



Preventing Camera Clipping Through Varied Terrain and Other Planetary Objects

Kristie O'Brien and Bryan W. Welch
Glenn Research Center, Cleveland, Ohio

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Glenn Research Center, Cleveland, Ohio

National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

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NASA STI Program/Mail Stop 050
NASA Langley Research Center
Hampton, VA 23681-2199

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Kristie O'Brien* and Bryan W. Welch
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Summary

Within the scope of computer visualization systems and technologies, camera objects allow users to navigate three-dimensional (3D) scenes much like a person would navigate the real world. As such, when one seeks to model a scene or environment based on real-world laws, the camera must often follow these same conventions. Accomplishing this in the world of computer renderings presents unique challenges for defining space, spatial relations, depth, distance, and height. Therefore, movement for a camera must be specifically designated and processed by the program in order to achieve accurate movement representations. Although this thought process involves each aspect of camera movement, one specific aspect of camera movement is the primary focus of this report: ensuring that the camera does not clip through an object and appear subsurface. This is important to mimic real-world movements because people in the real world would not go beneath the solid-surface terrain unless they intended to do so. By working with numerical definitions, equations, and variables, a computer can relate an object to its existence in space. Thus, such challenges in camera movements with computationally rendered 3D spaces can be mitigated.

Nomenclature

3D three-dimensional
GCAS Glenn Research Center Communications Analysis Suite

Introduction

The NASA Glenn Research Center Communications Analysis Suite (GCAS) models various planetary objects, ground stations, rovers, aircraft, and orbiting spacecraft within a three-dimensional (3D) representation of certain aspects of our solar system (Ref. 1). Although GCAS encompasses many various objects within our solar system, the scope of the objects discussed in this report will be just three of them: the Earth, the Moon, and Mars. The Earth and Mars are given texture at the time of this writing but lack visible changes in elevation in their respective terrain elements. The Moon, however, has terrain and textures such that there are distinctive mountains and craters (Ref. 2). As such, it should be noted that the surface of the Moon is defined by actual terrain data to render the rough surface. However, the objects for the Earth and Mars are defined by their respective radii, either polar, equatorial, or both where applicable. The radii derive the shape of the celestial body, which is used in the analysis and used to represent the model of the body in the scene. Nonspherical bodies are typically simplified using models composed of varying equatorial and polar radii, where more complex versions of the model would be based on terrain datasets. These changes in altitude on the surface of the Moon thus create the added challenge of elevation for a camera.

*NASA OSTEM Spring 2024 Intern, Southern New Hampshire University.

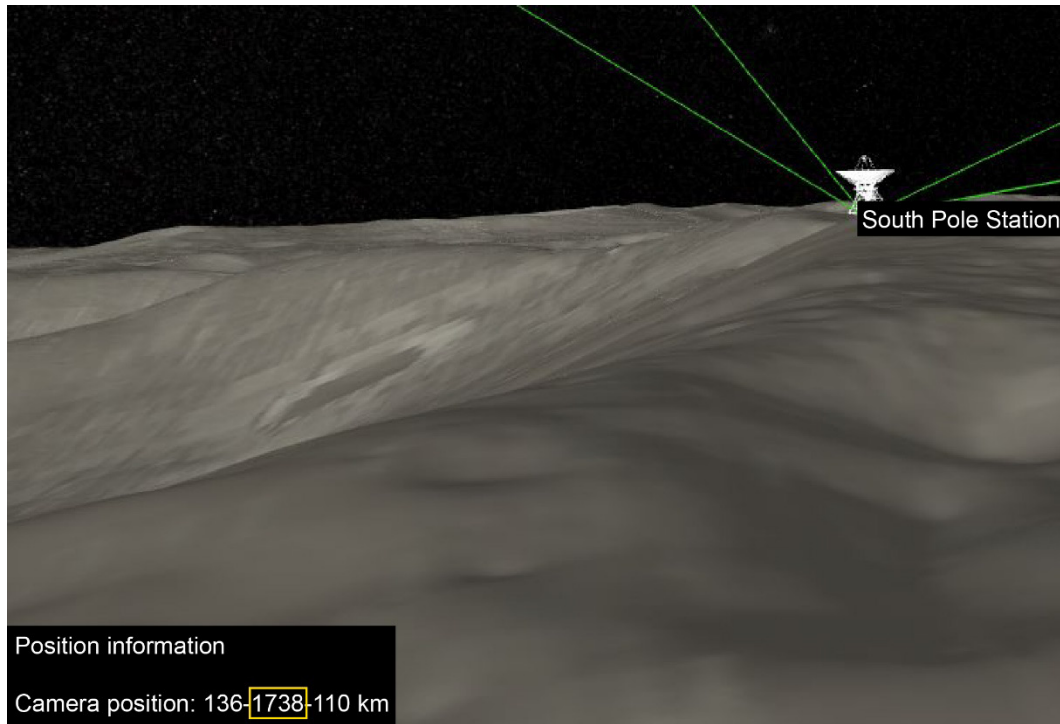


Figure 1.—Ground station on lunar south pole is now viewable. Value in yellow box corresponds to elevation.

A camera moving along a flat surface can almost always define what is above or below a defined proverbial ground level because the surface does not change in altitude on a flat surface. One can simply set a specific number to match the set altitude so the camera never goes below that limit. However, with terrain of varying elevations, the camera does not instinctively know where the ground is as the level is changing. A point that is above ground in a valley might be below ground if the camera tries to move towards a mountain, as can be seen in the differences between Figure 1 and Figure 2. A camera would clip through the surface, going below the mountain rather than up the slope. Figure 3 illustrates such a view. Consider a user who wants to use the camera to view something in the distance, such as a ground station. This ground station could be obstructed from view by mountains or other variations in terrain. Figure 3 shows an example of a view obstructed by terrain where the camera is above the surface. These are not ideal situations for navigating the terrain and viewing elements within the environment.

Note that in Figure 1 to Figure 3, the position variable that represents the y-axis is what represents the elevation of the camera in these instances. Between Figure 1 and Figure 2, the y variable does change in value, but the x and z variables remain the same. With this in mind, Figure 3 shows the camera located above ground but behind a mountain. Although it is looking toward the south pole station on the lunar surface, it cannot observe the station due to the terrain. Figure 1 shows that the camera has increased in elevation, in such a way that the south pole station is now visible. Figure 2 shows another change in elevation but not a change in position. Note how the terrain and the view of the surrounding areas appear to be unrealistic. This view shows the camera partially seeing through the terrain in a way that does not mimic real-world situations because the camera is now subsurface. Both Figure 3 and Figure 2 present their own challenges. However, the situation in Figure 2 must specifically be avoided due to its unrealistic nature.

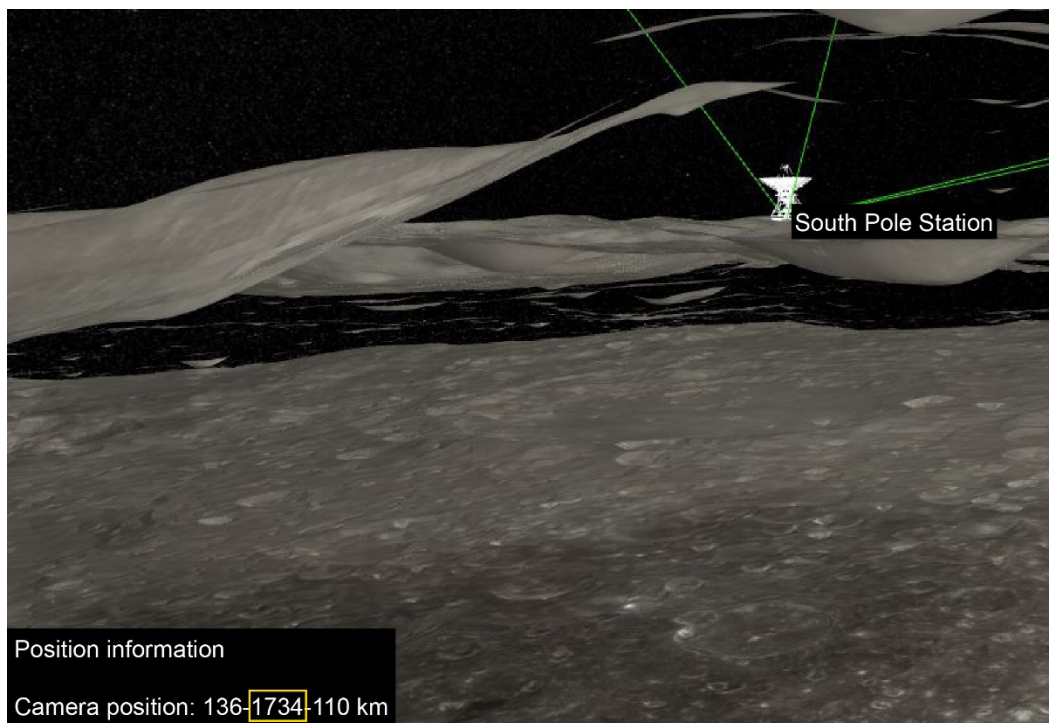


Figure 2.—Ground station on lunar south pole is viewable, but terrain is unrealistically seen due to camera being below surface. Value shown in yellow box corresponds to elevation.

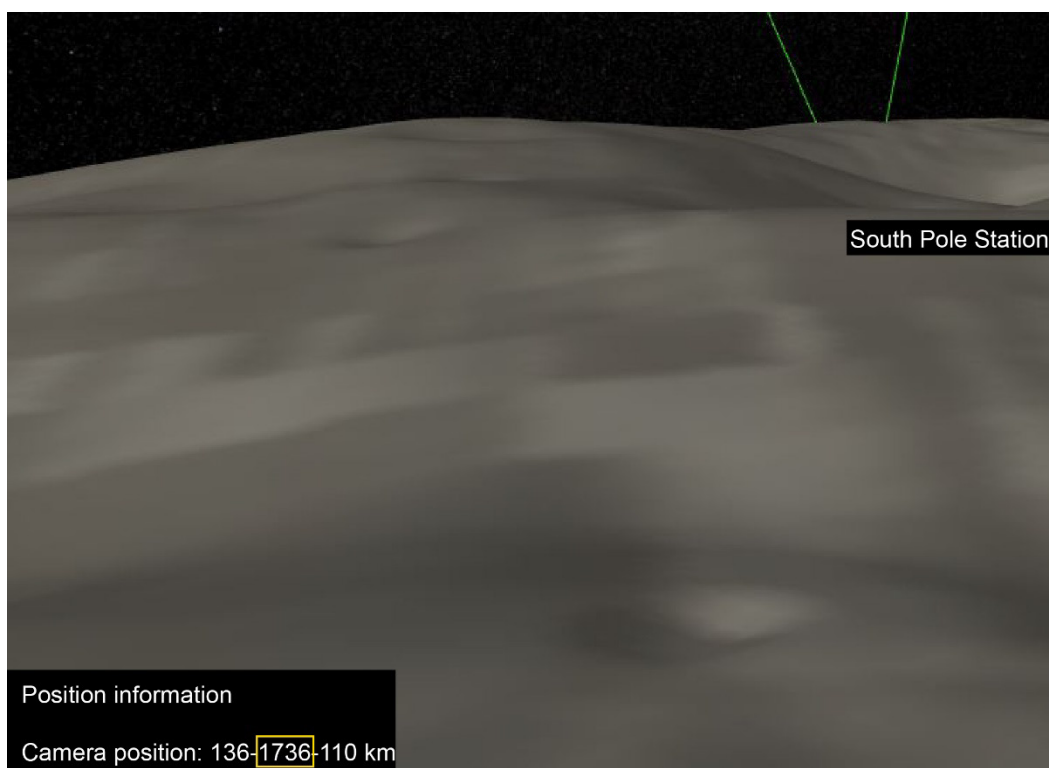


Figure 3.—Ground station on lunar south pole is obstructed by terrain. Value shown in yellow box corresponds to elevation.

Foundational Data for Lunar Terrain

The technique used to solve this issue works through understanding changes in elevation for the camera, much as one might observe the changes in depth from a boat to the ocean floor (Ref. 3). To determine the distance from the boat's position to the ocean floor, a sailor might drop a long pole or rope over the edge until it hits the bottom (Ref. 3). The distance from the boat to the floor would determine how long the pole or rope needs to be. Think of it like hanging a string from a suspended camera until it reaches the floor. The further from the ground the camera is, the longer the string will need to be. The closer to the ground the camera is, the shorter the string that is needed. This is the idea used when trying to determine the distance between the camera and the lunar surface using the method described in the following sections. This value is determined by setting key limits based on research and understanding of lunar terrain and respective planetary radii where an object other than the Moon is in view. By doing this, the computer can define where it should be in order to stay above ground and avoid clipping through the terrain. Figure 4 illustrates these concepts. Note how the length of the blue arrow pointing from the camera to the terrain changes depending on how far the camera is from the terrain.

In creating the limiting key factors, it is important to define and understand the data and the limits on the data related to the camera functionality in relationship to the terrain. This section of the report will deal primarily with the discussion of camera clipping through the lunar terrain details for the lunar surface. These surface variables are more complex than the texturing of the other primary objects in the program, so more complex definitions are required.

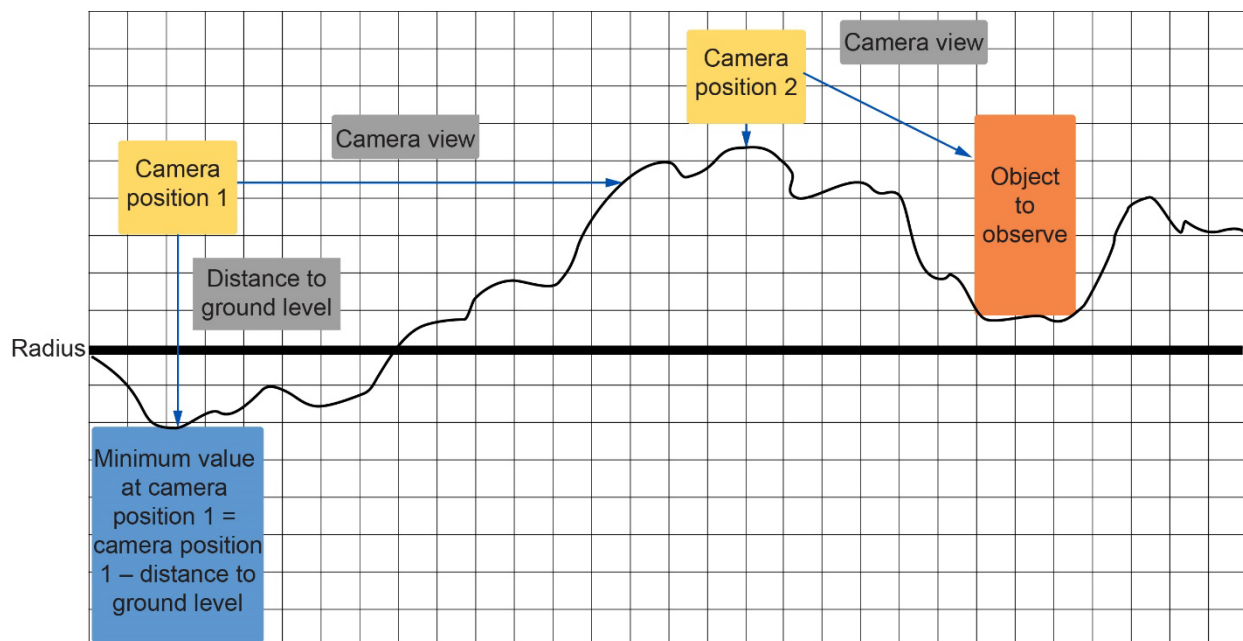


Figure 4.—Concept of camera's movement and ability to observe objects along rough terrain.

It is important to start with a concept of the radius, which is what informs the limits set for the camera to prevent it from clipping in this method. Technically speaking, an object like the Moon can be defined by two separate radii: the polar and equatorial radius (Ref. 4). In this program, the values of the two radii are the same, approximately 1,737.4 km, as defined by past research (Ref. 4). There are also specific maximum and minimum values that reflect whether an observer could still in theory be on the lunar surface. Note that these values could represent either the lowest point in a crater or the tallest peak of a mountain (Ref. 5). For the purposes of this program, these values will be referred to as “max.” and “min.” for a generalized understanding of the concept. Note, however, that these max. and min. values are based on compiled data of lunar terrain (Ref. 6).

Keeping in mind what had already been discussed in relation to the terrain, it is important now to consider the other variables involved. The key component that allows this method to work is that there is a minimum value that can change in relationship to the camera’s position in space with respect to the ground. So, the variables that would be involved would be the position of the camera object itself, a set starting point for determining the ground level, a distance variable to account for the distance between the starting point for the ground level, and a variable to store the information for the new minimum value for the camera. As these values will act as comparisons with one another, it is important that some of the variables remain constants. It might be useful to think about these variables as compass markers that remain the same, which travelers could use to compare their current position with their desired location. In this scenario, the starting point for determining the ground level would be constant. This is a variable that basically accounts for the fact that on relatively level ground with minimal elevational impacts, the position will be a certain value. In this case, the radius for the Moon is used.

There would then need to be a variable to represent the camera’s current position. As the camera is an object that will move freely through space and over terrain, this is a variable that will need to allow for making changes. In other words, it might not be in the same position from one moment to the next.

Furthermore, a variable is needed to represent the distance from the camera to the ground level, as defined by the radius. Because the camera is variable in its position, this variable’s value will also change. For instance, one might consider the camera resting on the tallest peak of a mountain to be zero, thus having zero distance between it and the surface. In contrast, the camera could be hovering in space above a crater, thus giving a different value to the distance the camera could be from the ground. However, it is important to note that in order to be on the lunar surface, the camera’s distance to the ground must be bounded by certain constraints. As discussed previously, these constraints could be either the max. above the radius or the min. below the radius. This means that the variable to represent the distance from the camera to the ground level could oscillate within the range of min. to max. if one considers ground level to equate to a 0 value for this variable. Note that the max. and min. variables will be calculated in the same unit of measure as the corresponding variables. Most of these calculations are done in kilometers, so max. and min. will also be expressed in kilometers.

The Math Behind the Method

As described in the previous section, the variables and their nature can be combined to implement a form of limiting factor that will allow the camera to quantify its location in space. Two distinct camera visuals are part of the GCAS program. One allows the camera view to move as a first-person perspective would appear. The other allows the camera view to be centered on a specific object. The mathematical equations in the following subsections detail the math underlying each method.

First-Person Camera for Lunar Terrain

The first-person camera for the lunar terrain requires the most finely tuned controls of all the objects due to the nature of the texture of the lunar surface. As such, the most detail on setting the limits occurs under this parameter. The limiting factors are set by making comparisons to certain values. An example of this process mathematically follows.

First, it is recalled that the camera might be the max. possible value above the radius, which can be represented like this:

$$\text{check to see if camera position} = 1,737.4 \text{ km} + \text{max. elevation km}$$

As it is assumed if the above is found true, the camera is at a peak, the distance to the ground level is set to 0, and the minimum value that the camera can go to is set as the ground level. From there though, options other than the camera being equal to the highest possible peak must be considered. This can be seen as follows:

$$1,737.4 \text{ km} + \text{max. elevation km} > \text{camera position} > 1,737.4 \text{ km} - \text{min. elevation km}$$

From here, it is now required to define how far the camera currently is from the ground level. This is shown as follows:

$$\text{distance to the ground level} = \text{camera position} - 1,737.4 \text{ km}$$

Then a new minimum value, which bounds how far the camera can go, can be established. This is shown as follows:

$$\text{minimum value} = \text{distance to the ground level} + 1,737.4 \text{ km}$$

Note that this will return the camera position depending on the camera location, which allows the camera to skim the surface of the terrain without going beneath it. Figure 5 shows an example of these principles being applied in action. Figure 5 begins close to the locations shown in Figure 1, Figure 2, and Figure 3. However, in Figure 5, the camera now moves forward, up the slope of the mountain that it was originally behind. As the change in elevation coordinates shows, the camera's elevation changes as it climbs the mountain rather than going through it. Once again, the change in elevation here is indicated in the yellow box surrounding the corresponding coordinate. Note that the elevation is shown in the y coordinate in the box for the lunar surface. In Cartesian coordinates, this would typically be represented by the z-axis. However, in 3D systems run on computers, other coordinate systems are often used that differ from more familiar ones. This difference in coordinate systems can also induce changes in variables based on position on the object. Note that the elevation data gathered here was taken at a specific spot on the lunar surface. The variable for representing this data might change based on location in space. As such, this variable representation difference between other graphing formats and this one is understandable.

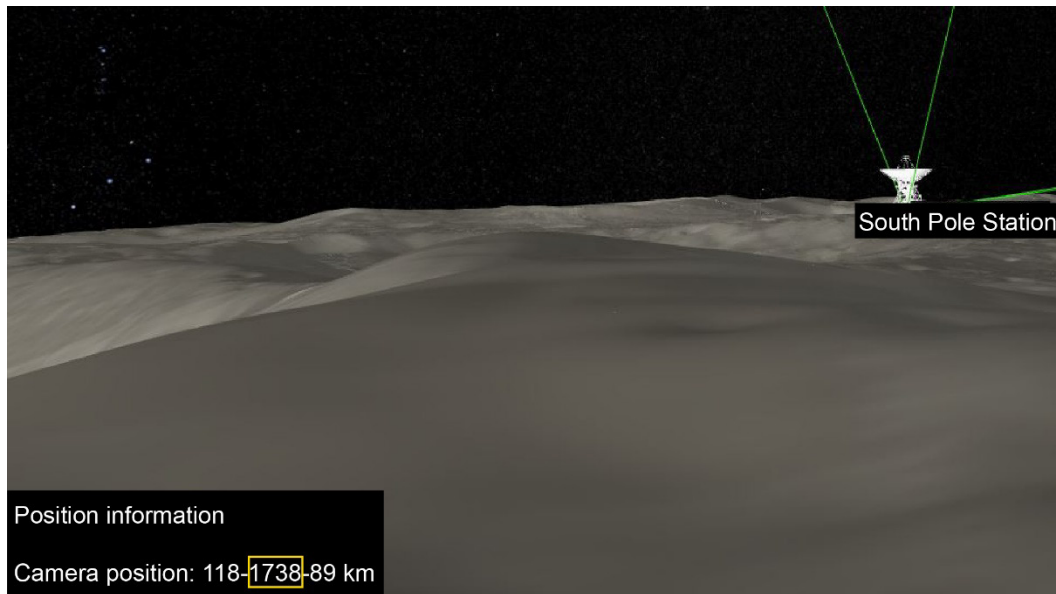


Figure 5.—Camera coordinates have changed to reflect climbing mountain rather than going through it.

Object-Relative Camera for Lunar Terrain

Although the first-person camera requires more fine-tuning to allow it to simulate actual motion, a camera focused on a specified object has its own unique requirements. In the object-relative camera focus, the camera might view a specified object on the lunar surface. This will cause the camera to move in an arc traverse path around the object with the camera always focused on the object, which could take the camera through mountains or over craters. Because the variation in position can be at greater speed, changes in elevation are made with less precision. Therefore, the mathematics underlying this method are a little less involved. In this math, the minimum value is most often kept as equal to the maximum elevation, with one exception. If the camera dips below the minimum for the ground level, the minimum value is set as equal to the ground level plus 0.1 km as follows:

If

$$\text{current position} \leq \text{ground level}$$

then

$$\text{minimum value} = 1,737.4 \text{ km} + 0.1 \text{ km}$$

If the camera's position does not drop below the ground level, then the position is left unchanged.

Considering Camera Clipping on Objects Other Than the Moon

GCAS includes representations of spherical objects other than the Moon, which might also face issues with camera clipping. However, at the time of this writing, these other objects are much simpler in the scope of GCAS as compared to the lunar surface. That is because the other objects lack terrain that changes in elevation. These objects have curvature, but they do not experience the same changes in elevation that the Moon does on its surface in this rendering. As such, the radius value for these objects is

sufficient to act as the lower bound for the camera. Therefore, the camera position can never go lower than that number. This can be represented mathematically as follows:

If

current position < object radius

then

minimum value = object radius

Figure 6 shows an example of the method described as shown on the surface of the Earth to help illustrate the point. Note that this method will work regardless of the camera's focus. In other words, it will work whether the camera is acting as a first-person view or focused on an object.

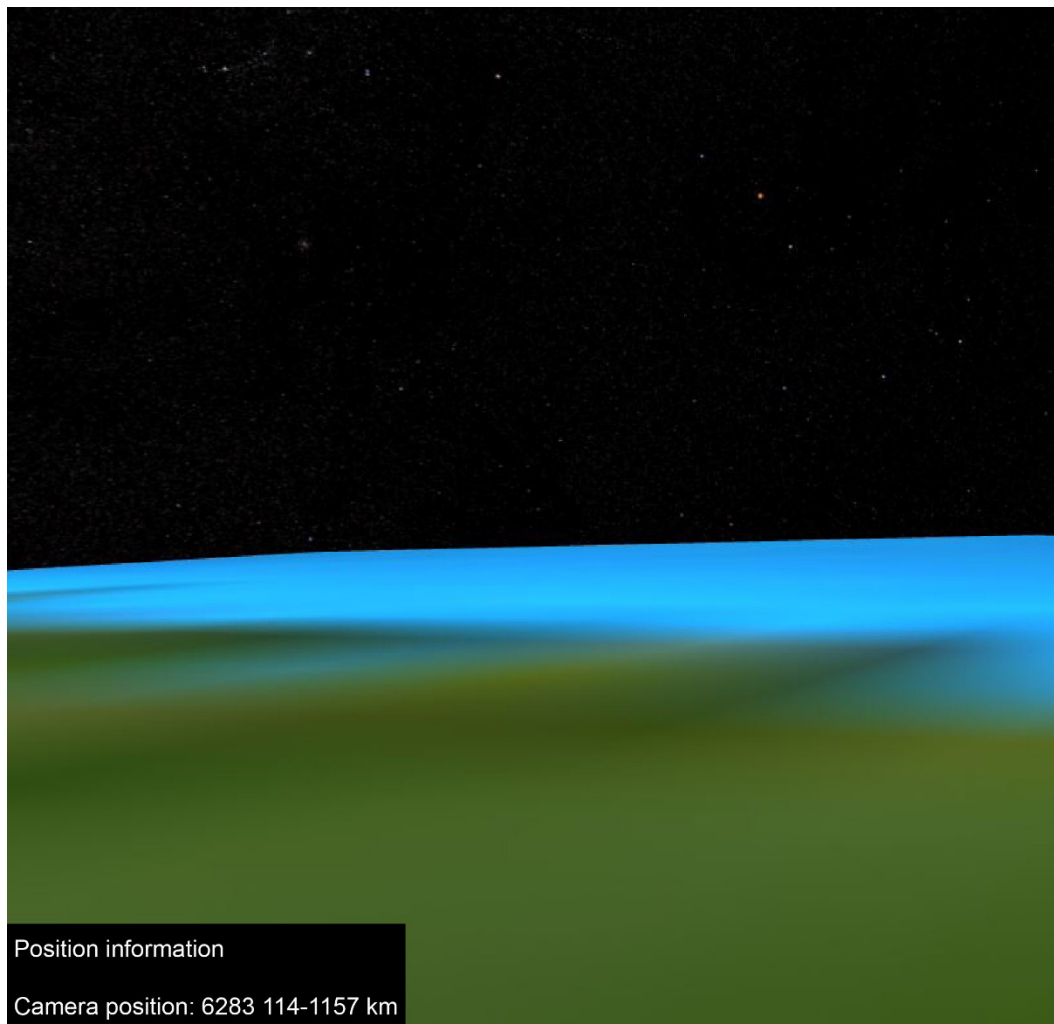


Figure 6.—Camera on Earth's surface does not go subsurface.

Results and Discussion

The camera clipping work described in this report has been effective in allowing the camera to stay above the surface as it moves about the GCAS program. However, the results are not without their limitations, specifically with regard to navigating the lunar surface. In the case of the first-person view, the camera must be moving at speeds slow enough for the method to work. Otherwise, the user could force the issue and cause the camera to clip beneath the surface if it is moving fast enough. Also, to achieve the best results on the most varied terrain, the camera needs to look in the direction and elevation of the horizon. Otherwise, the camera might accidentally clip through the terrain.

The object-relative camera views also have their own limitations. In object-relative views, the camera is limited in how low in elevation it can go on the surface. This prevents the camera from seeing through or moving through mountain objects unrealistically. However, it presents some limitations as to how the user navigates the surface in terms of how low the camera can be positioned.

At the time of this writing, none of the limitations described here apply to any objects other than the Moon in the GCAS program. This could change if these other objects are modified later. However, the camera can currently move and operate freely on the other objects modeled in the GCAS program.

Concluding Remarks

Future expansions of this project could involve implementing forms of collision detection that will allow for more accurate movement and detail. One potential option for future expansion on this concept is called ray casting, which allows for an object, such as the camera in this instance, to send out rays that determine where an object is and if collision has occurred. This allows for greater camera precision and freedom of movement while still achieving the desired outcome. Ray casting was not a viable option for the current Glenn Research Center Communications Analysis Suite (GCAS) due to limiting factors caused by the way three-dimensional (3D) models were loaded into the system and runtime issues. In future renditions of GCAS, there is reason to hope that ray casting and other collision detection methods might not only be viable but more impactful.

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