Analysis of the Light Flash in the STS-48 Video

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Introduction

The STS-48 video sequence from September 15, 1991 shows a flash of light preceding the abrupt change in course of several objects. After a cursory examination of the video, NASA scientists attributed the flash to an exhaust plume from one of the shuttle's reaction control system (RCS) rockets.

NASA telemetry records show that the firing of an aft vernier thruster designated L5D coincided most closely with the light flash. A 2003 paper[1] presented an analysis of the transits of stars across the “nightglow” layer suggesting that the flash actually occurred several seconds after the thruster fired. However, that interpretation cannot be stated with complete certainty, mainly because of the possibility of an unaccounted-for difference in the true altitude of the nightglow layer from what was assumed. The same paper described characteristics of the light flash itself that I believe are considerably stronger evidence that the flash was not associated with the thruster pulse. Specifically, the distribution of brightness in the video frames attributable to the light flash was shown to differ greatly from what had been expected up to that time based on the position of the thruster relative to the camera.

This paper is concerned exclusively with the characteristics of the light flash. It incorporates some of the discussion from the 2003 paper and presents significant additional information. It addresses an argument made by James Oberg in response to the 2003 paper that the light flash could still have originated from the thruster despite its unexpected brightness distribution. It also describes a more recent analysis of the variation of the flash brightness over time. The actual length of the light flash was found to be several times longer than the amount of time the thruster fired, completely precluding any relationship to the thruster firing.

The Thruster Plume Interpretation of the Light Flash

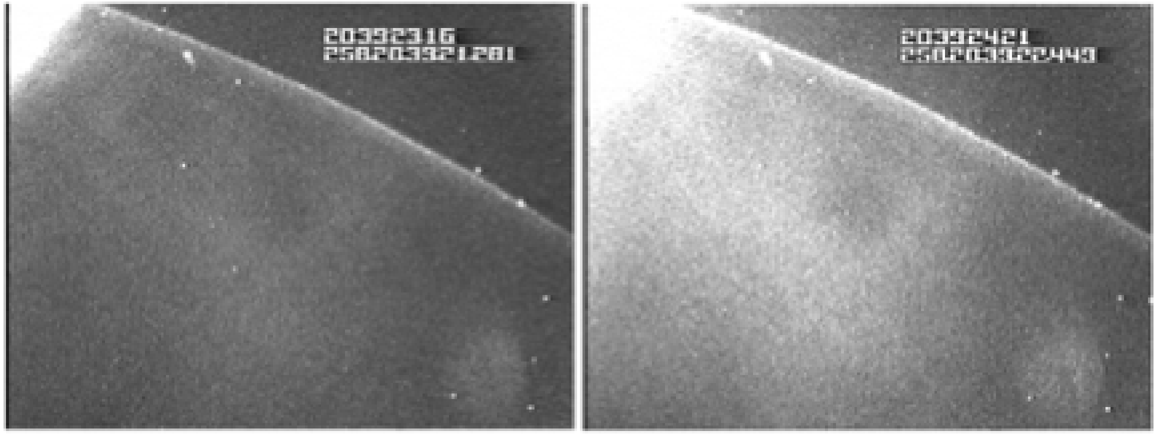
The L5D thruster is directed down relative to the shuttle's frame of reference. But as the exhaust plume moves down, it also fans out as the hot gases expand into the vacuum of space. A portion of the plume impinges on the shuttle's left wing and is reflected up toward the camera. According to the debris interpretation of the events captured by the camera, it is this portion of the incandescent plume that is seen as the flash of light in the video.

There would seem to be nothing that could cause a flash of light in space other than the shuttle's own thrusters. Because a number of the objects in the video abruptly change course within a second of the flash, the causal chain seems complete: a thruster fires, causing a light flash and small objects very close to the space shuttle are pushed away by the thruster exhaust gases. Obviously, spacecraft at a great distance from the shuttle would not react to the firing of one of its small thrusters by making the radical course changes seen in the video. If the thruster firing was in fact the source of the flash, then the objects that react to them could only be small nearby debris particles.

Spatial Distribution of Flash Intensity over the Camera Field of View

Proponents of the shuttle debris interpretation have noted that incandescent exhaust gases from the L5D thruster impinging on the shuttle's left wing would have entered the camera's field of view at the lower left and moved toward the upper right. In the past, investigators on both sides of the issue have accepted that the light flash originated in the lower left part of the video as would be consistent with the exhaust plume interpretation of its origin. The impression that the flash originates in the lower left part of the field of view is reinforced by the subsequent appearance of two objects moving rapidly from the lower left part of the video frame toward the upper right. To the proponents of the debris theory, these objects are ice particles that broke away from the thruster's nozzle when it fired or were entrained in the exhaust gases deflected off the wing.

While this explanation seems plausible after viewing the video at normal playing speed, the perceptible flash is really too brief (about 0.4 seconds duration) to confirm that it originates at the presumed lower left position. Figure 1 shows two video frames, one taken shortly before the flash and the other when the flash was at maximum brightness. There is little change in brightness at the lower left corner of the video between the two frames. Instead, the brightness appears to increase the most in the center of the image during the flash. The white patch in the upper left corner of each frame is lens flare caused by sunlight entering the camera. It first appeared as the sun rose prior to the light flash and persisted after the flash faded. As can be seen by comparing the two frames, this white patch briefly increases in size as the light flash intensifies and then quickly shrinks back to its former size as the flash fades.



A. Frame preceding flash.
20:39:23.53

B. Frame at maximum flash intensity.
20:39:24.7

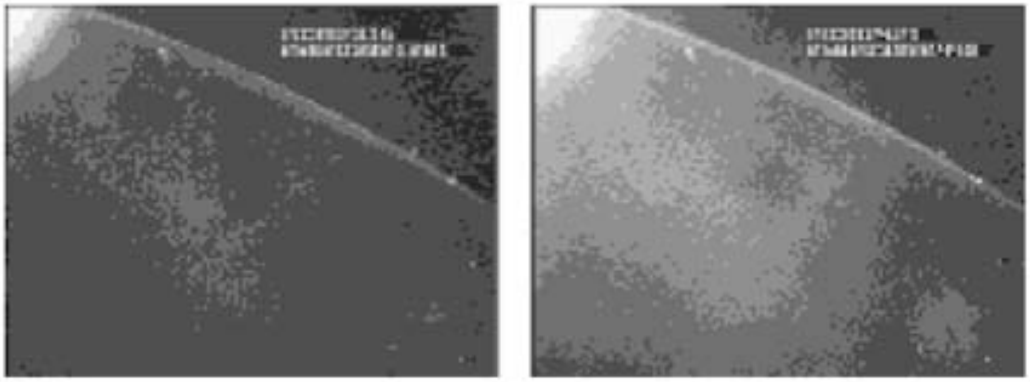
Figure 1. Two frames captured from the videotape. Times are from upper video time displays.

Because the white patch in the upper left corner of the video frame is known to be lens flare, the relationship between variations in its size and the light flash indicates that the flash is an intensification of the lens flare rather than incandescent rocket exhaust.

The relationship between the lens flare and the flash can be seen more clearly by "posterizing" the video frames. This image processing technique removes small pixel-to-pixel brightness differences to reveal the general contours of the brightness distribution over the image. For that reason, these posterized images are referred to subsequently as "brightness contour images." The contour images of the two frames of Figure 1 are shown in Figure 2. They were created by dividing the 256-value gray scale digital number (DN) range into equal intervals and setting the brightness of each pixel to the nearest interval value lower than the pixel's original DN value (the "floor" of the brightness interval the pixel occupies).

The contour image of the pre-flash frame in Figure 2A shows a relatively uniform brightness distribution, with the glare from the upper left corner extending diagonally to the lower right. In the frame of Figure 2B where the flash is at maximum intensity, the brightness can be seen to increase along the same upper-left to lower-right diagonal.

To determine whether the flash increased the brightness uniformly over the image as an incandescent rocket exhaust plume likely would, the original (unposterized) pre-flash frame of Figure 1A was subtracted from the frame with the peak flash intensity of Figure 1B. The resultant difference image was then posterized to generate the brightness contour image of Figure 2C.



A, Frame preceding flash.
20:39:23.52
DN interval size is 32.

B. Frame at peak flash inttensity
20:39:24.7
DN interval size is 32.

C. Frame A subtracted from Frame B.
DN interval size is 13.

Figure 2. Brightness contours for a pre-flash frame, a frame showing the light flash, and for a difference image created from the two frames. The shuttle's aft attitude control rockets are located below and to the left of the lower left corner of the images.

The difference image shows how much intensity the flash added at every point in the field of view[*]. It is clear that the flash has not been distributed uniformly over the frame

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[*] The relationship between input light intensity and signal output by a camera is often not linear, so the difference in the brightness between two frames at a particular pixel position may not be precisely proportional to the difference in input light intensity. However, in order for a uniform increase of input light intensity to increase the output brightness of already-bright areas more than darker areas, the response curve must be such that the slope of the curve increases with increasing light intensity. In the resultant images, this would tend to increase the brightness of brightly illuminated features relative to dimly illuminated features such as stars -- something that seems implausible for a camera designed for low levels of lighting.

and that it has added very little to the brightness at the lower left corner, the position closest to the RCS thruster. Instead, the contours of the difference image form curved bands that are markedly concentric with the upper left-hand corner of the frame at the point where the lens flare was already present. The area adjacent to the upper left corner is dark because that region was saturated (DN 255) in both frames, so the difference in brightness between them is zero.

While the light flash is clearly not at the location that everyone had always assumed it was, one final possibility has to be considered before eliminating the L5D exhaust plume as the source of the flash. It has been suggested that the incandescent plume would be most intense at the upper left corner from the camera perspective based on the assumption of specular reflection (angle of incidence equal to angle of reflection, as for light reflected off a mirror). This is illustrated in Figure 3, where the exhaust plume is shown moving from the lower left toward the upper right across the camera's field of view (left and right are reversed from the camera's perspective). Specular reflection off the wing would direct the exhaust gases across the camera’s field of view in such a way that they would be progressively less dense and less luminous going from the upper left corner of the field of view toward the lower right.

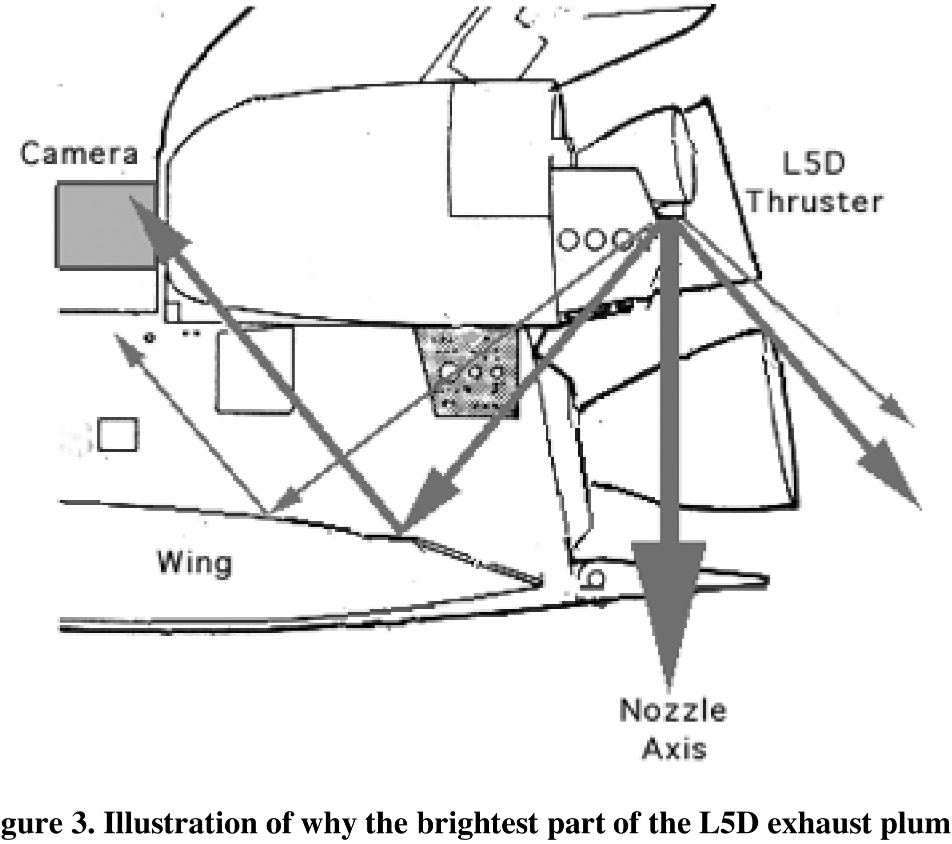

Figure 3. Illustration of why the brightest part of the L5D exhaust plume might appear in the upper left corner of the camera field of view (on viewer's right). The density of the exhaust gases is greatest along the axis of the thruster nozzle and decreases with increasing angles from the axis as indicated by decreasing thickness of the lines representing exhaust directions.

The assumption of specular reflection of the thruster plume is itself questionable. Previously, the proponents of the debris interpretation had argued that the impinging exhaust molecules conformed to a Lambertian (diffuse) reflection, distributing the rocket exhaust gases more uniformly across the camera's field of view. Lambertian reflection was suggested in order to account for the seemingly strong reaction to the flash by objects on the far right of the image. The density of the exhaust gas and therefore the pressures it would exert on objects in its path should be roughly proportional to its luminosity at any point in the image. If the exhaust gases were concentrated near the upper left hand corner of the image, the plume would have to have been considerably less dense on the far right and the pressures it generated correspondingly weaker in that direction. This would make it less likely that the thruster firing would affect objects in that region of the frame.

With no quantitative information available on the spatial distribution of L5D plume gases impinging on the shuttle's wing, the possibility cannot be completely discounted that the gases would be more luminous in the upper right hand corner of the image. However, it can be conclusively ruled out based solely on the shape of the contour bands in Figure 2C. The contour bands of the difference image in Figure 2C have a pronounced curvature centered on the upper left corner of the image, with the curvature the greatest along the image's diagonal from upper left to lower right. Figure 4 illustrates the general qualities of the brightness contours in an image of a rocket exhaust plume reflected in a specular fashion off the shuttle wing and passing in front of the camera. The contour bands would have to be straight and run from the lower left to upper right -- the direction in which the plume gases were traveling. There is nothing in space that could cause the trajectories of the plume's gas molecules to curve in such a way as to form the contour bands of the actual difference image of Figure 2.

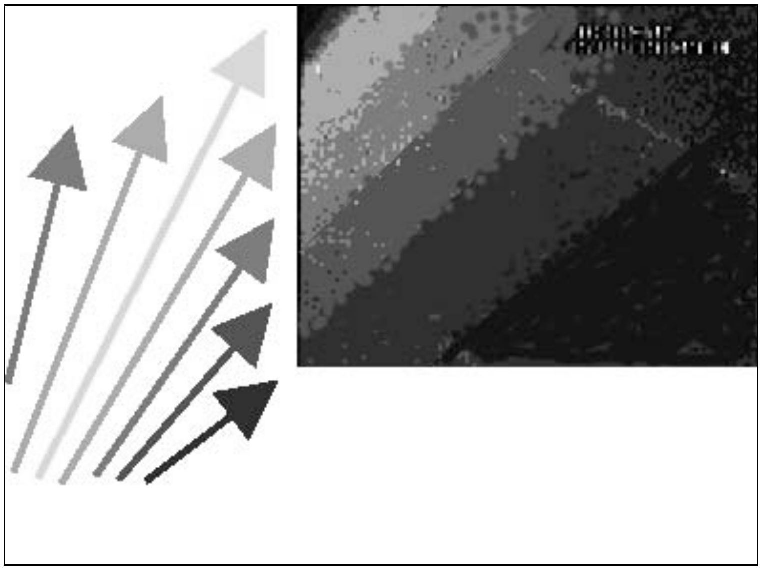

Figure 4. Illustration of the general contours of the brightness that would be added to the image by an L5D exhaust plume originating from the lower left. The darker arrows correspond to less dense -- and therefore less luminous -- exhaust gases.

Comparison of the simulated difference image of Figure 4 to the actual difference image of Figure 2C shows that a rocket exhaust plume passing in front of the camera is simply incapable of producing the distribution of brightness values over the image actually produced by the light flash.

Temporal Variation of Flash Intensity

Jack Kasher's 1991 paper[2] on the STS-48 video noted that the "main" flash previously described was preceded by what he called a "pre-flash" half a second earlier. To better characterize the relationship of the primary light flash to this pre-flash, a graph of the average frame brightness on frames of 500 X 375 pixels was constructed. The pre-flash reported by Kasher is clearly evident. Unexpectedly, the graph also revealed a "post-flash" of similar magnitude as shown in Figure 5.

Significantly, the elapsed time between the onset of the pre-flash and the end of the post-flash is 2.2 seconds. This is a full second longer than the 1.2-second duration of the L5D thruster firing, and one second is no small difference. The RCS exhaust plume travels at a speed of 3500 meters per second[3]. Only 1/10 of a second after the rocket firing ended, its exhaust gases were 350 meters from the shuttle and dispersed over a large volume of space. Such a diffuse cloud of gases would not have been visible at that distance even if the camera had been looking directly along the rocket nozzle axis at the densest part of the exhaust plume.

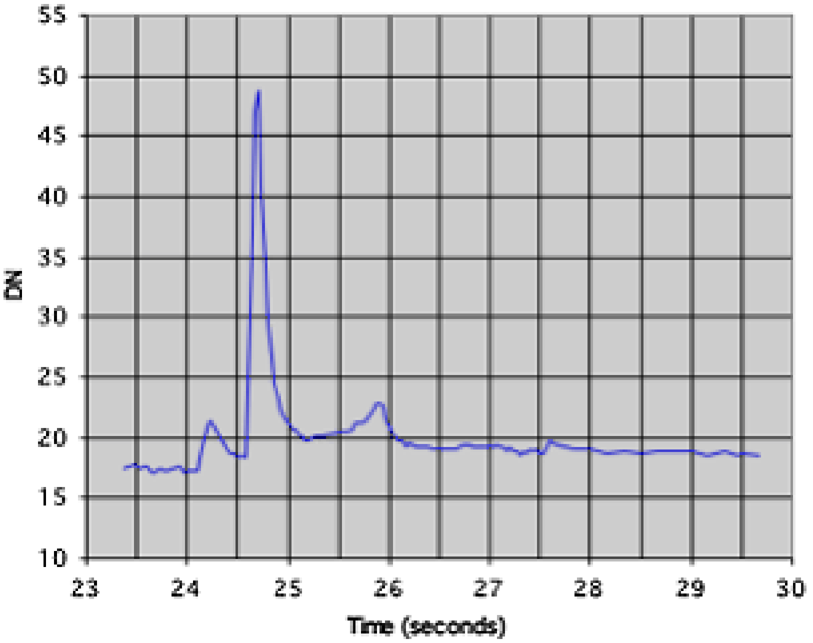

Figure 5. Average frame brightness over seven seconds plotted at 1/30-second intervals. Start time corresponds to the video display clock time of 20:39:23.

As can be seen in the graph, the average brightness never returns to the level it had in the frames prior to the pre-flash. This was somewhat puzzling. Since the sunlight reaching the camera was slowly increasing in intensity as the shuttle moved through space, some suggestion of an upward slope to the brightness curve would be expected. But the curve is essentially flat on both sides of the series of flashes and higher by 2 DN after the flashes than before. The graph would seem to suggest that the brightness increased in a discrete step at some point during the series of flashes. However, a graph of brightness versus time plotted over a much longer time period indicated that this was probably not the case.

The graph for the longer time period showed the average frame brightness curving upward with time but accompanied by small periodic fluctuations. This graph is shown in Figure 6.

The fluctuations in brightness may represent fluctuations in the camera's sensitivity, although they might also represent some variation in the amount of sunlight reaching the camera. Whatever their cause, it appears that these periodic fluctuations occasionally cancel out the continuously increasing brightness due to the change in the sun's position, resulting in short periods of time over which the image brightness remains relatively constant.

As would be expected, attempts to fit the measured brightness values to a hand-drawn curve always resulted in the measured values around the 2.2-second time span of the flash series falling noticeably farther from the curve than the values for other points in time. What was surprising was that the time span over which the points failed to fit any continuously rising curve was considerably longer than 2.2 seconds – perhaps as long as 12 seconds. It did not appear that this could be accounted for by the small periodic brightness variations. To confirm this impression, I performed a curvilinear regression for all the data points, excluding those in this 12-second interval, to produce the red curve also shown in Figure 6. This is a graph for the curve:

$$DN = b_0 + b_1T + b_2T^2$$

Where DN is the digital brightness, T is time, and $b_{0,}$ $b_{1,}$ and b_2 are the constants computed by the regression procedure.

Such a regression equation has no basis in physical theory, but it provides a meaningful description of a population if the points in the population conform to it reasonably well. As can be seen in the graph, the curve fits all of the data outside of the excluded time period quite well, with a standard deviation of 0.21 DN for the sample of 96 points.

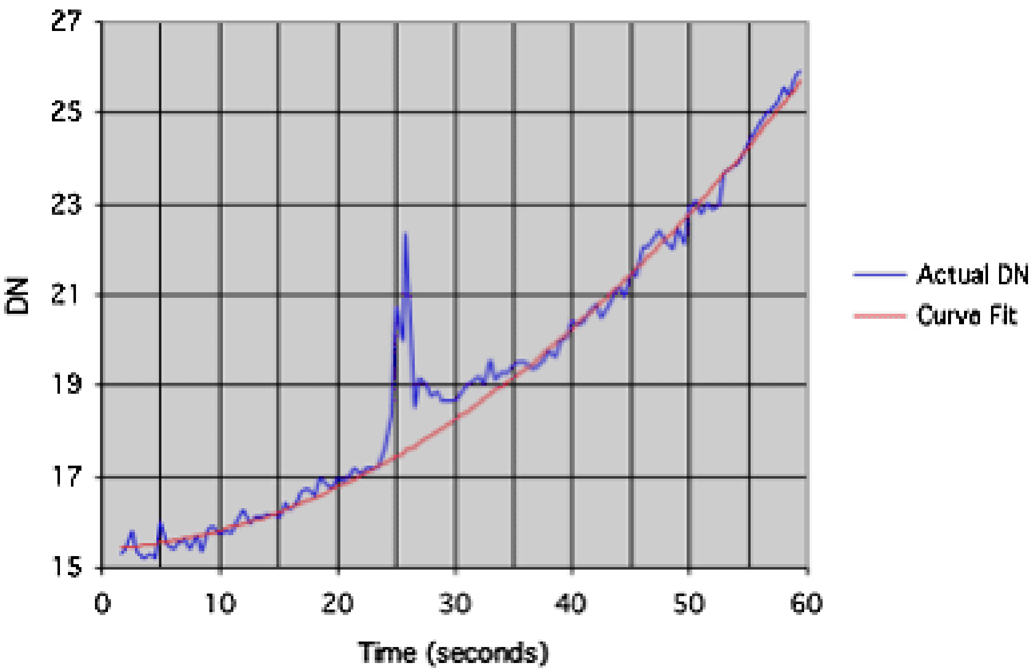

Figure 6. Average frame brightness over one minute plotted at 0.5-second intervals (blue line) and curve fit (red line). Zero time corresponds to the video display clock time of 20:39:00. Blue line is measured value.

Within the excluded time span, the difference between the curve-fit value and the measured value remains greater than three standard deviations for a time span of nearly 5 seconds, as shown in Figure 7.

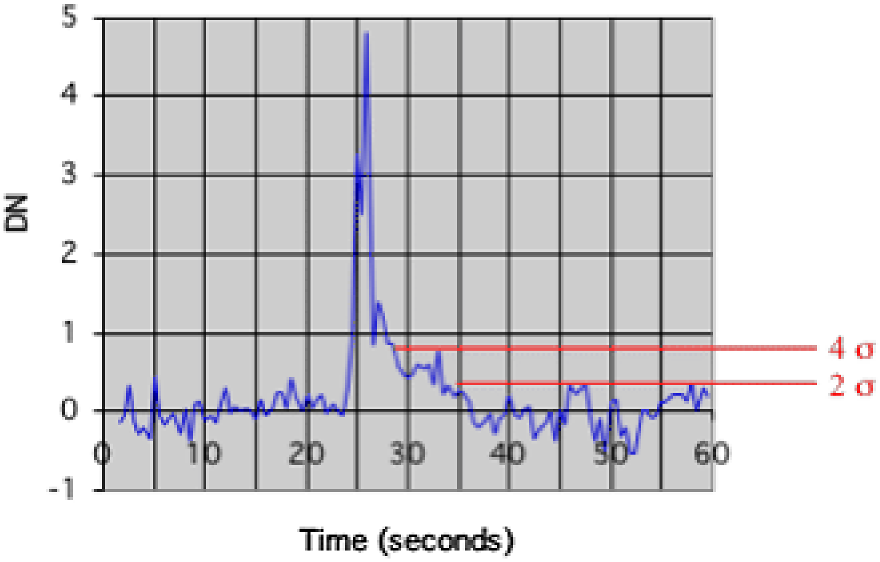

Figure 7. Plot of the difference between the measured brightness and the predicted value based on the curve fit of Figure 6.

The difference between the measured and computed value remains above two sigma for nearly 8 seconds. This means that it is virtually certain that the image brightness remained elevated for at least 5 seconds above what could be accounted for by the small periodic brightness fluctuations, and very likely for more than 8 seconds.

It should be noted that the peak in the graphs of Figure 6 and Figure 7 is the post-flash, not the “main” flash, which falls within the half-second sampling interval used for graphing over the one-minute time period. The post-flash brightness values all fall above the 3-sigma margin for the curve and so cannot be attributed to the normal brightness fluctuations over the rest of the one-minute time period.

Possible Causes of the Light Flash

If the light from L5D thruster plume passing directly in front of the camera is ruled out as the cause of the light flash, that still leaves the problem of what did cause it. Somewhat ironically, it was James Oberg who recognized what may be the key to unlocking this puzzle. The lens flare preceding the flash is sunlight, but not rays of the sun directly entering the optical path of the camera. The camera was in the shadow of the shuttle's body and was pointed away from the sun. The lens flare is a portion of the light scattered in all directions (as opposed to the light following paths of specular, or mirror reflection) from light-colored shuttle surfaces exposed to the sun after orbital sunrise. Oberg suggested that a disk-shaped antenna on the right side of the shuttle near the crew cabin was probably responsible for sunlight entering the camera, which was on the right side of the shuttle in the aft area of the cargo bay and looking over the left wing.

Figure 8 shows a sketch approximating this lighting geometry. At the bottom of the sketch is a second hypothetical light source that I proposed in 2003 as a reasonable explanation for the intensification of the lens flare that constitutes the main flash.

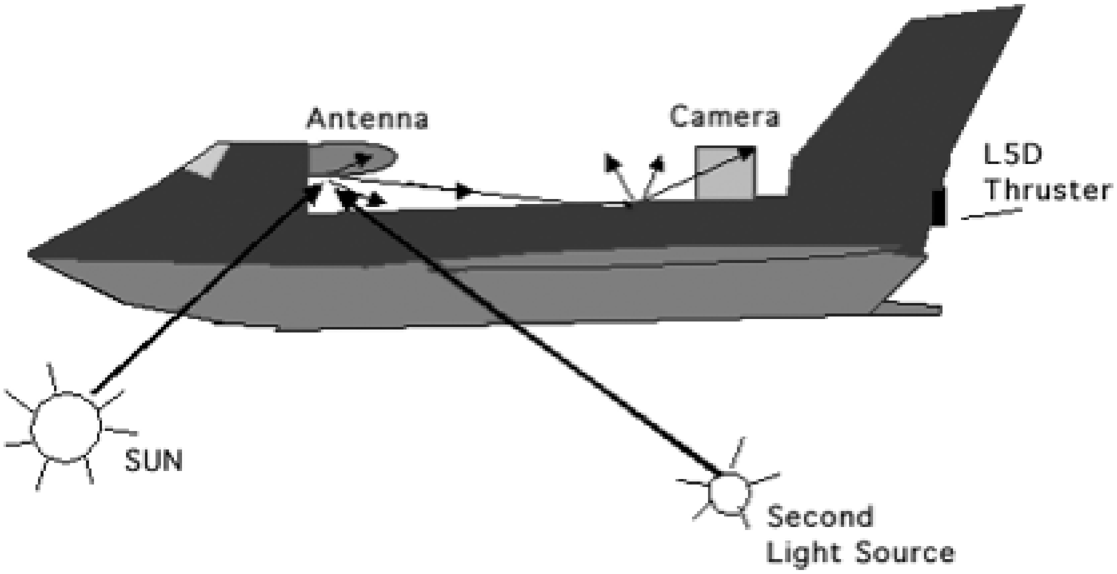

Figure 8. Sketch illustrating the lighting geometry that may have produced the lens flare seen in the upper left corner of the STS-48 video. Dimensions and angles are not to scale. Multiple arrows extending from the antenna and shuttle body surfaces denote diffusely scattered light from those positions. A proposed second light source is shown near the Earth. Camera line of sight is toward the viewer and downward toward the Earth.

Rays from this light source are shown reaching the antenna from the left side of the shuttle, although the light source could just as easily have been positioned so that its light reached the antenna from the opposite side of the shuttle. In either case light from the secondary source would have added to the sunlight already entering the camera. To intensify a specular reflection, a second light source must align precisely with the first source. But for non-mirror-like (Lambertian) surfaces that scatter light in all directions no precise alignment is necessary.

To make such a noticeable contribution to the existing lens flare caused by the sun, the brilliance of this second light source would have to have momentarily rivaled that of the sun. It might be conjectured that the L5D vernier thruster itself was the second light source if the normally faint exhaust plume flared up to an unusual brightness due to the supposed imbalance between rocket fuel and oxidizer alleged by Oberg. This seems unlikely, given the small size of the thruster. But it is impossible that the 1.2-second thruster firing could have caused the brightness of the video to be elevated for 5 or more seconds as has been shown here.

This “second light source” scenario was originally suggested only to explain the single primary flash that is easily seen in the video. It still seems plausible now that it is known that the main flash was only one of at least three light pulses that were part of a longer episode of elevated light intensity. A single source might have produced a sequence of pulses in rapid succession, the three most intense of which are resolved into distinct peaks. Alternatively, there could have been several light sources contributing greater or lesser amounts of extra light depending on their distances from the shuttle during the period of elevated light intensity. Since numerous objects are visible in the video, most of them could have been separately targeted, assuming that these events represent some sort of military action as some people suspect.

As was mentioned in the 2003 paper, Bruce Maccabee suggested a more mundane possibility: that the light flash might have been caused by a specular reflection of sunlight off of some shuttle surface momentarily aligned in the right way with the sun and the camera. Given the unexpectedly long duration of the elevated brightness associated with the flash, that may still be a viable hypothesis. Rather than a single specular reflection, additional diffusely reflected sunlight might have reached the camera for several seconds over a range of angles before the sun's position changed and that light path was cut off. However, it seems too great a coincidence that the abrupt changes in the motion of several of the objects occurred less than half a second after the main flash.

Whatever the correct explanation may be, the light flash can certainly be attributed to lens flare from a source that had nothing to do with the firing of the shuttle thruster.

In 1991, a small group of NASA scientists watched the video and without doing any actual analysis concluded that:

> 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[4].

The first assertion has been proven wrong beyond any reasonable doubt, making the second related assertion highly questionable. Even if Maccabee's suggestion is correct and the light flashes have a prosaic explanation unrelated to a thruster firing, then the nearly simultaneous occurrence of the two unrelated events necessary to support the debris interpretation would be an incredible but meaningless coincidence. Jack Kasher, Mark Carlotto, and I myself have raised what I think are serious objections, quite unrelated to the problem of the light flashes, to the interpretation of the objects in the video as small debris particles being pushed about by a shuttle thruster. These and many other aspects to the fascinating case of the STS-48 video will, I believe, continue to be of interest to people who will not uncritically accept the superficial explanations offered by NASA for phenomena they choose not to investigate.

REFERENCES

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[1] Fleming, Lan D. (2003). A New Look at the Evidence Supporting a Prosaic Explanation of the STS-48 "UFO" Video. *New Frontiers in Science* Online journal.

[2] Kasher, Jack. (1995/1996). Anomalous Images on Videotape From Space Shuttle Flight STS-48: examination of the Ice-Particle Explanation. *Journal of UFO Studies*, New Series **6**, 80-148.

[3] NSTS 07700, Volume XIV Space Shuttle System Payload Accommodations. Appendix 1: System Description and Design Data - Contamination Environment

[4] Letter to U.S. Representative Helen Delich Bentley from Martin P. Kress, Assistant Administrator for Legislative Affairs, NASA. November 22, 1991.