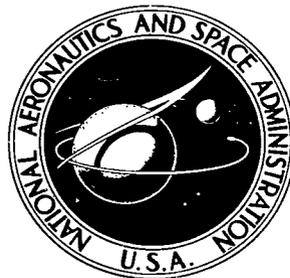


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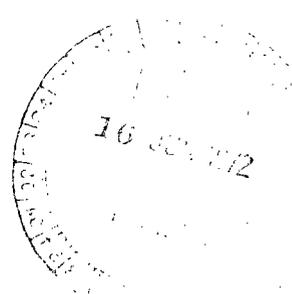
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APOLLO EXPERIENCE REPORT - THE APPLICATION OF A COMPUTERIZED VISUALIZATION CAPABILITY TO LUNAR MISSIONS

by Charles T. Hyle and Alfred N. Lunde

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Houston, Texas 77058





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16. Abstract <p>The development of a computerized capability to depict views from the Apollo spacecraft during a lunar mission was undertaken before the Apollo 8 mission. Such views were considered valuable because of the difficulties in visualizing the complex geometry of the Earth, Moon, Sun, and spacecraft. Such visualization capability originally was desired for spacecraft-attitude verification and contingency situations. Improvements were added for later Apollo flights, and results were adopted for several real-time and preflight applications. Some specific applications have included crewmember and ground-control-personnel familiarization, nominal and contingency mission planning, definition of secondary attitude checks for all major thrust maneuvers, and preflight star selection for navigation and for platform alinement. The use of this computerized visualization capability would prove valuable for any future space program as an aid to understanding the geometrical relationships between the spacecraft and the celestial surroundings.</p>				13. Type of Report and Period Covered Technical Note	
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APOLLO EXPERIENCE REPORT
THE APPLICATION OF A COMPUTERIZED VISUALIZATION
CAPABILITY TO LUNAR MISSIONS

By Charles T. Hyle and Alfred N. Lunde
Manned Spacecraft Center

SUMMARY

The complex and constantly varying geometry of the Earth, Moon, Sun, and spacecraft is difficult to visualize during a lunar mission. The geometry is even more difficult to visualize when the reference frame is in the moving spacecraft. A preflight knowledge of how the spacecraft should be oriented with respect to familiar objects that are visible through the spacecraft windows or through the optical instruments is considered valuable to the astronauts and to the contingency mission planning personnel. Therefore, the development of a computerized capability to obtain this insight was undertaken before the Apollo 8 mission. Improvements were added for later Apollo flights, and the results were adopted for several real-time and preflight applications. Some of these applications have included mission familiarization for crewmembers and mission analysts, establishment of visual attitude-reference capability for normal and abort thrust maneuvers (including the Apollo 13 emergency), and preflight star selection for navigation and for platform alinement. Based on this Apollo experience, it is believed that preflight computerized crew visualization capability will be valuable for future NASA programs and for any large, complex undertaking involving man in space.

INTRODUCTION

In any large, complex undertaking involving man and his relationship to his surroundings, man must become as familiar as possible with the expected surroundings and environment as part of his training. In the Apollo Program, the geometrical relationships of the various bodies and the attitude requirements were extremely complicated and difficult to visualize. In addition, successful operations in certain phases of the Apollo missions depended on the crewmen being able to visualize and understand what could be seen, either through the spacecraft windows or through the optical instruments. Much of the training for this ability was done by the use of various crew-training simulators. However, these simulators are of limited use for visual training because of mechanical or physical limits or because of limited availability to analytical and technical personnel other than the crewmen. Thus, a preflight method to depict the view through the spacecraft window or through the optical instruments at any time during the flight proved to be very helpful in nominal and contingency mission planning and crew

familiarization. Recognition of this need led to the augmentation of a somewhat dormant computer program that generated, as the principal output, frames of microfilm containing simulated photographs of objects that could be seen from the spacecraft at any given time. Originally, this computer program was developed as an aid in the early Gemini rendezvous and docking studies. The objective of having such a program for lunar missions was to provide a simple, manual method for the crewmen to use for a return-to-Earth maneuver using the observed celestial sphere for orientation in a contingency situation. Soon, a more basic application of the program was recognized by analytical personnel during the development of powered-flight-monitoring procedures. This application was to provide the personnel performing analytical studies a method to develop a gross attitude-check capability before normal maneuvers were executed.

DISCUSSION

Analytical work on an acceptable method for providing an out-the-window attitude check for the Apollo 8 lunar orbit insertion (LOI) maneuver prompted the original full-scale program-development effort. The basic objective was the development of a fast and accurate computerized method of preflight visualization of the objects that would be seen through the spacecraft window before LOI so that the range of acceptable attitude variations could be studied. Such views would be valuable to the analysts and to the flight crew because of the following reasons.

1. The knowledge of whether stars or the lunar surface would be visible before, at, and during LOI would provide cues for verification of attitude computations and maneuver progress. Attitude requirements are computed relative to stars, not relative to the Moon; therefore, provision is made for proper attitude, even for an improper trajectory. Also, attitudes are determined by use of the optics, which are located in another part of the spacecraft, and by sighting on objects different from those that are visible through the spacecraft windows.

2. Because of terminator movement across the Moon during the monthly launch window, the surface of the Moon is not always visible at LOI ignition.

3. The LOI maneuver is performed behind the Moon, in a heads-down attitude, with the spacecraft gimbal angles referenced to another inertial attitude (with no obvious visible correlation). Mental visualization of the appearance of the lunar horizon or of stars through the spacecraft windows is difficult using this method of attitude referencing.

The first basic objective was achieved with the view program by generating the window view of the lunar horizon at the Apollo 8 LOI ignition time and attitude. This view demonstrated for the first time that the information available to the crewmen could support an onboard go/no-go decision for LOI simply by verifying that the lunar horizon, as viewed from the window, was near a reference mark on the window.

In addition to the basic LOI objective, it was recognized that attitude information associated with translunar injection (TLI) was equally desirable for similar reasons. Specifically, a method was sought to enable the crewmen to obtain information needed to support a go/no-go decision for TLI based on out-the-window determination of attitude relative to the crew optical alignment sight and the Earth horizon (or features).

This requirement was evident because multiple TLI ignition opportunities precluded ground-dependent monitoring and evaluation techniques. Other complications that made such preflight window views desirable are the possibility of short time lines between orbit insertion and occurrence of darkness, the lack of assurance of spacecraft platform-realignment time, and the use of a launch reference stable member matrix (REFSMMAT) concept (spacecraft-attitude indicators referenced to inertial conditions at launch with no physical meaning to the crewmen).

Program Description

The view program operates on the UNIVAC 1108 computer. The program is written in the FORTRAN V language, which can be converted easily to operate on other computer systems. The program consists of two basic parts: the integrator portion and the graphic-display portion. The integrator portion uses either the Encke or the Cowell integration method and can integrate any nonpowered-flight trajectory after the initial state vector is known. To generate graphic displays, the numerical data that described the display must be available from the integrator portion of the program. The graphic data can be displayed at any *n*th value of the integration step. The graphic display consists of microfilm frames produced by a camera that photographs an image constructed on the surface of a cathode-ray tube. The image is formed by dots, and, depending on the segment desired, lines and curves may be produced by connecting the dots.

Although the principal form of output is microfilm frames, numerical data, as well as crude printer-plot images of the data, may be requested. The numerical data and images are helpful because they provide for a quick-look evaluation before the microfilm frames are received. For most uses, the microfilm frames are printed on standard sheets of paper.

The basic changes and modifications to the original program to achieve the desired objectives were associated with the input/output options, coordinate transformations, lunar- and solar-ephemeris installation, three-dimensional-display problems, and realistic spacecraft-window outlines. After the basic program objectives were identified, they were readily achieved or resolved. Additional mission applications then were determined to be feasible, and work was begun in this regard. A summary of the final lunar-mission view-program capabilities is provided in the appendix. Throughout the development of the program capabilities, verification of accurate results was performed manually.

Program Applications

Preflight views produced for the Apollo 8 mission included views as seen through the spacecraft windows during various critical maneuvers of the flight. These maneuvers were at TLI, LOI, transearth insertion (TEI), and the entry phase. In addition, views of the Earth and the Moon as they would appear from the spacecraft at various times during the mission were provided. Topographical features, such as outlines of continents on the Earth and major craters, rilles, and seas on the Moon, were shown in all views. On both celestial bodies, the terminator was shown with shading lines to indicate the darkened portions. The terminator was perpendicular to the subsolar point

through the center of the celestial body. However, the Earth terminator could not be duplicated accurately because of the atmospheric scattering of light.

For the Apollo 10 mission, a major question arose concerning the celestial view from the command and service module (CSM) when the lunar module (LM) was in the docked configuration. The docked LM blocked a considerable portion of the view through both the left and right rendezvous windows. However, the studies were indicative that, during LOI, several lunar features could be observed through the rendezvous windows and the hatch window.

As a result of data furnished for the Apollo 8 and Apollo 10 missions, the Apollo 11 crewmembers requested charts of views that would be seen, during various periods of the mission, through the command module (CM) scanning telescope and the LM alinement optical telescope. These views were used for preflight star selection for navigation and for platform alinement. In addition to the critical maneuver-attitude data for TLI (fig. 1), LOI, TEI, and entry (fig. 2), CM and LM optics views are shown in figures 3 and 4. The advantage afforded by charts such as these is the opportunity of the crewmen for preflight familiarization with the celestial sphere without being in the confines of a cockpit simulator. Therefore, installation of CM and LM optics geometry to accommodate alinement functions became part of the program capability.

Perhaps the most important application of this program was the production of detailed preflight views for the crucial lunar descent and landing phases. Such views were in demand immediately after use of the program in lunar reference was determined to be feasible. The results of this effort were promising, not only because of the uniqueness of these descent views, but because the Apollo 11 crewmen had elected to begin the descent with the LM windows face down. In that attitude, the lunar terrain was

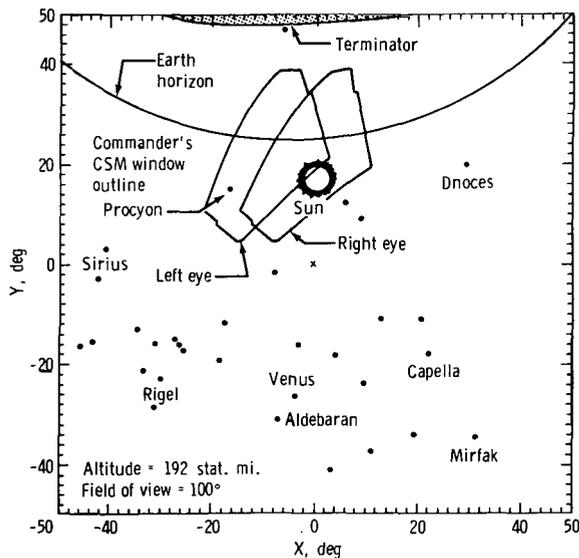


Figure 1. - View at TLI burn (Apollo 11).

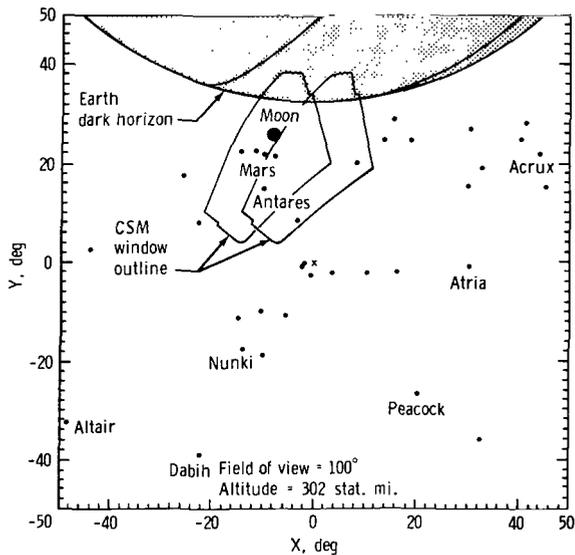
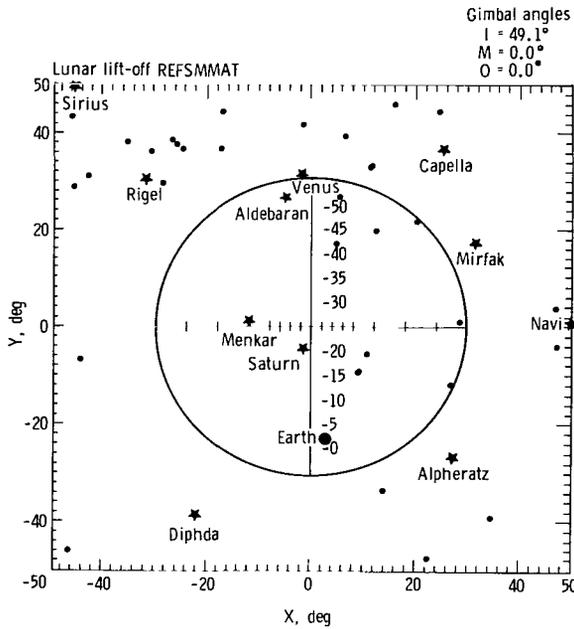
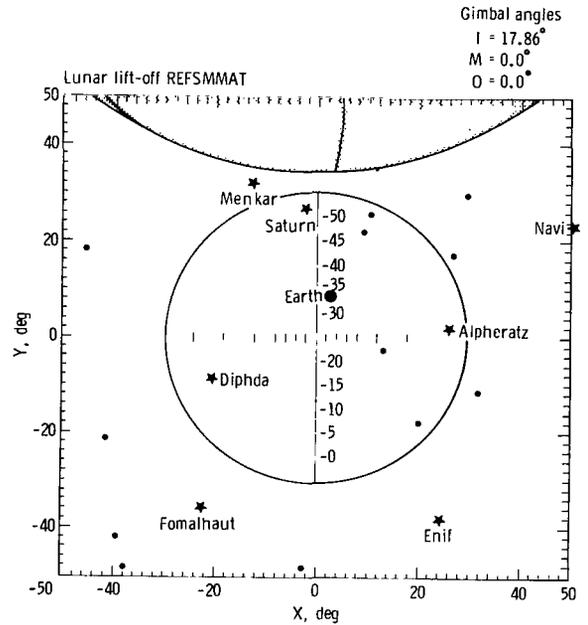


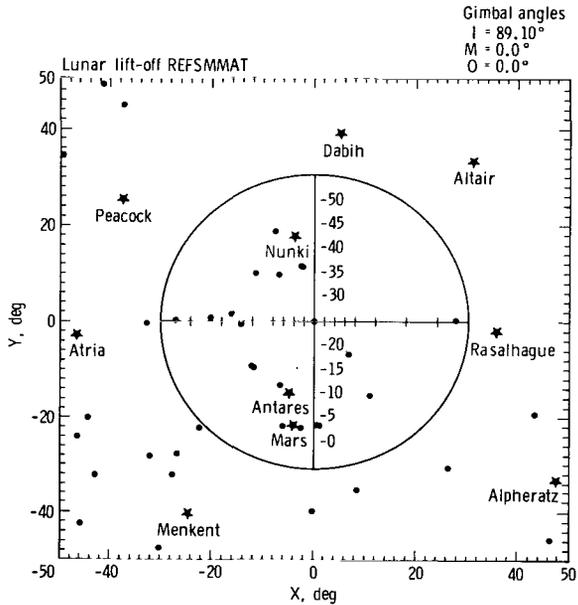
Figure 2. - View at entry phase (Apollo 11).



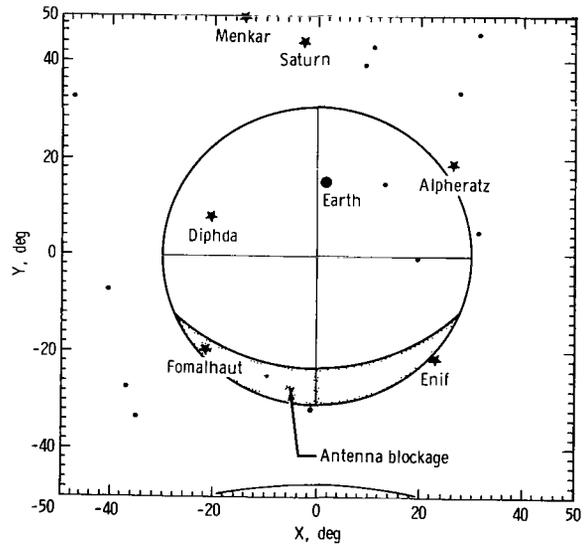
(a) At 124:40:00 hours ground elapsed time.



(b) At 125:00:00 hours ground elapsed time.



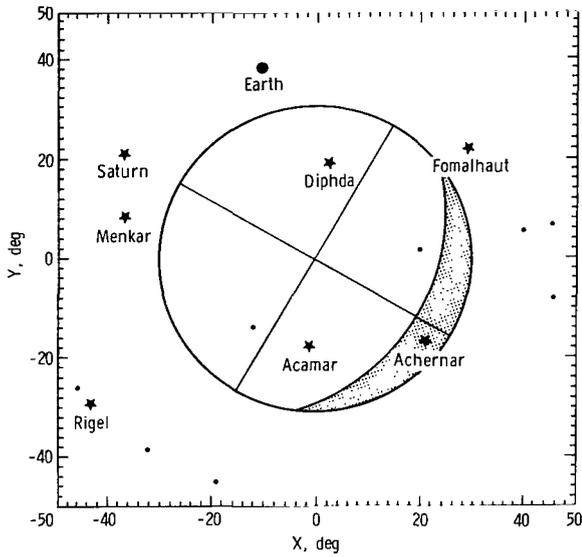
(c) At 125:15:00 hours ground elapsed time.



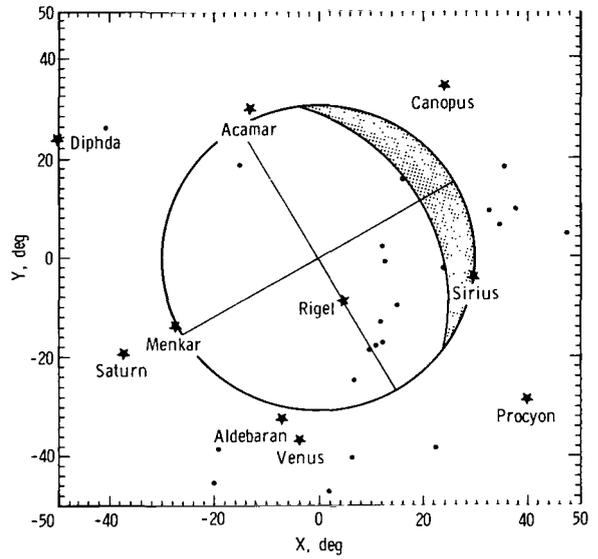
(a) Front detent position.

Figure 4. - Views through the alinement optical telescope (Apollo 11).

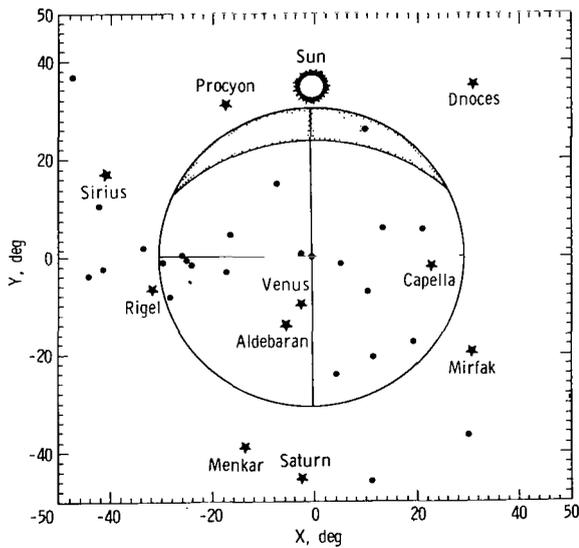
Figure 3. - Views through the scanning telescope (Apollo 11).



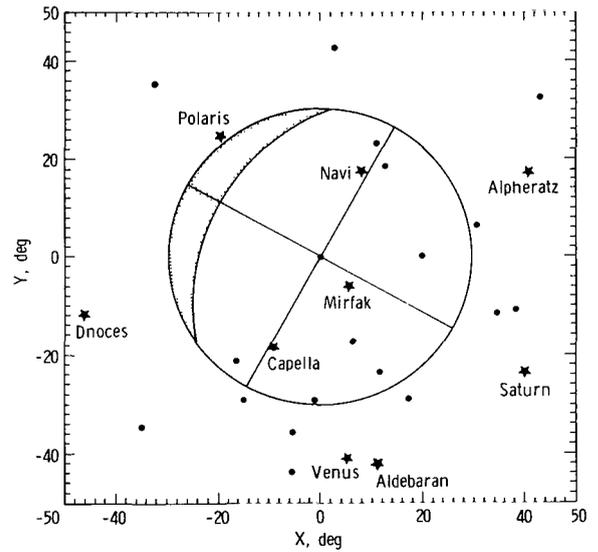
(b) Left front detent position.



(c) Left rear detent position.

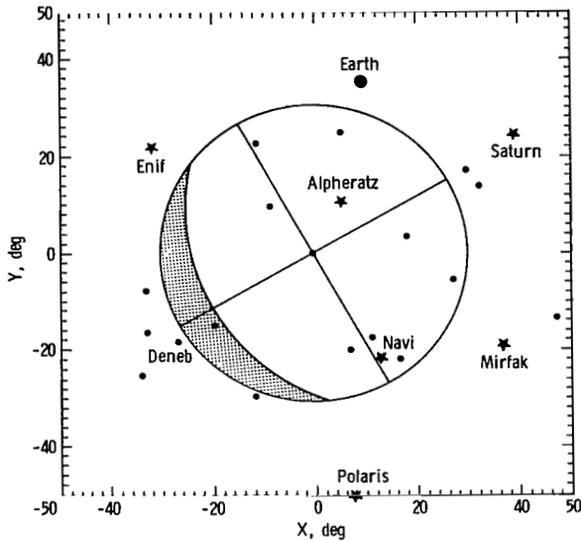


(d) Rear detent position.



(e) Right rear detent position.

Figure 4. - Continued.

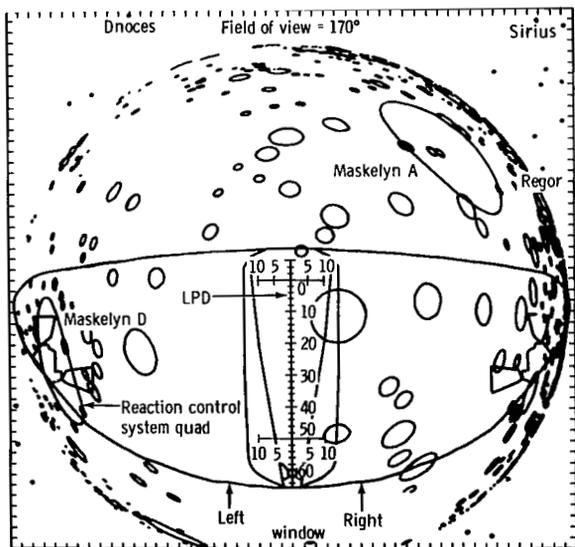


(f) Right front detent position.

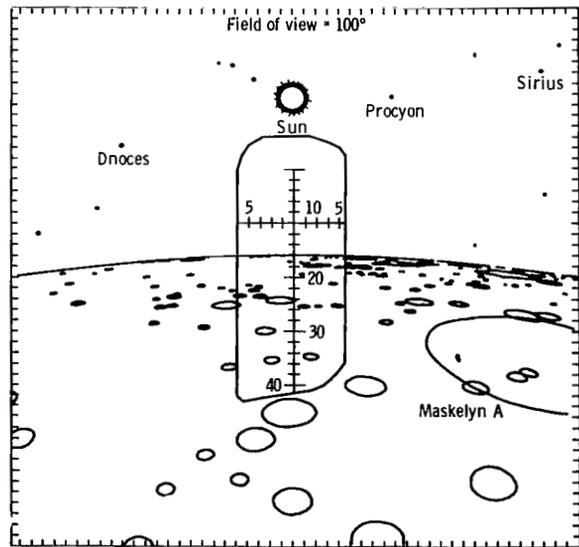
Figure 4. - Concluded.

visible, and the view of the terrain could be used to evaluate ignition-time errors and burn progress. Subsequently, the LM was yawed in the direction of the Earth to a forward-facing direction for final descent and landing. Photographs of the lunar surface near Apollo landing site 2 were used to produce two-dimensional crater models that were installed in the program. The engineering drawings of the left, right, and overhead LM windows, with the appropriate scribe marks, were obtained. From these drawings, the window outlines, as well as the lunar landing-point designator (LPD) and overhead docking scribe, were incorporated into the view program. These windows and the views through them during part of the Apollo 11 descent are shown in figure 5. Because the field of view through the two front windows is so large (170°), the view takes on a "fisheye" effect. The lunar horizon and the surface can be seen through the docking window. As can be seen in figure 5,

a particular crater passing across the window markings at a specific time provides an excellent means of preflight familiarization. Similar views have been produced for the lunar ascent phase, particularly to investigate a manually controlled attitude scheme that is based on observed features rather than on a computer-determined attitude sequence.



(a) Front windows.

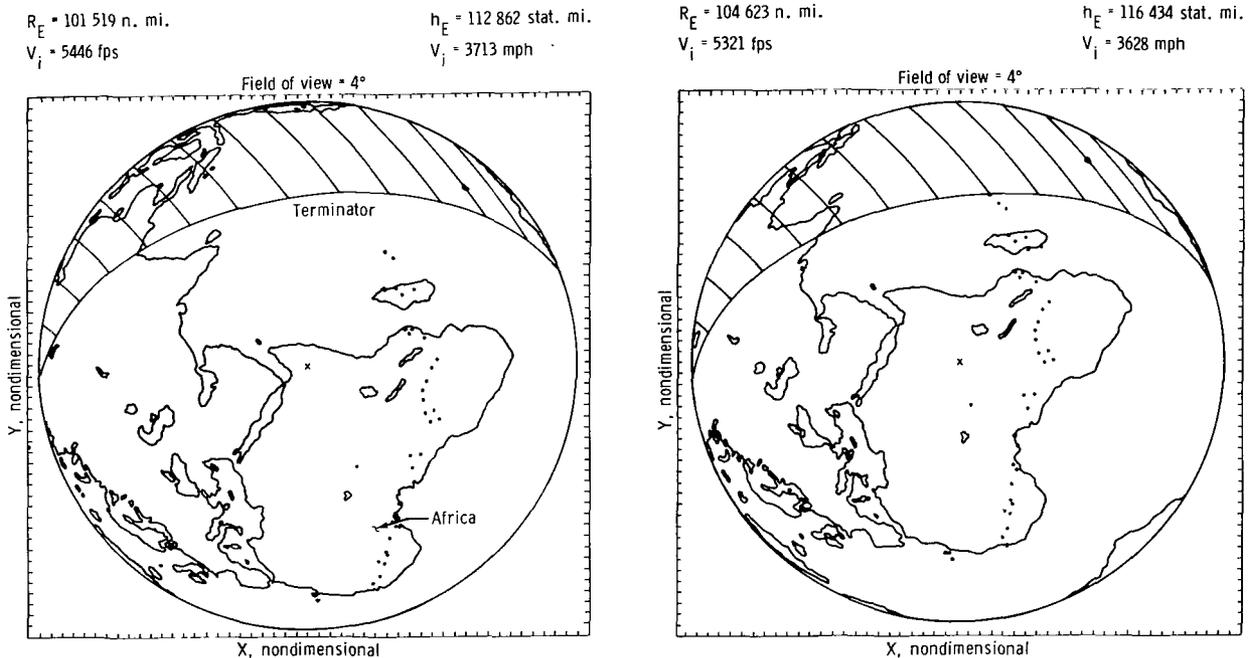


(b) Docking window.

Figure 5. - Views during the descent phase (Apollo 11).

Typical views of the Earth and Moon during translunar coast are shown in figures 6 and 7 (R_E = altitude above the Earth, nautical miles; V_i = inertial velocity, fps; h_E = altitude above the Earth, statute miles; and h_M = altitude above the Moon, statute miles). This program application has been used in preflight and postflight photographic planning and evaluation. Also, these views were useful for crewmember orientation during television transmissions from space.

Another important use was made of the program capabilities to aid in determining if sufficient landmarks were visible for candidate landing sites to allow the crewmen to orient themselves and land at a precise lunar location within 4 minutes. Because the lunar landing is performed in a particular attitude time line, the lunar surface is not visible until only 4 minutes of fuel remain. Therefore, the key issue was to determine how various landmarks appear in the LM window field of view during the last 4 minutes.



(a) At 23 hours ground elapsed time.

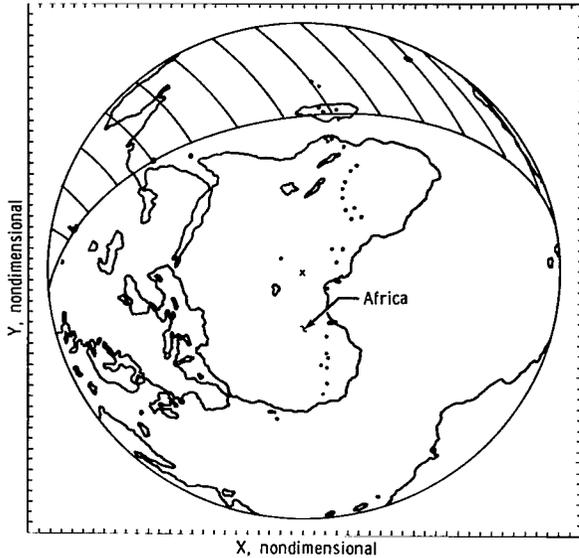
(b) At 24 hours ground elapsed time.

Figure 6. - Earth views during translunar coast (Apollo 11).

$R_E = 107\ 659$ n. mi.
 $V_i = 5203$ fps

$h_E = 119\ 928$ stat. mi.
 $V_i = 3547$ mph

Field of view = 4°

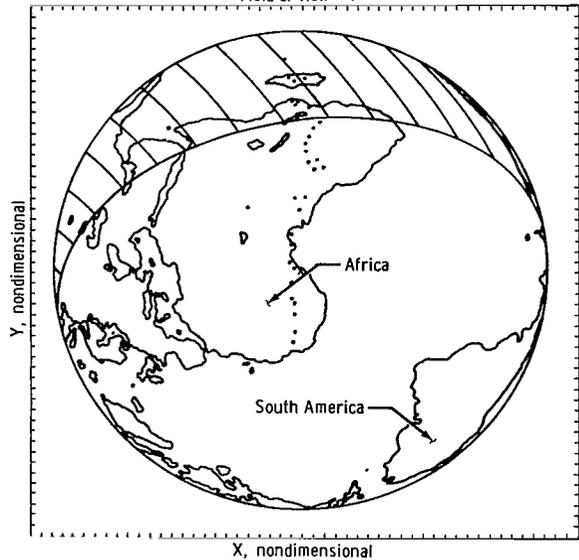


(c) At 25 hours ground elapsed time.

$R_E = 110\ 629$ n. mi.
 $V_i = 5091$ fps

$h_E = 123\ 345$ stat. mi.
 $V_i = 3471$ mph

Field of view = 4°

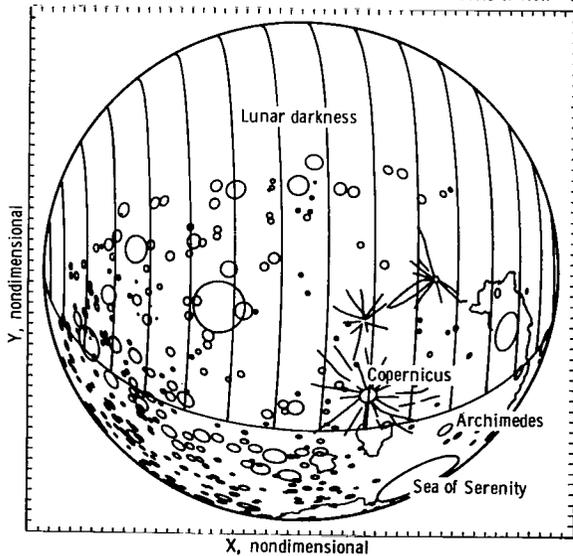


(d) At 26 hours ground elapsed time.

Figure 6. - Concluded.

Spacecraft relative to Moon
 $h_M = 20\ 876$ stat. mi.
 $V_i = 3794$ fps = 2587 mph

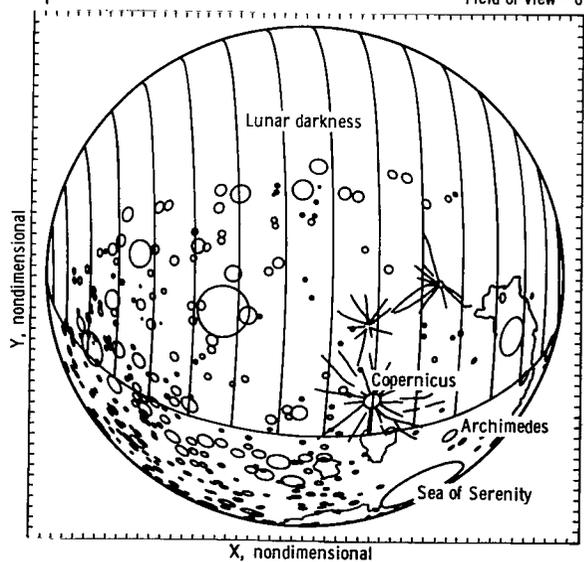
Field of view = 6°



(a) At 70 hours ground elapsed time.

Spacecraft relative to Moon
 $h_M = 15\ 593$ stat. mi.
 $V_i = 3927$ fps = 2677 mph

Field of view = 6°



(b) At 72 hours ground elapsed time.

Figure 7. - Moon views during translunar coast (Apollo 11).

To give a better resolution of the view through the left front window of the LM and to prevent the fisheye effect, the field of view was decreased arbitrarily. A typical view of a candidate site (Rima Prinz) is shown in figure 8. Only the left front window is shown because it had the LPD, with which the horizon movement is measured accurately. At the particular time shown, the lunar horizon is on the 58° reading of the LPD. Several surface features, including rilles and craters, are visible.

In the application of the program to the Apollo 13 contingency, not only were window-view descriptions relayed to the crewmen for the abort burn, but the views of the Earth were used as the sole attitude-reference source for a midcourse correction. Because normally the burn attitude is established by the use of an elaborate guidance and navigation system (unavailable because of power limitations), the use of the Earth horizon and terminator was significantly different from normal operations. A preflight view of an Apollo 13 abort maneuver (typical of those published for contingency planning to demonstrate the feasibility of such nonnominal operations) is shown in figure 9. Fortunately, the program had been developed and confidence had been established so that the program could be used during the Apollo 13 mission at the time when it was needed.

In addition to the applications mentioned, many other uses have been made of this program. Data generated for the Apollo missions have been used by the cockpit simulator personnel in checking or augmenting the flight-crew simulators. Because the simulators did not have some of the celestial bodies (planets, Sun, and, in some cases, the Earth) displayed, the view program was a valuable addition in this area. Also, a considerable portion of the preflight views prepared for each flight has been incorporated into the Apollo flight-plan documents. These views and others are of considerable help to the ground-control personnel in visualizing what the crewmen are seeing, or could see, either through the windows or through the optical instruments.

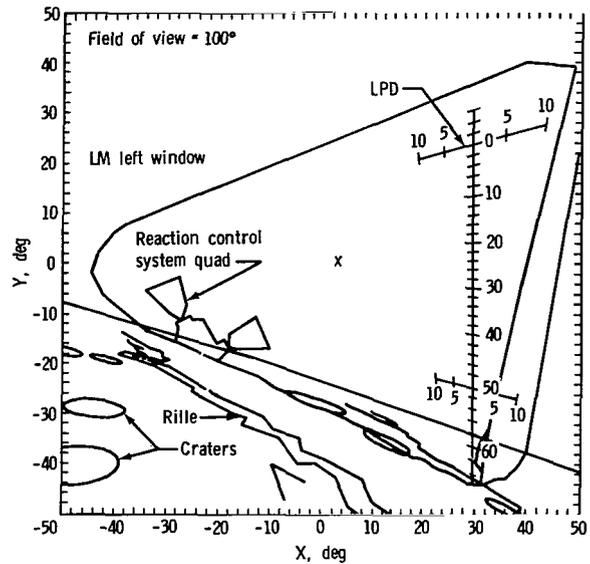


Figure 8. - View of Rima Prinz (candidate site).

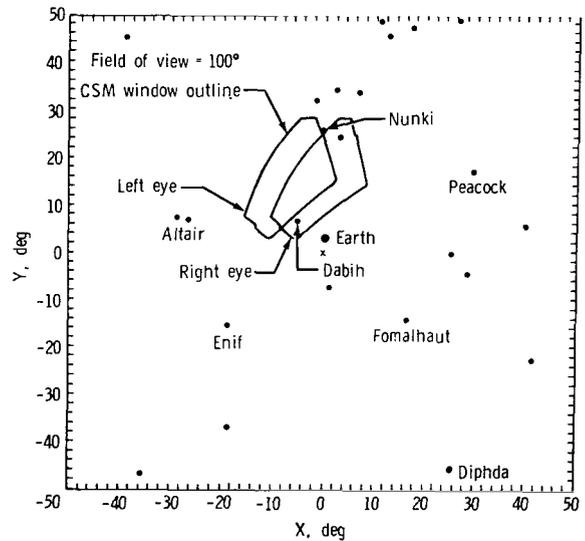


Figure 9. - Preflight view of abort at LOI plus 2 hours on the Apollo 13 mission (CSM burn).

CONCLUDING REMARKS

Although there were no requirements for spacecraft-window views of the celestial sphere during a lunar mission before the Apollo 8 flight, the recognition and development of such a computerized capability have proven to be valuable in the support of all subsequent Apollo missions. Specific mission requirements that were developed and fulfilled by the use of this computer program and a preflight report include the following.

1. Crewmember and ground-control-personnel familiarization
2. Backup attitude checks for all major thrust maneuvers
3. Preflight star selection for navigation and for platform alinement
4. Confirmation of trajectory progress during lunar descent and ascent through observed crater movement across the landing-point designator
5. Landmark identification

Although the program capabilities were developed and applied primarily for Apollo-related tasks, the capabilities are not limited to lunar missions. New requirements and applications presently are being formulated for future NASA programs. Some of these objectives will be achieved by use of the current computer program; other objectives will necessitate additional development. In either case, based on Apollo experience, this effort will continue to be valuable for planning and for actual space flights.

In any future endeavor involving man in space in which success and safety depend on man's understanding of his relationship to his surroundings, a computerized program of the type described in this report should prove valuable both as an analytical method and as a means of augmenting the training of both monitoring personnel and crewmen.

Manned Spacecraft Center
National Aeronautics and Space Administration
Houston, Texas, January 29, 1972
924-22-20-11-72

APPENDIX

LUNAR-MISSION VIEW-PROGRAM CAPABILITIES

Many new capabilities were added to the view program to support the initial Apollo lunar-landing mission as well as subsequent missions. The major capabilities of the view program are as follows.

1. As many as four vehicle trajectories can be integrated simultaneously. This capability is useful during rendezvous or after separation of the LM and the CSM or the CSM/LM and S-IVB vehicles. By integrating two trajectories and by using the graphic-display capability, a determination can be made whether or not the secondary vehicle is visible through a window of the optical system of the primary vehicle.
2. Command module and LM windows and optics outlines can be simulated. The size, look angles, and exact body-coordinate location of the windows are obtained from detailed engineering drawings of the spacecraft. The CM- and LM-window outlines are for the astronaut's design eye position. However, if the astronaut were to move from the design eye position, the outlines would change. Objects in a specified field of view, but not necessarily within the window outlines, are shown. This larger field of view is shown so that the observer can identify a star pattern, although part of the pattern is not visible through the window at the time the view is seen.
3. The user has the option of using two star catalogs. The one more often used consists of the 391 stars used by the Apollo crewmen for navigational sightings. The first 37 stars are the prime Apollo navigational stars and are identified by name on the microfilm. The remaining stars are represented by asterisks. The other catalog contains 1078 star listings, ranging in visual magnitude to +4.5. None of these stars is identified by name, but all appear as dots on the microfilm.
4. A true perspective of the lunar terrain during the descent maneuver is provided. As the descent is simulated, circular craters appear as ellipses from certain spacecraft attitudes.
5. Major topographical features of the Earth and the Moon are indicated.
6. The vehicle outlines of the CSM, LM, and the S-IVB can be drawn. The apparent size of the vehicles will be shown when viewed from a different vehicle.
7. Hidden-line models of the LM and the S-IVB can be produced; that is, given a certain spacecraft attitude, only the portion of the spacecraft visible to the observer will be shown.
8. A planetary ephemeris, which gives the position of the Sun and the Moon with respect to the Earth, is produced.

To use any or all of the capabilities listed, the vehicle position, velocity, and attitude and Greenwich mean time must be known. These data are obtained readily from the operational trajectory document, which is printed and available several months before each Apollo mission.

The coordinate systems that are available to the user are the Earth-fixed system, the Earth-centered inertial system, the selenographic system, and the body-axis system. The user has the option of using an inertially fixed platform or a local-vertical platform.

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