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Air Bag Restraints for Use in Patrol Vehicles

Donna J. Marts
Trudy K. Overlin

EG&G Idaho

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EG&G Idaho, Inc.
Idaho Falls, Idaho 83415

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ABSTRACT

This effort has produced a prototype design for an air bag restraint system for the rear seat of patrol vehicles for use when occupants become violent and dangerous. To address the concern of suffocation, a semipermeable air bag was suggested. Bench scale tests were performed to demonstrate the validity of that suggestion. Simple leaf blowers were used for the bench scale tests, and although they served those tests adequately, they were determined to be underpowered for the final design. A full-car-width air bag was also tested to evaluate the volume in the back seat having to be filled, as well as deployment from the ceiling. Information gained from these tests were used as input for the prototype design.

The objective of this system is to use an air bag to prevent an individual, or individuals, from continuing violent actions while being transported in a patrol vehicle without requiring immediate physical contact by the law enforcement officer. The air bag independently restricts the amount of physical activity occurring in the rear seat of the vehicle while allowing the officer to safely stop the vehicle. The air bag can also provide the officer additional time to get backup personnel to aid him/her if the situation warrants it.

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Air Bag Restraints for Use in Patrol Vehicles

INTRODUCTION

Frequently, persons arrested and under transport in the rear seat of a patrol vehicle engage in violent actions, resulting in harm to themselves, extensive damage to the patrol car, and danger to officers and the public. The law enforcement community suggested that vehicle safety air bags might be used to restrain individuals in these situations. The National Institute of Justice (NIJ) commissioned the Idaho National Engineering Laboratory (INEL) to perform a proof-of-principle design of an air bag restraint system that would address this issue.

The objective of this system is to use an air bag to prevent an individual or individuals from continuing violent actions while being transported in a patrol vehicle without requiring immediate physical contact by the law enforcement officer. The air bag independently restricts the amount of physical activity occurring in the rear seat of the vehicle while allowing the officer to safely stop the vehicle. The air bag can also provide the officer additional time to get backup personnel to aid him/her if the situation warrants it.

The design approach taken was to initially define the design requirements, investigate and evaluate the current state of technology of vehicle safety air bags, and then develop a conceptual design using as much off-the-shelf technology as possible. Since this concept addresses a need identified by law enforcement officers themselves, their input, along with legal liability constraints, were the primary contributors to the design requirements. Vehicle safety air bags initiated the air bag restraint concept, but the actual hardware was of little use in meeting the design requirements that were developed for the patrol vehicle air bag restraint system. Components were selected by their ability to meet the requirements and their cost. A conscious effort was made to design the system using as many commercial components as possible to keep costs down.

DESIGN REQUIREMENTS

The first task was to determine the requirements the air bag restraint system would need to be a functional tool for the law enforcement community. Discussions were held with local law enforcement personnel to get a realistic understanding of the process of transporting individuals in patrol vehicles. Under optimum conditions, individuals are handcuffed, placed in the vehicle, put in their seat belt, and then transported to their designated deterrent location, usually a police station. This scenario adequately defines the geometric configurations an individual can be in; however, these optimum conditions do not always occur. Since no single geometric configuration defines how a person sits in the vehicle, the air bag must be designed to handle all possible configurations. There is no standard profile of what type of person (e.g., large person, male, young, etc.) is most often involved in violent outbursts so no body type determinations could be made. The type of violence that occurs is also quite varied. Usually, individuals use their legs to break windows, push on the front seat or the barrier, or damage doors. Instances have occurred where officers have been injured by individuals using items such as belt buckles to cut them, as well as cases where individuals have broken out the rear window, crawled out, and then been killed by an oncoming vehicle. The conclusion drawn from discussions with law enforcement personnel was that there is no typical violent individual, no typical condition under which violence occurs, and no typical type of violent action. This information was used as a basis for determining the design requirements.

The other factor that heavily influenced the design requirements of the patrol vehicle air bag restraint was that of legal liability. At the point where an officer takes control of a suspect in an arrest, the officer then becomes responsible for the health and well being of the suspect. The situation becomes triangular in that an officer must ensure the safety of a suspect during transport, protect the public from becoming involved, either by being in an accident or in an altercation with the suspect, and protect themselves and other officers. This triangle requires the officer to balance the need to protect others with the need to also deliver the suspect into custody.

Departmental policy and law enforcement training has taught an officer that it is his/her responsibility, to the best of his/her ability, to protect a person that has become the officer's charge, without malice, and to maintain peace in the community. In a crisis, an officer's first priority is to protect innocent bystanders. An officer also has the duty and obligation to follow through with an arrest by transporting the suspect into custody and also to protect the suspect enroute during that transport.

The use of the air bag allows an officer the optimum ability to protect the public, to protect a suspect from personal injury, and to allow enough time to remove the patrol vehicle from traffic and regain control. Also, the use of the air bag is a safety valve to protect the officer from sustaining injury at the hands of a suspect who desires to break free or cause bodily harm.

Officers must make quick judgments and constantly weigh a situation against this triangular responsibility. This tool gives them a better means of ensuring public safety and delivering a suspect into custody without additional injury. Having this option available also relieves some of the stress associated with transport, maneuvering the patrol vehicle in traffic, and maintaining public safety.

The design requirements established for this system, and a brief discussion, follows:

1. **The air bag will be activated manually.** The officer needs to initiate any action regarding the air bag. He/she is the person who is liable; thus, he/she needs to be able to determine when an air bag should be deployed. A manually-activated system is also typically less expensive and less likely to have a malfunction than an automated system. Sensors can be placed in, and around, the rear seats to automatically activate the air bag based on motion or force criteria if this is determined to be useful or desired at a later time.

2. **The system must restrain individual(s) for at least 2 min.** This is the minimum time that officers felt would be adequate to get their vehicle safely out of traffic so they could then evaluate the situation at hand.

3. **Inflation time in tens of seconds is adequate.** A very rapid inflation time (less than 1 s) poses design and safety concerns. The officers who were consulted felt that the time required to inflate the air bag is not that critical as long as it is not in the minutes time frame.

4. **The system must be inexpensive.** Law enforcement is budget constrained, as with all government entities. Developing the greatest device in the world is of little use if it is too expensive for agencies to purchase and implement. Ideally, the air bag restraint device should be installed on all patrol vehicles, and the cost of the system should be no more than current commercially-available restraint seats.

5. **The system must be able to be installed in existing patrol vehicles.** This system is currently envisioned as being installed in patrols vehicles as time and costs allow; thus, the air bag restraint must be designed to be an add-on device. This allows new, as well as old, vehicles to be outfitted with the restraint device. Possibly, the air bag restraint could be offered as an option directly from the automotive dealers, but that is not the intent at this time.

6. **The air bag system must accommodate various seating arrangements (i.e., individuals with or without seat belts and handcuffs, one person or two, large person or small, etc.).** Since no unique seating configuration exists upon which to base the design, the air bag must serve all possible body configurations. Individuals sitting, lying on the seat, lying on the floor, kneeling, or standing on the seat will all have to be considered in the design.

7. **The air bag must restrain individual(s) without posing a suffocation threat or a physical hazard.** Since the minimum restraining time is 2 min, suffocation is a possibility. Therefore, the air bag must prevent this from occurring. Restraining does not mean that the individual must be pinned with all the air knocked out of him/her. Research has shown that a pressure of 1 to 2 psig (27.7 to 55.4 in. H_20) will not cause physical harm, but this restraint system should exert the minimum pressure to restrain individuals. This amount of pressure will need to be determined through testing.

8. **The air bag must be washable or replaceable and not rip or tear easily.** An assumption was made that blood and saliva will end up on the air bag itself. To mitigate any health concerns associated with this, the air bag must either be washable or so inexpensive that

replacing it is trivial. The air bag must also be rugged and not tear or rip easily. If a sharp belt buckle, or blow with the fist, could render the system useless, it probably is not worth the cost of installing it.

These design requirements are a foundation, but changes are anticipated to occur when full scale prototype air bag restraint units are available for field test evaluations. User input will help define specific hardware locations (i.e., the officer's view into the back seat must not be blocked), operability of removal/installation of an air bag, and adequate air bag inflation pressures. These baseline requirements are for a conceptual design and will be further developed as the design advances.

AIR BAG DEVELOPMENT

The development of the design requirements made the air bag obviously the critical component to this design. It must not suffocate or seriously injury, must be tear-and-rip resistant, and hold enough pressure to restrain an individual. Vehicle safety air bags certainly hold enough pressure, but they are designed for an entirely different purpose. Typically, safety air bags are a fabric material packaged inside the steering wheel or instrument panel. Sensors in the vehicle detect a frontal crash above a predetermined level of accident severity; then, a control module signals the inflation module to deploy the air bag. The inflator module includes a sealed canister containing sodium azide pellets. When the control module signals the inflator to deploy the air bag, the sodium azide undergoes a chemical reaction that rapidly generates nitrogen gas to inflate the bag. As the bag inflates, some residue will exist. This residue consists primarily of corn starch and/or talcum powder used by the manufacturer as a lubricant and byproducts of the chemical reaction. A small amount of sodium hydroxide dust, which is a potent irritant, is produced as a byproduct of the reaction, but the sodium hydroxide quickly converts to sodium carbonate and sodium bicarbonate. The bag inflates in approximately 0.05 s to full size, then deflates immediately through vent holes, helping to restrain the individual more gradually. If an occupant is very close to an inflating air bag, the force of deployment could cause serious injury, or even death.

Due to their contrasting end uses, the safety air bag and the restraint air bag have very little in common, other than the use of an inflated bag. The most glaring challenge is to design a bag that can inflate and hold a pressure without posing a suffocation threat. If the seating configurations of individuals were minimal, the bag could be designed to stay away from the head area; thus, location rather than material would prevent it from being a suffocation hazard. Unfortunately, the design has to take into consideration that people may be lying on the seat, or on the floor, so this air bag design becomes almost impossible. This necessitates the development of a new air bag design.

The first concept considered was a double-layered bag. The inner bag would be a impermeable material that would provide the holding force. It would inflate to occupy approximately one third of the volume of the back seat. The outer bag would be a permeable material, and a bypass flow from the inner bag would be constantly flowing air through it to keep it inflated. This bag would occupy the entire volume of the back seat. An individual could easily deform this bag, and press into it, but would eventually run into the impermeable bag that would be firm, e.g., like hitting a punching bag. Since the outer bag is permeable, a person's face could be entirely engulfed in it and yet not suffocate since air would be passing through the bag at all times. The areas that need to be investigated are the geometry and size of the inner bag, the bypass flow operation, and the packaging of the two bags.

The second concept considered was a bag fabricated from a permeable material. With a continuous air supply keeping the bag inflated, this type of bag could totally engulf the back seat. Since the bag material is permeable and air is blowing through it, suffocation would not be a threat. The capability of a permeable bag to provide enough pressure to restrain someone requires testing, but packaging of a single bag should be relatively simple.

The third concept considered was a semipermeable bag. Part of the bag would be made from permeable material and part would be made from impermeable material. The bag would engulf the entire back seat. The impermeable material would provide the restraining force while the permeable material would prevent suffocation. Only one bag would have to be packaged, but as with the permeable bag, the capability to provide adequate pressure requires testing. The semipermeable concept would also need to locate the permeable material in sufficient quantity to prevent suffocation.

The simplest concept, the permeable bag, was investigated first. Two bags were fabricated, one from cotton and the other from a cotton polyester blend. The bags were identical in dimensions, 24 in. wide, 24 in. high, and 6 in. deep, with a 6-in. square neck on one end to provide a fill opening. A commercial 1 hp shop vacuum was used to inflate the bags. The all-cotton bag filled in approximately 4.25 s to a pressure of 0.5 in. H_20. The cotton polyester bag filled in approximately 4.25 s to a pressure slightly below 0.5 in. H_20. The pressure is too low for use as a restraint device; however, both bags could be placed against the face, and breathing would still be adequate. A commercial leaf blower was substituted for the shop vacuum, and both bags were inflated to a pressure of approximately 1.5 in. H_20. The concept proved sound, but the low pressures suggested that the other options should be evaluated.

A slightly smaller bag, 22 in. wide, 22 in. high, and 3 in. deep, was fabricated from rip-stop nylon. This bag was placed inside the cotton bag with a leak path provided in the neck of the nylon bag. The nylon bag inflated to 8 in. H_20, and bypass flow did inflate the cotton bag. The cotton bag was easily collapsed, but the nylon bag was hard. This concept has merit, but the geometry of the bags will be extremely critical. The pressure in the cotton bag appears to be inadequate, but a material change and a higher pressure air supply could remedy this.

Two bags were fabricated from a combination of nylon and canvas. The bags are shown in Figure 1. The bag with one entire face fabricated from canvas filled in approximately 2 s to a pressure of 4 in. H_20. The bag with the canvas face framed with nylon filled in approximately 2 s to a pressure of 4.5 in. H_20. The nylon all around the sides and back made the bag firm. When force was put on the bag, the canvas let the air escape, resulting in the bag deforming, but not collapsing. Plenty of air passes through the canvas, and placing it around the face area supplies adequate air for breathing. This concept allows for relatively simple packaging (only one bag) and provides adequate restraining pressure. The location of permeable material will require detailed analysis and testing, but appears to be feasible. Although all three concepts showed merit, the semipermeable bag was selected to be the initial small scale prototype.

The back seat of a patrol vehicle equipped with a partition is a confined volume; thus, the first test of the semipermeable bag was to demonstrate how it would perform in a confined space. Individuals can push on the bag, but it will be volumetrically constrained by the partition, the roof, and the two doors. For this initial concept, only vehicles with partitions were considered. This minimizes the variables and focuses on the air bag and its interaction with violent individuals. An open area above the front seat would introduce a void that the air bag would have to fill. This void space would affect the performance of the air bag, but to a degree that can be designed around. A plywood box was used as a demonstration tool for the semipermeable air bag. The box is shown in Figure 2. The cutouts in the front are so a person can place his/her hands and forearms in the box. The blower is connected to the air bag using a simple hose clamp accessible through the side of the box. When the blower is turned on, the bag inflates and presses against the person's hands and forearms. The resultant force felt on the arms was impressive although individuals could still collapse the bag. This illustrated a basic scientific principle in an interesting way in that the more body

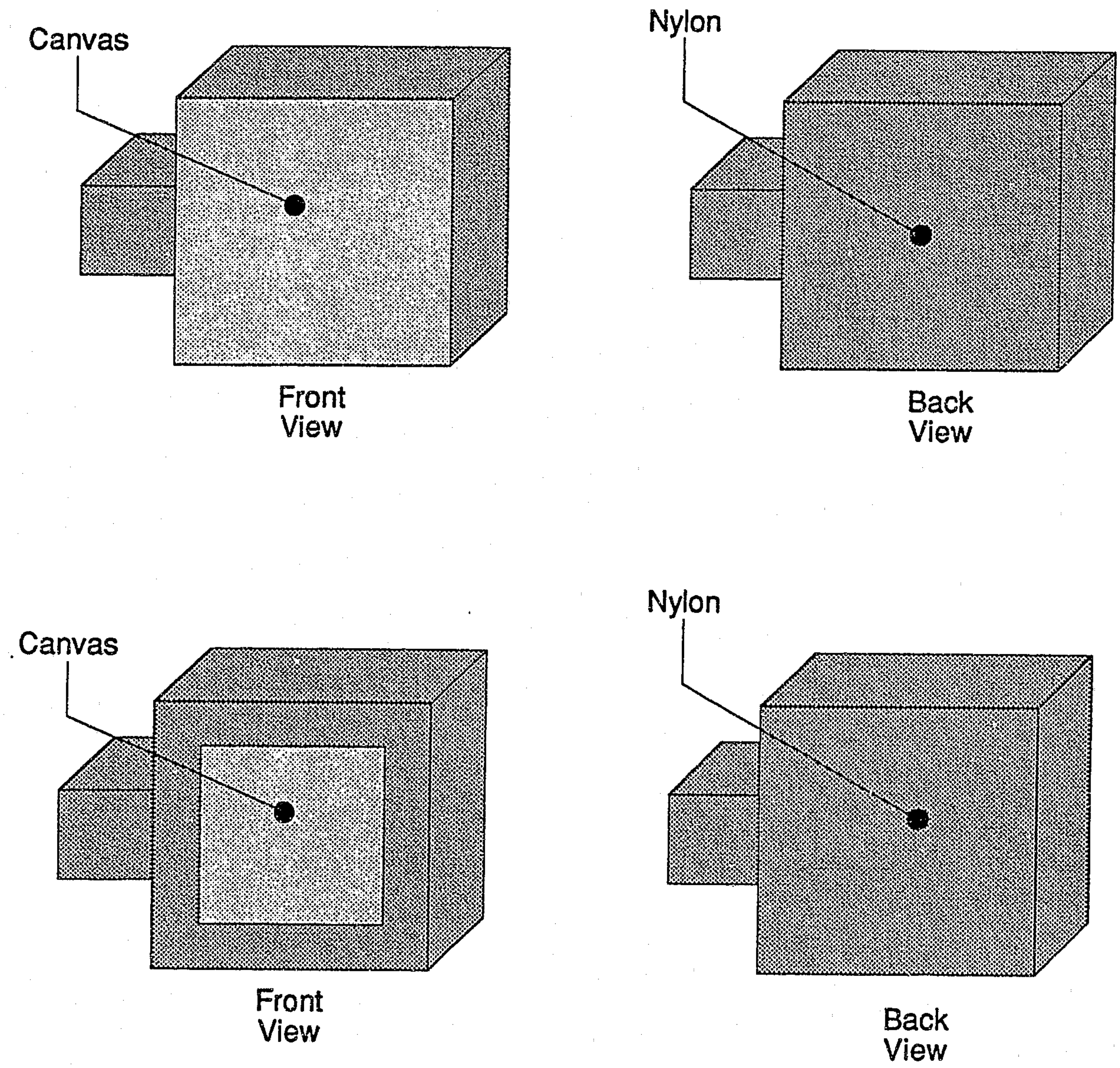

Figure 1. Combination nylon and canvas bag.

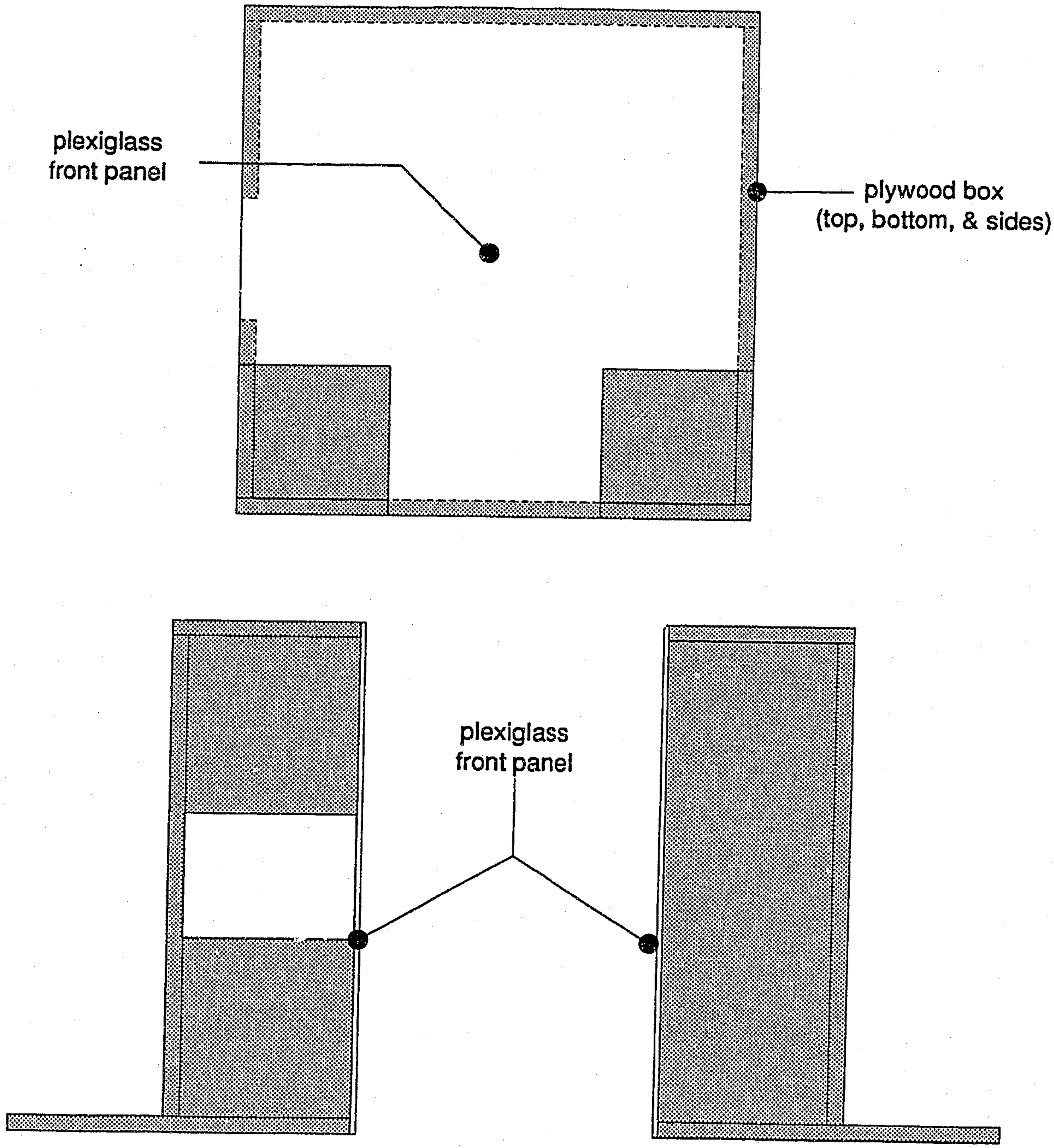

Figure 2. Demonstration box for testing air bag.

surface area exposed to the bag the greater the overall force exerted on the person. For the demonstration box, if the pressure of the air bag is 4.5 in. H_2O, each forearm and hand will be exposed to about 10 lb_f. That same pressure, exerted over a larger area such as the torso and thighs (the intended coverage area of the air bag restraint), will exert about 70 lb_f.

Two important lessons were learned from the demonstration box. The first lesson learned was that a small leaf blower cannot supply sufficient pressure to restrain an individual. However, several blowers are commercially available that have much higher static pressure ratings. The second lesson learned was that since the body surface area exposed to the air bag is variable, testing must be done to quantify pressure levels that are safe, but effective.

The next area of the air bag development that was explored was the air bag deployment location inside the vehicle. An air bag can be easily blown out from the center back and can be extended outward, but to do this in the rear seat of a patrol vehicle equipped with a barrier is extremely difficult due to space limitations. Also, the mounting hardware may block the officer's view from the front seat. The next most logical deployment location for the air bag restraint is from the ceiling of the vehicle. Deployment from above requires the bag to inflate downward, and then expand outward, pushing the individual down into the seat. To investigate how a simple rectangular air bag would deploy from the ceiling, one was fabricated as shown in Figure 3. Two identical leaf blowers were attached to the sleeves near the top of the bag using hose clamps. The bag was fastened to the ceiling using straps on the bag, wire, and tape. The bag was rolled up like a window shade to the top of the ceiling. Figure 4 shows a photograph of the bag inflated inside the vehicle. The bag rolled down easily, fully inflated, and pressed toward the seat. This makes sense since the air flow is coming from the top and back of the air bag. No attempt was made to have this bag fill the floor space in the vehicle, but future designs will have to fill this area as well.

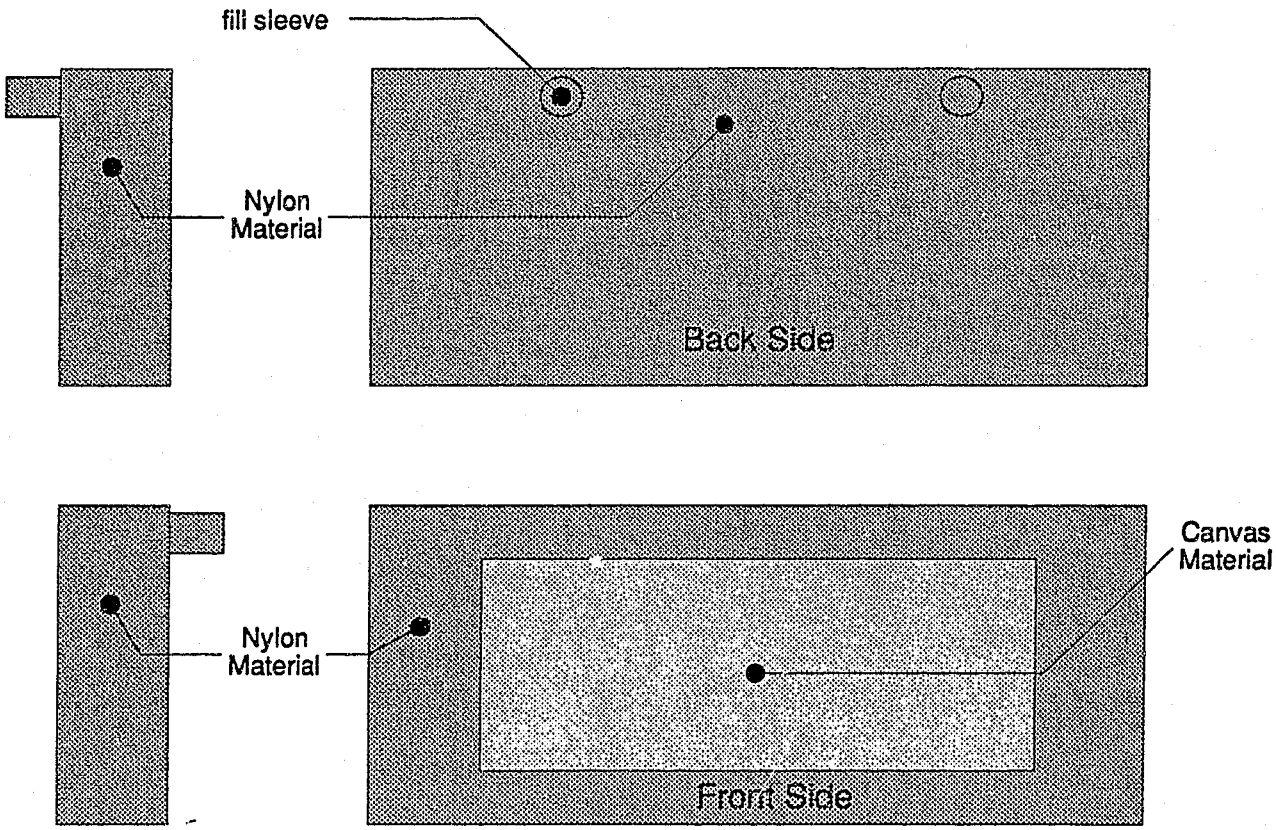

Figure 3. Air bag for deployment from the vehicle ceiling.

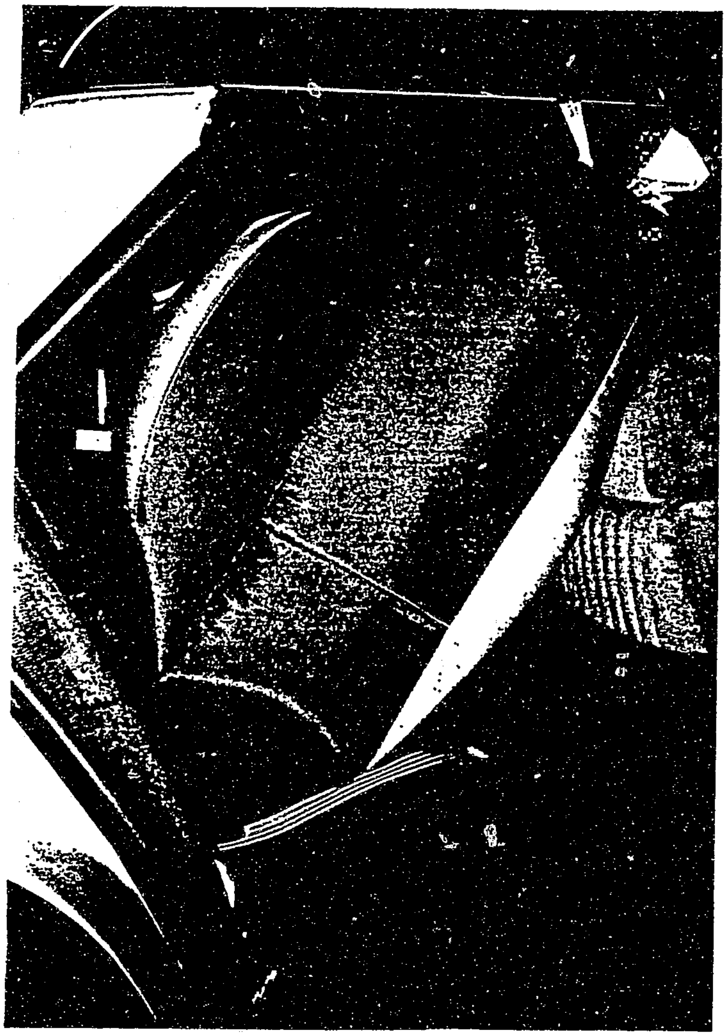

Figure 4. Inflated air bag deployed from the vehicle ceiling.

PROTOTYPE DESIGN

The next phase of the air bag restraint design was to develop a prototype system to be used as a working test bed to investigate pressure versus geometry issues. Insight gained from the demonstration box and from the air bag deployed in the vehicle was used in developing the prototype design. The design incorporated the semipermeable bag concept with a ceiling-deployment mounting configuration.

The bag is shown in Figure 5. Instead of one solid section of permeable material, four sections were used. This was done deliberately to try to direct individuals into, and have them remain in, the permeable areas. The top two sections provide breathable sections in the seat area, and the bottom two provide breathable areas for individual(s) that have worked their way down to the floor area. The amount and the location of permeable material are arbitrary at this point. Eventually, computer simulations can be run to better define these parameters, but prior to that, information needs to be obtained on the performance of a full-sized air bag with respect to how it deploys and inflates and the pressures that can be obtained in the four sections.

The mounting/deployment hardware is simple. The frame is attached to the vehicle at known hard points (the manufacturer can identify these). The air supply plenum is integral to the frame. Air supply lines will be connected to the frame and run along the front seat partition, down to the floor, and then to the blowers. The blowers are anticipated to be mounted in the trunk of the vehicle, but they can possibly be mounted under the front seat if their size and profile allow. To attach the air bag to the frame, the hinged side of the clam shell is swung open, and the collar of the bag is fastened using button snaps. Figure 6 shows the mounting and deployment hardware for an air bag. The air bag will be packaged in a rolled-up configuration with the attachment collar sticking out to facilitate installation. No tools will be necessary to install an air bag. When the system is activated, the air will begin to inflate the bag. As the bag begins to expand, the hinged clam shell will be forced open, and the bag will fully inflate. The material for the mounting and deployment hardware has not been selected yet, but probably a polycarbonate material will be used. An artist's concept of the deployed air bag is shown in Figure 7.

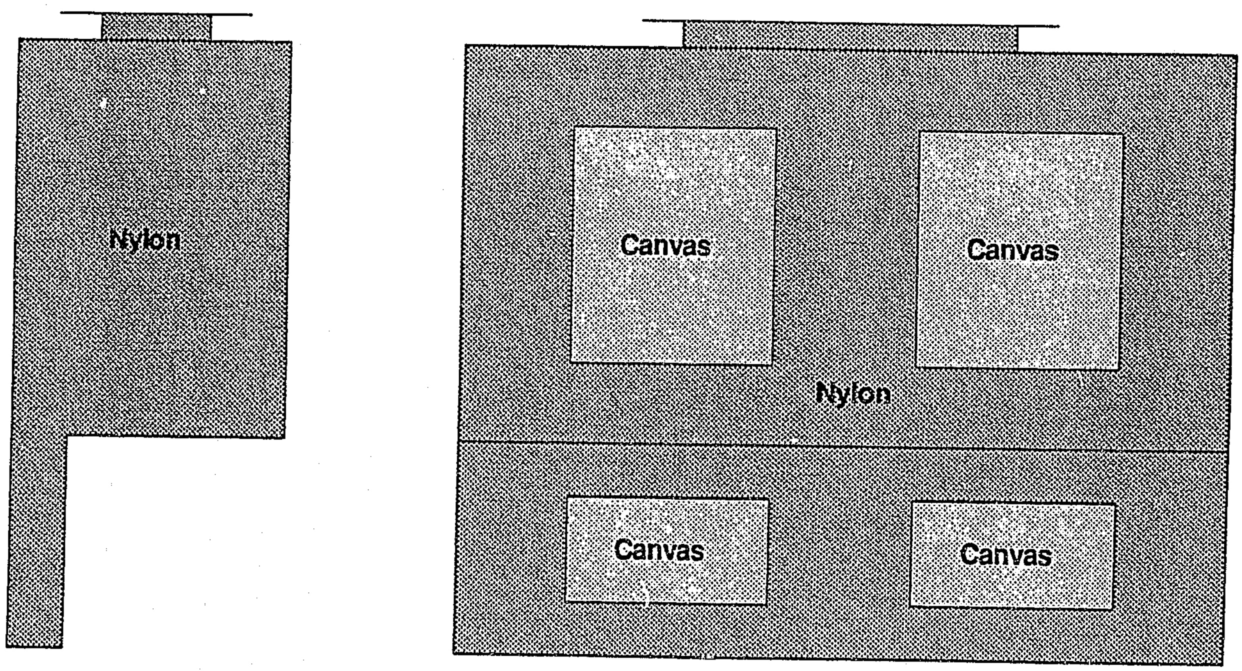

Figure 5. Semipermeable bag concept with a ceiling-deployment mounting configuration.

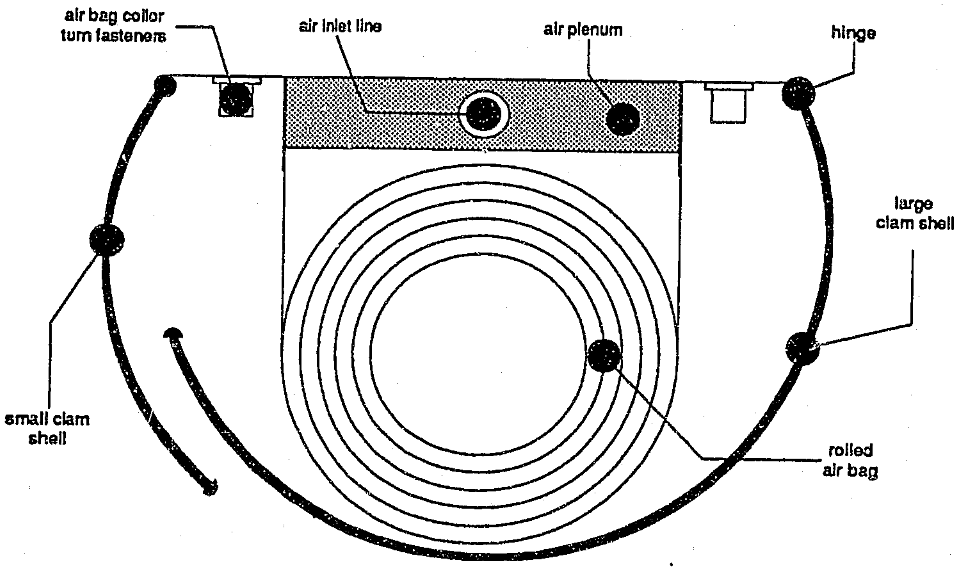

Figure 6. Mounting and deployment hardware for ceiling mount semipermeable bag.

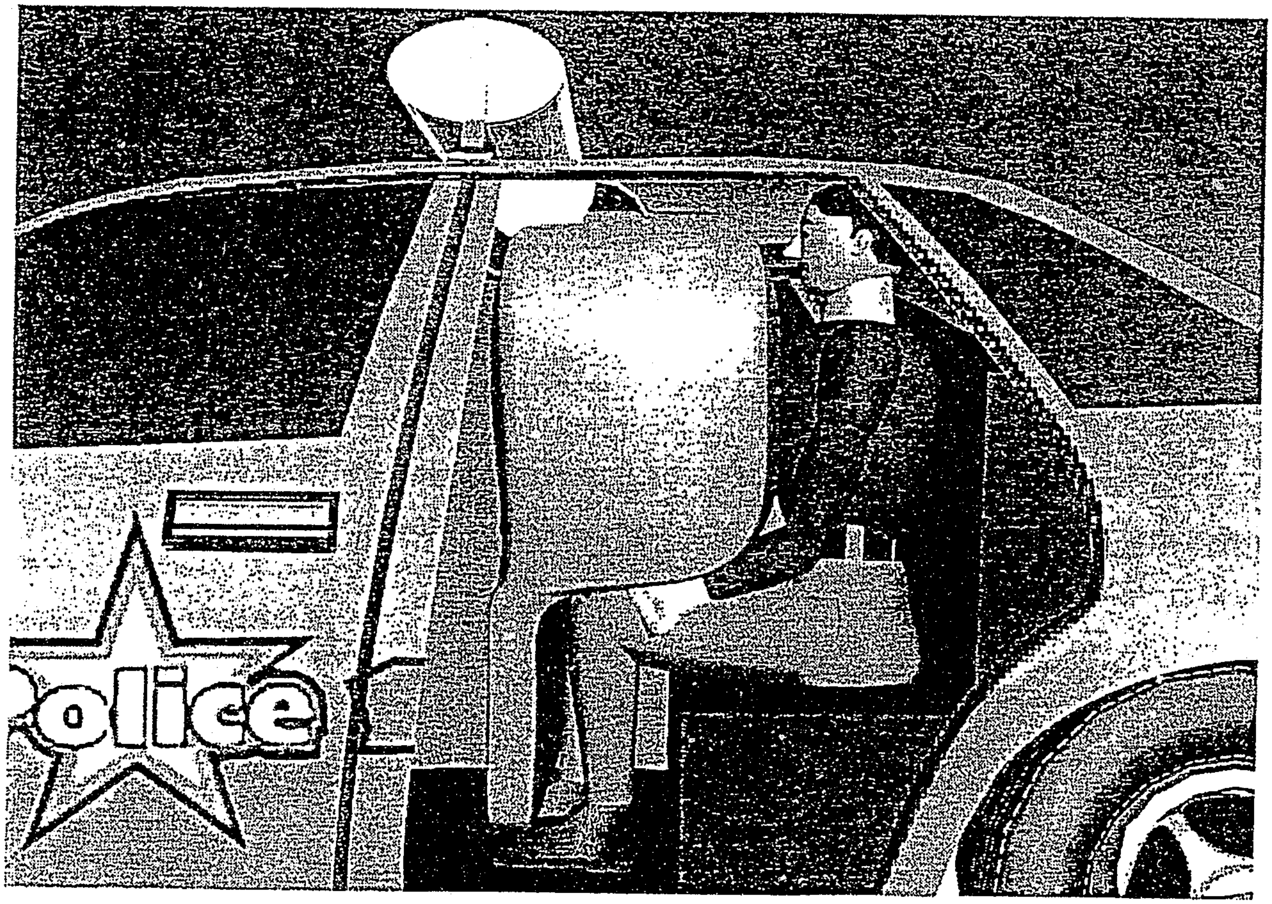

Figure 7. Artist's concept of deployed air bag.

SUMMARY

This effort has produced a prototype design for an air bag restraint system for the rear seat of patrol vehicles to be used when occupants become violent and dangerous. To address the concern of suffocation, a semipermeable air bag is suggested. Bench scale tests were performed to demonstrate the validity of that suggestion. Simple leaf blowers were used for the bench scale tests, and although they served those tests adequately, they were determined to be underpowered for the final design. A full car-width air bag was also tested to evaluate the volume in the back seat being filled, as well as deployment from the ceiling. Information gained from these tests were used as input for the prototype design.

Substantial work needs to be done before an air bag restraint system will be ready for field testing. First, a bag design will have to be completed, i.e., the material selection, the geometry of the bag, the ratio of permeable-to-nonpermeable material, as well as the location of the permeable material. The majority of these parameters will be determined once the issue of adequate restraining pressure is better defined. The correct pressure appears to be the minimal pressure required to restrain the most violent individual likely to be encountered. To define this pressure, an iterative testing process should be employed.

Although development work still remains to be completed, this concept has been shown to be plausible without any major technological advances. This should enable the restraining system to be manufactured quickly and ready for field testing in a short period of time.