United States General Accounting Office

GAO

Report to the Chairman and Ranking Minority Member, Committee on Commerce, Science, and Transportation, U.S. Senate

June 2001

VEHICLE SAFETY

Technologies, Challenges, and Research and Development Expenditures for Advanced Air Bags

GAO

Accountability * Integrity * Reliability

GAO-01-596

Contents

Abbreviations

NHTSA	National Highway Traffic Safety Administration
R&D	research and development

United States General Accounting Office
Washington, DC 20548

June 12, 2001

The Honorable Ernest F. Hollings
Chairman
The Honorable John McCain
Ranking Minority Member
Committee on Commerce, Science,
and Transportation
United States Senate

Air bags can help save lives in frontal crashes, especially when used with seat belts. However, the power of a deploying air bag can also injure or kill people. According to the National Highway Traffic Safety Administration (NHTSA), an estimated 6,856 lives have been saved by air bags, but 175 fatalities—primarily children and small women—have been attributed to the deployment of an air bag in relatively low-speed crashes as of April 2001. Concerned about these fatalities, the Congress directed the Secretary of Transportation in 1998 to require vehicle manufacturers to install advanced air bag systems. Advanced air bag systems tailor the deployment of the bags to the characteristics of the occupant and different levels of crash severity. On May 12, 2000, NHTSA issued a rule requiring vehicle manufacturers to install these systems in an increasing number of vehicles over several years beginning September 1, 2003.

You asked us to report on the development of technologies that vehicle manufacturers plan to use to comply with the advanced air bag rule. Accordingly, we examined the (1) current availability of and planned improvements to advanced air bag technologies; (2) challenges, if any, that the industry faces in complying with the rule; and (3) changes in federal and industry expenditures on the research and development (R&D) of advanced air bag technologies since 1998.

To address these issues, we met with representatives from eight companies that manufacture vehicles and five companies that supply air bag systems to these manufacturers. We chose the manufacturers—BMW, DaimlerChrysler, Ford, General Motors, Honda, Nissan, Toyota, and Volkswagen—because, according to the Alliance for Automobile Manufacturers, their combined sales account for over 90 percent of vehicles sold in the United States. We chose the air bag suppliers—Autoliv, Breed, Delphi, Takata, and TRW—because they are the primary suppliers of air bag systems for vehicles sold in the United States. We also met with officials from NHTSA, representatives from the Insurance Institute for Highway Safety, the National Transportation Safety Board, university researchers, and consumer groups. For the changes in industry expenditures on advanced air bag R&D, an industry association provided information aggregated from four manufacturers. We did not verify this aggregated information because individual vehicle manufacturers consider their R&D expenditure information confidential. (See app. I for a detailed discussion of how we conducted our work.)

Results in Brief

Some advanced air bag technologies are currently being installed in vehicles and others are still being developed. The principal advanced technology that is currently being installed in some vehicles is air bags that can inflate with lower or higher levels of power—rather than a single level—depending on the severity of the crash. For example, four manufacturers installed frontal air bag systems that can deploy with multiple levels of power in at least 25 percent of their model year 2001 vehicles. Some manufacturers have also installed other advanced technologies, such as sensors that enable the air bag system to adapt its deployment for belted or unbelted occupants or for drivers who are seated close to the steering wheel. Although frontal air bag systems with these advanced technologies represent improvements over previous systems, they do not contain all of the features that manufacturers believe are needed to meet the requirements in the advanced air bag rule, such as sensors that can distinguish among different types of occupants. To meet the requirements, manufacturers plan to introduce new technologies as well as continue to make further improvements in current technologies. The key new technologies that manufacturers plan to introduce are occupant classification sensors that can distinguish among infants and children (as well as their safety seats), and adults on the passenger side. The addition of these sensors is necessary to allow the air bag system to provide the appropriate deployment level—such as no deployment, low power, or high power—depending on the type of occupant.

The primary challenge in meeting the requirements in the advanced air bag rule is the development of occupant classification sensors that are accurate, durable, and suitable for mass production. Sensors that are currently being developed sometimes classify an occupant inaccurately, which could result in the air bag not deploying when it should, deploying when it should not, or deploying with greater or less force than intended. In addition, occupant classification sensors have not demonstrated the ability to operate reliably over the presumed 15-year life of a vehicle or to be consistently produced and integrated into vehicles in large quantities. Vehicle manufacturers are working with air bag suppliers to overcome these problems and plan to introduce these sensors in some of their vehicles by September 2003, as required. However, the development of occupant sensing technologies is taking longer than anticipated. For example, some manufacturers previously anticipated that occupant classification sensors would be installed in model year 2000 vehicles. These sensors were not sufficiently developed for installation at that time, and some manufacturers told us that these sensors have still not reached the level of development that a new technology should have reached to be ready by the September 2003 deadline—just over 2 years away. NHTSA and vehicle manufacturers have discussed these issues but, as of April 2001, none of the manufacturers have told NHTSA they will be unable to meet the deadline. Due to the uncertainty associated with developing occupant classification sensors, NHTSA officials told us they plan to stay abreast of manufacturers' progress by maintaining communications with manufacturers and conducting research on the feasibility of occupant classification technologies.

Expenditures on advanced air bag R&D by NHTSA and vehicle manufacturers have increased since 1998, when the Congress mandated the installation of advanced air bags in future vehicles. NHTSA's reported expenditures increased from about $6.3 million in fiscal year 1998 to nearly $7.0 million in fiscal year 2000. This spending was primarily for activities related to the development of the advanced air bag rule, such as investigations of real-world crashes and studies to determine how people are injured or killed by air bags. NHTSA's expenditures are expected to increase to $7.2 million in fiscal year 2001 to, among other things, monitor the performance of advanced air bags and develop specific advanced air bag technologies. Individual vehicle manufacturers did not provide information on their expenditures because they consider this information confidential. Instead, four manufacturers coordinated through an industry association to provide aggregated information on their advanced air bag R&D expenditures, such as staffing, developing technology, building test facilities and conducting tests, and integrating technologies into vehicles. According to the industry association, these expenditures generally total between $20 million and $30 million per vehicle "platform" (a group of vehicles that utilize the same basic design). The information aggregated from the four manufacturers shows that these expenditures increased by about 275 percent from 1998 through 2000 and are anticipated to increase overall by about 375 percent from 1998 through 2003, when the requirements in the advanced air bag rule take effect.

In commenting on a draft of this report, the Department of Transportation offered only one technical comment on the availability of occupant classification sensors. We verified that the information in our draft report was accurate and therefore did not change it.

Background

Air bags are one part of a vehicle's occupant protection system, which also includes the structure of the vehicle and seat belts. Seat belts are the primary restraint for an occupant during a crash, and air bags are intended to supplement this protection. In 1999, NHTSA reported that seat belt use alone (lap and shoulder belts) reduces fatalities by 45 percent in crashes involving an impact to the front of the vehicle, frontal air bags without seat belts reduce fatalities by 14 percent, and the combination of seat belts and air bags reduces fatalities by 50 percent.[1]

Between 1986 and April 2001, frontal air bags have saved an estimated 6,856 lives but have caused 175 fatalities that have been confirmed by NHTSA—19 infants in a rear-facing child seat, 85 children (not in a rear-facing child seat), 64 drivers, and 7 adult passengers—in relatively low-speed crashes.[2] NHTSA investigators have found that people who were killed by deploying air bags were typically in close proximity to the air bag in one of two ways:

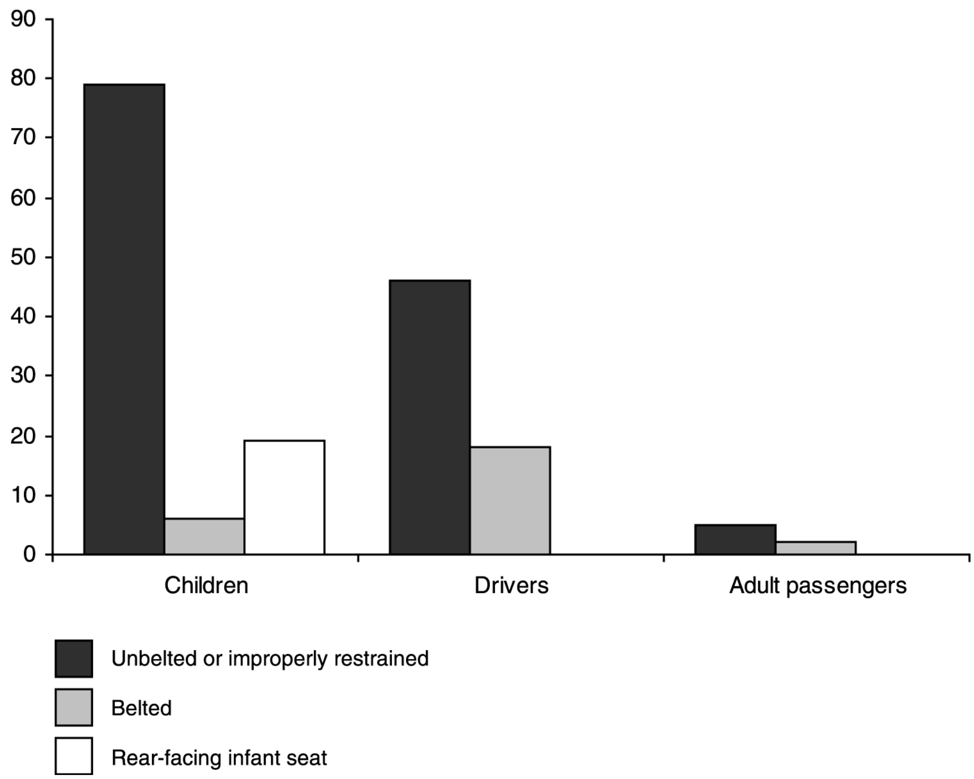
- The occupant was thrown forward by events that occurred before the air bag deployed, such as sudden braking immediately before the crash or multiple impacts. This usually occurred because the occupant was unbelted or improperly belted.
- The occupant's initial seating position placed them close to the air bag. According to NHTSA, these fatalities included shorter drivers who were belted but had moved the seat forward in order to more easily reach the steering wheel and pedals, infants in rear-facing child seats, and children sitting on the lap of another passenger.

The majority of people who were killed by deploying air bags in low-speed crashes were unbelted or improperly restrained, which made them more susceptible to being thrown into the path of the deploying air bag than belted occupants. (See fig. 1.)

[1] *Fourth Report to Congress: Effectiveness of Occupant Protection Systems and Their Use*, NHTSA, May 1999.

[2] As of April 2001, NHTSA is investigating an additional 61 unconfirmed air bag-related fatality cases: 1 infant in a rear-facing child seat, 43 children (not in a rear-facing child seat), 12 drivers, and 5 adult passengers. According to NHTSA, about 90 percent of unconfirmed cases are eventually confirmed.

Figure 1: Air Bag Fatalities, by Type of Occupant and Belted Status, as of April 2001



Note: Child fatalities in rear-facing infant seats are not considered "properly restrained" because children in a rear-facing infant seat should not be placed in a front seat with a passenger air bag.

Source: NHTSA.

The reported number of air bag-related fatalities increased from 1 in 1990 to 58 in 1997, as the installation of air bags in vehicles increased.[3] Since 1997, the number of fatalities has decreased; 17 fatalities were reported in 2000.[4] NHTSA attributes the decrease in part to actions that resulted from its November 1996 plan to address the risk of air bag-related fatalities. These actions included a public education effort to persuade people to properly restrain infants and children under 12 in the rear seat and issuing

[3]In September 1993, NHTSA required vehicle manufacturers to install air bags in all passenger cars beginning in model year 1998, and in all light trucks beginning in model year 1999. According to NHTSA, vehicle manufacturers installed air bags in advance of the federal requirements.

[4]Reported fatalities include confirmed and unconfirmed cases.

a rule in March 1997 that made it possible for manufacturers to quickly reduce the inflation power in the air bags installed in new vehicles. From model year 1997 through 1998, manufacturers lowered the inflation power by an average of 22 percent in driver-side air bags and 14 percent in passenger-side air bags.[5] NHTSA's 1996 plan also anticipated the need for long-term technological improvements—advanced air bag systems—to control or prevent deployment of the air bag, as appropriate.

In June 1998, the Transportation Equity Act for the 21st Century directed the Secretary of Transportation to issue a rule requiring vehicle manufacturers to install advanced air bag systems. The act specified that these systems should achieve two goals—provide improved protection for occupants of different sizes (belted and unbelted) as well as minimize the risk of injury or death from air bags for infants, young children, and other occupants. On May 12, 2000, NHTSA issued a rule specifying the requirements for such a system. Under the previous requirements, vehicle manufacturers performed tests that involved crashing vehicles into a rigid barrier with crash dummies—belted and unbelted—that represented average-sized males in the driver and passenger seats.[6] To provide improved crash protection for occupants of different sizes, the rule adds new crash tests that simulate different types of crashes and include the use of crash dummies that represent small adults (defined as a 5th percentile female).[7] To reduce the risk of injury or death to children and small adults, the rule requires a new battery of "static" tests using dummies representing infants, young children, and 5th percentile females. These tests involve placing the dummy in various positions in the seat to determine if the air bag system suppresses or activates the air bag, or placing the dummy against the air bag module and deploying the air bag to determine if the bag deploys in a "low-risk" manner that does not cause severe injury. Starting in the production year beginning September 1, 2003

[5]As of April 2001, NHTSA has found that depowered air bags appear to be as effective as previous air bags in protecting occupants, including larger occupants in medium- to high-speed crashes.

[6]NHTSA's March 1997 rule allowed manufacturers the option of certifying the performance of air bag systems using a "sled test" rather than crashing the vehicle into a rigid barrier. A sled test involves placing a vehicle on a "sled-on-rails" and accelerating the sled and vehicle very rapidly backward.

[7]Crash dummies do not sufficiently represent the human physiology, so the rule allows the use of appropriately sized humans to test the performance of the technologies in static suppression tests.

(approximately model year 2004)[8] and continuing over a 3-year phase-in period, increasing percentages of each manufacturer's vehicles must comply with the requirements of the rule.[9] (See app. II for a more comprehensive discussion of the rule's requirements.)

Some Advanced Technologies Are Available; Others Are Being Developed

Manufacturers have installed some of the advanced technologies that will be needed to comply with the advanced air bag rule in certain vehicles that are on the market today. (See table 1.) Manufacturers and companies that produce air bags are working on the development of other needed advanced technologies, with the aim of having them ready for installation in vehicles by September 2003, as required.

[8] The timing of the model year varies from company to company, but generally begins between August and October.

[9] The rule will be phased in during two stages. During the first stage phase-in—from September 1, 2003, to August 31, 2006—an increasing number of each manufacturer's vehicles must be certified each year as passing all of the requirements in the advanced air bag rule. During the second stage phase-in—from September 1, 2007, to August 31, 2010—the speed for one of the tests (the belted test for the 50th percentile adult male dummy) will be increased from 30 to 35 miles per hour. As with the earlier requirements, an increasing percentage of vehicles must comply with the new test speed each year.

Table 1: Current Availability of Advanced Air Bag Technologies and Planned Improvements to Comply With Advanced Air Bag Rule

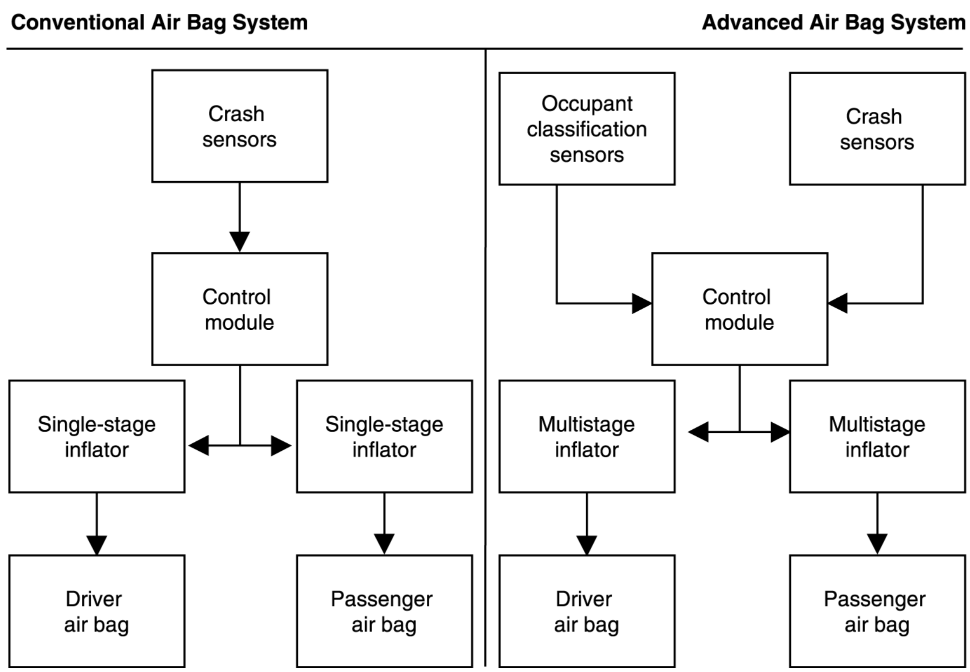
Component of advanced air bag system	Advanced technologies currently available	Improvements planned to comply with advanced air bag rule
Occupant classification sensors	Some vehicles with multistage air bags have one or more of the following: • Driver and passenger seat belt usage sensors • Driver seat position sensors • Sensors to detect the presence of an occupant in the passenger seat	• Increased use of seat belt usage and seat position sensors. • Weight-based or pattern-based sensors that can identify the type of occupant in the passenger seat (i.e., an infant or child in a child seat, a child outside of a child seat, or an adult). • Possible use of seat belt tension sensors and/or occupant position sensors to augment information provided by above sensors.
Crash sensors	Vehicles with multistage air bags have crash sensing systems that have been refined to better discriminate among crash severity levels. These sensors are located in the passenger compartment; some are augmented by front (crush zone) sensors.	Crash sensing systems with a greater ability to differentiate levels of crash severity as well as types of crashes. Use of front (crush zone) sensors expected to increase.
Control module	Vehicles with multistage air bags have more complex computational systems designed to make timely decisions about the appropriate level of air bag deployment based on input from crash sensors and, as applicable, occupant sensors.	Computational systems of increased complexity that will be able to process more inputs from crash sensors and occupant classification sensors and make timely decisions regarding the appropriate level of air bag deployment.
Multistage inflators	Vehicles with multistage air bags have inflators with 2 or 3 levels of deployment. Deployment decisions are based on input from crash sensors and, as applicable, occupant classification sensors.	Inflators with 2 or more levels of deployment. Deployment decisions will be based on input from crash sensors and occupant classification sensors.
Air bags	Newer vehicles have air bags with improved designs aimed at reducing the aggressivity of the deploying bag. Improvements have included moving the air bag module further away from the occupant, use of tethers within the bag, and changes in bag folding, shapes, and venting.	Further improvements may include increased use of innovative bag designs as well as new designs aimed at enhancing the ability of the deploying air bag to adapt to characteristics of the occupant.

Source: GAO analysis of information provided by vehicle manufacturers.

Components of Conventional and Advanced Air Bag Systems

Advanced air bag systems installed in future vehicles will be much more sophisticated than the conventional air bag systems in today's vehicles, because they will be capable of tailoring air bag deployment to characteristics of the front seat occupants as well as crash severity. Conventional frontal air bag systems deploy the air bags with a single level of inflation output for all crashes that exceed a predetermined severity threshold. These systems generally consist of separate components designed to work together: crash sensors, a control module, and a driver and passenger inflator and air bag. (See fig. 2.) The crash sensors and control module are typically located in one unit within the passenger compartment; the unit is often mounted within the floor between the driver and the passenger. The crash sensors detect the occurrence and severity of crashes and provide this input to the control module. The control module evaluates inputs from the sensors. If the control module determines that a crash has occurred that exceeds the severity threshold, it then sends a triggering signal to the inflators to deploy the air bags. The inflators and air bags are packaged together in air bag modules, which are located in the steering wheel on the driver side and in the instrument panel on the passenger side. Upon receiving a triggering signal from the control module, inflators generate or release gases that rapidly fill the air bags, generally within 1/20 of a second after impact. The purpose of the inflated air bags is to provide protective cushioning between the occupants and the steering wheel, instrument panel, and windshield. However, the “single-stage” inflators in most vehicles today, in some cases, provide more inflation power than necessary because they fill the air bags with one level of output when deployed, regardless of the types of occupants requiring protection or the degree of severity of the crash.

Figure 2: Comparison of Conventional and Advanced Frontal Air Bag Systems



Source: GAO analysis of information provided by vehicle manufacturers and literature on air bag technologies.

Future frontal air bag systems designed to meet the performance requirements of NHTSA’s advanced air bag rule will have additional features that will allow the deployment of the air bags to adapt to characteristics of the front seat occupants as well as different crash situations. Auto manufacturers anticipate that two new components will be needed to meet the rule's requirements: occupant classification sensors and multistage inflators. Occupant classification sensors will provide an additional input to the control module to detect different types of occupants and whether or not they are belted. For example, manufacturers anticipate installing sensors that will be able to identify whether the front passenger seat is occupied by an infant in a rear-facing child seat, a child, or an adult. Multistage inflators, which will replace single-stage inflators, will provide varying levels of inflation output that can be tailored to characteristics of the driver and front seat passenger as well as different crash scenarios. Deployment options could include no deployment, low-level output, and high-level output, as well as additional levels of deployment between the low- and high-output stages. While the occupant classification sensors and multistage inflators are the key new features of the advanced air bag systems envisioned by auto manufacturers, other components will also be improved. For example, manufacturers anticipate that these systems will include crash sensors that can more precisely discriminate among different types of crashes (such as a crash into a rigid concrete wall versus a crash with another car), control modules that can process the additional inputs provided by crash and occupant sensors and make more accurate and timely deployment decisions, and air bag designs that will allow the bag to deploy less aggressively.

These advanced air bag systems will be designed to reduce the likelihood of the types of fatalities previously caused by air bag deployments. For example, such systems would deactivate the passenger air bag or deploy it at a low level if the passenger seat is occupied by an infant or small child.[10] These systems may also adjust air bag deployment if the driver or passenger is a small adult.

[10]NHTSA has stressed that children are safest in the back seat and that this will continue to be the case even in vehicles that have advanced air bag systems.

Some Advanced Air Bag Technologies Are Currently Available

Some vehicles on the U.S. market today have frontal air bag systems with multistage inflators and some other advanced features, such as seat belt usage sensors and improved air bag designs.[11] However, no vehicles currently on the market have air bag systems with all the features manufacturers believe are needed to fulfill the requirements of the advanced air bag rule. In particular, no vehicles currently have frontal air bag systems with occupant classification sensors that can distinguish among child seats, children, or adults. Manufacturers are not required to produce vehicles that can meet the requirements of the advanced air bag rule until the production year starting in September 2003 (approximately model year 2004).

Frontal air bag systems with multistage inflators started appearing on the market in some model year 1999 and 2000 vehicles and became more widely available in model year 2001 vehicles. While three of the eight manufacturers we talked to installed multistage air bag systems in some or all of their model year 1999 vehicles, seven of the manufacturers installed this technology in some or all of their model year 2001 vehicles. Four of these seven manufacturers—BMW, DaimlerChrysler, Ford, and Honda—installed multistage air bag systems in at least one-quarter of their model year 2001 fleets.[12] While most of the multistage air bag systems installed in these model year 2001 vehicles have two stages of inflation, some have three stages. Manufacturers are planning to further increase the number of vehicles with multistage air bag systems in their model year 2002 fleets. (See app. III for more detailed information on the availability and features of multistage frontal air bag systems in U.S. market vehicles.)

Most of the multistage air bag systems installed in vehicles on the market today have one or more types of sensors that provide information about

[11]Many vehicles on the market today also have newer seat belt features that improve the performance of the occupant restraint system in protecting occupants. For example, seat belt pretensioners retract a limited amount of webbing to help minimize the forward movement of the occupant during a crash. Also, energy management features prevent belts from concentrating too much energy on the occupant's chest during a severe crash. These include "load limiters" built into the shoulder belt retractor and/or "tear stitching" in the webbing that causes the seat belt to extend gradually.

[12]BMW, DaimlerChrysler (Mercedes-Benz), and Honda introduced multistage air bag systems in their model year 1999 fleets; Ford and General Motors introduced them in their model year 2000 fleets; and Nissan and Toyota introduced them in their model year 2001 fleets. The availability of multistage air bag systems in model year 2001 vehicles, as a percentage of each company's fleet, was: BMW-100 percent, DaimlerChrysler-27 percent, Ford-31 percent, General Motors-10 percent, Honda-74 percent, Nissan-19 percent, and Toyota-1 percent.

the front seat occupants, such as the presence of an occupant in the passenger seat, driver seat position, and driver and passenger seat belt use. In air bag systems with these occupant sensors installed, the control module utilizes input from these sensors, in addition to input from the crash sensors, in making deployment decisions.

- Three manufacturers—BMW, DaimlerChrysler (Mercedes-Benz), and Ford—have offered some model year 2001 vehicles equipped with weight-based occupant presence sensors on the passenger side. In these vehicles, the control module deactivates the passenger air bag if the sensor detects that the passenger seat is unoccupied. The main purpose of these sensors is to prevent unnecessary deployment of the passenger air bag and save on repair costs. The sensors are not capable of identifying what type of occupant is in the passenger seat.[13]
- One manufacturer—Ford—has offered model year 2001 vehicles equipped with sensors that detect whether the driver's seat is positioned forward or rearward on the seat track. When the sensor detects that the seat is positioned forward, indicating that the driver is seated close to the air bag module, the control module deactivates the high-output stage of the driver's air bag.
- Four manufacturers—BMW, DaimlerChrysler (Mercedes-Benz), Ford, and Honda—have offered some model year 2001 vehicles that contain, as part of their multistage air bag systems, sensors that detect whether the occupants are wearing seat belts. The control module deploys the air bags at a higher crash severity threshold if the occupant is belted and a lower threshold if the occupant is unbelted.[14]

In addition to installing the new air bag technologies described above, manufacturers have also made improvements to crash sensors, control modules, and air bags. In currently available multistage air bag systems, the level of air bag deployment in a crash is based on the level of crash severity, although the occupant sensors described above also affect deployment decisions in some vehicles. The crash sensors in these systems have been refined to better discriminate crash severity levels.

[13]However, the occupant presence sensing system in Mercedes-Benz vehicles does have the capability of detecting the presence of a compatible child seat in the front passenger seat, through a tag in the bottom of the child seat. The control module deactivates the passenger air bag when the tag is detected.

[14]Although Volkswagen has not produced any vehicles with multistage air bag systems, some of the company's model year 2001 vehicles have these types of belt use sensors installed.

These crash sensors are generally arranged in one of two ways. In the first type of arrangement, which is typically used in conventional air bag systems, a "single-point" electronic crash sensor is located within the control module in the passenger compartment. In the second type of arrangement, called a "multipoint" electronic crash sensing system, one sensor is located within the control module and one or more sensors are located in the front (crush zone) of the vehicle.

In all of the multistage air bag systems installed in vehicles on the market today, the control modules contain more complex computational systems designed to make timely decisions about the appropriate level of air bag deployment. In multistage air bag systems that include occupant sensors and/or multipoint crash sensing systems, the control modules must process the additional inputs provided by these sensors in making deployment decisions.

Manufacturers have made a variety of improvements in their air bag designs aimed at reducing the aggressivity of the deploying air bag and, therefore, the risk of injury caused by deployment. One major area of improvement has been to change the location of the air bag module or the size, shape, and folding of the bag to increase the distance between the occupant and the deploying air bag. For example, on the driver side, manufacturers now often recess the air bag into the steering wheel and employ a fold and shape that allows the bag to deploy laterally rather than rearward toward the driver. Some passenger air bags in use today contain a device that directs the initial inflation of the bag away from the occupant if he or she is in close proximity to the bag at the time of deployment. Other improvements in bag design that are used in some vehicles include vents that can make the bag deploy more softly if it is obstructed by the occupant during deployment and the use of tethers within the bag to reduce extension when deployed. (For further information on advanced technologies currently installed in vehicles, see app. IV.)

Significant Improvements Are Under Development

Vehicle manufacturers, along with companies that supply them with air bag systems, are working now on developing frontal air bag systems that are intended to meet the requirements in the advanced air bag rule and be ready to be installed in model year 2004 vehicles, as required. The advanced air bag systems envisioned by manufacturers for meeting the rule's requirements include new technologies that have not previously been installed in vehicles as well as significant improvements in existing technologies.

The key new technologies that manufacturers anticipate will be needed to comply with the advanced air bag rule are occupant classification sensors that can identify whether the passenger seat is occupied by an infant in a child seat, a small child in or out of a child seat, or a small adult. Air bag suppliers have been working on the development of a number of such sensor technologies, and manufacturers are currently considering these technologies. The primary technologies under consideration are weight-based sensors and pattern-based sensors, which would be installed within or under the passenger seat. Weight-based sensors attempt to classify the occupant through various means of determining the amount of force or pressure applied to the seat. Pattern-based sensors attempt to classify an occupant using a mat, installed directly under the seat cover, which senses the occupant's applied pressure and imprint. Manufacturers are also considering augmenting some of these technologies with seat belt tension sensors to identify whether the amount of force applied to the seat is due in part to the seat belt rather than the occupant's weight. In addition to developing new sensors for identifying the type of occupant in the passenger seat, manufacturers plan to increase the use of driver and passenger seat belt use sensors and driver seat position sensors. As described in the previous section, these occupant sensor technologies are already developed and available in some vehicles.

Manufacturers also plan to continue making improvements in existing technologies for crash sensors, control modules, inflators, and air bags to comply with the advanced air bag rule. Manufacturers and suppliers are working on improving the ability of crash sensing systems to differentiate levels of crash severity and types of crashes. As part of this effort, manufacturers plan to increase the use of multipoint crash sensing systems. Manufacturers and suppliers are also developing more complex computational systems to be incorporated into control modules, in order to allow them to process the additional inputs in advanced air bag systems and to make accurate and timely decisions regarding deployment outputs. Manufacturers will use multistage inflators that have two or more stages of inflation output in their advanced air bag systems. Some manufacturers have already installed inflators with more than two stages of inflation on a limited basis, but other manufacturers have told us that they do not plan to use them until occupant classification and control module technologies are more fully developed. Finally, manufacturers and suppliers continue to work on improvements in air bag design, such as venting and bag shapes, in order to enhance the ability of vehicles to comply with the advanced air bag rule. Further improvements may include increased use of innovative bag designs as well as new designs that will enhance the ability of the deploying air bag to adapt to characteristics of the occupant.

Vehicle manufacturers and air bag suppliers are also researching some other advanced air bag technologies that are not considered necessary for complying with the advanced air bag rule but that may be used in the longer term to enhance the performance of air bag systems.

- Some manufacturers and air bag suppliers are researching “dynamic” occupant position sensing, which would continuously track the proximity of the occupant to the air bag. Inputs from these sensors, which would be installed in the passenger compartment, would be used by the control module to determine when the occupant is in close proximity to the air bag and, when this is the case, to deactivate the bag. “Static” sensors that periodically determine the occupant’s position may be installed on a limited basis in the near term to augment occupant classification sensors. Although researchers are examining various technologies for achieving dynamic occupant position sensing, it is not yet clear whether or when this technology will become widely used.
- Precrash sensing is another area of technology currently in the research stage. These sensors would identify the position, speed, and mass of objects prior to a collision and allow more time for the air bag system to respond. The feasibility of this concept has not yet been determined; therefore, it is not yet clear when this technology might become available.
- Some suppliers are researching inflator technologies that may produce continuous variation in inflation, rather than inflation in discrete stages, allowing air bag deployment to be more adaptive to inputs from crash and occupant sensors. These may be introduced by some manufacturers during the initial 3-year phase-in period for complying with the advanced air bag rule.

(For further details on anticipated advancements in air bag technologies, see app. IV.)

Occupant Sensing Is the Primary Challenge in Meeting the Advanced Air Bag Rule's Requirements

According to representatives of vehicle manufacturers and air bag suppliers, the primary challenge in meeting the requirements of the advanced air bag rule is developing occupant classification sensors for the passenger side that are accurate, durable, and suitable for mass production before September 2003. The rule requires manufacturers to install advanced air bag systems that either suppress the air bag if an infant or child is seated in the passenger seat or deploy it in a "low-risk" manner that does not cause severe or fatal injury, even if the infant or child is out of position.[15] If the system is designed to suppress the air bag in the presence of an infant or child, it must deploy if the passenger is a small adult (defined as a 5th percentile woman). To test whether a sensor accurately classifies an occupant so the air bag can deploy appropriately, the rule specifies tests using dummies representing infants, 3-year-old and 6-year-old children, and 5th percentile women. The dummies have fixed weights, heights, and stature that are easily distinguishable from each other. However, the rule also requires that some tests be conducted using child seats, variable seat belt tension, blankets, and with the dummies in various positions. These added factors make it more difficult for sensors to distinguish among the different occupants. In addition to the requirements in the rule, manufacturer and supplier representatives told us that they are designing occupant classification sensors for additional "real-world" situations that further challenge the ability of sensors to perform accurately. Such real-world situations could include variation in the actual weight of humans, changes in weight detected by sensors as the occupant moves forward, backward, and side-to-side, or increased weight from objects held on laps.

Manufacturers generally require that technologies perform accurately over 99 percent of the time before being installed in vehicles. However, manufacturer representatives told us that technologies that are currently being developed for occupant classification sensors, such as weight-based or pattern-based sensors, have not demonstrated the ability to consistently distinguish among various sizes of occupants. For example, weight-based sensors in seats have difficulty distinguishing between 6-year-old children and small adults because a 6-year-old child can appear heavier from additional weight (such as a booster seat and increased tension from a

[15]The rule also allows manufacturers the option of suppressing the air bag if the occupant moves out of position during a crash, as occurs in precrash braking. However, NHTSA has not developed performance requirements and test procedures for a system that dynamically suppresses the air bag. In addition, manufacturer representatives told us that they are not planning to install such a system before September 2003 because the technologies needed for this system—dynamic occupant position sensors—are not sufficiently developed.

tightly cinched seat belt); additionally, small adults can appear lighter because a portion of the occupant’s weight is borne by the legs resting on the floor. Pattern-based sensors must first be programmed to recognize various seating positions. If a child or a small adult sits in a position that was not previously anticipated and programmed for the sensor, the system could mistake the child for an adult or vice versa. Incorrect classification of an occupant could result in the system mistakenly deploying the air bag in the presence of a child, not deploying in the presence of an adult, or deploying the air bag with greater or less force than intended.

In addition to performing accurately, occupant classification sensors must also be durable and capable of being consistently produced and integrated into vehicles in large quantities. Air bag systems are expected to operate reliably over the life span of a vehicle, which could be up to 15 years. However, sensors are susceptible to aging and environmental influences over that time. For example, the performance of pattern-based sensors that are installed directly under the seat cover could be affected by deterioration of the seat cover. Sensor performance is also affected by variations in the manufacturing process that can affect the construction of the sensor or how easily it can be integrated into the vehicle. The parts of a sensor must be precisely constructed because inconsistencies in the parts can cause the sensor to malfunction. Sensors that are integrated into a seat are also subject to variations in how the seat is constructed. According to vehicle manufacturer representatives, companies that produce vehicle seats will have to significantly redesign seats and decrease the variation in the production of seats before occupant classification sensors can consistently function properly.

Vehicle manufacturers are working with the companies that supply air bag systems to find solutions to these accuracy, durability, and manufacturing issues. For example, to address the influence of seat belt tension on weight-based sensors, some manufacturers and suppliers are developing seat belt tension sensors that would detect when the seat belt is cinched tightly and causing the occupant to appear heavier. Individual manufacturers are simultaneously developing multiple occupant classification technologies with different suppliers to increase the likelihood of finding a solution by the deadline. Some manufacturers told us they have also postponed research on occupant position sensors so they can focus on occupant classification sensors.

According to representatives of some vehicle manufacturers, their goal is to install occupant classification sensors 1 year before the September 2003 deadline in order to get real-world experience with the performance of the sensors. However, a number of vehicle manufacturers have expressed concerns about their ability to develop occupant classification sensors that comply with the advanced air bag rule by the deadline—slightly more than 2 years away. Despite the fact that manufacturers have been working on technologies for occupant classification sensors for several years, the development of these technologies has not yet reached the level that a new technology would normally have reached to be ready for installation within that time frame. In 1998 and 1999, NHTSA reported that vehicle manufacturers anticipated having occupant classification sensors installed in model year 2000 vehicles.[16] However, accuracy, durability, and manufacturing issues were more difficult to overcome than anticipated. For example, General Motors anticipated installing a pattern-based sensor in its model year 2000 Cadillac Seville but abandoned this plan in part because the sensor did not perform accurately under different humidity and temperature settings, and the production process was so variable that only 10 percent of the sensors that were produced were suitable for installation in vehicles. More recently, in March 2001, after 2 years of work, a company that was to be the primary supplier of a weight-sensing system for DaimlerChrysler decided to abandoned work on the project due to technical reasons. As a result, DaimlerChrysler is reevaluating its options for occupant classification sensors.

NHTSA officials have met with industry representatives to discuss their efforts to develop advanced air bag systems. According to NHTSA officials, although vehicle manufacturers have stated that it will be difficult to develop occupant classification sensors by September 2003, none of the manufacturers have indicated that they will not be able to meet the deadline.[17]

Due to the uncertainty associated with developing occupant classification sensors, NHTSA plans to stay abreast of manufacturers' progress by holding periodic meetings with manufacturers. These meetings may be informal meetings that occur as NHTSA gathers information about technologies or more formal meetings for manufacturers to provide an update on the status of their progress. NHTSA also plans to conduct research on the feasibility of occupant classification technologies, including laboratory research on specific occupant classification

[16] *Advanced Air Bag Technology Assessment*, Prepared for NHTSA and the National Aeronautics and Space Administration by the Jet Propulsion Laboratory, April 1998; *Air Bag Technology in Light Passenger Vehicles*, NHTSA, December 16, 1999, Revision 1.

[17] Should a manufacturer be unable to meet the deadline, the manufacturer may apply to NHTSA for a temporary exemption from the requirements.

technologies and monitoring the performance of occupant classification technologies as they are installed in vehicles.

Other technological challenges described by manufacturers include designing an air bag that can generate enough power to protect an average adult male as well as deploy in a manner that does not severely injure a smaller occupant and developing crash sensors that can distinguish among the various types of crash tests required in the rule. In addition to the technological challenges of developing an advanced air bag system, manufacturers and suppliers are concerned about the accuracy and repeatability of some of the test procedures in the rule and using humans rather than dummies to test suppression systems. These concerns were highlighted in petitions for reconsideration of the rule filed by the manufacturers. (See app. II for further information on these petitions for reconsideration and NHTSA's response.)

Federal and Industry Expenditures on Advanced Air Bag Research and Development Have Increased Since 1998

NHTSA's reported expenditures on advanced air bag R&D increased from about $6.3 million in fiscal year 1998 to nearly $7.0 million in fiscal year 2000. (See table 2.) According to NHTSA officials, these expenditures were primarily for activities related to the development of the advanced air bag rule, such as investigations of crashes involving an air bag-related injury or fatality, evaluations of the performance and characteristics of air bag systems, and studies to determine how people are injured or killed by air bags. NHTSA officials estimate that expenditures on advanced air bag R&D will increase to $7.2 million in fiscal year 2001. According to NHTSA officials, future expenditures will focus on monitoring the performance of advanced air bags and continuing the R&D of specific technologies. NHTSA's planned activities include analyzing the protection provided by advanced air bags in real-world crashes, conducting crash tests—including tests at various speeds and angles with belted and unbelted crash dummies—to evaluate the performance of advanced air bags, and researching advanced air bag technologies that are anticipated to be ready for installation in vehicles in the next 3 to 5 years. NHTSA plans to conduct some of this research through cooperative agreements with air bag suppliers.

Table 2: NHTSA Expenditures on R&D for Advanced Air Bag Technologies, Fiscal Years 1998-2001

Dollars in thousands

Category	1998	1999	2000	2001(est.)
Special crash investigations	$1,331	$1,553	$1,553	$1,553
Air bag systems	1,850	2,431	2,431	2,480
Biomechanics (crash dummies)	3,150	3,000	3,000	3,200
Total	**$6,331**	**$6,984**	**$6,984**	**$7,233**

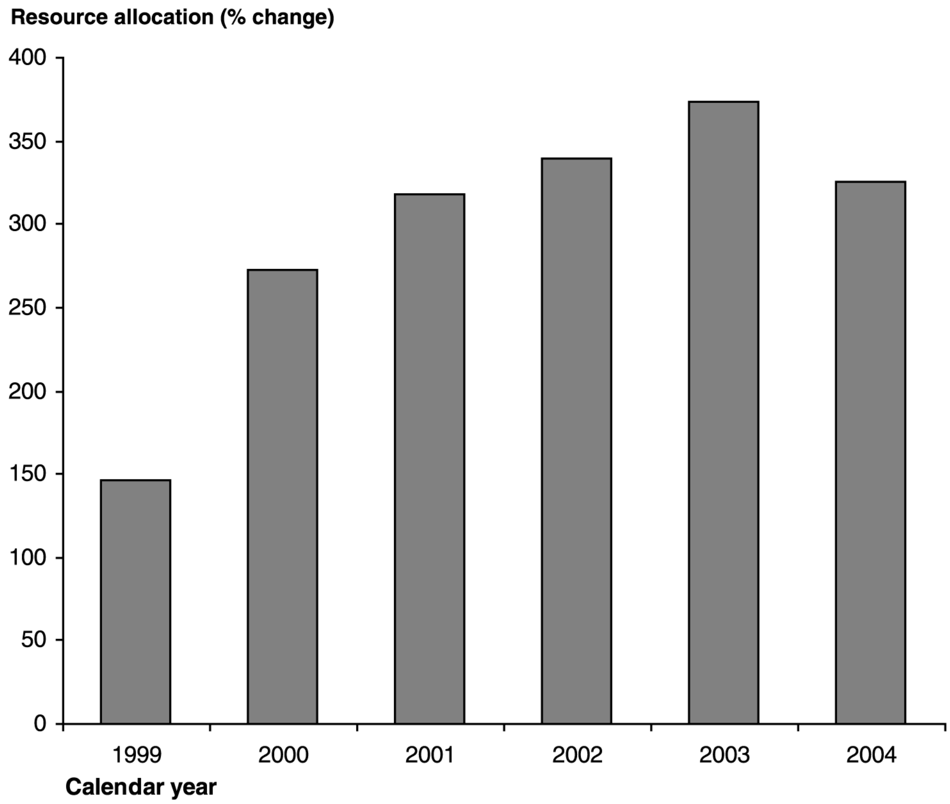
Note: These expenditures do not include other NHTSA expenditures that indirectly benefit air bag R&D, such as the New Car Assessment Program and compliance testing.

Source: NHTSA.

Vehicle manufacturers did not provide information on their individual expenditures for advanced air bag R&D because they consider this information confidential. Instead, an industry association—the Alliance of Automobile Manufacturers—coordinated with manufacturers to provide aggregated information on the extent to which expenditures have changed and are anticipated to change compared to calendar year 1998. Four manufacturers—Ford, General Motors, Nissan, and Toyota—provided information on expenditures for resources related to one or more of the following categories: staffing (including expenditures to support supplier staffing); technology development and testing; prototype parts; engineering resources; in-house testing and data analysis, analytical performance assessment (computer modeling), physical test properties and test costs; and implementation and integration of technologies into vehicles. According to the Alliance, these expenditures generally total between $20 million and $30 million per vehicle "platform" (a group of vehicles that utilize the same basic design).[18] The aggregated information from the four manufacturers shows that their expenditures increased by about 275 percent from 1998 to 2000 and are anticipated to increase overall by nearly 375 percent from 1998 through 2003. (See fig. 3.) According to the Alliance, the estimated increase from 1998 through 2003 is due to the cost of designing and installing advanced air bag systems for an increasing number of vehicle platforms to meet the phase-in requirements in the advanced air bag rule. These expenditures are estimated to decrease after advanced air bag systems have been installed in vehicles.

[18] A single vehicle platform could encompass one or several models of vehicles. According to the Alliance and vehicle manufacturers, the 8 vehicle manufacturers included in our review have 88 vehicle platforms.

Figure 3: Percentage Change in Four Vehicle Manufacturers' Advanced Air Bag R&D Expenditures, 1999 Through 2004



Note: 1998 is the baseline year. The Alliance adjusted each company's expenditures by its current market share and averaged the sum of the manufacturers' adjusted expenditures for each year.

Source: Alliance of Automobile Manufacturers.

Agency and Industry Comments and Our Evaluation

We provided a draft of this report to the Department of Transportation for its review and comment. The Department did not provide an overall assessment of our draft report. Rather, Department representatives, including the Director of NHTSA's Office of Vehicle Safety Research, provided one technical comment through e-mail. Specifically, the Director suggested that several manufacturers may have the necessary technologies for occupant classification sensors that can distinguish among various sizes of occupants, even though they may not have installed them in vehicles on a large scale. We verified with auto manufacturers that they have not installed occupant classification sensors that can distinguish among various sizes of occupants and are still developing such sensors for frontal air bag systems that are intended to meet the requirements of the advanced air bag rule.

We provided portions of our draft report to vehicle manufacturers and air bag suppliers for review to verify the accuracy of our descriptions of advanced air bag technologies and challenges in meeting the requirements of the advanced air bag rule. The manufacturers and suppliers generally agreed with our draft report and offered several technical corrections, which we incorporated as appropriate.

We are sending copies of this report to congressional committees and subcommittees responsible for transportation safety issues; the Secretary of Transportation; the Executive Director, National Highway Traffic Safety Administration; the Director, Office of Management and Budget; and other interested parties. We will make copies available to others upon request and on GAO's home page at http://www.gao.gov.

If you or your staff have any questions about this report, please contact me at (202) 512-2834. Key contributors to this report were Judy Guilliams-Tapia, Bert Japikse, James Ratzenberger, Phyllis Scheinberg, and Sara Vermillion.

John H. Anderson, Jr.

John H. Anderson, Jr.
Managing Director, Physical Infrastructure Issues

Appendix I: Scope and Methodology

To determine the current availability of and planned improvements to advanced air bag technologies, we collected and analyzed information from eight vehicle manufacturers (BMW, DaimlerChrysler, Ford, General Motors, Honda, Nissan, Toyota, and Volkswagen) and the five companies that are the primary suppliers of air bag systems in the United States (Autoliv, Breed, Delphi, Takata, and TRW). According to the Alliance for Automobile Manufacturers, the combined sales for the eight manufacturers account for over 90 percent of vehicles sold in the United States. We did not independently verify the information we received from manufacturers and suppliers. We reviewed literature on automotive technology for descriptions of the technologies used in advanced air bag development. We also met with officials from NHTSA, representatives from the Insurance Institute for Highway Safety, the National Transportation Safety Board, university researchers, and consumer groups.

To identify the challenges, if any, that the industry faces in complying with the advanced air bag rule, we reviewed the requirements of the rule and discussed these requirements with representatives of vehicle manufacturers and companies that supply air bags. We also reviewed comments on the rule submitted by manufacturers and suppliers.

To identify the changes in federal expenditures on advanced air bag R&D, we collected data on NHTSA's expenditures for fiscal years 1998 through 2001 and analyzed the changes in the individual categories of expenditures. Vehicle manufacturers did not provide information on their individual expenditures for advanced air bag R&D because they consider this information confidential. Therefore, to identify the changes in industry expenditures on advanced air bag R&D, we collected aggregated information from an industry association on the extent to which four manufacturers' expenditures have changed since 1998. We did not independently verify this aggregated information.

We conducted our work from July 2000 through May 2001 in accordance with generally accepted government auditing standards.

Appendix II: Selected Aspects and Status of the Advanced Air Bag Rule

The advanced air bag rule requires that future air bags be designed to create less risk of serious injury from air bags—particularly for small women and young children—and to improve frontal crash protection for all occupants. To achieve these goals, the rule includes requirements for additional test procedures using different sizes of dummies than were included in previous requirements. These new requirements will be phased in during two stages. During the first stage phase-in—from September 1, 2003, to August 31, 2006—an increasing number of each manufacturer's vehicles must be certified each year as meeting the requirements in the advanced air bag rule. During the second stage phase-in—from September 1, 2007, to August 31, 2010—the speed for one of the tests (the belted test for the 50th percentile adult male dummy) will be increased from 30 to 35 miles per hour (mph) and, similar to the first phase-in period, an increasing number of each manufacturer's vehicles must be certified each year.

In comments to the supplemental notice of proposed rulemaking on advanced air bags, there was a difference of opinion on whether the maximum speed for the unbelted rigid barrier crash test should be set at 25 or 30 mph. In the final rule, NHTSA set the maximum speed at 25 mph on an interim basis while the agency continues to investigate whether the higher speed is more appropriate. After the rule was issued in May 2000, consumer safety groups, vehicle manufacturers, and air bag suppliers filed petitions for NHTSA to consider changing certain provisions in the rule. NHTSA plans to respond to these petitions in July 2001.

Selected Requirements in the Advanced Air Bag Rule

To minimize risk to infants and children on the passenger side, the rule includes provisions for the air bag to be suppressed or deployed in a "low-risk" manner that is much less likely to cause serious or fatal injury. (See fig. 4.) For newborn infants in car beds, the rule requires that the air bag be suppressed. For 1-year-old infants in child seats, 3-year-old children, and 6-year-old children, manufacturers are allowed to install systems designed for suppression or low-risk deployment. Manufacturers may choose different strategies for different occupants. For example, a manufacturer could design an air bag system that would suppress the air bag for infants and deploy the bag in a low-risk manner for 3- and 6-year-old children.

Figure 4: Test Options in the Advanced Air Bag Rule to Meet Suppression and Low-Risk Deployment Requirements for Smaller Occupants

	OPTIONS		
	Suppress air bag if occupant is present	Suppress air bag if occupant is out of position[a]	Deploy air bag in low-risk manner
Car bed with newborn infant dummy (passenger position)	✓		
Rear- or Forward-facing child seat with 1-year-old dummy (passenger position)	✓		✓
3-year-old and 6-year-old child dummies (passenger position)	✓	✓	✓
5th percentile adult female dummy (driver position)		✓	✓

[a] This option allows manufacturers to suppress the air bag if the occupant (3-year-old or 6-year-old on the passenger side or small female on the driver side) moves "out of position," or close to the air bag module during a crash, as occurs in precrash braking. NHTSA has not adopted performance requirements and test procedures for such a system that would "dynamically" suppress the air bag, but may do so at a later date. Several manufacturers told us that they are not planning to install such a system before September 2003 because the technologies needed for this system—dynamic occupant position sensors—are not sufficiently developed.

Source: NHTSA.

To test for suppression on the passenger side, the dummies are placed in their appropriate child seats that are, in turn, placed on the passenger seat.[1] These tests may be conducted under various scenarios: using any of several models of safety seats; with the passenger seat in the forward, middle, or rear position; unbelted or belted with up to 30 pounds of tension on the belt; with any handles and sunshields on infant safety seats in fully open and fully closed positions; or with a towel or blanket on the infant safety seats. For the 3- and 6-year-old dummies, tests will also be conducted with the dummies unbelted and in various positions, such as

[1]Newborn infant dummies are placed in car beds. One-year-old dummies are placed in rear-facing or forward-facing child safety seats. Three-year-old dummies are placed in forward-facing child seats or booster seats. Six-year-old dummies are placed in booster seats.

sitting back or sitting on the front edge of the seat.[2] The rule requires that the car have a "telltale" light that, after the dummy is in place, indicates whether the air bag is suppressed or activated. Following each suppression test with an infant or child, a dummy representing a small (5th percentile) adult female will be placed in the passenger seat to ensure that the air bag is not suppressed for small adults.

To test for low-risk deployment on the passenger side, a 1-year-old dummy is placed in one of several models of rear- or forward-facing child seats on the passenger seat in the forward position on the seat track. The seat belt may be cinched with up to 30 pounds of tension. For the 3- and 6-year-old dummies, the unbelted dummy is placed "out of position" with their head or chest on the air bag module to simulate the situation where an unbelted child is close to the instrument panel due to sudden braking immediately before a crash. After the dummy (infant or child) is in place, the air bag is deployed. The amount of "injury" that occurs to the head and neck of the dummies (and the chest of the 3- and 6-year-old child dummies) must be below criteria specified in the rule.

To minimize risk to small drivers, the rule includes provisions to deploy the air bag in a low-risk manner, similar to the low-risk deployment tests for 3- and 6-year-old children.[3] The tests are conducted by placing the 5th percentile adult female dummy out of position, with the chin on the steering wheel rim or on the air bag module. The air bag is then deployed and the resulting "injury" to the head, neck, chest, and legs is measured. NHTSA has determined that, when all of the combinations of the various testing scenarios are considered, there are 129 tests for suppression and low-risk deployment: 95 suppression tests for infants in a car bed or child seat, 28 suppression tests for 3- and 6-year-old children, 4 low-risk

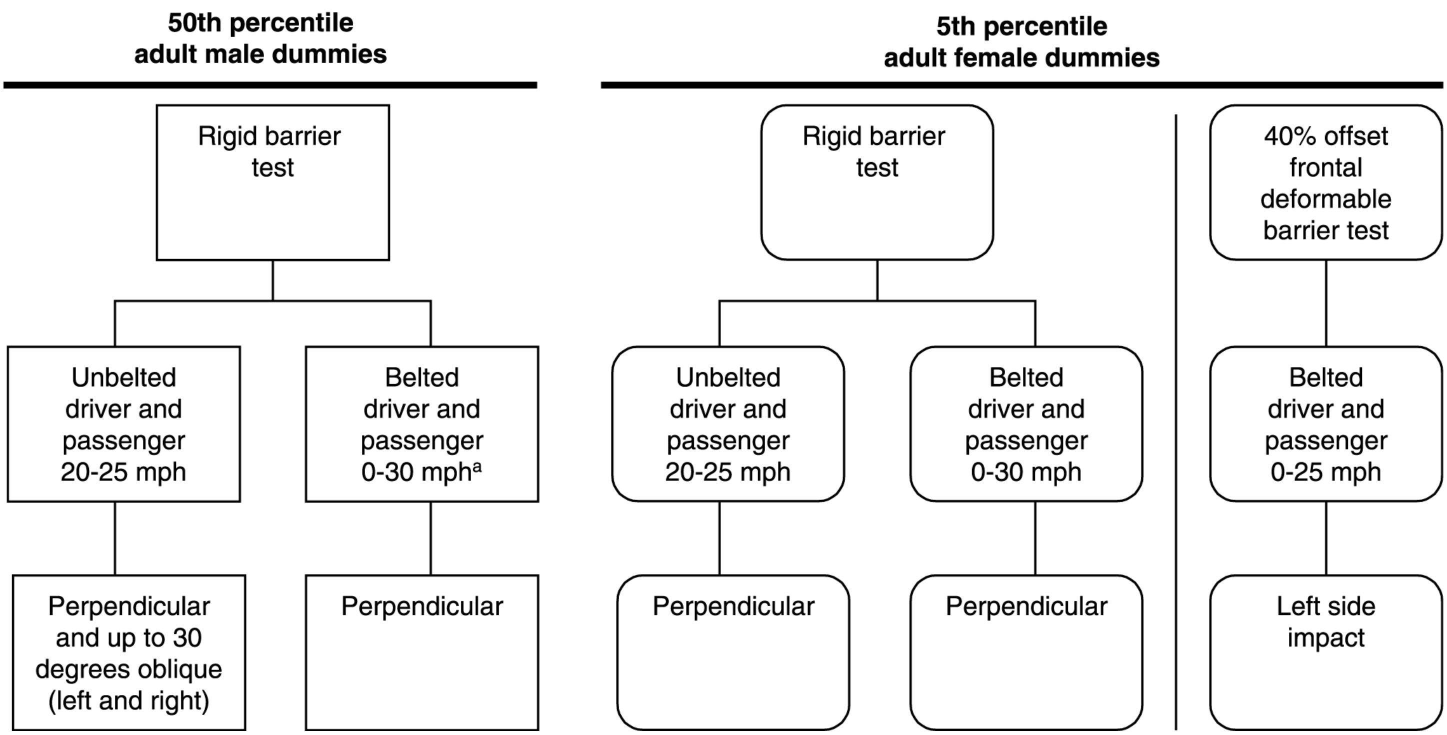
[2]Crash dummies do not sufficiently represent the human physiology, so the rule allows the use of appropriately sized humans to test the performance of the technologies in static suppression tests. The University of Michigan Transportation Research Institute is developing dummies that more accurately represent the human shape.

[3]The rule also allows manufacturers the option of suppressing the air bag if the occupant moves out of position during a crash, as occurs in precrash braking. However, NHTSA has not developed performance requirements and test procedures for a system that dynamically suppresses the air bag. In addition, manufacturer representatives told us that they are not planning to install such a system before September 2003 because the technologies needed for this system—dynamic occupant position sensors—are not sufficiently developed.

deployment tests for 3- and 6-year-old children, and 2 low-risk deployment tests for 5th percentile female drivers.

To improve protection in frontal crashes for occupants of different sizes, the rule includes seven tests that involve crashing vehicles into barriers at different speeds and angles and with dummies representing average (50th percentile) adult males and 5th percentile women, belted and unbelted. (See fig. 5.) Four of the tests are conducted with dummies that represent 50th percentile adult males and three are conducted with dummies that represent 5th percentile adult females. After the crash test, the resulting injury to the head, neck, chest, and legs of the dummies must not exceed the limits specified in the rule. The offset deformable barrier test was included in the requirements to ensure that manufacturers upgrade their crash sensors as necessary to prevent late air bag deployments in crashes that are less abrupt than those into rigid barriers. NHTSA did not include a requirement for an unbelted crash test at an oblique angle using a 5th percentile female dummy because the agency determined that the requirement for this type of crash using a 50th percentile male dummy would result in an air bag that is sufficient to protect smaller occupants as well.

Figure 5: Tests Required in the Advanced Air Bag Rule to Improve Protection for Occupants of Different Sizes

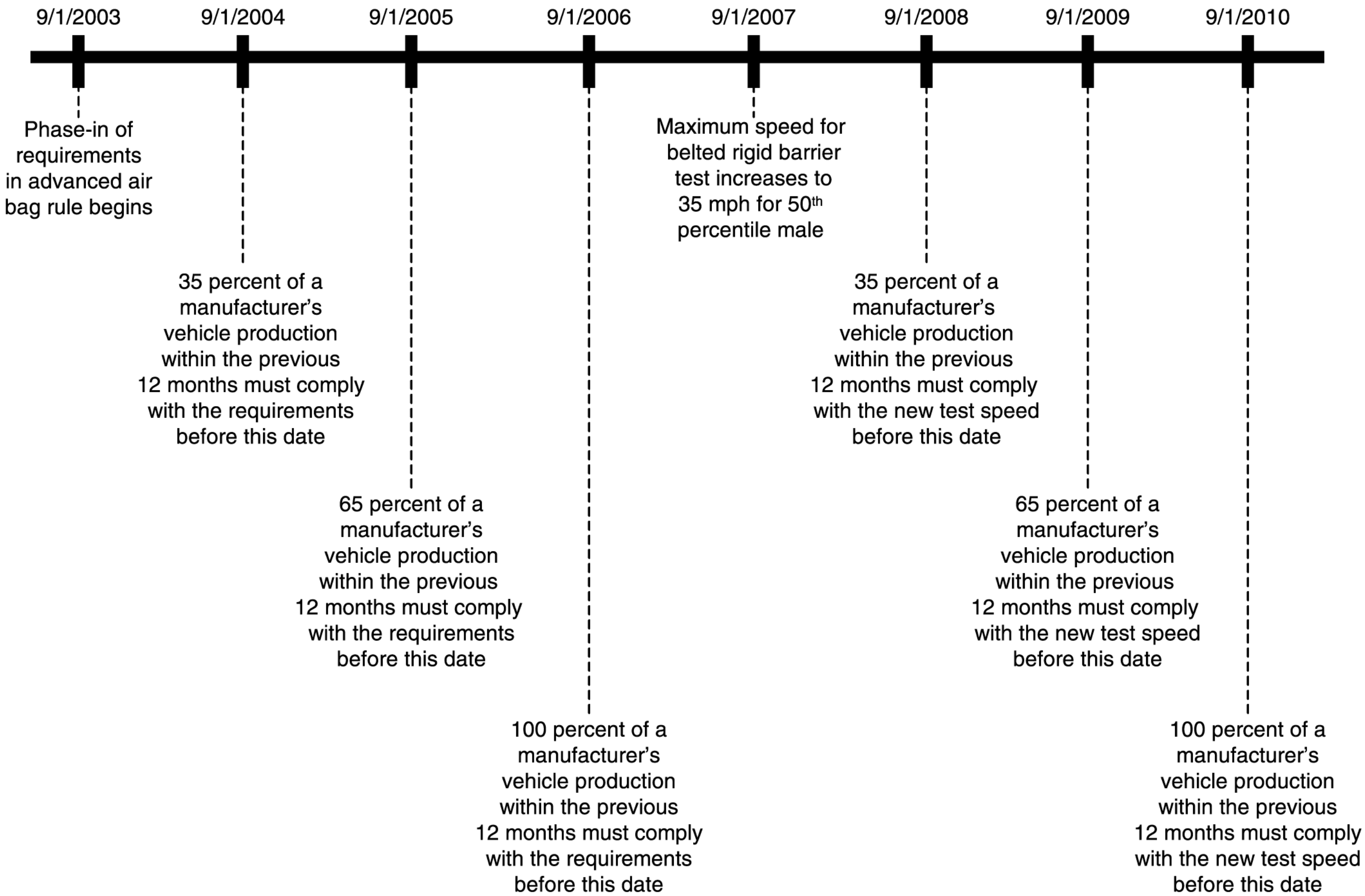


[a]Maximum speed will increase to 35 mph after September 1, 2007.

Source: NHTSA.

The rule will be phased in during two stages. The first stage phase-in—from September 1, 2003, to August 31, 2006—requires an increasing number of vehicles to be certified as passing all of the above tests each year. (See fig. 6.) During the second stage phase-in—from September 1, 2007, to August 31, 2010—the speed for the belted test for the 50th percentile adult male dummy will be increased from 30 to 35 mph. As with the earlier requirements, an increasing percentage of vehicles must comply with the new test speed each year.

Figure 6: Timeline for Phase-in of Requirements in the Advanced Air Bag Rule



Source: GAO analysis of information from NHTSA.

Comments on the Maximum Speed for the Unbelted Rigid Barrier Test

In the comments to the supplementary notice of proposed rulemaking for the advanced air bag rule, there was a significant difference of opinion on whether the top speed for the unbelted rigid barrier crash test should be set at 30 mph or 25 mph.[4] Comments from those who favored setting the maximum test speed at 30 mph—safety groups such as Public Citizen,

[4]While the speed of a rigid barrier crash test at 30 mph is 20 percent higher than a test at 25 mph, it represents a 44 percent increase in crash energy.

Center for Auto Safety, Consumers Union, and Parents for Safer Air Bags—included:

- half of all fatalities in frontal crashes involve a change in velocity greater than 30 mph, so a maximum test speed of 30 mph represents significantly more potentially fatal crashes than a test speed of 25 mph;
- in crash tests conducted by NHTSA, almost all vehicles with redesigned air bags passed the 30 mph unbelted rigid barrier test with the 50th percentile male dummy, so air bags would not have to be more aggressive (and potentially more risky to small occupants) to meet a 30 mph test;
- lowering the test speed to 25 mph would not offer improved protection, as required in the Transportation Equity Act for the 21st Century;
- advanced technologies can be used to enable all vehicles to meet requirements for high speed protection and risk reduction; and
- a 25 mph test speed would not encourage the use of advanced technologies.

Comments from proponents of a 25 mph maximum test speed—such as vehicle manufacturers, air bag suppliers, the Insurance Institute for Highway Safety, and the National Transportation Safety Board—included:

- redesigned air bags work well and there has been no loss in protection;
- a 25 mph test speed allows flexibility to design air bags for all occupants;
- a return to a 30 mph test would require a return to overly powerful air bags;
- there are significant technological challenges in meeting a 30 mph requirement for both the 50th percentile adult male dummy and the 5th percentile adult female dummy; and
- advanced technologies are not currently available that address problems posed by air bags designed to a 30 mph test.

NHTSA concluded that, given the uncertainty associated with simultaneously achieving improved protection for occupants of all sizes without compromising efforts to reduce the risks of injury to smaller occupants, a conservative approach should be taken. Consequently, NHTSA set the maximum speed for the unbelted rigid barrier test at 25 mph. However, the agency issued that part of the rule as an interim final rule and announced that it would issue a final rule after it monitors the performance of advanced air bags and determines whether increasing the maximum test speed to 30 mph would offer any advantages over a test speed of 25 mph. To monitor the performance of advanced air bags, NHTSA plans to, among other things, evaluate real-world crash data, perform compliance testing and publish an annual report on the extent to which advanced air bags comply with requirements, conduct crash tests, and conduct research on specific advanced air bag technologies.

Petitions for Reconsideration

After the final rule was issued in May 2000, consumer safety groups, vehicle manufacturers, and air bag suppliers submitted petitions to NHTSA for the agency to reconsider certain aspects of the rule. Consumer safety groups—Center for Auto Safety, Consumer Federation of America, Parents for Safer Air Bags, and Public Citizen—jointly filed a petition. The petition states that separate phase-in schedules for cars and sport utility vehicles are feasible because some cars can already meet a 30 mph unbelted rigid barrier crash test, but sport utility vehicles have more difficulty in complying with this test due to their stiffer frame, which produces a harder crash pulse and requires a more aggressive air bag than passenger cars. Specifically, the petition requests NHTSA to require the industry to meet a 30 mph unbelted rigid barrier test for passenger cars and a 25 mph test for sport utility vehicles, to be increased to 30 mph at a later date. The petition also requests NHTSA to: (1) add requirements for tests to simulate lower-speed, softer crashes in which the air bag deploys late and strikes an occupant who has moved forward before the air bag deploys, (2) require manufacturers to meet a 35 mph belted barrier test with the 5th percentile female dummy as well as the 50th percentile male dummy, and (3) require that manufacturers conduct all barrier tests in both the perpendicular and oblique modes, including tests using the 5th percentile female dummies.

Petitions from some vehicle manufacturers and air bag suppliers state that the directions for some tests in the rule, particularly those related to the positioning of dummies in suppression and low-risk deployment tests, need to be clarified. For example, some petitioners claimed that the procedure for positioning the child dummies for the low-risk deployment test do not always result in the dummies being against the air bag module, as intended. Other issues raised in petitions from manufacturers include: (1) limiting the amount of time required to collect data on the dummies' injuries during a low-risk deployment test in order to minimize inclusion of injury from interior components other than the air bag, (2) requesting that a generic child restraint test device be developed so that humans will not have to be used to test air bag suppression systems, and (3) reducing the upper limit on the amount of tension that can be applied to a seat belt.

According to NHTSA officials, NHTSA is drafting a final response to these petitions and plans to issue the response in July 2001. Some consumer safety groups and vehicle manufacturers have told us that they are concerned about the timeliness of NHTSA's response to the petitions. Some manufacturers have raised concerns that the issues with the compliance test procedures may not be resolved in time for them to finalize their advanced air bag system designs and perform the required testing to certify that the vehicles meet the requirements in the advanced air bag rule.

Appendix III: Multistage Frontal Air Bag Systems in Model Year 2001 Vehicles and Model Year 2002 Vehicles in Production as of April 1, 2001

		Stages of inflation			Types of occupant sensors that affect air bag deployment		
Manufacturer/ make/model year/vehicle line	Percentage of U.S. fleet[a]	Driver	Passenger	Type of crash severity sensor[b]	Occupant presence sensor on passenger side[c]	Seat position sensor on driver side[d]	Belt use sensor on driver and passenger sides[e]
BMW							
All 2001 vehicles	100	2	2	Single-point electronic	✔		✔
DaimlerChrysler							
Chrysler/Dodge/ Jeep							
2001 Sebring/ Stratus Sedan	5	3	3	Single-point electronic			
2001 Sebring Convertible	2	2	2	Single-point electronic			
2001 Caravan/ Voyager/Town and Country Minivans	16	3	3	Single-point electronic			
2002 Jeep Liberty	7	3	3	Multipoint electronic			
Mercedes-Benz							
2001 C-class	1	2	2	Single-point electronic	✔[f]		✔
2001 S-class	1	1	2	Single-point electronic	✔[f]		✔
2001 CL-class	<1	1	2	Single-point electronic	✔[f]		✔
2001 ML-class	2	2	2	Single-point electronic	✔[f]		✔
Ford Motor Company							
Ford/Mercury/ Lincoln							
2001 Taurus/Sable	12	2	2	Multipoint electronic		✔	✔
2001 Crown Victoria/Grand Marquis	6	2	2	Multipoint electronic		✔	✔
2001 Town Car	2	2	2	Multipoint electronic		✔	✔
2001 Windstar	5	2	2	Multipoint electronic	✔[g]	✔	✔
Volvo							

Manufacturer/ make/model year/vehicle line	Percentage of U.S. fleet[a]	Stages of inflation: Driver	Stages of inflation: Passenger	Type of crash severity sensor[b]	Types of occupant sensors that affect air bag deployment: Occupant presence sensor on passenger side[c]	Seat position sensor on driver side[d]	Belt use sensor on driver and passenger sides[e]
2001 S40	1	2	2	Single-point electronic			✔
2001 S60	<1	2	2	Single-point electronic			✔
2001 S80	1	2	2	Single-point electronic			✔
2001 V40	1	2	2	Single-point electronic			✔
2001 V70	1	2	2	Single-point electronic			✔
2001 Cross Country	<1	2	2	Single-point electronic			✔
Jaguar							
2001 XK Coupe and Convertible	2	2	2	Single-point electronic	✔	✔	✔
General Motors							
2001 Chevrolet Impala	4	2	2	Multipoint electronic			
2001 Chevrolet Monte Carlo	1	2	2	Multipoint electronic			
2001 Buick Lesabre	3	2	2	Multipoint electronic			
2001 Oldsmobile Aurora	1	2	2	Multipoint electronic			
2001 Pontiac Bonneville	1	2	2	Multipoint electronic			
2002 Cadillac Seville	2	2	2	Multipoint electronic			
2002 Buick Rendezvous	1	2	2	Multipoint electronic			
2002 Chevrolet Trail Blazer	2	2	2	Multipoint electronic			
2002 GMC Envoy	<1	2	2	Multipoint electronic			
2002 Oldsmobile Bravada	<1	2	2	Multipoint electronic			
Honda							
Honda							
2001 Accord	32	2	2	Single-point electronic			✔
2001 Civic	28	2	2	Multipoint electronic with mechanical front sensors			✔

Manufacturer/ make/model year/vehicle line	Percentage of U.S. fleet[a]	Stages of inflation: Driver	Stages of inflation: Passenger	Type of crash severity sensor[b]	Types of occupant sensors that affect air bag deployment: Occupant presence sensor on passenger side[c]	Seat position sensor on driver side[d]	Belt use sensor on driver and passenger sides[e]
Acura							
2001 CL	5	1	2	Single-point electronic			✔
2001 MDX	3	1	2	Single-point electronic			✔
2001 RL	1	1	2	Single-point electronic			✔
2001 TL	5	1	2	Single-point electronic			✔
2002 RL	N/A	1	2	Single-point electronic			✔
2002 TL	N/A	2	2	Single-point electronic			✔
Nissan							
2001 Maxima/ Infiniti I30	19	2	2	Multipoint electronic			
2002 Q45	N/A	2	2	Multipoint electronic			
Toyota							
2001 LS430	1	1	2	Multipoint electronic			

Legend:

N/A = not available

Note: Table includes U.S. market vehicles only. The checkmarks in the columns for occupant sensors indicate that these sensors have been installed on the corresponding vehicle.

[a]These figures are the approximate percentage that each specified vehicle line represents of the company's light vehicles produced during the model year for the U.S. market.

[b]Single-point electronic crash sensors are generally located within the control module in the passenger compartment. In a multipoint crash sensing system, one electronic crash sensor is located within the control module and one or more electronic or mechanical crash sensors are located in the front (crush zone) of the vehicle.

[c]An occupant presence sensor detects weight on the passenger seat to determine if the seat is occupied. If the sensor does not detect an occupant over a specified weight, the system deactivates the passenger air bag.

[d]Seat position sensors identify whether the driver's seat is forward or rearward on the seat track. When the seat is positioned forward, indicating that the driver is seated close to the steering wheel and the air bag module, the system deactivates the high output stage of the driver's air bag.

[e]Belt use sensors detect whether the front seat occupants are wearing their seat belts. The system deploys the air bag at a higher crash velocity threshold if an occupant is buckled and a lower threshold if an occupant is unbuckled.

[f]The occupant presence sensing system in these vehicles has the capability to detect the presence of a compatible child seat in the front passenger seat. When the sensor detects the presence of such a child seat, through a tag in the bottom of the child seat, the system deactivates the passenger air bag.

[g]An occupant presence sensing system was incorporated in the front passenger seat of model year 2001 Windstars beginning in May 2001.

Source: GAO analysis of information provided by vehicle manufacturers.

Appendix IV: Current Availability of and Anticipated Improvements in Advanced Air Bag Technologies

Technologies Currently Available and Planned Enhancements to Meet Requirements

Crash Sensors

Description: These sensors detect a crash and differentiate levels of crash severity. They provide this input to the control module, which uses it to make decisions about whether the air bag should be deployed and, if so, what level of deployment is appropriate.

Advanced technologies currently available: The crash sensors in vehicles equipped with multistage frontal air bags have been refined to better discriminate crash severity levels, so that the appropriate level of air bag deployment can be determined. Some of these vehicles have a “single-point” electronic crash sensor, which is generally located within the control module in the passenger compartment. Others have “multipoint” crash sensing systems, in which one sensor is located within the control module and one or more sensors are located in the front (crush zone) of the vehicle. In some of these multipoint systems all of the sensors are electronic while in others the sensor in the control module is electronic and the sensors in the front of the vehicle are mechanical. Some manufacturers have placed additional sensors in the front of the vehicle in order to produce more information on the crash earlier in the crash event, allowing additional time to determine crash severity and make the appropriate deployment decision. However, others have not yet installed up-front crash sensors in their multistage air bag systems, because the performance of these sensors in “real-world” conditions can be affected by irrelevant “background noise,” such as extraneous vibrations that occur during a crash event. (See app. III for information on the types of crash sensing systems installed in model year 2001 and early model year 2002 vehicles with multistage air bags.)

Anticipated improvements: In order to enhance the ability of their vehicles to comply with the requirements in the advanced air bag rule, manufacturers plan to improve the ability of their crash sensing systems to distinguish among levels of crash severity as well as identify the type of crash, such as a frontal rigid barrier crash, a pole crash, or an offset deformable barrier crash. As part of this effort, manufacturers plan to refine and increase the use of multipoint crash sensing systems.

Occupant Classification Sensors

Description: These sensing devices installed in the interior of the vehicle are intended to identify characteristics of the occupants, such as their belted status and size. They provide this input to the control module, which uses it to make decisions about whether the air bag should be deployed and, if so, what level of deployment is appropriate.

Advanced technologies currently available: Some vehicles currently equipped with multistage frontal air bag systems have occupant sensors that provide information such as seat position, occupant presence, seat belt use, and identification of a child seat. However, occupant sensors currently available in U.S. market vehicles are not capable of distinguishing among different sizes of occupants, such as whether the passenger is a child or an adult. A limited number of vehicles with multistage air bags contain seat position sensors on the driver side that identify whether the seat is forward or rearward on the seat track. If the seat is positioned forward, indicating that the driver is seated close to the steering wheel and the air bag module, the system deploys the air bag with reduced force. Some vehicle models contain weight-based sensors on the passenger side that identify whether the seat is occupied. If the sensor does not detect an occupant over a specified weight, the system deactivates the passenger air bag. These sensors are intended to prevent unnecessary deployment of the passenger air bag. Some vehicle models also contain, as part of their multistage air bag systems, seat belt use sensors on the driver and passenger sides that identify if the occupant is wearing the seat belt. The system deploys the air bags at a higher crash velocity threshold if the occupant is buckled and a lower threshold if the occupant is unbuckled. Finally, a limited number of vehicles with multistage air bags contain child seat sensors that identify a tag in the bottom of a compatible child seat. The system deactivates the passenger air bag when it detects the tag. NHTSA considers these child seat sensors to be an excellent supplement to other occupant classification systems. However, NHTSA will not allow manufacturers to use this sensing system alone to comply with the rule's requirements because it would be difficult to ensure that tags would be properly installed on the wide variety of child seats used by the general public. (See app. III for information on the types of occupant classification sensors installed in model year 2001 and early model year 2002 vehicles with multistage air bags.)

Anticipated improvements: To comply with the advanced air bag rule, manufacturers anticipate increasing the use of driver seat position sensors and driver and passenger seat belt use sensors. In addition, sensors based on weight classification and/or pattern recognition will be installed on the passenger side to distinguish among adults, children, and child seats. Technologies being considered primarily include load cells, pressure bladders, and pattern/pressure mats.[1] Load cells are electro-mechanical devices located at each attachment point of the seat frame to the vehicle. They estimate the force applied to the seat, allowing the system to classify an occupant based on their seated weight. A pressure bladder is a fluid- or air-filled bladder located under the seat cushion and above the seat frame. The system classifies an occupant based on the amount of pressure applied to the bladder. A pattern/pressure mat contains multiple sensor elements and is located between the seat cushion and upholstery. The system classifies an occupant based on the amount of pressure applied to the mat and the pattern of the occupant's imprint on the seat. Some of these technologies may need to be augmented by seat belt tension sensors to identify whether the amount of force applied to the seat is due in part to the seat belt rather than the occupant's weight. This is important information for identifying child seats. Occupant position sensors, which are described in the section below, may also be used to enhance occupant classification sensors.

Control Module

Description: This central processing unit stores the vehicle's sensing algorithms, computational systems that interpret and analyze inputs from the crash sensors and occupant sensors to determine whether the air bag should be deployed and, if so, what level of deployment is appropriate. In order to deploy the air bags in time to restrain the occupants, the control module must predict during the initial part of the crash whether a crash is occurring that exceeds a predetermined severity threshold. The control module generally triggers deployment from 10 to 100 milliseconds after the start of the crash, depending on the type of crash.

Advanced technologies currently available: Multistage air bag systems contain control modules with sensing algorithms of increased complexity that can determine the appropriate level of air bag deployment, based on available inputs. In multistage air bag systems that include occupant sensors and/or multipoint crash sensing systems, the algorithms process the additional inputs provided by these sensors in making deployment decisions.

Anticipated improvements: To comply with the advanced air bag rule, control modules will require algorithms of greater complexity that will be able to interpret and analyze additional inputs concerning crash scenarios

[1]Manufacturers are also considering other technologies, such as capacitive coupling sensors, which are embedded in the seat cushion and classify the occupant by detecting the disruption in a low energy electric field.

and types of occupants and use this information in making appropriate deployment decisions. Manufacturers also intend to make further improvements in control modules to increase the speed of processing of inputs and the accuracy of deployment decisions. As algorithms become more complex, it may be necessary in the longer term to move from a centralized control module to a system in which the processing and decision-making functions are decentralized, because of dramatic increases in the amount of information being input and in the computations needed.

Multistage Inflators

Description: Multistage inflators have two charges that can generate two or more stages of inflation. Firing one charge generates low-level deployment; firing both charges simultaneously or in sequence generates higher levels of deployment.

Advanced technologies currently available: A number of vehicle models currently have frontal air bag systems with multistage inflators. Most of these vehicles have inflators with two stages of inflation (low- and high-level deployment), while a limited number have inflators with three stages of inflation (low-, medium-, and high-level deployment). In most cases, the multistage inflators are on both the driver and passenger sides, but in some cases only the passenger side has a multistage inflator. In currently available multistage air bag systems, the deployment level is triggered based on crash severity and, in some cases, driver seat position. In addition, as previously explained, some of these systems deploy the air bags at different crash severity thresholds for belted or unbelted occupants and/or deactivate the passenger air bag if a sensor detects that the passenger seat is empty or contains a child seat. (See app. III for information on the multistage air bag systems installed in model year 2001 and early model year 2002 vehicles.)

Anticipated improvements: To comply with the advanced air bag rule, manufacturers will use multistage inflators with two or more stages of inflation. Some manufacturers have told us that their introduction of inflators with more than two stages of inflation depends on further advancements in crash sensors, occupant sensors, and the control module in order to be able to reliably determine the appropriate level of inflation. Various inflation technologies are under development that may provide continuous variation in inflation, rather than inflation in discrete stages, allowing greater adaptiveness to inputs provided by crash and occupant sensors. For example, one such technology would use a variable electric current to continuously control the rate of gas generation during inflation of the air bag. Inflators with these technologies may be introduced by some manufacturers during the 3-year phase-in period for complying with the advanced air bag rule.

Air Bag Features That Minimize Risk to Occupants

Description: In addition to characteristics of the inflators, some air bag design features can reduce the aggressivity of the deploying air bag and, therefore, the likelihood of serious injury caused by deployment. These features include the location of the air bag module (which contains the inflator and the air bag) and characteristics of the bag itself, such as folding, shape, compartments, tether straps, and venting.

Advanced technologies currently available: Manufacturers have made a variety of changes in bag design in order to make deployment less likely to cause injury. The location, folding, and shape of frontal air bags have been major areas of design change. On the driver's side, air bag modules have been recessed into the steering wheel in many vehicles to add space between the driver and the deploying air bag. Also, many driver air bags now have a fold pattern and shape that allows the bag to deploy in a radial manner, so that the initial "burst out" inflation force will inflate the bag laterally rather than rearward toward the driver. On the passenger's side, manufacturers often locate the bag module in a "top-mount" position on the instrument panel, to increase the distance between the occupant and the deploying bag, or use a smaller-sized bag if it is located in a "mid-mount" position in front of the passenger on the instrument panel.

Some newer fold and shape designs and venting schemes can make the deploying air bag adaptive to the position of the occupant. For example, some passenger air bags in use today contain a fabric flap attached to the bag, known as a "bias flap," which directs the initial burst out inflation of the bag to the side of and away from the occupant if he or she is out of position (in close proximity to the bag) at the time of deployment. Some bags have variable venting designs that inflate the bag more softly if it is obstructed during deployment, indicating that the occupant is out of position. Tethers, which are strips of fabric connecting the front and back panels of the bag, have been incorporated into some bag designs on both the driver and passenger sides to reduce extension of the bag and help position it more quickly when it is deployed.

Anticipated improvements: Although air bag design is a relatively mature technology, manufacturers and air bag suppliers continue to work on improvements in this area in order to enhance the ability of air bag systems to comply with the advanced air bag rule. Concepts under development that may become available in the longer term include venting systems that will work with multistage inflators to increase the adaptability of deployment (by controlling inflator output based on input from sensors) and bags with multiple compartments that inflate sequentially.

Additional Enhancements to Advanced Air Bag Systems Anticipated for the Longer Term

Occupant Position Sensors

Description: These sensors are intended to determine the proximity of an occupant to the air bag. Sensing devices installed in the interior of the vehicle would enable the system to suppress the air bag if an occupant is out of position and too close to the air bag.

Anticipated technologies: Infrared, ultrasonic, capacitive, and optical technologies are being researched to develop “dynamic” sensors that can continuously track an occupant’s position with respect to the air bag module. Infrared sensors utilize an array of invisible infrared light beams projected across the passenger compartment to identify the position of an occupant. For ultrasonic sensors, ultrasonic transducers emit sound waves and the sensors monitor the sound waves that are reflected by an occupant. Capacitive sensors utilize an electric field to identify the position of an occupant by detecting moisture in the body and optical sensors monitor the position of an occupant. While “static” ultrasonic sensors that periodically determine the occupant’s position may be installed on a limited basis to augment occupant classification sensors before 2003, researchers are not yet certain whether or when dynamic occupant position sensing will become widely used.

Precrash Sensors

Description: These sensors would identify the position, approach angle, velocity, and mass of objects prior to a collision and allow more time for the air bag system to respond.

Anticipated technologies: Radar (radio wave) is the principal technology being researched. Precrash sensing technologies are still in the early stages of research to determine if the concept is feasible. Therefore, it is not yet clear whether or when this technology might become available. The primary challenge in developing this technology is identifying the mass of an object in the path of the vehicle. “Adaptive cruise control,” which automatically reduces a vehicle’s speed to maintain a safe distance to vehicles in front, is currently available on some vehicles and is considered by some to be a precursor of precrash sensing.