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ANALYSIS OF APOLLO AS-501 MISSION

EARTH PHOTOGRAPHY

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

This report, covering the analysis of the photography taken during the Apollo AS-501 mission, represents the start of a series of such reports to be compiled by multidisciplinary groups concerned with the application of orbital photography in the study of earth resources. The report represents a cooperative effort between the National Aeronautics and Space Administration, the U. S. Geological Survey, the Environmental Sciences Services Administration, the U. S. Naval Oceanographic Office, and the Bureau of Commercial Fisheries. Although the information gathered from the photography reveals no new or startling discovery, the acquisition and analysis of the photographs represent the start of a joint venture in finding the best way to acquire, correlate, and analyze orbital data for multidisciplinary applications.

The authors are grateful to Paul Haney of the Manned Spacecraft Center Public Affairs Office and to George Low of the Apollo Spacecraft Program Office for making arrangements for the camera to be installed on the spacecraft, to Alfred Eickmeier and his team from the Instrumentation and Electronics Systems Division for their quick response in preparing and installing the camera system at the Cape, to John Brinkman of the Manned Spacecraft Center Photographic Technology Laboratory for processing and reproducing the film, to Morris Tepper of NASA Headquarters Space Applications Program Directorate for arranging the joint cooperation between the government agencies involved, and to John E. Dornbach for compiling this report.

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I. SUMMARY OF RESULTS AND RECOMMENDATIONS

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The purposes of the Apollo AS-501 mission were primarily to test the command module (CM) heat shield under atmospheric entry conditions similar to those of a lunar mission and to test the Saturn V launch vehicle and the Saturn S-IVB stage restart capability. A secondary objective was the acquisition and return of the highest altitude, color photographic-emulsion imagery ever made of the earth. The purposes of this report are to determine the possible scientific value of this photography for meteorology and earth resources disciplines and to recommend research activities and operational plans for procuring future photography for scientific analyses in these disciplines.

As stated by most of the investigators, the scale of the photography is too small for any useful detailed data analyses. Furthermore, the time of the mission was not planned for optimum illumination of the earth for photographic purposes. Therefore, although this imagery cannot be considered as significant data, it does have informational content which may lead to insights as to how future mission photography can be profitably programed and exploited.

The following conclusions were reached.

1. Because of scale and resolution limitations, no scientific data analyses could be performed in geology, geography, hydrology, or cartography. However, in meteorology and oceanography, the following specific comments were made by the Environmental Science Services Administration (ESSA) and the U.S. Naval Oceanographic Office (NAVOCEANO).

a. In comparing the ESSA 3 satellite views of the tropical Atlantic with those obtained from the Apollo spacecraft, color photography appears to facilitate the capability to differentiate between deep and shallow convective cloudiness (ESSA).

b. The areal extent of the sun glint appears larger in the Apollo AS-501 mission pictures than in the ESSA pictures, and there is a noticeable change in color of the sun glint as the spacecraft moves along the ground track. This suggests that color photography on future Apollo missions would be useful in studies of this color-change phenomena (ESSA).

c. The Apollo AS-501 mission photography is dramatic evidence of the importance of understanding how cloud patterns relate to sea surface circulations and how cloud patterns mirror ocean temperature patterns (NAVOCEANO).

d. Identification and discrimination of oceanographic features are extremely difficult without supporting photometric data on the camera and film. The variations in color tones have been marked mainly by atmospheric light background scattering (NAVOCEANO).

2. High-resolution color photography from space can provide extremely valuable data for immediate analysis in meteorology and earth resource disciplines and will supplement black and white imagery procured daily by electronic systems such as Tiros and Nimbus.

3. Oblique photography from manned spacecraft of "targets of opportunity" such as unique cloud formations, sun glint, large convective cells within extensive weather systems, et cetera, can provide valuable information for correlation with other data in postflight research analysis.

4. Much research is needed to provide the proper cameras, film types, and filter combinations for optimum data analyses.

5. The most significant contribution of "space acquired" imagery will be realized when it is combined with surface "ground truth" data procured simultaneously with the photography. For example, NAVOCEANO concludes that "solid numbers" from weather stations and oceanographic platforms would have facilitated data analyses.

The following recommendations were made.

1. For most analyses in the earth resources disciplines, photography procured during missions such as Apollo AS-501 should be vertical with at least a 50-percent overlap in the direction of flight and should have a ground resolution of at least 50 to 100 meters. On manned missions, provision should be made for photographing scientifically interesting "targets of opportunity."

2. Premission programing of the photography, precise geometric and photometric calibration of the camera system and window, and the acquisition of surface "ground truth" data during the photographic phase of the mission are required to obtain optimum results in data reduction and analyses.

3. An iterative and evolutionary program of data acquisition and data reduction, which utilizes aircraft and space vehicles, should be established to determine the camera systems, film types, filter combinations, and data reduction techniques most usable in meteorology and earth resources disciplines.

4. Earth scientists should play an active role with physical scientists, engineers, and flight operations personnel both in premission planning and in the data acquisition phases of the mission.

5. Photography and other data from each mission should be screened immediately by a team of meteorologists and earth scientists to determine whether the science mission objectives have been met and to provide inputs for planning subsequent missions.

6. All supporting data, such as the flight ephemeris, precise time of exposure of each photograph, image quality evaluation, and other pertinent information, should be delivered to the scientific investigators as soon after the mission as possible.

II. INTRODUCTION

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The unmanned Apollo AS-501 mission was launched on November 9, 1967. A J. A. Maurer 70-mm sequence camera was mounted in the command module (CM) to photograph the earth during the high-apogee portion of the mission on the third revolution. This camera was to procure, and return to earth for processing, the first color film photography taken from an altitude of approximately 10 000 n. mi. During the photographic portion of the mission (fig. 1), a total of 755 color exposures were made. Of this total, 712 exposures contained all or a portion of the earth. The film, returned to earth in the CM, was processed in the Manned Spacecraft Center (MSC) precision photographic laboratory. The resolution of the film (Kodak Ektachrome SO-368) was estimated to be approximately 30 lines/mm. The minimum ground resolution at the horizon, at an image scale of 1:294 000 000 (apogee point), was approximately 5 n. mi.

A science screening team convened on November 13, 1967, in the Lunar and Earth Sciences Division at the Manned Spacecraft Center, Houston, Texas, for a preliminary analysis of the scientific content of this photography. Equipment of the Mapping Sciences Branch, including light tables, zoom stereoscopes, and rear projection viewers was used for analysis of this photography. This screening team was composed of the following personnel.

MSC

John E. Dornbach, Team Leader
Jerry L. Modisette
David L. Amsbury
Michael C. McEwen
Dallas E. Evans

NAVOCEANO

Robert E. Stevenson
James B. Zaitzeff
Don Walsh

User agencies and representatives of the Environmental Science Services Administration (ESSA), the U.S. Geological Survey (USGS), the U.S. Naval Oceanographic Office (NAVOCEANO), and the Goddard Space Flight Center (GSFC) were also asked to participate in the preparation of this scientific evaluation. Duplicate film positive copies of the 70-mm color photography were provided to the evaluating agencies. The agencies were asked to screen and evaluate the photography and to provide information on the respective disciplines involved.

The scientific screening was accomplished by utilizing three color photographs, one taken near the beginning of the film sequence, one taken near the center, and one taken near the end (figs. 2, 3, and 4). Because of the great amount of redundancy of this photography, these three photographs formed the basis for most of the subsequent analyses which followed the initial screening.

This preliminary report includes the results of the meeting on November 13, 1967, and the more detailed subsequent study of this photography by the team members and other government scientists in the field of meteorology and the earth resources disciplines.

III. MISSION DESCRIPTION, ANALYSIS, AND EPHEMERIS

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Mission Objectives

The Apollo AS-501 mission involved the first use of the Saturn V launch vehicle in the Apollo Program. The mission had the following primary objectives:

1. To test the adequacy of the command module (CM) Block II heat shield under atmospheric-entry conditions similar to lunar-return conditions

2. To test the Saturn V launch vehicle and also to test the Saturn IVB (S-IVB) restart capability

The secondary mission objectives included the checkout of various launch-vehicle and command and service module (CSM) subsystems and also the task of obtaining color photography of the earth during the high-apogee portion of the mission.

Apollo AS-501 Mission Summary

Apollo spacecraft AS-501 was launched on a 72° flight azimuth at 07:00:01 eastern standard time on November 9, 1967, from pad A, complex 39 of the Merritt Island Launch Area. The boost profile to parking orbit consisted of Saturn IC (S-IC) and Saturn II (S-II) burns and a partial S-IVB burn. Thrust termination occurred at 00:11:15.6 ground elapsed time (g.e.t.) or at 22.68° North latitude and 54.68° West longitude in a 100-n. mi. circular parking orbit. During the parking orbit, final checkout of the S-IVB stage was concluded prior to S-IVB reignition, and the state-vector update of the CM Apollo guidance computer was made. At approximately the end of the second revolution, in the vicinity of the Eastern Test Range, the S-IVB was reignited for a 299-second burn. This burn placed the spacecraft in an elliptical orbit, characterized by an apogee altitude of 9297 n. mi. and a perigee altitude of -40 n. mi. This negative perigee altitude indicates an earth-intersecting ellipse.

Approximately 10 minutes after the second S-IVB engine cut-off, the Apollo guidance computer received the CSM/S-IVB separation signal. Upon receipt of the signal, the service module (SM) reaction control system (RCS) jets were activated for translation in the +X direction. After 1.7 seconds of thrusting, physical separation occurred, and the RCS jets continued to thrust for another 8.3 seconds. After the total of 10 seconds of RCS thrusting, the engines were commanded off, and the spacecraft coasted for

90 seconds to obtain adequate separation distance prior to the first service propulsion system (SPS) ignition. During the 90-second coast, the SPS oriented to the first SPS ignition altitude.

The first SPS ignition occurred at 03:28:07 g. e. t. after lift-off. This burn was a posigrade guided burn of 15 seconds duration, targeted to an in-plane coast ellipse. The target ellipse which was achieved had an apogee altitude of 9769 n. mi. and a perigee altitude of -40 n. mi.

Immediately following the first SPS cut-off, the CSM oriented to the desired solar attitude for the heat-shield cold soak. During the 4. 5 hours of this high-apogee coast, with the spacecraft holding an inertial attitude, 712 color photographs of the earth were taken (fig. 1). The camera used for the earth photography was placed in the command-pilot (+Y) side window, with the eye focal point of the camera (with respect to the window) of 12° toward the -Y-axis and 8° toward the -Z-axis of the spacecraft. Computer simulations of some of the pictures to be received during the actual flight are shown in appendix A. These simulations are based on a camera field of view of 41°6'. The relative positions of the spacecraft axes are shown on each picture frame, and the ten brightest stars that would have appeared in the photograph had the exposure been correct are identified by number. The latitude and longitude grid is superimposed on the earth, and the portion of the earth that is in shadow on the photographs is on the eastern side of the terminator. The time at the top of each picture represents the g. e. t. for the mission. Apogee occurred at 05:46:50 g. e. t.

After the 4. 5-hour cold soak, the spacecraft initiated a reorientation maneuver from the solar-soak attitude to the second SPS ignition attitude. At approximately 08:10:25 g. e. t., the RCS jets were turned on for a 30-second ullage which was followed by the second SPS ignition.

The second SPS ignition occurred at 08:10:55 g. e. t. This burn was of 281 seconds duration and achieved, at entry interface (at an altitude of 400 000 feet), an inertial velocity of 36 545 ft/sec and a flight-path angle of -6. 93°.

The spacecraft reentered the earth's atmosphere at 21. 86° North latitude and 152. 42° East longitude. Drogue-parachute deployment occurred at 08:31:49 g.e.t. from lift-off at 29. 97° North latitude and 172. 39° West longitude. The splash point was located approximately 2000 n. mi. down range from the atmospheric-entry point and was approximately 11 n. mi. from the recovery ship.

IV. CAMERA, FILM, AND FILM PROCESSING

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Camera

The Apollo AS-501 mission used a J. A. Maurer, Model 220 G, 70-mm sequence camera no. 5303 and magazine no. 5206 (fig. 5). The camera was designed for and used in the Mercury Program (MA-7) and, on that basis, was flight qualified for this mission. The lens (serial no. RE-516) was a Kodak Ektar f/2.8 with a focal length of approximately 76 mm. Prior to flight, the camera aperture was adjusted to f/8, and the exposure time was set at 1/500 of a second, the most efficient operational setting.

The entire camera and associated equipment were designed to operate and to be programed totally independent of any spacecraft system. The sole interface was the bolts which secured the camera in its proper location (fig. 6).

The timer system was activated by a gravity switch which was set at $g = 3$. However, it is possible that the system could have been activated by the initial vibrations and shock at lift-off. In either case, the operation would not be affected as long as the system became activated. Four hours and 28 minutes later (apogee minus 78 minutes) the timer sent an impulse to make the first exposure. Exposures then were made at intervals of 10.6 seconds for approximately 2 hours 13 minutes. A total of 755 exposures (appendix B) were made as the earth came into view in front of the command pilot's window. Power for the system was supplied by a battery designed to furnish electricity solely for the timer and the magazine motor drive.

Film

The film used was Ektachrome MS, 70-mm film (SO-368) with an ASA rating of 64. The film was produced by Eastman Kodak Company and was supplied in 150-foot lengths. This film is coated on a 2.5-mil Estar base with a plastic noncurl backing called pelloid.

Film Processing

The film was processed in Eastman Kodak's ME2A Ektachrome reversal chemistry to achieve a normal ASA rating of 64. All temperatures were normal at

75° ± 0.5° F. The machine speed was 3.3 feet per minute to achieve 10-minute processing time in the first developer. Prior to processing the flight film, Photographic Technology Laboratory and Eastman Kodak Company sensitometry was processed concurrently to have a cross-reference for complete processing quality assurance.

Prior to loading the flight film, two sensitometric exposures were placed on the leader of the film. Control exposures were made on the same emulsion and stored at 72° F with 60 percent Rh until the film was returned for processing. One of these controls was processed with the flight film. The maximum densities of each emulsion layer of this control film were consistently higher than the flight-film maximum densities. This density falloff, which was most apparent in the low-exposure areas of the imagery, probably was caused by slight fogging of the film during the flight by radiation. Other reasons for this degradation could be effects of radiation and other environmental factors on the dye and the dye binder, changes in the emulsion sensitivity, or preflight handling and magazine loading.

The observed density falloffs were at the low-exposure end of the D-log E curve and, in general, should not degrade the interpretation of the images in the most useful median density range. The coincidence of the three D-log E curves for the three color-emulsion layers in the median density range indicates that the color balance should be adequate for most qualitative and quantitative data analyses.

V. GEOGRAPHY AND CARTOGRAPHY

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To better understand the scale and geographic locations on the photographs used in this report, a photograph was made of a globe of the earth. Figure 7 illustrates the general location of the terminator as it was predicted to appear about halfway (frame 360) through the photographic portion of the mission. The figure also shows the approximate scale of the photographs as the scale decreases from the nadir point to the horizon. On the original 70-mm photography, the scale at the horizon was approximately 1:294 000 000 at apogee. Therefore, the photographs used in this report are about a 3.5- to 4.0-time enlargement of the original image.

The geographer and cartographer are primarily interested in vertical photography, that is, photography on which the principal point (the point where the optical axis of the lens intersects the focal plane) coincides with spacecraft nadir point (the point where a vector from the spacecraft at the moment of exposure to the center of mass of the earth intersects the surface). Figure 8 illustrates that frame 200 was a very oblique photograph, since the nadir point was not photographed. Frame 410 (fig. 9) contains the nadir point, but is still oblique since the principal point is tangent to the earth. It is evident in frame 580 (fig. 10) that as the principal and nadir points begin to converge on this mission, they do so on the shadow hemisphere of the earth.

From the standpoint of geography and cartography studies, the resolution of the photography is such that scientific evaluation is not possible. To study and map the geographic environment affecting man's occupance of the earth, an average resolution of approximately 50 meters or better would be required.

To establish geometric and photometric characteristics of the imagery, in order to update geodetic and topographic parameters of maps, the scale of the photography and scale of the resulting maps would, in large measure, dictate the precision required in the camera system; the precision required in preflight calibration; and the precision required in postflight processing, data reduction, and analysis.

Within the present capabilities of the Apollo spacecraft and with a camera such as that used on the Apollo AS-501 mission, it is recommended that the following be adopted.

1. Color film positives should be provided for analysis.

2. For most studies in these disciplines, the photography should be taken as near the nadir of the spacecraft as possible.

3. For special studies of cities and topography, at least a 50-percent forward lap should be obtained to provide for stereophotographic interpretation.

4. Comprehensive preflight geometric and photometric calibration data should be provided for the camera-film system and window.

5. Postflight image quality evaluation data should be provided for scientific analysts.

Requirements for cartography, other than some planimetric revision, cannot be met by the camera system flown on Apollo AS-501 mission, even if the camera system is modified.

VI. METEOROLOGY (NESC)

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The 70-mm color film strip was examined by using a Bausch & Lomb zoom microscope. The ESSA 3 weather-satellite imagery (fig. 11) for the same area viewed by the Apollo camera was also examined.

In comparing the ESSA 3 satellite views of the tropical Atlantic with those obtained from the Apollo spacecraft, the impression is received that the color photography facilitates differentiation between deep and shallow convective cloudiness. The more oblique viewing angle of the Apollo camera also contributes to this effect by increasing the visible areas of shadow and highlight in the clouds in the Apollo pictures. The color photography appears to be very helpful in making the distinction between deep and shallow convective cloudiness, even though the resolution in the Apollo imagery seems to be less than the resolution in the ESSA pictures.

The color pictures revealed more of the low-level, shallow, convective cloudiness (e.g., in the area from 0° to 10° North latitude and 35° West longitude) than is apparent in the ESSA 3 pictures. The detail in this low-level cloudiness visible in the Apollo pictures suggests that it might be possible to obtain low-level cloud motions from time-lapse movies prepared from Apollo film strips.

A major circulation feature of the Northern Hemisphere is represented by the cloudiness which extends into North Africa from the Atlantic just north of Dakar. This cloudiness is associated with the subtropical jet stream. Where this cloud band intersects the twilight zone, the high-lighting effects suggest that a considerable amount of high-level convection is associated with this cloud formation.

The color photographs taken early in the mission (fig. 8) appear to be helpful in identifying the isolated groups of cumulonimbus clouds over the South Brazilian Highlands. These groups of clouds are south of the major cloud band which extends from north of this area southeastward across the Atlantic. The cumulonimbus clouds are located near the horizon of the Apollo picture.

The sun-glint area which appears in the South Atlantic, south of the large-scale frontal band, has two interesting aspects (fig. 8). One aspect is the dark areas which appear within the area of reflection. These may be associated with areas of smoother water which are away from the center of specular reflection. Since the areal extent of the sun glint appears to be larger in Apollo pictures than in ESSA pictures, these dark areas are better delineated in the Apollo pictures and can be observed for a longer period of time as the spacecraft moves along the ground track, which suggests that color photography on future Apollo missions would be useful in studies of this sun-glint phenomenon. The second feature of interest regarding the sun glint is the yellowish color and the change in appearance of the sun-glint area as the spacecraft moves along the ground track. Since these pictures represent the first color pictures of the sun glint from this altitude, the implications of the variation in the color of the sun glint are not fully realized. The cumulonimbus clouds in the vicinity of Nigeria and near the eastern coast of the Gulf of Guinea fall in the twilight zone and can be easily identified in the pictures from the sunlit western sides of the convective towers. The pictures suggest that individual clusters of convective clouds extend to a considerable distance above the main anvil shield of cirrus clouds which is associated with this convection.

The overall impression in viewing all the pictures is that cirriform cloudiness is less detectable in the Apollo views than in ESSA satellite pictures. This may be a result of the lack of any good cirriform cloudiness in the area viewed, or it may be that the resolution of the Apollo pictures and the color photography combine to make the cirrus clouds less recognizable. This aspect should be the subject of further investigation.

Views of the south polar ice cap show a dark spot which is near the horizon but within the ice boundary. The ESSA 3 pictures suggest that this is an area of open water in the pack ice in the Amundsen Sea at approximately 74° South latitude and 111° West longitude.

The type of photography represented by this sample should prove very useful for meteorological investigations. The resolution of the pictures is sufficient to identify meteorological cloud systems down to the mesoscale. The color photography appears to be very helpful for qualitative assessment of the vertical structure of the cloud systems. The fact that the Apollo orbit allows views of the twilight zone in both the tropics and midlatitudes is also useful, because of the shadows and highlights visible in these areas. It would be desirable for future Apollo spacecraft to be equipped to take similar pictures, and for the pictures to be taken over a longer period of time. The 10-second interval between pictures does not seem to offer any advantages and produces redundancy.

VII. METEOROLOGY (MSC)

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Introduction

Three photographs from the Apollo AS-501 mission (frames 200, 410, and 580; figs. 2, 3, and 4, respectively) were reviewed for their meteorological content by the Atmospheric Physics Branch of the Manned Spacecraft Center (MSC).

The field of view of the photographs extends southwest across the South Atlantic Ocean, with the nightside terminator extending north through Africa and Asia Minor. A 1200 G.m.t. surface-analysis map (fig. 12) is included for weather-system reference and orientation.

Since portions of both hemispheres are viewed in these photographs, three differences are stated briefly as follows:

1. Although January is the coldest month and July is the warmest month in most parts of the Northern Hemisphere, the reverse is true in the Southern Hemisphere. Thus, November (the time of the flight) represents late fall in the Northern Hemisphere and late spring in the Southern Hemisphere.

2. Wind circulation around cyclones (low-pressure areas) and anticyclones (high-pressure areas) is opposite in the two hemispheres. Cyclonic circulation is counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. Anticyclonic circulation is clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere.

3. The great land masses of the earth are concentrated in the Northern Hemisphere. For most practical purposes, the Southern Hemisphere is a water hemisphere, and meteorological considerations in this hemisphere are, therefore, oceanic.

South Atlantic, West of Greenwich

The most dominant weather feature in the pictures is an area of low pressure (denoted by an L on figs. 13 and 14), which is centered at approximately 55° South latitude and 5° West longitude on the surface analysis map (fig. 12). The region north and east of the vortex is mostly covered (50 to 80 percent) by cumulus cloud elements which form a pattern of irregular polygons with less-cloudy or open centers. This type of pattern is referred to as open cellular and is observed mainly over the oceans, where large amounts of water vapor are available in the lower levels of the atmosphere. In the area of these cumuliform clouds, cold air is being heated from below as it moves over warmer water. Where open-cellular patterns are observed, the air is unstable throughout a relatively deep layer above the ocean surface.

Two frontal systems and the associated cloud bands appear to the north of the low-pressure area. The fronts (boundaries between different air masses) are shown in figures 13 and 14 as lines with symbols to indicate the kind of front and the direction of the frontal movement. A cold front (figs. 13 and 14; symbol), which consists of relatively cold air of polar origin, was observed to be moving from a point near the low-pressure area L into an area occupied by warmer air of tropical origin. Gough Island, located at 40° South latitude and 10° West longitude within this area and covered (>80 percent) by cumulus and stratocumulus clouds, reported a temperature of 14° C (57.2° F) at 1200 G.m.t.

An area of sun glint is located at point 1 in figures 13 and 14 in the less-cloudy region ahead of this cold front. This sun glint occurs when the image of the sun is reflected specularly from the earth to the camera lens. The brightness of the sun glint implies that the water is smooth and that there is little wind.

A second front, cold to the east and stationary (symbol) to the west, extends to the east coast of Brazil at point 2 in figures 13 and 14. Cirriform, cumuliform, and stratiform clouds are present. The cold front, which generally dissipates as it approaches the Equator, is often followed in the Southern Hemisphere winter season by cold-air outbreaks which bring heavy frontal and orographic rains to southeastern Brazil. If the cold-air mass is shallow, it will tend to parallel the coastline and will become quasistationary, thus causing steady rains of several days duration.

Throughout the year, a semipermanent anticyclone which touches the coastline of South America is located over the Atlantic Ocean. The anticyclone varies in intensity and oscillates with latitude, but may be seen as the high-pressure area at approximately 28° South latitude and 30° West longitude in figures 13 and 14.

Point 3 in figures 13 and 14 is a cloud-free area over Patagonia on the east coast of southern South America. With polar westerlies flowing from a low-pressure area located at approximately 64° South latitude and 78° West longitude (fig. 12) and depositing moisture on the windward side of the Andes, dry-air masses arrive over the Patagonia plateau and cause the desert conditions found there.

Point 4 in figures 13 and 14 approximates the position of the Falkland Islands. At 1200 G.m.t., South Georgia (54° South latitude and 37° West longitude) was reporting cumulus and cirrostratus clouds with a temperature of 2° C (35.6° F).

Region of Equator

A line of cumuliform clouds at point 5 in figures 13 and 14 approximates the position of the equatorial convergence zone located off the west coast of Africa. The convergence zone is denoted by the hatched area on the surface analysis map (fig. 12). The trade-wind systems of the two hemispheres converge in this zone, thus resulting in an upward motion of the air and the formation of clouds and rain. Relatively inactive areas of much less cloudiness are interspersed with the active cloud systems. The convergence zone migrates seasonally and reaches the northernmost point in September and the southernmost point in March. The width of the zone (approximately 5° of latitude) and the cloud activity within the zone vary with this seasonal migration.

South Atlantic, East of Greenwich

At point 6 in figure 13, sunlight is reflecting off the tops of cumuliform clouds which are just inland and are paralleling Angola on the southwest coast of Africa. Mocamedes, located at 15° South latitude and 12° West longitude, reported cumulonimbus clouds and a temperature of 24° C (75.2° F) at 1200 G. m. t.

In spite of extensive air-mass cloudiness, the west coast of Southern Africa is a region of slight precipitation because of the upwelling of the cold Benguela current. This oceanic condition favors low clouds and fog along the immediate coastline.

Antarctica and the Southern Ocean

Antarctica is covered almost completely by a thick ice cap which leaves only a few edges of the shore exposed. Unlike the Arctic, where glaciers tend to calve off at the edge of the water, Antarctic glaciers may extend from a few miles to several hundred miles into the ocean, thus forming huge ice tongues or high ice shelves. In fact, much of the apparent coastline of Antarctica is a series of ice shelves.

The area of the Antarctic Continent has been estimated to be 5.5 million square miles in the summer, and this size doubles in the winter when the sea freezes. The fact that November is a transitional season adds to the difficulty in discriminating ice and snow from clouds in these photographs.

The South Pole coincides approximately with the center of the polar anticyclone which persists over the very cold Antarctic Continent. In view of this weather phenomenon, it is probable that the skies of the interior of the Antarctic Continent are relatively cloudless.

The periphery of Antarctica, where cyclonic activity is reasonably intense in summer and winter, would be expected to display a relatively high degree of cloudiness because of its oceanic exposure. Such cyclonic activity, at 63° South latitude and 78° West longitude on the surface analysis map (fig. 12), is an area of precipitation and overcast skies over Graham Land, Antarctica (at approximately point 8 in fig. 15). Four stations on the west coast of Graham Land, located between 63° to 68° South latitude and 57° to 68° West longitude, reported the following conditions at 1200 G. m. t.

Station 1. Temperature, 0° C (32° F); dewpoint, -1° C (30.2° F); wind, calm; barometric pressure, 980 millibars; complete overcast; fractostratus and fractocumulus clouds of bad weather; continuous fall of snow, slight at time of observation.

Station 2. Temperature, 2° C (35.6° F); dewpoint, -6° C (21.2° F); wind, calm; barometric pressure, 979 millibars; complete overcast; intermittent fall of snow, moderate at time of observation.

Station 3. Temperature, -3° C (28.4° F); dewpoint, -5° C (23° F); wind, calm; barometric pressure, 979 millibars; nine-tenths overcast; stratocumulus and altocumulus clouds.

Station 4. Temperature, -3° C (26.6° F); dewpoint, -6° C (21.2° F); wind, southeast at 20 knots; barometric pressure, 978 millibars; complete overcast, dense cirrus and thin altocumulus clouds.

In the absence of synoptic data, the question arises as to whether the triangular-shaped forms at point 7 in figure 15 are clouds or ice, although they are on the periphery of Antarctica.

Across the Weddell Sea (possibly in the area of point 9 in fig. 15), Halley Bay, located at 75° South latitude and 26° West longitude, reported a temperature of -16° C (3.2° F) with drifting snow and accumulated high drifts. Winds were east at 15 knots under eight-tenths cloud cover.

Because of high pressure over the Pole and low pressure to the north (55° to 65° South latitude), the continent comes within the influence of surface easterlies, although topographical factors cause decided variations in wind force and direction.

Since the polar anticyclones are extremely cold, the pressure distribution changes from high pressure at the surface to low pressure aloft. Consequently, the prevailing easterlies of high latitudes reverse direction and become west winds aloft. The west winds increase in velocity with increasing elevation.

During the colder part of the year, these west winds in the lower stratosphere (at altitudes of approximately 9 to 20 km) may cover a broad zone from the Antarctic periphery to latitudes of 45° or 50° South. Within this zone, the belt of maximum westerlies is known as the polar-night jet stream. At altitudes greater than those regularly reached by sounding balloons, the absolute maximum speed of these westerlies has been estimated to be in excess of 200 knots.

VIII. METEOROLOGY (WEATHER BUREAU - ESSA)

By Kenneth M. Nagler
Space Operations Support Division
Weather Bureau - Environmental Science Services Administration
U.S. Department of Commerce
Washington, D.C.

The following examples illustrate the value of the pictures.

1. The pictures provide good examples as to the variance in detail observed in cloud pictures as a function of the distance from the earth.

2. They provide good examples of the reflection from a small surface on the Antarctic Continent, which could be used in studies of that phenomenon.

3. The pictures were taken over a period of time long enough for substantial movement of some cloud elements to have occurred. Measurements of these motions could be made to determine the upper-wind velocity-measurement potential from photography of this scale. To explore this cloud-movement potential, it would seem worthwhile to make a 16-mm film of the entire series of photographs to be run at normal motion-picture speed. In addition, a second motion picture might be made by exposing each photograph for perhaps 1 second. This technique would permit a slower survey of the clouds and their motions.

If similar pictures are to be taken on future Apollo flights, several points might be kept in mind.

1. The field of view of the AS-501 photographs was wastefully large.

2. Far more pictures were taken than were necessary to show the clouds and their movements.

3. If a comparable number of pictures could be taken automatically on future flights, it would be desirable to have them spaced throughout the daylight portion of the flights. The pictures from the Mercury-Atlas (MA-4 and MA-5) flights were taken automatically at intervals of approximately 6 and 33 seconds, respectively. The photographs directed toward the north after spacecraft turnaround gave good coverage and permitted stereo pairs across the Atlantic and Africa. The later pictures (MA-5) overlapped only slightly and gave coverage for about three revolutions.

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IX. OCEANOGRAPHY (SPACECRAFT OCEANOGRAPHY PROJECT)

By Lt. Comdr. Don Walsh, USN, and James E. Arnold
Spacecraft Oceanography Project
Department of Oceanography
Texas A&M University
College Station, Texas

(This report is comprised of the Abstract, Conclusions and Recommendations from a technical report* published by Texas A&M University)

Abstract

This paper resulted from requests by the U.S. Naval Oceanographic Office (NAVOCEANO) and the NASA Manned Spacecraft Center for an oceanographic appraisal of earth photography taken during the Apollo AS-501 mission on November 9, 1967.

A total of 755 70-mm color photographs were taken on this mission by a camera sighted through the pilot's window in the capsule. The area of photographic coverage was of the South Atlantic Ocean and Antarctica as seen from a point above the tip of Africa. The altitude from which the photographs were taken ranged from 7450 to 9850 n. mi.; however, coverage was limited by the location of the earth terminator along the west coast of Africa. As a result, only a crescent-shaped portion of the earth is visible.

Analysis of the information content of this photography was limited by a lack of hard data on surface oceanographic and meteorological conditions for the day of the mission. The authors, therefore, have relied on climatological data published in standard references as the basis for interpretation. This means that long-term records were applied to analysis of conditions for a single day, with the strong possibility of induced variance between the long- and short-term situations. This photography cannot be considered as data; it is information and must be regarded as such. Therefore, this analysis provides educated speculation about the information as developed by an oceanographer and a meteorologist.

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*Walsh, Don; and Arnold, James E.: Oceanographic Comment on Apollo 501 Mission Photography, Project NR 083-036, A&M Project 286-13, Ref. No. 67-23T. Texas A&M University, College Station, Texas. Nov. 1967.

The goals of this speculation are to determine whether future missions in this series should carry cameras and to determine under what conditions the cameras should be programed.

As a result of this analysis, the following recommendations are made.

1. As a minimum, a camera should be installed for the Apollo AS-502 mission in February 1968.

2. Premission planning must include scientific preplanning of predicted coverage and must consider ground truth.

3. Photography should be a permanent part of all missions in this series, to provide an early scientific return for the Apollo Program.

4. The Apollo photography should be published in an atlas-type format to provide greater scientific exposure to the data.

5. Considerations should be given to multicamera installations, thus permitting the use of various photographic emulsions and filter combinations.

Conclusions

1. Photography from all earth-orbital missions can be scientifically important. The quality of this photography, coupled with preprograming of photographic coverage, could give the scientist new perspectives on areas of interest. The lower-altitude Gemini missions have already proved this.

2. The study of cloud patterns over the oceans must receive greater emphasis. It is apparent from this photography that synoptic data on ocean surface conditions can be greatly enhanced through understanding the relationship between cloud patterns and surface-temperature patterns on the ocean.

3. Ground truth must be emphasized in premission planning. Without some solid "numbers" from weather stations and oceanographic platforms, much of the photography of this type will have to be analyzed in a speculative manner. Speculative analyses can be productive in developing generalized information and in planning future requirements, but only hard data from ground stations can lead to significant data for oceanography studies from spacecraft. The leadtime for establishing ground truth is much greater for oceanographic studies than for terrestrial applications. This problem should be investigated now.

4. Premission programing of photography is important to obtain optimum results. Since the costs of camera installation and operation are relatively fixed in this type of mission, it is only on the basis of the photography procured that the scientific value of this installation can be determined. For example, photography from the highest part of the orbit in the AS-501 mission is useful, but it is questionable if all 755 photos needed to be shot at what was essentially one point. A premission program,

developed by appropriate environmental scientists, would have insured final results which would have been far more spectacular and considerably more useful from a scientific point of view.

5. A properly planned earth-photography program can lead to early scientific payoffs for the NASA Earth Resources Survey Program. The degree of preplanning outlined in paragraphs 1 to 4 can fit in with the early Apollo missions without significant interference in the primary goals of these missions. This photography would permit key areas of the Earth Resources Survey Program to move forward well in advance of the Apollo Applications Program 1-A mission planned for 1969 and will make maximum use of every mission.

Recommendations

1. As a minimum requirement, a camera should be installed for the Apollo AS-502 mission in February 1968. A scientific team should be appointed to work out the photographic tracks for this mission and to provide an "on - off" schedule, to be used by the NASA mission control personnel, for the camera. Early appointment of the team would provide adequate prior study of key earth areas and would provide resolution of conflicting data interests among air, sea, and land scientific disciplines.

2. Premission planning must include ground truth. Some ground truth, such as weather information, requires only notification to appropriate agencies of a forthcoming data requirement on a specific day; while other requirements, such as those for oceanography studies, will require prior determination of what ships will be in areas of interest and will require early requests to their operators for cooperation. As an example, ships from Texas A&M and from the Bureau of Commercial Fisheries (Galveston, Texas) will be in the Gulf of Mexico during the February mission. With sufficient notice, they could provide some useful ground truth for both ocean and atmospheric parameters.

3. Ideally, photography should become a permanent part of all missions in this series. Even though earth photography is not the purpose of these early missions, it does provide NASA with an immediate scientific payback from this program, provided that requirements are preplanned and programed as previously noted. Primarily, this earth photography could greatly help the scientific community in planning for the multisensor requirements for the Apollo Applications Program 1-A mission.

4. The Apollo photography should be published in atlas form. The photography from these early engineering test missions should be made available to the scientific community through the means of a published atlas. The published atlas will bring more "trained minds and eyes" to bear on these data and will improve planning input for the Apollo Applications Program. As a minimum, these atlases should be made available to all principal investigators in the Earth Resources Survey Program. They should contain necessary ground truth and backup information to permit analysis.

5. Consideration should be given to multicamera installations. During the past mission, the camera was located behind the pilot's window. If, in future missions, cameras could be located behind all window openings in the capsule, photographic results would be greatly enhanced. Options would then be available for either selective

filtering or for using a variety of film emulsions. Specifically, color infrared photography would be extremely valuable when paired with conventional color coverage. This would require a minimum of two cameras on board.

X. OCEANOGRAPHY (NAVOCEANO)

By Henry J. Yotko
Spacecraft Oceanography Project
U.S. Naval Oceanographic Office
Washington, D.C.

The duplicate 70-mm film positives exposed during the recent Apollo AS-501 mission have been given a cursory evaluation by appropriate members of this office. In general, the reviewing group determined that the film is not satisfactory for oceanographic interpretation. The comments which follow may be of some use in future missions. These comments reflect ideals which may not always be practical to realize under operational circumstances.

The validity with which plausible inferences can be made depends, to a great extent, upon background information which can be made available at the time of analysis, for example, gridding of photographs, geometrical orientation of the camera, and photogrammetric and photometric calibration of cameras and films. This information should be supplied along with the photography.

The identification and discrimination of oceanographic features are extremely difficult without supporting photometric data on the camera and film. The variations in color tones have been marked mainly by atmospheric light background scattering.

With proper photometric data, it should be possible to obtain experimental measurement of atmospheric "sensing," terrain, and ocean luminance.

The reviewing group at this office recommends that future missions should include the following to enhance the analysis of oceanographic features.

1. Three cameras, optical axis 60° apart

2. Each camera to be equipped with a minus-blue filter

3. One camera to be equipped with false-color infrared film

4. Camera orientation (vertical) to minimize optical-path distance through atmosphere

5. Complete photometric and metrical camera-calibration data to be furnished

6. Preliminary geographic coordinates of camera nadirs and orientations to be furnished, based on orbit parameters

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XI. OCEANOGRAPHY (USDI)

By James S. Bailey
Space Oceanography Project
Fisheries and Wildlife Service
Bureau of Commercial Fisheries
U.S. Department of the Interior
Galveston, Texas

Examination of the Apollo AS-501 mission photographs of the earth reveals few oceanic data, per se. Detailed analyses of observable meteorological phenomena would provide the only insight to existing oceanic features, and these relations would be inferred. This situation is caused primarily by the obliqueness, time on, and altitude of the recording camera.

Significantly, however, the photographs do reveal the following details:

1. Good quality color photography of the earth's surface and atmosphere can be obtained from extreme orbital altitudes with relatively inferior photographic equipment.

2. Major earth features can be recognized.

3. Slight variations in water color can be discerned west of the 40° meridian between 30° and 40° South longitude.

4. The Apollo AS-501 mission photography clearly demonstrates the tremendous potential of space applications to meteorology and oceanography that can be realized with properly conducted experiments and realistic equipment.

Use of the Apollo missions for photographic coverage of the earth and the earth's atmosphere is a significant step forward in the Apollo Program.

XII. GEOLOGY AND HYDROLOGY

By Charles J. Robinove
EROS Program, Geological Survey
U.S. Department of the Interior
Washington, D.C.

The lack of some data on the Apollo AS-501 mission pictures detracts from their usefulness for this quick evaluation. For example, the exact time at which the photographs were taken is not known nor is the subspacecraft point at the time of exposure of any of the frames. Although most of the photographs appear to have been taken over the South Atlantic, it is not possible to be positive.

The photographs are at a scale of 1:382 000 000 and would have a ground resolution of about 5.5 miles at the subsatellite point, based on a resolution of 20 lines per millimeter on the film. This resolution would be degraded to about 10 miles at the outer limbs of the earth.

The major features in the photographs are continental land masses, oceans, cloud and meteorological phenomena, and sun glint on the ocean surface. Because of resolution limitations, the location of terrain features is not considered to be readily interpretable for geologic, hydrologic, or earth resources purposes. The meteorological features are probably the most important.

The third feature of importance is the sun glint on the ocean which seems to give a good idea of the relief of clouds. It may be possible to measure the height of the clouds by using this sun glint.

There are few advantages to be gained by additional study of the AS-501 mission photography for earth resources or geographic purposes. There may be some advantages to studying the photography for meteorological purposes, but data of this type are of only limited use because of the nonrepetitive nature of the data.

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XIII. GEOLOGY

By David L. Amsbury
Lunar and Earth Sciences Division
Manned Spacecraft Center
Houston, Texas

No geological features can be observed on the Apollo AS-501 mission photography. The only ice-free and cloud-free land areas that can be seen are at too small a scale and are too near the horizon of the earth for geological interpretation. This type of photography, from these altitudes and at a scale of approximately 1:285 000 000, might be interesting from a continental geological viewpoint if sunlit, cloud-free, and ice-free land masses were photographed in a vertical plane from the spacecraft.

Significant geological information can be obtained from the photography taken on the manned Gemini flights. These photographs were taken from much lower altitudes (generally between 100 and 200 n. mi.), with hand-held 70-mm cameras.

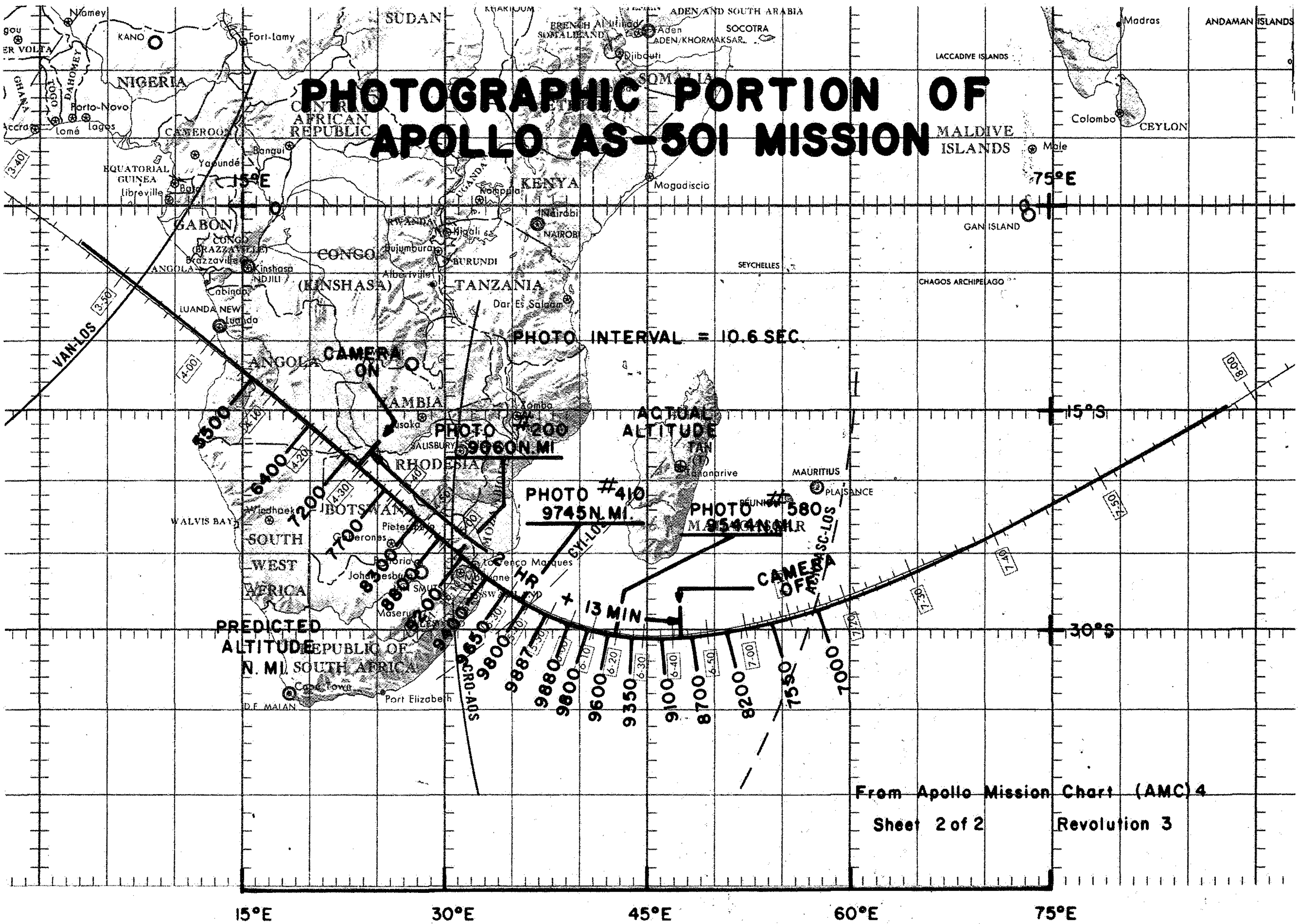


Figure 1. - Photographic portion of Apollo AS-501 mission.

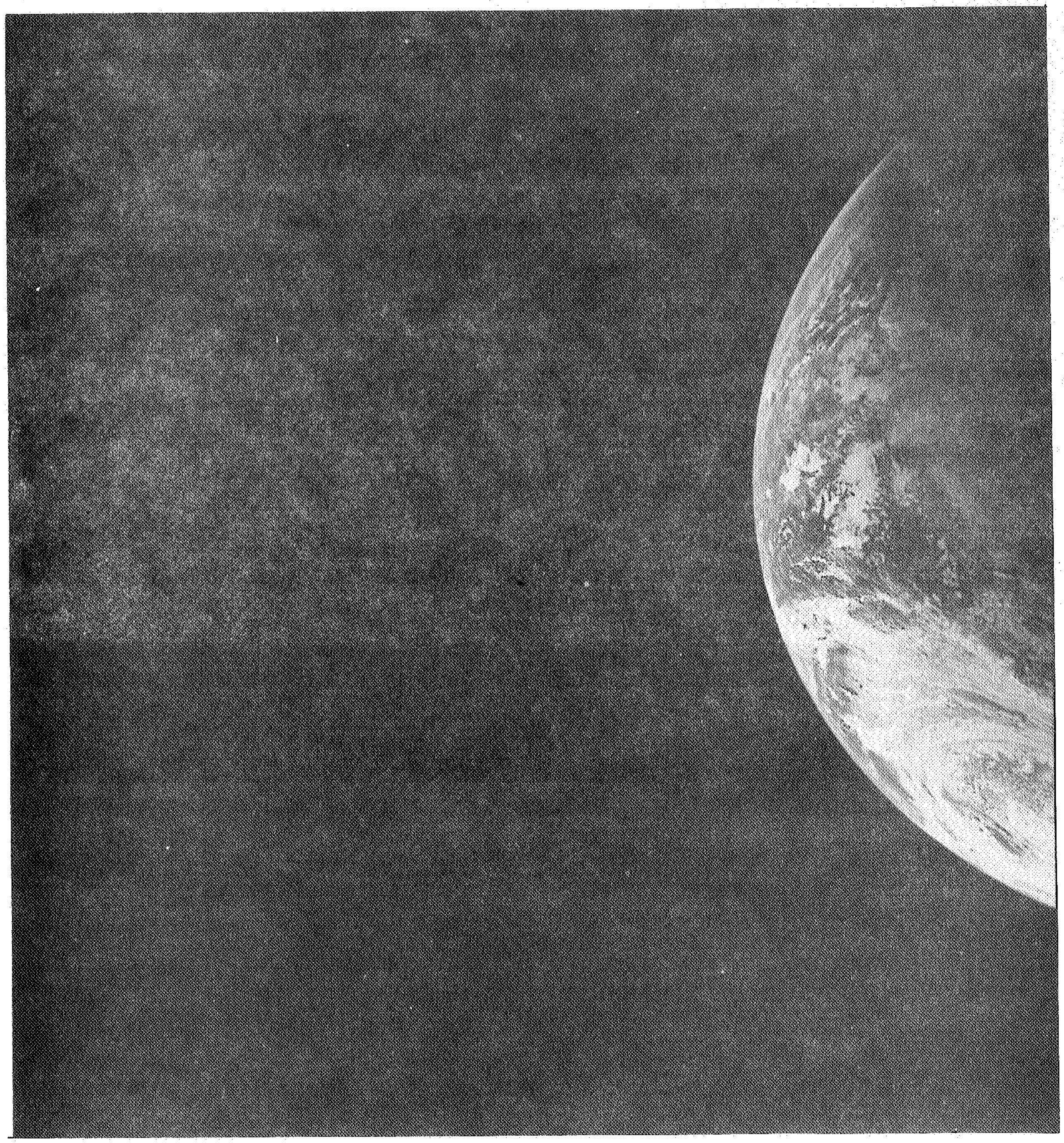


Figure 2. - Photograph AS4-1-200 of earth.

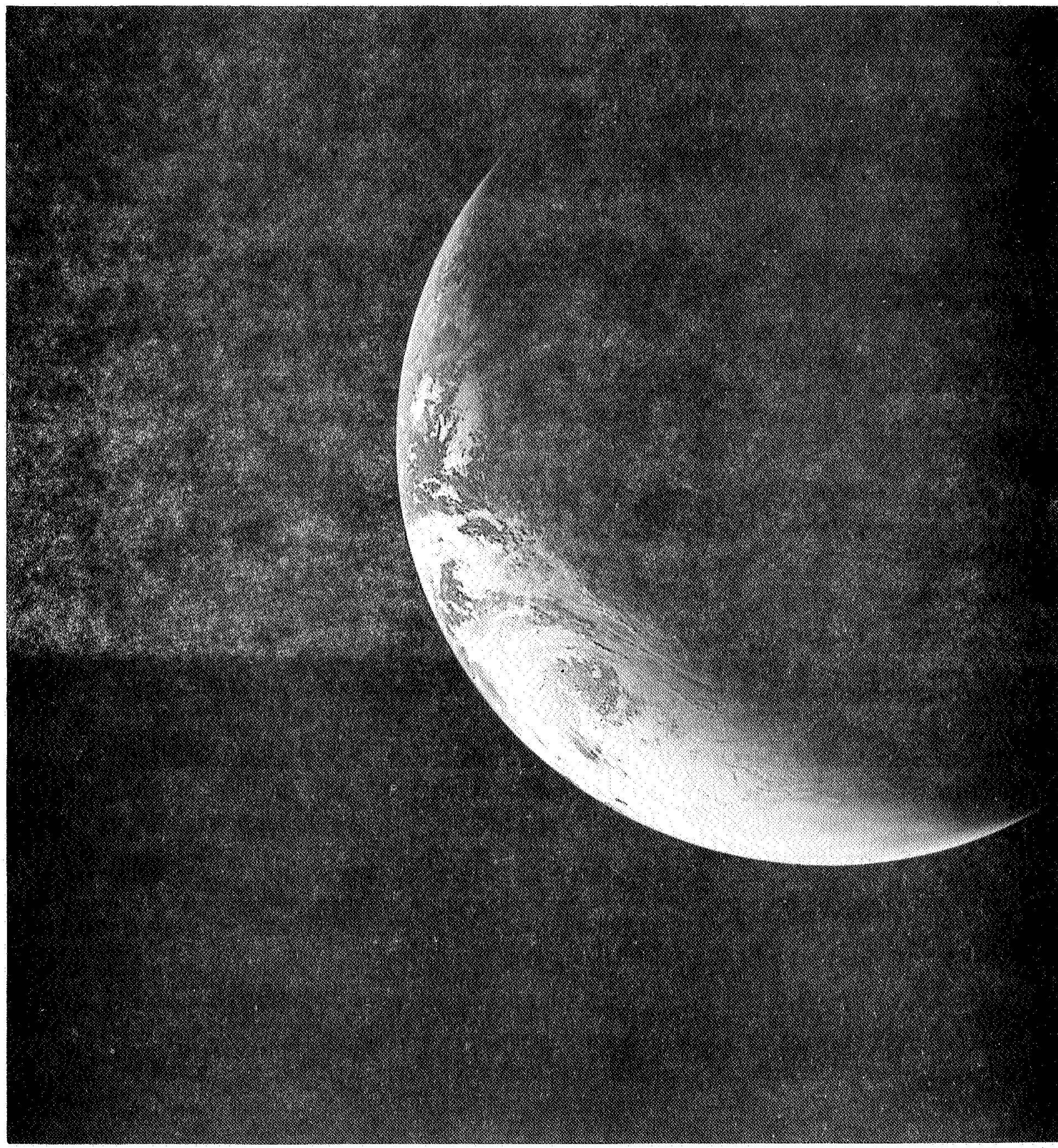


Figure 3. - Photograph AS4-1-410 of earth.

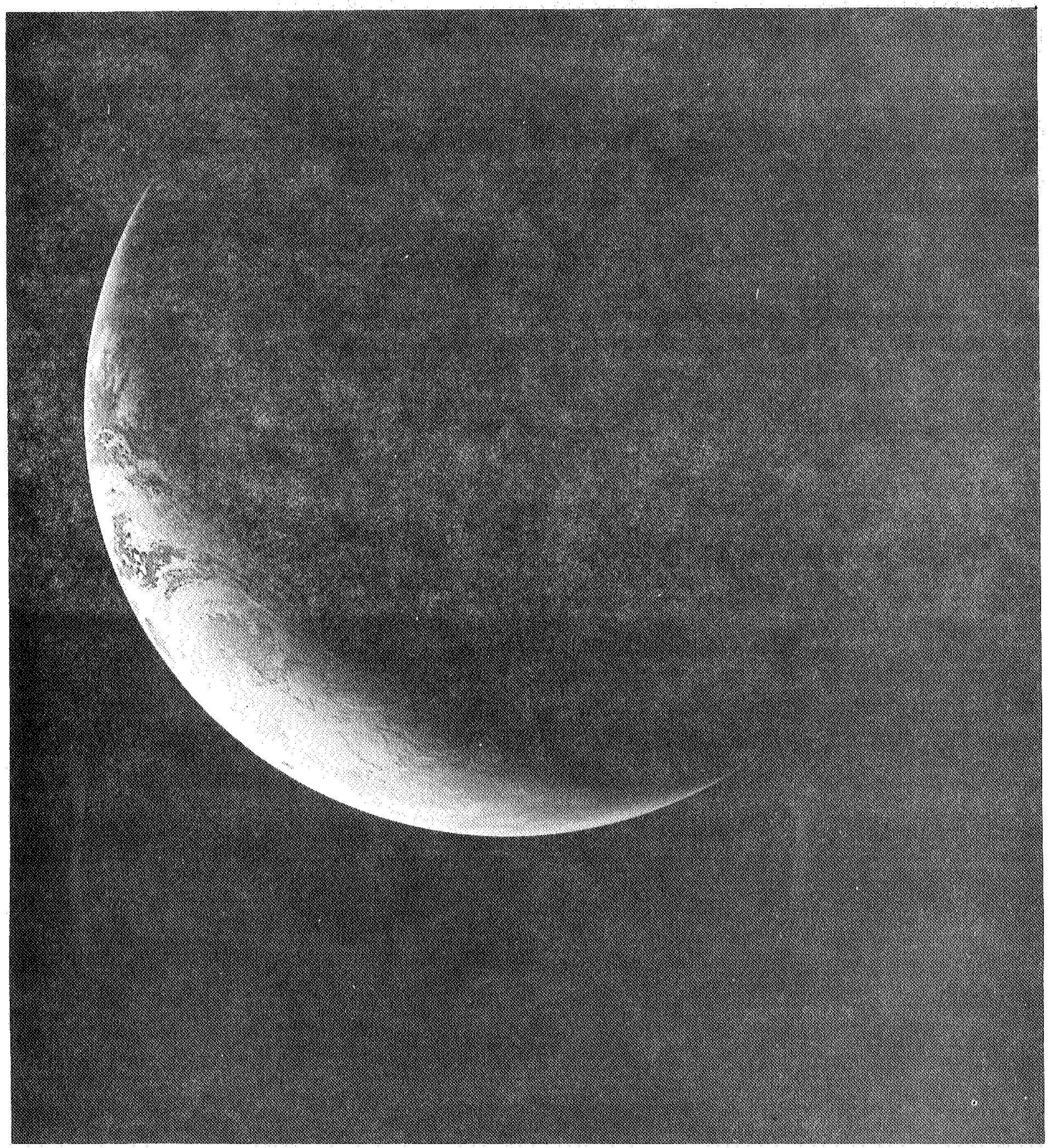


Figure 4. - Photograph AS4-1-580 of earth.

Figure 5. - Apollo AS-501 camera.

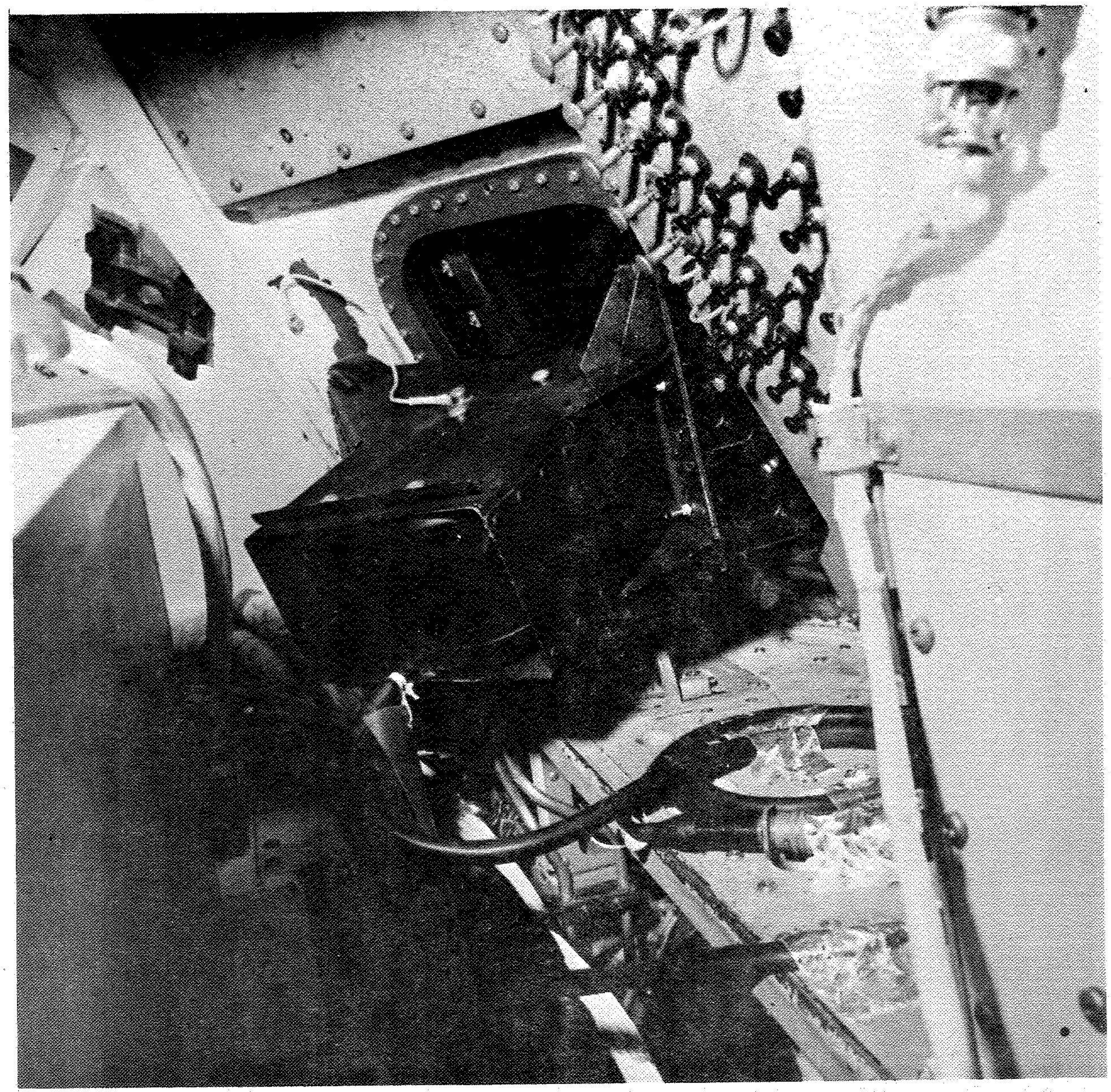
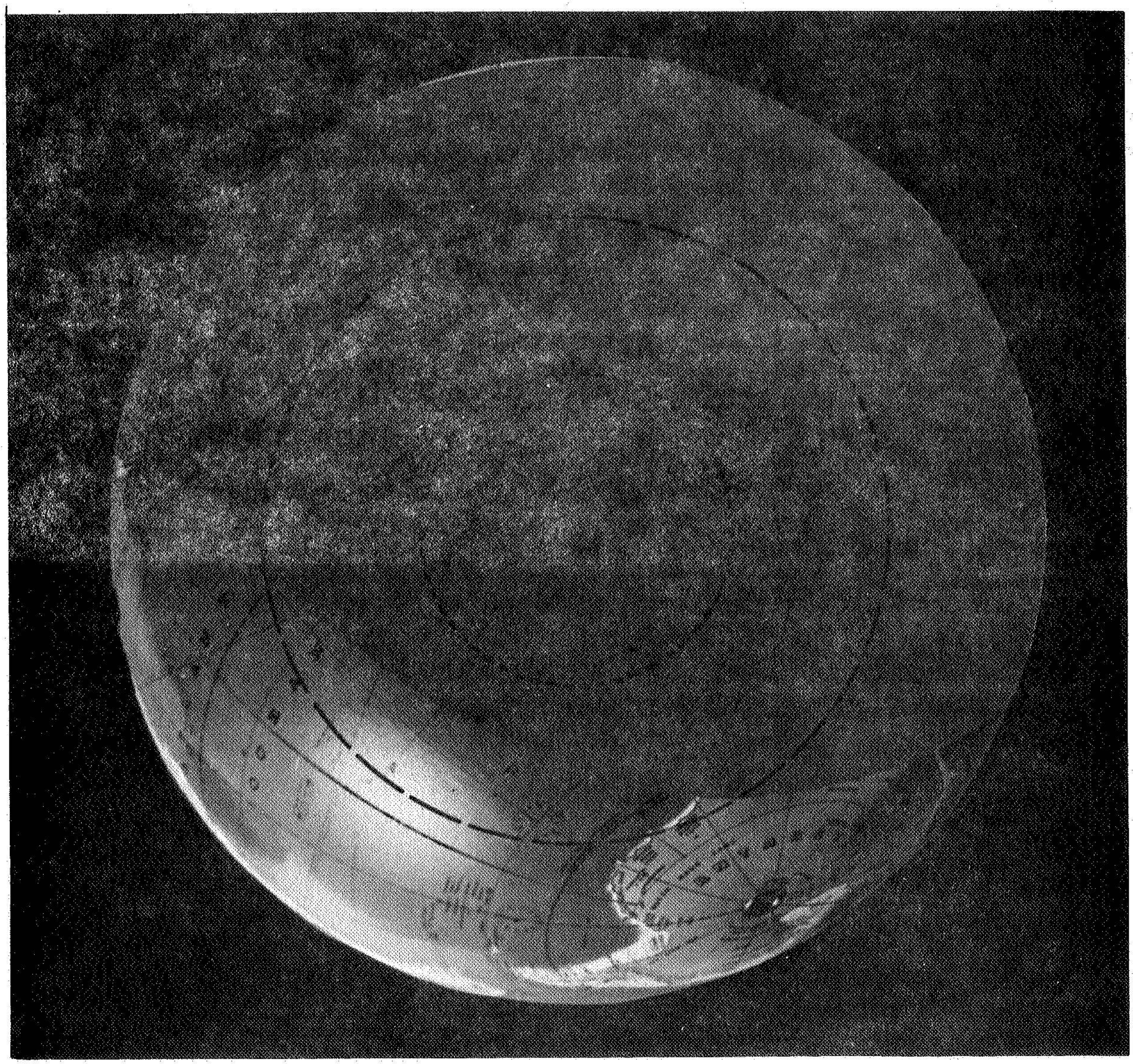


Figure 6. - Apollo AS-501 camera installations.

SCALES

NADIR	1:61 600 000
1 st. CIRCLE	1:62 400 000



2 nd. CIRCLE	1:65 066 666
HORIZON	1:78 400 000

Figure 7. - Predicted view of earth.

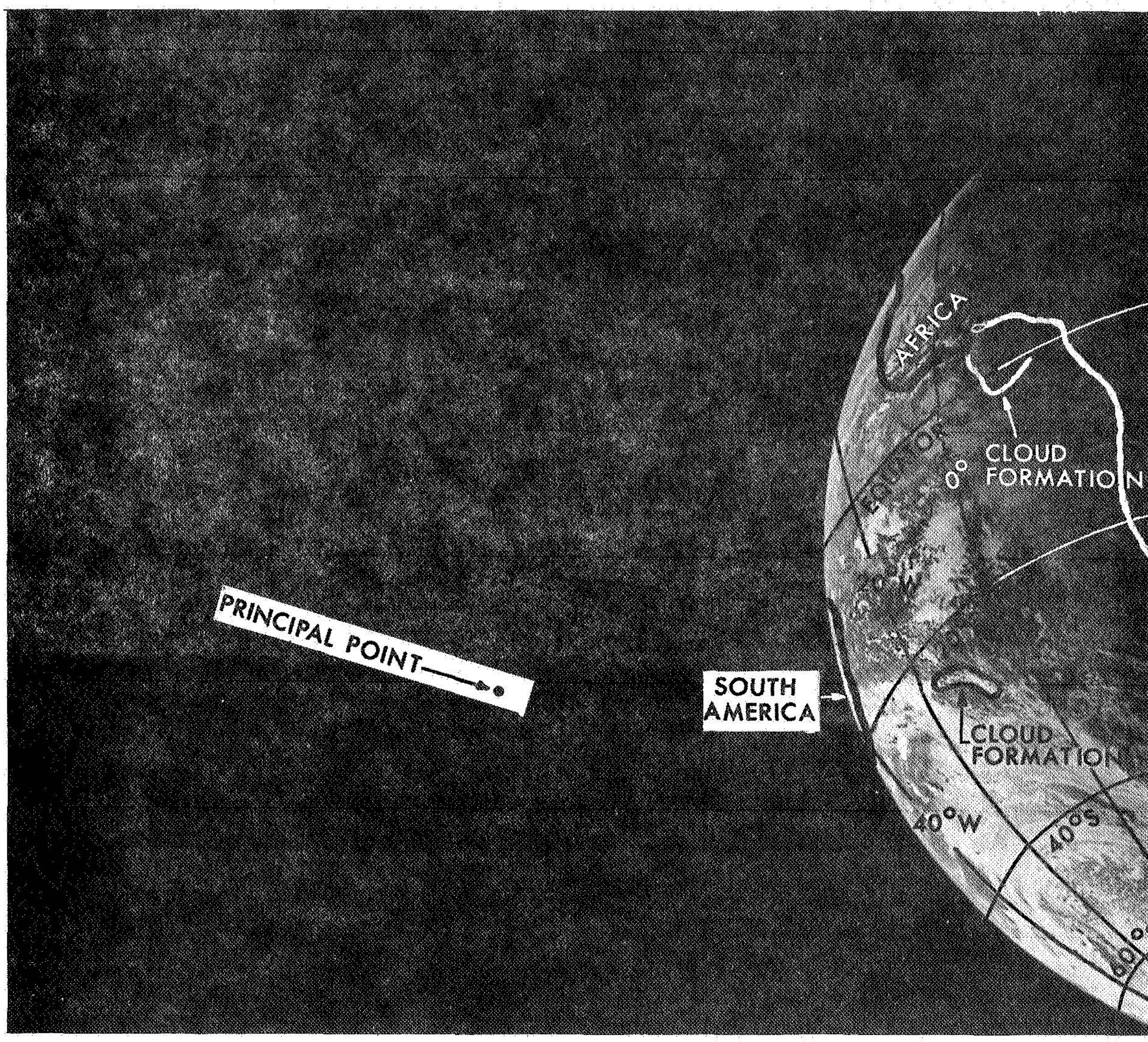


Figure 8. - Photograph AS4-1-200 of earth with grid overlay. (Approximate scale at intersection of equator and prime meridian — 1:70 400 000; spacecraft altitude — 9060 n. mi.) Cloud formations are register points.

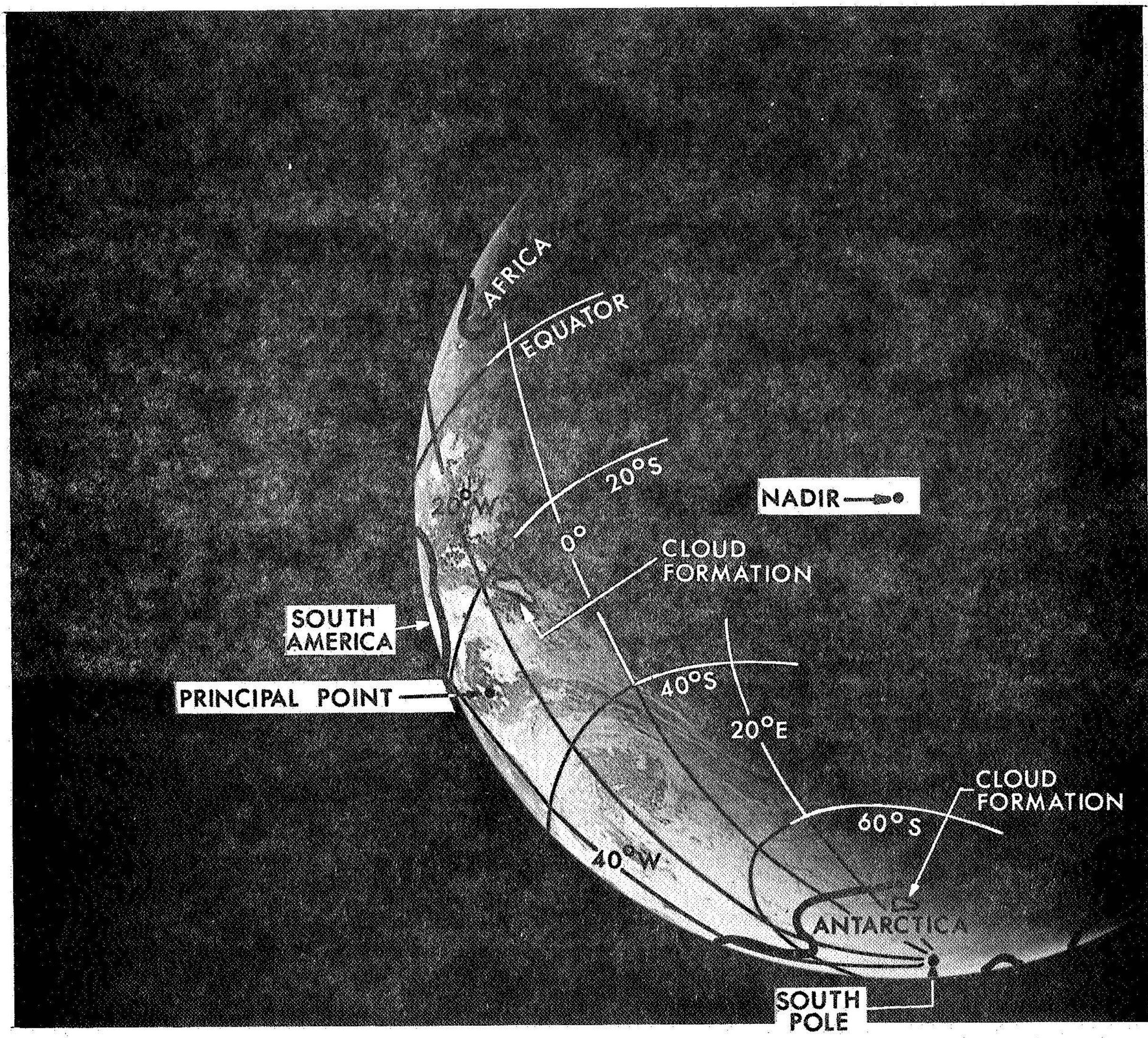


Figure 9. - Photograph AS4-1-410 of earth with grid overlay. (Approximate scale at intersection of equator and prime meridian — 1:73 100 000; spacecraft altitude — 9745 n. mi.) Cloud formations are register points.

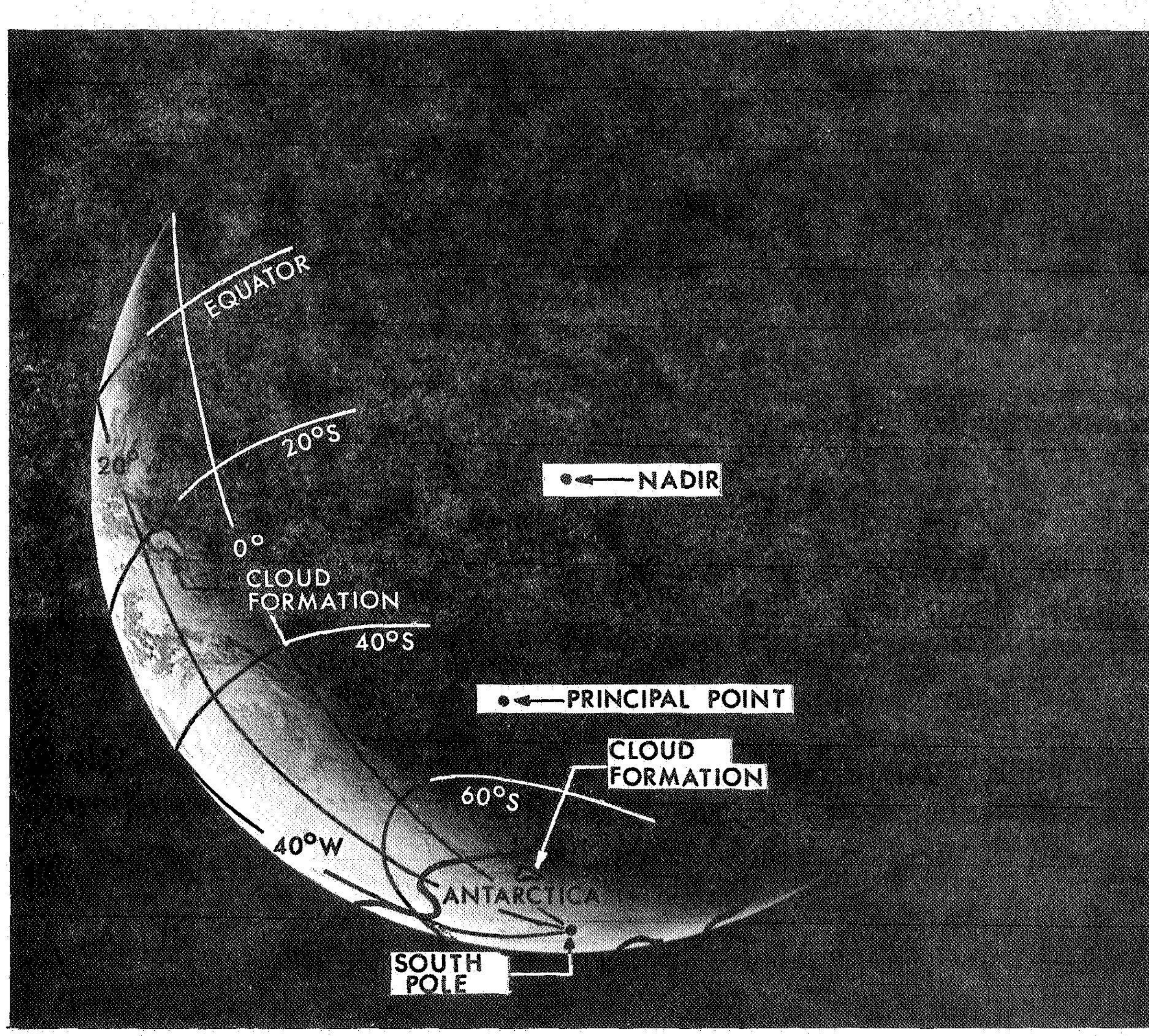


Figure 10. - Photograph AS4-1-580 of earth with grid overlay. (Approximate scale at intersection of equator and prime meridian — 1:74 700 000; spacecraft altitude — 9544 n. mi.) Cloud formations are register points.

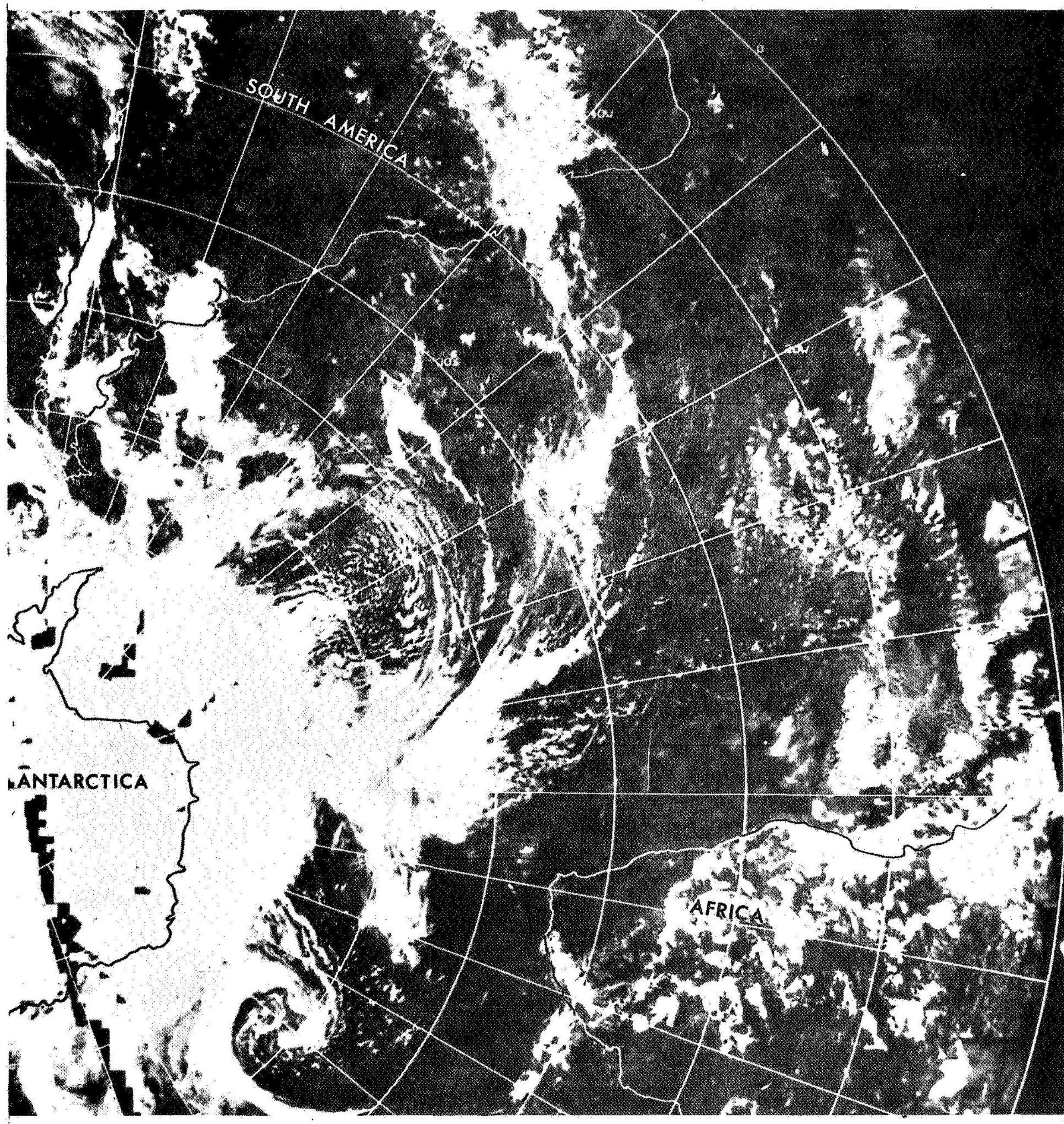


Figure 11. - ESSA 3 weather satellite imagery.

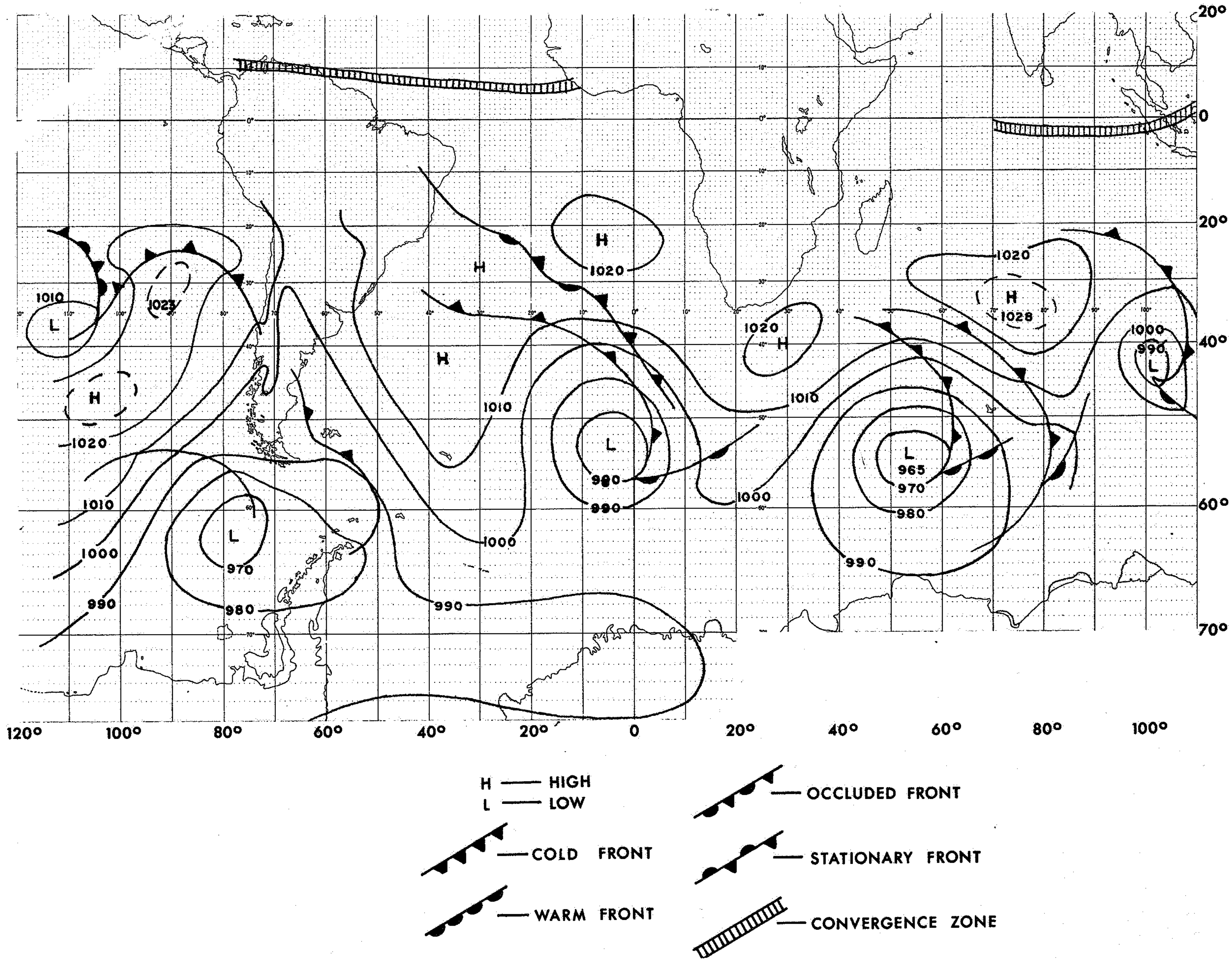


Figure 12. - Surface analysis map of the general area photographed during the Apollo AS-501 mission (G. m. t., Nov. 9, 1967).

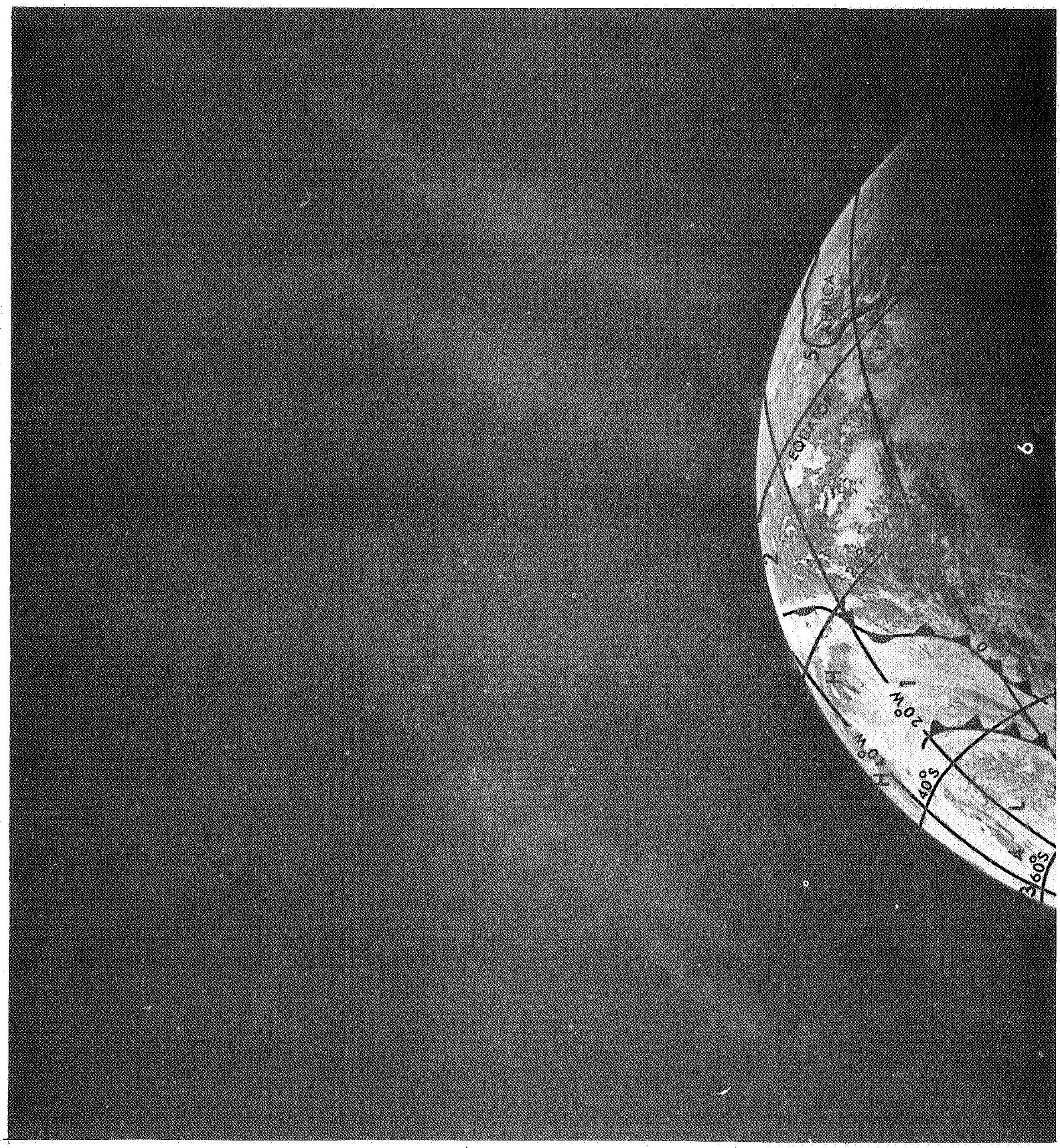


Figure 13. - Photograph AS4-1-200 of earth with grid and meteorology.

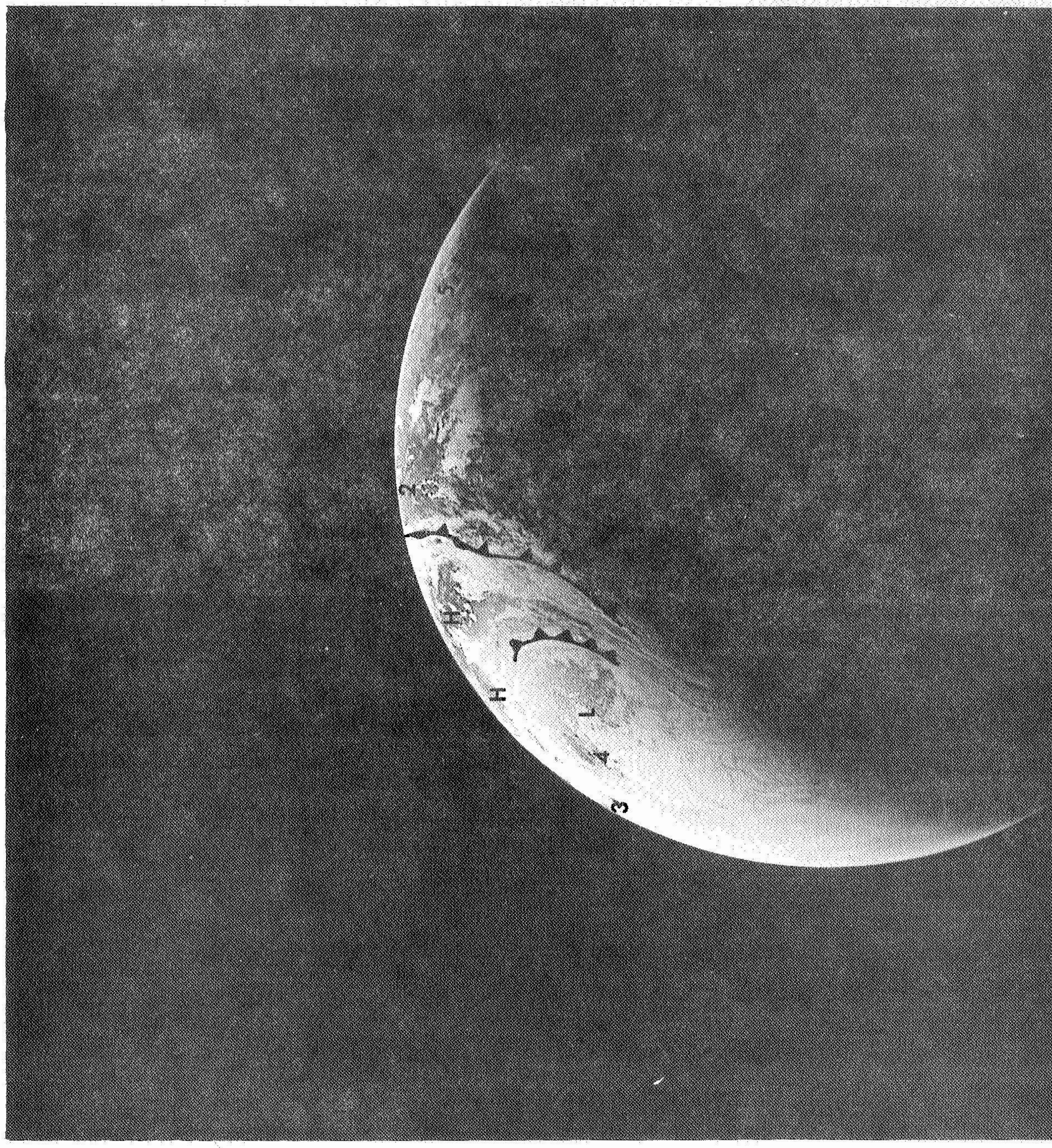


Figure 14. - Photograph AS4-1-410 of earth with meteorology.

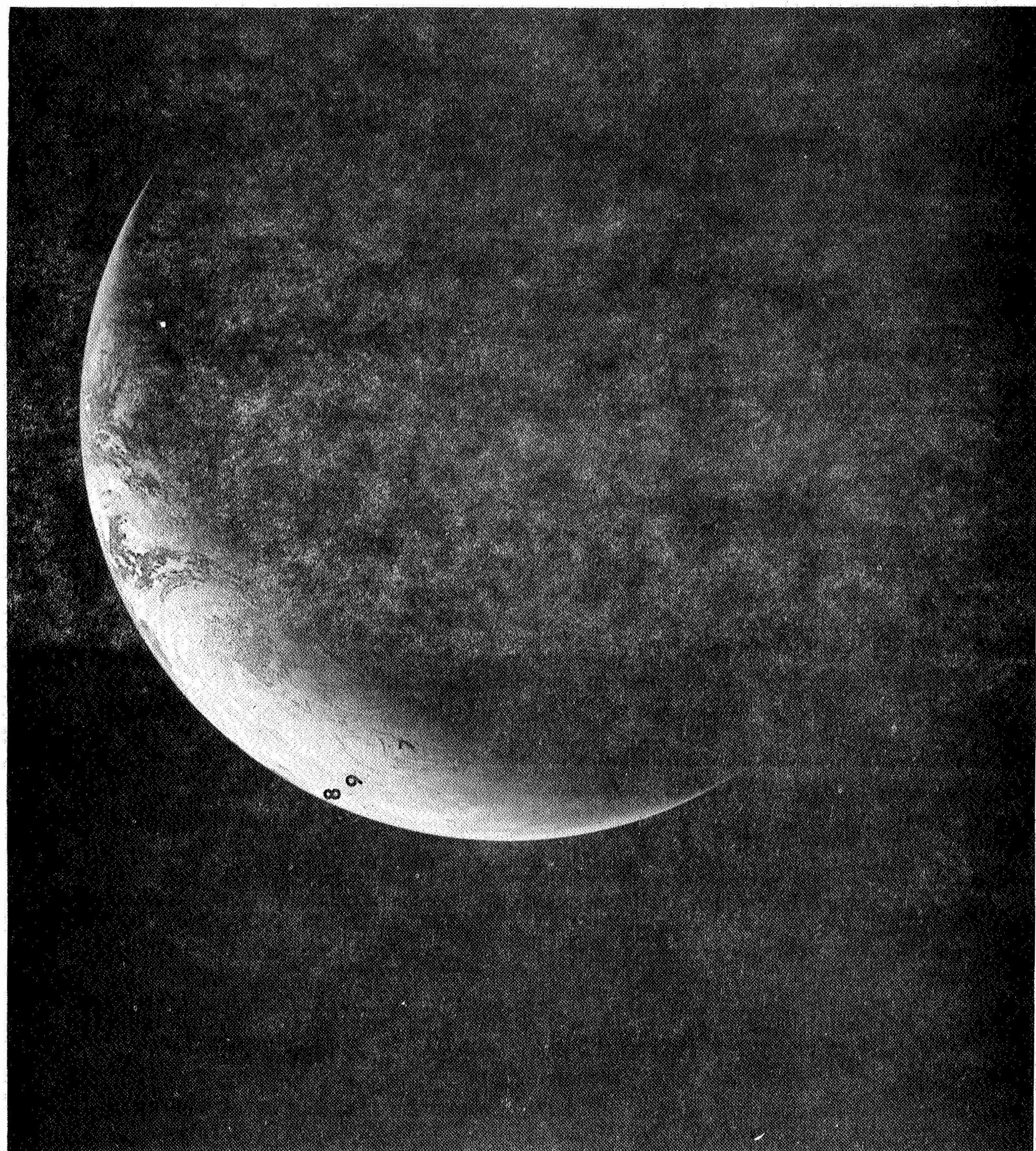


Figure 15. - Photograph AS4-1-580 of earth with meteorology.

APPENDIX A

PREMISSION COMPUTER SIMULATION OF CAMERA FIELD OF VIEW OF STAR FIELD AND EARTH FOR SELECTED EXPOSURES

The following figures are computer simulations of some of the pictures which were taken during the Apollo AS-501 mission. If the exposure time had been correct, the 10 stars identified in each figure would have shown up as the 10 brightest stars in the star field. The stars are further identified in the star catalog (table A-I).

TABLE A-I. - STAR CATALOG

Photograph star number	Smithsonian star number	Star name	Constellation	Right ascension, deg	Declination, deg	Magnitude, deg
1	14961		Leo Minor	10.856	34.404	3.92
2	15438	Zosma	Leo	11.204	20.716	2.58
3	15441	Coxa	Leo	11.207	15.621	3.41
4	15600		Leo	11.322	6.221	4.13
5	16135		Virgo	11.734	6.726	4.20
6	16189	Denebola	Leo	11.788	14.678	2.23
7	16512		Virgo	12.057	8.927	4.24
8	17557	Chara Cor Caroli	Canes Venatic	12.907	38.507	2.90
9	17687	Vindemiatrix	Virgo	13.007	11.147	2.95
10	17874		Coma Berenices	13.171	28.055	4.32

T =   3 HOURS, 45 MINUTES, 4.600 SECONDS, OR   1.3504600+04 SECONDS.
R.A. = 12.282 HRS DEC = 23.58 DEG SCALE = 41.1 DEG   YAW = -66.30 PITCH = 59.90 ROLL = -74.70
UNIT BODY AXIS VECTOR.   X = .64144960   Y = -.30836036   Z = .70246443

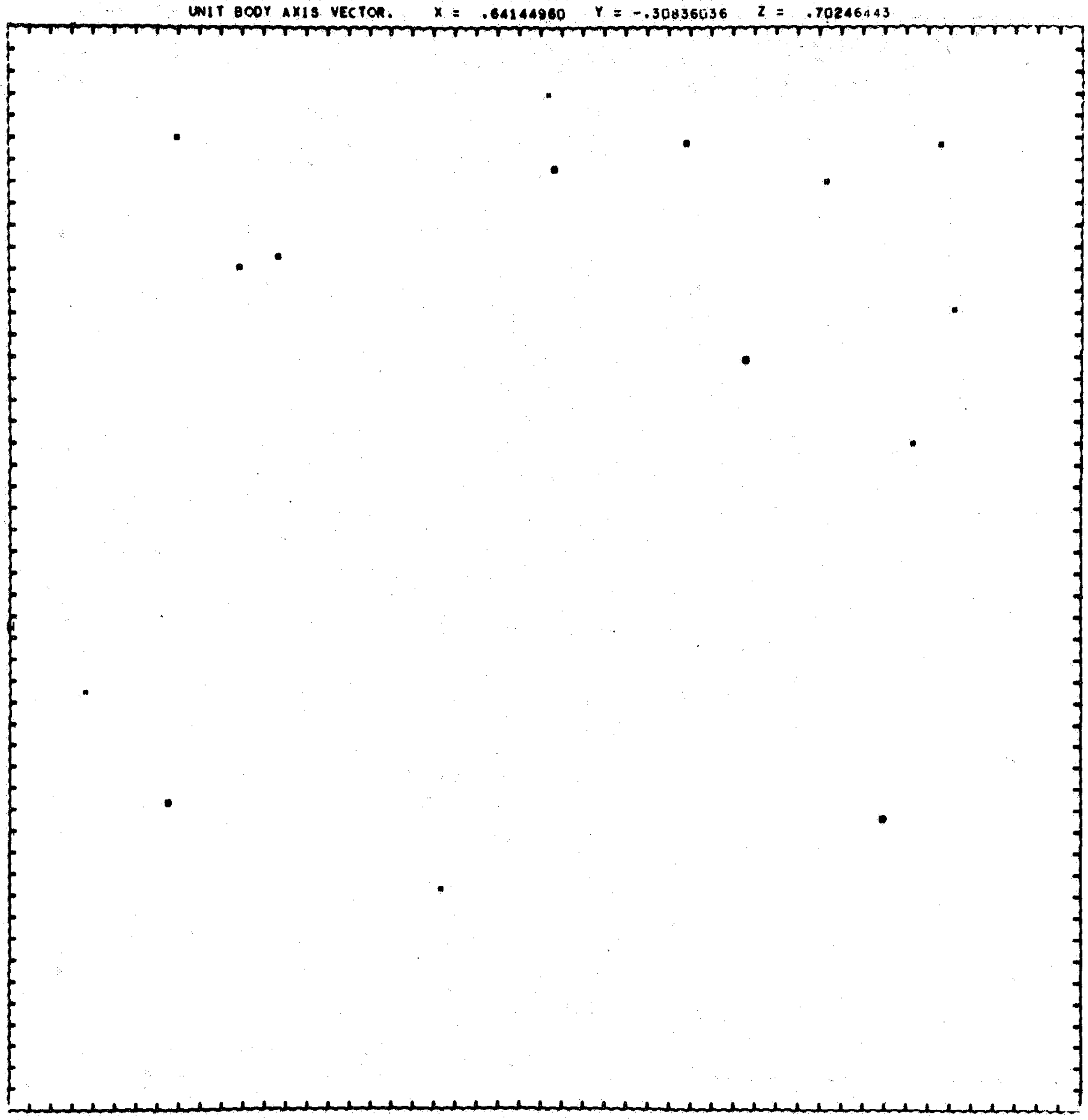


Figure A-1. - Simulation of star field at 03:45:04.6 g.e.t.

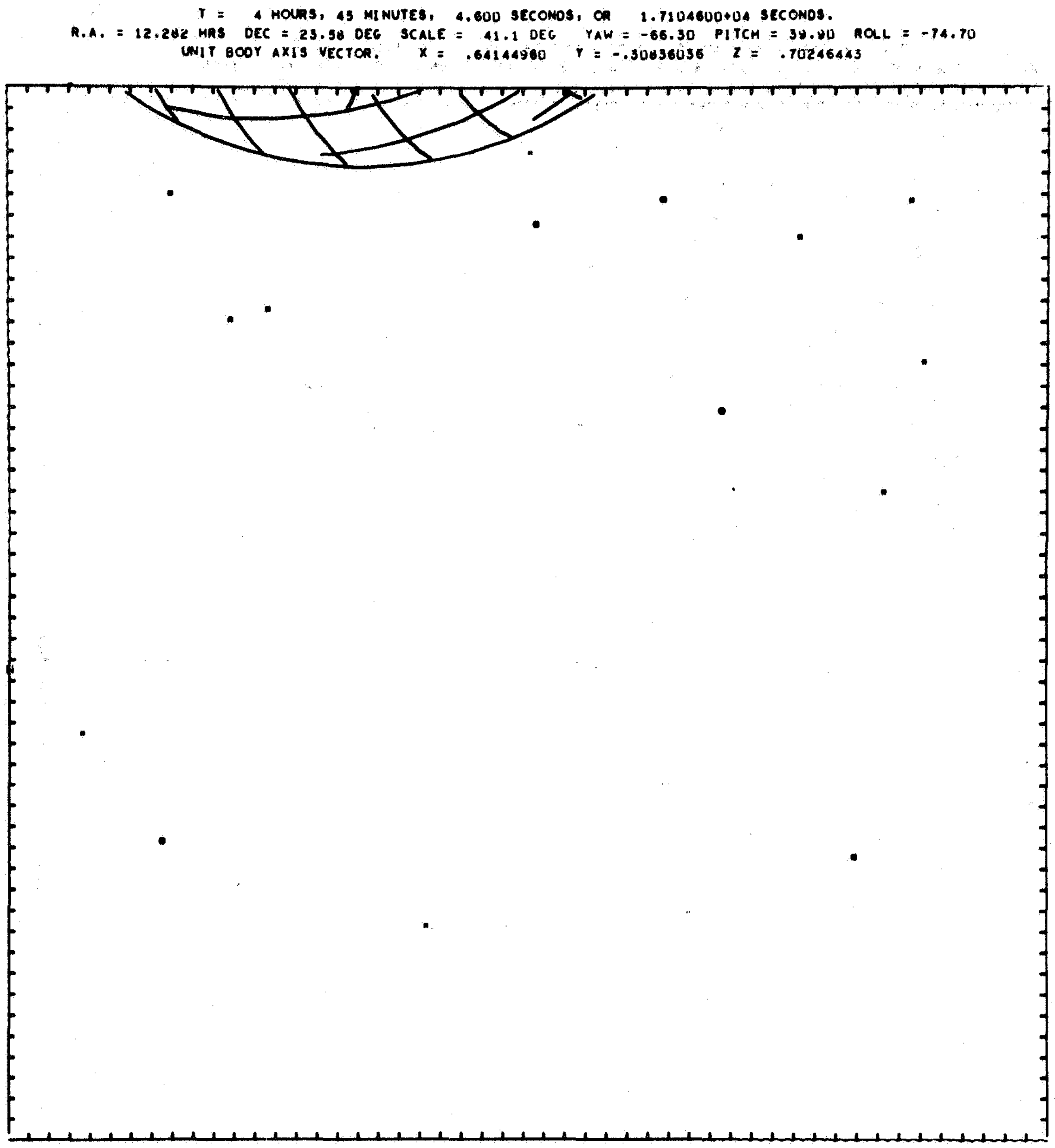


Figure A-2. - Simulation of star field at 04:45:04.6 g.e.t.

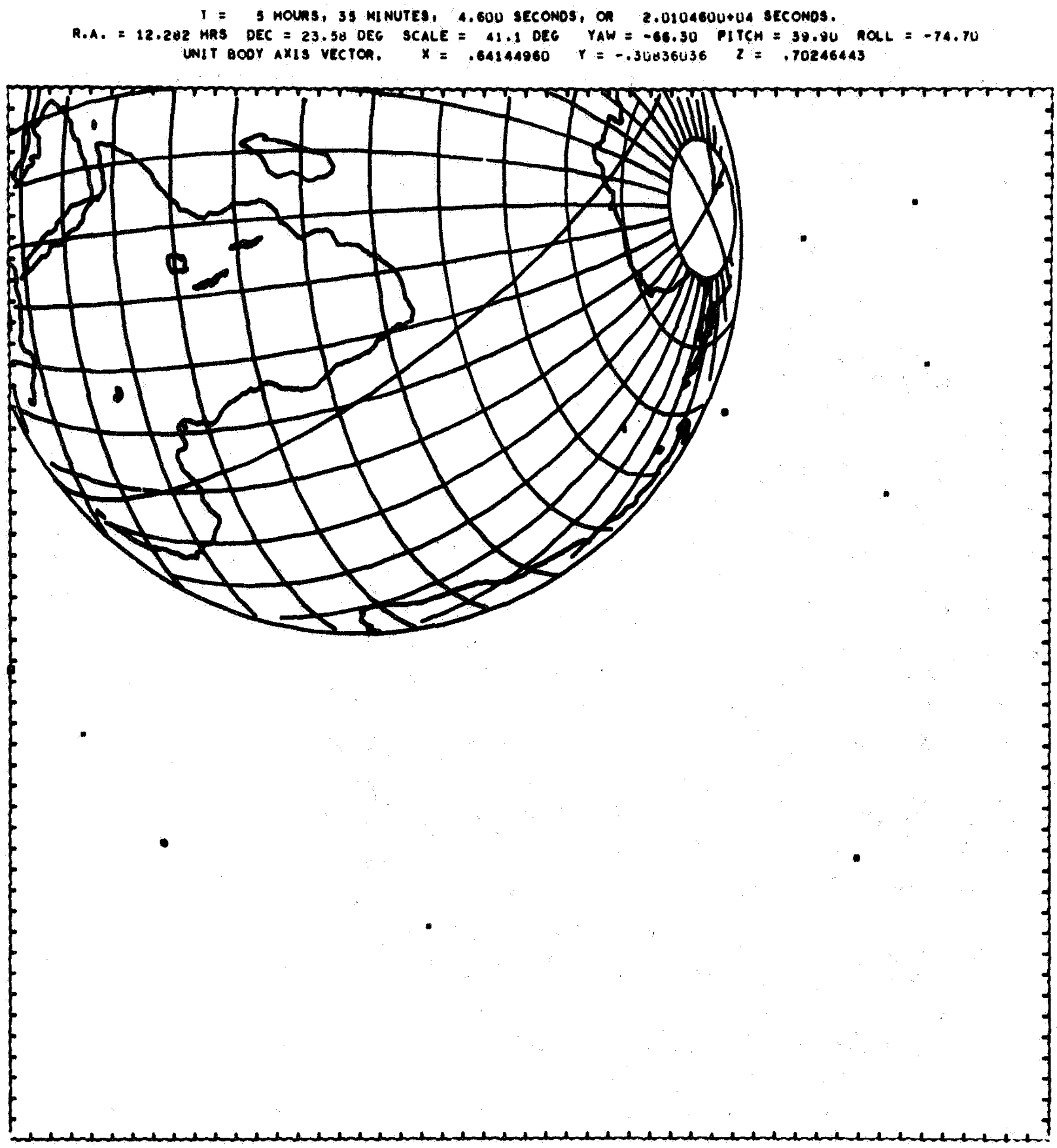


Figure A-3. - Simulation of star field at 05:35:04.6 g.e.t.

T = 6 HOURS, 25 MINUTES, 4.600 SECONDS, OR 2.3104599+04 SECONDS.
R.A. = 12.282 HRS DEC = 23.58 DEG SCALE = 41.1 DEG YAW = -66.30 PITCH = 39.90 ROLL = -74.70
UNIT BODY AXIS VECTOR. X = .64144960 Y = -.30836036 Z = .70246443

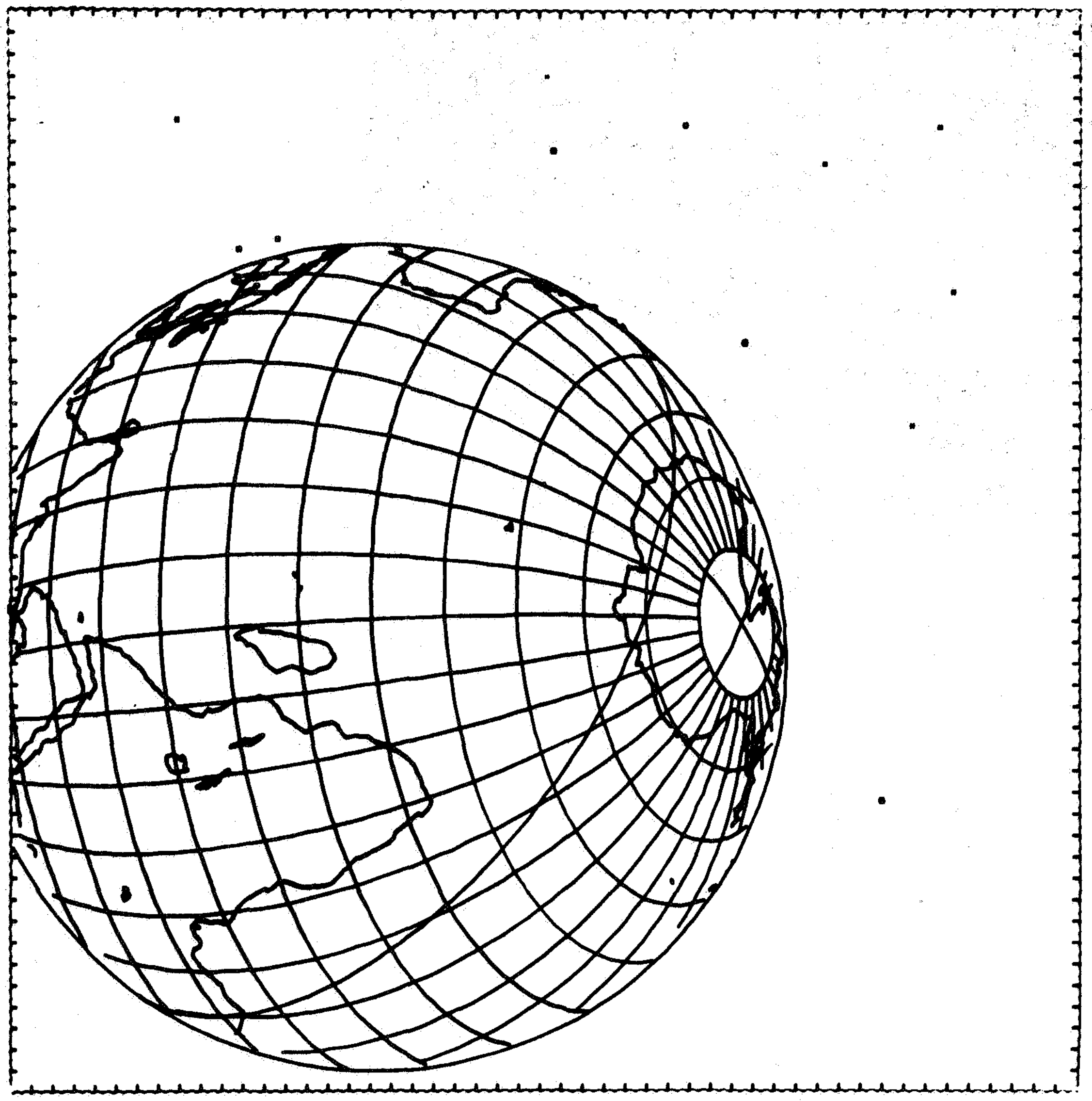


Figure A-4. - Simulation of star field at 06:25:04.6 g.e.t.

T = 7 HOURS, 5 MINUTES, 4.600 SECONDS, OR 2.5504600+04 SECONDS.
R.A. = 12.282 HRS DEC = 23.58 DEG SCALE = 41.1 DEG YAW = -66.30 PITCH = 39.90 ROLL = -74.70
UNIT BODY AXIS VECTOR, X = .64144960 Y = -.30836036 Z = .70246443

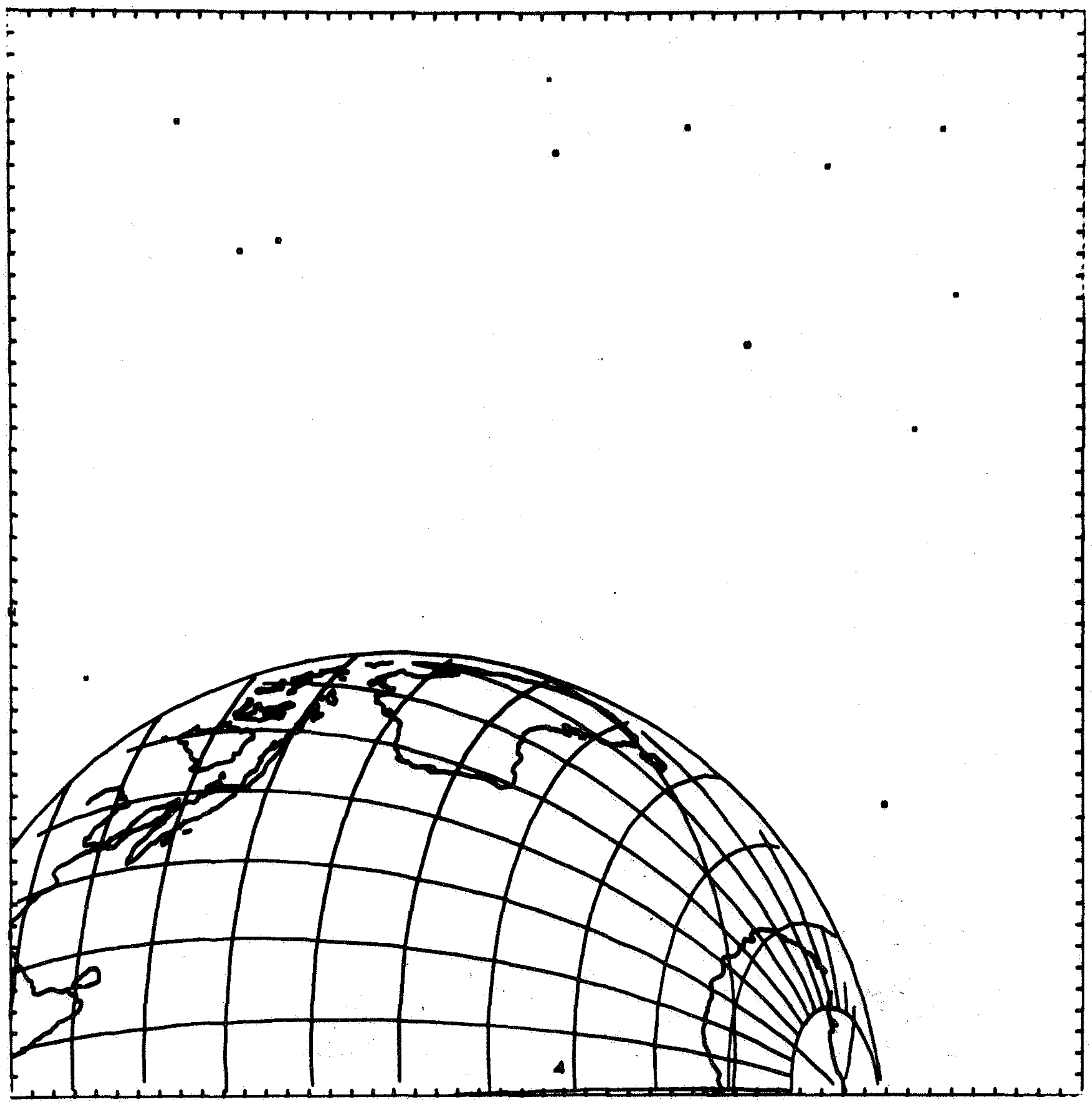


Figure A-5. - Simulation of star field at 07:05:04.6 g.e.t.

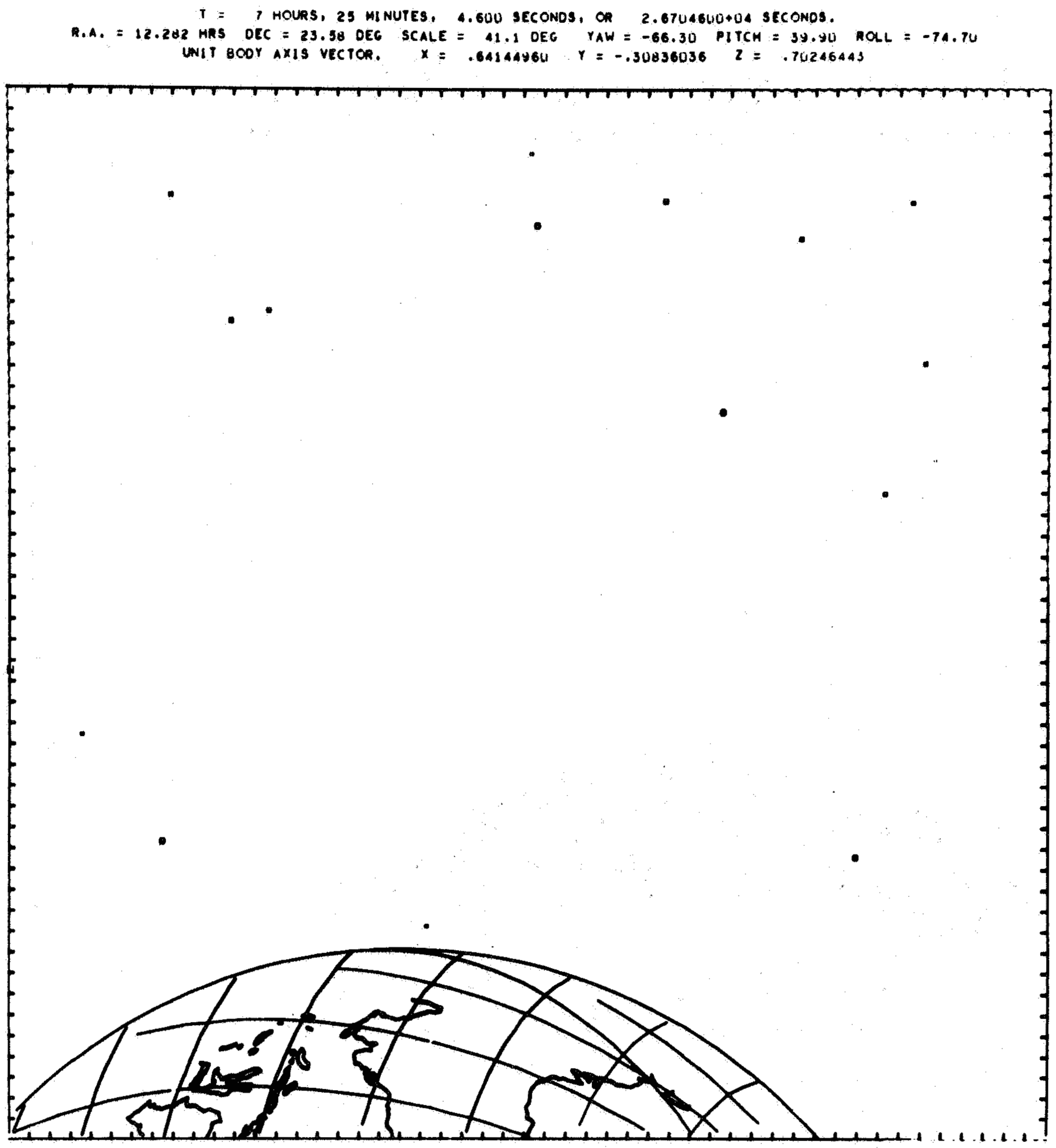


Figure A-6. - Simulation of star field at 07:25:04.6 g. e. t.

APPENDIX B

PHOTOGRAPHIC DATA, TIME, ALTITUDE, LOCATION, AND IDENTIFICATION

By Richard W. Underwood and Herbert A. Tiedemann
Photographic Technology Laboratory
Manned Spacecraft Center
Houston, Texas

General Information

The camera system was activated by a gravity switch set for $g = 3$. It is possible that the camera was activated by the initial vibration at lift-off. Therefore, times and altitudes are approximate but are within 1 minute of true. The first exposure was made at 04:28:00 g. e. t. with an exposure interval of approximately 10. 6 seconds. The spacecraft nadir point for the first exposure was approximately 18° South latitude and 23° East longitude. Apogee was reached at 05:46:48 g. e. t. at an altitude of 9769 n. mi. and at an approximate nadir point of 28° South latitude and 36° East longitude. All photographs were taken on the third revolution. Every 10th photograph is listed in table B-I. Intermediate exposures can be interpolated.

TABLE B-I. - APOLLO AS-501 MISSION ONBOARD PHOTOGRAPHIC IDENTIFICATION LIST (70 mm)

[November 9, 1967]

Camera: Maurer, Model 220 G

Lens: Kodak Ektar, f/2.8, 76 mm

Film: Kodak, Ektachrome, thin base, MS, SO-368, 70 mm

Lens Setting: f/8 at 1/500 second

Mounting: In command pilot's window

Launch: 12:00:01 Zulu from Complex 39-A Kennedy Space Center, Florida

Splash: 20:36:54 Zulu, southwest of Honolulu, Hawaii

Exposure number	Ground elapsed time, hr:min	Approximate altitude		Location and identification
		n. mi.	km	
AS4-1-1	4:28	7295	13 510	Black unlighted sky
AS4-1-10	4:29	7360	13 631	Black unlighted sky
AS4-1-20	4:31	7487	13 866	Black unlighted sky
AS4-1-30	4:33	7610	14 094	Black unlighted sky
AS4-1-40	4:35	7730	14 316	Black unlighted sky
AS4-1-50	4:36	7788	14 423	Atlantic Ocean between Africa and South America, horizon at edge of format

TABLE B-I. - APOLLO AS-501 MISSION ONBOARD PHOTOGRAPHIC IDENTIFICATION LIST (70 mm) - Continued

[November 9, 1967]

Exposure number	Ground elapsed time, hr:min	Approximate altitude		Location and identification
		n. mi.	km	
AS4-1-60	4:38	7902	14 635	Atlantic Ocean between Africa and South America, horizon at edge of format
AS4-1-70	4:40	8012	14 838	Atlantic Ocean between Africa and South America, horizon at edge of format
AS4-1-80	4:43	8171	15 133	Coastal Brazil (Fortaleza to Rio), Coastal Africa (Dakar to Casablanca), Atlantic Ocean
AS4-1-90	4:44	8222	15 227	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-100	4:46	8321	15 410	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-110	4:48	8417	15 588	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-120	4:50	8509	15 759	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-130	4:51	8554	15 842	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest

TABLE B-I. - APOLLO AS-501 MISSION ONBOARD PHOTOGRAPHIC IDENTIFICATION LIST (70 mm) - Continued

[November 9, 1967]

Exposure number	Ground elapsed time, hr:min	Approximate altitude		Location and identification
		n. mi.	km	
AS4-1-140	4:53	8641	16 003	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-150	4:55	8725	16 159	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-160	4:56	8766	16 235	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-170	4:58	8844	16 379	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-180	5:00	8920	16 520	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-190	5:02	8992	16 653	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-200	5:04	9060	16 779	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-210	5:06	9126	16 901	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest

TABLE B-I. - APOLLO AS-501 MISSION ONBOARD PHOTOGRAPHIC IDENTIFICATION LIST (70 mm) - Continued

[November 9, 1967]

Exposure number	Ground elapsed time, hr:min	Approximate altitude		Location and identification
		n. mi.	km	
AS4-1-220	5:07	9157	16 959	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-230	5:09	9218	17 072	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-240	5:11	9275	17 177	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-250	5:12	9302	17 227	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-260	5:13	9329	17 277	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-270	5:15	9380	17 371	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-280	5:16	9404	17 416	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-290	5:18	9450	17 501	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-300	5:20	9493	17 581	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest

TABLE B-I. - APOLLO AS-501 MISSION ONBOARD PHOTOGRAPHIC IDENTIFICATION LIST (70 mm) - Continued

[November 9, 1967]

Exposure number	Ground elapsed time, hr:min	Approximate altitude		Location and identification
		n. mi.	km	
AS4-1-310	5:21	9514	17 620	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, looking northwest
AS4-1-320	5:23	9551	17 688	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, Antarctica, looking west
AS4-1-330	5:24	9569	17 722	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, Antarctica, looking west
AS4-1-340	5:25	9587	17 755	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, Antarctica, looking west
AS4-1-350	5:26	9603	17 785	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, Antarctica, looking northwest
AS4-1-360	5:28	9641	17 855	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, Antarctica, looking northwest
AS4-1-370	5:30	9661	17 892	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, Antarctica, looking northwest
AS4-1-380	5:32	9691	17 948	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, Antarctica, looking northwest
AS4-1-390	5:34	9706	17 976	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, Antarctica, looking northwest

TABLE B-I. - APOLLO AS-501 MISSION ONBOARD PHOTOGRAPHIC

IDENTIFICATION LIST (70 mm) - Continued

[November 9, 1967]

Exposure number	Ground elapsed time, hr:min	Approximate altitude		Location and identification
		n. mi.	km	
AS4-1-400	5:36	9725	18 011	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, Antarctica, looking northwest
AS4-1-410	5:39	9745	18 048	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, Antarctica, looking west
AS4-1-420	5:41	9756	18 068	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, Antarctica, looking west
AS4-1-430	5:43	9763	18 081	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, Antarctica, looking west
AS4-1-440	5:45	9767	18 088	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, Antarctica, looking west
AS4-1-450	5:47	9769	18 092	Apogee, Coastal Brazil, Atlantic Ocean, West Africa, Sahara, Antarctica, looking west
AS4-1-460	5:49	9767	18 088	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, Antarctica, looking west
AS4-1-470	5:51	9762	18 079	Coastal Brazil, Atlantic Ocean, West Africa, Sahara, Antarctica, looking west
AS4-1-480	5:53	9754	18 064	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west

TABLE B-I. - APOLLO AS-501 MISSION ONBOARD PHOTOGRAPHIC IDENTIFICATION LIST (70 mm) - Continued

[November 9, 1967]

Exposure number	Ground elapsed time, hr:min	Approximate altitude		Location and identification
		n. mi.	km	
AS4-1-490	5:55	9743	18 044	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west
AS4-1-500	5:57	9729	18 018	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west
AS4-1-510	5:58	9721	18 003	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west
AS4-1-520	6:00	9702	17 968	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west
AS4-1-530	6:02	9680	17 927	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west
AS4-1-540	6:04	9655	17 881	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west
AS4-1-550	6:06	9627	17 829	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west
AS4-1-560	6:08	9596	17 772	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west
AS4-1-570	6:09	9579	17 740	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west

TABLE B-I. - APOLLO AS-501 MISSION ONBOARD PHOTOGRAPHIC IDENTIFICATION LIST (70 mm) - Continued

[November 9, 1967]

Exposure number	Ground elapsed time, hr:min	Approximate altitude		Location and identification
		n. mi.	km	
AS4-1-580	6:11	9544	17 675	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west
AS4-1-590	6:12	9521	17 633	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west
AS4-1-600	6:13	9504	17 601	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west
AS4-1-610	6:15	9463	17 525	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west
AS4-1-620	6:17	9418	17 442	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west
AS4-1-630	6:18	9394	17 398	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west
AS4-1-640	6:20	9343	17 303	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west
AS4-1-650	6:22	9290	17 205	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west
AS4-1-660	6:24	9234	17 101	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west

TABLE B-I. - APOLLO AS-501 MISSION ONBOARD PHOTOGRAPHIC

IDENTIFICATION LIST (70 mm) - Concluded

[November 9, 1967]

Exposure number	Ground elapsed time, hr:min	Approximate altitude		Location and identification
		n. mi.	km	
AS4-1-670	6:26	9174	16 990	Coastal Brazil, Atlantic Ocean, West Africa, Antarctica, looking west
AS4-1-680	6:28	9111	16 873	Coastal Brazil, Atlantic Ocean, Antarctica, looking west
AS4-1-690	6:30	9046	16 753	Atlantic Ocean, Antarctica, looking west
AS4-1-700	6:32	8976	16 624	Atlantic Ocean, Antarctica, looking west
AS4-1-710	6:34	8903	16 488	Atlantic Ocean, Antarctica, looking west
AS4-1-720	6:36	8827	16 348	Atlantic Ocean, Antarctica, looking west
AS4-1-730	6:38	8748	16 201	Atlantic Ocean, Antarctica, looking west
AS4-1-740	6:40	8665	16 048	Atlantic Ocean, Antarctica, looking west
AS4-1-750	6:41	8628	15 979	Atlantic Ocean, Antarctica, looking west
AS4-1-755	6:41	8601	15 929	Atlantic Ocean, Antarctica, looking west