(S) NATIONAL RECONNAISSANCE OFFICE
WASHINGTON, D.C.

THE NRO STAFF

September 23, 1966

Dr. Flax:

I have reviewed the attached and have the following comments:

1. Page 4, Para 1: The statement "50 targets per day can be photographed" needs clarification. The Diamond Study indicated almost 2100 camera operations in 30 days (133 camera operations per day, about 2/3 of which were stereo.) The statement should indicate about 65-70 targets per day are expected to be photographed cloud-free.

2. Page 24: The statement that G-3 is scheduled for 8 development launches is a little bit misleading. We have described these launches to COMOR and USIB as development/operational suitability. Further, we have estimated (conservatively) that the operational product from these 8 R&D/OST launches will equate to at least half of the "take" from 8 mature systems and have scheduled G's accordingly. (In the first G-3, the total number of targets covered was about 40% of what would be expected from a successful 8-day G-3. I hasten to add that this was 100% of what was anticipated from the first mission--5 days of camera operations, with restrictions on roll angles and frequency of operation).

3. Page 26: The omission of any "contingency" funds in the MOL line of the accompanying chart on page 27 probably needs explanation. It appears a statement justifying this omission should be made on page 26 (i.e., detailed project definition, thus high confidence in cost estimates) needed on page 26.

The preceding comments are not significant--all in all, this appears to be a good supplemental summary.

JS

James T. Stewart
Brigadier General, USAF

Attachment
BYE 21229-66

MOL/DORIAN RECONNAISSANCE

SYSTEM

Introduction

The attainment of [redacted] ground resolution with a satellite photographic reconnaissance system represents a major technical achievement. The basic objective of the MOL Program is to deliver this performance utilizing the DORIAN optical photographic sensor. Of the many factors which contribute to, or affect, sensor performance, none is more elemental than the optical system design itself. The DORIAN sensor design is conservative, and draws on an extensive background of experience and state-of-the-art technology. However, the DORIAN sensor is very much larger than reconnaissance sensors we have developed previously, and translation of current experience and technology into the high performance required of DORIAN hardware is challenging.

2

Optical System Design

The camera type selected is a tracking frame camera, which produces a number of individual photographs of a desired scene, rather than the more familiar film strip typically used in previous reconnaissance systems. A frame camera permits reduction of residual image smear to smaller values than appears practicable with a strip camera of similar size. This in turn permits use of a much longer focal length lens, reducing the effects of film grain on image quality. A desired scene may be photographed from several aspect angles on a single overflight, improving the stereographic rendition of a scene at preferred angles. Several different exposure times for each scene can be programmed to improve the image in highlight and shadowed areas. As the image in a frame camera is stationary, rather than moving past a slit, use of automatic devices to detect and correct residual image motion, and to correct for off-axis geometric image smear is greatly facilitated. In manned flights, the stationary image also permits direct crew observation through the main optics.

The camera primary optical system is version of a Newtonian telescope, an inherently simple design. The Ross corrector lenses inserted in the light beam correct for residual abberations, and provide telephoto action to increase the effective focal length of the system. This telephoto Ross system is similar to the GAMBIT CUBED camera lens, and is capable of superior optical performance. Alignment, and focus tolerances are moderate.

Fused silica mirrors of lightweight design were chosen for both of the large mirrors in the optical system. Other materials, particularly CER-VIT, and to a lesser degree Pyroceram, were also considered. Although they offer promise for the future, these latter materials are not as thoroughly developed as is fused silica. Fused silica is clearly the lowest risk material, and it does deliver the required performance.

Aiming the camera and its optical system at a desired scene from a moving satellite is a problem of major proportions with cameras the size and weight of the DORIAN sensor. Rather than moving the entire satellite, or gimballing the entire optical system and pointing it at a target, a simple flat mirror was selected for the moving element of the system. This configuration closely resembles those of both GAMBIT and GAMBIT CUBED, except that the DORIAN flat mirror, rather than being fixed at pre-selected angles, actively tracks the ground scene so that the image at the film plane remains stationary. This design is simple, makes the most of our current experience, and simplifies access to the camera, its film supply, and film recovery devices.

The above factors establish the basic performance potential of the sensor. They result in a sensor design optimized for the attainment of [redacted] ground resolution, yet are within the reach of technology.

OPTICAL SYSTEM DESIGN

CAMERA	FRAME	– REDUCED SMEAR
		– VARIABLE STEREO
		– VARIABLE EXPOSURE
		– FLEXIBLE LENS DESIGN
		– STATIONARY IMAGE
LENS	TELEPHOTO ROSS	– SIMPLE DESIGN
		– GOOD PERFORMANCE
		– MODERATE ALIGNMENT TOLERANCE
		– MODERATE FOCUS TOLERANCE
MIRROR MATERIAL	FUSED SILICA	– STATE OF ART
		– LOW THERMAL INERTIA
		– LIGHTWEIGHT CONSTRUCTION
		– GOOD PERFORMANCE
AIMING METHOD	FLAT TRACKING MIRROR	– LOW MOVING MASS
		– SIMPLE DESIGN
		– EASY CAMERA ACCESS

MOL OPTICAL PAYLOAD

The DORIAN sensor is assembled into the MOL Mission Module, 35 feet in length and 10 feet in diameter, together with its basic supporting equipment. The camera (two cameras in the manned version) is supplied with 16,800 feet of film which is adequate to produce 15,000 frames of photography, as many as 12 per target, per 30 day mission. 60-75 cloud free targets per day can be photographed. Photographs have a round image format, about 9 inches in diameter.

Both the flat tracking mirror and the parabolic primary mirror are about six feet in diameter, and each weighs, even with lightweight construction, in excess of 1500 pounds. [redacted]

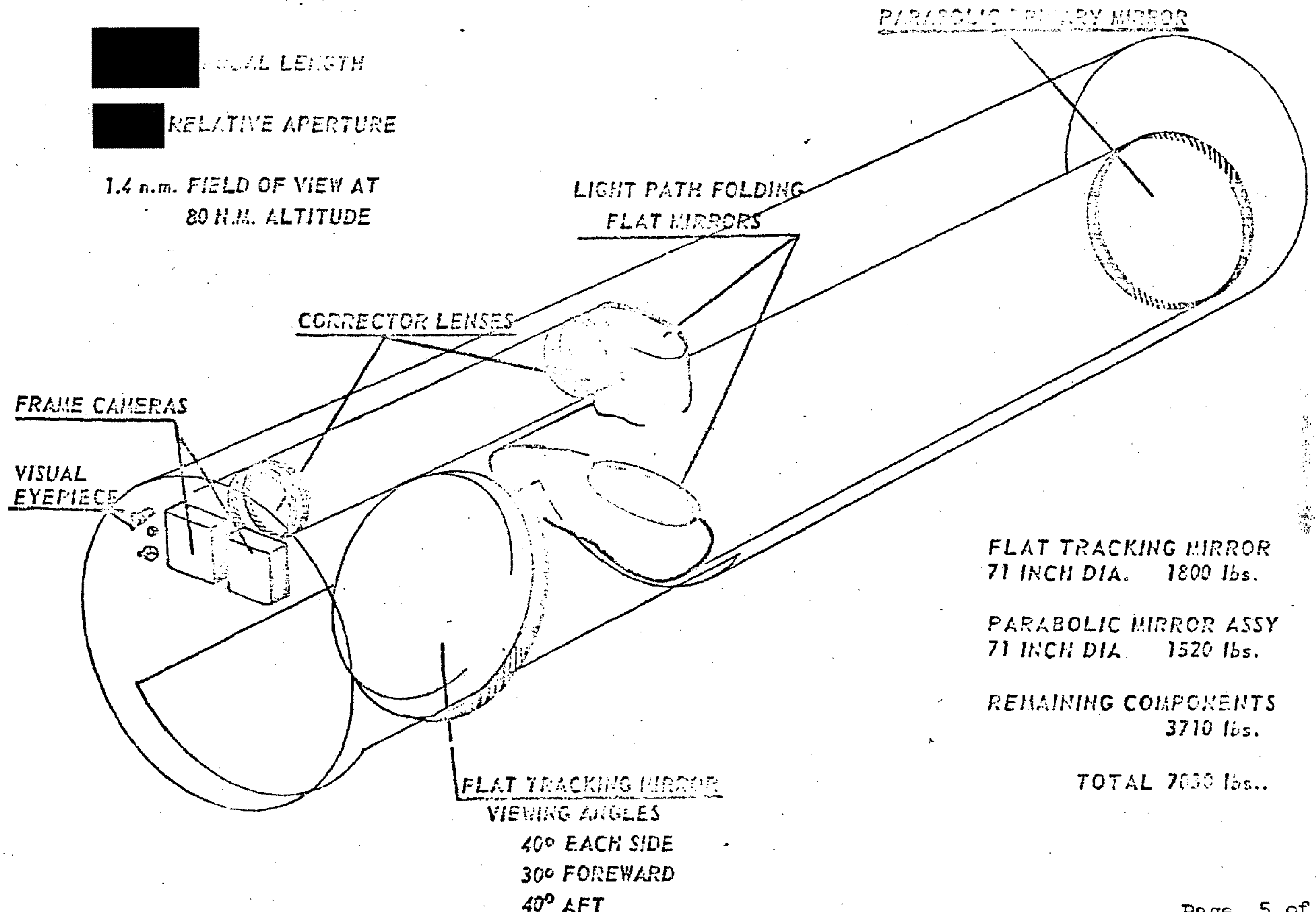
The basic resolution capability of the DORIAN sensor is established by the physical size of the major lens components and influenced by the design factors just discussed. The effective lens aperature, which is a function of the diameters of both the primary and tracking mirrors. [redacted] Best performance is obtained at the center of the field.

MOL PAYLOAD

[redacted]AL LENGTH

[redacted] RELATIVE APERTURE

1.4 n.m. FIELD OF VIEW AT
80 N.M. ALTITUDE



FLAT TRACKING MIRROR
71 INCH DIA. 1800 lbs.

PARABOLIC MIRROR ASSY
71 INCH DIA 1520 lbs.

REMAINING COMPONENTS
3710 lbs.

TOTAL 7030 lbs..

~~SECRET~~/DORIAN

RESOLUTION CONSIDERATIONS

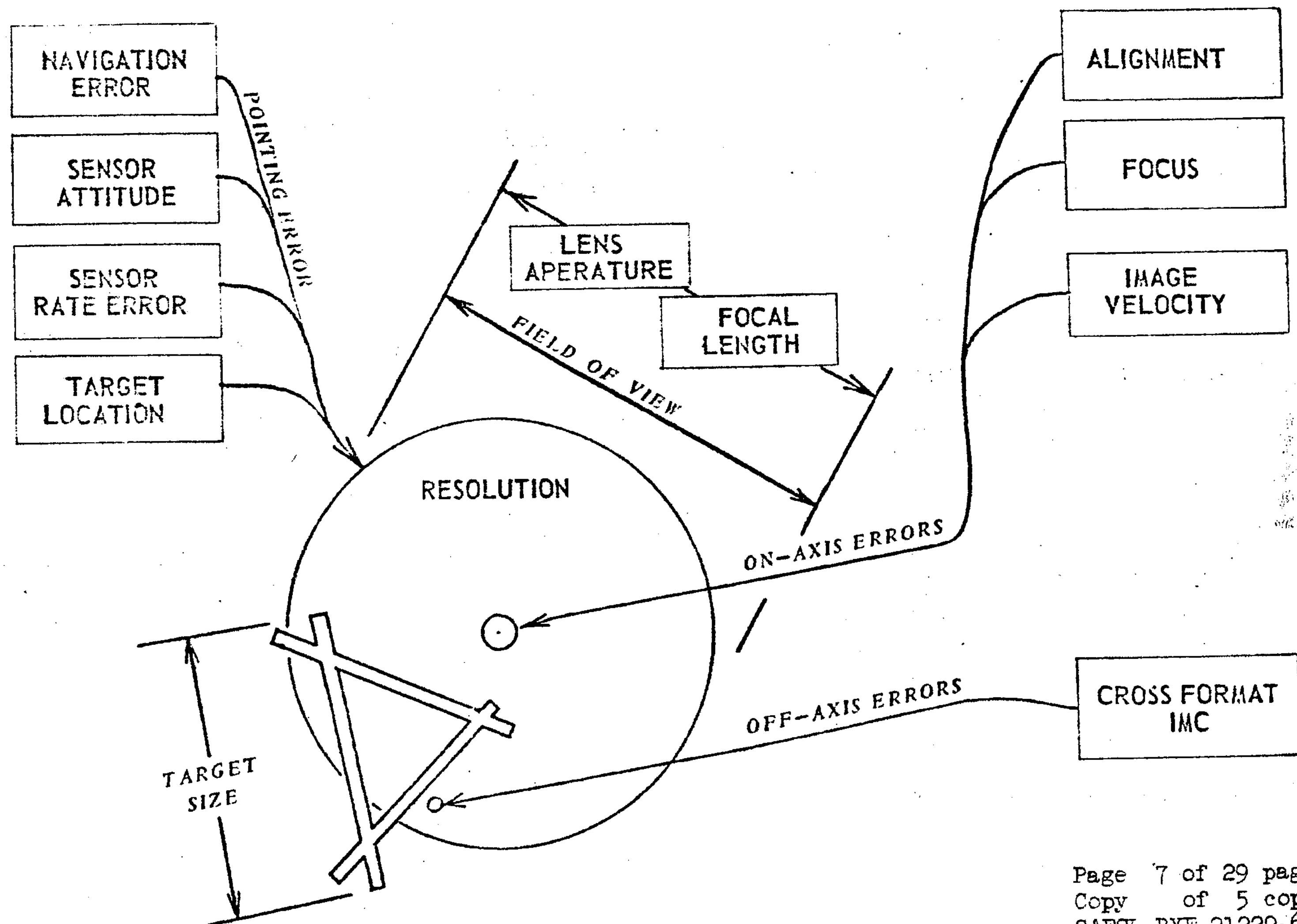
The physical design of the DORIAN sensor determines its static performance capabilities. When the sensor is used in orbit, other factors come into play in the determination of its dynamic performance.

To set up and maintain sensor performance in orbit, certain dynamic errors directly associated with the optical system and camera must be detected and corrected. These are principally on-axis errors caused by misalignments of optical components, by departure from best focus, and the image smear caused by residual motion of the image in the film plane due to differences in computed mirror tracking rates and actual tracking rates required. These errors occur continuously during flight, and must be continuously sensed and corrected. The basic optical system itself is used as a tool in performing these functions.

Sensor performance in orbit is also affected by Pointing Error, which is a combination of several different but interdependent errors, which result in displacement of the desired target from the center of the sensor field of view. Unlike the previous category of errors, Pointing Error is not a direct function of the basic sensor design, although the sensor field of view will affect its severity. It is largely due to effects external to the sensor itself, principally uncertainties in target location, in the exact location of the satellite in its orbit, and the precise attitude (and rate of change of attitude) of the satellite which carries the sensor. Target size, a fixed parameter, also influences the relative significance of the Pointing Error. For example, for large targets, it is important to keep Pointing Error sufficiently small so that none of the target falls outside of the field of view. Errors contributing to Pointing Error are most effectively minimized by careful vehicle system and ground navigation design and operation.

Another major error is due to smear across the entire format caused by geometric factors associated with location of the vehicle with respect to the target. This error is discussed further in the following pages.

RESOLUTION CONSIDERATIONS



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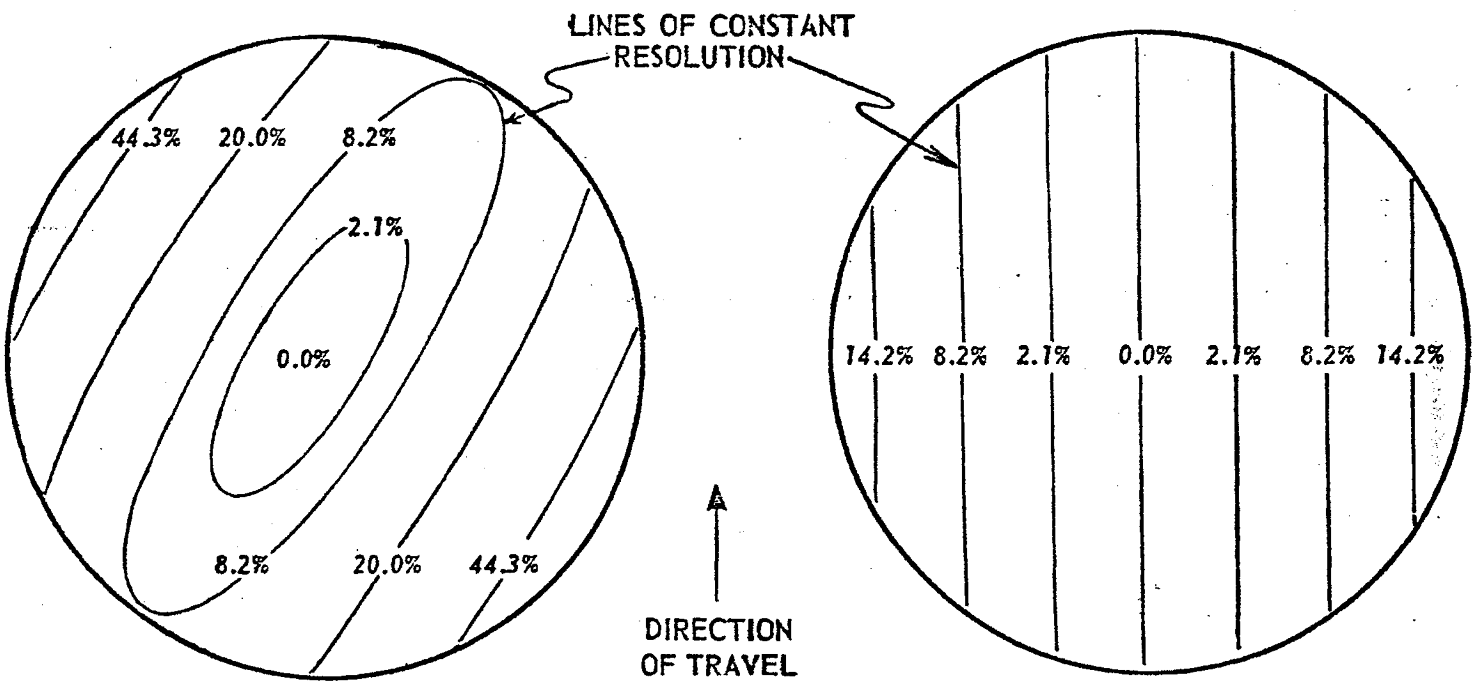
CROSS-FORMAT IMAGE SMEAR CORRECTION

Photographic images taken at oblique angles from the satellite will be subject to smear off the optical axis. That portion of a scene in the field of view farthest from the moving satellite will appear to move by at a slower rate than nearer portions of the scene. The image tracking sensor can compensate for motion at the center of the field of view, but cannot correct for the differential motion at the edges of the field. This will cause a fall-off of resolution toward the edges of the field of view which approximates 44% at moderate oblique angles of 20°. If a target cannot be placed with certainty in the center of the field of view, then additional correction must be provided. This can be done by adjusting the position of the slit in the camera's focal plane shutter, and, during the exposure sequence, rotating the camera platten to exactly match the differential image motion. This "cross-format" IMC device is intricate, and must be capable of exacting performance. However, its use results in a marked improvement in image quality for targets falling near the edge of the field of view.

CROSS-FORMAT IMAGE SMEAR CORRECTION

POINTING ANGLES: 20° OBLIQUE, 10° FOREWARD
DEPARTURE FROM ON-AXIS RESOLUTION, PERCENT



NO CORRECTION

SHEAR AND IN-TRACK
EXPANSION CORRECTION

PERFORMANCE REQUIRED FOR [redacted] RESOLUTION

A summary of the functions necessary to attain [redacted] resolution can be assessed in terms of the equipment needed to perform the functions, how well the functions must be performed, and the development risks involved. It becomes readily apparent that performance requirements for the automatic mode are quite demanding, and will require improvement over what current technology can provide.

In the past year considerable progress has been made in the evolution of technically feasible devices needed to produce photography at [redacted] resolution in the automatic mode. Although technically feasible, the development risk in producing flight worthy hardware remains moderately high, particularly for new devices for cross-format smear compensation, and image tracking. Also, the final performance capabilities of some devices, particularly the low drag accelerometer, will not be known until actual flight.

Departures from the performance required of the automatic devices add in a cumulative fashion. Hence all devices must perform to specification to produce [redacted] resolution. In the early development phases, crewmen can correct, or manually perform these essential functions while at the same time observing and analyzing defective equipment, so that remedial action can be taken for subsequent flights. This technique reduces overall development risk, and expedites the ultimate development of the automatic equipment.

PERFORMANCE REQUIRED FOR [redacted] RESOLUTION

FUNCTION	EQUIPMENT REQUIRED	REQ'D PERFORM AUTO MODE	REQ'D PERF. MANNED MODE	IMPROVEMENT REQ'D AUTO MODE	DEVELOPMENT RISK
TARGET AQUISITION	SCF	[redacted]	Cross track – 2.5 N.M. In track – 2.5 N.M. Altitude 1.0 N.M.	Factor of two	Low
Precision Navigation Pointing	Star Tracker		Not required	None	Moderate
Attitude Reference	Low drag accelerometer		Not required	Factor -≅Ten	Moderate
Image Tracking	Image velocity sensor		Aided tracking only required	New	Moderately high
Smear Correction	Cross-format Image smear compensator	50% reduction of smear at edge of field	Not normally required	New	Moderately high
Optical System Alignment	Automatic optical alignment system	Primary mirror [redacted]	Same	New	Moderately high
Focus	Focus sensor	[redacted]	Same	Factor of Two	Moderate

PROJECTED PERFORMANCE

The performance of the MOL vehicle with the DORIAN sensor can be described by a series of curves which plot the cumulative probability that photographs taken in a typical mission will equal or exceed a specified ground resolution. Referring to these curves, it can be seen that the great majority of photographs taken with either the fully automatic mode (curve 2) or the manned mode flown with the automatic equipment functioning (curve 1), will have ground resolutions of [redacted] These two curves are essentially the same, with a slight edge to the manned system due to a capability of crewmen to center targets in the sensor field of view. Curve 3 describes manned mode performance without help from automatic equipment, and again shows collection of the majority of photographs at [redacted] ground resolution. Curves 4 and 5 show successive degradation of performance which would result in the automatic mode with successive malfunctions of automatic equipment. During early development phases, crewmen aboard the MOL can substitute for malfunctioning equipment, and restore mission performance to the level of curve 3, thus insuring that the required level of performance can be maintained, until automatic equipment reaches the necessary level of development maturity.

[redacted]

GEOMETRIC MEAN GROUND RESOLUTION

BIMODAL SYSTEM CONFIGURATION

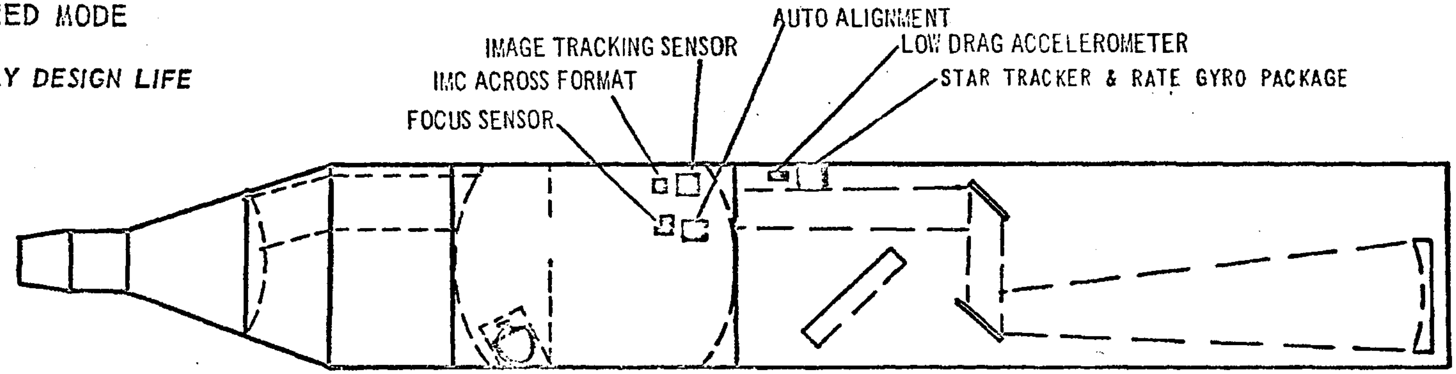
To insure that the [redacted] ground resolution objective is in fact obtained, it was considered prudent to develop MOL so that it was capable of operating in two modes - - completely automatically without crewmen aboard, and completely automatically with crewmen aboard, but so configured so as to permit crewmen to overcome malfunctions. The two modes, with the principal exceptions of life support, film handling and recovery, and design life-time in orbit, are essentially the same. Hence the problem observation and analysis performed by crewmen will, as intended, apply directly to the automatic mode.

When crew associated components, such as the Gemini B, are replaced by a conventional nose fairing, a series of data recovery capsules, and similar equipment, additional payload weight becomes available. This weight can be utilized for additional orbit sustenance fuel, and other consumables permitting the automatic mode to have a mission design lifetime of 60 days. In the automatic mode, an automatic film transport system is installed to feed exposed film to the data recovery capsules. In the manned mode, crewmen load the recovery capsules.

BIMODAL SYSTEM CONFIGURATION

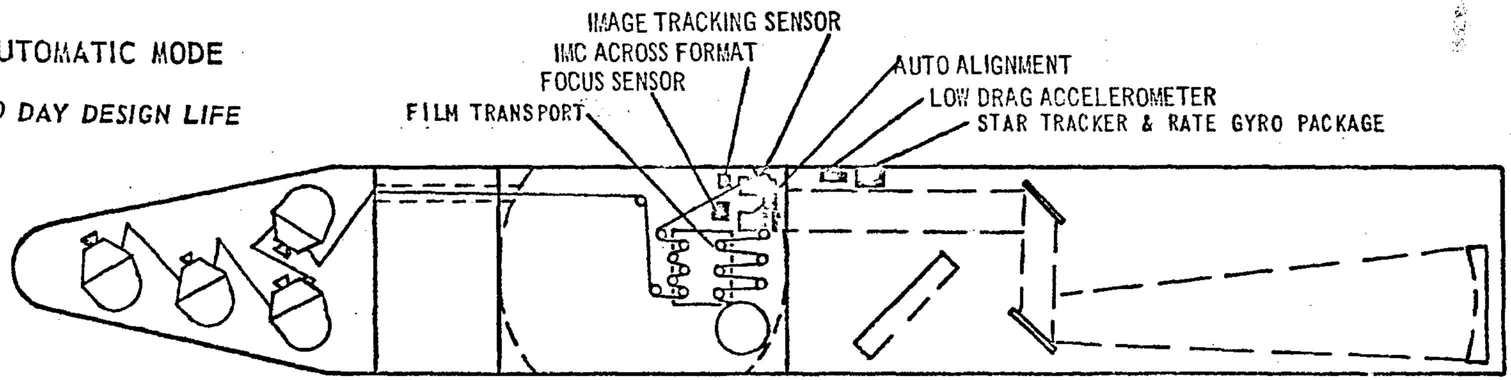
MANNED MODE

30 DAY DESIGN LIFE



AUTOMATIC MODE

60 DAY DESIGN LIFE



UTILIZATION OF MAN IN THE DEVELOPMENT PHASE

Man's utilization in the MOL development phase centers around three principal activities.

First. To preserve the quantity and quality of reconnaissance photography from the outset of the program. By being effectively functionally redundant, crewmen can perform the functions of most automatic equipment associated with mission photography.

Second. To preserve effective spacecraft performance throughout a full duration mission. Again through functional redundance, crewmen can avoid the necessity of early mission aborts by replacement, repair, or manually working around vehicle system malfunctions. In this sense crewmen also observe and analyze the nature and characteristics of malfunctions and failures, both in vehicle systems, and in sensor systems. The development process is accelerated through this activity, accompanied with a higher confidence that solutions to in-space difficulties will be effective.

Third. An experimental program to develop knowledge of how crewmen might improve quantity, quality, and reliability of photographic reconnaissance, and as well, to determine if use of crewmen would result in unique contributions to reconnaissance not otherwise attainable.

Ground simulations have shown that crewmen are definitely of direct mission value with respect to the first two points. Again, simulations lead us to conclude that man may also provide some unique values to intelligence returned, but experimental investigations in orbit would clarify and quantify this value.

UTILIZATION OF MAN IN DEVELOPMENT PHASE

- INSURE ATTAINMENT OF USEFUL RECONNAISSANCE CAPABILITY EARLY IN DEVELOPMENT PROGRAM

- AVOID EARLY MISSION ABORTS BY REPLACEMENT, REPAIR, OR MANUALLY WORKING AROUND MALFUNCTIONS

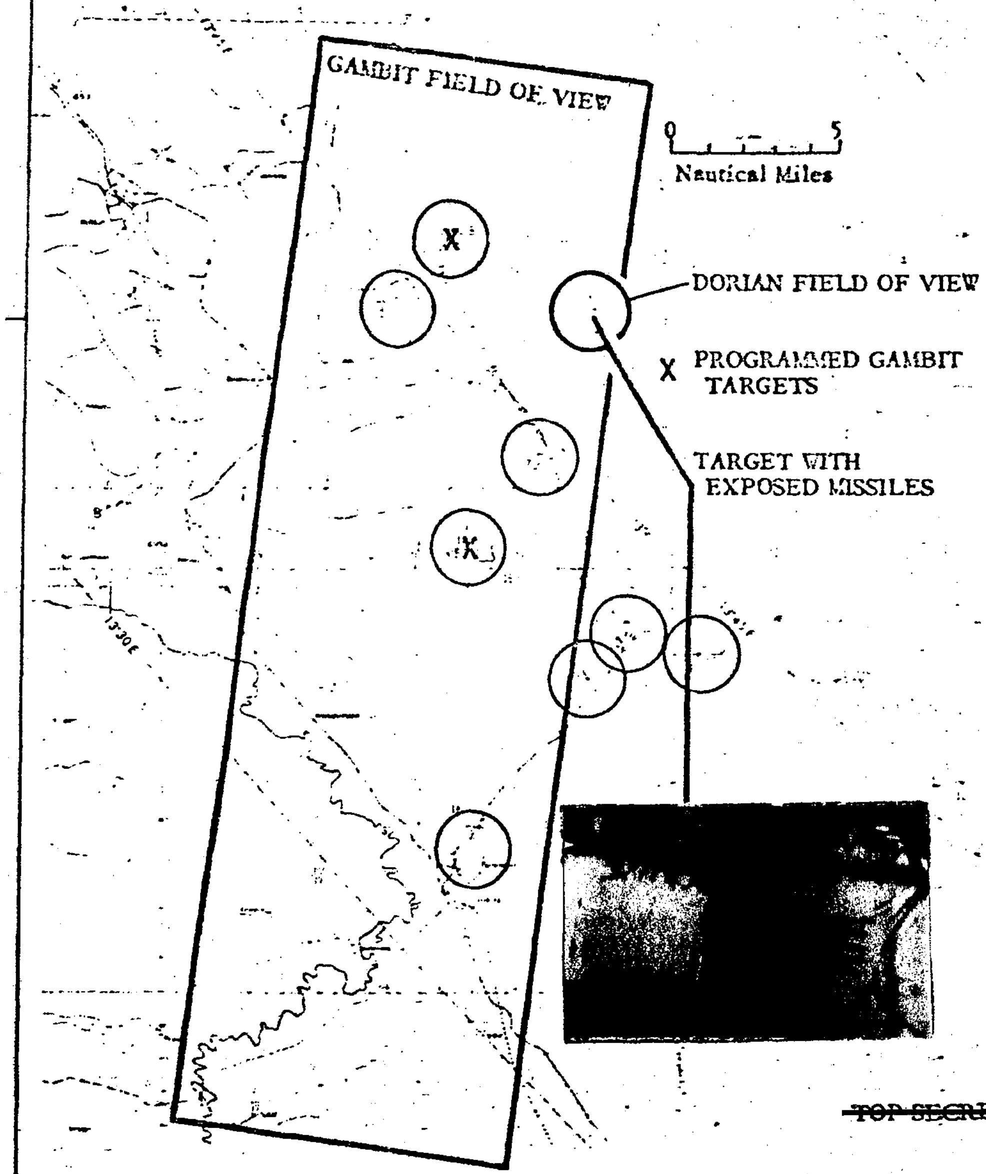
- EXPERIMENTAL INVESTIGATIONS INTO THE NATURE AND VALUE OF CRITICAL CONTRIBUTIONS OF MAN TO PHOTOGRAPHIC RECONNAISSANCE AND ENHANCEMENT OF INFORMATION CONTENT

DETECTING HIGH VALUE INTELLIGENCE

An example of a unique contribution which could result through utilization of crewmen is the examination of alternate targets ahead of the spacecraft. This technique becomes attractive because the DORIAN field of view is small compared with GAMBIT and GAMBIT CUBED.

The probability that additional or alternate targets will appear in the field of view is very low. Hence a premium is placed on the selection of targets of the highest intelligence value. Although preliminary studies show that about 70% of all targets can exhibit transient conditions which are of high intelligence value, these conditions will occur at only about 6% of the targets at a given time. These events are sufficiently rare as to render unlikely the possibility that they can be predicted for specific targets, and programmed for automatic photography. However, if crewmen were to examine alternate targets in the spacecraft's path, and interrupt the automatic photography sequence if a target of exceptional high intelligence value were encountered, a two to three-fold increase in the collection of this category of photographs would result over random encounter in the automatic mode. A recent GAMBIT mission illustrated here is shown with DORIAN fields of view overlaid on the targets collected in the GAMBIT film frame. The programmed GAMBIT targets are superscribed by an "X." They proved to be inactive. Two other unprogrammed targets did fall in the field of view. One of these contained intelligence information of inestimable value. As the inset shows, this particular photograph shows SS-7 missiles exposed on a soft Soviet ICBM site, and confirmed the suspected re-fire capability of these sites. This photograph would have been missed by the DORIAN sensor if the DORIAN sensor had photographed the pre-programmed targets only.

DETECTING HIGH VALUE INTELLIGENCE



TARGETS PROLIFERATE AT DORIAN FIELD OF VIEW

OPERATORS INSPECT ALTERNATE TARGETS

SIMULATIONS SHOW THE INSPECTIONS CAN BE DONE

70% OF ALL TARGETS INCUR TRANSIENT CONDITIONS WHICH EXPOSE HIGH VALUE INTELLIGENCE

MANNED MODE CAN PRODUCE 200% TO 300% OF THE OUTPUT OF SUCH PHOTOS BY RANDOM ENCOUNTER IN THE AUTOMATIC MODE

OTHER MANNED FUNCTIONS

Other functions which may be enhanced, or uniquely performed by crewmen have been studied, and will be subjected to experimental evaluation in orbit. Most of these functions are directly related to increasing the value of, or the timeliness of, intelligence returned. A specific activity of this nature is the selection of particular photographs for processing aboard the vehicle, and transmitting by radio link the intelligence bearing portion of the images to the ground.

The vehicle, in orbit, is immediately available for special surveillance activities during crisis conditions. The orbit altitude can be altered to cause, for example, the entire Sino-Soviet land mass to be brought under surveillance in a repeating 3 day cycle. Crewmen aboard, can be highly responsive to specific intelligence needs in rapidly developing situations where pre-programming may not be possible.

An alternate and interesting intelligence mission, which could be accomplished in the manned mode and without interference to the basic reconnaissance mission, [redacted]

Another aspect of the utilization of crewmen lies in visual reconnaissance. The values of this activity are very difficult to quantify at this point in time. Yet the human eye is capable of grasping much information which cannot be captured on film. Even simple functions such as color discrimination or counting, performed simultaneously with the programmed reconnaissance activities may have considerable value for detecting changes in order of battle, or in establishing levels of activity in particular target areas. A carefully devised experimental program is being developed to investigate the value of this technique.

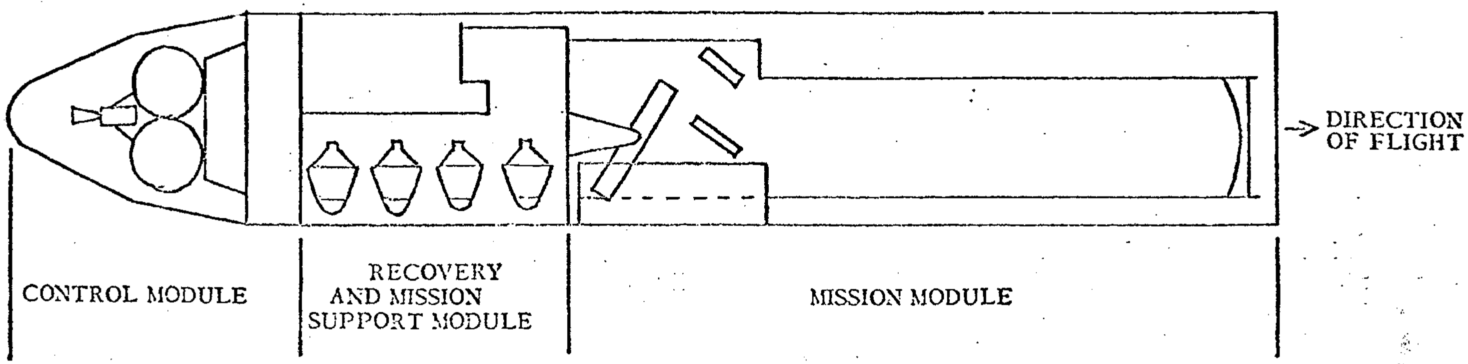
OTHER MANNED FUNCTIONS

- FINDING MOBILE AND TACTICAL TARGETS
- SELECTING PARTS OF PHOTOS FOR QUICK-RESPONSE READOUT
- LOADING COLOR FILM AND OTHER SPECIALIZED FILM
- SURVEILLANCE IN CRISIS CONDITIONS
- VERIFYING TARGETS HAVE BEEN PHOTOGRAPHED
- SELECTING CLOUD-FREE TARGETS
- [redacted]
- CHOOSING VIEW ANGLE REVEALING MOST INTELLIGENCE
- INSPECTING, INCIDENTAL TO OTHER FUNCTIONS, MANY MORE TARGETS THAN CAN BE PHOTOGRAPHED.

WHOLLY UNMANNED SYSTEM

The configuration shown schematically is one of several which resulted from a two-contractor (General Electric and Lockheed) study funded in response to the March 21, 1966 letter from the Director of the Budget. Although MOL is designed for a completely automatic mode of operation, Mr. Schultze's request was for a costing exercise on an independently-developed unmanned system. For study purposes, the DORIAN mission module was taken as government-furnished and it was assumed that all the critical automatic devices would function with the necessary precision. The tabulation shows a 30-day and a 60-day configuration. The 60-day design life was judged to be superior from the standpoint of economy and is the version most comparable to the MOL automatic mode, which also can achieve 60 days active orbital life. The 60-day wholly unmanned system would employ a 7-segment Titan IIIC.

WHOLLY UNMANNED SYSTEM



	T-III C, 5-SEG SRM	T-III C, 7-SEG SRM
DESIGN LIFE	30 DAYS	60 DAYS
WEIGHT ON ORBIT	21,000 pounds	32,000 pounds
DATA RECOVERY VEHICLES	4	6 TO 8
DEVELOPMENT LAUNCHES	10	10
DEVELOPMENT COST	$1131 MILLION	$1503 MILLION
RECURRING COST	45.5 MILLION	58.5 MILLION

REACHING PROGRAM MATURITY

The cost estimate for developing an unmanned system is based upon a 10-launch orbital test phase. MOL is scheduled to have only 7 launches, including the first two unmanned booster and GEMINI B reentry tests. The prediction of a greater number of unmanned test launches is supported by past experience. By comparison, GAMBIT CUBED, a much simpler design, is scheduled for 8 launches for development/operational suitability testing. These 8 launches are expected to produce an operational product equating to at least half that which would be produced by 8 mature GAMBIT CUBED systems. The first launch of the unmanned system would be paced by the mission module delivery date and the test program would continue for more than a year beyond the MOL schedule.

REACHING PROGRAM MATURITY

UNMANNED SPACECRAFT:

- IN ORBITAL TEST PHASE, EXPECT SOME FAILURES EARLY IN THE MISSION
- EXPECT SUCCESS RATIO TO GROW TO 70% IN 10 LAUNCHES

MANNED SPACECRAFT

- RELATIVELY HIGH SUCCESS RATIO FROM BEGINNING

NUMBER OF DEVELOPMENT LAUNCHES:

- MOL: 7 LAUNCHES, INCLUDING 2 BOOSTER QUALIFICATION, 3 MANNED, 2 AUTOMATIC MODE
- UNMANNED: 10 LAUNCHES

COMPARATIVE SCHEDULES:

	CY 69				CY 70				CY 71				CY 72			
MOL		B	B	M	M	M	A	A								
UNMANNED				A	A	A	A	A	A	A	A	A	A			

B=booster M=manned A=automatic

DEVELOPMENT COST COMPARISON

The major expense items in MOL above the cost of unmanned systems are the laboratory module and the GEMINI B. The total unmanned mission module cost figure is higher because of the greater number of launches. The control vehicle, replacing the laboratory, would be an important development task. The figures on this chart constitute the comparison requested by the Director of the Budget. Our confidence in the accuracy of MOL cost figures has improved as a result of Contract Definition activities, hence no contingency figures are shown.

DEVELOPMENT COST COMPARISON

	30 – DAY Wholly Unmanned (10 LAUNCHES)	60 – DAY Wholly Unmanned (10 LAUNCHES)	MOL (7 LAUNCHES: 2 Booster, 3 Manned, 2 Unmanned)
LABORATORY OR CONTROL VEHICLE	235	370	720.4
MISSION MODULE	532	532	426.8
GEMINI B	–	–	216.5
BOOSTER	183	340	312.0
OTHER SYSTEMS	30	63	31.0
SUPPORT	17	30	48.1
HEAT-SHIELD TEST	–	–	22.5
MILITARY CONSTRUCTION	31	31	40.7
CONTINGENCY	103	137	–
TOTAL	1131	1503	1818.0

SUMMARY

The principal points which have been discussed are summarized here. The detailed work of the past year has added confidence that the [redacted] objective can be achieved, resulting from the concentrated attention which has been directed toward the major technical problems. It will be remembered that early in the MOL planning stages some experienced contractors expressed considerable doubt that an optical system of the desired performance could be built. Such doubts no longer exist. A similar effect on automatic system design has been noted in which increased attention during the past year has been productive in the evolution of concepts for new devices for correction of focus and image motion errors.

The results of the cost study just completed show that the cost differential between MOL and an unmanned system comparable to MOL automatic mode is in conformity with the previous estimate ($300 - $400 million) made in the August 24, 1965 Memorandum for the President.

SUMMARY

1. THE MOL PROGRAM IS PROGRESSING WITH THE DEVELOPMENT OF A [redacted] RECONNAISSANCE SYSTEM

2. THE [redacted] OBJECTIVE CAN BE ACHIEVED WITHIN THE PROGRAM SCHEDULE.

3. DURING THE PAST YEAR, PROMISING DESIGN CONCEPTS HAVE EVOLVED FOR AUTOMATIC-MODE DEVICES.

4. THE MANNED MODE HAS THE POTENTIAL TO:
   - A. EXPEDITE DEVELOPMENT OF AUTOMATIC DEVICES
   - B. REDUCE THE NUMBER OF DEVELOPMENT LAUNCHES
   - C. INCREASE INTELLIGENCE PRODUCTION DURING DEVELOPMENT PERIOD
   - D. INCREASE THE VALUE OF THE INTELLIGENCE

5. THESE FACTORS WILL BE EVALUATED IN THE MOL PROGRAM

6. THE MOL COST ESTIMATE IS $1.82 BILLION. A SEPARATE UNMANNED SYSTEM COMPARABLE TO THE MOL AUTOMATIC MODE COULD BE DEVELOPED FOR $1.5 BILLION. THE PRICE, THEREFORE, OF CONTINUING THE DUAL OPTION IS ABOUT $320 MILLION.