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AIRLIFT: ENABLING BLAST PROTECTION AND RAPID, STABILIZED VEHICLE EXTRACTION

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ABSTRACT

The AirLift is a novel device that enables rapid stabilized extraction of injured personnel from a ground vehicle. When deployed from its pre-installed position as a seat cover, the AirLift rigidizes for stabilizing the occupant's spine by pressurizing an inflatable panel. After extraction from the vehicle with the occupant stabilized in the seated position, the AirLift can convert to a backboard so that the occupant can be safely transported in the supine position. The inflatable panel was designed and tested to provide stiffness while also being durable and manufacturable at volume. Pressure mapping tests were also performed to demonstrate that the AirLift did not change seat comfort compared to the standard seat.

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1. INTRODUCTION

In recent military conflicts, protection against vehicle underbody blasts has been a key survivability issue. Underbody blasts from buried mines and Improvised Explosive Devices (IEDs) have resulted in significant casualties [1,2]. Severe lower leg injuries commonly result from rapid acceleration and local deformation of the vehicle floor. Similarly, pelvic and lower spine injuries often occur as a result of potentially both local and global accelerative loading through the seat. Finally, head and neck injuries can also occur due to accelerative loading as well as impact on nearby interior structures (roof, walls, equipment, etc.).

While occupant protection technologies aim to reduce occupant exposure to injury [3,4], significant injury risk remains throughout these events. Not only is there risk of failure of one of these occupant protection devices due to misuse or extreme hull/wall deflections, but there is also substantial risk of an overmatch scenario – where the blast loading exceeds the design capability of

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the protection devices. Moreover, even in the perfect scenario when these protection devices limit loading to within design levels, there is still typically a 10-20% risk of injury associated with these acceptable injury tolerance levels. As such, in seating and vehicle design, it is important to consider how an injured occupant can be rapidly treated and evacuated post-event.

In the event of injury, the occupant should be stabilized prior to extrication from the vehicle and subsequent evacuation. Since hardware components such as the seat structure or seat substructures may not be reliably removed after significant deformations from the blast, the patented AirLift was developed as a lightweight, durable, and flexible seat cover system that is installed over an existing vehicle seat as shown in Figure 1. Such a softgoods system is reliably removable after significant hull/seat deformations for occupant extrication.

Figure 1: AirLift prototype installed on troop seat.

2. AIRLIFT OVERVIEW

The stabilization features of the AirLift are based on the standard of care for vehicular extrication - the Kendrick Extrication Device [5] (KED) shown in Figure 2. In use, the KED [6] is placed behind the injured occupant after stabilizing the neck using cervical collar. The KED lower flaps wrap around the body and, when secured with straps, stabilize the spine and the upper flaps wrap around the head and stabilize the neck. The KED is built using a series of wooden slats inside a fabric housing to provide rigidity and contiguous support from the lower spine up to the head. In the AirLift, a pressurized inflatable provides the rigidity to keep the occupant stabilized for evacuation.

Figure 2: Kendrick Extrication Device used for stabilization of patients prior to extrication. Stabilization features of AirLift are based on the KED.

The AirLift is pre-installed on the seat in an undeployed state and acts as a seat cover. A medic or fellow soldier deploys the AirLift after the blast event by removing the head rest cover and detaching the AirLift from the seat fabric sides. At this point the AirLift is in a deflated state and correctly positioned behind the occupant. The torso section of the AirLift inflatable is then pressurized to reach its rigidized state for stabilization of the back and head. Once the head, neck, pelvis, and back are stabilized in the sitting position (Figure 3), the occupant and AirLift is detached from the seat frame for extraction from the vehicle. In this state, the AirLift replicates the main functionality of the KED to stabilize the spine and neck.

Figure 3: AirLift upper inflatable deployed and rigidized for extraction from vehicle.

Outside of the vehicle, the patient can be lowered into the supine position with the lower section of the AirLift rigidized through inflation, as shown in Figure 4. The AirLift then acts as a rigidized backboard with handholds to safely lift and transport the patient.

Figure 4: AirLift torso and leg section inflated; acting as rigid backboard.

3. INFLATABLE DEVELOPMENT

In an initial prototype of the AirLift, the inflatable was constructed of a liquid crystal polymer (Vectran^{TM}) based fabric as shown in Figure 5. This prototype had the torso and leg sections along with inflatables on either side of the head. The fabric was constructed into of a series of spars which ran the length of inflatable with connecting channels to allow air to flow between the spars. This type of construction allowed the inflatable to stay flat when pressurized, rather than taking a cylindrical shape.

Figure 5: Initial prototype inflatable (2.5” thickness)

Testing was conducted on a 3-point bend test platform, shown in Figure 6, to identify the force vs deflection curves in the head section. Characteristic force vs deflection curves at inflation pressures ranging from 5 to 20 psi are shown in Figure 7. At 20 psi, testing was conducted using a ½” diameter center fulcrum (A) and a 1” wide bar at the center (B). The slope in the initial portion of the curves provides an estimate on the bending stiffness. The results indicate that increasing inflation pressure provides a higher bending stiffness. The load at which the curves level off provide an indication of the load carrying capacity where the panel starts to fold over. When pressurized, the outer skin of inflatable is in tension and when under a bending load, the top surface is subject to compression and the bottom surface is tension. Buckling of the top surface of the inflatable may be understood to occur when compression of the top surface overcomes the tension due to inflation and, at this point, the surface may be deformed to reduce overall thickness. As with bending stiffness, a higher inflation pressure provides greater load carrying capacity. In use, the inflatable would be subject to a more distributed loading from the occupant lying on the AirLift. However, these 3-point bend test observations provided useful insight into the bending behavior of the inflation.

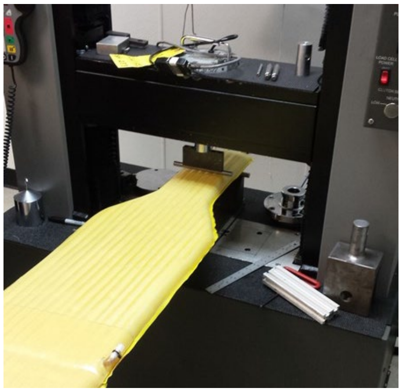

Figure 6: 3-point bend test of inflatable

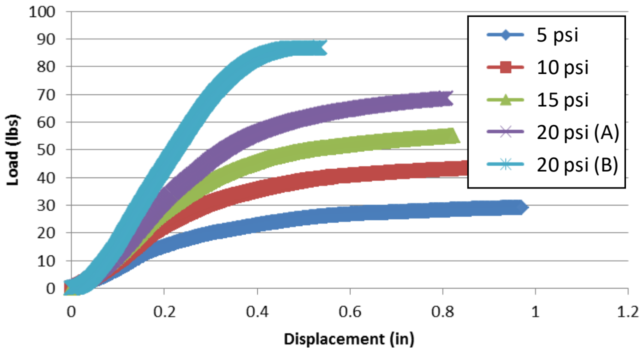

Figure 7: Force vs deflection from 3-point bend test

In order to realize the concept of operations described in Section 2, the inflatable panel was separated into two separate, independently pressurized, sections: an upper section for the torso and a lower section for the legs. When both sections are inflated, however, bending loads must be efficiently transferred across these two sections to ensure sufficient rigidity as a backboard. To achieve this, a root band was implemented to connect between the torso and leg sections as shown in Figure 8. In this region, the two sections are butted against each other and kept in place using a band of material around the outer surface. When both the sections are pressurized, root band forces the two abutted surfaces to remain in contact and effectively equalize pressure between the two sections, thereby acting as a contiguous panel.

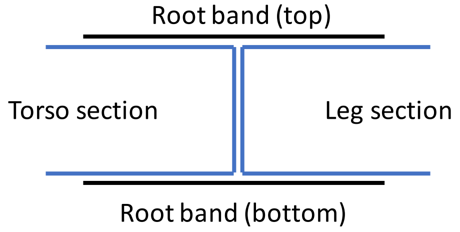

Figure 8: Cross-section of root band

The initial prototype demonstrated feasibility of a 2-section inflatable with sufficient stiffness at 10 psi inflation pressure. Fabrication and assembly time of the spars, however, was significant and would result in high production costs. Other material and assembly process technologies were investigated to simplify construction and reduce labor. Of the technologies available, drop-stitch materials were chosen for further investigation. Drop stitch material consists of two layers (typically neoprene) that are connected using a multitude of vertical fibers as shown in Figure 9. When inflated, the vertical fibers constrain the top and bottom layers to maintain a flat shape. Additional layers are laminated to the top and bottom surfaces for pressure holding and to help tailor the elasticity (or stretch) properties. Drop stitch fabrication have been used to make lightweight and stiff inflatable boat hulls and inflatable stand up paddleboards. Since drop stitch materials have been used for fabricating commercial devices, this material provides a cheaper alternative compared to the custom designed Vectran laminated spar inflatable design. Drop stitch pile height (length of the vertical fibers) range from 1.3 to 8 inches – thus there is no need to design and fabricate a custom drop stitch material.

Figure 9: Drop-Stitch material cross-section showing internal drop yarns between the top and bottom layers. Drop yarns range from 1.3 to 8 inches.

As noted from our initial prototype testing, the bending stiffness of the pressurized panel is improved by increasing inflated thickness and increasing inflation pressure. An increase in the inflatable thickness also increases the bending rigidity by moving the top and bottom surfaces away from the neutral axis - similar to bending in a box beam. Increasing pressure and thickness of inflatable, however, does come at the expense of a larger compressed gas bottle. Additionally, a larger panel thickness would also push the occupant forward when inflated on the seat. To minimize this, the overall thickness was limited to under 3 inches. To fit within these parameters, a 2.7 inch thick, off-the-shelf drop-stitch fabric was chosen for further evaluations.

To limit the size of the compressed gas bottle, target inflation pressure was sent to 20 psi or lower. In order to maximize bending stiffness for a given inflation pressure, the use of high modulus lamination materials on the top and bottom surfaces were explored. Candidate materials that were readily available and compatible with the lamination process are shown in Table 1. The “Cooley” and “Heavy Cooley” fabrics are drop-stitch fabrics made at high volume by a commercial laminator. The Laminated Sailcloth was also chosen for investigation as it is a low-stretch fabric and available at large volumes. Panels made from these material systems are shown in Figure 10. These panels were made in the shape of the AirLift inflatable including the root band section to separate the leg and torso regions.

Table 1: Candidate materials for drop-stitch inflatable

Fabric ID	“Cooley”	Laminated Sailcloth	“Heavy Cooley”
Lamination Material	Nylon	Nylon	Polyester
Thickness	0.10 in	0.120 in	0.142 in
Denier	420d	420d warp, 640d fill	420d warp, 640d fill
Weight	66 oz/yd^2	81 oz/yd^2	120 oz/yd^2

Figure 10: Panels made from candidate materials; from left to right, Heavy Cooley, Laminated Sailcloth, Cooley. Each panel is 56 inches long.

Bend testing on these panels were performed on a 3-point load fixture shown in Figure 11. Testing was conducted near the root band section as this region experienced the highest bending loads. The force vs deflection curves for drop-stitch inflation pressure of 10, 15, and 20 psi are shown in Figure 12, Figure 13, and Figure 14 respectively.

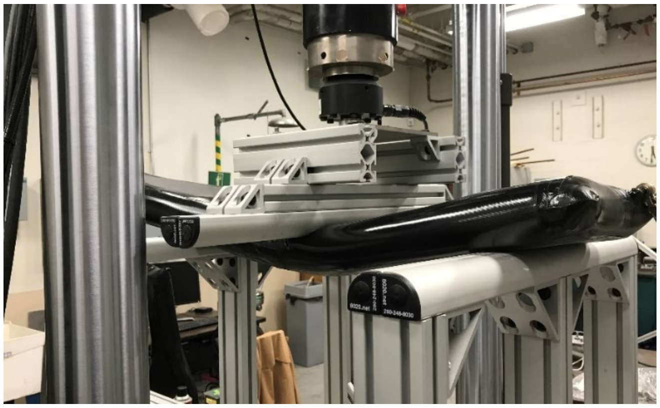

Figure 11: Bend testing of drop-stitch panels

The results at 10 psi inflation show equivalent to slightly lower stiffness to the initial prototype panel (Vectran) for the Heavy Cooley and Laminated Sailcloth panels and a lower stiffness for the Cooley panel. Load carry capacity, the point where the curves appear to level off or drop due to buckling, were significantly greater than the initial prototype panel with the Heavy Cooley and Laminated

Sailcloth panels performing better than the Cooley panel.

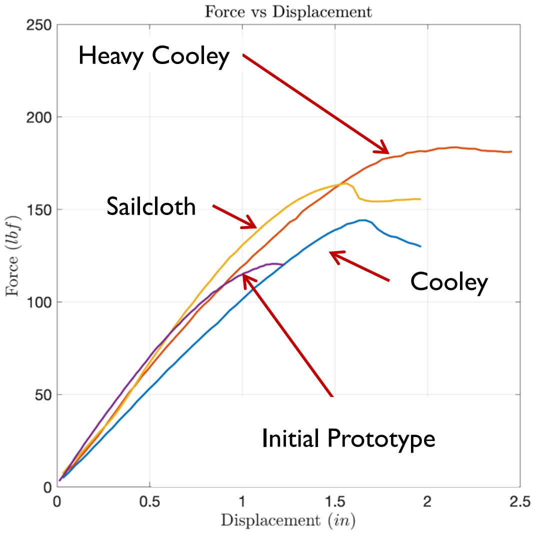

Figure 12: Bend test results at 10 psi

The results at 15 and 20 psi inflation showed greater stiffness than at 10 psi, as expected. At 15 psi pressure, the Cooley panel showed equivalent stiffness as compared to the initial prototype panel. Additionally, the load carrying capacity was greatly increased for all the drop-stitch panels with larger load carrying capacity at 20 psi compared to the lower pressures.

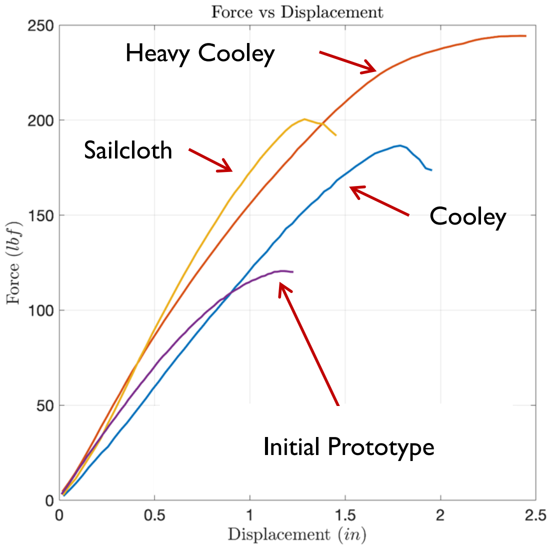

Figure 13: Bend test results at 15 psi

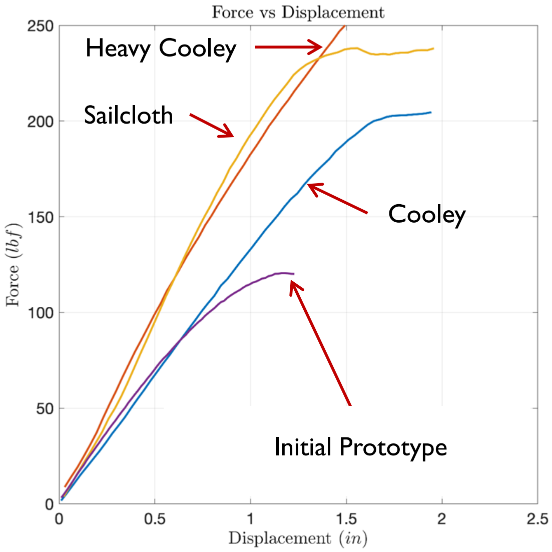

Figure 14: Bend test results at 20 psi

A comparison of the stiffness of the drop-stitch panels compared to the initial prototype panel inflated to 10 psi is shown in Figure 15. Stiffness was linearized over the 0-1 in. portion of the force vs displacement plots shown earlier. The panels made from the Heavy Cooley and Laminated Sailcloth demonstrate improved stiffness at 15 and 20 psi inflation pressure. A comparison of the load carrying ability of the panels compared to the initial prototype panel is shown in Figure 16. All of the panels at 10 psi and up show greater load carrying capability. The Heavy Cooley at 20 psi did not buckle during testing under the loads considered. In user evaluations, load carrying capability was found to be more significant than stiffness.

In summary, this testing demonstrated:

1) The Cooley panel is slightly less (15%) stiff, but had slightly higher (12%) load carrying ability than the initial prototype panel at the 10 psi inflation pressure.
2) The Heavy Cooley panel had approximately the same stiffness as the initial prototype panel at the 10 psi inflation pressure, but had significantly higher load carrying capability.
3) The Laminated Sailcloth panel had slightly higher (10%) stiffness than the initial prototype

panel at the 10 psi inflation pressure, but had significantly higher (40%) load carrying capability, albeit less than the Heavy Cooley panel.

4) Significant increases in stiffness and load carrying ability are achieved as pressure is increased.
5) The Heavy Cooley panel tends to be slightly less stiff, but has a higher load carrying ability than the Laminated Sailcloth panel.

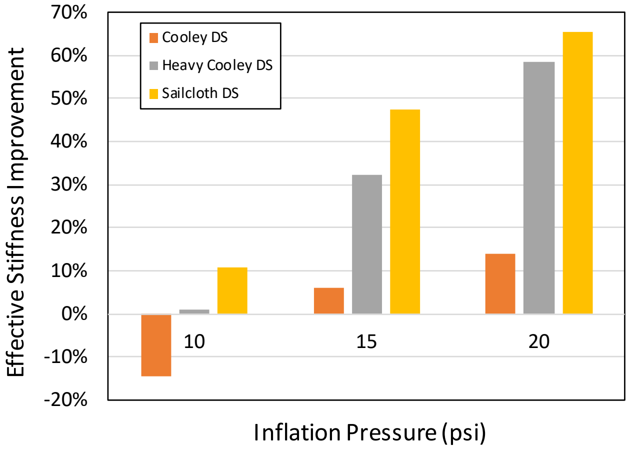

Figure 15: Stiffness improvement of drop-stitch panels compared to initial prototype panel at 10 psi.

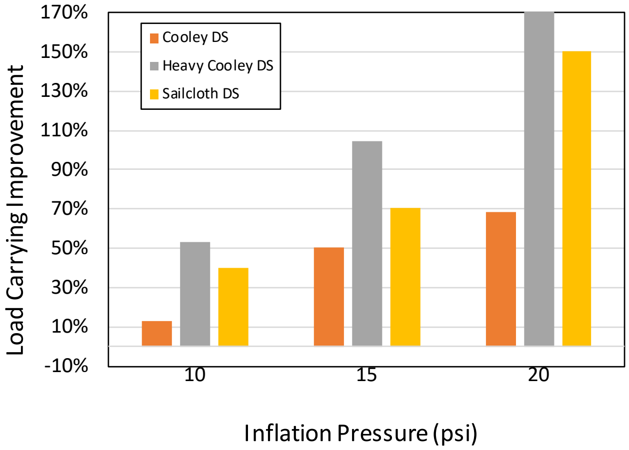

Figure 16: Improved load carrying capability of drop-stitch panels compared to initial prototype panel at 10 psi

4. INFLATION

The overall layout of the AirLift inflatable panel is shown in Figure 17 along with the inflation components for the torso and leg. The torso region is an inflated volume of ~743 cubic inches and the leg region has an inflated volume of ~543 cubic inches. In order to reach 15 psi inflation at 50°F, the torso region would need approximately 46 grams of CO2 which is provided using a compressed gas bottle that is approximately 1.2" diameter and 5.5" long (Leland part #87202z). The leg region would need approximately 34 grams of CO2 that can be supplied by a smaller 1" diameter and 5.5" long CO2 bottle (Leland part #85202z). At -25°F, inflated pressure would drop to 12.8 psi and at 135°F, the pressure would reach 17.5 psi. Low-cost inflators are mounted to the inflatable panel and includes a threaded port for the gas bottles. To inflate, a lanyard is manually pulled which pushes a pin into the cap gas bottle and releases the compressed air into the inflatable.

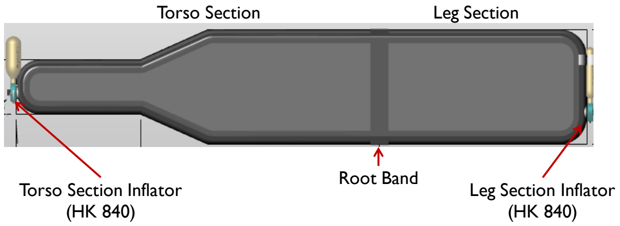

Figure 17: Layout of inflatable panel.

5. DEPLOYMENT AND USE

The AirLift inflatable is inserted into a cover that is made from 500 denier Cordura fabric. The AirLift is deployed by removing the headrest cover and inflating the torso section by pulling the inflator lanyard as shown in Figure 18. The chest straps are released as shown in Figure 19 and buckled around the occupant. This step also tensions the diagonal cords as shown in the figure highlighted by the red arrow. The diagonal cords keep the occupant in the seated position when removed from the seat and simplifies extrication from the vehicle. Available handholds for carrying or dragging the AirLift-stabilized occupant out of the vehicle are shown in Figure 20.

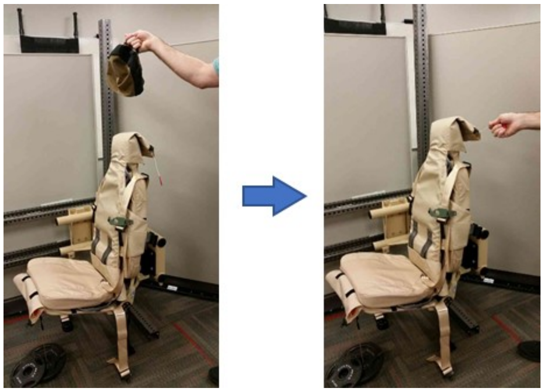

Figure 18: Initial deployment of AirLift. Remove headrest cover and inflation of torso section.

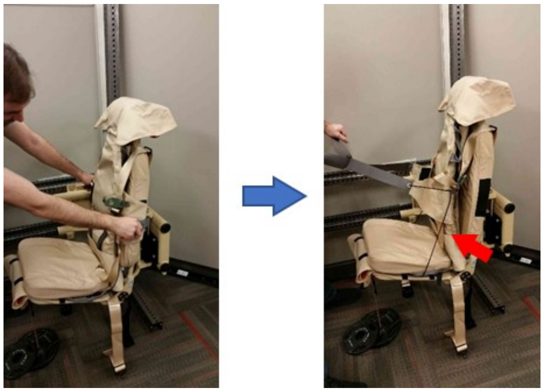

Figure 19: Release chest straps and tensioning diagonal cords.

Figure 20: Handholds available behind the occupant, at the shoulders, and at the seat.

Once outside the vehicle, the occupant is lowered to the supine position by pulling out a flap under the leg that releases the tension on the diagonal cords (Figure 21). The leg section is inflated by pulling the lanyard to the leg inflator. A pelvic sling, already integrated with the cover, is available to stabilize the pelvis as shown in Figure 22.

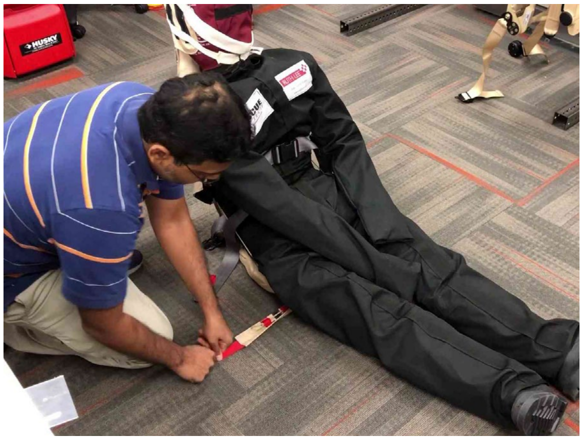

Figure 21: Lower to supine by releasing diagonal cords. ATD is stabilized in the AirLift and a flap on the AirLift is pulled out to give access to the cord release and inflation lanyard.

Figure 22: Pelvic sling for additional stabilization

When the occupant is lowered to the supine position with the leg section of the inflatable pressurized, the AirLift acts as a rigid backboard. The handles on the AirLift allow caregivers to lift the injured occupant from the both sides or from an end-to-end lift.

6. SEAT COMFORT

Testing was conducted to compare seat comfort with and without the AirLift installed on the MMPV Type II Seat. Pressure maps were averaged over 12 seconds after subjects had been sitting on the seat for an extended period of time – this allowed the seat cushion to adjust to the test subject. Test subjects were within a 25-32 BMI range. In order to make sure that the weight on the seat was consistent between the AirLift on vs AirLift off cases, a weight scale was placed underneath the test subject's feet to ensure that feet position and proportion of the occupant's weight in the seat remained the same between two tests. A test subject on the standard MMPV seat and with the AirLift installed is shown in Figure 23. The AirLift was installed underneath the seat cushion and supported by the metal seat pan underneath. In this area, the AirLift consists of the drop-stitch inflatable and a custom cover made from Cordura® fabric – this stackup is less than ½" and is unnoticeable to the subjects when sitting on the seat.

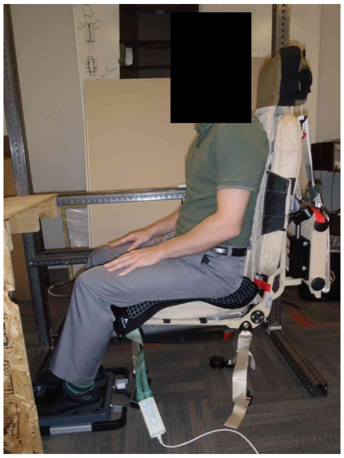

Figure 23: Test subject on MMPV Type II seat with AirLift installed. Pressure pad underneath test subject. Scale placed below feet keeps feet position and weight on floor consistent between tests.

The pressure maps (averaged over 12 seconds) for one of the test subjects is shown in Figure 24. The pressure scale is consistent between the two sets of data for each subject. Pressure maps indicate that peak pressures are primarily located at the ischial tuberosities. Similar pressure maps were taken for all subjects.

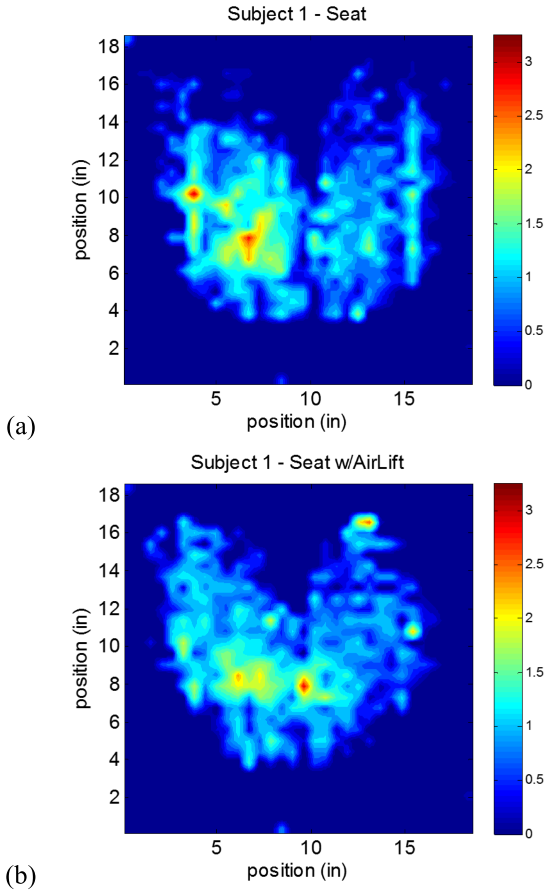

Figure 24: Pressure map for Subject 1. (a) MMPV Seat, (b) Seat with AirLift installed. Pressure scale is in psi.

Peak pressures from the mapping were identified for each subject and a comparison of the peak pressure with and without the AirLift is shown in Figure 25a. Peak pressures were used as a measure of seat comfort. For the first three subjects, the peak pressure was slightly lower with the AirLift than without (i.e. on the standard MMPV Type II seat). For the 4th subject, the peak pressure with the AirLift was higher and on the 5th subject, the peak pressure with the AirLift was lower. The change in peak pressure is shown in Figure 25b and shows that for 4 out of 5 subjects, the pressure with the AirLift is lower. While care was taken to ensure the subject, seat cushion, and AirLift were consistently positioned on the seat pan, large differences in peak pressures may be due to position differences with and without the AirLift.

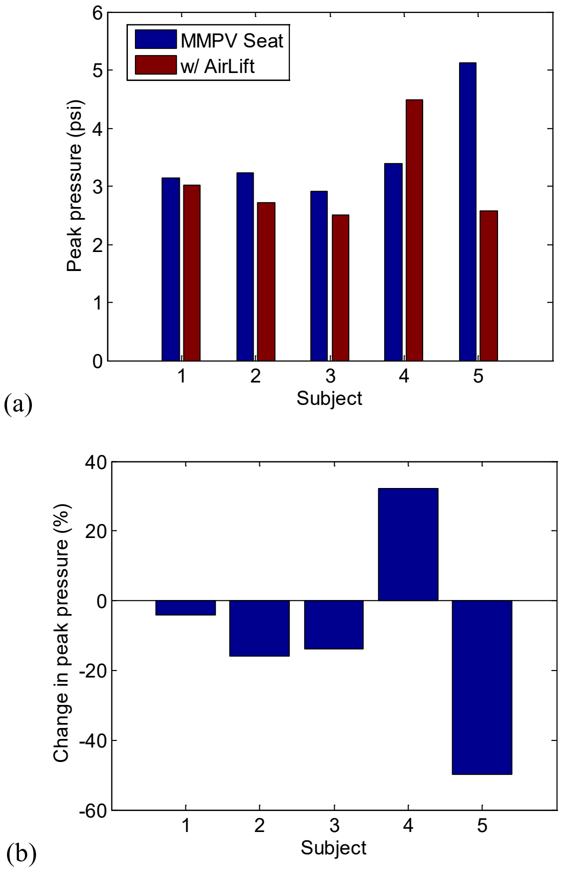

Figure 25: Pressure data for each test subject. (a) Comparison showing peak pressure without and with the AirLift for each subject (b) Change in pressure (as percentage) due to the AirLift

These results indicate that the AirLift does not negatively affect the comfort for the seat occupant. Care was taken to ensure that test conditions were consistent in the two scenarios and that the occupant was in the seat for enough time for the cushion to conform to the individual occupant.

7. FUTURE WORK

The drop-stitch material technology simplifies material and fabrication costs associated with manufacturing the AirLift. The drop-stitch material is made domestically, and inflatable fabricators are accustomed to working with the material. Components including the CO2 bottles and inflation hardware are commercially available products. The cover is sewn from Cordura® with additional commonly available softgoods. The AirLift has reached a high manufacturability level due to its simplicity and use of currently available materials.

Additional testing is planned to evaluate the AirLift in simulated environments. Vertical drop tests will be used to simulate blast events in order to demonstrate that the AirLift does not negatively impact the blast protection capabilities of the original seat. Seat pan accelerations and measurements from an anthropometric test device (ATD) will be gathered in test scenarios with the AirLift installed on a seat and without the AirLift and compared to ensure that key injury metrics are not negatively affected. Durability testing, including jounce/squirm and ingress/egress will also be conducted to evaluate repetitive wear on the AirLift. Finally, environmental testing, including hot/cold, fungus growth, blowing sand and dust, salt fog, and fluid resistance will be conducted. Completion of these tests will demonstrate that the AirLift is ready for field use.

8. CONCLUSION

The AirLift is a novel device designed to rapidly stabilize and extract injured personnel from a vehicle in a blast event. It is installed as a seat cover and is pre-positioned for use behind/under the occupant. The stabilization features have borrowed from established devices (i.e. KED) for vehicle extraction. The AirLift offers distinct advantages over other vehicle extraction concepts:

1) AirLift features have been guided by an existing standard of care device, trained emergency care providers, including emergency physicians and combat medics, and thereby leverage standard care protocols and existing training regimens for rapid patient stabilization and extraction to avoid secondary injuries.

2) The softgoods AirLift design is inherently impervious to structural deformations of the hull/wall from a blast event and will remain easy to detach from the seat. In contrast, a hardware

extractable seat design has a high probability of binding at "quick-release" attachment points.

3) Weighing well under 10 lbs and conforming to the occupant, the AirLift presents no additional burden/obstacle for extraction through tight vehicle cabins and hatches, whereas seat structure adds considerable weight/bulk that can complicate extraction.

4) The AirLift deploys into a litter for patient transport and/or can be secured directly to a standard poled litter.

5) In the event of multiple casualties or dismounted casualty(ies), the AirLift can be removed from the seat to treat patients – AirLift features such as a pelvic sling, head stabilization, back board, etc., effectively add to the medic's available (and otherwise limited) equipment. In such an event, a usable seat remains after AirLift removal.

6) The AirLift design is easily tailored to retrofit any seat design or seat type (squad vs. driver/commander).

7) The time and cost to field the AirLift is considerably less than a new seat designed with the AirLift's capabilities. New seat designs in general require time-consuming and costly structural analysis and to add a requirement to be able to detach from a deformed wall will add significant complexity and would also increase fabrication costs. Following the design phase, substantial testing is required to clear the seat for use in military ground vehicles.

9. REFERENCES

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