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# EFFECTS OF POINTING AND TARGET TRACKING ON DORIAN PHOTOGRAPHY

244 Pages

If the smear free, or static, resolution of a system is better than the design goal, smear can be tolerated up to the point that the dynamic (with smear) resolution equals the design goal. For the Dorian System the on-axis tolerance in terms of angular rate is [redacted] radians/second (2 sigma). Although many factors are involved, the key item in achieving this specification is the reduction of the residual smear attributable to tracking errors to about [redacted] radians/second (2 sigma).

While this tracking error and the associated noise are the main contributors to smear, pointing accuracy is also a major concern, since any deviation of the target from the center of format produces smear which degrades the photography. Pointing errors of more than [redacted] of arc will exclude a target entirely from the 9000' diameter field of view. It is evident then that accurate pointing is critical to both acquisition and reduced smear.

There is high confidence that man can point the system well within the specified limits, since by use of the acquisition and tracking scope he can compensate for ephemeris and target location errors. To achieve this same goal automatically with an Image Velocity Sensor will take a great deal of effort and success depends on several current and proposed projects to be successfully completed and demonstrated in the next 2-3 years.

## The Smear Budget

The first step in establishing the smear budget is to identify the direct causes of smear and apportion the total smear tolerance among the direct causes on the basis of their 2-sigma variabilities. On-axis smear is caused by steady-state angular velocity errors in tracking the central point of the target (tracking rate error), random perturbations about

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the steady-state tracking rates (tracking jitter), and vibrations of the camera platen and the optical elements. The current smear rate tolerances allocated to tracking-rate error and vibration and jitter in microradians/second (2 sigma) are:

| | Manned/ Automatic | Automatic |
|---|---|---|
| Navig/Control | [redacted] | |
| Vibration | | |
| Image Motion | | |

Pointing and Tracking are associated directly with Navigation/Control and Image Motion and are the subject of the succeeding paragraphs. While Vehicle Vibration is also very important it will not be considered here.

## Pointing

The Dorian System will achieve its goal of collecting [redacted] resolution photography only under specified conditions. One of the prerequisites is that the selected target be acquired in the center of the photographic format. Any deviation from this degrades the resolution [redacted] The problem of where the selected targets will be in the format (9000' diameter at nadir on the earth from 80N.M.) and therefore what resolutions will be achieved will be in part determined by how well the MOL system is able to point at the target. Pointing accuracy is a function of target position accuracy, orbiting vehicle position accuracy and the MOL system electro-mechanical pointing accuracy.

Each of the three prime contributors to the pointing problem (geodetics, ephemeris, AVE) will be discussed individually, then in a systems context. Results from the latest (1 April '68) Mission Payload System Segment Performance

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Analysis Progress Report (CDRL-100) will be used in assessing the total system pointing capability.

Target location (geodetics). The main optical system has a half angle field of view of approximately 0.54° (4500' at nadir from 80NM) which establishes the upper bound for allowable target position error for the automatic MOL system. Although acquisition is the first and paramount requirement, accuracy of positioning the target within the field of view has an important impact on resolution. This is true primarily because all rate nulling systems assume that the target is in the center of the format.

Figure 1a shows the smear that results from target position errors. Noting that the root sum square error budget for the Navigation and Control System is [redacted] radian/second and assuming that the allocation to target error would be comparable, it follows that the target location should be within [redacted] if this error source is not to produce excessive smear.

Extensive effort has been devoted to establishing accurate geodetic positions for missile targets. SAC has identified 2077 targets and has designated 1406 as "Hard" sites and 671 as "Soft" sites. Hard sites require horizontal position accuracies of 450 ft (90% CE), while soft sites have a requirement for 1000 ft (90% CE). As of 29 Dec '67, ACIC reported the following status on these targets:

| Horizontal Uncertainty (90% CE) | Nr. of Targets |
|---|---|
| 0-450' | 732 |
| 451' - 750' | 792 |
| 751' - 1000' | 498 |
| 1000' | 55 |

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Residual Velocity – μ RAD/SEC

[redacted]

TARGET LOCATION ERROR ~100 FT

Figure 1a Residual Image Motion After IMC (2 σ)

Residual Velocity – μ RAD/SEC

[redacted]

Figure 1b IN-TRACK POSITION ERROR ~1000 FT

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The positioning accuracies discussed above pertain to only the SAC missile targets which have the highest priority. Intelligence targets for satellite photography are located by many agencies, using various methods, and in most instances much less accurately than these missile targets. The large fields-of-view of current photographic satellite systems do not require very accurate target locations to insure that the target is within the frame. Most important to MOL, however, is that even among the highest priority targets there are a large number whose locations are not known within the [redacted] limit necessary to achieve the MOL photographic design goals. In most of the Eastern Eurasian land mass, target location accuracies even approaching those in the SAC missile target deck are not available. ACIC indicates that using DAFF (KH-5) photography accuracies from 1000 to 2000 ft in these areas are achievable but not necessarily programmed.

Investigations to date indicate the following in regard to target positions:

1. There is no standard method of defining a reference point for the center of a collection requirement target.

2. Target coordinates are not referenced to the same datum.

3. The accuracy of the target coordinates presently used by Imagery Collection Requirements Sub-Panel (ICRS) is not known.

4. The accuracy of target location varies with geographic location. ACIC estimates that by 1970 most targets of interest will be in areas where source material will give them the capability to provide locations within about 750 ft. to 1000 ft.

The seriousness of this problem to the automatic unmanned MOL becomes evident when it is realized that all necessary improvements to the geodetic situation must occur in the next 2 to 3 years. No large scale effort to dramatically

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improve in this time frame is currently evident, although the capability to do so is said to exist.

Ephemeris Prediction

The solution to this problem is primarily the responsibility of the Satellite Control Facility which will provide the ephemeris to the MOL. The MOL Computer will interpolate the ephemeris table provided and with the aid of inputs from the low G accelerometer will refine its predicted positions against time.

The MOL specification to meet precision acquisition and smear requirements requires the navigational capability of the system to be [redacted] (For the effects of in-track error on smear see Figure 1b.) The numbers quoted are two sigma, and assume error propagation of 2.5 orbit revolutions. These requirements imply something substantially beyond the capabilities of current ground tracking and orbit prediction. These accuracies require such things as employment of a low G accelerometer (LGA), a much improved atmospheric model, improved tracking capabilities and advanced orbital prediction techniques.

Current estimates of navigation prediction accuracy after 2½ orbits, based on ground tracking and computation alone are given below:

IN-TRACK ERROR (TWO SIGMA, FT)
(No LGA, Radar Data Only)

| | | Internal To Data Fit (No Predict) | 2.5 Revs Predict |
|---|---|---|---|
| | No Drag | 1600 | 2000 |
| Current | Low Activity | 1800 | 3200 |
| | High Activity | 3600 | 8800 |

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It should be noted that the current capability is only marginally adequate to acquire the targets in the 4500 foot radius allocation and that during periods of high solar activity that the targets would not be acquired at all.

The estimated prediction capability for the 1970 - 72 time period not using the low G accelerometer is shown in Figure 2. This estimate is based on the Space Ground Link System (SGLS) and the Advanced Orbit Ephemeris System (AOES) reducing the current conservative in-track prediction estimate of about 8800 ft. to about 6000 ft. The improved atmospheric modeling based on LOGAX data to further reduce the error to 3000 ft. and the combination of these in conjunction with the low G accelerometer to ultimately equal or better the specified 1800 ft. is shown in Figure 3. Figure 4 is an error budget table for 1970 - 72 based on all the above improvements contributing properly and utilizing the low G accelerometer.

While these accuracies may be achieved there is great dependence on several large improvements occurring in series. In any case the feasibility and practical demonstration of these combined innovations will not occur until 1970 at the earliest.

AVE

The mechanical pointing or AVE pointing requirement of [redacted] appears to be reasonably achievable based on analytical and test data to date. The task is demanding but considered well within the state of art.

System Pointing

An analytical estimate of pointing accuracies achievable in the 1970 - 1972 time period is provided as Figures 5 and 6. These estimates are based on the following assumptions:

a. Target location accuracies less than [redacted]

b. All improvements to the ephemeris prediction system operating properly (AOES, ADS, SGLS, Improved Atmospheric Model).

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Estimated Vehicle Position Errors, No LGA, $2\sigma$

| Propagation ~ Revs | 1.25 | 2.5 | 3.5 |
|---|---|---|---|
| **In-track Error ~ Ft** | [redacted] | | |
| 1. Drag + Geopotential | | | |
| 2. Ephemeris Interpolation | | | |
| 3. Attitude (1%)* | | | |
| RSS | | | |
| **Altitude** | | | |
| 1. Drag + Geopotential | | | |
| 2. Ephemeris Interpolation | | | |
| 3. Attitude (1%)* | | | |
| RSS | | | |
| **Cross-Track** | [redacted] | | |
| 1. Atmospheric Rotation + Geopotential | | | |
| 2. Ephemeris Interpolation | | | |
| RSS | | | |

*Allocations

Figure 2

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# MINIMIZATION OF EPHEMERIS UNCERTAINTY

## 2-SIGMA IN-TRACK FOR 2.5 REV PREDICT SPAN
(1000 ft)

CURRENT

SGLS AOES

SGLS AOES
LOGAX

SPEC

SGLS AOES
LOGAX LGA

[redacted]

Figure 3

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Estimated Vehicle Position Errors with LGA, $2\sigma$

| Propagation ~ Revs | 1.25 | 2.5 | 3.5 |
|---|---|---|---|

**In-Track Error - Ft**

1. Geopotential
2. Position Estimation Procedure (1%)*
3. Ephemeris Interpolation
4. Attitude Control Rotations
5. LGA Systematic Errors (1%)*
6. LGA Random Errors (0.1%)*

[redacted]

**Altitude**

1. Geopotential
2. Ephemeris Interpolation
3. Position Estimation Procedure (1%)*
4. LGA Systematic Errors (1%)*

RSS

[redacted]

**Cross-Track** (Same as Figure 2)

*Allocations

Figure 4

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TWO SIGMA POINTING ERROR (ARC MIN)

[redacted]

REVS

① AUTOMATIC MODE - INCLUDES EPHEMERIS AND TARGET LOCATION ERRORS WITH NO LEARNING EXCEPT LOW G ACCELEROMETER

② SPEC REQUIREMENT - EXCLUDES EPHEMERIS AND TARGET LOCATION ERRORS

③ POINTING ANGLES DERIVED FROM ATS

④ SAME AS 1 BUT EXCLUDES LOW G ACCELEROMETER

Figure 5

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Line-of-Sight Pointing Error

| | Pointing Error* (2 Sigma) |
|---|---|
| **Automatic Mode (A Mode)** | |
| Including all errors without LGA<br>Including all errors with LGA | [redacted] |
| Neglecting vehicle ephemeris and target positions error | [redacted] |
| **Pointing Angles Derived from ATS** | |
| With ATS boresighting on two targets<br>With ATS boresighting on three targets | [redacted] |
| **ATS Pointing Error** (Automatic Mode, after boresighting) | |
| Including all errors without LGA<br>Including all errors with LGA | [redacted] |
| Neglecting vehicle ephemeris and target positions errors<br>(2 Target Boresighting)<br>(3 Target Boresighting) | [redacted] |

* Assumes uniform target density on the ground

Primary optics scan field

$$|\Omega| \leq 40^{\circ}$$

$$-30 < \Sigma \leq 20^{\circ}$$

ATS scan field

$$|\Omega| \leq 45^{\circ}$$

$$0 < \Sigma \leq 70^{\circ}$$

Figure 6

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c. AVE pointing error of no more than [redacted] of arc.

It is important to emphasize that large improvements in target location and emphemeris prediction are mandatory for the unmanned system but are only desirable for the manned system. This is true since man, using the acquisition and tracking scopes to point and track targets, effectively eliminates the navigation and geodetic errors.

Image Motion Compensation

Smear due to image motion which would result in photographic degradation comes from two sources:

1. Changing relationships between the orbiting vehicle and the ground target and

2. Tracking rate errors.

In the first case the scene appears to expand and turn about the nulled axis (the tracked point) as the target is approached and the reverse action takes place as the target is passed.

At extreme look-angles, geometric image motion near the periphery of the format can be as much as 7.5 times the budgeted on-axis smear rate of [redacted] radian/sec (2-sigma). The effect of this off-axis smear at the edge of the format is to degrade the ground resolution to a value three times the on-axis ground resolution (for the nominal exposure time).

With a focal plane shutter, only a narrow strip of the format is exposed at a given instant. If the image motion within this strip can be matched by moving the film, the smear occurring in the area of the slit can be eliminated without effecting smear of points beyond the slit. This technique is called across-the-format IMC (X-format IMC). The nulling of this motion is to be achieved by manipulating the platen and the solution seems quite feasible at this time.

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The more serious and currently assessed as more difficult motion compensation is that of nulling in-track rates.

Reduction of the tracking-rate error is accomplished in two control steps: preprogrammed computer control followed by fine control by either a crewman or an Image Velocity Sensor (IVS). The tracking-rate error allowed by specification in programmed rate control is [redacted] radians/second, 2 sigma. The crewman or IVS is required to reduce the tracking-rate error from this level to about [redacted] radians/second or less. [redacted] radians/second smear would yield photography on the order of [redacted] assuming a set of conditions which would yield [redacted] photography with a residual tracking rate error of [redacted] radians/second.

It is therefore evident that without man or the IVS the very high resolution goals for MOL cannot be achieved.

Extensive simulation test runs by the crewmembers provide a high degree of confidence that the specified levels of residual smear can be easily achieved. The same confidence for the IVS accomplishing this job is not enjoyed at this time.

It is too early in the IVS testing program to state that the specified rate nulling job cannot be accomplished automatically in the necessary time frame. It is, however, safe to say that much redesigning, testing, and perhaps re-inventing must be done before a confidence factor approaching the current confidence in man's ability is achieved.

Recent evaluations of the contenders for the IVS production contract were given the following general evaluation by General Electric (direct quotes):

a. All sensors correctly sense input velocities for <u>some</u> scene conditions.

b. All sensors have center of power tracking characteristics.

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c. All sensors sensitive to scene detail.

d. All sensors have light level problem.

e. All sensors have "cloud" problem.

On the basis of this test program which was quite comprehensive one vendor was recommended for elimination and the other two were "sent back to the drawing board" to try to eliminate the deficiencies noted in their hardware.

There were two basic deficiencies evident in all contenders. One was that they focused on what G.E. terms "Center of Power" (the area in the format providing the most stimulus to the sensor). This means that the velocity of the "Center of Power" rather than the desired center of format will be measured and compensated for. The other and more serious problem comes from the fact that all sensors centered on clouds when they were present. This characteristic introduces significant errors the magnitude of which depends on the altitude and velocity of the cloud deck and the percent of cloud cover. It is estimated that if the sensor measures on a cloud rather than the target desired that an induced error of about 100 X $10^{-6}$ radians/sec for each 1000' of cloud altitude above the target, would result.

Careful study of the General Electric Company's IVS Vendor evaluation report (DIN 50366-38-1, 240 Pages) leaves little doubt that the IVS is a high risk item in terms of the MOL goal of achieving very high resolution photography in an automatic mode.

Summary

The ability of the MOL system to provide [redacted] resolution of specified targets depends not only on the AVE under development but also on the accomplishments of other agencies such as ACIC and the AFSCF. Without considerable improvement in geodetic and ephemeris prediction accuracy in the next 2-3 years, the photographic resolution desired, and

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even automatic target acquisition in many cases is in doubt. This fact coupled with the development and testing difficulties and uncertainties associated with the IVS makes the unmanned version of MOL appear as a rather high risk development at this time. There is consolation however in the fact that man can essentially eliminate most of the difficulties associated with tracking and pointing. This fact provides confidence in the manned version as an operational reconnaissance system as well as a test bed available for developing more sophisticated automatic systems.