repetitivity would reduce costs. A further development toward fuel-efficiency tests would also be possible, as well as INCOLL cycles for diagnostic purposes.

The past few years of development of the INCOLL system have shown the following:

1. It is a transient test that does not need any chassis dynamometer;
2. It could be executed in 4-5 min, including adoption, automatic calibration, some automatic warming up, automatic testing, and dismantling;
3. It could be laid out to give test results comparable to certification tests that deal with emissions and consequent fuel consumption;
4. It could indicate and define errors or malfunctions within the engine system;
5. It could be laid out to sample from any load-rpm area of interest; and
6. It could (in a short time) supply large amounts of statistical data.

Thus, the main future area of use might not be emission investigations as such but quality and diagnostic investigations based on emission results.

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Transverse Air-Cushion Restraints for Commuter Vans and Small Buses

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The recent proliferation of commuter vans and small buses has directed attention to their safety deficiencies and the need for better restraint of their occupants. A promising alternative to lap belts, which are generally ignored by van and bus commuters, would be the patented transverse air cushions described in this paper. Details are given of full-scale tests on a deceleration sled, where these air cushions restrained anthropometric dummies in simulated frontal barrier crashes up to 48 km/h.

During the past few years, the problems of urban air pollution coupled with the soaring cost and prospective shortage of motor vehicle fuels have forced changes in the patterns of commuting in private motor vehicles. More commuters are driving small cars in order to save fuel and an increasing number of commuters are vanpooling for even greater savings (1-2).

Safety experience in vanpooling so far has been good (3,4). Most vanpooling arrangements use experienced and prudent drivers, optimum routing, and well-maintained equipment. Driving is done in daylight (for the most part) and during hours when there is minimal likelihood of encountering conflict with other drivers under the influence of alcohol or other impairments. These and other factors foster an excellent safety situation for commuting in vans and small buses.

Nevertheless, there is cause for concern because commuter vans carry up to 15 persons in each vehicle, and small buses even more, so that many more commuters are at risk in any accident than would be the case with automobiles. Furthermore, vans lack some of the safety features of passenger cars (5), and accident studies indicate that they are less crashworthy (6,7). An effective countermeasure would be the use of lap and shoulder belts (8,9), but there are no indications that their use by U.S. commuters in vans and buses is any greater than in passenger cars, where currently only one in nine car occupants uses restraints (10).

Air bags are an obvious solution to the restraint problem for people who will not wear seat belts. Conventional air-bag systems could be used for the front-seat occupants of a van, but for the other passengers they would have serious disadvantages. First, a conventional air bag deflates in a controlled manner after being triggered by the vehicle impact (11), so that afterwards there is little protection afforded during any subsequent collisions or rollover in a multiple-event accident. Second, there would have to be a large penalty in vehicle weight due to the massive seat structures required to withstand the enormous forces created by several human bodies in forward, high-gravity deceleration.

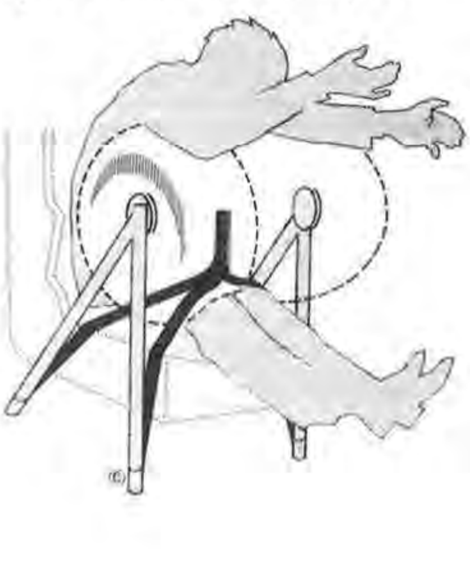
TRANSVERSE AIR-CUSHION RESTRAINTS

The transverse air-cushion restraints developed by Liberty Mutual Insurance Company circumvent these problems. On deployment during a collision they would form a rigid cylinder of air cells in front of each row of passengers and extend across the width of the van or bus. The air cushions are constrained (as described later) in such a way that no body impact forces are transmitted to seats in front. These air cushions contain air pressure that would be maintained for a number of seconds until the vehicle comes to rest after any multiple collisions or rollover. The full-coverage crash protection of this air-cushion system would be available to van and small-bus occupants without subjecting them to the nuisance and discomfort of strap restraints.

Transverse air-cushion restraints act more like very wide strap restraints than like conventional air bags. They are resilient and extend the deceleration time of the body while at the same time spreading the collision force over an extended area of the torso. The dynamic tests described in the next section show how the body tends to jackknife in a frontal collision and drape itself over the air cushion, as shown in Figure 1, while the thighs are forced tightly into the seat. The air cushions form a cylinder about 0.33 m in diameter so that a person's body does not move forward very much during a frontal collision, as it would with strap restraints that stretch or with conventional air bags that collapse. This means that the head and knees are fully protected from striking the back of a seat in front. Furthermore, while the air cushions are somewhat compliant, they maintain shape well enough during a collision to restrain an adult's body (whether large or small) centered in the seat, so that dangerous lateral movement would be prevented during an angle or side collision. Because the air cushions remain fully inflated for 5 s, the torso would be fully restrained during a rollover more effectively than with the air-bag restraints currently in use.

Prior to deployment, the air-cushion material would be folded compactly and stowed in armrest canisters 15-20 cm in diameter and 8-10 cm thick. These would be fastened to a steel framework, as shown in Figure 1. This framework can be formed of thin metal tubing since, when deployed in a collision, the air cushions would be braced together in a column across the width of the vehicle. A mainstay and a backstay would be folded and stowed with the air bags and securely anchored to strong cross members under the floor pan. Canisters, stays, and framework would be concealed behind the upholstery of the vehicle seat and rip out only when deployed during a dangerous collision. Although the air cushions are pressed together by gas pressure, there is a tendency in a frontal collision for the forward-moving torso of a seat occupant to force itself between the air cushions. This is prevented by restraining the bags with the diagonal backstays shown in Figure 1, as well as with the mainstays, which also serve to press the thighs down in the seat cushion and center them. In the preinflation tests described in the next section, this arrangement of occupant restraints dynamically adjusted itself to accommodate a range of body sizes from 5th percentile female to 95th percentile male anthropometric dummies. The air bags are flexible enough to form themselves over a passenger's legs if, prior to the collision, they were crossed or angled sidewise in the seat. Further details concerning the actions of these restraints are given in the U.S. patents (patent numbers 3,981,519 and 3,981,520).

Figure 1. Transverse air-cushion-restraint system.



The potentially active elements of the air-cushion-restraint system include a canister that contains the folded air bag and stays and a manifold for distributing the gas during inflation. These would be concealed in humps at the front of the armrests of the passenger seats, as shown in Figure 2. The driver would have a steering wheel air bag of a conventional kind (11). Either gas generators or bottles of stored air could be used for the passenger air bags. In order to provide protection from any direction, deployment of the air bags would be triggered by sensors that indicate vehicle deformation. These would be located in the front and rear bumper supports and in several door frames. They would signal deployment for collision velocities around 20 km/h. For redundancy, there also should be omni-directional inertial sensors in the front and rear of the vehicle. A signal from any one of these sensors would cause all the air cushions in the vehicle to inflate within 0.04 s. This means that even in a moderately fast collision (such as 50 km/h), the air cushions would blow up in front of a passenger before the torso moved forward significantly.

The inflation pressure in this air-cushion-restraint system is approximately 0.07 kg/cm². Ordinary air bags are porous or have venting valves so that their internal pressures drop rapidly within less than 1 s. The transverse air cushions, however, are constructed of a plastic-coated fabric in order to restrain high pressure for an extended period. It is envisioned that timers would automatically activate release valves after about 5 s. This is a time duration that examination of accident reports indicates would encompass complex, multiple-event accidents.

The strength of the transverse air-cushion system for keeping vehicle occupants in place is derived partly from the mainstays and backstays and partly from the air cushions being forced against each other so as to create a rigid cylinder between the door frames at the sides of the vehicle. An artist's rendering of this situation is shown in Figure 3. For lack of suitable load cells, lateral pressures were not measured during the sled tests of this system. They may be high enough to warrant stiffening the side-frame members in a van.

In addition to superior occupant protection for

Figure 2. Commuter van equipped with air-cushion restraints.

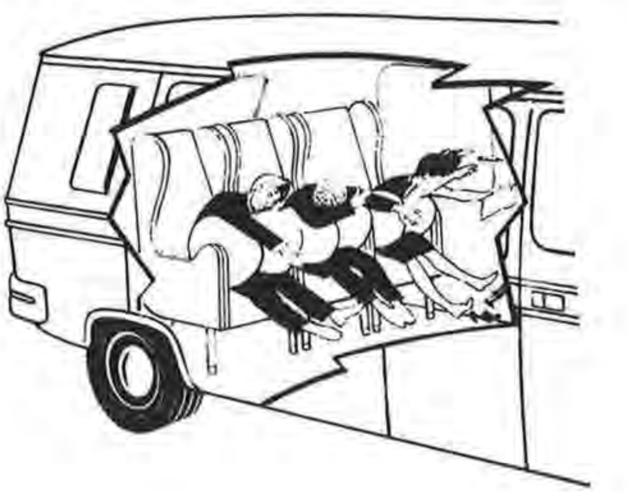


Figure 3. Commuter van with activated air cushions.

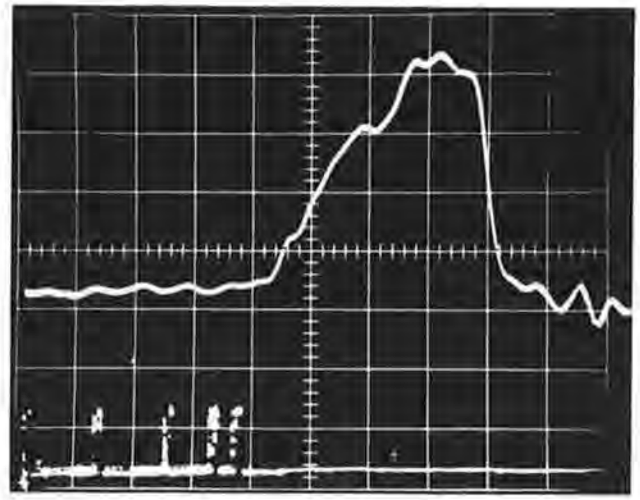


Figure 4. Sled deceleration pulse.

nearly all types of serious collisions, the transverse air cushions have the important advantage of not compromising passenger comfort in any way. The safety devices would be unobtrusive and would not limit the design of comfortable and commodious seating. One such possible arrangement is illustrated in Figure 2.

DECELERATION SLED TESTS

Valid and fully believable tests of the transverse air-cushion restraints would require the entire system to be deployed normally during a full-scale vehicle collision. Unfortunately, we did not have the expertise and resources available to develop all the necessary hardware. However, we did conduct sled tests with a safety seat mock-up that involved preinflated air cushions and anthropometric dummies.

Tests were performed with the Liberty Mutual automotive crash simulator (12). A 2-m sled was accelerated by compressed air over a distance of 2.7 m at up to speeds of 50 km/h (the upper limit of the sled system for realistic testing). After coasting free for 0.6 m, the sled was decelerated by a combination of an aluminum honeycomb and a hydraulic decelerator. Velocity was measured electrically and strain-gauge accelerometer data were transmitted through trailing cables to an instrumentation tape recorder. A typical deceleration pulse [filtered according to Society of Automotive Engineers, Inc. (SAE) standard J211b] measured at the sled frame is shown in Figure 4. It simulates a vehicle-to-barrier collision.

The air cushions employed for these tests were 25 cm thick and 38 cm in diameter (before inflation) and were sewn from plastic-coated cloth. About 5 cm of automotive seat belt material was sewn to the bags to form the mainstays and backstays. In order to maintain inflation pressure accurately while the sled propulsion system was being pressurized, inside bladders made from inner-tube material were employed. Tests indicated that an air-cushion pressure of 0.07 kg/cm^2 was adequate for torso retention at 50 km/h, and it was employed thereafter.

The air cushions in the test set-up were attached to 20-cm circular reaction plates bolted to the arms of the seat mock-up. The latter was constructed of a structural steel channel and fitted with plastic-foam cushions covered with vinyl. The air cushions were centered on an axis about 35 cm forward of the seat H-point (SAE standard J1100) and 20 cm higher. Sierra 5th percentile female, 50th percentile male, and 95th percentile anthropomorphic dummies were employed. The test seat is shown in Figure 5.

The dynamic action of the air-cushion restraints and dummy motions are best studied by high-speed motion-picture photography. For this purpose, a rotary-prism Fastax camera was employed at 400 frames/s. A significant observation from the test films is that rebound velocity of a dummy is less than one-third of the entrance speed into the restraint system. At 48 km/h, the maximum rebound observed was 13 km/h, which would present no safety hazard.

Manually synchronized still photographs were also made, and typical examples are shown in Figures 6 and 7. They illustrate how the upper thighs, abdomen, and chest of the human surrogates are wrapped around the air-cushion restraint; thus, the collision force is distributed harmlessly over a wide area of the torso. Pelvic and chest decelerations in the dummies were well within survivability limits and there were no lacerative injuries or any other skin damage.

DISCUSSION

The crash simulations just described are worst-case tests because frontal collisions are the most frequent and the most dangerous (13) of all automotive accidents. Therefore, it is strong evidence of their potential value that the transverse air cushions successfully restrained representative human surrogates in realistically simulated collisions at speeds up to 48 km/h and in a manner that most likely would not have harmed their human counterparts. Insofar as sled tests can be considered realistic, these were crucial tests of this restraint concept. Since tests for an out-of-position occupant, side collision, and rollover would by no means be as formidable as the frontal collision, our inability to perform them is not considered critical at this stage.

Most of the essential design elements in the transverse air-cushion-restraint system concept, notably collision sensors and air-bag inflators, have been fully developed elsewhere. The only important item as yet undeveloped is the air-cushion material itself, which must be (a) strong, (b) able to remain flexible while stowed tightly for years, (c) capable of deployment within 40 ms, (d) able to

Figure 5. Air-cushion test seat mounted on deceleration sled.

Figure 6. Sled test with 5th percentile dummy.

Figure 7. Sled test with 50th percentile dummy.

maintain adequate pressure for several seconds, and (e) manufacturable in the form required. Informed vendor opinion is that such a material is feasible, although casual inquiry did not develop a source. Availability of such a material is obviously a prerequisite to further development of this restraint system.

CONCLUSION

Transverse air-cushion restraints would offer crash injury protection to van and small-bus occupants without the necessity of having them buckle up, which experience indicates few riders will do.

The proposed system differs from conventional air bags in the following respects:

Difference	Benefit
Side-acting	Lack of forward body thrust obviates need for strong seats; tends to center occupant
Prolonged inflation	Protects in side impacts and rollovers
Backstays	Centers occupant in seat
Mainstays	Maintains torso position and low profile

Although the transverse air-cushion-restraint system has not been completely developed, its dynamic capabilities have been demonstrated in realistically simulated crash tests, and construction of fully operable hardware appears to be feasible. Accordingly, it is proposed as a practical occupant-restraint concept for passenger vans and small buses where large numbers of riders are at risk without adequate crash injury protection.

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Positive-Guidance Demonstration Project at a Railroad-Highway Grade Crossing

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A rural railroad-highway grade crossing used exclusively by local drivers was selected for a positive-guidance demonstration project. Initially, and throughout the project, the crossing was controlled by STOP signs because of sight-distance restrictions. The project first upgraded the motorist-information system at the site by installing improved advance-warning signs and markings that conform to the Manual on Uniform Traffic Control Devices. (The crossing is on a minor county road, not on the state system.) Then, application of the positive-guidance procedure resulted in the addition of rumble strips on both approaches and LOOK FOR TRAIN and HIDDEN XING signs on the more restricted approach. The as-is condition and the two levels of improvement were evaluated by observing the extent to which drivers slowed down at a safe rate, stopped at a safe distance from the track, and looked both ways before crossing. It was found that the positive-guidance procedure was workable, and the project yielded field-tested schemes for evaluation that can be recommended to other agencies that desire to use the positive-guidance system at grade crossings. However, overall, the project did not produce an improvement in driver behavior. In fact, the rumble strips induced some swerving into the oncoming lane and may have been responsible for the observed increase in vehicles crossing at reckless speeds. These findings, while essentially negative, are important because they document the difficulty of influencing drivers who are thoroughly familiar with a road. Rumble strips should be reserved for nonresidential areas where unfamiliar drivers are numerous.

Positive guidance is a set of rational steps developed during the 1970s by the Federal Highway Administration (FHWA) (1,2) to provide drivers with sufficient information where they need it and in a form that they can best use to avoid hazards. It combines highway engineering and human factors technologies to produce an information system matched to facility characteristics and driver attributes. Positive guidance often provides high-payoff, short-range solutions to safety and operational problems at relatively low cost. The procedure consists of six major functions, which are as follows:

1. Data collection at problem locations,
2. Specification of problems,
3. Definition of driver-performance factors,
4. Definition of information requirements,
5. Determination of positive-guidance information, and
6. Evaluation.

SITE CONDITIONS

This paper describes a positive-guidance demonstration project funded by FHWA through a contract with the Georgia Department of Transportation (DOT). A railroad-highway grade crossing in rural Georgia was the site of the project. The crossing is used exclusively by local drivers and was controlled by STOP signs throughout the project. The project first upgraded the motorist-information system at the site by installing improved advance-warning signs and markings that conform to the Manual on Uniform Traffic Control Devices (MUTCD) (3). (The crossing is on a minor county road, not on the state system.) Then, the positive-guidance procedure was applied to determine the type and location of additional improvements and modifications in the overall information system. Rumble strips and certain nonstandard signs were identified and installed. The as-is condition and the two levels of improvement were evaluated for improvement in driver performance. This paper briefly summarizes the final report to the Georgia DOT (4).

Figure 1 is a condition diagram for level 1, the as-is condition. Stanley Road, located northwest of Atlanta in Kennesaw, is a rural 18-ft two-lane road that crosses the L&N Railroad with poor sight distance from both roadway approaches (Figure 2). Before any improvement, the crossing had warning and protective devices that consisted of two STOP signs, one stop-ahead sign, and a wood crossbuck that faced in both directions. Figures 3 and 4 give further indication of the sight-distance restrictions due to fences, trees, and hillocks in the four quadrants of the crossing. These figures also show the stations of the hidden observers who collected performance data during the project.

Stanley Road has an average daily traffic (ADT) of 1100 vehicles/day and is used only by local drivers. The speed limit is 35 mph. The crossing averaged only about 8 trains/day during daylight hours when data were collected. County records over a number of years showed no accidents at this site. Federal records listed a recent accident when a train struck an unoccupied car that had stalled on the track on a rainy night. The Peabody-Dimmick hazard-index formula, which considers traffic volume, train volume, and level of crossing protection, predicts over eight accidents over a five-year period. Train arrivals were entirely unpredictable; drivers had no expectancy as to when a train might arrive. Train speed varied widely from 5 to 30 mph, depending on block signals.

Pilot observations showed that a significant fraction of the motorists ignored the STOP sign and slowed down no more than necessary to negotiate the crossing, i.e., between 20-25 mph. With sight distance limited as it is, they relied entirely on the locomotive engineer's duty to sound the horn for the crossing. Those who stopped did so too close to the tracks. The site typified the classic problem of the inattentive local motorist who lacks respect for the danger of a crossing.