POSSIBLE EFFECTS OF AIRBAG INFLATION ON A STANDING CHILD

By

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Introduction

In an automotive collision where the velocity of a car is rapidly changed, an empty space between the occupant and the interior of the vehicle will result in a difference in velocity between the occupant and the car in the direction of travel. The deceleration of the vehicle and the distance of unrestrained relative motion will determine the occupant´s impact velocity against the vehicle interior at the end of travel, as shown in Figure 1. Since such impacts often result in occupant injury, restraint systems are used to control this relative motion. The basic principle for such systems is the interposition of load-carrying, deformable elements between the vehicle interior and the occupant.

In some restraint systems these elements are in contact with the occupant´s body already during normal driving. This type of restraint system does to some extent control the occupant´s posture and thereby also the spatial relation between the human body and the restraint system during the collision sequence.

One characteristic of the airbag restraint system is that the deformable element - the airbag itself - is not inflated during normal driving but remains stored, usually in the instrument panel. This is an important characteristic of this system, because it leaves a seated occupant more freedom to move and change position than do most other systems. In order to obtain this advantage, however, the system must be activated at an early stage of a collision. Thus the airbag must inflate and be placed in position between the vehicle interior and the occupant very quickly, as shown in Figure 2. The spatial relation between the occupant and the restraint cannot be controlled in the same manner in airbag restraint systems as it can in most other systems.

The current requirements of US FMVSS 208 take into consideration only the normally seated "grown up" car passenger. It may seem quite possible that a grown up passenger only very seldom is out of position to such an extent that this would cause any serious problems. If, however, the occupant is not only out-of-position but also has other body dimensions and weight that differ too much from that of an adult occupant, these problems may become more intricate, Figure 3. A child standing by the dashboard in front of the seat during an accident would fit this description quite well and the standing child problem has been discussed at some length in the literature. Patrick and Nyquist 1972 found that, in the airbag system that they studied, there was a risk for head and internal organ injuries to an out-of-position child during static inflation. Wu, Tang and Petrof in 1973 considered the impact of the folded portion of a deploying airbag to the chest of a standing child to be the main problem, Figure 4. Static airbag deployment tests, however, indicate that a child substitute in this position can be vigorously pushed away by a deploying airbag, Figure 5. The potential danger of airbag inflation to a standing child, therefore, would probably be related to the inflation time sequence, Figure 6. Some variations of the inflation pulse are possible without hazardous increase of the inflation time. This has for instance been pointed out by Lundstrom et al. 1974.

Scope

The scope of this investigation was to study the influence of the three different airbag inflation pulses, shown in Figure 7, on the kinematics of and the possible mechanisms of injury to a living body in the standing child position.

The possibility that the child may be injured by being impacted by the unopened portion of the airbag has already been mentioned. This would occur at an early stage of inflation and could explain the high initial peak of acceleration recorded with child dummies.

An exact analysis of the forces exerted on the body of a standing child during the inflation period is difficult, since the shape of the airbag is quite irregular and easily influenced by contact with the child body at an early stage of deployment. However, if a child dummy is well centered in front of the airbag outlet area, it will be violently pushed away by the inflating airbag. It seems quite possible, therefore, that the acceleration of the entire child body and the simultaneous deformation of that body during a large part of the inflation sequence, could be damaging to susceptible body structures of a child.

After having been accelerated by the deploying airbag, the child´s body has aquired a certain speed relative to the vehicle and will eventually impact the interior of the car. This impact may well result in injuries if the impact velocity is high enough and the orientation of the body is unfavorable.

These three possible mechanisms of injury to a standing child, 1) the momentum of the unopened airbag, 2) the acceleration and deformation during inflation and 3) the impact of the body on interior car structures after deployment, are all related to the airbag inflation time sequence and should be observed, therefore, in experiments with different inflation pulses. At a distance of 10-15 cm (4-6 in.) from the airbag outlet area the deploying airbag has gained some momentum but has still a small volume. This was therefore judged to be the most dangerous position for a standing child.

Materials and methods

Previous tests with airbag systems used in this investigation indicate that such systems give adequate protection to a normally seated 50th percentile male front seat passenger in simulated frontal car-barrier collisions at 48.2 km/h (30 mph).

The systems consist mainly of a package mounted in the usual glove compartment space in the dashboard. This package includes a high pressure bottle with the energy sources for the deployment of the airbag, and the folded airbag in a container. The folded airbag is kept in place in the container by a special cover, which opens in a predetermined way, when the airbag is pressurized.

The gas flow into the airbag is principally controlled by and distributed through a diffusor (Figure 8). The energy sources are compressed gas and a chemical gas generator. The latter begins to produce gas at the same moment as the compressed gas is let into the airbag through the diffusor. Two simultaneously ignited detonators open the passage from the bottle into the diffusor.

The volume of a fully deployed airbag is 190 litres (6.7 ft^3).

In production vehicles these systems also have two sensors (acceleration detectors) which close the circuit through the detonators on and above a certain g-level, applied during a certain length of time. The tests in this paper were performed on a 12 in. Hyge sled and the sensors were replaced by a timing device.

Three different airbag inflation pulses, Figure 7, were used and their influence were studied on living bodies of approximately the same size and stage of biological development as children 3-6 years of age. Ordinary domestic pigs weighing 14-15 kilograms were used as test animals. After 24 hours of starvation the animals were anesthesized by intraperitoneal injections of 0.5-0.8 g thiopentan sodium which induced sleep and relaxation within 15-30 minutes without serious respiratory depression. The following test program was carried out.

Airbags were deployed with test animals at a distance of about 10-15 cm (4-6 in) from the center of the airbag outlet area in a stationary car and in a car body during rearward acceleration on a test sled. The dynamic tests were made using the lowest vehicle pulse (12 g peak, 17.5 mph or 28 km/h), Figure 9, which would trigger an airbag. Tests were made with and without actual airbag deployment.

In two of the eight static tests, the animals were suspended in a forward facing position with their heads and front legs resting on the instrument panel and the apex of the heart at a distance of 10 cm (4 in.) from the airbag outlet. This posture of the test animal deflected the airbag downwards in such a way that it was trapped in front of the seat cushion. In order to avoid this influence, it was necessary to suspend the other test animals in a straight vertical position. There is one difference in shape between the thoracic part of a pig and that of a child which had to be taken into account. The sagittal diameter of the pig´s thorax is slightly longer than the transverse diameter, while the opposite is the case in a child´s thorax. Since this could possibly influence the tolerance, it was decided to suspend all the pigs with their right side towards and at a distance of 10-15 cm (4-6 in.) from the airbag outlet. Their vertical positions were adjusted so that the apex of the heart was at the level of the horizontal center line of the airbag outlet, Figure 11. The suspension included a loop of straps stuck to the animal by means of adhesive tape. The strap loop was fastened to a plastic bar which in turn was fixed by means of paper strings to a series of holes drilled in the roof of the car body. During the tests these strings were easily cut by the sharp-edged roof sheet metal.

Each test was covered by three high-speed cameras and the films were analyzed. In order to compare the results of different tests, still pictures were made from every tenth millisecond of these films.

Animals which survived the test were sacrificed after 30 minutes. An autopsy was made on each animal, still pictures were taken of the injuries and the animals were grouped in accordance with the Abbreviated Injury Scale (AIS) as described by States 1969.

Results

At an early stage of deployment, the airbags proved to be easily influenced by the presence of a test object and could expand in almost any direction. In such tests, where the major part of the airbag expanded to the side, either right or left the animal was accelerated to the opposite side quite violently and one was even ejected from the passenger compartment. An initial tendency to expand laterally would be further enhanced by this particular test arrangement in a car body without doors and without simultaneously deploying the driver airbag. In some of these tests the airbag also deviated in a vertical direction which could be up or down.

Table 1.

Airbag deployment	Lateral deviation	Vertical deviation	No deviation	No airbag deployment
Fatal (6)	2	2	3	1
Critical (5)			2	
Serious (4)	1	4	1	1
Severe (3)	2			2
No injury (0)	3			
Total number of animals	8	6	6	4
Total AIS	22	28	32	16
Average AIS	2.75	4.7	5.3	4

The airbag deviated laterally in eight cases, vertically in six cases, deployed without deviation in six cases and was purposely not inflated in four cases. To judge from the injuries as listed in Table 1 (average AIS), deviation in the vertical plane is almost as serious as a direct hit, while deviation to the side results in less injury.

In the test series (Tables 2 and 3) numbers 1-9 were static airbag tests with inflation pulse D_1. These were all performed in a stationary car. Numbers 9-11, 16-21 and 30-33 were dynamic airbag tests performed in a car body mounted on a rearward accelerating test sled. The car body had a windshield, an instrument panel with one airbag on the right side and a front passenger´s bucket seat. In test numbers 12-14 no attempt was made to trigger the airbag. In test 15 as well as in numbers 22-24 the airbag was not triggered and the animal was restrained in a rear-facing child seat. In tests 25, 26 and 29 a child dummy (Alderson VIP 6C) and in 27 and 28 (Alderson VIP 3C) in a rear-facing child seat replaced the test animals. Number 34 was a static test in the car body without an animal or a dummy. It was performed to check the normal inflation of the airbag. In tests 7 and 8 the front seat was filled with soft, energy-absorbing material in an attempt to exclude injury from impact against the surroundings. These two animals were injured, one fatally and one critically, both with large tears in the liver as the main injury. Pig number 18 was ejected and died from head injuries which were considered to be the result of the impact on the floor. Since these injuries were of no interest to the test conditions, they were not allowed to influence the AIS rating, which, due to lung contusions and subcapsular liver hemorrhage was judged as AIS 4. Number 19 died from an overdose of anesthetic, it had no injuries and was consequently considered as uninjured AIS 0. In test number 30, the airbag was cut open by sharp sheet metal which by accident had been left uncovered and this test has been referred, therefore, to the group where no airbag was deployed.

The first moment after impact, at which airbags with different inflation pulses were able to accelerate the test animal, was judged from still pictures from the film. Airbags with inflation pulse D_1 began to influence the animals at an earlier stage (25 milliseconds) than airbags with inflation pulses D_2 and

D_3 (40 milliseconds). As mentioned earlier, the airbag is easily influenced by the position of the test animal. The comparison between the three inflation pulses has been made only from those tests where the animals were well centered and the airbag did not deviate to the side.

The injuries to the liver were mainly ruptures of different size located close to structures by which this organ is suspended in the body. For this reason this type of injury was considered to be due to displacement of the liver caused by body deformation rather than to a blow from some folded part of the bag (Hellström 1966). In the myocardium and in the lungs two types of injuries were found. In a few cases there were fairly large bleedings as can be seen as a result of direct impact. In several cases, however, there were petechial bleedings on the inner side of the thoracic cage under the pleura and in the myocardium. This type of bleedings have been described in experimental air blasts (Clemedson 1949). In the six tests where the animals were well centered in front of the airbag those two types of injury were distributed in the following manner on the three types of inflation pulses. In Table 4, P denotes pressure pulse or air blast effects and D displacement or impact injuries.

Table 4.

Inflation pulse:	D_1	D_2	D_3
Severity and type of injury:	fatal (P) fatal (D) critical (D)	critical (P+D) serious (P+D)	fatal (D)

The number of cases is of course too small to draw any conclusions about the effect of the different inflation pulses on type and severity of injuries.

The distribution of injury severity on all of the 24 animals in the airbag material is shown in Table 5.

Table 5.

Description	AIS	Number of animals
No injury	0	3
Severe	3	4
Serious	4	7
Critical	5	2
Fatal	6-7	8

Three animals remained uninjured, one in each of the inflation pulses tested. This seems to be mainly due to the deviation of the airbags which was of the same order in these three cases.

The anatomical distribution of 34 injuries of different types is shown in Table 6.

Table 6.

Type of injury	Pressure wave (P)	Displacement (D)	Other
Heart	6		
Lungs	10		
Thorax	2		
Liver		10	
Spleen		1	
Kidney		2	
Mesenterium	2		
Head			1

The main cause of death was heart injury in 3 cases, liver injury in 4 cases and asphyxia in one case.

With the exception of the three animals which escaped injury when the airbags deviated considerably to the side during inflation all the animals in the airbag test series were injured. The severity of the injuries were rated from severe (AIS 3) to fatal (AIS 6). This includes the four tests where the airbags were not deployed although the peak acceleration of the test sled was not more than 12 g and the velocity change 28 km/h (17.5 mph). Test number 15 was made in order to exclude the possibility that the animals were too sensitive when anesthesized and placed in a vertical position like the one used. In this test the animal was strapped into a rear-facing child seat, Figure 12, and subjected to the same vehicle acceleration pulse as was used in the airbag tests. This animal revealed no injury at all at the autopsy. As this had also been seen occasionally in other tests it was decided to subject three more animals to accelerations in rear-facing child seats but with acceleration pulses simulating a frontal car-barrier impact test at 48.2 km/h (30 mph) with a peak of 24 g, Figure 10. As all these animals seemed to be completely uninjured by the tests, it was decided to let them live and to study their further development. As soon as they had recovered completely from anesthesia they were brought back to the sty and kept there together with one animal of the same litter which had been neither anesthesized nor accelerated. These four animals were observed for several weeks. They had a completely normal development including a normal weight increase over these weeks.

Summary and conclusions

In this investigation the influence of three different inflation pulses on the risk of injury to a standing child was inferentially studied. Pigs weighing 14-15 kilograms were used as test animals. When anesthesized and kept in an upright position in a rear-facing child seat these animals were able to withstand a simulated car-barrier impact at 48.2 km/h (30 mph) without any sign of injury. When anesthesized in the same way and suspended in a vertical position with their right side 10-15 cm (4-6 in.) from the airbag outlet area in the instrument panel and subjected to an acceleration pulse with a peak of 12 g and a velocity change of 28 km/h (17.5 mph) these animals were injured whether or not the airbags were inflated with any of the inflation pulses. Injury severity was rated from severe (AIS 3) to fatal (AIS 6) in the Abbreviated Injury Scale. Two types of injuries were seen: Tears in the liver

and large bleedings in the heart or lungs as seen in impacts with displacement of the organs due to body deformation and multiple petechial bleedings mainly under the pleurae and the endocardium as seen in experimental air blasts.

Our conclusions from these results are:

- that an out-of-position passenger of the size of a child 3-6 years of age could be injured by airbag inflation even at the triggering level of vehicle acceleration (~ 12 g),

- that injuries could be due to not only deformation of the body and displacement of internal organs but also to the air blast effect close to the airbag outlet,

- that injuries could also result from impact on the instrument panel at the same level of acceleration (~ 12 g) if the airbag is prevented from deploying,

- that proper restraining in a rear-facing child seat is apparently safe during collisions comparable to vehicle-barrier impacts at 48,2 km/h (30 mph), and

- that the airbag during its early phase of deployment is so easily influenced in its deployment direction that it is difficult to obtain reproduceable results.

Table 7.

Number	Facing Pos.	Restraint	Bag- +) deviation	Injury	AIS Rating	
1 stat	Forward	Airbag	Dl v	Contusion: heart	Serious	4
2 "	"	"	" v	Contusion: heart	Serious	4
3 "	Lateral	"	" s	-	No injury	0
4 "	"	"	" n	Contusion: heart, abdominal organs	Fatal	6
5 "	"	"	" v	Contusion: heart, lung	Serious	4
6 "	"	"	" v	Laceration: liver Contusion: lung	Serious	4
7 "	"	"	" n	Laceration: liver	Fatal	6
8 "	"	"	" n	Laceration: liver	Critical	5
9 dyn	"	"	" s	Laceration: liver Contusion: heart and lung	Fatal	7
10 "	"	"	" v	Laceration: liver and kidney Fracture: ribs	Fatal	7
11 "	"	"	" n	Laceration: liver Contusion: lung and heart	Fatal	7
12 "	"	No restraint	-	Contusion: heart	Fatal	6
13 "	"	" "	-	Contusion: lung	Severe	3
14 "	"	" "	-	Contusion: lung	Severe	3

+) s = lateral deviation, v = vertical deviation, n = no deviation

Table 7 (continued).

Number	Facing Pos.	Restraint	Bag- +) deviation	Injury	AIS Rating	
15 x)						
16 dyn	Lateral	Airbag	D2 n	Laceration: liver		
				Contusion: lung	Critical	5
17 "	"	"	D2 s	Contusion: abdominal organs	Severe	3
18 " xxx)	"	"	" n	Cerebralinjury (ejected) to-		
				ward outside structures	Fatal	(4) 6
19 " xxx)	"	"	" s	Overdose anestesia	Fatal	(0) 6
20 "	"	"	" s	Laceration: liver		
				Contusion: lung	Serious	4
21 "	"	"	" s	Contusion: lung	Severe	5
22-29 x)						
30 dyn	"	"	" -	Contusion: lung, heart	Serious	4
31 "	"	"	D3 s	Laceration: liver	Fatal	6
32 "	"	"	" s	-	No injury	0
33 "	"	"	" v	Laceration: liver	Fatal	6
34 xx)						

x) tests no 15, 22-29 in this series are summarized in table 2

xx) test no 34 was static airbag inflation on the sled without human substitute

xxx) see text

+) s = lateral deviation, v = vertical deviation, n = no deviation

Table 8.

Number	Test object	Facing pos	Restraint	Result
15	pig	Rearwards	Child safety seat	No injury
22	"	"	" " "	" "
23	"	"	" " "	" "
24	"	"	" " "	" "
25	dummy	"	" " "	S1 384 HIC 319
26	"	"	" " "	S1 1104 HIC 894
27	"	"	" " "	S1 584 HIC 413
28	"	"	" " "	S1 416 HIC 413
29	"	"	" " "	Instrumentaion failure

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ERRATA

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Table nr 7 should have nr 2 and table nr 8 should be substituted by enclosed table nr 3.

Table 3

Number	Test object	Facing Pos	Restraint	Result
15	pig	Rearwards	Child safety seat	No injury
22	"	"	" " "	" "
23	"	"	" " "	" "
24	"	"	" " "	" "
25	dummy	"	" " "	SI 200 HIC 539
26	"	"	" " "	SI 264 HIC 337
27	"	"	" " "	SI 252 HIC 208
28	"	"	" " "	SI 316 HIC 220
29	"	"	" " "	SI 312 HIC 328

Additional tests were performed with Alderson VIP-3C dummy in a standing child position in front of the instrument panel. Following injury criteria were received.

Number	Test object	Facing Pos	Restraint	Pulse	Result
1	dummy	Forwards	Airbag	D2	SI 384 HIC 319
2	"	"	"	D2	SI 1104 HIC 894
3	"	"	"	D3	SI 584 HIC 413
4	"	"	"	D3	SI 416 HIC 413

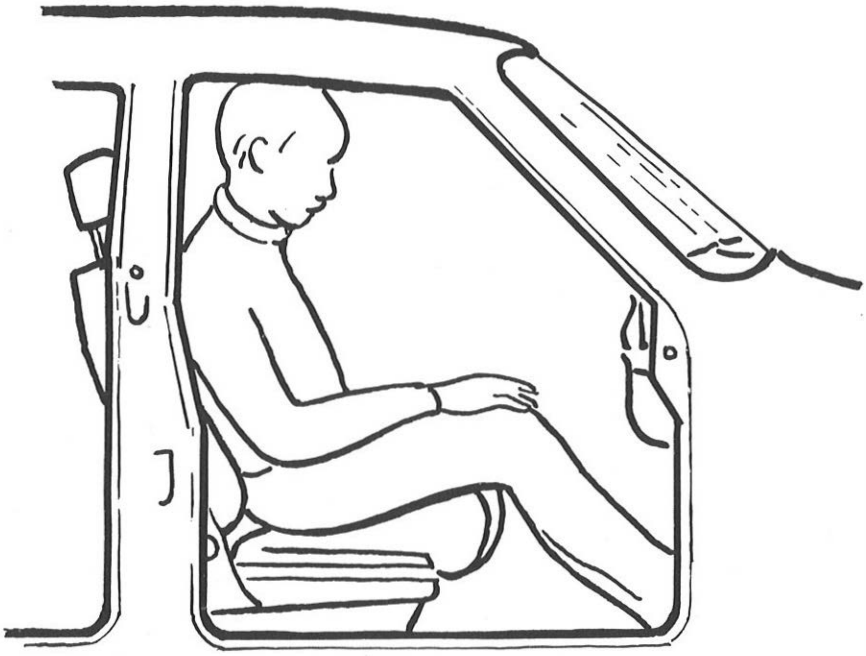

FIGURE 1

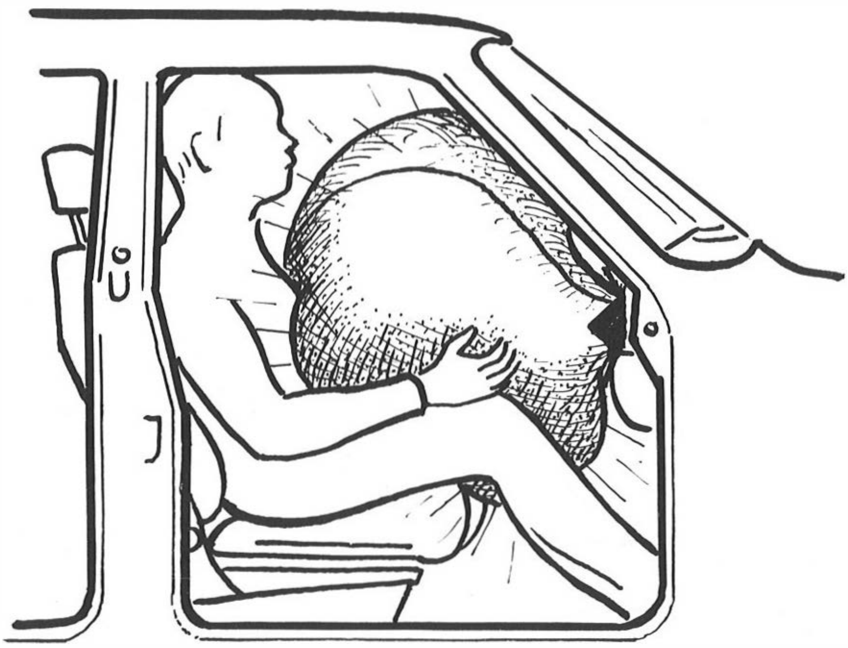

FIGURE 2

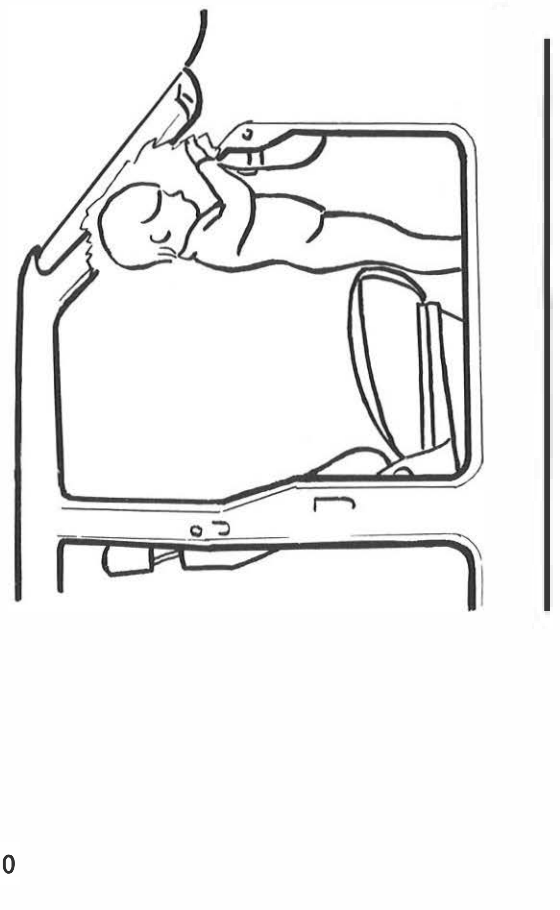

FIGURE 3

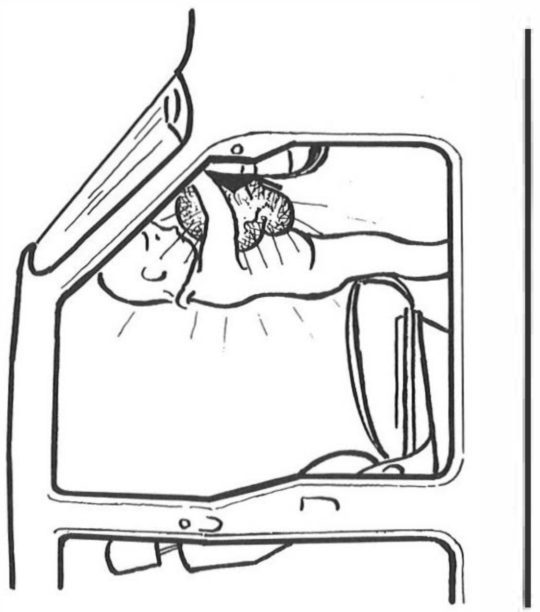

FIGURE 4

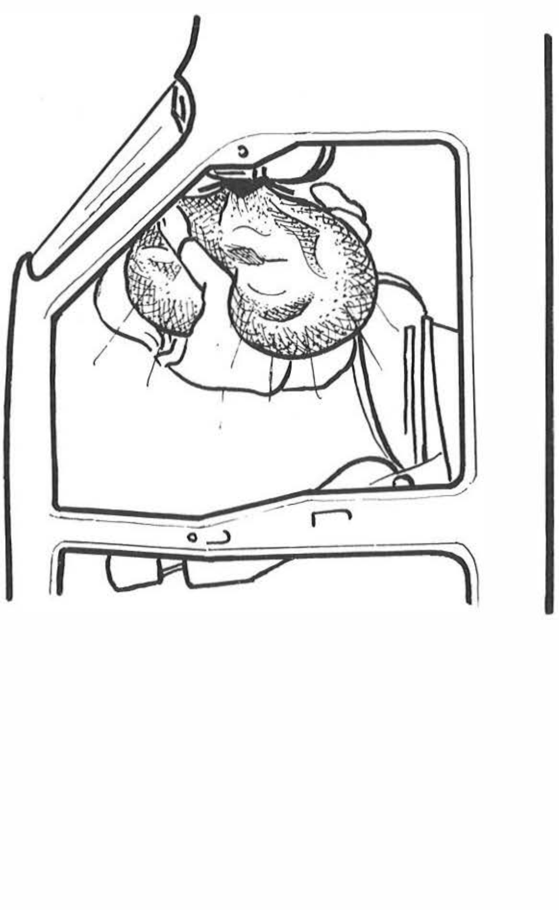

FIGURE 5

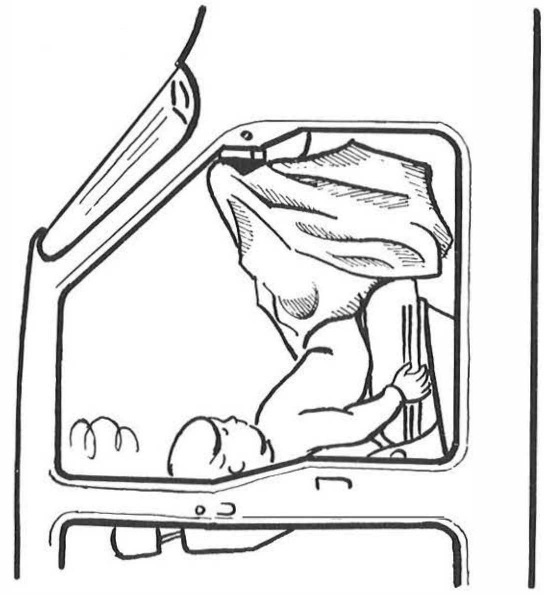

FIGURE 6

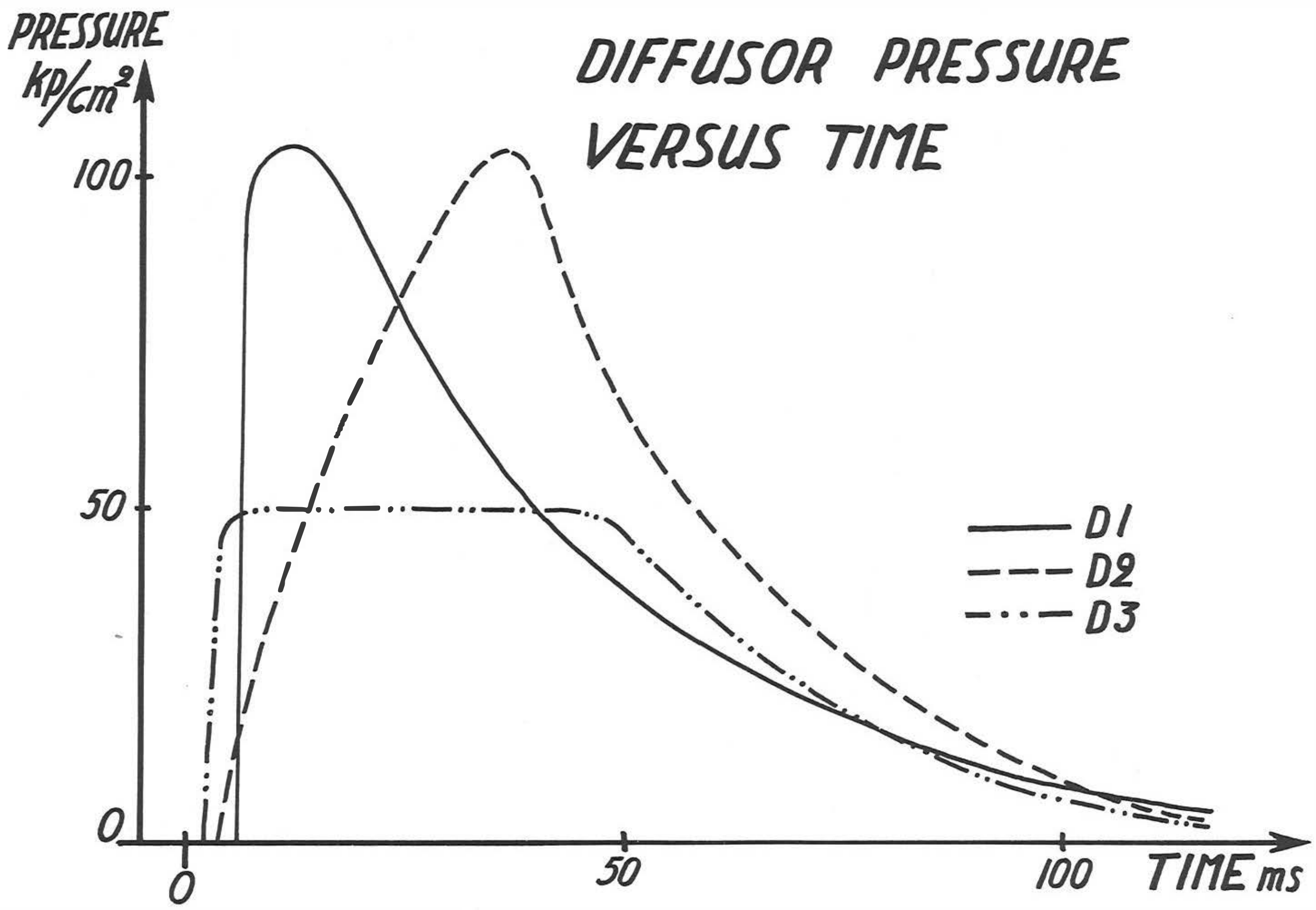
PRESSURE kp/cm²
DIFFUSOR PRESSURE VERSUS TIME
100
50
0
0
50
100
TIME ms
D1
D2
D3

FIGURE 7

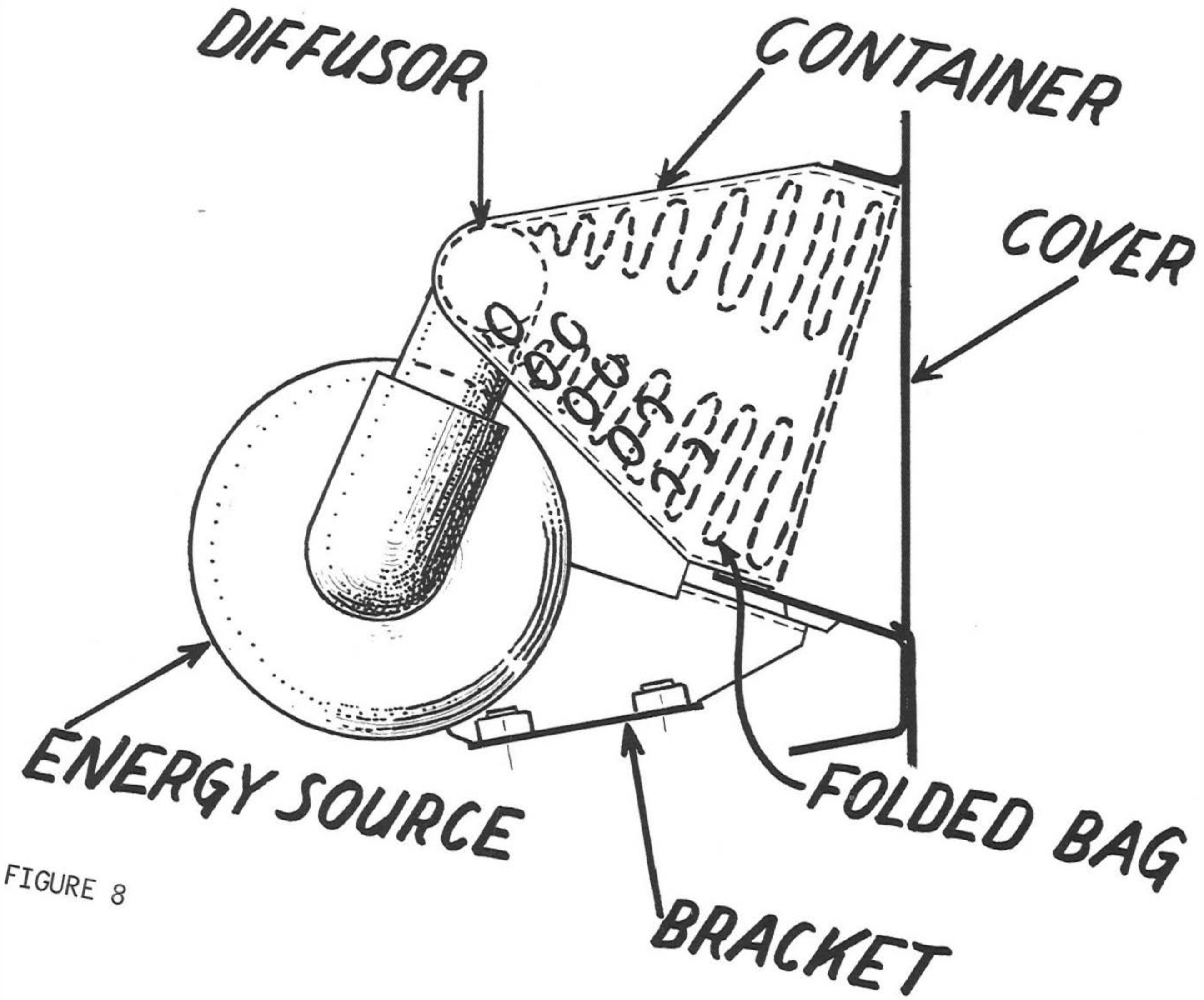
DIFFUSOR
CONTAINER
COVER
ENERGY SOURCE
FOLDED BAG
BRACKET

FIGURE 8

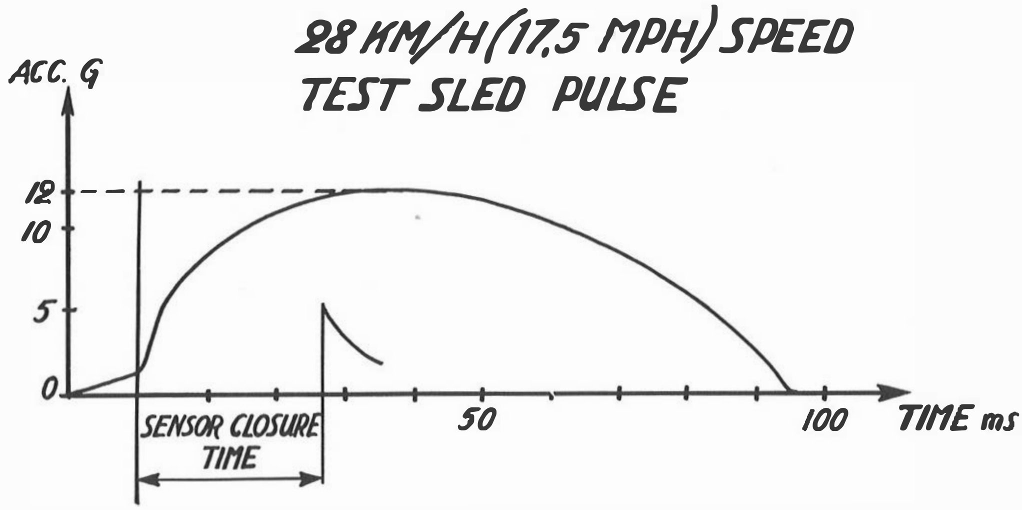

FIGURE 9

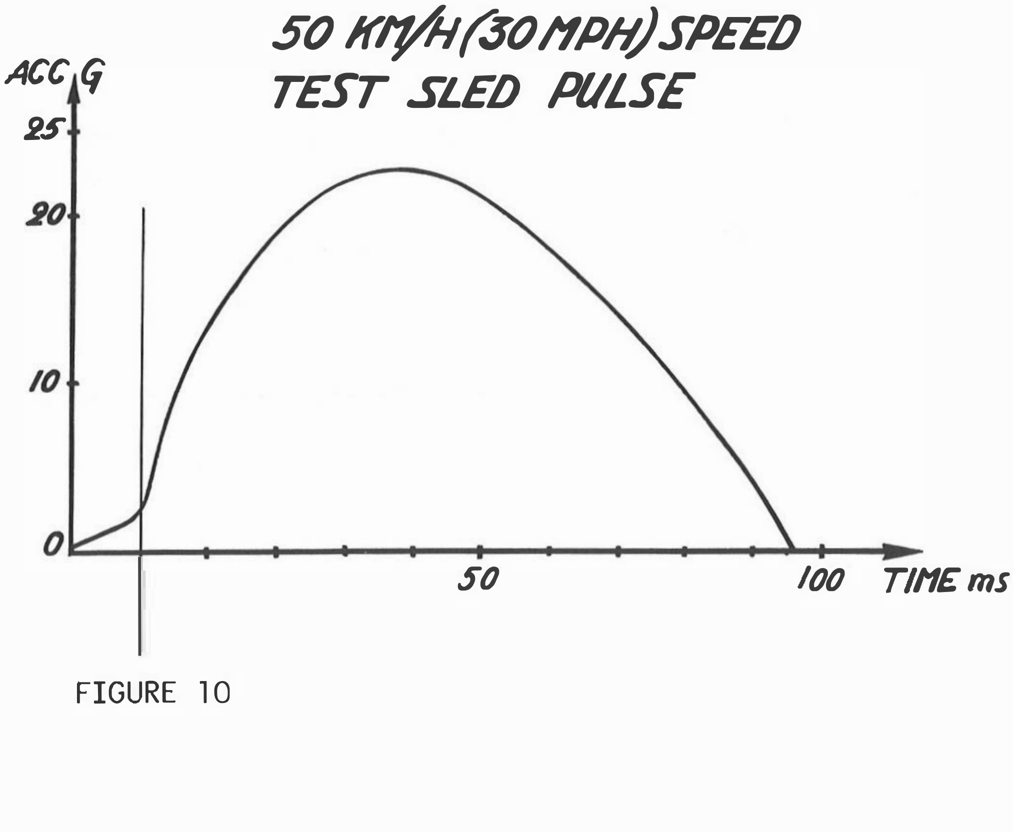

FIGURE 10

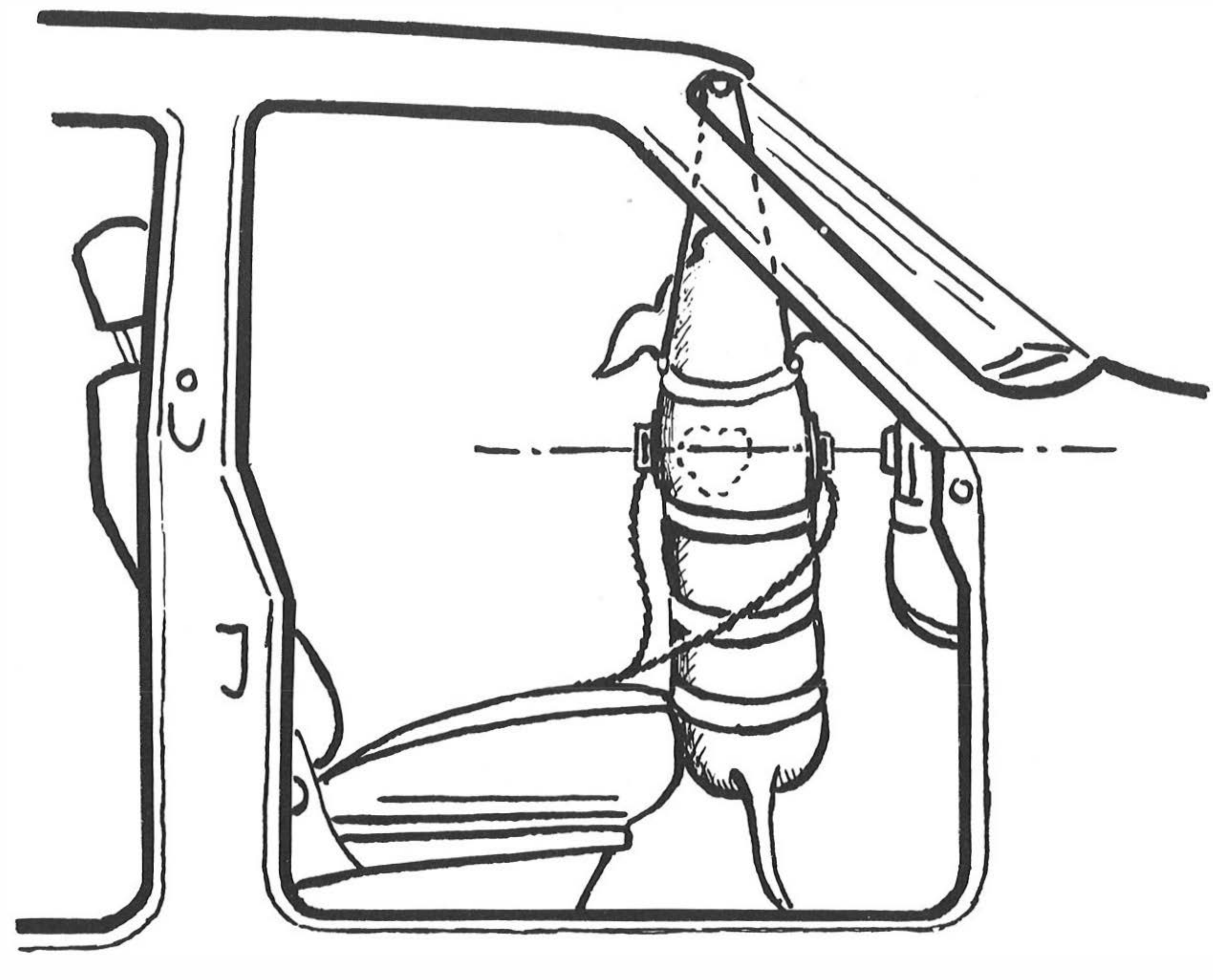

FIGURE 11

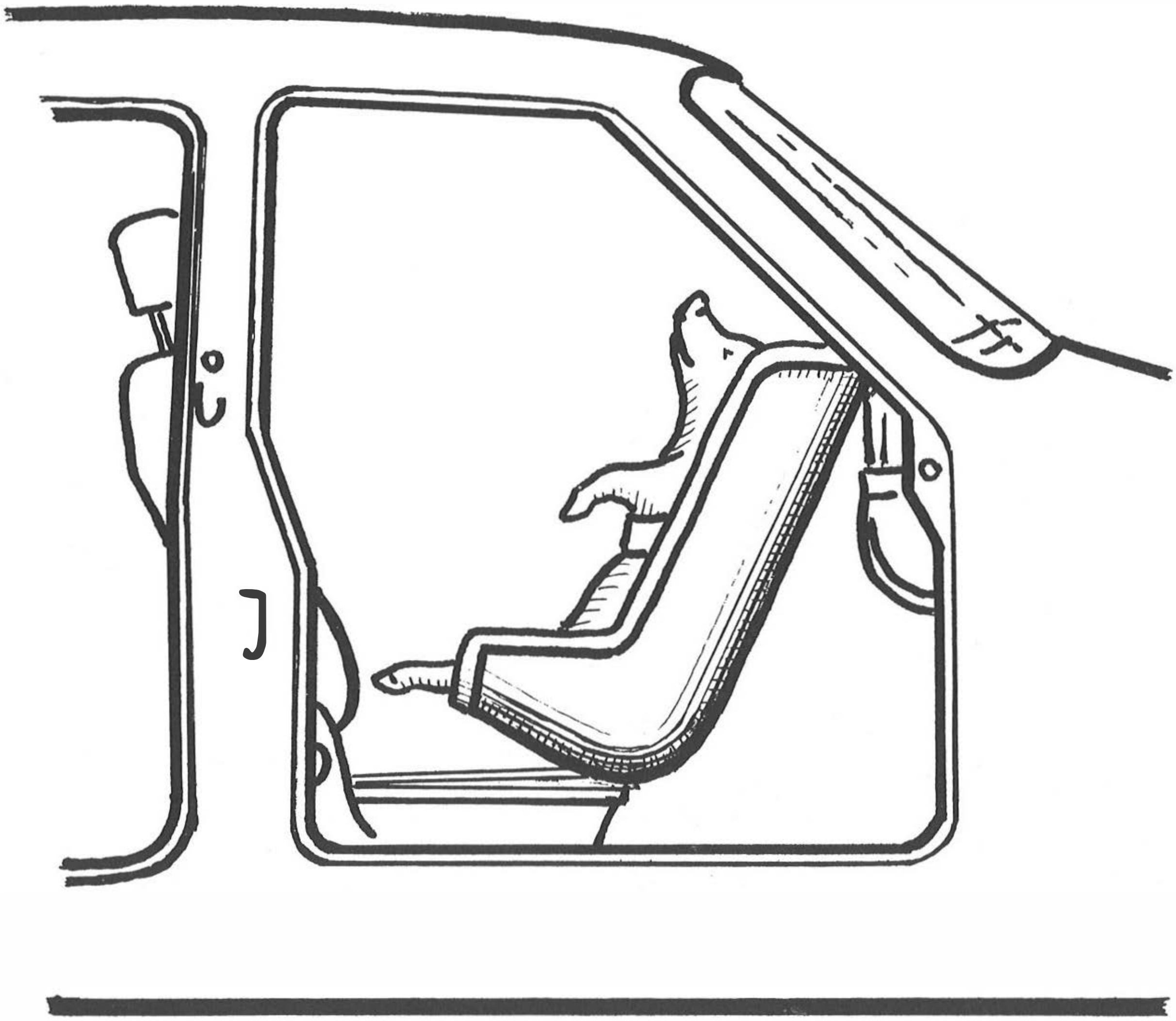

FIGURE 12