A Quarter of a Century of Photography from Space

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Photographic space missions have been designed to accomplish a variety of objectives, some scientific, some applied, and some commercial. In this talk I shall discuss primarily those scientific missions dealing with lunar and planetary exploration. I will mention meteorological satellites in passing. I plan to talk a little about Landsat, as it represents a new class of very important application satellites.

When considering photographic options for space missions, a number of system choices must be made early in the design phase. What type of camera should be used--film or television? Is storage of the pictures required--is a tape recorder necessary? Are the pictures to be returned to earth by telemetry or by physical recovery of the film? These topics are fundamental to all photographic space missions and dictate the style and characteristics of the overall operation. Today I shall discuss space missions in terms of their camera sensors and in terms of data storage and the method of return of the data.

The Early Years

Following World War II, a number of organizations, including Rand, investigated the feasibility of launching a man-made satellite. Rand's first report on the subject was published in May 1946, while satellite design studies continued and investigations into applications for these vehicles received increased emphasis. As early as 1951, Rand was engaged in studies involving photography of the earth from satellites. This ongoing program was under the direction of James Lipp and Robert Salter. James Thompson was responsible for the camera system; I worked on this part of the study.

One imaging system design consisted of two image orthicon cameras with 38-in. focal length, f/17 lenses mounted behind a scanning drum designed to take pictures across track. The camera scanned 558 lines per frame and took pictures at a rate of 23 frames per second. The expected ground resolution was 20 meters high contrast and 65 meters low contrast. The camera read-out rate was 6.5 Mc, thus requiring the development of a high-speed tape recorder.

The orbit proposed for the photographic satellite was circular at 300 miles altitude and 97 degrees inclination. This inclination was chosen so that the orbital precession due to the earth's equatorial bulge would keep the illumination angle constant throughout the year (see Fig. 1). The Landsat satellites and most meteorological satellites are launched into this type of orbit.

In 1954, the Viking 11 high-altitude rocket was launched at the White Sands Proving Ground in New Mexico. The rocket was equipped with a modified K-25 aircraft camera with an f/4.5, 163-mm focal length lens;

the aperture was set at f/8 and a shutter speed of 2 msec was used in the flight. The camera format was 4 x 5 in.; 20 ft of 5-1/4 in. high-speed infrared film were loaded in the camera magazine. The rocket reached an altitude of 158 miles and the camera took excellent pictures of the earth through much of its trajectory.

The pictures obtained from altitudes of 100 to 158 miles were of particular interest as they clearly showed atmospheric effects such as contrast reduction which could not be simulated in the laboratory. Thus, these pictures illustrated what could be expected from satellite photography. The ground resolution of the pictures was about 100 to 150 meters; the Rio Grande river could be seen easily, many railroads were visible, approximate street patterns of El Paso could be discerned, and the large airports--El Paso International, Biggs Field, and Holloman Airbase--were conspicuous. The photographs confirmed the usefulness of pictures taken at satellite altitudes to detect, recognize, and identify man-made features.

During this period many engineers who had contributed to the early studies left Rand to work in industry; however, Amrom Katz came to Rand to work on photographic systems for space vehicles. He had a great deal of experience with aircraft cameras.

A new satellite study was started in early 1957 aimed at simplifying the engineering design and operational concepts of a photographic mission. Amrom Katz and I headed the research effort. Incorporated in the study were spin stabilization of the spacecraft, physical recovery of film, and the idea of a spinning panoramic camera designed to move the film past a slit during exposure at a rate to compensate for the image motion (see Fig. 2).

The slit served as a shutter and the exposure was controlled by varying the width of the slit. The spin pan camera was to have a 12-in. focal length and carry 500 ft of 5-in. wide film. A ground resolution of 20 meters was expected from a nominal altitude of 180 miles. The spin pan camera was a new concept in camera design; a patent was applied for and was issued in 1964.

A major study on lunar exploration was carried out at Rand from 1956 to 1959 under the direction of Robert Buchheim. In the context of this study, I wrote papers in 1958 and in 1960 describing photographic missions in which the spacecraft trajectory would pass around the Moon, take pictures of its far side with a spin pan camera, and return to earth for ocean recovery of the film (see Fig. 3). This mission was not carried out until many years later, in 1968, when the Soviet Zond 5 spacecraft flew around the Moon and its ejected capsule was picked up in the Indian Ocean.

In 1958 a camera was designed at the Jet Propulsion Laboratory to take pictures of the far side of the Moon from the Pioneer IV spacecraft. The camera was to take the pictures on 35-mm film with a 180-mm focal length lens, the film was to be processed on board the spacecraft, and the pictures were to be transmitted to the ground through the telemetry channel by a photoelectric scanner. This camera was built and tested but never flown.

Because of the concern that film might suffer radiation damage on the way to the Moon, another approach was developed at JPL using a slow-scan vidicon camera. The vidicon tube had a "sticky" or long-time-constant photoconductor which could be read out over a 2 second period, thus greatly reducing the bandwidth requirement of the tape recorder. This first vidicon system was flown on the Pioneer IV spacecraft, launched in 1959. The camera used an f/2, 50-mm focal length lens and a 1.5-msec focal plane shutter. The spacecraft failed to return pictures because it passed too far from the Moon. With this beginning, JPL has opted to fly vidicon cameras on all of their photographic missions to the Moon and planets.

On October 4, 1959, the Soviets launched the Luna 3 spacecraft on a trajectory to fly by the Moon. On October 7, fifteen pictures of the back of the Moon were taken on special 35-mm film by a camera designed to take pictures simultaneously with 200-mm, f/5.6 and 500-mm, f/9.5 focal length lenses. The film was processed with liquid on board the spacecraft and pictures sent to Earth by means of an optical scanner. With this very successful beginning, the Soviets have flown cameras using film and optical readout on most of their photographic missions to the Moon and planets. This was the start of photography from space.

The Photographic Space Missions

The characteristics of the cameras flown on many of the space missions have been listed in four tables. Table 1 contains those missions in which the pictures were taken on film, with the film processed on board the spacecraft and returned to earth by means of an optical scanner and telemetry. Table 2 contains missions in which the pictures were taken on film and the film was returned to earth for processing. Table 3 contains missions which used vidicon cameras to take pictures, and Table 4 contains missions which used line-scan devices to form pictures.

Table 1

MISSIONS WITH FILM CAMERAS AND TELEMETRY READOUT

Program	Year Active	Lens: Focal Length (mm)	Lens: Focal Ratio (f/no.)	Format (cm x cm)	Film Width (mm)	Minimum Distance Between Scan Lines (μm)
Luna 3	1959	200	5.6	2.5 x 2.5	35	25
		500	9.5	2.5 x 2.5	35	25
Mars 1	1962	35	2.0	4.8 x 4.9	70	33.3
		750		4.8 x 14.25	70	33.3
Zond 3	1965	106.4	8	2.4 x 2.4	25.4	21.8
Luna 12	1966	106.4	8	2.4 x 2.4	25.4	21.8
		500	9.5	2.4 x 2.4	25.4	21.8
Lunar Orbiter	1966-1967	80	5.6	5.5 x 6.5	70	2.54
		610	5.6	5.5 x 21.9	70	2.54
Mars 2, 3	1971	52				20
Mars 4, 5	1973	52	2.8	2.3 x 2.25	25.4	12.2
		350	4.5	2.3 x 2.25	25.4	12.2

Table 2

MISSIONS WITH FILM CAMERAS AND FILM RECOVERY

Program/Camera	Years Active	Lens: Focal Length (mm)	Lens: Focal Ratio (f/no.)	Format (cm x cm)	Film Width (mm)	Number of Frames
Mercury/Hassalblad	1962-1963	80	2.8	6 x 6	70	
Gemini/Hassalblad	1965-1966	80	2.8	6 x 6	70	
Vostok/Konvas	1961-1963	50 75 135	2 3.5 2.8	1.6 x 2.2	35	
Vashkod/Konvas	1964-1965	50 75 135	2 3.5 2.8	1.6 x 2.2	35	
Zond 5, 6, 7, 8	1968-1970	400	6.3	13 x 18	190	200
Apollo/Hassalblad	1968-1972	80 250	2.8 5.6	6 x 6	70	
Apollo/Hycon	1970-1971	450	4	11 x 11	127	469
Apollo/Itek	1971-1972	610	3.5	11 x 113	127	1617
Apollo/Fairchild	1971-1972	75	4.5	11 x 11	127	3600

Table 3

MISSIONS WITH VIDICON CAMERAS

		Lens				
Program	Years Active	Focal Length (mm)	Focal Ratio (f/no.)	Format (cm x cm)	Number of TV Lines	Distance Between Scan Lines (µm)
Tiros	1960-1967	5.4	1.5	.62 x .62	500	12.4
		5.8	1.8	.62 x .62	500	12.4
		40	1.8	.62 x .62	500	12.4
Nimbus		17	4	1.12 x 1.12	830	13.4
		5.8	1.8	1.12 x 1.12	830	13.4
ESSA 1, 2, 3, 5, 6	1967-1969	5.8	1.8	1.12 x 1.12		
Meteor	1966					
Ranger	1964-1965	76	2	1.14 x 1.14	800	14.25
		25	0.95	1.14 x 1.14	800	14.25
		76	2	0.28 x 0.28	200	14
		25	0.95	0.28 x 0.28	200	14
Mariner 4	1965	305	8	0.56 x 0.56	200	28
Mariner 6, 7, 9	1969,	50	5.6	0.96 x 1.25	704	13.6
	1971-1972	500	2.5	0.96 x 1.25	704	13.6
Mariner 10	1974-1975	1500	8	0.96 x 1.25	700	13.7
Surveyer	1966-1968	25-100	4		600	
Lunokhod 1, 2	1970, 1973	6.7	4		625	
Landsat 1, 2	1972-	126		2.5 x 2.5	4200	5.95
Viking 1, 2	1976	475	3.5	1.25 x 1.4	1056	11.8

Table 4

MISSIONS WITH LINE-SCAN CAMERAS

Program	Years Active	Lens Focal Length (mm)	Lens Focal Ratio (f/no.)	Angular Resolution (degrees)
Luna 9, 13	1966-1967			0.06
ATS-1	1966-	250	2	
ATS-3	1967-	375	3	
SMS	1974-			
Lunakhod 1, 2	1970-1973		6	0.06
Luna 19	1971			
Pioneer 10, 11	1973, 1975			0.03
Venera 9, 10	1975			
Viking Lander	1976-			
Landsat 1, 2	1972-			

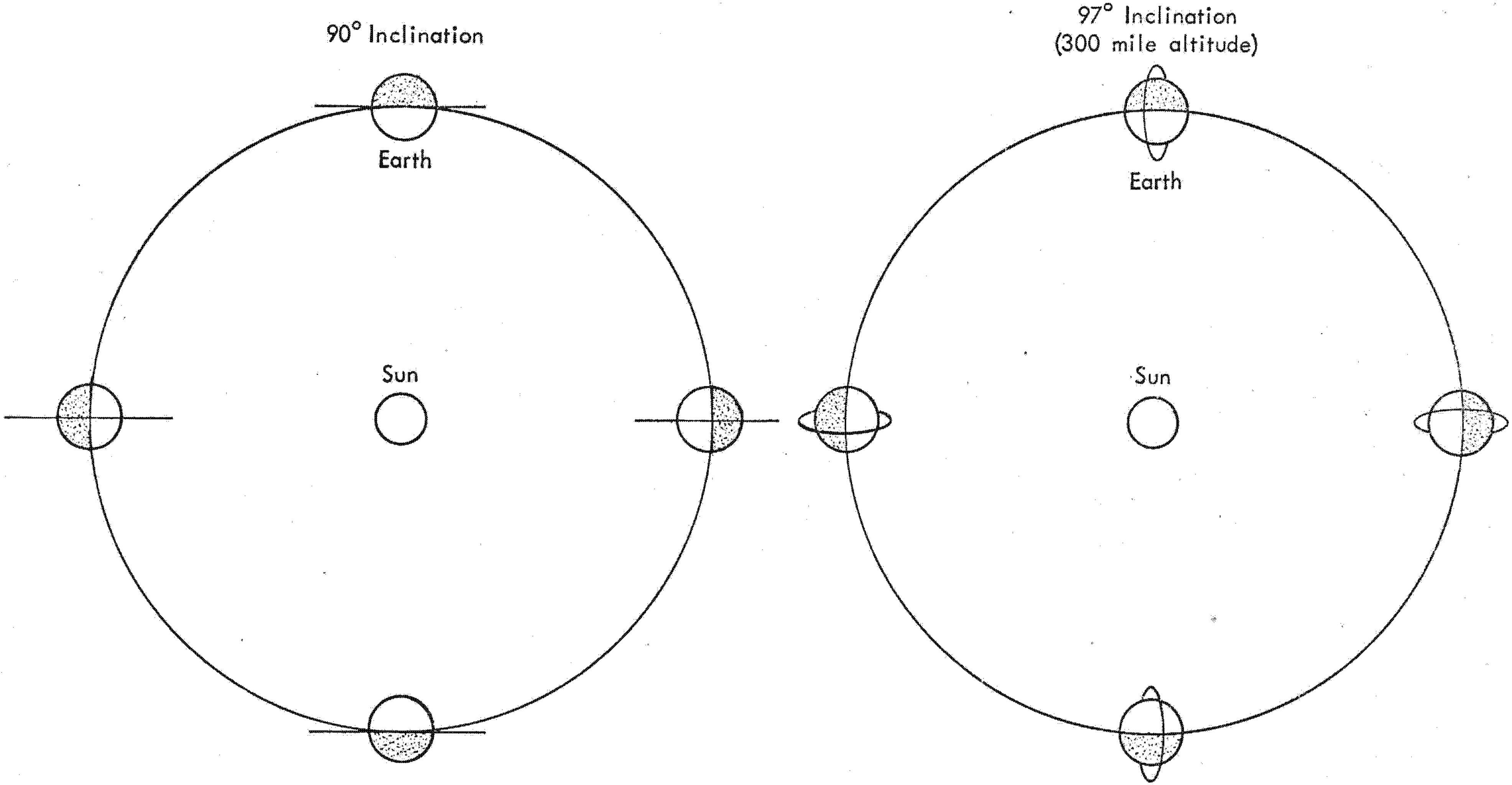

Fig. 1 — The Earth's Equatorial Bulge Causes the Satellite to Precess

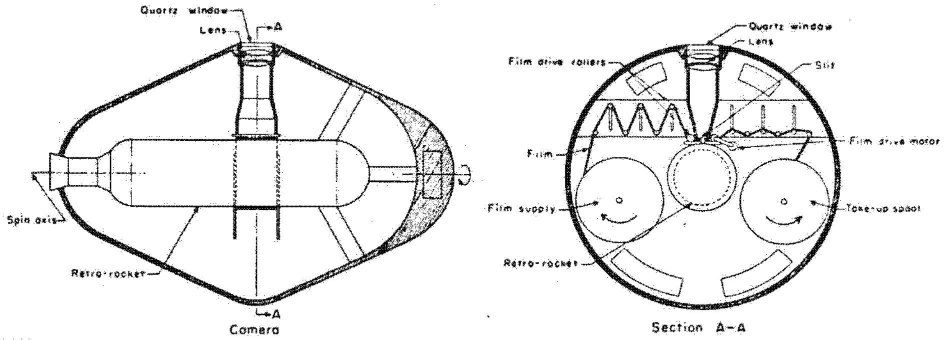

Fig. 2. Schematic of spinning panoramic camera

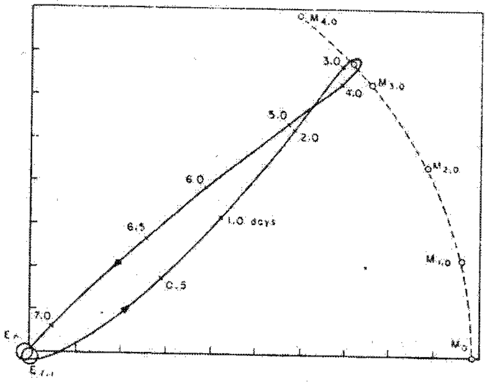

Fig. 3. Typical trajectory
of a lunar photographic vehicle

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In this talk I plan to discuss projects with which I have been associated or in which I have been especially interested. The talk is not a historical survey, and thus many important and exciting projects will not be mentioned. It is not intended to be a balanced and comprehensive treatment of the subject.

When considering photographic options for space missions, a number of system choices must be made early in the design phase. What type of camera should be used--film or television? Is storage of the pictures required--is a tape recorder necessary? Are the pictures to be returned to earth by telemetry or by physical recovery of the film? These topics are fundamental to all photographic space missions and dictate the style and characteristics of the overall operation. Today I shall discuss space missions in terms of their camera sensors and in terms of data storage and the method of return of the data.

For reference, I have broken the time period into three eras, corresponding roughly to the decades of the 1950s, the 1960s, and the 1970s. The Soviet approach to photography from space also will be touched on.

The 1950s

( ) The 1950s were characterized by the establishment of the feasibility of launching satellites, the initiation of development programs, and the achievement of some successes. It was also necessary to identify important uses for the space vehicles to assure continued progress.

( ) Following World War II, the military agencies sponsored a number of studies that investigated the feasibility of launching satellites. Rand was asked by the Air Force to make one such analysis; the first study was published in 1946, followed by a more comprehensive series of reports in 1947. A subsequent investigation of the uses for satellite vehicles resulted in a series of publications in 1951; these included scientific, military, and commercial applications. At this time, the decision was made to proceed with a design study of an observation satellite system in sufficient detail to establish objectives, to confirm the ability to flag potential problem areas, and to cost the program. Called Project Feedback, the program was placed under the direction of James Lipp and Robert Salter. James Thompson was responsible for the camera system; I worked on this part of the program.

( ) When this study started, there had been very little experience with complex systems, rockets were still a novelty, and there were no satellite launchers, tracking, or communication facilities. Everything had to be built from scratch.

( ) As best as I can recall, the mission design rationale for the study was as follows. Because the total system would be very expensive, it should operate for a long time, perhaps a year, and be capable of returning a large amount of data. To be assured of a year's operation, an altitude of 300 miles was chosen to be safely free from atmospheric drag. A television system was selected to take the pictures and return them to earth by telemetry for one year or more. Since the readout stations were to be far from the picture-taking areas, a tape recorder would be needed for storage. Furthermore, because the power requirements for operating the television system and for data transmission were high, it was felt that a nuclear auxiliary power system was necessary. Needless to say, the resulting satellite design was complex (see Fig. 1).

( ) The imaging system consisted of two image orthicon cameras with 38-in. focal length, f/17 lenses mounted behind a scanning drum designed to take pictures across track. The camera scanned 558 lines per frame and took pictures at a rate of 23 frames per second. The expected ground resolution was 70 ft. high contrast and 200 ft. low contrast. The camera read-out rate was 6.5 Mc, thus requiring the development of a high-speed tape recorder.

( ) The orbit was circular at 300 miles altitude and 97 degrees inclination. This inclination was chosen so that the orbital precession due to the earth's equatorial bulge would keep the illumination angle constant throughout the year (see Fig. 2).

( ) The satellite was to be launched by a two-stage rocket (see Fig. 3). Frequent discussions with the Air Force were held, and in 1954, after the Project Feedback reports were published, Rand recommended that the Air Force proceed with the development of an observation satellite.

( ) Using the Feedback studies as a starting point, the Air Force contracted for three one-year competitive bids for the overall satellite system. These studies comprised the Pied Piper Project. By this period, the ballistic missile program was sufficiently advanced so that it would not be necessary to develop the entire satellite launcher; we could simply add a second stage to the Atlas ballistic missile. The Pied Piper competition was won by Lockheed Aircraft and the WS-117L program was started. This project was sometimes referred to as Samos.

( ) In the course of the Rand-Air Force Feedback discussions, Amrom Katz, a physicist and photo-interpretor at Wright Field, heard the virtues of observation satellites described. To satisfy himself that low-resolution pictures would be of value, he had a lens from an 8-mm movie camera mounted on his Leica and took a series of pictures from an aircraft at high altitude. These pictures convinced Amrom that observation satellites were going to be very important in the future, and after a little persuasion he came to Rand to work.

( ) In May 1954, the Naval Research Laboratory launched its vertical rocket Viking 11, which contained a modified K-25 aircraft camera. This camera had a 163-mm focal length lens and a 4 x 5 format. Although pictures from vertically fired rockets had been taken before, these taken by Viking 11 were important because they were good quality photographs taken through the atmosphere at altitudes up to 158 miles at a time when atmospheric effects and scale and film resolution trade-offs were controversial.

( ) Following the Project Feedback studies, a number of engineers left Rand to go to Lockheed and other organizations so that, before long, Amrom and I were the only scientists left actively concerned with picture taking from space vehicles. During this period, we kept informed of the progress of the Pied Piper competition and acted as advisors to the Air Force on the WS-117L program.

( ) Eastman was the contractor for the Samos camera system. The pictures were to be taken on 70-mm film, processed on board by a web process (later known as Bimat), and transmitted to the ground using a high-resolution scanner to be developed by CBS Laboratories. The camera was not a frame type but a strip camera in which the film moved during exposure at a rate to compensate for the forward movement of the satellite in orbit. The camera focal length was 6 in.; a ground resolution of 100 ft. was expected from a 300 mile orbit. The Agena stage of the launch vehicle was to be developed by Lockheed and in combination with an Atlas first stage was to put the satellite in orbit.

( ) The development of the Samos satellite system continued for a number of years and resulted in a few test flights. Although the program was cancelled because of the cost and limited growth potential, many of its components were important to future missions. The web processor and the high-resolution scanner were used in the very successful Lunar Orbiter Program in the mid-sixties.

( ) By 1956 it became apparent that ablative materials could be used to protect vehicles returning to earth from orbit. It was also obvious that photographic film was an excellent light-weight storage medium for pictures (particularly when compared to television tape recorders). Moreover, the development of the Thor missile was proceeding faster than the Atlas, and the Thor, with an additional stage, could orbit a small satellite. The ingredients for a new concept in observation satellites were in hand.

( ) During this period, the U.S. ballistic missile and satellite programs were experiencing many failures. Rand engineers felt that reliability could be improved by simplifying the engineering design and operation. One example was to use spin stabilization for space vehicles. Such concepts, together with the idea for a spinning panoramic camera, led to the start of a new observation satellite study in early 1957. The principal objective of the new design was to minimize the development time and to obtain operational reliability quickly. Amrom Katz and I headed the study.

( ) This new observation satellite study was completed and the report written in less than six months. The satellite was to be launched using the Thor as a first stage, the second stage of the Vanguard launcher, and a small third stage to orbit the vehicle. The satellite, to be spin stabilized, was to contain a panoramic camera in which photographic film was moved past a slit during exposure at a rate to compensate for the image motion. The slit thus served as a shutter (see Fig. 4). The spin pan camera was to have a 12-in. focal length and carry 500 ft of 5-in. wide film. A ground resolution of 60 ft was expected from a nominal altitude of 180 miles. After about one day in orbit, a retro rocket was to be fired by ground command and the film recovered in a specific region in the ocean. In November of

1957 Rand sent the Air Force a recommendation that the Air Force proceed with the development of this type of satellite system. The spin pan camera was a new concept in camera design; a patent was applied for and was issued in 1964.

( ) A major study on lunar exploration was carried out at Rand from 1956 to 1959 under the direction of Robert Buchheim. In the context of this study, I wrote papers in 1958 and in 1960 describing photographic missions in which the spacecraft trajectory passed around the Moon and returned to earth for ocean recovery of film. Spin pan cameras were to take pictures of the far side of the Moon (see Fig. 5).

( ) In 1958 a camera was designed at the Jet Propulsion Laboratory to take pictures of the far side of the Moon from the Pioneer IV spacecraft. The camera was to take the pictures on 35 mm film with a 180 mm focal length lens, the film was to be processed on board the spacecraft, and the pictures were to be transmitted to the ground through the telemetry channel by means of a photoelectric scanner. This camera was actually built and tested but never flown.

( ) Because of the concern that film might suffer radiation damage on the way to the Moon, another approach was developed at JPL using a slow-scan vidicon camera. The vidicon tube had a "sticky" or long-time-constant photoconductor which could be read out over a 2 second period, thus greatly reducing the bandwidth requirement of the tape recorder. This tube, with its "sticky" photoconductor, was a very important development and was used, with modifications, on the television systems flown on the Mariner 4, Mariner 6 and 7, Mariner 9, and Mariner 10 spacecraft and will fly on the Mariner Jupiter/Saturn missions to be launched this year. The first vidicon system, flown on the Pioneer IV spacecraft, was launched in 1959 and used an f/2 50 mm lens and a 1.5 msec focal plane shutter.

The 1960's

Ranger 6, 7, 8
Mariner 4
Lunar Orbiter 1, 2, 3, 4, 5
Manned Flights
Mariner 6, 7

The 1970's

Apollo 15, 16, 17
Mariner 9
Mariner 10
Landsat 1, 2
Viking A, B

The Soviet Photographic Systems

Luna 3
Mars 1
Zond 3
Venera 2
Luna 12
Zond 5, 6, 7, 8
Mars 2, 3, 4, 5
Lunakhod 1, 2
Luna 19
Venera 9, 10

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Total Weight (lb)

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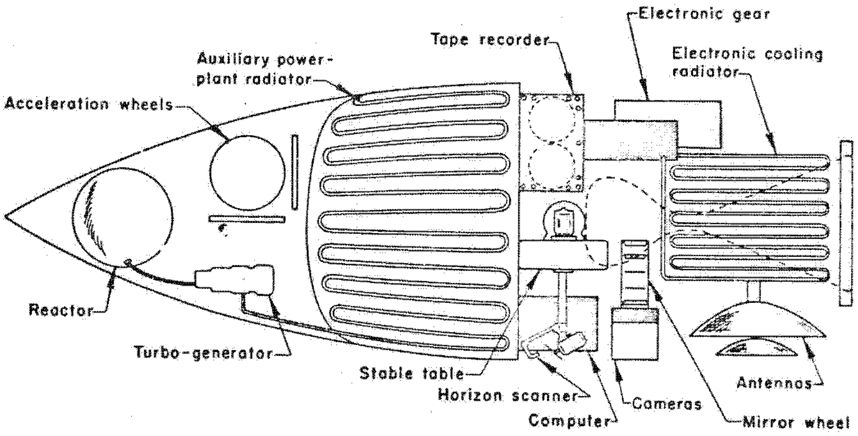

Fig. 1—Schematic of Orbiting Vehicle

FIG 1

a desirable isolation of the nuclear powerplant from the electronic equipment. As mentioned elsewhere in this report, heat rejection from the powerplant is obtained through external radiation. The proposed configuration is such that the radiator is located in the outer skin of the fuel and oxidizer tank section* (see Fig. 1). The various heat quantities to be dissipated from the vehicle and the corresponding radiator sizes are summarized in Table 2, below.

Table 2

SUMMARY OF HEAT DISSIPATIONS AND RADIATOR CHARACTERISTICS

Heat Source	System	Radiator Temperature (°F)	Heat Rate (kw)	Radiator Area (ft²)
Powerplant	Mercury	627	74	133
Powerplant	Water (moderator)	300*	4	30
Electronic equipment	Water (cooling)	90	2	56

*68 psia.

Ascent and Orbital Guidance. The major components of the ascent and orbital guidance system include a stable platform, ascent computer, orbital computer, horizon scanner, and acceleration wheels. Acceleration wheels per se have no climatization or shielding requirements and are located just aft of the

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*The remaining portion of the vehicle's skin aft of the fuel tank is jettisoned during booster separation.

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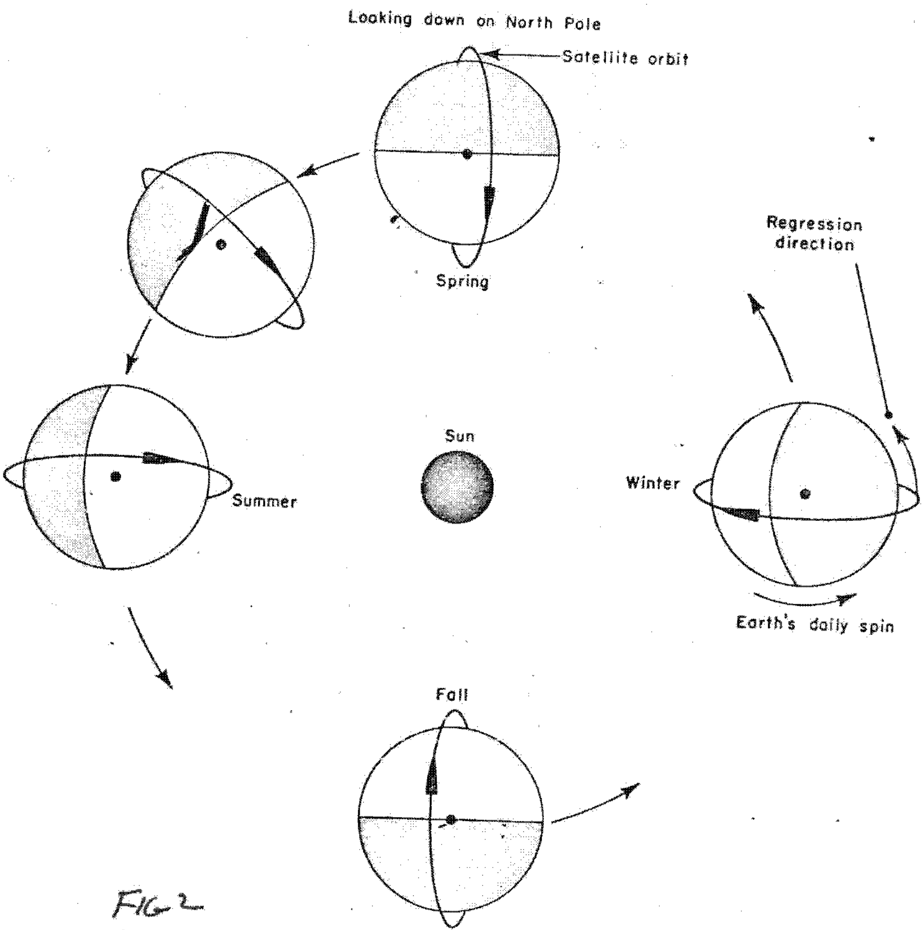

FIG 2

~~Fig. 45~~—Effect of seasons on satellite (83° retrograde orbit)

~~period of the 83° retrograde orbit, the satellite would be able to operate in maximum daylight brightness over targets of interest throughout all seasons of the year.~~

~~With an 83° orbit, a change of 1° in inclination would result in a variation in the regression period of about 50 days. It will be shown under "Guidance and Control," page 127, that the tolerance for establishing the orbit (based on anticipated initial guidance accuracy) would be about 0.1° in azimuth. This would introduce a 5-day or 1½ per cent uncertainty in the yearly regression period.~~

~~**Ground Coverage Attained by Successive Revolutions of the Satellite.** Reasons have been shown for choosing a retrograde orbit of 83° inclination and an altitude of 300 mi.~~

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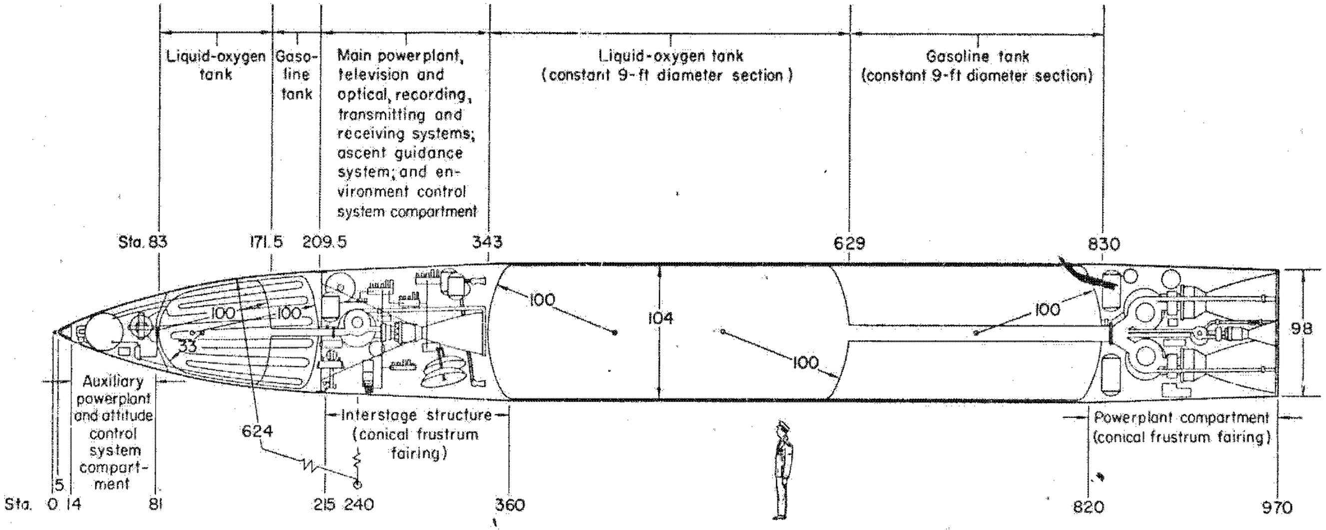
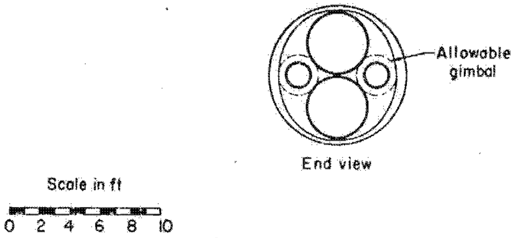


Vehicle characteristics	Booster plus satellite stage		Satellite stage	
	Full	Empty	Full	Empty
Weight (lb)	177,900	35,400	22,520	4,480
Primary structure weight (lb)	2,485		620	
Covering and secondary structure weight (lb)	1,750		335	
C G location, station number	524	381	168	207
Mass moment of inertia, pitch and yaw (slug ft^2)	1,447,102	675,558	12,320	6,186
Mass moment of inertia, roll (slug ft^2)	49,405	7,805	3,393	495
Thrust developed (lb)	284,660*		36,030	
Propellant flow rate (lb/sec)	1,140		122	
Motor exit area to throat area ratio	10		20	
Combustion chamber pressure (psia)	600		600	
Propellant system	$O_2 + CH_{2.1}$		$O_2 + CH_{2.1}$	
Specific impulse (sec)	271.4†		299	

* Sea level static. † Integrated time average value.



~~Fig. 10~~—Schematic of satellite vehicle

Fig 3

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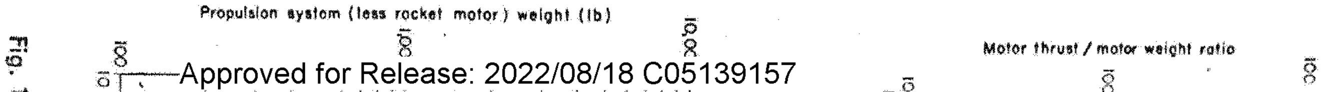

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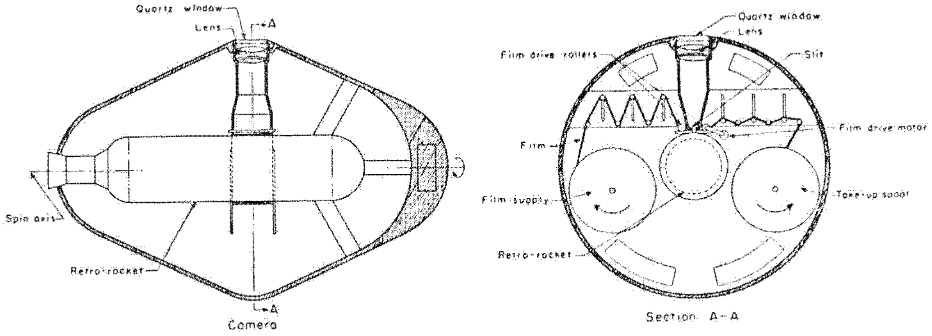
in the Pioneer III to measure the proximity of the moon could be used to measure the spin rate and lunar direction as well as to initiate camera operation. Another method would be to measure the passage of the sun through a slit with a photocell; a simple computer could then adjust the film velocity to compensate for the measured spin rate. To maintain the focus of the lens and to keep the film flexible it is probably desirable to pressurize the camera and to control the temperature and humidity near the lenses and film. Fig. 2 shows the camera operation.



~~Fig. 2.~~ FIG 4 Schematic of spinning panoramic camera

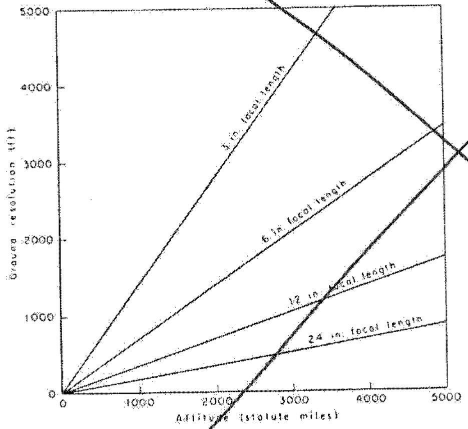


Fig. 3. Ground resolution as a function of altitude—vertical view. $x = 207.7 \frac{h}{RF}$

x = ground resolution (ft)
h = altitude (statute miles)
$R = 50$ = film resolution (lines/mm)
F = lens focal point (in.)

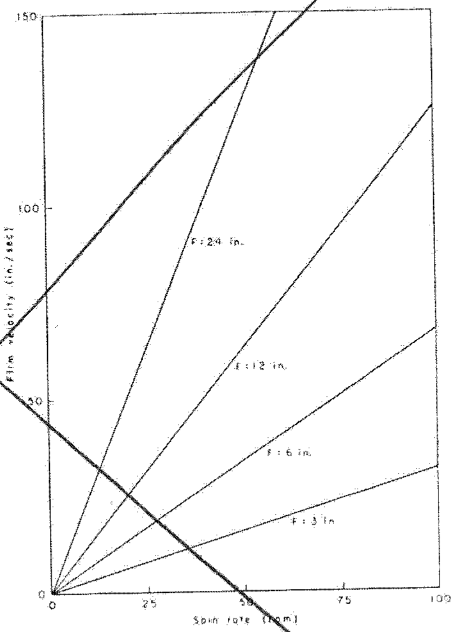


Fig. 4. Spin rate, lens focal length and required film velocity

$V = .10472\ F$ (rpm)
V = film velocity (in./sec)
F = focal length (in.)
rpm = spin rate (rpm)

The main factor contributing to the loss of contrast in high-altitude aerial photography of the earth is the scattering of non-image forming light into the optical system by the earth's atmosphere. If, for example, the original contrast is 10:1 and scattered light increases the exposure of both black and white areas mi is indica[illegible]/sec in velocity and 1 mil in path angle for trajectories defined by an initial velocity of 34.860 ft/sec at an altitude of 350 s mi above the earth [6]. For this example, the design lunar altitude is varied by specifying the path angles of the velocity vector at the 350 s mi altitude point.

Interesting circumlunar flights which return to the earth are limited to those which move in retrograde motion relative to the moon. These are the figure eight paths which cross the moon's orbit before the moon arrives. Fig. 5 shows an example of a trajectory which satisfies the requirement [5]: the path passes within 3000 mi of the moon; the total flight time is 7.1 days. Total flight times of 6 to 12 days are possible for reasonable trajectories, depending upon the particular initial conditions.

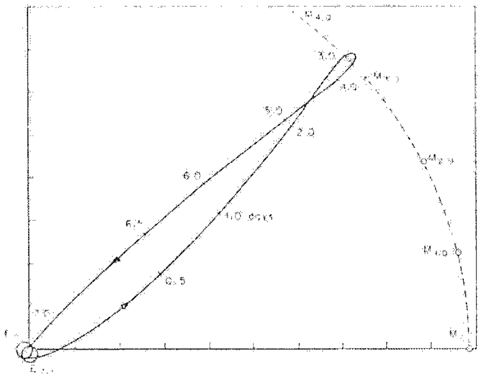


Fig. 5. Typical trajectory of a lunar photographic vehicle

FIG 5

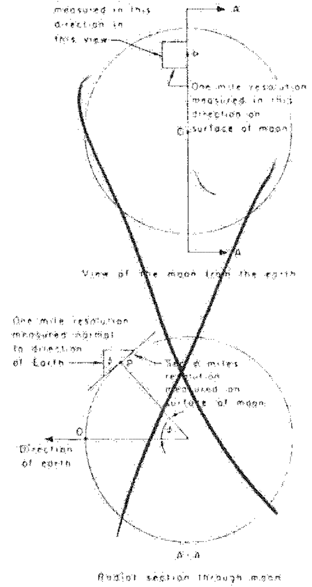


Fig. 6. Ground resolution as measured on the surface of the moon

[illegible]

Sun-Moon Attitude

In discussing the geometrical relationships between the moon's surface, the vehicle spin axis, and the direction of the sun, it is necessary to examine the photographic objectives. Certainly, one of the major purposes of the first few flights will be to maximize the area of photographic coverage so as to completely map the back side of the moon. Later priorities may shift to obtaining better quality pictures of particular interesting areas; these should include the front, as well as the back side of the moon.

The ground resolution (i.e., resolution measured at the surface of the moon) of pictures taken from the surface of the earth is determined by three factors: (1) the earth's atmosphere, (2) the distance to the moon, and (3) the angle between the tangent plane at the point in question and the normal to the line joining the centers of the earth and the moon. The turbidity of the atmosphere limits the resolution of earth-based telescopic photography to about one second of arc, which at the distance of the moon corresponds to about one mile in the plane normal to the light ray. For this reason, as illustrated in Fig. 6, the ground resolution of excellent moon pictures is about one mile in the direction normal to a plane passing through the center of the moon's face and one mile times

~~Fig. 8, an enlargement of a portion of the trajectory shown in Fig. 5, indicates the relative motion of the vehicle as it passes around the moon. Its velocity is about 5000 ft/sec relative to the surface of the moon and is about 3000 mi from it at the point of closest approach. The sun and the vehicle spin-axis are shown in a preferred orientation to record maximum-area pictures of the back of the moon.~~

~~After obtaining the first pictures and naming the newly discovered lunar formations, there will remain the task of obtaining better quality photographs for scientific study. For this purpose it is very important to make a close approach to the moon with a long focal length camera so that surface detail will be recorded. The ability to make a close approach depends greatly upon the performance~~

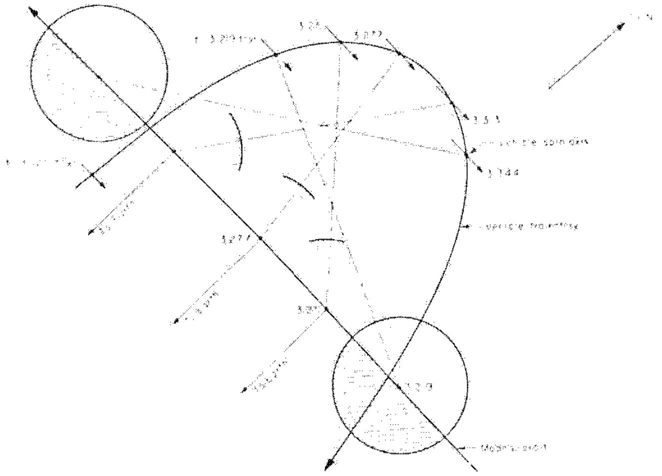


FIG 5 ~~Fig.~~ 8. Trajectory of vehicle in the vicinity of the moon New Moon
Note: Vehicle spin and sun position for photographing the back side

~~of the particular vehicle. Design planning figures of about 3000 mi ± 2000 mi altitude at the point of nearest approach seem reasonable for vehicles available in the near future.~~

~~Both astronomers and aerial photointerpreters are aware of the fact that 'flat' pictures, where the sun is behind the camera, are less interesting and have lower resolution due to the low contrast than pictures taken with side lighting. With this in mind, Figs. 9 and 10 show typical sun-moon positions and camera spin axis for obtaining excellent lunar pictures. Another effect used by both astronomers and photointerpreters for special purposes is the study of the long shadows when the sun is near the horizon. These high contrast shadows are larger than the objects causing them and so are much easier to resolve. Astronomers find such pictures useful in computing the altitude of lunar formations and in contouring. The photo-interpreter sometimes uses such pictures for computing the height of objects on the ground and for studying the texture of terrain. High resolution lunar pictures of this type will prove to be extremely interesting.~~

Since the best results will be obtained where the spin axis is parallel to the lunar surface, it is desirable to select the preferred direction of the spin axis. The spin axis shown in Fig. 8 is approximately normal to the line joining the

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When considering photographic options for space missions, a number of system choices must be made early in the design phase. What type of camera should be used--film or television? Is storage of the pictures required--is a tape recorder necessary? Are the pictures to be returned to earth by telemetry or by physical recovery of the film? These topics are fundamental to all photographic space missions and dictate the style and characteristics of the overall operation. Today I shall discuss space missions in terms of their camera sensors and in terms of data storage and the method of return of the data.

The Early Years

Following World War II, a number of organizations investigated the feasibility of launching a man-made satellite. Rand was one of these and their first report on the subject was published in May 1946. Satellite design studies continued at Rand and investigations into applications for these vehicles received increased emphasis. As early as 1951, Rand was engaged in studies involving photography of the earth from satellites. This continuing program was under the direction of James Lipp and Robert Salter. James Thompson was responsible for the camera system; I worked on this part of the study.

One imaging system design consisted of two image orthicon cameras with 38-in. focal length, f/17 lenses mounted behind a scanning drum designed to take pictures across track. The camera scanned 558 lines per frame and took pictures at a rate of 23 frames per second. The expected ground resolution was 70 ft. 20 meters high contrast and 200 ft. 65 meters low contrast. The camera read-out rate was 6.5 Mc, thus requiring the development of a high-speed tape recorder.

( ) The orbit was circular at 300 miles altitude and 97 degrees inclination. This inclination was chosen so that the orbital precession due to the earth's equatorial bulge would keep the illumination angle constant throughout the year (see Fig. 1). The Landsat satellites and most of the meteorological satellites are launched into this type of orbit.

In 1954, the Naval Research Laboratory launched the Viking 11 rocket at the White Sands Proving Ground in New Mexico. The rocket reached an altitude of 158 miles and contained a camera which took excellent pictures of the earth through much of its trajectory. The rocket was equipped with a modified K-25 aircraft camera with a f/4.5, 163-mm focal length lens; the aperture was set at f/8 and a shutter speed of 2 msec was used in the flight. The camera format was 4 x 5 in.; 20 ft of 5-1/4 in high-speed infrared film were loaded in the camera magazine.

The pictures obtained from altitudes of 100 to 158 miles were of particular interest as they clearly showed atmospheric effects such as contrast reduction which could not be simulated in the laboratory. Thus, these pictures illustrated what could be expected from satellite photography. The ground resolution of these pictures was about 100 to 150 meters; the Rio Grande river could be seen easily, many railroads were visible, approximate street patterns of El Paso could be discerned, and the large airports--El Paso International, Biggs Field, and Holliman Airbase--were conspicuous. The photographs confirmed the usefulness of pictures taken at satellite altitudes to detect, recognize, and identify man-made features.

During this period many engineers who had contributed to the early studies left Rand to work in industry; however, Amrom Katz came to Rand to work on photographic systems for space vehicles. He had a great deal of experience with aircraft cameras.

A new satellite study was started in early 1957 aimed at simplifying the engineering design and operational concepts of a photographic mission. Amrom Katz and I headed the research effort. Incorporated in the study were spin stabilization of the spacecraft, physical recovery of film, and the idea of a spinning panoramic camera designed to move the film past a slit during exposure at a rate to compensate for the image motion (see Fig. 2). The slit served as a shutter and the exposure was controlled by varying the width of the slit. The spin pan camera was to have a 12-in. focal length and carry 500 ft of 5-in. wide film. A ground resolution of 20 meters was expected from a nominal altitude of 180 miles. The spin pan camera was a new concept in camera design; a patent was applied for and was issued in 1964.

A major study on lunar exploration was carried out at Rand from 1956 to 1959 under the direction of Robert Buchheim. In the context of this study, I wrote papers in 1958 and in 1960 describing photographic missions in which the spacecraft trajectory would pass around the Moon, take pictures of its far side with a spin pan camera, and return to earth for ocean recovery of the film (see Fig. 3). This mission was not carried out until many years later, in 1968, when the Soviet Zond 5 spacecraft flew around the Moon and its ejected capsule was picked up in the Indian Ocean.

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( ) Because of the concern that film might suffer radiation damage on the way to the Moon, another approach was developed at JPL using a slow-scan vidicon camera. The vidicon tube had a "sticky" or long-time-constant photoconductor which could be read out over a 2 second period, thus greatly reducing the bandwidth requirement of the tape recorder.

This first vidicon system, flown on the Pioneer IV spacecraft, was launched in 1959 and used an f/2, 50-mm focal length lens and a 1.5-msec focal plane shutter. The spacecraft failed to return pictures, as it passed too far from the Moon. With this beginning, JPL has opted to fly vidicon cameras on all of their photographic missions to the Moon and planets.

On October 4, 1959, the Soviets launched the Luna 3 spacecraft on a trajectory to flyby the Moon. On October 7, fifteen pictures of the back of the Moon were taken on special 35-mm film by a camera designed to take pictures simultaneously with 200-mm, f/5.6 and 500-mm, f/9.5 focal length lenses. The film was processed with liquid on board and pictures sent to Earth by means of an optical scanner. With this very successful beginning, the Soviets have fly cameras using film and optical readout on most of their photographic missions to the Moon and planets. This was the start of photography from space.

The Photographic Space Missions

The characteristics of the cameras flown on many of the space missions have been listed in four tables. Table 1 contains those missions in which the pictures were taken on film, the film processed on board, and returned to earth by means of an optical scanner and telemetry. Table 2 contains missions in which the pictures were taken on film and the film was returned to earth for processing. Table 3 contains missions which used vidicon cameras to take pictures and Table 4 contains missions which used line scan devices to form pictures.

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In discussing U.S. space photography programs, I have arbitrarily broken the time period into three eras, corresponding roughly to the decades of the 1950's, the 1960's, and the 1970's. I will also review some of the Soviet photographic space missions.

The 1950's

Following World War II, a number of organizations investigated the feasibility of launching a man-made satellite. Rand was one of these and their first report on the subject was published in May 1946. Satellite design studies continued at Rand and investigations into applications for these vehicles received increased emphasis. [~~In 1951, a Rand report titled Utility of a Satellite Vehicle for Reconnaissance was published. About 1953, Rand recommended that the Air Force initiate a systems program in this area. As a consequence, the advanced reconnaissance system (ARS) or WS-117L program was established with Lockheed as the prime contractor. This system was to use the Atlas booster.~~]

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Rand (7.D. 41)
File

Harw,

I have rewritten the paper. It is all unclassified material, however I do not like it. Hope I do not have to use it.

Mert

(b)(3)

Rand will be mostly closed next week. I will be working some and home some. Please do not hesitate to call me. Home [redacted] phone [redacted]

Mert

— THE FACT OF IS "SECRET" —

28 Dec. 76

Morton Davies

visited 28 Dec 76

Disappointed in cuts in
latest papers
but understood. Data
had to come out

Dec. 22, '76

KIETH PEYTON

QUICK LOOK -

I WANT TO
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MERT. TODAY

I PLAN TO CALL MERT THIS MORNING AND TELL HIM THAT NATIONAL POLICY PRECLUDES HIS DISCUSSION OF AREAS X^{D} OUT. FURTHER HE WILL NOT BE HELPING AT ALL BY FIRST TALKING OF SECURITY RESTRICTIONS AND THEN REFERRING PEOPLE TO [redacted]' "SECRET SENTRI (b)(3)

Harve.

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DACOM Transmission Receipt

TRANSMISSION NUMBER 625

DATE 23/12/76

CLASSIFICATION Unclas

TO SA-3/ Mr Cohen FROM SS-5

SUBJECT ~~[illegible]~~ NOTE (unclassified only)

NUMBER OF PAGES 1

SENDER Mille (signature of transmitter)

RECEIVED BY ______________________ (signature of recipient)

DEPARTMENT OF THE AIR FORCE
OFFICE OF THE SECRETARY

MEMORANDUM 23 Dec

SAFSP-3 Mr Cohen

On your RAND speech, take out the reference to National Security restrictions (1st ¶ 4th sentence) → next sentence should be altered to read "interested in military programs.."

The rest is OK.

[redacted] (b)(3)

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THE USAF SCIENTIFIC ADVISORY BOARD

Its First Twenty Years

1944-1964

by

Thomas A. Sturm

USAF Historical Division Liaison Office

1 February 1967

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington, D.C., 20402 - Price $1.25

CHAPTER EIGHT

WITH SURVIVAL THE GOAL

> **. . . if we talk about the present then I know that all the experts are in the Air Force and they know what they are doing and they don't need a glass. When we talk about the future then there are no experts anywhere and therefore, also, people like ourselves qualify.**
>
> ——Edward Teller*

Sputnik I, the 184-pound satellite which the Russians shot into orbit on October 4, 1957, confirmed the scientific and military communities' oft-repeated warning that the United States lagged in space research and development. While a few high government officials unwisely chose to publicly deprecate the launch as "a neat scientific trick," or a sort of "outerspace basketball game," worried DOD agency heads promptly acted to assess the Russian achievement in terms of its threat to U.S. security.[1]

Within the SAB, one officer felt the new crisis sufficiently grave to suggest that the board consider the coming months as ones "of national emergency, when survival may be determined."[2] And, as in previous crises, the Air Force quickly solicited the SAB's counsel. After attending the series of high-level conferences held between October 8-15, Secretary of the Air Force James H. Douglas called for a study of steps the Air Force might take to assist in countering world reactions to the Soviet space accomplishment. Lt. Gen. Samuel E. Anderson, ARDC commander, assumed responsibility for the study and, with Dr. Doolittle's help prevailed upon Dr. Teller of the SAB Nuclear Panel to spearhead it.[3] Dr. Teller immediately

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*During a discussion at a December 1957 SAB meeting.

See notes on page 186.

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E GOAL

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——Edward Teller*

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assembled an ad hoc committee of SAB members, industry experts, and ARDC technical advisors who met on October 21-22, 1957, and submitted a report through channels to Mr. Douglas on the 28th. They stated their conclusions and recommendations briefly and to the point. The United States had slipped behind the Soviet Union in the technological race because of complacency and swollen bureaucracy. As a result, neither civilian nor military research and development agencies had been able to establish stable, imaginative programs. To correct the situation, the Teller Committee urged that the organization and management of ballistic missile and space flight programs be consolidated and simplified from the Office of the Secretary of Defense down through the services. The government then had to give these programs top priority "without reservation as to time, dollars, or people used."[4] As for the manner in which the nation's leaders ought to react to the Soviet success, the committee felt America should honestly admit it had been eclipsed and honestly recognize the reasons for it. The members warned that "an attempt to counter the sobering effect of Sputnik . . . by a spectacular, but technically superficial demonstration would be to seriously and perhaps fatally deceive ourselves as to the gravity of the present technical position of our country."[5]

The SAB underwrote expenses of its members who served on the Teller Committee and would have proudly accepted credit for its work. But the Teller Report was never considered a SAB product in the official sense. However, by a fortuitous circumstance, SAB had formed a space study group of its own several months before Sputnik. In November 1956, the Fuels and Propulsion Panel had recommended that the problem of national defense in cislunar space be studied on as broad a basis as possible.[6] General Putt, finding the idea appealing, requested the SAB to form an ad hoc committee on advanced weapons technology and environment. This was done in May 1957 with Dr. Stever as chairman and Drs. Kaplan, C. B. Millikan, Mills, William H. Radford, Simon Ramo, and White members. Studies under way at Ramo-Wooldridge, RAND, Western Development Division, and Headquarters USAF gave promise that the ballistic missile program would soon produce vehicles capable of operating in space. Since this would have a "severe impact" on military operations, Putt considered it imperative that the Air Force "keep abreast of the latest thinking in these

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See notes on page 186.

areas and . . . be immediately informed of potential breakthroughs." Consequently, he asked the committee to assess current technological knowledge on the subject then advise the Air Force of the direction it should take to explore the new environment and to study the weapon systems required for operating there.[7]

The committee began its meeting in late July 1957 and submitted a report to Dr. Doolittle just before the first Sputnik shot. Doolittle completed final coordination and amendment and forwarded it to the Chief of Staff, General White, on October 9, five days after Sputnik.[8] The report recommended that the Air Force strongly support pure research on matters of space exploration. This would have two major benefits. It would provide the Air Force with new information applicable to space flight and, at the same time, ready the Air Force to assume what would appear to be its logical future mission of performing space logistics "analogous to the Navy's logistics capability in bringing scientific data back from the Antarctic." The committee believed the Air Force should act promptly on its recommendations, "the urgency here [being] substantially above that of the average problem submitted to the SAB."[9] These words expressed the view of the SAB as a whole and served as SAB's first official declaration of concern over the lead the Russians held in space technology.

Members of the Stever and Teller Committees present at the first full board meeting after the Sputnik crisis (held December 4-6, 1957, at Chandler, Arizona) reviewed their reports in concert and discussed further thoughts they had had on the subject in the intervening weeks. They agreed that "Sputnik and the Russian ICBM capability [had] created a national emergency." They also agreed on the course the Air Force should pursue to meet the emergency. Accordingly, Dr. Teller and Prof. Griggs joined with the Stever Committee (who were all in attendance except Dr. Ramo) to form a new ad hoc committee on space technology chaired by Dr. Stever.[10] They then issued a new statement which Dr. Doolittle submitted to General White a few days after the meeting, noting that it reiterated "previous statements made by SAB members which we feel need reemphasis in light of the critical post-sputnik situation now existing."[11] The terse report advocated prompt and vigorous action on six fronts:

See notes on page 187.

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> (1) Obtain a massive first-generation IRBM and ICBM capability as soon as possible. (2) Establish a vigorous program to develop second generation IRBM's and ICBM's having certain and fast reaction to Russian attack. (3) Accelerate the development of reconnaissance satellites. (4) Establish a vigorous space program with an immediate goal of landings on the moon. (5) Obtain as soon as possible an ICBM early warning system. (6) Pursue an active research program on anti-ICBM problems. The critical elements are decoy discrimination and radar tracking. When these problems are solved, a strong anti-ICBM missile system should be started.

Soon after these recommendations went forward, General Putt called on the SAB to review continental air defense programs. The new show of Russian technological progress "reemphasizes the need for a thorough examination of our defensive requirements to meet these threats in the next 10-year period," he said.[12] He listed the "spectrum of possible threats," as he saw it, and in January 1958, a SAB ad hoc committee under Dr. Sherwin set out "to determine the minimum number of integrated systems necessary to meet all threats." General White was disappointed in the committee's first findings, sent him in draft form in mid-1958. As one secretariat officer expressed it, the Air Force had hoped that some "new and radical air defense techniques" would emerge from the committee's labors.[13]

The committee expanded its search after members Sherwin, Ernst H. Plesset, Radford, Richard C. Raymond, and Valley met with General White in late August to gain a better idea of his views.[14] Their final report, completed in January 1959, noted various "serious gaps" in air defense programs and stressed "the need for accelerated and specialized research and development" in such areas as ICBM warning and anti-ICBM missiles.[15] After the committee disbanded, General Putt stated that he felt the members had accomplished their primary purpose and congratulated them on their work.[16] There seemed to be a lingering note of disappointment among all concerned, however. Unlike the Valley Committee's air defense studies following the first Russian atomic explosion in 1949, the Sherwin study was unable to stimulate any "new approach" to the problem. Subsequent experience made clear why this was an inevitable result. While the Air Force could and did accelerate the development and installation of missile warning systems, the state of the art was not sufficiently advanced to enable anyone to conceive reliable systems for intercepting and destroying missiles.

See notes on page 187.

During 1960, the reconstituted Space Technology Panel (1) met frequently for briefings on space projects and problems, (2) prepared one report on the need for closer Air Force/NASA cooperation on lunar exploration and another on the need for more vigorous action on space counterweapon sensor systems and missile target signature experiments, (3) provided verbal consultation on various space problems, and (4) assisted several SAB ad hoc space committees. At the close of the year, Dr. Stever submitted a summary estimate of the Air Force's space program to date. In the panel's opinion, the Air Force had about reached a point of diminishing return, technologically, in ballistic missilery. That is, the ICBM's already in operation or under development were about as effective as science could make them, and further increase in their reliability now rested with operations officers and site engineers. It was a different story with such newer aspects of the military space program as reconnaissance and warning satellites, satellite interception, and manned space vehicles. Here the surface of advanced technology had "only been scratched," and the panel suggested various means whereby the Air Force might proceed to exploit current knowledge in these areas.[23]

This proved to be the final report of the Space Technology Panel. The reorientation of the national space program in 1961 resolved most of the issues with which it had been concerned. Also, the nature of the space projects which the SAB undertook that year required a cross-panel approach. As a consequence, the Executive Committee concluded that the panel had outlived its usefulness and disbanded it in the fall of 1961.

The Air Force's increasing concern over the quality and management of its basic research facilities prompted establishment of a second new panel—Basic Research—in June 1959. Dr. Valley accepted the chairmanship and, by the fall of that year, had defined the panel's mission to encompass investigation of "all matters of policy, procedure and composition pertinent to Air Force basic research" and enhancement of USAF relations with the basic research community. Comprised of Dr. Valley and Dr. J. C. R. Licklider with Prof. Leo Goldberg and Dr. Charles H. Townes serving as liaison members, the panel met for the first time on December 7, 1959, and agreed that the Air Force, "to derive maximum benefit from new, advanced scientific knowledge," had to maintain its role as an active participant in the basic research community-at-large. The Air

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See notes on page 188.

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DISCONTINUED PANELS

Date	*Subject*
15 Jan 52	*Guided Missiles:* Infrared research and development program.
7 Apr 53	*Physical Sciences:* Functions, procedures, and support of OSR.
3 Aug 53	*Intelligence Systems:* Observations on USAF intelligence requirements and programs.
29 Jan 54	*Intelligence Systems:* Aerial photography by moonlight, balloon reconnaissance by moonlight, covert photography.
28 May 56	*Reconnaissance:* Reconnaissance from satellite vehicles.
28 May 56	*Reconnaissance:* Reconnaissance from high altitude balloons.
Apr 58	*Reconnaissance:* WS-117L program.
8 Apr 59	*Space Technology:* Review of elements of ballistic missile program.
9 Apr 59	*Space Technology:* Space technology problem areas.
25 Jun 59	*Space Technology:* Estimate of new ballistic missile capability.
Dec 59	*Reconnaissance:* Overall USAF reconnaissance requirements and current state of technical development.
29 Apr 60	*Space Technology:* USAF studies on requirements for a lunar base.
30 Dec 60	*Space Technology:* Summary report on space technology.
Jun 61	*Arms Control:* Arms control developments.
Apr 62	*Arms Control:* Implications of observation satellites.

Table 4

MISSIONS WITH LINE-SCAN CAMERAS

		Lens		
Program	Years Active	Focal Length (mm)	Focal Ratio (f/no.)	Angular Resolution (degrees)
Luna 9, 13	1966-1967			0.06
ATS-1	1966-	250	2	
ATS-3	1967-	375	3	
SMS	1974-			
Lunakhod 1, 2	1970-1973		6	0.06
Luna 19	1971			
Pioneer 10, 11	1973, 1975			0.03
Venera 9, 10	1975			
Viking Lander	1976-			
Landsat 1, 2	1972-			

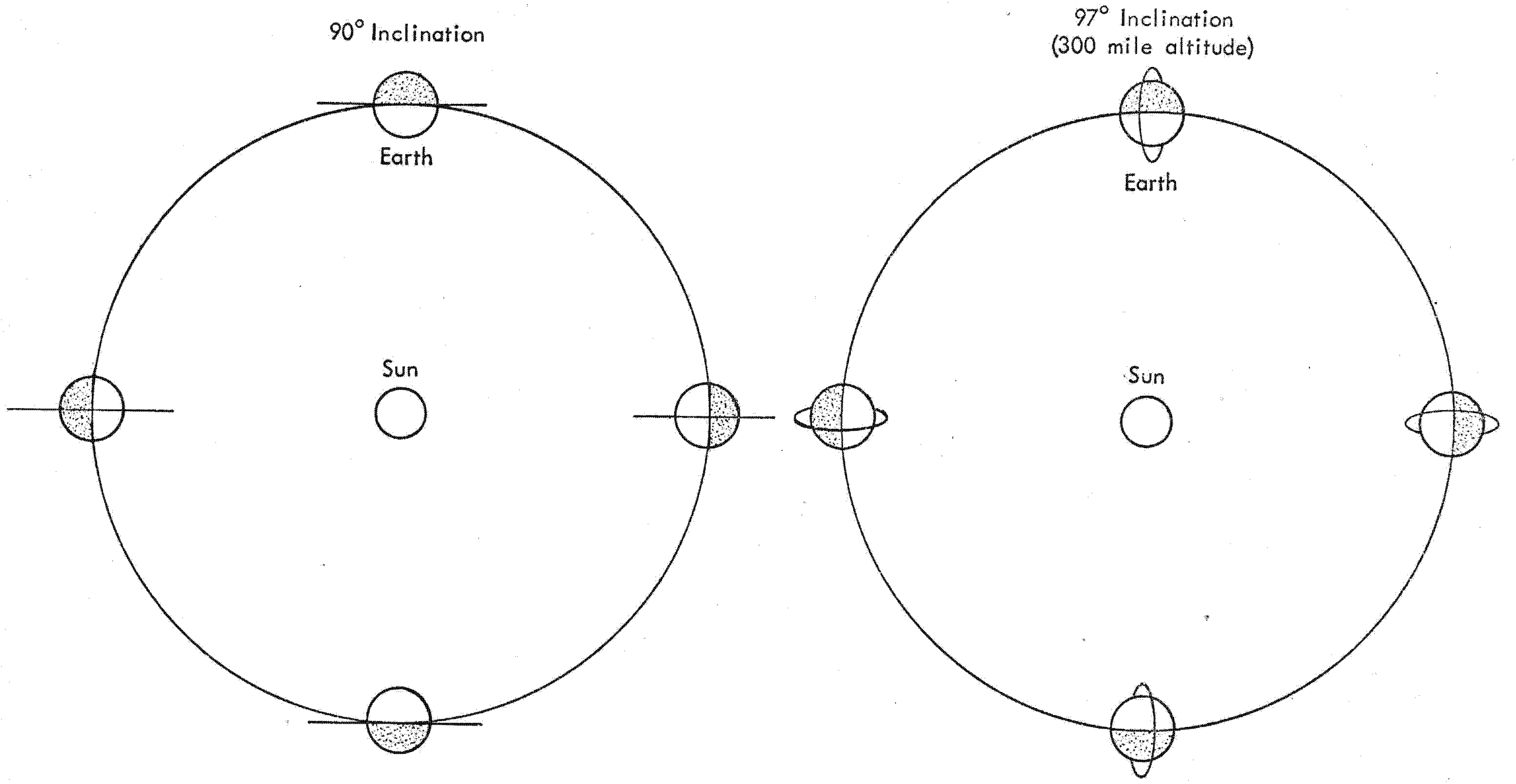

Fig. 1 — The Earth's Equatorial Bulge Causes the Satellite to Precess

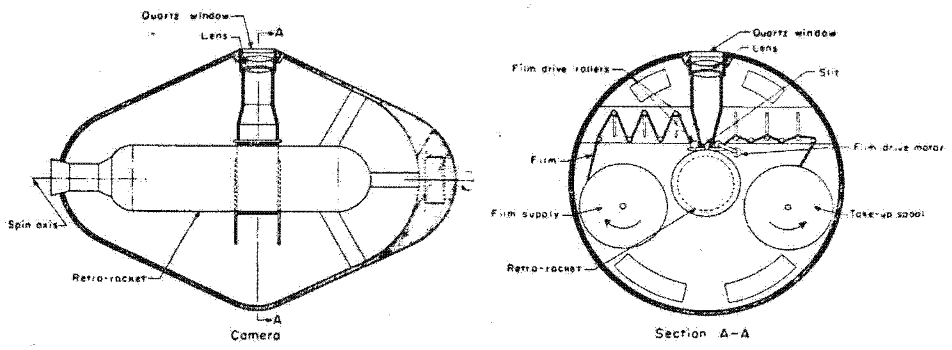

Fig. 2. Schematic of spinning panoramic camera

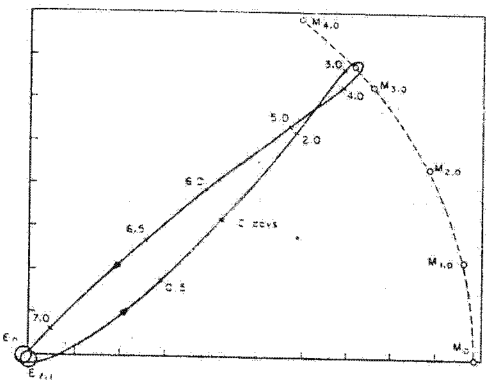

Fig. 3. Typical trajectory
of a lunar photographic vehicle

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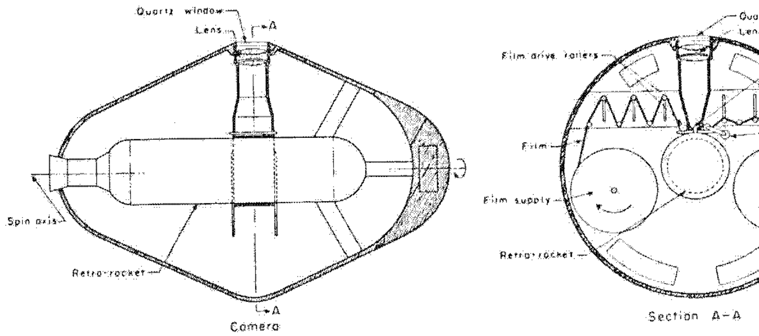
in the Pioneer III to measure ~~the proximity of the moon could~~ be used to measure the spin rate and ~~lunar direction as well as to initiate camera~~ operation. Another me~~thod would~~ be to measure the passage of the sun through a slit with a photo-



~~Fig. 2.~~ Schematic of spinning panoramic camera.

FIG 4

cell; a simple computer could then adjust the film velocity to compensate for the measured spin rate. To maintain the focus of the lens and to keep the film flexible it is probably desirable to pressurize the camera and to control the temperature and humidity near the lenses and film. Fig. 2 shows the camera operation.

The main factor contributing to the loss of contrast in high-altitude aerial photography of the earth is the scattering of non-image forming light into the optical system by the earth's atmosphere. If, for example, the original contrast is 10:1 and scattered light increases the exposure of both black and white areas

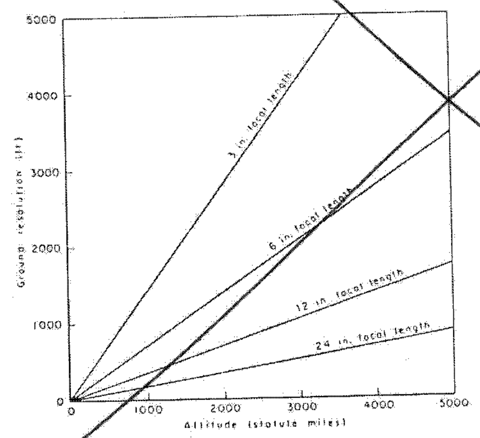


Fig. 3. Ground resolution as a function of altitude—vertical view. $x = 207.7 \dfrac{h}{RF}$

x = ground resolution (ft)
h = altitude (statute miles)
$R = 50$ = film resolution (lines/mm)
F = lens focal point (in.)

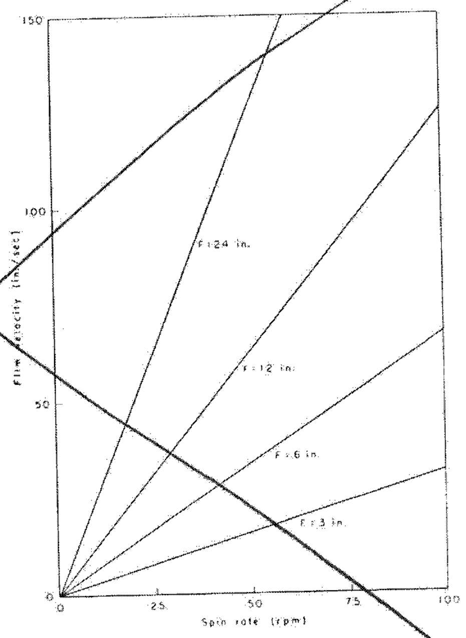


Fig. 4. Spin rate, lens focal length and required film velocity

$V = .10472\ F$ (rpm)
V = film velocity (in./sec)
F = focal length (in.)
rpm = spin rate (rpm)

mi is indica[illegible]/sec in velocity and 1 mil in path angle for trajectories defined by an initial velocity of 34,860 ft/sec at an altitude of 350 s mi above the earth [6]. For this example, the design lunar altitude is varied by specifying the path angles of the velocity vector at the 350 s mi altitude point.

Interesting circumlunar flights which return to the earth are limited to those which move in retrograde motion relative to the moon. These are the figure eight paths which cross the moon's orbit before the moon arrives. Fig. 5 shows an example of a trajectory which satisfies the requirement [5]: the path passes within 3000 mi of the moon; the total flight time is 7.1 days. Total flight times of 6 to 12 days are possible for reasonable trajectories, depending upon the particular initial conditions.

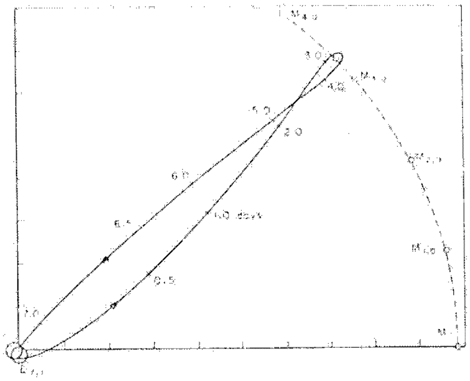


Fig. 5. Typical trajectory of a lunar photographic vehicle

FIG 5

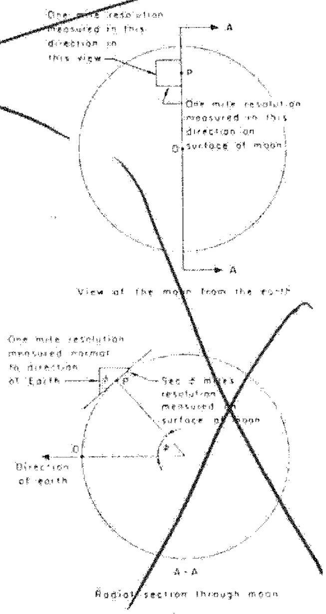


Fig. 6. Ground resolution as measured on the surface of the moon

Sun-Moon Attitude

In discussing the geometrical relationships between the moon's surface, the vehicle spin axis, and the direction of the sun, it is necessary to examine the photographic objectives. Certainly, one of the major purposes of the first few flights will be to maximize the area of photographic coverage so as to completely map the back side of the moon. Later priorities may shift to obtaining better quality pictures of particular interesting areas; these should include the front, as well as the back side of the moon.

The ground resolution (i.e., resolution measured at the surface of the moon) of pictures taken from the surface of the earth is determined by three factors: (1) the earth's atmosphere, (2) the distance to the moon, and (3) the angle between the tangent plane at the point in question and the normal to the line joining the centers of the earth and the moon. The turbidity of the atmosphere limits the resolution of earth-based telescopic photography to about one second of arc, which at the distance of the moon corresponds to about one mile in the plane normal to the light ray. For this reason, as illustrated in Fig. 6, the ground resolution of excellent moon pictures is about one mile in the direction normal to a plane passing through the center of the moon's face and one mile times

~~Fig. 8, an enlargement of a portion of the trajectory shown in Fig. 5, indicates the relative motion of the vehicle as it passes around the moon. Its velocity is about 5000 ft/sec relative to the surface of the moon and is about 3000 mi from it at the point of closest approach. The sun and the vehicle spin-axis are shown in a preferred orientation to record maximum-area pictures of the back of the moon.~~

~~After obtaining the first pictures and naming the newly discovered lunar formations, there will remain the task of obtaining better quality photographs for scientific study. For this purpose it is very important to make a close approach to the moon with a long focal length camera so that surface detail will be recorded. The ability to make a close approach depends greatly upon the performance~~

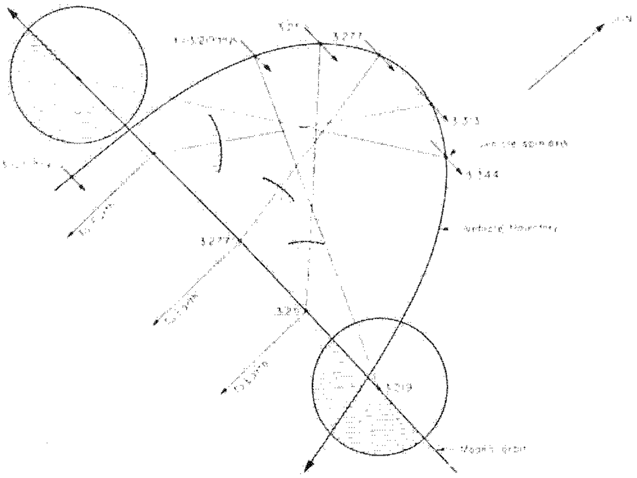


FIG 5 ~~Fig. 8~~. Trajectory of vehicle in the vicinity of the moon — New Moon
Note: Vehicle spin and sun position for photographing the back side

~~of the particular vehicle. Design planning figures of about 3000 mi ± 2000 mi altitude at the point of nearest approach seem reasonable for vehicles available in the near future.~~

~~Both astronomers and aerial photointerpreters are aware of the fact that 'flat' pictures, where the sun is behind the camera, are less interesting and have lower resolution due to the low contrast than pictures taken with side lighting. With this in mind, Figs. 9 and 10 show typical sun-moon positions and camera spin axis for obtaining excellent lunar pictures. Another effect used by both astronomers and photointerpreters for special purposes is the study of the long shadows when the sun is near the horizon. These high contrast shadows are larger than the objects causing them and so are much easier to resolve. Astronomers find such pictures useful in computing the altitude of lunar formations and in contouring. The photo-interpreter sometimes uses such pictures for computing the height of objects on the ground and for studying the texture of terrain. High resolution lunar pictures of this type will prove to be extremely interesting.~~

~~Since the best results will be obtained where the spin axis is parallel to the lunar surface, it is desirable to select the preferred direction of the spin axis.~~ The spin axis shown in Fig. 8 is approximately normal to the line joining the