SURVEYOR RETRO-ROCKETS IN LROC IMAGES.

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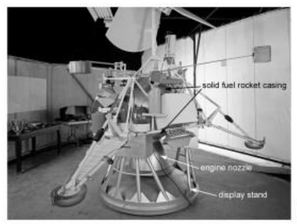
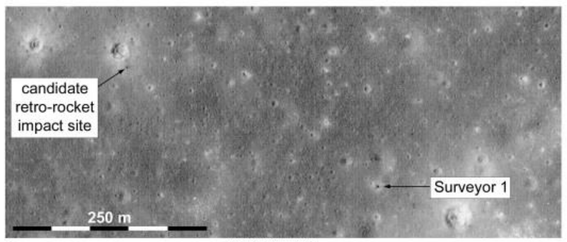
Introduction: Five of NASA's seven Surveyor missions landed successfully between 1966 and 1968. Most were sent to regions where astronauts might land on the early Apollo missions: near the equator in the western, central, and eastern maria. As the Surveyors reached the Moon they were braked to near-zero velocity by a solid fuel retro-rocket mounted under the lander. The retro-rocket was ejected near the surface and three small Vernier thrusters ignited to bring the lander safely to the ground. None of the retro-rockets were imaged by the Surveyors themselves, and Apollo 12 astronauts did not see the Surveyor 3 retro-rocket when they landed nearby. Can any of them be found in LROC images?



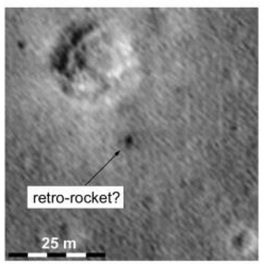
NASA/JPL image

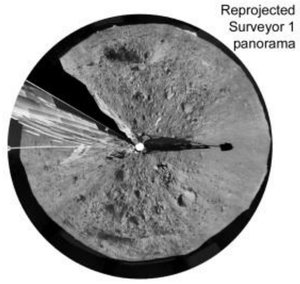
Surveyor 1

This landing site was not imaged at high resolution by Lunar Orbiter before the landing, so unlike Surveyors 3 and 6 there is no before-after image comparison. High sun images show two dark spots which are plausible candidates, and one, a dark halo crater on the bright ejecta of a fresh crater 300 m NW of the lander, seems most likely to be the retro-rocket. It was hidden behind the lander body and not visible in surface images even if topography permitted.



M122495769L





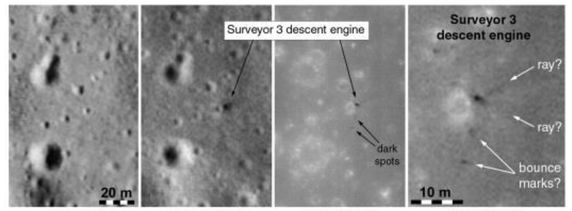
Reprojected Surveyor 1 panorama

Surveyor 3

The Surveyor 3 retro-rocket was observed previously and reported in 2010 [1]. It was seen as a dark spot visible in LROC-NAC images but was not present in a pre-landing Lunar Orbiter image.

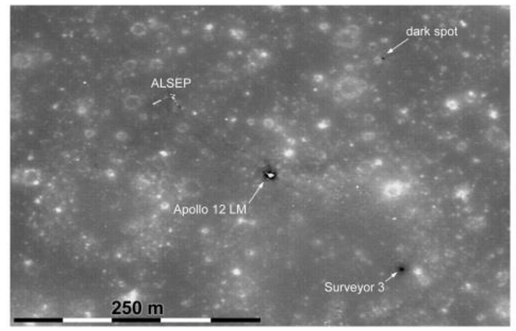
More details are reported here. Other than the pre-landing image, the best evidence of the retro-rocket seems to be its appearance as a very dark spot in high sun images. Possible bounce marks were also suggested in an enlarged image.

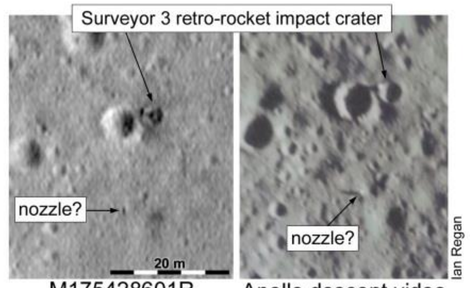
The highest resolution (25 km altitude) LROC-NAC image (M168353795R) reveals the dark spot as a crater. A small spot previously considered a bounce mark is now seen as a positive relief feature, possibly the engine nozzle, thrown clear of the rocket casing impact.



LO3-154-H2 M104662862R M109386083R M109386083R

The Apollo 12 astronauts could not see the impact site because it was in a local depression and not visible from the LM windows, but an analysis by Ian Regan has shown that the Apollo 12 descent video includes the impact crater. If this video had been compared with Lunar Orbiter images in late 1969 the retro-rocket would have been found at once.



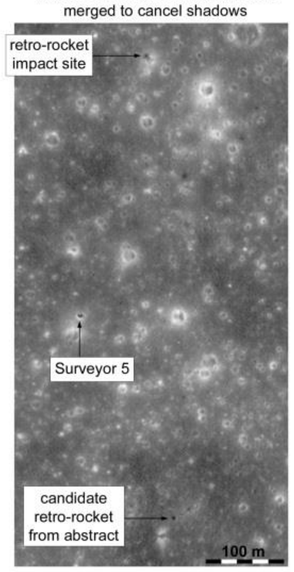


M175428601R Apollo descent video

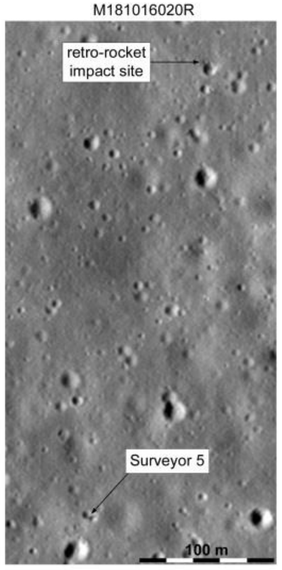
Surveyor 5

This landing site was not imaged at high resolution by Lunar Orbiter or Apollo. LROC-NAC images were required to find the lander itself [2]. High sun images were examined for dark spots near the lander, and several candidates were found. Only one resembles the Surveyor 3 crater, and is assumed to be the retro-rocket impact site. Note that this is different from the site identified in the abstract!

M106726943L and M1105774283L merged to cancel shadows



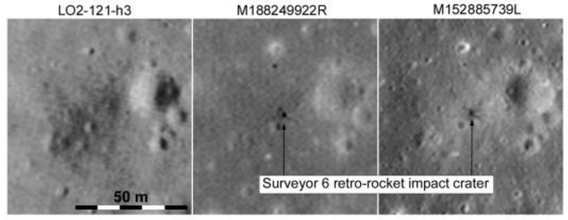
M181016020R



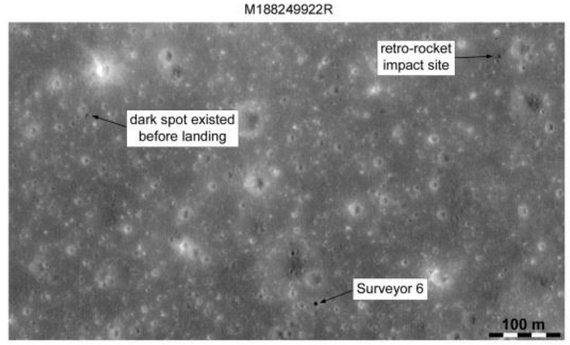
Surveyor 6

High sun images of this site were examined for dark spots near the lander, and two obvious candidates are apparent, but comparison with Lunar Orbiter 2 frame 121-H3 shows that one was present before the landing. The other is a new feature. This dark spot is also a small crater and has several dark rays, as also seen at Surveyor 3. This must be the Surveyor 6 retro-rocket impact.

LO2-121-h3 M188249922R M152885739L



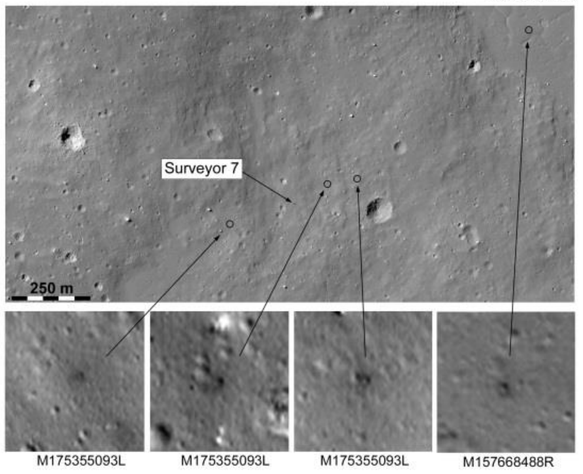
M188249922R



Surveyor 7

Here the search is complicated by the latitude, which precludes the possibility of high sun images. Despite this, three small dark spots can be found within a few hundred m of the lander, two to the ENE and one to the WSW. Another is located on the impact melt pond 1000 m NE of the lander which was the landing target. That distant spot is probably too far away to be correct, but any of the other three might be the retro-rocket impact. Other candidates may be found as small dark spots are common. These examples are seen to be small craters in enlarged images.

M119936760R



M175355093L M175355093L M175355093L M157668488R

Discussion

At Surveyor 3 and Surveyor 6 we see impact craters which have clearly formed since the pre-landing Lunar Orbiter images were taken. There is no doubt that these features were caused by the impact of the Surveyor retro-rockets, falling from a height of over 10 km.

At Surveyor 1 and Surveyor 5 very similar craters are found. These are very probably the retro-rocket impact sites. At Surveyor 7 there are three candidates for the retro-rocket impact site.

The two obvious sites are craters 4 to 5 m across and 250 to 400 m from the landers. The two probable sites are similar in size and about the same distance from the landers. Analysis of the Surveyor descent trajectories might help confirm the identifications and possibly help identify the Surveyor 7 retro-rocket.

References: [1] Stooke, P. J. (2010) 41st LPSC, Abstract #1116. [2] Robinson, M, 2010. Blog post, http://lroc.sese.asu.edu/posts/14 , March 21, 2010.