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SUPPLEMENT TO THE 9 JUNE 1966 REPORT

OF RE-ENTRY VEHICLE STUDY FOR

THE HEXAGON SYSTEM

31 MARCH 1967

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SECTION I

INTRODUCTION

1. Reference

a. Memorandum for General Martin from Dr. Flax, 30 April 1966, Subject: Implementation of HEXAGON Development Program.

b. Report of Re-Entry Vehicle Study for the HEXAGON System, 9 June 1966.

c. The forwarding letter to ref. b; General Martin to Dr. Flax, 16 June 1966.

d. WHIG Msg 5832 from Dr. Flax to General Martin; Subject Hexagon, 21 Oct 1966.

e. CHARGE Msg 4908 from Hexagon SPO to WANDO, 18 February 1967.

f. WANDO Msg 5125 from Col Howard to Col Buzard, 24 February 1967.

2. The number of Re-entry Vehicles for the Hexagon System has not been established as yet. Ref b. covered the technical and operational aspects available at that time pertaining to the optimum number of RV's; however, no recommendation was made. This report updates ref b. and includes information from the bidders responses to the Hexagon System RV request for proposal and recently completed analysis relating to Sensor Subsystem performance, cost and schedule, for the 2 vs 4 RV configuration.

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Section II

CONCLUSIONS

1. There are operational considerations which clearly require 4 RV's.

2. There are no technical considerations which rule out the 4 RV configuration.

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Approved for Release: 2018/11/08 C05115735
Unclassified

SECTION III

DISCUSSION OF FACTORS CONSIDERED

1. Summary

The effect of RV size on design considerations, on the recovery force, and on RV handling was investigated. In addition the effect of RV numbers on the system operational effectiveness, on the SS design, and on System reliability was analyzed.

It was found that the difference in RV size between a 2 and a 4 RV configuration is not a significant factor. The differences in system reliability between the two configurations is too small to influence the decision on numbers of RV's.

The only factors on which a decision can be based are operational considerations. These considerations require four RV's.

2. Re-entry Vehicle Design Considerations

The RV RFP requested proposals for RV's capable of returning from orbit 2100 pounds of film in either two or four RV's. Tables 1 and 2 are based on the bidders response to the RFP. Included in Table 1 are all the components that do not depend on RV size and would be identical for either size RV.

TABLE I

ITEM	WT-LBS
Electrical Power & Distribution System	45
Tracking, Telemetry and Programmer	29
Recovery Aids	20
Miscellaneous Hardware	15
Total Common Items	109

Table 2 contains those items which are a function of Vehicle size and will be discussed below.

TABLE 2

ITEM	WT PER RV - LBS 4 RV/SV	2 RV/SV
Structure	152	281
Propulsion	163	278
Spin Stabilization	32	53
Heat Shield	84	137
Parachute Subsystem	66	106
Total Wt Dependent on Size	497	855
Payload Wt*	555	1120
Total From Table 1	109	109
Total RV Wt per RV	1161	2084
Total RV Wt per SV	4644	4168

*This weight includes the film and light weight take up reels. The design concept used for these weights has all non-orbit loads transferred from the film directly to the RV cannister and support structure. With this concept the reel flanges are used primarily as film guides and are not required to carry large loads. Current weight estimates from the SSSPO are based on a design in which the reel flanges carry all film loads. This results in take ups which weigh 122 pounds more for the 4 RV and 130 pounds more for the 2 RV configurations. The total RV wt per SV would then be 5132 pounds for the 4 RV's and 4428 pounds for the 2 RV's. The SPO feels that after the RV contractor is selected, the finished designs will be close to the weights given in Table 2, consequently these weights were used to compare the 2 and 4 RV configurations in the study.

Structure - The structural design and testing requirements between the two configurations are essentially the same. The primary structure for either configuration will be Titanium and Aluminum. The heat shield substructure will be a fiberglass phenolic honeycomb sandwich. These materials have been used in many space applications and it is not anticipated that either configuration will present unique or difficult design, testing or production problems.

Propulsion - The propulsion subsystem for either configuration will be a single solid-propellant rocket motor. This motor will have a spherical case, a polybutadiene propellant, and pyrogen igniters. Off the shelf rockets of the proper size do not exist for either configuration; however, either motor would be a scaled version of existing flight proven motors. Neither configuration should present unusual problems.

Spin Stabilization - either configuration will use a cold gas spin - despin system. This concept is presently used on 846 and the difference in size between 846 and either of the configurations does not present a problem.

Heat-Shield - the heat shield for either configuration will be ESM. Similar materials have been used on Gemini and Apollo. The design, development, testing, and manufacturing problems are not considered difficult for either configuration.

Parachute Subsystem - the weight of both configurations is sufficiently different from existing systems that a new parachute will have to be developed. The type of parachute used, the development program required and the associated risk will be the same for either configuration.

In summary, there are no technical areas of RV design and development that suggest one configuration is better, or has less risk, than the other.

2. Re-entry Dynamics Considerations

All of the RV proposals had the axis of the take up reels perpendicular to the RV axis. This arrangement is best considering film path but causes the RV center of gravity to shift off of the RV axis when one reel has more film on it than the other. The effect of uneven RV loading on the RV dynamics and dispersions was included in the bidders response to the RFP. It was found that with one reel full and the other empty the resulting C.G. offset did not cause RV instability and dispersions were within the allowable box for either the 2 or 4 RV configuration.

3. Recovery Force Considerations

It was assumed that the recovery force available in the time period in which Hexagon will be operational will have capabilities at least as great as the present recovery force.

The 9 June 1966 Report contains a detailed discussion of the present capabilities of the recovery force aircraft. The conclusion reached at that time was that either RV size could be handled in a routine manner. Nothing has happened since then to change this conclusion.

4. Handling Considerations

The relative size of the 2 RV and 4 RV configurations is given in Figure 1. The size and weight of either vehicle is such that they can not be handled and transported without the aid of handling gear and hoists. Although a smaller RV is easier to handle, the difference between a 1161 lb and a 2084 lb RV are not considered too significant.

5. SV Considerations

The only significant effect on the SSA design between a 2 RV and a 4 RV configuration is that the 4 RV configuration will weigh approximately 150 pounds more. Also, a 4 RV configuration will increase the SS weight, excluding take ups, by 160 pounds. These weights added to the Total RV Wt for 4 RV's makes the SV weigh 790 pounds more.

6. Cost Considerations

The cost of the 2 RV and the 4 RV configurations is presented in Table 3.

TABLE 3

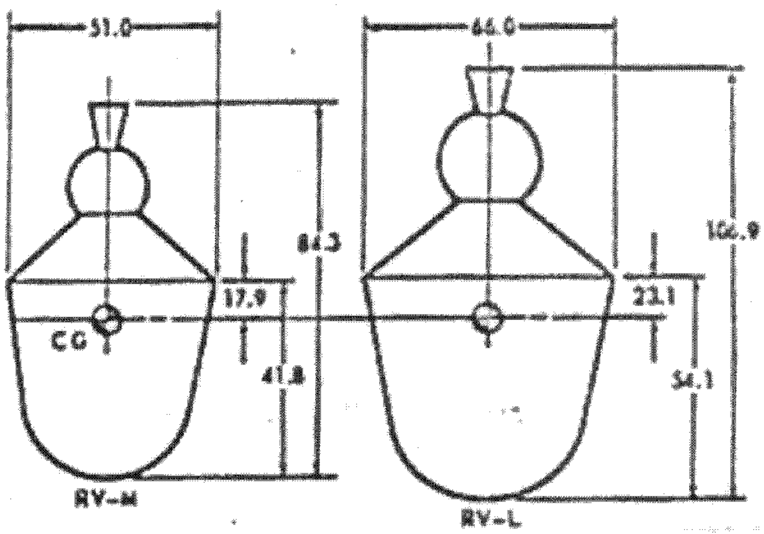
COST COMPARISONS

IN MILLIONS

	Non Recurring Costs	*Unit Cost/RV	*Unit Costs/SV
2 RV/SV	24.01	.78	1.56
4 RV/SV	23.31	.49	1.96

*The unit costs given here are average cost for 30 launches.

RV PHYSICAL DATA



4 RV CONFIGURATION 2 RV CONFIGURATION

		RV-M	RV-L
	Frontal Area (Ft^2)	14	24
Heat Shield	Wetted Area (Ft^2)	37.2	62.4
	Material (Ft^3)	33.7	72.9
	Weight (Lb)	1161	2034

Shape Modified Discoverer

FIGURE 1

7. Operational Considerations

All of our experience since the first successful CORONA recovery demonstrates that in time of crisis the intelligence community wants to collect information for the decision makers by means of satellite photography. At such a time little thought is given to whether or not the satellite system was designed for that particular mission. The only question is, "Can the mission be accomplished?" Thus we have had requests for CORONA and GAMBIT missions in 62 and since to cover Cuba, in 64 and 65 to cover South China, and in 65 and 66 to cover Lop Nor. Many times these missions were requested on a crash basis because the information was urgently needed for special studies or because the information was believed to be perishable. It seems reasonable to expect that the HEXAGON Search and Surveillance system will also be employed on special missions that are not presently conceived as part of the HEXAGON mission. Examples of the types of special missions which might be expected are included in the flexibility discussion below.

Since the HEXAGON System is to be both a Search and a Surveillance system there are two basic requirements which must be considered when evaluating the merits of a 2 or a 4 RV configuration. The first, Flexibility, comes primarily from the surveillance mission; the second, Efficient Film Use, is a requirement of both Search and Surveillance. These two requirements will now be discussed in detail.

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Flexibility - A surveillance system requires the ability to obtain timely information relative to changes that occur in a given target area in a short period of time. This information might include the massing of troops at a particular point, the movement of men and equipment into a given area, the launch of a satellite or space probe, the detonation of a nuclear device, the confirmation of a disaster (man made or natural), or the extent of civil disorders such as riots and civil war.

An example of massing of troops and/or the movement of men and equipment might be the massing of a force in a staging area in China near North Vietnam prior to the Chinese directly entering the Vietnam conflict. Another example might be the movement of troops to and along the Chinese-Russian border which might indicate a start of hostilities between them. Another might be a build up of men and equipment in Eastern Europe which might indicate an attack along the iron curtain boundary. The C-5 aircraft will give the capability during the Hexagon life span to airlift forces quickly to any place on the globe; consequently, timely information on the need for troop deployment is required. Timely knowledge of a future troop build up at some particular point, followed by the rapid deployment of a counter force might prevent the initiation of a military action by some hostile government or at least the success of such action might be prevented.

In the case of a one-time-event such as a space probe, the detonation of a nuclear device or the occurrence of a disaster, it is important to obtain a limited amount of photography, return the exposed film, and then proceed with a normal mission with the remaining film. Obviously, the timely return of this one-time-event information, with minimum perturbation to the normal mission, requires the use of several RV's. For example, it might be expected that during the mission an important event is to take place, but the exact time of the event is unknown. The mission would proceed normally until the event occurred and then recover immediately. If this happened when an RV was only partially filled, there would be an amount of film represented by the unfilled portion which would be wasted. In this case, the smaller the RV and the more frequent the planned return, the less film is wasted. If it was decided not to waste this film, the return of the RV would have to wait until it was full, in which case a small RV would permit more timely return of the film. A somewhat similar situation might be presented if a disaster such as the accidental detonation of a nuclear warhead or test device should occur within the Sino-Soviet Block. It is conceivable that rapid information on the exact place and damage caused by such a catastrophe might be very important. Five 30 day missions a year means that there is a 41% probability that there will be a vehicle in orbit at the instant an unexpected one-time-only event occurs. If the typical mission is longer, this probability is even greater.

For some events, such as a Russian moon launch, an approximate date of the event might be available but a closer estimate desired. This would entail returning the film before the event took place. The mission might then be continued in a normal manner until the event actually occurred. The film would then be recovered and, if there were film and RV's available, the normal mission continued.

In the case of a crisis it is important to obtain daily information on such items as massing of troops, civil disorder, or an international confrontation so that any action taken by our government can be based on reliable information of the present status of an opposing force. This clearly requires as many RV's as possible. The Cuban Missile Crisis is a representative case in which constant photographic reconnaissance was required. Fortunately, in the Cuban Crisis the photography could be obtained by aircraft, but it is certainly possible to visualize a situation in which, either by deliberate action or location, it would be impossible to obtain the required photography by aircraft. Also in the case of such a crisis it might be a requirement to have frequent return of information on the strategic posture of the Sino-Soviet Block and any change in that posture which might indicate an escalation of the crisis.

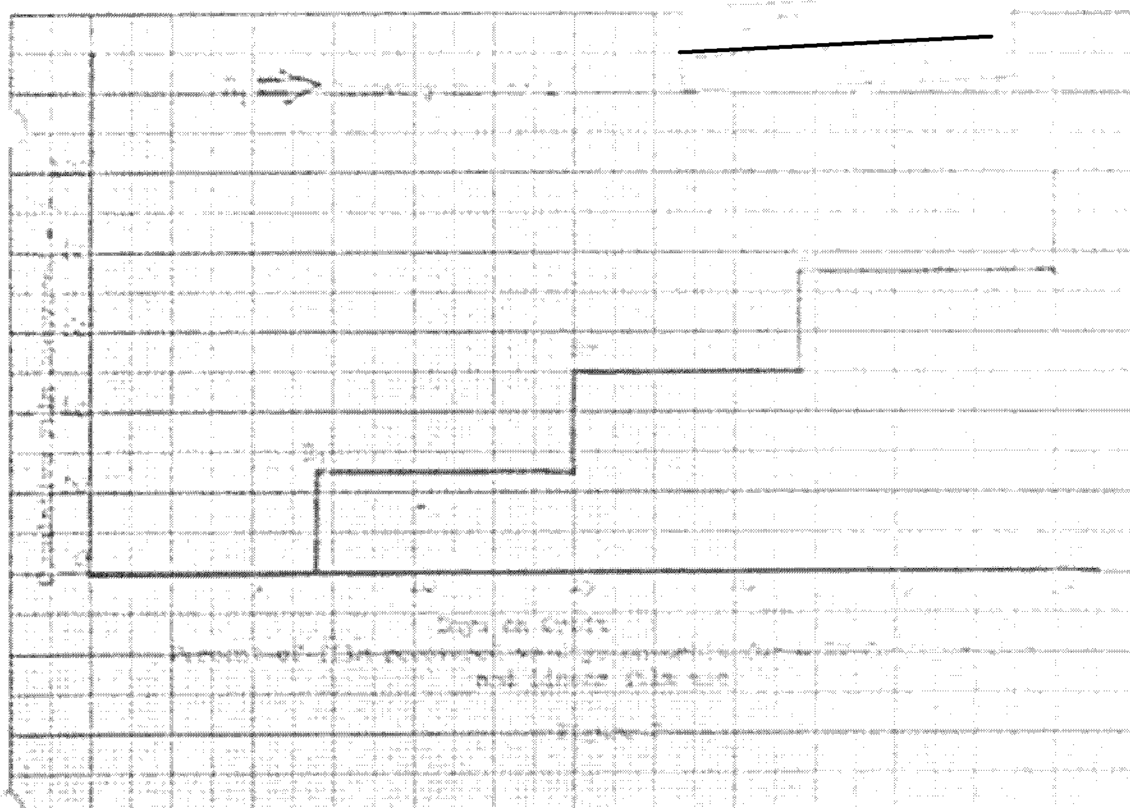
The recent civil disorder in China represents a situation in which frequent return of film might have proved extremely useful. If these riots had proceeded to the civil war stage, continuous and timely photographic surveillance of China would have provided information on which to base U.S. actions. The China - Russia rift is potentially another situation in which frequent return of film may be required.

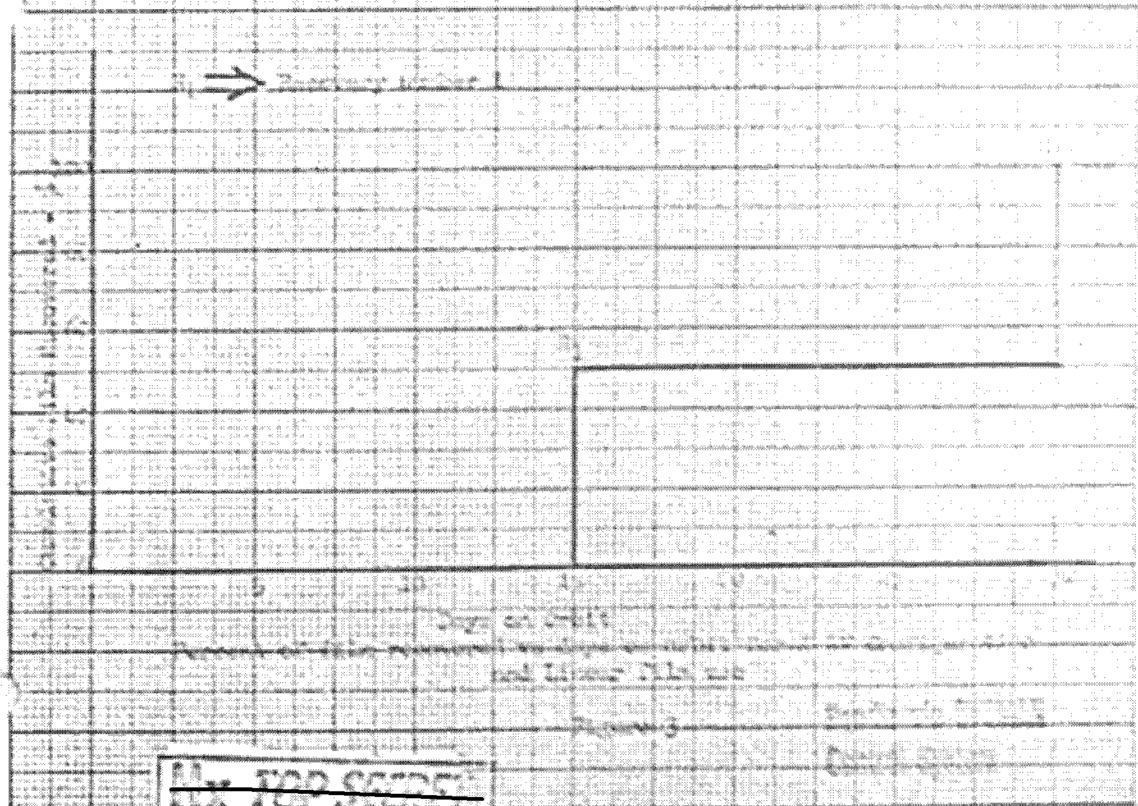
It is difficult to catalog today all the possible uses of the Hexagon system. Certainly, as the world situation changes, the requirements which the Hexagon system will have to satisfy will change. An examination of aircraft missions of the present and recent past illustrates this, i.e. the B-52 dropping conventional bombs, the B-47 performing low altitude

"Toss Bombing," or the C-47 performing an attack mission.

An example of an unexpected requirement for the Hexagon system might be the search for the landing area of an Apollo or MOL vehicle which was forced down in an isolated or unfriendly area because of some emergency. Aircraft, of course, would be dispatched to search for the vehicle, but this might take considerable time and aircraft search is not always successful, particularly in mountainous jungle areas. Use of the Hexagon system might be the quickest way to locate the downed vehicle, particularly if the Hexagon system were already in orbit. If the vehicle went down in an unfriendly area such as China, the Hexagon system might be the only means available to determine the status of the downed vehicle and its crew.

Figures 2 and 3 illustrate the amount of film recovered as a function of days on orbit for either a 2 or a 4 RV configuration with constant film use. Figures 4 and 5 cover a more efficient film use and include the ability of returning the S.I. film in the last RV. Tables 4 and 5 give a comparison of the age of the oldest recovered exposed film for each RV. The average age of exposed film for the 4 RV configuration is one half the average age for the 2 RV configuration. These figures are for a 30 day mission. For a 45 day mission the times would increase proportionately. It is evident that if timely return of exposed film is important, 4 RVs are better than 2.





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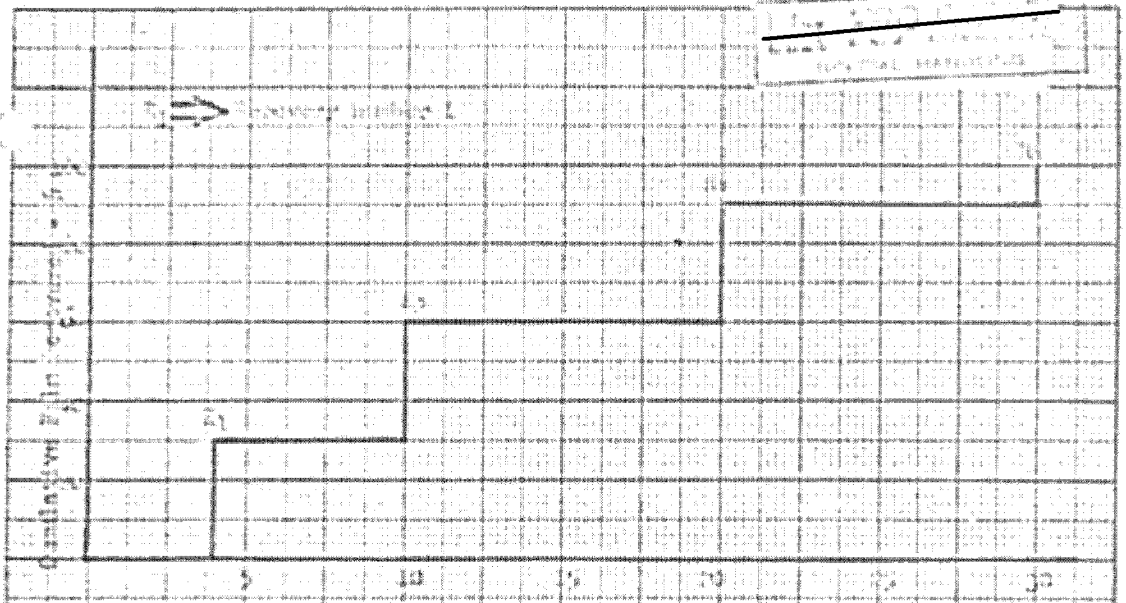
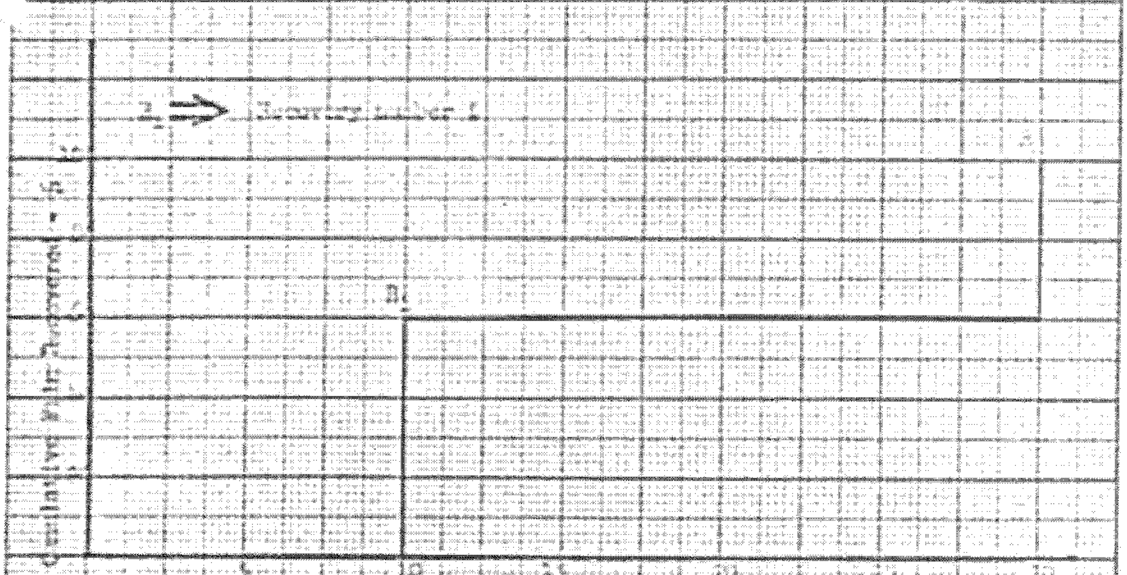


[illegible] efficient film use and [illegible]



Percent of film recovered vs days on orbit for [illegible] with more efficient film use and [illegible] film [illegible]

Figure [illegible]

TABLE 4

Age of Oldest Recovered Exposed Film with Linear Film Use

30 Day Mission

4 RV Configuration		2 RV Configuration	
RV	Age	RV	Age
1st	7		
2nd	8	1st	15
3rd	7		
4th	8	2nd	15

TABLE 5

Age of Oldest Recovered Exposed Film With More Efficient Film Use

30 Day Mission

4 RV Configuration		2 RV Configuration	
RV	Age	RV	Age
1st	4		
2nd	6	1st	10
3rd	10		
4th	10	2nd	20

During the design definition of any system, it is important to make the system as flexible as possible so that these unexpected requirements can be satisfied without undue perturbation. Four RV's provide this flexibility better than 2 since the film can be returned on a more timely basis.

Four RV's also provide the capability to off load in smaller increments. Different mission requirements such as unusual orbits and/or the need to carry research or survivability payloads could require the normal system be off loaded to provide the necessary weight capability.

In "The Military Planner's Challenge: Reconciling Technology with Policy" by the Honorable Harold Brown, Air Force and Space Digest, March 1967, the Secretary points out the uncertainty associated with the prediction of future requirements and the importance of incorporating flexibility into our weapon systems. Although Hexagon may not be a weapon system in the normal use of the term, flexibility should certainly be one of the dominant criteria for evaluating design trade offs such as 2 vs 4 RV's.

Film Use - The decision to take or deny photography of a given target area is based on the predicted weather over the target. This prediction in turn is based on weather observations which may be as much as two hours old; hence, the weather in the target area is not precisely known at the time of photography. The best way to positively state that a given target was indeed photographed cloud free is to look at the exposed film. Therefore, efficient use of film requires that the film be recovered and evaluated after each access cycle. In this manner it can be positively determined that a target has been successfully photographed and can be deleted from the target list.

If the film is not available for evaluation, an estimate, based on weather observations before and after photography, must be made of the probability that the target area was indeed photographed unobscured by clouds. If this probability is high enough, the target will not be photographed again, if not, the photography will have to be repeated. This procedure results in some targets not being successfully photographed and others being photographed more than is required, thus wasting film.

The SOC in Ref f states that statistics and experience dictated seven complete accesses per Hexagon mission; hence, if the film were to be returned after each access, seven RV's would be required. As the number of RV's increase the total system weight increases. Present estimates indicate that the SOR requirements can be met with a 4 RV Configuration. The use of 4 RV's would permit the film from the 1st and 2nd RV's to be evaluated in time for use in programming the 3rd and 4th RV's. While this is not as useful as 7 RV's would be, the SOC considers 4 RV's an acceptable compromise.

8. Reliability Considerations

Attachment one is an analysis of the effect on system effectiveness of using two or four RV's. System effectiveness as used here is a measure of the amount of exposed film that is successfully returned from orbit and recovered. Hence, the higher the system effectiveness, the more exposed film that is successfully recovered.

The Backup Recovery Attitude Control system (BRAC) is an entirely independent attitude control system which is used to position the SV for recovery in the event of SV attitude control system failure. BRAC is non-operational until needed and not in series with the rest of the SV; consequently, its use makes the system effectiveness essentially independent of the number of RV's.

9. Sensor Subsystem Considerations

The Sensor Subsystem contractor has been proceeding on the assumption that Hexagon will have a 2 RV configuration. Consequently, any change from a 2 RV configuration would require re-direction. The SSSPO states that redirection to a 4 RV configuration would increase non-recurring costs by $470,000 and increase the cost per launch by $290,000.

The SSSPO has stated that the SS reliability difference between a 2 and a 4 RV configuration is insignificant.

Attachment 3 is a discussion furnished by the SSSPO on the probability of the effect of weather on a Hexagon mission.

10. System Weight Considerations

Table 5 gives the system weight and the Titan IIID, 5 segment booster capability for a 45 day mission with an 82 n.mi. perigee and a 144 n.mi. apogee. Table 6 gives similar information for a 92.5 n.mi. perigee. These weights are for the 4 RV configuration, thus it is evident the Hexagon mission requirements can be met with a 4 RV configuration.

TABLE 5

SATELLITE VEHICLE WEIGHT

ORBIT: h_p = 82 n.mi., h_a = 144 n.mi., i = 96.4°, ω_p = 55°N

MISSION DURATION: 45 DAYS

SS WEIGHT: 4,500 POUNDS

	CURRENT ESTIMATE	GROWTH	PREDICTED AT LAUNCH
SBA (EQUIVALENT)	9,230 lbs	10%	10,150 lbs.
SS	4,500		4,500
SS FILM	1,830	---	1,830
SI	430	15%	495
SI FILM	90	---	90
RV (4)	2,590	15%	2,780
TOTAL SV	18,670 lbs		19,845 lbs.
BOOSTER CAPABILITY			20,250 lbs.

TABLE 6

SATELLITE VEHICLE WEIGHT

ORBIT:	h_p = 92.5 n.mi., h_a = 145 n.mi., i = 96.4°, θ_p = 55°N
MISSION DURATION:	45 DAYS
ES WEIGHT:	4,500 POUNDS

	CURRENT ESTIMATE	GROWTH	PREDICTED AT LAUNCH
SBA (EQUIVALENT)	7,710 lbs.	10%	8,480 lbs
ES	4,500		4,500
ES FILM	1,830	---	1,830
SI	430	15%	495
SI FILM	90	---	90
RV & TARGETS (4)	2,590	15%	2,760
TOTAL SV	17,150 lbs		18,175 lbs.
BOOSTER CAPABILITY			20,040 lbs.

ATTACHMENT 1

SPECIAL HANDLING

To: F. S. Buzard
Attn: R. E. Anderson

EYS-044
Copy 1 of 2
Pages 1
24 March 1967

Subject: System Reliability and Effectiveness

* *

The results of a reliability study are being transmitted with this cover letter for your information. The study (EYS-043) summarizes the results of several reliability analyses and calculates effectiveness for the system.

It should be noted that this report is a working paper and does not reflect an official position.

J. D. Sorrels

JDS:EF:mw

Attachment: EYS-043, Same Subject as Above,
9 Sheets

SPECIAL HANDLING

TO: J. D. Sorrels

FROM: [redacted]

SUBJECT: System Reliability and Effectiveness

EYS-043
Copy 1 of 1
9 Pages

10 March 1967

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INTRODUCTION:

A brief investigation of Aerospace Vehicle (AV) reliability has been made. The goal was to (1) determine the effect of each major item of the AV on overall AV reliability and effectiveness, (2) insure that the reliability predictions and specifications were consistent with system requirements, and (3) verify the reliability budget.

DISCUSSION:

Reliability for three of the proposed Satellite Basic Assembly (SBA) designs has been predicted by an independent reliability analysis. It was found that, regardless of which contractor is chosen, a reliability of 0.98 should be achievable for initial operation. For 30-day operation the independent evaluation predicted reliabilities between 0.915 and 0.972 for three of the SBA contenders. This is based on the use of high reliability parts and a good reliability program. With MIL-STD failure rates assumed, the reliability is predicted to be between 0.614 and 0.874 depending on the contractor. Thus, it appears that the originally specified number of 0.90 reliability can be achieved if attention is paid to reliability.

The independent reliability analysis has also considered the Back-up Reentry Attitude Control (BRAC) mode of SBA operation. Since the back-up equipment is in standby until needed, it exhibits very low failure rates. For the three proposers, the BRAC mode is predicted to have a reliability of at least 0.98 for standing-by for 30 days and then operating.

The Sensor System (SS) contractor proposal states that the uncaging of the SS will have 0.999962 reliability; but, nothing is stated as to probability of initial operation. Since the single day reliability of the SS is stated to be 0.99726, it appears that the reliability of initial operation of the SS should be assumed to be near 0.997 rather than the 0.999962 stated.

The failure rate stated by the SS Contractor gives a 30-day reliability of 0.915 if 0.997 is assumed for the initial operation reliability. This is slightly better than the 0.90 reliability which was specified in the RFP. Thus, for this investigation, a 30-day reliability of 0.90 will be used.

Reliability numbers for the SS and SBA are plotted in Figure 1 as a linear function of time. The independent evaluation indicated that this is a close approximation for the SBA; and, the SS proposal equations give similar results.

The reliability of the new SI designs is predicted by one proposer to be 0.9868 for the 30-day mission. However, this number is based on operation for only five or six hours. The other proposer predicted a reliability of 0.9988 for a 30-day mission. This number is based on operation for 20 hours, a somewhat conservative operating time, with no allowance for non-operating time. Thus, the previously specified reliability of 0.97 will be used until a comprehensive reliability analysis can be made.

Reentry Vehicle (RV) reliability predicted by the proposers ranged from 0.9283 to 0.985. The one contractor who presented an extensive and sound analysis predicted 0.9883. Thus a budgeted reliability of 0.98 appears reasonable.

The reliability of the T-III-D is expected to be at least 0.95. This includes placing the SV into the desired orbit within the tolerances specified in the Booster Requirements Document.

ANALYSIS

The HEXAGON mission can be broken into two parts, a search and surveillance mission and a mapping mission. Success of these missions is dependent on the probability of the buckets allocated to a given mission requirement being loaded with information and successfully recovered.

Search and Surveillance Mission

Satisfactory performance of the search and surveillance mission requires that the T-III place the SV in orbit properly, the SS and SBA function satisfactorily, and the RV carrying each bucket returns to earth safely.

In addition, SBA and SS failures occurring prior to the planned time of return of a bucket are assumed to terminate the mission, but the data may be recoverable. If the failure is of the SS it is assumed that the data acquired can be recovered; or, if the SBA fails and the DRAG mode operates, the data can be recovered.

Let I_o be the expected percent of the total information (i.e., properly exposed) returned aside (from that which is recoverable under a failed condition. Then

$$I_o = R_{THI} R_{RV} \sum_{i=1}^{n} \left\{ R_{SBA}(t_i) R_{SS}(t_i) \left[I(t_i) - I(t_{i-1}) \right] \right\}$$

where:

R_{THI} is the reliability of the [illegible]

$R_{SBA}(t_i)$ is the reliability of the SBA evaluated at a time t_i

$R_{SS}(t_i)$ is the reliability of the SS evaluated at a time t_i

R_{RV} is the reliability of each RV

$I(t_i)$ is the information gathered up to time t_i

t_i is the time of return of the ith RV

t_o is the time of injection on-orbit

n is the number of RV's

Let I_i be the expected per cent of the total information returned under a failed condition during the interval prior to return of the ith RV. Then

$$I_i = R_{THI} R_{RV} R_{SS}(t_o) R_{SBA}(t_o) \int_{t_{i-1}}^{t_i} \lambda_S \left[I(t) - I(t_{i-1}) \right] \left(\frac{\lambda_{SBA} R_B(t)}{\lambda_{SBA} + \lambda_{SS}} + \frac{\lambda_{SS}}{\lambda_{SBA} + \lambda_{SS}} \right) e \text{ [illegible]}$$

where it has been assumed that $R_{SS}R_{SBA}(t) \cong R_{SS}(t_o)\ R_{SBA}(t_o)(1-\lambda_s t)$.

In other words, the Search and Surveillance system reliability is represented by a reliability of initial operation on-orbit $(R_{SS}(t_o)R_{SBA}(t_o))$ and a constant failure rate (λ_S) thereafter. Also:

λ_{SBA} is the failure rate of the SBA

λ_{SS} is the failure rate of the SS

$R_B(t)$ is the reliability of the BRAC Mode

The information function I(t) has been found to be an exponential function:

$$I(t) = K(1-e^{-at}) = 1.107(1-e^{-.078t})$$

where t is in days and K has been normalized to give I(30) = 1.

$R_B(t)$ is near unity and thus does little to cause loss of information. Therefore, it will be assumed that $R_B(t) \cong R_B(30) = .98$ to simplify the integral.

Thus the total per cent of the maximum possible information I_T gathered during a 30 day mission may be expressed as:

$$I_T = I_o + \sum_{i=1}^{n} I_i = Z_{S\&S}$$

$$Z_{S\&S} = R_{TH}R_{RV}R_{SS}(t_o)R_{SBA}(t_o)\sum_{i=1}^{n}\left\{(1-\lambda_S t_i)\left[I(t_i) - I(t_{i-1})\right]\right\} +$$

$$+ K\lambda_S \left[\frac{\lambda_{SBA} R_B}{\lambda_{SBA} + \lambda_{SS}} + \frac{\lambda_{SS}}{\lambda_{SBA} + \lambda_{SS}} \right] \int_{t_{i-1}}^{t_i} \left[(1 - e^{-\alpha t}) - (1 - e^{-\alpha t_{i-1}}) \right] dt$$

Here search and surveillance mission effectiveness ($E_{S\&S}$) is equated to the per cent of the total film load which is properly exposed and returned (I_T).

Mapping Mission

Mapping information and effectiveness is derived in a manner similar to the above. There are slight differences in that the SI will be using only one RV (the last) and the information function is linear rather than exponential. This leads to an expression:

$$E_M = R_{TIII} R_{RV} R_{SBA}(t_o) R_{SI}(t_o) \Big\{ (1 - \lambda_M T)\, I\,(T) + \lambda_M \left[\frac{\lambda_{SBA} R_B}{\lambda_{SBA} + \lambda_{SI}} + \frac{\lambda_{SI}}{\lambda_{SBA} + \lambda_{SI}} \right] \int_0^T \frac{t}{T}\, dt \Big\}$$

where

λ_M is the failure rate of the mapping system

$$\left(R_{SBA}(t)\, R_{SI}(t) = R_{SBA}(t_o)\, R_{SI}(t_o) \left[1 - \lambda_M t \right] \right)$$

T is the time the mission ends (i.e. $T = 30$ days)

λ_{SI} is the failure rate of the SI

E_M is the effectiveness of the mapping mission.

RESULTS

Effectiveness has been calculated for four search and surveillance cases and two mapping cases. The HEXAGON System was assumed to consist of a four or a two RV configuration with and without the BRAC mode. Thus the above effective equations were evaluated with $n = 2$ and 4 while $R_B = .98$ and $R_B = 0$. For the search and surveillance case the timing of RV returns were assumed to be as shown in Table 1.

TABLE 1

Case \ i	1	2	3	4
4 RV's	$I_1 = 0.30$ $t_1 = 4$ days	$I_2 = 0.60$ $t_2 = 10$ days	$I_3 = 0.875$ $t_3 = 20$ days	$I_4 = 1.0$ $t_4 = 30$ days
2 RV's	$I_1 = 0.60$ $t_1 = 10$ days	$I_2 = 1.0$ $t_2 = 30$ days		

The following results are obtained when the reliability numbers previously discussed are used in the effectiveness equations derived above.

	Two RV's	Four RV's
No BRAC	$E_{S\&S} = .839$ $E_M = .827$	$E_{S\&S} = .848$ $E_M = .827$
with BRAC	$E_{S\&S} = .856$ $E_M = .852$	$E_{S\&S} = .856$ $E_M = .852$

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CONCLUSIONS

The current philosophy of planning five flights a year to achieve at least the effectiveness of four flights with no failures, requires that the individual flights be at least 0.80 effective. This is achieved if the reliabilities are maintained at or above the levels used in this analysis. Of course, it is desirable to maintain the effectiveness above the 0.80 level to insure that vehicles will be available for crises situations. Therefore, the numbers used in this analysis are needed and should be maintained. Thus, the system reliability budget is as shown in Table 2.

There is a slight gain in effectiveness for the four RV case over the two RV case and a slight gain in the BRAC case over the non-BRAC case. However, the gains are not significant. In fact, the four and two RV cases with BRAC give the same effectiveness.

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TABLE 2

System Reliability Budget Required

Titan III Injection into Orbit within Tolerances	0.95
SBA Initial Operation On-Orbit*	0.98
SS Initial Operation On-Orbit*	0.997
SBA Operating Throughout 30 Days*	0.90
SS Operating Throughout 30 Days*	0.90
SI Operating Throughout 30 Days*	0.97
RV Successful Functioning Through Recovery (each RV)	0.98

* See Figure 1

ATTACHMENT 2

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HEXAGON
NORTH FOR GENERAL MARTIN
ADIC FOR MR. SHELDON
FROM DR. FLAX
SUBJECT: HEXAGON

THE HEXAGON SOURCE SELECTION ACTIVITIES WILL BE CONCLUDED IN THE NEAR FUTURE. IN ADDITION TO THE SELECTION OF CONTRACTOR SOURCES THERE ARE SEVERAL SYSTEM DECISIONS WHICH ARE ESSENTIAL IN AN ORDERLY TRANSITION TO THE DEVELOPMENT PHASE OF THIS PROGRAM. THE PURPOSE OF THIS MESSAGE IS TO IDENTIFY THE MOST CRITICAL OF THESE AND TO REQUEST THAT THE NECESSARY STUDIES BE UNDERTAKEN WITHOUT DELAY.

THE REQUIRED ACTIONS ARE DESCRIBED BELOW:

I. A STUDY OF THE FACTORY-TO-PAD HARDWARE FLOW SHOULD BEGIN AS SOON AS THE SBA CONTRACTOR IS ANNOUNCED. THE SPO, ASSISTED BY THE SSSPO, SHOULD EVALUATE THE PROS AND CONS, COSTS, (BOTH DIRECT AND INDIRECT), AND OTHER SIGNIFICANT ASPECTS OF THE ALTERNATIVE HARDWARE FLOW OPTIONS INVOLVING THE SBA AND SENSOR SUBSYSTEM CONTRACTORS.

II. THE NUMBER OF RV'S MUST BE ESTABLISHED AT AN EARLY DATE. I UNDERSTAND THAT THE INITIAL ACTION ON UPDATING THE EARLIER SPO/SSSPO STUDY IS UNDERWAY. THE SPO SHOULD BE ASSISTED IN THIS EFFORT BY A REPRESENTATIVE OF THE SOC AS WELL AS THE SSSPO; COLONEL HOWARD SHOULD BE CONTACTED DIRECTLY FOR THE NAME OF HIS REPRESENTATIVE. THE COMPLETED STUDY SHOULD CONSIDER RECOVERY OF THE RECORD FROM THE TERRAIN AND STELLAR INDEX SYSTEMS AS WELL AS THE FILM FROM THE MAIN CAMERAS.

III. A STUDY OF CERTAIN SYSTEM OPERATIONAL CHARACTERISTICS IS REQUIRED TO DETERMINE THE FILM LOAD, AND VARIOUS SENSOR CHARACTERISTICS SUCH AS THE EXPECTED NUMBER OF CYCLES PER DAY, THE STOP-START TIME CYCLE, MINIMUM BURSTS, VARIABLE SCAN, ETC. THIS EFFORT SHOULD EVALUATE TRADE-OFFS BETWEEN CAPABILITIES, COSTS AND THE TECHNICAL ASPECTS OF EACH. I WOULD LIKE FOR THE SOC (COLONEL HOWARD) TO CHAIR A TEAM COMPOSED OF SPO AND SSSPO REPRESENTATIVES TO ACCOMPLISH THIS TASK. COLONEL HOWARD WILL CONTACT YOU FOR THE NAMES OF YOUR REPRESENTATIVES.

IV. THE MASTER SYSTEM DESIGN SPECIFICATION AND INTERFACE SPECIFICATIONS MUST BE PREPARED AS SOON AS POSSIBLE. THE SPO, ASSISTED BY THE SSSPO, SHOULD UNDERTAKE THIS TASK WITH ASSISTANCE FROM THE SOC, THE STC, ETC., AS REQUIRED.

I UNDERSTAND THAT INITIAL MEETINGS HAVE BEEN SCHEDULED TO CONSIDER THE HARDWARE FLOW AND THE NUMBER OF RV'S. THESE STUDIES AND THE STUDY OF THE OPERATIONAL CHARACTERISTICS SHOULD BE COMPLETED AS SOON AS POSSIBLE. THE RESULTS OF THESE STUDIES AND RECOMMENDATIONS SHOULD BE PRESENTED TO ME AT THAT TIME.

IT IS RECOGNIZED THAT THE SYSTEM AND INTERFACE SPECIFICATIONS ARE DEPENDENT IN PART ON THE DECISIONS ON HARDWARE FLOW, NUMBER OF RV'S AND OPERATION CHARACTERISTICS. NEVERTHELESS, EFFORT NECESSARY TO PREPARE THESE SPECIFICATIONS SHOULD BE INITIATED NOW SO THAT COMPLETED SPECIFICATIONS CAN BE PREPARED AS SOON AS THE DECISIONS ON HARDWARE FLOW, NUMBER OF RV'S AND OPERATIONAL CHARACTERISTICS HAVE BEEN MADE. WHEN THE KEY SYSTEMS CAPABILITIES HAVE BEEN ESTABLISHED, THE NRO STAFF WILL UPDATE THE SOR.

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HEXAGON

1. REF. DISCUSSIONS BETWEEN CAPT RICHARDS AND LT COL ANDERSON AT HEXAGON PROGRAM OFFICE ON 17 FEBRUARY.

2. DURING THE PAST NINE MONTHS THE HEXAGON PROGRAM OFFICE HAS CONDUCTED ANALYSES ON THE NUMBER OF RV'S FOR THE HEXAGON SYSTEM. RELIABILITY AND PROBABILITY OF FILM RECOVERY STUDIES SHOW THAT THE DIFFERENCES BETWEEN A TWO RV AND A FOUR RV CONFIGURATION ARE INSIGNIFICANT.

3. THE CHOICE OF A 2 OR 4 RV CONFIGURATION THEN DEPENDS LARGELY ON OPERATIONAL CONSIDERATIONS SUCH AS CRISIS MANAGEMENT, PROCESSOR LOADING, AND TIMELINESS OF RETURN OF PHOTOGRAPHY.

4. REQUEST YOU RE-EXAMINE THE OPERATIONAL REQUIREMENTS OF THE HEXAGON SYSTEM AND PROVIDE US YOUR RECOMMENDATIONS ON RV CONFIGURATIONS.

5. IMMEDIATE ACTION IS REQUIRED IN ORDER THAT RECOMMENDATION CAN BE PRESENTED TO THE DNRO EARLY IN MARCH.

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ATTACHMENT 3

A-73
3 April 1967
Copy No. 1

TO: Col. F. S. Buzard, SP-7

FROM: [redacted]

SUBJECT: Forwarding 2 vs 4 RV Configuration Information

1. Attachments (1) and (2) are forwarded herewith for information and retention.

2. Attachment (1) supersedes ABP-2719 dated 28 March 1967 which was transferred to L/C R. Anderson on 31 March 1967. It is intended as an attachment to the 2 vs 4 RV report to be transmitted to NRO.

3. On 31 March L/C Anderson made a draft copy of sections 7, 8, and 9 available to me. If the system can meet the SOR design requirements of 82 X 144 nm and 45 days, it is requested that the top paragraph of attachment (2) be added to section 7 of the report.

4. I plan to discuss the draft with L/C Anderson today.

[redacted]

Attachments:
(1) ABF 2723, Operational Capability - 2 vs 4 R/V Configuration, 3 Apr 67, BX TS, 12 pages, copy 3

(2) Attachment (2)/A-73, 1 page, BX TS, copy 1

Distribution:
D. W. Patterson, HQ, without attachments
SETS, without attachments
SSC without attachments

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ADF-2733
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Total pages: 12

To: File

1 April 1967

From: [redacted]

Subject: Operational Capability - 2 vs 4 R/V Configuration

Reference: ADF-1272, "Request for Proposal, Sensor Subsystem for General Search and Surveillance System," dated 19 May 1966

1.0 Introduction

This memo presents the results of an analysis of the operational capability of the Hx System, for the search and surveillance mission, with two or four re-entry vehicles. The measure of System capability which is used herein is the percentage of targets (area) photographed with less than [illegible]% cloud cover and the expected resolution value (see reference) of a target.

2.0 Background and Assumptions

The film load for the Hx System is based on attempting up to two photographs per target for the high priority, 90 day interval targets (Cat. 2 targets) and one photograph per target for the 180 or 360 day interval targets (Cat. 7 or 8). In addition, it was assumed that in the interval between launches the film would be evaluated and the results of this evaluation would be utilized in planning and targeting subsequent missions. Thus, the ability to evaluate photography during a mission would affect only that portion of the film load devoted to the Cat. 2 targets (approximately 30%).

It is assumed that

- Design life (N) = 45 days
- On-orbit failure rate (λ) = 0.033/day

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- Time interval from R/V recovery to data contained in that R/V being delivered, processed and interpreted sufficiently to determine cloud free areas photographed (D) = 4 days
- Recovery probability (P_r) = 0.98 (primary and back-up)
- Each R/V contains equal quantity of film
- Reliability of cloud cover prediction (P_{cc}) = 0.80 (based on SOC studies)
- There are no sources of data concerning cloud cover at the time of photography other than the IIx photography and the predictions.
- Film utilization schedule as per Figure (2) based on simulation results
- Since this is a comparative study it is assumed that the probability of successfully achieving orbit is unity.

3.0 Discussion

The number of R/V's in the recovery system have only a secondary influence on the performance capability of the IIx System. The primary factors influencing the search and surveillance performance are weather statistics, geometrical coverage (orbital parameters) and the time on orbit.

Figure 1 is a plot of the expected return* as a function of design life and number of R/V's for the search targets. These results are based on detailed simulations utilizing typical target distributions and four years actual cloud cover data. In 45 days approximately 90% of the surveillance targets will be photographed; however, because of imperfect cloud cover predictions only 80% of the photographs will be successful. The ability to determine, during a mission, that a photograph was not successful is the

*Fraction of targets successfully acquired in a mission period. See enclosure A for applicable equations.

vehicle whereby additional R/V's can enhance the Hx mission capability. Thus, we have the potential for improving the capability against some 18% of the targets.

Based on the film utilization schedule shown in Figure 2, assessment opportunities occur on the 6th, 13th, 24th and 45th day for the 4 R/V configuration and on the 13th and 45th day for the 2 R/V configuration. These times assume a fail free system. For a system which had a non-zero failure rate, the recovery times would be as given in Figure 2 or on the day of failure, whichever occurred first.

For a 45 day mission and a fail free system, out of the 18% unacceptable photos (based on single take attempt) in a mission, 10.7% of the target population would be successfully re-photographed with a 4 R/V configuration compared to 7.6% with a 2 R/V configuration. These estimates assume a 4 day assessment time after the recovery of each R/V. If the assessment time were 10 days, the percentage of successfully re-photographing would be reduced to 9.5% and 7.0% for 4 and 2 R/V's respectively.

The success of retaking a target will decrease with shorter mission life. Thus in an operational environment, the performance difference of the two configurations will decrease due to failure. By accounting for all failures which can shorten the useful life, the expected performance gained from the assessment process can be computed and compared. The results are tabulated in Table I for both the zero failure and a non-zero failure system with a failure rate of .013 per day.

Table I

Performance Gain with Assessment of the
Returned Film During a Mission

Targets Classification	Surveillance		Search	
No. of R/V's	2	4	2	4
Incremental Return				
Zero failure rate	4.7%	5.8%	7.6%	10.7%
Failure rate = 0.013/day	3.2%	3.7%	3.[illegible]	5.5%

Other studies have indicated that the use of either 2 or 4 R/V's poses no serious design problems on the Hx System. Therefore, for a System which is not payload limited, the only remaining question is the monetary and schedule costs associated with an increase of 0.5% to 2% in the expected return.

However, if the System is weight limited, the performance degradation due to the weight difference in the two configurations must be factored into the trade study. Current studies indicate that the use of a 4 R/V configuration will impose about a 600 lb penalty compared to that of a 2 R/V configuration.

Based on the film utilization strategies currently under consideration for the Hx System, the quantity of film expended in either configuration will be essentially the same. Thus it is not anticipated that film saving of a 4 R/V configuration will offset the 600 lb loss. Further, since the maximum average weather forecast error allowance has been added in the film load analysis, the Hx film capacity, as currently specified, is adequate for either a 2 R/V or a 4 R/V design.

Assuming we are weight limited, a 600 lb loss at the SOR specified design orbit (82 x 144 nm) can mean only a reduction of expendables. It is important to recognize that the weight deficit in terms of expendables would produce a performance loss exceeding the 2% gain obtainable with a 4 R/V configuration. A 600 lb reduction in film load corresponds to 33% decrease in returned imagery. If the choice is made to off-load orbit adjust and maintenance propellants the orbit life capability and hence the mission capability will be reduced. Figure 4 is a plot of the loss in expected return as a function of propellant per day requirement.

A possible alternative to reconcile the 600 lb loss is to operate Hx at a higher design altitude. It has been estimated that a 45 day life can be maintained with the current weight distribution at 92 n.m. However, at this altitude the resolution will be degraded by about 12% across the entire format. At the extreme scan limit and nominal 30° sun angle, the 6.5 foot resolution will increase to 7.5 ft at 92 nm altitude. From a survey of the intelligence community on resolution value, Reference (1), the 12% degradation in resolution would result in a 4% loss in the value of the returned photographs. Thus we would be trading a 0.5 to 2% increase in the number of cloud free photographs for a 4% degradation in the value of all photographs. It should be recognized that this loss in value is relatively insensitive to the initial altitude, that is, approximately the same loss would occur if we were discussing a change from 92 to 102 nm. (See Figure 3.)

In summary, the increase in efficiency achievable from a 4 R/V configuration due to increased frequency of assessment of the exposed film is a modicum. Moreover, when the use of this configuration precludes operation at the design altitude for 45 days, this benefit becomes a liability to Hx operational capability. A 4 R/V configuration appears to be an unjustifiable choice.

Enclosure A

Equations for Expected Mission Return

1.0 Cat. 7, 8 Targets

$\mathcal{R}(t)$ = return function, i.e., probability that a target will be photographed on or before time t

= $1 - \exp(-\beta_7 t)$

β_7 = Cat. 7, 8 access rate (geometric and predicted cloud free)

$F(t)$ = probability that System will fail[1] on day t

= $\lambda \exp(-\lambda t)$

t_i = recovery time for ith R/V

$\overline{(\ )}$ = $1 - (\ )$

$E_2(R)$ = expected return for 2 R/V configuration

$$= P_{cc} P_r \left[\int_0^{t_1} \mathcal{R} F\, dt + \mathcal{R}(t_1) \int_{t_1}^{\infty} F\, dt\right] +$$

$$\left[\bar{P}_r + P_r \bar{\mathcal{R}}(t_1)\right] P_{cc} P_r F(t_1) \left[\int_0^{t_2-t_1} \mathcal{R} F\, dt + \mathcal{R}(t_2-t_1) \int_{t_2-t_1}^{\infty} F\, dt\right] +$$

$$\mathcal{R}(t_1) P_r^2 \bar{P}_{cc} F(t_2-t_1-D) \left[\int_0^{t_2-t_1-D} \mathcal{R} F\, dt + \mathcal{R}(t_2-t_1-D) \int_{t_2-t_1-D}^{\infty} F\, dt\right]$$

$E_4(R)$ = expected return for 4 R/V configuration

$$= P_{cc} P_r \left[\int_0^{t_1} \mathcal{R} F \, dt + \mathcal{R}(t_1) \int_{t_1}^{\infty} F \, dt \right] +$$

$$\left[\overline{P}_r + P_r \overline{\mathcal{K}}(t_1) \right] P_{cc} P_r F(t_1) \left[\int_0^{t_2 - t_1} \mathcal{R} F \, dt + \mathcal{R}(t_2 - t_1) \int_{t_2 - t_1}^{\infty} F \, dt \right]$$

$$+ \mathcal{R}(t_1) P_r^2 \overline{P}_{cc} F(t_1 + D) \left[\int_0^{t_2 - t_1 - D} \mathcal{R} F \, dt + \mathcal{R}(t_2 - t_1 - D) \int_{t_2 - t_1 - D}^{\infty} F \, dt \right]$$

$$+ F(t_2) P_{cc} P_r \left[\overline{P}_r^2 + \overline{P}_r P_r \overline{\mathcal{K}}(t_2) \right] \left[\int_0^{t_3 - t_2} \mathcal{R} F \, dt + \mathcal{R}(t_3 - t_2) \int_{t_3 - t_2}^{\infty} F \, dt \right] +$$

$$P_r^3 \mathcal{R}(t_2) \overline{P}_{cc} P_{cc} F(t_2 + D) \left[\int_0^{t_3 - t_2 - D} \mathcal{R} F \, dt + \mathcal{R}(t_3 - t_2 - D) \int_{t_3 - t_2 - D}^{\infty} F \, dt \right]$$

$$+ P_{cc} P_r F(t_3) \left[\overline{P}_r P \overline{\mathcal{K}}(t_3) + \overline{P}_r^3 \right] \left[\int_0^{t_4 - t_3} \mathcal{R} F \, dt + \mathcal{R}(t_4 - t_3) \int_{t_4 - t_3}^{\infty} F \, dt \right] +$$

$$P_{cc} P_r^2 F(t_3 + D) \overline{P}_r^2 \mathcal{R}(t_3) \overline{P}_{cc} \left[\int_0^{t_4 - t_3 - D} \mathcal{R} F \, dt + \mathcal{R}(t_4 - t_3 - D) \int_{t_4 - t_3 - D}^{\infty} F \, dt \right]$$

2.0 Cat. 2 Targets

The equations for the Cat. 2 targets are similar to those for the Cat. 7, 8 targets except for the return function. For the Cat. 7, 8 targets the probability of obtaining a cloud free photograph (w/fail free system) on or before time t is

$$P_{cc}\left[1 - \exp(-\beta_1 t)\right]$$

However, because of the "two take" strategy for the Cat. 2 targets this becomes

$$P_{cc}\left[\exp(-\beta_2 t) - \exp(-\beta_2' t)\right] + \left[1 - P_{cc}^2\right]\left[1 - \exp(-\beta_2' t)\right]$$

where

$1 - \exp(-\beta_2 t)$ is the probability of obtaining at least 1 photograph and

$1 - \exp(-\beta_2' t)$ is the probability of obtaining exactly 2 photographs

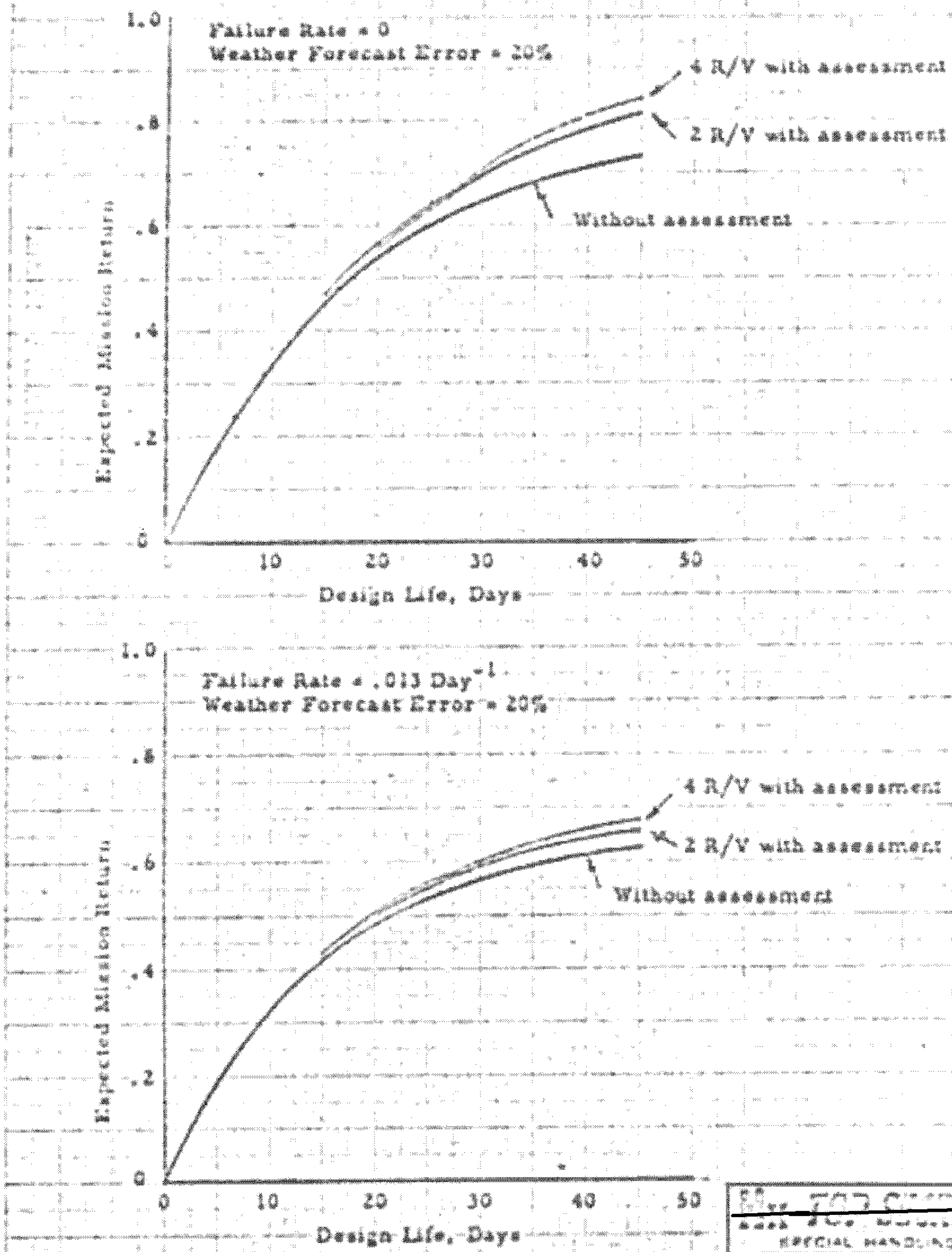

Figure 1. Effect of 2 and 4 R/V Configuration on Performance

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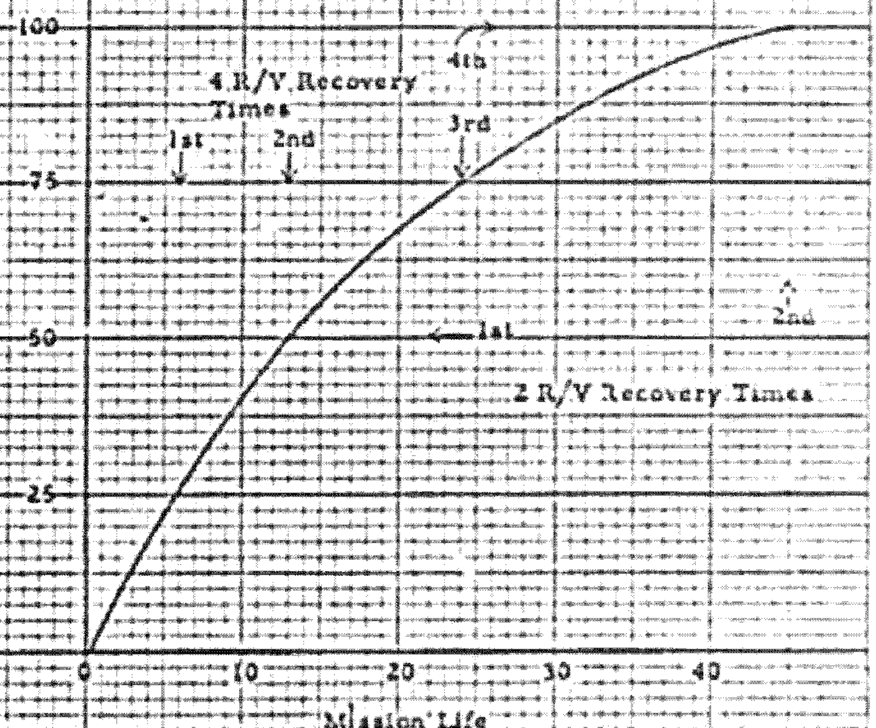

Figure 2, Hx Film Expenditure Schedule

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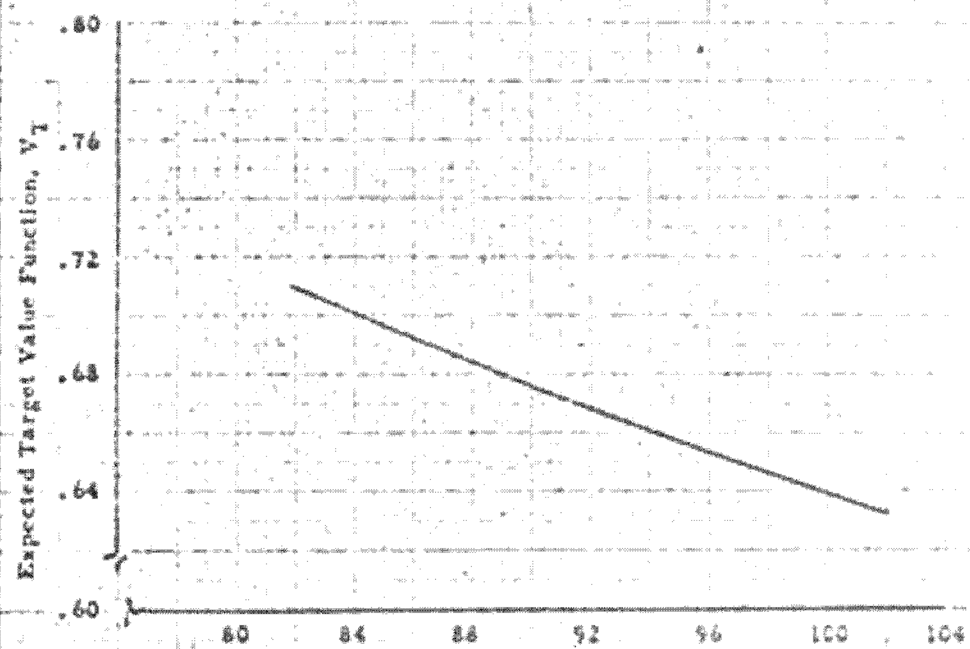

$$\text{Expected Target Value Function} = \Sigma K(R) \cdot \left[\frac{A(R)}{A_{total}}\right]$$

where $K(R)$ = Resolution value function

$A(R)$ = Total non-overlapping ground area in a frame with resolution less than R ft

A_{total} = Total non-overlapping ground area in a frame

Resolution	K(R)
R ≤ 3 ft	.85
3 < R ≤ 5 ft	.70
5 < R ≤ 8 ft	.50
R > 8 ft	$2.5/_R$

Figure 3. Effect of Altitude on Target* Value Function

*Target selected randomly in a frame

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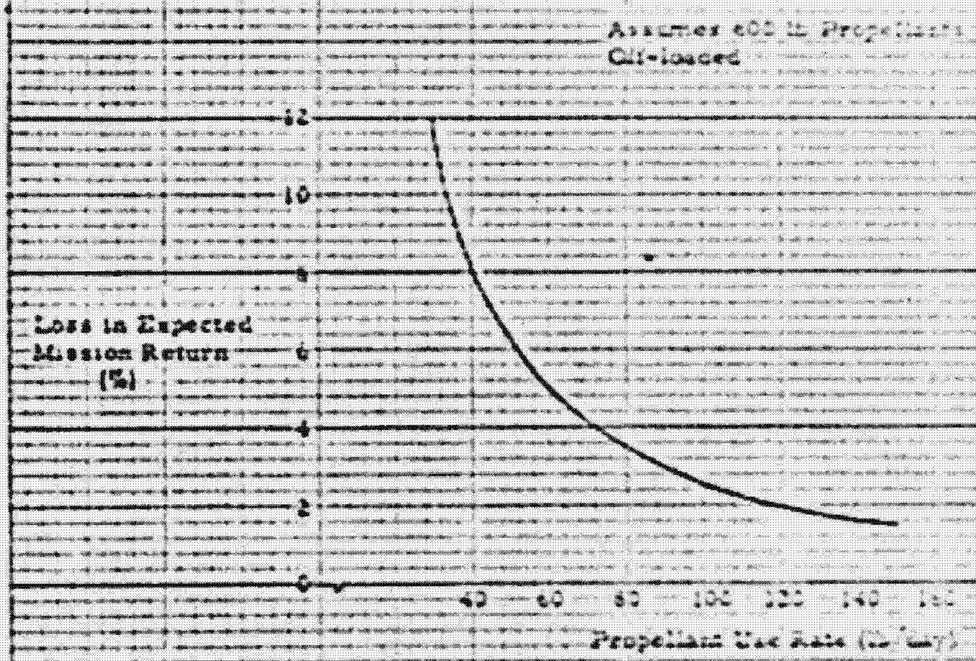

Figure 4. Loss in Expected Mission Return vs Propellant Use Rate

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Attachment (2)/A-73
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Attachment two is an analysis of the percentage of targets successfully photographed with the 2 and 4 R/V configurations. This analysis considers only the normal Search and Surveillance mission. For this mission, the 4 R/V configuration will be more effective than the 2 R/V configuration only if the System is not weight limited, i.e., if it can operate in the design orbit (82 x 144 nm) for 45 days. Under these conditions the 4 R/V configuration will provide less than 3% increase in the expected return per mission.

This paragraph should be added to Section 7 if and only if the System can in fact meet the design requirements (82 x 144 nm, 45 day). Otherwise it should be expanded to reflect trade-offs for actual System capability - see Figures 1-4 of Attachment two.

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Control System

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