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# LANDMARK ORBITAL NAVIGATION PLAN FOR APOLLO 7

By Richard E. Eckelkamp,
Mathematical Physics Branch

(This revision supersedes MSC Internal Note No. 67-FM-163 dated November 1, 1967)

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PROJECT APOLLO

# LANDMARK ORBITAL NAVIGATION PLAN FOR APOLLO 7

By Richard E. Eckelkamp
Mathematical Physics Branch

July 17, 1968

MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

Approved: James C. McPherson, Chief
Mathematical Physics Branch

Approved: John P. Mayer, Chief
Mission Planning and Analysis Division

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# LANDMARK ORBITAL NAVIGATION PLAN FOR APOLLO 7

By Richard E. Eckelkamp

## SUMMARY

This report presents the nominal navigation plan for orbital navigation for Apollo 7. Included are the landmark sighting schedule, the times for vector and schedule uplinks, and the erasable weighting structure load.

## INTRODUCTION

One of the test objectives of the Apollo 7 mission (Mission C, or AS-205/CSM-101) is to exercise the procedures and programs of a new space-navigational method, landmark sighting, and to evaluate its potential. This method is capable of determining both the coordinates of the landing site and the orbit of the CSM during the lunar missions.

Basically, telescope or sextant sightings on landmarks are processed through a statistical filter in order to correct the command module computer's (CMC's) state vector for the command and service modules (CSM) or a landmark, or both. As currently planned, during the first lunar landing mission this orbital navigation method will be used for landing site determination in the landmark or landing site mode, i.e., the updating matrix will be a 3 × 3 and will update the coordinates of the landmarks only. This procedure determines the landing site position relative to the CSM-LM orbit and/or transmits the mark data by telemetry to the ground processor without affecting the vehicle position and velocity portion of the state vector. Two days of orbital navigation are planned for Apollo 7. On day 3, the 3 × 3 mode will be exercised; on day 6, the 9 × 9 mode. This order is preferred because

1. The astronant will be aided by the auto-optics being more accurate for 3 × 3 navigation since updates are provided by MSFN.

2. More unknown landmarks must be used at the beginning of sighting passes on day 3, a condition which is detrimental to 9 × 9 navigation and indifferent for 3 × 3.

3. 3 × 3 is the planned method for lunar mission use and should be given preference in the sequencing of tests in the event that fuel constraints or the premature termination of the mission prevent the day 6 exercise.

## SELECTION OF A NAVIGATION PLAN

Since the primary purpose of landmark sightings during Apollo 7 is to provide data for postflight evaluation of the method as a navigational tool, it is necessary that the onboard state vector and other pertinent data be downlinked. This requirement plus the requirement for accurate RTCC state vectors for postflight analysis indicate the need for maximum MSFN coverage. Without this coverage no comparison would exist for the command module computer (CMC) vectors. Secondly, use of the recorder presents data limitations due to the speed of readout over a station.

Accordingly, the majority of sightings must be made during the passes over the United States, Mexico, and Central America. Only those orbits during which the crew timeline and ground coverage were optimal were investigated. Maneuvers and some other test objectives also require optimal coverage. With these considerations orbital navigation will occur on days 3 and 6 (ref. 1). It should be noted that, if during real-time mission planning, orbital navigation should be moved to another day, its exercise still demands optimal MSFN passes for success.

### Selection of a Sighting Schedule

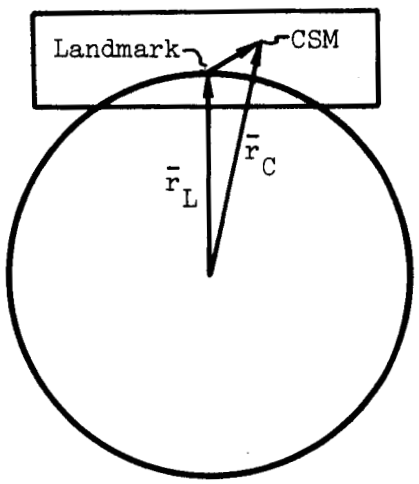
To determine the availability of landmarks during the optimal passes, an ephemeris of the CSM was first generated from the Apollo 7 operational trajectory (ref. 2). The initial vectors (in the nearest Besselian year coordinate system) for the ephemeris were

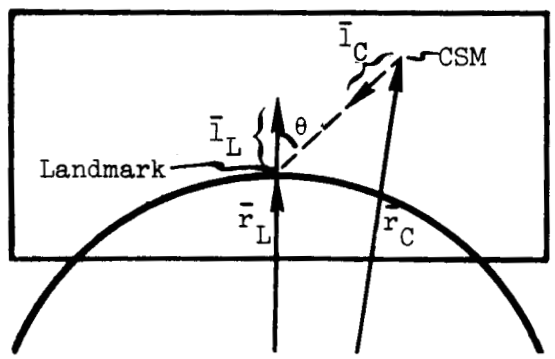
| Day 6 | | Day 3 | |
|---|---|---|---|
| X, ft . . | 21543591. | X, ft . . | 21657322. |
| Y, ft . . | -2615935. | Y, ft . . | 2246621. |
| Z, ft . . | 1001103. | Z, ft . . | -1249560. |
| $\dot{X}$, fps . | 1811. | $\dot{X}$, fps . | -1598. |
| $\dot{Y}$, fps . | 21716. | $\dot{Y}$, fps . | 21602. |

| Day 6 | | Day 3 | |
|---|---|---|---|
| $\dot{Z}$, fps . | 13110. | $\dot{Z}$, fps . | 13246. |
| t . . . . | 8557.9481 min g.e.t. | t . . . . | 4374.0918 min g.e.t. |

The vehicle area was taken to 129.4 $ft^2$, and the drag parameter, 0.137798 $ft^2$/slug. At designated times a check was made to see if any landmarks were visible. Contraints on the check are discussed in the following sections.

Occultation Constraint.- A necessary property of a usable landmark (see illustration below) is that it not be occulted by the horizon.




Let $\bar{r}_L$ = the vector from the center of the earth to the top of the landmark.

$\bar{l}_L$ = a unit vector pointing along $\bar{r}_L$

$\bar{r}_C$ = the vector from the center of the earth to the CSM

$\bar{l}_C$ = a unit vector pointing along $(\bar{r}_L - \bar{r}_C)$

Now, using the definition of the dot product,

$$\cos\theta = -\bar{1}_C \cdot \bar{1}_L$$

$$\theta = \cos^{-1}\left[-\bar{1}_C \cdot \bar{1}_C\right]$$

From results of the Gemini program, $\theta$ must be less than 55°, if a landmark is to be perceived. Some disagreement exists, however, on the value of $\theta$. Since its value is critical for fuel calculations during landing site observations in lunar orbit, $\theta$ should be tested during an earth orbit mission.

Lighting Constraint.- Most critical among the constraints to be tested on Apollo 7 is lighting. The sun elevation angle at a given landmark directly affects whether it can be distinguished from the surrounding features. Despite the presence of an atmosphere on earth, much meaningful information can be derived from Apollo 7 which will be useful for lunar sighting. Albedo effects on the moon are secondary to those of sun elevation angle. The value for the minimum elevation angle affects the sequencing of landmark and landing-site sightings and possibly introduces constraints on the lunar launch window.

Weather Constraint.- Cloud coverage will probably occult many otherwise acceptable landmarks. During real time, information on cloud coverage will be available through the MSC Weather Bureau and will be based on local forecast and weather reports, satellite data, and airplane pilot reports. For selection of the premission nominal plan, results of cloud coverage probability studies were used when available. Alternate landmarks were provided when available for areas with highly probable cloud coverage.

The Sighting Schedule.- Table I indicates the view periods for the available landmarks. Landmark numbers (ref. 3) are in the left-hand column. Time of acquisition, accurate to the nearest 7.5 seconds is given in the second column. At succeeding increments of 7.5 seconds, the landmarks were checked again. If visible, a number representing $\theta$ in the previous discussion apears. A pass is measured from 90°E longitude eastward.

Table II presents the nominal Apollo 7 sighting schedule. Alternate landmarks in the general area of the primary ones are given in the right-hand column. The landmarks selected were chosen because they could be easily distinguished (ref. 4). Those which might be difficult to recognize were rejected or chosen as alternates and indicated with a footnote. Unknown landmarks were selected at convenient times when

the CSM groundtrack was void of known landmarks and was over land.

## Update and Alignment Times

The times for ground uplink for the state vector and landmark schedule (which will be discussed below) are contained in table III. Realignment of the IMU must occur prior to each sighting pass. This procedure prevents the insertion of large IMU errors into the observation data, an occurrance which would seriously affect the usefulness of the data for postflight evaluation. For both days, the state vector need be uplinked only before the first pass. The vector uplink should be voice checked through use of CMC program P21 or DSKY display of the erasable cells containing the vector. The latter procedure allows the astronaut to record the vector for possible use if a MSFN vector is needed for some contingency. For 3 × 3 navigation, it is desirable, but not mandatory to uplink the state vector before the second and third passes if the uplink does not interfere with the IMU realignment. If the uplink interferes, it should be omitted.

## Weighting Structure Load

Table IV contains the values for the initial W matrix to be used for 3 × 3 and 9 × 9 navigation. The values for 3 × 3 will be loaded premission. Sometime after the 3 × 3 tracking and before the 9 × 9 tracking, the values for 9 × 9 must be punched into the erasable memory by the astronaut and verified by the flight controller. (A document describing the selection of the weighting structure load will be published.)

## Operational Constraints

When processing landmark data (after taking marks) while over an area without continuous MSFN coverage, the recorder must be turned on. Since the low-bit mode is advantageous for fast readout, it should be used. One disadvantage of the low-bit mode, however, is that the downlink list is scanned only every 10 seconds. Therefore, when utilizing the recorder while processing marks, it is essential to allow the delta r - delta v display to remain on the DSKY for a least a fraction over 10 seconds. This is the only way that the data for the particular mark can be recorded for future studies. For high-bit rate or for processing over tracking stations, the delta r - delta v display must remain on the DSKY for a fraction over 2 seconds.

To aid in acquisition of landmarks, the use of auto-optics positioning is available. Updating of the CSM vector each pass during 3 × 3 navigation will aid auto-optics accuracy. During 9 × 9 navigation auto-optics for the first landmark on the second pass may be inaccurate due to poor propagation. Later in the mission, e.g., on day 8, 9, or 10, some time should be devoted to the use of auto-optics with various perturbations on the state vector.

### Data Requirements

Each landmark is to be marked five times as the CSM passes over it. A minimum of four distinct landmarks with five marks apiece are required for postflight analysis. If the scheduled known landmarks are not visible due to cloud coverage or inability to acquire, other known landmarks should be used. (Program P21 provides the CSM groundtrack). If no known landmarks are available, unknowns should be marked. Practice sessions before the actual planned three consecutive passes should be taken.

## CONCLUDING REMARKS

The sighting schedule presented above was labeled the nominal Apollo 7 sighting schedule. During the mission any changes from the groundtrack presented in the operational trajectory affect which landmarks may be visible to the astronaut. For example, with a $\theta$ of 55° (discussed above) he may see only 2 1/2° to 3° on either side of his groundtrack, depending on his altitude. Secondly, a number of possible landmarks will be covered by clouds. Thirdly, the schedule needs to be planned so that visibility constraints are tested. (The latter can possibly be done in practice sessions.) For these reasons, the actual landmark tracking schedule will be uplinked real-time to the astronaut.

TABLE I.- AVAILABLE LANDMARKS

| Landmark no | Time of acquisition, t, min g.e.t. | θ, deg | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | at t | at t plus 7.5 sec | at t plus 15 sec | at t plus 22.5 sec | at t plus 30 sec | at t plus 37.5 sec | at t plus 45 sec | at t plus 52.5 sec |
| (a) Day 3 | | | | | | | | | |
| First sighting pass | | | | | | | | | |
| 4 | 4383.87 | 54 | 54 | 54 | 54 | | | | |
| 6 | 4393.50 | 54 | | | | | | | |
| 8 | 4393.50 | 52 | 51 | 51 | 52 | 54 | | | |
| 10 | 4393.75 | 55 | 51 | 47 | 44 | 42 | 42 | 45 | 48 |
| | 4394.75 | 52 | | | | | | | |
| 18 | 4395.12 | 53 | 47 | 39 | 31 | 21 | 14 | 18 | 27 |
| | 4396.12 | 36 | 44 | 51 | | | | | |
| 20 | 4398.12 | 54 | 53 | 53 | 54 | | | | |
| 37 | 4399.87 | 51 | 46 | 40 | 34 | 31 | 32 | 36 | 42 |
| | 4400.87 | 48 | 48 | 53 | | | | | |
| 44 | 4400.62 | 55 | 49 | 42 | 33 | 22 | 13 | 14 | 24 |
| 45 | 4400.75 | 50 | 43 | 35 | 24 | 14 | 12 | 21 | 32 |
| 43 | 4400.87 | 55 | 50 | 46 | 42 | 40 | 41 | 43 | 47 |
| 46 | 4401.00 | 53 | 49 | 44 | 41 | 40 | 42 | 45 | 49 |
| 47 | 4401.37 | 53 | 52 | 52 | 52 | 54 | | | |
| 44 | 4401.62 | 34 | 43 | 50 | | | | | |
| 45 | 4401.75 | 41 | 48 | 54 | | | | | |
| 43 | 4401.87 | 52 | | | | | | | |
| 46 | 4402.00 | 54 | | | | | | | |
| 224 | 4427.00 | 51 | 46 | 40 | 35 | 30 | 28 | 30 | 34 |
| | 4428.00 | 40 | 45 | 50 | 55 | | | | |
| Second sighting pass | | | | | | | | | |
| 5 | 4487.00 | 55 | 51 | 47 | 43 | 41 | 42 | 44 | 48 |
| | 4488.00 | 52 | | | | | | | |
| 6 | 4487.25 | 52 | 47 | 40 | 33 | 27 | 25 | 29 | 36 |
| | 4488.25 | 43 | 49 | 55 | | | | | |
| 7 | 4488.37 | 55 | 54 | 55 | | | | | |
| 18 | 4489.62 | 53 | 47 | 41 | 33 | 26 | 23 | 27 | 34 |

TABLE I.- AVAILABLE LANDMARKS - Continued

| Landmark no | Time of acquisition, t, min g.e.t. | θ, deg | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | at t | at t plus 7.5 sec | at t plus 15 sec | at t plus 22.5 sec | at t plus 30 sec | at t plus 37.5 sec | at t plus 45 sec | at t plus 52.5 sec |
| (a) Day 3 - Continued | | | | | | | | | |
| Second sighting pass - Continued | | | | | | | | | |
| | 4490.62 | 41 | 48 | 54 | | | | | |
| 21 | 4492.00 | 54 | 50 | 47 | 45 | 44 | 46 | 49 | 52 |
| 20 | 4492.25 | 53 | 47 | 39 | 29 | 17 | 6 | 12 | 25 |
| | 4493.25 | 35 | 44 | 40 | 51 | | | | |
| 38 | 4495.25 | 53 | 49 | 45 | 43 | 43 | 45 | 48 | 52 |
| 39 | 4495.25 | 52 | 48 | 45 | 43 | 43 | 45 | 49 | 53 |
| 40 | 4495.50 | 55 | 49 | 43 | 35 | 27 | 23 | 25 | 32 |
| 48 | 4495.75 | 55 | 49 | 43 | 35 | 27 | 22 | 24 | 31 |
| 49 | 4496.25 | 52 | 50 | 48 | 48 | 50 | 52 | | |
| 40 | 4496.50 | 39 | 46 | 52 | | | | | |
| 52 | 4496.50 | 51 | 45 | 39 | 33 | 30 | 30 | 35 | 41 |
| 48 | 4496.75 | 39 | 46 | 52 | | | | | |
| 50 | 4496.75 | 53 | 49 | 46 | 44 | 44 | 46 | 49 | 53 |
| 51 | 4496.75 | 54 | 49 | 44 | 39 | 35 | 35 | 38 | 43 |
| 53 | 4497.00 | 55 | 49 | 43 | 37 | 32 | 29 | 32 | 37 |
| 54 | 4497.25 | 51 | 44 | 35 | 24 | 11 | 3 | 17 | 29 |
| 55 | 4497.37 | 54 | 48 | 41 | 32 | 21 | 12 | 15 | 25 |
| 52 | 4497.50 | 48 | 53 | | | | | | |
| 56 | 4497.62 | 53 | 47 | 39 | 29 | 18 | 8 | 14 | 26 |
| 51 | 4497.75 | 48 | 53 | | | | | | |
| 57 | 4497.75 | 51 | 46 | 39 | 33 | 29 | 30 | 35 | 41 |
| 53 | 4498.00 | 43 | 49 | 55 | | | | | |
| 58 | 4498.12 | 55 | 49 | 42 | 33 | 22 | 10 | 9 | 21 |
| 65 | 4498.12 | 52 | 48 | 45 | 42 | 44 | 48 | 52 | |
| 54 | 4498.25 | 39 | 47 | 53 | | | | | |
| 55 | 4498.37 | 35 | 43 | 50 | | | | | |
| 56 | 4498.62 | 36 | 44 | 51 | | | | | |
| 57 | 4498.75 | 47 | 53 | | | | | | |
| 66 | 4498.75 | 52 | 46 | 39 | 32 | 25 | 24 | 28 | 35 |
| 58 | 4499.12 | 32 | 41 | 49 | 54 | | | | |

TABLE I.- AVAILABLE LANDMARKS - Continued

| Landmark no | Time of acquisition, t, min g.e.t. | θ, deg | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | at t | at t plus 7.5 sec | at t plus 15 sec | at t plus 22.5 sec | at t plus 30 sec | at t plus 37.5 sec | at t plus 45 sec | at t plus 52.5 sec |
| (a) Day 3 - Continued | | | | | | | | | |
| Second sighting pass - Concluded | | | | | | | | | |
| 68 | 4499.37 | 54 | 49 | 42 | 35 | 28 | 25 | 27 | 33 |
| 69 | 4499.50 | 53 | 48 | 43 | 37 | 33 | 33 | 36 | 41 |
| 66 | 4499.87 | 43 | 49 | 55 | | | | | |
| 68 | 4500.37 | 40 | 47 | 53 | | | | | |
| 71 | 4500.37 | 50 | 44 | 36 | 28 | 22 | 22 | 28 | 36 |
| 69 | 4500.50 | 47 | 52 | | | | | | |
| 72 | 4500.50 | 55 | 49 | 41 | 32 | 21 | 8 | 8 | 21 |
| 73 | 4501.00 | 51 | 44 | 35 | 25 | 12 | 2 | 15 | 28 |
| 74 | 4501.25 | 54 | 49 | 43 | 37 | 32 | 30 | 33 | |
| 71 | 4501.37 | 44 | 50 | | | | | | |
| 72 | 4501.50 | 32 | 41 | 48 | 54 | | | | |
| 73 | 4502.00 | 38 | | | | | | | |
| Third sighting pass | | | | | | | | | |
| 8 | 4582.37 | 53 | 47 | 40 | 31 | 22 | 17 | 22 | 30 |
| 9 | 4582.87 | 53 | 48 | 42 | 37 | 35 | 35 | 39 | 44 |
| 10 | 4582.87 | 53 | 48 | 42 | 35 | 29 | 27 | 31 | 37 |
| 11 | 4583.25 | 55 | 49 | 42 | 33 | 23 | 14 | 15 | 25 |
| 8 | 4583.37 | 39 | 47 | 53 | | | | | |
| 9 | 4583.87 | 49 | 54 | | | | | | |
| 10 | 4583.87 | 44 | 50 | | | | | | |
| 11 | 4584.25 | 35 | 43 | 50 | | | | | |
| 15 | 4585.25 | 54 | 54 | | | | | | |
| 16 | 4585.25 | 55 | 55 | | | | | | |
| 22 | 4586.75 | 50 | 43 | 35 | 25 | 16 | 15 | 23 | 33 |
| | 4587.75 | 42 | 49 | 55 | | | | | |
| 23 | 4588.50 | 53 | 48 | 42 | 38 | 35 | 36 | 39 | 44 |
| 24 | 4588.75 | 53 | 48 | 44 | 41 | 40 | 41 | 45 | 49 |
| 23 | 4589.50 | 49 | 54 | | | | | | |

TABLE I.- AVAILABLE LANDMARKS - Continued

| Landmark no | Time of acquisition t, min g.e.t. | θ, deg | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | at t | at t plus 7.5 sec | at t plus 15 sec | at t plus 22.5 sec | at t plus 30 sec | at t plus 37.5 sec | at t plus 45 sec | at t plus 52.5 sec |
| (a) Day 3 - Concluded | | | | | | | | | |
| Third sighting pass - Concluded | | | | | | | | | |
| 25 | 4589.50 | 54 | 52 | 52 | 52 | 54 | | | |
| 24 | 4589.75 | 53 | | | | | | | |
| 26 | 4589.75 | 54 | 52 | 51 | 51 | 52 | 54 | | |
| 27 | 4591.00 | 51 | 47 | 42 | 40 | 40 | 41 | 45 | 49 |
| | 4592.00 | 54 | | | | | | | |
| 126 | 4593.00 | 54 | 48 | 41 | 34 | 26 | 22 | 24 | 30 |
| 125 | 4593.12 | 50 | 44 | 38 | 32 | 29 | 30 | 34 | 41 |
| 127 | 4593.87 | 54 | 53 | 52 | 52 | 54 | | | |
| 126 | 4594.00 | 38 | 45 | 51 | | | | | |
| 128 | 4594.00 | 51 | 46 | 41 | 38 | 36 | 37 | 41 | 46 |
| 125 | 4594.12 | 47 | 52 | | | | | | |
| 128 | 4595.00 | 51 | | | | | | | |
| 70 | 4595.25 | 54 | 52 | 50 | 49 | 50 | 51 | 54 | |
| 130 | 4595.25 | 54 | 52 | 50 | 49 | 50 | 52 | 54 | |
| 145 | 4604.25 | 55 | 50 | 43 | 36 | 27 | 17 | 10 | 14 |
| 144 | 4604.87 | 55 | 53 | 53 | 52 | 54 | | | |
| 145 | 4605.25 | 23 | 32 | 40 | 47 | 52 | | | |
| Fourth sighting pass | | | | | | | | | |
| 107 | 4687.87 | 55 | 50 | 46 | 41 | 38 | 36 | 38 | 41 |
| 108 | 4687.87 | 52 | 46 | 39 | 29 | 19 | 8 | 10 | 21 |
| 109 | 4688.12 | 54 | 50 | 47 | 44 | 42 | 43 | 45 | 48 |
| 106 | 4688.37 | 54 | 53 | 53 | 54 | | | | |
| 107 | 4688.87 | 46 | 50 | 55 | | | | | |
| 108 | 4688.87 | 32 | 40 | 47 | 53 | | | | |
| 109 | 4689.12 | 52 | | | | | | | |

TABLE I.- AVAILABLE LANDMARKS - Continued

| Landmark no | Time of acquisition, t, min g.e.t. | θ, deg | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | at t | at t plus 7.5 sec | at t plus 15 sec | at t plus 22.5 sec | at t plus 30 sec | at t plus 37.5 sec | at t plus 45 sec | at t plus 52.5 sec |
| (b) Day 6 | | | | | | | | | |
| First sighting pass | | | | | | | | | |
| 008 | 8572.12 | 41 | 29 | 15 | 3 | 18 | 32 | 43 | 51 |
| 009 | 8572.00 | 52 | 48 | 44 | 43 | 44 | 48 | 53 | |
| 010 | 8572.62 | 49 | 41 | 30 | 18 | 12 | 22 | 34 | 52 |
| 011 | 8573.00 | 50 | 43 | 36 | 32 | 44 | 33 | 39 | 46 |
| 011 | 8574.00 | 52 | | | | | | | |
| 018 | 8575.50 | 53 | 53 | 54 | | | | | |
| 020 | 8576.75 | 55 | 52 | 50 | | | | | |
| 037 | 8578.75 | 53 | 47 | 42 | 39 | 41 | 46 | 52 | |
| 044 | 8579.62 | 48 | 38 | 25 | 8 | 11 | 27 | 40 | 50 |
| 045 | 8579.62 | 51 | 44 | 35 | 29 | 29 | 36 | 45 | 52 |
| 043 | 8579.75 | 54 | 49 | 42 | 38 | 38 | 42 | 48 | 54 |
| 209 | 8593.62 | 51 | 45 | 41 | 40 | 43 | 49 | 54 | |
| 212 | 8596.75 | 53 | 51 | 51 | 53 | | | | |
| 213 | 8596.75 | 50 | 46 | 43 | 42 | 45 | 50 | 54 | |
| 214 | 8596.75 | 54 | 48 | 40 | 32 | 28 | 30 | 37 | 45 |
| 214 | 8597.75 | 52 | | | | | | | |
| 222 | 8604.87 | 51 | 46 | 40 | 36 | 35 | 38 | 42 | 47 |
| 222 | 8605.87 | 52 | | | | | | | |
| 239 | 8609.37 | 52 | 49 | 47 | 45 | 46 | 48 | 51 | 54 |
| 238 | 8611.00 | 51 | 47 | 42 | 39 | 37 | 38 | 41 | 45 |
| 238 | 8612.00 | 49 | 54 | | | | | | |
| 237 | 8611.12 | 54 | 48 | 41 | 33 | 23 | 13 | 9 | 18 |
| 237 | 8612.12 | 28 | 37 | 44 | 50 | | | | |
| 236 | 8611.50 | 54 | 50 | 46 | 42 | 40 | 40 | 42 | 45 |
| 240 | 8613.50 | 51 | 45 | 38 | 29 | 19 | 7 | 5 | 17 |
| 240 | 8614.50 | 28 | 37 | 44 | 50 | 55 | | | |

TABLE I.- AVAILABLE LANDMARKS - Continued

| Landmark no | Time of acquisition t, min g.e.t. | θ, deg | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | at t | at t plus 7.5 sec | at t plus 15 sec | at t plus 22.5 sec | at t plus 30 sec | at t plus 37.5 sec | at t plus 45 sec | at t plus 52.5 sec |
| (b) Day 6 - Continued | | | | | | | | | |
| Second sighting pass | | | | | | | | | |
| 006 | 8665.62 | 55 | 50 | 47 | 45 | 46 | 50 | 54 | |
| 018 | 8667.87 | 53 | 46 | 36 | 26 | 21 | 27 | 38 | 47 |
| 018 | 8668.87 | 55 | | | | | | | |
| 020 | 8670.62 | 49 | 42 | 37 | 36 | 40 | 47 | 53 | |
| 037 | 8672.62 | 51 | 46 | 42 | 42 | 46 | 51 | | |
| 038 | 8673.25 | 54 | 46 | 36 | 24 | 17 | 25 | 37 | 47 |
| 038 | 8674.25 | 55 | | | | | | | |
| 039 | 8677.25 | 53 | 44 | 34 | 22 | 17 | 27 | 39 | 49 |
| 046 | 8673.75 | 50 | 45 | 43 | 45 | 49 | 54 | | |
| 047 | 8673.75 | 49 | 40 | 31 | 25 | 28 | 38 | 47 | 54 |
| 049 | 8674.12 | 53 | 45 | 34 | 22 | 15 | 25 | 37 | 47 |
| 048 | 8674.25 | 52 | 50 | 50 | 52 | | | | |
| 052 | 8674.75 | 54 | 50 | 48 | 48 | 51 | 55 | | |
| 050 | 8674.87 | 48 | 41 | 34 | 32 | 37 | 44 | 52 | |
| 051 | 8675.00 | 53 | 49 | 45 | 44 | 47 | 52 | | |
| 053 | 8675.37 | 55 | 52 | 51 | 52 | 55 | | | |
| 225 | 8700.50 | 52 | 46 | 38 | 29 | 19 | 9 | 11 | 21 |
| Third sighting pass | | | | | | | | | |
| 010 | 8760.50 | 49 | 40 | 31 | 25 | 28 | 38 | 47 | 54 |
| 011 | 8761.00 | 52 | 47 | 44 | 44 | 47 | 51 | | |
| 021 | 8764.12 | 53 | 52 | 52 | 54 | | | | |
| 024 | 8766.50 | 54 | 54 | 52 | 47 | 43 | 42 | 45 | 50 |
| 024 | 8767.50 | 55 | | | | | | | |
| 059 | 8768.12 | 51 | 41 | 28 | 12 | 7 | 24 | 38 | 48 |
| 060 | 8768.75 | 51 | 42 | 28 | 16 | 13 | 26 | 38 | 48 |
| 061 | 8768.75 | 51 | 42 | 30 | 15 | 8 | 23 | 37 | 47 |
| 061 | 8769.75 | 55 | | | | | | | |
| 062 | 8769.25 | 53 | 45 | 35 | 26 | 23 | 30 | 40 | 49 |
| 129 | 8771.37 | 53 | 46 | 37 | 31 | 30 | 35 | 43 | 51 |

TABLE I.- AVAILABLE LANDMARKS - Continued

| Landmark no | Time of acquisition, t, min g.e.t. | θ, deg | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | at t | at t plus 7.5 sec | at t plus 15 sec | at t plus 22.5 sec | at t plus 30 sec | at t plus 37.5 sec | at t plus 45 sec | at t plus 52.5 sec |
| (b) Day 6 - Continued | | | | | | | | | |
| Third sighting pass - Concluded | | | | | | | | | |
| 131 | 8772.37 | 50 | 44 | 37 | 34 | 36 | 42 | 49 | |
| 132 | 8772.50 | 51 | 43 | 33 | 24 | 21 | 29 | 39 | 48 |
| 132 | 8793.50 | 55 | | | | | | | |
| 134 | 8773.62 | 55 | 51 | 47 | 46 | 48 | 51 | | |
| 135 | 8774.50 | 51 | 43 | 32 | 20 | 13 | 21 | 33 | 44 |
| 136 | 8776.62 | 52 | 49 | 48 | 48 | 51 | 54 | | |
| 137 | 8778.00 | 50 | 45 | 39 | 36 | 37 | 41 | 47 | 53 |
| 138 | 8779.00 | 49 | 40 | 29 | 15 | 2 | 16 | 30 | 40 |
| 138 | 8780.00 | 48 | 55 | | | | | | |
| 139 | 8780.75 | 53 | 52 | 53 | 54 | | | | |
| 141 | 8781.62 | 54 | 51 | 50 | 50 | 52 | 54 | | |
| 142 | 8781.62 | 55 | 50 | 45 | 41 | 39 | 40 | 43 | 48 |
| 143 | 8781.75 | 50 | 43 | 34 | 24 | 17 | 19 | 28 | 37 |
| 143 | 8782.25 | 45 | 52 | | | | | | |
| 144 | 8782.12 | 54 | 53 | 53 | 54 | | | | |
| 030 | 8861.87 | 54 | 48 | 42 | 37 | 36 | 39 | 45 | 52 |
| 031 | 8862.00 | 50 | 42 | 32 | 25 | 26 | 34 | 43 | 50 |
| 028 | 8862.12 | 55 | | | | | | | |
| 029 | 8862.12 | 53 | 51 | 50 | 52 | | | | |
| 032 | 8862.25 | 50 | 41 | 29 | 18 | 17 | 27 | 38 | 48 |
| 033 | 8862.25 | 54 | 51 | 49 | 50 | 52 | 55 | | |
| 034 | 8863.25 | 50 | 42 | 30 | 16 | 7 | 20 | 33 | 44 |
| 034 | 8864.25 | 52 | 55 | | | | | | |
| 035 | 8863.37 | 53 | 46 | 38 | 31 | 30 | 34 | 41 | 49 |
| 103 | 8864.37 | 55 | 49 | 42 | 35 | 32 | 35 | 41 | 47 |
| 103 | 8865.37 | 53 | | | | | | | |
| 101 | 8864.50 | 54 | 53 | 53 | 54 | | | | |
| 102 | 8864.50 | 53 | 49 | 47 | 48 | 50 | 54 | | |
| 105 | 8864.75 | 51 | 47 | 43 | 42 | 45 | 49 | 53 | |
| 104 | 8865.62 | 55 | 54 | | | | | | |

TABLE I.- AVAILABLE LANDMARKS - Concluded

| Landmark no | Time of acquisition, t, min g.e.t. | θ, deg | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | at t | at t plus 7.5 sec | at t plus 15 sec | at t plus 22.5 sec | at t plus 30 sec | at t plus 37.5 sec | at t plus 45 sec | at t plus 52.5 sec |
| (b) Day 6 - Concluded | | | | | | | | | |
| Fourth sighting pass | | | | | | | | | |
| 146 | 8875.75 | 55 | 50 | 44 | 38 | 32 | 29 | 30 | 35 |
| 146 | 8876.75 | 41 | 47 | 52 | | | | | |
| 147 | 8875.75 | 51 | 47 | 43 | 41 | 40 | 42 | 45 | 49 |

TABLE II.- NOMINAL LANDMARK SIGHTING SCHEDULE

| Acquisition g.e.t. | | Landmark | Location | View time, sec | Alternate landmarks in area |
|---|---|---|---|---|---|
| Total min | Days:hr:min:sec | | | | |
| (a) Day 3 | | | | | |
| First sighting pass | | | | | |
| 4383.87 | 3:1:03:52.2 | 4 or unknown | Hawaii | 30.0 | |
| 4393.75 | 3:1:13:45.0 | 10 | Gulf of Calif. | 60.0 | |
| 4400.75 | 3:1:20:45.0 | 45 | N Florida | 75.0 | 44, 46 |
| 4427.00 | 3:1:47:00.0 | 224 | W Angola | 82.5 | |
| 4432.00 | 3:1:52:00.0 | Unknown if lighted | Africa | | |
| Second sighting pass | | | | | |
| 4476.50 | 3:2:36:30.0 | Unknown | Fr. Frigate Schoals | | |
| 4487.25 | 3:2:47:15.0 | 6 | San Diego, Calif. | 75.0 | 5 |
| 4492.25 | 3:2:52:15.0 | 20 | Galveston, Texas | 82.5 | 21 |
| 4498.75 | 3:2:58:45.0 | 66 | Dominican Rep. | 75.0 | 51, 52, 56, 72 |
| Third sighting pass | | | | | |
| 4568.60 | 3:4:08:36.0 | Unknown | Midway Islands | | |
| 4582.87 | 3:4:22:52.2 | 10 | Gulf of Calif. | 67.5 | [a]8, [a]9 |
| 4586.75 | 3:4:26:45.0 | 22 | Tampico, Mexico | 75.0 | 23 |
| 4593.00 | 3:4:33:00.0 | 126 | N Columbia | 75.0 | 125, 127 |

[a]Difficult to perceive

TABLE II.- NOMINAL LANDMARK SIGHTING SCHEDULE - Continued

| Acquisition g.e.t. | | Landmark | Location | View time, sec | Alternate landmarks in area |
|---|---|---|---|---|---|
| Total min | Days:hr:min:sec | | | | |
| (a) Day 3 - Continued | | | | | |
| Third sighting pass | | | | | |
| 4599.00 | 3:4:39:39.0 | Unknown | Central Brazil | | 128 |
| 4604.25 | 3:4:44:15.0 | 145 | Salvador, Brazil | 90.0 | |
| Fourth sighting pass | | | | | |
| 4688.12 | 3:6:08:52.2 | 109 | W Ecuador | 60.0 | [a]107 |
| | 7.2 | | | | [a]108 |
| | | | Unknowns till dark | | |
| (b) Day 6 | | | | | |
| First sighting pass | | | | | |
| 8572.62 | 5:22:52:37.2 | 10 | Gulf of Calif. | 52.5 | [a]8, [a]9 |
| 8579.62 | 5:22:59:37.2 | 45 | N Florida | 52.5 | 44, 37 |
| 8596.75 | 5:23:16:45.0 | 214 | W Guinea | 60.0 | 213 |
| 8604.87 | 5:23:24:52.2 | 222 | W Angola | 60.0 | |
| 8609.37 | 5:23:29:22.2 | 239 | Central Africa | 52.5 | [a]238 |
| 8613.37 | 5:23:33:22.2 | 240 | S Madagascar | 90.0 | |

[a]Difficult to perceive

TABLE II.- NOMINAL LANDMARK SIGHTING SCHEDULE - Continued

| Acquisition g.e.t. | | Landmark | Location | View time, sec | Alternate landmarks in area |
|---|---|---|---|---|---|
| Total min | Days:hr:min:sec | | | | |
| (b) Day 6 - Continued | | | | | |
| Second sighting pass | | | | | |
| 8665.62 | 6:0:25:37.2 | 6 | San Diego, Calif. | 45.0 | |
| 8670.62 | 6:0:30:37.2 | 20 | Galveston, Texas | 45.0 | 37, 38, 39 |
| 8675.37 | 6:0:34:58.2 | [a]53 or unknown | Bahama Islands | 30.0 | 50, 51 |
| 8700.50 | 6:1:00:30.0 | 225 | Southwest Africa | 82.5 | |
| Third sighting pass | | | | | |
| 8746.40 | 6:1:46:24.0 | Unknown if lighted | Fr. Frigate Schoals | | |
| 8760.50 | 6:2:00:30.0 | 10 | Gulf of Calif. | 52.5 | 11 |
| 8766.50 | 6:2:06:30.0 | [a]24 | Merida, Mexico | 60.0 | 59, 60, 61, 62 |
| 8771.37 | 6:2:11:22.0 | 129 | Island N of Venzuela | 52.5 | |
| 8776.62 | 6:2:16:37.2 | 136 | French Guiana | 37.5 | 137, 138 |
| 8781.75 | 6:2:21:45.0 | 143 | East Brazil | 67.5 | 141, 142 |

[a]Difficult to perceive

TABLE II.- NOMINAL LANDMARK SIGHTING SCHEDULE - Concluded

| Acquisition g.e.t. | | Landmark | Location | View time, sec | Alternate landmarks in area |
|---|---|---|---|---|---|
| Total min | Days:hr:min:sec | | | | |
| (b) Day 6 - Concluded | | | | | |
| Fourth sighting pass | | | | | |
| 8802.00 | 6:3:42:00.0 | 31 | W Costa Rica | 52.5 | 32, 33 |
| 8867.00 | 6:3:47:00.0 | Unknown | S America | | |
| 8871.00 | 6:3:51:00.0 | Unknown | S America | | |
| 8876.00 | 6:3:56:00.0 | 147 | E Brazil | 60.0 | 134 |

TABLE III.- TIMES FOR GROUND UPLINK AND

IMU ALIGNMENT

| Ground station | Approximate g.e.t.,[a] hr:min | Event |
|---|---|---|
| (a) Third day | | |
| HTV | 71:50 | State vector update time tagged to $73^h00^m$. Landmark schedule uplinked |
| First sighting pass | | |
| CRO, CNB | 72:25 | P52 IMU realign |
| Second sighting pass | | |
| CRO | 73:55 | P52 IMU realign |
| CRO | 74:10 | State vector update (optional) |
| Third sighting pass | | |
| CRO | 75:25 | P52 IMU realign |
| CRO, GWN | 75:45 | State vector update (optional) |
| (b) Sixth day | | |
| TEX | 139:45 | State vector update |
| CRO | 140:35 | P51 IMU orientation |
| HTV | 141:20 | Landmark schedule uplinked |
| First sighting pass | | |
| CRO | 142:10 | P52 IMU realign |
| Second sighting pass | | |
| CRO | 143:35 | P52 IMU realign |

[a]Approximate times from reference 5.

TABLE III.- TIMES FOR GROUND UPLINK AND

IMU ALIGNMENT - Concluded

| Ground station | Approximate g.e.t.,[a] hr:min | Event |
|---|---|---|
| (b) Sixth day - Concluded | | |
| Third sighting pass | | |
| CRO | 145:10 | P52 IMU realign |

TABLE IV.- WEIGHTING STRUCTURE LOAD[a]

(a) 3 × 3 Mode on the third day

| | |
|---|---|
| WORPOS, ft | 0 |
| WORBEVEL, ft/sec | 0 |
| WLMK, ft | |
| Known landmark | 10 000 |
| Unknown landmark; hardwired | 1 500 |

(b) 9 × 9 Mode on the sixth day

| | |
|---|---|
| WORPOS, ft | 200 |
| WORBEVEL, ft/sec | 0.2 |
| WLMK, ft | |
| Known landmark | 500 |
| Unknown landmark; hardwired | 1 500 |

[a]WORPOS - initial value for vehicle position portion of W matrix
WORBEVEL - initial value for vehicle velocity portion of W matrix
WLMK - initial value for landmark position portion of W matrix

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