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3 July 1963

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MEMORANDUM FOR: The Director of Central Intelligence

SUBJECT : Panel for Future Satellite Reconnaissance Operations

1. The Panel which you appointed to consider questions related to the future satellite reconnaissance program has concluded its study, and I am transmitting herewith our Report. May I say at the outset that the group of Panel members and consultants over which you asked me to preside was an extremely well-informed, thoughtful, and conscientious group. I want to express my personal gratitude to the Panel members and consultants, and also my appreciation for the excellent staff support with which we were provided.

2. I know that you appreciate that time was a severely limiting factor. Because our study had to be compressed into so short a period, we had to limit the number of questions we could come to grips with. Within these limitations, however, I think the Panel has examined carefully and objectively the major questions you set before us.

3. The Panel had two full day meetings on 4 and 5 June which were preceded by special briefings of some of the members. Our Report has gone through several stages of drafting in the course of which the Panel members were consulted, individually or in small groups. Except for very minor editorial changes our Report, as submitted herewith, has been reviewed by all Panel members, who concur substantially in its findings except where specifically noted to the contrary in the Report itself.

4. In behalf of the Panel members and consultants, I wish to express our appreciation of the privilege and responsibility you have

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assigned to us in calling on us to serve in this way. It is our sincere hope that our counsel, in some way, will benefit the work of the Intelligence Community.

SIGNED

EDWARD M. PURCELL
Chairman
Reconnaissance Panel

Dr. Purcell
Dept of Physics
Harvard
Cambridge, Mass.

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PURCELL PANEL

REPORT

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MEMBERSHIP

Dr. Edward M. Purcell, Chairman
Dr. Allen F. Donovan
Dr. Eugene G. Fubini
Dr. Richard L. Garwin
Dr. Edwin H. Land
Dr. Donald P. Ling
Dr. Arthur C. Lundahl

CONSULTANTS

Dr. James G. Baker
Dr. Henry C. Yutzy

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PURCELL PANEL REPORT

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1. INTRODUCTION

In response to a request from the Director of Central Intelligence, the Panel was assembled to examine some broad problems in satellite reconnaissance. The Panel addressed itself to the following questions:

a. What is the capability of existing and programmed systems to provide photographic coverage of the quantity and quality required to meet future intelligence requirements?

b. What are the technical possibilities for the future development of satellite photography, and how should these affect systems planning and research?

c. What should be the technical goals in the next phase of development?

d. What is the vulnerability of our systems to countermeasures; how serious is the threat, and what steps should be planned to meet it?

In addition to these central questions, the Panel considered a number of proposals and ideas for special systems. Finally, although the Panel did not undertake a study of the A-12 airborne system as such, its importance in the whole picture was very much in our minds. The capabilities and the complementary roles of airborne and satellite systems were compared at relevant points.

To state our problem even more briefly, we tried to look into the future to see how far satellite reconnaissance may reasonably be expected to develop in the service of our intelligence needs, and what work needs to be done to insure that it develops as rapidly as possible in the right directions. It is obvious that so short a study had to leave many important problems untouched.

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1. GENERAL OBSERVATIONS ON COVERAGE AND RESOLUTION

The remarkably successful development of photographic reconnaissance from satellites, represented by our currently operating systems, has brought the technology to a point where future progress can be made in two rather different directions. Naturally, high resolution and full coverage are both desirable. In any single program, however, some choice will have to be made. The excellence of resolution now foreseeable, if we strive for resolution alone, is so high that full search coverage at that same resolution would produce a volume of information substantially exceeding the capacity of our present resources for interpretation and exploitation. This argument is hardly a decisive one. Ways could be found to cope with such an embarassment of riches. What is more important is that the development of systems required to provide full search coverage is not the speediest way to attain the resolution capability which the state of the art permits. In other words, the natural incompatibility of wide coverage and high resolution, within a given payload, is becoming more acute, rather than less, as the art advances. The attempt to obtain both simultaneously is likely to prevent the achievement of either one.

On the other hand, the ground resolution achieved under the best conditions by the M system now operating appears to be adequate to meet a large fraction of those intelligence requirements which depend on general coverage. We believe, therefore, that an attempt to make a completely new system which would provide equally wide coverage with only a modest improvement in resolution (5 foot, say, instead of 10 foot ground resolution) would not be a wise investment of resources. Instead, as we proceed beyond the current system, we ought to aim primarily at high resolution accepting the coverage limitation that will be entailed, at least at the beginning. Coverage capability can evolve after the resolution has been obtained. We believe that very substantial improvements in ground resolution are obtainable and that in the foreseeable future there will always be very important uses for spot coverage at the very highest possible resolution.

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3. CURRENT PROGRAMS

The M system operates at its ultimate photographic capability only about 10% of the time or less. Some of the degradation is due to causes which are understood - inaccurate image motion compensation, yaw, exposure inappropriate for the light conditions at a particular time, etc. It seems entirely feasible to bring most of these factors under control so that one could count on peak resolution performance from the M system on 90% of the exposed film. This would represent an enormous gain in information acquisition, and the information would still be in the form which our interpretation and handling facilities are designed to match. On the operational side, it has the merit of keeping things moving in the pattern already established with obvious advantages in reliability. It may be good for political security too; what could be less provocative than to keep doing, without visible change, what one has been inconspicuously doing already?

We believe that improvement in the operation of the M system is the most promising way to make an immediate and substantial gain in photographic reconnaissance. Our first recommendation is simply: Make the M system work well all the time. Some of the important steps in effecting the desired product improvement will be:

a. Better V/H determination and IMC.

b. Yaw detection and control.

c. Exposure control.

d. Automatic focus.

Some carefully designed experiments should be carried out with the operating system to separate and assess the factors contributing to loss of resolution, and to evaluate the remedies.

We need, even now, a standardized objective test of resolution quality in the final M negative; for the programs recommended above, such a test is absolutely indispensable. The test need not be applicable

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to all films and cameras; nor need it measure any precisely defined theoretical parameters. It need not even relate closely to the military specification involving bar targets, but it must be applicable routinely and simply to any segment of useful M negative. Possibly a simple measurement of something related only to the cut-off of the spatial-frequency power spectrum in the final negative can be devised. If it can be diagnostic, so much the better, but the overriding need is for an unambiguous quality control test.

This "product improvement" program for M presents a really golden opportunity, not a thankless chore. If carried through in that spirit, with determination, its quantitative yield in intelligence information may surpass that of any single more advanced system we could now design.

The G and L programs are moving in the right direction and if successful will be very significant steps toward higher resolution. In addition to the actual intelligence we can expect from G system reconnaissance, the performance of this system will teach us a great deal about the opportunities of higher resolution photography - that is, its performance should and will have a decisive influence on our choice and design of future systems. For this reason, we recommend that special attention be given early in the G operations to acquiring some photography with the G camera under ideal photographic conditions. In other words, the urgency of collecting intelligence should not prevent us entirely from ascertaining exactly what this kind of system can do under ideal conditions. The L system is a valuable backup for G, and, at the same time, its parameters are different enough so that any additional experience with L will significantly advance our understanding of the problem of higher resolution photography.

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4. PLANNING BEYOND CURRENTLY PROGRAMMED SYSTEMS

The VALLEY program is an example of a bold step in what we would think is generally the right direction, that is, in pushing resolution to the limit even at some expense in coverage. Actually, as now conceived, the VALLEY system with its considerable flexibility would offer substantial coverage in some modes. We feel, however, that it is a little too early to freeze the concept of the next advanced system. The reasons for this are the following: in the current state of the art, as was convincingly demonstrated by the excellent parametric studies presented to us, the controlling parameters of film speed, film resolution, vehicle attitude stability, and the laws of wave optics, lead one to a compromise in which size, weight and complexity of the instrument are affected by even a modest change in a basic parameter. One can almost say that a modest factor in film speed could mean the difference between a thrust-augmented THOR and a TITAN for the transporting vehicle. In other words, in the next generation of reconnaissance cameras it will be even more important than before, if that is imaginable, to take the utmost advantage of every advance in optical materials and techniques. In the following section, we discuss some possibilities for technological advances which can probably be evaluated soon enough so that one can estimate their importance for the coming generation of systems. In a few months' time, it may be possible to see much more clearly than now what kind of system we ought to go for.

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5. TECHNOLOGICAL ADVANCES

a. Emulsion Properties

Current camera designs, when optimized, turn out to be an expression of the properties of the SO-132 emulsion. Within limits at a given state of the emulsion art, there is a trade off between sensitivity and resolution which can be manipulated to get better results in a particular context. On the other hand, it appears not unreasonable to hope for some absolute improvement in emulsion properties which would yield a faster film at the same resolution or its equivalent. Probably a factor of 4 in speed for a given resolution is too much to hope for, but we have some confidence that a factor of 2 may be obtainable. This would be an extremely significant gain, which would of course be welcome in our current systems. It could be immediately exploited in the design of new systems to alter materially the weight-size-stabilization requirements in the next generation of instruments. Within a few months one may know whether such an improvement in emulsions can indeed be anticipated. We think it extremely important that this question be pursued.

b. Image Intensifiers

The electronic image intensifier is a device which is now being developed vigorously in a number of forms. It may possibly present an opportunity for a major breakthrough in satellite photography. In the image intensifier, light from the original scene falls on a photo-cathode rather than on the film directly. The electrons ejected from the photo-cathode are accelerated to bombard the phosphor, where they make more light. This light can then expose a photographic film or the process can be cascaded to make more electrons, more light, etc., until at some stage photographic recording occurs. It remains to be seen whether the required resolution in lines per millimeter can be maintained. There is no fundamental reason why it cannot be. Some preliminary calculations suggest that several hundred lines/mm is not out of the question. Indeed, in the application to satellite cameras, we appear to have a situation peculiarly favorable to the application of the image-intensifier technique. In most of the current and future designs the light is

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recorded at any given instant along a narrow strip or slit, a geometry highly advantageous for control of the electron trajectories. This technique may permit the further flexibility of recording photographically at a scale different from that of the primary image. We recommend that the possibilities of image-intensifier techniques be immediately investigated. If closer investigation corroborates our present optimism, a vigorous program of development should be started. Here, too, we expect that a few months' study could give us a very much clearer picture of the implications for planning of our future systems.

c. Very Large Optics

Advances in the design of very large optical systems are continuing to be made. These include not only new geometrical arrangements of reflecting surfaces, correcting plates and lenses, but also new techniques for constructing large mirrors that are accurate but not enormously heavy. It is reasonable to contemplate apertures at least as large as 60" diameter operating, so far as their intrinsic optical performance is concerned, close to the "diffraction limit" set by the wave length of light. To be more specific, it appears that a 60" diameter f/2 system forming a good image on a 10" slit is entirely feasible, as is a 40" diameter, f/1.5 with a 6" slit. If and when we move into larger vehicles, it is these larger systems we should be thinking about. It is not too early to support research and development on components, in view of the fact that the lead time on the very large optical elements involved may be as much as two or three years. (Of course we must not forget that the lead time on launching facilities may be another critical element in the utilization of larger vehicles.)

The impression gained from our discussions of these large optical systems is that bulk is likely to be a more stringent limitation than weight, especially if the development of large beryllium mirrors continues to proceed as successfully as it has to date.

d. Stabilization

The problem of vehicle stabilization is likely to remain with us in spite of all optical inventions and will grow more acute rather than

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less. Hence, there will be a continuing need for innovation and ingenuity in the development of vehicle stabilization techniques appropriate to the camera platform. Some degree of image stabilization (as contrasted with vehicle stabilization) may be possible in some of the new optical systems, including the hypothetical image-intensifier system just mentioned.

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6. EVENTUAL LIMITS OF RESOLUTION

There is no evidence that our present systems are running into any fundamental limitations on ground resolution. Of course, the inexorable relation between angular resolution and lens diameter does impose an ultimate lower limit on the size of our instrument. It takes a 10 inch aperture to resolve a foot at 100 miles if everything else is perfect. Probably one can push as far as one foot ground resolution without severe trouble from the atmospheric medium. The question remains as to where the inhomogeneity of the atmosphere will make itself evident, preventing any further useful advances. On this question we have no conclusive experimental evidence. The astronomers are familiar with the inverse problem of seeing up through the atmosphere, but their experience does not necessarily provide the answer. We are also unable to predict at present whether this eventual limitation will be relatively more or less serious for the satellite borne camera than for an airborne camera. As we advance into a new domain of performance this fundamental question will deserve serious research attention. In advance of empirical tests, we may well be able to draw useful conclusions from calculations for various models of a turbulent atmosphere.

Satellite systems are completely free from one problem which may eventually limit the resolution of airborne cameras, the optical irregularities in the airstream adjacent to the vehicle. Where this limit will set in, for airborne systems, is an open question at the moment, but tests in the actual environment which are now scheduled should provide a reliable answer, at least for ground resolution of the order of one or two foot. This problem, if it ever becomes serious, is perhaps not entirely beyond remedy.

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7. SATELLITE VULNERABILITY

The Panel was given a detailed briefing on satellite vulnerability and on the current program aimed at the planning of counter countermeasures and protection of reconnaissance satellites. On the whole, the facts, as presented to us, were reassuring, in the following limited sense: a) It appears that if the Soviets were to mount an attack employing their existing radar capability with a medium-range ballistic missile as the attacking vehicle, the problem the attacker would face in predicting the satellite trajectory accurately enough is so severe that relatively modest counter countermeasures on our part would defeat such an attack. The main reason for this is that the missile has to be committed to its trajectory before the satellite appears over the horizon; thus it has to be committed on the basis of extrapolation from a previous pass; b) the analysis of pellet attack pretty convincingly shows that our present satellite configurations, shielded as they are anyway by the AGENA stage forward, would be quite difficult to hit with pellets and that a very moderate amount of judiciously placed shielding can protect them very effectively. In short, it looks from this analysis, as though the attacker will have to employ a nuclear burst. How severely this will inhibit him from resorting to attack is, of course, a question that involves much more than technical considerations.

It seems probable, however, that the Nike Zeus Target Track Radar at Kwajalein (and therefore perhaps also the 54-foot dish at Sary Shagan) could acquire the satellite as it came over the horizon. This might be done on the basis of SPASUR-like data accummulated over a period of a couple of days. A Thor could thus be launched when the satellite is about 600 miles away (about 45 seconds after radar detection) and could intercept approximately overhead. The recent MUDFLAP experiment, in which Zeus was sent against a small satellite, gave a miss distance of about 200 meters, at which distance 3,000 pounds of pellets spread in a 600 foot radius pattern would give about 1.5 grams of pellets per square foot. It is clear that reliable information is required concerning the effectiveness of the proposed shielding against pellets in the few-gram range. Such an intercept could not be made so readily against satellites whose ground tracks pass more than about 100 miles from the launch site.

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However one may feel about these estimates, it is certainly wise to take all reasonable steps to meet such a threat, in particular the studies of methods for reducing radar detectability and for adding some capability for maneuver deserve continuing support. It seems that even more could be done than was indicated to us in the way of radar cross-section reduction. We raise the question whether all the advances of technique and measurement which have been developed in similar work on other programs are being taken advantage of effectively in this project. As concerns reduction of radar cross-section, it would probably be too optimistic to hope that the cross-section could be reduced to the point where it would be undetectable by radars of a class designed for AICBM acquisition. Nevertheless, reduction of radar cross-section makes decoying easier, and it can hardly be anything but beneficial to make our targets less conspicuous.

It will probably ease the situation if there are more satellites other than reconnaissance satellites in polar orbit. We must hope for and, where possible, foster a proliferation of space activity in polar orbit. Meteorological satellites, among others, can provide welcome company. There are many scientific objectives, and they are probably growing more numerous, which could benefit from instruments in polar orbit. With enough of this going on, the work on modification of radar signature might have the specific aim of making the reconnaissance satellite look like a certain class of open satellites.

In the long run our greatest hope may well lie in the gradual establishment of public recognition of the freedom of space for passive transit. The strength of our present position derives from the past conduct of our space program and our official policy with respect to freedom of space. We should be alert to every opportunity to reinforce this position.

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8. READ-OUT SYSTEMS

The Panel considered rather briefly the current status of developments in read-out systems. This technique has, of course, had a long history of development. The original technical objectives were met; we know that read-out can work, but there has been no practical application to reconnaissance. The basic limitation of present read-out systems is still imposed by the radio frequency channel capacity and the read-out time available, and this handicap has grown, if anything, relatively more discouraging in comparison with photographic recording and recovery. A constant which pretty well characterized read-out systems was stated in the following form: one or two square inches of picture per megacycle band, per minute, for a picture with 100 lines per millimeter resolution. One can perhaps invent missions aimed at quick recovery of 1 or 2 pictures of a few small targets which would make a read-out system attractive, but these would have to be compared with what we might do by a quick-reaction satellite with recovery, or by other means, such as a reconnaissance satellite stored in orbit for use when needed. On the whole, we can generate very little enthusiasm for the read-out technique. Some research in this area might reasonably be kept going. In particular, new means should be sought to expand the capacity of the over-all film-to-ground channels by ultra-fast scanning techniques and very wide band communications. But we conclude that there are no evident opportunities in read-out systems which ought to affect our major plans for further development and use of photographic systems with recovery.

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8. SOME SPECIAL SYSTEMS AND MISSIONS

The Panel considered briefly a number of special systems; some are already under study, others may warrant examination.

a. Quick Reaction Satellite. Clearly our present capability for prompt acquisition of important photographic intelligence is limited, not so much by the recovery cycle, as by the lead time involved in the launching of a previously unscheduled flight. The Panel shares the rather obvious view that something ought to be done about this and that in addition to the general streamlining of the launching operations, which is a problem already being attacked on other fronts, the possibility of a specially planned quick reaction vehicle should be studied. Whether this is feasible or not will have an important bearing on the relative utility of such other means as readout satellites and drones.

b. Storage in Orbit. The so-called zombie mode of operation offers a variant of the quick reaction satellite. [redacted] We see no obvious difficulty in storage of the photographic material, although the radiation exposure would, of course, need to be assessed. What is needed is a small system study of such an operation to evaluate its general promise. The problem of observing at will any point on earth a short time after an order is given should not be minimized. Program computations, in-orbit trajectory corrections, engines with accurate multiburn capabilities need to be examined; the total number of satellites required may, in some cases become so high that a quick reaction device may be more desirable.

c. Fully Covert Satellite. The Panel feels that the time is not ripe to make a definitive position on the usefulness or feasibility of the covert satellite and recommends that the current preliminary study proceed as planned. It is our impression that an air launch may prove to be the most practicable means, and we hope that this aspect will be carefully investigated. Under the concept of "graduated deterrents" a situation can be described where both the Atlantic Missile Range and the Pacific Missile Range have been rendered inoperable just when reconnaissance is most necessary. Then certainly a mobile, if not truly covert satellite, would be needed. The idea of a covert satellite should not be abandoned if one cannot now establish the feasibility of truly covert operation in all respects. A covert launch capability is a more limited but still attractive objective.

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d. Night Photography. There may be some attractive possibilities in night photography from a satellite. In its least ambitious form the objective would be to record simply artificial lights on the ground. There are some known intelligence targets for which this kind of information might be extremely interesting and significant. It may even lie within the capabilities of the present M system to do this; the G and L systems would be even better. Accepting a sacrifice in ground resolution, which would not be serious in this application, one would switch to the fastest emulsion available and lengthen the exposure time. The latter change could be tolerated because at lower resolution the image motion problem is somewhat eased. In any case, there is enough information available to decide whether the M camera could meet this objective technically. Looking ahead to a more ambitious goal it is possible one can imagine an extremely fast optical system which could produce ground pictures in moonlight. In northern latitudes in the winter, snow cover, moonlight, and the aurora provides a good photographic combination. We suggest that it would at least be worthwhile to encourage a theoretical study of the technical requirements and possibilities.

e. Balloons. The question of the possible utility of balloons was raised during our discussions, but for lack of time and background material, the Panel was unable to examine this problem.

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10. A-12 DRONE

The possible role of the A-12 drone was discussed by the Panel from various points of view. It is not our place to assess the political advantage of an unmanned as opposed to a manned reconnaissance vehicle. To the extent that we had intuitive opinions on this, they were probably not unanimous. Some members of the Panel expressed a concern that the TAGBOARD project, whatever its intrinsic merits might be, is diverting some of the effort which is necessary to make the A-12 itself a complete success. (Perhaps an even more serious threat to progress with the A-12 is the simultaneous emergency R-12 and AF-12 programs). This question, too, involves other than purely technical considerations. As for the technical capability of the drone to collect intelligence in the special situations for which it might be deemed the appropriate instrument, we would point out that the photographic performance of the TAGBOARD camera, as now planned, will be inferior to the capability of the A-12 system itself. Therefore in evaluating the utility of the TAGBOARD, it may be as important to compare it with the performance of the G system as with the performance of the A-12. Indeed, the G system which will be operating soon should achieve a ground resolution not much inferior to what the TAGBOARD camera may do, and this without any of the political risks which still surround the drone operation even with the pilot absent. The drone, of course, does have the advantage in certain operational situations of being able to get quickly to a particular target or area. It involves, however, a rather complicated and inflexible overall operation; certainly less flexible than the use of the A-12 itself. It will take a careful analysis of an entire operation to establish its real usefulness.

One member of the Panel, Dr. Fubini, feels that the TAGBOARD matter was not dealt with in sufficient depth and he does not wish to be recorded as concurring with section ten (10).

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II. SUMMARY OF OUR MAIN CONCLUSIONS

Returning to the central questions from which we began, we find emerging from our discussions a few important conclusions. First, the M system itself, successful as it has been, still holds great potential for better work and more return. We cannot emphasize too strongly the importance of this opportunity. Second, the technological possibilities for growth in the direction of higher resolution systems are extremely promising. The eventual goal of ground resolution approaching one foot is not too high for optical photography to aim at. Third, there is a good chance that a new technique developed around the electronic image intensifier can greatly widen the technical possibilities for photography from satellites. With these prospects before us, we may clearly look forward to an extremely active enterprise in this area.

The compact and competent management organization, under which the present operational systems were developed, we believe has contributed largely to the past success of the program. The Panel did not consider at this time the effect of recent changes in the management structure. It recommends, however, that this subject be continuely reviewed to ensure that the clearness of focus and purpose, originally achieved, has not been diffused.