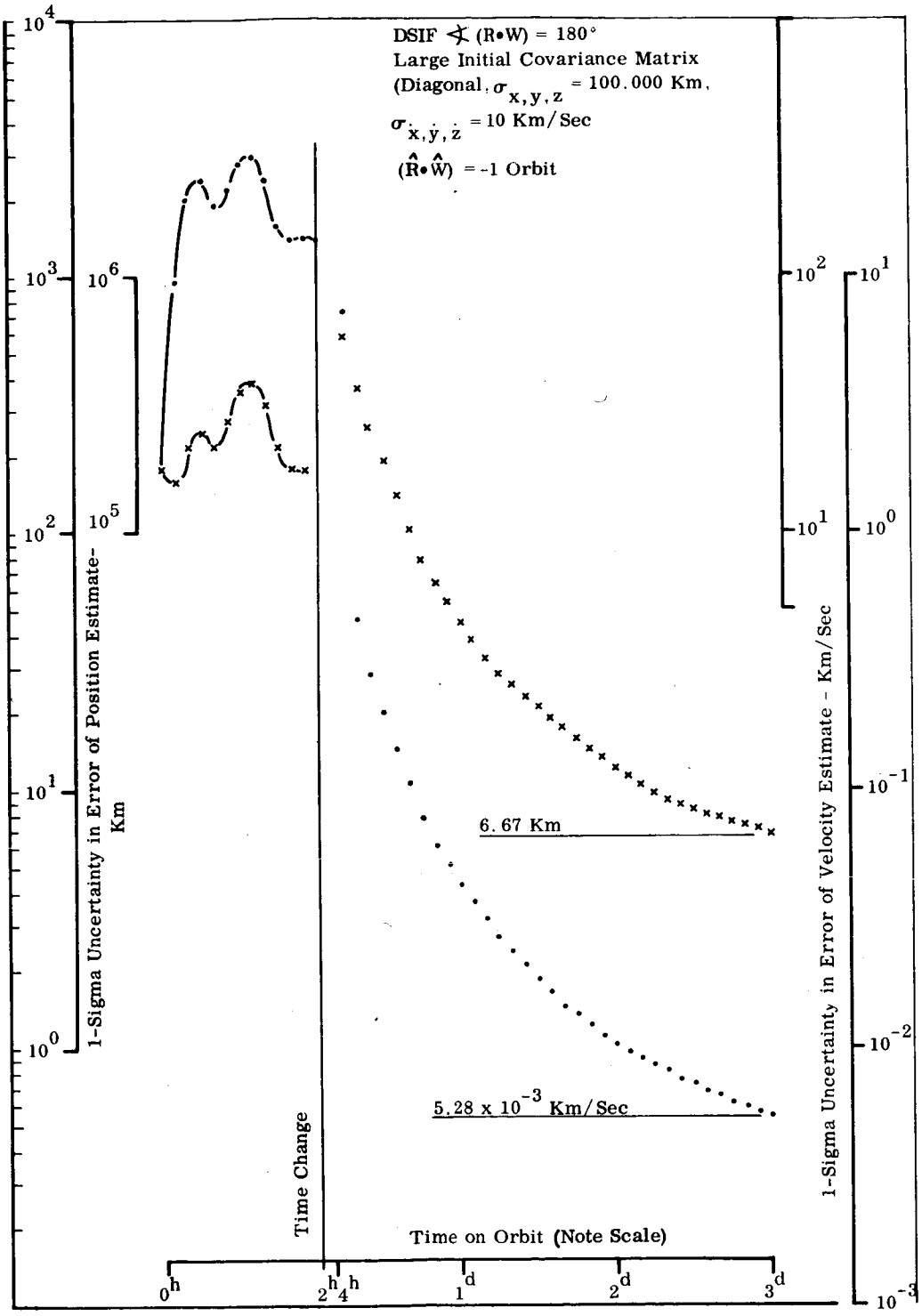


Figure 7-23 RMS Position and Velocity Uncertainties, DSIF - $\measuredangle(\hat{R} \cdot \hat{W})$ = 180 Degrees

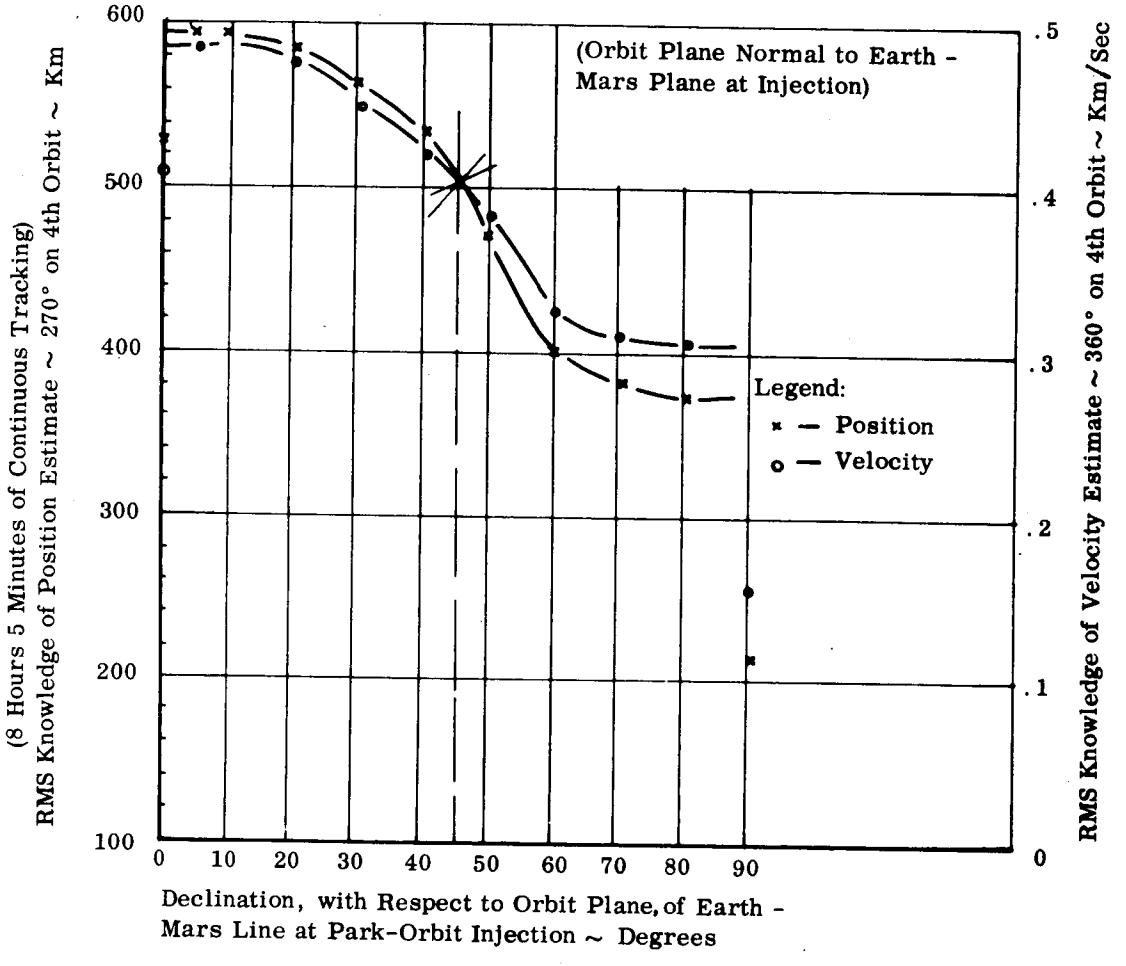


Figure 7-24 RMS Position and Velocity Estimate Knowledge at 270 Degrees True Anomaly on the Fourth Orbit vs. Earth-Mars Declination Angle

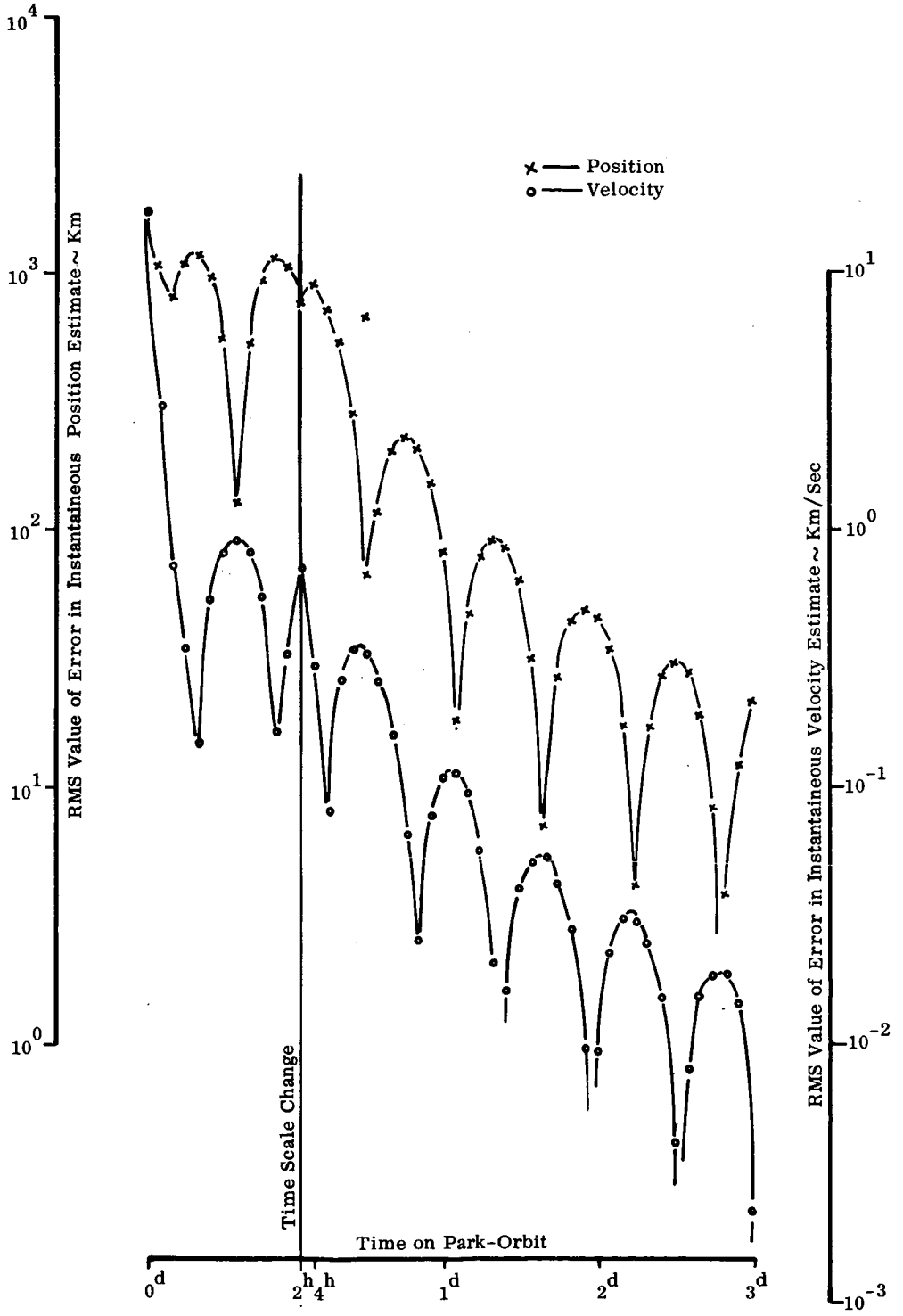


Figure 7-25 RMS Position and Velocity Uncertainties - DSIF - Radar (Nominal Orbit)

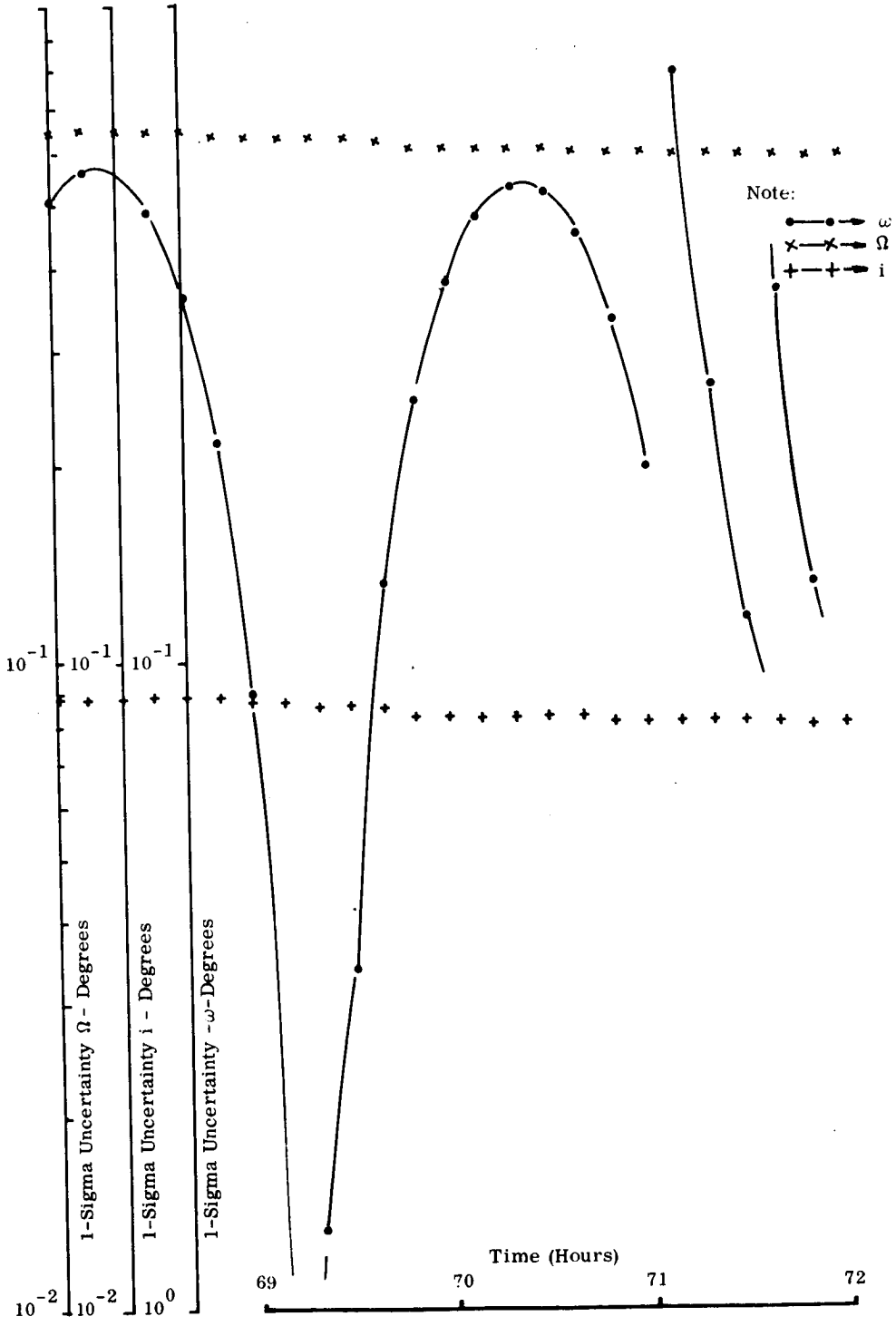


Figure 7-26 Orbital Element Uncertainties - DSIF-Radar (Nominal Orbit)

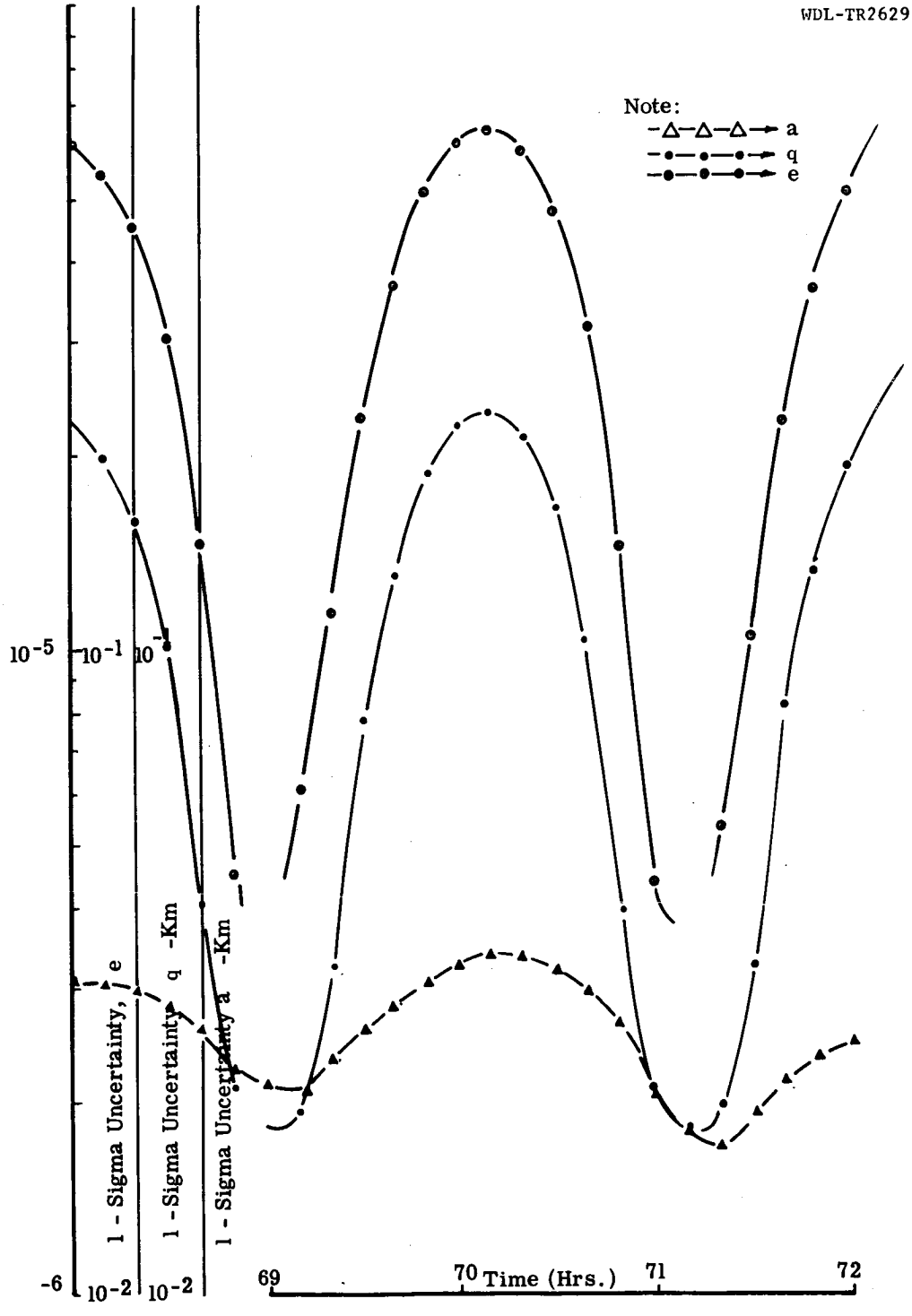


Figure 7-27 Orbital Element Uncertainties, DSIF-Radar (Nominal Orbit)

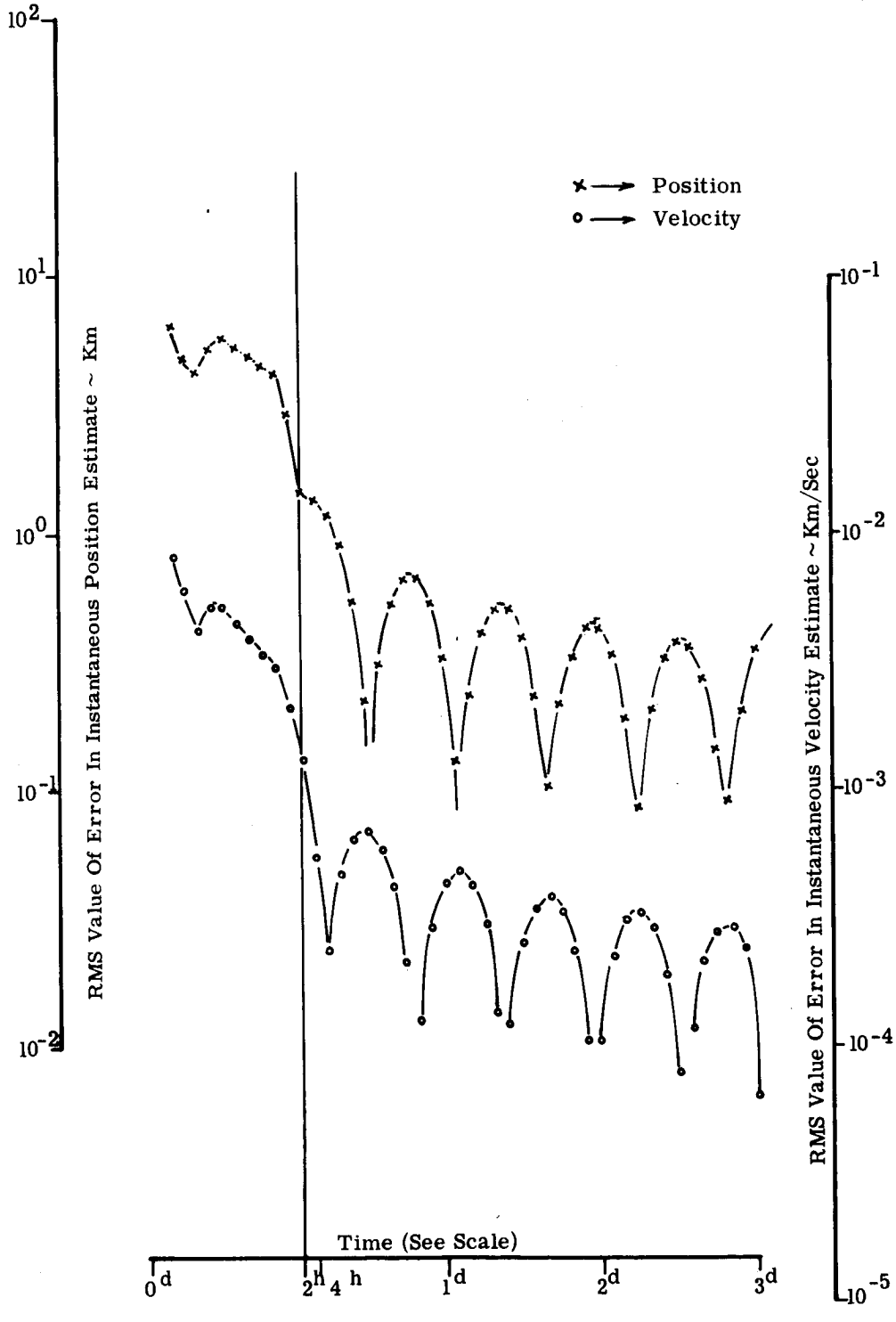


Figure 7-28 RMS Position and Velocity Uncertainties, DSIF-Sextant (Nominal Orbit)

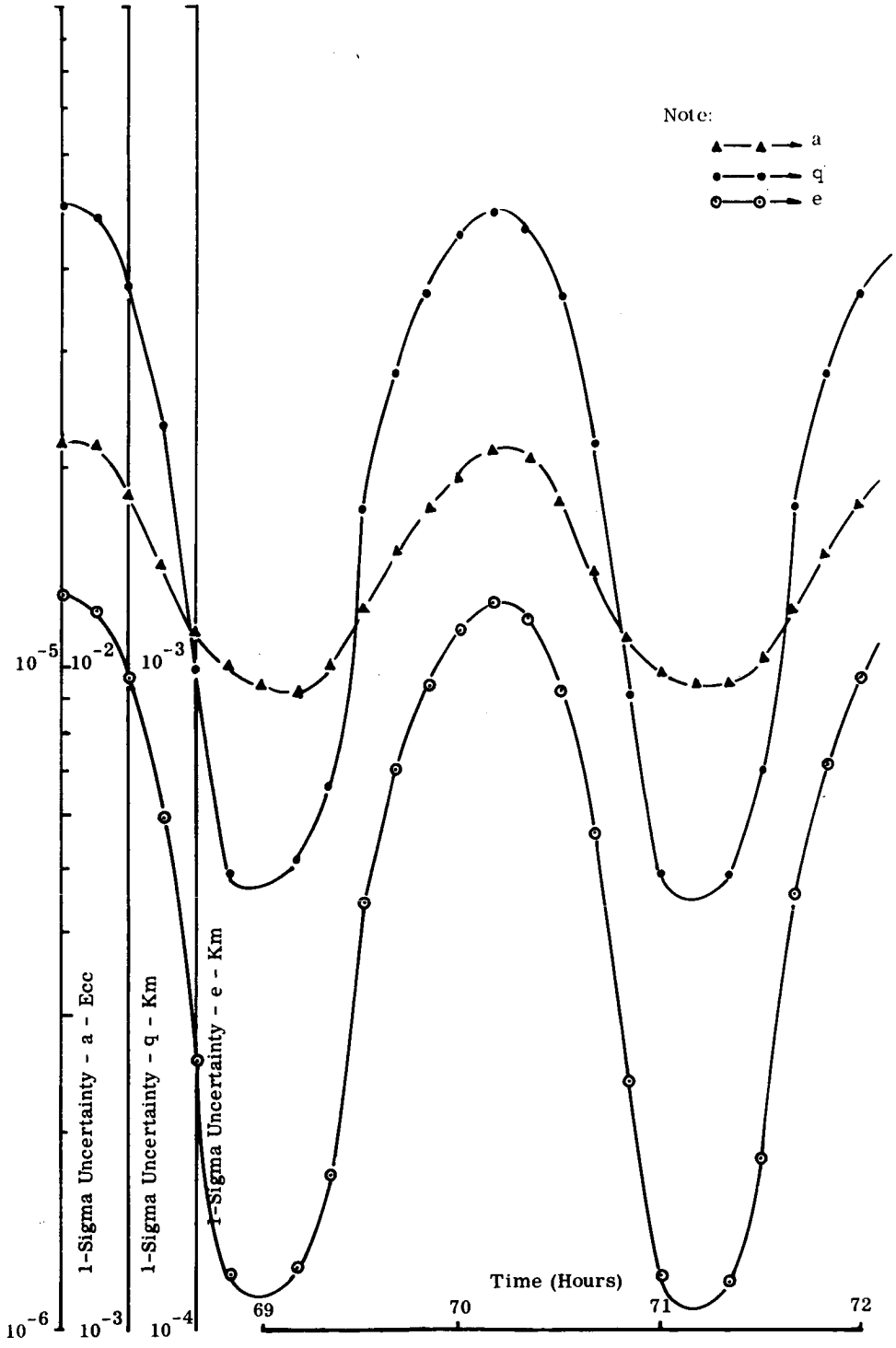


Figure 7-29 1-Sigma Uncertainties in Orbital Elements, DSIF-Sextant (Nominal Orbit)

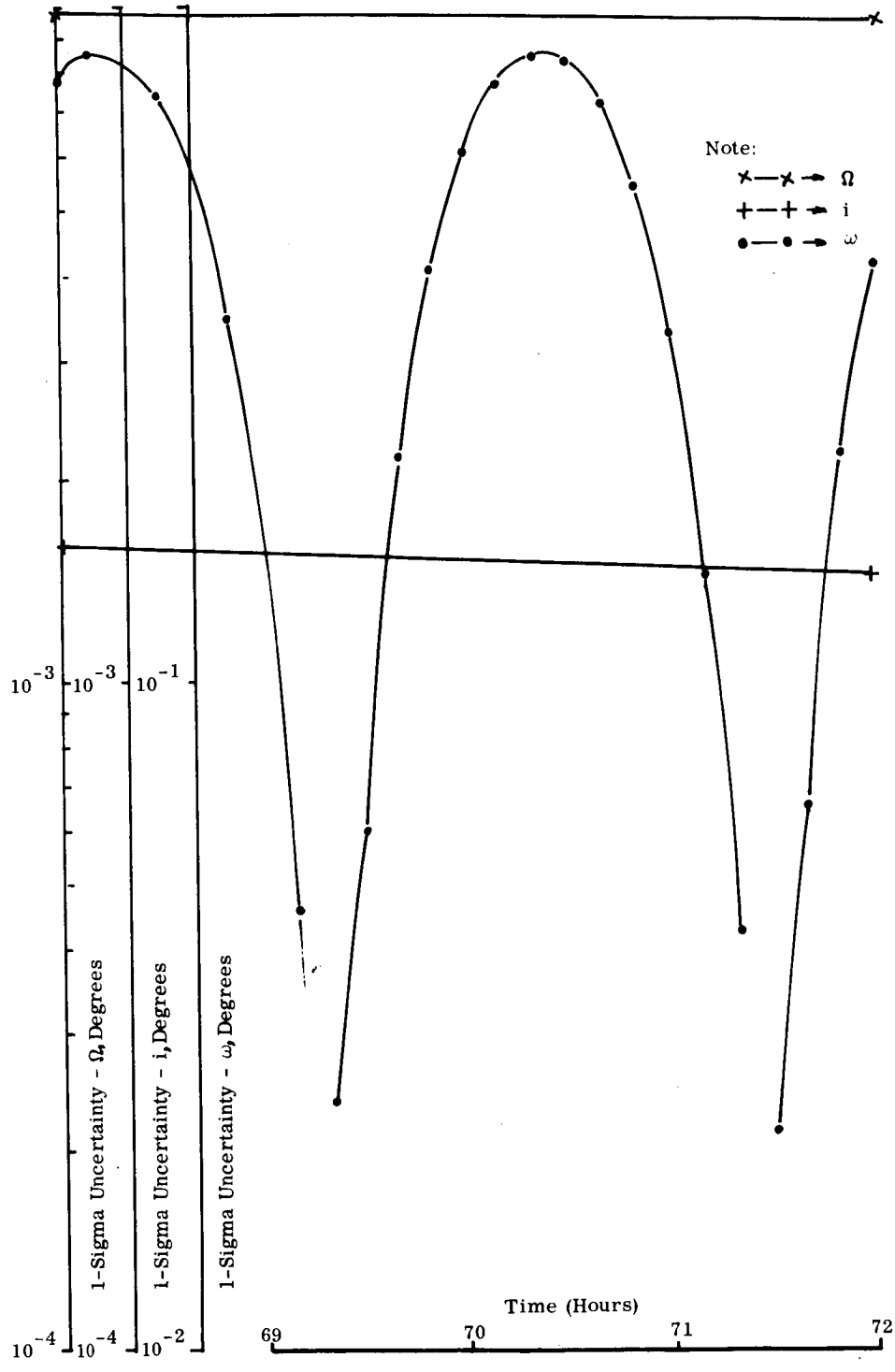


Figure 7-30 1-Sigma Uncertainties in Orbital Elements - DSIF-Sextant (Nominal Orbit)

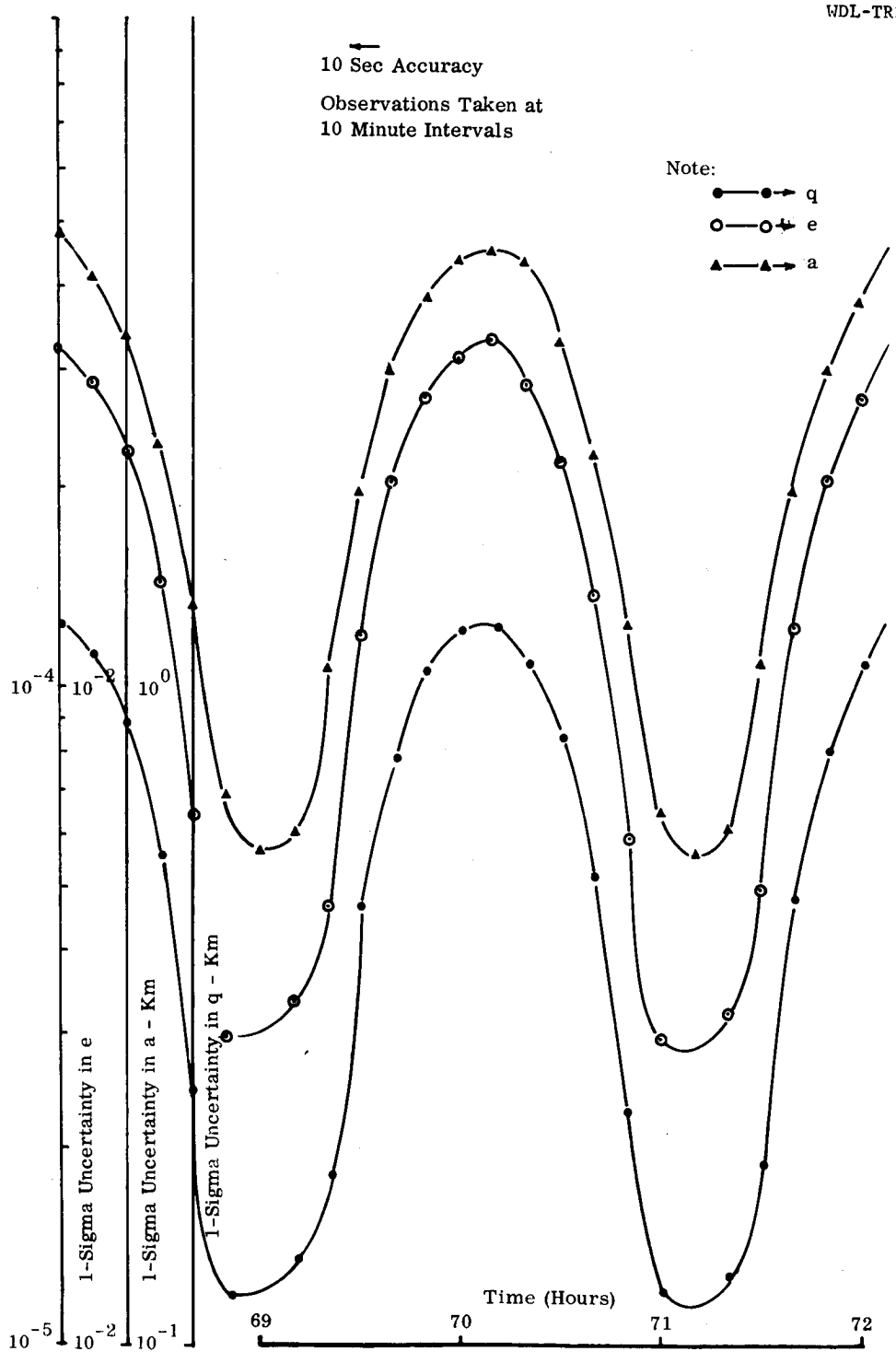


Figure 7-32 Uncertainties in Orbital Elements - Sextant (Nominal Orbit)

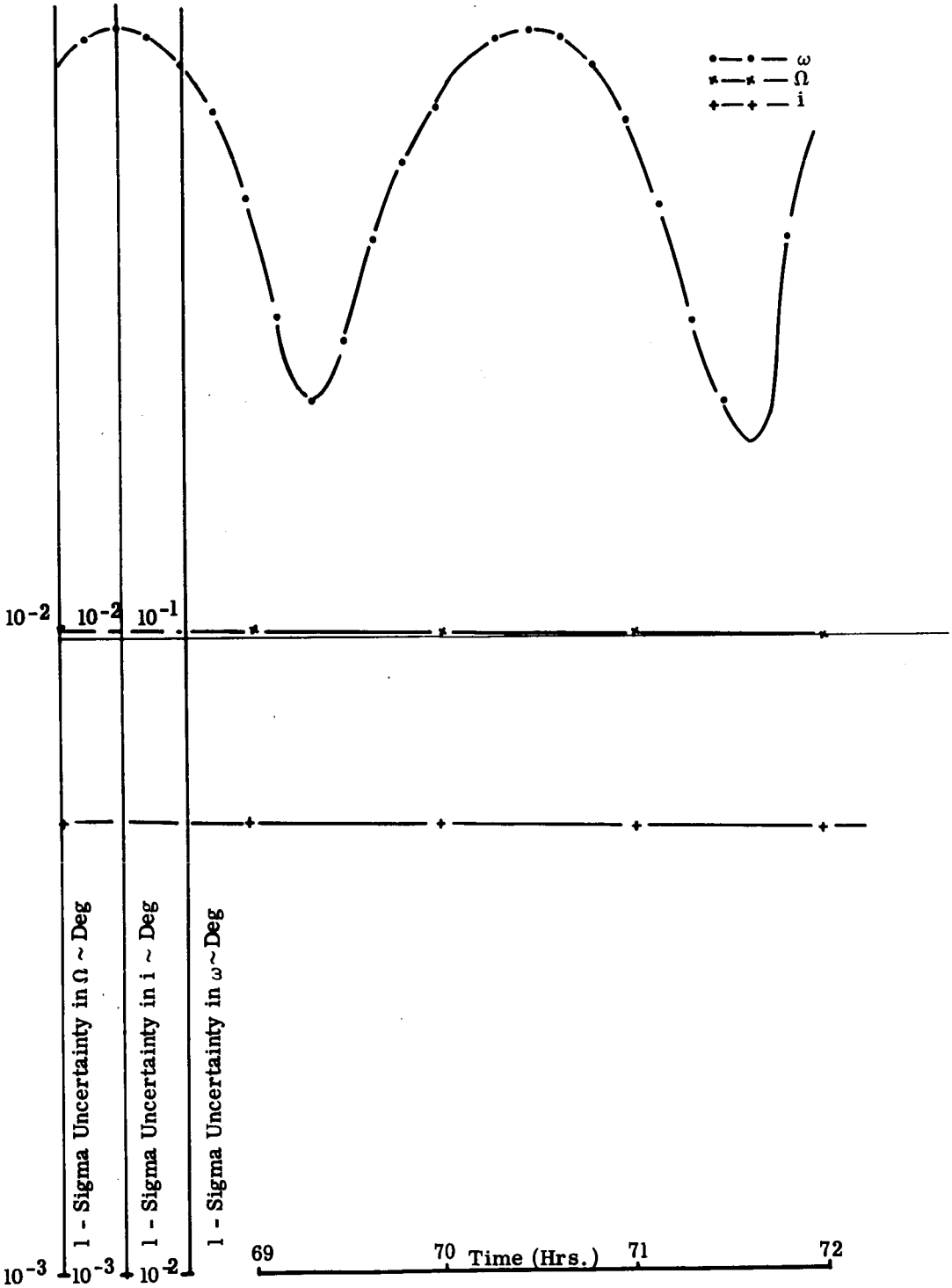


Figure 7-33 Uncertainties in Orbital Elements - Sextant (Nominal Orbit)

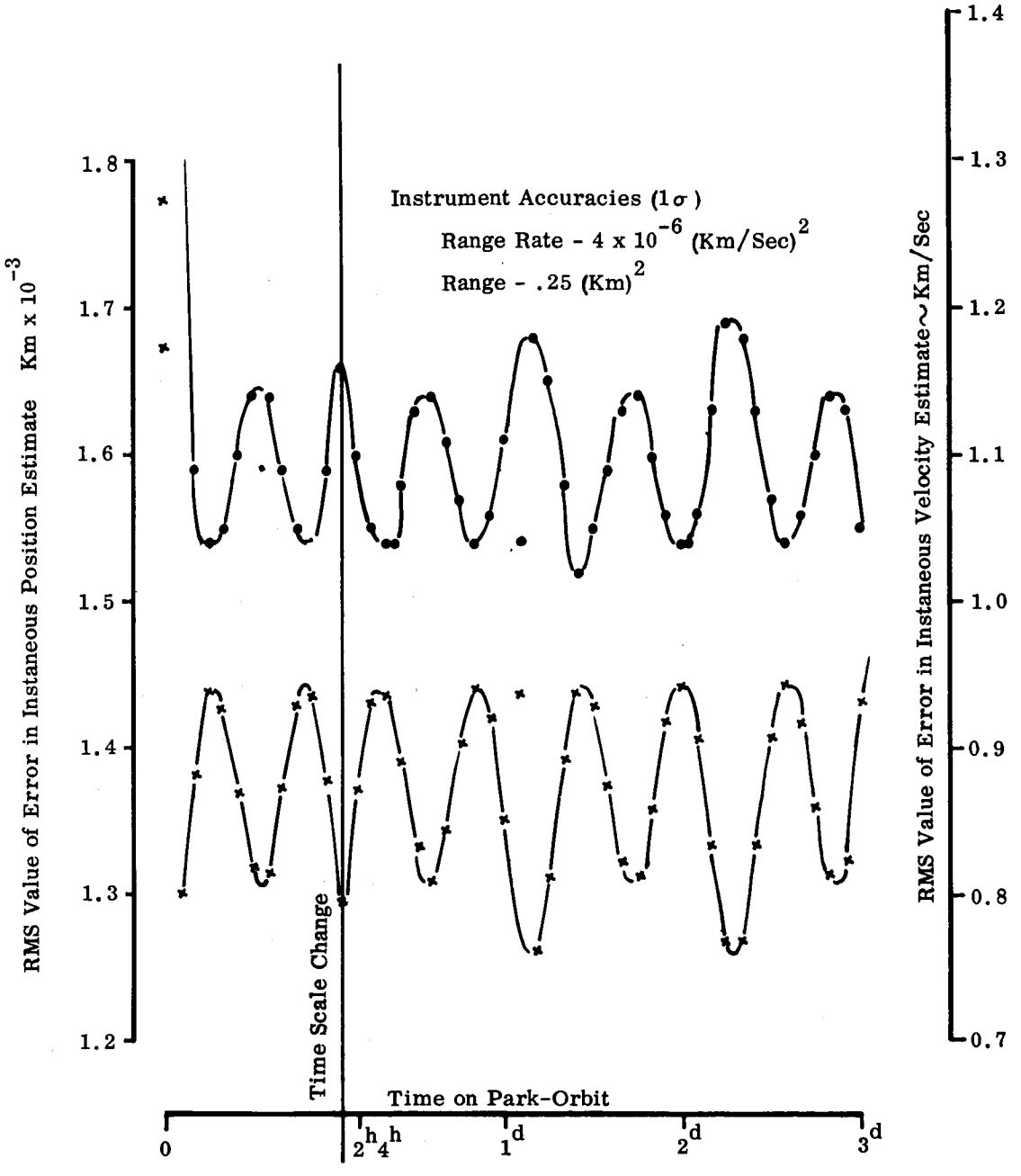


Figure 7-34 RMS Uncertainties in Estimated Position and Velocity - Onboard Radar (Nominal Orbit)

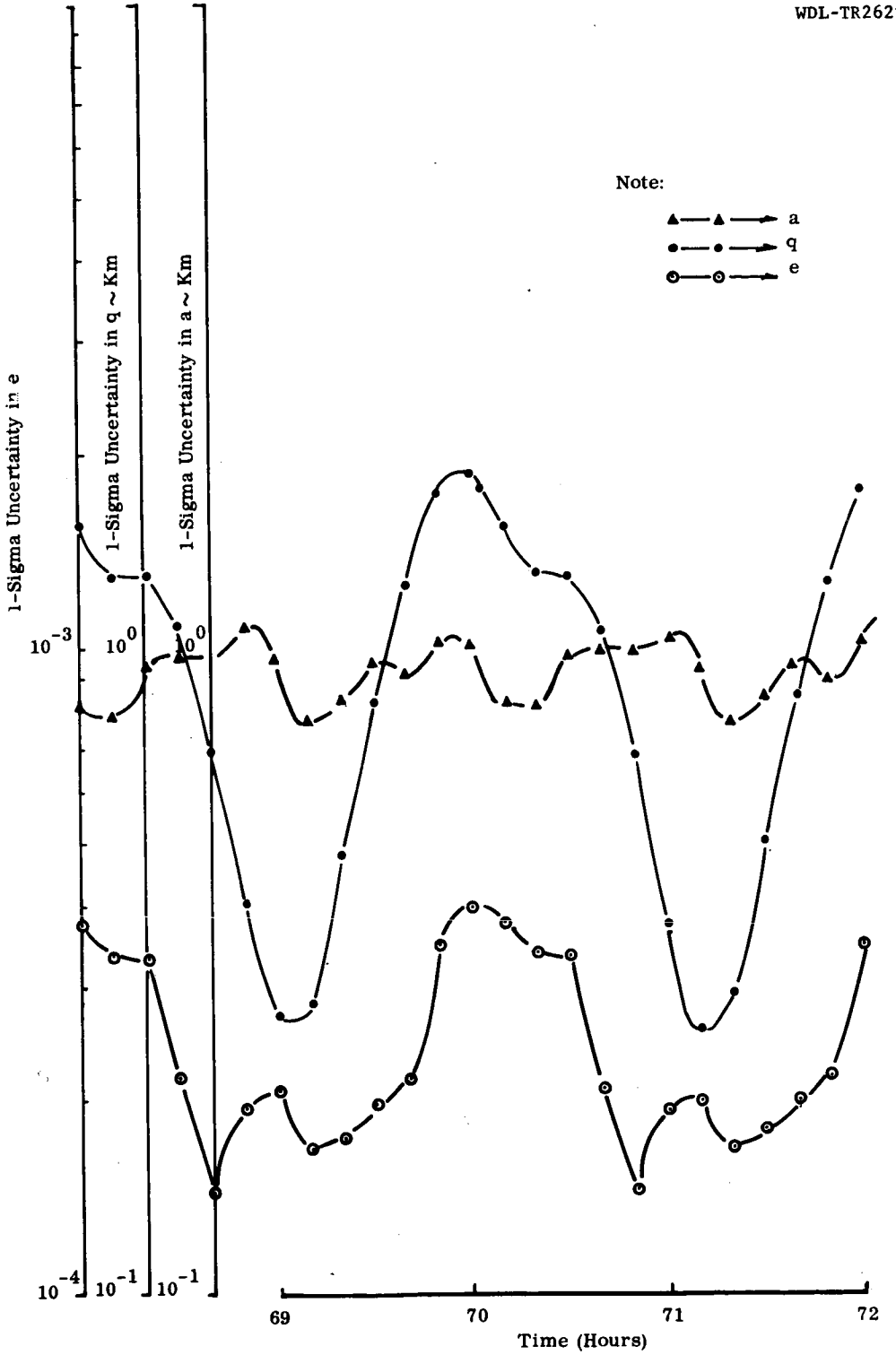


Figure 7-35 Uncertainties in Orbital Elements - Onboard Radar (Nominal Orbit)

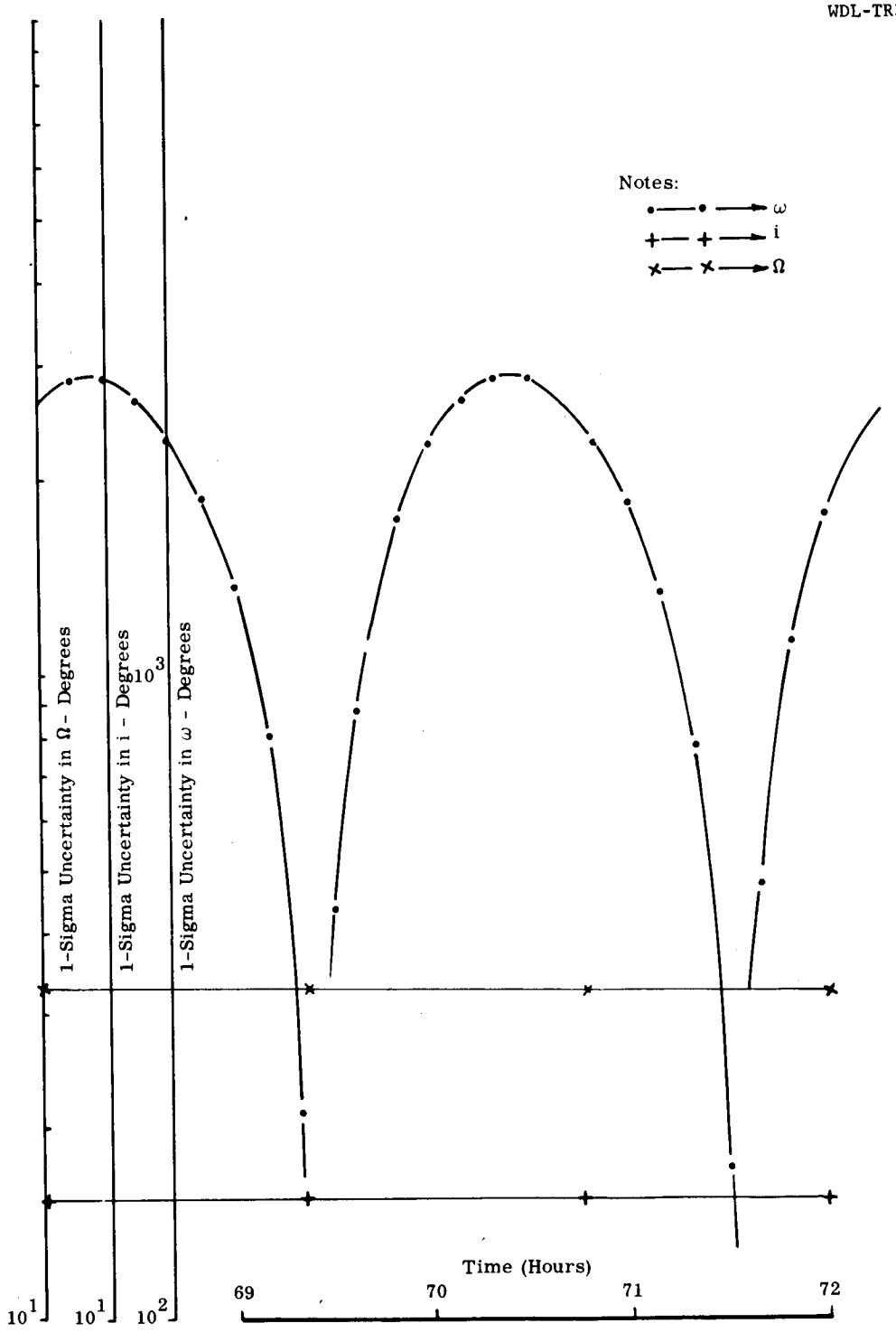


Figure 7-36 Uncertainties in Orbital Elements - Onboard Radar (Nominal Orbit)

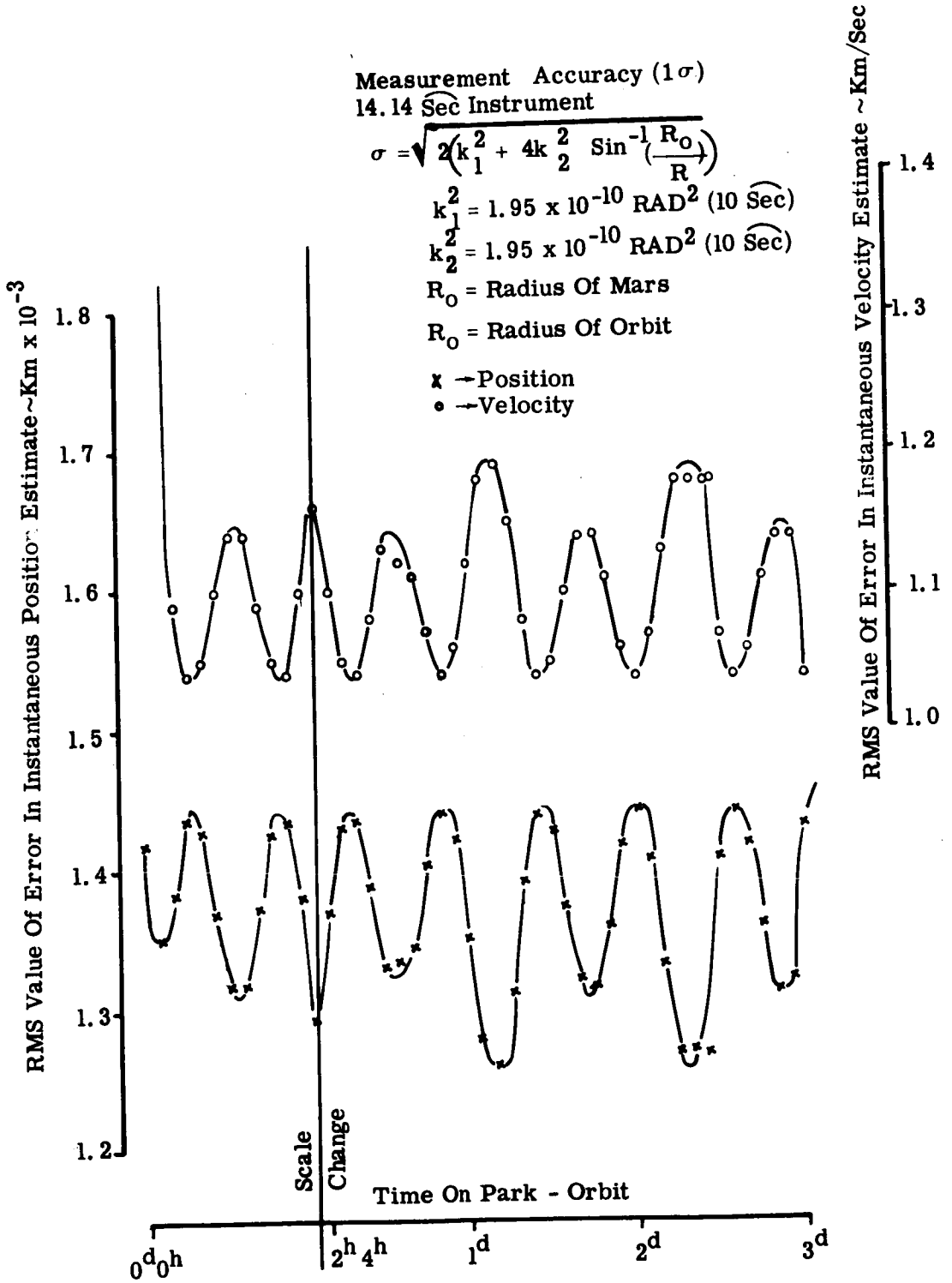


Figure 7-37 RMS Uncertainties in Position and Velocity - Subtended Angle (Planet Tracker)

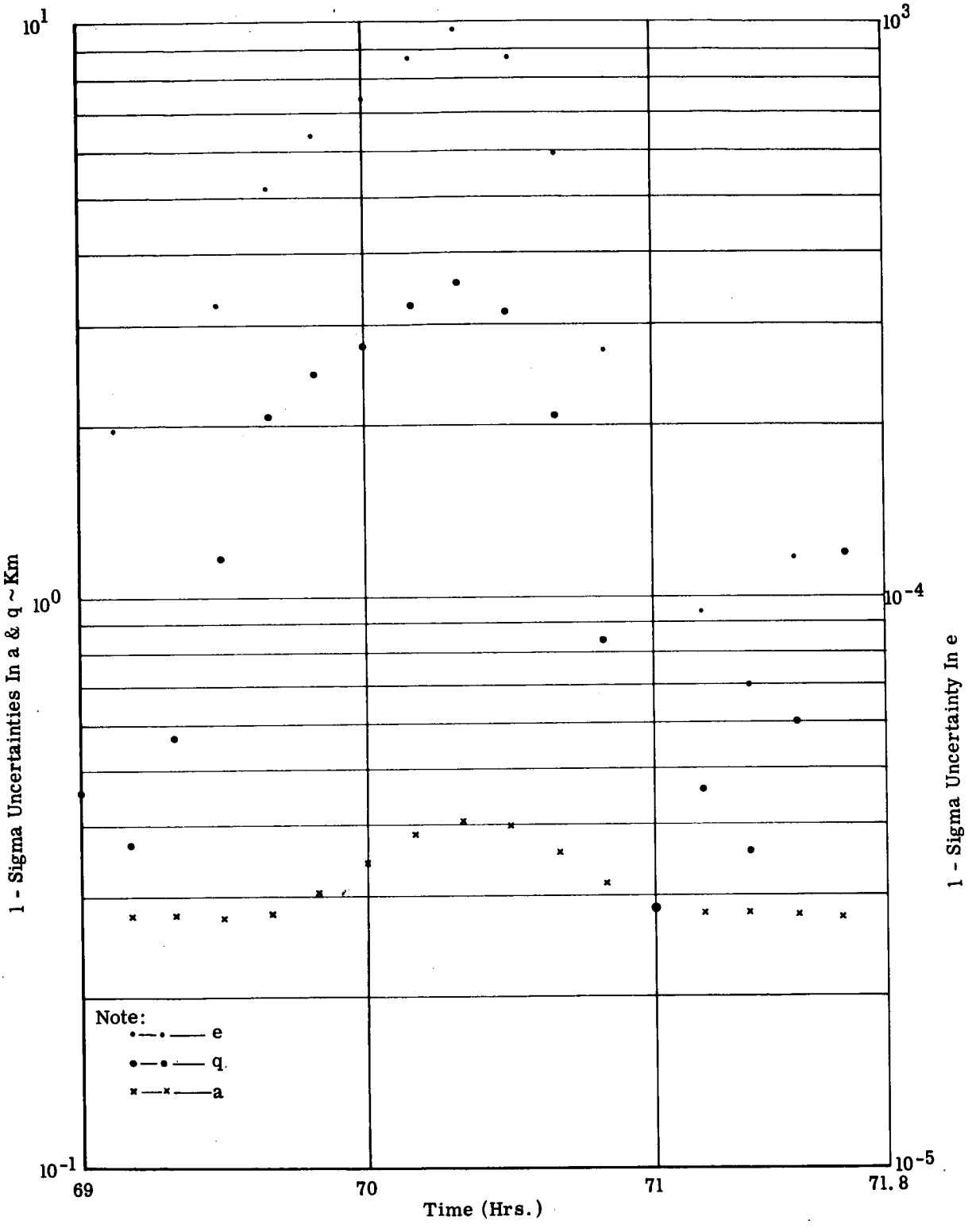


Figure 7-38 Uncertainties in Orbital Elements - Subtended Angle (Nominal Orbit)

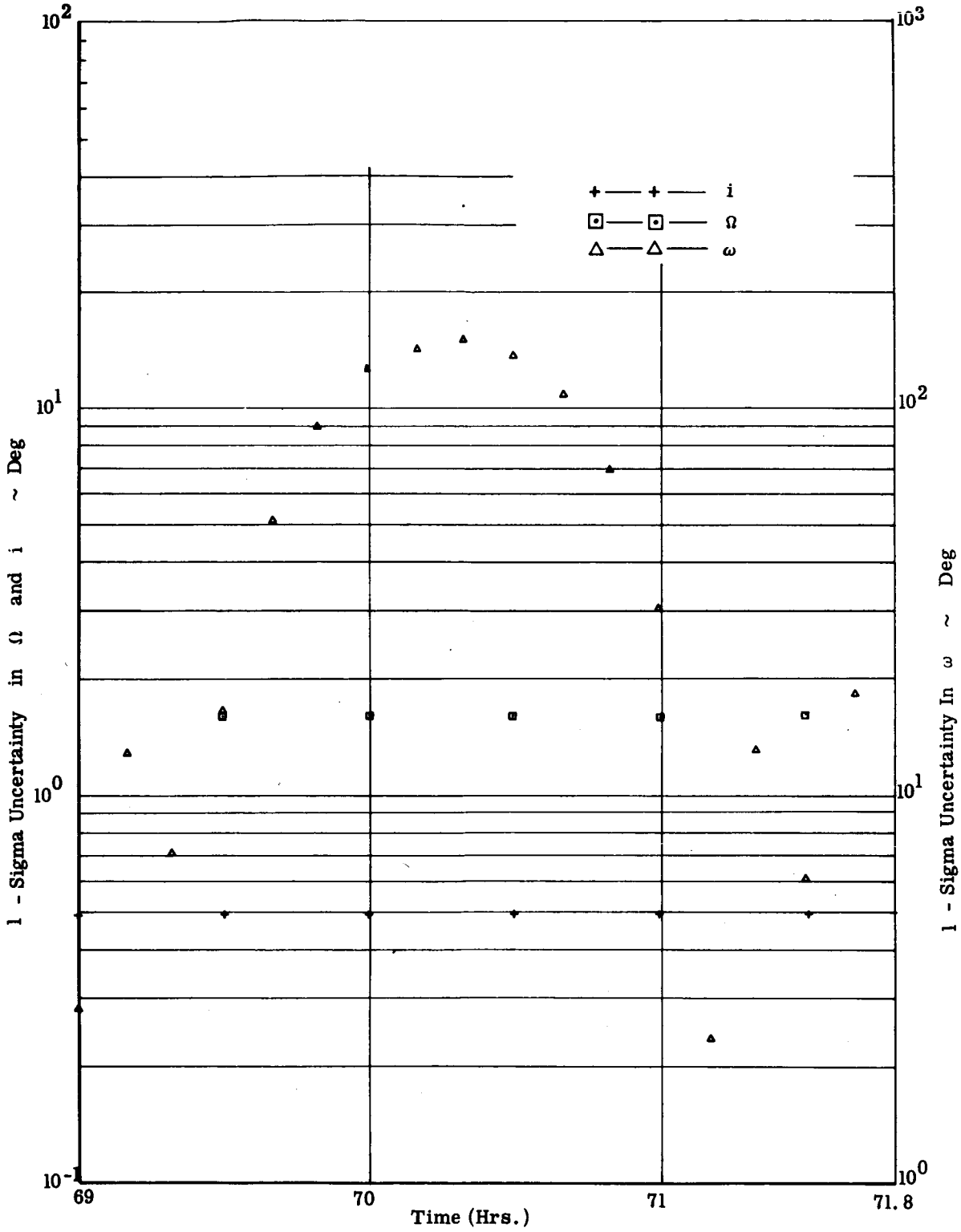


Figure 7-39 Uncertainties in Orbital Elements - Subtended Angle (Nominal Orbit)

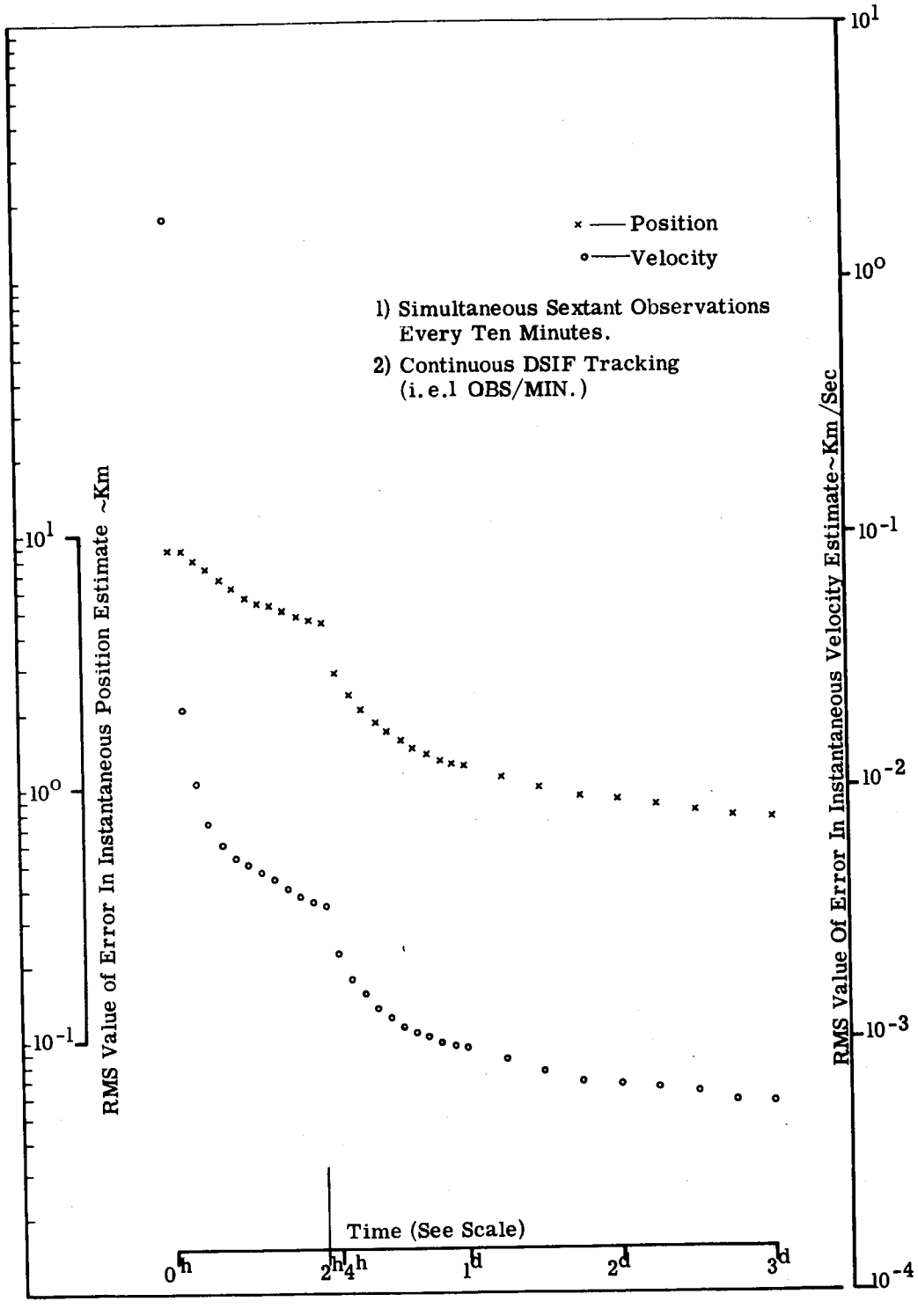


Figure 7-40 RMS Position and Velocity Uncertainties - Sextant-Subtense

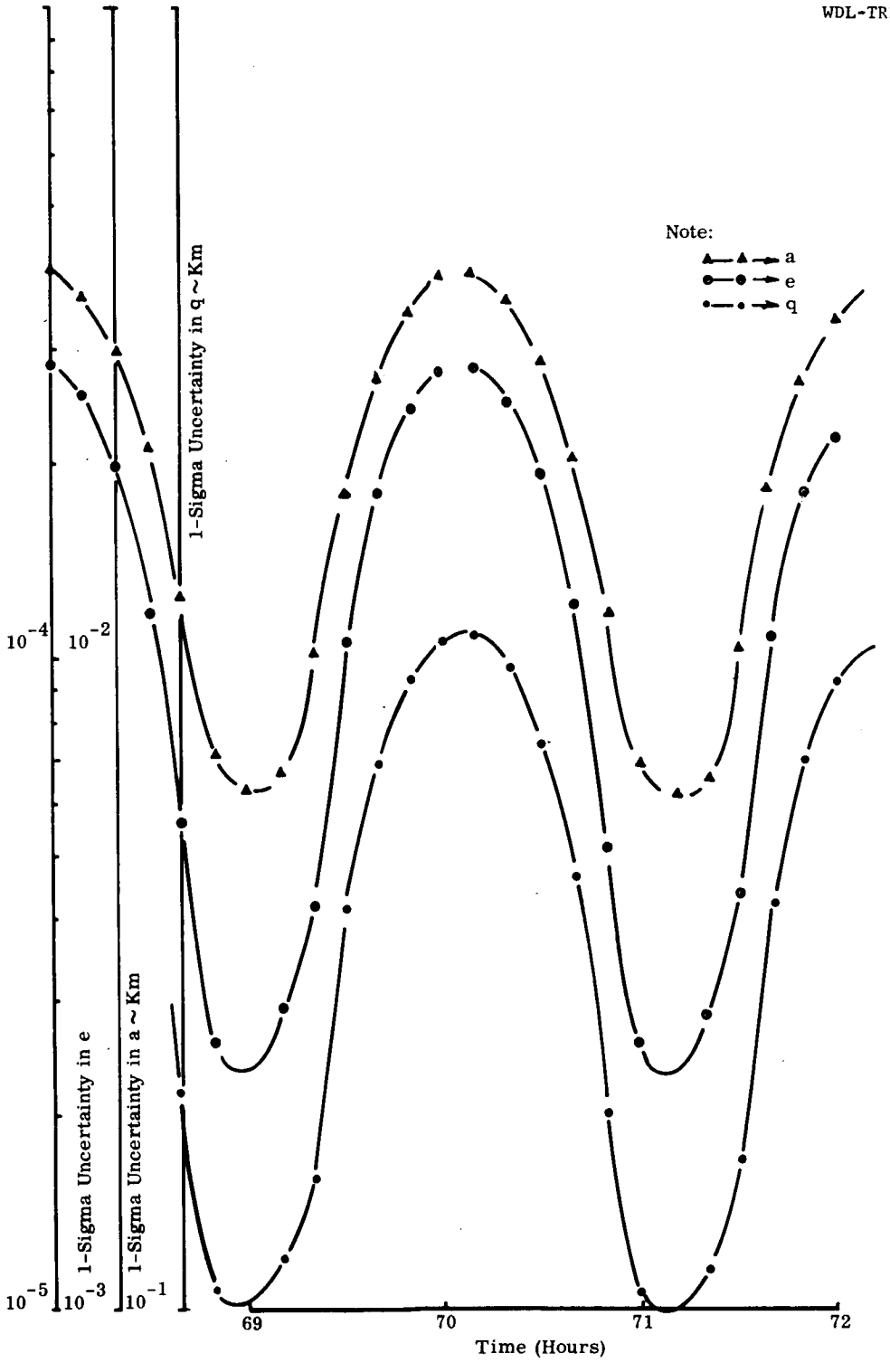


Figure 7-41 Sextant-Subtended Angle (Nominal Orbit)

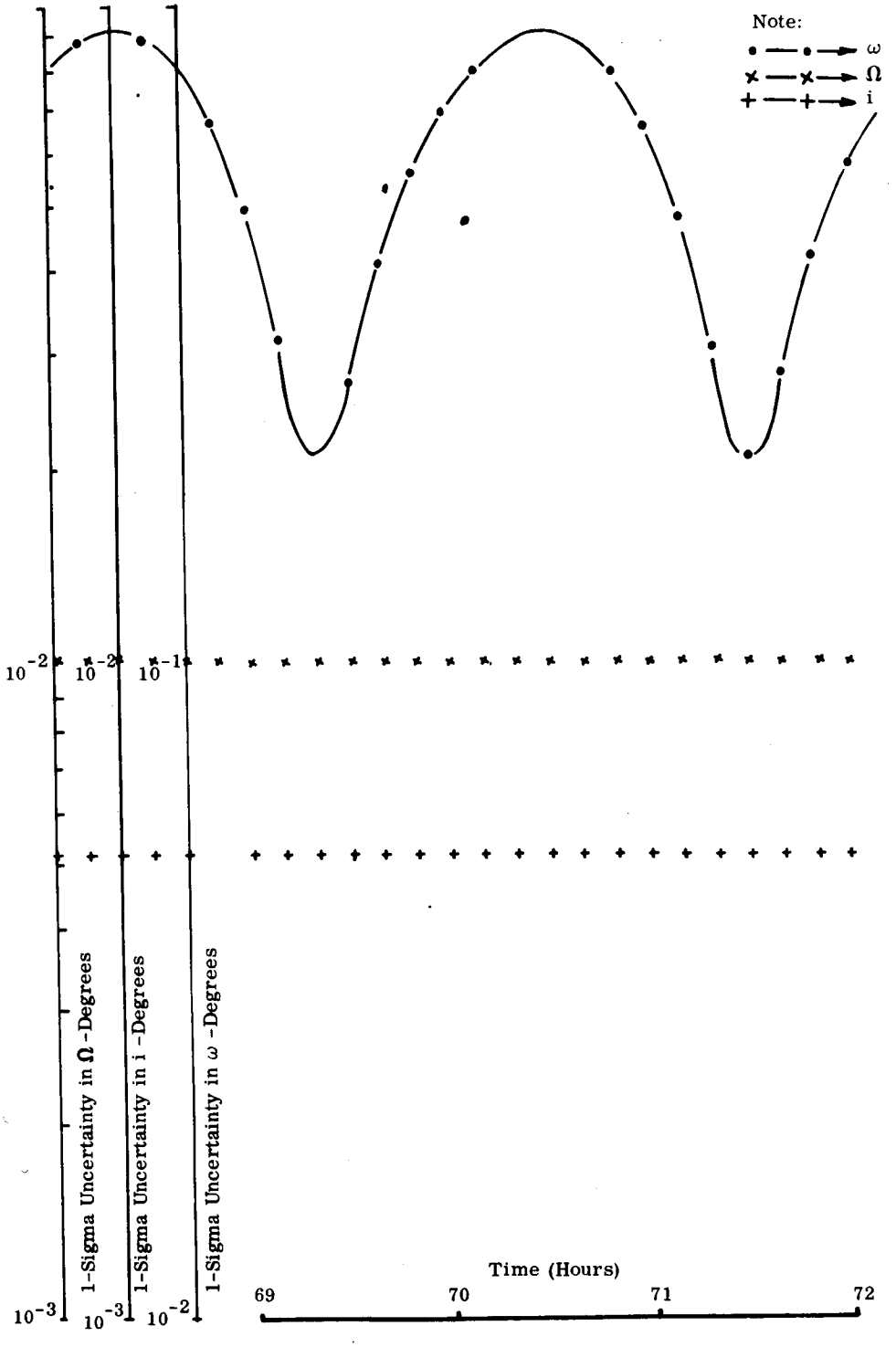


Figure 7-42 1-Sigma Uncertainties in Orbital Elements - Sextant-Subtended Angle (Nominal Orbit)

TABLE 7-1

NOMINAL ORBIT CHARACTERISTICS:

ORBITAL PARAMETERS AND INJECTION CONDITIONS

1950 EQUATORIAL COORDINATES	
ORBIT PARAMETERS	INJECTION CONDITIONS
a = 4031.9357 Km	V = 3.32886 Km/Sec.
q = 3951.7951 Km	R = 3951.7951 Km
i = 30.353 293 Deg.	RA = 246.967260 Deg.
Ω = 11.961 921 Deg.	DEC = 25.628 328 Deg.
ω = 238.863.65 Deg.	AZ = 106.84640 Deg.
NOTE: AN e = 0.019876480 WAS USED IN ALL ORBIT CALCULATIONS.	
ECLIPTIC COORDINATES	
(ORIENTATION AND INJECTION ANGULAR COND.)	
i = 8.7469044 Deg.	RA = 249.65866 Deg.
Ω = 43.890325 Deg.	DEC = 3.826690 Deg.
ω = 206.03184 Deg.	AZ = 97.871276 Deg.

TABLE 7-2

DSIF SPECIAL STUDIES

$(\hat{R} \cdot \hat{W}) = 0$

1950 EQUATORIAL COORDINATES	
ORBIT PARAMETERS	INJECTION CONDITIONS
a = 4031.9398 KM	V = 3.378 KM/SEC.
e = .019 876 105	R = 3951.7957 KM
q = 3951.7957 KM	LAT = 23.050614 DEG.
i = 23.883 577 DEG.	LON = 44.290 DEG.
Ω = 10.850 653 DEG.	AZ = 96.474 DEG.
ω = 255.150 570 DEG.	

ECLIPTIC COORDINATES	
(ANGLE INFORMATION ONLY - ORIENTATION AND INJECTION CONDITIONS)	
i = 4.371 324 DEG.	LAT = 23.050 614 DEG.
Ω = 89.567 477 DEG.	LON = 44.290 DEG.
ω = 175.889 73 DEG.	AZ = 96.474 DEG.

TABLE 7-3

DSIF SPECIAL STUDIES

(R·W) = -1

1950 EQUATORIAL COORDINATES	
ORBIT PARAMETERS	INJECTION COORDINATES
a = 4031.934 8 Km	V = 3.328 Km/Sec.
e = .019 876 105	R = 3951.7957 KM
q = 3951.7957 Km	LAT = 23.052 385 Deg.
i = 113.038 99 Deg.	LON = 44.289 783 Deg.
Ω = 354.680 39 Deg.	AZ = 83.681 210 Deg.
ω = 83.525 798 Deg.	
ECLIPTIC COORDINATES	
(ANGLE INFORMATION ONLY - ORIENTATION AND INJECTION CONDITIONS)	
i = 89.686 980 Deg.	LAT = 23.052 385 Deg.
Ω = 355.469 12 Deg.	LON = 44.289 783 Deg.
ω = 85.639 879 Deg.	AZ = 4.110 2789 Deg.

TABLE 7-4
WEIGHTING OF POSITION UNCERTAINTY COMPONENTS

δ	PREDOMINENT COMPONENT	RELATIVE WEIGHTING	MAX. 1σ UNCERTAINTY ON 4th ORBIT (KM) N	(KM) V	(KM) W	TREND
0°	W	W>>V V>N	.107	1.18	522.	W>>V
10°	V,W	W≈V,W>V V>>N	2.06	99.	582.	
20°	V,W	W≳V,W>V V>>N	3.97	193.	547.	W>V
30°	V,W	W≳V,W>V V>>N	5.56	278.	484.	
40°	V,W	W≳V V>>N	6.86	333.	410.	W=V
50°	V,W	W≳V,V>W W>>N	7.15	347.	301.	
60°	V,W	W≳V,V>W W>>N	6.91	336.	200.	V>W
70°	V,W	W≳V,V>W W>>N	7.26	352.	132.	
80°	V,W	V>W W>N	7.55	360.	66.	
90°	V	V>N N>>W	25.5	188.	.455	V>>W

NOTE: δ is the declination of the Earth-Mars line from Park Orbit Plane at Park Orbit Injection.

TABLE 7-5

WEIGHTING OF VELOCITY UNCERTAINTY COMPONENTS

δ	PREDOMINANT COMPONENT	RELATIVE WEIGHTING	Max. 1 Uncertainty On 4th Orbit			TREND
			N Km/Sec	V Km/Sec	W Km/Sec	
0°	W	W>>N N>V	$1x10^{-3}$	$6.65x10^{5}$	$4.\Omega x10^{-1}$	W>>N
10°	W	W>N N>>V	$8.3x10^{-2}$	$9.3x10^{-5}$	$4.8x10^{-1}$	
20°	N,W	N≈W W>N N,W>>V	$1.6x10^{-1}$	$1.3x10^{-4}$	$4.5x10^{-1}$	W>N
30°	N,W	N≈W, W>N N,W>>V	$2.3x10^{-1}$	$1.7x10^{-4}$	$4.0x10^{-1}$	
40°	N,W	N≈W, W>N N,W>>V	$2.8x10^{-1}$	$2.0x10^{-4}$	$3.4x10^{-1}$	W=N
50°	N,W	N≈W, N>N N,W>>V	$2.9x10^{-1}$	$2.4x10^{-4}$	$2.5x10^{-1}$	
60°	N,W	N≈W, N>W N,W>>V	$2.8x10^{-1}$	$2.5x10^{-4}$	$1.6x10^{-1}$	N>W
70°	N,W	N≈W, N>W N,W>>V	$3.0x10^{-1}$	$3.1x10^{-4}$	$1.1x10^{-1}$	
80°	N	N>W W>>V	$3.1x10^{-1}$	$4.4x10^{-4}$	$5.4x10^{-1}$	
90°	N	N>V V>>W	$1.6x10^{-1}$	$1.8x10^{-2}$	$3.8x10^{-4}$	N>>W

TABLE 7-6

FTAV RESULTS*

Conditions at 3 days	DSIF	Sextant	Radar	Subtense	DSIF-Radar	Sextant-Subtense	DSIF-Sextant	Initial Conditions
Secular Term RMS	$1x10^{1}$	$7.5x10^{-1}$	$1.375x10^{3}$	$1.375x10^{3}$	$1x10^{1}$	$7.5x10^{-1}$	$2x10^{-1}$	$1.732x10^{3}$ Km
Position Actual (72 hours)	$1.81x10^{1}$	$7.7x10^{-1}$	$1.431x10^{3}$	$1.433x10^{3}$	$2.17x10^{1}$	$7.58x10^{-1}$	$3.54x10^{-1}$	
Secular Term RMS	$7.5x10^{-3}$	$6x10^{-4}$	$1.09x10^{o}$	$1.09x10^{o}$	$7.5x10^{-3}$	$6.0x10^{-4}$	$1.7x10^{-4}$	$1.732x10^{o}$ KM/Sec.
Velocity Actual (72 hours)	$1.91x10^{-3}$	$5.67x10^{-4}$	$1.05x10^{o}$	$1.04x10^{o}$	$2.28x10^{-3}$	$5.68x10^{-4}$	$6.44x10^{-6}$	
RMS Position Components Actual (72 hours) N	$4.19x10^{-2}$	$1.77x10^{-1}$	$1.46x10^{1}$	$1.48x10^{1}$	$5.08x10^{-2}$	$1.56x10^{-1}$	$6.51x10^{-3}$	$1x10^{3}$ KM
V	1.93x10	$6.59x10^{-1}$	$7.85x10^{2}$	$7.89x10^{2}$	$2.32x10^{o}$	$6.50x10^{-1}$	$4.70x10^{-2}$	$1x10^{3}$ KM
W	$1.8x10^{1}$	$3.57x10^{-1}$	$1.000\ 10^{3}$	$1.000\ 10^{3}$	$2.15x10^{1}$	$3.57x10^{-1}$	$3.51x10^{-1}$	$1x10^{3}$ KM
RMS Velocity Components Actual (72 hours) N	$1.55x10^{-3}$	$4.69x10^{-1}$	$6.27x10^{-1}$	$6.30x10^{-1}$	$1.85x10^{-3}$	$4.75x10^{-1}$	$3.63x10^{-5}$	$1x10^{o}$ KM/Sec.
V	$1.94x10^{-5}$	$1.42x10^{-1}$	$3.51x10^{-4}$	$1.33x10^{-3}$	$2.21x10^{-5}$	$1.25x10^{-1}$	$5.10x10^{-6}$	$1x10^{o}$ KM/Sec.
W	$1.12x10^{-3}$	$2.84x10^{-1}$	$8.4x10^{-1}$	$8.4x10^{-1}$	$1.32x10^{-3}$	$2.84x10^{-1}$	$5.29x10^{-5}$	$1x10^{o}$ KM/Sec.

*Nominal Trajectory

TABLE 7-7

FAVT COMPARISON

(Constant Observation Frequency)

SYSTEM	TIME AND COMMENTS	
	RMS POSITION ACC	RMS VELOCITY ACC
DSIF	Continuous Tracking Reaches a minimum of approximately 10Km secular or 3Km Actual	Continuous Tracking Attains a secular error of approximately 7 m/s or actual error of approximately 2 m/s.
SEXTANT	1^d 14^h Freq. of 1 obs/10 min.	0^d 20^h Freq. of 1 obs/10 min.
RADAR	Achieve nominal of approximately 1600 Km. Cannot reduce out-of-plane error.	Secular of .875 KW/Sec. cannot reduce out-of-plane error.
	(Continuous meas. of Range and Range Rate 1 obs/min.)	
SUBTENSE	Same as Radar	Same as Radar
	(i.e. For Instr. chosen, subtense and Radar Estimate almost matches identically.)	
DSIF-RADAR	Same obs schedule as above NO IMPROVEMENT OVER DSIF	
SEXTANT-SUBTENSE	1^d 12^h	0^d 20^h
	NO SIGNIFICANT DIFFERENCE FROM SEXTANT	
DSIF-SEXTANT	0^d 7^h Secular & Actual	0^d 2^{h+} Secular & Actual

NOTE: "Required" position ACC. = 1Km
"Required" Velocity ACC. = 1 metor/sec.

TABLE 7-8

SYSTEM COMPARISON - ALL SYSTEMS AND SPECIAL DSIF CASES

	SPECIAL TRAJECTORY			NOMINAL TRAJECTORY						
	DSIF (R.W)=0	DSIF (R.W)=1	(RR)ONLY DSIF (R.W.)=1	DSIF	SEXTANT	RADAR	SUBTENSE	DSIF-RADAR	SEXTANT SUBTENSE	DSIF-SEXTANT
e	10^{-4} $3x10^{1}$ 1	$2x10^{-4}$ $5x10^{1}$ 2	$2.5x10^{-4}$ $6x10^{1}$ 2	$1.25x10^{-5}$ $3x10^{o}$ 0	10^{-4} $3x10^{1}$ 1	$2.5x10^{-4}$ $6x10^{1}$ 2	$3x10^{-4}$ $8x10^{1}$ 2	$2x10^{-5}$ $5x10^{o}$ 1	10^{-4} $3x10^{1}$ 1	$4x10^{-6}$
q	$4x10^{-1}$KM $2x10^{1}$ 1	1 $6x10^{1}$ 2	1 $6x10^{1}$ 2	$5x10^{-2}$ $3x10^{o}$ 0	$4x10^{-1}$ $2x10^{1}$ 1	$7x10^{1}$ $4x10^{1}$ 1	1 $6x10^{1}$ 2	$7x10^{-2}$ $4x10^{o}$ 0	$3.5x10^{-1}$ $2x10^{1}$ 1	$1.75x10^{-2}$
a	$2x10^{-1}$KM $1x10^{2}$ 2	$1x10^{-1}$ $7x10^{1}$ 2	$5.5x10^{-2}$ $4x10^{1}$ 1	$1.75x10^{-2}$ $1x10^{1}$ 1	$1.5x10^{-2}$ $1x10^{1}$ 1	$9x10^{-1}$ $6x10^{2}$ 3	$3x10^{-1}$ $2x10^{2}$ 2	$2.5x10^{-2}$ $2x10^{1}$ 1	$1.75x10^{-2}$ $1x10^{o}$ 0	$1.5x10^{-3}$
Ω	$9.5x10^{o}$RAD $1x10^{3}$ 3	$4x10^{-4}$ $4x10^{-2}$ -2	$1.75x10^{-4}$ $2x10^{-2}$ -2	$5.25x10^{-1}$ $6x10^{1}$ 2	10^{-2} $1x10^{o}$ 0	3.25 $3x10^{2}$ 2	$1.75x10^{o}$ $2x10^{2}$ 2	$6x10^{-1}$ $6x10^{1}$ 2	10^{-2} $1x10^{o}$ 0	$9.5x10^{-3}$
i	2.5 RAD $2x10^{3}$ 3	$2.75x10^{-3}$ $2x10^{o}$ 0	10^{-3} $7x10^{-1}$ 0	$7.25x10^{-2}$ $5x10^{1}$ 2	$5x10^{-3}$ $3x10^{o}$ 0	1.5 $1x10^{3}$ 3	$5x10^{-1}$ $3x10^{2}$ 2	$8x10^{-2}$ $5x10^{1}$ 2	$5x10^{-3}$ $3x10^{o}$ 0	$1.5x10^{-3}$
ω	$3.5x10^{3}$RAD $1x10^{3}$ 3	$5.5x10^{-1}$ $2x10^{o}$ 0	$4.5x10^{-1}$ $2x10^{o}$ 0	$1x10^{1}$ $4x10^{1}$ 1	$5x10^{-1}$ $2x10^{o}$ 0	10^{3} $4x10^{3}$ 3	2 $8x10^{o}$ 1	$1.5x10^{1}$ $6x10^{1}$ 2	$5x10^{-1}$ $2x10^{o}$ 0	$2.5x10^{-1}$

NOMENCLATURE: Standard Deviation
Ratio (i.e. System/DSIF-SEX)
Order of Magnitude By Which
DSIF-Sextant is Superior

TABLE 7-9

SYSTEM COMPARISON ON BASIS OF
ORBITAL ELEMENT KNOWLEDGE (DSIF - BASIS)

Power of Ten Decrease in Knowledge of Orbital Elements
as Compared to the DSIF - Sextant Mechanization

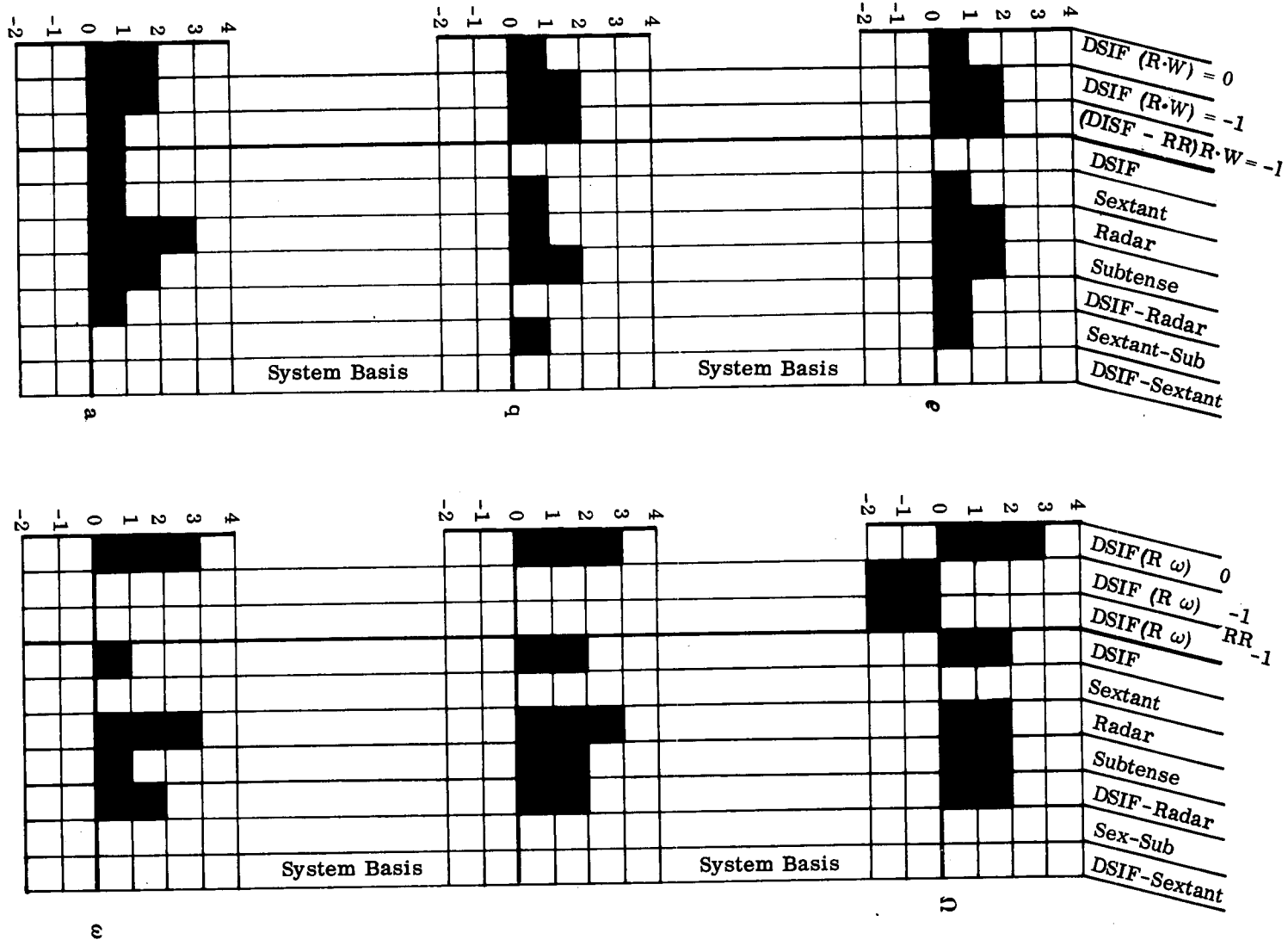


TABLE 7-10

NAVIGATION SYSTEMS PERFORMANCE - ORBITAL PHASE

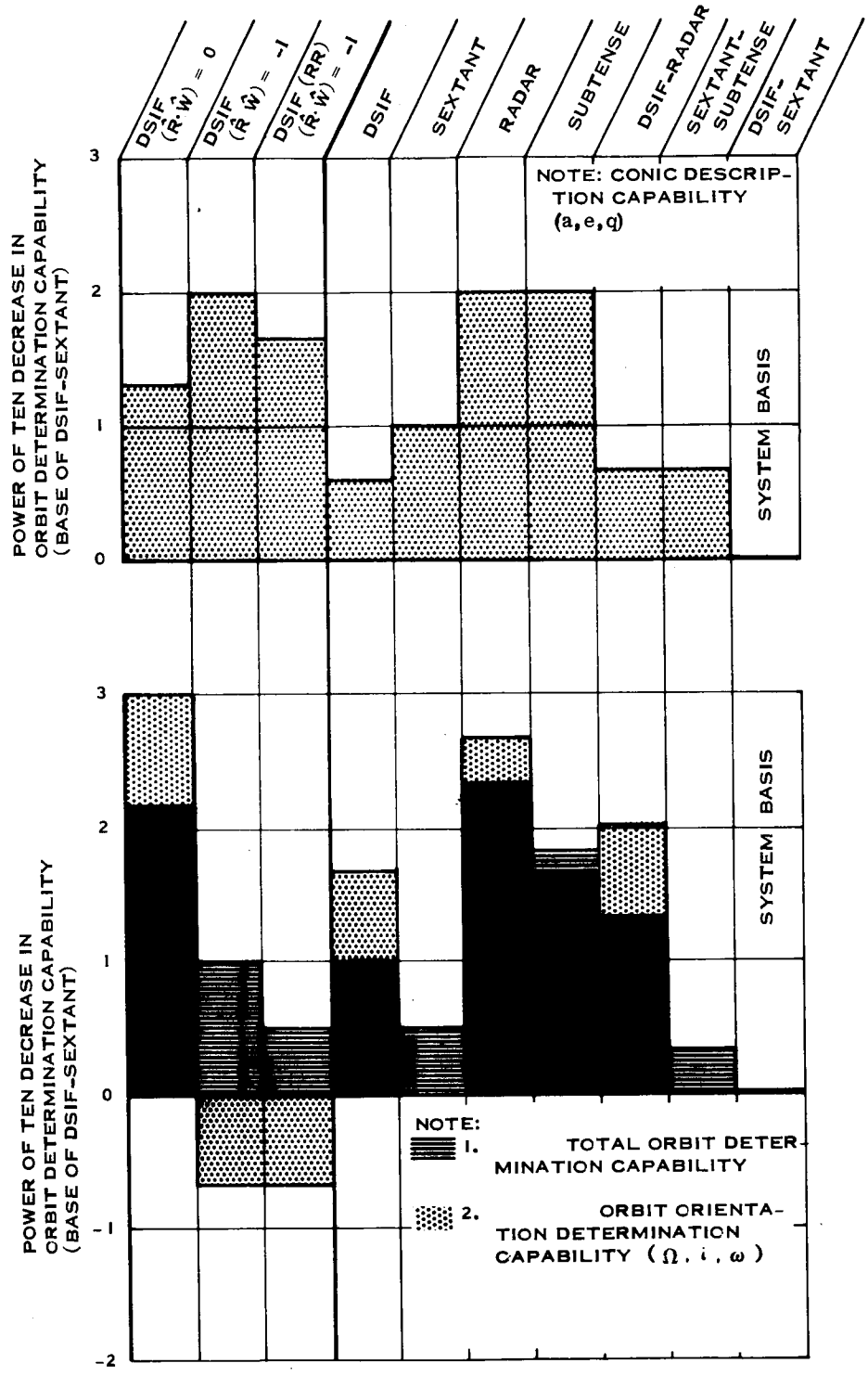


TABLE 7-11

GROUND-BASED COMPOUND SYSTEMS
(SIMULTANEOUS PROCESSING)

		NOMINAL TRAJECTORY	
	DSIF-SEX.	DSIF-RADAR	DSIF
e	4×10^{-6} 3.2×10^{-1} -1	2×10^{-5} 1.6×10^{0} 0	1.25×10^{-5}
q	1.75×10^{-2} 3.5×10^{-1} -1	7×10^{-2} 1.4×10^{0} 0	5×10^{-2}
a	1.5×10^{-3} 8.75×10^{-2} -3	2.5×10^{-2} 1.43×10^{0} 0	1.75×10^{-2}
Ω	9.5×10^{-3} 1.81×10^{-2} -2	6×10^{-1} 1.14×10^{0} 0	5.25×10^{-1}
i	1.5×10^{-3} 2.1×10^{-2} -2	8×10^{-2} 1.1×10^{0} 0	7.25×10^{-2}
ω	2.5×10^{-1} 2.5×10^{-2} -2	1.5×10^{1} 1.5×10^{0} 0	1×10^{1}

TABLE 7-12

ON-BOARD SYSTEM COMPARISONS

	NOMINAL TRAJECTORY			
	RADAR	SUB.	SUB. SEX.	SEX.
e	2.5×10^{-4} 2.5×10^{0} 0	3×10^{-4} 3×10^{0} 0	10^{-4} 1×10^{0} 0	10^{-4}
q	7×10^{-1} 1.75×10^{0} 0	1 2.5×10^{2} 2	3.5×10^{-1} 8.75×10^{-1} 0	4×10^{-1}
a	9×10^{-1} 6×10^{1} 1	3×10^{-1} 2×10^{1} 0	1.75×10^{-2} 1.16×10^{0} 0	1.5×10^{-2}
Ω	3.25 3.25×10^{2} 2	1.75×10^{0} 1.75×10^{2} 2	10^{-2} 10^{0} 0	10^{-2}
i	1.5 3×10^{2} 2	5×10^{-1} 10^{2} 2	5×10^{-3} 10^{0} 0	5×10^{-3}
ω	10^{3} 2×10^{3} 3	2 4×10^{0} 0	5×10^{-1} 10^{0} 0	5×10^{-1}