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Design of Rapid Medical Evacuation System for Trauma Patients Resulting from Biological and Chemical Terrorist Attacks

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***Abstract*—In the event of a large scale, biological or chemical terrorist attack it is unlikely that local emergency response organizations will have sufficient quantities of dedicated ambulances to evacuate all of the affected victims. As a potential solution to this problem, we have developed a device that can be retrofitted to a variety of government or civilian utility vehicles in order to convert them for emergency medical transport(US Pat. 7,028,351). Each installed device allows the host vehicle to safely transport either a single patient on a stretcher or multiple ambulatory patients. Additionally, each device provides a means for temporary or permanent attachment of emergency medical equipment. When not in use, the device can be collapsed to improve ease and efficiency of storage.**

Preliminary analyses of certain highly loaded structures on the device were carried out using known principles of solid mechanics. The analyses were carried out assuming the highest reasonable loading condition. This condition was determined to occur when the device is configured for the transport three 95th percentile males and 20kg of medical equipment. This loading condition was assumed to be more severe than any that might occur due to an attendant performing CPR, or any other medical procedures, on a single supine patient. The base sections of the load bearing stretcher supports were then modeled using 3D CAD software and run through a finite element analysis (FEA) as a means to more accurately simulate the stresses that are likely to occur in the actual parts. As the device must be highly mobile, these analyses were used to confirm that the load bearing structures can be manufactured from low cost materials and still be light enough to be easily transported.

Future work will include sizing and installation studies to ensure that the production version of the device can be rapidly implemented in a wide variety of private, commercial, and government utility vehicles.

I. Introduction

The release of deadly biological or chemical agents can quickly cause a mass casualty situation. Accordingly, there is now great concern that such a release may occur in the form of a terrorist attack. If such an attack were to occur, there could be an immediate need for the evacuation of many thousands of people. Given a limited supply of dedicated ambulances, emergency response services could quickly be overwhelmed by the number of patients requiring medical transportation.

In the event of a biological or chemical attack, those affected would first be transported from the site of exposure to a decontamination location, and then on to a permanent medical facility[1]. Though in some cases patients can safely be decontaminated and treated up to one hour after initial exposure, if a patient has been exposed to certain substances, such as nerve agents, he must receive medical care within minutes[2],[3]. In many cases, a patient's chance of survival will rely on how quickly he is removed from the contaminated area or Hot Zone, as well as the medical care that is provided to him while in transit. While significant medical care is ideally initiated after decontamination, it is known that patients with immediately life threatening conditions need to receive treatment prior to being decontaminated[3]. Given these combined needs for rapid evacuation from the Hot Zone and for the immediate initiation of medical care, the availability of vehicles equipped for medical transport is critical to the survival of those affected by an attack.

With emergency treatment of victims being initiated either at the location of exposure or while in transit, medical transport vehicles will play a vital role in the response to a major biological or chemical attack. Ideally, the vehicles used for evacuation will be equipped with the medical equipment necessary to begin immediate treatment of critical patients and will also be capable of transporting multiple patients simultaneously. They will provide first responders with the specific tools necessary to treat those affected by the agent and will be able to transport a greater number of patients more efficiently than standard ambulances.

II. Rapid Medical Evacuation Device

A. Purpose

The design of the device is based on the premise that in the event of a large scale attack a variety of civilian and government utility vehicles can quickly be converted for medical transport[4]. The device is firstly intended to provide emergency response organizations with an alternative to either borrowing or stockpiling large numbers of ambulances. As a system that can be retrofitted to many types of utility vehicles, the device allows emergency workers to rapidly equip nearby pickup trucks, vans, busses trailers, etc. for the transport of affected victims. By using

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the device, emergency responders can quickly assemble a fleet of evacuation vehicles larger than that which could be amassed using any other means.

A secondary intent of the device is to provide a self-contained, patient and medical equipment support system that is ideally suited for treating victims of a biological or chemical attack. When installed in a host vehicle, the device provides the flexibility to transport either a single patient on a stretcher, or multiple ambulatory patients. It allows emergency workers to carry a maximum number of patients per vehicle, thereby reducing the amount of time victims must wait at either the site of exposure or at a decontamination location before being transported to the next higher level of care.

B. Design Summary

The device is designed so that it is easily transformable between any of three possible configurations. It can be configured for the transport of a single patient on a NATO style stretcher, the transport of three ambulatory patients sitting upright, or can be collapsed for storage purposes. In each of the two patient carrying configurations, the device has been designed to safely support 95th percentile male patients.

In addition to providing a means for transporting patients, the device includes mounting rails that can be used to attach various types of medical equipment.

1) *Single Patient*: Fig. 1 depicts the device as configured for the transport of a single patient on a stretcher. The device is installed by positioning it such that the seat/equipment mount frame is oriented parallel to and coincident with an inner, side wall of the host vehicle. The adjustable telescoping legs are then extended such that the stabilizing feet press firmly against the floor and roof. If the space provided does not have a roof, as is the case in the bed of a pickup truck, the tie down loops can be used to secure the device to the vehicle. When the device is installed in a roof-less vehicle, adjustable straps would be attached on one end to a tie down loop, and on the other to a load bearing point on the vehicle. Such points may include existing seat belt mounts, cargo net attachment points, or other reinforced locations of the host vehicle's chassis.

The adjustability offered by the telescoping legs allows the device to fit within a wide range of vehicles, and provides the additional benefit of allowing the height of the patient to be adjusted to suit the preference of the onboard medical attendant. The telescoping legs may also include springs and dampers to the reduce harmful energy that can be transmitted to a patient in the event that the host vehicle must traverse rough terrain.

Either prior to or after installation, various types of medical equipment can be attached to the underside of the seat/equipment mount frame using the equipment mount rails. These universal mount rails ensure that the device can be rapidly configured with medical equipment appropriate to a given emergency situation, or even to the specific needs of an individual patient.

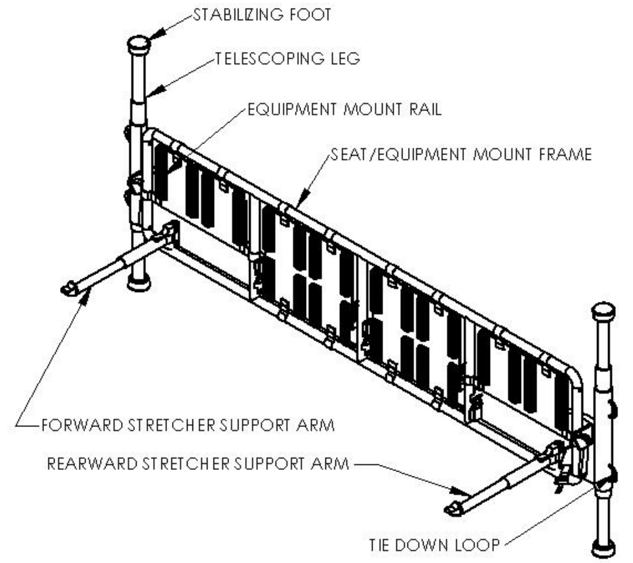

Fig. 1. Device shown prior to attachment of equipment and loading of patient.

When a patient on a stretcher is ready to be transported, the handles of the stretcher are fixed to the stretcher support arms. Once a patient has been loaded onto the device, an onboard medical attendant may provide emergency care as he would aboard a standard ambulance.

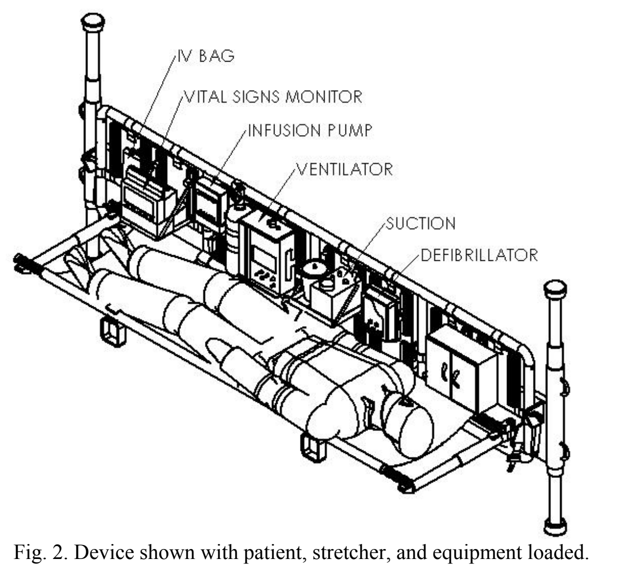

Fig. 2. Device shown with patient, stretcher, and equipment loaded.

Fig. 2 shows the device as it would appear while transporting a single patient on a stretcher. In this configuration the device provides a means to attach life support equipment such as a vital signs monitor, suction apparatus, ventilator, etc. that are necessary for the treatment of a severely affected victim. With access to four sides of the patient, an onboard attendant can perform CPR, an endotracheal intubation, or other life saving procedures. The orientation of the patient on the device also allows the attendant to initiate decontamination of the victim by removing clothing, shaving body hair, and applying necessary topical skin treatments.

2) *Three ambulatory patients:* Fig. 3 depicts the device as configured for the transport of up to three ambulatory patients. The device is first installed in a vehicle using the telescoping supports and tie down loops, exactly as it would be for the transport of a single patient on a stretcher. Once mounted within a host vehicle, the seat/equipment mount frame is rotated downward so that its outer tubular structure rests horizontally upon the stretcher support arms. When locked in place, the seat/equipment mount frame supports three seats, and a small section of equipment mount rails. Each seat is equipped with seat belts so that the patients being transported will be restrained in the event that the host vehicle becomes involved in an accident. Basic care items, such as a first aid box or decontamination solutions, can be attached to the small section of equipment mount rails on the upper side of the seat/equipment mount frame, while the advanced life support equipment used during treatment of a patient on a stretcher can remain safely affixed to the mount rails on the under side.

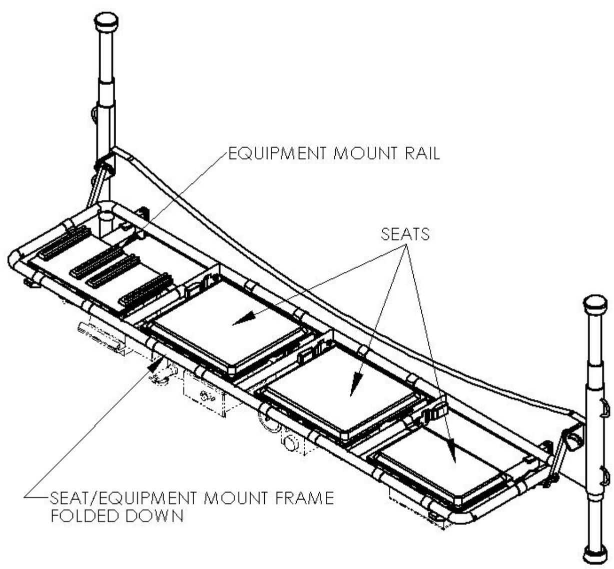

Fig. 3. Device shown as configured for the transport of three ambulatory patients.

3) *Collapsed*: Figure 4 depicts the device as configured for storage or shipping. In this configuration the device is collapsed in the vertical and transverse directions in order to maximize the number of units that can be stored per given volume.

The device is collapsed by placing the seat/equipment mount frame in the upright position, folding the stretcher support arms inwards, and fully retracting each of the four telescoping legs.

Once the device is in the collapsed configuration, the attached medical equipment can either be removed for use elsewhere, or can remain affixed to the mounting rails. The space provided on the underside of the seat/equipment mount frame is sufficient for the mounting of a collapsed NATO stretcher.

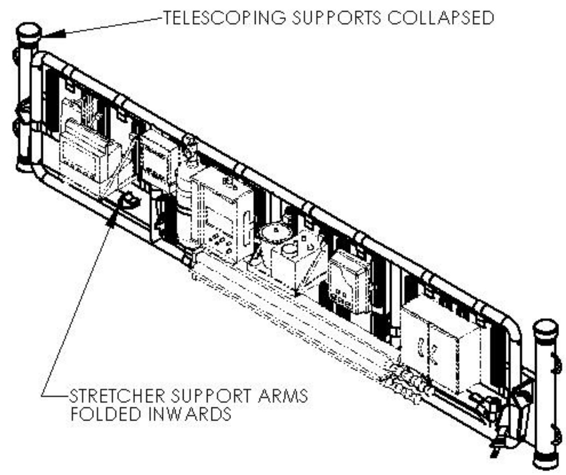

Fig. 4. Device shown as configured for storage or shipping

C. Strength Analysis

We believe the structural components of the device are likely to experience the highest loading when configured for the support of three ambulatory patients. In this configuration the device's load bearing members must safely withstand the weight of three 95^{th} percentile male patients, as well as an estimated 20kg of emergency medical equipment. Accordingly, this patient arrangement was used to create the boundary conditions for a preliminary strength analysis. Determined to be the most critical structures, the stretcher support arms were the first to be analyzed for strength. It was assumed that each of the three patients were 95^{th} percentile males with masses of 98.5kg each[5]. It was also assumed that equipment with a mass of 20kg was attached to the small section of upward facing equipment mount rails. As the seat/equipment mount frame has a length 251.5cm, and the seats are evenly spaced, the vertical load on the tip of the rear stretcher support arm was calculated using standard force and moment summations[6]. Solving these equations using the given values yields a reaction force of 1770N at the tip of the rearward stretcher support arm. This support arm was then conservatively modeled as a continuous hollow tube with an outer diameter of 5.08cm, an inner diameter of 4.57cm, and a length of 55.88cm. The support was analyzed as a cantilever beam, fixed at one end and free at the other, using known principles of solid mechanics. Standard equations for maximum moment, area moment of inertia, and bending stress, were used to determine an approximate value for the peak bending stress in the wall of the support[7]. Solving these equations for maximum stress yielded a value of -224MPa. While this preliminary design of the stretcher support arms makes use of round tubes, future design iterations may incorporate alternate cross sections in order to maximize the area moment of inertia.

A basic finite element analysis(FEA) was then performed as a means to simulate the stresses that would likely occur in the actual parts. Though the complete stretcher support arm is composed of a two part assembly with a total length of 55.88cm, only the hinged portion of the arm, with a length of 24.13cm, was used for the finite element analysis. A 3D solid model of stretcher support arm was created in Solidworks®, then exported into COSMOSXpress™ for meshing and analysis[8], [9]. The support arm model was discretized using an element size of 6.56mm, resulting in the formation of 9913 elements and 18124 nodes[10]. For the purposes of this analysis, the material was assumed to be linear elastic and isotropic 6061-T651 Aluminum alloy. Using the reaction forces determined through the abovementioned force and moment summations, boundary conditions for the meshed model were configured such that a 4,110N force was applied to the vertical face of the tubular end of the part, while the cylindrical bearing surfaces of the hinge section were constrained in all directions. Fig. 5 graphically depicts the results of this analysis.

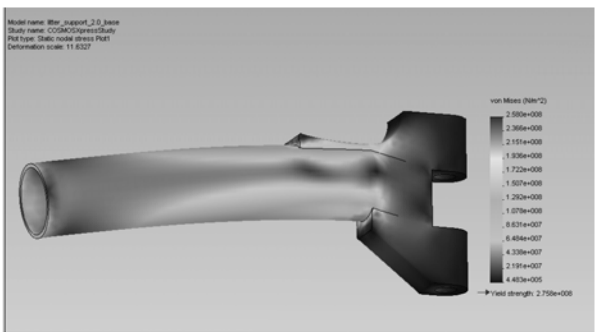

Fig.5. Stress analysis results using the von Mises criterion.

The FEA results yielded a maximum compressive stress of -258MPa. We believe the difference between this value and that achieved through the hand calculations to be the result of a stress concentration occurring near the hinge section of the meshed model.

These results are significant in that the maximum anticipated stresses are low enough to ensure that the current design could be manufactured from a low-cost aluminum alloy[11]. Given the intent to create a device that can be produced and deployed in large numbers, it is essential that the load bearing structures be manufactured from light weight, yet inexpensive, materials.

Further static and dynamic analyses of the structural components of the device will be carried out prior to construction of an initial physical prototype.

III. Discussion

In light of the specific needs of the victims of a biological or chemical terrorist attack, emergency responders will be most successful in saving lives if provided with appropriate medical evacuation vehicles. As standard, dedicated ambulances are neither ideally equipped nor plentiful enough to be relied upon for transportation of patients during a large scale attack, emergency responders will need to find alternative methods of evacuating victims. Our solution to this problem is a device that can quickly transform readily available vehicles such as pickup trucks and SUVs into fully capable medical evacuation platforms.

To date, we have created an initial design for the device and performed basic structural analyses. Though further testing and analyses will be necessary, preliminary results based on classical solid mechanics and the finite element method indicate that the structural members of the device will be manufacturable from materials that are both lightweight and low-cost. Additionally, further studies will be conducted in order to optimize the device's exterior dimensions and installation mechanisms. This future work will be focused on the examination of the cargo compartments and reinforced mount locations in potential host vehicles, as well as methods to minimize the time required to both install and uninstall the system.

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