

DIGITAL VIDEO ANALYSIS OF ANOMALOUS SPACE OBJECTS

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Video data showing multiple objects moving in unusual trajectories in space is examined. The video was captured by a camera aboard the Space Shuttle Discovery (mission STS-48) between 20:30 and 20:45 GMT on 15 September 1991 near the West Coast of Australia. Digital video analysis is performed to determine if the objects in question are ice particles disturbed by a thruster firing as contended by NASA or other objects moving independently of the shuttle. Results of our analysis show that it is unlikely that a thruster firing occurred since the attitude of the spacecraft does not change. Our analysis indicates that there are two groups of correlated object motions. One group changes direction at the time of a flash, claimed by NASA to be due to a thruster firing. The other group changes direction 1.5 seconds later. Assuming the objects are roughly the same size, brightness measurements of the objects as they pass over the airglow layer near the limb suggest that the objects in the first group are farther away yet they change direction first. This behavior is inconsistent with the thruster firing hypothesis. For one of the objects known as the "target", it is shown that the only hypothesis that is consistent with the data is that the object is at or near the physical horizon. We go on to show that several other objects in the video are clearly moving in circular arcs and are thus likely to be relatively far away from the shuttle. The estimated speed of one of these objects, about 35 km/sec, is approximately the same as that of target if we assume that it is at the physical horizon. At the end of the event, the shuttle's camera pans down to reveal a number of objects moving below the shuttle. One of the objects appears to have a definite structure consisting of three lobes arranged in a triangular pattern.

1. INTRODUCTION

On September 15, 1991, live video showing multiple objects moving in unusual trajectories was captured by cameras aboard the Space Shuttle Discovery (STS-48). The video, which was being broadcast over NASA Select TV, was recorded by Mr. Donald Ratsch. Mr. Ratsch observed what he believed to be four anomalous events. One of those events was recorded by a camera in the shuttle's payload bay between 20:30 and 20:45 GMT near the West Coast of Australia. The event involves perhaps as many as a dozen objects moving in different directions relative to the spacecraft. One of the objects appears at a point near the horizon and moves in a path that seems to follow the horizon. After a flash, the object abruptly changes direction and speed. This is followed a few seconds later by a streak that moves rapidly across the field of view and crosses the path of the object. At the end of the event, the camera pitches down to reveal several objects moving below the shuttle. One of the objects has a triangular shape.

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Within days Mr. Ratsch provided copies of his original recording along with detailed descriptions of four anomalous events to various investigators including NASA. Two months later after reviewing the video, NASA agreed with his descriptions of the events but disagreed with his interpretations (i.e., that they were UFOs). NASA concluded the objects seen in the video were either ice particles or orbiter-generated debris illuminated by sunlight¹. Concerning the event considered in this paper they stated:

"The objects seen are orbiter-generated debris illuminated by the sun. The flicker of light is the result of firing of the attitude thrusters on the orbiter, and the abrupt motions of the particles result from the impact of gas jets from the thrusters."

The purpose of this paper is to examine this event in detail in order to determine if the objects in question are indeed debris in close proximity to the shuttle disturbed by a thruster firing as contended by NASA, or more distant objects moving independently of the shuttle. After providing additional background information in Section 2, the motions of all key objects are examined in Section 3. The remaining sections focus on specific objects and phenomena observed during the event. Section 4 analyzes the trajectory and brightness of one of the objects (the "target") in detail. Section 5 focuses on several objects on the other side of the frame, including a very bright pulsating object, which appear to move in circular paths. An enlargement of a triangular-shaped object traveling below the shuttle is also presented in Section 5. Section 6 summarizes our findings and suggests future work.

2. BACKGROUND

STS-48 was the 43rd shuttle mission and the 13th flight of Discovery. The crew was John Creighton, Ken Reightler, Jim Buchli, Mark Brown, and Sam Gemar. STS-48 was launched from the Kennedy Space Center on September 12 and landed at Edwards Air Force Base on September 18, 1991. The shuttle's orbit was inclined 57 degrees to the equator. Its altitude was about 570 km with an orbital period of 96.1 minutes.

The event considered in this paper occurred when the shuttle was passing near the West Coast of Australia. The approximate location of the event is indicated in Fig. 1 and occurred between 20:30-20:45 GMT. (We note that Mr. Ratsch recorded another anomalous event not considered in this paper one orbit earlier in approximately the same location.) At this point in the mission, Discovery was traveling in a southeasterly direction in darkness, nearing the day-night terminator as shown in Fig. 2. Flying "belly-first", one of the cameras in the payload bay was looking back toward the earth and the horizon; the sun was beginning to rise towards the right.

¹ Letter dated 22 November 1991 to Representative Helen Delich Bentley from Martin P. Kress, Assistant Administrator for Legislative Affairs, NASA.

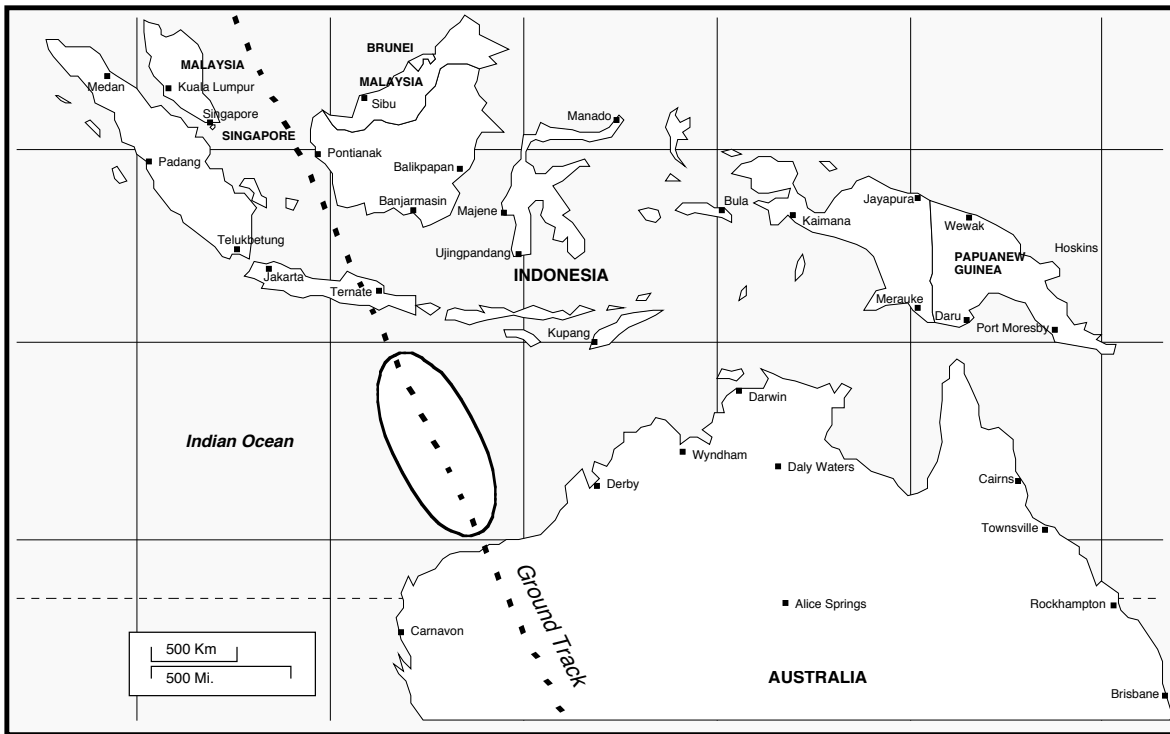


Fig. 1 Approximate Location of Event

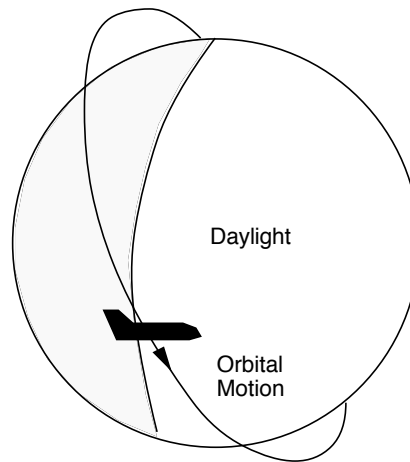


Fig. 2 Shuttle Orbital Geometry

To more precisely define the attitude of the shuttle during the event, video keyframes prior to the event were digitized from the video data. Stars visible in these keyframes were extracted and assembled into an image strip and identified using a star chart. The image strip and star

chart are shown in Fig. 3. The two most prominent stars seen during the event are Errai and Polaris (designated M2 and M3 in the next section) with apparent magnitudes of 3.21 and 2.02. The angular separation between Polaris and the Sun is approximately 87° (Fig. 4). We are thus able to verify that the shuttle's camera is in fact looking north with Polaris and Errai within the field of view and the sun rising to the right of the camera.

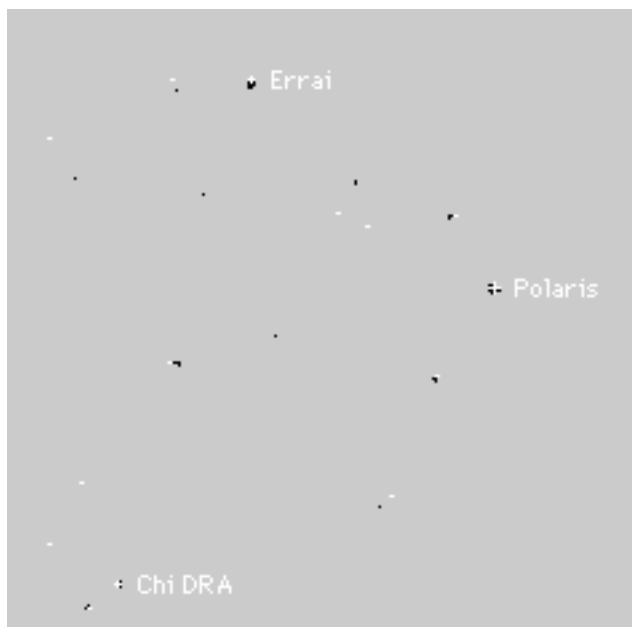


Fig. 3 Star chart (white) overlaid on stars from shuttle video (black) with gray background

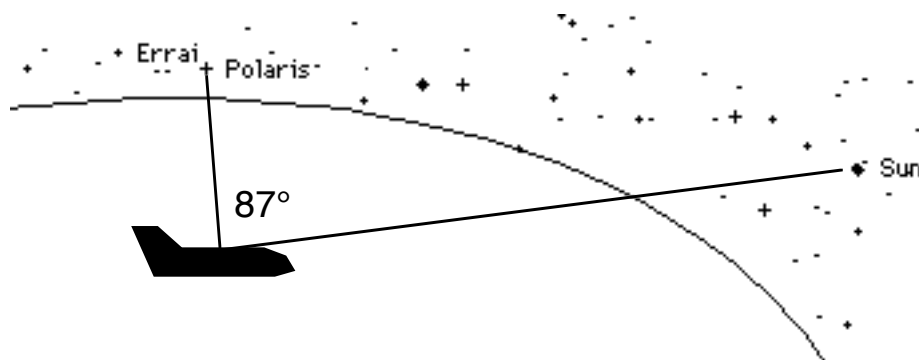


Fig. 4 Relation between Shuttle, Polaris, and Sun

The event was recorded by Mr. Ratsch in VHS format. Our analysis was performed on digitized portions of a first-generation VHS copy of his original recording. In most cases the objects of interest are only a few pixels in size so it is not possible to resolve their actual spatial extent. Brightness values were scaled to 8 bits ($0 \leq \text{DN} < 256$) with the brightest pixels kept well below saturation ($\text{DN}=255$).

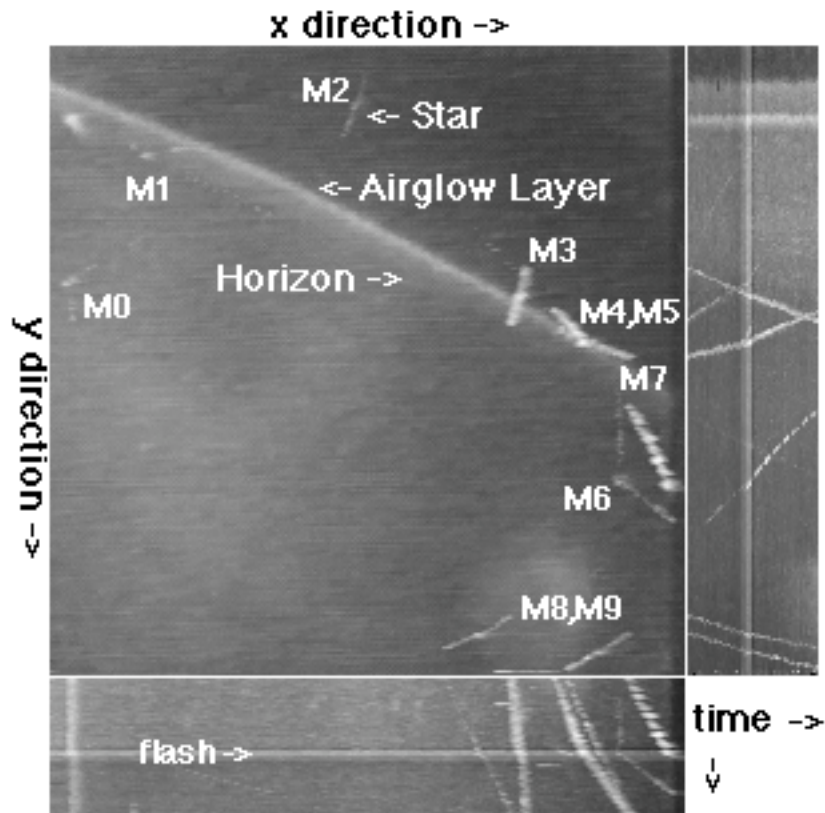


Fig. 5 Overview of Event Presented as "Unfolded Volume"

3. TRAJECTORY ANALYSIS

First we captured the overall event in 51 key frames, digitized one second apart. Since the shuttle had just moved into sunlight, the full video frame (640x480) was cropped to 480x480 pixels to eliminate lens flare from the sun reflected on the left side of the frame. Fig. 5 summarizes the overall sequence in the form of an unfolded volume. The x-y plane shows a time average of the object motions over the full 51 seconds; the x-z and y-z planes show cross-sections of the motions over time. Key objects are denoted M0-M9. The location of the flash in time is also noted in the figure. Objects M2 and M3 are setting stars (Errai and Polaris). Over the 51 second sequence, M2 and M3 move 3.18 degrees. Their measured displacement in the video frame was 49 pixels which yields a scale factor of 0.065 degrees/pixel. The field of view shown in Fig. 5 is thus approximately 31 degrees in size.

Fig. 6a plots the 2-D motions of all 10 objects derived from the 51 frames. Object locations were manually extracted from each digitized frame. The general direction of motion of each object is indicated in Fig. 6b.

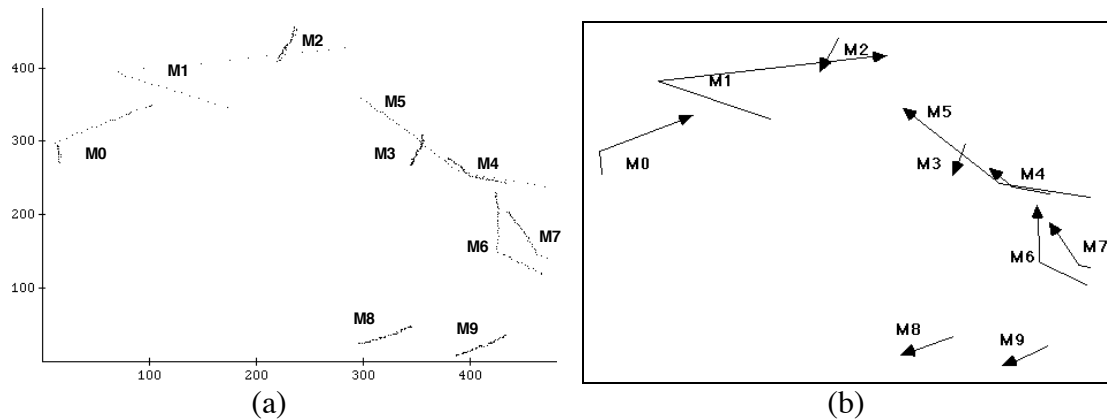


Fig. 6 Summary of 2-D Object Motions

Fig. 7a shows the direction of motion in the viewing plane of two objects (M0 and M1) that appear to change direction at the same time. Directions are in the range 0 to 2π radians where 0, $\pi/2$, π , and $3\pi/2$ radians are to the left, down, to the right, and up, respectively. In Fig. 7b the direction of motion of M4-M7 are overlaid on those of M0 and M1. We note that M4-M7 appear, as a group, to change direction about 1.5 seconds after M0 and M1. Objects M2, M3, M8 and M9 do not appear to change direction in Fig 6 and are thus not shown in Fig 7. M2 and M3 are setting stars as noted above; M8 and M9 are moving towards the shuttle but cannot be lights on the earth's surface. (Since the camera is looking back, lights on the surface would move away from the shuttle toward the horizon.)

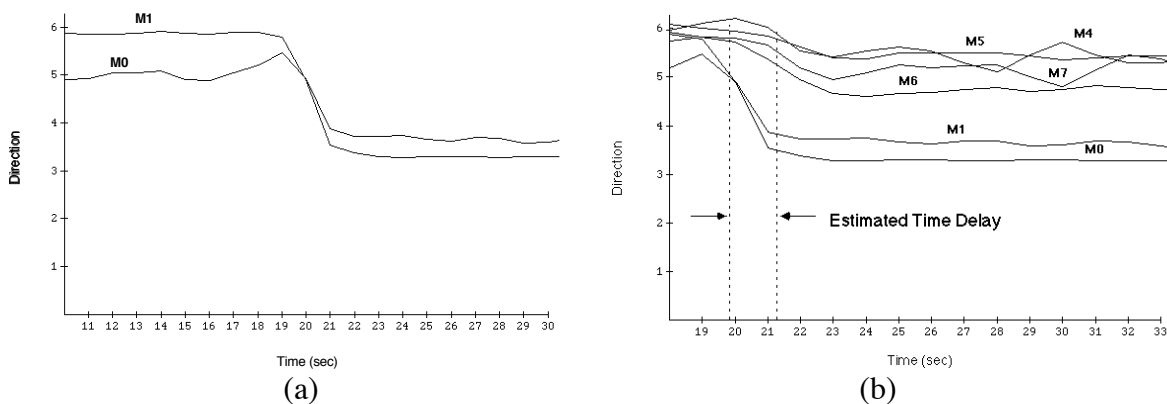


Fig. 7 Correlated 2D Object Motions

NASA's explanation is that the observed flash is the firing of an attitude control thruster whose exhaust gases subsequently altered the trajectory of particles floating near the shuttle. There are three groups of thrusters on the orbiter: in the left- and right-hand Orbital Maneuvering System/Reaction Control System (OMS/RCS) pods on the aft fuselage and in

the forward fuselage². The RCS provides thrust for velocity changes and attitude control. Each of the aft RCS pods has 12 primary and 2 vernier engines with 870 and 25 lbs. of thrust respectively. The verniers burn either in 80 millisecond pulses or continuously from 1 to 125 seconds. The main thrusters fire in 80 ms pulses only.

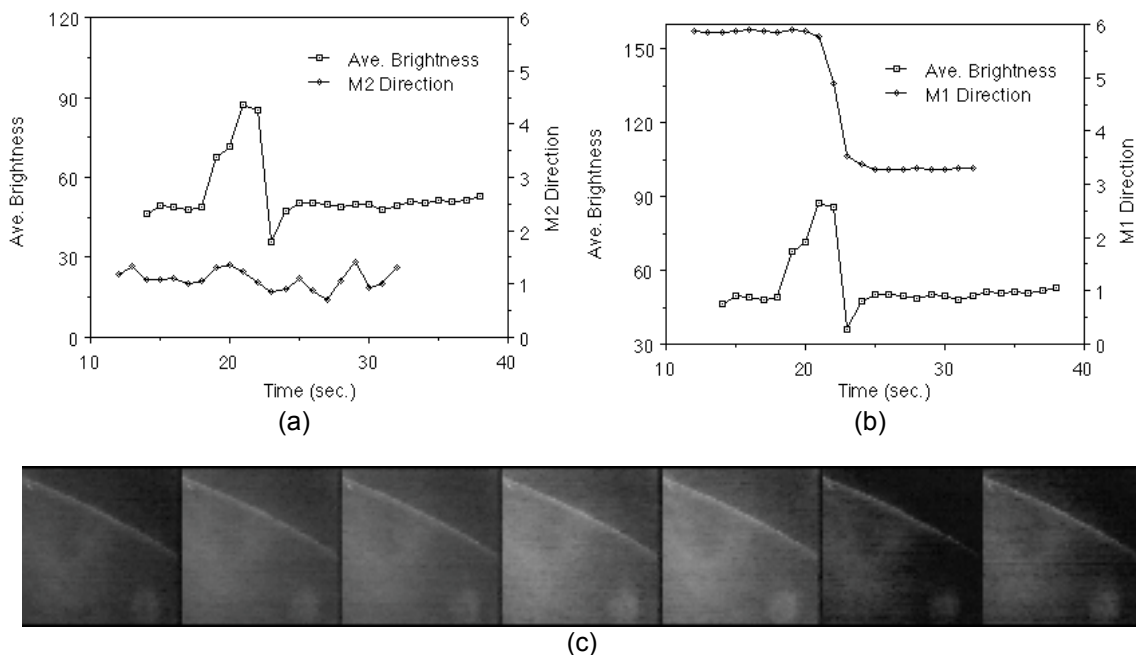


Fig. 8 Frame brightness during thruster firing

Fig. 8a plots the average brightness of the video frame as a function of time along with the direction of motion of one of the stars M2. (A plot of the frame brightness and the motion of M1 is shown in Fig. 8b for reference.) Following the jump in brightness, purportedly due to the thruster firing, there is no detectable change in the direction of M2. Yet the apparent motion of all objects including M2 must change if the attitude of the spacecraft was altered by the thruster firing. Fig 8c shows seven frames spaced 1 second apart between t=19 and t=25 seconds. From the length of the brightening observed in the video it is likely that the thruster in question is probably one of the verniers located in the aft OMS/RCS pod to the left of the camera. According to Oberg³ the angular rates induced by the primary thrusters are between 0.05 and 0.1 deg/sec. An 80 ms burn of the vernier thruster would cause a much smaller motion, between 0.0014 and 0.0029 deg/sec. However the length of the flash indicates a longer burn. If we assume the vernier thruster fired for 1 second (conservative), the angular rate would be between 0.0175 and 0.0363 deg/sec. Ten seconds after the thruster firing, the attitude would change by 0.175 to 0.363 deg, or 2 to 6 pixels which should be easily detectable either in a deflection in the apparent motion of the stars or a shift of the

² S. Z. Rubenstein, "Space shuttle orbiter," in *Space Shuttle: Dawn of an Era, (AAS 79-271) Proceedings of the 26th American Astronautical Society Annual Conference*, November 1979, Los Angeles.

³ Letter dated 23 November 1992 to Erik Beckjordan from James Oberg. Courtesy copy sent to Dan Ratsch.

location of the horizon. The lack of any deflection in star motion or change in the location of the horizon line suggests that the flash was not caused by a thruster firing.

4. ANALYSIS OF OBJECT M1

The most interesting object is M1 which appears at a point just below the horizon. It then moves along a line parallel to and just below the horizon. Prior to the flash mentioned earlier, the object slows and seems to stop. After the flash it changes direction, accelerates and moves across the airglow layer. Shortly thereafter, a streak crosses the object's trajectory as it continues into space. The streak, which is somewhat difficult to see in the video, has been interpreted by Hoagland⁴ as a discharge from a kinetic energy weapon aimed at M1 - As a result M1 has been called the "target". Hoagland also speculates that the flash is an electromagnetic pulse effect induced in the camera by the weapon.

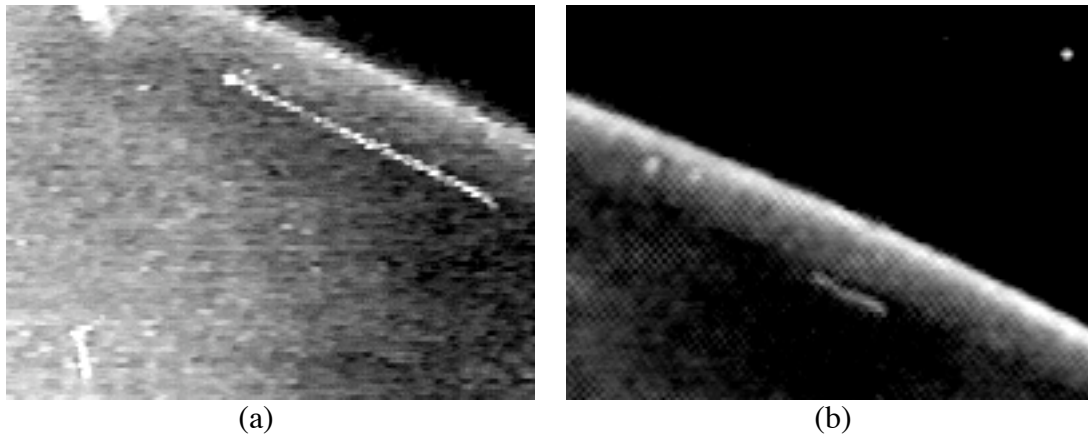


Fig. 9 M1 Track Along the Horizon

Fig. 9 shows time exposures computed from a sequence of images of M1 as it moves along the horizon. Fig. 9a is the maximum pixel brightness across the sequence and clearly shows the object appearing at a point just below the horizon line and moving in a path that follows the curve of the earth. Fig. 9b is the average brightness for a subset of images in the beginning of the previous sequence. This second figure more clearly delineates the boundaries between the earth, atmosphere, and airglow layers, and better shows the object appearing and moving below the horizon.

⁴ R.C. Hoagland, *The Discovery Space Shuttle Video*, B.C. Video Inc., New York, 1992.

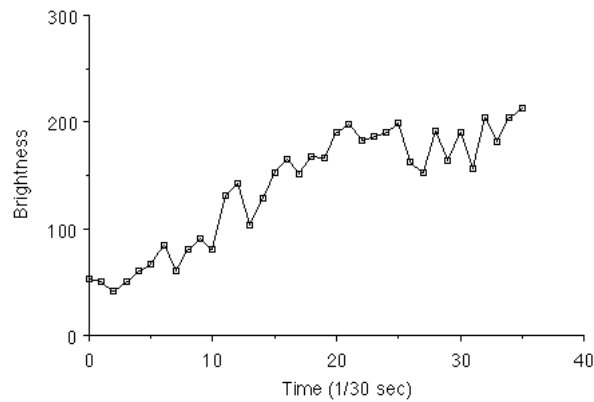


Fig. 10 M1 Brightness at Point of Appearance

A slight tail at the beginning of the track (Fig. 9a) suggests that the object may be moving up and out of the atmosphere. This hypothesis is consistent with measurements of the M1's brightness. Fig. 10 shows the brightness of M1 at the point where it appears. Instead of changing abruptly as one would expect of an ice particle near the shuttle passing from shadow into sunlight, the brightness increases gradually over a 1 second period. M1's brightness then remains relatively constant as it moves along the horizon line. We also note that there is a lack of significant variations in brightness (with the exception of random measurement errors). Large fluctuations in brightness are typically observed over time when viewing ice or other rotating particles reflecting sunlight as discussed later in the paper.



Fig. 11 Time Exposure of M1 Passing across Airglow

Fig. 11 is another time-exposure that shows M1 beginning approximately 2/3 seconds after the flash, after it has changed direction. The dashed line is M1 captured in 1/3 second intervals as it moves across the limb and atmosphere into space. The fainter line is the streak mentioned earlier that quickly moves from the bottom to the top of the image. It appears about 3 seconds later crossing the path of M1.

After M1 changes direction and accelerates, it decreases in brightness. Fig. 12a plots the distance in pixels of M1 from the point where it changes direction and accelerates. This distance appears to increase at a constant rate. If the object is moving in a straight line, the lateral distance measured in the image plane is proportional to the total distance traveled. Since the lateral distance appears to be increasing at a constant rate, we hypothesize that the total distance is increasing at a constant rate as well. If this is true, for an object of constant radiance, the measured irradiance (brightness) should decrease at a rate proportional to the inverse square of the distance.

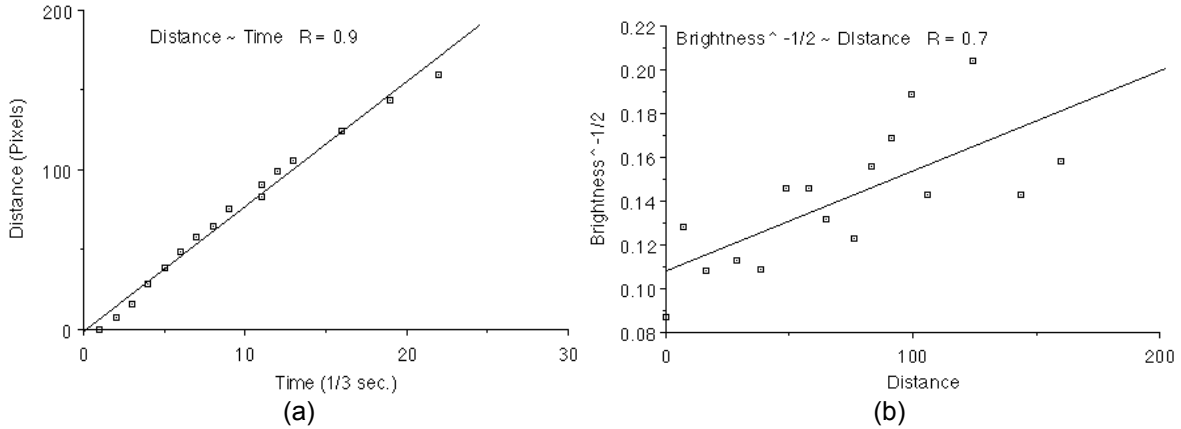


Fig. 12 Position and Brightness of M1 over Time

The brightness of M1 as a function of time was estimated as follows. First a series of background measurements across the limb and atmosphere were made along a path parallel to that of M1. These values were then subtracted from the corresponding brightness measurements of M1. For an object of constant radiance, the brightness $b = kd^{-2}$ where k is a constant and d is the distance from the object. Let b_0 be the initial brightness of an object at a distance d_0 from the observer. This initial distance is unknown. The brightness as a function of time can be written as

$$b(t)^{-1/2} = d(t)k^{-1/2} = [d_0 + \Delta d(t)]k^{-1/2}$$

$$b(t)^{-1/2} = b_0^{-1/2} + \Delta d(t)k^{-1/2}$$

where Δd is increase in distance as the object travels from point B to C (Fig. 13a). To test if the object is indeed moving away from the observer we plot the measured brightness values raised to the $-1/2$ power, $b(t)^{-1/2}$, versus the corresponding distances, $\Delta d(t)$ (Fig. 12b). The slope is $k^{-1/2}$ and the y-intercept is $b_0^{-1/2}$. The measured correlation (0.71) supports our hypothesis at a reasonable level of confidence that, following the flash, the object moves away from the shuttle at a constant velocity.

The above observations suggest a possible model for the 3-D motion of M1. With reference to Fig. 13b, we hypothesize that M1 initially moves at a constant velocity in a plane parallel to the horizon and observer from point A to B. M1 then changes direction and moves away from the observer (point B to C). Since the brightness decreases by a factor of at least 1/2, we conclude that the distance between M1 and the observer increases by a factor of $\sqrt{2}$ or more from point B to C.

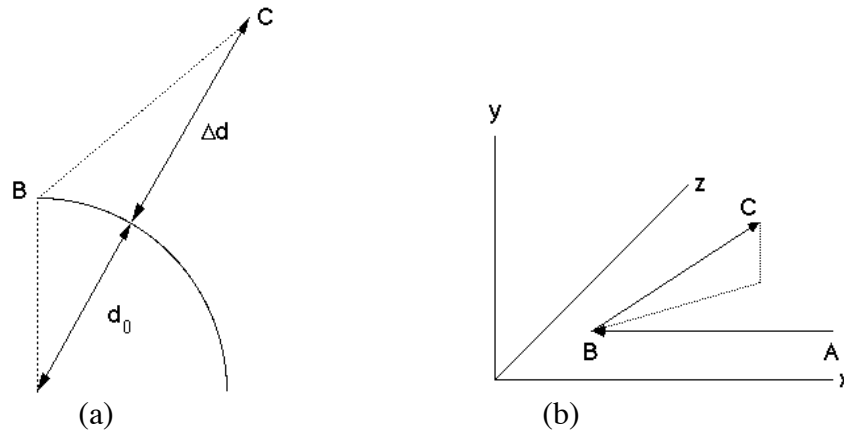


Fig. 13 Model to Determine 3-D Motion

The key question is: How far is M1 from the observer? Unfortunately, there is no direct way to determine this distance from the available data. However, M1 must be either 1) near the shuttle, 2) at the physical horizon, or 3) somewhere in between.

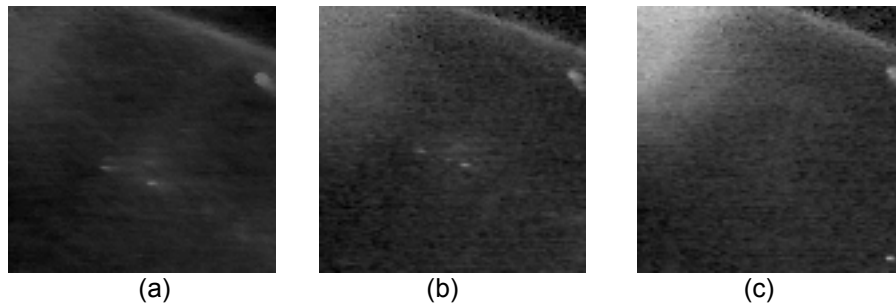


Fig. 14 Increase in lens flare at sunrise

Fig. 14 shows the upper left portion of the video frame before sunrise (a), at sunrise (b), and 50 seconds later (c). The brightening in the upper left is caused by an increase in scattered light from the right side of the camera lens. Thus when M1 appears in the video, the shuttle is in daylight with the sun to the right. M1 is downtrack from the shuttle and thus cannot be emerging from its shadow. It is thus unlikely that M1 is near the shuttle since there is no mechanism to explain its appearance.

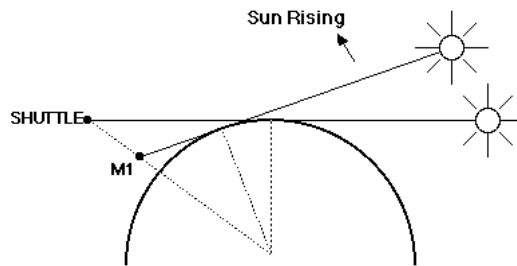


Fig. 15 Geometry for M1 Moving across Terminator

Another possibility is that M1 is farther away, somewhere in between the shuttle and the physical horizon. In the video, M1 appears about 50 seconds after Discovery enters daylight. The terminator is thus below the shuttle and moving away. One possible scenario is that M1 moves across the terminator from shadow to light as depicted in Fig. 15. The brightness at a point in the image is proportional to the total energy incident on the corresponding detector element. Since the angular extent of M1 is much less than the resolution of the camera, it could appear to increase gradually in brightness as it moves from shadow to light due to a gradually increasing fraction of its surface illuminated by the sun being summed by the detector element. However the object cannot move by more than one pixel over the period of brightening (about 1 second) for this effect to occur. Between points A and B in Fig. 13b, M1 moves 66.2 pixels in the video frame over an 8 second period. The lateral velocity, which is relatively constant over this interval, is thus about 8 pixels per second. M1's brightening is inconsistent with this scenario since it is moving too quickly.

This then leaves only one possibility - that M1 is farther away, perhaps at or near the physical horizon. Several observations made at the beginning of this section support this hypothesis. M1 appears as if emerging from up out of a cloud layer (recall the slight tail in Fig. 9a and gradual brightening measured in Fig. 10). It then moves along the horizon over an appreciable distance (Fig. 9) prior to the flash. Although this is the only hypothesis that is consistent with the data, it is at the same time seemingly impossible. If M1 is at the physical horizon then it is a most extraordinary object. Its distance, about 2700 km from the shuttle, implies that from the point where it appears in the video to the point where it seems to stop prior to the flash, its velocity is about 25.8 km/sec. Then, after the flash it changes direction and accelerates within seconds to a speed of 400 km/sec!

5. OTHER OBJECTS

With reference to Fig. 16, if an object is within or behind the atmosphere, the image brightness T is proportional to the sum of the object radiance F plus the atmospheric path radiance G (Case 1). If the object is between the atmosphere and the sensor and is smaller than the resolution limit of the sensor, then $F \leq T \leq F + G$ (Case 2). If the object is between the atmosphere and the sensor and is larger than the resolution limit of the sensor, the sensed brightness $T = F$ and the object occludes the background (Case 3).

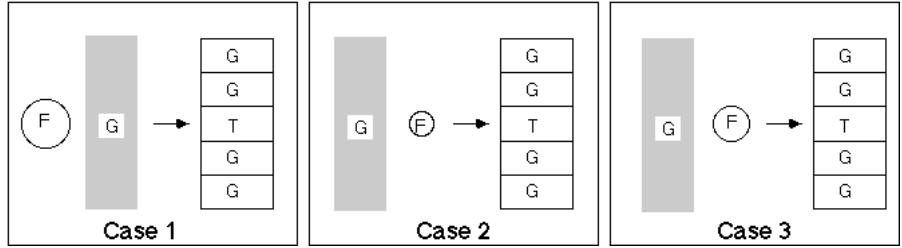


Fig. 16 Object/background models

The video seems to show two groups of correlated objects. At the left, M1 and M0 are one group of objects which appear to change direction at the time of the flash. The other group consisting of M4-M7 appear to change direction about 1.5 seconds later. Fig. 17a plots M1's brightness after the flash when it changes direction and briefly passes across the airglow. M1 must be either Case 1 or 2 since it increases in brightness as it passes across the airglow. M4, an object in the second group, appears somewhat brighter and larger in angular extent than M1. Unlike M1, M4's brightness is relatively constant as it passes across the airglow as indicated in Fig. 17b. Thus it must be Case 3, either larger than M1 or closer to the shuttle. As noted earlier, M4 appears to change direction 1.5 seconds after M1. Assuming the objects are ice particles that are roughly the same size, the above brightness measurements suggest that the objects in the first group are farther away, yet they appear to be affected by the thruster gases and change direction first. This apparent inconsistency further decreases the likelihood that the thruster firing/ice particle hypothesis is correct.

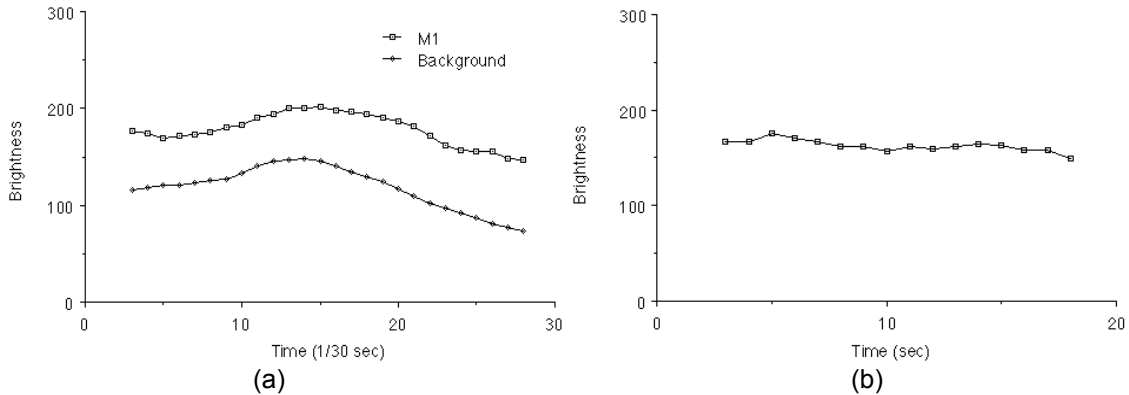


Fig. 17 Objects M1 and M4 Moving Across Airglow

While objects such as M1 and M4 exhibit a relatively constant brightness over time, others do not. For example, M6 pulsates at a rate of about 5/16 cycles per second (Fig. 18a). We contrast this with the brightness fluctuations of ice particles reflecting sunlight. Fig. 18b shows the brightness fluctuation of an ice particle released in the separation of the Apollo Command/Service Module from the LEM/Saturn V third stage⁴. The ice scintillates at a much faster rate - about 7 cycles/second compared to less than 0.5 cycles/second for M6.

Typically there is a range of rotational rates with larger ice particles rotating more slowly (longer fluctuations) than smaller ice particles. All of the objects in the shuttle video appear to be about the same size, yet some scintillate and others do not.

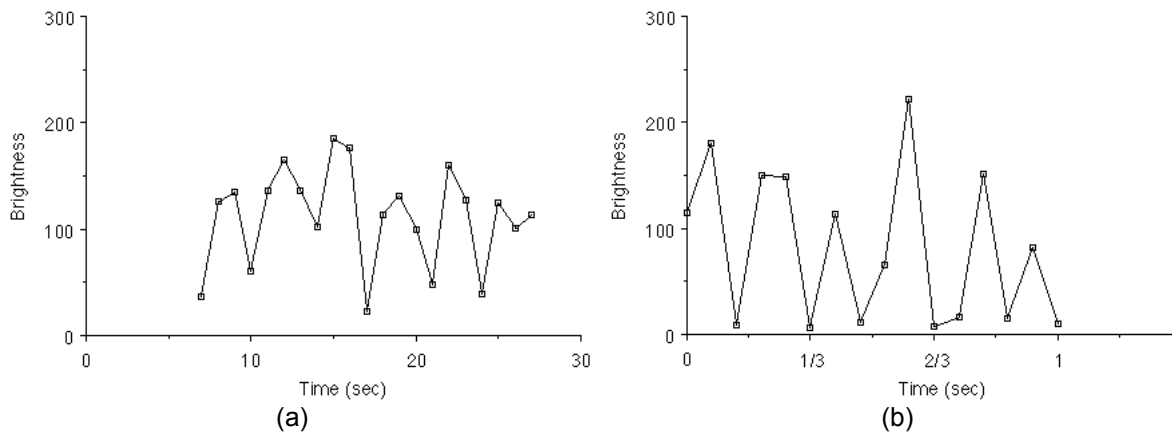


Fig. 18 Brightness Fluctuations of M6 and Ice Crystal



Fig. 19 Time Average of Objects M3, M4, M6, and M7.

The above observations suggest that we may be viewing a variety of objects - some closer to the shuttle than others, some pulsating, and others relatively constant in brightness. Perhaps the strongest indication that, at least, some of these objects are far from the shuttle and moving in independent trajectories is evident in the following set of measurements. A time average of 126 frames ($1/3$ second apart) from the right portion of the video frame is shown in Fig. 19. The three right-most traces are from M7, M6, and M4. M5 is too faint to be visible in this rendition. M3 (Polaris) is the straight line near the center of the picture. One can clearly see that the paths of M4, M6, and M7 are not straight lines but circular arcs. Prior to the alleged thruster firing, any debris near the shuttle that had been previously accelerated would appear to move in a straight line. On the other hand, an object moving in a different orbit far from the shuttle would follow a circular path. By measuring the arc length A and

chord C distances along an arc, the angle θ subtended by the arc can be found by solving the following transcendental equation:

$$2\left(\frac{A}{C}\right) \sin\left(\frac{\theta}{2}\right) = \theta$$

For M7, we obtained arc and chord distances of 52.01 and 51.87 pixels from averaging several sets of measurements. The angle was computed numerically and found to be 12.4 degrees. M7 cannot be orbiting the earth since the angular velocity 12.4 degrees/42 seconds = 0.29 degrees/second is too fast. We conclude that M7, M6, and M4 are far from the shuttle, moving around the earth, but not in orbit. If M7 is at about the same altitude as the shuttle, its estimated velocity is on the order of 35 km/sec. This is about the same speed M1 moves from point A to B along the horizon if we assume that it is at the physical horizon.

At the end of the event, the shuttle's camera pans down to reveal a number of objects moving below the shuttle. Fig. 20 is an enhancement of the largest object obtained by time averaging several registered video frames to reduce noise. The object appears to have a definite structure consisting of three lobes arranged in a triangular pattern.

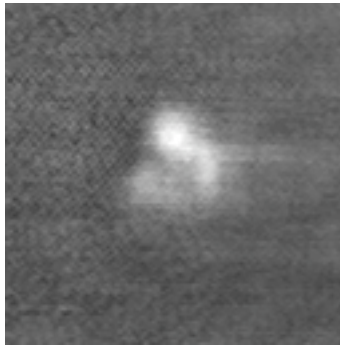


Fig. 20 Triangular-shaped Object Moving Below Shuttle

6. SUMMARY

Our analysis of the STS-48 video shows that the "ice particle/attitude thruster firing" hypothesis is not consistent with the observed behavior of the objects in question. The firing of an attitude control thruster might have altered the trajectories of particles close to the shuttle but would also have altered the apparent motion of the background (i.e., the earth's limb and the stars). Yet, no such change was measured in the video data.

We found that one of the objects (M1) emerges from point just below the horizon line. Rather than suddenly appearing, its brightness increases gradually over ~ 1 second interval. It moves in a path parallel to and just below the horizon line as its brightness remains relatively constant. The object then slows down, changes direction, and accelerates just after a flash is

observed. It moves at a constant velocity across the earth's limb, atmosphere, and airglow layer decreasing in brightness by at least a factor of 1/2 over a 7 second interval. The decrease in brightness implies that the distance from observer increases by at least factor of $\sqrt{2}$ over the same interval. We hypothesize that M1 emerges from up out of a cloud layer at or near the physical horizon, moves parallel to the horizon, changes direction, and rapidly moves away from the observer. If this hypothesis is correct then M1 must be very luminous to be detectable at such a great distance. Assuming a distance of 2700 km from the shuttle, the apparent magnitude of M1 (between 2 and 3) implies an intrinsic luminosity of between 2×10^5 and 5×10^5 watts.

Time exposures of three other objects M4, M6, and M7 suggest that, on the basis of the curvature of their arcs, they are far from the shuttle, moving around the earth, but not in earth orbit. If M7 is at about the same altitude as the shuttle, its estimated velocity is on the order of 35 km/sec. This is about the same speed computed for M1 as it moves along the horizon assuming that it actually is at the physical horizon.

We believe that the measurements and analyses contained in this paper establish beyond a reasonable doubt that the objects captured in this video are not orbiter-generated debris (e.g., ice particles) disturbed by a thruster firing. However, it is beyond the scope of this paper to speculate on what they might be. It can only be said that they are not meteorites flashing in the atmosphere, as it has been claimed for flashes seen from the shuttles, because the trajectories, velocities, and sudden changes in direction of certain objects studied in this paper are not compatible with this hypothesis.

An attempt should be made in future missions to detect and record similar events. In particular when not otherwise in use, the fore and aft cameras in the shuttle's payload bay should be monitored so that they can be positioned to allow stereo imagery of similar phenomena to be acquired and analyzed.

Acknowledgments

The author wishes to thank Dan Ratsch for recording this extraordinary video and Richard Hoagland for sharing it with me. I'd also like to thank Gerald Hawkins for taking the time to critique an early version of the manuscript.