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AUTOMOTIVE MANUFACTURING PROCESSES
VOLUME II - MANUFACTURING PROCESSES FOR PASSIVE RESTRAINT SYSTEMS

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4330 East-West Highway
Bethesda MD 20014

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FINAL REPORT

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16. Abstract

Extensive material substitution and resizing of the domestic automotive fleet, as well as the introduction of new technologies, will require major changes in the techniques and equipment used in the various manufacturing processes employed in the production of automobiles. The purpose of this report is to document (and analyze) the publically available data on current and projected motor vehicle production processes and equipment and to report on impending changes.

This report presents a detailed description of various passive restraints and the manufacturing processes and facilities required to produce them in volume. Other key issues, dealing with cost and product liability, and the uncertainties of passive restraint implementation are discussed. Quality control and testing methodology are also discussed.

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PREFACE

This report is Volume II of a series of five reports which address changes occurring in motor vehicle manufacturing processes, materials, and equipment during the period 1978 to 1980. The reports present an overview of the major manufacturing processes and materials, and a summary of historical improvements in motor vehicle fuel economy, emissions reduction, and safety. Also included are detailed discussions of vehicle components designed to improve motor vehicle fuel economy, emissions, and safety. The reports also present detailed examination of motor vehicle manufacturing process industries, trends, and issues.

The five volumes in this "Automotive Manufacturing Process" series are listed below:

Volume I - "Overview"

Volume II - "Manufacturing Processes for Passive Restraint Systems"

Volume III - "Casting and Forging Processes"

Volume IV - "Metal Stamping and Plastic Forming Processes"

Volume V - "Manufacturing Processes and Equipment for the Mass Production and Assembly of Motor Vehicles."

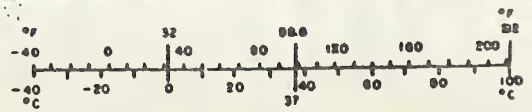
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

The National Traffic and Motor Vehicle Safety Act of 1966 directed the Secretary of Transportation to issue Federal motor vehicle safety standards to which motor vehicle manufacturers must conform. The first such standards became effective on all vehicles manufactured after January 1, 1968, and additional standards have been added each year. Standard Number 208, Occupant Crash Protection, announced in June 1977, requires the auto manufacturers to phase in passive restraints on passenger cars beginning in 1982, and to equip all cars with passive restraints beginning in 1984.

The occupant protection standard is part of a series of new occupant crash protection standards that will be issued over the next five years. The major, long-term objectives of the program* are to consolidate and upgrade all occupant protection rules to comprehensively cover frontal, side, rear, and rollover crash protection. The passive restraints mandated by Standard 208 will afford passenger car occupants increased protection in frontal crashes only.

Two types of technology are expected to be employed to satisfy the requirements of occupant protection in frontal crashes in 1982, 1983 and 1984 model year automobiles. These technologies are:

- Passive Belt Systems. Passive belts are designed to move into place as each front seat occupant enters the vehicle and closes the door. Most passive belt systems have a single diagonal belt which fits across the chest, plus a padded knee bolster below the dashboard which prevents the occupant from submarining or sliding out from under the belt in a crash (see Figure 1-1). Some systems also

* DOT, NHTSA, Five Year Plan for Motor Vehicle Safety and Fuel Economy Rulemaking, Calendar Years 1980-1984, April 20, 1979.

have an active lap belt (not shown in Figure 1-1) which the occupant can choose to buckle to increase the level of protection in other than frontal crashes, such as rollovers. There is also an emergency release for the diagonal belt, to facilitate post crash escape.

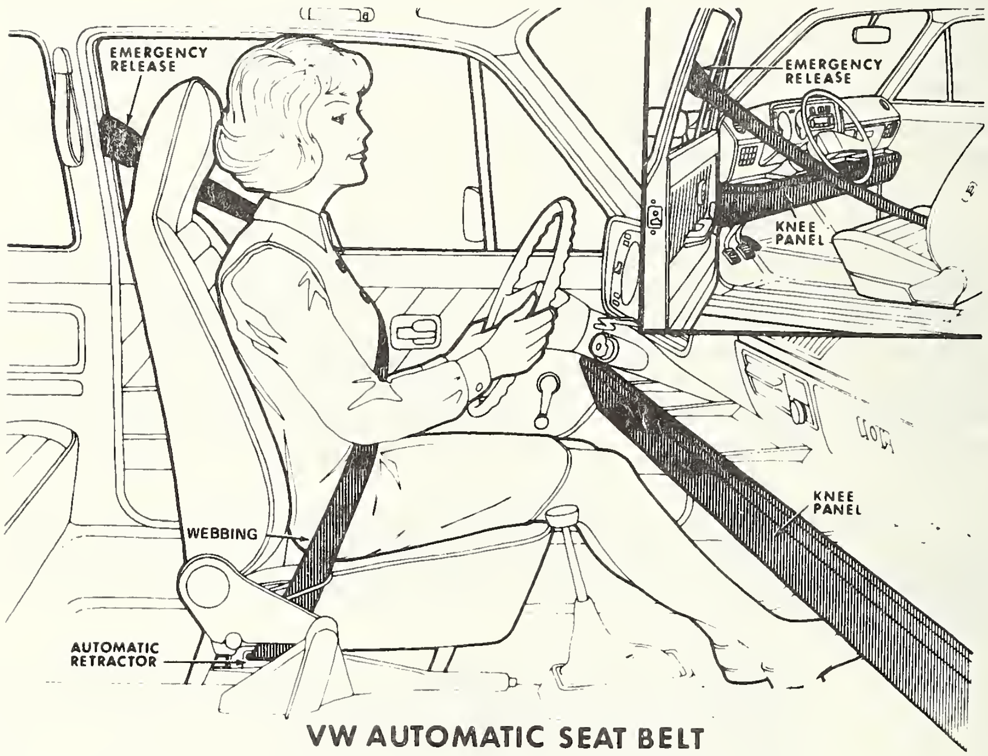
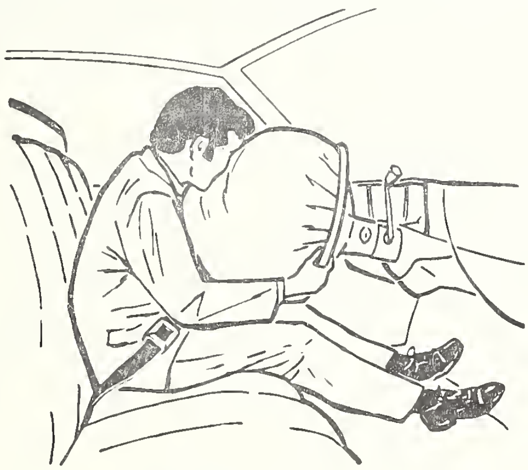
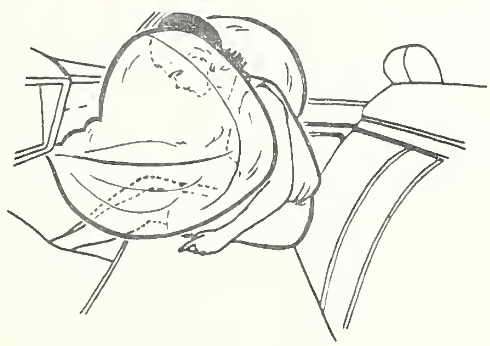


FIGURE 1-1. PASSIVE BELT SYSTEM EMPLOYED BY VOLKSWAGON

- <u>Air Bag Systems</u>. An air bag is a device which inflates automatically in head-on accidents to cushion the auto passengers from injury. The air bag system consists of a crash detector or sensor, an air bag and inflator package, and padded or inflatable knee restraints. When a car is involved in a frontal crash, the impact causes the sensor to activate the inflator. The vehicle occupant's torso and head move forward into the bag while the lower body is restrained by the combination of the air bag and knee restraints (see Figure 1-2).



DRIVER SIDE
(Air bag in Steering Wheel—
Steering Column Absorbs Energy)



PASSENGER SIDE
(Torso and Knee Air Bags
Absorb Energy)

FIGURE 1-2. AIR BAG PASSIVE
RESTRAINT SYSTEM

This report presents a detailed discussion of the processes and materials used in the manufacture of air bag and passive belt systems. Chapter 2 provides a description of the components and the manufacturing processes for the air bag system, as well as the characteristics of a typical air bag manufacturing plant. Chapter 3 describes the alternative designs, major components and manufacturing processes of passive belt systems. This chapter also provides the characteristics of a typical passive belt manufacturing plant.

Finally, Chapter 4 examines manufacturers' plans for the introduction of passive restraint systems and other factors which affect the outlook for these systems.

2. MANUFACTURING PROCESSES FOR AIR BAG SYSTEMS

2.1 GENERAL

Air bag technology is not new. It has been evolving since 1962. Original air bag system designs utilized argon gas to inflate the bags. The gas was stored in a pressurized vessel which was activated upon vehicle crash by igniting a small amount of propellant within the pressure vessel. While the system worked satisfactorily, the pressure vessel air bag system added 70 to 80 pounds to the weight of the vehicle.

In contrast to this system, virtually all of the air bag designs under development today employ pyrotechnic* materials which are ignited to generate the gas for inflation of the bags. In total, air bag systems based on the use of pyrotechnic materials weigh approximately 40 pounds, thus providing a weight savings of 30 to 40 pounds over the original pressure vessel-type system.

2.2 ALTERNATIVE AIR BAG DESIGNS

Although variations exist in propellant charge and air bag configurations among different manufacturers' designs, there are essentially only two types of air bags:

- Driver position air bag
- Passenger position air bag.

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* Current technology combines sodium azide with a suitable oxidizer material. When the mixture is ignited, gas is generated at an extremely rapid rate. Oxidizer selection is based on factors such as cost, availability, sensitivity of mixture to ignition on impact, and other factors. The precise configuration and composition of the propellant charge (sodium azide/oxidizer) are the key to effective performance of the system. The term propellant is used since this technology was initially developed for solid propellant rockets in the space program.

The driver's bag must be deployed from the steering wheel while the passenger's bag is contained in the instrument panel. The two designs are similar in major subassemblies and components.

2.3 MAJOR SUBASSEMBLIES/COMPONENTS OF AN AIR BAG SYSTEM

The major subassemblies/components of an air bag system are shown in Figure 2-1. As shown, the major subassemblies/components are:

- Cushion and Inflator Assembly (Driver and Passenger Sides)
- Sensor System
- Readiness Monitor/Indicator Assembly (Indicator Warning Light).

Driver and passenger knee restraints can be included with air bags for added occupant protection. On the passenger's side this knee restraint is typically part of the cushion and inflator assembly. On the driver's side, it is a separate interior trim item.

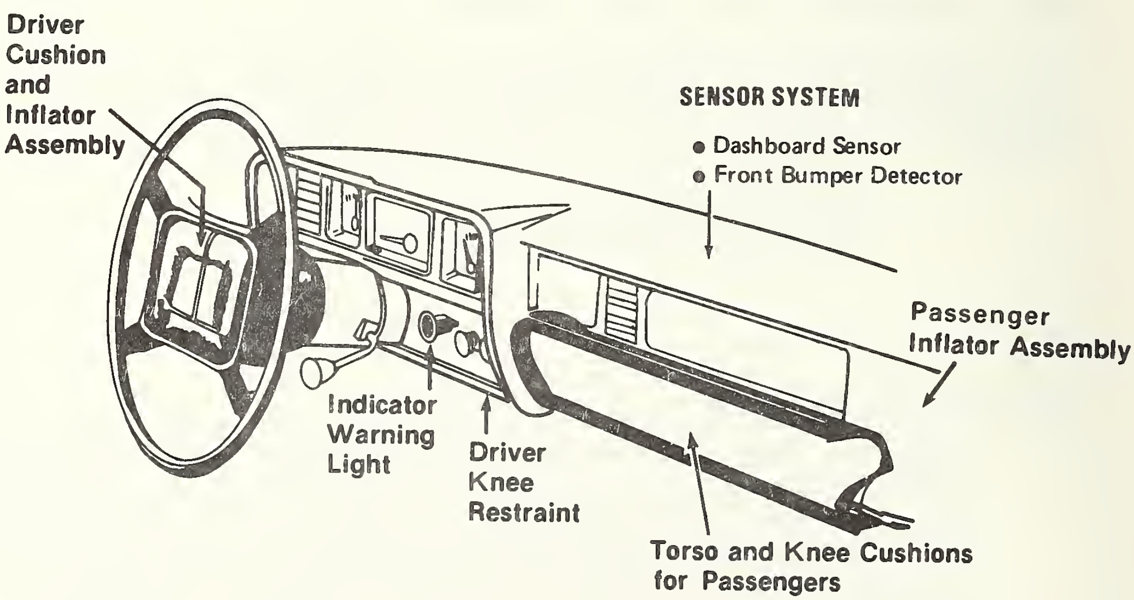

FIGURE 2-1. MAJOR SUBASSEMBLIES/ COMPONENTS OF AN AIR BAG SYSTEM

2.3.1 <u>Cushion and Inflator Assembly</u>

The cushion and inflator assembly is the major sub-assembly of the overall air bag system since it contains the potential lifesaving device, the air bag. Figure 2-2A shows the major components of the assembly on the driver's side, while Figure 2-2B shows the assembly on the passenger's side. As shown in Figure 2-2A, the assembly consists of the air cushion or bag, the gas generator (inflator), the housing for the bag and generator (shown in the figure within the steering wheel) and the trim cover. The cover's central portion is incised such that it opens by fracture in a petal-like fashion as the air bag expands.

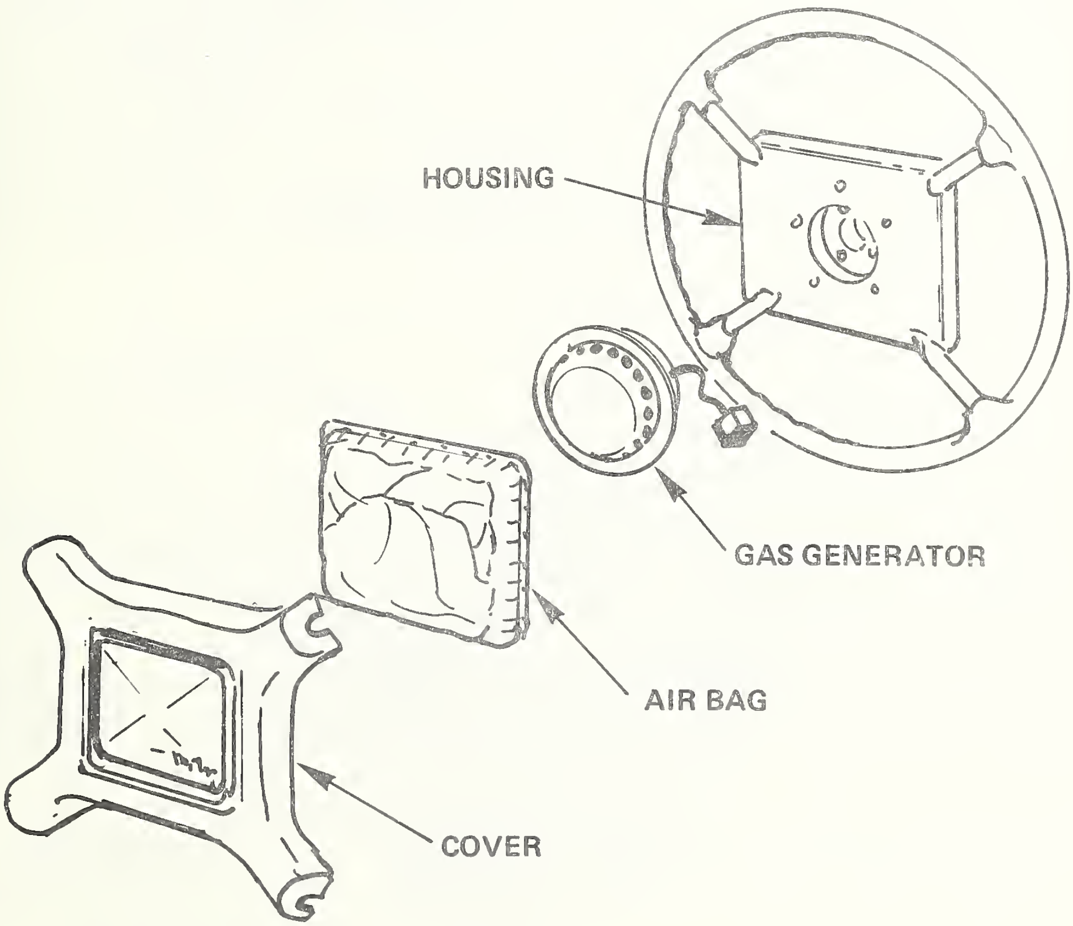

FIGURE 2-2A. MAJOR COMPONENTS OF THE CUSHION AND INFLATOR ASSEMBLY (DRIVER'S SIDE)

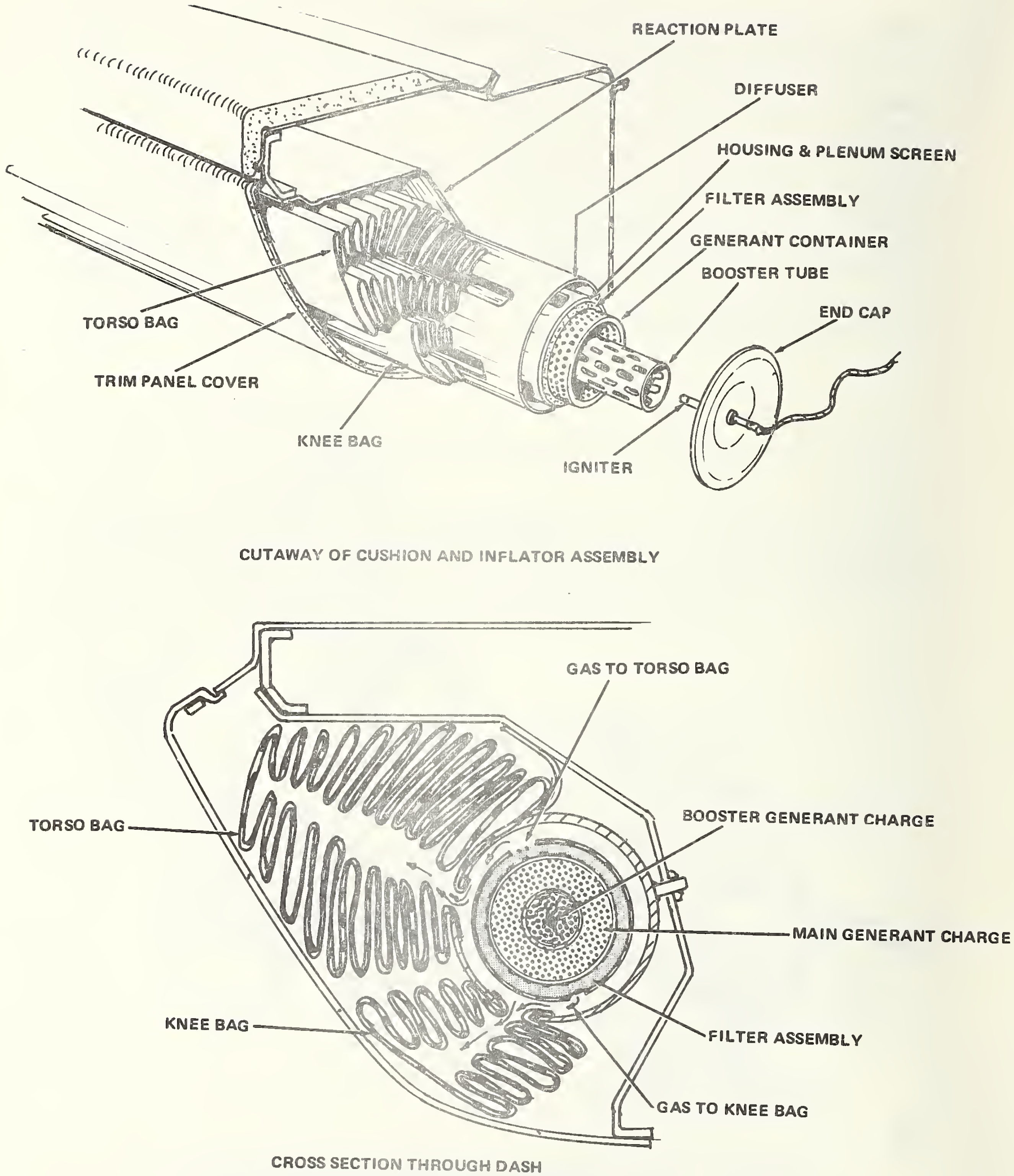

FIGURE 2-2B. MAJOR COMPONENTS OF THE CUSHION AND INFLATOR ASSEMBLY (PASSENGER'S SIDE)

The bag shown in the diagram is porous sturdy nylon cloth stitched together. For added strength, the driver bag is coated with neoprine and vulcanized.* The gas generator or "inflator" is a metal canister containing 90 to 100 grams of pyrotechnic chemicals, a squib or "electric match" and associated wiring. The pyrotechnic materials contained in the driver canister include a series of oxidizer chemicals plus the chemical sodium azide. During a crash the squib is fired, igniting the mixture of oxidizers and sodium azide thereby generating nitrogen gas to inflate the air bag. A filter within the gas generator traps any unburned toxic chemical particulates.

The passenger air cushion and inflator assembly employs the same basic concept and components, but is larger and somewhat more complex (see Figure 2-2B). The driver assembly fits entirely within the steering wheel and column assembly and works in conjunction with the collapsible steering column to protect one person (the driver). The passenger assembly fits entirely within the dash and is designed to protect up to two front seat passengers by deploying both torso and knee restraint air bags simultaneously.

2.3.2 Sensor System

The sensor system is used to actuate the air bag system. The two functions of the sensor system are (1) to rapidly detect a severe impact, and (2) to provide the necessary triggering signals to deploy the bags. Existing designs use a two-sensor system as identified in Figure 2-1. The two sensors—the dashboard sensor and the front bumper detector—are spring-mass type sensors connected in series. As such, the deployment criteria of both sensors must be satisfied for the air bag to deploy. The reason for the two sensors/series connection is to prevent inadvertent deployment of the bags, if one sensor fails in such a way as to give an erroneous triggering signal.

A recent development by the Essex Group of United Technologies, however, may supercede the dashboard and front bumper "spring-mass" type two-sensor system. The sensors

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* Vulcanizing is the process of treating a fabric with sulfur or its compounds and subjecting it to heat in order to increase its strength and elasticity.

developed by Essex are purported to provide more precise and repeatable performance. In addition, they are much smaller and lighter than the existing dashboard and front bumper sensors. The Essex sensor is estimated to be approximately one-half the size and one-fifth the weight of the existing dashboard and front bumper sensors. Existing sensors and housings weigh about two and one-half pounds each.

The problem with the Essex sensor, however, is that it is "unidirectional." That is, it can only measure the change in acceleration in one specific direction. Unlike existing sensors, it cannot detect crashes at great angles off the principal axis of the sensor. Therefore, use of the Essex sensor will require several sensors, possibly as many as six or seven, mounted in different parts of the vehicle. While this adds complexity and cost it also offers the potential for improved fail-safe redundancy, i.e., greatly reduced likelihood of inadvertent deployment due to sensor failure. A detailed description of the existing dashboard and front bumper sensors and of the proposed Essex sensor is given below.

Dashboard Sensor and Front Bumper Detector

The typical current dashboard sensor is essentially a velocity interpreter which senses a true crash as differentiated from a sudden stop or road impulse, i.e., pothole. As shown in Figure 2-3, the sensor consists of a pendulum held in place by a magnet and contact points. When a crash of significant G forces occurs, the pendulum, overcoming the magnetic field, swings across and hits the opposite side. An electrical contact is then made which activates the air bag system.

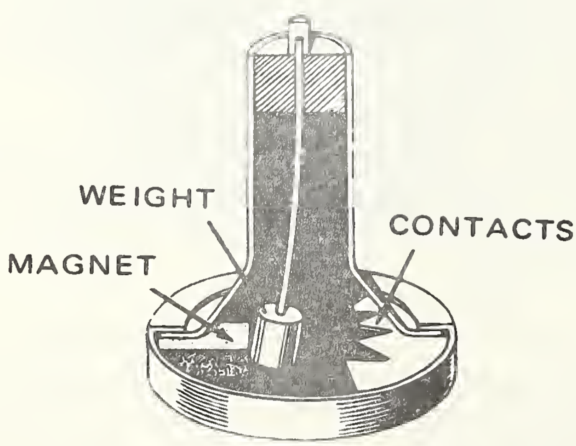

FIGURE 2-3. EXISTING DASHBOARD SENSOR DESIGN

In a similar fashion, the current front bumper detector senses the degree of deformation of the bumper of a vehicle in a crash. As shown in Figure 2-4, the front bumper detector is based on a principle similar to the dashboard sensor. Here, however, the weight or contact mass is held in place by a tensioned leaf spring instead of a magnet. As with the dashboard sensor, as soon as a crash of sufficient deceleration rate occurs, the weight overcomes the force of the spring, and makes an electric contact. The function of the diagnostic resistor shown in the diagram is to permit verification that the system is operating.

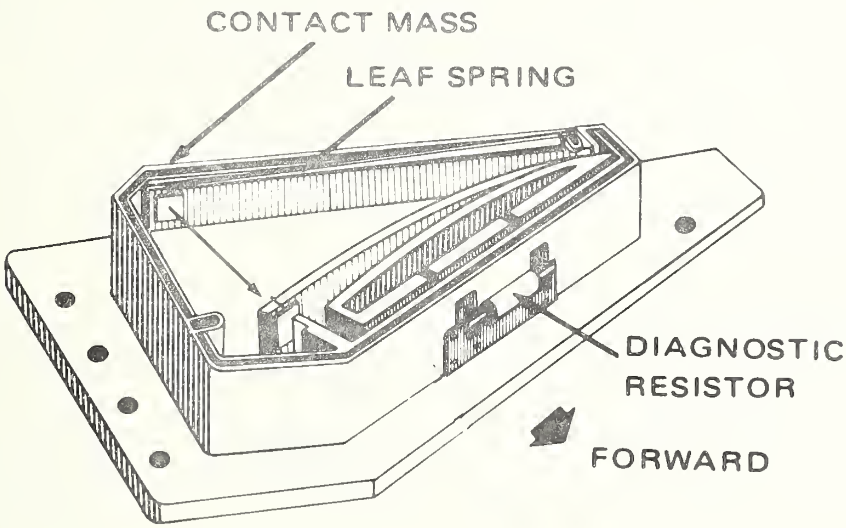

FIGURE 2-4. EXISTING FRONT BUMPER DECTECTOR DESIGN

As described previously, if electric contact is made both by the dashboard sensor and front bumper detector, the bag is deployed. Usually a two to three-millisecond delay is programmed into the electronic triggering system to provide for maximum gas deployment volume, to occur at the time of maximum occupant deceleration.*

* The precise calibration of air bag deployment rate is also a strong function of reliable, repeatable performance of the gas generation portion of the cushion and inflator assembly. The development and testing costs necessary to ensure this have been and will continue to be substantial. Also the potential product liability implications of air bags require a high degree of manufacturing quality control which adds to manufacturing costs as will be discussed later in this report.

Essex Sensor

The Essex sensor, unlike the dashboard and front bumper sensors, is a "true" velocity integrator. That is, the sensor measures velocity change duration as well as G forces experienced in a crash and combines them to determine whether the air bag should be deployed. The sensor accomplishes this based on the principle of dampening.

As shown in Figure 2-5, the sensor is essentially a sealed tube with a set of contacts at one end and a magnet at the other. A gold-plated ball inside the tube remains at the magnet end until a crash occurs. The ball then moves toward the set of contacts. Gas in the tube, however, dampens its forward motion. Thus, the deceleration of the impact must be long enough to permit the ball to overcome the dampening effect of the gas. Once contact is made, a signal would be generated. If the appropriate number of signals is generated the deployment pulse will be set to trigger the air bag system.

A gold-plated ball is used in this design because of gold's excellent conductivity and corrosion-resistant characteristics. Once again, the advantage of this design is that it measures velocity change, direction, and G forces and thus reduces the probability of inadvertent deployment of the bags as compared to the current two-sensor system which measures only deceleration (G forces).

It is typical that sensors are supplied to the vehicle manufacturer from a different supplier than the one which supplies the cushion and inflator assembly. Final system integration is performed by the vehicle manufacturer.

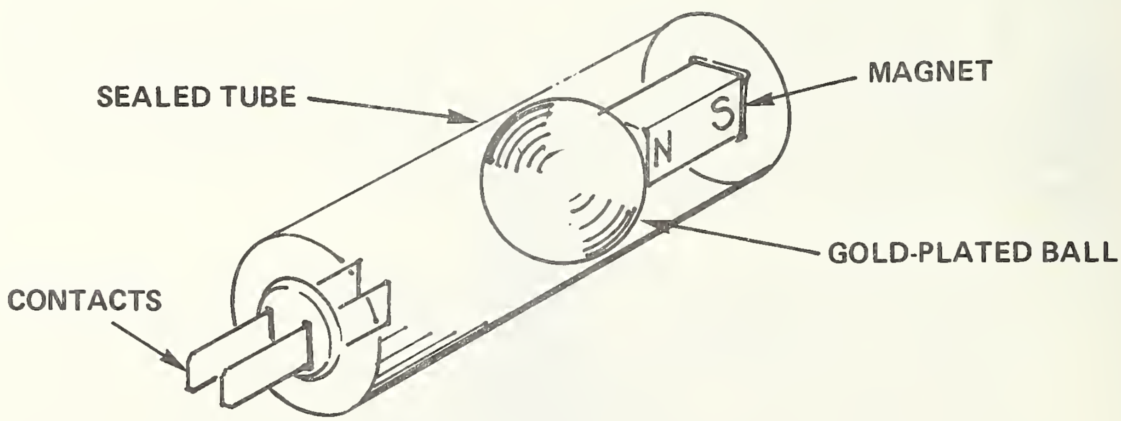

FIGURE 2-5. ESSEX GAS DAMPENED SENSOR

2.3.3 Readiness Monitor and Indicator Assembly

The readiness monitor and indicator assembly is a system designed to continuously check the electronic integrity of the air bag. As shown in Figure 2-6, the assembly is simply a light bulb encased in a plastic housing. The bulb is connected to the sensors described above which in turn contain the necessary logic to determine whether or not the system is functioning. The monitor in essence acts as an informant on the electronic and sensor system's "readiness." This is an extremely important function since it may be as much as five to ten years before the bag is needed.* A summary of the monitor's operation is as follows.

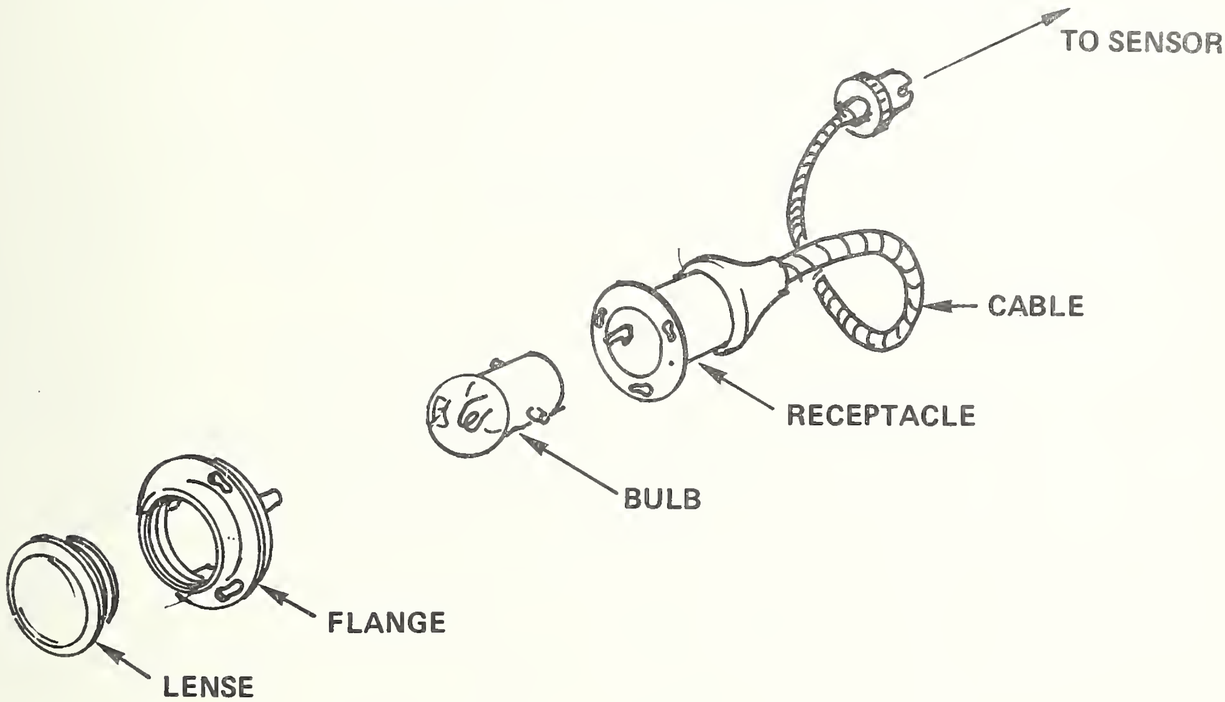

FIGURE 2-6. READINESS MONITOR AND INDICATOR ASSEMBLY

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* Note: There exists no practical test of the readiness of the inflator and cushion assembly. The propellant unit is a hermetically sealed device which presumably has a long storage and dormant use life. Only statistical quality control techniques featuring sampling and destructive testing of these assemblies can assure (in a statistical sense) "readiness." Because of this, if a high level of readiness assurance is required for product liability reasons a high percentage of the manufactured assemblies must be destructively tested to assure that those not tested will actuate when triggered.

- When the car ignition switch is turned on, the readiness monitor automatically performs a check of the air bag system electrical components to determine readiness.

- During this diagnostic check, which lasts five to ten seconds, an indicator light on the instrument panel goes on. When the diagnosis is completed and the system is found in satisfactory condition, the light goes off automatically.

- If the indicator fails to light or continues to light beyond the short diagnostic check-out, or lights while driving, the system may have a malfunction. This is an indication to the motorist that the electrical or sensor portion of the system should be serviced for correction of the fault. Periodic servicing of the inflator and cushion assembly is not appropriate.

2.3.4 Knee Restraints

Knee restraints are used to prevent front seat occupants, who are not wearing their optional lap belts, from submarining or sliding under the inflating air bag during a crash. The restraints provide a cushion for the legs and knees and thereby hold the lower portion of the body so that the head and upper torso are suitably positioned during bag inflation. There are two types of driver knee restraints. One type is reusable and regains its shape after an impact. The other type is sacrificed and permanently deformed upon major impact with the occupant's knees. On the passenger side the knee restraint function is provided by a knee restraint air bag.

2.4 DESCRIPTION OF THE PROCESSES INVOLVED IN THE MANUFACTURER OF AIR BAGS

Manufacture of the air bag componentry and subassemblies described above is a relatively straightforward process. It employs traditional manufacturing techniques. No specialized or particularly sophisticated machinery is required at present, although specially made automated equipment may be required in the future as increased volumes of air bags are required. Presently, the low volumes of air bags that are required are produced with inexpensive machinery in a very labor intensive fashion.

The following sections describe the manufacture and vehicle installation of the air bag and its associated components:

- Manufacture of the Cushion and Inflator Assembly
- Manufacture of the Electronic Sensors
- Manufacture of the Readiness Monitor and Indicator Assembly
- Manufacture of the Driver Knee Restraints
- Installation of the Air Bag and Its Associated Components.

Figure 2-7 displays the integration of the major components into the final installed vehicle system. Note that there are typically three separate portions of the system that are supplied by:

- Cushion and Inflator Assembly Supplier
- Specialist Sensor (Decelerometer) Supplier
- Readiness Monitor Vendor.

The vehicle manufacturer in performing final integration and installation must add the trim cover, wiring, fasteners and some electronics in most cases.

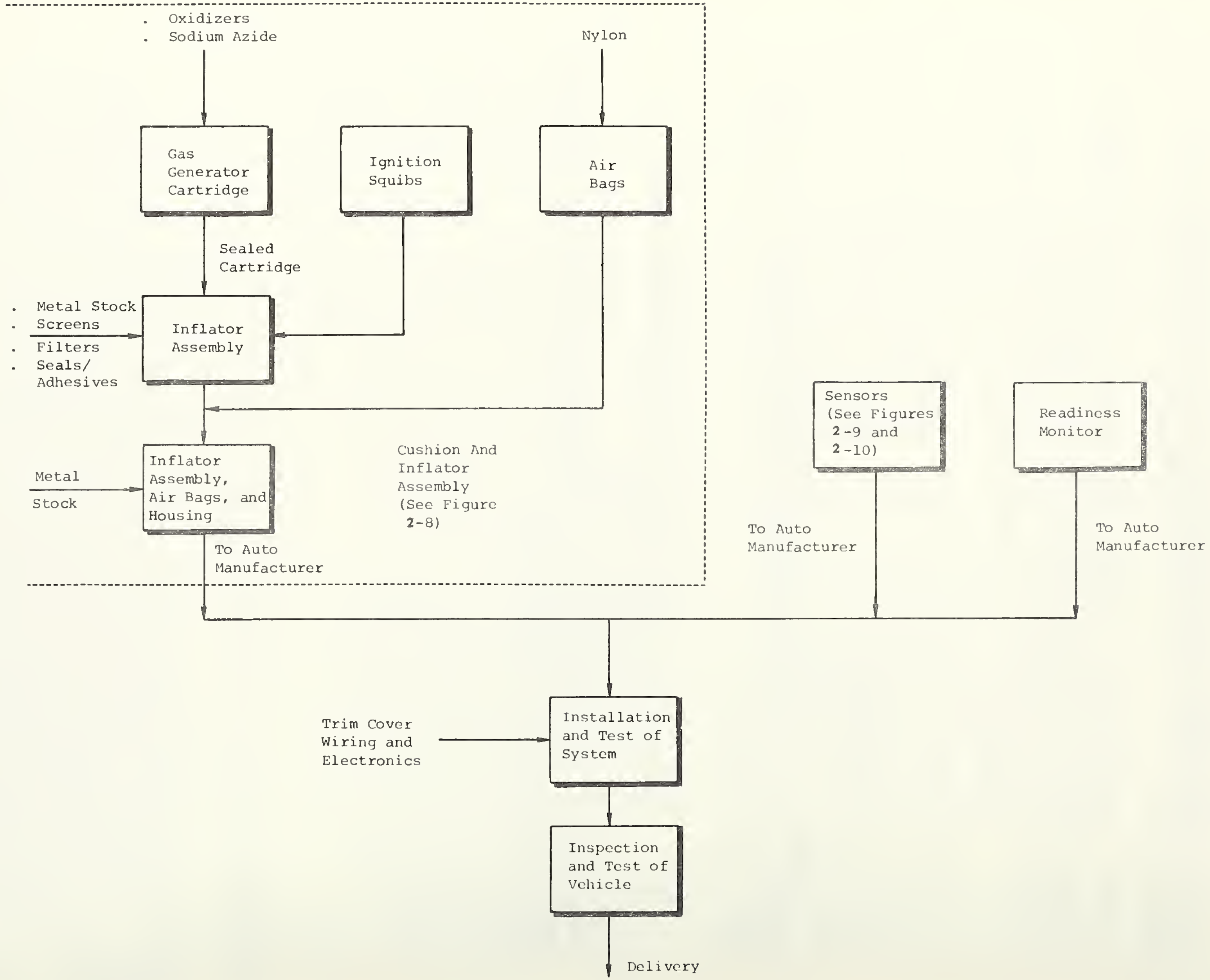

FIGURE 2-7. PROCESS FOR OVERALL MANUFACTURE AND INTEGRATION OF AIR BAG SYSTEM IN A VEHICLE

2.4.1 Manufacture of the Cushion and Inflator Assembly*

Figure 2-8 presents a diagram of the basic processes involved in the manufacture of the cushion and inflator assembly. This is the most complex portion of the overall system and basically involves four very different design and manufacturing technologies as follows:

- Solid rocket/gas generator technology (gas generator cartridge)
- Textile manufacturing technology (nylon air bags)
- Ignition squib technology (electrically activated initiator)
- Traditional metal fabrication and assembly technology (containers and housings).

The following discussion of the manufacturing processes employed for the cushion and inflator assembly is intended as an overview. Detailed discussion of specifics as to plant layout, equipment, and labor requirements are presented later in a discussion of the "typical" air bag manufacturing plant.

It may be useful for the reader to refer back to pictorial representations of the passenger side air bag system (Figure 2-2B) to better relate the physical portions of the system to the process descriptions.

Gas Generator

The manufacturing overview of the gas generator involves the combination of two chemicals (sodium azide/oxidizer) with appropriate supporting interior structures into a propellant cartridge. Figure 2-8 (left side) describes the basic process for manufacturing the cylindrical cartridge used in the passenger side system. Because the manufacturing process involves extensive handling of toxic chemicals it is

* This section discusses manufacture of the bag, gas generator, and housing. Manufacture of the cover is not discussed since this would normally be performed by the automobile manufacturer for consistency with interior trim.

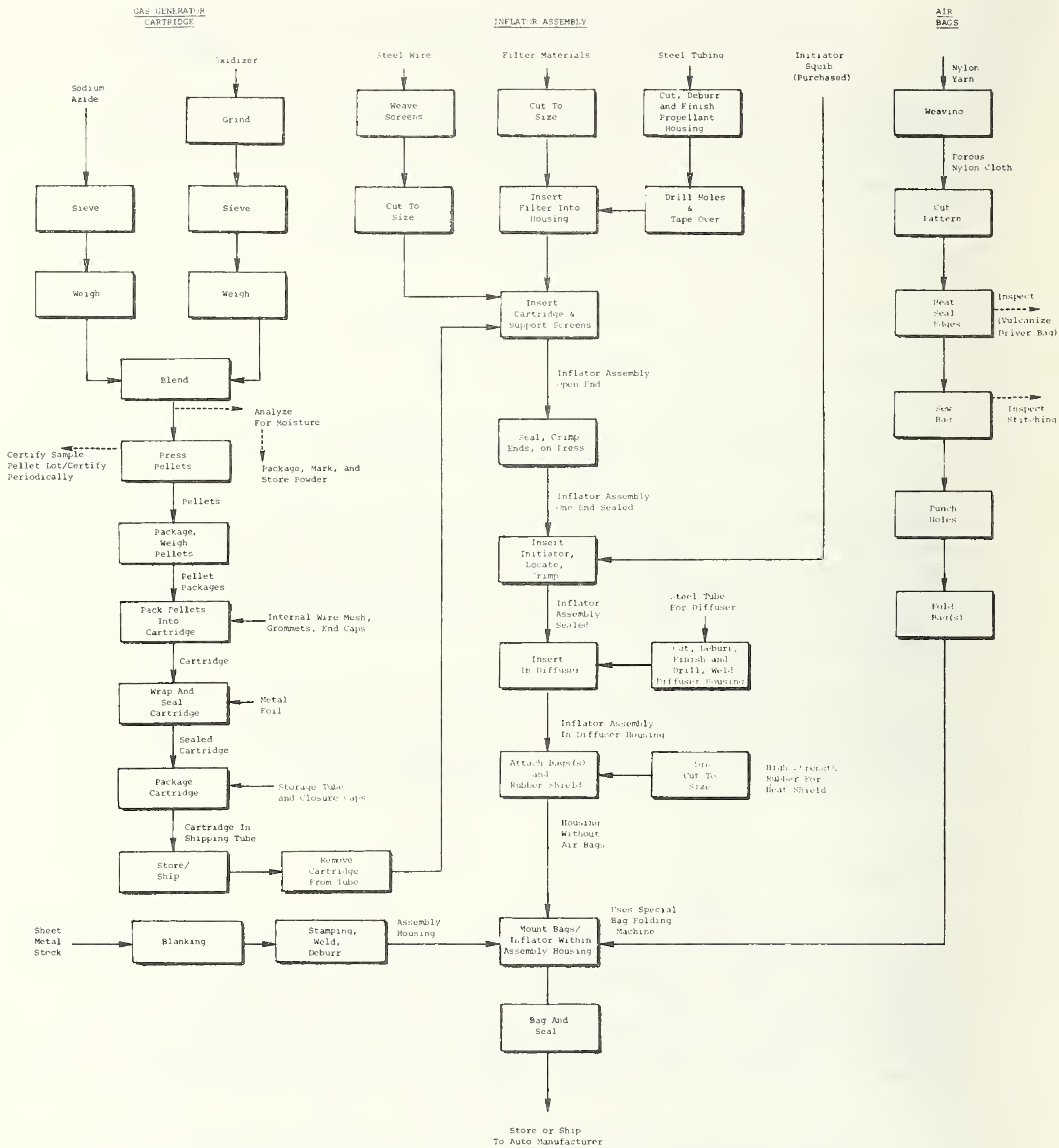

FIGURE 2-8. OVERVIEW OF THE PROCESSES INVOLVED IN THE MANUFACTURE OF THE CUSHION AND INFLATOR ASSEMBLY* (PASSENGER SIDE)

* At this time no plant exists for the volume production of cushion and inflator assemblies. Therefore, this diagram represents a description of the processes that are likely to be employed during the next few years when air bag systems begin to be produced in quantity.

automated to the extent feasible to reduce hazards to plant workers. A typical facility includes special features such as remote and/or controlled storage of chemicals, extra high ventilation volume fans/filter systems for portions of the plant, building construction with blast doors, and appropriate related alarms and firefighting equipment.

As shown in Figure 2-8, the chemicals are initially ground to powder, sieved, and weighed. In volume production an automated powder sieve apparatus is employed. Blending of the powdered chemicals takes place in propellant blending cells and is performed in a propellant blender controlled by a suitably protected worker in the cell. Quality checks for moisture are performed at this point in the process. The blended mixtures are then pressed into pellets of the desired size in automated pelletizing machines located in exterior facing propellant press bay cells equipped with blast doors. Pellet composition is certified in initial sample lots and periodically checked each day that the line is operating. The diagram in Figure 2-8 is simplified in that it implies that a single mixture of sodium azide/oxidizer and a single size pellet is used in the entire cartridge. In fact, all air bag systems now being considered employ two to six different types of pellets (size, composition) in each cartridge. This is the key to generating gas at the appropriate rate after ignition.

Once all the chemical pellets are weighed, packaged, and certified, they are inserted into a cartridge along with wire mesh screens and filters to separate the various types of pellets from each other in the appropriate configuration. This is done in large specially designed propellant loading line machines involving six to ten different stations. Because the final cartridge of propellant is potentially toxic and susceptible to contamination by the environment, it is sealed hermetically within a metal foil wrap which is a permanent feature of the cartridge. To protect the fragile foil from puncture in handling, the last step is to encase the cartridge in a storage package (cardboard type tube with end caps in the case of the cylindrical passenger's side cartridge). The cartridge can then be stored or shipped to the inflator assembly area.

Air Bags

The overview of the manufacturing processes for air bags is shown on the right side of Figure 2-8. The processes are somewhat unique to automotive applications and are more typical of textile manufacturing. The first step is to weave nylon yarn into porous nylon cloth such as 24 x 24, 5½ ounce per square yard type. The appropriate pattern is then cut out. Initial production will probably employ industrial-type textile machinery and conduct cutting and critical heat sealing operations separately. Long-range potential exists for the use of laser cutting/sealing machines, but these require high production to justify costs. Air bags are sewn on industrial-type sewing machines. This is a highly labor intensive operation and will be very difficult to automate even at very high volume production rates. Meticulous manual inspection of the stitching of each bag is then performed. It is a rough preliminary estimate that one stitching inspector will be required for each two people sewing air bags. It is conceivable that holes may be punched in certain portions of the bags. Folding and attachment of the air bags to the assembly containing the gas generator cartridge is a performance critical step. To assure consistency of folding, it is conceivable that "folding machines" will be developed and utilized.

Inflator Assembly

The overview of the manufacturing process for the inflator assembly is shown in the middle of Figure 2-8. As shown in Figure 2-2B (the passenger's side air bag), this assembly forms a sealed housing for the propellant, a diffuser for gases generated, and an attachment point for torso and knee air bags. Manufacture of the inflator assembly is generally in accordance with traditional automotive manufacturing approaches. The following discussion refers to the passenger's side system, although the manufacture of the driver's side system is similar.

As shown on Figure 2-8, a first step is wrapping suitable structural and filter material around the gas generator cartridge and then inserting gas generator cartridge/filters within a steel tube. This tube contains strategically drilled gas orifices which are taped shut. The initiator squib is inserted and the entire package is sealed. In the case of the passenger's side air bag system such sealing is accomplished in a large press, by crimping the ends of the steel tube enclosing the gas generator cartridge over the end caps. A second, slightly larger steel tube with two sets of strategically drilled holes is used as a diffuser and an attachment point for the air bags. This is most clearly shown in the sectional view at the bottom of Figure 2-2B. The basic manufacturing processes for making the diffuser tube are similar to that for the smaller cartridge housing tube, i.e., cutting tubing to length, deburring, finishing, drilling holes and in this case welding mounting points for attaching air bags and heat shields. Heat shields are made of high strength rubber cut to size. These shields keep the bag from burning after firing by separating the bag from the hot metal cylinders.

Cushion Inflator Assembly Housing

The manufacture of the cushion/inflator assembly housing is a fairly straightforward process primarily involving blanking and stamping. The housing is mounted eventually to the under portion of the automobile's dashboard. Because the geometry of the housing is critical to the appropriate expansion geometry (and performance) of the air bag, some welding operations are typically necessary. Deburring and finishing of the housing are also necessary to assure that the bags wrapped around the diffuser are not ripped upon insertion into the housing. After the cushion and inflator assembly is completed, it is typically bagged and sealed before being shipped to the automobile manufacturer.

2.4.2 Manufacture of the Electronic Sensors

Manufacture of the electronic sensors involves the basic manufacturing processes of stamping/forming, casting, and/or joining/assembly and, depending on the type of sensor, also the processes of electroplating, electromagnetizing, and cutting. The following is a description of the manufacturing processes associated with the three basic types of sensors discussed previously:

- Dashboard Sensor
- Front Bumper Detector
- Essex Gas Dampened Sensor.

The appropriate number of sensors for each vehicle system would typically be purchased to specification by the vehicle manufacturer. The only special manufacturing area would be the provision of mounting brackets or surfaces on the part of the sensor supplier compatible with the specific vehicle application.

Dashboard Sensor

The manufacturing processes involved in the production of dashboard sensors are summarized in block diagram form in Figure 2-9. As shown, both the pendulum weight and housing are die cast metal products. The housing is die cast zinc for extra corrosion resistance while the pendulum weight is die cast iron. Iron is used because of its high density and good conductivity. The pendulum shaft may be extruded and is made of a good conductive metal. The pendulum shaft and weight are joined either by epoxy or are set together during the casting process.

The magnet is cast non-alloyed iron which is then electromagnetized. The magnet is joined to the wall of the housing by epoxy. Similarly, the contacts are also joined to the wall of the housing by epoxy. The contacts, as shown in the figure, are made by stamping and then cutting rolled stock of copper. The wiring is soldered to the electrical contacts.

As with all sensors, a relatively high level of manufacturing quality control, inspection, and testing is required to ensure high reliability levels specified by the vehicle manufacturer.

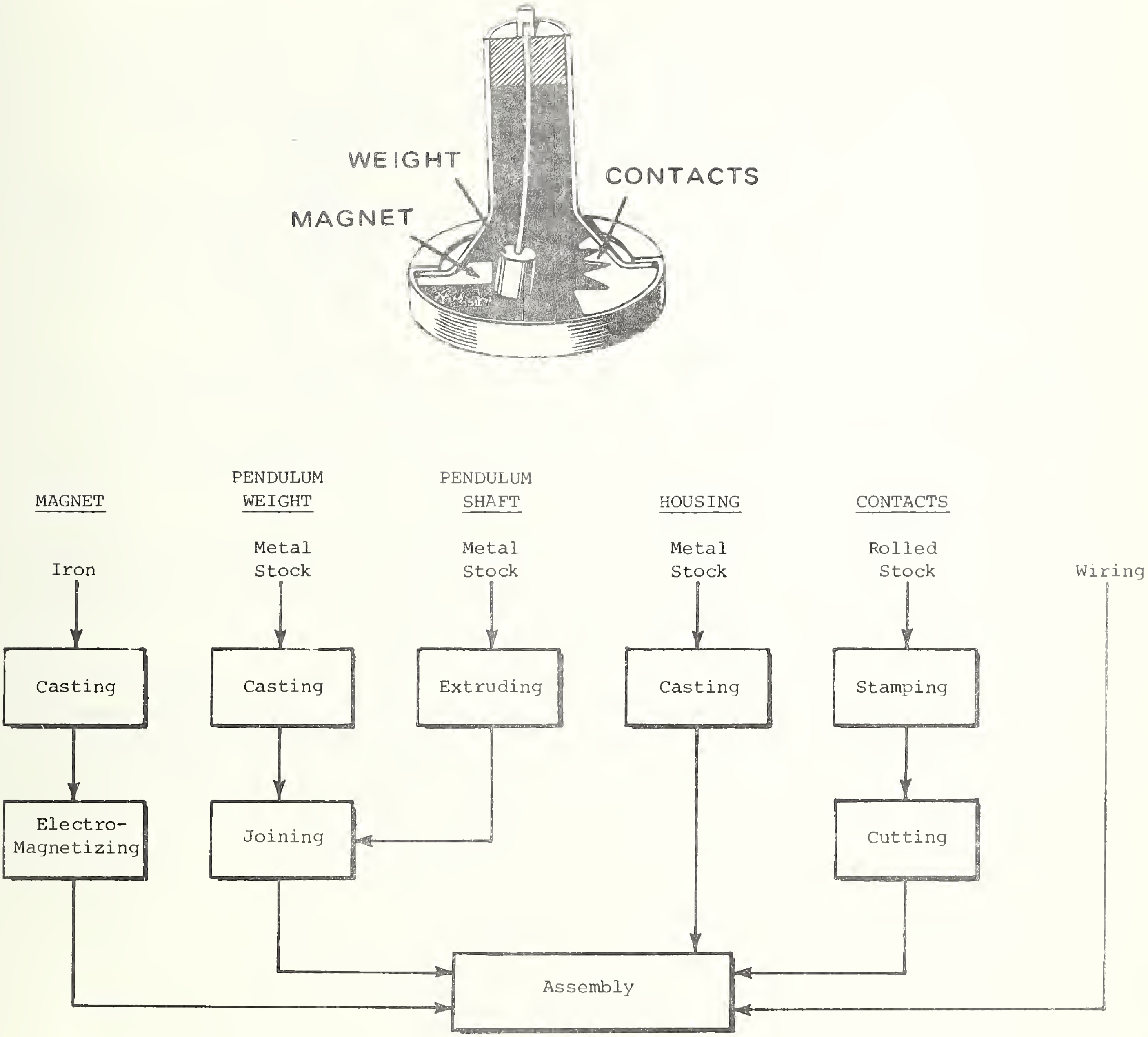

FIGURE 2-9. MANUFACTURING PROCESS FLOW DIAGRAM FOR DASHBOARD SENSOR

Front Bumper Detector

Figure 2-10 shows the basic processes involved in the manufacture of the front bumper detector. As shown in the diagram at the top of the figure, the major components of the front bumper detector are the housing, leaf spring, contact mass, diagnostic resistor and wiring.

As shown in the diagram, the housing is injection molded plastic while the leaf spring is conductive metal, such as spring steel or copper alloy, which is stamped and cut into metal strips. The contact mass is cast metal which is also conductive.

Joining of the contact mass to the leaf spring is simply a bonding operation, while assembly of the leaf spring and diagnostic resistor into the housing involves either press fitting or soldering. Wiring of the unit involves soldering. The cover to the housing is either press-fit or mechanically fastened.

Mounting surface configuration and the size/position of mounting holes drilled in the mounting plate base would be specified by the vehicle manufacturer and would be specific to the particular vehicle in most cases.

Again a high reliability performance level and ability to withstand severe environmental conditions would be specified by the vehicle manufacturer. This would require considerable inspection and testing on the part of the sensor supplier in support of the sensor manufacturing operation.

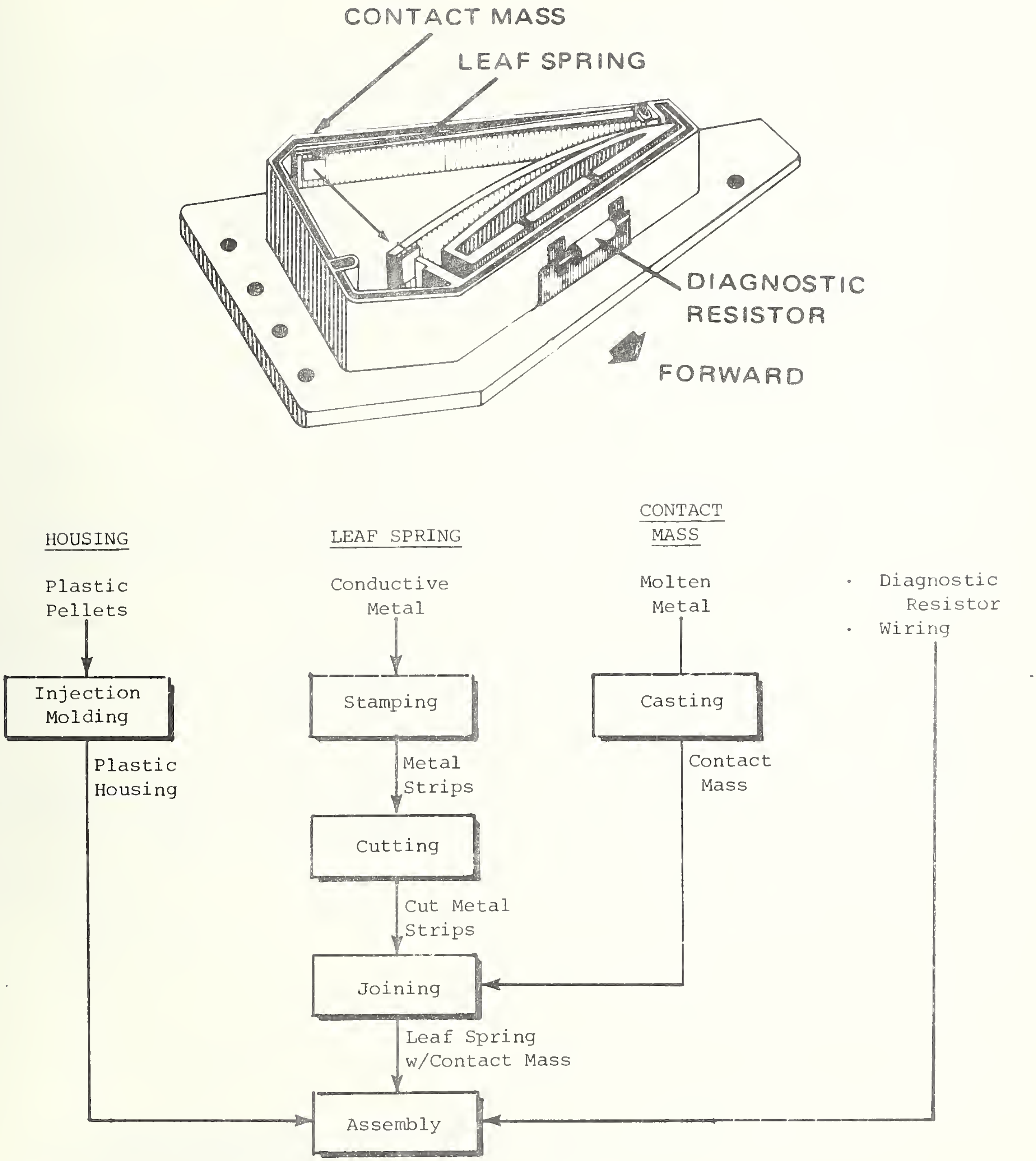

FIGURE 2-10. MANUFACTURING PROCESS FLOW DIAGRAM FOR SPRING MASS SENSOR DESIGN, THE FRONT BUMPER DETECTOR

*Essex Gas Dampened Sensor**

The Essex sensor described earlier is a relatively simple device consisting of a metal tube, magnet, gold-plated ball, electrodes and associated wiring. As shown in Figure 2-11, the tube is made by the process of extrusion while the magnet is made through the two processes of casting and electromagnetizing. The gold-plated ball is made under very close tolerances through the processes of forging, machining, polishing, and electroplating with gold. Gold is used as discussed previously because of its excellent conductivity and corrosion-resistance characteristics. Only perfectly formed balls of metal are selected and electroplated. The reason is that the gap between the outside diameter of the ball and inside diameter of the tube determine the G force sensitivity of the sensor.

Final assembly of the sensor involves bonding the magnet to one end of the tube and either press fitting or soldering the electric contacts to the other end of the tube. Prior to fitting the electric contacts, however, the ball is manually inserted into the tube. Wiring of the sensor involves soldering.

Because of tight tolerances on the gold balls, this process would appear to require fairly sophisticated statistical quality control and have the potential for high scrappage rates of expensive materials. Features for mounting sensors are not shown in Figure 2-11, but would vary from one vehicle to the other and might require various mounting surfaces to be added to the sensor, or these could be provided by the vehicle manufacturer.

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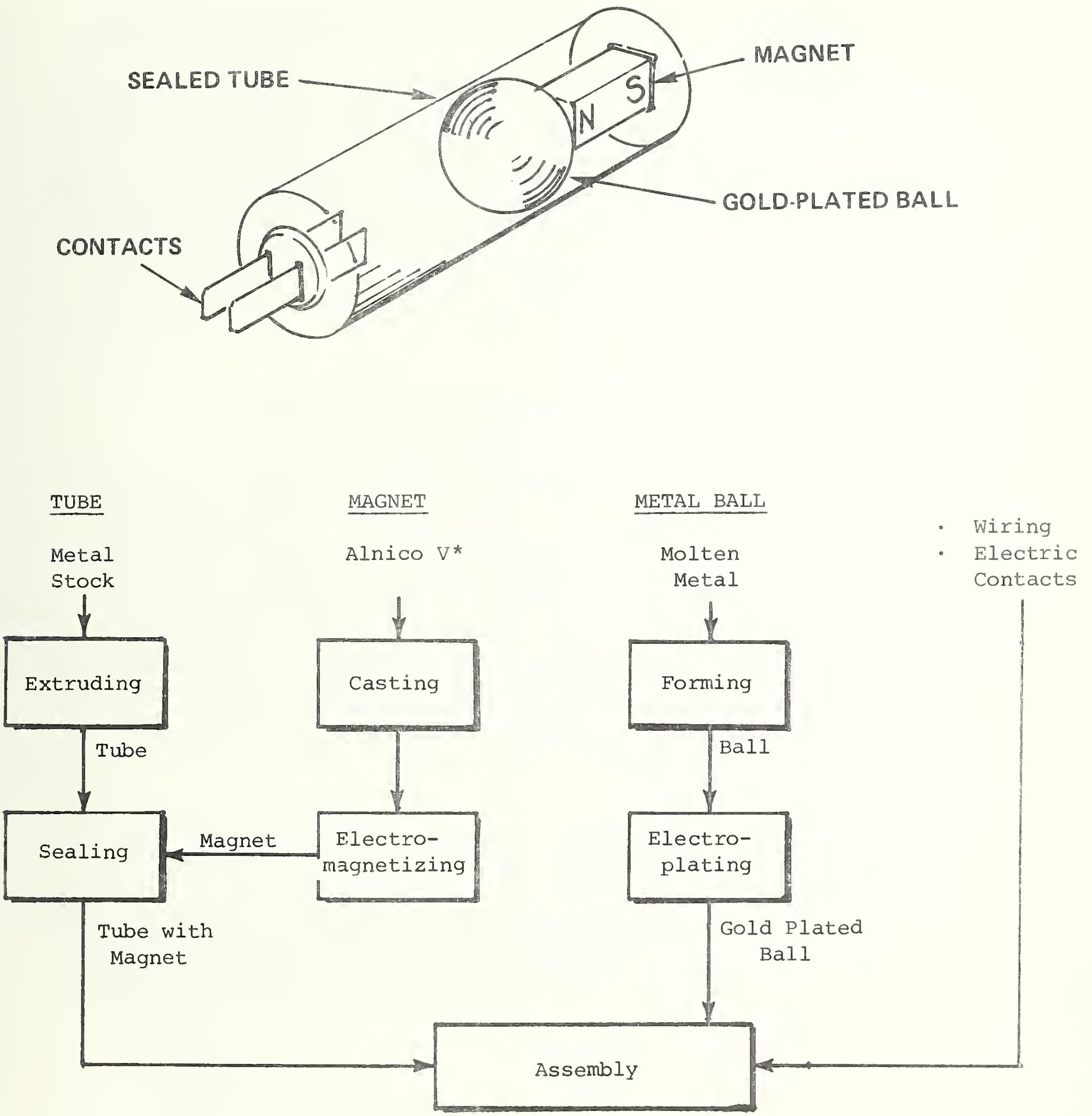
* The gas dampened sensor design developed by the Essex Group of United Technologies is not at present a production unit. Rather, it is still in the conceptual design stage. Thus, the processes associated with the manufacture of this sensor are not well-defined.



* Alnico V is a carefully heat-treated alloy of nickel, iron, aluminum, cobalt, and copper.

FIGURE 2-11. MANUFACTURING PROCESS FLOW DIAGRAM FOR ESSEX GAS DAMPENED SENSOR DESIGN

2.4.3 Manufacture of the Readiness Monitor and Indicator Assembly

The readiness monitor and indicator assembly consists of a plastic housing (lens/flange), bulb, receptacle, and cable. Except for the bulb, all parts are made from injection molded plastic. The small light bulb used as part of the assembly is similar to present day bulbs used on instrument panels. These are mass-produced in great volume from thin gauge tin and molten glass in highly specialized machinery. Assembly of the unit consists of screwing the bulb into the receptacle and then manually placing the housing over the bulb.

2.4.4 Manufacture of Driver Knee Restraints

The manufacture of the driver knee restraints involves the injection molding of plastic on traditional machinery. Two general types of plastic are under consideration for knee restraint manufacture, a type that regains shape after impact and a type that is permanently deformed. The type that is permanently deformed may offer superior energy-absorbing characteristics, but would require replacement once it is damaged. Regardless of the type of plastic used, the same manufacturing processes and machinery would be employed. Knee restraints would probably be supplied through the vehicle manufacturer as part of the overall interior trim package.

2.4.5 Installation of the Air Bag and Its Associated Components

Installation of the cushion and inflator assembly, sensor system, readiness monitor and warning system, and knee restraints are performed at the automobile manufacturers' assembly plants. All of the components of the air bag system are very accessible during assembly and all would be installed manually.*

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* The air bag system, however, may not be very accessible to the service mechanic after the vehicle is completed. The passenger side air bag is mounted in the lower portion of the dashboard, with wiring and triggering electronics behind it. On certain car models, cars with air conditioning and other electronics convenience items, access to the air bag could be somewhat difficult.

Typically the three parts of the system, i.e., cushion/ inflator assembly, sensors, and readiness monitor, would be purchased from different suppliers by the automobile manufacturer. Final integration, assembly, and inspection of the total air bag system would be performed by the automobile manufacturer. The vehicle manufacturer would also experience cost to modify the vehicle to accommodate the air bag, which would vary by make/model and type of interior option package.

The changes in vehicle interior design required to accommodate the introduction of air bag systems include:

- Changes in the steering column angle to optionally accommodate the driver cushion and inflator assembly including the addition of support bracketry to hold the air cushion assembly and steering column in place

- Changes in the dash and instrument panel to accommodate the passenger air cushion and inflator assembly, readiness monitor and warning system, and dashboard sensor system.

The costs of making such changes would of course be minimal if the automobile manufacturer were changing over the particular model line of vehicles at the same time air bags were introduced. This will not typically be the case, since as discussed later in Chapter 4, standards potentially requiring air bags would become effective on a specific date for specific classes of vehicles on the basis of wheelbase length. Therefore, for those models which would not otherwise require interior trim changes, the introduction of an air bag system would require substantial additional engineering, and manufacturing changeover costs for the vehicle manufacturer in making the changes listed above.

2.5 CHARACTERISTICS OF A TYPICAL AIR BAG MANUFACTURING PLANT

At present no integrated facility exists which manufactures all of the components of an air bag system nor do any production plants exist which manufacture in volume only the air cushion and assembly system.* Production facilities are in the planning stage, but continuing uncertainty regarding the size of the potential market for air bags, required production start-up time, and other factors have delayed decisions on capital expenditures for constructing such facilities.

The description of a typical air bag plant which follows (see Figure 2-12) is therefore hypothetical. The discussion will focus on an integrated plant with single shift capacity of about 75,000 passenger side cushion inflator assemblies per year. If pushed, maximum plant capacity is about twice single shift capacity. Plant expansion would be required in the final assembly area to increase capacity beyond 150,000 units per year.

2.5.1 Overview of Typical Plant

In Figure 2-12, the facilities required to manufacture the cushion and inflator assembly for the passenger side are shown as Building No. 1 and Building No. 2. This physical separation of propellant manufacturing/propellant assembly facilities from those involved in subassembly construction/final assembly is expected to be typical because:

- Manufacturing technology specialization may require two separate companies
- If one company performs all manufacturing, the facility requirements of propellant manufacturing (hazardous materials) favor physical separation.

The squib assembly plant is shown as Building No. 3 for completeness. In fact the initiator squib is a purchased part requiring a specialist manufacturer and is unlikely to ever be produced in an air bag manufacturer's plant. Similarly, the sensor assembly plant (Building No. 4—Figure 2-12) requires a specialist manufacturer and provides a

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* Facilities do exist for the manufacture of pre-production prototypes which are used for testing and system verification.

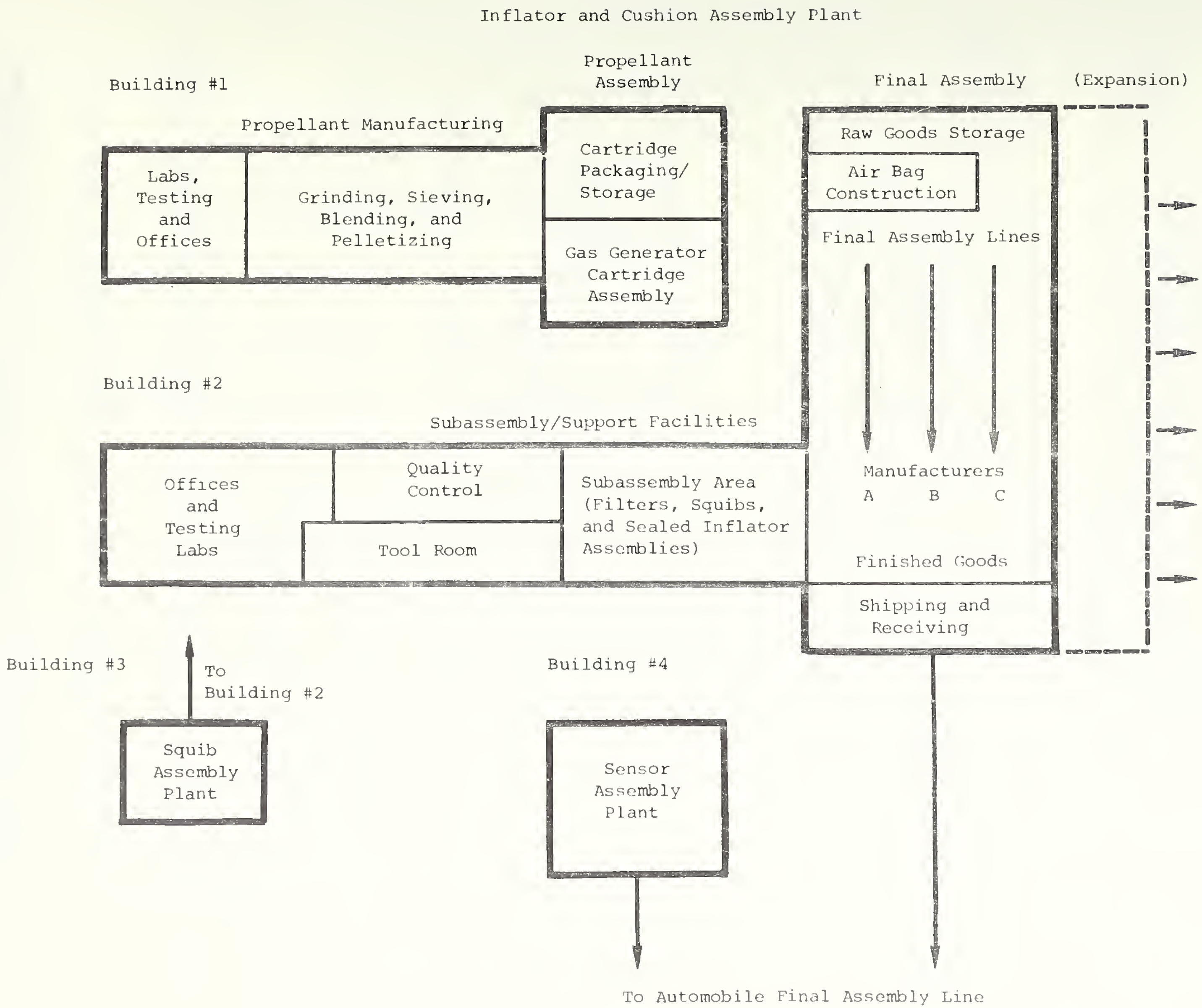


FIGURE 2-12. OVERVIEW OF AN INTEGRATED AIR BAG ASSEMBLY PLANT

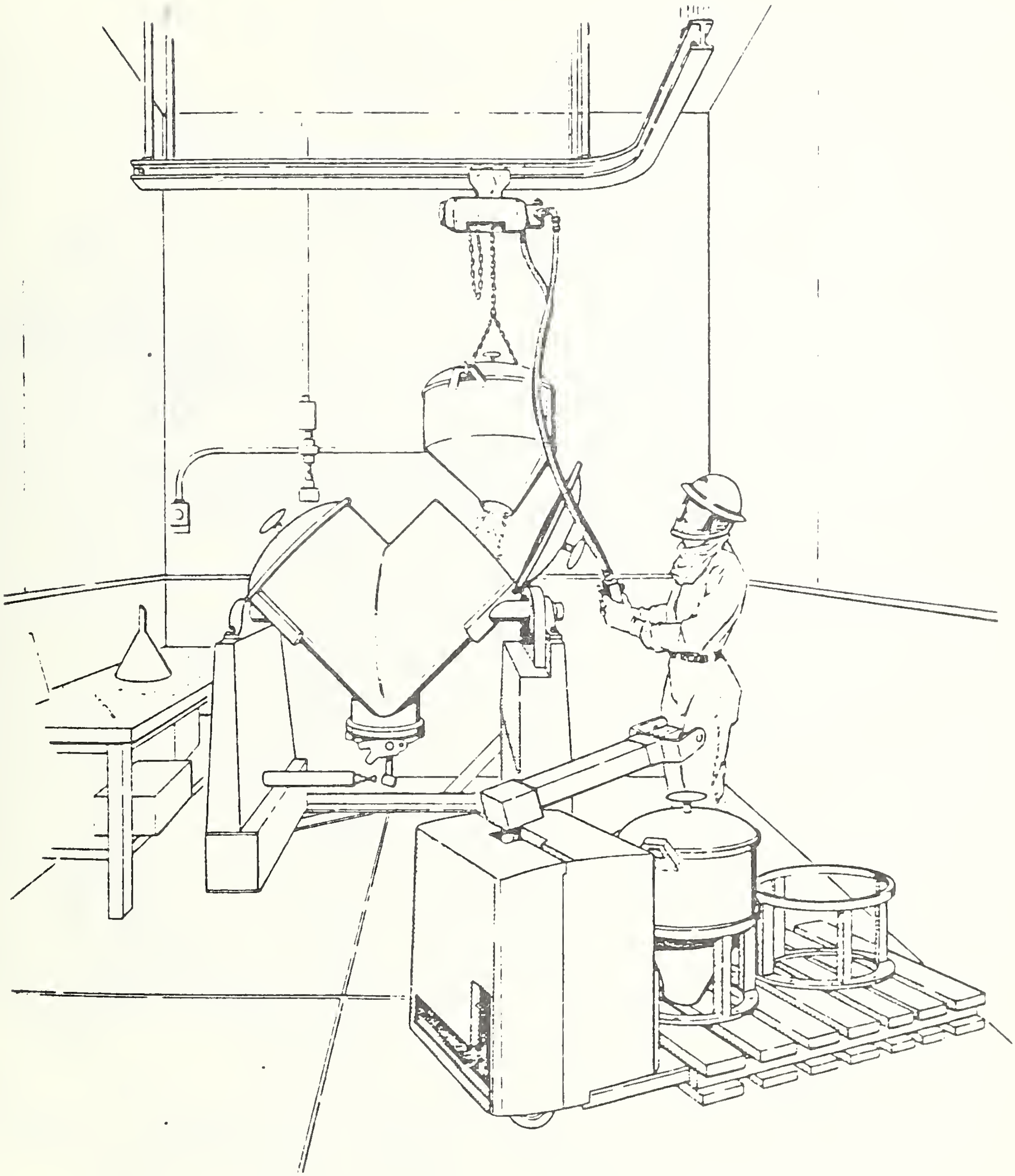
purchased part or parts directly to the automobile manufacturer. An overview of manufacturing processes for possible sensors was provided earlier. It is not possible to detail specific "typical" plants until specific types of sensors are selected. In general, the bulk of the resources required for air bag system manufacturing (capital, facilities, equipment, labor, and energy) will be utilized by the cushion and inflator assembly manufacturers (passenger's side and driver's side).

At the level of detail shown in the illustration (Figure 2-12) the inflator and cushion assembly plant is generic; i.e., it describes the basic facilities required for either the the driver's or passenger's side device. At the next level of detail, some significant differences would be apparent between the subassembly and final assembly portions of the plants. This is because the driver's side air bag system design utilizes a much higher degree of stamped parts, while the passenger's side is constructed from axially symmetric tubing.

2.5.2 Typical Propellant Manufacturing/Assembly Facility

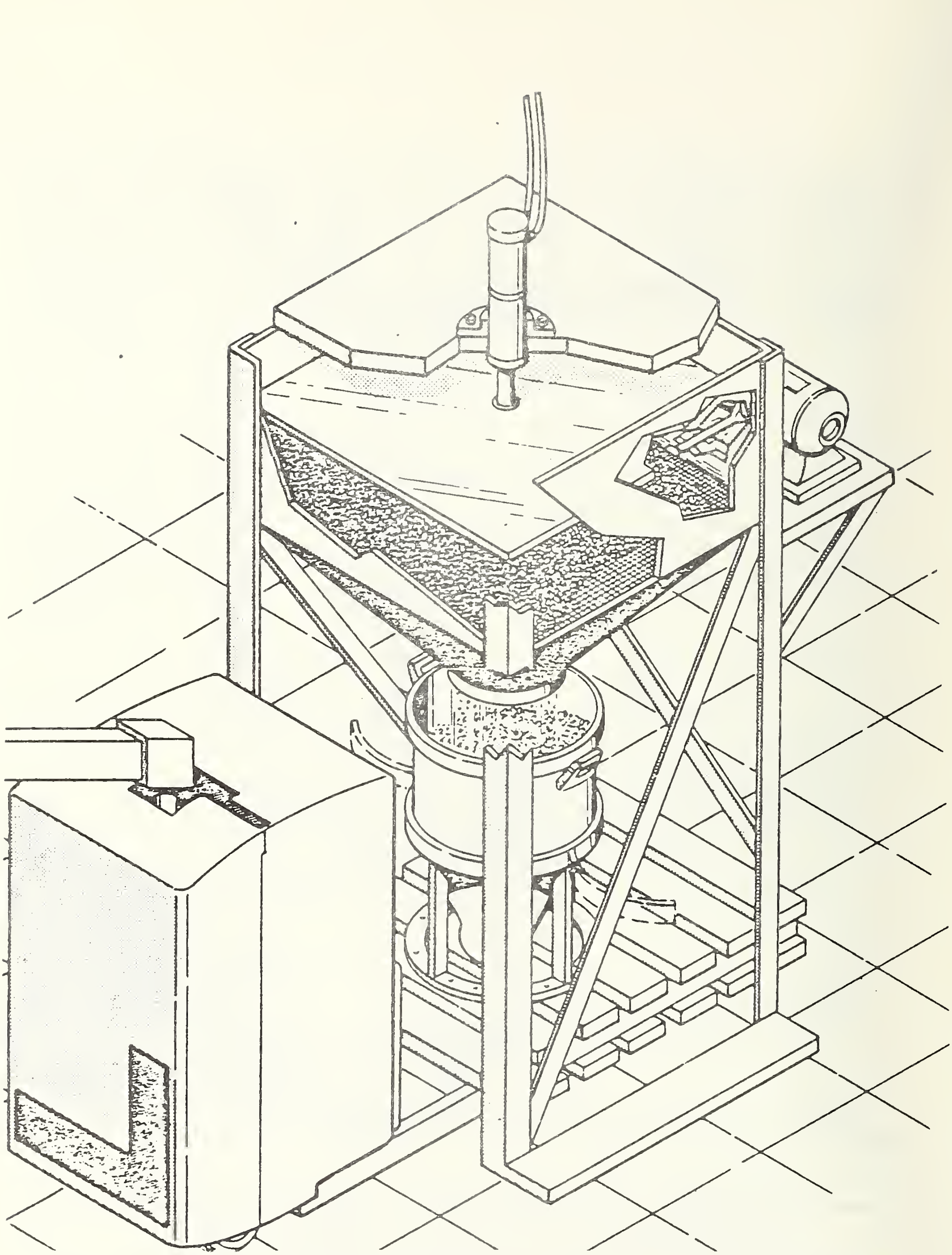
Building No. 1 shown on Figure 2-12 occupies about 35,000 square feet. The portion of this building directly involved with propellant manufacturing would be 15,000 to 20,000 square feet. This portion of the building contains the following major pieces of process equipment:

- A power grinder for grinding propellant material to powder
- Propellant blending machines (2 to 3) (see Figure 2-13)
- Power sieve machine to sieve powders/blends of propellant (see Figure 2-14)
- Propellant presses/pelletizers (5 to 7) to create pellets of appropriate size from powders (see Figure 2-15)
- Pellet dusters to remove residual powder from pellets
- Related process equipment such as: a large drying oven, 5 or 6 scales for weighing propellant charges, and a chemical lab/quality control facility



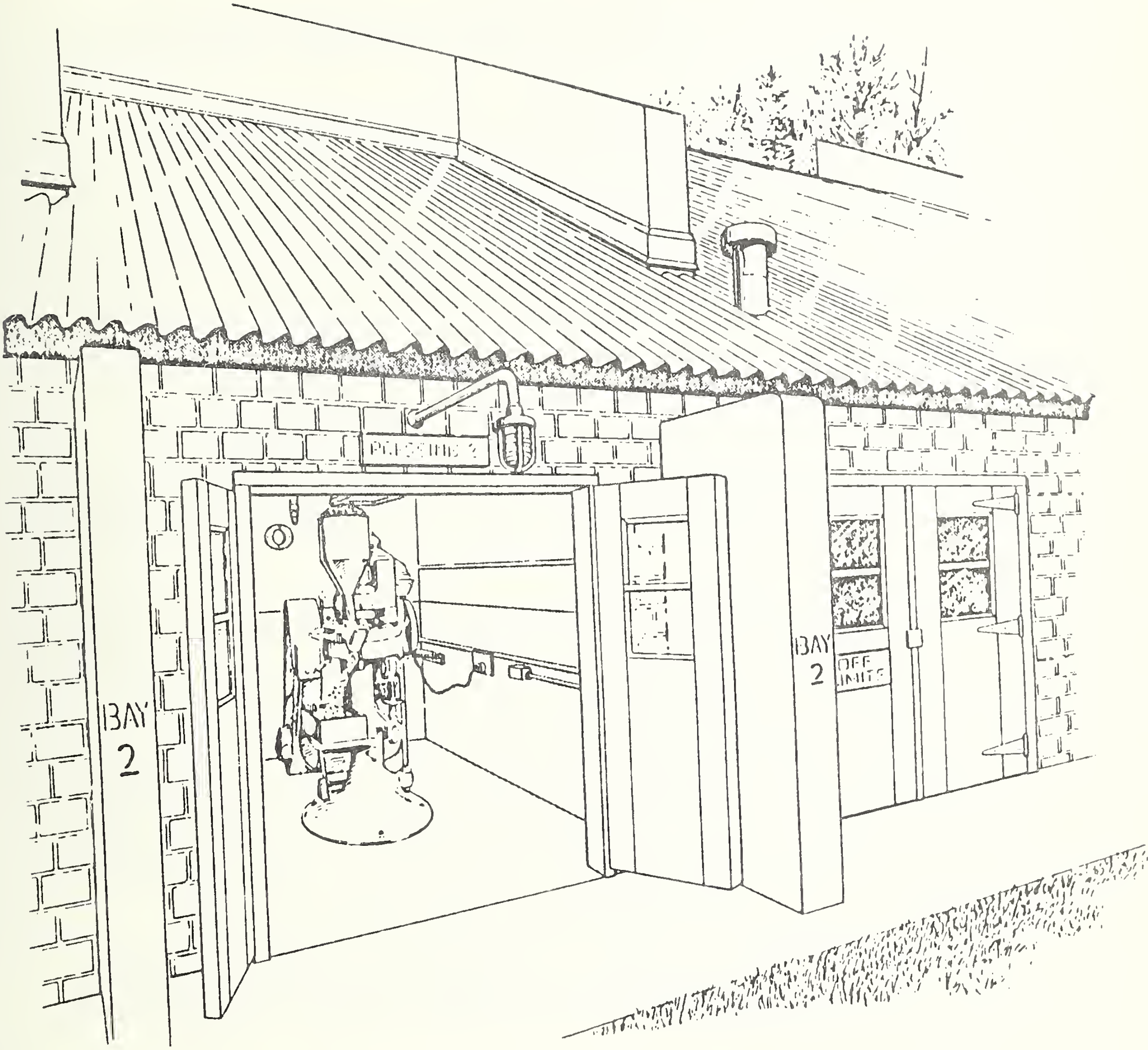
Source: Courtesy of Hamill Manufacturing Company, Division of Firestone. Note worker protection from toxic powder.

FIGURE 2-13. A TYPICAL PROPELLANT BLENDING INSTALLATION



Source: Courtesy of Hamill Manufacturing Company, Division of Firestone.

FIGURE 2-14. A TYPICAL POWER SIEVE MACHINE



Source: Courtesy of Hamill Manufacturing Company, Division of Firestone. Note special building construction and warning systems required for potentially hazardous pelletization operation.

FIGURE 2-15. A TYPICAL PROPELLANT PRESSING AND PELLETIZING OPERATION

- Related materials handling equipment such as: hoists, numerous in-process storage racks, trays, tables, and transfer trucks.

The remainder of Building No. 1 is the propellant assembly area, which with storage space occupies about 12,000 to 15,000 square feet. Current plans call for this to be a highly automated facility. The machines which perform the packing of the various types of pellets into the propellant cartridge along with separator screens and filters are shown in Figure 2-16 for the passenger's side, i.e., the cylindrical cartridge. This specially-designed propellant load line machine, which is located in the gas generator cartridge assembly area, represents a major capital investment. This investment is not recoverable if markets for air bags fail to materialize because of the customized nature of the machine. A fairly substantial portion of the propellant assembly portion of Building No. 1 is devoted to packaging (temporary) and storing the gas generator cartridges, before they move on to Building No. 2.

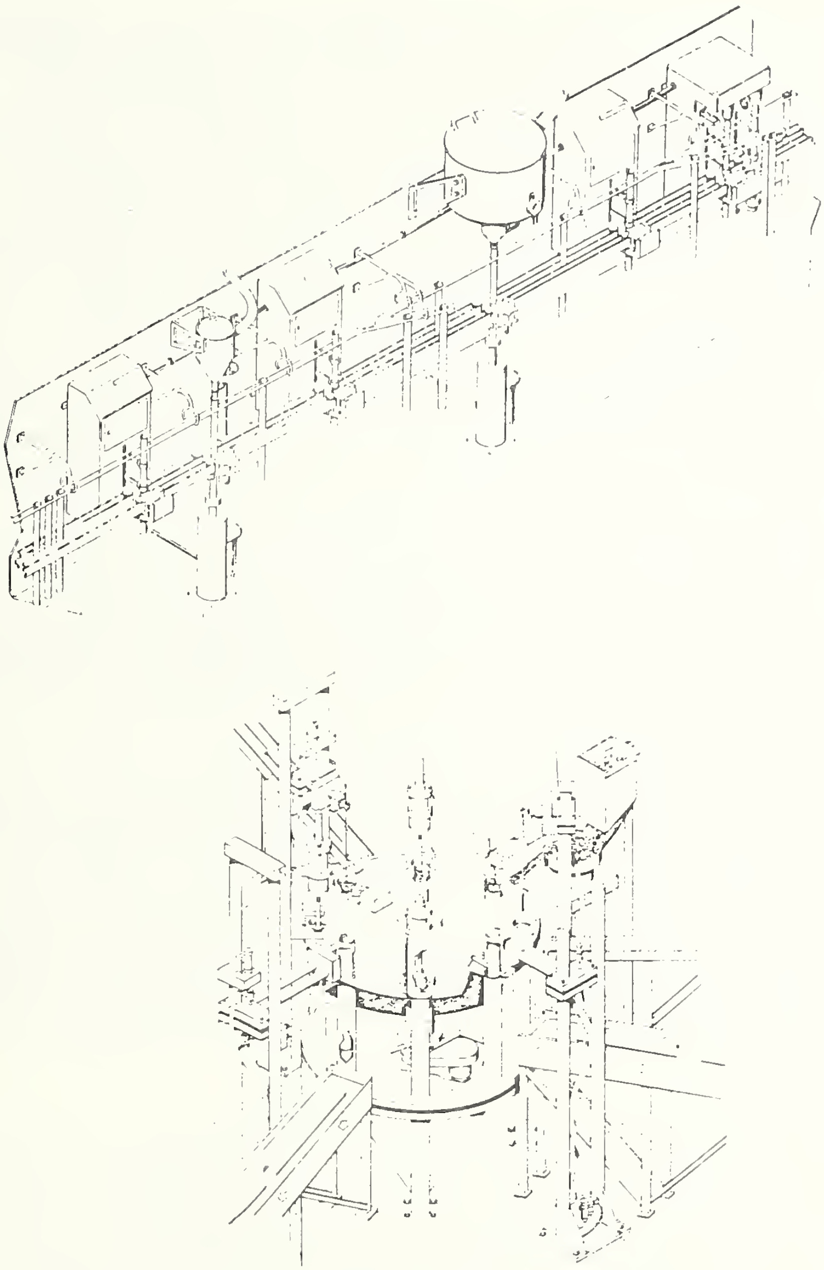
2.5.3 Typical Cushion/Inflator Subassembly/Final Assembly Facility

Building No. 2 shown on Figure 2-12 is the facility which merges the gas generator cartridge, the initiator squib, the air bag(s) and the metal parts of the canisters and housings into a complete cushion and inflator assembly for shipment to the automobile manufacturer. At the level of detail shown in Figure 2-12 the facility is more or less generic, i.e. typical of either the driver's side or passenger's side air bag system. Building No. 2 will vary in size from 50,000 square feet to 85,000 square feet for producing 75,000 units per year. Expansion to meet demands of twice that annual volume in single shift operation would require an additional 30,000 to 40,000 square feet primarily in the final assembly area as shown with dotted lines in Figure 2-12.

Building No. 2 has two major parts as follows:

- An area for manufacturing subassemblies and housing support facilities for quality control, inspection and destructive testing of samples drawn from the production line

- A final assembly area, which includes the air bag manufacturing area, finished and raw goods storage, and shipping/receiving.



Source: Courtesy of Hamill Manufacturing Company, Division of Firestone. Drawings are intended for illustrative purposes only; the details of these specially built machines are considered proprietary by the manufacturer, since they are specific to passenger's side cartridge assembly process and Hamill design for cushion and inflator assembly.

FIGURE 2-16. TYPICAL PROPELLANT LOAD LINE PROCESSING EQUIPMENT FOR PASSENGER'S SIDE GAS GENERATOR CARTRIDGE

The relative size of these two portions of Building No. 2 is a strong function of the specific air bag system design. For the driver's side air bag about 25,000 square feet would be set aside for manufacturing of stampings, which are inherent to the construction of that design. Construction of subassemblies for the passenger's side air bag was described previously in detail in Figure 2-8. In this case, subassemblies are made from cylindrical steel tubes, wire mesh and filter material, which are cut to size, deburred, finished and drilled as required. The space requirement in this case, even with allowances for the squib subassembly and separation of the manufacturing of inflator assemblies into three separate rooms, is about half that required for stamping, finishing, and preparing equivalent pieces for the driver's side air bag. A substantial portion of the subassembly/support facility space is devoted to support facilities such as quality control/inspection, tool room, and test labs. This space, which is well in excess of 10,000 square feet, primarily results from the high level of quality and reliability required by the automobile manufacturer. As a consequence fully one-third of the total manufacturing staff complement in Building No. 2 are devoted to inspection, sampling and destructive testing of components in process or finished assemblies. The percentage of finished systems that must be tested destructively to assure reliability of the system as installed in the vehicle remains a subject of discussion between suppliers and various automobile manufacturers at this time. It is, however, relatively safe to speculate that consumers who receive one air bag set in their car, will be paying for the manufacture of more than one set, since destructive testing of samples is the only way to assure statistically that the installed device will be safe and reliable.

In Figure 2-12 the final assembly area includes an area of 5,000 to 8,000 square feet devoted to air bag construction and related raw goods and material in process storage. This area may be larger for the passenger side system (two bags per unit) but probably smaller for the driver's side air bag. Overall space requirements for final assembly, as shown in Figure 2-12, including hold areas and rework areas could be about 30,000 to 50,000 square feet. In final assembly separate lines are maintained for each automobile manufacturer, who will mandate complete separation of their component throughout the assembly process and can be expected to station in-plant quality control personnel at the supplier's plant.

Although it will vary by system design, final assembly will be labor intensive. Similarly, air bag construction even in volume quantities will be labor intensive. A typical air bag construction area might contain two or more larger layout/cutting tables, 10 to 15 industrial grade sewing machines, edge-sealing equipment, and areas for stitching inspectors as well as folding and storage space. If the market for air bags is assured and designs stabilize, suppliers may invest in automated sophisticated cutting and heat sealing equipment and other automation approaches being pioneered in the textile industry. Estimates of capital investment in equipment projected at this time do not include such costs. The final assembly process is fairly straightforward (see Figure 2-8 for overview). It involves constructing the final inflator assembly housing (diffuser) and mating with the inflator and squib subassemblies. Perhaps the most specialized equipment required is that for attaching the air bag(s) and folding it to the manufacturer's specification.* The final steps involve adding the assembly's overall housing/reaction plate and packaging the device for shipment.

2.5.4 Capital Requirements

The capital investment required for the typical inflator and cushion assembly plant shown in Figure 2-12 has been estimated to be seven to nine million dollars. This includes both building/land costs and equipment costs, and assumes purchase of new land, building new facilities, etc. In reality, manufacturers would attempt to lease facilities and utilize excess plant capacity if any were available.

Building/Land Costs

Building/land costs are a function of many variables including geographic location, type and quality of materials, and size. Building and land costs for the inflator and cushion assembly facility shown in Figure 2-12 are estimated to be five to eight million dollars. This is based on a plant size of 150,000 square feet located

* Air bag performance depends on folded configuration; automobile manufacturers have patents pending on various folding techniques and will each specify different folded configurations.

in a suburban Michigan area. It is also based on a building constructed of steel and reinforced concrete both in the walls and floor. Substantial land costs are associated with the plant because of remote storage required for certain chemicals. Also, portions of the plant which package chemicals require explosion contingency-type construction and evacuation fans/filters to remove toxic particulates. Table 2-1 presents a detailed breakdown of costs for both the driver's side and the passenger's side air bag inflator/cushion manufacturing costs.

Equipment Costs

Equipment costs are also a function of many different variables including the number of different operations/functions the equipment is capable of performing, the sophistication of the machinery (i.e., computer versus manually controlled), and the amount of customized equipment utilized. A summary of the types of equipment that could be employed in a high volume air bag system manufacturing plant is shown in Table 2-2. Total equipment costs for the plant shown in Table 2-1 are estimated to range from $1.0 to $2.3 million by potential manufacturers. Detailed equipment cost build-ups were not attempted to verify these estimates, because these depend upon type of air bag system design and the amount of customized automated processing equipment utilized. A review of Table 2-2 indicates that equipment costs estimated by potential manufacturers appear to be reasonable.

Not included in Table 2-2 are such equipment as laser beams and minicomputers which could be used to cut the nylon fabric before it is sewn into bags. This technique/equipment is currently used in the apparel industry to cut complex patterns in high volume, but air bag production levels at least initially do not justify this major development investment.

TABLE 2-1. ESTIMATE OF BUILDING AND LAND COSTS

Inflator/Cushion Assembly Type	Size	Cost	Comments
Driver's Side			
- Building No.1	35,000 ft^2*	$ 2,450,000	Special blast-proof construction, ventilation, etc.; assume $70/$ft^2$
- Building No.2	85,000 ft^2*	4,250,000	Standard light shop facility; assume $30/$ft^2$
- Land	30 acres	1,300,000	Large land area required to keep Building No. 1 remote
- Equipment	---	1,000,000*	Manufacturer's estimate
TOTAL		$ 9,000,000	
Passenger's Side			
- Building No.1	21,300 ft^2**	$ 1,491,000	Special blast-proof construction, ventilation, etc.; assume $70/$ft^2$
- Building NO.2	45,000 ft^2 to 80,000 ft^2**	2,250,000 to 4,000,000	Standard light shop facility, assume $50/$ft^2$
- Land	30 acres	1,300,000	Large land area required to keep Building No. 1 remote
- Equipment	---	1,800,000** to 2,300,000	Manufacturer's estimate
TOTAL		$ 6,841,000 to $ 9,091,000	

* Estimated by potential manufacturer.

** Estimated by Booz, Allen based upon data provided by potential manufacturer.

NOTE: It is believed that summary level facility site requirements obtained from a potential driver's side supplier and used directly are high.

TABLE 2-2. EQUIPMENT REQUIREMENTS OF A TYPICAL AIR BAG PRODUCTION MANUFACTURING PLANT

Building or Portion of Plant	Type of Equipment	Comments
Building No.1: Propellant		
. Manufacture Propellant	. Power Sieve	One or two required at $25,000 each (see Figure 2-14).
	. Power Grinder	One required
	. Propellant Blender	One to three required at $20,000 to $35,000 each (see Figure 2-13).
	. Pelletizer Presses	Probably require 5 or more at a cost of $30,000 to $40,000 each (see Figure 2-15).
	. Miscellaneous	Ovens, scales, chemical labs, material racks and materials handling equipment.
. Propellant Cartridge Assembly	. Wire Cloth Weaver	
	. Wire Cloth Winder	
	. Wire Cloth Slitter/Die Cutter	
	. Automated Propellant Load Line or Various Assembly Fixtures	See Figure 2-16; customized equipment portions of loading line could cost $200,000 to $300,000 installed, or more.
Building No.2:		
. Subassembly/ Final Assembly	. Cloth Weaving	Usually purchase cloth
	. Cloth Coating	Vulcanize (neoprene) driver bag only
	. Cloth Cutters, Heat Sealers	Manual, but could be done later by laser
	. Industrial Sewing Machines	10 to 15 required
	. Presses for Stamping, Crimping	30, 60, 80 and 140 ton presses required
	. Lathes	Amount of machining depends on design
	. Drill Presses	
	. Various Finishing and Surface Treatment Equipment	Degreaser, Phosphatizer, Paint Booths
	. Bag Folding Machines	Customized machines, at least 3 required
	. Pipe Cutters	For passenger side only
	. Miscellaneous Transfer and Materials Handling Equipment	Varies with layout of plant, primarily on final assembly line
	. Welders	Limited usage
	. Inspection Gauges, Scales, Tools	Extensive inspection required, at many process stations
	. Quality Test Lab	Destructive testing required on line samples

2.5.5 Labor Requirements

Potential manufacturers of air bags supplied the following rough estimates for personnel required in manufacturing:

- Driver's side air bag: Only about 50 people initially (1981 production)

- Passenger's side air bag: About 75 people in Building No. 2, of which 20 to 25 are related to quality control.

If a total complement of about 100 people is utilized for the typical plant shown in Figure 2-12 (Buildings 1 and 2), then Table 2-3 provides a rough breakdown of personnel by skill level, process area, or function.

The above estimates are based upon a traditional type of manufacturing organizational hierarchy typical to Detroit and the auto supplier industry. The fairly high percentage of laboratory and inspector personnel is typical of the air bag industry, which must package hazardous materials and assure an extremely high level of product reliability.

TABLE 2-3. LABOR REQUIREMENTS OF A TYPICAL AIR BAG PRODUCTION MANUFACTURING PLANT

Title, Function/Process Area	Workforce
Plant Manager	1
Supervision (Production/ Quality)	4
Chemical Laboratory and Quality Test Laboratory	4
Inspectors*	15
Propellant Manufacture and Assembly Workers	8-12
Air Bag Production Workers	10-15
Metal Subassembly Worker	8-10
Final Assembly Line Worker	12-18
Skilled Tradesman/Maintenance of Equipment	3-5
Materials Handling/Shipping	4-6
General Maintenance	4-6
Staff Personnel**	4
TOTAL	77-100

* Some of these may be from automobile manufacturer.

** Safety officer, production staff engineer, quality control analyst, etc.

2.6 ECONOMIES OF SCALE IN AIR BAG MANUFACTURING

There has been much discussion of the potential economies of scale that would result after model year 1981, as air bag production rates would increase from perhaps 50,000 vehicle units per year (1981) up to and perhaps exceeding 1,000,000 units per year. In a letter of March 8, 1979 to NHTSA,* Talley Industries, a potential supplier of the driver air bag module, presented the information employed to construct Figure 2-17 . The estimate was based on the following:

- A driver module similar to that shown in Figure 2-2A
- A simple basic configuration module, i.e., all automobile manufacturers utilize same hub-mounted configuration
- Radio Frequency Interference (RFI/EMI) issue of electrical initiators not addressed
- No adjustment for future inflation, June 1978 economics used to establish base prices
- Quantity of 5,000 units per year used to establish base price.

The plot displays a ratio of 4:1, in part due to Talley's presumably conservative estimate of a 5,000 unit per year baseline. However, even if first year shipments were 30,000 units, which would be more consistent with "typical" plant discussions of this report, a price ratio of 3:1 is shown between first year price and the very high volume production price. A very important point is the fact that this plot is appropriately labeled as price, <u>not manufacturing cost</u>. The reason for the sharp decline in price with increased production is really twofold as follows:

- Actual economies of scale in manufacturing learning curve improvements as the new process becomes more familiar; potential for higher levels of automation at higher production volume.

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* From John A. Drexler; Director, Program Management/ACRS, Talley Industries of Arizona, Inc. to Guy Hunter, Office of Vehicle Safety Standards, Crashworthiness Division, NHTSA.

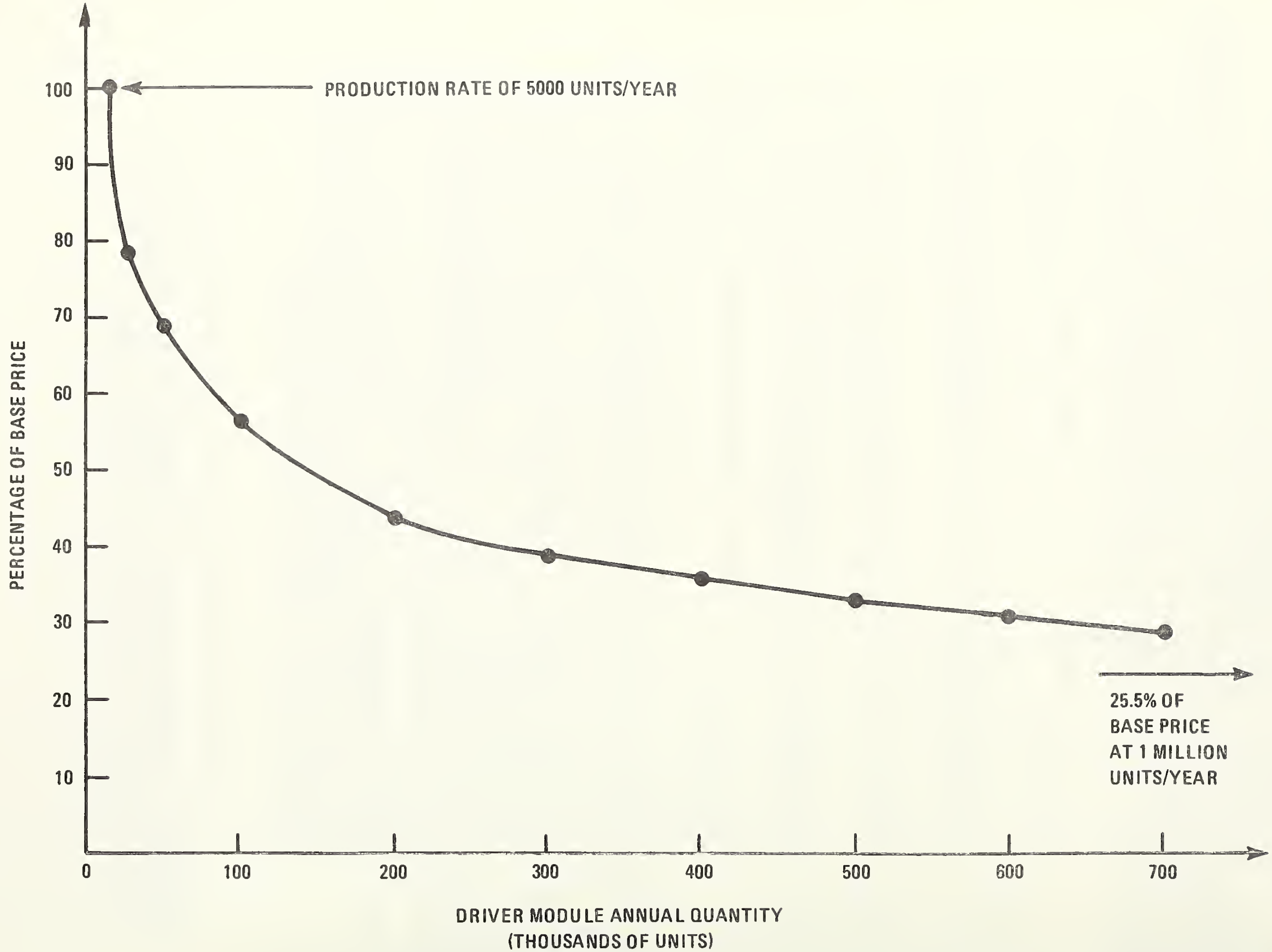


FIGURE 2-17. MANUFACTURER'S ESTIMATE OF ECONOMIES OF SCALE IN DRIVER MODEL AIR BAG PRICE

- The level of risk and uncertainty that were assumed in arriving at an initial baseline price. If risk is high a prudent businessman seeks a high rate of return on invested capital.

A detailed financial analysis of manufacturing cost related resource data presented earlier in this report might, depending upon assumptions made, yield a much flatter economies of scale curve. This would be misleading.

It is very frankly the level of risk and uncertainty with regard to the air bag market and potential product liability risks that would inevitably cause a prudent businessman to price initial production quantities at the levels currently being discussed. From the potential air bag supplier's viewpoint the following are some of the key risks:

- <u>Market Uncertainty Both in Terms of Size and Timing</u>: The potential air bag market is based on Government regulation, sale trends of automobiles by size class and normal competitive factors. Skepticism of potential suppliers is based upon the following:

    - Uncertainty about Government regulatory will or at least timing given the major controversy being expressed in current public debate about the costs and benefits of air bags

    - The lack of a specific significant quantity order for air bags from any automobile manufacturer for air bags for 1981 models

    - Recent sales trends indicating a strong shift to four and five passenger vehicles which can likely meet passive restraint requirements with a passive belt system, because such vehicles can be equipped with twin front bucket seats.

- <u>Potential Product Liability Problems</u>: There is general agreement that air bags have the potential for generating at least a few potentially costly product liability suits as a result of the following:

    - Failing to deploy in a crash
    - Deploying when there is no crash

- Deploying or exploding when improperly maintained

- Being tagged as a health hazard (sodium azide dust is toxic).

The relatively small supplier firms are concerned by two factors given the potential hazards of the device:

- The rate of escalation of cash judgments awarded to plaintiffs in automotive-related product liability suits such as the Ford Pinto case and others

- The lack of strong assurances from the Federal Government and/or the automobile manufacturers in the form of limitation of liability or pooled risk underwriting.

- <u>Start-up Costs Associated With a Completely New Product</u>: Almost inevitably manufacturers underestimate start-up difficulties for new production lines and products. Air bags are so new and different that potential suppliers probably feel that such costs could be substantial.

- <u>Extremely High Levels of Reliability and Quality Control</u>: These built-in inherent costs are displayed in the relatively high level of inspection, test, and quality control personnel requirements for air bag manufacturing. But it appears at this point that considerable uncertainty exists as to the success of suppliers in being able to meet extremely rigid statistical quality testing certification requirements of the automobile manufacturers. These levels are apparently so high that an initial manufacturing problem that might cause a few first-off-the-line inflator and cushion assemblies to fail, would in a statistical sense require the air bag supplier to destructively test a very high percentage of all subsequent units produced just to "prove" reliability and meet automobile manufacturers' specifications. This risk that quality specifications can become a very onerous stick in the hands of the customer in this particular case should be of great concern to suppliers of air bags.

- <u>Continued Problems in Meeting Performance Specifications</u>: While testing and experience to date have significantly improved the understanding of factors which influence air bag performance, there remain a number of basic technical requirements difficulties with such factors as repeatable onset rate and burn rate performance, repeatable bag inflation configuration as strongly influenced by bag folding, RFI/EMI problems with initiators, and a number of other concerns which are not totally solved in a technical sense.

In summary, potential air bag suppliers face a high risk venture situation. A basic principle of a successful business is that rate return on investment should be balanced with level of risk across all endeavors or product lines. From an air bag supplier's point of view there are clearly a number of significant risks. If initial pricing constraints do not provide for adequate, rapid return, potential suppliers could seek other endeavors.

The above discussion was included in this report in the hopes that it could contribute to the discussion of issues related to air bag system prices. The detailed technical data on manufacturing resource requirements could form a basis for financial calculations, but these are beyond the scope of this report.

* * * * *

3. MANUFACTURING PROCESSES FOR PASSIVE BELT SYSTEMS

3.1 GENERAL

A significant amount of work has gone into the development of passive belt systems. In most of the belt concepts, automatic donning and doffing of the belts with minimum occupant participation is the primary concern. Passive belts of a simple design are currently available on some cars, while design improvements continue to be developed to improve both comfort and performance of passive belt systems.

The major increase in complexity and cost could occur if belt system designs must use pretensioners and motorized retractors to provide occupant protection required to meet regulations. Short of going to pretensioners, it is anticipated that significant performance improvements can be made by utilizing modified belt webbing and an independent gripping of the webbing (the so-called belt grabber). At present, no configuration of a passive belt system using a pretensioner has been marketed or developed beyond the prototype stage. Discussions with current seat belt suppliers indicated a general belief that passive belt systems meeting standards for the foreseeable future would not require complex devices such as pretensioners.

3.2 DESCRIPTION OF ALTERNATIVE PASSIVE BELT SYSTEM DESIGNS

Passive belt systems can be classified into two-, three-, or four-point connection systems. Each is described below.

3.2.1 <u>Two-Point Connection System</u>

The two-point system consists of a single automatic upper torso belt, connected to the door and the retractor. As shown in Figure 3-1, the shoulder belt encloses the occupant as soon as the door is closed. This configuration is found in both the Volkswagen Rabbit and the General Motors Chevette.

With this type of design, the driver or passenger is protected only to the extent of the belt system's capability. This configuration does not prevent sliding underneath the webbing (submarining). In order to prevent this effect and minimize knee injury, the two-point systems are used with knee pads.

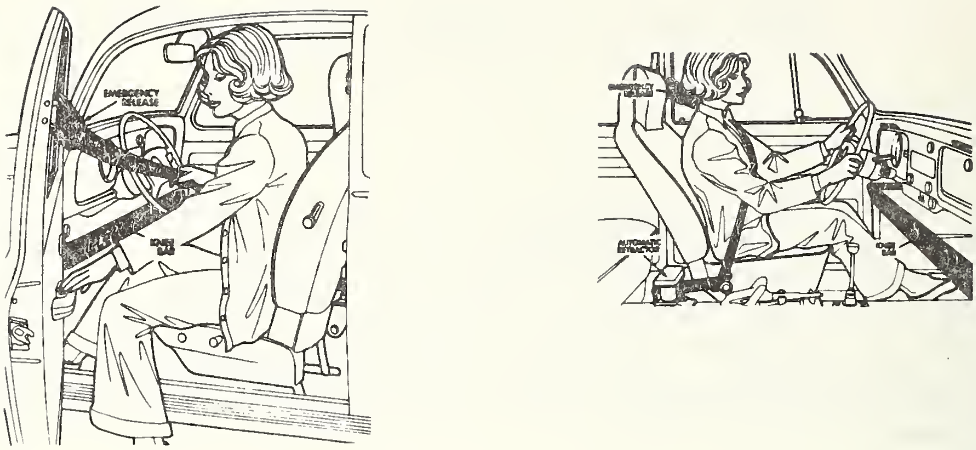


FIGURE 3-1. VOLKSWAGEN TWO-POINT PASSIVE RESTRAINT SYSTEM

In addition to the configuration illustrated in Figure 3-1 where the retractor is located inboard on the floor, alternative designs utilize outboard retractors and D-rings attached to the door (see Figure 3-2). Placing the retractor outboard allows the webbing to fit more comfortably across the body of the occupant. The inboard retractor, on the other hand, with the fixed anchor on the door, causes the webbing to rub the occupant's shoulder whenever he leans forward.

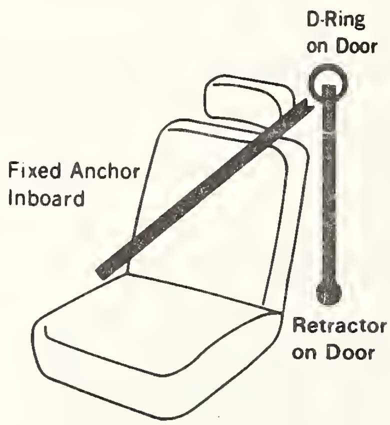


FIGURE 3-2. TWO-POINT PASSIVE BELT DESIGN WITH RETRACTOR AND D-RING ON DOOR

3.2.2 Three-Point Connection System

The three-point system consists of a combined automatic torso belt and lap belt. In most cases, the two automatic belts are permanently attached at some point so that the belts move together. Although this system would appear to inhibit submarining, some of the three-point systems are also used with knee pads. As shown in Figure 3-3, this system is connected at the door, roof rail, and floor pan.

The three-point system illustrated in Figure 3-3, shows the advanced passive, mechanically actuated belt designed by General Motors. The belt slides into place when the car door is closed. Extensive modification of the door and roof rails will be required in order to house the electrical motor and the two sets of sliding rails for this system. Because of its complexity and cost such a system would likely find first application and perhaps only to a limited production in General Motors luxury, performance model automobile.

Various alternative combinations of retractors and their location have been considered for the three-point systems. The sketches in Figure 3-4 show some of these designs.

In Figure 3-4(a), where the retractor is located inboard on the floor, the continuous loop passing through the D-ring tends to cause an increase in pressure on the occupant's body. In Figure 3-4(b), the retractor has been switched to the door side, but this change does not significantly improve belt comfort. Relocating the retractor to the upper door location helps, although it tends to create head interference [see Figure 3-4(c)].

One of the more successful combinations features a double retractor with a fixed webbing juncture. [See Figure 3-4(d).] This system improves the fit and the pressure on the occupant, as long as the D-ring is properly designed.

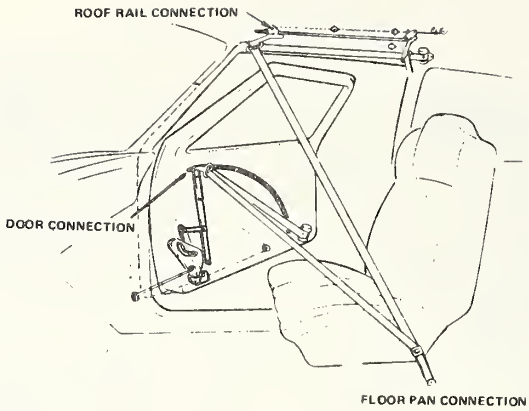


FIGURE 3-3. THREE-POINT CONNECTION PASSIVE BELT SYSTEM

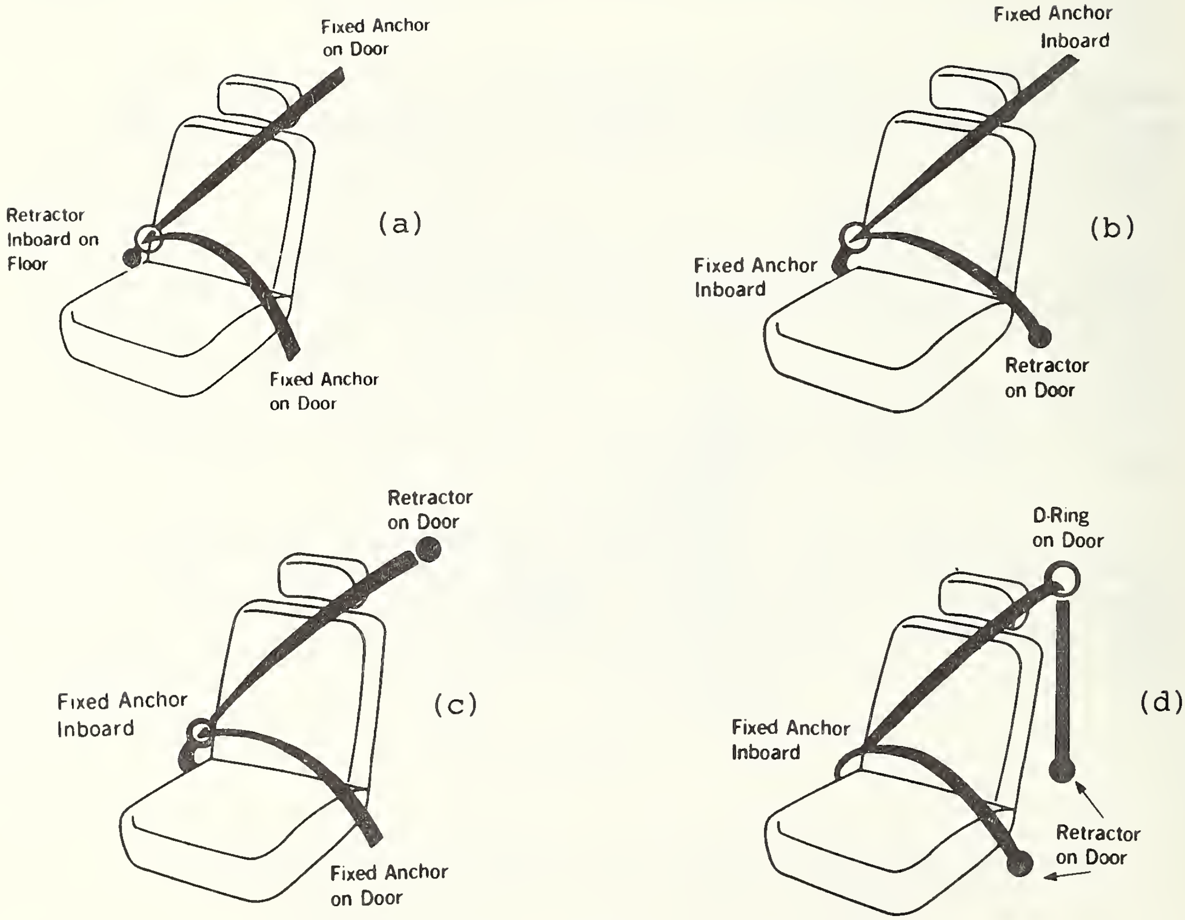


FIGURE 3-4. THREE-POINT SYSTEM ALTERNATIVE COMBINATIONS

3.2.3 Four-Point Connection System

While the two- and three-point systems include the configurations considered by most manufacturers, there are also other designs now in the prototype stage. The four-point system provides upper torso and lap belt restraints utilizing three retractors. As shown in Figure 3-5, the inboard lap belt and shoulder belt retractors are located on the floor, and the outboard lap-belt retractor is connected to the door. The third connecting point, the outboard shoulder belt anchor, is also connected to the door.

The fourth point of connection is on the steering wheel or column. Once the occupant has been seated, the clips are detached and fastened temporarily by using a magnet, stow ring, or stow clip. When detached, the excess webbing is retracted into the two housings and the occupant is restrained.

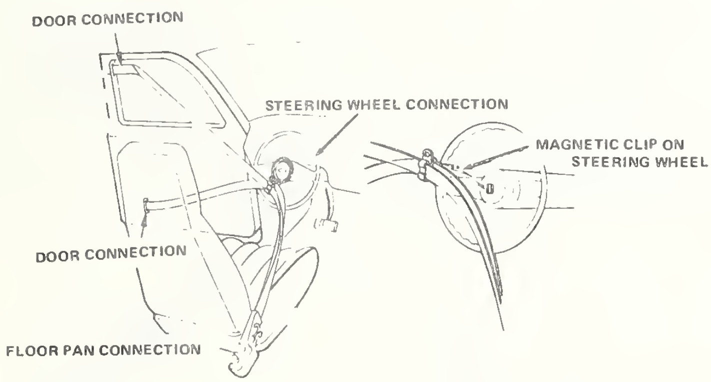


FIGURE 3-5. FOUR-POINT, THREE-RETRACTOR PASSIVE LAP/SHOULDER BELTS

Even if the occupant did not unclip the webbing, the system would still work. On impact the retractor motors would rapidly detach the webbing and hence passively restrain the occupant. This second prototype passive belt system by General Motors does not have the potential for track-sliding failures of the system shown in Figure 3-3, but is also complex.

3.3 MAJOR COMPONENTS OF PASSIVE BELTS

Existing passive belt systems have three major components:

- Belt webbing
- Belt retractor
- Buckle or emergency release.

In addition to these components, advanced design passive belt systems presently in the prototype stages feature components to improve belt tightness during a crash. Major passive belt components are shown in Figure 3-6 and their operations are described below.

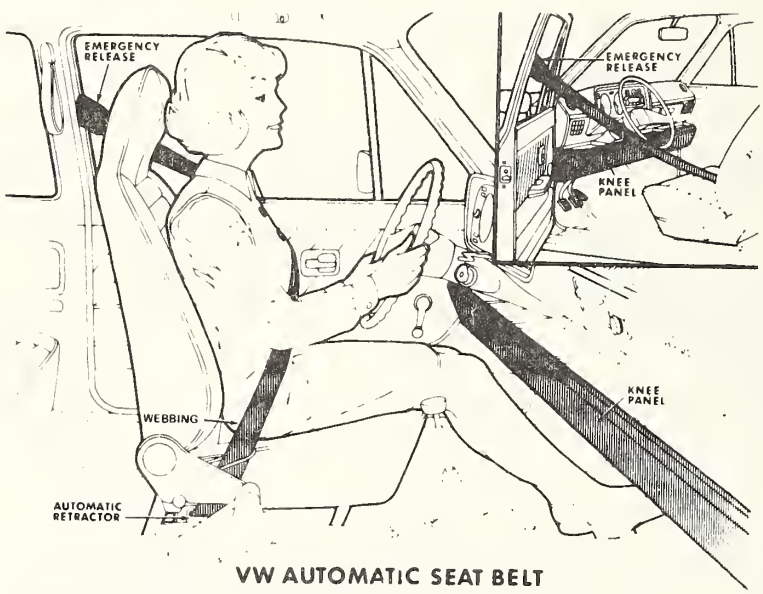


FIGURE 3-6. MAJOR COMPONENTS OF PASSIVE BELT SYSTEMS

3.3.1 Belt Webbing

The belt webbing is the part of the passive belt system which directly touches and, upon impact, restrains the body of the motorist. It is made of a continuous band of tough flexible material designed to bear weight but not to cause injury or discomfort to the motorist.

The webbing operates as a harness. The ends are attached to the frame and/or door of the car, and the mid-part fits diagonally across the motorist's chest from the shoulder to the waist. Thus, the webbing very lightly yokes the motorist into the car. In the event of a sudden stop or accident, the belt prevents the motorist from being propelled forward through the windshield or sideways out of the car.

3.3.2 Belt Retractor

The retractor is a small, spring-powered device which serves two important functions in the passive belt system. First the retractor reels the webbing in and out as the motorist enters the car. Second, it locks the webbing into position when sudden force is applied. As shown in Figure 3-7, the retractor has five components: spool, ratchet wheels, springs, pendulum and pawl, and housing. Each is discussed below.

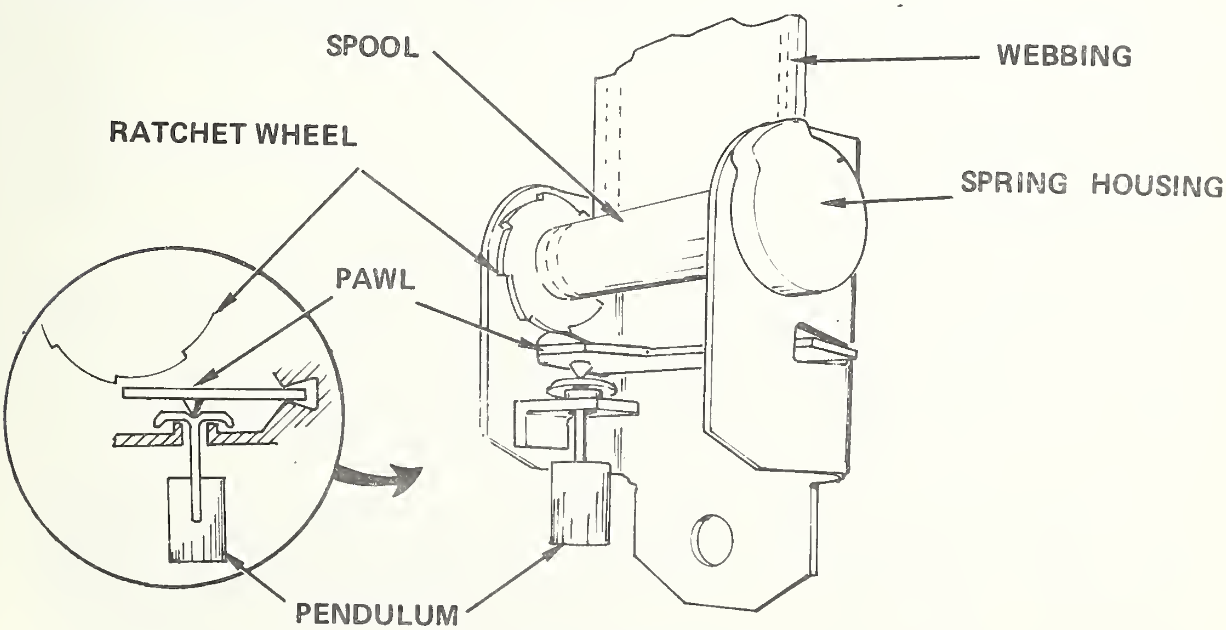


FIGURE 3-7. DIAGRAM OF PASSIVE BELT RETRACTOR

- Spool. The spool is the heart of the retractor. It is a smooth hollow cylinder approximately 2½ inches long and 1½ inches in diameter, and forms a base around which the webbing is anchored and wound. It is usually made of steel.

- Ratchet Wheels. The ratchet wheels are circular steel plates with inclined teeth around their perimeters. They are welded to both ends of the spool and control its motion.

- Spring. The spring provides energy to the belt retractor. It is firmly connected to the ratchet wheel and provides the force and pressure needed to rotate the spool and retract the webbing.

- Pendulum/Pawl. The pendulum is a small lead weight which is suspended from a wire and swings freely, detecting any sudden motion in the vehicle. When the pendulum swings suddenly, it moves a short prong or "pawl" into the teeth of the ratchet wheel thus preventing further motion of the wheel, spool and webbing.

- Housing. The final retractor component is the housing. This is essentially a hard plastic case to protect the retractor mechanism from dirt or other injury.

3.3.3 Buckle

What most motorists know as the "buckle" on seat belts, has become an "emergency release" on passive belts. The whole point of the passive belt system is that the motorist does not have to "buckle up." However, the basic function of the buckle is still served, that of joining the two ends of the webbing together while providing a point of voluntary exit for the motorist. After the webbing, the buckle is the most standardized component of the passive belt system.

The buckle, or emergency release, consists of two parts, the clasp and the prong. Either part, or both may be fitted with a plastic grip. The prong is a narrow smooth projectile which fits into the clasp. It is held in place by a spring activated latch which locks into place upon insertion of the prong. Figure 3-8 shows a diagram of a passive belt buckling device.

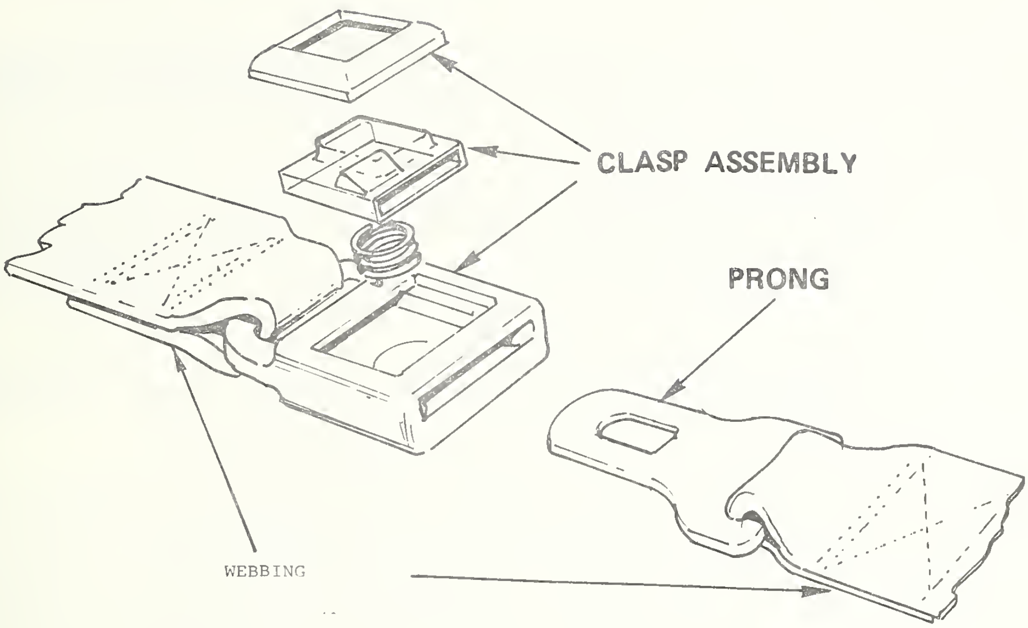


FIGURE 3-8. PASSIVE BELT BUCKLING DEVICE

3.3.4 Pretensioner and/or Belt Grabber

A major problem with future passive lap and shoulder belts utilizing retractor spools is belt slack. In this respect the manual belt length adjuster of static belts is optimal as it is mechanically simple and lightweight. But since people do not like to be tightly restrained they avoid properly adjusting static belts. Because belt length is inherently longer on passive systems, slack becomes a problem.

The retractor belt, in principle, provides for automatic length adjustment without slack. But it has one basic deficiency: when it is crash-loaded, not only the webbing on the occupant's body but also the webbing portion between the D-ring and retractor is elongated. Furthermore, the portion which normally is rather loosely wound up on the retractor reel must first be driven tight around the locked reel before a restraint force can develop. This "spool-out" and additional elongation result in some 10 to 20 cm of webbing running out which means an equivalent additional forward displacement of the occupant's shoulders and head, and consequently an additional injury risk. In general passive belt systems with substantial additional webbing wound up in the retractor tend to be more subject to spool-out and elongation.

There are basically two approaches to reducing this problem. In order of increasing complexity and cost these are:

- A belt grabber—A device built into the retractor mechanism, which senses belt "spool-out" and clamps the belt not the spool. This is a relatively simple and inexpensive safety performance enhancing feature.

- A pretensioner—A somewhat more complex device, which automatically tightens belt system around occupant very shortly after accident begins.

The pretensioner can be added to retract a certain length of webbing during the first few milliseconds of a crash to compensate for the "spool-out" and indirect static slack due to, for instance, thick clothes or extra space between the belt and the human body. As shown in Figure 3-9, pretensioner assembly consists of a crash sensor and a propulsion unit, such as a gas generator, both known from air bag technology.

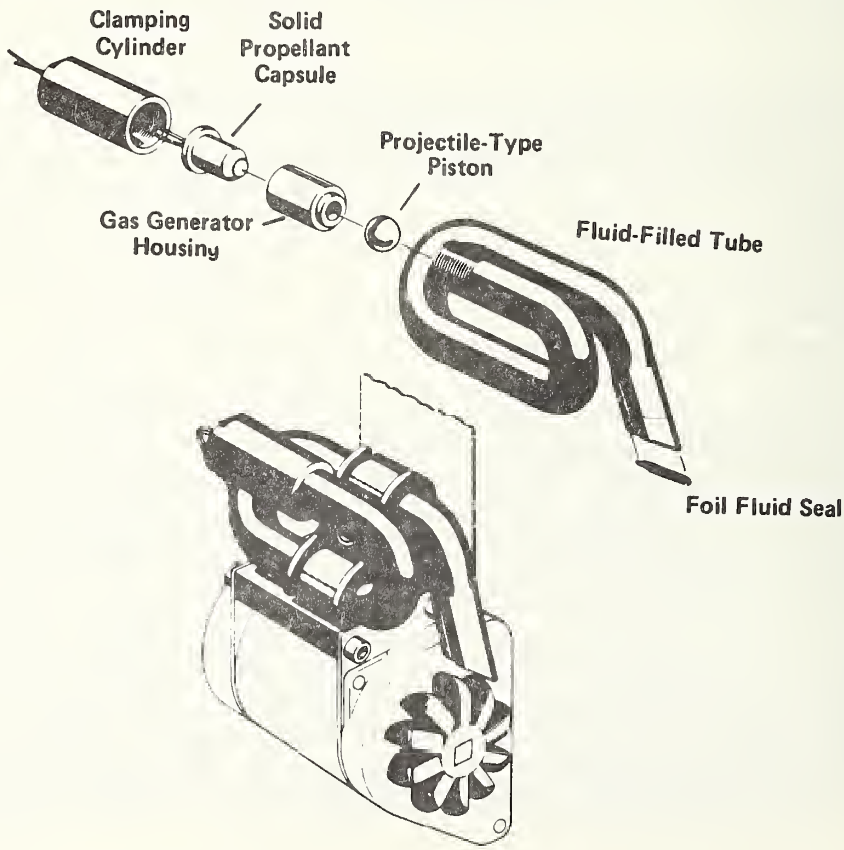


FIGURE 3-9. DIAGRAM OF A PELTON WHEEL PRETENSIONER

Pretensioners are not presently manufactured for passive belts. They have been included in certain prototypes which have been suggested for mass production. The following discussion of pretensioners is presented for completeness only. As will be seen such devices are somewhat complex and probably expensive. One design applies a rapid backward rotation of the retractor reel thus not only anticipating the "spool-out" but also absorbing additional indirect static belt slack.

Two propulsion mechanisms have been proposed:

- One similar to a rotary engine driven directly by admitted gas which is rapidly generated from a solid propellant

- One similar to a Pelton turbine wheel driven by water which is propelled toward the wheel by a gas generator as mentioned above.

The whole system has to be designed to survive vibration, mechanical shocks, thermal stresses, humidity and corrosion. A permanent automatic control (self-monitoring) of all electric circuitry during car operation can also be provided.

As shown in Figure 3-9, the Pelton wheel pretensioner has several components:

- Gas Propulsion Unit
    - Clamping cylinder
    - Propellant capsule
    - Generator housing
    - Projectile

- Fluid-Filled Tube

- Pelton Wheel
    - Wheel
    - Shaft.

The pretensioner is activated when a sensor in the vehicle firewall detects an impact. Solid propellant contained in a capsule is ignited by a squib. The explosion forces a round projectile-type piston into the fluid-filled tube. The moving piston pushes the fluid through the tubing until it is ejected and hits the blades of the Pelton wheel. The wheel then turns a reel to retract the belt firmly against the body of the motorist.

Although it has yet to be definitively proven in development testing on specific pre-production prototypes of 1983 and 1984 models, it appears at this time that passive belt system performance standards may be achievable on many models without the need for pretensioner devices. For completeness in the manufacturing cost analysis which follows, however, a summary description of manufacturing processes required for such a component are included.

3.4 DESCRIPTION OF THE PROCESSES USED TO MANUFACTURE PASSIVE BELTS

This section explains the detailed processes which are used in the manufacture of four passive belt components:

- Webbing
- Retractor
- Buckling Mechanism
- Pretensioner (may not be required).

In final assembly, these components are joined, assembled and permanently attached to the car. The first component, webbing, is the simplest and most standardized of the belt components. The next simplest component is the buckling mechanism. The retractor and pretensioner vary considerably in design and manufacture among different suppliers. There are also subtle variations between make/model applications from the same supplier to fit the specific needs as specified by automotive manufacturers. This "tailoring" of seat belt systems to specific makes/models makes it difficult for seat belt manufacturers to achieve significant economies of scale in mass production manufacturing of seat belts. For example, the geometric, mounting and performance constraints lead to the need for a large number of different retractor designs, although all are functionally similar.

3.4.1 Manufacture of the Belt Webbing

Manufacture of the belt webbing begins with a nylon compound which is extruded through a die with a small aperture to form nylon fiber. As shown in Figure 3-10, the nylon fiber is then stretched to give it the necessary high tensile strength. The stretched fibers are woven into long webbed nylon strips, and finally cut into separate webbed belt lengths and the cut ends are heat sealed.

3.4.2 Manufacture of the Retractor

The passive belt retractor has four principal components:

- Spool
- Ratchets
- Pendulum
- Housing.

WEBBING

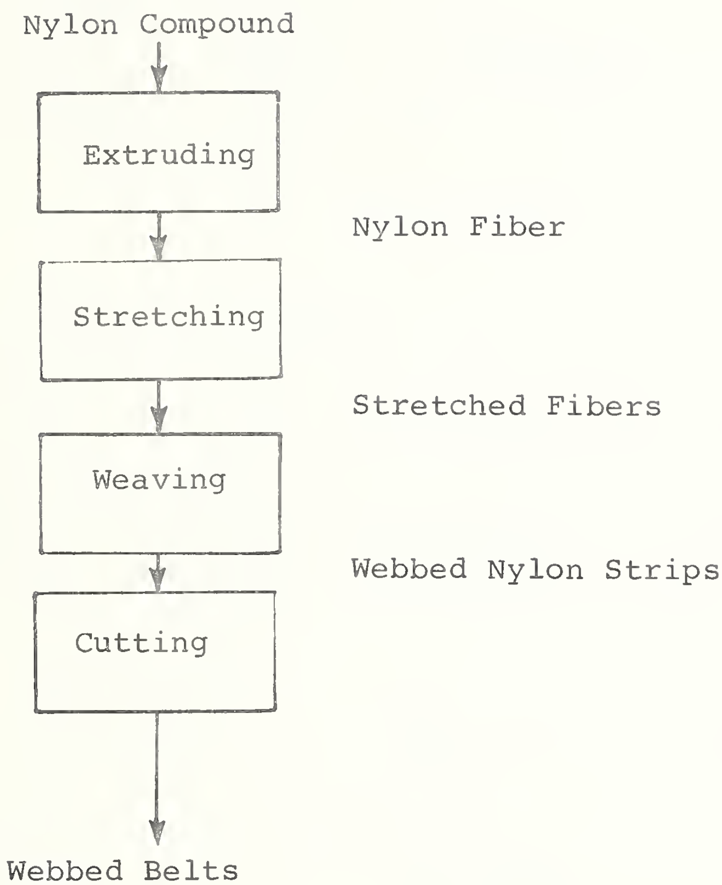
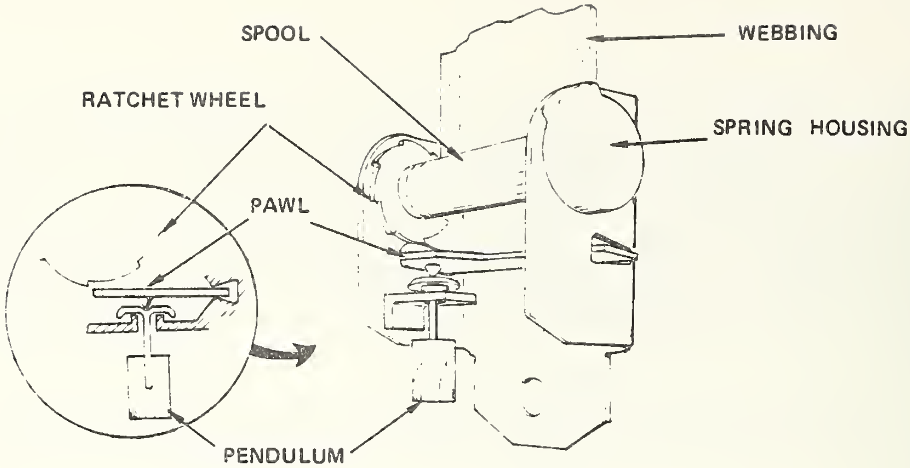


FIGURE 3-10. MANUFACTURING PROCESSES FOR BELT WEBBING

These are manufactured from steel, lead, and plastic using, among others, the processes of blanking, stamping, die casting and blow molding. The processes used in manufacture of the retractor are outlined in Figure 3-11 and are explained in detail below.

Spool

The retractor spool serves as a reel around which the belt webbing is wound. The spool is manufactured by shaping steel into a hollow cylinder approximately 2½ inches long and 1½ inches in diameter. One of the most common techniques



RETRACTOR

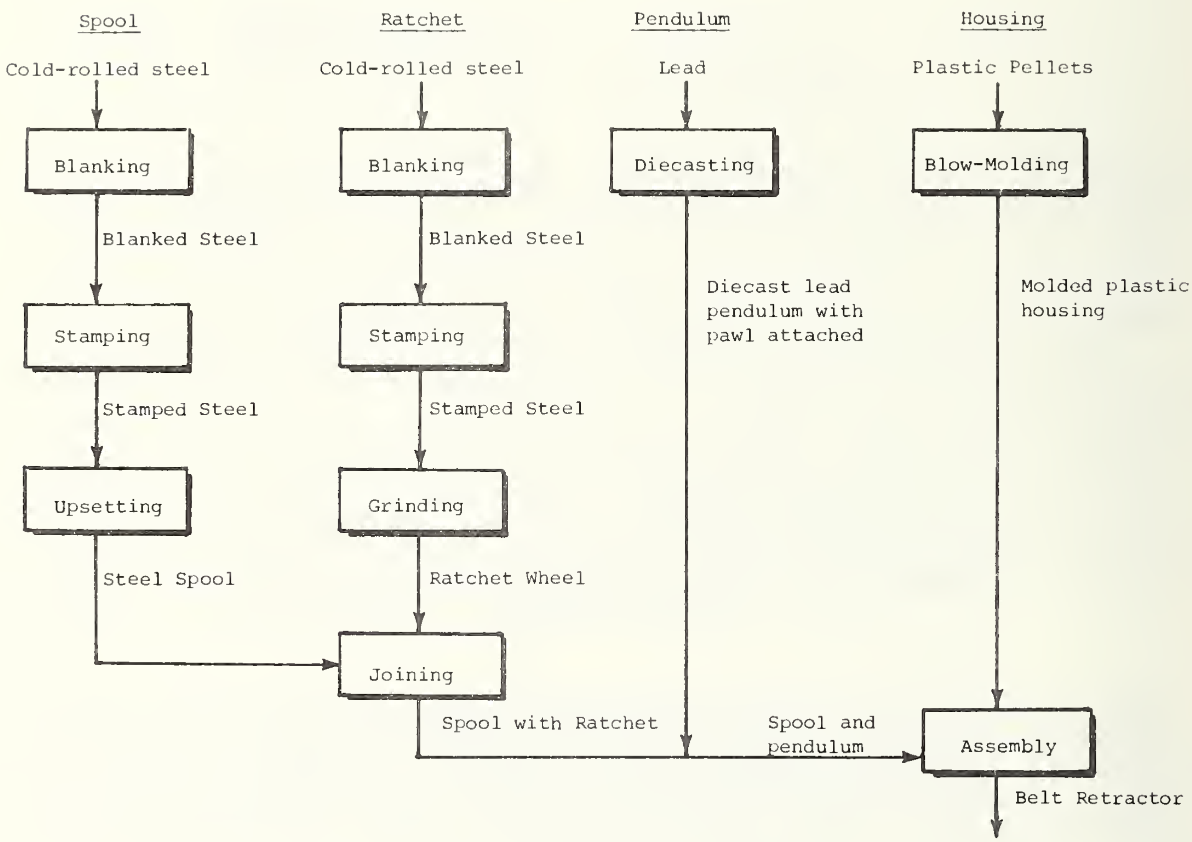


FIGURE 3-11. FLOW DIAGRAM OF PASSIVE BELT RETRACTOR MANUFACTURING PROCESSES

for shaping the spool, as outlined in Figure 3-11, begins with sheets of cold-rolled steel which are blanked into small rectangular plates or sheets. Each sheet is then stamped so that niches or recesses are made along the two short edges of the rectangular plate. The plate is then upset into a cylindrical shape and the niched edges pressed or bonded together. The spool is now ready for attachment of ratchets to the cylinder openings.

Ratchets

The retractor ratchets are round metal plates with jagged teeth, which are attached to both ends of the spool. As outlined in Figure 3-11, the ratchet is manufactured by first blanking thin cold-rolled steel sheets into round plates. The plates are stamped so that teeth are cut completely around the perimeter. A grinding process is then performed to make the teeth jagged so that they will "catch" when sudden force is exerted. The completed ratchets are permanently joined to the spool through spot welding or other joining techniques.

Pendulum

The third component of the retractor, the pendulum, is the part which "catches" the teeth of the ratchet. The pendulum is a small metal weight suspended from a wire which activates a prong or pawl. The pawl is caught in the ratchet teeth whenever sudden force swings the pendulum. As shown in Figure 3-11, the pendulum is made of die cast lead. It is attached to the ratchet and spool, and the entire assembly is then bolted to the vehicle floorpan or frame.

Housing

The housing for the retractor is a plastic casing which protects the mechanism inside. It is made by blow-molding thermoplastic pellets into a housing mold. The completed housing is snap-fit onto the spool-ratchet-pendulum assembly.

3.4.3 Manufacture of the Buckling Mechanism

The two components of the passive restraint buckle, the clasp and the prong, are both manufactured from steel using the processes of stamping, joining and finishing.

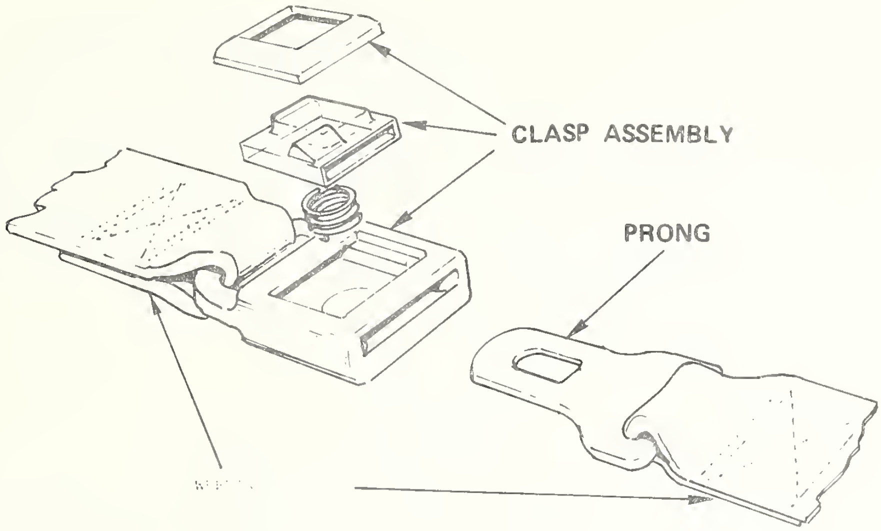
The clasp is covered by a plastic grip, and both the clasp and the prong are attached to the belt webbing. The manufacturing processes are diagrammed in Figure 3-12.

Clasp

The clasp is made by stamping sheets of cold-rolled steel into a double-sided clasp, using approximately six stampings with progressive dies in a single press. The stamped clasp is then folded over and both sides are joined, usually by spot welding. The metal clasp is cleaned and polished to remove burrs or rough spots and then it is chrome-plated. Quality assurance standards require the clasp to be able to withstand a sixty-hour salt spray test without damage from corrosion. After finishing, the clasp is snap-fit with an injection-molded plastic grip, and assembled onto the webbing.

Prong

As shown in Figure 3-12, the prong is manufactured using the same processes as the clasp. Cold-rolled steel is stamped to form the basic prong piece. Each piece is cleaned, polished and chrome-plated, and then assembled onto the belt webbing. The webbing is looped through a hole in the prong, folded back and sewn.



Buckling Mechanism

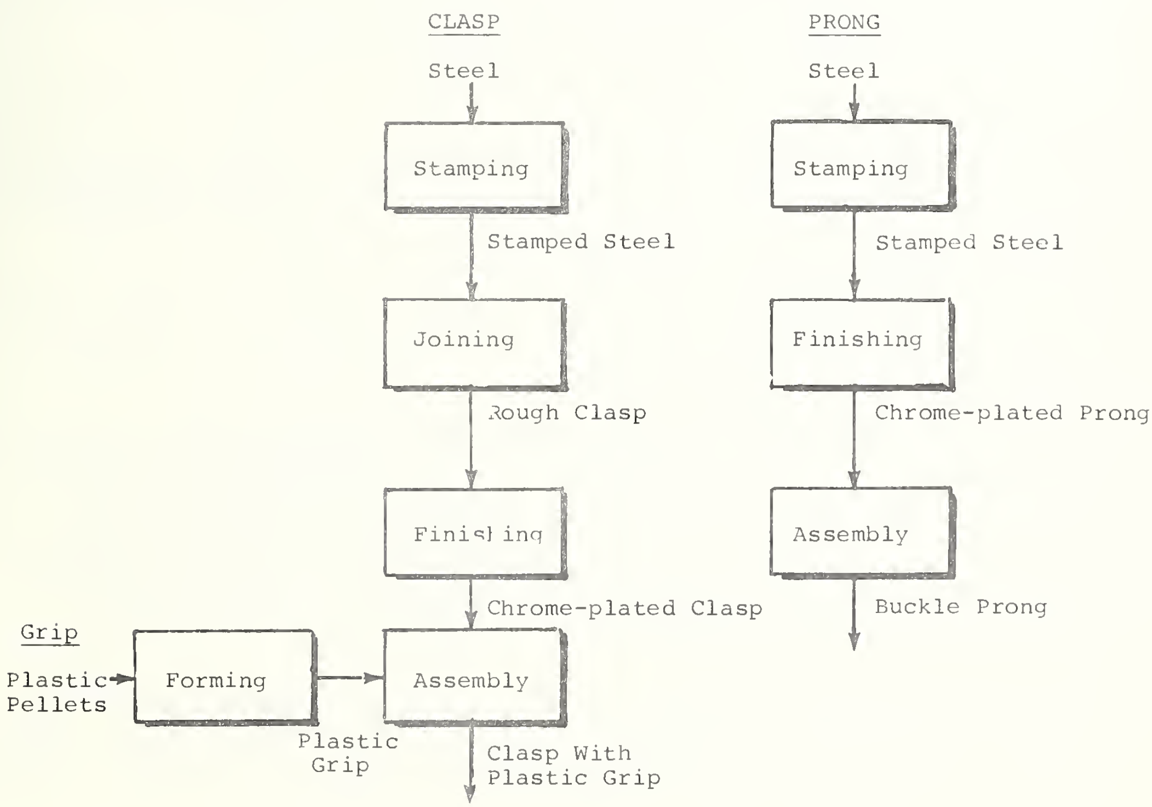


FIGURE 3-12. DIAGRAM OF
BUCKLE MANUFACTURING PROCESSES

3.4.4 Manufacture of the Pelton Wheel Pretensioner

The Pelton wheel pretensioner is the most complex passive belt component. The basic concept of the pretensioner is to add an active device to the belt retractor so that the belt webbing is automatically pulled taut over the motorist upon detection of an impact. The following sections describe a hypothetical manufacturing process for a Pelton wheel pretensioner having the following components:

- Gas Propulsion Unit
- Tube
- Pelton Wheel.

The electrical sensor system which senses the impact and triggers the pretensioner is similar to sensors used in air bag technology, discussed in Chapter 2. The belt retractor used with the pretensioner is the same type of retractor discussed earlier in this chapter. Figure 3-13 summarizes a possible set of manufacturing processes for the pretensioner. This component is nct likely to be in even limited production for some time so Figure 3-13 should be viewed as very preliminary.

Gas Propulsion Unit

The gas propulsion unit combines four steel components which are principally forged and machined:

- Clamping Cylinder
- Propellant Capsule
- Gas Generator Housing
- Piston Ball.

The propellant capsule, gas generator housing, and piston ball are assembled and enclosed within the clamping cylinder, as outlined in the process flow diagram in Figure 3-13. The clamping cylinder is then joined to a liquid-filled tube. The manufacturing processes for each of the gas propulsion unit components outlined in Figure 3-13 are as follows:

- Clamping Cylinder. Steel is extruded or forged to form a hollow cylinder open at both ends. The cylinder is then threaded so that it can be joined to the liquid-filled tube.

- Propellant Capsule. Steel is extruded or forged to form a small steel capsule. Solid propellant is injected into the interior, and the capsule is sealed closed.

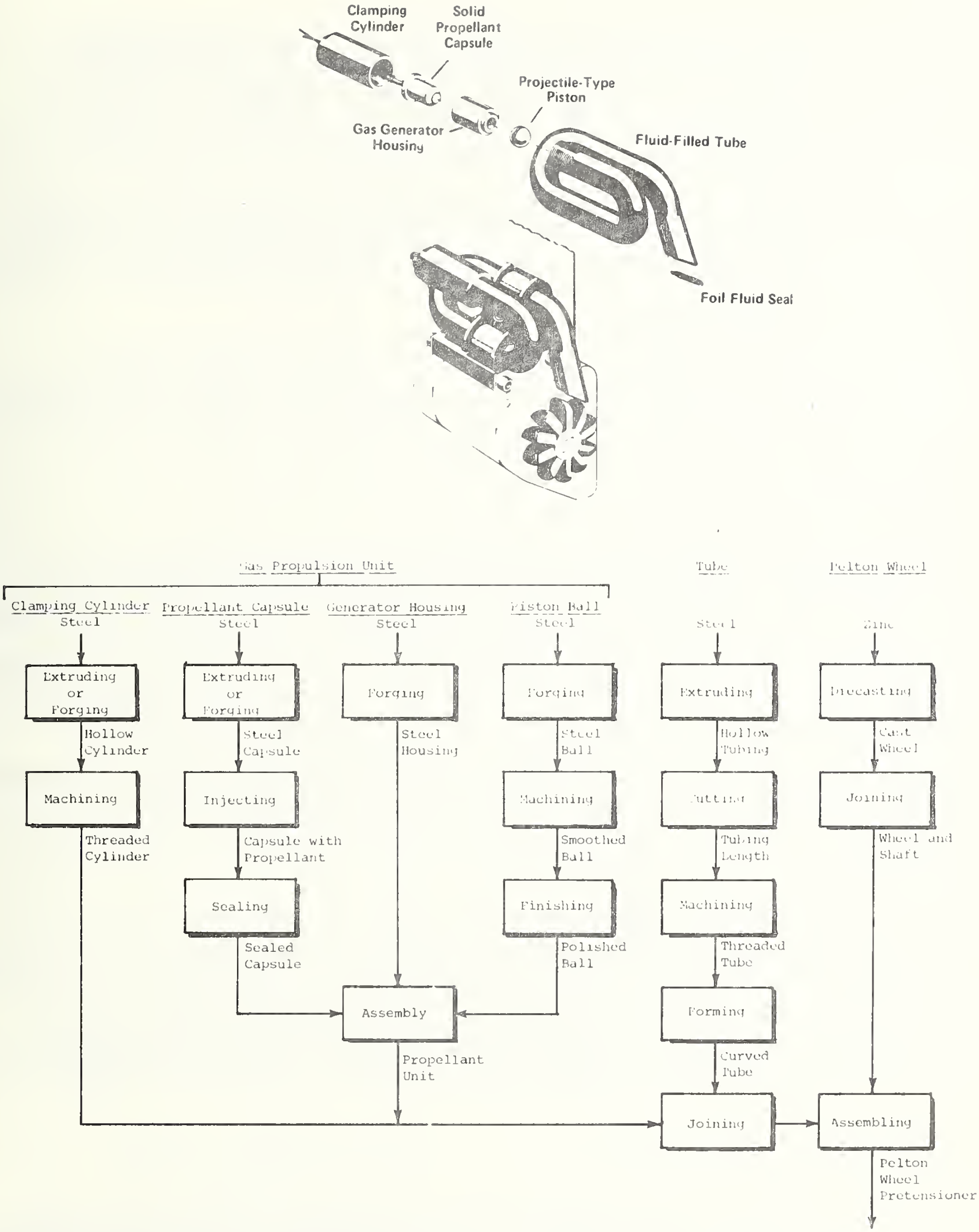


FIGURE 3-13. MANUFACTURING PROCESSES FOR A PELTON WHEEL PRETENSIONER

- Gas Generator Housing. Steel is upset-forged into a cylindrical shape with a slightly larger diameter than the propellant capsule. The propellant capsule is fitted into the gas generator housing.

- Piston Ball. Steel is cold-forged into the shape of a ball and then machined to obtain a smoother surface. The ball is polished before being fitted between the gas generator housing and the liquid-filled tube.

The gas propulsion unit is screwed into the liquid-filled tube and connected to the electrical sensor system by wires. Once it has been activated, the entire unit must be replaced.

Liquid-Filled Tube

The tube section of the pretensioner contains an inert liquid which is forced out onto the blades of the Pelton wheel by the propellant and piston ball. To manufacture the tube, steel is extruded into long poles of hollow tubing. The tubing is cut into individual lengths which are threaded at one end. The tube is pressed into an S-shaped curve with a narrow opening at one end. The opening is fitted with a foil fluid seal and the tube is filled with glycerine or some other inert fluid. The other end of the tube is screwed into the clamping cylinder of the gas propulsion unit.

Pelton Wheel

The Pelton turbine wheel has curved vanes on a central rotating spindle. It is actuated by the impulse of a current of fluid propelled toward the vanes by the gas generator. The wheel is die cast from zinc to provide the thin vanes with close tolerances and high strength, and is press-fit with a shaft which is also fitted to the retractor spool.

Assembly of the Pretensioner

In final assembly, the gas propulsion unit is screwed into the fluid-filled tube. This assembly is then bracketed to a platform which is bolted to the retractor housing. The Pelton wheel and shaft are press-fit into the retractor spool and housing and the entire apparatus is bolted into the interior of the mid-door pillar of the car.

3.4.5 Vehicle Installation of the Passive Belt System

There are many different designs of passive belt systems. The foregoing discussion explained the types of materials and processes used in the manufacture of a typical passive belt system but does not provide an exhaustive description of all systems. Variations may exist particularly in the design and manufacture of the buckling mechanisms and retractor. Similarly, the installation of different passive belt systems varies.

In the final assembly of a typical belt system, the webbing is looped around the retractor spool and tightly stitched or glued in place. The retractor is bolted to the floor pan of the car and the webbing is fed through a guide ring to position it diagonally across the seat. The prong of the belt is locked into the clasp which may be bolted to the door. In the case of a belt system with a pretensioner, the pretensioner would be bolted inside the mid-door pillar and the webbing would be fed along guide rings inside the pillar to be attached to the retractor spool. Thin paneling would be press-fit over the pillar.

3.5 CHARACTERISTICS OF A TYPICAL PASSIVE BELT MANUFACTURING PLANT

The typical passive belt manufacturing plant will have the same characteristics as a present-day seat belt/shoulder harness plant. Manufacturing processes, as previously described, include weaving, stamping, and finishing of the individual belt components. The assembly of a passive belt system is a semi-automated process using a conveyor belt system where each belt fixture moves along the line and short operations are performed. The process is labor intensive and requires large numbers of semi-skilled workers. Most of the production workers in current safety belt plants are members of the United Auto Workers. Seatbelt and passive belt manufacturers must meet the requirements of Federal Motor Vehicle Safety Standard 209 - Seatbelt Assemblies.

3.5.1 Capital Requirements

In discussions with existing seat belt system manufacturers a strong indication was obtained that some excess capacity capacity exists in current facilities. Capital requirements for introduction of the additional components for passive belt systems are very dependent on the specific configurations chosen. As shown in Figures 3-1 through 3-5 a multitude of configurations are possible. There is no single dominant "typical" configuration, hence there is no "typical" plant modification that can be defined. In fact, the changeover to passive belts could probably be accomplished within a typical product improvement cycle.

Building/Land Costs

Introduction of passive belt system manufacturing to replace current seat belt system manufacturing is unlikely to have a measurable impact on overall industry building and land costs, since excess capacity exists today.

Equipment Costs

Many of the processes for manufacturing passive belt systems take place in the factories of vendor firms. These include weaving the nylon on looms into webbing and some stamping operations. The additional parts and tooling needed to accommodate installation of certain passive belt system configurations are the responsibility of the auto manufacturer, not the passive belt supplier.

These costs are highly dependent on specific installation configurations chosen in relation to vehicle interior trim packages and vehicle structural configuration. Thus, there is no "typical" equipment cost and additional costs experienced by the automobile manufacturer are incremental and very difficult to estimate.

Labor Requirements

Changeover to passive belt systems will probably have a minimal effect on labor requirements of the belt supplier. The impact on the installer (automobile manufacturer) will vary substantially by belt configuration and vehicle make/model/body design. Additional requirements would be reflected as additional installers on the vehicle assembly line and in some cases as an additional station. Of course, automobile manufacturers will seek, especially on high volume models, to minimize additional personnel. If they are successful additional labor requirements for passive belt changeover may be minimal.

3.5.2 Summary

The changeover to passive belts could have very little impact on the resources of the existing seat belt manufacturing industry. The only sure increase in resources is the increase in nylon belt quantities because belts will be longer. Other changes will occur but probably not at a rate much more rapid than continuing product improvement trends of the past few years.

4. OUTLOOK FOR PASSIVE RESTRAINT SYSTEMS

4.1 GENERAL

With passive restraint systems planned for introduction beginning in model year 1982, the auto manufacturers and their suppliers are moving toward fulfilling the FMVSS 208 mandate. In fact, three of the auto manufacturers (GM, Ford, and Chrysler) have publicly announced plans to voluntarily install air bags in at least one car line in the 1981 model year, one year ahead of the time when passive restraints will be required by FMVSS No. 208. Similarly, passive belts will be introduced as regular options by major U.S. manufacturers and several foreign manufacturers well ahead of the date required by the 208 standard.

Thus, it appears that progress is definitely being made toward full implementation of the standard. Nonetheless, questions/concerns still remain. One concern is the capability of the supplier industry to meet the demands of the auto manufacturers within the timetable established. Other issues include such items as the effectiveness/reliability of passive restraint systems, the safety of the chemical sodium azide, public acceptance of passive restraints, the problems surrounding cost and maintenance of passive restraint systems and disposal of air bag systems when automobiles are ultimately scrapped.

The purpose of this chapter thus is to discuss these and other factors which affect the outlook for passive restraints. The chapter is divided into the following sections:

- Manufacturers' Plans Regarding Introduction of Passive Restraint Systems
- Material and Component Requirements Dictated by Manufacturers' Plans
- Capability of the Supplier Industries to Meet Manufacturers' Plans
- Other Factors Affecting the Outlook for Passive Restraint Systems.

4.2 MANUFACTURERS' PLANS REGARDING INTRODUCTION OF PASSIVE RESTRAINT SYSTEMS

Assessment of the supplier industries' capability to meet auto manufacturers' demands requires knowledge of the auto manufacturers plans with respect to the introduction of passive restraint systems. A summary of these plans based on discussions with a major supplier of inflator modules (i.e., gas generators) is presented below. Also presented is a summary of the introduction schedule for passive restraints required by FMVSS 208. Based on the information provided in this section, the next section estimates passive restraint system material and component requirements.

4.2.1 Introduction Schedule for Automobiles with Passive Restraint Systems

The schedule for introduction of passenger vehicles with passive restraint systems is clearly specified in the 208 standard. The standard calls for passenger vehicles with wheelbases over 114 inches to have a passive restraint device in model year 1982 and passenger vehicles with wheelbases of 100 inches or more to have passive restraint devices in model year 1983. All passenger motor vehicles, regardless of wheelbase size, are to have passive restraints in model year 1984.

Based on this schedule, it is estimated that (see Table 4-1):

- Approximately 50 percent of the passenger automobiles sold in model year 1982 will be equipped with a passive restraint device
- Approximately 70 percent of the passenger automobiles sold in model year 1983 will be equipped with a passive restraint device.

In model year 1984, it is estimated that 11,170,000 vehicles will be sold with passive restraint devices.

TABLE 4-1. ESTIMATED VEHICLE SALES* AND VEHICLES REQUIRING PASSIVE RESTRAINTS BY VEHICLE CLASS AND MODEL YEAR (THOUSANDS OF VEHICLES)

Vehicle Class	Wheel Base (inches)	Model Year		
		1982	1983	1984
Mini	Less than 100	1,109	1,197	1,240
Subcompact	Less than 100	1,933	2,009	2,088
Compact	Less than 100	2,379	2,352	2,324
Intermediate	100 - 114	3,230	3,334	3,440
Full	More than 114	2,115	2,097	2,078
TOTAL VEHICLE	--	10,766	10,964	11,170
Vehicles Requiring Passive Restraints	--	5,345	7,783	11,170
Percentage of Vehicles with Passive Restraints	--	50	70	100

* Includes both sales of domestic and foreign cars.

4.2.2 Automotive Manufacturers' Anticipated Plans

The manufacturers' decision as to which passive restraint system—air bag or passive belt—to employ to meet the 208 standard is a complex problem involving the consideration of many factors, including styling, comfort, cost, performance and public acceptance.

- Styling/Comfort. The decision of whether to use passive belts or air bags on a given model car can almost be viewed as a styling/comfort decision. For example, many cars today, especially the subcompacts and compacts, come equipped with bucket seats. To meet the 208 standard on these models, it is logical that the industry would lean toward use of passive belts, principally based on the lower costs associated with the system. Similarly, many of the larger cars today come equipped with bench seats. Thus, it is also logical to assume that industry would lean toward the use of air bags on these models since only air bags will restrain the middle occupant of the front seat.

- Cost. Air bags have been estimated at a price to the consumer between $131 (NHTSA), and $650 (GM)*, while passive belts have been estimated to cost the consumer approximately $83. Because of the higher cost associated with air bags, it is likely that the manufacturers will first introduce air bags on full-size cars where the percentage impact (i.e., increase) on cost is least. Air bags on intermediate and smaller size cars are expected to be offered as options.

- Public Acceptance. Public acceptance is another key factor in the manufacturers' decision process since it is the public to whom the manufacturers are selling their vehicles. Thus, the manufacturers are faced with the problem of selecting the passive restraint option for each model that (1) consumers of that model will be willing to accept, and (2) will have the least number of impacts (i.e., cost, styling, etc.).

Given the above factors, Table 4-2 outlines the manufacturers' introduction schedule for passive restraint systems by type. The figures shown in the table for vehicles with air bags are based on discussions with a major supplier of inflator modules to the auto industry. The figures shown for vehicles with passive restraints were derived by subtracting the figures shown for vehicles with air bags from the figures shown for vehicles requiring passive restraints. The table assumes no delays or modifications to the standards timetable.

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* Cost differences are due to design details, assumed production volumes, contractual arrangements with suppliers and other factors. These price estimates were presented in the following documents:

- (NHTSA): Occupant Protection Program Progress Report No. 2, April 1979.
- (Allstate): Automotive Occupant Protective Safety Air Cushion Expenditure/Benefit Study for the Allstate Insurance Company by the John Z. DeLorean Corporation.
- (DOT): Analysis of Cost, Leadtime and Production Capabilities for Implementation of Passive Restraint Systems in Automobiles.

TABLE 4-2. ESTIMATED NUMBER OF VEHICLES WITH AIR BAGS AND PASSIVE BELTS BY MODEL YEAR: 1981 - 1984 (NUMBERS IN THOUSANDS)

	Model Year			
	1981	1982	1983	1984
Total Vehicle Sales	10,255	10,766	10,964	11,170
Vehicles Requiring Passive Restraints	0	5,345	7,783	11,170
Vehicles w/Air Bags**	50	600	900	1,500
Vehicles w/Passive Belts	*	4,745	6,883	9,670

* Unknown at this time. Passive belts are now included on certain VW Rabbits as standard equipment and are available as options on Chevettes.

** A sales shift to smaller cars would substantially reduce the size of the market for air bags shown here.

4.3 MATERIAL AND COMPONENT REQUIREMENTS DICTATED BY MANUFACTURERS' PLANS

This section estimates the annual material and component requirements dictated by the auto manufacturers' plans with respect to passive restraint system introduction as discussed in the previous section.

4.3.1 Materials Requirements

Table 4-3 summarizes annual material requirements for passive restraint manufacture (both passive belts and air bags) for model years 1982 to 1984, the phase-in period for passive restraint systems. The figures are based on:

- The estimated number of vehicles with air bags and passive belts as shown in Table 4-2.

TABLE 4-3. ESTIMATED ANNUAL MATERIAL REQUIREMENTS FOR PASSIVE RESTRAINT SYSTEMS (MILLIONS OF POUNDS)

	Model Year		
Material	1982	1983	1984
Plastic	17	24	35
Metal Alloy	53	78	118
Nylon	6	8	12
Explosive Charge	0.9	1.4	2.3

- A total air bag system weight of approximately 42.1 pounds composed of 83 percent steel, ten percent plastic, three percent nylon, and four percent explosive charge, as shown in Table 4-4.

TABLE 4-4. MATERIAL COMPOSITION OF AN AIR BAG SYSTEM

Material/Component	Weight Per Vehicle (Pounds)	Percent of Total
Plastic		
Readiness Monitor/ Indicator Light	0.7	
Cushion & Inflator Assembly Cover	3.4	
Total Plastic	4.1	10%
Alloyed Metal		
Dashboard Sensor**	2.7	
Front Bumper Detector**	2.4	
Inflator Module**	25.0*	
Other Metal Components	5.0	
Total Metal	35.1	83%
Nylon		
Bag	1.4	
Total Nylon	1.4	3%
Explosive		
Sodium Azide	1.5	
Total Explosive	1.5	4%
TOTAL	42.1	100%

* Includes passenger and driver combined.

** Includes housings for the components.

- A total passive belt system weight of approximately 10.8 pounds composed of 63 percent steel, 9.2 percent nylon, and 27.8 percent plastic, as shown in Table 4-5.

Not included in Table 4-3 are those material requirements associated with any modifications to the vehicle which are necessary to accommodate passive belts or air bags*. Also not included are material requirements associated with the componentry of advanced passive belts or air bag systems, such as pretensioners and advanced sensors (i.e., Essex gas dampened sensor).** Thus, the material requirements estimates shown in Table 4-3 are conservative. Adding material requirements associated with vehicle design changes would substantially increase some of the figures shown in Table 4-3.

4.3.2 Component Requirements

A summary of the component requirements associated with the estimated introduction of passive restraint systems in model years 1982 through 1984 is provided in Table 4-6. The figures are based on:

- The estimated number of vehicles with air bags and passive belts shown previously in Table 4-2.
- The number of components required per vehicle shown in the second column of Table 4-6.

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* While it is generally known that certain vehicle modifications will be necessary, the net weight effect of these modifications is not known.

** It is still questionable whether pretensioners will be required to meet near term safety performance standards. From the lack of earnest development ongoing in the industry there appears to be a belief that pretensioners will not be needed for some time to come. Simpler belt grabbers may be adequate.

TABLE 4-5. MATERIAL COMPOSITION OF A PASSIVE BELT SYSTEM

Material/Component	Weight Per Vehicle (Pounds)	Percent of Total
PLASTIC		
Retractor Housings	2.5	
Buckle Grip	0.5	
Total Plastic	3.0	27.8
METAL ALLOYS		
Buckle Assembly	4.4	
Emergency Lock Retractor	2.4	
Total Steel	6.8	63.0
NYLON		
Webbing	1.0	
Total Nylon	1.0	9.2
TOTAL	10.8	100.0

TABLE 4-6. PASSIVE RESTRAINT SYSTEM PARTS AND COMPONENTS REQUIREMENTS (NUMBERS IN THOUSANDS)

Passive Restraint System/Componentry	Quantity Per Vehicle	Model Year		
		1982	1983	1984
<u>Air Bag System</u>				
Readiness Monitor/ Indicator Light	1	600	900	1,500
Cushion and Inflator Assembly	2	1,200	1,800	3,000
Dashboard Sensor	1	600	900	1,500
Front Bumper Detector	1	600	900	1,500
Canisters of Sodium Azide	2	1,200	1,800	3,000
<u>Passive Belt System</u>				
Webbing	34.2*	1.6×10^8*	2.3×10^8*	3.3×10^8*
Belt Retractor	2	18,980	27,532	38,680
Buckling Mechanism	2	47,450	68,830	96,700

* Quantities shown are in feet.

4.4 CAPABILITY OF THE SUPPLIER INDUSTRIES TO MEET MANUFACTURERS' PLANS

Two supplier industries are critical to the ability of the auto manufacturers to meet DOT's mandate for passive restraints beginning in 1982 -- the materials suppliers and the component manufacturers. The following sections discuss the capability of these industries to supply the necessary parts and materials for installation of passive restraints.

4.4.1 Capability of the Materials Industries to Meet Passive Restraint Requirements

The materials used in the manufacture of both air bags and passive belts listed in Table 4-3 are conventional materials, none of which are in short supply. The principal material requirements for the air bag system are nylon, steel, plastic, heat shield silicon, sodium azide and various primers and chloromates, all of which are readily available to the manufacturers. The principal material requirements for the passive belt systems are plastic, steel and nylon. More sophisticated systems in the future may require sodium azide or some other explosive chemical as well, but no difficulty is anticipated in supplying the needed materials.

4.4.2 Capability of the Seat Belt Manufacturing Industry to Meet Passive Restraints Requirements

A second area of concern in assessing suppliers' capability is the ability of the component suppliers to manufacture sufficient passive restraint systems to meet the auto makers' needs. Both air bag and passive belt manufacturing firms have developed their product designs and indicated a willingness to produce the necessary components. The next step requires the companies to begin to equip their production facilities.

Passive Belt Systems

In the case of passive belts, little special tooling or other preparation is required on the part of the suppliers since the processes are essentially the same as those used in the manufacture of current seat belts. Seat belt suppliers will be able to gradually substitute the passive belt systems for their existing products.

If more complex passive belt systems are manufactured in the future, modification to the doorframe and mid-door post of the affected automobiles may be necessary.

These changes, however, will be the responsibility of the auto manufacturers and will doubtless be combined with other considerations relating to comfort, cost and interior styling. Should pretensioner-powered passive belt systems be needed to meet performance standards, a production capability for this component will have to be developed. At present, however, production facilities for pretensioners and other advanced passive belt components are not contemplated.

The current major suppliers of seat belt systems are Hamill, American Safety Equipment, Irvin and Pontineer. These companies as shown in Figure 4-1 are expected to be the principal suppliers of passive belt systems. The only major sub-component is the webbing, which is made largely by Southern Weaving. Other basic materials will be supplied by companies such as Dupont and Monsanto.

Air Bags

In the case of air bags just about every component is new and unique to the automobile. The troubling fact is that, to date, no air bag mass-production facility is in place.* The suppliers have developed designs and indicated their willingness to produce air bags, but have not committed funds to develop the necessary production capability. Since the available production leadtime before the manufacturers must begin full scale production of air bags is waning, the absence of this capability is of some concern to the industry.

The explanation of this lack of production capability lies in the potential risk facing the suppliers. Manufacturers cannot justify spending corporate funds to evolve a mass production capability without the assurance of a significant and long-term market. The very concept of mass production provides economies of scale to the manufacturers only after a large volume of standardized production has been reached. Thus, when sufficient orders are assured, the air bag manufacturers will begin to put the production facilities in place. At the current time, investment in new plant and equipment is restrained by product liability issues, lack of firm orders from the automobile manufacturers, and the relatively large business risk of plant and equipment investment for a market (air bags) that might be substantially delayed and/or smaller than predicted.

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* Plans are, however, underway to build such plants.

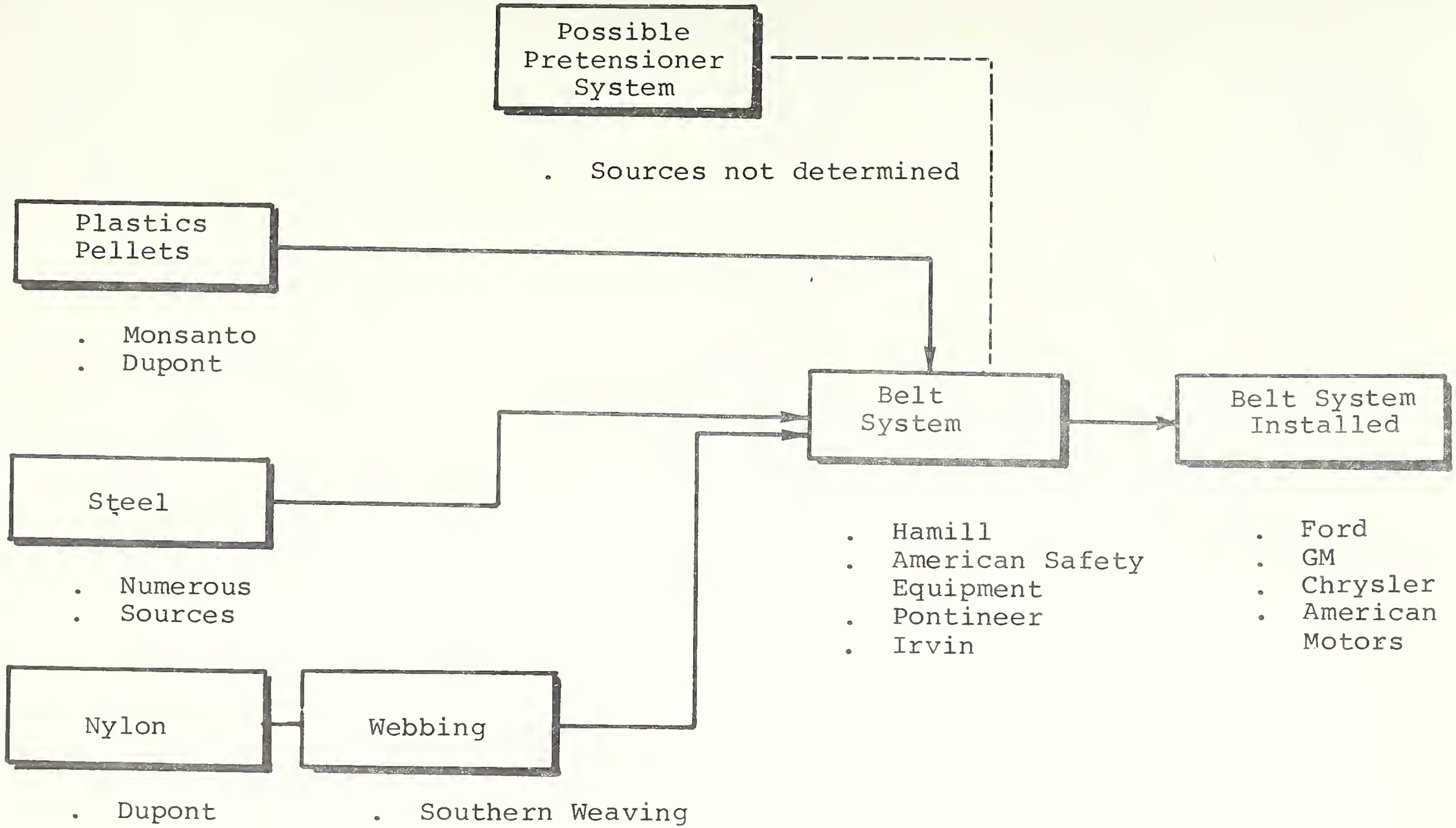

FIGURE 4-1. ANTICIPATED PRINCIPAL SUPPLIERS FOR PASSIVE BELT MATERIALS AND COMPONENTS

Figure 4-2 shows the key potential air bag component suppliers. The air cushion and inflator assembly, the major air bag component, will be manufactured by Hamill Manufacturing Company, and Talley Industries. Hamill will make the passenger-side system and Talley will make the driver-side system. These companies will make the bag, the housing, and associated parts, and assemble them with the gas generator to form the cushion and inflator assembly.

The gas generator will be made elsewhere. Thiokol Chemical Corporation and Rocket Research, Inc. are the likely manufacturers of these units. The sodium azide propellant will be produced by Canadian Industries, Ltd., and PPG Industries, Inc. These companies are presently producing sodium azide, and they have indicated they would be capable of expanding their processing capability should this be required for large numbers of air bags. This can be accomplished within one year, and a new plant can be constructed within two years to greatly expand capacity.

Uniroyal will be the major supplier of the nylon cloth used for the air bags, and Dupont will be the major supplier of nylon yarn. Various other materials are needed to make air bags. As indicated in Figure 4-2, these suppliers will include Monsanto, Dupont, Rocket Research, and Thiokol.

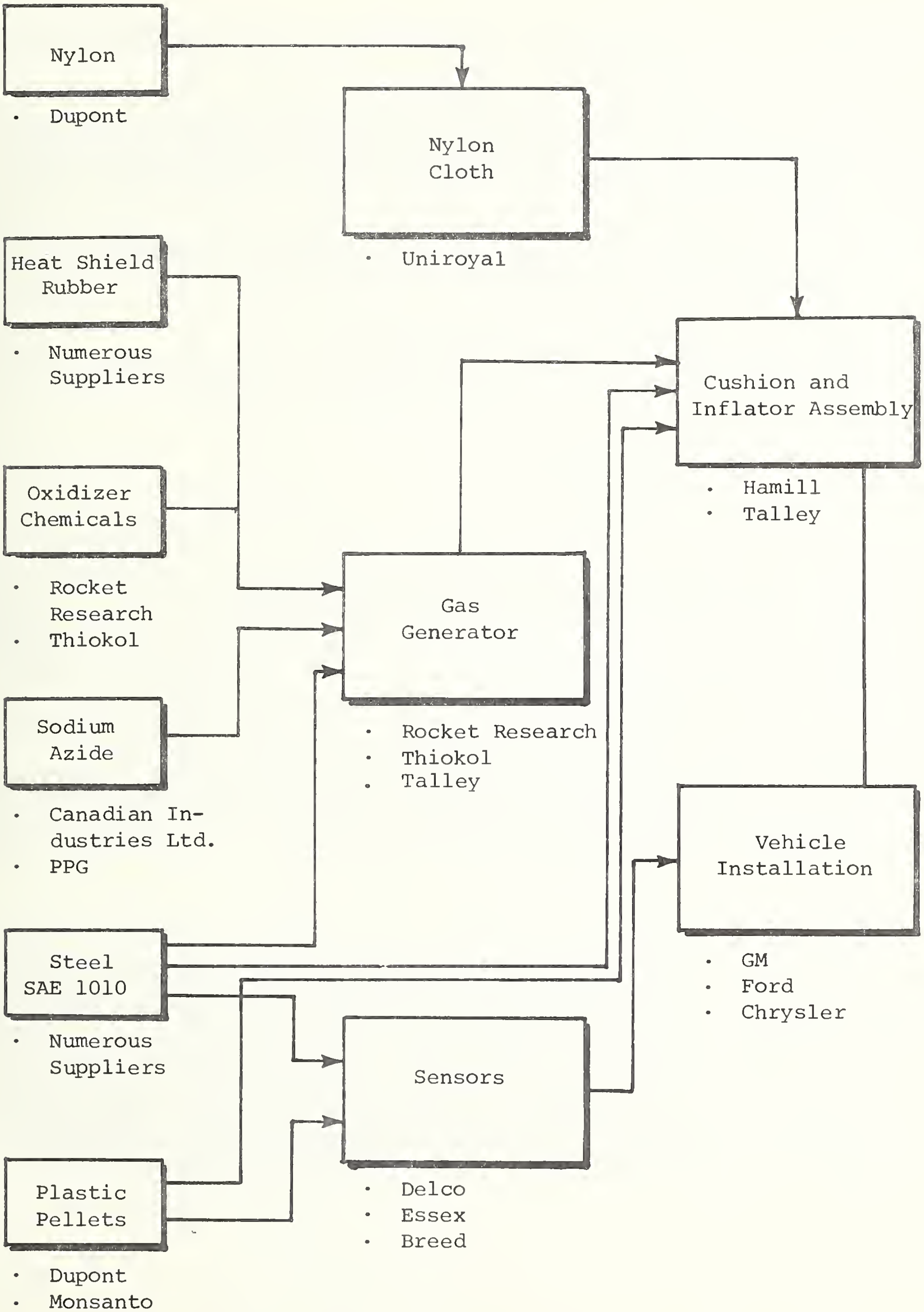

FIGURE 4-2. ANTICIPATED PRINCIPAL SUPPLIERS FOR AIR BAG MATERIALS AND COMPONENTS

4.5 OTHER FACTORS AFFECTING THE OUTLOOK FOR PASSIVE RESTRAINT SYSTEMS

In addition to the supplier industries capability to meet auto manufacturer demand, there exist a number of other key issues affecting the outlook for passive restraint systems. These include:

- The effectiveness and reliability of passive restraint systems
- The toxicity of sodium azide
- Maintenance of passive restraint systems in the aftermarket
- Product liability.

Each is discussed below.

4.5.1 Passive Restraint System Effectiveness

Approximately 60 percent of all auto injuries involve the driver, and a high percentage of fatal accidents involve impacts to the left frontside of the car. Clearly, the driver's position must be adequately protected if highway fatalities are to be reduced through the use of passive restraints. Neither air bags nor passive belts are completely effective in protecting the driver during a collision, but each offers some advantage over the other.

Air Bag

Air bags offer a considerable advantage over the passive belt system in that the driver's face and neck are cushioned and protected from pieces of flying glass and impact with the steering wheel. The major weakness of the bag system is that it is designed to deploy only upon a frontal impact. It will not protect the driver in an accident involving a side impact, rear collision, or rollover. For complete effective protection under all possible accident conditions, both a lap and shoulder harness must be worn in a vehicle equipped with an air bag.

Passive Belt

The passive belt is superior to the air bag system in that it will hold the driver securely in the car under all conditions of impact—side, rear, front, or rollover. There is some possibility, however, that the driver's head will whip forward onto the steering wheel, or his face will be cut with glass, depending upon the severity of the accident. Another danger facing the user of a passive belt system is that he will be forcibly contained within his seat during a direct impact to the area where he is sitting. If the emergency release can be activated in time the motorist may be released, but not all accidents have a sufficient time margin for this action to be taken. A compensating factor is that comparatively few accidents involve impacts of this type.

4.5.2 Passive Restraint System Reliability

Considerable research and inquiry has surrounded the question of passive restraint system reliability. The majority of investigations have been directed at air bags, but some reliability problems affect passive belt systems as well.

Air Bags

Critics of air bags are concerned that the bags will not function as designed. That is, they will deploy inadvertently, or will not deploy upon impact. Experience to date, however, does not bear out these concerns.

Of the 11,000 cars with air bags built by GM during the three-year period 1973 to 1976, the bags deployed in crashes in which they were designed to open. Furthermore, of approximately one dozen inadvertent openings, all but one were traced to security oversights or willful attempts to trigger the bags. None of the non-crash deployments caused an accident, injury, or loss of control. Nevertheless, because of product liability potential, very strict quality control inspection and test requirements which add to production cost will be required by automobile manufacturers of air bag system component suppliers.

Passive Belts

Passive belts are designed to always be in position to protect the passenger in case of an accident and, when used, offer superior reliability over the air bag. Passive belt systems are not immune to reliability problems, however. They may be subject to tangled webbing, malfunctioning retractors, or other hardware breakdowns that now contribute to non-usage of belts. The much greater complexity of future passive belt systems with pretensioners would cause belt reliability problems to increase.

4.5.3 Toxicity of Sodium Azide

Considerable controversy surrounds whether or not the use of sodium azide in air bags will present a hazard to motorists. Proponents of air bags argue that the chemical is stable in its pure form and converts to harmless nitrogen gas when ignited by a spark. They point out that the rate of expansion of the gas can be controlled by mixing other agents with the sodium azide, and that the gas deteriorates harmlessly when exposed to the atmosphere. In addition, recently developed air bags have improved filtering of particulates and better controlled complete burning of the sodium azide. These factors contribute to reduced undesirable gaseous and particulate effluents during bag deployment.

Opponents of air bags point out that the chemical is indeed dangerous. The greatest potential threat stems from experiments which have shown sodium azide to cause gene mutations in living organisms. There is some expectation, they say, that exposure of humans to this chemical may cause premature aging, cancer, and even induce birth defects. Information on the minimum safe level of exposure has not been developed, however, nor is data available which proves or disproves this hypothesis. A second concern is that sodium azide in combination with battery acid produces hydrazoic acid, a very toxic and highly explosive material.

Officials of the EPA and the OSHA* have determined that sodium azide, as used in the air bag inflators, does not appear to present a significant environmental or occupational hazard. The reason cited is that the chemical is essentially inaccessible to the motorist in hermetically sealed heavy steel containers deep in the steering wheel hub or under the dashboard. When a crash occurs, the sodium azide is completely burned in producing the nitrogen gas to inflate the bag, and no exposure to the chemical is risked.

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* DOT, NHTSA Occupant Protection Program Progress Report No. 2, April 1979.

4.5.4 Passive Restraint System Maintenance

Maintenance and replacement of passive restraint systems is a serious problem facing the repair industry and a critical issue in the government's mandate for the systems. The greatest concern is whether or not a mechanic will be able to effectively replace the air bag system.

Air Bags

Research on repair of air bags by Vale Laboratory technicians concludes that although Detroit is refining the system that will become common on many cars in the next decade, most service shops and dealers are either unprepared or unwilling to fix damaged vehicles with air bags. The main problem seems to be the training of mechanics to replace and test the replaced systems. Even in the first few years that the bags are offered, so few will be on the road that there will be no incentive for a mechanic to become skilled in this repair.

The requirements for working on the air bag system do not appear, at first, to be greater than for many other parts. No specialized expensive equipment is needed to replace or maintain the system. However, the location of the sensors and passenger air bag will not be easily accessible to the mechanic. The driver's side bag will be more accessible. Removal of the passenger's side air bag will involve reaching up under the instrument panel with potentially difficult accessibility problems.

The principal maintenance problem associated with the air bag has to do with the electronic diagnostic system. When the electronic sensor indicates that the integrity of the system has been compromised, there is a question as to whether the auto mechanic should attempt to diagnose and correct the problem given the limited diagnostic information or merely replace the entire system. This factor, coupled with the potential liability of the repair garage should it undertake such a repair, combine to make repair of the system unattractive to most repair businesses.

Replacement costs to the consumer have been estimated by manufacturers to be as high as 2.5 times the initial sales price due to accessibility issues. Mr. James Wasylik, Director of Research for Vale Laboratory, has also stated that air bags pose a signficiant inflationary threat to auto damage claims and costs.

Passive Belt Systems

Passive belt systems do not present as great a problem in the aftermarket as air bags due to the readily discernible status of passive belt operability. A mechanic can readily inspect most passive belt components (webbing, D-rings, retractor spool, ratchet wheels, and pendulum) and may be able to correct minor mechanical problems. Failure of the retractor will necessitate replacement.

Replacement costs for the current Chevette passive belt system are $9.00 for parts for each front side and $50.00 for labor.

Future Pelton wheel pretensioner belt systems like air bags may not be considered serviceable. Once the propellant is expelled from the propellant capsule and the Pelton wheel has been activated, the unit will require complete replacement. Testing such a system for readiness would require sacrificing the sodium azide (or other propellant) content.

4.5.5 Manufacturer's Product Liability

Current product liability law holds a manufacturer liable for injuries caused by defective products. Field experience with passive restraint-equipped cars has demonstrated that air bags and passive belts are highly dependable and effective. Even if the passive restraints are nearly 100 percent reliable, however, there will still be a number of accidents each year in which persons will be injured. It is not possible to predict how many suits will be brought against the manufacturers in these instances or what the cost of such settlements will average.

The manufacturers and component suppliers are concerned that they will be held liable for injuries even if the passive restraints operate as designed. Persons suffering injuries in these cases may attempt to show that the passive restraints did not serve the purpose intended—preventing injury during an impact.

The problem of manufacturer's product liability is a serious issue facing the Government, the manufacturers, and their suppliers, but it is difficult to solve the problem of the suits before they occur. Crash testing and research is therefore continuing on passive restraint systems.

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