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U.S. AIR FORCE
Project RAND

RECOMMENDATION

TO THE AIR STAFF

PHOTOGRAPHIC RECONNAISSANCE SATELLITES

12 MARCH 1956

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1700 MAIN ST. · SANTA MONICA · CALIFORNIA

12 March 1956

Deputy Chief of Staff, Development
Headquarters, United States Air Force
Washington 25, D. C.

SUBJECT: PHOTOGRAPHIC RECONNAISSANCE SATELLITES

Until the past winter, most of the photographic coverage of the interior of the Soviet Union available to the Director of Intelligence was that obtained by the Germans in 1943 and 1944. This was incomplete, covering only part of European Russia, and is obviously out of date. Recently a balloon operation has resulted in some up-to-date information, but it appears unlikely that balloon reconnaissance on a scale sufficient to complete the coverage can be undertaken again under prevailing political conditions, or that the reconnaissance system requiring overflight by airborne vehicles should be considered.

To overcome our initial disadvantage and make sure that we can secure a continuing supply of reconnaissance information in the future, we must develop a continually improving series of reconnaissance vehicles with greater capability, lower vulnerability, and more flexibility of operation.

RAND recommends that the Air Force accelerate the 117L program for development of the advance reconnaissance satellite so as to obtain early operational use of two specific types of photographic reconnaissance satellites.

- The simpler type would give complete coverage of the Sino-Soviet bloc in a short time at a scale of 1:250,000 (1 inch = 3.5 n mi), with an expenditure of 20 to 30 vehicles.

- A somewhat more complicated one would yield coverage of selected areas of interest at a scale of 1:50,000 (1 inch = 0.7 n mi).

Both satellites would use modern cameras and conventional photographic techniques to obtain the pictures, and a system for recovery of the films on the ground.

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The proposed photo-reconnaissance satellites would be difficult to detect and practically invulnerable to defense systems. They could cover any part of the earth entirely from bases within the continental U.S. Launching for coverage of the Sino-Soviet area would preferably be toward the South. The geometry of ballistic orbits is such that there would be little chance of interpreting the vehicles as intercontinental missiles. There would be no radio signals or other obvious indications of the true purpose of the vehicles during operations outside the U.S.

An SM-65 ICBM booster would be used to bring a specially designed final stage to orbital altitude and nearly to orbital speed. A small liquid-fueled rocket in the final stage would establish orbital speed after separation from the SM-65. For film recovery, a solid rocket motor would launch a film capsule with a parachute back along the orbit at an instant scheduled by radio command on a preceding pass over the United States. Conservative estimates of tracking and guidance errors and impulse variations in such a rocket indicate that the recovery package would land in a predictable area a few miles wide and less than 200 miles long. A radio beacon operating in the capsule from the time of ejection until well after impact would facilitate rapid location and recovery of the package.

The recommended satellites are similar to the test satellite proposed as part of the 117L program by Headquarters, Western Development Division, ARDC. In addition to providing reconnaissance at a relatively early date, they would be logical steps in a development series aimed at the ultimate surveillance goal of the 117L program.. Although development of the large-scale-photography satellite will require more effort than development of the small-scale-photography satellites, it may be possible to have both types ready for use with early production SM-65 boosters.

Appendixes to this recommendation give more details on the following topics.

Reconnaissance Requirements	Appendix I
Vehicle Design	Appendix II
Trajectory Selection	Appendix III
Launching	Appendix IV
Guidance and Control	Appendix V
Command Communications	Appendix VI
Recovery of Films	Appendix VII

RAND stands ready to help implement this recommendation in any way possible.

Very truly yours,

F. R. Collbohm
Director

3-12-56

Appendix I

RECONNAISSANCE REQUIREMENTS

RAND has studied many aerial photographs taken under different conditions with the idea of selecting photographic scales appropriate for complete coverage of the Sino-Soviet Bloc, or any other large area of the earth, and for more detailed analysis of smaller areas. At a scale of 1:250,000 one can expect to see all major airfields, heavy transportation facilities, populated areas, and military and industrial concentrations of any magnitude. Unless resolution qualities of film and cameras are improved somewhat, individual items such as trains or aircraft could not be seen at this scale. A map made from the photographs at a scale of 1:250,000 would, however, show where man and his works exist in any appreciable quantity. Such a map could be used to direct photographic reconnaissance at a larger scale to areas of special interest.

At a scale of 1:50,000 aircraft and trains as well as canal barges and individual buildings will be discernible. Focusing the attention of a number of satellites at this scale onto all of the airfields discovered on the smaller-scale map would permit a count of the aircraft on these fields during a relatively short interval of time. Examination of areas near heavy transportation which indicate construction activity would show where new industrial or military installations are being built and would tell something about the nature of the installations.

The timing of reconnaissance activities is of great importance. At present we have a major interest in the Soviet long-range air force. In the period of operation of the proposed vehicles the Soviet Union will be installing and improving an ICBM weapon system. Fixed installations for ICBM launching and guidance will undoubtedly be harder to detect from the air than are the airports and aircraft of the long-range air force. On the other hand if they are to be detected from the air at all, a complete coverage along major railroads, highways, canals, and rivers offers the best chance. Such coverage will be useful during the construction period, while the surface texture of the terrain is disturbed, buildings are new, and there has been no chance to camouflage the installations. A periodic coverage at intervals of six months to a year will undoubtedly find some number of installations in various phases of construction as the system is installed and expanded. Once the pattern of buildings, roads, and area assignments common to an installation of this type has been determined, the identification of other previously completed installations will be easier.

We conclude that while the proposed satellite vehicles will not fulfill all possible requirements for aerial photography of inaccessible areas, they will do far better than any other vehicles proposed for the early ICBM period in securing total area coverage at small scale and partial coverage at an intermediate scale. Complete coverage of all places at which significant activities are going on can be obtained quickly, and more detailed coverage of the significant places can be obtained somewhat more slowly. The results should be used to guide the operations of aircraft or other types of vehicles better suited to limited coverage at large scales, if such operations become feasible.

Appendix II

VEHICLE DESIGN

The Western Development Division of ARDC has prepared a development plan for a satellite test vehicle. The major features of the vehicles proposed here are similar, although the payload and operational considerations are quite different.

Preliminary design data for a vehicle which could reach orbital operation after being launched on the nose of the SM-65 booster are:

Gross weight	3500 lb
Length	14 ft
Diameter	5 to 7 ft

The gross weight is made up as follows:

Structure, motors, and tanks	1000 lb
Fuels and lubricants	1100 lb
Controls and payload	1400 lb

The vehicle would be designed to fit the nose cone attachment ring of the SM-65 with little or no modification. Two versions of orbital vehicle are contemplated here.

SMALL-SCALE PHOTOGRAPHY

For small-scale photography at 1:250,000, a flight altitude of approximately 750,000 to 1,000,000 feet (142 to 183 statute miles) is suggested. An altitude in this range is compatible with a satellite lifetime of a few days to a few weeks and permits achievement of the desired scale with a camera of three to four feet focal length. A film 18 inches wide corresponds to a strip 60 nautical miles wide on the ground. Using three cameras aimed at parallel strips on the ground permits coverage of a strip 180 nautical miles wide without going to angles of view at which obliqueness or haze will pose great problems. If a polar or nearly polar orbit is used and the flight strips are required to overlap along the 30th parallel from 0 to 150 degrees east, 43 flight strips are required for a single coverage. The average length of a strip is about 3,000 nautical miles, requiring approximately 72 feet of film. Loading each camera with 500 feet of film will permit each vehicle to make seven useful passes over the area of interest before exhausting its film supply. Six vehicles will give complete coverage if no cloud cover or other difficulty is experienced. Most of the area will be covered two or more times. The Soviet Union's average cloud cover is such that five or six random observations will give a 95 per cent chance of seeing the entire surface. If weather forecasts and guidance from coverage already obtained are used, complete coverage can be obtained with twenty to thirty vehicles.

A weight budget based on short-period operation is as follows:

Autopilot and controls for entry on orbit	200 lb
Attitude control for two days' operation	100
Radio beacon, command receiver, programmer	200
Three cameras, 3 to 4-ft focal length	300
1500 feet of 18-inch thin film	50
Film case and spools for recovery	60
Recovery parachutes	20
Recovery beacon	10
Solid rocket recovery motor	90
	1,030

This leaves a contingency reserve of 370 pounds for failures to meet design weights.

LARGER-SCALE PHOTOGRAPHY

For larger-scale photography at 1:50,000 the operation is envisioned as one in which individual photographs are taken at desired places, and no effort is made to cover complete strips. The Sino-Soviet Bloc comprises roughly 9 million square miles. If ten per cent of this proves interesting enough to require photography at 1:50,000 the total film requirement for single coverage will be approximately 10,000 feet of 18-inch film. If each vehicle carries 1500 feet of film, and if a factor of four to six is allowed for cloud cover and other incidental effects, thirty or forty vehicles will be needed for this phase of the coverage. Each vehicle can take approximately 1000 pictures, using an 18-inch by 18-inch format to picture objects on the ground which lie within a twelve- by twelve-mile square.

Assuming that a minimum of ten seconds during flight is used in acquiring each picture, and that a total of approximately one hour of flight time in multiple passes is spent over Sino-Soviet territory per day, the rate of picture taking can be as high as 360 pictures per day, so that a minimum of three days of orbital operation is needed to exhaust the film load. On the other hand it may be desirable to program pictures at a considerably slower rate such as one per minute, so that an orbital lifetime of the order of twenty to thirty days per vehicle may be required. This means that the vehicle should be capable of operation at an altitude of at least 1,000,000 feet. The control systems and power supplies must then have longer lives also. The focal length of the camera must be twenty feet. A weight budget is as follows:

Autopilot and controls for entry on orbit	200 lb
Attitude control for 30 days' operation	150
Radio beacon, command receiver, programmer	250
Camera of 20-ft focal length in roll mount	250
1500 feet of 18-inch thin film	50
Film case and spool for recovery	40
Recovery parachute	20
Recovery beacon	10
Solid rocket recovery motor	90
	1,060 lbs

This leaves a contingency reserve of 340 pounds.

RAND has not as yet attempted to design a layout of equipment for either vehicle. In the small-scale-photography vehicle, the three cameras are fixed, and the vehicle should be stabilized in attitude so that the center camera is vertical and the other two point out to the sides of the flight path. It may be necessary at the time of film recovery to turn the vehicle to another orientation so that the rocket motor which starts the recovery will fire in the proper direction. In the larger-scale-photography vehicle the single camera will be required to turn about the roll axis of the vehicle through an angle of 30 or 40 degrees to either side of the vertical so that it may be aimed at desired installations which fall to one side or the other of the flight path. The eighteen-by-eighteen film will subtend more than four degrees, so that aiming within a degree or two of the desired direction and timing within half a second will be satisfactory. The camera design could call for a balanced rotor system so that no net rotation of the whole vehicle about the roll axis need be tolerated. Alternatively, it might be possible to calibrate the vehicle so that rotation in a sense opposite to that of the camera would be tolerated by the attitude stabilization system, with all angles being referred to the stable platform in the guidance system or to a sun tracker mounted on the camera. Although development of this vehicle will require more effort than development of the simpler one, it may be possible to have both types ready for use with the first production boosters.

Appendix III

TRAJECTORIES

The selection of trajectory altitudes for the two types of vehicles has been discussed in Appendix II. An altitude which provides a few days of operation is estimated to be 750,000 feet. For a few weeks' operation the minimum altitude may be as high as 1,000,000 feet. Both of these altitudes depend to some extent on the aerodynamic design of the vehicle.

Coverage of the whole of the Sino-Soviet Bloc will require orbits with latitudes up to polar, although the majority of the area of interest can be seen from orbits with latitudes up to 70 or 80 degrees. A variety of orbits should be planned to secure most economical coverage. Regression of the orbit plays no part in these considerations because of the short life of the vehicle. Launching should occur at a time of day which will give the desired shadow angles in the region to be photographed. In most instances the plane of the orbit should be within thirty degrees of the plane containing the sun. Coverage of the domain above the Arctic Circle will require summer operations. For regions below this circle, a comparison of summer and winter pictures may often be informative.

At the low altitudes selected, each vehicle would make approximately sixteen revolutions about the earth per day. Successive passes would be 90 minutes in time or 22.5 degrees in earth rotation apart. Figure 1 shows that launching within a few hours of midnight, Pacific time, on a polar orbit toward the south would bring the vehicle over the Soviet Union for a first pass extending roughly from the Caucasus to Novaya Zemlaya. The following pass would run over Bulgaria, Roumania, the Ukraine and the Baltic States.

Several periods later there would be a daylight pass over the United States, during which a few calibration pictures could be taken. Then a

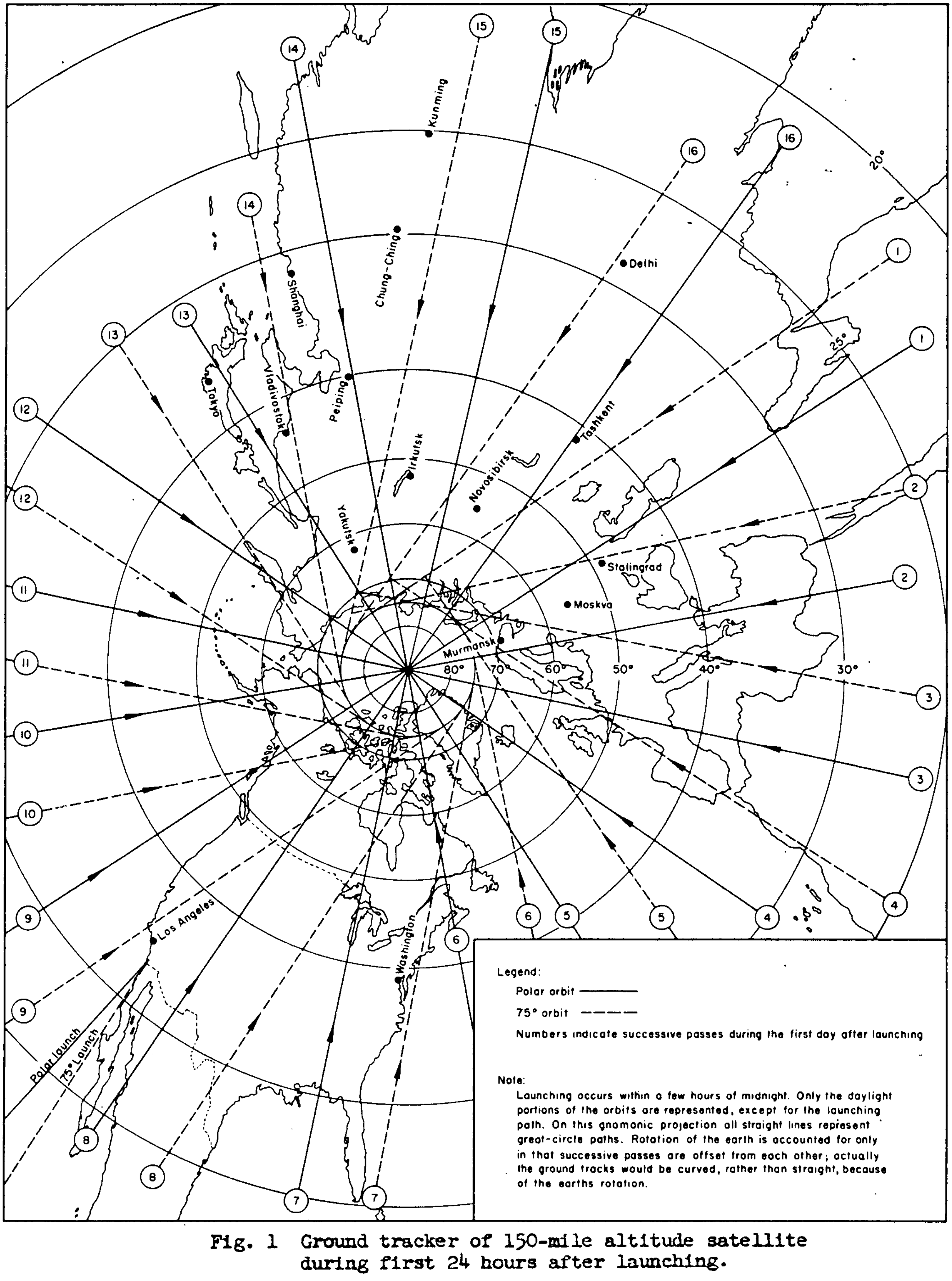

Fig. 1 Ground tracker of 150-mile altitude satellite during first 24 hours after launching.

few periods later there would be useful passes over Siberia beginning at the eastern tip and working west. The fourteenth pass would be over the eastern United States at night, and the fifteenth pass would go over the Middle West at night. Either of these periods could be used to command the vehicle to initiate recovery on the next pass. In the case of the small-scale-photography vehicle, the film package would come down in the designated recovery area on the fifteenth or sixteenth pass. In the case of the larger-scale-photography vehicle, a few days or weeks might be required to use all of the film, and command instruction for the next day's photography could be relayed to the missile each night.

Appendix IV

LAUNCHING

Use of the SM-65 means that the first half-stage motors will fall to earth 300 to 500 miles from the launching site. The remaining booster motor and tankage will re-enter the atmosphere approximately 4000 nautical miles down range. In addition to the hazards from these objects, there is the possibility that propulsion will fail early so that the whole assembly may come down at any point along a path extending 4000 to 5000 miles from the launcher. The chance of large lateral deviations from the desired course can be minimized by conventional range safety precautions based on data from the launching guidance radar; but it is obviously desirable that a launching path of sufficient length over water or over uninhabited land be available.

To reach the desired orbits from Cape Canaveral would require that the launching path pass over either the northeast United States or a large part of South America, or that launching be in the southwest direction with the path passing over portions of Florida, Cuba, and Panama. Launching from the central United States toward the north would require that large portions of the launching path go over heavily populated regions of the United States and Canada. Most of these alternatives are undesirable.

From a suitable location on the Southern California coast, it would be possible to secure a clear sea range in the desired directions east or west of south. The satellites could be launched on a variety of high-latitude orbits from a point between San Diego and Santa Barbara without passing over either land or heavily traveled sea lanes. Satellites launched toward the south would also run less risk of being mistaken for intercontinental missiles by the Soviet Bloc nations.

Appendix V

GUIDANCE AND CONTROL

It is proposed to use the equipment developed for the SM-65 to guide the missile up to the point of burnout of the booster. After burnout it will be possible to compute from the guidance radar the time at which the vehicle will reach its highest altitude, the highest altitude, and the required orbital speed. If these computations show that a satisfactory orbit can be attained through use of the final-stage rocket, the time of firing, the correction to the anticipated direction, and the velocity increment needed will be transmitted by radio command to the guidance system of the final stage. The final stage will separate gently from the booster during the coasting portion of the flight between booster burnout and final firing, and the final-stage autopilot will take over attitude control, uncage a velocity meter, and prepare for final burning. At some point along the launch course the final stage will start and burn until the velocity meter indicates that the required additional velocity has been achieved. The direction of final burning will be controlled to bring the final stage onto an orbit as nearly circular as possible, with the altitude as near the design altitude as possible. A more complete design study of this system will be needed to determine the tolerances which can be expected, but a study in connection with the scientific satellite has shown that even with much cruder guidance provisions than those envisioned here useful orbits can be attained.

Attitude control in the final stage is required for photography. No design study has been made of this, but it appears entirely feasible to stabilize the vehicle's attitude for the short period required. The gyros in the autopilot and an occasional directional reference from the horizon or the sun could be used to sense the attitude and monitor the torquing devices. Hydrogen peroxide or bottled gas valved out through small motors or jets properly located to rotate the vehicle would serve to apply the required torques. The vehicle may have to be oriented in an attitude somewhat different from normal at the time of ejecting the film-recovery capsule, but no other guidance is needed for recovery.

Appendix VI

COMMAND COMMUNICATION

For the short duration, small-scale-photography vehicle, a pre-set timing device will be adequate to turn the camera on and off if some tolerance is allowed for uncertainty as to the exact orbit period. The same programmer could be used to turn on and off a command receiver and radio beacon in the vehicle so that response to interrogation and ability to receive radio commands would be limited to periods when the vehicle is over a selected station in the United States.

A radio beacon could provide a signal from the vehicle which could be followed by ground tracking equipment. Operation on a frequency in the UHF is suggested so that there will be no need for a highly directive antenna on the vehicle. A command message transmitted from the ground tracking and command station and received by the beacon receiver could be used to specify the time for initiation of recovery, after the orbit had been established.

A variety of tracking equipment could be used on the ground. A relatively simple system using a ground transmitter with a broad-beam antenna aimed in the general direction of the vehicle and a receiver system which tracks the radiation received from the radio beacon is suggested. The transmission could consist of either pulsed radiation or continuous waves with suitable modulation, and the receiver system can use a large trainable antenna or a number of spaced antennas. Data from the receivers processed through a suitable computer would give the information from which the computer could predict the future orbit of the vehicle. In the case of the small-scale-photography vehicle this information would be used only to select the time to initiate recovery and to predict the recovery area.

In the case of the larger-scale-photography vehicle, a separate command will be required for each picture. The computer could generate the proper command sequence on the basis of the desired centers of the pictures.

A single command station in the United States would be in contact with each vehicle for at least two successive passes every day. The total time available for transmission of information from a single station will be at least twenty minutes. If, in the case of the larger-scale-photography vehicle, 360 pictures are taken each day, the transmission of data required to schedule each picture must be accomplished in 3 seconds. Assuming that a computer "word" of 5 bits is used to establish the angle of the camera for each picture, a rate of transmission of 5 bits per second will allow adequate time for establishing, checking, and correcting the program each day. Using pulse code signals for security and redundancy would permit continuous transmission, checking, and error correction with rates of the order of 25 pulses per second. The memory of the programmer could be a magnetic tape using phosphor bronze or mylar base and driven by a precision clock through its full length in a period of one day.

Times would be established by positions along the tape, and angles would be established by pulse code on several tracks of magnetic spots on the tape. The angle commands on the tape would be compared continuously with angles sensed from the camera and vehicle control system, and error signals derived from this comparison would be used to adjust the camera angle. Commands to snap the shutter and advance the camera film would be recorded on a separate track which would actuate the camera at the indicated times. Using one tenth of an inch of tape motion per second of operation, a total of approximately 1000 feet of tape is required. The signals could be recorded at each command interval during rapid re-wind of the tape. By moving the tape at 100 feet per minute during re-wind and 6 inches per minute during operation the schedules could all be met. Neither of these tape speeds is unreasonable.

Appendix VII

RECOVERY OF FILMS

Work leading to the design of ICBM warheads which can re-enter the atmosphere successfully has shown that bodies with sufficiently high ratio of drag to weight do not suffer excessively from heating. While it would be desirable to recover as much as possible of each vehicle, the most important item is the exposed photographic film. Large amounts of information can be stored on small quantities of the new thin-base aerial film. A mild steel case with interior insulation will survive re-entry at the contemplated speeds if a parachute is used to slow the vehicle during its descent. Contact with the ground will be fairly gentle. The case will be designed to float in water. A small radio beacon in the UHF range will be started at the time of firing the recovery rocket so that the fixing network can follow the capsule during re-entry. The beacon will continue to operate for some time after impact. Aircraft equipped with standard UHF homing gear can locate the package.

If the rocket imparts a backward speed of approximately 2000 feet per second relative to the orbiting body in a direction within a few degrees of the original path, the re-entry body will fall into an elliptic trajectory similar to those followed by ballistic missiles. The impact area will be about 2000 miles ahead of the point at which the reverse impulse is applied, and within a few miles laterally of the projected flight path. A lateral error of 10 degrees in the direction of reverse thrust would mean a deviation of less than 30 miles to one side or the other beneath the flight path. If the reverse thrust produces a relative velocity uncertain in magnitude by as much as five per cent, the distance from initiation to impact will vary by less than 100 miles. The recovery area can therefore be predicted from orbit data quite early in the orbiting flight. Selection of a proper pass and moment for initiating recovery will permit the selection of terrain in which recovery should be easy with helicopters or light aircraft. A recovery crew could be dispatched to the center of the predicted area several hours before ejection of the capsule and should be able to pick it up within an hour after impact.

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Santa Monica, California

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TRIP NOTES

MANAGEMENT COMMITTEE VISIT TO THE

AIR RESEARCH AND DEVELOPMENT COMMAND (U)

13 May 1955

by

Brownlee W. Haydon
The Rand Corporation

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Detection and Vulnerability of Balloon Systems

This briefing was delivered by Mr. Richard Coons. He acknowledged the early and continuing efforts in this field by RAND (chiefly Will Kellogg). It was viewed as an important reconnaissance system.

Right now we have balloons that will go to 80,000 ft (actually less than that at night) and we are advancing the state-of-the-art of ballooning as we learn more about winds at these altitudes. Right now we only know enough to be sure that sometime the so-called prevailing westerlies go toward the east for periods up to several weeks, and that our present balloons won't go far enough to achieve the desired mission.

He mentioned the effect of sunset and earthset on the balloons: we can program it so it will come down to lower levels at night to take advantage of the higher-velocity wind-streams (c. 40,000 ft) and then let it rise again at dawn.

The problem of detection is not easy to lick. They are familiar with RAND's work on the detection of balloons in the upper atmosphere by infrared devices. They are using glass boxes and cardboard boxes for instrumentation, but they have about 1000 lb of steel shot or dust aboard as ballast. And it's really easy to see these things in daylight. When they're cruising along at 80,000 ft they look like they're at about 20,000 ft and you can follow them from town to town. The balloon is not vulnerable to interception except when they are at the fighter's altitude.

The question was asked: What's it cost to knock down relative to the cost of getting the balloons up there? Maybe we should let lots of them go to make the Soviets expend money and effort in a counter-system. If the balloons are not too costly, and if a single operation is contemplated, maybe you just saturate the defenses--let them knock a lot of them down;

they can't get them all. Or can they?

It seems probable the flights would entail numbers up to 100. The estimated cost of a balloon is $1200 and the payload--depending upon instrumentation--may cost $8,000 to $10,000. The objective at ARDC is to develop a system that will carry a one-ton payload aloft for periods up to 10 days. More must be learned about the wind patterns at these altitudes. They have been talking about launching rates of 2500 in three months. This is a $25,000,000 program for the balloons alone.

Someone asked how rapidly the balloons regained altitude after sun-up and a specific number was given which I missed--several hundred ft/min I think.

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