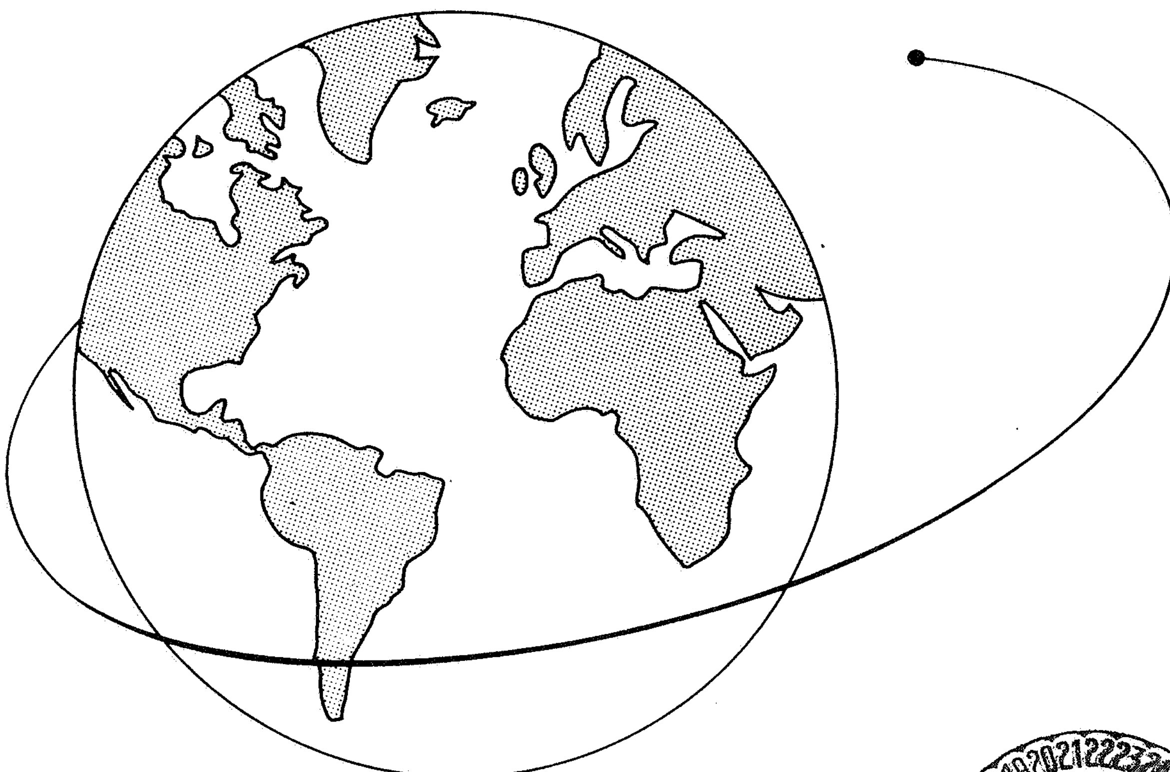
TRACKING STUDIES OF APOLLO 7 AND INTELSAT II

M. GRANDFIELD, D. HANLON, K. HEBB, E. JENTSCH, R. YORKE, and M. R. WOLF



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APOLLO 7 RETROFIRE AND REENTRY OF SERVICE PROPULSION MODULE

Mary Grandfield, Daniel Hanlon, Karen Hebb,
Edward Jentsch, and Robert Yorke

FURTHER STUDY OF INTELSAT II F-2 APOGEE BURN

Michael R. Wolf

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Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

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ABSTRACT

The retrofire of the Apollo 7 manned spacecraft was photographed by the Smithsonian Astrophysical Observatory (SAO) Baker-Nunn camera at Maui, Hawaii. Shortly thereafter, the service propulsion module was photographed by the SAO Baker-Nunn camera in Arizona and visually observed by several Moonwatch teams as it entered the earth's atmosphere.

This report presents the data from these observations and a preliminary analysis of the retrofire photographs.

La mise à feu des rétrofusées du vaisseau spatial piloté Apollo 7 a été photographiée par la caméra Baker-Nunn du Smithsonian Astrophysical Observatory (SAO), à Maui, Hawaii. Peu après, le moteur du module de service a été photographié par la caméra Baker-Nunn du SAO en Arizona, et il a été observé visuellement par plusieurs équipes "Moonwatch" lors de son entrée dans l'atmosphère terrestre.

Cette publication donne les résultats de ces observations et présente une analyse préliminaire des photographies de la mise à feu des rétrofusées.

Смитсонианская Астрофизическая Обсерватория (САО) засняла огненный хвост управляемого человеком космического корабля Апполон 7 с помощью камеры Бэкер-Нунн в Мауи на Гавайских островах. Вскоре после этого с помощью той же камеры САО в Аризоне сфотографировала приводящуюся в движение вспомогательную модель, при этом эта модель визуально обозревалась несколькими ведущими наблюдения за луной группами в момент ее вхождения в атмосферу земли.

В этом сообщении приводятся данные этих наблюдений и предварительный анализ фотографий огненного хвоста.

APOLLO 7 RETROFIRE AND REENTRY OF SERVICE PROPULSION MODULE

Mary Grandfield, Daniel Hanlon, Karen Hebb, Edward Jentsch, and Robert Yorke

1. INTRODUCTION

Apollo 7 (COSPAR designation 6808901), the first manned mission in the series, was launched from Cape Kennedy, Florida, on October 11, 1968, at 15^h03^m UT. During the 10.8 days of the mission, the Apollo 7 spacecraft was optically tracked by the worldwide network of Baker-Nunn cameras and Moonwatch teams operated under the direction of the Smithsonian Astrophysical Observatory (SAO).

Among the major events during the mission were eight maneuvers of the spacecraft that were performed by using the engine of the service propulsion system. The last of these, the deorbit manuever (Event SPS-8), was photographed by the Smithsonian astrophysical observing station at Maui, Hawaii.

Shortly after this event, the Smithsonian astrophysical observing station at Mt. Hopkins, Arizona, as well as several Moonwatch teams, observed the service propulsion module (which had been separated from the command module after retrofire) during its reentry into the atmosphere. These observations were made at the request of NASA's Goddard Space Flight Center.

This report will present a preliminary analysis of the photographs of the deorbit maneuver and will list the observations of the service-propulsion-module reentry.

This research was supported in part by grant NGR 09-015-002 from the National Aeronautics and Space Administration.

2. APOLLO 7 RETROFIRE

2.1 Predictions

Before launch, nominal orbital parameters for the Apollo 7 mission (see Table 1) were supplied to SAO by the Mission Planning and Support Office of NASA's Manned Spacecraft Center in Houston, Texas. As the mission progressed, revisions to the planned trajectories were provided by telephone.

The parameters for Event SPS-8 (retrofire) were converted to classical elements and used as input to SAO's general ephemeris program (EPHEM), which generated look-angle predictions at 15-sec intervals on both sides of the expected ignition time.

2.2 Observations

Well in advance of the expected time of ignition, the Baker-Nunn camera (Henize, 1957) at Maui, Hawaii, was set up at the position predicted for retrofire. The sky area was then searched both visually and photographically. The observers (D. LeConte, W. Perry, W. Phillips, and M. Salisbury) selected a camera operating cycle of 16 sec, which provided a 1.6-sec exposure (including chop time) per frame at intervals of 8 sec between exposures.

Retrofire occurred on October 22 at $10^h42^m00\overset{s}{.}94$ UT or 2 min and 28 sec earlier than was anticipated from the nominal orbital parameters; however, the spacecraft was in the field of view of the camera, and the camera shutter was open when ignition took place.

Table 1. Apollo 7 orbital parameters (nominal)

Event	Ground elapsed time	Longitude of ascending node	Orbital inclination	Argument of perigee	Eccentricity	Apogee altitude (n. mi.)	Perigee altitude (n. mi.)	True anomaly	Period (min)	Semimajor axis (ft)
S-IVB/CSM separation	$02^h55^m00^s$	175°.356	31°.636	69°.48	0.00693	171.432	127.013	-43°.979	89.98	21823499
Phasing maneuver	03 20 00	152.645	31.619	77.425	0.00635	168.355	126.188	50.732	89.86	21803729
SPS 1	26 24 56	168.710	31.611	21.223	0.01048	197.161	121.569	-89.796	90.392	21889280
SPS 2	27 59 56	145.603	31.622	82.387	0.00500	157.032	117.033	-131.695	89.478	21741504
Rendezvous	30 01 25	122.67	31.605	88.464	0.00588	162.471	124.290	-81.749	89.678	21773967
SPS 3	91 42 35	-117.651	31.987	92.501	0.00751	154.676	96.902	124.273	89.071	21675520
SPS 4	120 52 02	148.092	31.966	102.666	0.00971	160.256	94.921	80.687	89.097	21679717
SPS 5	165 07 49	-156.951	31.322	111.635	0.02135	242.806	92.306	-28.478	90.606	21923929
SPS 6	210 13 15	-130.073	31.312	131.801	0.02067	237.535	89.949	-73.17	90.522	21910254
SPS 7	239 04 37	128.846	31.191	124.804	0.01955	229.536	94.464	2.014	90.453	21899152
SPS 8	259 41 4	-171.17	31.201	148.592	0.03248	230.95	-4.814	-125.232	88.704	21615966

At the time of retrofire, the spacecraft was in the earth's shadow approximately 10° above the observers' horizon. The burn lasted for 10 sec at a thrust of 21,500 lb (Normyle, 1968).

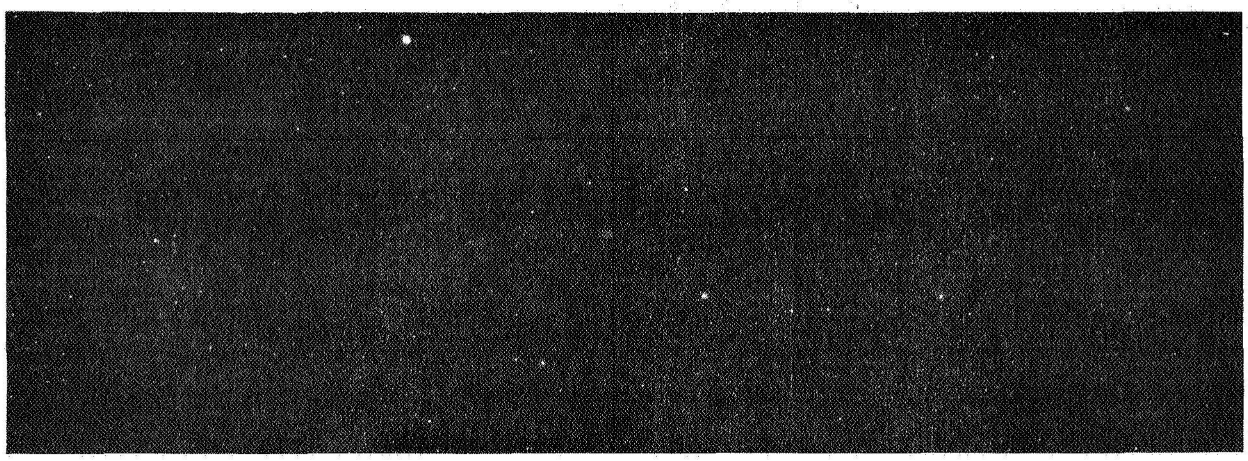
2.3 Description of Photographs

The first photograph (Figure 1a) was taken with the camera stationary. The clamshell shutter was open for 1.6 sec with the midpoint of the exposure occurring at $10^h42^m01\overset{s}{.}245$ UT (approximately 0.3 sec after ignition).

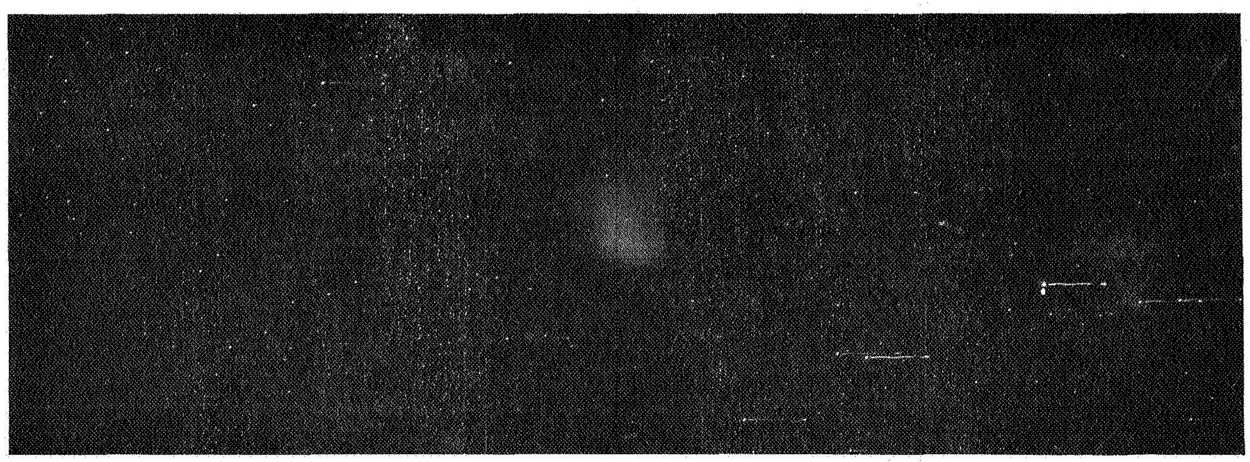
During the exposure, the exhaust cloud was moving from right to left across the photograph, thus creating a triangular-shaped image with the apex representing the ignition point. The "break" in the image was caused by the rotating chopping shutter, which interrupted the exposure five times (the third interruption represents the center, or time, of the exposure). In this case, the only "break" visible is the third; the first two occurred before ignition, and the last two are not evident, owing to the expansion of the cloud. The apex of the image is located at right ascension $06^h20\overset{m}{.}0$ and declination -32°33'. At the end of the exposure, the dimension of the cloud perpendicular to the motion of the spacecraft was approximately 6 arcmin. The uncertainty of these measurements is ±0.7 arcmin.

During the second exposure (Figure 1b), the camera was slewed while the shutters were open. However, since the slewing was unidirectional and parallel to the spacecraft's motion, the dimension of the cloud image normal to the path can still be measured. The image was scanned normal to the path at 500-μ intervals with a microdensitometer. At its widest point, it measures approximately 52 arcmin, with an uncertainty of ±2 arcmin. Burnout occurred approximately 0.9 sec after the end of this exposure.

The camera was slewed in a much more complex pattern during the third exposure. An analysis of this photograph was not attempted.



(a)



(b)

Figure 1. Apollo 7 retrofire photographed at 8-sec intervals by the Smithsonian astrophysical observing station at Maui, Hawaii, October 22, 1968.

2.4 Station–Satellite Range

The final, actual orbital elements before Event SPS-8 (see Table 2) were input to the general ephemeris package to determine the right ascension, declination, and range of the spacecraft from the Maui station* at the approximate time of retrofire. The computed values are the following:

Time	$22^{d}10^{h}42^{m}01^{s}$
Right ascension	$6^{h}20\overset{m}{.}1$
Declination	$-32\overset{\circ}{.}8$
Range	1188.9 km.

Table 2. Actual Apollo 7 orbital elements before retrofire (Event SPS-8)†

Epoch	$259^{h}38^{m}15^{s}$ elapsed time from T = 0
Semimajor axis	21897672 ft
Eccentricity	0.0185488
Inclination	$29\overset{\circ}{.}88417$
Right ascension of ascending node	$17\overset{\circ}{.}58052$
Argument of perigee	$143\overset{\circ}{.}85149$
Mean anomaly	$242\overset{\circ}{.}51662$
Period	$90\overset{m}{.}44355$

*Geocentric coordinates of Maui Station: X = -5.466055 Mm, Y = -2.404275 Mm, Z = 2.242170 Mm.

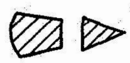
†Provided by NASA's Manned Spacecraft Center, Mission Planning and Analysis Division, Houston, Texas.

2.5 Preliminary Photometric Results

In Figure 1a, the exhaust-cloud image was scanned along the y axis of the frame with a microdensitometer. The lever ratio was 20:1; the magnification, 6×. A 1-mm slit, or aperture, was used. Since the image of the cloud appears in two sections owing to the rotating chopping shutter, both sections were scanned; they are labeled I(1) and I(2) in Figure 2.

The width of the image I(1) is 0.6 mm on the film. The Baker-Nunn plate scale is 1 mm = 418". The image I(1), then, is 4.1 arcmin in actual size. If we follow the same calculation for I(2), the image is 0.95 mm on the film, and 6.61 arcmin in actual size.

The densitometer scan of Figure 1b is shown in part in Figure 2b. In this instance, the cloud was scanned at intervals of 500 μ. The actual size of the image on film is 7.50 mm. Integrating the multiple scans renders for the cloud a total brightness of a 4th-magnitude star.



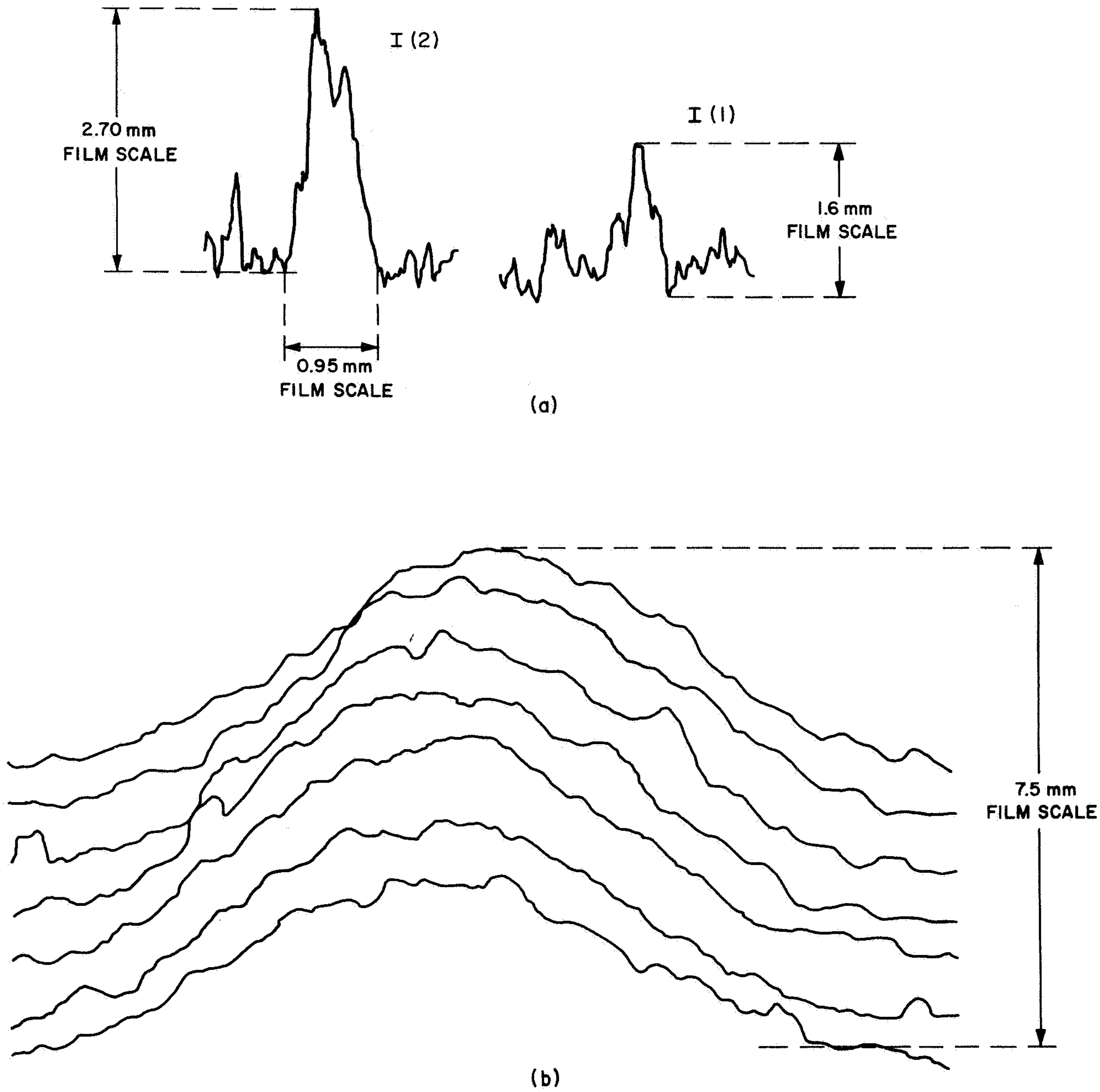


Figure 2. Graphic representation of microdensitometer scans of Figures 1a and 1b.

3. SERVICE-PROPULSION-MODULE REENTRY

3.1 Predictions

An ephemeris giving subsatellite points was run with the nominal orbital parameters for the spacecraft following retrofire (Event SPS-8, Table 1). Culmination look-angles for each potential observing site were then derived from the subsatellite path on the assumption of a 100-km altitude (the height at which reentering objects become incandescent) for the service propulsion module.

A letter was sent to each potential observing site, notifying them that they should be able to witness the reentry. This was followed by a telegram giving the predicted culmination look-angles.

3.2 Observation Descriptions

Relevant portions of reports received from sites that witnessed the reentry are quoted below, in order of their position along the reentry path. The time of the Dallas observation does not correlate with those of the others. A photograph of the reentry taken at the Mt. Hopkins observing station is reproduced in Figure 3.

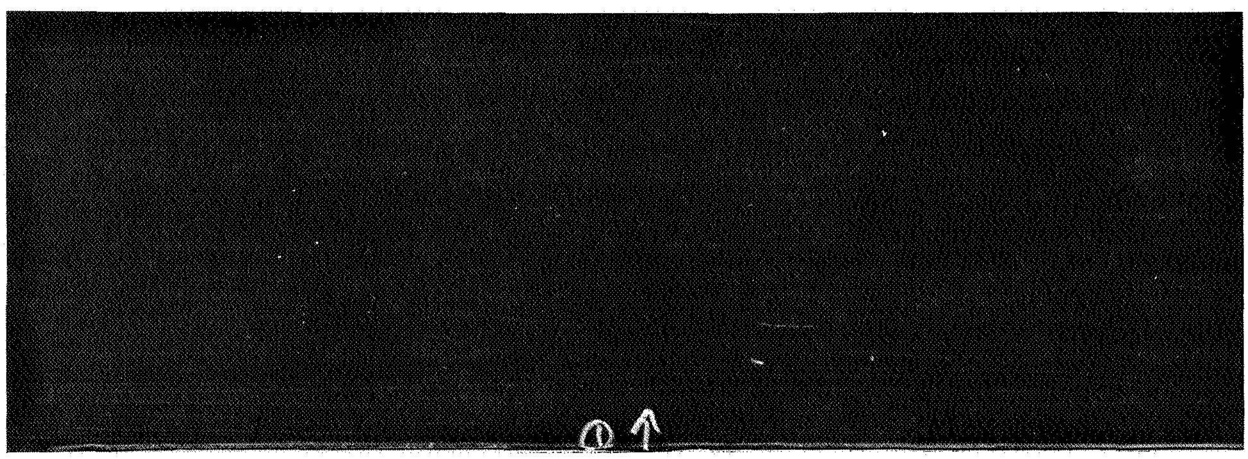


Figure 3. Service-propulsion-module reentry photographed by the Baker-Nunn Camera at Mt. Hopkins, October 22, 1968.

3.2.1 Smithsonian astrophysical observing station, Mt. Hopkins, Arizona (observed by Jeffrey Bosel)

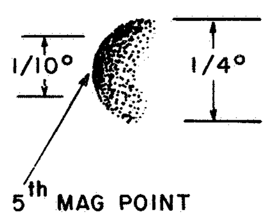
At approximately 1030Z I went up to watch for the reentry that was predicted for 1044Z. The camera was at the predicted settings of az. 175°, alt. 15°, which placed the controls in an inconvenient position. Therefore, I reset to az. 355° and alt. 165°.

At approximately 1051Z a relatively large glowing and fluctuating object was sighted traveling W to E at about 3000 arcsec sec^{-1}. The altitude was slightly higher than predicted, being about 20° above the horizon. The camera was started before the object came into the field. The tracking motor was switched on and the velocity adjusted in an attempt to follow the object . . . .

The object did not fluctuate as an entity but rather as if different parts of it were tumbling. The overall color of the object was a dull red. The appearance of the object did not change noticeably from when it was first sighted until it disappeared into the haze.

3.2.2 Moonwatch Team, Phoenix, Arizona (reported by R. K. Reynolds)

At 13° altitude our field is limited to about 35° in azimuth between two trees, i. e., from about 145° to 180°. Rhoda watched the area with naked eye, while I scanned it with an M-17 mounted piggy-back on one of the apogee scopes. I caught it at about 180° and tracked for 2 or 3 sec before switching to the apogee, with which I tracked it for 8 or 9 sec before taking a time at a good star field. The satellite appeared like a fat sausage with the leading edge much brighter than the rest, which had a comet-like glow (see sketch below).



From the reticule divisions in the apogee telescope, I estimated the bright portion to be 0°.10 and the trailing portion to be 0°.25. The brightest spot in the leading edge I estimated at 5 mag, compared with the 5-mag star under which I timed the satellite. At no time was it visible to the naked eye in our limited field.

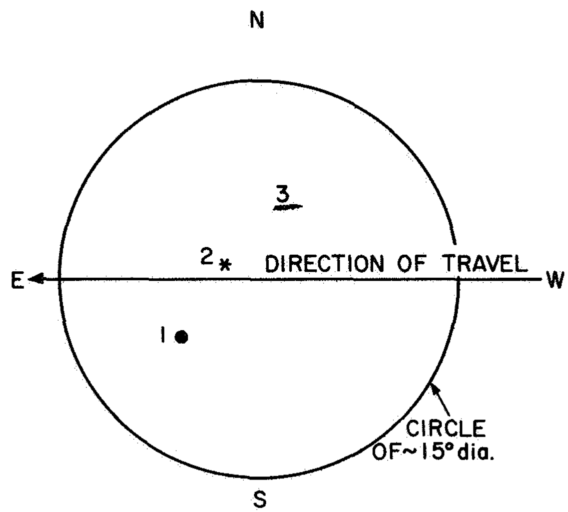
3.2.3 Moonwatch Team, Dallas, Texas (observed by H. W. Rose)

At . . . about 5:53 or 5:54 A.M., although it was still dark, I noticed that the dull gray of the clouds seemed to have a few breaks toward the SSE close to the designated look-angle, so I continued to watch, hoping to see something. I was looking SSE at approximately 5:58 A.M. when I became aware of a faint but definitely noticeable brightening behind the cloud layer to my S and SSW, at an altitude of about 20° to 25°. The brightening increased slightly for several seconds, although it never did get very bright; it remained at a relatively constant intensity for the next 10 to 15 sec and then gradually diminished back to the former dull gray during the next 10 to 15 sec. The brightening made the clouds change from a very dull gray to a faint golden pink. The whole phenomenon lasted less than a minute, between 5:58 and 5:59 A.M. CDT. I could detect no apparent motion of the bright area from W to E, nor did I see anything in any of the few openings in the clouds to the SSE, not even any stars. Because I did not really expect to see anything under the cloudy conditions, I did not have my binoculars with me. The observations were made with naked eye, and altitudes were estimated.

3.2.4 Moonwatch Team, Panama City, Florida (observed by Dr. M. A. Elliot)

On the morning of October 22, 1968, three objects, all traveling together, were observed to pass near the zenith (est. ±10°) at . . . $4^h57^m49^s$ CST. The zenith crossing was timed by naked eye and stopwatch (the stopwatch was checked 2 hr later against WWV), with an estimated accuracy of ±2 sec. The objects were traveling from W to E or possibly from slightly S of W to slightly N of E.

The following figure shows the objects plotted in their relative positions as seen overhead. They are numbered 1, 2, and 3. I estimate that all of them would fall within a circle of 15° diameter. They were first observed about 2 or 3 sec before reaching the zenith, and observation continued until they passed behind the clouds at an angle of altitude of about 45°. They were observed part of this time through 8 × 30 binoculars.



The sky overhead was dark and clear. There was no noticeable wind, and the background noise was low. No noise was heard to come from the objects. Total time of observation was estimated to be less than 60 sec. The objects were traveling at a higher angular rate of speed than normally observed for satellites in orbit or for high-flying planes.

Object no. 1 was brighter than a 1-mag star (possibly -1) and was yellow orange. Object no. 2 was much dimmer than no. 1 and varied in brightness as if tumbling or flashing. The color of no. 2 was similar to that of no. 1 but possibly more red and of estimated +2 or +3 mag. Object no. 3 was dimmer yet than no. 2 (estimated +3 to +4 mag) and consisted of a trail of sparks or fire of about 1° angular length. This trail (object no. 3) was dull red and could have been from a burning object; there was no noticeable head.

These objects are thought to have been the Apollo 7 craft and associated parts, but they were considerably off the predicted path.

3.2.5 Moonwatch Team, Panama City, Florida (observed by Mr. and Mrs. R. F. Suber; reported by N. K. McKinnon)

[Mr. and Mrs. Suber describe three separate objects, which they identify as I, II, and III (see figure below).]

Object I: appeared flaming on trailing (W) side; magnitude -4; red.

Object II: small and bright, with comet-like tail 10' (approx.) long; magnitude 0; red.

Object III: magnitude +2; white.

The colors are thought to have been due to burning, not to reflected sunlight.

Objects II and III disappeared about the zenith.

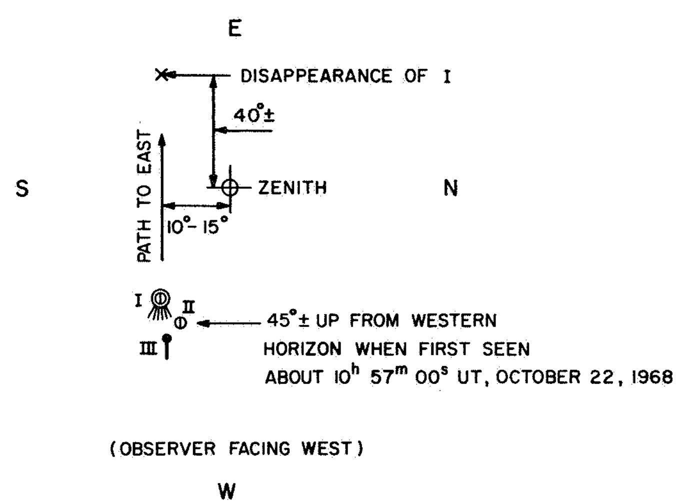
Object I disappeared 40° (approx.) E of the zenith, its color changing to light orange at disappearance; it grew fainter toward disappearance.

Estimated separation:

I – II	$0\overset{\circ}{.}25$ to $0\overset{\circ}{.}5$
I – III	$0\overset{\circ}{.}75$
II – III	$0\overset{\circ}{.}25$.

Total duration of visibility was something less than 1 min.

Speed of travel appeared to be too slow for meteors.



3.2.6 Panama City, Florida (observed by J. Wellhower, Jr.; reported by Dr. M. A. Elliot and D. P. Scott)

A few minutes before 6 A.M. CDT [they did not have a stopwatch but estimated the time], they saw three objects go directly overhead on a W to E path. The brightest object led the others and gave off a steady light. The second brightest object blinked.

They interpreted this second object as a craft with a red light blinking in it. The third object was observed to be fainter and less well defined. All the objects appeared to be traveling together and were yellow orange to reddish. All observations were by naked eye.

The objects were seen fairly soon after coming over the horizon in the W sky and followed until they disappeared at an elevation of about 40° to 45° in the E. The objects were visible for a total time estimated as less than 60 sec.

No sound of aircraft was heard at the time. Another reason why aircraft can be ruled out is that observers at all three local sites saw these objects as passing near the zenith. The spread from N to S of these sites is nearly 8 mi. Since the objects were moving on an approximately W to E line, they could not have appeared to be nearly overhead at both the northernmost and the southernmost sites unless they were much higher than conventional planes can fly.

A summary of these observations is given in Table 3.

Table 3. Summary of reentry observations

Site		Topocentric coordinates			Predicted position		
Location	Number	Longitude E	Latitude N	Height (m)	Azimuth (degrees)	Altitude (degrees)	Results
Mt. Hopkins, Arizona	9021	249°07' 18."618	31°40' 51."60	2420	175.0	15	Module reentry photographed with Baker-Nunn camera. Oct. 22/105238.155Z at position RA(1950) 07^h54^m3, Dec. -30°00' (see Figure 3 and description in text).
Phoenix, Arizona	8154	247 57 40	33 30 50	354	176.1	11	Module reentry observed visually. Oct.22/105221.74Z at position RA(1950) 07^h17^m, Dec.-39°13^m (see description and sketch in text).
San Antonio, Texas	8634	261 27 38.7	29 28 15.9	229	6.4	34	Clear sky, not observed.
Dallas, Texas	0129	263 14 27.76	32 51 09.77	172	164.1	22	Total overcast, not observed.
Dallas (Rose), Texas		263 13.7 (3 mi. NW of 0129)	32 52.5	170			Glow seen through cloud. Oct. 22/1058 to 1059Z at position az. S/SSW, alt. 20° /25° (see description in text).
Ft. Worth, Texas	0139	262 37 30	32 42 15	204	176.8	22	Dense cloud, not observed.
New Orleans	0031	269 52 54	29 56 21	6	351.9	25	"Did not see it—telegram not delivered, may have looked too high" (a bright reentry should have been seen).
Chattanooga	0062	274 45 52.56	35 01 02.43	234	185.9	12	Dawn fog, not observed.
Panama City	8673	274 20 26	30 09 22	6	359.4	32	Not observed, partly cloudy in predicted area.
Panama (Elliott)		274 14.6	30 11.43	6			3 objects visually observed. Oct. 22/105749Z near zenith (±10) bearing 85° from N toward E (see description and sketch in text).
Panama (Suber)		274 21 58	30 09 11	6			3 objects visually observed. Oct. 22/105700Z. Culmination az. S, alt. 75°/80° (see description and sketch in text).
Panama (Wellhoner)		274 21 15	30 16 35	3			3 objects visually observed. Oct. 22, a few minutes before 1100Z, from W through directly overhead (see description in text).
West Palm Beach	0147	279 56 34	26 38 13	2	350.2	07	Cloudy in area predicted, not observed.

4. ACKNOWLEDGMENTS

We thank Dr. Charles A. Lundquist, Assistant Director for Science at SAO, for his guidance in preparing this report, and John R. Gurley and Ben McCreary of NASA's Manned Spacecraft Center for their assistance in obtaining information on the Apollo 7 mission.

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FURTHER STUDY OF INTELSAT II F-2 APOGEE BURN

Michael R. Wolf

ABSTRACT

The Intelsat II F-2 communications satellite was placed in a synchronous earth orbit on January 14, 1967. This was accomplished by firing its 3000-lb-thrust apogee motor for 16 sec at the seventh apogee after launch. Three Baker-Nunn satellite-tracking cameras recorded the event simultaneously. From these films, the position during firing, probable ignition time, cloud brightness, and total magnitude are calculated. The possibility of photographing such events at even greater distances is discussed.

RÉSUMÉ

Le satellite de communication Intelsat II F-2 fût placé en orbite synchrone autour de la terre le 14 janvier 1967. Ceci fût accompli par la mise à feu de son moteur d'apogée de poussée de 3000 lbs., pendant 16 secondes, à la septième apogée après le lancement. Trois caméras Baker-Nunn pour le dépistage des satellites ont simultanément enregistré l'événement. On a calculé à partir de ces films la position pendant la mise à feu, le moment probable de l'ignition, la brillance du nuage et la magnitude totale. On discute de la possibilité de photographier de tels événements à des distances encore plus grandes.

КОНСПЕКТ

Спутник связи Интелстат II F-2 был помещен в синхронизированную орбиту 14го января 1967 г. Это было осуществлено запуском его мотора с 3000 фунтовым апогеем тяги в продолжение 16 секунд в седьмом апогее после запуска. Три Бэкер-Нунн камеры слежки за спутниками, одновременно записали происшествие. Из этих фильмов, высчитываются положение во время запуска, вероятное время воспламенения, яркость облака и общая величина. Обсуждается возможность сфотографирования таковых происшествий на даже больших растояниях.

FURTHER STUDY OF INTELSAT II F-2 APOGEE BURN*

Michael R. Wolf

1. INTRODUCTION

On January 14, 1967, three Baker-Nunn cameras photographed the firing of the apogee motor of the Intelsat communications satellite. These cameras were located at Tokyo Astronomical Observatory (TAO), Mitaka, Japan; Johnston Island, Pacific Ocean; and Rosamund, California. The photography was requested by NASA Goddard Space Flight Center for optical confirmation of the event.

The resulting films were as follows: Mitaka — 36 frames for 1^m43^s; Rosamund — 39 frames for 5^m37^s; Johnston — 9 frames for 4^m55^s. Photography at Mitaka was curtailed because of a bright sky low toward Tokyo.

The data were analyzed with the following questions in mind:

1) What was the position of the satellite during burn?

2) What was the probable time of ignition?

3) How did the brightness decrease with time after burnout?

4) What was the total magnitude of the cloud after burnout, and did it change with time?

5) How far away could one expect to observe such events?

The answers to these questions are discussed below.

This work was supported in part by grant NGR 09-015-002 from the National Aeronautics and Space Administration.

*Presented at the Astronomical Society of Japan Conference at Mizusawa, Japan, October 18, 1967.

2. SATELLITE POSITION

The Mitaka and Rosamund films were analyzed at the Smithsonian Astrophysical Observatory (SAO) headquarters in Cambridge, Massachusetts, to determine the satellite position during burn. Several contiguous frames from each station were chosen, and right ascension and declination for each image on each frame were determined. Parameters relating right ascension and declination to time were obtained by a least-squares process. A common time for both stations (January 14, 1967, $10^h11^m42^s.997$ UT1) was chosen, and corresponding α, δ pairs were determined for each station for that time. From these two positions, the satellite position in the earth's coordinate system (x, y, z) was obtained by a triangulation. The results of this analysis follow.

Satellite position:

x_s = -42,879 km,

y_s = -5047 km,

z_s = 39 km,

Distance from geocenter: 43,175 km,

Range from Mitaka: 39,999 km,

Range from Edwards: 40,590 km.

3. PROBABLE IGNITION TIME

In order to calculate probable ignition time, we decided to scan the best sequential frames with a microdensitometer and, from cloud dimensions versus time, extrapolate backward to find the time when the cloud dimension was zero. This was assumed to be ignition time. Frame nos. 1 through 15 for both Mitaka and Rosamund were chosen for the scans. The time span was therefore 30 sec, since the exposure interval was 2 sec for both stations.

The cloud dimension versus midexposure epoch was submitted to a linear least-squares program to obtain the parameters of the relationship between cloud dimension and time. From the constant term, the x intercept or ignition time can be calculated. Residuals of this fit were small and randomly distributed in sign, indicating good fit. The resulting ignition time must be corrected for finite densitometer slit width, finite image diameter, the velocity of light, and the fact that the image size really relates to the time at the end of the exposure and not to the time presented on the film. With all these steps completed and the ordinate converted to kilometers, the results are those shown in Figures 1 and 2. (Cloud dimension is to be considered approximate because foreshortening effects have not been taken into account.) Table 1, which gives the results of these calculations, shows that the mean of the two determinations agrees to about 0.2 sec with the telemetry-confirmed ignition time. We consider these to be rather good quantitative results from a completely photographic method.

Table 1. Plume-expansion rates and ignition times

	Mitaka	Rosamund
Projected plume-expansion rate	≈ 3.52 km/sec	≈ 3.31 km/sec
Calculated ignition time (compared to telemetry-confirmed ignition time)	0.347 ± 0.481 sec earlier	0.216 ± 0.867 sec later

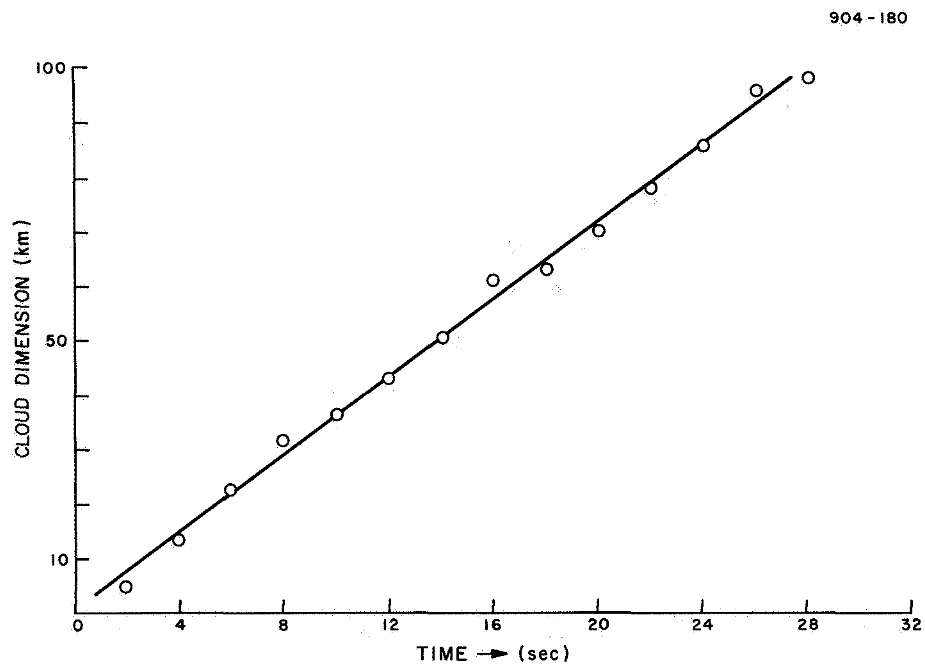

Figure 1. Intelsat cloud expansion (Mitaka data).

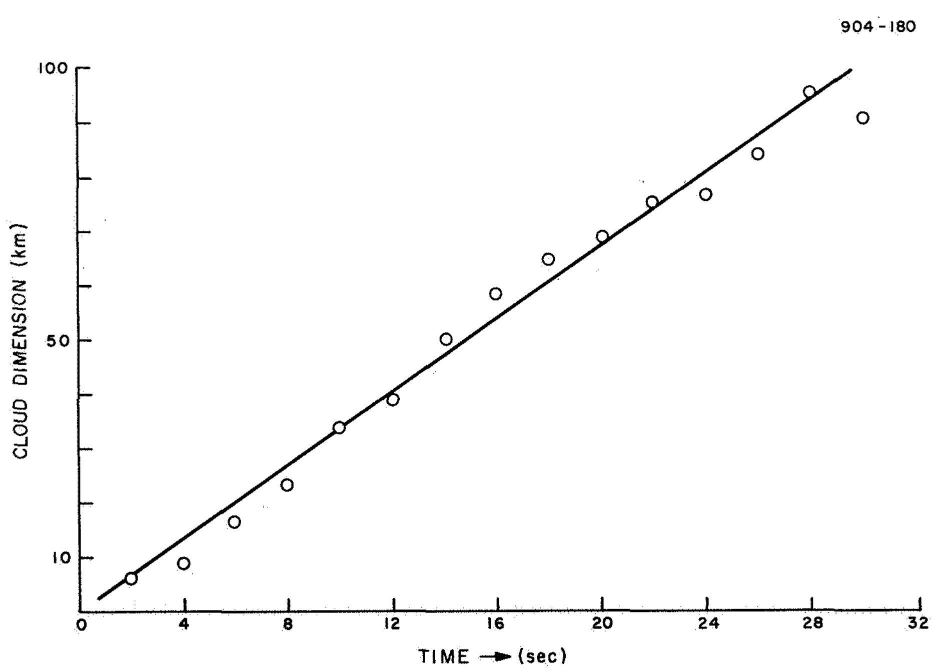

Figure 2. Intelsat cloud expansion (Rosamund data).

4. CLOUD PHOTOMETRY

Two basic features of the cloud photometry will be considered. The first is the "brightness," or lumens per unit area per steradian. This quantity relates to an extended source only and consequently is independent of the distance of the source from the observer. This means that the density of the image of a diffuse extended source on a plate is independent of that distance. As the distance changes, only the size of the image on the plate changes, not the density. The second feature is the total magnitude of the cloud. We integrate the light from the image and calculate the total lux, or lumens per square meter, that falls on the collecting lens. From this quantity we can calculate the magnitude from the relation $m = -2.5 \log(\text{lux}) - 13.94$. This magnitude, unlike the brightness, obviously depends on the source-observer distance.

In the following analysis, extinction will be ignored because we decided that to apply it <u>a priori</u> to the observations would be unjustified and no data were taken during the observations that would allow its calculation. A sensitometer strip exposed on the Mitaka film was crucial to its analysis. The actual intensity that fell through each step of the wedge was accurately known. By scanning the wedge with a densitometer, we could plot D vs. log (E), the familiar Herter-Driffield (H-D) curve. Since the wedge was on an area of the film not exposed to the sky, it could be used to calculate the average magnitude per square degree of the sky "background" light. Within the range of interest, the H-D curve was quite linear. No increase in accuracy could be gained by assuming a nonlinear shape for the H-D curve. The programs used to reduce the data assumed the linear relationship $\log E = D/\gamma + i$, where E is the exposure in meter-candle-seconds, D is the "instrumental density,"* γ is the contrast, and i is the inertia. Given the empirically determined H-D curve (from the sensitometer strip), the density measurements on incrementally small areas of the image of the Intelsat burn can be made and the instrumental density can be converted to meter-candle-seconds. If the effective meter-candle-seconds that came from the sky background light are subtracted from this, what is left is the light from the object within the scanned area. Figure 3 shows exactly this kind of analysis applied to an area of 45 × 45 μ on each of seven Mitaka frames. The area chosen for the density readings on each image was the center of the brightest spot. The resulting values were converted to brightness by means of the formula

$$B = \text{lux/solid angle} \quad .$$

The brightness of the cloud decreases with time. When plotted on both log-log and semilog scales, the data appear to follow a rule more of the form $B = k\,T^{-n}$ than $B = B_0\,e^{-at}$ (see Figure 3). The value of n seems to be approximately 4, but "noise" in the data makes probably fruitless any further speculation, such as an attempt to derive an analytical expression for the brightness versus time and compare it with the data.

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*The term "instrumental density" is used to avoid any reference to absolute density, which is difficult to define. Here, "instrumental density" means the density as measured on the actual densitometer, with rather accurate scale and arbitrary zero. This definition introduces no problems, as the sensitometer wedge was measured in the same run as the film of the Intelsat burn, with the same slit and other parameters. Calibration to an absolute standard of density is unnecessary. The important thing is that the scale of the instrument be accurate, i. e., that density differences be accurately measurable. To test this, the density wedge from the Kodak sensitometer was read on the machine. This wedge has 21 steps, from nominal density of 0.05 to 3.05 in steps of 0.15. When read on the machine with the same scan parameters used to read the films, the density <u>differences</u> were as close to 0.15 as the width of the ink line on the chart, i. e., as accurate as could be read from the instrument.

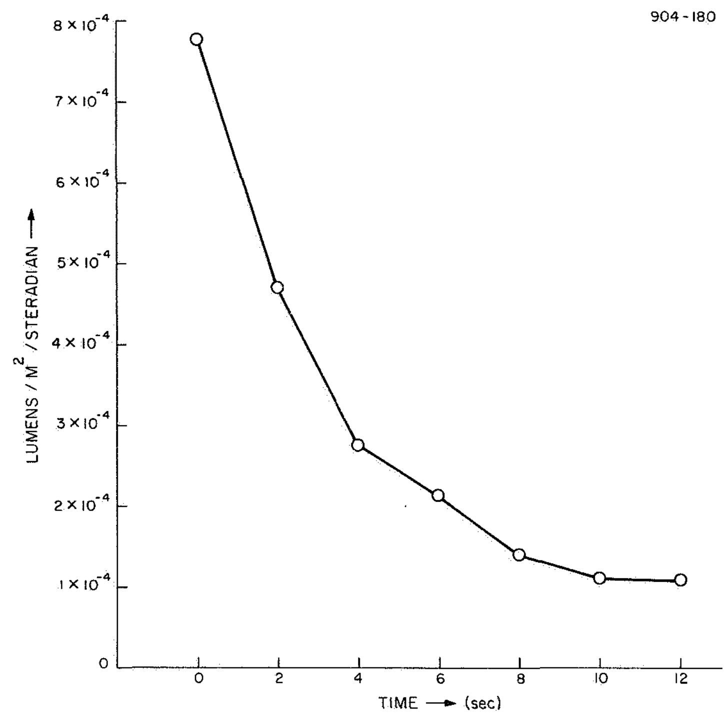

Figure 3. Cloud brightness versus time after burnout.

The total magnitude of frames no. 9 and no. 13 from Mitaka was calculated in a way similar to the brightness scheme already outlined, except that more than one intensity was involved per image. Actually, the images were digitized in density, and a total of about 150 incremental areas per image resulted. Each of these density values was converted to lux and the value for the sky background, calculated in a similar way from the density of the sky near the image, was subtracted. Then all the values were summed to give the total light intensity from the source. The intensity was converted to magnitude via the familiar formula

$$m = -2.5 \log (\text{lux}) - 13.94.$$

The value +8.77 resulted for frame no. 9, and +9.12 for frame no. 13. Hence, the total magnitude increased 0.35 m in 8 sec. One might expect perhaps a slight increase due to condensation or clumping of the grains after burnout.

The program used to determine total magnitude also calculated total magnitude per square degree for sky background. For Mitaka it yielded a value of +1.9 compared to +1.3 derived photoelectrically at Mitaka some years ago at the same azimuth and elevation.

Since the Rosamund film had no sensitometer strip, the parameters γ and i had to be determined in a different way. Fortunately, the Orion nebula was on the film. Also, since the film appears to have been taken under perfect sky conditions, a sky background of +4 magnitude per square degree was assumed. These two facts enabled us to calculate γ and i in the following way. The image of the Orion nebula was digitized in density as in the preceding analysis, except that for the Orion nebula, more than 700 points resulted instead of 150. The program used to calculate total magnitude also calculated magnitude per square degree for the sky from the background density above developer fog. The γ and i were chosen so that this calculation came out +4. Then the total magnitude for the nebula was calculated. If it did not agree with the published value, a new pair of γ, i was chosen and the process repeated. The fact that it is possible to covary γ and i in such a way as to maintain a constant sky brightness makes the process much speedier. A pair γ, i can always be chosen so that the background magnitude comes out +4. In fact, this restraint establishes a single-valued relationship between γ and i. A choice of γ determines i automatically. Thus, all that had to be done was to choose successive values of γ until the magnitude of the Orion nebula agreed with the published value. Then the values that the computer used for γ and i were printed out. These values were assumed to be physically meaningful for the film. Once γ and i were determined, the Intelsat image was digitized in density and the same process that was used for the Mitaka film was employed to calculate the total magnitude, which was +8.04 for frame no. 9 from Rosamund. This is rather remarkable agreement for such a crude method.

Ignoring the extinction would affect the results in the following manner. The Edwards data were calibrated on the light from the Orion Nebula diminished by extinction, while the value used for the nebula's magnitude was that for outside the atmosphere. This procedure tends to make the Intelsat magnitude too small (8.04). The Mitaka data were calibrated on sensitometric data and yielded a magnitude for light immediately in front of the lens (i.e., diminished by extinction) that is too large (8.77). Since we know the values were affected in opposite directions and, at least roughly, by the same amount by extinction, we take the logarithmic mean as our best value, i.e., m = +8.34.

5. PHOTOGRAPHY AT GREATER DISTANCES

One rather interesting and useful feature of photographing "extended sources" such as Intelsat is that the density of the image is independent of the distance from source to camera. This is true as long as the image dimension is appreciably larger than the stellar image size for the camera involved. This means that the event would have had the same apparent brightness no matter how far away, except for the above limit. The only thing that would change with distance would be linear image dimension, which would vary inversely. When the source is appreciably farther than would yield an image size equal to stellar image size, then the same rules apply that apply to stellar sources; i.e., we need consider only the total magnitude of the source in relation to the magnitude limit of the camera. The distance to Intelsat for which the cloud length of 50 km (size at burnout) would have yielded a point image is roughly 1.8 times the earth-moon distance. (Actual firing took place at about 0.1 times the earth-moon distance.) If the total magnitude of the cloud is taken as +8.3 at the actual distance of 4×10^4 km, then the apparent magnitude at 1.8 times earth-moon distance is +14.7. The magnitude limit of the New Mexico Baker-Nunn under perfect sky conditions has been determined to be +15.5, although most Baker-Nunn cameras are perhaps closer to +14.5. The cloud, then, could have been photographed by Baker-Nunns in good optical "tune" under perfect sky conditions at distances up to 2.5 times the earth-moon distance. We must remember that we are assuming a shutter speed of 0.4 sec. The Baker-Nunn can and does photograph at longer exposure times: routinely up to 3.2 sec and up to 2 min for special purposes, although longer intervals between exposures would make the data on the cloud less meaningful.

6. ACKNOWLEDGMENTS

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APPENDIX

Intelsat II F-2 Motor Plume Composition*

(mole percent)

H_2	24.94%
CO	20.61
H_2O	18.75
HO_1	16.41
N_2	8.40
AL_2O_3	7.40
CO_2	2.64
H	0.51
CL	0.24
OH	0.06
$AlCl_2$	0.02
AlCl	0.01
NO	0.01

*Data courtesy of Comsat Corp.

BIOGRAPHICAL NOTES

MARY GRANDFIELD received the A. B. degree in 1964 from Trinity College in Washington, D. C.

Miss Grandfield worked at Smithsonian Astrophysical Observatory from 1964 to 1969. From 1967 to 1969 she served as chief mathematician and supervised the Data Division's orbit evaluation unit.

DANIEL HANLON received the B. B. A. degree in 1959 from the University of Massachusetts at Amherst.

Mr. Hanlon has been with the Smithsonian Astrophysical Observatory since 1959 and is currently working in the Moonwatch Division.

Mr. Hanlon is now involved in the gathering of information about satellite observations.

MISS KAREN HEBB received a B.S. in astrophysics from Marlboro College in 1965.

Miss Hebb joined SAO in 1964 and completed her thesis work on stellar and comet photometry. She is currently an astronomer with the Celescope and satellite geophysics programs.

EDWARD H. JENTSCH was graduated with a B. S. in mechanical engineering from Newark College of Engineering in 1963. He joined SAO in 1963 and worked as an observer at Florida, Cold Lake, Canada, and Spain. He was transferred to headquarters as a mechanical engineer in 1967 and is now Operations Officer for the Satellite-Tracking Program.

ROBERT YORKE expects to receive the B. S. degree from Boston University in 1970.

Mr. Yorke has been with the Smithsonian Astrophysical Observatory since 1959 and is currently assistant manager of the Mount Hopkins Department.

MICHAEL R. WOLF received his Bachelor of Science degree from the Massachusetts Institute of Technology in 1964 and joined the Smithsonian Astrophysical Observatory as an observer in the same year.

Mr. Wolf is currently working in Cambridge, in the satellite geophysics group. He was the SAO representative at the Tokyo Astronomical Observatory when he wrote this Special Report.

NOTICE

This series of Special Reports was instituted under the supervision of Dr. F. L. Whipple, Director of the Astrophysical Observatory of the Smithsonian Institution, shortly after the launching of the first artificial earth satellite on October 4, 1957. Contributions come from the Staff of the Observatory.

First issued to ensure the immediate dissemination of data for satellite tracking, the reports have continued to provide a rapid distribution of catalogs of satellite observations, orbital information, and preliminary results of data analyses prior to formal publication in the appropriate journals. The Reports are also used extensively for the rapid publication of preliminary or special results in other fields of astrophysics.

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