FLASHING-BEACON EXPERIMENT FOR MERCURY-ATLAS 9 (MA-9) MISSION

by Charles C. Laney, Jr.

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SUMMARY

This paper describes the research, design, and evaluation of the flashing beacon developed and used for the Mercury-Atlas 9 (MA-9) visual perception test. The unit is designed to produce light pulses at the rate of 1 per second which at distances of 10 statute miles (approximately 8.7 international nautical miles) visually appear as bright as a second-magnitude star. The light package is capable of surviving the vibration conditions of the MA-9 launch and of operating in an orbit 100 nautical miles in altitude for at least 5 hours. Electrical design and packaging techniques are discussed. Data obtained on the spherical light outputs, characteristics, and the results of the thermal environmental tests of space are presented, as well as pertinent information obtained on individual components.

INTRODUCTION

The progress made in the next few years in the United States manned space effort depends largely on the ability to rendezvous and dock in space. One of the major problems is that of locating another object in orbit with which rendezvous can be effected. A possible solution to this problem is the use of a flashing beacon attached to the object. When this method is used, there are many questions which must be answered. These questions include: How much light energy per flash of light is needed? Should the light be "white"? Can a flashing light be distinguished against a star background?

To answer these questions it was proposed that a flashing beacon of known luminosity be built. This unit was to be launched from the Mercury spacecraft while in orbit and observed by the Astronaut as its distance from the spacecraft varied. The orbit, hence the distance from the spacecraft as a function of time, can be calculated when the ballistic number of the beacon, the launch velocity, and the angle at which the beacon was launched are known. Since the energy per flash of light and the distance from the observer are known, the Astronaut's readings can give designers an insight into the requirements for perception of flashing beacons in space and can establish the requirements for ground-based simulation experiments. This paper is a report of the development of a source to meet the Mercury-Atlas 9 (MA-9) mission requirements.
SYMBOLS

a/e ratio of solar radiation absorptance to material emittance
C capacitor; capacitance, μf
E battery voltage, v
f frequency, cps or flashes per minute
g acceleration due to gravity at surface of earth, ft/sec²
i current, amp
i_peak peak current, amp
I intensity, candles or lumens
R resistor; resistance, ohm
R_lamp resistance of flashlamp under conductance, ohm
t time, sec
V voltage, v
η intrinsic standoff ratio
φ angle between detector and axis through the two flashlamps, deg

Subscripts:
1, 2, 3, ... designate particular component or time

Component designations:
B battery
(FT) flashtube
Q transistor
S switch
(SCR) silicon controlled rectifier
T transformer
REQUIREMENTS

The basic requirements for the flashing beacon are dictated primarily by the physics of the experiment and secondarily by the weight limitations of the MA-9 mission. The beacon must be spherical and its light output, omnidirectional in space. Other requirements are as follows:

- Maximum diameter, excluding lamps, in. \(\frac{53}{4}\)
- Weight, lb 10
- Minimum operating life, hr 5
- Flashing rate, per sec 1
- Maximum variation of allowable light output, percent 20
- Maximum storage period, month 1

Also, there must be a minimum light output; that is, the flashing beacon must appear (visually) as a second-magnitude star at a distance of 10 statute miles (approximately 8.7 nautical miles) from the observer. The environmental conditions in which the flashing beacon must operate are as follows:

- Shock of launch for 11 milliseconds, g units 15
- Acceleration of launch for 3 minutes, g units Up to 20
- Vacuum range, torr \(1.75 \times 10^{-6}\) to \(7.3 \times 10^{-10}\)
- Minimum launch temperature, °F 70
- Vibration of launch, cps, for 100 seconds at
  - ±5g \(\pm 15\) to 100
  - ±50g \(\pm 100\) to 500
  - ±10g \(\pm 500\) to 2,000
- Vibration of launch for 0.3-inch double amplitude, cps 5 to 15

There should also be the condition of unattenuated solar radiation.

PROCEDURE

Design Criteria

Spectra.- The average spectral response curve for the human eye may be described as bell shaped with zero sensitivity at 4,000 and 7,000 angstroms and maximum sensitivity at 5,550 angstroms. From the standpoint of energy conversion, it is desirable to use a source which has a peak energy close to 5,500 angstroms or a blackbody temperature of about 5,000° C. The spectral output of a xenon lamp meets this requirement fairly well; the lamp has a high-energy conversion efficiency and a large amount of continuum and line structure in the visible region of the spectrum. The xenon spectral output may be
described as a continuous spread of energy over the entire visual region with broad superimposed lines of xenon.

Flashlamp output.- The minimum light energy output of the flashlamp must be such that at a distance of approximately 8.7 nautical miles it has an "effective" intensity equal to that of a second-magnitude star. According to the work of reference 1, the threshold for the dark-adapted eye for light-pulse (intensity—time-history) durations up to 0.10 second is energy dependent (i.e., the eye tends to integrate), and that energy is constant. In other words, the light energy required to be barely perceived by the dark-adapted eye is constant for pulse durations below 0.10 second. For time durations of 0.1 second and longer, threshold for the dark-adapted eye is intensity dependent, and that intensity is constant. The transition from \( I = \text{Constant} \) to \( I = \text{Constant} \) is fairly abrupt and occurs at about 0.10 second. This fact is very useful in predicting the amount of pulsed light energy or steady illumination needed for threshold if one or the other is known. For the calculation of the amount of energy needed in a pulse of light that will equal a steady second-magnitude star, the following proportion was set up with the assumption that the response of the eye is linear from threshold to intensities of a second-magnitude star:

\[
\frac{\text{Minimum detectable pulse energy, lumen-sec/sq cm}}{\text{Minimum detectable steady illumination, lumen/sq cm}} = \frac{\text{Second-magnitude pulse energy, lumen-sec/sq cm}}{\text{Second-magnitude steady illumination, lumen/sq cm}}
\]

According to reference 1,

\[
\frac{\text{Minimum detectable pulse energy}}{\text{Minimum detectable steady illumination}} = 0.1 \text{ second}
\]

Second-magnitude steady illumination equals \( 3.315 \times 10^{-11} \) lumen/sq cm (ref. 2); therefore, the second-magnitude pulse energy is

\[
0.1(3.315 \times 10^{-11}) = 0.3315 \times 10^{-11} \text{ lumen-sec/sq cm}
\]

\[
= 0.308 \times 10^{-8} \text{ lumen-sec/sq ft}
\]

At a distance of approximately 8.7 nautical miles (10 statute miles) this value corresponds to the following source power:

\[
4\pi(52,800)^2(0.308 \times 10^{-8}) = 107.8 \text{ lumen-sec}
\]

It should be noted here that when the Blondel-Rey equation of reference 3 is used, the figure for source power agrees with the results of reference 1, assuming that \( a = 0.1 \):

\[
\int_{t_1}^{t_2} I \, dt = I_e(a + t_2 - t_1)
\]
where

\[ I_e \quad \text{effective intensity (steady light)} \]

\[ \int_{t_1}^{t_2} I \, dt \quad \text{total energy of light pulse} \]

\[ t_2 - t_1 \quad \text{time duration of light pulse} \]

\[ a \quad \text{constant (0.2 sec at threshold, less than 0.2 sec at intensities above threshold)} \]

The results of references 2 and 3 disagree at threshold by a factor of 2.

**Electrical-System Analysis**

On the basis of the physiological requirements for the light output, the flashing beacon must emit a minimum of about 100 lumen-seconds into 4π steradians. When a lamp efficiency of 25 lumen-seconds per watt-second is assumed, 4 watt-seconds per lamp is required. Figure 1 is a circuit diagram of the circuitry for the flashing beacon which meets this requirement. The circuit consists basically of four parts; namely, the power supply, the storage capacitors, the timing module, and the flashlamps. Upon closure of the switches \( S_1 \) and \( S_2 \), the circuit is set in operation. The power supply, battery \( B_1 \), charges the storage capacitors \( C_1 \) and \( C_2 \) through the charging resistors \( R_1 \) and \( R_2 \), respectively, and also charges capacitors \( C_3 \) and \( C_4 \) in the timing module. One second after \( S_2 \) is closed, the unijunction transistor \( Q_1 \) in the relaxation oscillator supplies a gate to the silicon control rectifiers \( (SCR)_1 \) and \( (SCR)_2 \), which in turn discharge \( C_3 \) and \( C_4 \), respectively, through transformers \( T_1 \) and \( T_2 \), thus triggering flashlamps \( (FT)_1 \) and \( (FT)_2 \). The trigger pulse ionizes the flashlamps and allows the storage capacitors to discharge through them. The light given off is approximately 100 lumen-seconds per lamp.

**Power supply.** - The power supply \( B_1 \) is a stack of mercury batteries connected in series. Their open-circuit voltage is approximately 1.37 volts, which gives the power supply an open-circuit voltage of approximately 272 volts. Mercury batteries were chosen as the power supply because of their high ratio of energy to volume and weight (30 watt-hours per pound, 5.0 watt-hours per cubic inch; see ref. 4), their ability to function dependably after long periods of idleness (3-percent decrease in capacity after 6 months; see ref. 5), and their resistance to impact vibration and acceleration. The primary difficulty in using mercury batteries is their poor performance at low temperatures (i.e., lower than 70°F).

The mercury batteries used for this investigation are rated at 1,000 milliamp-hours and are recommended for use with loads from 1 to
20 milliamps. Power supply B₁ must supply peak currents of approximately 185 milliamps once a second for a minimum of 5 hours. In order that the batteries could be tested under these adverse conditions, a test circuit as shown in figure 2 was constructed. Note that the peak current drawn in the test circuit is nearly three times that drawn in the actual circuit and that the energy per unit cell is relatively close to that of the actual circuit (0.0425 watt-second in the actual circuit and 0.039 watt-second in the test circuit). Approximately 10 mercury batteries were tested with this circuit. Figure 3 shows the typical results of these tests. On the basis of these tests it can be concluded that if the mercury batteries are operated at temperatures no lower than 75°F, the power supply B₁ will last in excess of 7 hours. At higher temperatures the life of the battery is extended, and at lower temperatures the life is decreased.

The circuit in figure 3 was again employed to test the batteries for recovery under adverse temperature conditions (65°F). Several batteries were coated with silicon rubber and were submerged in water at 65°F, after which life tests were conducted. When the battery voltage reached 0.7 volt, the batteries were removed from the water and were heated to approximately 85°F. The results of this test are shown in figure 4.

Storage capacitors.- Two storage capacitors, one for each flashlight, are used in the flashing beacon. The type chosen for this application is an aluminum-foil electrolytic capacitor. The capacitors were built especially for this application to meet the following specifications:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitance, µF</td>
<td>150</td>
</tr>
<tr>
<td>Direct-current voltage rating</td>
<td>250</td>
</tr>
<tr>
<td>Temperature range, °C</td>
<td>0 to 85</td>
</tr>
<tr>
<td>Internal series resistance, ohm</td>
<td>0.1 or less</td>
</tr>
<tr>
<td>Leakage current, ma</td>
<td>0.2 or less</td>
</tr>
<tr>
<td>Watt-second rating</td>
<td>4</td>
</tr>
<tr>
<td>Altitude of operation in vacuum of space, nautical miles</td>
<td>100 to 150</td>
</tr>
<tr>
<td>Withstanding of launch vibration at 10g, cps</td>
<td>15 to 25</td>
</tr>
<tr>
<td>Minimum number of times energy must be supplied to a flashlamp (approximately 1 ohm)</td>
<td>30,000</td>
</tr>
</tbody>
</table>

Trigger circuitry.- The trigger circuit supplies a high-voltage pulse to each of the flashlamps at 1-second intervals. This circuit consists basically of two silicon controlled rectifiers with a charged capacitor in series with an ignition transformer across the anode and a unijunction relaxation oscillator which gates the rectifiers at 1-second intervals. When the relaxation oscillator gates the rectifiers, the high-voltage pulse output of the ignition transformers triggers the two flashlamps simultaneously. The silicon controlled rectifiers are three-junction hermetically sealed semiconductor devices functioning, in this application, similarly to a thyratron.

The relaxation oscillator is used as the timing circuit for the system and gates the two silicon controlled rectifiers. The unijunction transistor, which is the heart of the timing circuit, is a three-terminal semiconductor device with
these features: (1) a stable firing voltage which is a fixed fraction of the applied interbase voltage, (2) a very low value of firing current, (3) a negative-resistance characteristic which is uniform from unit to unit and stable with temperature and life, and (4) the capability of a high-pulse current. (See ref. 6.) Figure 5 shows the trigger circuitry in operation and the waveforms at various points in the circuit.

The frequency of oscillation in cps is determined by the following equation:

\[ f = \frac{1}{R_7 C_5 \log_e\left(\frac{1}{1 - \eta}\right)} \]

where \( \eta \) is the intrinsic standoff ratio (0.62 nominal for this unijunction). The resistance for \( R_7 \) is selected from 100 to 180 kilohms to yield a frequency of approximately 1 cps for each combination of \( C_5 \) and \( \eta \). The typical value of \( R_7 \) is 120 kilohms. For temperature compensation, \( R_5 \) is used. At its value of 150 ohms, the oscillator frequency would shift approximately 2 percent higher when the temperature of the unijunction transistor goes from 25°C to 85°C. The resistance for \( R_5 \) is set at this value to compensate for the increase in \( C_5 \) and, consequently, the decrease in frequency when the temperature is increased. Typical temperature characteristics of the complete timing module at two different room-temperature frequency settings, the unijunction transistor, and \( C_5 \), are shown in figure 6.

Note that the timing module has a separate power supply B2. (See fig. 1.) The power supply is made up of 12 series-connected mercury batteries similar to those discussed in the section entitled "Power Supply." On the basis of the capacity of these cells and the load imposed by the timing module, power supply B2 should last in excess of 150 hours.

When the unijunction relaxation oscillator gates \((SCR)_1 \) and \((SCR)_2\), \( C_3 \) and \( C_4 \), which are charged to an approximate voltage of \( B_1 \), discharge through \( T_1 \) and \( T_2 \), creating an ionizing voltage of approximately 6 kilovolts to be applied to \((FT)_1 \) and \((FT)_2 \).

Flashlamps.- The flashlamps used in the flashing beacon consist of a U-shaped glass bulb filled with xenon at a pressure of about 150 mm of Hg. It is recommended for stroboscopic use at energies between 0.1 and 10 watt-seconds. The operating voltage range is from 160 to 300 volts.

For this application, the flashlamp must flash a minimum of 18,000 times at maximum energy inputs of 5 watt-seconds. The flashlamp was tested and it was found that for energy inputs of 20 watt-seconds over 21,000 flashes at 1 flash per second could be obtained. In addition, the flashlamp was vibrated in three directions, with no failure, at 5.6g from 15 to 25 cps, 1kg from 25 to 2,000 cps to 20g from 30 to 50 cps, and at 55g from 50 to 2,000 cps.
Construction of Flashing Beacon

The physical requirements for the flashing beacon are that the maximum
diameter be $5\frac{3}{4}$ inches (excluding lamps) and that the minimum weight be 10 pounds.
Figure 7 shows the component layout of the flashing beacon (the sphere diameter
is $5\frac{3}{4}$ inches). The component package is contained in a 2024-T4 aluminum-alloy
shell with a $5\frac{3}{4}$-inch outer diameter and a 1/16-inch thickness which is coated
inside with 8 mils of Teflon. A mold in which the components are assembled for
potting and which has the same dimensions as those of the inside of the com-
ponent housing is also coated inside with 8 mils of Teflon. The component
package is constructed in three parts: the timing module (unijunction relaxa-
tion oscillator), the flashlamp module, and the power supply. The timing module
consists of two of the power supply batteries $B_2$, $C_5$, $R_5$, $R_6$, $R_7$, and $Q_1$, all
potted in silicone rubber. The timing module is 1.875 inches long and
0.656 inch in diameter. The flashlamp module consists of the flashlamp and the
ignition transformer; the ignition transformer is coated with Glyptal, and the
flashlamp and ignition transformer are installed in a flashlamp-module mold,
after which silicone rubber is added for potting. The finished flashlamp module
is 1.875 by 0.69 by 0.69 inch, excluding the protruding lamp. The battery
stacks consist of three to seven batteries connected in series and are built as
follows. The anode tab is removed from all batteries. The batteries are then
placed in the wooden clamp jig, and the cathode tabs are soldered to the anode
(case) of the battery ahead of it. The stack of batteries is then removed,
sanded to remove any sharp edges, and then taped with two layers of 3.5-mil
Teflon tape. All wiring is AWG 20, 10/30 stranded, 1/64-inch thermoplastic insula-
tion. After the wiring is completed, the mold is placed in the facility for
vacuum potting. The silicone rubber is pumped into the mold which is in a pres-
sure environment of 28 mm of Hg and held at this pressure for $1\frac{1}{2}$ hours to assure
no voids in the component package. At this time the pressure is changed to
100 lb/sq in. for 24 hours, after which the mold is cured at $140^\circ$ F for 12 hours.
The component package is then removed from the mold, the (FT)$_1$ and (FT)$_2$
flash-
lamp modules are installed, and the component package is placed in the aluminum
shell; the completed flashing beacon is shown in figure 9. The protruding brass
devices are used to hold switches $S_1$ and $S_2$ open to keep the satellite in an
inoperative state. The total weight of the flashing beacon is 10.0 pounds and
is comprised of the weights of the components, 6.7 pounds; the shell, 1.0 pound;
the silicone rubber, 1.8 pounds; and the lead, 0.5 pound. The lead is added to
assure the proper ballistic number. The volume inside the shell is 89.5 cubic
inches, of which 48 cubic inches is occupied by the components.

Thermal Problems in the Flashing Satellite Program

The problem of temperature control in the case of the flashing beacon
departs from many satellite situations because of the large amount of heat
generated within the sphere by the light circuit. In most satellites, the
internally generated heat is only a fraction of the heat received from the sun and the earth and therefore can be safely neglected in the heat-balance analysis. However, in this problem more heat is generated internally than is received from external sources, and the internal temperatures are always above the skin temperatures. This high power density of the sphere presented a problem in heat dissipation which had to be solved if the temperature limitations of the electronic components were not to be exceeded. The desired sphere conditions were a maximum component temperature of approximately 130°F after 5 hours of operation.

Thermally, the sphere consists of electronic components (capacitors, resistors, batteries, and so forth), all potted in a rubbery insulator (silicone rubber) and contained in a thin spherical aluminum shell. In addition, the batteries have to be wrapped with Teflon tape because the metal battery case serves as a terminal. The total power dissipated as heat is assumed to be generated in four resistors which are close to the aluminum shell and positioned more or less symmetrically with respect to the center of the sphere.

The best means of controlling the temperature within the sphere seemed to be to change the ratio of solar absorptance to long wavelength emittance a/e of the surface of the outer shell and/or to reposition the electronic components within the sphere and to provide better conductive paths for heat dissipation (putting resistors on metal rods attached to the shell, and so forth). The first method, which was by far the more simple, was used.

TEST PROCEDURES AND RESULTS

The completed flashing beacon was exposed to a series of tests to study its characteristics in space. There were three main tests performed: (1) operation of the flashing beacon in a thermal vacuum facility, (2) spatial-distribution tests of the light output, and (3) high-altitude visual tests.

Operation of Flashing Beacon in a Thermal Vacuum Facility

A number of tests were conducted in a thermal simulation facility to determine an optimum surface coating of the satellite and to analyze any peculiar electrical and light-output effects caused by operation in the space environment. The test facility used operates at a pressure of $2.5 \times 10^{-5}$ torr, equivalent to an altitude of about 80 nautical miles. A shield, cooled with liquid nitrogen, partially surrounds the test specimen, simulating the radiation heat sink of space. A pyrheliometer located near the model is used to control a carbon-arc system used for the solar-heat flux. The spheres tested were internally instrumented with thermocouples to give a temperature time history as the carbon arc was regulated to simulate the day-night conditions of the expected 105-minute orbit.

The first model tested had a polished aluminum surface ($a/e = 4$ to 6). The test results showed that the internal temperature rise (35°F per hour) was too great for the electrical components to be expected to operate reliably for
periods up to 5 hours. The successful test model was coated with white silicone paint to give a diffuse white appearance with an a/e of approximately 0.25. By coating the aluminum with this paint, the infrared radiative quality of the sphere was vastly improved. The results of models tested with this coating (fig. 10) showed a substantial decrease in internal temperature rise. After 5 hours of "space" operation, the average internal-component temperature of the painted sphere was 130° F, compared with 230° F for the polished aluminum sphere. Figure 11 shows the characteristics of a coated satellite launched at 75° F.

In addition to the overheating problem, there is a low-temperature problem dictated primarily by the cold low-capacity characteristics of the mercury batteries. Starting with an ejection temperature of 65° F, 10° below that expected, output measurements were made under the simulated orbital conditions. The results (fig. 12) showed a reduced voltage output for about 100 minutes, after which the voltage remained within 10 percent of that expected. The results of a test in which the ejection temperature was 60° F showed that the output was extremely low for the first 45 minutes after launch and then became very irregular in frequency and light output.

Spatial Distribution of Light Energy Output

The spatial distribution of light energy output was measured by the National Bureau of Standards by use of a photometer, specially developed for measurement of effective intensity of capacitor-discharge lights. The results of these tests are shown in figure 13. The flashing beacon was positioned as shown in the figure and rotated around the axis shown. Note that in this case the intensities of the two lamps are not equal. This apparent attenuation occurs because the switch-holding devices were not removed during this test; thus the light output was attenuated. Under actual conditions the outputs will be equal. Also note if the intensity is assumed to be 137 lumen-seconds, the variation will in no case at any orientation be greater than 20 percent.

A typical time history of the light output for a single flash is shown in figure 14. The time base is 50 microseconds per division and the intensity scale is 0.33 megalumens per division. The total light energy under the curve is 125 lumen-seconds, as ascertained by evaluating the integral \[ \int_0^1 I \, dt. \]

High-Altitude Visual Tests

The flashing beacon was attached under the nose of a trainer airplane, as shown in figures 15 and 16. The sphere is completely covered (except for the protruding lamps) with 1/2 inch of fiber glass and foam insulation to protect it from severe low temperatures. This airplane and another one piloted by Astronaut Cooper flew at various altitudes and distances apart (distances determined by radar). Astronaut Cooper, who was equipped with a photometer (small rotary variable-density filter), was to make visual readings as to the apparent intensity of the satellite under various conditions. The flight was initiated
45 minutes before darkness to allow for some daylight observations. The moon was nearly full, low, and 90° in azimuth from sight of light. The results of these visual tests are shown in table I.

Astronaut’s Observations in MA-9 Flight

The flashing-beacon flight model 3 was installed in its launching can on the retropack at Cape Canaveral (now Cape Kennedy) on April 9, 1963. The characteristics and qualification tests of this unit are given in table II.

The results of this MA-9 experiment performed by Astronaut Cooper on May 15, 1963, have been previously reported in reference 7. In summary, it can be said that the flashing beacon was easy to distinguish from the stars and that the intensity appeared to be less than expected but that it was adequate for nighttime perception up to a distance of 8 nautical miles. Chronologically, the beacon was deployed at the attitude and time as planned, about 15 minutes before sunset on the third orbital pass. The beacon temperature was estimated to be slightly above 60°F. The Astronaut was unable to perceive the beacon after launch or during the following night. The recorded comments of the Astronaut indicate that he had trouble establishing the desired attitude for viewing the light. Going into the second night after deployment, Astronaut Cooper first saw the beacon as a steady reddish-brown light when it was still in the sunlight but far enough below the local horizontal that it was seen against a dark earth background. This observation was obviously sunlight reflected by the beacon. The calculated range was about 3 nautical miles. Later that night at calculated distances of 4 and 8 nautical miles the beacon appeared as a second- and third-magnitude star, respectively, one magnitude dimmer than expected. During the third night some 210 minutes after deployment and at a calculated distance of 11 nautical miles, he again perceived the beacon. Again, the intensity was less than predicted.

CONCLUDING REMARKS

A flashing beacon operating entirely on self-contained components and designed for a Mercury-Atlas 9 (MA-9) visual perception experiment has been successfully used on the manned orbital flight as a visual perception source. The unit produced light pulses at the rate of 1 per second which at distances of 10 international statute miles (approximately 8.7 international nautical miles) appeared as bright as a second-magnitude star. It proved to be easily distinguishable against a star background and was reasonably easy to perceive. Its uniqueness is in its high-energy-output characteristics per volume, and the relatively small change of pulsed light output with time and view angle.

It is believed that Astronaut Cooper’s trouble with the attitude of the spacecraft kept him from perceiving the beacon the night after its ejection. This explanation is the most logical since the subsequent positive sightings of normal beacon operation preclude the probability that the beacon was inoperative the first night. Thermal tests showed that for the beacon to operate for over 2 hours (second orbit) the internal temperature of the unit should never be
below 60° F. If the lights had not operated the first night, no internal heat would have been generated and the battery temperature would have been near 50° F. The brightness estimations made by Astronaut Cooper during the second and third nights were a star magnitude less intense than theory and test had predicted.

On the basis of all the tests conducted, it is concluded that the beacon design meets all the specified environmental requirements.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., April 15, 1964.

REFERENCES


<table>
<thead>
<tr>
<th>Time of day</th>
<th>Altitude, ft</th>
<th>Distance between airplanes, nautical miles</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daylight</td>
<td></td>
<td>2 to 2.5</td>
<td>Barely discernible</td>
</tr>
<tr>
<td>23 minutes after sunset</td>
<td>25,000</td>
<td>6</td>
<td>Same magnitude as Betelgeuse, a first-magnitude star</td>
</tr>
<tr>
<td>25 minutes after sunset</td>
<td>24,000</td>
<td>7</td>
<td>Same magnitude as a star in the belt of Orion, magnitude from 1.7 to 2</td>
</tr>
<tr>
<td>32 minutes after sunset</td>
<td>24,000</td>
<td>15</td>
<td>Distinguishable in the star background</td>
</tr>
<tr>
<td>1 hour after sunset</td>
<td>25,000</td>
<td>7.5</td>
<td>Brighter than Polaris, a second-magnitude star</td>
</tr>
<tr>
<td>(complete darkness)</td>
<td>27,500</td>
<td>18</td>
<td>If light was lost sight of, it could be seen again at 15 nautical miles</td>
</tr>
</tbody>
</table>
TABLE II.- CHARACTERISTICS AND QUALIFICATION TESTS
OF FLASHING BEACON

[Information ascertained 40 days before MA-9 launch]

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Weight, lb</td>
<td>10.032</td>
</tr>
<tr>
<td>Frequency, flashes per minute</td>
<td>62</td>
</tr>
<tr>
<td>Lamp output at $\phi = 0^\circ$, lumen-sec:</td>
<td></td>
</tr>
<tr>
<td>No. 1 ($0^\circ$ position, see fig. 13)</td>
<td>117.6</td>
</tr>
<tr>
<td>No. 2 ($180^\circ$ position, see fig. 13)</td>
<td>117.6</td>
</tr>
<tr>
<td>Vacuum qualification test, torr</td>
<td>$4 \times 10^{-5}$</td>
</tr>
<tr>
<td>Vibration qualification test for 0.2-inch double amplitude, cps</td>
<td>5 to 15</td>
</tr>
<tr>
<td>Vibration of launch (2 minutes per sweep), cps, at -</td>
<td></td>
</tr>
<tr>
<td>$\pm 2g$</td>
<td>15 to 100</td>
</tr>
<tr>
<td>$\pm 3.34g$</td>
<td>100 to 300</td>
</tr>
<tr>
<td>$\pm 6.67g$</td>
<td>500 to 2,000</td>
</tr>
<tr>
<td>Life used, minutes</td>
<td>15</td>
</tr>
</tbody>
</table>
Figure 1.- Flashing-beacon circuitry.
**Actual Circuit**

\[ i \text{ peak} = \frac{V}{R} = \frac{220}{1,200} = 0.1832 \text{ ampere} \]

\[ RC = (1,200)(0.00035) = 0.42 \text{ second} \]

\[ E = \frac{1}{2} CV^2 = \frac{1}{2} (350 \times 10^{-6})(220)^2 = 8.46 \text{ watt-second} \]

*Average voltage and resistance of the 199 batteries

**Test Circuit**

\[ i \text{ peak} = \frac{V}{R} = \frac{1.1}{2} = 0.56 \text{ ampere} \]

\[ RC = (2)(0.061)(1.1) = 0.128 \text{ second} \]

\[ E = \frac{1}{2} CV^2 = \frac{1}{2} (0.061)(1.1)^2 = 0.03875 \text{ watt-second} \]

Figure 2.- Battery-life test circuit.
Test circuit

Note: E measured an instant before switch closure.
Cell temperature = 75°F.

Figure 3.- Typical test results of battery under pulsed conditions.
Test circuit

Note: E measured an instant before switch closure.

Battery A

Battery B

Temperature

Figure 4. - Test results of two batteries at low temperatures under pulsed conditions.
Figure 5.- Waveforms at various points in trigger circuitry.
Figure 6.- Typical temperature characteristics of transistor (2N491), $C_5$, and timing module at two different room-temperature settings.
Figure 7a- Component layout of flashing beacon showing the number, type, and placement of individual battery stacks and components. (Integers denote number of batteries per unit.)
Figure 8.- Component buildup in mold before potting.
Figure 9. - Flashing beacon.
Figure 10. - Comparison of internal heating rates in coated and aluminum spheres.
Figure 11.- Characteristics of flashing beacon at launch temperature of 75° F.
Figure 12.- Characteristics of flashing beacon at launch temperature of 65°F.
Figure 13. - Spatial distribution of light-energy output from flashing satellite.
Figure 14.- Time history of single flash.
Figure 15.- Flashing beacon attached under nose of trainer airplane for high-altitude observations.
Figure 16.- Close-up of flashing beacon attached under nose of trainer airplane.
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—National Aeronautics and Space Act of 1958

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