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DEVELOPMENT PROBLEMS INHERENT IN AN UNMANNED DORIAN SYSTEM

INTRODUCTION

Recent discussions have again called attention to the feasibility and/or desirability of developing an unmanned DORIAN reconnaissance satellite system (i.e., one employing the MOL Program camera system) in a program consisting of unmanned launches only.

The technical feasibility -- albeit, very difficult to achieve in several areas associated with the camera/optical system -- of the purely unmanned approach to [redacted] resolution satellite photography is generally accepted. The principal question concerns the length of time to bring such a system to an acceptable level of maturity.

This question has been under consideration since the beginning of the MOL Program. In mid-1966, two funded contractor study efforts of an unmanned system program were completed, and a similar study was conducted in-house for comparison purposes. During the past year, MOL program/contract definition plus engineering analyses and test results have all provided additional pertinent information. This paper synthesizes the data and information from those sources which are applicable to the time-for-maturity question.

MATURITY STANDARDS

The point in time and level of performance at which a space system is "mature" is a more or less arbitrary judgment. Further, the standards of maturity are different for particular space missions.

DORIAN/GAMBIT

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The current J-1 model of the KH-4 is certainly a mature system -- both in longevity and demonstrated reliability. For example, in 1966, in estimating the number of launches required for the KH-4 and in setting a production rate, the NRO went through the following process. First, the number of "successful" days on orbit necessary to meet USIB requirements was calculated (a "successful" day on orbit was considered as all stereo photography; resolutions generally within the system potential for the conditions encountered; and a proportionate percentage of the available film exposed, more than 50 percent of which had to be cloud free). KH-4 launches were then calculated on the basis of achieving 85 percent "successful" days on orbit of the maximum possible (which varied from 10 to 13 days depending on the inclination flown).

A mature DORIAN system should meet the expected standards of technology (for example, part failure rates) in the missile and space industry projected ahead to the 1970 period. It should be essentially free of learning curve failures, having reached a point at which it can be said the system is properly designed, is manufactured and tested with nearly flawless quality control, and is handled in manufacture and operations with tried and proven procedures.

In light of the preceding, the following definition has been developed as a DORIAN maturity standard.

1. A successful DORIAN mission, or any successful portion thereof, will deliver the minimum specified quantity of photography (100 or more targets attempted per day) at or near specification resolution [redacted]

at 80 nautical miles, 2-1 contrast, etc.). Any substantial degradation of photography -- for example, [redacted] at 80 nautical miles, 2-1 contrast, etc. -- will be categorized properly as a failure.

2. The orbital mission duration will be based on the concept of aiming at a 60-day lifetime. Sufficient expendables will be carried to fly the basic mission profile (90° inclination, 80 x 180 mile orbital altitudes) for 60 days, and all components will have wear-out lifetimes much in excess of that time. Averaged over a number of launches, a mature system of this kind would be expected to give satisfactory results over about 70 per cent of the maximum possible duration.

BASIS OF RELIABILITY ESTIMATES

The following general principles apply to the discussion of the factors which would influence the orbital development period of an unmanned DORIAN system:

1. The estimates are based upon an across-the-board design practice or incorporating redundancies wherever possible.

2. Where applicable, full use is made of derivatives of both NASA and DoD technology.

3. Extensive ground testing is incorporated in the baseline.

4. The same policies apply to the mission payload, but with a recognition that there is a greater extension of the technology, a consideration which will be discussed in a separate section which follows.

5. There is also a recognition that a considerable advancement in mean times to failure over current military standards will be achievable.

The VELA experience of very high reliability is an example. The following table shows the corresponding relation of the figure chosen for DORIAN:

Parts Failure Rate per 10^6 Hours

MIL-217	1970 DORIAN	VELA
1.0	0.1	0.04

The funded studies and the earlier Aerospace work have provided some foundation for the reliability numbers, which, when combined for the entire system will characterize the success-rate of the mature system. Since that time, extensive program definition, analyses and tests have provided an update of the calculations and increased confidence in their validity. In addition, a great amount of information has been generated concerning the mission payload, which was treated as a government-furnished item in the previous contractor studies.

The paragraphs below will discuss the reliability of each of the major segments of an unmanned DORIAN system as it would be determined by MOL design and test standards and as influenced by the individual nature of each segment.

THE LAUNCH VEHICLE

An up-rated Titan III with newly-developed 7-segment solid-propellant rocket motors will be needed to provide the lifting capability for a 60-day system. This booster is currently under development for MOL in a man-rated configuration with very high reliability. If it were applied to an unmanned development, some of the man-rating features probably would be eliminated, but many of the high-reliability characteristics no doubt could be retained. The outlook therefore is that the booster employed could be expected to be very reliable from the beginning.

THE ORBITAL CONTROL VEHICLE

The studies cited previously provided, from parts analysis, a good appraisal of mature reliability for the orbital control portion of the system was made, showing that high standards could be met. A further review based upon MOL development and test experience to date has reconfirmed that the studies were correct. This examination does not, however, give consideration to the errors and failures which occur to a greater or lesser extent in the early launch history of missile and satellite programs. A projection from past experience provides a means of exploring this portion of the problem.

A study was made of the launch history of the first portion of the GAMBIT program. Tab A is a listing of the results of the first 15 tests and the orbital control vehicle performance of the first 19 launches. It is interesting to note that 74% of the GAMBIT failures during this period were not of the statistical type which are the subject of reliability analyses. They all occurred during the first day of the mission and could be classified in the following categories:

1. Design deficiencies.
2. Errors in procedure.
3. Faulty quality control.

The GAMBIT experience is shown here not because it is believed to be typical of the expected DORIAN case, but rather to show the risks involved in a completely new and highly advanced segment of a system when it is tested in an unmanned configuration. In the GAMBIT case, the orbital control vehicle was almost completely untried throughout, and lessons were learned through flight failures. This fact is demonstrated by the mature GAMBIT record -- 15 of the last 16 missions were completely successful.

As a further illustration of how launch experience can be applied to advantage, the early record of the current GAMBIT 3 system can be cited. No orbital control vehicle failures have occurred in the first 8 launches (there was one booster failure.) The reason for this success is that the OCV is a basic AGENA, fully mature, and which is tested and prepared for launch through well-established procedures. There is good reason to expect that the DORIAN orbital control vehicle can apply nearly all of this past experience to achieve an early reliability which will approach the maturity figure.

THE MISSION PAYLOAD

In contrast to the OCV success, the GAMBIT 3 mission payload history has shown the effects of immaturity associated with the extension of technology that is being accomplished. So far, the best of these tests, quite predictably, have produced photography averaging about 70 percent above the ground resolution which the mature system will achieve. In the case of GAMBIT 3, which is fulfilling an operational function, valuable intelligence information is being delivered because the performance of the system already is exceeding its predecessor. In the DORIAN case, however, a performance 70 percent above specification would not be considered of substantially increased value and any launch otherwise satisfactory still would have to be classed as a failure. There is a considerable risk that initial testing of DORIAN in the unmanned mode would yield degraded photography. The reasons, which are discussed below, are different in specifics from the GAMBIT 3 case.

The MOL camera/optical system is extremely sophisticated in comparison to systems such as GAMBIT (KH-7) and Advanced GAMBIT (KH-8). There are a multitude of possible contributors to off-nominal performance situations which could radically increase the complexities of and time requirements for diagnosis and correction over those of previous unmanned development programs. Not only must this camera be manufactured with great precision, but several technically difficult-to-achieve functions associated with its operation must be performed on orbit also with great precision. These involve automatic devices many of which either have never before been used in orbit or represent large extrapolations in precision, accuracy, or other capabilities.

a. Alignment

Because of its size and the large mass of the optical elements, the MOL optical assembly is not a rigid structure as is the case with present (and smaller) unmanned systems. The primary mirror (at the aft end of the optical assembly) must be protected by being clamped down during the launch and boost phase and released after orbit is achieved.

The zero-g alignment of the optical assembly differs sufficiently from the one-g alignment that a means to correct for alignment shifts is necessary. For example, on the ground, gravity-induced factors contribute to bending of the Ross Barrle, deflection of the mirror support structure, stretching or deflection of the Camera Optical Assembly structural shell, etc. On-orbit, cyclic thermal stresses encountered during each revolution also induce structural stresses.

Misalignment from tilt and/or decentering of the primary mirror with respect to the optical axis of the Ross corrector assembly results in a loss of Optical Quality Factor. This is translatable into lesser static resolution capability. For example, an equivalent primary mirror tilt angle of [redacted] and approximately the same loss in resolution. (A five percent allowable loss in OQF due to misalignment is the maximum permitted in the error budget.

b. Focus

Resolution is affected not only by optical quality, misalignment, smear, etc., but also by noncoincidence of the film emulsion plane and the plane of best focus during exposure. The mismatch between these two is referred to as the focus error. The allowable tolerance in the MOL camera system for this mismatch is [redacted] Focus errors beyond this limit cause a rapid drop in resolution (for example, another [redacted] out of focus system has been incorporated in the MOL camera system which, when operating properly, will keep the focus error well within allowable limits, but it does involve a technology advancement.

c. Pointing Error

Accurate pointing is essential to the MOL camera system both because of the small field of view (approximately a 9000 foot diameter circle at nadir and 80 mile altitudes) and the fact that the very best resolution occurs in the center of the picture format.

A small portion of the degradation in resolution outward from the center of the frame is caused by diffraction and the lower illumination at the edges; however, this is relatively small (about 10 percent worse in the outer portions of the frame). The majority of the degradation results from the inability to compensate perfectly for image motion across the entire format during exposure. In a typical off-axis oblique photograph, the resolution near the edge of the format with the IMC operating properly, will be approximately 33 percent worse than at the center. If the cross-format image motion compensation device were not operating properly, the degradation in resolution from center to edge could be as much as 160 percent.

Pointing errors can result from a variety of factors (malfunctioning star tracker; errors in precise location of the spacecraft; geodetic uncertainties with regard to the targets; misalignment between the tracking mirror and the Camera Optical Assembly, etc.) From all such sources, the MOL expects an average pointing error in the automatic mode of about

[redacted]

d. Tracking

Since the MOL camera system is a frame rather than a strip camera, the tracking mirror must track the target continuously during photographic exposure. To achieve [redacted] resolution, with all other essential elements of the camera system and spacecraft operating properly, the tracking rate error must be controlled to within [redacted]

Based on altitude and velocity data estimates provided the on-board computer, by ground sources, the tracking mirror rate error can be controlled to an average approximately [redacted] If the tracking rate error were this gross during photography, and all other essential elements of the camera system and spacecraft were operating properly, the resolution could be as poor as [redacted]. Thus, an on-board automatic Image Velocity Sensor is included in the camera system which, when operating properly, will provide the vernier adjustments to control tracking rate error to within the specified limit.

The Automatic Image Velocity Sensor, however, is a relatively high risk technology development. Three different approaches are being investigated -- at least two of which will be carried into prototype hardware.

In the DORIAN case there is an added factor which prohibits a complete test of the camera before launch. A valid dynamic test must include a realistic driving of the large tracking mirror during photographic operations, since the slewing of the mirror is the means of retaining the target image on the format, in contrast with the KH-7 and KH-8 strip cameras. Any test of the DORIAN mirror drive in the 1-g field would be completely different from the zero-g orbital condition. The validation of dynamic camera operation must therefore be performed on orbit, presenting another source of uncertainty.

THE SUPPORT MODULE

The components of the DORIAN support module generally are of a nature similar to those in the OCV and the reliability can be predicted to be about the same. The film handling system, however, may be a special case. For a 60-day lifetime, 6 or 8 recovery capsules should be included and the film path to fill these capsules will be more complicated than any experienced previously. The capsules themselves can be considered as mature. They will be the same as those in current use and the record shows that no failure to recover a capsule has occurred in over 100 of the last attempts. The transport of the film in a remote and unattended system will have initially some added susceptibility to failure or to a loss of at least part of the mission product. The initial system probability of success will be affected by this factor.

THE DORIAN SYSTEM

The previous analysis has examined the characteristics of each segment of an unmanned DORIAN system with the determination that no special difficulty would be expected either from the launch vehicle or from the orbital control segment. The support module is normal except for a capsule-loading film path which is more complicated than any ever tested before. Some loss of product during the early launch period may be expected from the film transport.

By far the most important segment from the reliability viewpoint is the mission module, primarily because of novel devices and because quality of photography is essential to mission success. Any of a number of components can perform out of specification to the extent that the mission must be classed as a failure. Regardless of rigidity of specification, the extent of ground testing or the number of back-up developments, there are unique conditions that can be experienced only on orbit and perhaps some surprises that will not be found until the launch program begins. The inability to perform dynamic testing, mentioned previously, is a significant contributor to the uncertainty.

In estimating the time to maturity, the schedule before the decision is made to perform the first launch may well be extended if it is thought that any of the automatic photography devices is not yet ready for remote testing. Beyond this period, the launch intervals have an uncertainty based upon the time necessary to diagnose failures and to correct them. If the orbital development process were to require about 15 launches, for instance, allowing for several delays, as long as five years could pass before it could be said that the system had reached maturity. With better success the number of launches could be less and the time could be shorter, but a ten-launch program seems truly to be the minimum that could be expected.

The course to be followed, then, in reaching maturity must be influenced strongly by these two fundamental goals:

1. The assurance of meeting the resolution standards established for the program.

2. The assurance of a significant quantity of intelligence product early in the program.

These considerations were material to the decision which has been made to follow the course upon which the MOL Program is proceeding. Some of its advantages as they relate to achieving maturity are listed in the concluding section which follows.

THE MOL LAUNCH PROGRAM

The five-launch orbital test program which has been approved is designed to take full advantage of the crew as an integral part of the plan to bring the DORIAN system to maturity. An especially important factor is the problem referred to above of making a positive diagnosis of the cause of a failure, with the shortening or elimination of costly stand-down times or perhaps avoiding a repeat failure in a subsequent launch. The system is designed so that the crew can enter the loop at any time for this function or as operators.

The crew's role in system development lies in three general areas. First, they can keep the manned vehicle operating on orbit for the maximum possible duration, thus permitting the obtaining of more operating data and more reconnaissance product. This is facilitated by their ability to operate the system in a degraded mode (thus circumventing many types of failure situations) and/or restore the system to a normal operating configuration often more rapidly than can be done from the ground. Second, the crew can perform health checks on various subsystems -- primarily in the camera/optical system area, but also for the Laboratory segment -- and directly assess performance. Third, in situations of either failures or out-of-spec performance, the crew can perform certain diagnostic functions to verify and supplement the telemetry provided to the ground. These diagnostic actions will, in many instances, permit the identification and isolation of the source of off-nominal performance quite rapidly as opposed to the extended analyses frequently required for unmanned vehicles.

The presence of the crew in the initial flights of the MOL system will, by virtue of their abilities to perform switching, maintenance, manual backup, and in particular, diagnostic functions in situations of failures or off-nominal performance, significantly contribute to an early maturing of the unmanned system. At the same time, the missions will simultaneously be gathering high-resolution photography of significant intelligence value.

Analyses of the kinds which have been summarized in this paper were influential in the decision to follow the manned route in the DORIAN system. The current reexamination, aided by the experience gained in the MOL development program and in other satellite programs, has clarified the nature of many of the problems bearing upon the attainment of maturity. They serve to reconfirm the validity of the manned system approach.

	4001	4002	4003	4004	4005	4006	4007	4008
Launch Date								
Planned	13Jul63	15Aug63	11Oct63	6Dec63	3Feb64	10Mar64	9Apr64	19May64
Actual	12Jul63	6Sep63	25Oct63	18Dec63	25Feb64	11Mar64	23Apr64	19May64
Incl. Angle								
Planned	94.46	94.2	99.96	97.7	95.8	95.8	103.5	101.0
Actual	95.34	94.36	99.19	97.88	95.6	95.69	103.5	101.1
Apogee								
Planned	115	169.3	184.0	145.0	123.0	123.0	206	210
Actual	115.65	165.75	183.0	155.0	124.4	126.9	210.6	190
Perigee								
Planned	115	101.9	99.0	85.0	94.0	94.0	81.5	92
Actual	108.05	101.5	81.0	77.0	95.3	98.8	83.9	57
Days on Orbit								
Planned	1	3	2	2	2	3	3	4
Actual	1	2	2	1	2	3	4	2
Total COMIREX Targets Reported by NPIC	3	10	4	0	0	143	209	52
Best Resolution/Range Achieved on Msn	10' - 15'	4' - 5'	4' - 5'	--	--	3'	2'6"	2'3" - 2'6"

~~TOP SECRET~~
Handle via BYEMAN
Control System

	4009	4010	4011	4012	4013	4014	4015
Launch Date							
Planned	30Jun64	22Jul64	26Aug64	30Sep64	26Oct64	10Nov64	16Dec64
Actual	6Jul64	14Aug64	23Sep64	8Oct64	23Oct64	4Dec64	23Jan65
Incl Angle							
Planned	93.0	95.5	93.0	96.7	95.5	97.0	102.5
Actual	93.1	95.5	92.9	----	95.52	97.02	102.53
Apogee							
Planned	184.0	200.0	147.0	151.0	169.8	172.5	169.9
Actual	180.6	176.5	157.0	----	175.07	192.57	174.42
Perigee							
Planned	85.0	84.0	85.0	88.0	84.0	85.5	83.2
Actual	83.0	84.45	85.0	----	81.69	85.43	79.9
Days on Orbit							
Planned	4	5	5	5	5	4	4
Actual	2	2	4	-	4	1	4
Total COMIREX Targets Reported By NPIC	0	105	240	0	0	37	688
Best Resolution Achieved on Msn	-	5' - 10'	8'	-	-	2'6"	2'6"

~~TOP SECRET~~
Handle via BYEMAN
Control System

5,6,1

"OCV PERFORMANCE"

G-1
951
"HITCH UP". Heat loss had depleted 4400 lb-sec of the 6300 lb-sec of stabilization thrust available at separation from AGENA on Vehicle 18. All gas lost on Rev 34 when valves went to high thrust mode. Command decoder inadventently turned off due to noise or "switch bounce."

G-2
952
"HITCH UP." While "hitched up" to AGENA it was noted that OCV control gas temperature was decreasing to point where solo OCV operation would be marginal. Recovery executed on Rev 34 and OCV "solo-ed." At pressurization of the pneumatic system all control gas was expended. Probable cause--cover left off a fuel valve in the OCV pneumatic system. Spurious real time command accepted by vehicle on Rev 14. Attitude control power supply lost on Rev 35.

G-3
953
"HITCH UP." Recovered on Rev 33. Solo after recovery. Some problems in proper roll rates due to switching anomalies "Prohibited modes" resulted in excess gas usage.

G-4
954
Successful recovery Rev 18 on lifeboat. No useful photographs. Vehicle unstable Rev 4 due to gyro heater malfunction over heating rate gyro which exploded. No L.B. telemetry due to problem during countdown.

G-5
955
Successful recovery Rev 34. No pictures. Error in commanding sequence on Rev 2 caused vehicle to drift in yaw. After slewing film forward cause of error found and corrected. Lifeboat failed on post-recovery test. Rev 65--clock recycle and delay time erase (Command System problem).

G-6
956
Successful recovery Rev 51. Roll maneuvers o.k. but impingement of gas on bulkhead gave vehicle thrust effect (high thrust only). Lifeboat failed on post-recovery test. Orbit Adjust engines show erosion effects.

G-7
957
Successful recovery on Rev 64, fourth day.

1. 4°-6° negative pitch error after Rev 41. Attributed by GE to short in the H.S. mixer box.

2. Flew low o.k.

G-8
958
Successful recovery Rev 34, after bad injection from AGENA.

1. Vehicle unstable Rev 15 due to IR Scanners losing horizon reference. Attributed by GE to bad

~~SECRET~~ [illegible] Control System

initial orbital environment.

2. Also thermal blanket tore, bound the TARS platform and perhaps reflected into H.S.

3. No useful photographs after Rev 15.

4. 10pps time signal failed on Rev 16.

5. Command readout failure--certain stored program commands were not executed after Rev 16.

6. On Rev 37 the telemetry did not turn on as programmed. By BUSS command telemetry revealed store program commands were not being executed. Attributed to programmer power supply failure due to high temperature.

G-9
959 OCV.

1. Recovered on Rev 34. No useful photography.

2. Vehicle lost lock from the beginning in the vicinity of the South Pole. Did not re-stabilize away from the pole.

   a. Causes of the instability:

      (1) Horizon Sensor "spooked" by cold environment at S.P.

      (2) Re-located "Roll Nozzles" reflected into H.S.

      (3) Thermal blanket at rear of OCV reflected into H.S. (if it expanded in vacuum due to trapped air).

   b. Fixes:

      (1) Operational procedure--turn off H.S. in vicinity of South Pole.

      (2) Re-locate "Roll Nozzle."

      (3) Restrain thermal blanket and reduce its reflectivity

3. A pressure leak on secondary propulsion system between Rev 32 and 34.

4. Wrench handle left in the R.V.

G-10
960 OCV.

1. Recovered on Lifeboat on Rev 66. (Attempted on 50 but failed due to Kodi problem).

2. No useful photos after Rev 23 due to command problems (started Rev 10).

3. SI--did not work after Rev 2.

4. Command Problem. Could not load stored program commands. Isolated to decoder and associated circuitry. Most probable cause--coaxil cable problems.

G-11 962 Successful recovery on Rev 67. Orbit adjust system malfunction during mission. Only 1 engine apparently burned. Also pressurizing gas leaked. SI worked fine. Soft photos.

G-12 961 No orbit. Agena burned less than one second. Agena engine received a shut down command. No SI on board.

G-13 963 Recovery capsule did not deorbit. Retro rocket did not fire. Destruct system worked.

G-14 964 Lost stability on Rev 9 due to power trouble.

G-15 965 Recovery on Rev 84. Mirror stuck in forward position on Rev 59 attributed to micro switch failure.

G-16 966 Recovery on Rev 81. Mirror stuck in vertical position on Rev 16. TM anomalies on Rev 63 and 64. Transmitter on but no data when first seen. Erroneous readings on secure word counter, environmental power turned off and pneumatic control system was in high thrust. Attributed to EMI from tape recorder.

IT	
[illegible]	Primary door actuator failed Rev 4. One 100 second focus test not executed due to G minute timer. Focus control malfunctioned by rev 31. Excellent photos. Two incidents: (1) mirror servo mechanical interference. (2) Buss test not successful due to ground system problem.
[illegible]	One delay line failed. Slightly reduced programming flexibility.
[illegible]	Short in 28 volt power system during Agena burn. Unstable. No payload functions