ENABLER OPERATOR STATION

Andrea Bailey, John Kietzman, Shirlyn King, Rae Stover, and Torsten Wegner

Abstract

The objective of this project was to design an onboard operator station for the conceptual Lunar Work Vehicle (LWV). The LWV would be used in the colonization of a lunar outpost. The details that follow, however, are for an Earth-bound model. The operator station is designed to be dimensionally correct for an astronaut wearing the current space shuttle EVA suit (which includes life support).

The proposed operator station will support and restrain an astronaut as well as to provide protection from the hazards of vehicle rollover. The threat of suit puncture is eliminated by rounding all corners and edges. A step-plate, located at the front of the vehicle, provides excellent ease of entry and exit. The operator station weight requirements are met by making efficient use of rigid members, semi-rigid members, and woven fabrics.

Problem Statement

The design of the lunar work vehicle's operator station must meet the following requirements both on the Earth-bound model and the conceptual lunar design:

- support the combined weight of astronaut and current space shuttle EVA suit
- provide operator restraint system
- provide rollover protection based on static load of half vehicle weight with appropriate safety factor (4) to account for dynamic loading
- provide easy access to vehicle controls
- maintain ease of ingress/egress to operator station
- remain within maximum chassis mounting width on the forward T-section of vehicle
- meet within maximum weight requirements through selection of materials

The dimensions for this operator station design are based upon the current shuttle suit dimensions due to lack of concrete information on either the Mark III or AX-5 suit:

• helmet height	381 mm
• shoulder width:	726 mm
• seat height-foot to buttock:	508 mm
• primary life support system height:	813 mm
• shoulder height-seated:	940 mm
• seated height to top of helmet:	1016 mm
• arm reach:	813 mm

Design Descriptions

The seat design is divided into three categories: structure, fabric, and restraint. The actual design for each of these categories is discussed in detail in sections that follow.

Structure

The actual seat structure consists of the roll cage and the step-plate support mounted to the front of the T-section. Also considered were the material selection and the chassis mounting mechanism.

Roll Cage: Design. The primary consideration for the main structure of the operator station was to protect the operator in the event of a vehicle rollover. In order to provide such protection, the structure to the operator station was designed to be similar to a roll cage used in automobile racing. The general design consists of a slanted U-shaped main hoop with two vertical support bars (Figure 5). The front T-section of the vehicle is about 1067 mm wide, which allows the hoop to be designed with a wide radius, thus producing only simple curves.

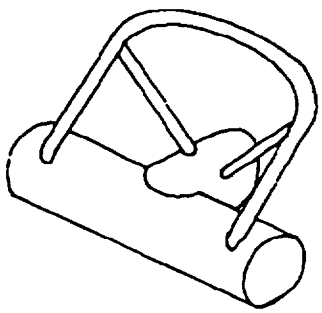

Fig. 5 U-shaped roll cage design

While this configuration would be preferred, integrating this design with the basic model of the Enabler forced a redesign. In redesigning the roll cage, the width given for mounting on the forward T-section was kept in mind. On the forward T-section, the wheel drives and their hubs are designed to detach easily from the central chassis section. This arrangement requires that the roll cage attach only to the central section of the chassis. The width at this point is approximately 510 mm. After allowing for welding, attachment hardware, and tool clearances, the usable width of the front T-section is roughly 460 mm. This is a limiting factor which forced design modifications, as seen in Figure 6.

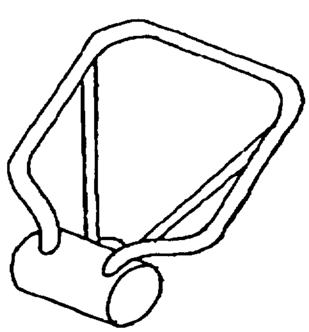

Fig. 6 Roll cage designed to meet mounting limitations

Roll Cage: Material Selection. Preliminary materials selection was based on the standards specified by automobile racing sanctioning bodies, NHRA and NASCAR. Roll cage standards were consulted and found to specify either mild steel (AISI 1020 or 1018) or stainless steel (AISI 4140). Since steel is in widespread use and is cheaper and easier to work than composites involving carbon, it was selected for this design.

After the tubing sizes specified for racing roll cages were examined, a tubing manufacturer was consulted for information about available materials, diameters, and wall thicknesses. Reasonable tubing sizes, which are commercially produced, are those with outside diameters from 31.75 to 76.20 mm (1.25" - 3"). Available wall thicknesses for such tubing range from 2.11 to 3.96 mm (0.083" - 0.156"). The minimum bend radius specified for the design is five times the nominal diameter of the tubing. This factor of five results in a minimum bend radius which can easily be accomplished in most standard metal working facilities.[14]

ASTM data on the 1020 steel rated a yield strength of 262 MPa and a strength of 620 MPa on the 4140 steel. Because of its higher yield strength, 4140 stainless steel was specified for the design. In this application, the safety and space requirements were judged more important than the increased cost and difficulty created by using stainless steel.

In order to determine material strength requirements and final dimensions, a finite element analysis of the structure was performed. ALGOR software was used to prepare a model and analyze its performance. Due to constraints of the software used, each curved member was approximated as two separate straight tubular segments. Several design refinements based upon information from the models were incorporated into the final design chosen.

The forces used in this analysis were based on the assumption that static loads of half the vehicle weight, approximately 5300 N or 1200 lb., were acting upon the roll cage. The actual dynamic loads on the roll cage were considered by designing for a safety factor of four. A 5300 N force was placed at six locations oriented along the roll cage. The highest resultant stresses occurred in the case of a horizontal force, acting sideways, located at the top of the roll bar.

The finite element analysis was performed for various tubing sizes. The results indicated 76.2 mm outer diameter tubing with a 3.05 mm wall thickness as the most appropriate choice. Using 4140 steel results in a maximum stress in the structure of 143 MPa, with a safety factor of approximately 4.3. While smaller diameter tubing may be lighter in weight and more normal in appearance, any tube sizes below 50.8 mm with a 3.96-mm wall thickness cannot withstand the forces which act upon the structure. A choice of 50.8-mm tubing with 3.96-mm wall thickness material results in a safety factor of only 1.8. This was regarded as too small a margin for a human safety application where the true forces are not known.

The force analysis also showed that the highest stresses in the tubing occur near where the roll cage connects to the chassis. Thus, the design of the structure above the attachment points was not critical from a stress standpoint. The structure at the top of the roll cage was therefore designed for astronaut clearance in ingress/egress and minimal tubing use for minimal weight of the structure. Other structural configuration attempts yielded negligible improvements in reducing the critical stress near the chassis attachment points.

Seat Frame. The actual seat and backrest for the operator station are supported by 6.35-mm diameter steel cable held by cycles which are welded to the roll cage. The steel cable has a load limit of 6228 N (1200 lbs), which easily supports the estimated operator weight of 890 N (200 lbs). For the seat and backrest, cable was chosen for all structural members in tension because it weighs less than steel tubing. The cable passes through an eyelet and is fastened to itself with standard cable ties. The seat and backrest also include a cotton twill fabric, which is discussed in the section on fabric.

Step Structure Design. Because of the height of the vehicle and the mobility restrictions upon a suited astronaut, a step is required for ease of ingress/egress to the operator station. This step was integrated into the operator station design by placing it immediately forward of the front T-section. The size of the plate was based upon the competing requirement ease of ingress/egress and minimum weight. Operator ingress is accomplished by stepping onto the plate, turning around the plate, and then sitting in the seat. The roll cage main hoop is used for position and orientation references during this action.

The step-plate is supported by steel tubes which connect it to the front T-section. The loads produced when an astronaut steps upon the plate are quite severe because of the long moment arm attached to the chassis. A finite element analysis of the step-plate and its supports was performed in order to specify the tubing size. The same ranges of tubing diameters (31.75 - 76.20 mm) and wall thicknesses (2.11 - 3.96 mm) considered for the roll cage were investigated for the step-plate.

A final design of a 31.75-mm outside diameter tubing with a 3.96-mm wall thickness was chosen for the supports of the step-plate. When a 1000 N (225 lbs) load is applied at the corner of the step-plate, a maximum stress of 358 MPa develops in the supports. Because of this high stress value, AISI 4140 steel was chosen for the support tubes. This material results in a safety factor of 1.7 for this load. While this safety factor is lower than that of the roll cage, the step-plate is not critical to the safety of the operator. An additional consideration is that the use of larger diameter tubing would have resulted in insufficient leg space for a suited astronaut.

The step-plate itself was designed of 6061-T6 aluminum for its superior strength-to-weight ratio compared to that of steel. It is bolted to the support arms using standard grade 5 bolts and washers.

Attachment to Chassis. The nature of rollover loads greatly complicates the attachment of the roll cage to the chassis. While dynamic loads are difficult to produce, the obvious static load in the event of a rollover is the weight of the front half of the vehicle. Therefore, the weight of the chassis must be transferred to the roll cage so that the operator will not be crushed. As a result, the connections between the roll cage and the chassis must support not only the weight of the roll cage but also the weight of the front of the vehicle.

The roll cage and step structure are welded to thin steel pads that distribute the point loads over a greater area. The pads are then welded to the skin of the chassis structure. Since that skin is relatively thin and would deflect under such distributed loads, a load-carrying bulkhead system was designed into the front chassis T-section.

The use of steel for the chassis T-section as well as for the roll cage and step structure allows the assembly to be welded together. Standard TIG welding procedures for joining steel to steel can be implemented using a standard filet weld to join the pipes. A weld depth of 3 mm was specified based on the welding of pipe of 3-4 mm wall thickness.[2]

Fabric

The operator station's seat will have fabric in two locations on the structure, the backrest and the seat. The fabric will be looped around each cable and double-stitched to itself with polyester/cotton thread.

In choosing the fabric, several factors were taken into consideration. First, the fabric must be strong enough to support the entire weight of the astronaut. It must also have low elongation so that it will not creep of deform. Finally, cost and availability play a major role in the fabric selection.

For this design, a cotton twilled fabric will be used. This decision is based on the availability and cost of this type of fabric.

The fabric dimensions and shapes for the seat are given in Figure 7.

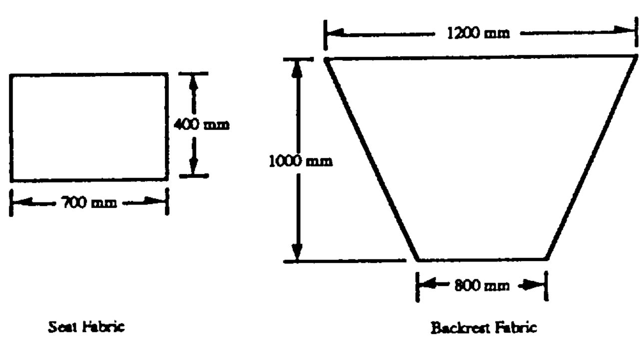

Fig. 7 Fabric dimensions and shapes

Restraint

After considering a number of complicated seat belt designs, an aircraft-style lap belt was selected as a preliminary design. At low speeds, this type of lap belt, together with the contoured seat design should adequately restrain the astronaut. Also, the addition of an upper body restraint would hamper the astronaut's ingress/egress.

The restraint will be attached to the chassis by using the clip, already attached to the seat belt, and an eyelet that will be welded to the chassis near the seat attachments.

Weight of Operator Station

The weight of the operator station, as described above, complete with mounting hardware is approximately 55 kg.

Conclusions and Recommendations

The initial goal for this project was to design an operator station for the lunar work vehicle that would meet dimensional considerations of a suited astronaut and provide rollover protection. The design described in this report and supporting technical drawings list meets these requirements. While the design meets the constraints previously listed, further modifications could improve the existing design.

First, a re-analysis should be done on the roll cage of the operator station. The first recommendation would be to analyze the roll cage structure using materials other than steel. Other materials (aluminum, carbon fiber composites, etc.) would allow development of a lighter weight structure with potentially smaller tubing sizes. Also, the utilization of the Algor FEA system requires each member to be approximated as a straight tubular member. The number of members which approximate a curve could be increased to improve the accuracy of the FEA results.

Before some of the analysis can occur, the building of a full-scale model is necessary. The actual ingress/egress of the suited astronaut needs to be investigated. Along with this, the structural integrity of the cable needs to be analyzed. The loaded shape of the fabric and cable must be studied experimentally. Depending on fabric thickness, the present design should be adequate; however, a mathematical analysis should be performed to determine the actual tensile loads present in the fabric and on the structure. In the analysis of the seat fabric, the actual pressure distribution caused by the astronaut should be investigated.

The restraint used in this design could also be improved. While this style of restraint (single lap belt with aircraft-style buckle) would work well, a larger size buckle would allow easier manipulation by the suited astronaut. Another style buckle to consider is similar to the handle-pull type used by tree climbers. Additionally, some type of spring or stiffer webbing should be used to hold the seat belt in an upright position to aid the astronaut in locating the belts.

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