

Techniques and Results for Determining Window Placement and Configuration for the Small Pressurized Rover (SPR)

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A natural component to driving any type of vehicle, be it Earth-based or space-based, is visibility. In its simplest form visibility is a measure of the distance at which an object can be seen. With the National Aeronautics and Space Administration's (NASA) Space Shuttle and the International Space Station (ISS), there are human factors design guidelines for windows. However, for planetary exploration related vehicles, especially land-based vehicles, relatively little has been written on the importance of windows. The goal of the current study was to devise a proper methodology and to obtain preliminary human-in-the-loop data on window placement and location for the small pressurized rover (SPR). Nine participants evaluated multiple areas along the vehicle's front "nose", while actively maneuvering through several lunar driving simulations. Subjective data was collected on seven different aspects measuring areas of necessity, frequency of views, and placement/configuration of windows using questionnaires and composite drawings. Results indicated a desire for a large horizontal field-of-view window spanning the front of the vehicle for most driving situations with slightly reduced window areas for the lower front, lower corners, and side views.

INTRODUCTION

An important concern of any space-vehicle, particularly those that involve manned operations, is visibility. However, there has been relatively little written on the importance of spacecraft windows, much less land-based vehicles that involve manual driving in an alien environment. In the past, there have been human factors evaluations for field-of-view (FOV) and window placement with experimental spacecraft that could have implications to the current configuration.

In a human factors study involving the HL-20 personal launch system (Willshire, Simonsen, & Willshire, 1993), four pilots judged the amount of acceptable window area based on previous flight experience. By systematically either covering or uncovering the windows by sections, experimenters were able to gather subjective ratings of acceptability for general flying with an emphasis on landing. Pilots reported that the middle and lower sections were the most needed for flying functions, while the upper and center sections was desirable for the FOV, but not critical. In addition, all agreed that side windows needed to be as low as possible with less structure between the window segments. Adjustability of seats was desirable to help with the vision during certain flying activities such as takeoff, cruising, and landing.

While the current study does not deal with flight, the reasons of *why* these participants chose certain viewable areas over others does have implications. During flight there is little reason to be concerned with objects above the vehicle. However, there is a great deal of concern about the environment below the craft, especially during takeoff and landing. If we apply this same logic to rover operations on the lunar surface, then we would expect middle and upper areas of the FOV about the horizon line to be of importance for proper navigation. Lower and side areas would not be as important to navigation, but could be for operational issues such as obstacle avoidance or greater visibility of terrain, which is not a

concern when flying. Windows closer to the lunar surface could also aid in geologic inspections of materials such as rocks. Before the astronauts take the time and waste vital consumables, they could simply drive up to a rock and view its importance prior to donning an ExtraVehicular Activity (EVA) suit and leaving the vehicle.

With Shuttle and ISS, there are human factors design guidelines for windows. The same will eventually need to be written for lunar vehicles. However, the most important aspects for any window design, for example those listed for ISS (Haines, 1987), is they must adequately support all operations while maximizing safety.

The purpose of the current evaluation was to obtain preliminary human-in-the-loop data on window placement and configuration for the small pressurized rover (SPR). The evaluation focused primarily on forward windows employing a novel methodology developed by the investigators. All testing was conducted by the Usability Testing and Analysis Facility (UTAF) and took place in the Reconfigurable Operational Cockpit (ROC) facility at Johnson Space Center (JSC), in which a 2-D simulation was projected upon a domed screen. In many ways, this study could be considered a baseline development that could be leveraged to future engineering designs and human factors evaluations, which would take into account more critical issues such as structural integrity, thermal factors, and weight.

METHODS

Participants

Nine participants (7 males and 2 females) took part in the SPR window evaluation. All were right-handed and of various working backgrounds such as astronauts, geologists, and engineers. Each was very experienced with the current and prior SPR configurations as the majority of the participants

were in previous evaluations. Testing was conducted over four days with each session lasting about an hour and a half.

Equipment

The ROC at JSC was configured for lunar driving simulation (see Figure 1). A simulation of medium to high resolution of a lunar environment was provided and deemed capable to evaluate window concepts. The SPR mock-up was placed front-first inside the dome area toward the screen. However, due to the size of the rover mock-up in comparison to the dome, there was no side or bottom views available with the simulation (see Figure 2). The participants “drove” the vehicle while seated on the left-side with a joystick mounted on the right-side of the participant. The rover simulation mimicked the movements of the six-paired wheel vehicle. By pushing the joystick forward or back, the rover simulated movement in that direction. However, moving the joystick left or right, the rover remained forward facing and would “crab” in that direction. To actually turn left or right the joystick needed to be twisted, while simultaneously pushing the joystick in that direction. While the rover mockup did not move, the simulation on the screen did. For example, if a person turned left, the screen cycled to the right to simulate motion.



Figure 1. The rover mockup positioned inside dome.

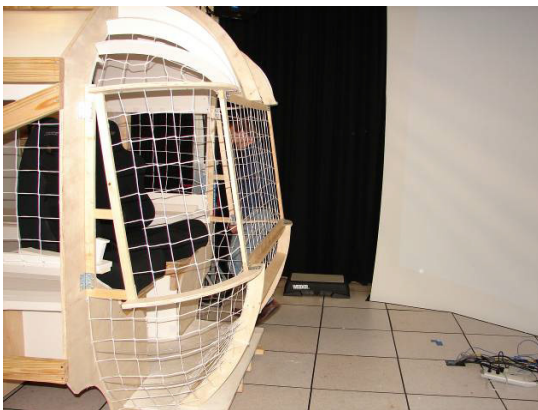


Figure 2. The rover nose inside the dome area. Notice the limitation of the screen not wrapping around the sides and bottom, thus, preventing accurate evaluation of those areas.

Four lipstick video cameras were utilized; two were positioned inside the rover with one aimed from the rear and the other focused on the participant. A third camera focused on the navigation screen attached to a computer running the lunar simulation and the fourth camera was attached to a pair of safety glasses worn by the participants (see Figure 3).



Figure 3. Display showing the four camera views obtained during the evaluation.

Procedures

Given the “open” cockpit configuration and the amount of metal in ROC, an eye-tracker and virtual reality system was unsuitable to gather data. Therefore, a unique methodology was developed where a grid was wrapped over the front and sides of the frames (see Figure 4). Inside the cockpit, the grid was numbered vertically and lettered horizontally to aid participants in window location and size description (see Figure 5). Ten different areas were assessed for necessity and size: upper left and right corners, left and right sides, left and right side arch, front, left and right lower corners, and lower front (see Figure 6).



Figure 4. Rover mockup showing the grid placed around the cockpit area.



Figure 5. The grid allowed a frame of reference to describe window placement and configuration. The insert photo (upper left) shows the grid's number and letter mapping scheme.

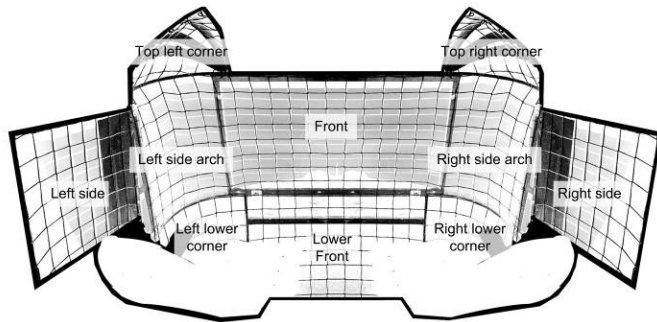


Figure 6. Schematic shown to define the necessity of each location.

Participants were exposed to five different driving scenarios in order. Driving began at a rock field which allowed assessment of general navigation and obstacle avoidance. Participants then entered a smooth/flat terrain, followed by hilly, then mountainous. Participants were able to drive up mountains or move down into caverns. The experimental session ended with driving about a crater – moving along the rim then down the side, making a 360° turn-around and maneuver sideways up the crater rim. These scenarios were designed to exploit different areas of the grid area for accurate assessment. Therefore, ten different areas of the cockpit were evaluated using seven different “driving” conditions.

Table 1

Means for Task by Rover Cockpit Area for Necessity of Windows

Task	Upper Corners	Sides	Side Arch	Front	Lower Corners	Lower Front
Smooth Flat	1.67	1.50	4.44	5.00	1.44	1.33
Hilly Terrain	1.44	1.78	4.56	5.00	2.11	1.44
Mountain Terrain	3.50	1.89	5.00	5.00	1.67	1.56
General Rock Field	1.00	2.00	4.89	5.00	2.67	2.22
Rock Avoidance	1.00	2.28	4.94	5.00	2.67	1.67
Circling Rock	1.00	1.38	4.69	5.00	2.13	1.88
Crater Incline	2.13	3.00	4.88	5.00	2.13	1.88
Overall Rating	2.22	2.78	4.89	5.00	2.67	2.33

N = 9.

After completion of driving, a questionnaire was completed where locations were rated on window necessity, 1 (unnecessary) to 5 (necessary). Participants stated whether each location should be directly viewed (i.e., have a window), indirectly viewed (i.e., a monitor or display), or did not matter. In addition, participants drew the location and shape of the windows on a transparency. They indicated three different colors to denote necessity: red (high priority/must have), green (like to have), and blue (low priority).

RESULTS

Subjective ratings of window placement across the driving terrains were consistent for left and right areas; therefore, for ease of interpretation the left and right areas were averaged for reporting. In addition, the frequency of viewing each area either directly, indirectly, or did not matter was counted. Finally, several composite drawings were developed from participants drawings for window placement and configuration. One drawing shows the combination of all red areas denoted by the participants as “high priority”, while another illustrated only the congruent areas along with the “like to have” and “low priority”.

Ratings for Areas of Necessity

The two areas that were obviously necessary were the front and side arch areas (see Table 1). The upper corners were rated unnecessary when driving in the smooth/flat or hilly terrain, but increased with mountain and crater incline. This is because as the rover traverses caverns or enters craters those areas became more utilized. In the simulation, when a person drove into the crater their FOV on the screen shifted up, meaning the bottom of the crater was at the top of the screen. When driving around the crater, depending on the direction, either the lip of the crater or the bottom of the crater was located at the top of the dome screen, thus utilizing those areas. In fact, if we contrast code those terrains (mountainous and crater) versus all others, there is found a significant correlation, $r(58) = 0.617, p < 0.001$, with upper window necessity. The lower windows, both the corners and front, were most necessary with rock field driving and obstacle avoidance for obvious reasons.

As discussed, there were limitations in the simulation where the dome did not completely wrap around the side and bottom areas of the rover. Presumably, it is this fact that led to lower necessity ratings for these areas (see Table 1). For example, with the lower corners and sides, all scores were below a rating of 3 (neutral), suggesting they found those to be somewhat unnecessary. Similarly, for the lower front area, most of these scores were below 2 (somewhat unnecessary). Future studies in a larger dome will hopefully resolve this limitation.

Frequency of Views

During the evaluation, the participants answered whether they would like to view each of the ten areas directly, indirectly, or it did not matter (see Table 2). Just as with the ratings of necessity, participants unanimously stated that the front and side arch areas should be directly viewed. Other views did not seem to matter with exception of direct views for the upper corners with mountain terrain, and lower corners for rock avoidance.

Window Placement and Configuration

Participants were given a blank grid, similar to Figure 6, and asked to color-in the location and configuration of the windows they felt were necessary. To further rate the necessity, they were asked to use three different colors, red (must have), green (like to have), and blue (low priority). Figure 7 illustrates the combination, or union, of all red areas drawn by the participants. As shown, participants desired a large FOV encompassing all the front and side arch area horizontally. In addition, they carried the vertical height into the upper corners and top area above the front location which was not originally defined. The total square feet of window area defined by this drawing equals 26.46.



Figure 7. Diagram showing the union of all red areas drawn by the participants. Each square is approximately 4 inches.

Next, we examined the intersection, or congruent, areas of red drawn by the participants, along with green and blue (see Figure 8). The total area for the red (must have) in this illustration equaled 14.28 square feet. This picture suggests that participants are willing to sacrifice the upper corner areas for more front window height. However, the side, lower corners, and bottom front areas are drawn rather small, but this could be a result of their inability to accurately access those areas. Further testing will have to be conducted to properly define those locations. Also notice that participants preferred a lower FOV for side arch sections versus the front. It was our belief that this configuration was a highly viable concept and was carried forward in the functional prototype.

Participants did comment that the front areas were used primarily for navigation, while the side and lower areas would be for obstacle avoidance. The lower center area could be used for geological surveys, but this will need to be further tested in a “real world” environment. In addition, most concept illustrations have depicted this area to have a domed structure. However, when participants were questioned about preference, they all stated that a flat surface would probably suffice.

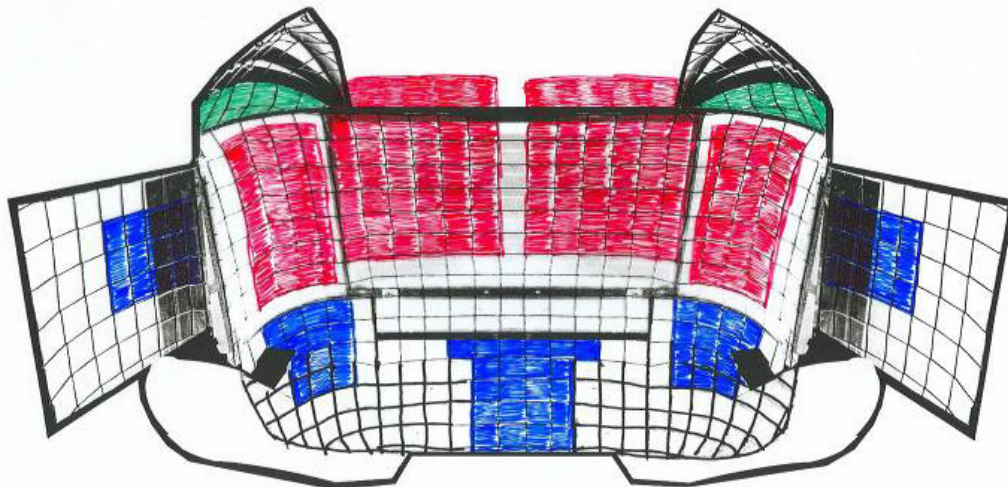


Figure 8. Diagram showing the intersection of all red, green, and blue areas drawn by the participants. Each square is approximately 4 inches.

CONCLUSIONS

While there were a number of limitations due to the dome screen size, this evaluation did shed some light on a proposed baseline for the front window areas of the SPR. For example, participants desired a large horizontal FOV of 7.3 feet across (ref. Figure 7). Although, this space could be divided vertically based on some participants' inputs, this could aid in any future structural issues (ref. Figure 8). As for the vertical space, participants overall desired nearly 3.3 feet (ref. Figure 7), but would sacrifice some upper corner area for more upper front area. Additionally, they preferred a lower FOV at the arches as compared to the direct front (ref. Figure 8).

For the sides, lower front, and corners, all the participants were able to do was to give a best estimate. We believe these estimates will change, in terms of increased window area, once higher fidelity or real world simulations are conducted. The current evaluation revealed that participants wanted less side window area than previously thought given that these areas could aid in docking maneuvers. However, this was not simulated and this configuration could then change.

For future evaluations, it is recommended that the sum area (ref. Figure 7) be developed as the baseline. This would allow for a more comprehensive evaluation with higher fidelity and real world simulations. Figure 9 shows a model of the recommend forward design that has been carried forward.

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Table 2
Frequency of View for Task by Rover Area

Task	Upper Corner			Sides			Side Arch			Front			Lower Corner			Lower Front		
	Direct	Indirect	DNM*	Direct	Indirect	DNM*	Direct	Indirect	DNM*	Direct	Indirect	DNM*	Direct	Indirect	DNM*	Direct	Indirect	DNM*
Smooth Flat	2	0	7	1	1	7	9	0	0	9	0	0	2	1	6	1	1	7
Hilly Terrain	0	1	8	1	2	6	9	0	0	9	0	0	2	1	6	0	1	8
Mountain Terrain	5	0	4	1	0	8	9	0	0	9	0	0	1	1	7	0	0	9
General Rock Field	0	1	8	2	1	6	9	0	0	9	0	0	4	1	4	2	2	5
Rock Avoidance	0	1	8	2	2	5	9	0	0	9	0	0	6	0	3	1	0	8
Circling Rock	0	1	7	2	3	3	8	0	0	8	0	0	3	1	4	3	0	5
Crater Incline	1	0	7	3	0	5	8	0	0	8	0	0	2	0	6	1	0	7
Overall Rating	1	0	8	4	1	4	9	0	0	9	0	0	4	0	5	2	0	7

*Does Not Matter

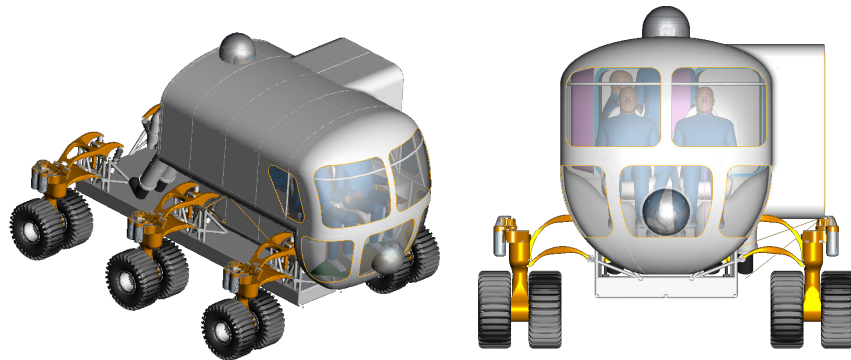


Figure 9. Recommended design to be moved forward for future test and evaluation.