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ABSTRACT

The ASPECT program was conducted to develop new Automotive Seat and Package Evaluation and Comparison Tools. This paper presents a summary of the objectives, methods, and results of the program. The primary goal of ASPECT was to create a new generation of the SAE J826 H-point machine. The new ASPECT manikin has an articulated torso linkage, revised seat contact contours, a new weighting scheme, and a simpler, more user-friendly installation procedure. The ASPECT manikin simultaneously measures the H-point location, seat cushion angle, seatback angle, and lumbar support prominence of a seat, and can be used to make measures of seat stiffness. In addition to the physical manikin, the ASPECT program developed new tools for computer-aided design (CAD) of vehicle interiors. The postures and positions of hundreds of vehicle occupants with a wide range of body size were measured in many different vehicle conditions. Data from these studies were analyzed to develop posture-prediction models that will allow human CAD models to be used accurately for vehicle design. The ASPECT program also produced a CAD representation of the new physical manikin, and high-quality, three-dimensional surface representations of small-female, midsize-male, and large-male drivers. The new tools developed in the ASPECT program represent a major step forward for vehicle and seat design.

INTRODUCTION

During the 1950s, vehicle designers were among the first to take advantage of the newly emerging science of engineering anthropometry: the application of the human body measurement and data analysis techniques of physical anthropologists to the problems of designing tools, workspaces, and products. In 1955, Professor Wilfred Dempster of the University of Michigan published a comprehensive study titled “Space Requirements of the Seated Operator,” which revolutionized vehicle-interior design (1)[1]. In the auto industry, S. P. Geoffrey of Ford Motor Company developed a two-dimensional human body template specific to the needs of the vehicle interior designer (2). A 1961 Society of Automotive Engineers (SAE) technical paper documented his methods for using x-rays to identify the locations of the skeletal joints that provide torso and limb range of motions. The result was a two-dimensional, articulated template of the human body used to incorporate anthropometric data into the vehicle design process.

At about the same time, Michael Myal of General Motors constructed a three-dimensional “comfort dimensioning” tool, a weighted manikin with legs and a torso that could be placed in a vehicle seat (3, 4). Because one application of the manikin was to measure legroom, the manikin was based on men who were 90th percentile by stature, and hence likely to have long legs. However, an average seat deflection was sought, so the eight men who were measured to determine the shape of the manikin back and buttock surfaces were selected to be 50th-percentile U.S. male by weight but 90th-percentile U.S. male by stature. A casting made of one of these men sitting on a typical car seat was used to develop the contoured shells for the manikin. Fitted with leg and thigh segment lengths set to 90th-percentile male values, the new tool defined the H-point of a seat and provided measures of leg room based on knee and hip angles.

1. Numbers in parentheses denote references at the end of the paper.

Beginning in 1962 with the adoption of SAE Recommended Practice J826, these two early tools were modified and standardized through the SAE Design Devices Committee, becoming the SAE 2-D template and the SAE H-point machine. Today, when an automotive human factors engineer measures a vehicle interior, the primary tool used is still the SAE J826 H-point machine (5), which has remained essentially unchanged in design and performance since the late 1960s, when vehicle seats and vehicle interiors were substantially different from today's models. The H-point machine is a weighted manikin named for its most important reference point, which is intended to represent the hip-joint pivot between the thighs and torso of an adult vehicle occupant. It is now normally used with 95th-percentile leg-segment lengths, although the weighting and shell contours remain based on 50th-percentile-male body weight. When the manikin is installed in a vehicle seat within a particular vehicle interior, the location of the H-point and the relative angles between the manikin's thigh, leg, foot, and torso segments provide key measures of the vehicle interior geometry. Many industry design practices and government standards are based on measurements obtained with this tool.

In 1994, Manary et al. (6) compared the J826 H-point location and back angle measures of the H-point manikin to the postures and hip joint locations of male and female drivers in three vehicle seats with different levels of foam stiffness, lumbar support, and seat contouring. The results indicated that the J826 H-point machine produced reasonably consistent representation of human hip joint location across a range of seat styles, although the H-point tended to be rearward of, and lower than, the mean driver hip joint locations. However, the back angle measured by J826 did not vary in a consistent way with human torso posture across these seats. The rigid torso shell of the J826 manikin appeared to be inadequate to provide effective and meaningful measures of occupant seatback interactions, particularly for highly contoured and firm seatbacks.

Manikin users have noted that the J826 manikin may be outdated for current and future seats and vehicles, and that it is used in many applications for which it was not designed or intended (e.g., seat design, seat pressure measurements, measurements of head restraint locations). As a result of these concerns, a task group of the SAE Design Devices Subcommittee met to establish a plan for redesigning the H-point manikin to better meet current and future needs. In response to these task group meetings, researchers from UMTRI's Biosciences Division and the Michigan State University Biomechanical Design Research Laboratory outlined a four-year research and development program, known as ASPECT (Automotive Seat and Package Evaluation and Comparison Tools).

Funds to support the effort were provided by eleven international auto manufacturers and suppliers, including BMW, DaimlerChrysler, Ford, General Motors, Johnson Controls, Lear, Magna, PSA Peugeot-Citroen, Toyota, Volkswagen of America, and Volvo. Representatives of these companies form an Industry Advisory Panel (IAP) that has worked closely with the research team to ensure that the new tools address current and future industry needs and practices. The Society of Automotive Engineers has coordinated the collection and distribution of funds to the university researchers. Now nearing the end of its fourth and final year, the program is completing manikin development and production of an integrated set of new tools that will provide the industry with new, easier to use, and more accurate methods for designing and measuring their products.

This paper presents an overview of the methods and outcomes of the ASPECT program. Details of human subject testing, manikin development, application procedures, computer tools, posture-prediction models, and other ASPECT outcomes are found in the accompanying papers (7-13).

METHODS

PROGRAM GOALS – The ASPECT program had two primary goals. The first and foremost objective was to design, develop, and evaluate a new physical manikin and related usage procedures to revise SAE J826. The second objective was to create an extensive vehicle occupant posture database, and to use this database to formulate statistical posture-prediction models for use with CAD tools. Additional objectives and tasks were defined to ensure that the ASPECT outcomes met the needs of industry for an integrated set of tools.

Accomplishing these program goals required the coordination of numerous interrelated and interdependent design, research, and development tasks. A number of foundational tasks were conducted during the first year to establish the scope of the program and to address important issues that would affect the direction of the research. As shown in Figure 1, these activities included:

- conducting surveys of industry manikin users and vehicle package and seat designers to identify current and future manikin applications and manikin design needs and priorities,
- surveying human modeling groups to assess the capabilities of the currently available CAD manikins,
- developing procedures and methodology for describing and measuring occupant posture and position,
- identifying anthropometric, vehicle package, and automotive seat factors that potentially affect occupant posture and positioning,
- establishing an anthropometric basis for manikin size,
- developing criteria and strategies for subject selection and sampling in ASPECT posture research studies,
- establishing and modifying test facilities and associated instrumentation, and
- developing an initial statement of ASPECT manikin design and performance objectives.

Using the results of the foundational activities as a basis, the effort during years two and three of the program was directed primarily toward vehicle occupant posture measurement and manikin design and development. Experimental research to understand driver and passenger posture as a function of body size, vehicle factors, and seat factors, as well as testing to define manikin contours and examine seat interface pressure distributions, was conducted in laboratory vehicle mockups and in actual vehicles. Manikin design and development was carried out simultaneously with development of new manikin usage procedures and new concepts for vehicle design and audit.

FOUNDATIONAL ACTIVITIES

User Surveys – In addition to obtaining industry input from IAP representatives during preprogram meetings, two surveys were taken of manikin users within the IAP companies to identify and prioritize current and future applications of the physical manikin, and to identify problems that the new manikin and procedures should be targeted to resolve. These surveys confirmed that the first and foremost application of the manikin is to *define and measure vehicle reference points* that are functions of both interior package geometry and vehicle seat features. These measurements are made for *auditing* of a manufacturer's own vehicles to verify seat and vehicle build accuracy relative to design specifications, as well as for *benchmarking* of competitor vehicles, for which package dimensions and seat characteristics are unknown.

The second and increasingly important use of the manikin is for *designing* vehicles and seats for user accommodation and comfort. In large part, this is accomplished through the use of manikin reference points and to assess and design vehicle geometry. Dimensions measured relative to the design H-point or SgRP are used in population accommodation models such as the seating accommodation model of SAE J1517 and the eyellipse model of SAE J941. However, the dimensions of the physical manikin are sometimes used to guide the design of seat features, such as spacing of cushion bolsters and seatback wings, and the pressure distributions produced by the manikin are sometimes used as a basis for seat comfort assessment. These and other potential uses of the manikin were considered, along with the primary applications, in the development of the new tools.

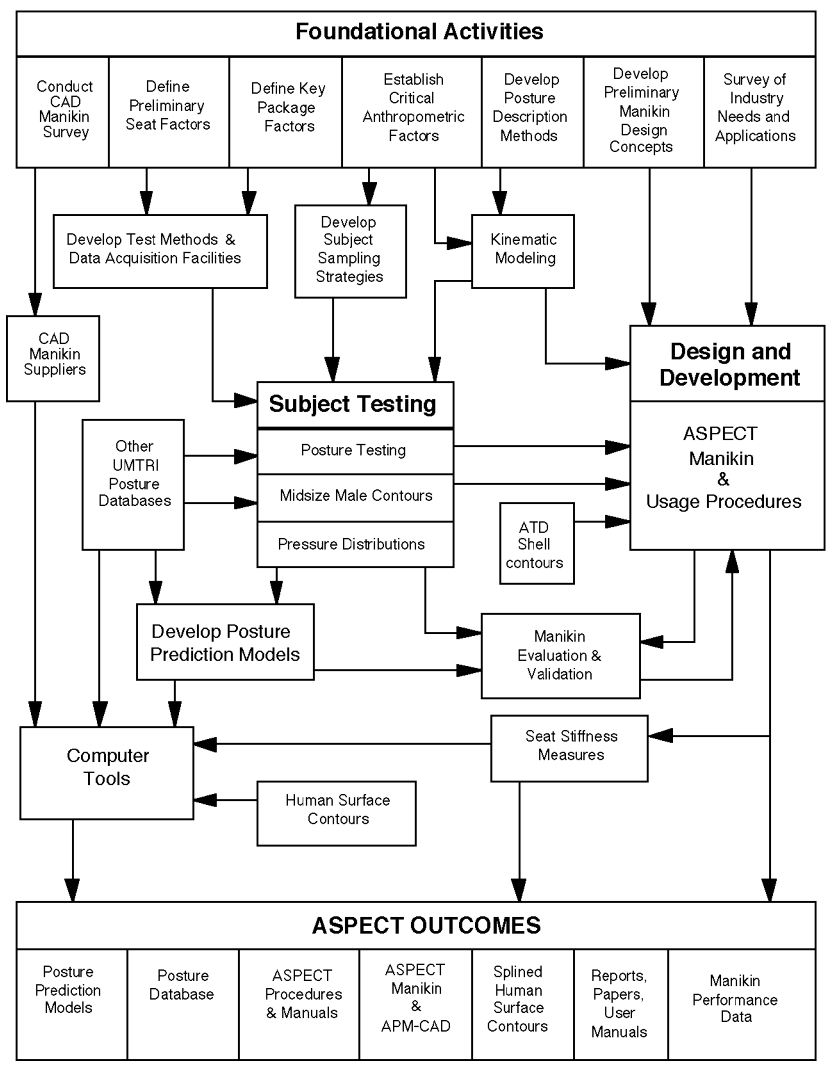

Figure 1. ASPECT program activities and outcomes.

The user surveys revealed three principal areas for manikin improvement based on current problems and experience with the J826 manikin. These include improving manikin *ease of use*, *repeatability and stability*, and *accuracy*. When used in modern seats with contoured, firm seatbacks, the rigid torso of the J826 manikin is unstable, making it difficult to obtain consistent measurements. The current manikin is relatively heavy to lift and position into a vehicle seat, and the leg and shoe segments are cumbersome and hard to install. The accuracy of the manikin with respect to human posture and position was also of concern, primarily because of the way the rigid torso interacts with seatbacks.

The user surveys also documented the use of the J826 manikin for purposes that have not been standardized in SAE recommended practices. In particular, add-on devices have been developed for head restraint measurement (14) and seatbelt fit assessment (15). These applications of the current H-point manikin were considered during the development of the new tool.

<u>*CAD Manikin Survey*</u> – One of the initial goals of the program was to identify developers of human models who could implement the products of ASPECT in versions of their software adapted for automotive applications. A survey of state-of-the-art computer human models identified RAMSIS, SafeWork, MDHMS, Jack, and JOHN as the models with potential to incorporate the products of the ASPECT program in CAD tools for the automotive environment. Of these, only the RAMSIS model, published by TecMath, had been developed specifically for the auto industry, using posture, position, and anthropometric data collected in the automotive environment. For this reason, representatives from TecMath were invited by the IAP to participate in the ASPECT program during the second program year. In the third year of the program, representatives of Transom Jack and SafeWork were also invited to participate and to implement the ASPECT products into their models.

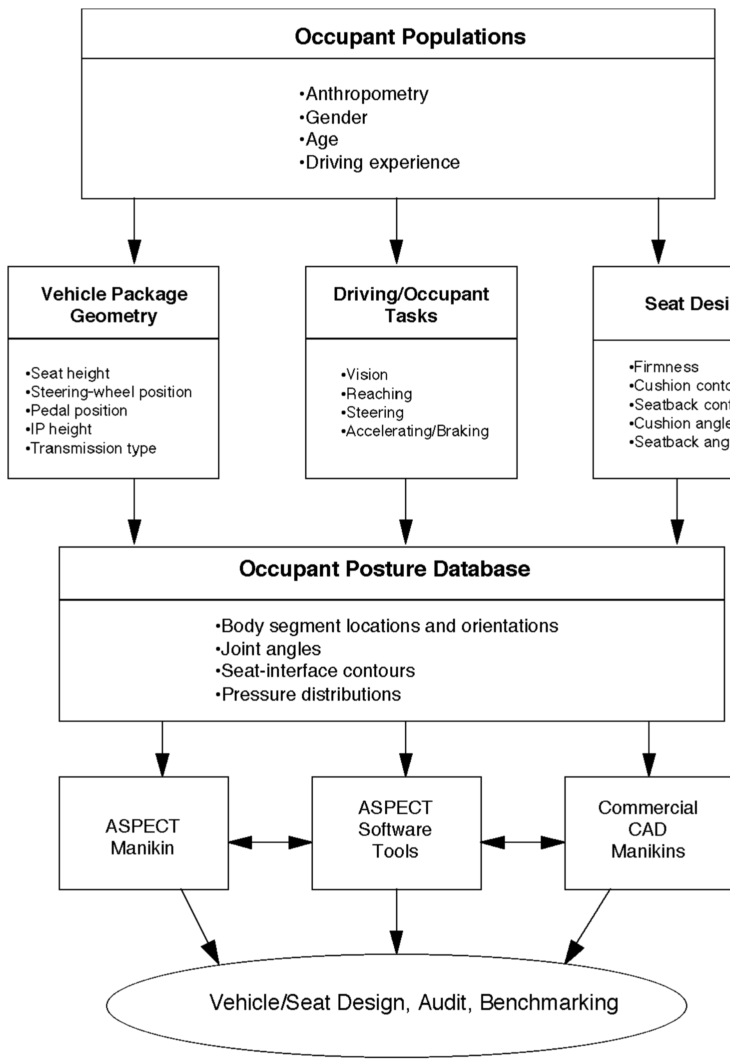

Figure 2. Hypothesized relationships between anthropometric, vehicle interior package, seat, and task factors on occupant posture for use in developing physical and computer design and measurement tools.

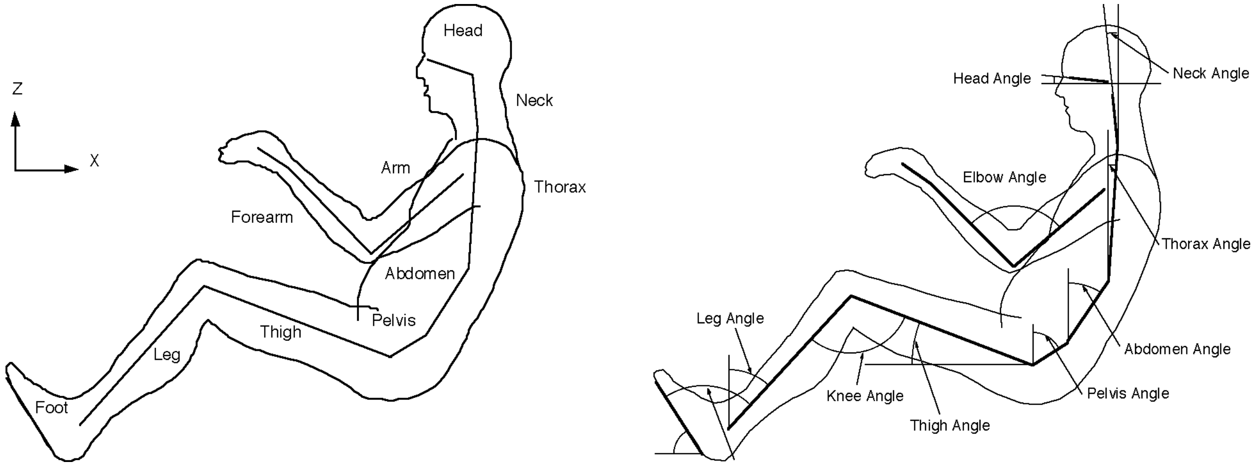

Figure 3. Kinematic model used to represent vehicle occupant posture showing body segment (left) and segment angles (right).

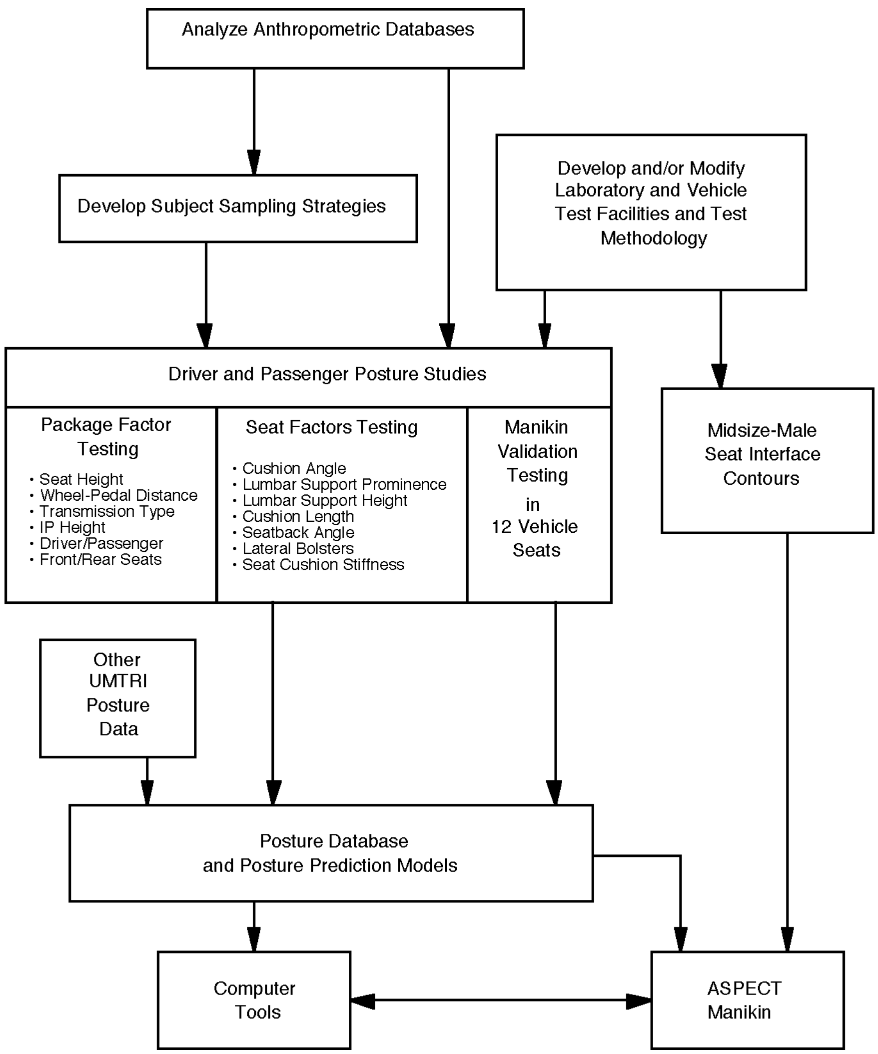

Figure 4. Scope and information flow in ASPECT subject testing.

Identification of Anthropometric, Package, and Seat Factors – As illustrated in Figure 2, occupant posture and position in a motor vehicle are influenced by a number of important anthropometric, vehicle, and seat factors. In addition, for drivers, there are operator tasks, such as using the pedals, steering, and seeing inside and outside of the vehicle, that have important influences on posture and position in the context of the package geometry. As part of the initial ASPECT activities, these critical factors were identified and defined to aid in the design of experiments for posture studies. The results of ASPECT subject testing, combined with findings from previous posture studies, were then used to establish statistically based posture-prediction models for positioning CAD manikins in motor vehicle environments, and to guide the design and performance of the new manikin.

Posture Description and Measurement – New methods for measuring and describing occupant posture and position were developed. Body landmark locations were recorded using coordinate measurement equipment. These landmark locations were used to estimate body joint locations, using techniques developed for ASPECT (8). These methods provide a consistent method to quantify subject postures and to apply posture data to physical and computer versions of the ASPECT manikin, or to whole-body CAD manikins (10). Figure 3 shows the kinematic linkage and angles of body segments used to represent human body posture in the ASPECT program.

DATA COLLECTION – During the ASPECT program, the postures of hundreds of men and women with a wide range of body size were measured in dozens of vehicle and seat conditions. Testing was conducted both in vehicles and in laboratory vehicle mockups. Figure 4 illustrates the scope of subject testing. The experiments were designed to determine the effects of anthropometric, vehicle, and seat factors on driver and passenger posture. Seven different posture studies were conducted over the course of the program. The subjects' postures were measured by recording the three-dimensional locations of body landmarks using a sonic digitizing system or FARO arm, as shown in Figures 5 and 6. Details of the posture studies are presented in Manary et al. (12). In addition to posture testing, the seat interface contours of midsize men were measured to develop new contours for the ASPECT manikin (13).

Figure 5. Digitizing a subject's body landmarks using a FARO arm.

Figure 6. Digitizing a subject's body landmarks using a sonic digitizer

ASPECT MANIKIN DEVELOPMENT – Many of the ASPECT tasks were focused on the primary objective of developing a new physical manikin to replace the J826 H-point manikin. The program also provided the opportunity to take a fresh look at the procedures by which the manikin is used for seat and vehicle design and measurement. Early in the first year of the program, a set of questions were put forth with regard to manikin design features, including the following:

- How many manikins are needed?
- What size people should the manikin represent?
- Should the manikin have a fixed or articulating torso?
- Should there be articulations between the pelvis and the thighs?
- What should the manikin measure for different applications, and what are its performance specifications?
- If an articulating torso is used, how many articulations and where should they be located?
- Does the manikin need to have legs and feet?
- Should the manikin provide for leg and thigh splay?
- Should the manikin have arms and hands? Neck and head?
- Should the manikin shells be rigid or deformable?
- Should the manikin respond to both seat and package factors?

Answers to some of these questions were established during the first year of the program, but answers to other questions required considerably more exploration and evaluation of prototype manikins using an iterative process illustrated in Figure 7.

Starting with modifications to the J826 manikin, several versions of the ASPECT manikin were developed and tested. The term APM has been used to refer to the ASPECT physical manikin and subsequent prototypes have been numbered sequentially as APM-1, APM-2, etc. In successive versions of the manikin, design features and modifications were implemented, tested, and evaluated as performance results of a previous iteration suggested and as design concepts evolved. Modifications were made to manikin linkages, contours, and mass distribution to improve manikin stability in seats with highly contoured seatbacks and to improve sensitivity to lumbar support prominence across a range of seat types. Thigh splay was implemented in one version of the manikin prototype design, but was subsequently dropped because it added complexity that is not needed for primary manikin measurements. Details of the manikin design and development are provided in Reed et al. (7).

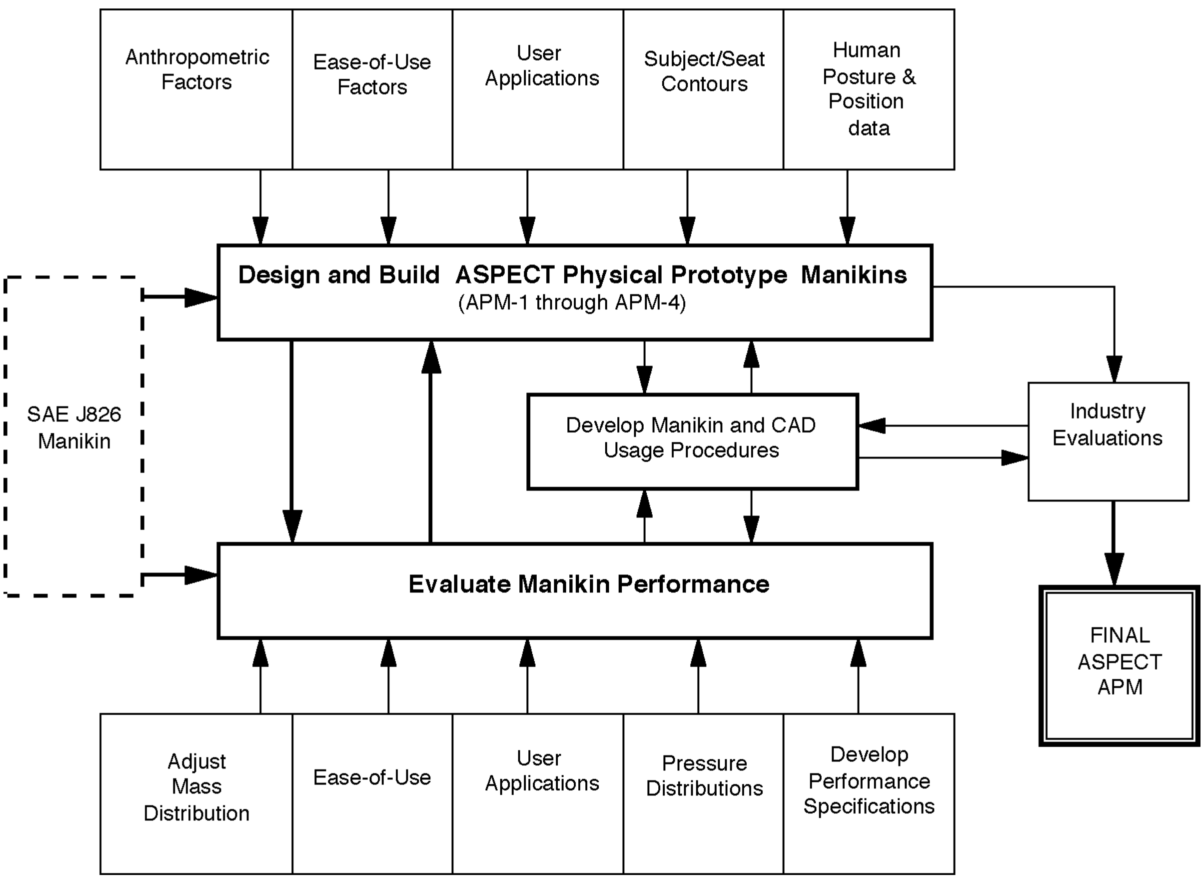

Figure 7. Iterative process of manikin design, development, and evaluation.

RESULTS

The ASPECT program produced an integrated set of new tools for vehicle and seat design and measurement. Table 1 lists the tools and some of their features and functions. The primary ASPECT development is a new physical manikin intended to replace the SAE J826 H-point machine. A CAD version of the manikin has been developed for use in design. New posture-prediction models have been developed to facilitate the accurate use of CAD manikins in vehicle and seat design. In addition, three human body reference forms, representing the three-dimensional body surfaces of small-female, midsize-male, and large-male occupants, were developed for use in CAD.

ASPECT PHYSICAL MANIKIN (APM) AND USAGE PROCEDURES

Manikin Design Features – The new ASPECT manikin represents an evolution of the J826 manikin, preserving much of the functionality of the old manikin while adding additional features and measurement capability. Figure 8 shows the ASPECT manikin along with the current J826 manikin. The most important difference between the tools is the new articulating torso in the ASPECT manikin. Figure 9 shows the torso linkage, which includes two joints that simulate human lumbar spine motion. A torso rod stabilizes the manikin and provides continuity with the current manikin torso line.

Table 1. New Tools Developed in the ASPECT Program

Tool	Function	Key Features
ASPECT Physical Manikin (APM)	Define and Measure Seat and Package Characteristics	Articulated Torso New Contours New Procedures
APM-CAD	Represent APM in CAD for use in design	Essential Geometry of APM as a 3-D CAD File
ASPECT Posture Prediction Models	Predict Posture for Any Vehicle Occupant	Anthropometric, Seat, and Package Factor Inputs Emphasis on Accuracy in Eye and Hip Locations Applicable to any CAD Manikin Software
Human Body Reference Forms (Small Female, Midsize Male, Large Male)	Standardized, Three-Dimensional Body Surface Contours for Vehicle Occupants	Three Sizes Spanning a Large Range of the Population High-Quality Parametric Surfaces (NURBS) in CAD Files

Figure 8. Current SAE J826 manikin (top) and new ASPECT manikin prototype (bottom).

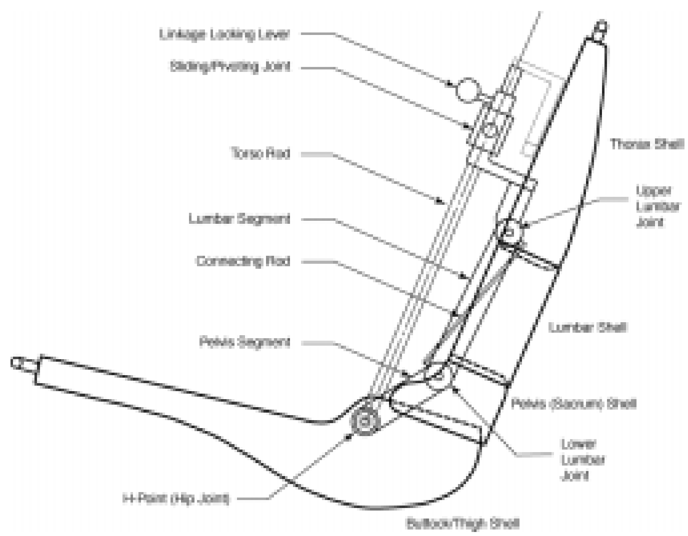

Figure 9. Schematic of ASPECT manikin showing articulated torso linkage.

A connecting rod in the lumbar linkage distributes flexion motion between the two lumbar joints. The torso shell is comprised of separate thorax, lumbar, and sacral sections, each connected to a corresponding segment in the torso linkage. Figure 10 demonstrates the variation in torso contour provided by the linkage. The dimensions of the ASPECT manikin were determined after specifying a set of reference anthropometric dimensions. Because the purposes of the manikin would be best served by a manikin that was approximately the same dimensions as the current J826 manikin and the midsize-male crash dummy, ASPECT manikin dimensions were chosen to be representative of midsize U.S. males (7).

The external shell sections of the ASPECT manikin are constructed of molded fiberglass, like the shells of the J826 manikin. Shells made of deformable materials were considered, but were ultimately rejected because of manufacturing, weight, and durability concerns. The shells are designed to represent the typical deflected flesh contour of a midsize male. The buttock and thigh contours were developed from data collected for ASPECT (13), while the torso contours were developed using data collected in earlier research to develop anthropometric standards for crash dummies (16, 17). The total weight of the manikin was determined by subtracting a typical resting heel weight from the target weight defined by the reference anthropometry (7).

Independent Seat and Package Measures – The current J826 H-point manikin, shown at the top of Figure 8, takes simultaneous measures of the vehicle seat and the vehicle interior geometry. When the manikin is installed with the legs and feet according to standard practice, the H-point location in the seat may be influenced by the seat height and fore-aft seat position via the orientation of the thigh and leg segments. In practice, this has meant that any change in the package geometry requires redefinition and remeasurement of the H-point location. Using the primary application procedures, the ASPECT manikin is installed in the seat without leg segments, so that it contacts only the seat. The H-point and other seat measures, such as lumbar-support prominence, are thus independent of the seat position in the vehicle, and do not need to be redefined or remeasured if the seat is moved during the design process.

The ASPECT manikin makes four primary measures of the seat: H-point location, seat cushion angle, seatback angle (i.e., manikin back angle), and lumbar support prominence, shown in Figure 11. Lumbar support prominence is measured by the displacement of the manikin lumbar segment relative to a neutral, flat-back condition. Typical lumbar-support prominences in auto seats range from –10 to +20 mm of lumbar support, measured in this manner. The ASPECT manikin is the first measurement tool to provide a quantitative measure of effective lumbar support that is closely related to the seatback contour experienced by occupants.

The ASPECT manikin can also be used with supplemental thigh, leg, and shoe segments to measure the vehicle package geometry. Figure 12 shows these segments and associated tools schematically and Figure 13 shows the leg and thigh segments installed on the ASPECT manikin. The thigh and leg segments are constructed of lightweight materials so that installing them does not change the H-point location or other measures of the seat. In conjunction with the ASPECT program, proposals have been developed for a new pedal reference point (PRP) that can be defined independent of the manikin (11).

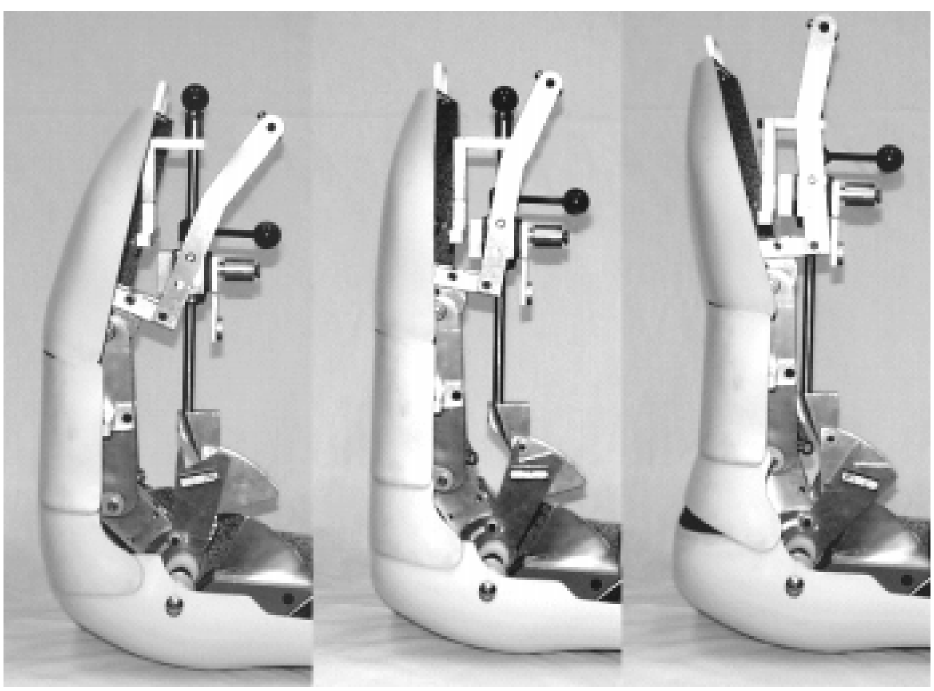

Figure 10. Side view of ASPECT manikin prototype showing torso articulation.

In addition, new techniques for orienting the manikin shoe relative to the accelerator pedal in more humanlike positions have been developed. Using these new procedures, the supplemental thigh, leg, and shoe tools can be added to the ASPECT manikin installation to measure package dimensions in driver or passenger seating positions. Detailed procedures for using the ASPECT manikin in design, audit, and benchmarking applications are presented in Roe et al. (9).

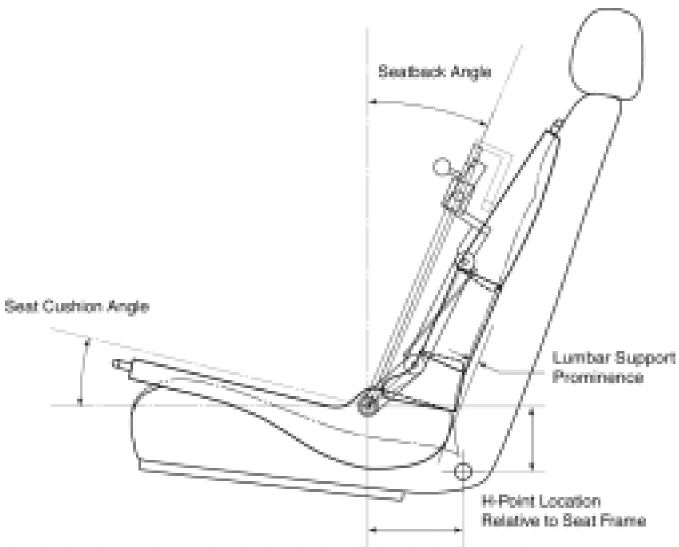

Figure 11. Primary ASPECT manikin measures of the seat.

APM-CAD – In current design practice, the SAE J826 manikin, or the two-dimensional template based in part on the J826 manikin geometry, are commonly represented in CAD to facilitate vehicle packaging. The orientations of the manikin segments are used to assess the package geometry, and clearances to vehicle components are measured relative to the template contours. To provide continuity with current practice, a CAD version of the ASPECT physical manikin (APM-CAD) was developed. APM-CAD includes the essential geometry of the manikin, including the external shell contours, the linkage geometry, and the thigh, leg, and shoe segments.

ASPECT POSTURE PREDICTION – Along with the manikin development, a primary goal of the ASPECT program was to develop data and models to facilitate the use of CAD manikins. Software tools that depict human occupants have become an increasingly important part of vehicle and seat design processes. Industry surveys conducted early in the ASPECT program demonstrated that although the currently available CAD manikins have sophisticated capabilities for anthropometric scaling, only RAMSIS has posture prediction capability specifically validated for vehicle occupants. There is a clear need for a comprehensive, systematically constructed database of occupant posture data that can be applied to any CAD manikin.

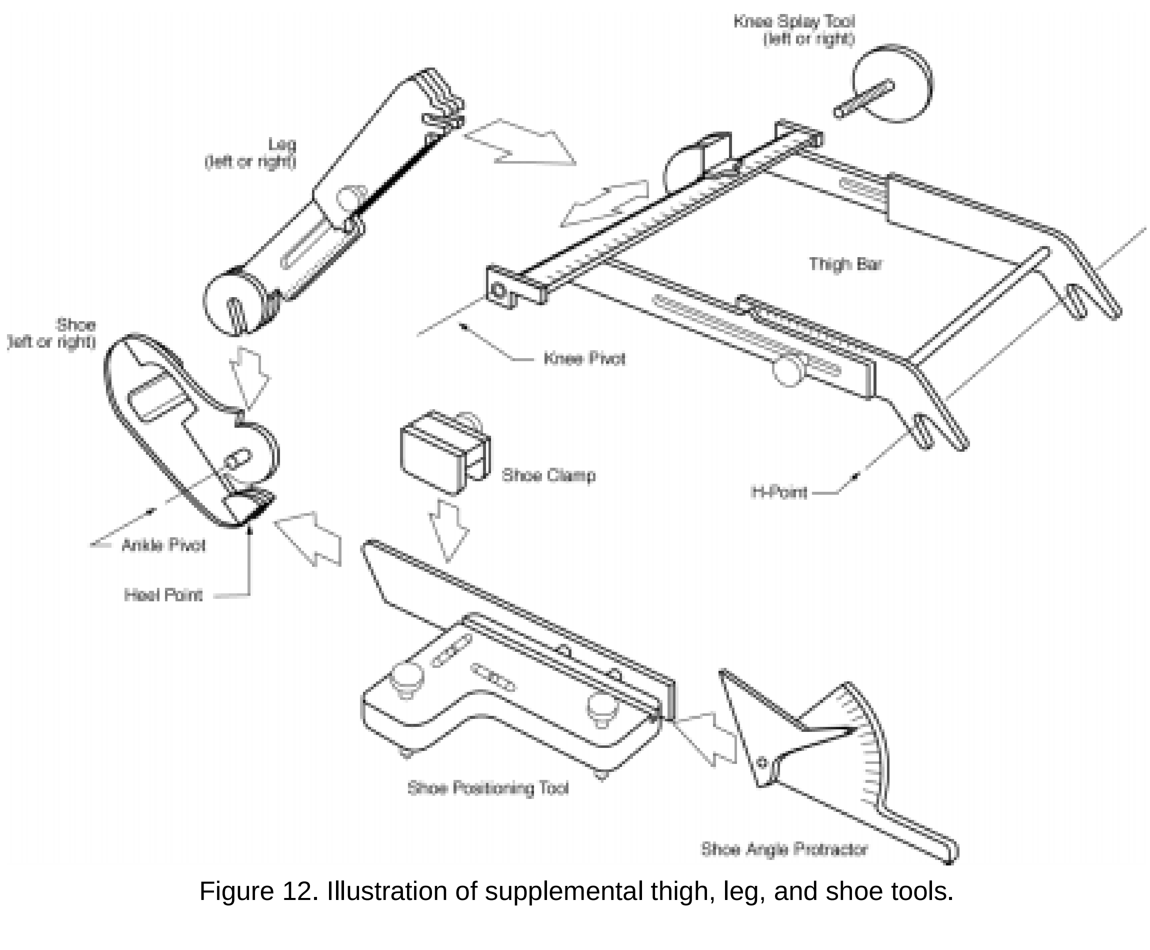

Figure 12. Illustration of supplemental thigh, leg, and shoe tools.

Figure 13. ASPECT manikin with thigh and leg segments installed between H-point and foot tool.

The extensive posture database gathered in ASPECT studies was analyzed together with other UMTRI data to create a set of posture-prediction models. A new approach to posture prediction was developed, called the Cascade Prediction Model (CPM). The CPM emphasizes accurate prediction of hip and eye locations, since these body landmarks are usually the most important for conducting accurate assessments of vehicle interior geometry. A “cascade” of submodels, using inverse kinematics combined with heuristics based on the findings from the posture data analysis, creates a three-dimensional prediction of whole-body posture for drivers or passengers. Inputs to the models include anthropometric variables, such as gender and stature; vehicle package variables, such as seat height and steering wheel position; and seat characteristics, such as seat cushion angle and lumbar support prominence. Details of the development and validation of the ASPECT posture prediction models are presented in Reed et al. (10). The developers of the RAMSIS, Transom Jack, and SafeWork CAD manikins have joined the ASPECT program to implement ASPECT posture prediction models in their software. These new tools will allow accurate placement of CAD manikins within a design, providing more accurate fit, vision, and reach assessments.

HUMAN BODY REFERENCE FORMS – In current design practice, there are no standard three-dimensional representations of the human body other than the SAE J826 manikin and the crash dummies. The SAE J826 manikin does not include a full three-dimensional body surface, and crash dummies have been designed primarily for dynamic performance, not for the representational accuracy of their external geometry.

Although collecting new whole-body contour data was beyond the scope of the ASPECT program, whole-body contours were available that were based on detailed anthropometric measurements. In a previous study at UMTRI, three standard reference shells, shown in Figure 14, were developed to form the basis for future crash dummy anthropometry (16, 17). Digitized versions of these shells were manipulated using a commercial software package (Imageware Surfacer) to produce parametric splined surfaces (NURBS) that can be used in many CAD programs. The midsize-male body reference form is shown with the ASPECT manikin in Figure 15.

Figure 14. Large-male, midsize-male, and small-female standard reference shells developed for crash dummy anthropometry.

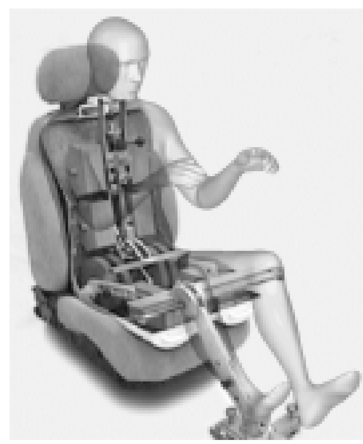

Figure 15. Midsize-male reference form and ASPECT manikin

There are a number of potential uses for these three-dimensional representations in vehicle design. The reference forms can be used to visualize vehicle occupants of different sizes in a vehicle package, and provide a way of ensuring consistency in body contour among CAD manikins. The standardized body surfaces could also function as three-dimensional tools for conducting some of the analyses that are currently performed using the two-dimensional SAE J826 template. Details of the development and use of the human body reference forms in vehicle design are presented in Reed et al. (11).

DISCUSSION AND CONCLUSIONS

At the conclusion of the ASPECT program in June 1999, the industry will have a new set of tools for vehicle and seat design and assessment. The program has produced a new, easier-to-use, physical manikin designed to function better in current vehicle seats and to measure important seat characteristics. The new manikin measures H-point and other important seat factors without interacting with package geometry, and has an articulated torso that provides for improved measures of seatback geometry. To measure a vehicle package, lightweight thigh, leg, and shoe segments can be installed without affecting the H-point location.

The ASPECT program has also established new procedures by which the manikin is used and has proposed new concepts for integrating the manikin with CAD tools in designing and evaluating vehicle and seat designs. A substantial amount of new data on driver and passenger posture and position were collected in the program. These data have been analyzed, along with data from other studies, to develop posture-prediction models that establish accurate driver and passenger postures for a wide range of occupant sizes and vehicle environments.

Considerable work remains to implement the products of ASPECT as accepted industry standards. The ASPECT researchers will work with the SAE Human Accommodation and Design Devices Committee to turn the detailed specifications of the new manikin and associated procedures into new SAE recommended practices. Because the H-point manikin defines reference points that are used in many other SAE practices, which are in turn referenced by national and international safety standards, implementation of ASPECT program results will also involve working with federal and international organizations such as NHTSA and ISO.

Although the ASPECT program is a large step forward in vehicle-interior design methods, there are many issues that remain to be addressed in future research. The manikin and the associated posture-prediction models were developed using primarily passenger car conditions, but the manikin must ultimately be applicable to the design of heavy-duty trucks and buses, as well as off-road equipment. Additional studies will be necessary to validate the manikin for those applications and to extend the posture prediction models to those environments.

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