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(U) EVALUATION OF GEODETIC CAPABILITY OF MOL OPTICAL TRACKING SYSTEM

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SECTION I

SUMMARY

The problem was to evaluate the total accuracy to which the geodetic coordinates of a surface target could be determined by post-flight reduction of the recorded angular orientation of a tracking telescope whose cross-hairs were to be kept aligned on the target by the astronaut. In addition, a laser might be slaved to the telescope axis to obtain slant range data.

The following essentially independent sources of error were identified:

1. The satellite ephemeris errors over the target
2. The target position resolution errors relative to the ephemeris.

Based on an extensive post-flight analysis of ephemeris accuracy by R. J. Farrar of the Astrodynamics Department, Aerospace Corporation, it is concluded that the one-sigma ephemeris errors in one orbital fit to 16 revs of Satellite Control Facility (SCF) tracking data to a well-behaved (non-maneuvering) satellite in a 150 nautical mile (n mi) circular orbit are roughly 1000 feet in-track (latitude for a polar orbit), 500 feet cross-track (longitude), and 500 feet in altitude. It is suggested that by the use of multiple fitting techniques or by the use of the improved earth models which will become available over the next few years, these values can readily be reduced to 500 feet in latitude, 300 feet in longitude, and 300 feet in altitude, including the errors introduced by the reference ellipsoid parameter errors. Thus, the above errors are with respect to true geodetic coordinates.

By the use of a star tracker reference system, it appears that an inertial platform can be aligned to a one-sigma accuracy of roughly 0.1 mr (20 seconds of arc). It is assumed that with the combined errors in telescope aiming, structural deflection, multiple cross-referencing, platform alignment, and data recording, the angular error in target resolution will have a one-sigma average value of 0.3 mr. It is assumed that the laser ranging system

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will have an average one-sigma error of 100 feet. Using these figures, the target coordinate errors relative to the local ephemeris are computed for target locations within 115 n mi to either side of the satellite ground trace. Our resultant estimates of the geodetic coordinate errors in feet are:

	Latitude (feet)	Longitude (feet)	Altitude (feet)
Ephemeris	500	300	300
Optics	200	200	500
RMS Total	540	360	600
Optics with Laser	150	150	150
RMS Total	520	340	340

Because of the predominately overhead geometry of the pass, the laser slant range is required for good determination of the critical altitude coordinate.

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SECTION II

DISCUSSION

The basic problem is to evaluate the accuracy to which the geodetic coordinates of a surface object can be determined by post-flight analysis of optical tracking data from a manned satellite. This problem breaks readily into the following sub-problems:

1. Determine the characteristics and local ephemeris accuracy of the satellite orbit.
2. Determine the characteristics, including accuracy, of the optical tracking system.
3. Evaluate the interface between ephemeris coordinates and geodetic coordinates.

The orbit of interest is a 150 n.mi. circular polar orbit. The satellite will be tracked for several weeks time by the USAF satellite control facility (SCF). As discussed in Appendix I, results obtained in an extensive post-flight study by R. J. Farrar indicate that, with care, a one-sigma ephemeris accuracy of 500 ft in-track (latitude), 300 ft cross-track (longitude), and 300 ft altitude should readily be obtained from 16 rev least squares fits to this data using presently available orbit determination programs. We will use these figures even though they may be pessimistic by as much as two-to-one when applied to 1966 capabilities.

It can be seen that in the target coordinate determination problem, the satellite position errors are truly independent of and can be rms'ed with the contribution of the angular tracking system errors in computing the target coordinate determination errors. The same is not true of satellite velocity errors. But the latter are sufficiently small that their effect during a short tracking pass can safely be ignored. Otherwise the ephemeris errors would necessarily be larger than they are and change more rapidly than they appear to.

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The tracking system will include a telescope with cross-hairs which are to be kept centered on the target by the astronaut. The alignment of the telescope axis will be continuously recorded with respect to the MOL reference inertial system. The latter may consist of an inertial platform system which is kept in alignment by star trackers.

Several angular reference systems are discussed briefly in Appendix III. The state of the art satellite inertial reference accuracy is estimated to be 0.1 mr (20 arc seconds). This same estimate is given in Reference 5. We estimate the inertial angular alignment of the tracking telescope will have a one-sigma post-flight computational error of 0.3 mr. This figure includes the combined structural, aiming, referencing, platform alignment, and read-out instrumentation errors.

The MOL tracking telescope is described in Reference 4. It provides continuous tracking within a viewing cone which has a 45 degree half-angle about an axis which normally leads the vertical by 15 degrees in the direction of satellite motion.

The target coordinates are to be obtained by post-flight analysis of data from the above angular tracking system. The contributions of the angular errors to target coordinate errors is discussed in Appendix II. With angular biases of 0.3 mr and for passes within 115 n. mi. to the side of the target it is shown that latitude and longitude can be determined relative to the ephemeris to one-sigma accuracies of roughly 200 feet but that the one sigma altitude error will be roughly 500 feet. These results depend primarily on the assumed data biases and are only a weak function of the assumed data rate, random data noise, and foreward tilt of the tracking cone. It is suggested that the results probably cannot be improved by the use of angular rate data in place of angular position data.

Unfortunately, as indicated in Reference 6, for relatively low-energy ICBM trajectories the most serious target coordinate error (in terms of miss-coefficient sensitivity) is the target altitude error. It is shown in Appendix II that with the addition of a laser ranging system with a one-sigma accuracy of

100 feet, the above errors can be reduced to roughly 150 feet in each coordinate. This capability may be necessary to obtain worthwhile ICBM targeting information from the system.

Rms'ing the ephemeris errors with the above targeting errors we arrive at the following estimates of the one-sigma errors in the computed geodetic coordinates of the target (in feet):

	Latitude	Longitude	Altitude
W/o Laser	540	360	600
With Laser	520	340	340

as shown, the primary contribution of the laser is in reducing the resultant altitude error.

Let us now examine the significance of the above results in terms of the basic meaning of "geodetic coordinates". It must be recognized that all reference geodetic constants are in error by some small but unknown amount.

The orbit determination programs presently use the 1960 world geodetic survey (WGS-60) as a source of reference ellipsoid parameters and tracking station coordinates. It is estimated that the equatorial radius of this reference ellipsoid may be in error by as much as 100 feet. Since the SCF stations are referenced to the North American Datum, the orbit determination procedure will tend to force a good fit of the reference ellipsoid to this datum with the result that there may be an error of up to 200 feet in the computed earth-central radius to the correct satellite position on the far side of the earth.

As pointed out in Appendix I, the estimated radial ephemeris accuracy of 300 feet can only be achieved by the use of a reasonably complete and accurate set of longitudinal geopotential harmonics. The most satisfactory fixed set of harmonics which has been investigated by Aerospace is that set derived by W. H. Guier of the Applied Physics Lab (APL) by post-flight analysis of Transit range rate data (Reference 7). Because the Transit

Doppler stations are reasonably well distributed over the earth, the good results obtained in the use of this earth model for SCF data reduction provides evidence that the reference ellipsoid parameter errors are not the major source of error in orbit determination. Because earth rotation provides good SCF coverage of the orbital arc in the northern hemisphere, it is clear that displacements of the reference ellipsoid towards the North American datum will contribute to ephemeris errors of the type observed by Farrar. Thus, the reference surface errors are already partially included in the ephemeris error figures.

The above discussion suggests the following significant points:

1. It is basically dangerous to solve for earth model parameters with a local tracking net such as the SCF if the results are to be used for geodetic purposes. The model parameters thus obtained will tend strongly to cancel the contributions of reference ellipsoid errors to ephemeris errors at the tracking stations for the given orbital inclination and ground track at the expense of magnified ephemeris errors far from the reference (local) datum.
2. It appears that Guier's 1963 harmonic set may permit the computation of ephemerides to an accuracy of roughly 500 feet in-track, 300 feet cross-track, and 300 feet altitude including the contribution of the geodetic parameter errors. With the ANNA and other future geodetic satellite post-flight earth models, there should be a significant improvement in these results. With the omission of all longitudinal harmonics, the ephemeris errors are of the order of 3000 feet in-track, 1000 feet cross-track, and 1000 feet altitude.
3. For there to be an advantage in the precise knowledge of target coordinates in the ICBM targeting problem, accurate values of the significant geopotential harmonics should be included in computing the desired trajectories.
4. It would appear that a near-optimum way to obtain ICBM target coordinates is by sightings from a satellite whose orbital inclination is near that to be used by the ICBM. If the ICBM then flies with the same earth-model as was used in satellite data reduction there are compensating errors which do not exist in the case of the determination of target coordinates by triangulation.

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APPENDIX I

EPHEMERIS ACCURACY

The ephemeris accuracy of low altitude orbits is a function of many variables. However, if the vehicle is passive (no significant thrust nor attitude control perturbations of either the vehicle frontal area or the velocity vector) and if perigee is above 120 n mi so that atmospheric density fluctuations are not the major source of error, and if typical SCF tracking data are available over at least one day's time, then it is possible to obtain a realistic estimate of the post flight ephemeris accuracy which can be expected.

Using relatively recent Discoverer data, R. J. Farrar of Aerospace has conducted an extensive post flight orbital error analysis. His results indicate that with a good least squares orbit determination program (Farrar used the Aerospace TRACE program) and with 10-to-20 passes of SCF Verlort data taken over 16 orbital revolutions, the major source of ephemeris error is the incomplete and incorrect modelling of the geopotential harmonics.

The geopotential expansion has the form

$$U = \frac{u}{r}\left[1 - \sum_{n=2}^{\infty} J_n\left(\frac{a}{r}\right)^n P_n (\sin \phi) + \sum_{n=2}^{\infty} \sum_{m=1}^{n} J_n^m\left(\frac{a}{r}\right)^n P_n^m (\sin \phi) \cos m\left(\lambda - \lambda_n^m\right)\right]$$

where

u = product of universal gravitational constant and mass of the earth
r = earth-central radius to satellite
a = average equatorial radius of earth
ϕ = geocentric north latitude of satellite
λ = geocentric east longitude of satellite
λ_n^m = east longitude of tesseral harmonic
J_n^m = mass coefficient of harmonic
P_n^m = Legendre polynomial

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The first of the above series contains the zonal harmonics (oblateness, pear shape, etc.). The double series contains the longitudinal (tesseral) harmonics. Those for which n = m are called sectorial harmonics. One of the larger of these is the equatorial oblateness term, J_2^2.

In the post-flight solution for the zonal mass coefficients, Jn, a technique of long term averaging of the secular effects (such as orbit plane and perigee precession rates) may be used. But because of the longitude dependence of the tesseral harmonics and because of earth rotation the most readily observable effect of the J_n^m terms is the cyclic oscillation of the orbital elements at a period of 1/m day. Because of this it is very difficult to separate the effects of those terms of equal period (such as J_2^2, J_3^2, J_4^2, etc.) in the combined post-flight solution for the tesseral mass coefficients and longitudes and the necessary truncation of the infinite series at some arbitrary point results in a folding back of the effects of the higher order terms of the same longitudinal frequency into an error in the solution for the lower order terms. As a result of this, a set of tesseral harmonics derived from an orbit of a given inclination tends to produce more accurate ephemeris prediction for orbits of roughly this same inclination than for orbits at a significantly different inclination.

Because of errors in the tesseral harmonics, superior ephemeris accuracy is obtained by fitting an integer number of days of tracking data and thereby obtaining smoothing over an integer number of cycles of tesseral harmonic oscillation. Because of the secular effects of tesseral harmonic errors and because of fluctuations in atmospheric density, superior ephemeris accuracy may be obtained by one-day (16 rev) fits rather than by fitting data taken over two or more days time. In addition, the fits over longer time spans require at least proportionately more computing time.

Based on considerations such as the above, Farrar performed 16 rev fits which provided solutions for the initial orbital position, velocity, and average drag (the ballistic coefficient). These fits remove most of the secular error due to geopotential harmonic errors and atmospheric density errors from the subsequent ephemeris computation. In addition, Farrar experimented with the simultaneous solution for several of the lower order tesseral harmonics and compared the resultant ephemeris prediction with that obtained using several of the presently available sets of harmonics. In this study the prime accuracy criterion was the observed period error (that solution was assumed to be the most accurate which minimized the time of arrival errors at the stations which tracked during the day beyond the end of the fitted one-day interval). On this basis, Farrar found that the most accurate of the available sets of geopotential harmonics was that set derived in 1963 by W. H. Guier of APL, using Transit tracking data (Reference 7).

Some typical results from Farrar's study are tabulated below:

				Prediction Error (ft/day)	
Flight	Incl. (deg.)	Perigee (n mi)	Apogee (n mi)	Guier	Alternate
A	65	118	187	9100	21,000
B	75	115	223	4600	3,700
C	82	164	179	6100	nil

The above prediction error is the approximate in-track error 16 revs after the last fitted tracking pass using Guier's geopotential harmonic set and, alternatively, solving for the coefficient and longitude of one 24 hour harmonic ($m = 1$) plus J_2^2 and λ_2^2. The results for the 65 degree inclination orbit were significantly poorer than for the higher inclination orbits as a result of the significantly smaller number of tracking passes per day. This, in turn, resulted from the reduced number of tracking passes by the northern SCF stations.

Farrar found that even with the 115 n mi perigee, the prediction error was less sensitive to a change from the sophisticated Lockeed-Jacchia atmospheric model to the crude ARDC 59 model than to changes from one geopotential model to another. With the exception of the 65 degree inclination orbit, Farrar obtained superior results when solving for two geopotential terms over those which he obtained by the use of Guier's set. The in-track error beyond the end of the fitted interval generally increased somewhat parabolically rather than linearly. Thus the initial rate tended to be significantly less than one n mi per day (400 ft per revolution).

In a number of cases, Farrar cross-compared ephemerides obtained by fitting alternate 16 rev spans. Based on the results of these tests and other results Farrar has estimated that the one-sigma ephemeris errors within the interval of the 16 rev fits may be as large as 1000 ft in-track and 500 feet in the cross-track and altitude coordinates. The in-track errors at the tracking stations within the 16 rev spans were generally smaller than 500 ft but, because data from these stations were included in the process of the least squares orbit determination, this number is a lower limit estimate of the average in-track error. This is true if, as found by Farrar, the major source of ephemeris error is the earth model error and not tracking station survey errors.

It is not unreasonable to postulate a two-to-one reduction within the next few years in the contribution of earth model errors to ephemeris errors. This can be obtained with improved knowledge of the geopotential mass coefficients and/or by the development of techniques to reduce the effects of model errors on ephemeris prediction (such as Farrar's solution for model terms). Alternatively, given several days tracking data to a well behaved orbit, a two-to-one post-flight improvement over the accuracy of a single 16 rev fit could very probably be obtained by the following technique:

1. Perform 16 rev fits to revs 1-16, 2-17, 3-18, etc.
2. Generate ephemerides at the desired time points within each of these fits.
3. Using these multiple estimates of the satellite's position at a given time, compute the mean and variance of the coordinate errors.
4. The above mean values are the best estimates of the ephemerides. The variances provide a lower limit estimate of resultant accuracy. It is a lower limit because the sliding 16 rev fits do not completely average out the contribution of a given component of model error (or station location or drag error) to the resultant estimate.

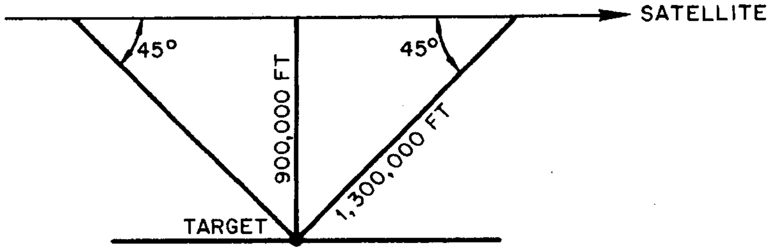
Based on Farrar's results plus considerations such as the above, we have taken 500 ft in-track, 300 ft cross-track, and 300 ft altitude as conservative estimates of the one-sigma ephemeris errors which can be expected several years hence from careful post-flight massage of the SCF data obtained from several days tracking of a well-behaved satellite in a 150 n mi circular orbit. It must be emphasized that future improvements in ephemeris accuracy from the Farrar type fits depend on the development of more accurate geopotential mass coefficients and/or improved orbit determination techniques. Relatively little improvement can be obtained by improving basic sensor accuracy. But greater accuracy can be obtained by improved orbital coverage such as would result if additional tracking stations were added to the net.

APPENDIX II

TARGET LOCATION ACCURACY

Our present problem is to evaluate the accuracy to which the coordinates of a surface object can be determined relative to the 150 n. mi. MOL orbit by post-flight analysis of the tracking telescope angular readings.

To simplify the problem, let us assume that the angular readings have a constant bias of 0.3 mr (one minute of arc) and, that tracking occurs over a 45 degree (half-angle) cone about the vertical. The geometry of a zenith pass over the targets with approximate dimensions in feet is given in the following sketch:



It is immediately apparent that the two extreme measurements alone pin down both the in-track coordinate (latitude) and the altitude to an accuracy of roughly 400 feet ($R\sigma_E$) and that the minimum range reading pins down the longitudinal coordinate to a one-sigma accuracy of better than 300 feet ($R\sigma_E$ again).

To verify the above estimates of accuracy it was decided that the FEIGN error analysis program should be used to simulate the least squares determination of geodetic coordinates in the presence of measurement noise and bias. It was concluded that the assumptions of a noise and bias of 0.3 mr each at a data rate (quantization increment) of 120 measurements per minute would suffice for this study.

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The results of the FEIGN study are presented graphically in Figures 1, 2, and 3. The curves show the coordinate accuracies which would result from the least squares reduction of all data taken prior to the times given for the five representative cases. The passes had a nominal length of 1.2 minutes.

The curves indicate that data taken prior to midpass (0.6 minute) will permit the computation of target latitude and longitude to one-sigma accuracies of roughly 200 feet. With angles only data, the altitude error is 400-to-600 feet depending on the cross-track displacement of the target. Including the data from the second half of the pass improved the computed latitude and longitude by a factor of roughly 4-to-1 but apparently caused some degradation in the computation of altitude from a zenith pass of angular data. In fact, the use of the full zenith pass resulted in a one-sigma altitude error of 665 feet versus only 565 feet for a pass 115 n. mi. to the side of the orbital plane or when using only the first and last 0.2 minutes of data from the zenith pass. These results deserve some explanation and qualification.

The two angles with which FEIGN specifies target direction from the satellite are downward elevation (which goes from 45 degrees through 90 and back to 45 for a zenith pass) and azimuth which is measured clockwise from the north and goes through a 180 degree switch at zenith. In the least-squares fit to a zenith pass of angular data, it is the time of this azimuth switch which provides the prime indication of the zenith position and, hence, of the in-track target coordinate (latitude). As shown in Figure 1, the mid-pass improvement in latitude determination did not occur for the pass 115 n. mi. to the side of zenith and was less pronounced for that zenith pass which included range measurements.

It should be noted that the FEIGN constant bias in elevation is geometrically detrimental to the determination of target altitude but not necessarily to the determination of latitude and longitude. For an equal amount of tracking on each side of the minimum range point, the effect of the elevation bias

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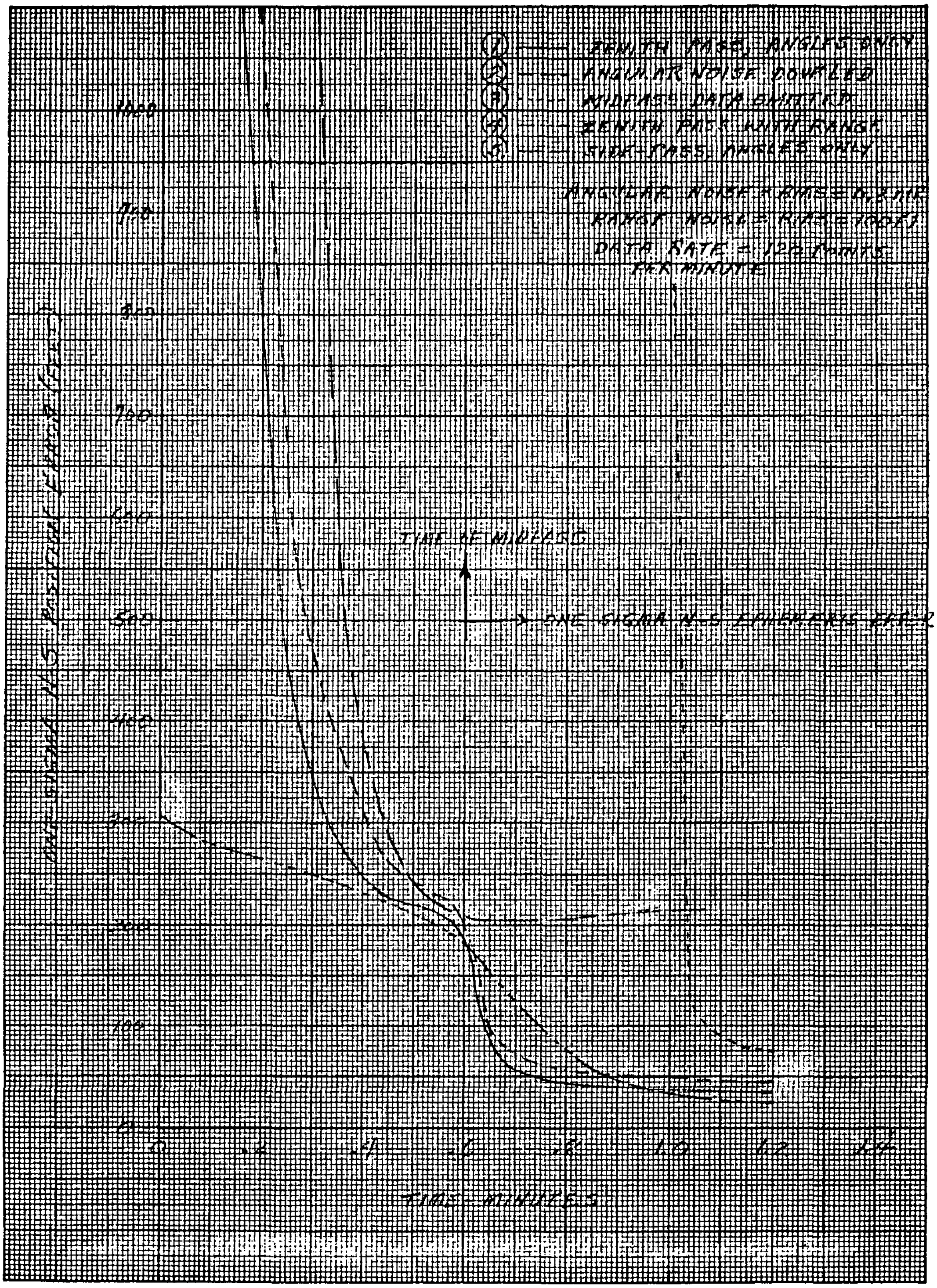

Figure 1. Latitude Error Relative to Ephemeris

[redacted]

[redacted]

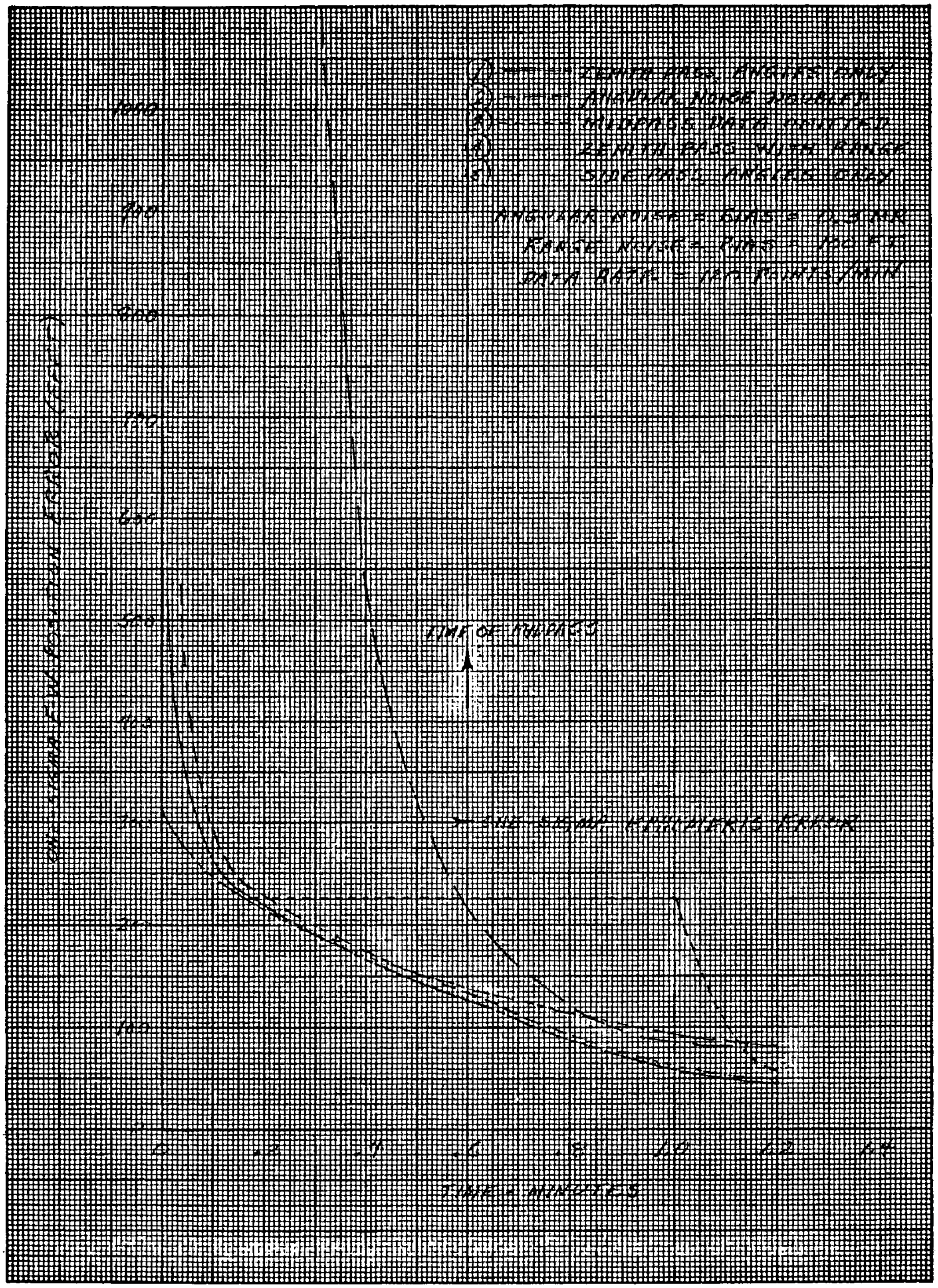

Figure 2. Longitude Error Relative to Ephemeris

[redacted]

[redacted]

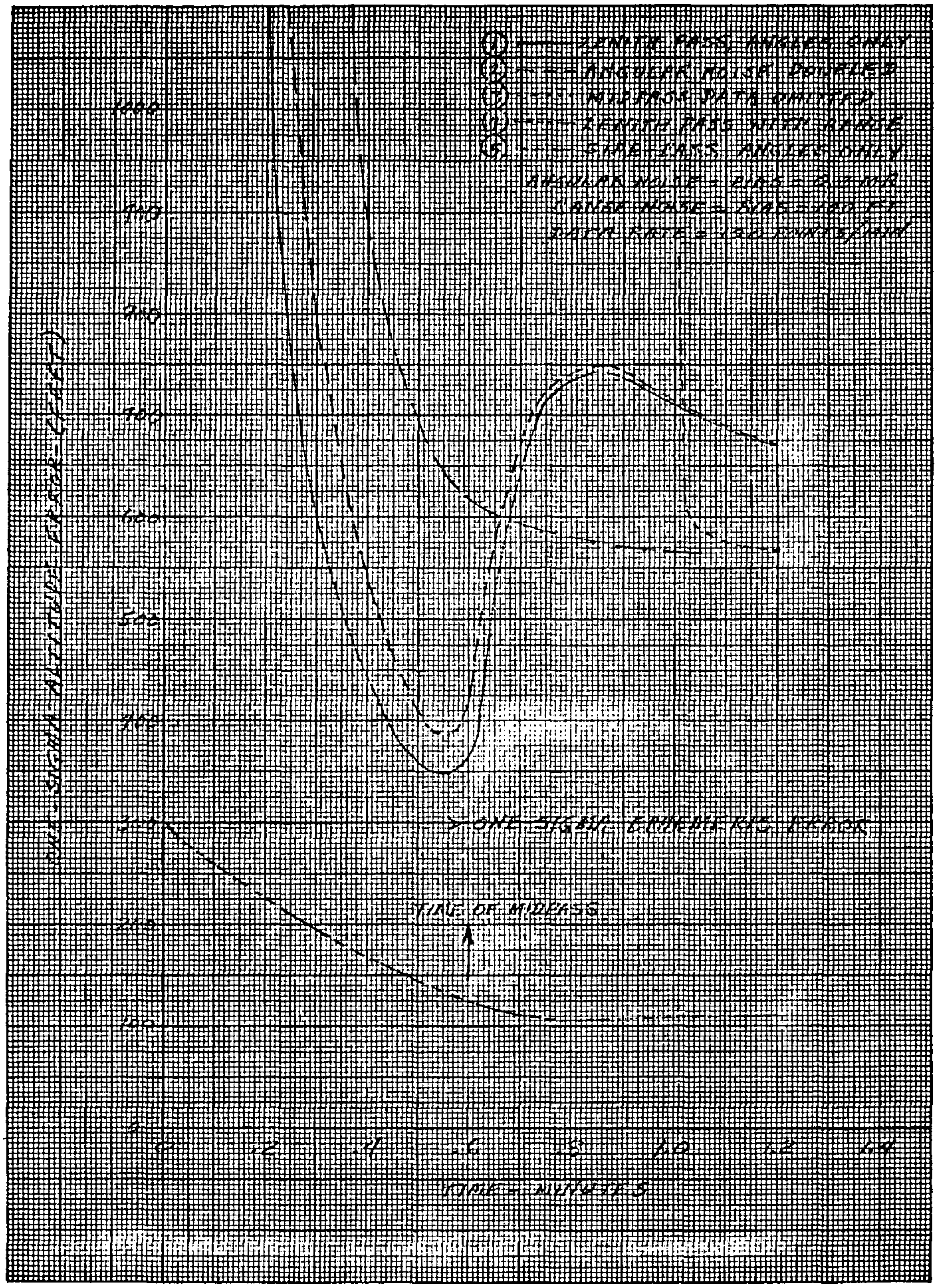

Figure 3. Altitude Error Relative to Ephemeris

[redacted]

beyond mid-pass cancels the effect along the corresponding arc ahead of midpass in the solution for latitude and longitude but re-inforces the error in the altitude computation. By picturing the geometrical effect of the elevation bias on the least squares fit, it can readily be understood why the omission of the midpass data for the zenith pass resulted in the reduction in the altitude error illustrated in Figure 3 (case 3).

To investigate the sensitivity of the above results to data rate and noise, both of these parameters were changed by a factor of two-to-one on separate additional runs. As expected, since granularity is not a problem at the 120 point per minute data rate, the effect of reducing the data rate to 60 points per minute was very similar to the effect of doubling the assumed data noise. Because of the smoothing provided by the high data rate, the least squares fit was relatively insensitive to two-to-one changes in the assumed data rate and noise. This is illustrated by case 2 of Figures 1, 2, and 3.

Because of the dynamic error introduced by a high azimuth-tracking rate, the MOL tracking telescope is not designed to operate in an azimuth-elevation coordinate system. Instead, its angular orientation will be continuously recorded in terms of inertial platform direction cosines. In this case (or any other realistic case) the bias smoothing evidenced in the FEIGN runs will be much less pronounced. Nonetheless, the fit to a full pass of angular data will tend to result in an improved estimate of latitude and longitude but negligible improvement in altitude over the results obtained by simply fitting the end points of the pass.

Based on the geometry and the above considerations, we estimate that the midpass results of Figures 1, 2, and 3 are representative of the accuracies which can be expected from careful post-flight reduction of the tracking telescope data. Thus, for either an overhead or a side pass, latitude and longitude can be resolved to an accuracy of roughly 200 feet. To obtain altitude to an accuracy of better than 400 feet, range data are needed. With a zenith pass the altitude can be determined to roughly the accuracy of the ranging system. We have conservatively estimated that a laser-ranging device will have a one-sigma bias of 100 feet. This figure includes the error due to uncertainty in the exact target point from which the laser return is received. Then, for the more representative case of a pass 115 n. mi. to the side of the target, we estimate that the one-sigma accuracy of relative target coordinate determination will be 200 feet in latitude and longitude and 500 feet in altitude with 0.3 mr angular data but that this can be reduced to a spherical position uncertainty of 150 feet by the addition of a 100 foot ranging capability. In connection with this latter estimate it should be noted that in the FEIGN study the range data were not subjected to the same unreasonably favorable bias smoothing as were the angular data.

Since the above results were dictated almost entirely by the assumed data biases, let us consider the possibility of fitting rate data rather than position data. This appears inadvisable for the following reasons:

1. The FEIGN study assumed constant biases for convenience only. Actually, much of the systemmatic error in computing the tracking telescope direction cosines is sensitive to changes in telescope alignment. This will produce a ramp-type error of significant magnitude in the angular measurements whose effect will be greatly accentuated by fitting to angular rate data rather than position data.
2. The effects of high frequency data noise and orbital velocity errors will be accentuated by the use of rate data rather than position data.
3. Rate data provides a weak solution for position coordinates. If rate data rather than position data are used then that component of error which results from poor convergence of the target coordinate computational procedures will be accentuated. This component is also accentuated by the increase in data noise level which results from differentiation of the position data.

APPENDIX III

SATELLITE ANGULAR REFERENCE SYSTEMS

The following is an outline of several present and potential satellite angular reference systems with short discussions of approximate accuracy, system problems, and some potential interfaces with a manned system.

1. Gyrocompassing--Rate Gyros plus Horizon Sensor

This is a proven satellite attitude control technique. The horizon sensor maintains the orbital pitch rate while rate gyros prevent roll and yaw misalignments. The fundamental lack of definition of the horizon to an accuracy of better than 5 mr is a major limitation on system accuracy. At a target slant range of 200 n mi this alone dictates a position prediction error of one nautical mile.

2. Three-Axis Star Reference

This could be three separate instruments or one instrument which used star map (correlation) techniques. In either case, initial positive alignment and maintaining alignment can present problems. But an accuracy of better than 0. 1 mr (100 ft at 200 n mi) is potentially available. Unfortunately, the angles between the stars are essentially the same from anywhere within the solar system. The star reference system requires an independent vertical reference to the earth. If a horizon sensor is used, then its 5 mr accuracy is again the limiting system accuracy.

3. Three-Axis Gyro System

Because of drift (at least .1 mr/day) and the initial alignment problem, this system is of primary value in providing smoothing and stable aiming of other angular reference equipment. A stable table might provide a good reference for obtaining and maintaining star-tracker lock-on. Whether used alone or with star trackers, the gyro system requires a separate vertical reference system. If the gyrocompassing technique is used, star-trackers are not required.

Because the primary need of the above systems is for a good vertical reference to the earth, let us now consider alternate techniques for satisfying this requirement.

1. Crude Vertical Reference Systems

The vertical has been obtained by both magnetic field and gravity gradient techniques. These suffer from the small magnitude of the effects. Neither technique has an accuracy of better than 50 mr. Both methods are degraded by placing a man aboard the satellite and allowing him to move either during or after initial alignment.

2. Horizon Sensors

The basic problems with the horizon reference from a near-earth satellite are the uneven distribution of cloud heights and the day-night illumination problem. The limiting accuracy appears to be roughly 5 mr. Considerably more accurate alignment to the sun and moon can be obtained but, when reflected back to a computed local vertical to the earth, the error is much greater than 5 mr.

3. Computed Vertical

With star trackers or gyros for an inertial angular reference and satellite ephemerides computed by an orbit determination program, the direction of the vertical with respect to the inertial reference at any given time can be computed. With one-day's tracking data to a well behaved 150 n mi orbit the accuracy is limited to the 500 foot accuracy to which the ephemerides can presently be computed. At lower altitudes where atmospheric drag errors become significant, the accuracy is poorer. It is also possible to compute target positions from certain reconnaissance data without the need for angular reference data.

4. Monopulse Altimeter

Ocean return radio-altimeter data holds considerable promise for improving ephemeris prediction accuracy. In addition, a monopulse capability could provide a vertical determination to an accuracy of better than 1 mr. This assumes an 8 Kmc frequency with a 2 ft antenna. General Electric has proposed an 8 Kmc altimeter in a 24 lb package with an average power level of 30 watts. A disadvantage is the disruptive effect of the high instantaneous power level of the transmitted pulses on other satellite electronics.

5. Interferometer Angular Reference

The vehicle angular alignment over tracking stations could be determined by interferometer methods using multiple satellite sensors and a cw ground signal. Such a system has been proposed by Cubic Corporation and a similar system has been designed by Bendix for commercial airliner use. Unfortunately, the knowledge of the vertical beyond the alignment point is again dependent on computed ephemeris accuracy. But this system could provide gyro reference alignment. The Cubic system had a computed accuracy of better than 1 mr.

Let us now consider how a man could help or hinder the operation of the above systems. It is clear that, because of his motion, angular aiming of all instruments could be made more difficult. But either the instruments or the entire satellite could be provided with a good attitude stabilization system. It is also clear that the man could provide improved target selectivity. The following points appear pertinent:

1. The man could be of value in obtaining and maintaining alignment of star trackers and/or other instruments.
2. The man could telescopically track known landmarks and thereby provide a new source of angular alignment information. He could also maintain instrument alignment during target tracking.
3. By identification of unsuspected targets and selectivity in data collection the man could significantly improve system yield. There would be less danger of missing pre-selected targets because of angular aiming or ephemeris errors.
4. With the aid of charts and pre-selected logic the man could provide a significant on board decision making capability. He could add in a major way to the system flexibility and quick reaction capability.

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5. The man could provide back-up in varying degrees to all on-board systems. He could try to repair failed systems or switch to alternate systems. He could provide on-the-spot evaluation of aiming accuracy and requirements at each target area.

[redacted]

[redacted]

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