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16. Abstract

The air belt concept first studied in the 1960's and 1970's is reexamined in terms of today's airbag and seat belt restraint technology. Design criteria for a contemporary air belt are established and prototype systems fabricated and tested. Favorable test results and proposed solutions for producing a consumer acceptable system strongly suggest the further pursuit of this technology.

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1.0 Introduction and Summary

In the 1960's and 1970's the air belt (also called Inflataband by Allied) was considered to be, when used with automatic belt hardware, a major competitor of the air bag. In fact the air belt was the restraint selected for the Calspan RSV, reference 1, until the very end of that project when an air bag was substituted for the driver side (the passenger side remained an air belt).

This author had restraints responsibility for that RSV, but as we tried to incorporate a motor driven belt with a web clamp, force limiting webbing and an inflatable belt section, we came to view the air belt as the "worst of both worlds" (in the belt vs. bag wars). In other words the air belt had all the inconvenience features of a belt system (spaghetti) and at the same time the expensive and complicated features of an air bag, i.e. it required a sensor, gas generator, and an inflatable bag. For these reasons the air belt has gone nearly forgotten for the past fifteen years.

On the other hand, the air belt has always had great potential regarding its restraint capability, see reference 2. and advantages over a conventional belt. First it acts as a belt tightener since the inflated section of the belt shortens when deployed. Second, it acts as a load distributor reducing the well recognized occurrence of belt injuries. Third, it has the potential to provide head and neck protection if it can be correctly located.

For these reasons and especially for the reasons stated below the air belt deserves a second chance.

1. The belt versus bag wars are over. These systems are today complimentary. Because of litigant dominated society the air bag is called "Supplementary Restraint System", SRS, but as we look ahead toward greater acceptance of manual belt use the systems can more properly be thought of as complimentary. This means the air belt will be an improved manual belt design in the same sense as belt-in-seat, adjustable upper anchor point and belt pretensioners are improved manual belt designs. Once freed of its requirement to be automatic the air belt gets a new lease on life.

2. Belt pretensioners, which include pyrotechnic belt retractor pretensioners, as well as torsion bar, coil spring and pyrotechnic buckle pretensioners are all in production vehicles. This means these belt systems already incorporate crash sensors, diagnostics and pyrotechnics. Hence these components are available for air belt use.

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3. A gas generator suitable for an air belt already exists and is in production in Europe for small facial driver airbags, the "Euroflator".

Over the past fifteen years REI has worked with each of the above referenced systems and therefore was ready to take the next logical step, which was to initiate their merger. In the remaining sections of this study we will show how we conducted the marriage of these 1990's technologies.

In section 2.0 a review of early work on the air belt is presented and reasons for discontinuance of its development are given. Past problems are reviewed in the context of present restraint system developments. In section 3.0 new air belt design criteria are developed and a specification for a contemporary air belt is listed. Using the design criteria of Section 3.0, a prototype system was built. In section 4.0 slow shop air inflation of the system is discussed. Then deployments using a gas generator were conducted. Two air belt construction techniques were tested. The first used conventional air bag fabric. The second used Simula' patented braid-bladder ITS technology. ITS technology is described in reference 3.

Drop tower crash simulation tests are described in Section 5.0 and discussion of the test results are presented in Section 6.0. Cost and production issues regarding the developed prototype are given in Section 7.0. Recommend actions for further work are then presented in Section 8.0.

2.0 Review of Previous Work

2.1 Air Belt History

In the 1970's the air belt was studied in depth by two independent teams. In both of these studies the air belt was developed to act passively since in both cases it was proposed as an alternative to the air bag. One of these teams, led by Allied, strongly pursued the air belt commercially calling it by their trade name, "Inflataband". Through Klippan, their seat belt company in Europe, they developed the Inflataband with Citroen being the principally interested automotive customer. Secondly, Calspan seriously pursued use of the air belt as the passive restraint system for the Calspan-Chrysler RSV.

The history of both these studies was fully available to this program because the present Director of Research for Autoliv Klippan France (AKF), Michel Kozyreff, is a close associate of this author and was the Allied (Klippan) project engineer for the Citroen inflatable belt program. (Approximately in 1984 Autoliv acquired Klippan from Allied Bendix.) Furthermore, this author was, at the time, the program manager for restraints for the Calspan-Chrysler RSV, and the developer of the air belt for that program.

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Over the past two years this author had numerous discussions with Mr. Kozyreff regarding the Inflataband. In addition, Mr. Kozyreff has retained his Inflataband files all these years. On a visit to AKF in Gournay-en-Bray, France, this author spent some time reviewing these files and discussing the project with Mr. Kozyreff. This was of great benefit since he has very strong opinions concerning the use of an air belt and the practical concerns which would need to be overcome if it were to be used commercially.

At Calspan the air belt was replaced by an air bag on the driver side, but at the end of the RSV program, the air belt was still retained as the passive restraint system. Excellent dummy and cadaver injury mitigation results were obtained with this system, see references 1 and 2. Nevertheless, the life of the air belt more or less ended after these programs. Historically, rescission of automatic restraint system requirements by the DOT in the early 1980's ended any further study of this concept. Allied at that time sold its restraint system companies. No further work was funded in this area by the NHTSA. Hence, the air belt "died" along with the near death of the air bag.

Now, as stated in the proposal for this project, it is time to re-think the air belt.

In summary, the air belt as proposed in the 1970's was an air bag alternative, and thus needed to be an automatic or passive system. The present situation is completely different for the following reasons:

1. Automatic seat belts have been abandoned in favor of air bags.

2. Air bags are or will be at 100% usage for front seat driver and right front passenger, thus fulfilling passenger restraint requirements.

3. Sensors and gas generators small enough and inexpensive enough for use in belt pretensioners and side air bags exist and could be used for the air belt.

4. There is great interest in side impact protection systems.

Today the air belt would be an advanced seat belt concept to be used in conjunction with a front seat air bag. For rear seats, where air bags are not cost effective on a societal benefit basis, they would act alone.

2.2 Past Problems

The following is a list of problems associated with previous development of the air belt:

1. Gas generator was too big and heavy

2. Sensor was too big and timing was too critical

3. System had to be passive

4. System had to be wearable

5. System had to be stowable

6. System had to be safe when deployed

Gas Generator

Because the gas generator was so big and heavy it could not be carried or worn along with the air belt. Therefore, in both the Klippan and Calspan designs the gas generator was fixed as part of the inboard buckle assembly. When the belt tongue was inserted into the buckle the inflatable part of the belt became attached to the gas generator. Some type of snap together, male-female hose connection was envisioned.

This could have never withstood the tens of thousands of cycles of snapping and unsnapping of the coupling which would have been required for normal use. The concern would have been leakage of hot gas when gas generator ignition occurred.

Sensor

To be effective, the air belt may need to deploy very early in the crash sequence in order to not overload an occupant who has started forward. Most probably the sensor closure times would have needed to be much shorter than those used for an air bag deployment. This would have led to a very large number of low speed deployments, an occurrence which is already a big problem for the air bag.

Passive System

The requirement that the system be passive meant a motor driven upper anchor point was necessary. This more or less necessitated the need to inflate the air belt from the lower inboard end. Thus, the passive requirement, notwithstanding all the problems practically incurred with non-air belt passive belts, created a nearly unsolvable gas generator location problem.

Wearability

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If the inflatable section of the air belt is too heavy, bulky, or thick it will never be accepted by the user. This concern was never really addressed because the early air belt systems never progressed to the stage of evaluating user comfort and acceptance.

Stowage

In the Klippan and Calspan designs the gas generator attachment was inboard at the belt tongue. Hence, as long as the length of the inflatable section was less than the distance between the tongue and the D-ring of the passive system, there was no problem with stowage. However, if it had been conceded that inboard location of the gas generator was impractical, there would be no solution for stowage of the air belt.

Safety

In the designs studied the gas generator is joined to the inflatable section of the belt through attachment of a specially designed tongue. This is, however, believed to be unacceptable with regard to leakage.

3.0 Present Design Considerations

3.1 Present Problems

Today an air belt would have different design goals than when first proposed. The main differences are:

1. The system would not be passive, i.e., require a motor driven, movable upper anchor point.

2. For front seat use, driver and passenger air bags would also be used. Hence, the system would need to work together with the air bag.

3. Considerable interest exists in using the system for side impact head protection.

4. Gas generators, crash sensors, height adjusters, and web clamps are all available as production equipment. This hardware would not need to be designed, only modified in some cases.

These are the reasons the air belt should be reconsidered. The main problems or concerns are practical ones:

1. Can the air belt be made comfortable enough to wear that the user will accept it?

2. Can the air belt be practically retracted and stowed when not in use?

These are the problems or concerns to be resolved. The restraint effectiveness of the air belt is not in question.

The proposal for this project was first submitted in August 1992. From then until the present, thought has often been given to the air belt. Its possible use has been debated with many of the author's colleagues in the restraint field. This includes people from both restraint manufacturers and automobile manufacturers. Therefore, the requirements for the design have in fact been considered at length. Aside from restraint effectiveness, the two most important and necessary design characteristics are wearabiltity and stowability. These will be discussed next.

In the proposal submitted for this project, it was thought that the gas generator could be located at the outboard lap belt anchor point. The inflatable section of the belt, therefore, would extend from this position as a lap belt, and pass through a sliding belt tongue to then become the lower part of the torso belt. Based upon our discussions with experts in the field these past two years, however, we have rejected this concept in favor of locating the gas generator at the top of the torso belt.

The following three reasons have led to this change:

1. The development of an inflatable section which could pass through a sliding tongue tens of thousands of times over the life cycle of the normal belt wear was considered unrealistic.

2. It was believed that the inflatable section would most likely be collapsed or pinched off at the tongue during the inflation process.

3. A shift in program emphasis toward providing side impact head protection required more specific placement of the upper torso section of the inflatable belt than would be possible if lap belt length variation was required.

In view of the many considerations which have come forth during study of this project, the following design requirements or preliminary specifications have been assembled:

1. The inflatable section will be the torso belt of the three point belt assembly.

2. The inboard end of the inflatable section of the belt must be fixed with regard to the tongue to buckle attachment point. It must in all cases begin nearly at this juncture, i.e., at the inboard H-point of the occupant.

3. The inflatable section will not be able to move through a sliding tongue. Therefore, the tongue must be fixed with respect to the air belt section.

4. Consequently, two retractors will be required; one for the lap belt and one for the torso belt.

5. The inflatable section will not be able to be taken up on a retractor.

6. The inflatable end connection to the gas generator must be at the outboard or upper end of the torso belt.

7. The inflatable length should extend from the tongue to beyond the head of a large male. A 95^{th} percentile dummy is used to size this length.

8. The torso belt must be accurately placed with regard to the occupant head if side impact head protection is to be sought as part of the design.

9. The best chance to arrive at a practical system will be with an integrated or belt-in-seat design. This will best control the belt position and minimize the required variation in placement of the inflatable section with respect to the occupant head.

10. For a belt-in-seat design, it should be possible to allow the inflatable section of the torso belt to pass over a rather large roller located at the normal D-ring position in the seat back.

11. When stored, the inflatable section can roll over a special D-ring roller and be contained within the height of the seat back. The torso belt retractor can be located at the base of the seat back.

12. The lap belt retractor spring may need to be greater than the torso belt retractor spring such that the fixed tongue will, when stored, be located just above the lap belt retractor. This will minimize the length of inflatable section which must roll over the D-ring.

BMW has been kind enough to supply us with an integrated seat from their model 850 i series vehicle. This seat was used to fabricate a mock-up of the system design using the above listed specifications.

3.2 Lap Belt Considerations

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After review of the preliminary specifications of Section 3.1, the Contract Monitor suggested that the inflatable section be able to preload the lap belt as well as the torso belt. This would require that upon inflation, the lap belt be able to slide up through the buckle tongue. In other words it would be necessary to provide at least a one-way sliding tongue rather than a fixed tongue.

A fixed tongue was proposed in order to assure that the inboard end of the inflatable section would always be properly positioned close to the H-point or just above the buckle. Since the length of lap belt can vary by more than 24 inches to accommodate small to large waisted occupants, it was further determined that a lap belt retractor as well as a torso or shoulder belt retractor would be required.

In answer to the Contract Monitor's suggestion it was concluded that a one-way sliding tongue could be used but only if it could still be certain that the inflatable section was properly located. This would be certain if:

1. The lap belt retractor spring was much stronger than the torso belt retractor spring such that the inboard end of the inflatable section was always pulled down to a stop against the sliding tongue, or

2. The tongue was fixed in normal use but the fixation could break away, or pull out or through the buckle tongue upon inflation when a significant force occurred.

The second method is preferred because it is easy to imagine that the inflatable section would likely be mislocated, i.e., not always be pulled down to its stop by the lap belt retractor spring. The spring would need to be so strong as to always overcome all belt friction across the occupant and through the sliding tongue. In such a case the spring would probably cause occupant discomfort.

Regardless, this point can be left open for future study since the inclusion of a strong lap belt retractor spring or a breakaway snap or button at the tongue will not affect the rest of the design.

One final note on the need for a lap belt retractor. We made length requirement measurements in a Chevrolet truck. The belt in this truck uses two retractors and a fixed tongue. The lap belt total length in this vehicle with the seat in mid-position can be varied form 27 inches to a maximum of 54 inches. The shortest length, 27 inches, occurs with no one in the seat and the belt buckled. For a person with a 34 in waist, the lap belt extended length is 36 inches. A small person with, for example, a 24 inch waist would require little more than the 27 inch belt length while a large person could use the entire belt available. Thus, there could be over 2 feet of variability in lap belt length. If the inflatable section of the torso belt were to be correctly located for the largest person, its inboard (lower) end location would then be nearly at the shoulder of a small person if a lap belt retractor were not used.

3.3 Torso Belt Considerations

As initially designed, the inflatable section inflates to a diameter of approximately 5 inches from a flat folded width of approximately 2 inches.

The length of the inflatable section is based upon the following reasoning. The length (uninflated) required for a 50th percentile male person was measured to be approximately 32 inches. If as a starting point we assume the length variation with torso size is equal to one half the height variation from 5th percentile female to 95th percentile male, we get a length requirement variation of approximately plus or minus 4 inches. Thus, the inflatable section length requirement is roughly 28 to 36 inches. The inflatable section length used in the prototype is approximately one meter or 39 inches. This should cover the range of interest. For the shortest person approximately one foot of inflatable section would extend over the shoulder point roller and into the seat back. This length is accommodated by locating the torso belt retractor at the at the base of the seat back.

4.0 Static Deployment Tests

4.1 Slow Inflation Tests

A prototype air belt system installed in the BMW integrated seat was fabricated at REI in Alpine, Wyoming and then taken to Simula in Phoenix, Arizona. This prototype used unconventional air belt construction technology, namely Simula ITS braid and bladder design, see reference 3. A demonstration of its use (slowly inflating the air belt section with shop air) was evaluated by a dozen or so volunteers. Included in this group were a number of visiting engineers from BMW. The initial impressions were very favorable. Relatively high air belt pressures, typically 6 to 12 psig were accepted by the volunteers. The feeling was one of very significant restraint, being pushed deeply into the seat and held very rigidly while experiencing no sharp or localized pain or discomfort. This is due to the large loading surface of the inflated section. At the same time the neck was rigidly supported from moving outboard, hence the head was also held in place. In a side or oblique impact the subjective feeling was that the upper torso, neck, and head would be significantly restrained from moving outboard of their initial positions.

Shop-air slow inflation tests were then conducted with an air belt fabricated using conventional air bag material. Subjective evaluations of restraint capability were made using some of the same people.

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For myself, (approximately the size of a 50th percentile male dummy) the inflatable section of the air belt extended through and aft of the D-ring. Since the inflated section clamps itself at the D-ring the shortening capability of the air belt was lost at this end. (Note: the shortening capability of an inflatable air belt, fabricated from conventional airbag material occurs from the ends of the section trying to become hemispherical.) At 10 PSIG, lateral control of my head was good, but there was little sensation of chest loading. Further, the inflated section tried to straighten out and since the upper end was more or less oriented horizontally by the D-ring, the bottom of the air belt actually moved away from my lower torso. In summary, the overall feeling of being pulled into the seat was lost compared to results using the Simula ITS braid bladder design.

For a test subject that has a much larger chest than I, perhaps that of a 98th percentile male, the upper end of the air belt did not extend aft through the D-ring. His chest pulls 6 inches more belt through the D-ring than mine. The air belt did not try as much to move away from the lower torso as in my case because the D-ring was not trying to force the air belt into a horizontal orientation. However, his head lateral restraint was greatly reduced compared to mine since only seat belt webbing was located at the at the D-ring as compared to the air belt in my case. Other volunteers had results that fell between myself and this test subject.

An overall conclusion is that the air belt made from conventional material will provide considerably less restraint or ride down, i.e., fixation of occupant to the seat, compared to the air belt made using ITS braid bladder design.

4.2 Deployment Tests

Air belt deployments were conducted using a 50th percentile test dummy without vehicle motion. Crash simulations called Dynamic Drop Tower Tests are discussed in Section 5.0. All tests were conducted at Simula. A design using conventional air bag material was selected which utilized 210 denier nylon 6-6 with a urethane coating on one side. The air belt was cylindrical in shape having a 5 in. diameter and a length of 38 in. The air belt had one seam along its length and two end seams which were sewn and seam taped. A fill hose and pressure tube was bonded to the ends of the air belt.

A bag burst test was conducted on the air belt to determine bag strength. This unit was tested with Simula's cold gas equipment. The unit was constrained at the fill hose end. A pressure transducer was attached to the pressure tube at the free end of the belt. A plenum was filled with nitrogen gas which was dumped into the bag through a solenoid valve. Inflation and belt failure occurred in less than 0.2 seconds. The peak pressure was 90 psig when the belt failed at the opening where the fill hose was attached.

Three static deployment tests were performed. A 50th percentile dummy was used for the tests. An 8g euroflator gas generator was used to inflate the air belt. Both inertia reels were in the unlocked position prior to testing.

The first static deployment resulted in a belt failure. The hot gases and particles impinged on the bag material causing the belt to fail.

A heat shield was added to the air belt for the second test. The test conditions were the same as above. The heat shield provided the added protection required to inflate the air belt.

After reviewing video coverage of the deployment and the slow inflation tests, Section 4.1, it was decided to increase the length of the air belt. The air belt design was changed to assure the inflatable section would pass through and aft of the D-ring. This was achieved by adding 3.78 inches to its length (38in to 41.7 in.). The heat shield was lengthened by 2 inches so that it would extend into the D-ring. The lengthened heat shield added thermal protection to the belt in the confined region of the D-ring.

The third test was performed with the longer air belt. An 8g gas generator was used. No attempt was made to increase the gas generator output to compensate for the increase in air belt volume. The test conditions were the same as the other two deployments. The air belt deployed as desired. This design is referred to as air belt 1 in Section 5.0.

5.0 Dynamic Drop Tower Tests

The purpose of the tests was to determine the effectiveness of the air belt (as specified in Sections 3 & 4) in limiting occupant movement and reducing the potential for injury when compared to a standard 3-point seat belt system. The effectiveness was determined through analysis of occupant motion, HIC, thorax acceleration, and belt loads.

A BMW seat with the seat back angle and seat pan angle in the mid-point adjustment, and with the seat pan at its lowest position was used for the tests. The baseline tests utilized an integrated seat belt system which has the inertia reel located in the seat back. The seat was slightly modified to accommodate the air belt. These modifications included: the addition of a larger D- ring above the existing D-ring to provide room for the restraint's inflation and a second inertia reel at the outer lap belt anchor location. The two inertia reels were necessary in order to properly position the inflatable restraint at the buckle end and to allow for adjustment of the belt webbing across the lap and the shoulder areas.

The seat was mounted to a framework which interfaced with the drop cage. Since multiple tests were conducted with the same seat, straps were used to support the back of the seat. A grid for motion analysis was fabricated and mounted to the drop cage. The grid was positioned as close to the seat as possible to reduce parallax error when analyzing occupant motion. No automotive structures such as knee-bolsters, dashboards, steering wheels, columns, or doors were used.

The air belt using either conventional material or Simula ITS braid bladder design consists of a tubular air bag approximately 5 inches in diameter and 41 inches long. A fill hose was attached to the upper end of the air belt. A tube was attached to the lower end of the air belt for pressure measurements. The air belt was attached to the webbing of the inertia reel at the seat back, then fed through the larger D- ring. The lap belt webbing was threaded through the tongue and then was attached to the air belt making one continuous restraint system from the inertia reel in the seat back to the lap belt inertia reel. The air belt was folded so its width was the same as the webbing.

The gas generators used for these test were Livbag euroflator combustion chambers loaded with 8g's of double-base propellant. The generator was placed in a housing which consisted of a back shell, a gasket, a perforated disk, a knitted wire filter, and a nozzle. The housing was attached to the webbing between the inertia reel in the seat back and the inflatable restraint. The fill hose was attached to the nozzle with hose clamps.

A total of eight dynamic drop conditions were tested at Simula, Inc. in Phoenix, Arizona.

The nominal crash pulse used for all tests is a 100 msec trapezoidal wave form with an 18 g, 33 msec plateau. This yields a nominal velocity change of 25 mph.

A 50^{th} percentile male dummy was used for all tests. The right arm of the dummy was removed for photographic purposes.

The simulated forward and lateral crash tests were performed using a vertical drop tower and drop cage making initial positioning of the test dummy more difficult and less accurate than would occur with a conventional test sled. This, in addition to the fact that each test condition is represented by only a single test point, requires that the test program and data to be considered exploratory. This, of course, is in line with the intent of the project which was to obtain preliminary evaluation of the relative effectiveness of the systems.

The occupants in the tests were held in place with masking tape prior to testing. The tape was slit so that it would tear under low loads. Past experience showed that this method is successful in holding the occupant in position with little effect on occupant motion during the crash. The restraints were positioned in intimate contact with the occupant but without any appreciable initial load on the restraint.

The inertia reels were locked for all tests. Drop cage accelerations ranged form 19.3 to 23.1 g's and velocity changes from 24.3 to 25.5 mph which could adds some uncertainty to the results.

A second air belt design using conventional material was included in these tests. The air belt for these tests (air belt-2) consists of a tubular air bag approximately 4.25 inches in diameter and 41 inches long. This can be compared to air belt - 1 which is 5 inches in diameter, and 41 inches long.

6.0 Results and Discussion

The air belt test data obtained in the program are presented in Table 1 and consist of eight crash simulations, four in the forward or frontal direction and four in the lateral or side direction. In each case, the data are from tests using a baseline 3 pt belt., two tests using a torso air belt constructed of conventional airbag material and one test using Simula's patented ITS technology. The air belt application of the Simula ITS technology is hereafter called ITTR (inflatable tubular torso restraint).

The primary test dummy measurement of interest is excursion or displacement of the dummy's head. Plots of these excursions are presented in Figures 1-2, other dummy results are presented in Table 1. Regarding the test data presented in Table 1 and Figures 1-2, the preliminary conclusions which have been made are listed below. However, all conclusions must first be prefaced with the understanding that a rather unsophisticated method of test was employed, (a drop tower in which the occupants had to be initially positioned using masking tape) and the fact that only one test exists for each of the test conditions. Hence, the study must be considered to be of an exploratory nature, and the conclusions are subject to verification.

1. Air belt - 1 which had a peak inflated pressure of approximately 1 bar showed little or no demonstrated benefit over the conventional 3 pt. belt.

2. Air belt - 2 which had a peak inflated pressure of approximately 3 bars demonstrated a significant improvement over the 3 pt. Belt. Head displacement was reduced by 6 inches in the forward crash test simulation and by 2.5 inches in the lateral test. Head rotation, a possible indicator of neck injury, was also significantly reduced.

3. The ITTR, with a peak pressure of approximately 2 bars produced the greatest improvement in occupant kinematics. Head displacement was reduced from 20.5 inches to 5.0 inches in the forward direction and from 23 inches to 15 inches in the lateral direction.

4. The significant improvement seen by the ITTR as compared to a conventional air belt is attributable to the vastly superior shortening capability of the patented ITS design.

5. Since there are no known disadvantages to the ITTR technology, any further effort regarding research and development of an air belt system should be directed toward ITTR.

6. These conclusions are based upon results of the dynamic tests. Practical concerns regarding production costs and manufacturability are covered in Section 7.0.

Table 1 - Summary of Test Results

Forward - Occupant Restraint Results

	3 pt	Air belt 1	Air belt 2	ITS
Displacement, in	20.5	18.0	14.5	5.0
Rotation, degree	110	61	42	28
HIC	129	406	194	99
C_R, g's	32	51	27	26
Torso belt, lbs	1,466	790	618	500
Lap belt, lbs	1,534	1,294	1,193	554
Pressure, PSI	NA	16.0	45.4	33.4

Lateral - Occupant Restraint Results

	3 pt	Air belt 1	Air belt 2	ITS
Displacement, in	23.0	24.0	20.5	15.3
Rotation, degree	86	74	15	50
HIC	121	126	73	ND
C_R, g's	53	20	ND	35
Torso belt, lbs	709	421	410	417
Lap belt, lbs	595	693	700	383
Pressure, PSI	NA	17.3	40.6	31.3

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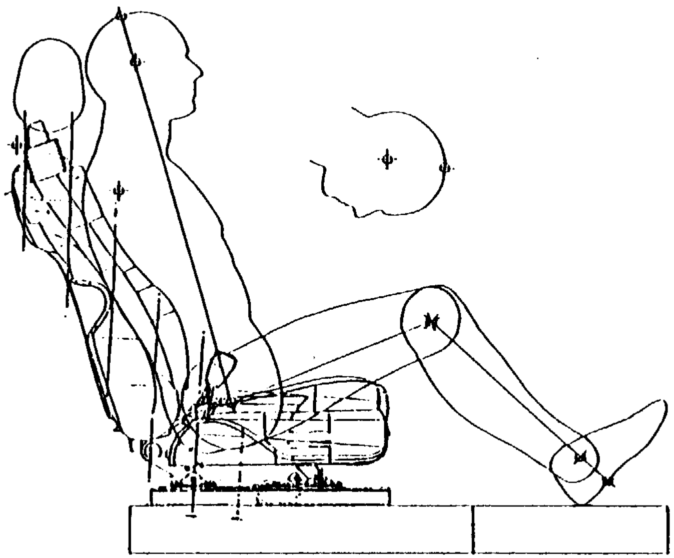
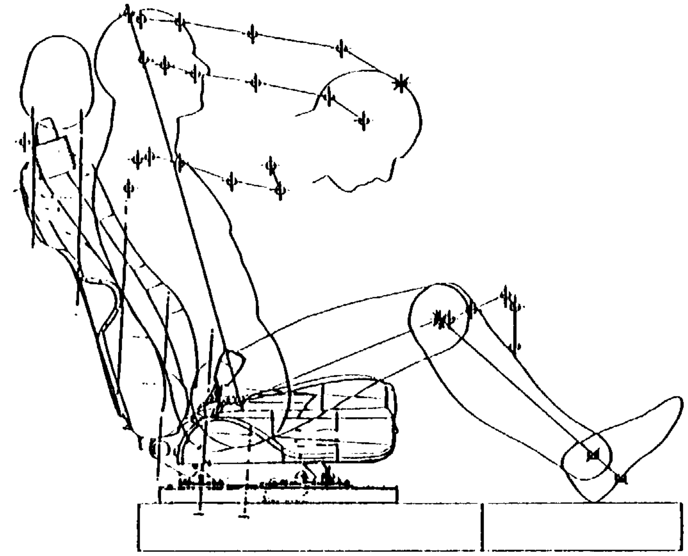
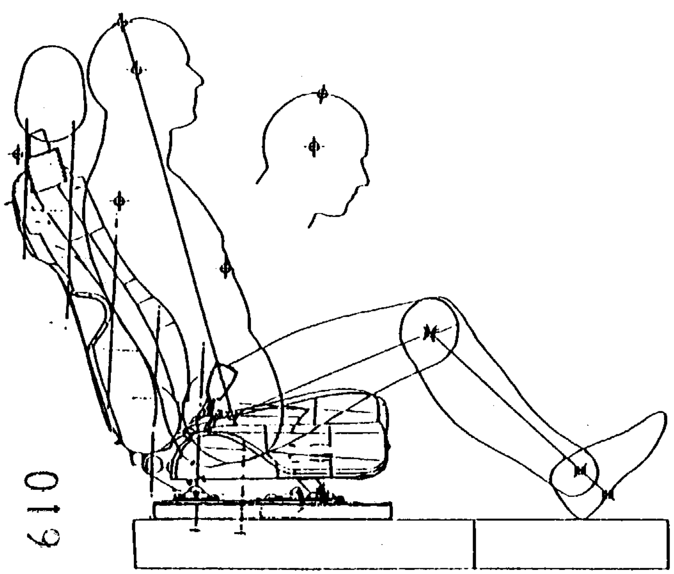


BASELINE FORWARD IMPACT

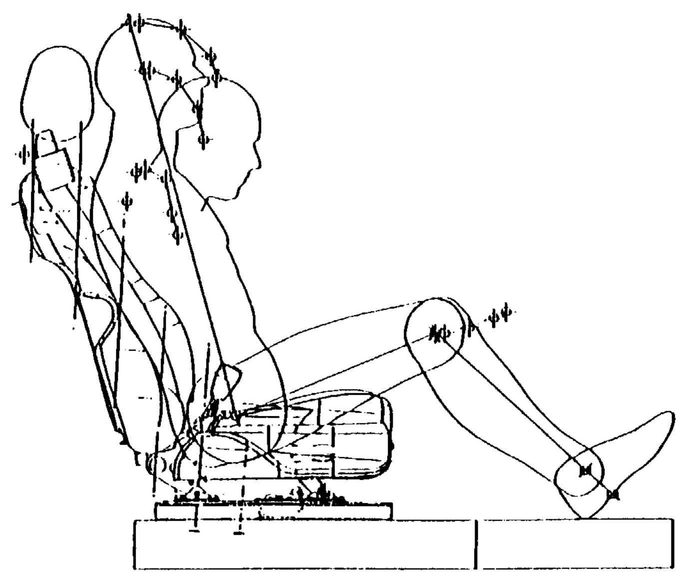


NHTSA AIRBELT-1 FORWARD IMPACT

FIGURE 1 FRONTAL CRASH TEST RESULTS

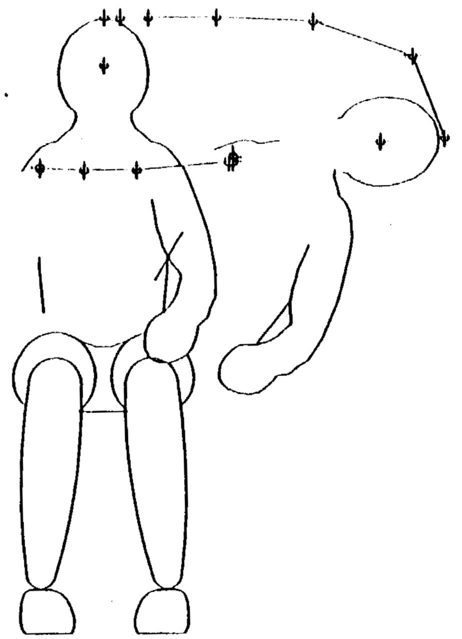


NHTSA AIRBELT-2 FORWARD IMPACT

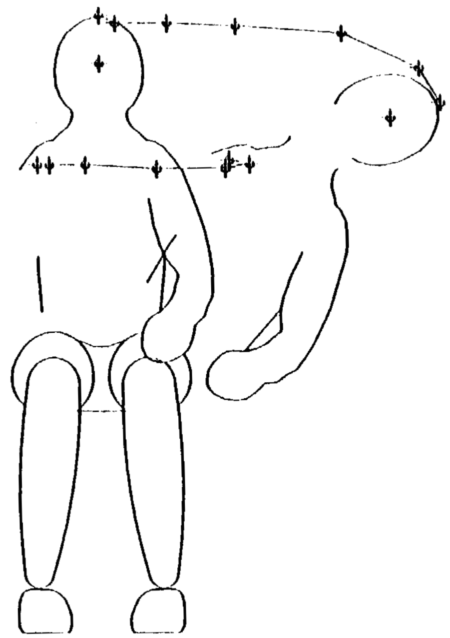


ITTR FORWARD IMPACT

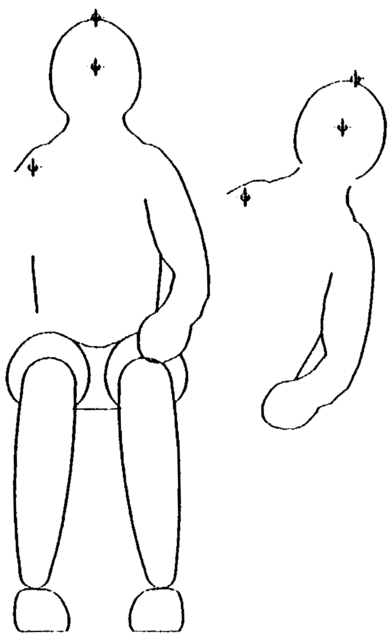
FIGURE 2 SIDE IMPACT CRASH TEST RESULTS



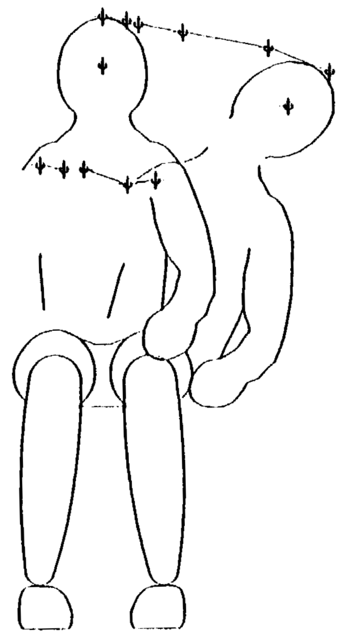
BASELINE LATERAL IMPACT



NHTSA AIRBELT-1 LATERAL IMPACT



NHTSA AIRBELT-2 LATERAL IMPACT



ITTR LATERAL IMPACT

7.0 Cost and Production Analysis

7.1 Cost Analysis

The earliest an air belt can be introduced in a production vehicle at this time would be model year 1999 or 2000. At that time all vehicles of interest will already have at least frontal airbag systems and many will have pyrotechnic belt pretensioners. Hence, one of the elements of the air belt system, the sensor-diagnostic, will already be part of the vehicle restraint system and therefore not an incremental air belt system cost. If the vehicle has belt pretensioners which the air belt would replace, the incremental cost will be even less. Therefore, if it can be assumed that every vehicle which would use an inflatable belt system will already have a crash sensing and diagnostic system on the vehicle and furthermore a seat belt pretensioner, we can look at incremental costs. The actual cost increments are listed below.

Plus	US$	Minus	US$
Air belt Segment	12	One meter of belt	
Lap belt retractor	8	Belt pretensioner	8
Gas Generator	12		
Cover	2		
D-ring, misc.	2		
	36		8

The cost listed for the cover and special D-ring of $2.00 each are pure estimates based upon REI's engineering and manufacturing experience and surely are on the high side. The cost of the lap belt retractor, the belt pretensioner and the gas generator are provided from industry sources known to REI and are believed to be quite realistic. Simula was not able at this time to provide a cost estimate for the airbag segment using the patented ITS technology. Hence, this estimate is based upon use of conventional airbag fabric and manufacturing methods, (approximately .6 square yards of material).

If the air belt replaces a pyrotechnic pretensioner, the incremental or additional cost for the air belt would be approximately $28.00 per seat position. If the vehicle does not have belt pretensioners, the incremental cost would be approximately $36.00. If because of changes in restraint systems philosophy, the air belt replaces a frontal airbag system and/or side airbag systems, a substantial net cost saving will be realized.

It should be noted that if the air belt is intended to provide side impact head protection, the vehicle would need to have side impact sensors or be connected to a side airbag systems. No attempt was made to estimate these additional possible costs.

Further as noted in section 7.2, it most probably would be necessary to add sensing systems and logic algorithms so that the system would not deploy if the belt was unbuckled, used to secure a child restraint, or secure a small child. Again, no attempt was made to establish cost.

7.2 Production Analysis

This task dealt with the reality of the air belt concept. That is to say, can it actually be produced. This question is answered by first listing all components of the system and stating if these components or their equivalents are already in production. Once this has been done, we will look at real world practical concerns which must be resolved before a producable system could be introduced into production automobiles. (Failure to realistically address all practical problems has led to our present critically serious problems concerning frontal air bag systems).

All components of an airbag system are listed below along with a conclusion regarding their production state.

Component	Equivalent Part Already in Production
Sensor	Yes
Diagnostic	Yes
Belt-Webbing	Yes
• buckles and hardware	Yes
• retractors	Yes
Special D-ring	No
Air Belt Segment (ITS	No
Segment Cover	No
Gas Generator	Yes

From this list we can see that only three components are in question regarding producability the D-ring, the air belt segment, and the cover. All three are easily made in prototype quantities sufficient for occupant restraint performance evaluation. The critical question is whether or not they can be produced in a manner which is consumer acceptable. This acceptability can be divided into two main categories; wearability and due to the cyclic nature of its' use, durability.

Wearability includes normal use, comfort and convenience and potential deployment hazard. Durability means can these components withstand normal seat belt cycle life requirements.

Factors which determine comfort are: size, weight, stiffness, tension.

Size will not be a problem, the air belt segment will be thicker but the same width as present belts. The greater thickness in fact will probably improve comfort. Weight will also not be a direct concern. This is believed to be the case because we know from experience that retractor tension will apply far greater forces on an occupant than the belt weight possible can. In fact, regarding size and weight, aftermarket covers are sold which people slide over their torso belts to increase comfort and these covers, of course add size and weight to the belt. Our real concern is the increased stiffness which will be added to the torso belt. This is why we believe a large radius D-ring will be necessary to accept movement of the air belt segment around or through the D-ring without causing too great a requirement in retractor positioning tension. Most probably belt stiffness which must be overcome through use of higher retractor spring tension will ultimately be the largest comfort problem to overcome. Second in wearability is convenience of use. Since the air belt will be put on and taken off in the same manner as a conventional dual retractor 3 pt belt, no convenience problems are anticipated.

Third and perhaps most critical to practical application of the air belt is evaluation of potential deployment hazard. Some of the first considerations to be studied are as follows.

1. System should not deploy unless belt is buckled.

2. System should not deploy if belt is used to secure a child restraint.

3. System should not injure properly belted adults in normal or abnormal seating positions.

4. Some child size threshold may be required below which the system would not deploy.

On the positive side, longer inflation times, i.e. slower deployment than belt pretensioners or airbags, especially side impact airbags may be possible.

Belt pretensioners have insufficient tensile forces to pull or shorten once loaded by a deceleration occupant. Hence, sensor closure or threshold must be very low and actuation time very short. Frontal airbag deployment (inflation) times can be as little as 30 msec and side impact airbags, 15 msec. Our thought is that air belt inflation times might be able to be as long as 50 msec or more if we are able to accept the early sensor closure time of the belt pretensioner and the fact that the air belt can shorten in the presence of relatively large belt loads.

Of the three components not already produced: air belt segment, cover, special D-ring, there appears to be no serious concern regarding the special D-ring as this will be simply a mechanical part. It may or not have a roller element but even if this is necessary its' design will be straight forward.

The cover will require development. It must:

- Withstand wear for 15 years
- Not add stiffness to the air belt segment
- Tear open to allow air belt segment deployment

We have made plain weave nylon cloth cover samples, essentially sewing the sample along a longitudinal seam to form an envelope. This may be acceptable but since the material must curve over the person and over the D-ring it tends to crinkle or develop creases rather than bend in a nice uniform fashion. Probably what we need is a fabric with some elasticity, something like a spandex or knitted fabric. The cover will need some work regarding development but we are sure a workable solution can be found.

The air belt segment will be the most difficult part of the system to develop, particularly as based upon ITS design. The ITS is an inflatable assembly consisting of a urethane bladder bonded to an outer braided polyester material. The stiffest part of this assembly is the urethane bladder. Folded, it forms a "C" shape such that the total segment thickness is on the order of 3/32 to 1/8 inches thick. Regarding manufacture of the ITS segment we can say that this part as an ITS unit will be in serial production By March 1997.

Hence, in summary our real concerns regarding practicability on the system will be user comfort, a stiffness concern and any possible deployment hazard effects. Both these concerns are beyond the scope of this cooperative agreement.

8.0 Recommendations

Following are tasks recommended for further study.

1. *Candidate Vehicle* - Select a candidate vehicle in which to evaluate the air belt system. Use of a real world vehicle will force the consideration of real word issues such as those outlined in Section 7.0.

2. *Component Design* - Design of the special D-ring, air belt segment and cover should be undertaken. These designs need to be taken to the point of actual production prototypes, again using the criteria of Section 7.0

3. *Evaluate Potential Deployment Hazard* - In view of today's political climate regarding frontal air bags, we can not emphasize enough the need to deal with this aspect from the onset of the project. Some aspects we must deal with are as follows:

- Infant seat use with the ITTR - the ITTR should be disabled
- Seat belt not buckled - the ITTR should be disabled
- Occupant below some specified size - the ITTR may want to be disabled
- Normal belt use - the ITTR may not cause injury
- Abnormal belt wear - the ITTR may need to be disabled or if not, not cause injury.

4. *Sled Tests Frontal, Frontal Offset and Side* - This is a major development task and should use the vehicle selected in the first task for the test buck.
The purpose of these tests is to evaluate improved performance capability of the ITTR over a conventional 3 pt belt with and without belt pretensioning in frontal and frontal offset simulations. In side impact, evaluate side impact head protection capability. In these tests comparisons will be made to side impact ITS and head-torso air bags. Without generating a test matrix, we can at this time list the most probable test variables.

- Sled buck - to be selected
- Crash condition - velocity, orientation i.e. NCAP, FMVSS 214, AMS, EEC, etc.
- Occupant size - 5^{th}, 50^{th}, 95^{th}
- ITTR - pressure, tension, closure time, deployment time, fixed vs. sliding tongue, etc.

5. *Crash Tests* - We do not anticipate dedicated crash tests of the ITTR for quite some time. However, we should be prepared to provide ITTR productions prototypes systems which can be used in piggy-back frontal, side and rollover crash tests schedule to be conducted by NHTSA. If a rear seat application of the ITTR is selected, there is a good chance that piggy-back opportunities will occur.

6. *Optimize ITTR Design* - Based upon results of testing, tasks 4 and 5, component design, task 2, and Deployment Hazard, task 3, optimize the design with regard to :

- Bladder thickness
- Segment length
- Braid thickness

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- Braid strength
- Cover performance

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2. "Sled Tests of Three-Point Systems Including Air Belt Restraints" - Calspan Report No. ZP-5852-V1. Michael J. Walsh. January 1997

3. "ITS, A New Restraint System for Side Impact Protection" - SAE Report 961018, Gershon Yaniv, David Romeo, Klaus Kompas, Josef Mayer, February 27, 1996.

FIGURE 1 FRONTAL CRASH TEST RESULTS

FIGURE 2 SIDE IMPACT CRASH TEST RESULTS

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