Apollo 11's View of Moon

Robin Stuart

This photograph was taken from the Command Module of Apollo 11 of the crew began their homeward journey following the trans-Earth Injection maneuver on July 22, 1969. Any WAA member can instantly see that this is not the Moon as it appears in the sky, but it surprising how many of the general public don't recognize it as such. The photograph shows the view from almost directly above Mare Crisium, which we see from Earth near the Moon's eastern limb (west in the sky). One might therefore ask, "If they're trying to head back home, aren't they going in the wrong direction?" The Moon orbits the Earth at a little over 1 km/s and the return trip requires expending a component of the main engine's thrust to counter the orbital angular momentum by flying west. The balance is directed toward target Earth.

Maybe because of its eerie subliminal unfamiliarity, a version of the photograph featured in the opening credits of the TV series *Buffy the Vampire Slayer*.

The photograph is also seen on the NASA website https://www.nasa.gov/mission_pages/apollo/40th/images/apollo_image_25.html, where it is described as having been taken when "the spacecraft was already 10,000 nautical miles away."

The July 2019 WAA newsletter, page 8, reported my attempt to replicate the Apollo 11 photograph by transforming my own Earth-based images using code written in *Mathematica*. As noted there, to obtain a near match the spacecraft distance had to be set to 8,000 km from the Moon's center. This is obviously very different from the 10,000 nautical miles that NASA claims. At the time I supposed that there was probably a wrong factor somewhere in my code but as my aim was principally aesthetic I didn't think much more about it.

Recent favorable librations of the Moon allowed me to image more of the eastern limb than previously and to get a more complete match to the Apollo 11 photograph. This also prompted me to pursue the apparent inconsistency in the distance. Arizona State University hosts the fantastic Space Exploration Resources archive of high resolution scans of the original photographs from the US Space program. Those from Apollo 11 are at http://tothemoon.ser.asu.edu/gallery/Apollo/11/Hasselblad%20500EL%2070%20mm

The photograph in question is the last in a sequence showing the Moon's disk shrinking in the Command Module window and bears the designation AS11-44-6667. Scans are available in various resolutions from a 1.3-gigabyte raw image down to a 12-kilobyte thumbnail shown here.

Apollo 11's Photographic Equipment

The ASU archive lists AS11-44-6667 as having been taken on Kodak Ektachrome SO-368 medium speed ASA 64 color reversal film with a Hasselblad 500EL camera equipped with a Zeiss Sonnar 250 mm f/5.6 lens. This is one of two Zeiss lenses for the Hasselblad that Apollo 11 carried, the other being a Planar 80mm f/2.8 lens.

The Hasselblad used 70-mm film, which is the overall width of the film strip including the sprocket holes. Since the ASU scans cover the complete film, it is possible to accurately measure the physical size of the Moon's image on the film plane.

It can be shown that the radius of the image, r, is related to the focal length of the lens, f, the Moon's physical radius, a = 1,737 km, and observer's distance, d, from the center, by

$$r = \frac{f}{\sqrt{\left(\frac{d}{a}\right)^2 - 1}}$$

The same formula applies when imaging the Moon or other spherical body through a telescope from Earth but in that case since d is very much greater than a, the approximation $r = f \times (a/d)$ is adequate for most practical purposes. The quantity a/d is the body's angular semi-diameter (radius) expressed in radians.

Conversely if the image radius is measured, the focal length of the lens that was used to take it can be calculated.

A careful measurement of the scan finds that Moon's radius on the film plane is 19.7 mm. Inverting the formula above then places the Command Module at a distance of 22,100 km from the Moon's center or 11,000 nautical miles from the surface, which is presumably where the NASA's round figure of "10,000 nautical miles away" comes from.

Apollo 11's Distance from the Moon

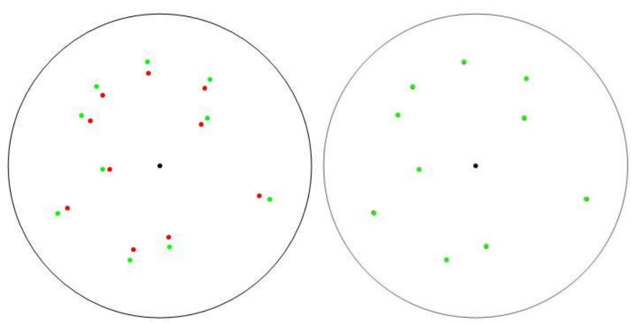
The distance at which the photograph was taken can be determined from the image itself without reference to the photographic equipment used. The higher an observer gets the more of the surface is visible. As the height changes the locations of individual features on the face of the disk also change.

Working with the medium resolution scan http://tothemoon.ser.asu.edu/data_a70/AS11/extra/AS11-44-6667.med.png I selected 10 small bright features and measured their pixel locations. The Moon's radius was measured as 992 pixels. Google Earth was then used to find their selenographic latitudes and longitudes. The coordinates of the point at dead-center of the Moon's disk is also needed and the results of these measurements are tabulated below.

Feature	Pixel Coordinates		Selenographic Coordinates	
	X	Y		
Moon Center	1709	2226	5°40.7'N	58°19.1'E
Moltke	1632	2905	0°36'S	24°9.4'E
Mare Crisium Shore	1337	2202	22°40.3'N	54°26.4'E
Lacus Spei	1045	1916	43°26'N	65°56.9'E
Bellot	2023	2539	12°39.7'S	48°7.5'E
Dawes	1295	2744	17°10.7'N	26°15.3'E
Neper	1777	1700	8°49.4'N	84°7.8'E
Rosse	2040	2794	17°59.4'S	34°50.1'E
Humboldt	2429	2007	27°25.4'S	81°10.2'E
Hubble	1519	1613	22°0.6'N	87°10.2'E
Near Romer	1199	2557	24°23'N	33°52.6'E

For a given distance of the observer, this information, along with a little spherical trigonometry, allows calculation of the locations of these features on the image of the lunar disk.

In the plots below the red dots are pixel positions of the features as measured from the scan and the green dots are their positions calculated from their corresponding selenographic coordinates. The plot on the left is for d = 10,000 nautical miles and the one on the right is the best fit obtained for d = 7,336 km. In the latter the two sets of dots are essentially coincident.



As a check Google Earth can be used to simulate the view of Moon above any point on its surface and from any distance.

Both of these images are centered on 5°40′42″N 58°19′3″E. For the image on the left the altitude was set to 16,783 km (10,000 nautical miles the center) and 5,599 km (7,336 km from the center) for the one on the right. The right hand image is a close match to the Apollo 11 photograph. The one on the left is not. In it, Mare Crisium is smaller and Mare Humboldtianum, Mare Marginis and Mare Smythii are further from the limb. The shapes of Mare Nectaris and Mare Humboldtianum are clearly different.

Now that the correct distance of the Moon as seen in the photograph is known, the focal length of the lens used to take it can be calculated using the formula given above. It is found to be 80.8 mm which is consistent with the 80-mm lens and not the 250-mm as currently recorded.

Given the historical significance of these photographs I considered it important that their associated metadata be correct and reached out to the ASU archive via their 250-character limit contact form. Although fully expecting to be dismissed as a crazy person I received a brief note agreeing that AS11-44-6667 and a number of other photographs on the roll were taken with a different lens than recorded. It was indicated that they would work to the update the information. ■

WAA Member Owen Dugan Named Regeneron Scholar

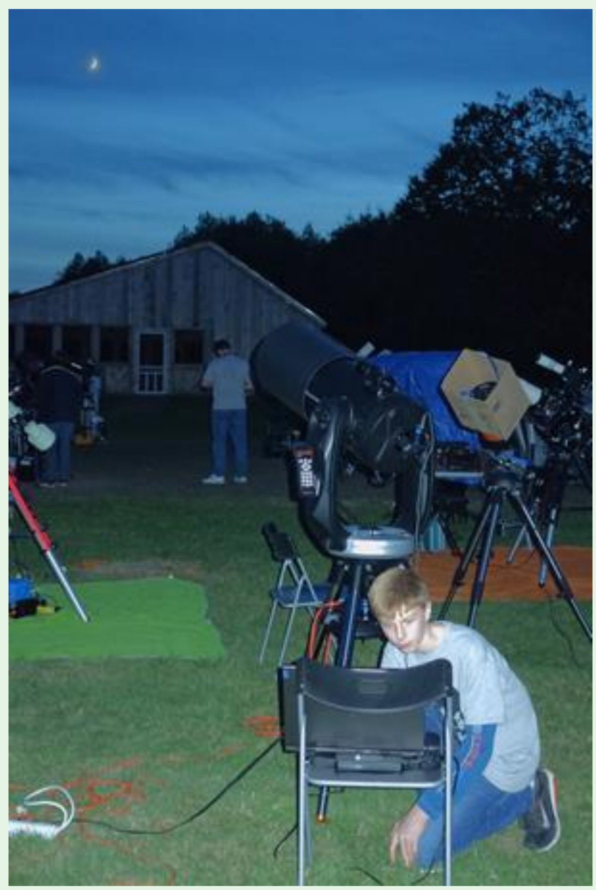
One of Westchester Amateur Astronomers' youngest active members, high school senior Owen Dugan of Sleepy Hollow, has been named a Regeneron scholar in the national Regeneron Science Talent Search competition.

Owen's project, *Astronomy Will Not Trail Off: Novel Methods for Removing Satellite Trails from Celestial Images*, was one of 300 selected from 1,760 national submissions. Forty of these students will be selected as finalists, with a national winner named in March. The scholar award comes with a $2,000 grant. Owen will attend the Massachusetts Institute of Technology next fall.

Owen did original research on the double star WDS 07106 +1543, a study that was published in the *Journal of Double Star Observations*. The story is in the February 2019 SkyWAAtch. Owen presented his work at the club's September 2019 Members Night meeting.

Owen told us "I am really excited! WAA has played a critical role in fostering my love of astronomy."

The Regeneron competition is the successor to the Westinghouse Science Talent Search, which started in 1942. It was later sponsored by Intel before the Westchester-based biotechnology company Regeneron took it over. The competition "focuses on identifying, inspiring, and engaging the most promising scientists among the nation's high school seniors." Top prize is $250,000.



Owen Dugan at the 2017 Medomak Astronomy Retreat and Seminar in Maine.