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CORONA Program History

Volume III

CORONA Cameras

DIRECTORATE OF SCIENCE AND TECHNOLOGY
CENTRAL INTELLIGENCE AGENCY

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CORONA PROGRAM HISTORY

VOLUME III

CORONA CAMERAS

19 May 1976

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Volume III of V Volumes
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PUBLICATION REVIEW

This report has been reviewed and is approved.

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CORONA Project Officer
Directorate of Science & Technology
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HISTORICAL BACKGROUND

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SECTION I

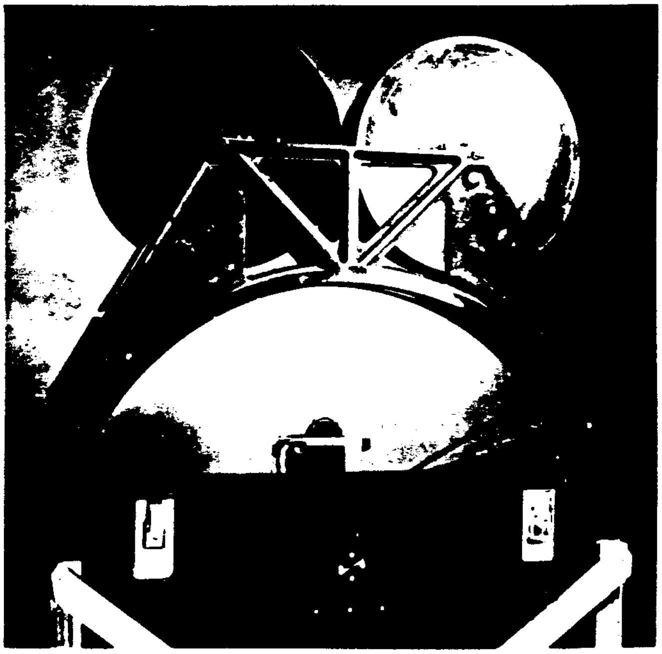
HISTORICAL BACKGROUND

During World War II, the Air Corps persuaded Dr. James Baker, an astronomer at the Harvard University Observatory, to establish an optics laboratory at Harvard to expand this nation's optical systems design capabilities. Up until this time, the US had been largely dependent on other countries for precision optics. By 1946, the laboratory staff of approximately 36 people had achieved a number of spectacular results. Their accomplishments included the test or production of the following cameras by the end of World War II: the 6 inch, f/2.8, 120 degree wide angle; the 40 inch, f/5.0, low distortion telephoto; the 60 inch, f/5.0 telephoto; the 100 inch, f/10.0 anastigmat; and the 36 inch, f/8.0 apochromat.

At the end of the War, Harvard decided to terminate the laboratories' activities, and Dr. Baker returned to teaching and his work at the Observatory. Dr. Duncan Macdonald, an assistant to Dr. Baker at Harvard, agreed to head up the group. It was also decided to move this function to Boston University. Here, the Physical Research Laboratory (BURPRL) was formed with the goal of studying all the parameters of the aerial photographic process from atmospheric effects to the process of photographic information extraction by humans. Faced with an Air Force decision in 1957 to cut back the effort at the Laboratory, a group headed by Richard Leghorn and Dr. Macdonald were successful in securing sufficient financial backing to buy the laboratory from Boston University. In October 1957, Itek Corporation was founded with Richard Leghorn as President. In January 1958, Itek acquired more than 100 personnel and the facilities of the Boston University Physical Research Laboratory.

During the mid-fifties, a milestone in Itek's history was achieved when the Laboratory, under the direction of Duncan Macdonald and Walter Levison (then assistant director of the Laboratory), developed the 12 inch HYAC I camera, a panoramic camera designed for high altitude, balloon-borne operation. The camera demonstrated its capability with a startling photograph of Omaha, Nebraska, taken under cloudy conditions from an altitude of nearly 20 miles. This picture of Offutt Air Force Base showed several B-52 aircraft parked in a line and ready to be counted. Levison took a 10X blowup (2 x 20 feet) of this picture to General Curtis LeMay, then Air Force Chief of Staff, and graphically convinced the General of Itek's camera design and development capability. From this acceptance, Itek received its first major aerial reconnaissance camera program for the HYAC I. The camera produced a negative 2.75 inches by 25 inches over a field of 120 degrees by rotating the lens about its rear node at the center of a cylindrical platen. HYAC I incorporated an f/5.0 lens and consistently achieved high altitude photography at over 80 lines per millimeter. A picture of the HYAC I camera and the 10X HYAC I enlarger is shown as Figure 1-1.

THE HYAC I PANORAMIC CAMERA AND 10X ENLARGER



Panoramic Camera

10X Enlarger

Figure 1-1

At about this time, the CORONA Program request for proposal was issued, and Itek scaled up its basic HYAC I design to 24 inches and proposed this camera in competition with Fairchild Camera Company. Itek won the competition, but because there was doubt as to Itek's ability to meet the manufacturing requirements of the program, Fairchild was directed to manufacture the camera and Itek to provide the lenses. It should be noted that up until this point in time, the Boston University group had primarily built only prototypes, with the final cameras being manufactured in quantity by other companies. This was the beginning of the CORONA Camera Program and the start of a decade of development that would see: (1) ground resolved distance improved from 25 feet to better than 4.5 feet by the last configuration (J-3); (2) mission life extended from one day to 19 days; and (3) significantly improved reliability. A summary of the evaluation of CORONA camera systems is given in Table 1-1. The number of flights, camera type, and film load for each system are presented in Table 1-2. The history of original film returned by CORONA camera systems is summarized in Table 1-3.

TABLE 1-1

CHARACTERISTICS OF CORONA CAMERA SYSTEMS

Characteristics	C	C'	C'''	M	J(J-1)	J-3
Camera Manufacturer	Fairchild	Fairchild	Itek	Itek	Itek	Itek
Units Launched	10	10	6	26	52	17
Lens Manufacturer	Itek	Itek	Itek	Itek	Itek	Itek
Design Type	Tessar, 24 inch, f/5.0	Tessar, 24 inch, f/5.0	Petzval, 24 inch, f/3.5	Petzval, 24 inch, f/3.5	Petzval, 24 inch, f/3.5	Petzval 24 inch, f/3.5
Camera Type	70° pan, vertical, reciprocating	70° pan, vertical, reciprocating	70° pan, vertical, reciprocating	70° pan, 30° stereo, reciprocating	70° pan, 30° stereo, reciprocating	70° pan, 30° stereo, rotating
Exposure Control	Fixed	Fixed	Fixed	Fixed	Fixed	(4) Slits selectable
Filter Control	Fixed	Fixed	Fixed	Fixed	Fixed	(2) Filters selectable
Primary Film (film/base)	1213/ acetate	1221/ polyester	4404/ polyester	4404/ polyester	3404/ polyester	3404, 3414/ polyester
Recovery Vehicles	1	1	1	1	2	2
Subsystem (Stellar/Index)	None	None	0/1	1/1	2/2	2/1
Time Period	1959-1960	1960-1961	1961-1962	1962-1963	1964-1969	1967-1972

TABLE 1-2

CAMERA SYSTEM TYPE AND FILM LOAD

No of Flights	System Designator	Camera Type	Film Load
10	C	Mono Camera	40 lbs
10	C'	Mono Camera	40 lbs
6	C'''	Mono Camera	40 lbs
26	M	Stereo Camera	80 lbs
52	J (J-1)	Stereo Camera/2 buckets	160 lbs
17	J-3	Stereo Camera/2 buckets	160 lbs
121			

TABLE 1-3

SUMMARY OF RECOVERED FILM

Year	No of Flights	System Designator	Film Recovered		Mission Flight Numbers
1959	5	C	0%		9001-9005
1960	5	C	20%	9009 1st recovery	9006-9010
	3	C'	33%		9011-9013
1961	7	C'	29%		9015, 17, 19, 21, 26-28
	5	C'''	66%		9022-25, 29
1962	1	C'''	0%		9030
	17	M	69%		9031-41, 43-45, 47-50
1963	9	M	66%		9051-54, 56, 57, 60-62
	2	J	50%		1001, 02
1964	13	J	73%		1003-15
1965	13	J	87.5%		1016-28
1966	9	J	87%		1029-37
1967	7	J	99%		1038-44
	2	J-3	100%		1101, 02
1968	5	J	97%		1045-49
	3	J-3	99%		1103-05
1969	3	J	94%		1050-52
	3	J-3	83%		1106-08
1970	4	J-3	94%		1109-12
1971	2	J-3	99%		1114-15
1972	2	J-3	100%		1116-17

The Itek management and technical organization responsible for the design, development, and fabrication of CORONA cameras and components are outlined by camera system in Figure 1-2.

The facilities employed by Boston University and Itek Corporation in the period leading up to and during the CORONA era expanded to meet changing requirements. The following comments relate to these facilities. A composite photograph of the facilities identified by these numbers is presented in Figure 1-3.

1. <u>Original Boston University Physical Research Laboratory (BUPRL), 320 Bay State Road</u>

During 1946 to 1950, it included complete optical and machine shops combined with system design and test capabilities. From this plant came numerous aerial camera prototypes which eventually led to the CORONA cameras.

2. <u>BUPRL, 700 Commonwealth Avenue</u>

Here the capabilities were expanded, the staff enlarged, and BUPRL entered the aerial reconnaissance field on a nationally recognized level. The Institute of Aerial Photography was held here jointly by Boston University and the BU Research Laboratories.

3. <u>Former Vectron Building, Route 128</u>

The Vectron Company was acquired by Itek in 1958; this acquisition significantly improved Itek's manufacturing and allied capabilities. This became Itek's Environmental Test Laboratory (ETL) which was responsible for the component and system environmental testing of the Fairchild and Itek satellite camera systems.

4. <u>The Waltham Watch Plant</u>

This Plant was leased in part to house the management, engineering, and technical staff utilized on the CORONA Program. The staff consisted of both former BUPRL employees and new personnel.

5. <u>The Newton Plant</u>

This former dairy proved to be a natural facility for the assembly of the CORONA, M, J-1, and the Stellar/Index cameras. Having been a dairy, all walls and floors were tiled, effectively creating a semi-clean room atmosphere.

6. <u>Burlington 9 Facility</u>

This Facility housed the staff for the J-3 design, fabrication, and assembly which was later tested at Itek's ETL area.

7. <u>Lexington 1</u>

This was Itek's largest building. It housed the Optical Systems Division management, corporate

ITEK MANAGEMENT AND TECHNICAL ORGANIZATION FROM 1958 TO 1972

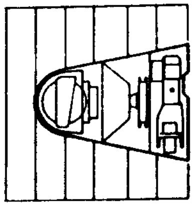
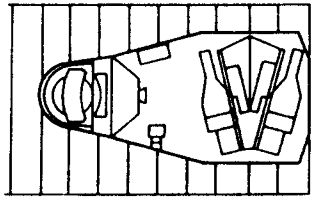
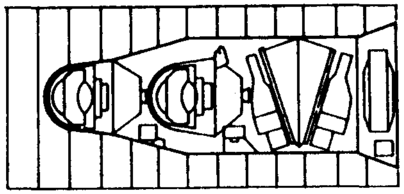
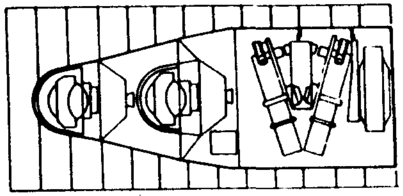
	— 1958 to 1961 —	— 1961 to 1963 —	— 1963 to 1967 —	— 1967 to 1972 —
	C, C', and C'''	C''' and M + Index	J-1 + Stellar/Index	J-3 + DISIC
System Identification				
Itek President	R. Leghorn	[redacted]	[redacted]	[redacted]
Scientific Advisor	[redacted]	[redacted]		
Operations Director	[redacted]	W. Levison (V.P.)	J. Wolfe (OSD Pres.)	J. Wolfe (OSD Pres.)
Project Manager	[redacted]	J. Wolfe, [redacted]	[redacted]	[redacted]
Engineering and Operations Staff	[redacted]	[redacted]	[redacted]	[redacted]
Technical Contributors	[redacted]	[redacted]	[redacted]	[redacted]

Figure 1-2

BOSTON UNIVERSITY AND ITEK FACILITIES UTILIZED DURING THE CORONA PROGRAM

Figure 1-3

research and development, optical engineering, test and fabrication, environmental testing, research and administrative computers, and other allied elements.

SATELLITE CAMERA EVOLUTION

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SECTION II

SATELLITE CAMERA EVOLUTION

The following is a chronological summary of the parameters and flight history of each CORONA camera configuration:

THE C AND C PRIME (C') CAMERAS

The first ten C cameras and ten C' cameras were manufactured by Fairchild with only minor differences between the two versions. The camera was a 70 degree scan, vertical-looking, reciprocating, panoramic camera that exposed film by scanning at right angles to the line-of-flight. Both the C and C' incorporated a 24 inch, f/5.0 high acuity Tessar lens manufactured by Itek. Figure 2-1 provides a composite of photos of the C camera and its elements.

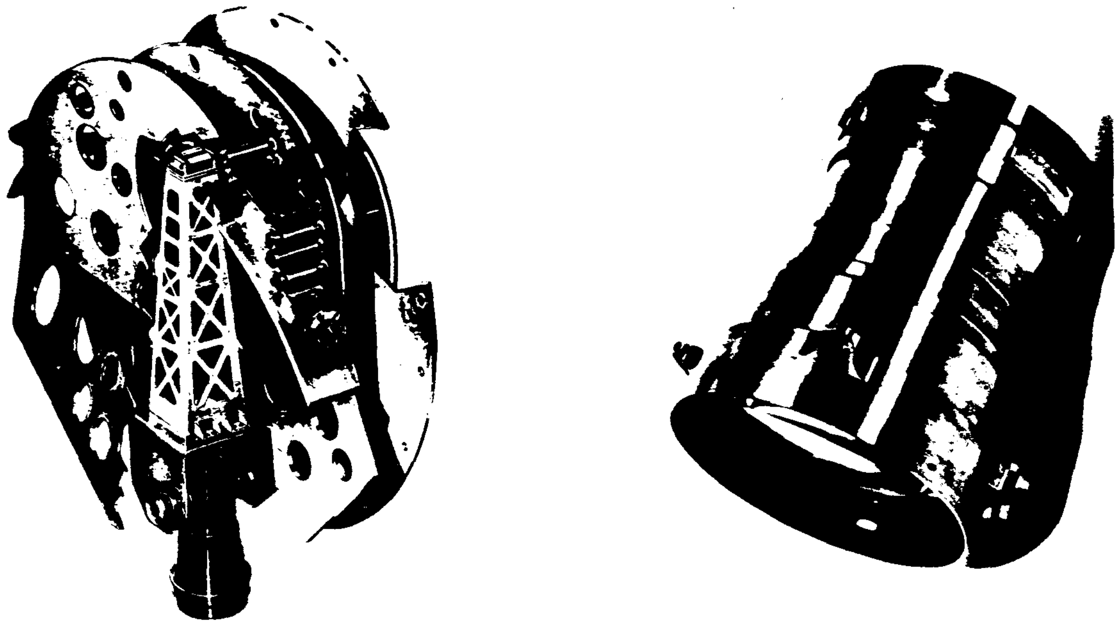
During 1959, five C systems were launched and of the three that achieved orbit, all failed; one on the first revolution, one on the second, with the third camera not operating at all. In 1960, eight missions were attempted; five cameras were orbited, and three capsules were retrieved. DISCOVERER XI marked the first apparently successful (according to telemetry) camera operation. Unfortunately, the recovery failed and the payload was lost. On DISCOVERER XIII, a diagnostic mission without cameras aboard, the capsule was successfully recovered. This was immediately followed by DISCOVERER XIV.

The historic first, DISCOVERER XIV, was launched on 18 August 1960. The camera operated satisfactorily and the capsule was recovered. It is worth noting that the film recovered from this single, 7 revolution mission yielded more photographic aerial coverage of the Soviet Union than all of the U-2 flights to that point. A major deficiency in the recovered film was the presence of plus and minus-density bars (pressure streaks) running diagonally across the format, an anomaly not detected during the preflight test simulations. The photography yielded ground resolution of approximately 25 feet. Telemetry indicated that camera operation was again good on DISCOVERER XV, but the re-entry vehicle (RV) sank before it could be retrieved.

DISCOVERER XVI carried the first C' camera, but the AGENA failed to achieve orbit. DISCOVERER XVIII was the first successful operation of the C' camera and 7,012 feet of film were retrieved. Image quality was judged to be as good as the best from DISCOVERER XIV. Therefore, although five cameras were orbited in 1960, only two returned film loads, two failed, while the other apparently operated well, but the capsule was lost.

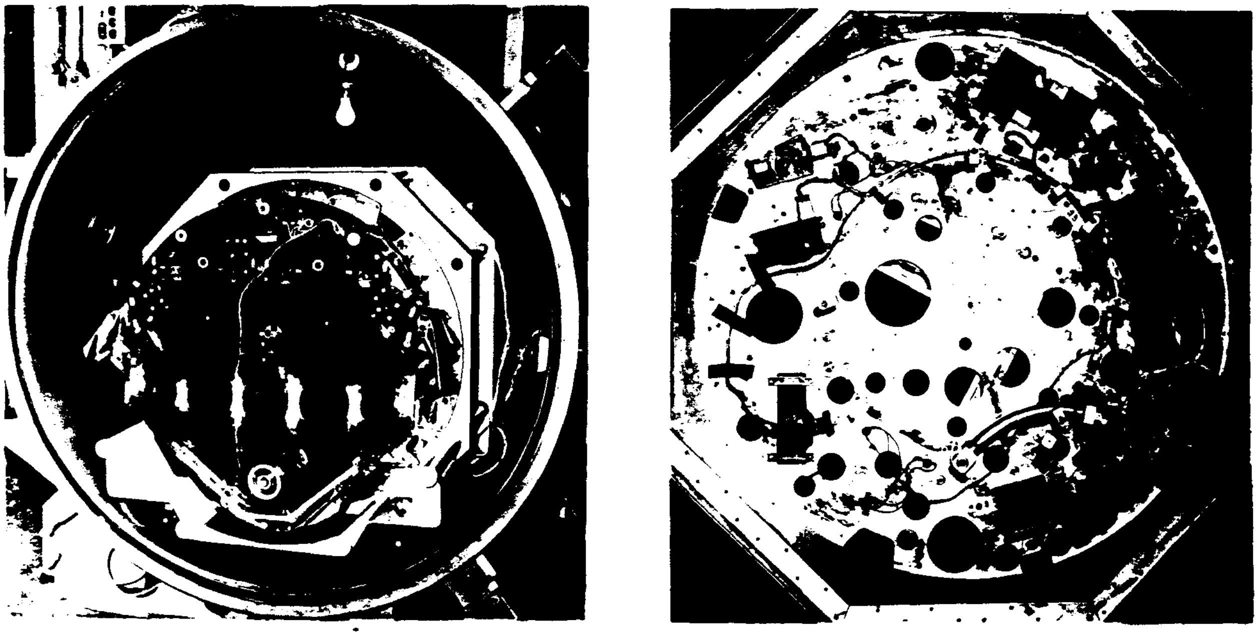
During 1961, the last four of the Fairchild C' systems were flown. Of the four C' cameras launched, two achieved orbit, one camera failed on revolution 22, and the fourth returned a full roll of film. In summary,

THE FIRST SATELLITE CAMERA CONFIGURATION - C MODEL



Artist's View of Camera

Itek's f/5.0, 24 Inch Lens



Camera in Vacuum Chamber

Rear View (film spool side) of Camera

Figure 2-1

from June 1959 to December 1961, a total of 20 C or C' camera missions were launched with five of them yielding usable photography. The failures resulted from a variety of system problems, only some of which were camera related.

THE C TRIPLE PRIME (C''') CAMERA

The operational history of the early C camera flights and the experience gained during the environmental testing prompted Itek to undertake a number of basic design changes to the camera. Improved photographic performance and operational reliability were the goals of this effort. This design change work began in the fall of 1959. The formal unsolicited proposal for the C''' camera was submitted in late 1959, and shortly thereafter a contract awarded to Itek.

The basic operational problems and design changes addressed by the C''' camera were: (1) the main structure, (2) camera controls, (3) the method of metering film and achieving and maintaining camera focus, (4) the lens/scan arm design and operation, and (5) the lens itself.

The camera structure proposed for the C''' consisted of a single honeycomb main plate so that all components had a common reference surface. The Fairchild C and C' cameras used three plates, similar to a watch. With this Fairchild "sandwich" design, a number of shafts and rods supporting components and attached to gears passed through all three plates. However, with thermal differentials as high as 150°F between the two outside skins of the vehicle and as high as 50°F across the camera, the shafts were susceptible to misalignment. The Itek single main plate concept eliminated this possibility. It should be noted that construction of a honeycomb plate of this size (4 feet in diameter) back in 1959 was considered experimenting in a relatively advanced stage of fabrication techniques.

To improve the camera control network reliability, Itek proposed that the C and C' electrical timing network actuated through switches (thus creating effectively an open loop) be replaced with a system in which all sequential camera operations were mechanically linked together with hardware. Further, to reduce the noise (primarily vibration) introduced to the camera system, Itek proposed to replace the camera gear system with rubber coated stainless steel timing and drive belts. The Geneva drive mechanism is a highly reliable mechanical sequencing system used for film transport throughout the camera system.

In the earlier camera design, film was metered across a curved metal platen, and spring-loaded pressure rollers mounted on the scan head pressed the film against the platen during exposure to achieve correct focus. This system was susceptible to pressure marking of the film and out-of-focus operation. First, the current state-of-the-art in casting was not sufficiently advanced to consistently provide platens of sufficient smoothness across the total scan area. Further, high temperature differentials across the camera could introduce distortions to the curvature of the platen. These same temperature extremes could also cause a fluctuation in the tension of the springs that force the focal plane rollers against the film, again affecting focus and possibly inducing pressure marking.

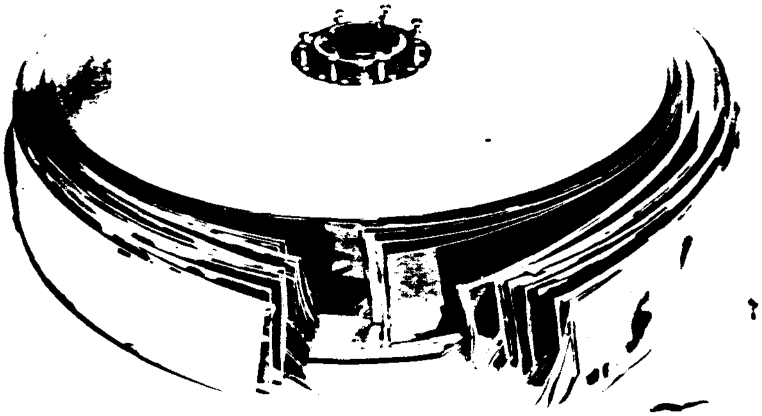
In the C''' design, Itek eliminated the platen and metered film onto rails with a radius slightly less than the lens focal length. Rollers rigidly attached to a scan head which carried the rear lens element lifted the film off the rails to position it in the exact focal plane. With this design, the machining and temperature effect tolerances of the rails were far less stringent. With the total lens and scan head structure athermalized, focus was maintained, thus permitting some thermal excursions throughout the life of a given mission.

The early C''' camera scan heads incorporated two rollers for positioning the film at the focal plane of the lens. It soon became apparent, however, that the zero-g and vacuum environment of the spacecraft was causing the edges of the wrapped film on the supply spool to outgas. This outgassing would then cause a curl differential across the film when it was metered off the supply spool. In the later C''' cameras, Itek introduced a four roller scan head which added a leading and trailing roller so that the film was dynamically dampened and flattened just prior to exposure. This modification virtually eliminated curl which had produced discernible focus change across the film web.

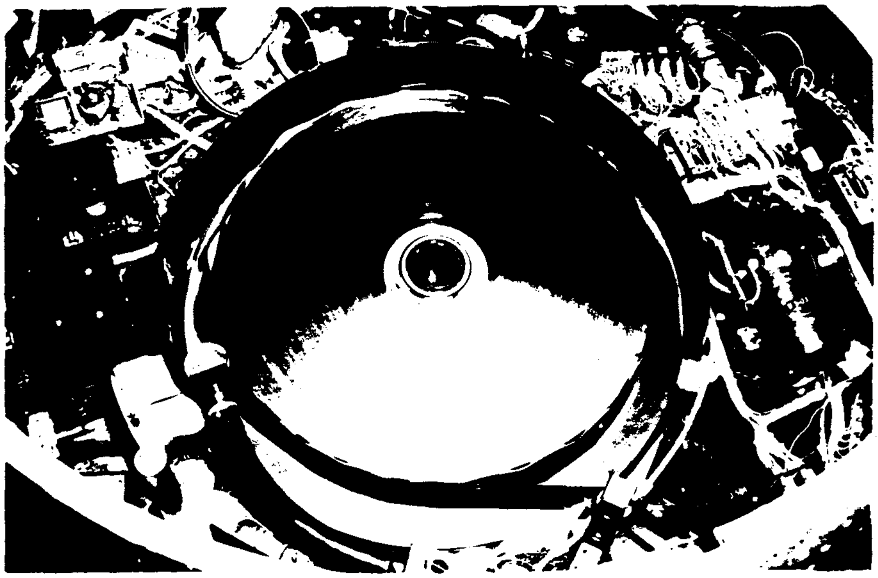
During vibration testing of the C and C' cameras, problems were encountered in controlling the large diameter (20 inches) film spools required for the CORONA missions. When simulating the vibration input of launch, the film tended to despool, and the spool flanges flexed so that the film wraps could slide against each other. This sliding action generated heat in local areas that caused adjoining wraps of film to weld. When the film was metered off the supply spool, these welded spots often tore holes in the film. Figure 2-2 shows examples of film welding, fracturing, and rippling resulting from flight simulation testing. The problem was resolved by introducing a backup tension on the supply spool hub to take up the film slack and mechanical snubbers that limit the excursion of the spool flanges. With this design, the film wrap remained firm despite the launch induced vibration.

In the Fairchild design, the lens and scan arm formed a single unit which reciprocated after each photographic scan. The torque generated by this back and forth motion of a relatively large mass resulted in vacillating motions to the AGENA, and elaborate electrical and mechanical counterbalancing features were required to compensate for these effects. Itek proposed uncoupling the lens and the scan arm so that the heavier lens rotated constantly and the lighter scan arm oscillated. Only when the scan arm was ready to

EXAMPLES OF FILM DAMAGE FROM FLIGHT SIMULATION TESTING



Welding and Fracturing Caused by Simulated Launch Vibrations



Ripple Caused by Simulated Vacuum Environment

Figure 2-2

start exposure were the lens and scan arm recoupled. At the end of scan, the lens would continue to rotate, film was metered, the scan arm returned to the start-scan position, and again the lens and scan arm were recoupled for the next exposure. This design eliminated most of the compensating mechanisms required by the earlier design, and again reliability was improved by simplifying the camera. Velocity over height input to the camera was accomplished by a motorized potentiometer which had 10 start and stop levels that were selectable by real time command. Image motion compensation (IMC) was accomplished mechanically by causing the lens system to move opposite to the direction of flight during scan and then return for the next cycle.

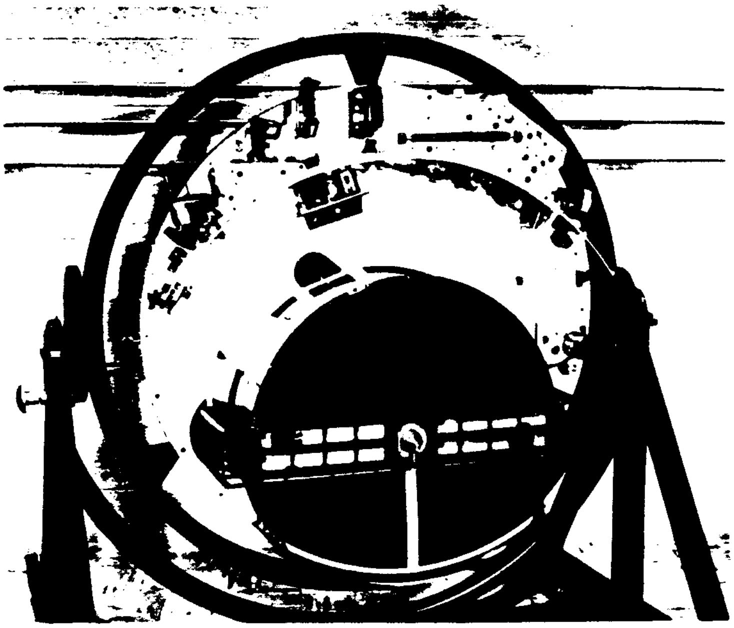
The basic goal of any camera design is to permit, as far as is possible, the lens to perform up to the limit of its capability. The simplicity of the C''' camera made it possible to introduce a faster lens system (24 inch, f/3.5, Petzval) in place of the f/5.0 Tessar. The improved camera design of the C''', combining simplicity and reliability together with the higher quality, faster Petzval lens, could now produce photography with twice the ground resolution as that acquired from the C and C' cameras. A Wratten 12 filter was used, and slit width exposure times were provided. Unperforated thin base (3.5 mils) mylar 70mm film (Film Types SO-221 and 8402) was used; and a full supply weighed 40 pounds. Figure 2-3 presents two views of the C''' camera in a test stand.

The physical characteristics of the Petzval lens remained virtually unchanged throughout the life of the CORONA Program. However, performance of the lenses was continually upgraded. This continuing improvement in lens performance was accomplished by taking advantage of improved optical glass, Itek computer technology, advanced lens and lens cell fabrication and test techniques, and an overall constriction of lens tolerances. From the introduction of the Petzval lens in the C''' to the conclusion of the program, lens performance improved by better than 40 percent.

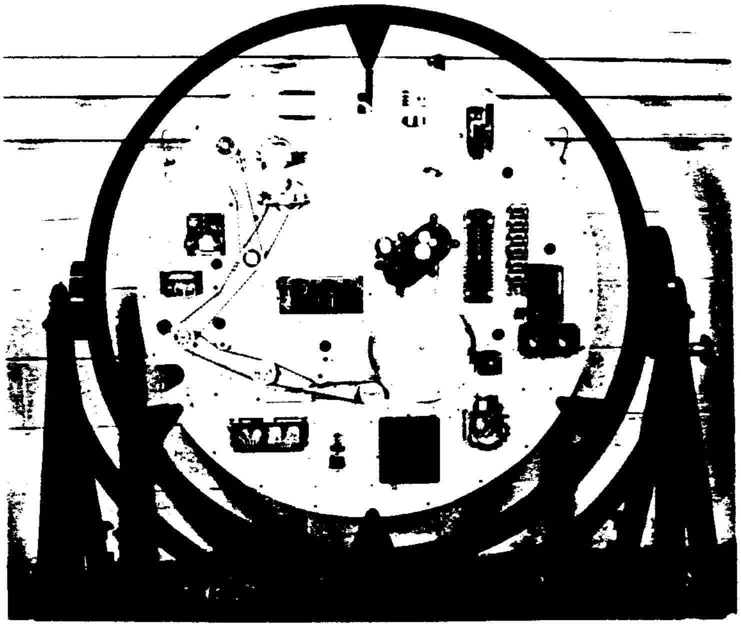
Two horizon cameras with a 90mm focal length and shutter speed of 1/200 second were used for attitude determination. The C''' system was designed to operate at an altitude of 100 - 110 nautical miles for a duration of four days and was expected to produce resolutions in the area of ten feet ground resolved distance (GRD).

The first C''' mission, DISCOVERER XXIX, was launched on 30 August 1961. The full 6,798 foot film load was exposed and successfully retrieved. Image quality was significantly improved over any previous flight, as this mission achieved 12 foot ground resolution versus the 25 feet from earlier missions. What is even more significant is that this quality was achieved despite a film focus problem. The new Petzval f/3.5 lens was computed to require a 0.016 inch adjustment from the air focus in order to be correct in the vacuum

THE C TRIPLE PRIME (C''') CAMERA IN TEST STAND



Front View



Rear View

Figure 2-3

of space. This setting proved to be too high with the result that the first C''' photography was slightly out-of-focus. New glass and vacuum index figures were prepared by the National Bureau of Standards. These figures, together with significantly refined thermal lens shift data, allowed for a lower (0.015 inch) preflight focus setting. With this modification, the cameras were eventually achieving photographic quality nearly identical to that achieved in preflight testing.

A total of six C''' units were delivered to Itek. Following the first successful flight in August 1961, a second successful mission was launched on 12 September 1961; the recovered photography was again excellent, and the out-of-focus problem of the previous mission had been eliminated. Power problems plagued the next two missions. DISCOVERER XXXI failed before recovery although camera operation was good. Suspected AGENA power problems prompted early recovery of DISCOVERER XXXII with only 2,107 feet of film retrieved, again with excellent quality. DISCOVERER XXXVI, carrying the fifth C''' camera, provided the best results to date. Not only was the image quality outstanding, but this mission also included the successful testing of 2,000 feet of SO-132 film, marking the introduction of this new high definition aerial film to the program. In the final C''' mission, launched 13 January 1962, the AGENA failed and no orbit was achieved.

THE ARGON CAMERA

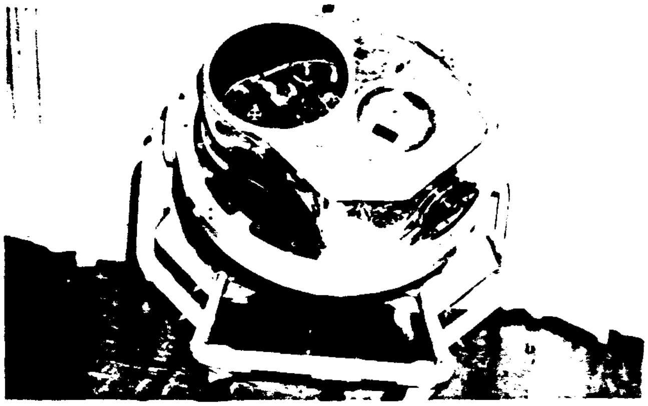
ARGON was a framing camera designed to satisfy the earth mapping requirements of the Army Map Service (AMS). This camera was built by Fairchild Camera and Instruments Company. The ARGON camera had a focal length of 3" and was designed to operate at an altitude of 165 nm. The film width was 5 inches. Although the image resolution was low the per frame area coverage was high. This system provided significant mapping and geodetic data on the Soviet Bloc in support of US military requirements. Of the ten systems launched between 17 February 1961 and 29 October 1963, only four were recovered. Three failed to achieve orbit, two failed to separate, and one separated but was not recovered. A contract was let for a follow-on program consisting of four additional systems. Two were launched (June and August 1964) and successfully recovered. The remaining two systems were never launched and were stored by the Government. Figure 2-4 shows different views of the components of the ARGON system.

THE MURAL CAMERA

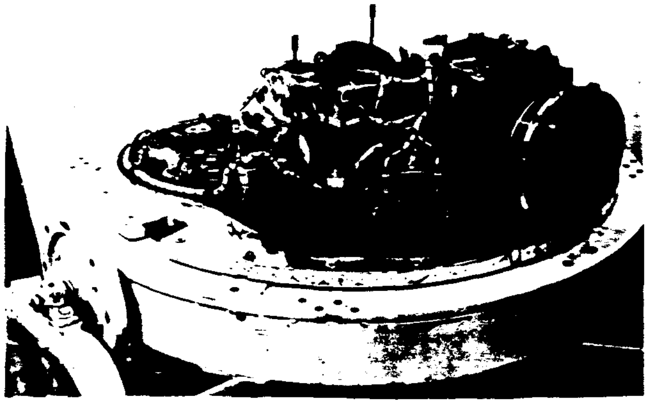
During 1961, Itek developed the MURAL (M) camera system which provided stereoscopic photography. It is an axiom of aerial reconnaissance that the information content of photography is improved by a factor of two and one-half times with stereo coverage. Thus, the introduction of the M system marked a major step forward in the CORONA Program.

The M system consisted of two C''' cameras on a common mount, one looking 15 degrees aft from

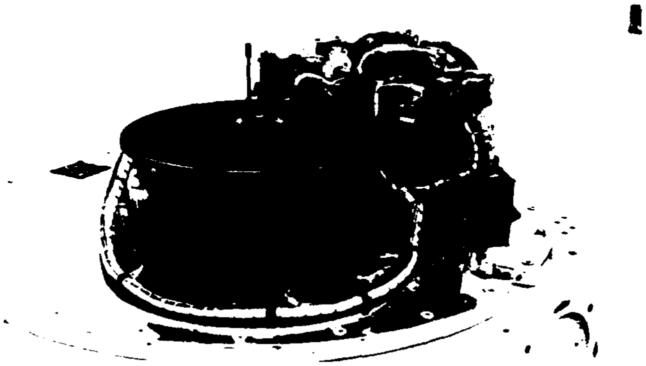
THE ARGON CAMERA



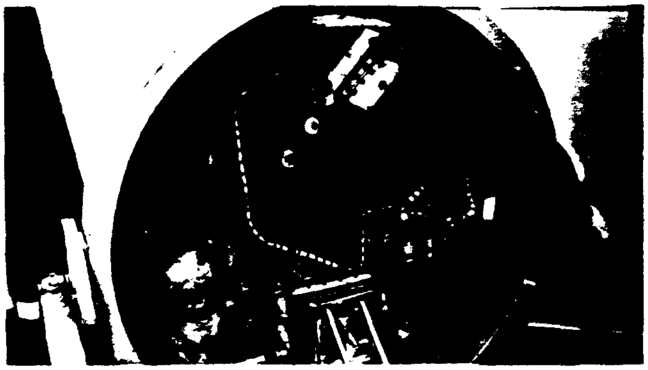
Camera System with Cannister



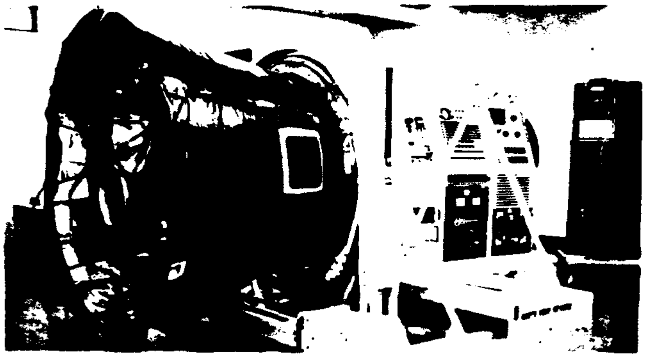
Camera Showing Terrain and Stellar Lenses



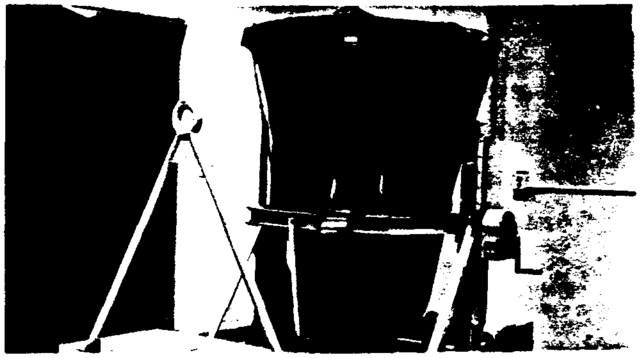
Film Supply



Clock, Pneumatics, and Film Chute



Camera Installed in the Structure



Fully Assembled ARGON System

Figure 2-4

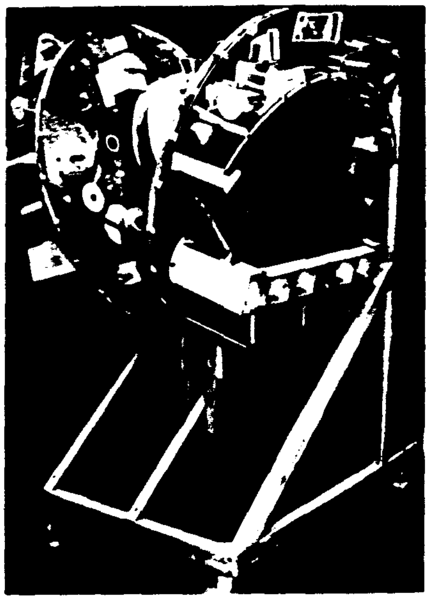
vertical and the other 15 degrees forward. Each camera was fed from an individual supply spool (40 pounds of film) mounted on the back of the camera's main plate. The film was panoramically exposed through 70 degrees of lens cell assembly rotation. After exposure, the film from each camera was fed into individual takeup spools in a common cassette. When the forward-looking camera photographed a scene, this same scene would be photographed six frames later by the aft-looking camera, thus providing a 30 degree convergent angle for stereo photography. Simultaneous operation of both cameras was required for stereo photography. The M system configuration further improved CORONA reliability by mounting the two cameras back to back. Because the cameras operated (scanned) in opposite directions, they tended to offset any operating imbalances and thereby improved overall system dynamic balance. The M system was capable of a six to seven day mission compared to the three to four day missions of the C''' and the earlier one day missions. The system was designed for nominal altitudes of 110 nautical miles. Dynamic resolution was 80 - 110 lines per millimeter. Figures 2-5 thru 2-7 present different portrayals of the M system.

The first M system, Mission 9031, was launched on 27 February 1962, and the stereo photography was excellent. It should be noted that there were no more missions designated as DISCOVERER flights. In addition to acquiring the first stereo photography, this mission also provided the first binary data block on the film. The M system continued the high degree of performance reliability achieved by the C'''. Between 27 February 1962 and 21 December 1963, 26 M systems were launched, 24 achieved orbit, and 20 were recovered. There were no camera failures. The overall quality rating of this photography was excellent.

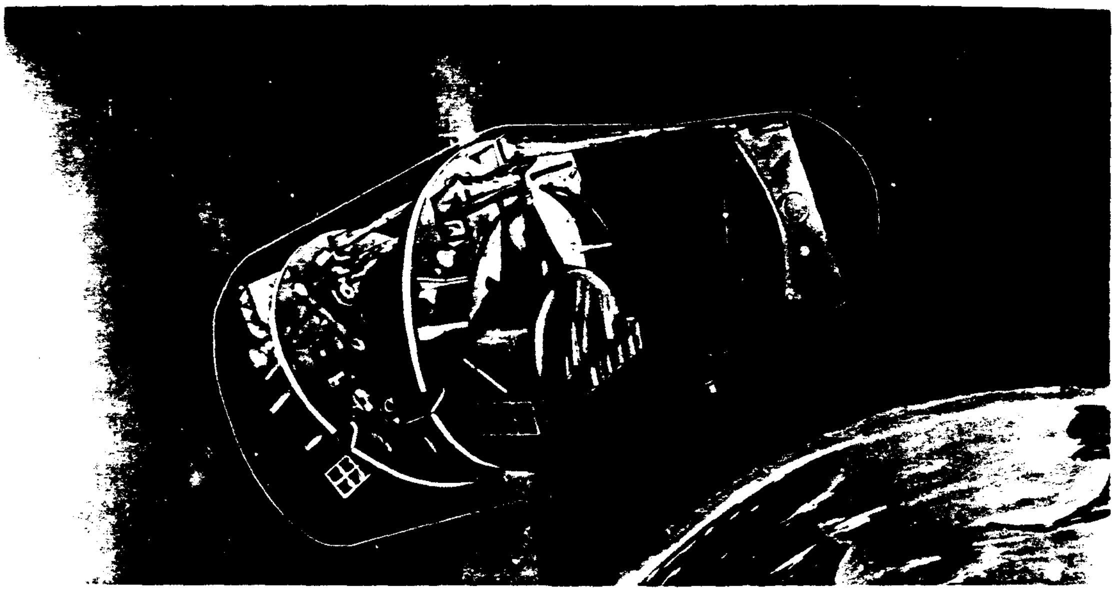
During the M system portion of the program, a serious problem developed because of electrical discharging on the exposed film. This marking, commonly known as corona discharge, was first noted on the flight film of Mission 9040 launched on 27 July 1962. The problem persisted, and Itek consulted Dr. Edward Purcell, then a Nobel Laureate member of the Itek Science Advisory Board. Dr. Purcell identified the problem as the film, traveling at high speeds over the rubber rollers in a vacuum, creating in effect a Van DeGraff generator. The film picked up the charge going over the rollers, and the charge was then released over the film. Although Dr. Purcell successfully identified the problem, unfortunately, he was unable to offer any solutions on how to resolve it.

Finally, after experimenting with numerous varieties of rubber compound, a source of suitable rubber was found through the joint efforts of technicians from Itek and the rubber roller manufacturer. Through an extensive testing program, those rollers which avoided the corona discharge under simulated flight conditions were identified. While the precise scientific reason for this selective process was not understood, the results were successful. Shorly after the new rollers were introduced to the system, a pressure makeup unit (PMU) was designed and incorporated to control the spacecraft environment by introducing dry nitrogen with each

THE MURAL STEREO CAMERA



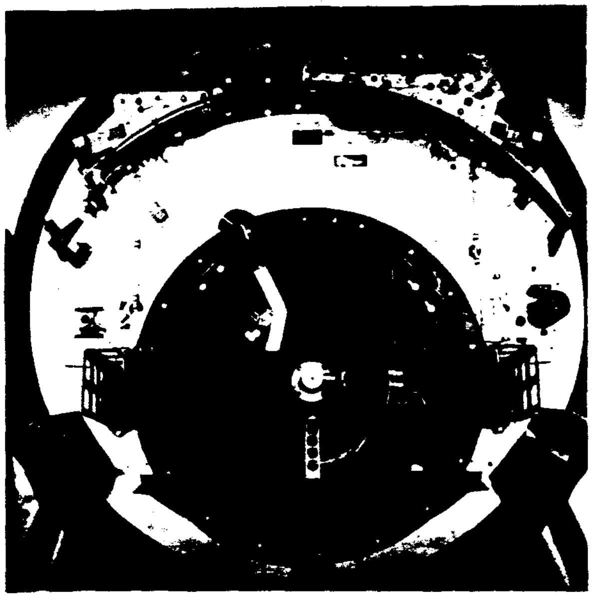
Wooden Mockup of Proposed Stereo Camera



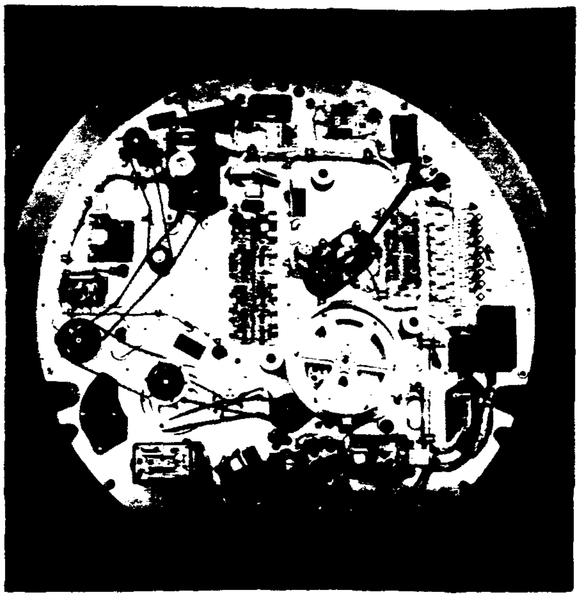
Artist's View of Camera

Figure 2-5

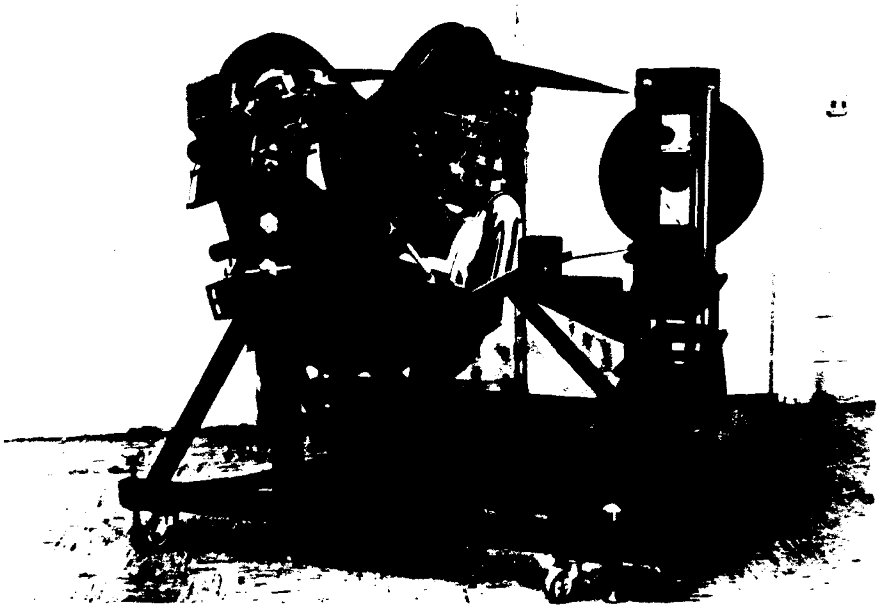
THE MURAL STEREO CAMERA



Front View



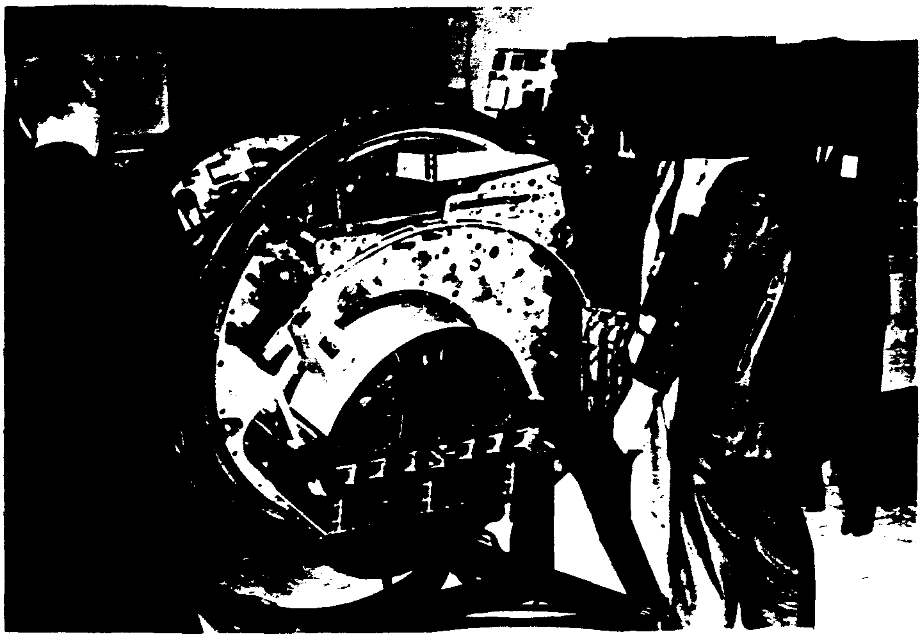
Rear View



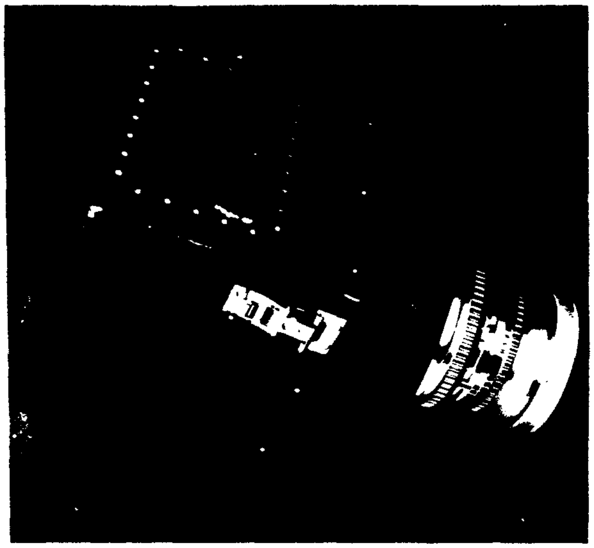
M System with Index Camera
and Film Takeup Spools in Test Stand

Figure 2-6

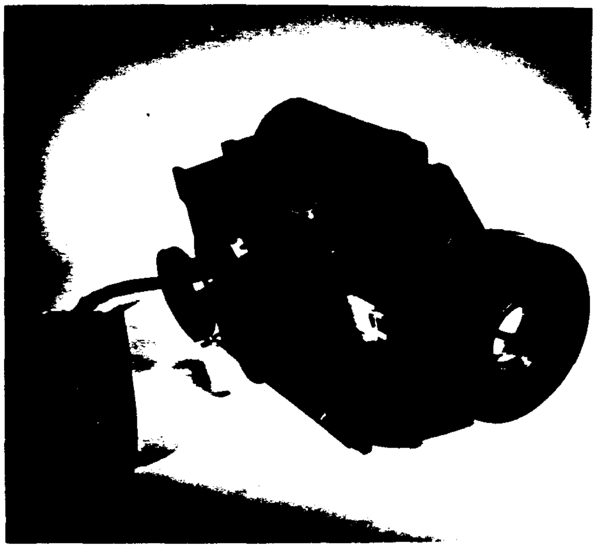
THE MURAL STEREO CAMERA



[redacted] observe camera at Itek's Environmental Test Facility



Index Camera



Stellar-Index Camera

Figure 2-7

camera-operate command. The PMU maintained a predetermined pressure environment where corona discharge would not occur. However, the PMU unit was always considered as a backup system as it was a prime requirement that the camera system should be capable of providing corona-free photography without a PMU.

During the M system lifetime, two frame cameras were introduced to the system; first an Index and later a Stellar-Index (SI). The Index camera was first flown on Mission 9031 (27 February 1962), and the first SI camera on Mission 9045 (30 September 1962). Although the Index camera was beset by early problems, the SI camera ultimately evolved into a valuable tool for photo interpreters. The Stellar camera was mounted on a common, rigid, L-shaped frame with the Index camera, and provided photography which enabled a more precise determination of the vehicle's orbital altitude. The Stellar-Index camera photography, when combined with known orbital data, made it possible to match the panoramic photography with the terrain.

A calibration of the knee (90 degree) angle between the Index and Stellar units, as well as the distortions of these two lenses, was established on a precision goniometer. This calibration in conjunction with the mid-exposure time of the three shutters (Main Panoramic cameras, Index camera, and Stellar camera) established the position in space for each photographic acquisition. Many relatively small scale maps were made from this combined photography. At a later date, the CORONA panoramic cameras were geometrically calibrated, which further refined the mapping potential.

THE LANYARD CAMERA

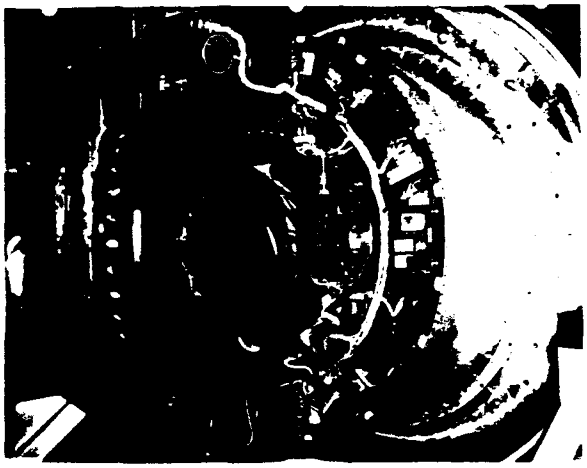
The LANYARD (L) was a panoramic spotting camera with an oscillating lens cell which viewed a large mirror aimed at a 45 degree angle toward the earth. Movement of the mirror enabled the system to produce stereo or mono photography. The five inch film was fed from a supply spool (capacity 8,000 feet/80 pounds of film) to the platen for exposure and then to a takeup cassette in the recovery system. Servo drive rollers controlled the film movement. Because of the limited scan angle of the lens, a roll joint (Z) was incorporated in the structure to increase the scan capability. The effective focal length of the optical system was 66 inches. This camera system was manufactured by Itek. Figure 2-8 presents different views of the L system.

The LANYARD camera system had been intended for interim use only until the Air Force's [redacted] camera system was fully developed and operational.

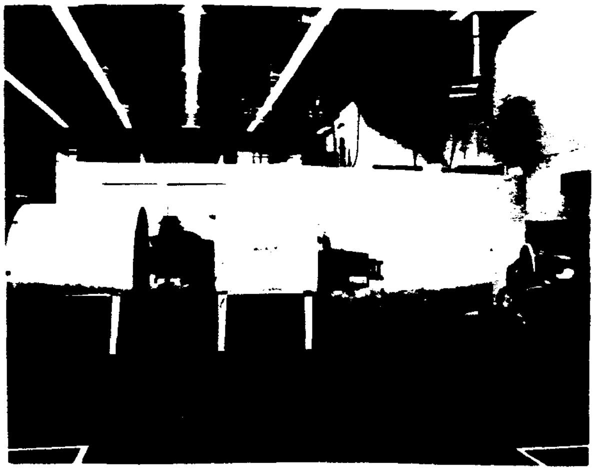
Time was recorded on the film by means of a data head driven by the digital recording clock generator. Other bits in the data head recorded attitude, roll steering, and rate data.

Commands consisted of recovery commands, and stored and real time commands to operate a decoder in the L system. The decoder selected operate programs and controlled the Z-roll joint. Telemetry consisted of continuous and commutated channels transmitting diagnostic and operational data. The system was designed for a 112 nautical mile altitude with a mission duration of four days. It was predicted that this system was

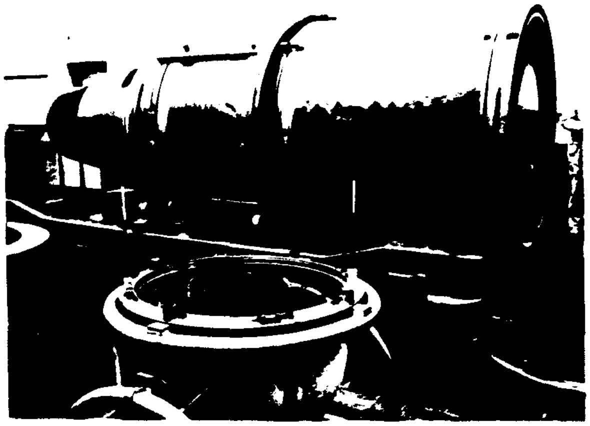
THE LANYARD CAMERA



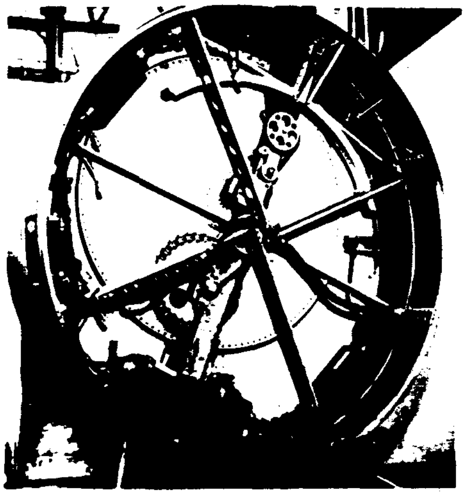
View of Large Berylium Mirror



L System Mockup



System in Test



Z-roll Joint

Figure 2-8

capable of returning ground resolution of five to six feet from a swath width of about 40 miles. It was felt that this system would provide the Intelligence Community with better quality area search/mapping imagery from which technical intelligence could also be derived.

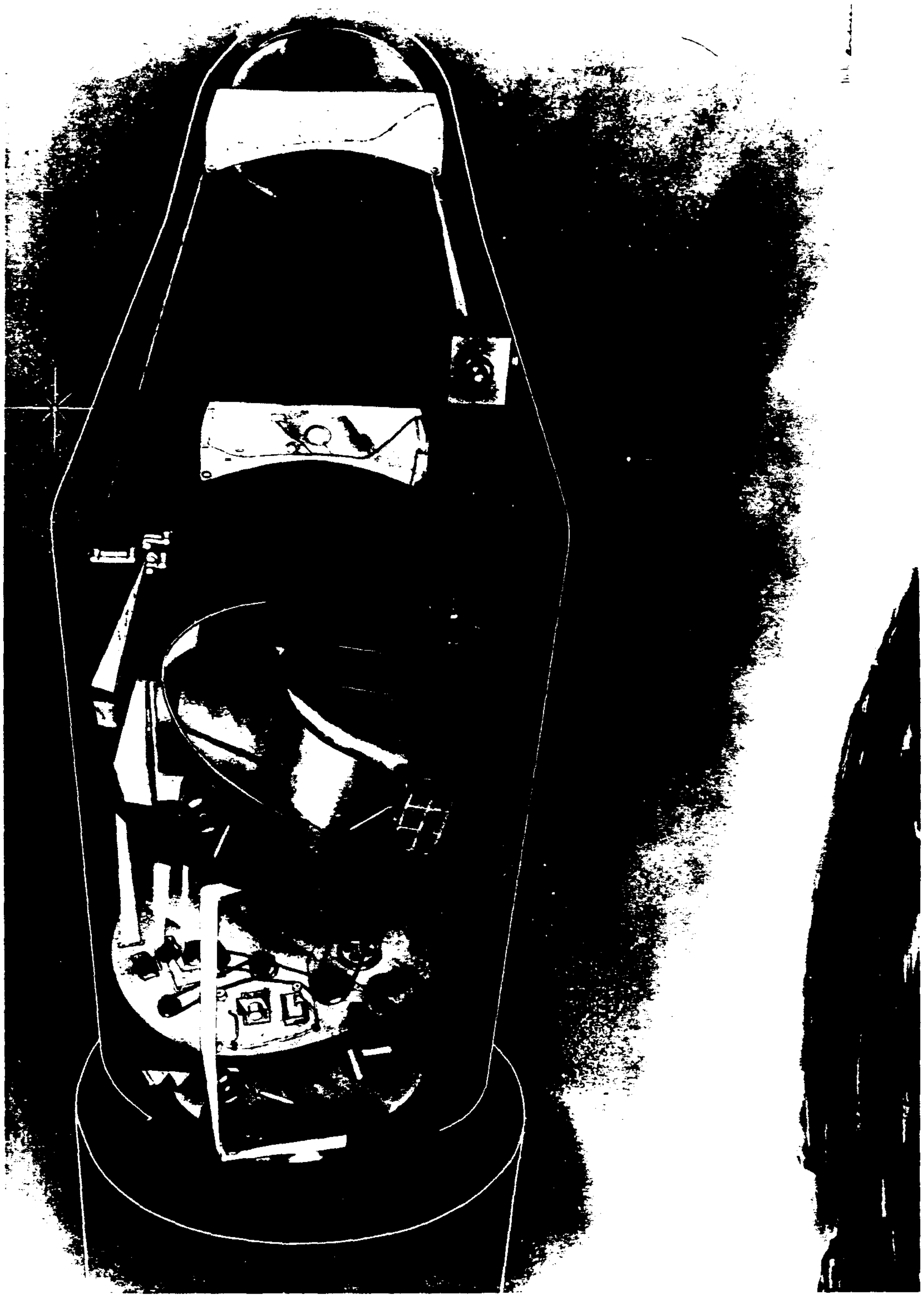
There were three launches of this system. The first system failed to achieve orbit while the other two were recovered. Flight 3 (L-3) contained exposed film, and although a lens thermal problem was discovered, a best resolution of 5.5 feet GRD was acquired. However, because of the success of an Air Force [redacted] camera system which was under parallel development, the L system was terminated.

THE J-1 CAMERA

A continuing goal throughout the CORONA Program was increased film capacity. The fewer the launches required to obtain a given amount of photographic coverage, the less the cost and the lower the risk of problems involved in launch and achieving orbit. The primary constraint of film capacity was boost capacity of the launch vehicle. Throughout the entire history of this program, launch capacity was the primary constraint on camera design. In 1963, three solid propellant rockets were added to the first-stage THOR to increase substantially its boost capacity. The Thrust Augmented THOR (TAT) was first launched successfully in March 1963 and made possible the introduction of the next generation CORONA camera system.

The J-1 camera system was essentially the same as the MURAL system with the addition of a second film recovery capsule (bucket). With the two bucket system, the first could be recovered after half the film load had been exposed. The second bucket could then be filled for recovery later. The system was designed so that the camera could be deactivated (Zombie mode) after the first bucket was ejected. Mission 1015, launched 19 December 1964, was deactivated for a three day period before restarting the cameras. To accommodate the two bucket system, considerable redesign was required for the command and control system and the film takeup. The significance of this redesign is underscored by the realization that early CORONA film loads were 20 pounds; C''', 40 pounds; MURAL, 80 pounds; and now the J-1 with 160 pounds. As a result of this system, the early capability of acquiring 4,500,000 square mile coverage had now expanded into a capability of achieving 18,000,000 square mile stereo coverage. The J-1 system also significantly improved the duration of staying on-station. Mission 1051, launched on 2 May 1969, flew 256 orbital revolutions (16 days). Figure 2-9 presents an artist's portrayal of the J-1 system.

A total of 52 J-1 systems were launched between 25 September 1963 and 22 September 1969. During this six years, 94 film buckets were retrieved. The J-1 routinely yielded ten foot ground resolved distance and, at its best, achieved better than seven feet. The reliability of the J-1 cameras was phenomenal for out of the 50 that achieved orbit, only one failure could be attributed to the camera.



ARTIST'S VIEW OF THE J-1 CAMERA WITH DUAL RECOVERY CAPABILITIES

Figure 2-9

[redacted]

Handle via [redacted]
Controls Only

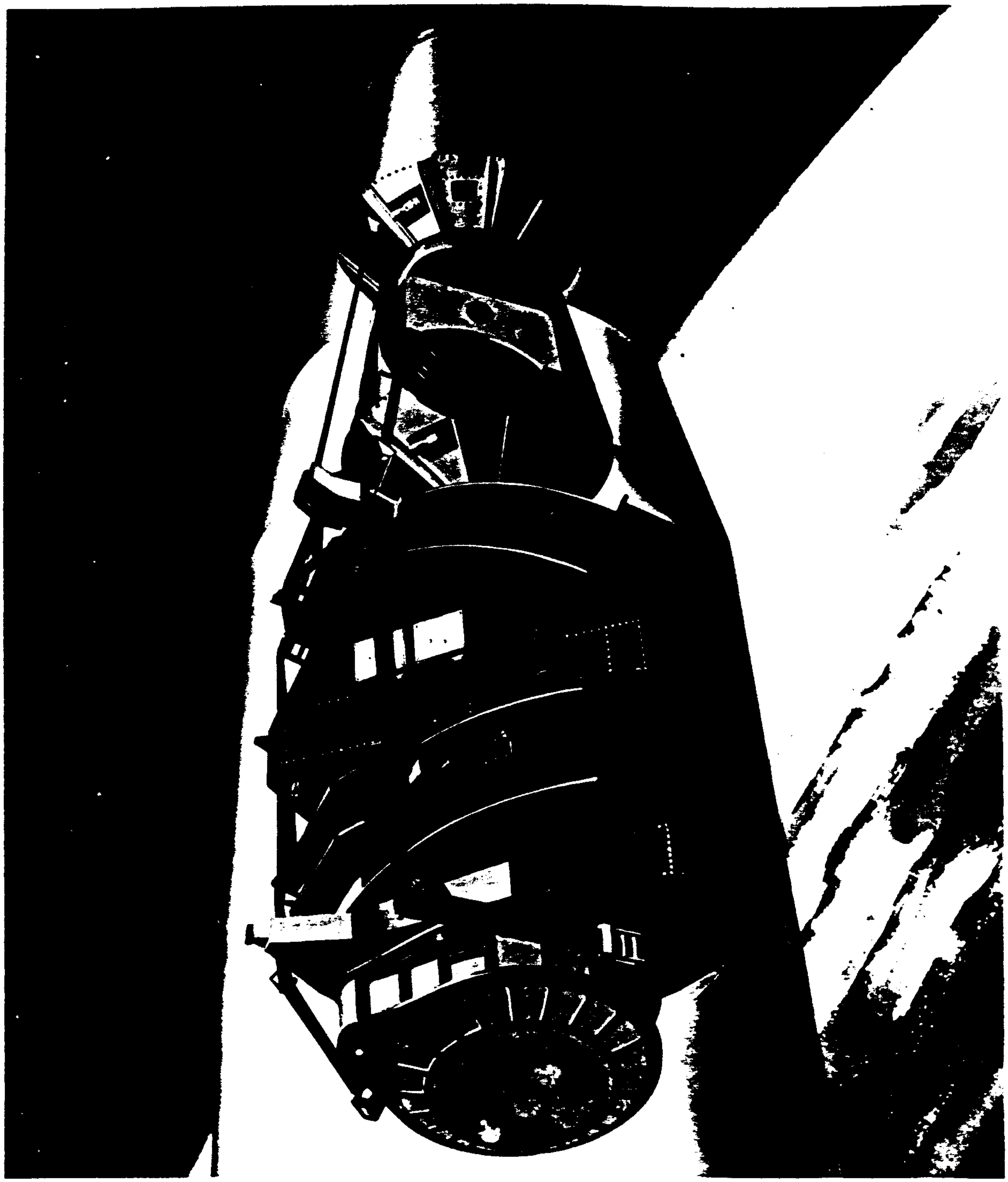
THE J-3 CAMERA

In early 1965, a camera design was proposed which would once again provide a significant improvement in ground resolution and camera flexibility. It had long been recognized that constantly rotating the complete lens and scan arm assembly rather than coupling and uncoupling a rotating lens and an oscillating scan arm would improve camera performance. Itek proposed such a constant rotator, designated J-3. It was determined that such a design could be accommodated by increasing the diameter of the payload equipment barrels to the diameter of the AGENA. Photographic flexibility was considerably increased by introducing a multiple exposure/filter capability (four slit widths and two filters per camera). With this capability, the cameras could accommodate a variety of film types and operate more effectively under varying exposure conditions. Refinement of the camera cycle rate command controls allowed J-3 to operate in orbits as low as 80 nautical miles, thereby considerably improving photographic scale (J-1 operated at a minimum altitude of 100 nautical miles). With this system and the further improved Petzval lens design, the J-3 was able to achieve ground resolved distances of better than 4.5 feet. An artist's conception of the J-3 system is shown in Figure 2-10. Figure 2-11 presents a photograph of the J-3 camera. During the period from 15 September 1967 to 25 May 1972, 17 J-3 cameras were launched, 16 orbited, and all 32 buckets were recovered. The J-3 camera system is detailed in Section III of this volume.

The J-3 cameras incorporated a newly developed panoramic geometry calibration technique, elements of which had been introduced in the last J-1 flights. Due to the fact that a panoramic frame is not simultaneously exposed, new calibration techniques were developed based on proven photogrammetric calibration concepts. Specifically, the Petzval lens was calibrated by the standard method in a direction parallel to its axis of rotation (short dimension of the format). This calibration involves the precise location of the principal point of autocollimation of a fully assembled lens in relation to two fiducial marks at the edges of the lens field. When the lens rotated in the fully assembled camera, these fiducial marks generated two thin dark lines along the edge of the format.

In the long dimension of the format, the fiducial marks consisted of small round dark spots. These were generated by two light sources on the lens which illuminated the edges of the film through tiny holes in the rails supporting the film. The holes were equally spaced and were calibrated in terms of scan angle by an optical shaft angle encoder mounted on the lens shaft.

A technique referred to as the "Dr. A" test, was developed to accurately measure film position relative to the scan rollers by [redacted] In this test, an opaque plate is mounted just below the scan rollers with clear lines (slits) on the plate running parallel to the direction of scan. Two lamps positioned at



ARTIST'S VIEW OF THE J-3 (CONSTANT ROTATOR) CAMERA

Figure 2-10

THE J-3 (CONSTANT ROTATOR) CAMERA

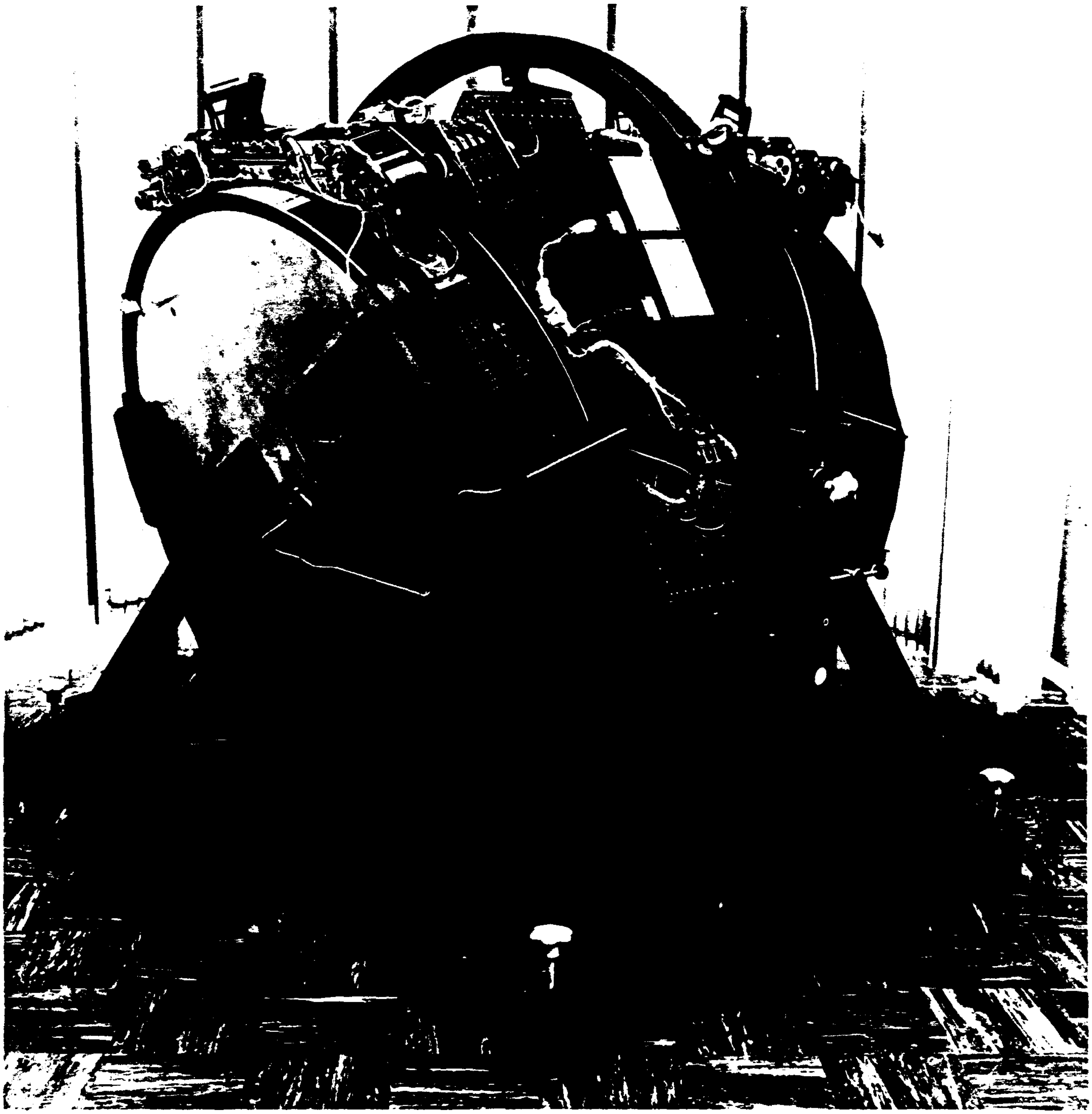


Figure 2-11

a known distance from each other and from the plate are imaged on the film by each slit at a greatly reduced size. When the scan rollers move along the film, the lamp filament images parallel lines for each slit along the length of scan. The separation between the parallel lines is then measured and compared to a controlled exposure on a glass plate. Any plus or minus deviation measured on the film represents film lift or depression during the time of exposure. The measurements derived from these tests were graphically contoured and then analyzed to determine film flatness. This test gave the Government a valid means of determining whether the design goal specifications of ±0.0005 inch film flatness over 90 percent of a frame were met.

THE J-3 SYSTEM

SECTION III

THE J-3 SYSTEM

The fundamental purpose of the J-3 system was to provide extensive stereoscopic photographic coverage of the ground with sufficient detail to allow a photo interpreter to recognize, evaluate, and monitor selected targets. Consequently, the J-3 system contained certain features which were designed specifically toward this goal. First, a high acuity, diffraction limited lens was used in this camera system to take advantage of the high resolution available over a narrow field angle. Secondly, auxiliary horizon recording cameras were mounted in a fixed relationship to the panoramic camera to provide an expeditious means for determining vehicle roll and pitch. A time reference system was implemented which provided a ready reference on the film format to the time of any photographic acquisition, as well as the time relationship of horizon optics exposure to panoramic optics exposure.

The secondary purpose of the J-3 system was to provide photogrammetric control data with the required geometric accuracy to assist the cartographer in constructing accurate terrain maps from the photography obtained by the system. Of equal importance was the ability to assign accurate geodetic coordinates to these maps. The J-3 system had the capability of supplying the required geodetic control, assuming the availability of accurate orbital and attitude information. For cartographic purposes it is essential to establish the geometrical relationship between points on the film format and corresponding ground points. In order to accomplish this, it is necessary to calibrate the internal geometry of the camera. Generally, this involves the use of special equipment in preflight testing of the system and special data reduction techniques. The calibration information obtained from the tests is supplied to the cartographic community. Additional data is recorded on the film during mission operation. This data permits the correlation of the photography with the previously obtained calibration information. Thus, for every point on the film, the cartographer can determine two angles, α (cross-track or scanning angle), and β (along-track angle), with a root mean square (RMS) accuracy of 4 arc-seconds in each direction.

A summary of the basic physical features and operational parameters is provided in Table 3-1. The complete J-3 system payload consisted of the following:

A. Two identical, 24 inch focal length, f/3.5 panoramic cameras, each having two integrated 55 millimeter focal length, f/6.3 horizon optics.

B. One auxiliary structure that supported both panoramic cameras and the electronics packages which form the camera module.

C. One supply cassette.

D. One supply support structure.

E. One intermediate roller assembly.

The following ancillary equipment was used to support the system in the field:

A. Test and checkout console.

B. Camera module transit case.

C. Single camera transit case.

D. Camera module dolly.

E. Single camera dolly.

F. Spool assembly dolly.

The panoramic cameras were positioned on the auxiliary structure in a V-configuration to provide a 30 degree stereo angle. The auxiliary structure was three-point mounted to the vehicle so that the even serial numbered camera was located forward and viewed toward the rear (aft-looking), and the odd serial numbered camera was located aft and viewed forward (forward-looking). The auxiliary structure also provided the mounting surface for the system's electronic packages. The supply cassette, which contained the total film supply for both cameras, was located aft of the camera module. The supply cassette was fastened to its support structure which also was three-point mounted to the vehicle. Takeup A, located in recovery vehicle one (RV-1), and takeup B, located in RV-2, each took up half of the film of both cameras. The intermediate roller assembly was attached to the vehicle between takeup B and the camera module.

The system was basically designed to use 3.0 mil, 70 millimeter, EK 3414 Film. Either camera would also operate with a split load of any two of the following types of film: 3414, SO-121, SO-180, SO-230, SO-380. The supply cassette contained two $28\frac{1}{4}$ inch diameter spools, each capable of storing 16,000 feet of film. Each of the two takeup A spools was capable of storing 8,000 feet, and each takeup B spool was capable of storing 7,750 feet of film. Therefore, the system's total film capacity was 31,500 feet.

The power requirements of the J-3 system were 24 vdc, unregulated, and 115 vac at 400 cps. Unregulated 24 vdc power was utilized for general service in the camera, supply control, and takeup control. The 115 vac, 400 cps power was utilized in the camera to develop regulated direct current power; plus and minus low

TABLE 3-1

SUMMARY OF J-3 PHYSICAL FEATURES AND OPERATIONAL PARAMETERS

Physical Features

Configuration	30 degree convergent stereo panoramic cameras
Lens	24 inch focal length, f/3.5 Petzval design
Film capacity	15,750 feet of 70 millimeter, 3.0 mil, polyester base film per camera
Film size (format)	31.632 x 2.754 inches
Usable format	29.323 x 2.147 inches
Power	1620 watt-hours (24 vdc, unregulated, at 2.5 radians per second)
	270 watt-hours (115 vac, 400 cps, at 2.5 radians per second)
Weight (empty)	Approximately 437 pounds
Weight (with film)	Approximately 597 pounds
Cycle period	1.5 to 4.2 seconds per cycle
Exposure time	Variable
Overlap	Fixed at 7.6 percent
Filter	Variable (2 position)

Operational Parameters

V/h range	.0525 to .021 radians per second
Altitude	80 to 200 nautical miles
Cross-track coverage per frame	116 to 290 nautical miles
Along-track coverage per frame	7.73 to 19.33 nautical miles
Total along-track coverage	41,167 nautical miles at 80 nautical mile altitude
Total operating time	169 minutes at 80 nautical mile altitude

voltages were developed for the camera drive servo and exposure control circuits; and high voltage direct current power was developed for the frequency marker lamp requirements.

The power supply returns were carefully segregated within the system to provide isolation between the 115 vac, 400 cps return and the 24 vdc unregulated return. Also, isolation was provided between power returns and all shielding and bonding requirements. In addition, regulated dc power returns were joined to the unregulated dc return at only one point (drive servo). This was required to maintain proper referencing of the V/h programmer signal to the tachometer feedback signal.

The no-load and average-load requirements of the J-3 system were:

A. Unregulated direct current
   No-load +22 to +29.5 volts
   Average-load +21 to +28.5 volts

B. Alternating current
   No-load 113.7 to 117.3 volts rms
   Average-load 111.7 to 115.3 volts rms

The total system power consumption was nominally 1,890 watt-hours (based on 40 frames per pass at a 2.5 second per cycle rate and 150 starts and stops per mission).

The J-3 system contained several component temperature and operation monitors which provided telemetric data during operation. In addition to the telemetry, monitor points which could be checked during ground testing were provided.

The camera module consisted of a triangular, riveted, sheet metal, auxiliary structure on which were mounted two panoramic cameras and the system electronics boxes. The main electronics box contained the control package, the interface package, the data signal conditioner, and the ac-to-dc power supply. The auxiliary electronics box contained the main servo and the panoramic geometry electronics circuit.

The panoramic cameras were independent and similar but were not interchangeable. Each camera consisted of its own machined frame upon which most of the camera components were mounted. Because some camera components were attached to the auxiliary structure, the structure was considered as an integral part of the panoramic camera. The primary components of the panoramic camera were drive system, lens, scan head assembly, drum, film transport mechanisms, film metering capstan (FMC) mechanism, panoramic geometry system, and the horizon optics. The actions of these components were related and timed through a system of belts, pulleys, and special function gear packages, all of which were driven from a single camera drive motor.

The 24 inch focal length lens was a Petzval design consisting of five elements mounted within a cast magnesium cell. A sixth element, the field flattener, and the scan head assembly were mounted on the end of a titanium tail cone which is secured to the lens cell at the nodal point.

The scan head assembly, which contained the slit width and filter change devices and the focal plane rollers, was mounted on the end of the lens cone. This device consisted of a bi-directional, four position slit width changer and a two position filter changer. A slit width failsafe mode or nominal slit width position was also provided. The slit blades were driven through a clutch and a dual potentiometer by a servo motor. The filter was driven by a stepper motor and a dual potentiometer. During exposure, the focal plane rollers lifted the film from the guide rails into the exact focal plane.

In order to prevent light from entering the vehicle compartment through the vehicle/camera interface, a drum housing the lens rotated within a network of non-rotating light shields that nodded with the drum. The drum itself was light-tight except for the clear aperture end and a smaller opening for the scan head access cover. Two specially formed pieces of sheet metal, which were attached to the drum around its periphery, rotated inside a labyrinth preventing light from entering alongside the drum. The inside diameter of the light shields were slightly larger than the diameter of the drum. The shields encompassed the drum over a sufficient portion of the circumference to prevent light from passing around the drum itself. The drum assembly also served as a thermal shield for the lens when the camera was inoperative.

A series of rollers, located around the circumference of the drum and placed parallel to the lens rotation axis, revolved with the drum just beneath the film guide rails to prevent film from being pulled through the rails. These rollers did not contact the film during normal operation.

The camera film transport system comprised an input metering roller which was geared through a 99/101 percent clutch to provide continuous input metering at a nominal rate. Film guide rails guided the film over the 70 degree format, and film clamps located at either side of the format were actuated during exposure. A frame metering roller pulled one frame of exposed film out of the format area during the non-exposure portion of the cycle. A shuttle mechanism stored extra loops of film arising from continuous film input/output and intermittent frame metering. The shuttle also was used to control the 99/101 percent clutch.

Each camera contained its own FMC mechanism. The FMC mechanism was comprised of a cam, which was driven by the camera drive motor, and a four bar linkage, which was driven by the cam. The linkage was fixed at one point such that the action of the cam against the linkage caused the cameras to rock about an axis parallel to the vehicle pitch axis.

The panoramic geometry subsystem contained several equipment elements. This subsystem was used to gather data on each panoramic frame to enable a calibration of the panoramic camera. The elements of the panoramic geometry subsystem included the following:

A. Holes in the film guide rails which were angularly spaced about one degree apart, and two incandescent lamps which were mounted on the scan head of the lens and were exposed through the rail holes.

B. A subsystem consisting of an accurate optical encoder, electronic circuits, xenon flashtube, two sections of optical fiber bundles, a rotating optical coupling, and a lens, all of which combined to expose dots on the film to represent the nod angle of the camera.

C. An accurate pulse generator which triggered a neon tube and exposed timing marks on the film to permit the determination of the time difference between the exposure of two different points of the format.

D. Two lights mounted on the scan head which provided the panoramic geometry traces.

Each panoramic camera contained two horizon camera assemblies that allowed the photo interpreter to quickly determine the pitch and roll attitude of the panoramic camera during exposure. The horizon camera consisted of a 55 millimeter, f/6.3 lens, a between-the-lens leaf shutter, a shutter trip solenoid, a filter change mechanism, and an assembly housing. The horizon camera assemblies were mounted on each end of the film transport bridge. This facilitated the sharing of a common film supply and path with the panoramic camera. The optical axes of the horizon lenses were nominally, but not precisely, coplaner with the optical axis of the panoramic camera.

The horizon camera used an integral filter equivalent to a Wratten 25. The lens provided a format of 2.1 by 0.9 inches. The corresponding half angles are 26 and 12 degrees, respectively. The horizon camera housing provided a support structure for the lens, shutter mechanism, lens cone, lens hood, and filter change mechanism. The filter change mechanism, mounted in front of the lens, consisted of a sliding filter on a track, a drive motor, and connecting linkage. An attenuating filter could be slid in front of the lens when emulsions faster than the basic Film type 3404 were used.

The supply cassette, which remained integral with its support structure after final assembly, contained the supply spools for both panoramic cameras; a radius sensor arms which controlled the output of each torque motor; and a set of tension rollers, a torque motor, and brakes for each spool.

The triangular-shaped support structure was a riveted, magnesium skin construction with machined fittings. It had a support ring centrally located to which the rear cover of the supply cassette was mounted. The supply cassette was composed of three individual machined magnesium castings (two end covers and a center section) which were lightened by chemical milling. The cassette assembly was light-tight except in the area of the tension rollers located on each side of the center section where the film exited from the cassette. The areas could be sealed to prevent light leaks during testing. The supply spools consisted of a 6 inch outside diameter machined magnesium hub and two 28 1/4 inch diameter by 3/8 inch thick aluminum honeycomb and magnesium skin flanges. Tension was provided by torque motor output to a gear attached to the hub of each supply spool. A brake on each torque motor prevented rotation of the spools when the power was off.

The takeup cassettes consisted of a structure, spools, spindle, sensor arm, component boards, and cable. An additional assembly, the roller carriage, was used in takeup B. The structure consisted of two magnesium honeycomb side plates which were aligned, bonded, and secured in two shear plates. Mounted on this structure were the cable, component board, resistor plates, transistors, heaters, and thermostat (takeup A only). The spools were of lightweight magnesium construction. The B takeup spool had a larger core diameter which resulted from having three hub rollers and a set of wrap around plates installed. The spindle assemblies consisted of a three-piece magnesium housing into which were assembled two torque motors, drive gearing, and two anti-backup systems for the A takeup or two brakes for the B takeup. The anti-backup unit consisted of a ratchet wheel coupled to the motor shaft through a one way clutch, a pawl, suitable linkage, and a release solenoid. The brake used in the B spindles was keyed to the motor shaft and was released electrically. The sensor arm assembly consisted of a magnesium frame into which were assembled two potentiometers, gearing, and a spring loaded sensor arm and puck assembly. The roller carriage assembly, contained only on B takeups, consisted of two magnesium side plates, input and output rollers, deflection roller, roller shafts, and film guard.

Tables 3-2 and 3-3 and Figures 3-1 thru 3-5 present additional details, graphs, and data on the J-3 system.

TABLE 3-2

THE J-3 ORBIT HISTORY

Mission	Inclination (degrees)	Life (days)	Mean Perigee Altitude (nm)	Mean Frame Altitude (nm)
1101	80.1	14	85	84.6
1102	81.6	14	85	86.7
1103	83.0	14	85	88.1
1104	82.1	15	83	87.3
1105	82.1	17	84	85.1
1106	81.5	9	81	83.5
1107	74.9	19	98	99.5
1108	81.5	17	95	94.2
1109	88.0	19		97.3
1110	83.0	19		96.2
1111	60.0	18		100.4
1112	83.0	19		100.0
1113		0		
1114	81.5	16	86.5	97.0
1115	74.9	19	86.0	85.4
1116	81.5	19	91.5	87.0
1117	96.4	6	93.3	88.0

TABLE 3-3

CORONA J-3 PERFORMANCE PREDICTIONS FROM ERROR BUDGET
(Two Sigma Low)

	Second Generation Lens				Third Generation Lens			
	Along-Track		Cross-Track		Along-Track		Cross-Track	
Parameter	0°	30°	0°	30°	0°	30°	0°	30°
Resolution (cycles/mm)	130	132	126	72	155	158	151	76
Blur (microns)	3.28	3.01	2.64	11.0	3.28	3.01	2.64	11.0
GRD (feet)	6.4	7.3	6.6	13.5	5.6	6.3	5.6	12.8

NOTE: These performance predictions were calculated using the following conditions:

Altitude: 82 nm

Film type: 1414, 3414

Exposure: 2.44 msec

Contrast: 2:1

Field angle: 0°

MAJOR COMPONENTS OF THE J-3 LAUNCH VEHICLE

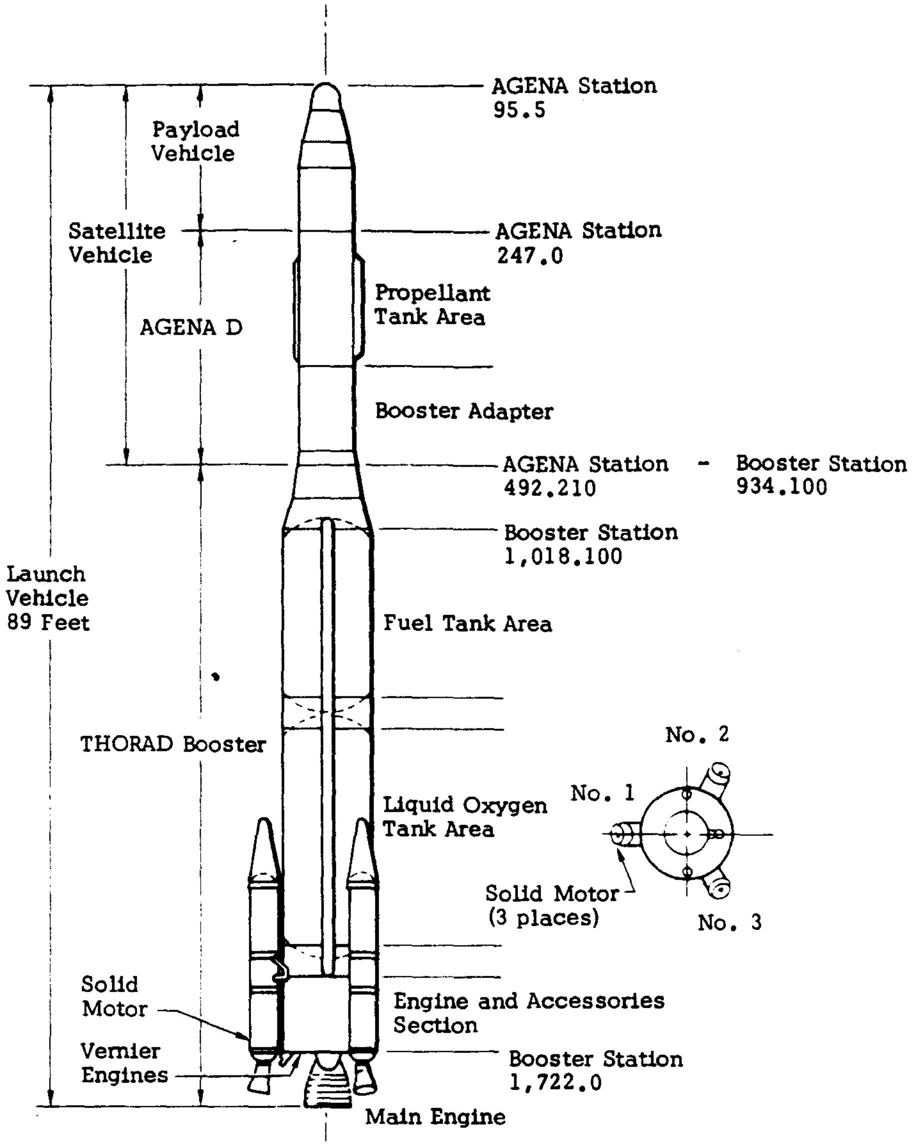


Figure 3-1

MAJOR COMPONENTS OF THE J-3 SUBSYSTEM

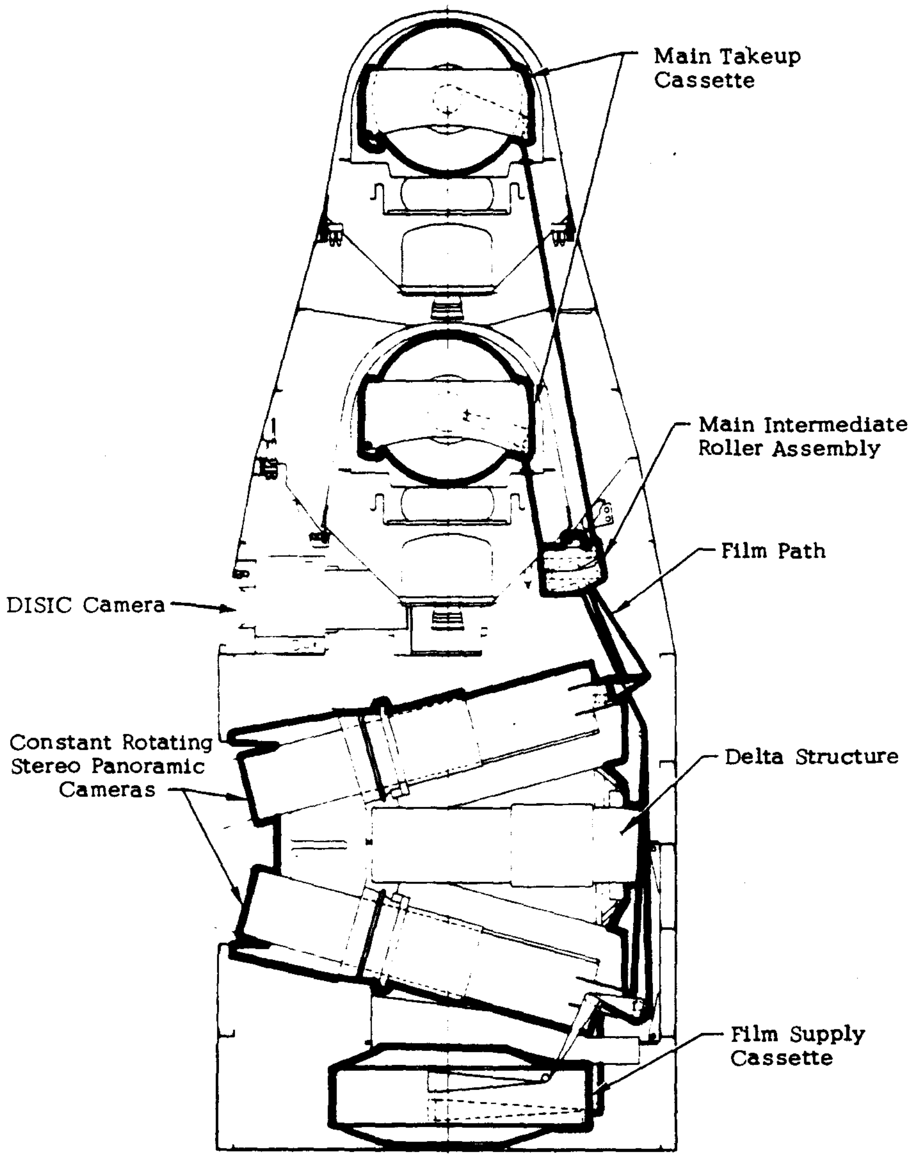


Figure 3-2

THE J-3 FILM TRANSPORT PATH

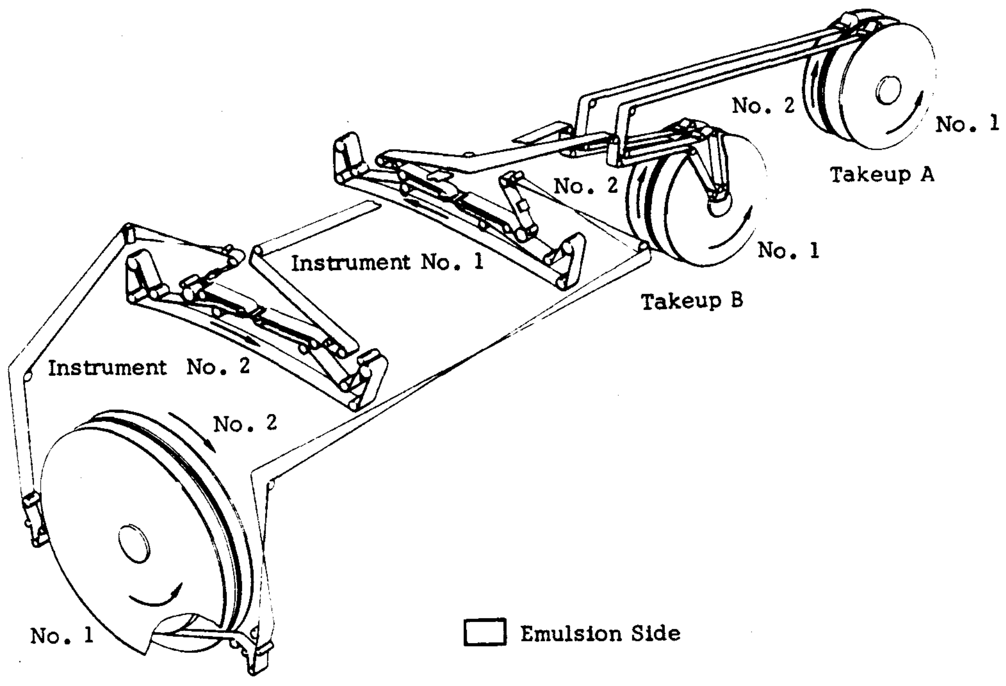


Figure 3-3

COMPARATIVE GROUND COVERAGES OF THE J-3 AND DISIC SYSTEMS

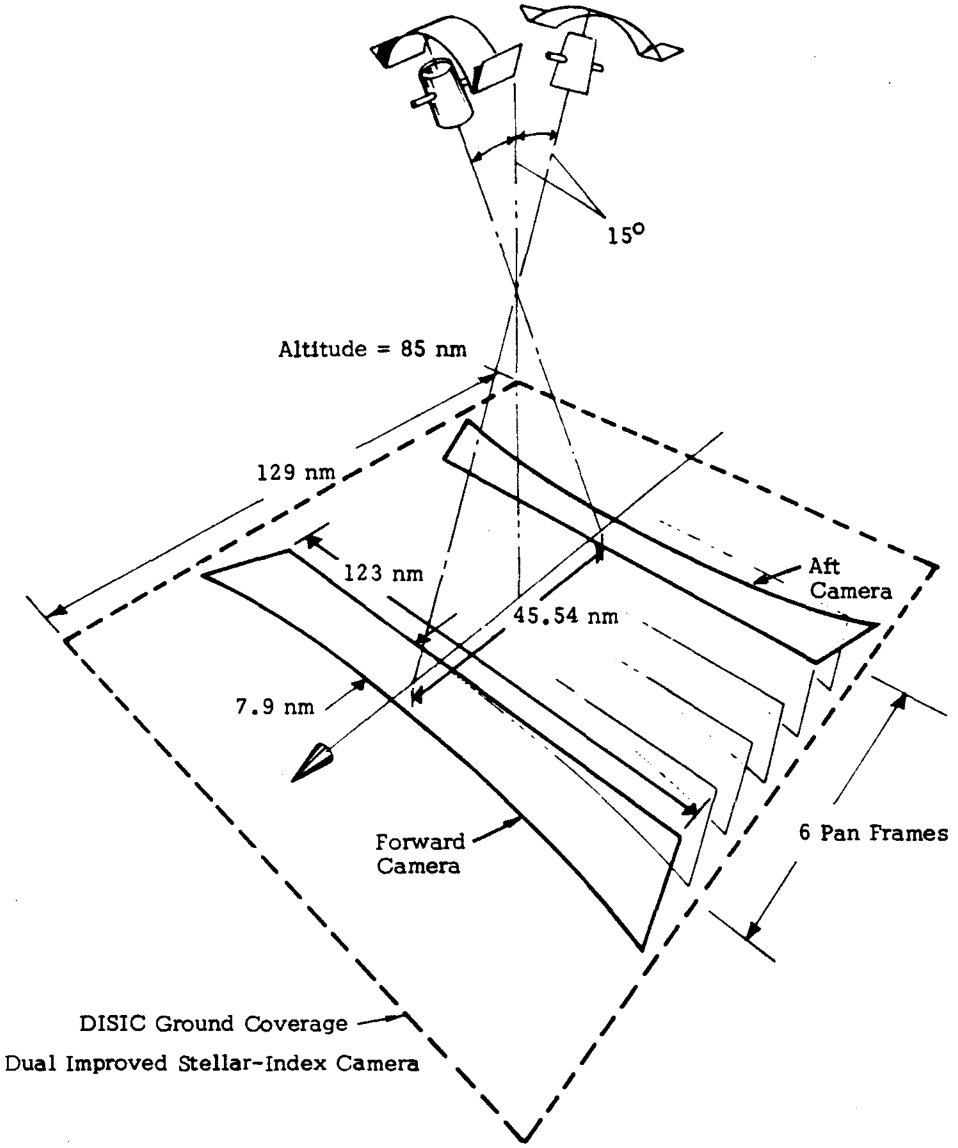
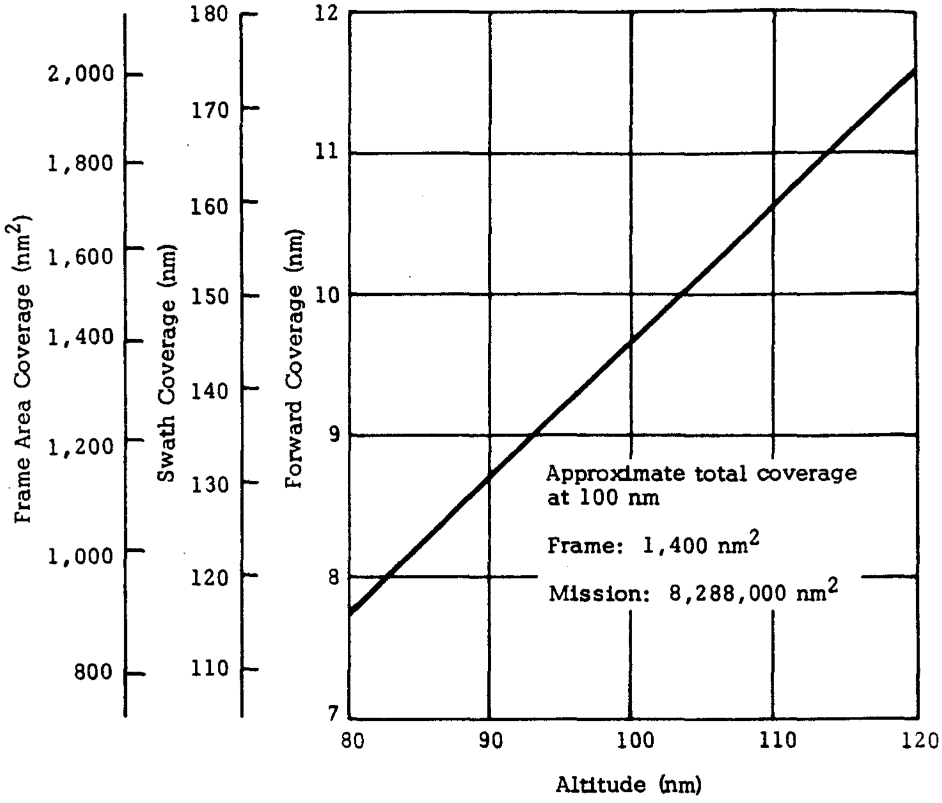


Figure 3-4

J-3 COVERAGE AS A FUNCTION OF ALTITUDE



Approximate total coverage at 100 nm

Frame: 1,400 nm^2

Mission: 8,288,000 nm^2

Figure 3-5

Handle via [redacted] Controls Only

THERMAL CONTROL

SECTION IV

THERMAL CONTROL

The art of thermal control in space was in the same state as most other space age disciplines; and that is having some knowledge of how to address the problem, but no available experienced personnel to identify the important parameters. Technological advances were needed in systems thermal analysis techniques which in turn required the utilization of large scale digital computers.

Thermal control design is concerned with the prelaunch, boost, orbit, and recovery phases of the spacecraft lifetime. Of these, experience had been gained on all but the on-orbit phase by the time of the first CORONA design.

The prelaunch phase required protection for the exterior skins from the salt water atmosphere at the launch base as well as providing temperature control for the camera and supporting subsystems during pad checkout and countdown. It was decided that the best protective device for this purpose would be a shroud. Several types were tried before the final selection of a tubular type nylon shroud. In at least one instance, however, the shroud did not provide adequate protection from a rain storm, and the magnesium skins began to corrode from the exposure. A hurried sanding job, a make shift paint pattern, and an early launch date saved one J-3 from near destruction. Subsequently, a plastic frangible glove type environment sheath was developed for this prelaunch phase. This type of sheath worked very well.

Boost and re-entry phase experience, which had been gained on the Lockheed X-17 rocket and other programs, provided the basic knowledge that thermal control could be maintained during these flight phases. There were problems in the areas where the fairing met the cylindrical structure. There was also extreme concern over the re-entry heating until after several capsules and a heat shield were recovered. However, the area in which thermal problems persisted longest was that of thermal control of the camera system on-orbit.

Some of the progress in orbital thermal design was provided by [redacted] and his associates at Lockheed, Palo Alto, where they established the methodology for approaching thermal control. [redacted] presented the solar, albedo, and earthshine heat rates that served as the standard to thermal engineers for some years to come. Thermal control work was also accomplished by [redacted] [redacted], and [redacted] at the Vidya Division of Itek Corporation.

The thermal control design task was to balance the temperature of an orbiting space vehicle between the solar temperature of 10,000° F and the outer space temperature of -460° F while the vehicle is passing into and out of the earth's shadow. This balancing is accomplished by defining/selecting exterior surface finishes for the space vehicle which have differing properties of solar absorptance and infrared emittance. The surface solar absorptance modified the amount of solar energy striking the space vehicle. The infrared emittance attenuates the amount of energy which is radiated from the space vehicle at its own surface temperature. For example, black painted surfaces have both high absorptance and emittance, white painted surfaces have low absorptance and high emittance, and bare metallic surfaces such as gold or aluminum have a moderate absorptance but very low emittance. These properties were utilized in combination to provide the desired temperature levels. The first pattern developed for this purpose was uniform around the vehicle skins. This pattern was a combination of gold plated barrels overlaid with white and black stripes. These stripes were varied in width and position according to the temperatures experienced on the previous flight and the orbital parameters of the anticipated flight as they might affect the predicted temperatures. The Program Office could not totally understand the scientific bases for these pattern adjustments, and as a result attached the cognomen of "Chicken Bone Specialists" to the thermal engineers.

The first camera thermal design considerations implemented on the original CORONA unit were based on the work of [redacted], [redacted], and [redacted]. In recognition of the effects of differential thermal expansion, the basic structure was designed utilizing the low thermal expansion characteristics of titanium. However, the effects of temperature on the optical performance of the HYAC IIA lens were not factored into this design.

The C''' was designed with a magnesium lens cell, drum, and stovepipe, but the thermal problems associated with this design became obvious after the first few operations. Analysis of the differential thermal expansion of the structure resulted in changing the drum to titanium and the stovepipe to invar. Thermal/optical tests of the lens cell were also performed by [redacted] and [redacted] Their findings were factored into the new drum and stovepipe designs. On the basis of the lens cell tests, an optical design effort was undertaken by [redacted] to consider the effects of temperature-induced changes in optical element radii and spacing. Several problems were encountered in the work, i.e., there were some difficulties in algebraic signs where, in design, focus shift went in one direction while, in practice, it went in the other direction.

From the system standpoint, thermal control design information for the early CORONA vehicles was generated from the analysis of Vidya engineers and coordinated with and implemented by [redacted] of Lockheed's Advanced Projects Office. Unfortunately, this system had its problems in this area as evidenced by the significant variance of a plot of vehicle temperatures versus flight number. At this time in 1964, [redacted] and [redacted] of the Lockheed Orbit Thermodynamics Department entered the program.

They undertook the task of setting up a large thermal mathematical model of the system in order to provide better thermal control. This task was later assigned to [redacted] who also participated in the conceptual design studies of the J-3 system at Lockheed and introduced the use of non-uniform external surface finish patterns as a better means of stabilizing on-orbit temperatures.

Meanwhile, Itek Optical Design Engineers, [redacted]nd [redacted] were busy reducing the various suggestions for an "Athermalized" Petzval lens cell to a practical design for use in the J-3 series. These suggestions came from many sources including [redacted], [redacted] [redacted], and [redacted] in Lexington and [redacted] at Vidya. To athermalize the lens, changes in index of refraction and radius of curvature of the various elements with temperature were carefully balanced against the thermal expansion characteristics of the elements, cell, and tail cone. In this manner, a constant relationship between image position and focal plane rollers could be maintained for uniform temperatures (+40° F to +90° F) of the lens cell assembly.

The Petzval Lens Cell Thermal/Optical Test Program was subsequently conducted at Itek's Palo Alto Facility. These tests utilized the unique capabilities of Itek's Thermal/Optical Research Facility to subject the lens cell to a series of temperature conditions while simultaneously allowing optical data to be gathered. The results of this test series substantiated the "Athermalized" lens cell design for uniform temperature level changes and also pointed out that substantial radial temperature gradients existed in the glass elements during the soaks. Further testing, utilizing flight data feedback on the periodic lens cell temperature variations, indicated a substantial (± .002 inch) change in focal plane position over the same period. The recommended solution was to wrap the lens cell and tail cone with five layers of aluminized mylar super-insulation. Testing of this configuration showed the focal plane movement to be reduced to less than ± .00025 inch. This insulation was applied to the lens cells effective with Mission 1106.

Improved temperature sensors were implemented on Mission 1107 which allowed the lens cell temperature variation to be more closely monitored. Subsequent flight data did not indicate any noticeable lens cell periodic temperature variations. This modification was a big factor in the improvement of the photographic performance of the CORONA cameras.

FILMS, FILTERS, AND SAMPLES OF CORONA IMAGERY

Handle via [redacted]
Controls Only

SECTION V

FILMS, FILTERS, AND SAMPLES OF CORONA IMAGERY

Aerial films designed for reconnaissance and space application require characteristics which differ from conventional films. Aerial films must withstand the influence of environment, the requirements of system designs, and the handling from film manufacture through the duplication stage. Advances in emulsion making technology have made possible aerial films having a broad range of sensitivity, speed, and definition. Aerial color films are subjected to the same environment and design requirements as are black and white films. However, aerial color films have more critical exposure and color balance requirements. These special photographic characteristics are combined with a dimensionally stable estar base to provide added dimensional stability. In the CORONA system, a number of black and white film types were used. These included SO-1221, the original acetate base film; SO-1188; SO-221, the first estar base film; 4400; SO-132; 4404; and finally 3404. Two color films were used in the J-3 panoramic cameras, SO-121 and SO-180. For the Stellar-Index cameras, the film types were SO-102, 3400, and 3401. High definition aerial 3404 film has high contrast, maximum definition, extremely fine grain, and extended red sensitivity. The 3404 emulsion is coated on a 2.5 mil estar base for use on cameras specifically designed for extremely high altitude, stable platform photography. Several different processing conditions were used for 3404. A three-level interrupted process provided three sensitometric curves, each separated by 1/2 stop. In addition, a single-level "Dual Gamma" process was used starting with Mission 1104 that produced a wider exposure range. For 3404 the RMS granularity was 9.5, and resolving power was 615 cpm at a T.O.C. of 1,000:1 and 185 cpm at a T.O.C. of 1.7:1.

Eastman Kodak manufactures a wide variety of gelatin filters for use in almost all fields of pictorial and scientific photography. Most of the filters are .005 inch gelatin that have been coated with a lacquer for protection. A few of the filters are available in glass only, while most of the gelatin filters are cemented between glass. There are four main classes of filters: Wratten, Color Correction, Photometric, and Light Balancing.

The Wratten filters are available in approximately 100 different spectral colors. They range from almost clear to saturated colors visually representing most wavelengths and some cases combinations of wavelengths in the spectrum. This class of filters includes the haze cutting filters used by CORONA. The Color Correction filters are used to adjust the color balance for color films with both ground and aerial photography. These filters, unlike the Wratten filters, are not saturated but are pastel in color. The Photometric and Light Balancing filters are used to change the color temperature of a light source to match that required for a particular color film sensitivity. These filters are not generally employed in aerial reconnaissance.

Filters are required for most aerial reconnaissance systems in order to counteract the contrast reduction effects from the bluish haze light. The spectral filters commonly employed are Wratten gelatin filters and are yellow to red in color. Generally, the deeper red the filter, the greater the haze cutting ability and, hence, the higher the contrast. There is a tradeoff that must be considered in selecting the best filter for any given camera. The redder the filter, the higher the filter factor which in turn requires longer exposure times. Increased exposure has a direct relationship to smear. Thus, filters are chosen that provide the best contrast and minimize image smear. These considerations are then incorporated into the lens design so that performance can be optimized for that region of the spectrum.

The haze cutting filters for CORONA black and white photography consisted of either a Wratten 21, 23A, or 25, the characteristics of which are given in Figure 5-1. Operational conditions and specific lens types govern the choice of a specific filter for a mission. A third generation Petzval lens, for example, is designed for a Wratten 25 filter. However, for a winter mission, where the exposure time would be long, total system performance could be enhanced by using a Wratten 23A filter with an appropriate reduction in exposure time due to the lower filter factor. The CORONA J-3 system had a filter switching mechanism that allowed the mission to be flown with two filters per camera. The primary filter position was generally used for most of the mission, the alternate filter could be commanded into position on real time or automatically with a material change detector (MCD) on the film. This was particularly useful when a split film load was flown. It also should be noted that a filter change in the J-3 system could be accommodated by changing the exposure slits.

The higher f/number of the DISIC index camera system required the filter factor to be low. The Wratten 12 filter was used having a factor of 1.5. In order to maintain the precision geodetic characteristics of the camera, the filter was an integral part of the system, and therefore a filter changing mechanism was not employed. The Wratten 12 filter is yellow in color and has the widest bandpass of all filters used on CORONA. The purpose of the stellar portion of DISIC is to provide interlocking photographs of star patterns with the terrain photography. There were no requirements for filters on these lenses.

Figures 5-2 thru 5-7 illustrate samples of photographic imagery of airfields acquired by each of the CORONA camera systems beginning with the first success, Mission 9009 launched on 19 August 1960. All photos have been enlarged 20 times from their original scale. Figure 5-8 illustrates operational imagery using both high definition aerial color (SO-121) and infrared color film (SO-180) produced by the CORONA J-3 system. Table 5-1 lists the mission parameters of each sample of CORONA photography shown in Figures 5-2 thru 5-8.

CHARACTERISTICS OF FILTERS USED WITH PANORAMIC AND DISIC CAMERAS

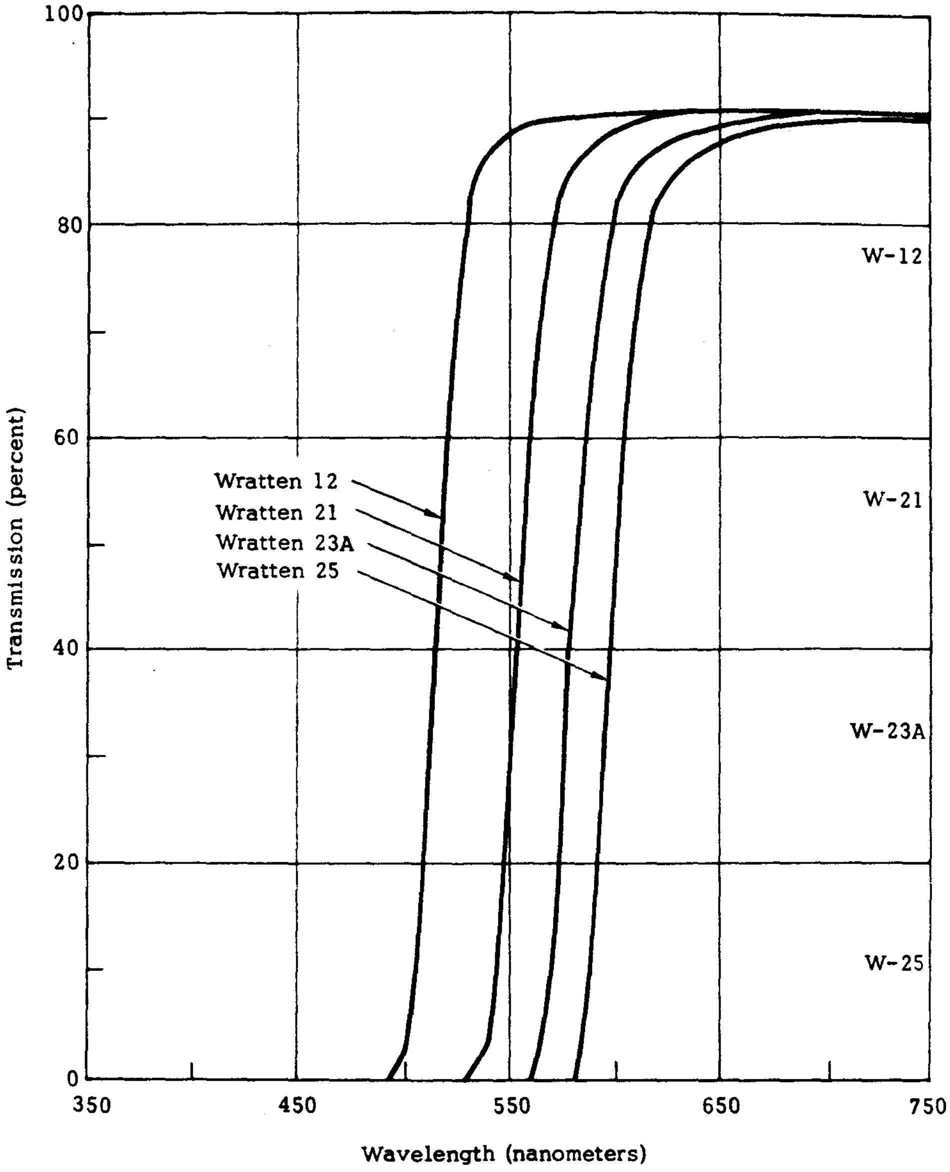


Figure 5-1

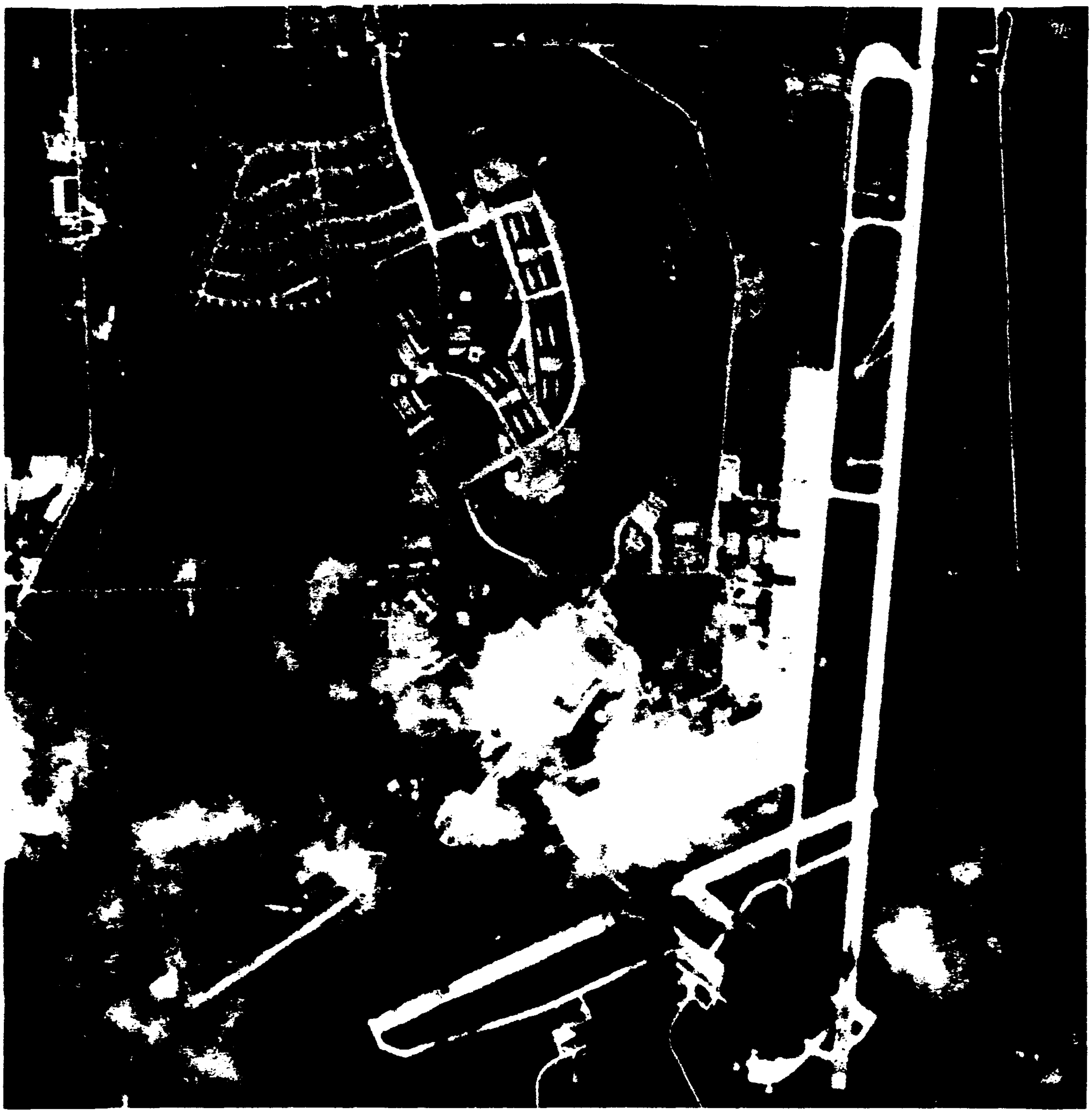
TABLE 5-1

SUMMARY OF MISSION PARAMETERS FOR PHOTOGRAPHIC IMAGERY SAMPLES SHOWN IN FIGURES 5-2 THRU 5-8

— Black and White Films —

Figure Number	Page Number	Mission Number	Requisition Date	Filter Type	Film Type	Scale	Altitude (nm)	Solar Elevation (degrees)
5-2	5-5	9009	19 Aug 1960	W-21	SO-1188	1:345,165	114	-63
5-3	5-6	9017	17 Jun 1961	W-21	4400	1:427,384	141	-49
5-4	5-7	9022	12 Sep 1961	W-21	4404	1:431,225	142	-33
5-5	5-8	9037	23 Jun 1962	W-21	SO-132	1:348,388	115	-36
5-6	5-9	1006	9 Jun 1964	W-21	4404	1:329,000	105	-58
5-7	5-10	1104	15 Aug 1968	W-21	3404	1:261,300	83	-61
— Color Films —								
5-8 (Top)	5-11	1105	Nov 1969	-	SO-121	-	-	-
5-8 (Bottom)	5-11	1104	Aug 1968	-	SO-180	-	-	-

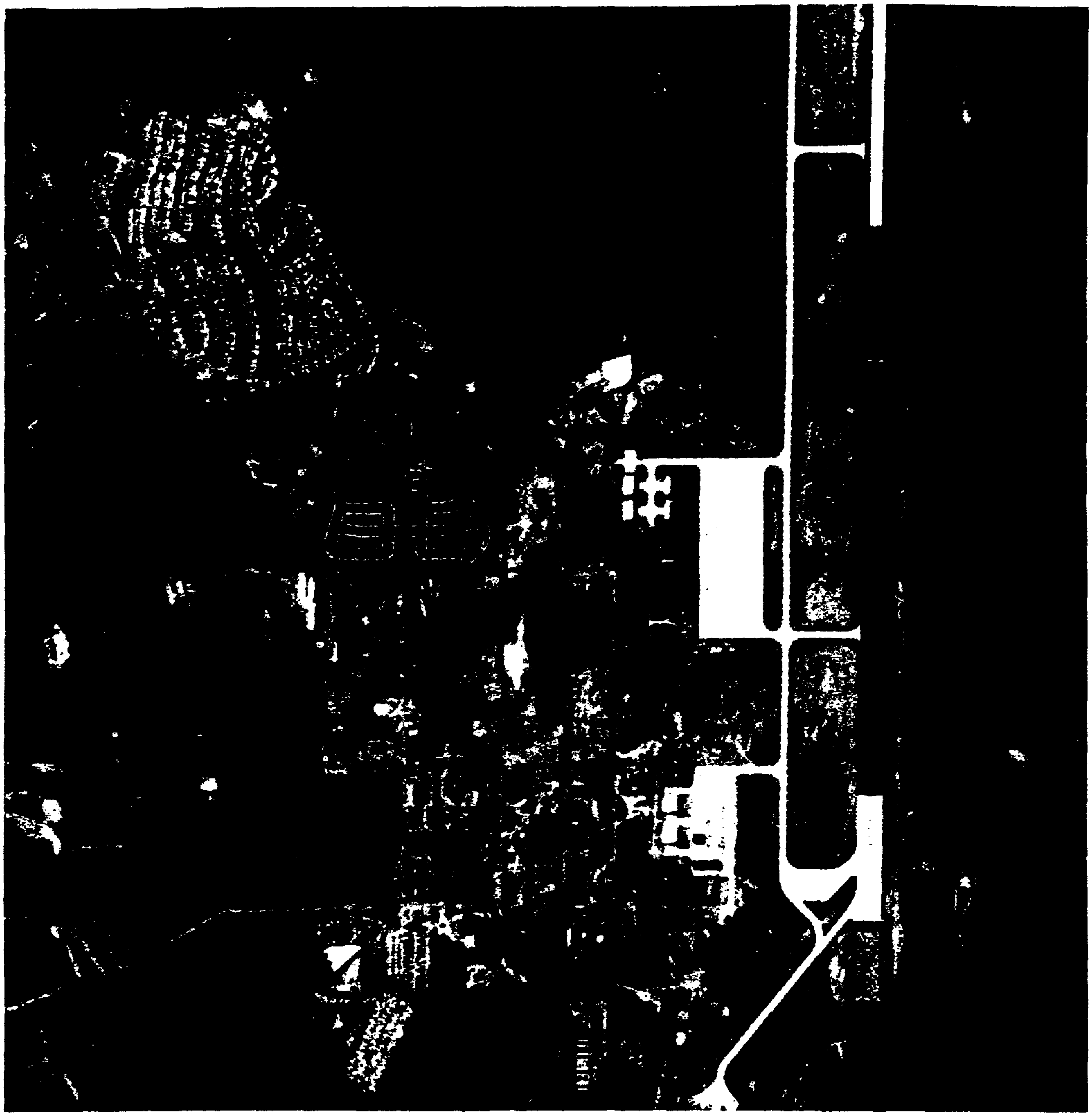
SAMPLE OF C CAMERA IMAGERY



20X ENLARGEMENT

Figure 5-2

SAMPLE OF C' CAMERA IMAGERY



20X ENLARGEMENT

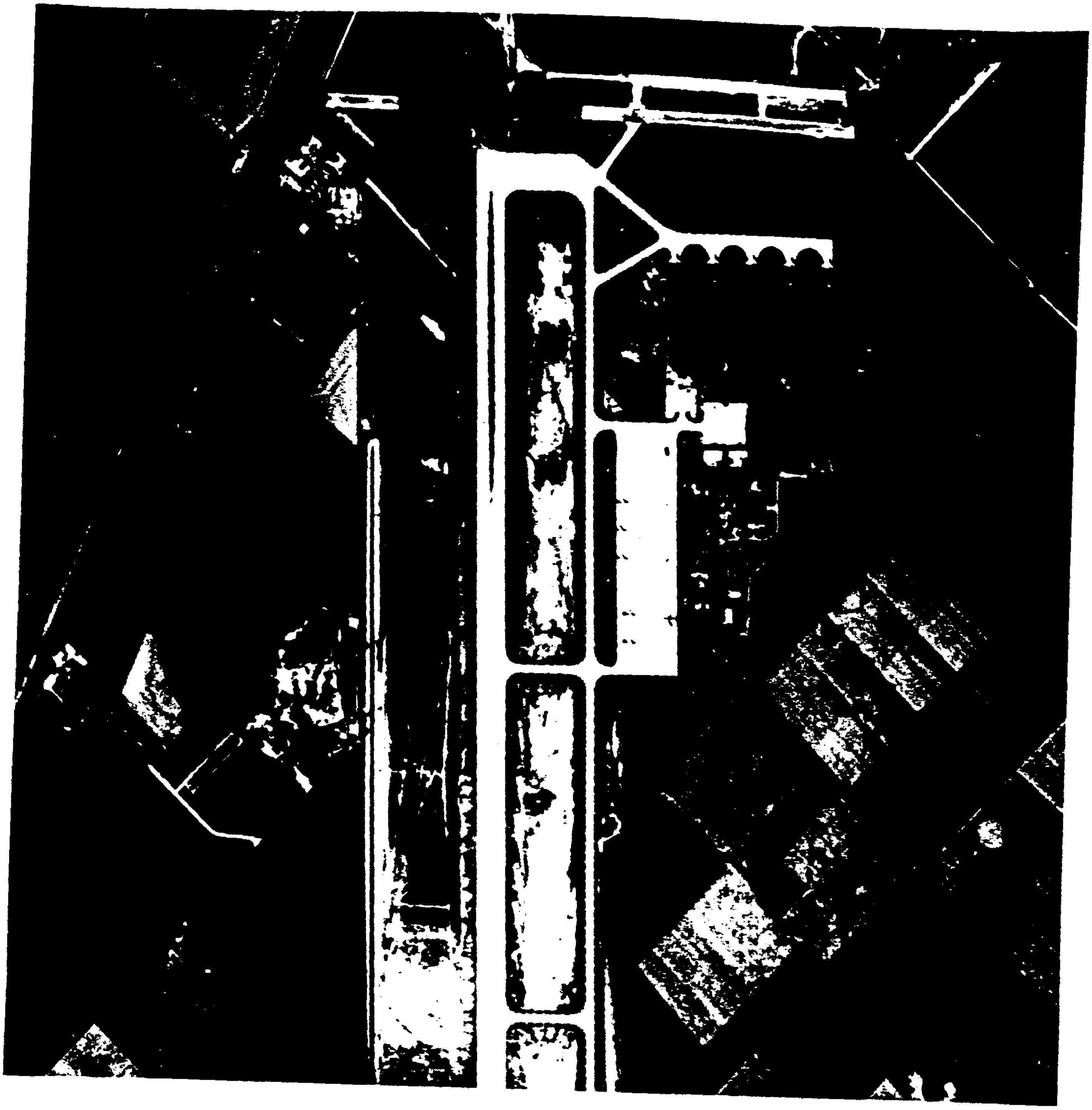
Figure 5-3

SAMPLE OF C''' CAMERA IMAGERY

20X ENLARGEMENT

Figure 5-4

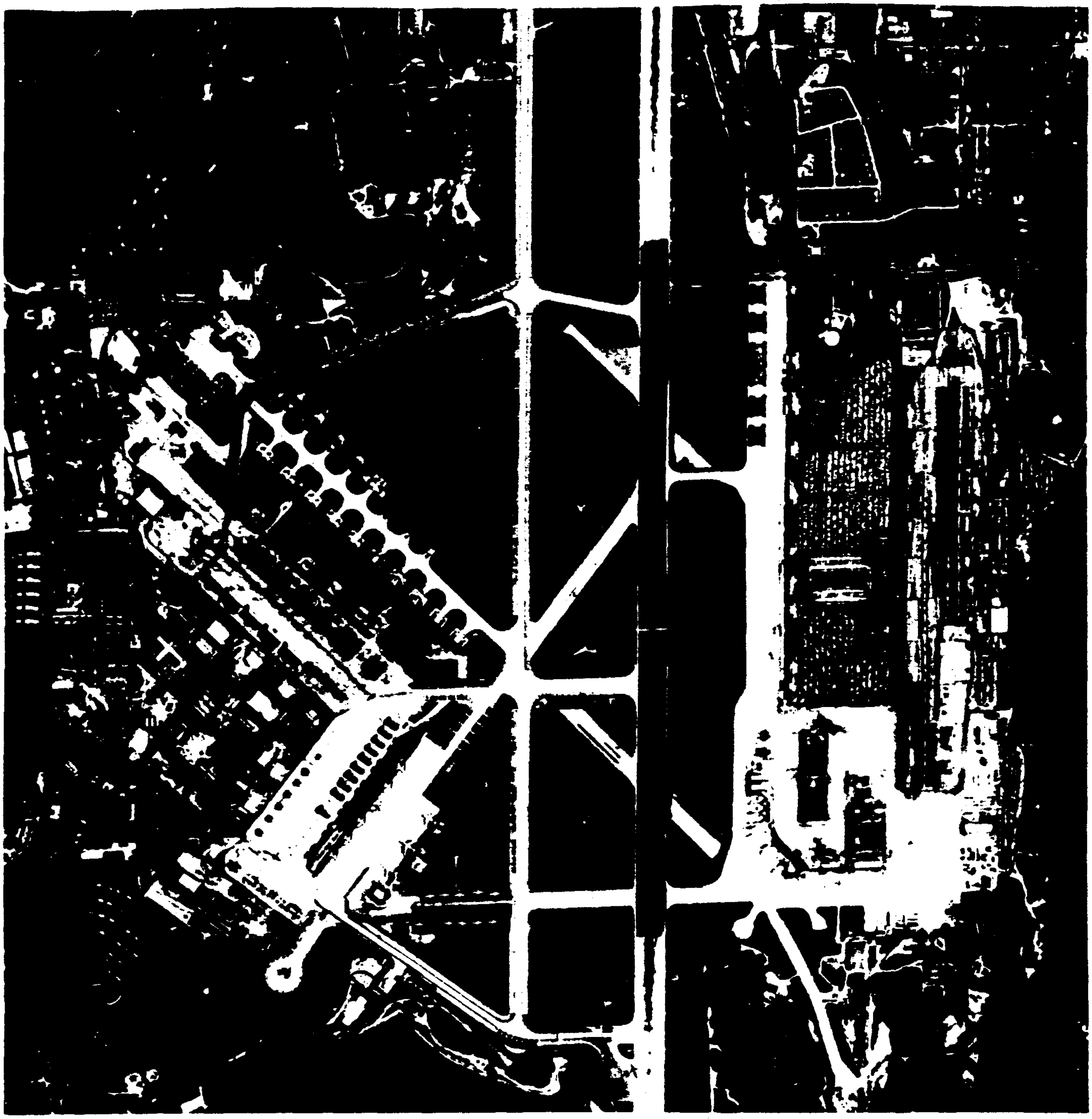
SAMPLE OF M CAMERA IMAGERY



20X ENLARGEMENT

Figure 5-5

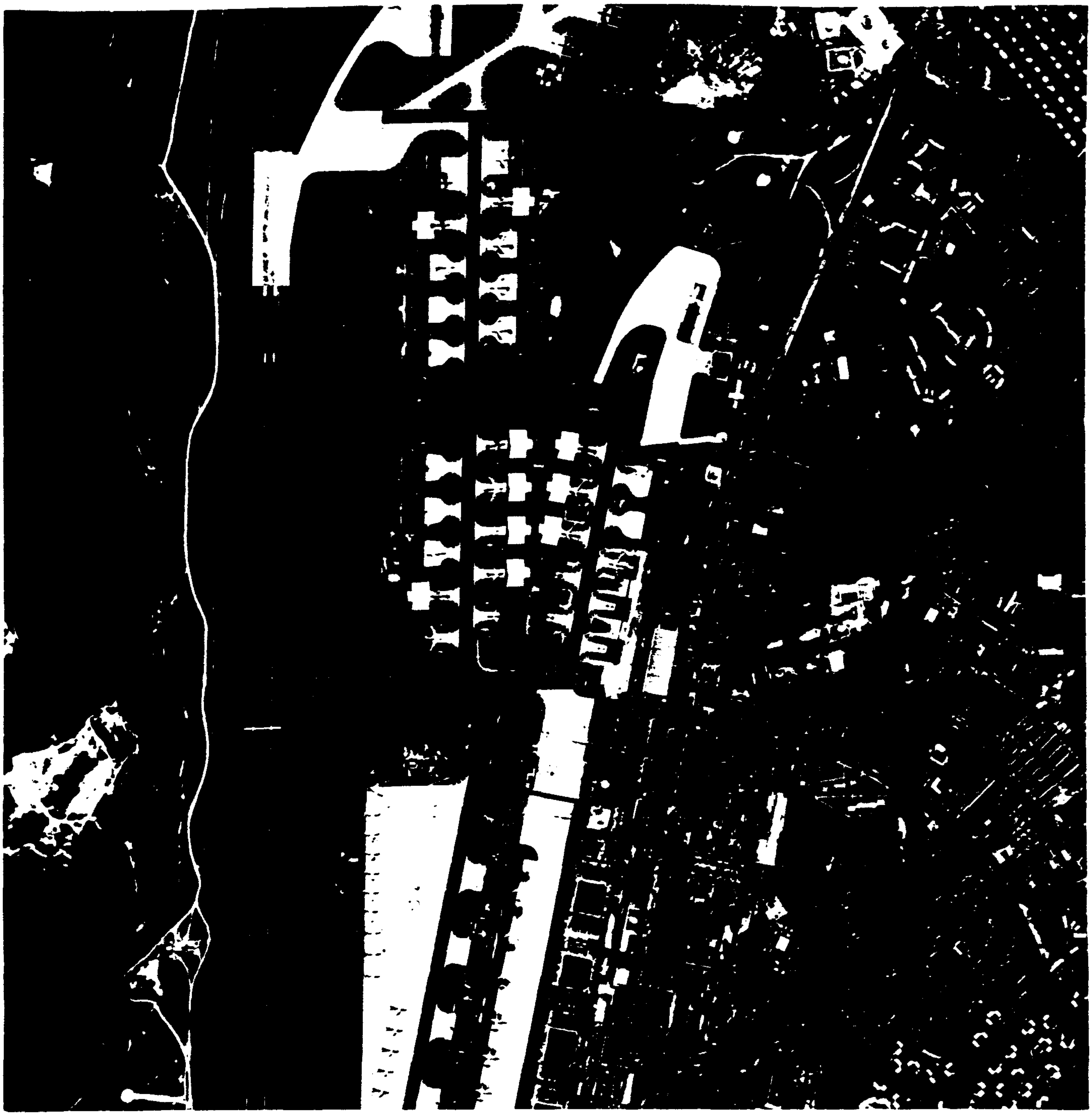
SAMPLE OF J-1 CAMERA IMAGERY



20X ENLARGEMENT

Figure 5-6

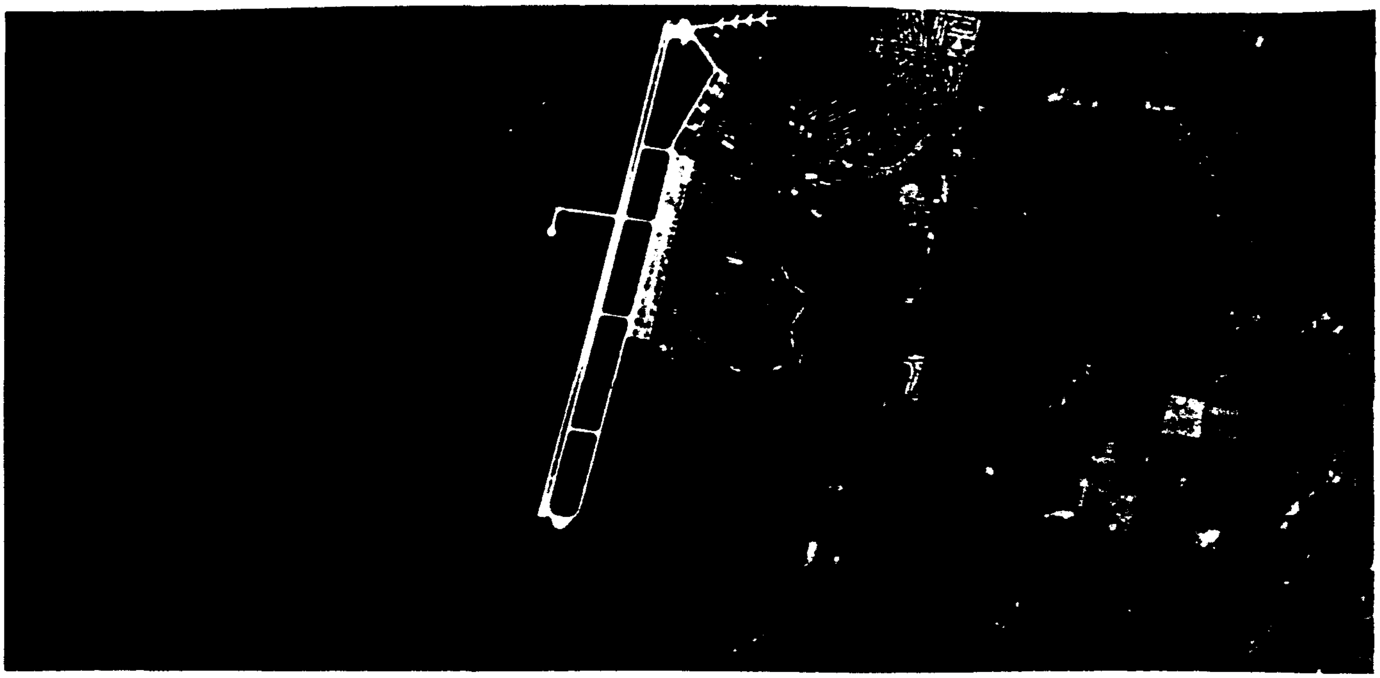
SAMPLE OF J-3 CAMERA IMAGERY



20X ENLARGEMENT

Figure 5-7

SAMPLES OF J-3 CAMERA COLOR IMAGERY



— SO-121 High Definition Aerial Color Film —

—SO-180 Infrared Color Film —

20X ENLARGEMENTS

Figure 5-8