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"Vehicle Induced Feedback Cues and Their Relationship to Driver Performance and Safety"

under

Heavy Truck Crash Avoidance Research

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16. Abstract

This report documents findings from a task order intended to review current knowledge in the area of driver-vehicle-technology interactions and to recommend follow-on tests and procedures to guide how NHTSA might proceed in subsequent research. The basic concern here is related to how drivers may react to and alter their driving behavior in response to vehicle designs and associated technologies that are becoming increasingly relied upon in new vehicles. The focus is primarily upon chassis control technologies as opposed to ITS driver-assist and warning technologies. A basic observation and conclusion from much of this work has been the recognition that meaningful evaluation of various driver-vehicle-technology systems will ultimately depend upon the collection and analysis of test data obtained under fairly realistic driving conditions. Some of this reasoning is related to the complexity of individual technologies as well as the diversity of possible technologies that are being considered. No overarching rule appears as yet available that allows generalizations to be offered about the impact of specific automotive technologies on driving performance. Various hypotheses can be put forth, but eventually the final evaluation and arbiter of whether or not a particular vehicle design or technology influences driver behavior in an adverse manner lies in the examination of real world data. A variety of test track and simulator experiments are proposed to help further investigate and understand the likely impact of new automotive technologies on driving performance and safety.

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1.0 Introduction

This document is a final reporting and summary of basic findings from the Task Order No. 3 entitled, "Vehicle Induced Feedback Cues and Their Relationship to Driver Performance and Safety," under the Heavy Truck Crash Avoidance Research Project No. NRD-01-4-07247. The technical discussion in this document is supplemented by a set of appendices containing material from the literature review task. Items from these appendices are referred to periodically in the discussion summary and are included as background resource materials.

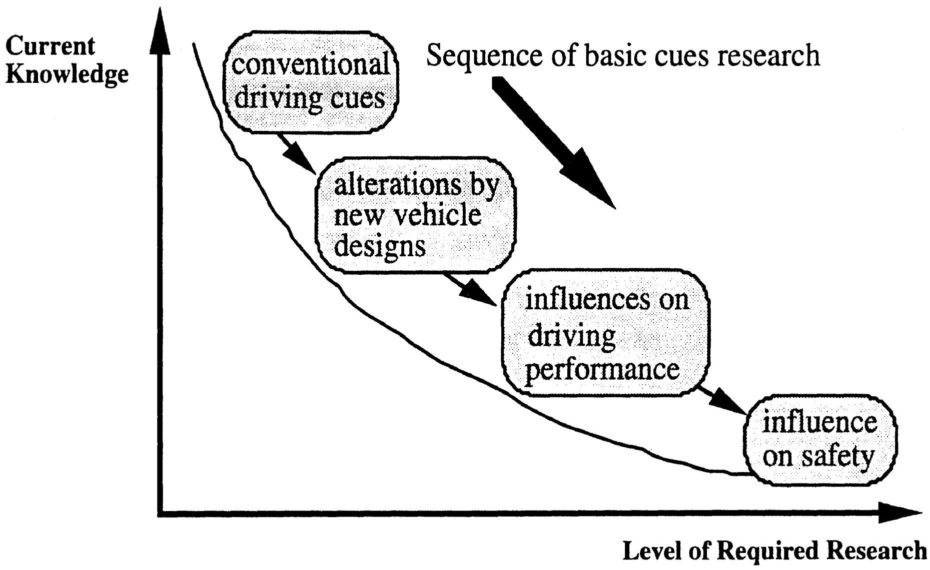
In brief, this task order was largely a "paper study" intended to review current knowledge in the area of driver-vehicle-technology interactions and to recommend follow-on tests and procedures to help guide NHTSA in subsequent research. The basic concern here is related to the question of how drivers may react to and alter their driving behavior in response to vehicle designs and associated technologies that are becoming increasingly relied upon in new vehicles. The focus is primarily upon chassis control technologies, as opposed to ITS driver-assist and warning technologies. For example, an active suspension system significantly reduces the roll, pitch, and bounce motions of a vehicle and may cause drivers to modify their steering, braking, and acceleration behavior. The types of questions then posed are: 1) do drivers indeed alter their driving behavior in response to the presence of active suspension (or similar) chassis technologies, and 2) if so, what are the consequences, if any, on driving performance and, ultimately, safety. Various scenarios are possible here. For example, driving behavior may be influenced by such vehicle alterations, but largely as an adaptive control response that results in no significant change in driving performance or safety. That is, drivers respond to the presence of the new technology with modified steering, braking, or acceleration responses, but only to maintain their same level of driving performance prior to the introduction of the new technology. Or, alternately, driving behavior is influenced but now is accompanied by degraded/improved driving performance and an associated potential impact on safety.

A basic observation and conclusion from many of these task order inquiries has been the recognition that meaningful evaluation of various driver-vehicle-technology systems will ultimately depend upon the collection and analysis of test data obtained under fairly realistic driving conditions. Some of this reasoning is related to the complexity of individual technologies, as well as to the diversity of possible technologies that are being considered. No overarching rule appears as yet available that allows generalizations to be offered about the impact of these specific automotive technologies on driving performance. Various hypotheses can be put forth, but eventually the final evaluation and arbiter of whether or not a particular vehicle design or technology influences driver behavior in an adverse manner lies in the examination of real world data.

A good starting point for reaching such evaluations is the test track and the collection of test data under near real-world conditions with actual driver-vehicle-technologies being exercised and monitored for their evaluation. This observation is also the basis for recommendations on follow-up research and analysis relating to the feedback cues research subject. These recommendations are offered subsequently in Section 3. The collection and analysis of such test track data can also answer many basic questions about whether or not there are measurable influences on driving behavior, the extent of such influences, and how to best evaluate and interpret, in a very practical sense, the implications of altered driving behavior due to the introduction of new automotive technologies.

Beyond these near term test track recommendations is the question of where, in general, basic cues research should be headed in order to further address these larger safety concerns. Figure 1 lays out a very simple relationship between available knowledge on driving cues and likely levels of required research.

Figure 1. Interplay Between Current Knowledge on Driving Cue Influences and Likely Levels of Required Research



As we progress to the right on this diagram toward the eventual issue and goal of safety, the amount of available knowledge is very limited and suggests an increased level of required research in order to meet that goal. In Section 2.3 a set of research initiatives/experiments are suggested that try to address some of these longer term questions by incorporating use of future NHTSA facilities, such as the NADS (National Advanced Driving Simulator), the VDRV (Variable Dynamic Response Vehicle), and other simulator facilities like the IDS (Iowa Driving Simulator). These resources are identified here primarily because of their expected availability and applicability for some of the more difficult human factors and driver control questions that may need specialized test facilities further downstream.

In the meantime though, many basic questions can still be pursued in a test track setting such as NHTSA's VRTC (Vehicle Research and Test Center). Thus, the track testing option is the more immediately available and logical option to NHTSA for sorting out many of these types of driver-vehicle interaction questions, at least in the near term. The test track option also brings with it a certain degree of authenticity or "credentialing" of the test results — a benefit that a new simulator or other test device must acquire more gradually over time through validation exercises and hands-on experience.

Section 3 of the report lays out recommended follow-on track tests proposed for VRTC. The first proposed VRTC track test series is designed to collect and evaluate cues-related, human-response test data as a follow-on to current tests being conducted on ABS-equipped vehicles by NHTSA. The same ABS-equipped vehicles would be used but with the addition of a set of lay drivers for evaluating and characterizing human braking response behavior to the ABS systems and their cycling characteristics (pedal vibrations, longitudinal accelerations, etc).

In addition to the proposed ABS / human factors tests, an additional series of tests using VRTC test drivers and an Infiniti Q45 (equipped with its active suspension option) is also being recommended in order to collect a sample of driver control response behavior using a currently marketed active suspension vehicle. (An identical Q45 without its active suspension option would also be used in these tests to collect side-by-side test data for direct comparison). The collection of these driver-vehicle response data will permit a direct and simple evaluation of feedback cues phenomena using a representative vehicle — differing from its identical counterpart only by the presence or absence of an advanced technology device. This, of course, is key to a basic question being posed by this task order. Namely, is driver behavior modified by the use of such devices and, if so, what are the measurable impacts on driving performance and safety. These proposed active suspension tests also are discussed in Section 3.

Section 2 discusses and reviews what was done under this task order over the course of the last year. Section 3 recommends what to do next using follow-on track testing and the collection of driver-vehicle response data to provide a reliable means for evaluating some of the specific questions raised under this task order work.

2.0 Summary of Tasks: Observations / Findings

This section summarizes the basic observations and findings from the various project tasks undertaken during this past year. These include: 1) the literature review, 2) conceptual model considerations related to driver-vehicle-technology interactions, 3) hypotheses and optional plans for follow-on experiments (both long term and near term), and 4) data processing and analysis methods applicable to driver-vehicle test data. Each of these activities is discussed below in Sections 2.1 to 2.5.

2.1 Literature Review Task

We begin with an overview discussion and some general observations from the literature review task. Basic knowledge about perception and human performance, particularly that related to the driving process, is then summarized. The primary concern and emphasis here is on feedback cues used in the driving process and how alteration of such cues by new vehicle designs or advanced vehicle technologies can affect driving performance. Reference material for this discussion is primarily contained in Appendices A-J.

A discussion of cue rankings is also included with ideas on how ranking procedures may be applied to specific technologies examined under this project work. Example scenarios describe how various technologies can impact and alter driving cues normally used by drivers and how results of prior research may be used to estimate their relative importance. Analyses that try to use these cue-ranking observations, combined with estimates of expected market penetrations, may help identify priorities for future NHTSA research.

Following the discussions on human performance and associated cues, example automotive technologies currently being used or planned for introduction into future vehicle designs are then identified through recent patent applications. Appendices K-P contain summaries of patents from 1994 that help to define the functional operating concepts of the various devices. The amount or frequency of patent material also provides some insight about plans by vehicle manufacturers for future utilization of various devices, as well as current technological interests.

The expected market penetration of selected automotive technologies over the next decade or so is primarily addressed using Delphi forecast information taken from two sources. Appendix Q contains the background reference material for that discussion.

Much of the information contained in the appendices was obtained from the Knight-Ridder Dialog on-line database (formerly Dialog Services Inc). The searches primarily focused on existing information related to driver-vehicle-cue interactions and on patents related to recent automotive chassis control technologies. Transportation and engineering databases (TRIS, NTIS, Compendex, AeroSpace, Inspec, SciSearch, and Current Contents) were used to gather much of the former information. Recent patent information covering antilock braking, four-wheel steer, traction control, drive-by-wire, active suspensions, and related systems was obtained from the US Patents, World Patents, and Japanese Patents databases.

2.1.1 General Observations

Most of the cue-related studies indicate, not unexpectedly, that a cue-rich environment is helpful to driving performance (or human operator task performance, more generally). Systematic cue removals/alterations within controlled simulator environments generally lead to changes, and in many cases degradations, in driving (or flying) performance, depending upon the cue and the definition of performance being used in the particular study. A basic question then is whether or not such observations also extend to actual vehicles and drivers operating on real highways and which are equipped with new automotive technologies or vehicle designs that effectively alter or remove certain feedback driving cues. If the reference condition is a conventional vehicle operating in a so-called normal driving environment (comprised of the usual visual, motion, audio, and tactile driving cues), diminishment or removal of sufficient feedback cues by the introduction of certain technologies or vehicle design changes can imply changes in driving performance. The question of how much diminishment or cue removal must occur before degradations in driving performance occur is often not clear and can be a difficult question.

There is also a significant body of well regarded technical literature that observes how human operators interacting with and controlling different dynamical elements, such as highway vehicles, tend to adapt to and compensate for changes in vehicle dynamical properties [Li et al 1965, Miller & Elkind 1967, Phatak & Bekey 1968, Weir & Phatak

1967, Young & Stark 1965].[1] The changes in vehicle properties may be gradual or abrupt. In both cases though, compensation to varying degree usually occurs by the human driver. This then leads to the issue of adaptation and the extent to which drivers can modify their control behavior when faced with changes to, and in certain cases, diminishment of, expected feedback cue information.

So, on the one hand, there is evidence that suggests the potential for degradation in driving performance due to the alteration or removal of cue information; on the other hand, there is evidence that suggests human drivers are capable of compensating for significant alterations of the vehicle dynamics and corresponding cue changes. It would appear that resolution of such questions needs to be addressed in an ad hoc manner. That is, each of these particular questions raised by specific technologies may need to be addressed individually. Some technologies may produce a change in vehicle dynamical behavior that falls within the realm of driver compensating abilities; others may not.

For example, the primary effect of a four-wheel steering system is to alter the "mixture" of lateral displacement and heading angle feedbacks that the driver experiences when moving laterally. The magnitude of heading angle change required of a four-wheel steered vehicle, compared to a front-wheel steered vehicle, is normally reduced for the same amount of lateral maneuvering. Consequently, the driver of the comparable four-wheel steered vehicle experiences less rotational motion information under such circumstances. This could clearly be classified as a case of cue diminishment. However, as of now, there seems to be no evidence that this particular design feature results in degraded driving performance. In fact, most proponents of such systems argue that four-wheel steering enhances lateral maneuvering capabilities [Sano et al 1986]. Granted, very few such systems are operating on today's vehicles and such arguments may be premature. However, it could be, as some studies have demonstrated [McLane & Wierwille 1975], that loss or diminishment of feedback cue information must be more significant, or involve loss of multiple feedback cue channels, in order to produce observable degradations in driving performance. This assumes a complete and highly realistic cue environment (such as an actual driver/vehicle/highway scenario or nearly equivalent simulator environment) as the starting point prior to cue removal/diminishment. Other human performance studies indicate that when multiple feedback or perceptual channels are available, distortion of information on a particular channel can be compensated

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[1] All reference citations refer to Appendix A, unless otherwise noted.

for by increased use of accurate information on alternate channels [Appendix D: Peterka & Black 1992]. If so, the importance of studying each technology or vehicle design modification individually is further underscored, since each may have particular idiosyncrasies or features that may be important for this issue.

Antilock braking systems or traction control systems are other examples of these new technologies. Since such systems do not operate very frequently, reported pedal vibrations and noises [Sano & Kishimoto 1994; Appendix P: Beck et al 1994, Iwata 1994] that accompany their operation can be surprising to some drivers, especially if they have not experienced them beforehand. The vibrations and operating sounds are likely to be different, depending on the manufacturer or operating conditions. Consequently, it may be difficult to generalize about the impact of such systems on driving performance without specific examination and study of their characteristics using a representative population of driving subjects.

It would appear, therefore, that as time goes on and different advanced technologies are introduced into the market and then considered for review under future research, there is a probable need to treat each technology, and perhaps even specific manufacturer models, on a case-by-case basis. As different technologies become evaluated by follow-on research or other studies, a pattern may develop that will permit a greater generalization about the impact of certain types or categories of these technologies on driving performance.

With regard to expected trends in automotive technologies and their likely market penetrations over the next decade or so, the number of example patent citations in 1994 alone (Appendices K-O) suggests a great deal of ongoing activity and plans for utilization in the near term. A number of these patent citations relate to componentry or sub-systems within the broader technology topics. In general, it is apparent that a wide variety of technologies are being pursued in areas that are intended to enhance or alter conventional vehicle dynamic properties (such as active suspension systems, antilock braking, four-wheel steering, drive-by-wire/throttle control systems, electric steering systems, etc.). There is also some growing activity in areas related to cue augmentation as intended aids for drivers (examples of such technologies would be various types of head-up displays, warning lights [Appendix N: Harold 1994], or active steering system torque feedback devices [Schumann 1994, Murray 1994], all intended to provide additional or enhanced feedback cues to drivers). Much of this basic patent material is also supported by the Delphi forecast information appearing in Appendix Q, which is focused primarily upon current and past opinions of vehicle manufacturers and automotive parts suppliers [Cole 1994, Underwood 1991].

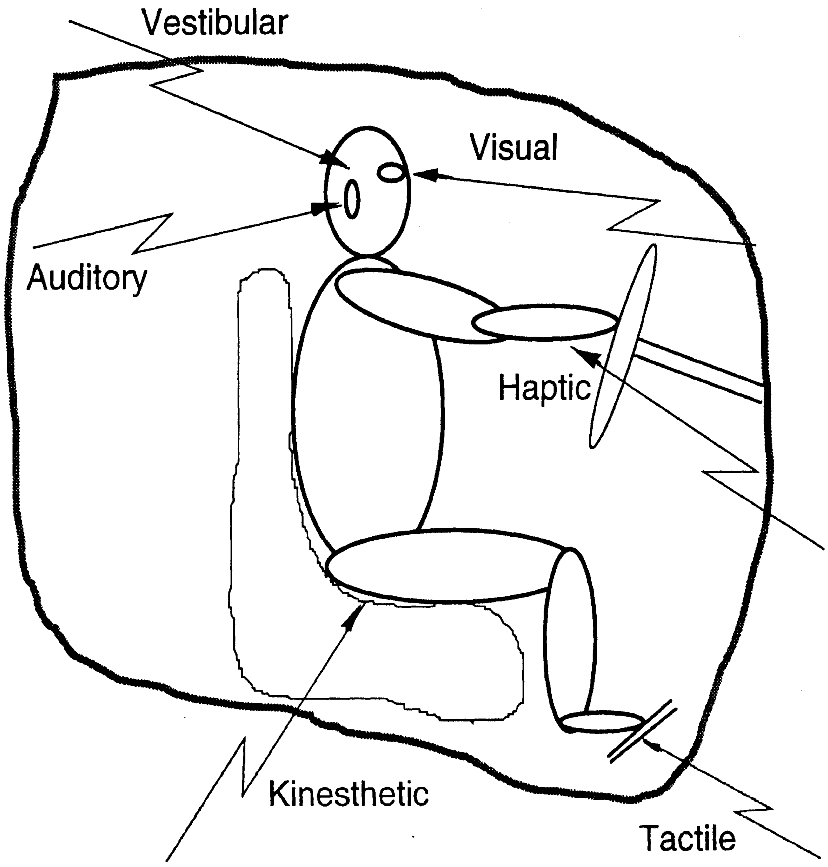
2.1.2 Driver-Vehicle-Cue Interactions

We now turn attention to the general topic of driver-vehicle-cue interactions and the literature that relates to it, primarily that appearing in Appendices A-J. A broad overview and discussion of this topic is first offered, followed by a general coverage of certain observations from the literature.

Figure 2 depicts the primary human sensory centers used in the driving task. The sensory centers are comprised of:

- visual (eyesight)
- vestibular (inner ear)
- kinesthetic (body-distributed)
- tactile (cutaneous; touch)
- auditory (hearing)

Figure 2. The Primary Human Sensory Centers Used in Driving



Perhaps 90 percent or more of our information used in driving is acquired through the **visual** channel [Riemersma 1987]. It is primarily used in providing positional and velocity information, and to a lesser extent, acceleration information (at least for slowly moving objects) [Gottsdanker 1952].

Vestibular organs located within each inner ear are highly complex and interesting structures used for maintaining balance and orientation with respect to gravity. They also permit sensing of translational and rotational accelerations, as well as rotational velocities. The saccule and utricle elements provide linear acceleration information; the vestibular (or semicircular) canals provide rotational motion information [Jex et al 1978].

The **kinesthetic** sense is often referred to as the "body-distributed" sense and permits individuals to locate limbs and other body parts with respect to one another, as well as to sense forces/torques acting on the body or generated by the body. Receptors within the muscle and tendon tissue and at joints provide the physical mechanism by which such movement-related information is detected. Body accelerations are also sensed through accompanying tissue compression changes.

Tactile sensing is associated with touching and light cutaneous pressure at the skin surface. Object texture, roughness etc., as well as small vibratory sensations, can be detected via this information channel.

The **auditory** or hearing sense provides many useful types of information, especially for the estimation of speed through sounds emanating from engine RPM, wind noise, body rattle, and tire-road interactions. Acceleration information is also detectable to some extent from sounds associated with tire noises generated during cornering or braking.

Other commonly used terms for describing the sensory centers are:

Haptic — which refers to a combination of tactile and kinesthetic sensing, often associated with active grasping, such as with a steering wheel or certain foot-pedal interactions, wherein both light touching (tactile) and more aggressive tissue compression (from engaging the kinesthetic receptors) occurs.

Somatosensory — often referred to as the "seat-of-the-pants" sense or cue; essentially the kinesthetic sense emphasizing body-centered sensations.

Proprioceptive — terminology used to describe the kinesthetic sense, but often specifically associated with force/torque production by muscles and tendons.

Principal cues used in the driving process are those signals or sensations that we experience as drivers. They include:

- **Positions**
  lateral, longitudinal, and vertical location of the vehicle on the road,
  vehicle heading (yaw) angle, roll angle, pitch angle
  steering wheel position, brake/throttle position

- **Velocities**
  forward vehicle speed, lateral speed, vertical bounce rate
  yaw rate, roll rate, pitch rate
  rate of steering wheel movement, application rates for brake & throttle

- **Accelerations**
  lateral acceleration, longitudinal acceleration, vertical acceleration
  yaw acceleration, roll acceleration, pitch acceleration

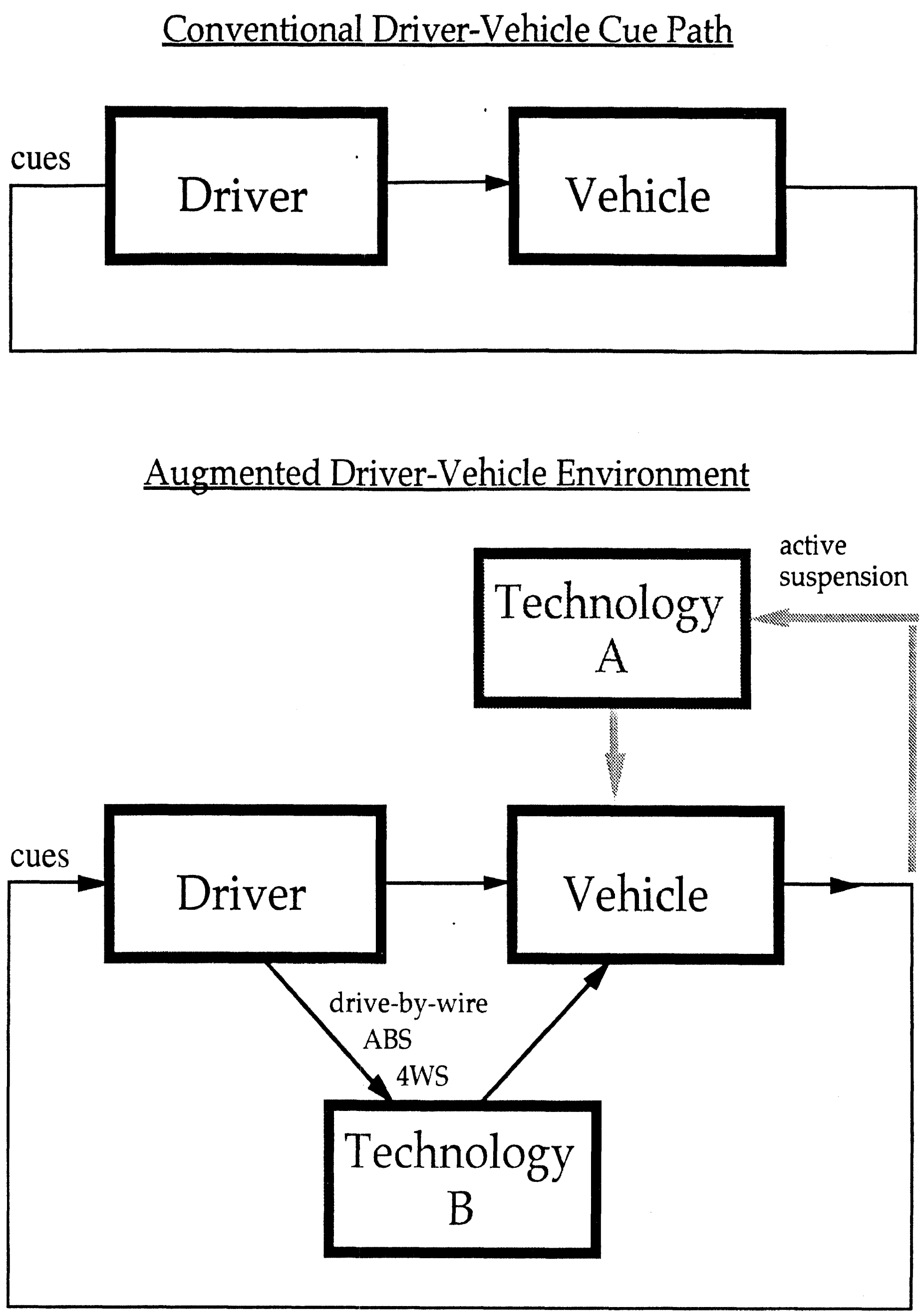
- **Forces & Torques**
  steering wheel torques/forces, brake & throttle pedal forces
  seat/harnessing/bracing reaction forces due to cornering/braking/ride

- **Sounds**
  engine rpm, wind noise, tire/road noise, tire squeal, compartment & body rattle

The relationship between driving cues, human sensory centers, and most modifying technologies can be depicted by the following Figure 3. The top portion of Figure 3 shows a conventional driver-vehicle block diagram, absent of any intervening technology. The cues received by the driver are provided directly by the vehicle response, including any steering/braking/throttle control feedback reactions.

The bottom portion shows a modification of the original figure wherein technologies are now included at two alternate locations. The presence of the "Technology B" block indicates a technology that acts directly upon and modifies the control response of the driver prior to acting on the vehicle. The "Technology A" block suggests a technology that reacts to the response of the vehicle prior to intervening. Some technologies may act at both locations (e.g., an active suspension that senses driver steering behavior, as well as vehicle suspension and vehicle acceleration responses).

Figure 3. Driver-Vehicle Systems Modified by New Technologies



A further clarification of these driver-vehicle-technology interactions can be described with two more explicit figures. First, Figure 4 shows an expanded interpretation of the flow and sequence of information applicable to the "Technology B" category. That is, the driver control response output is processed by the technology block prior to being applied to the vehicle. Figure 5 shows the alternate "Technology A" category, where the vehicle input comes directly from the driver control response block, with the vehicle response output then being processed by the technology block. In either case, the resulting feedback cues perceived and sensed by the driver are altered in the information flow sequence by the presence of an active technology within the loop.

Figure 4. Driver Control Response Modified by Technology

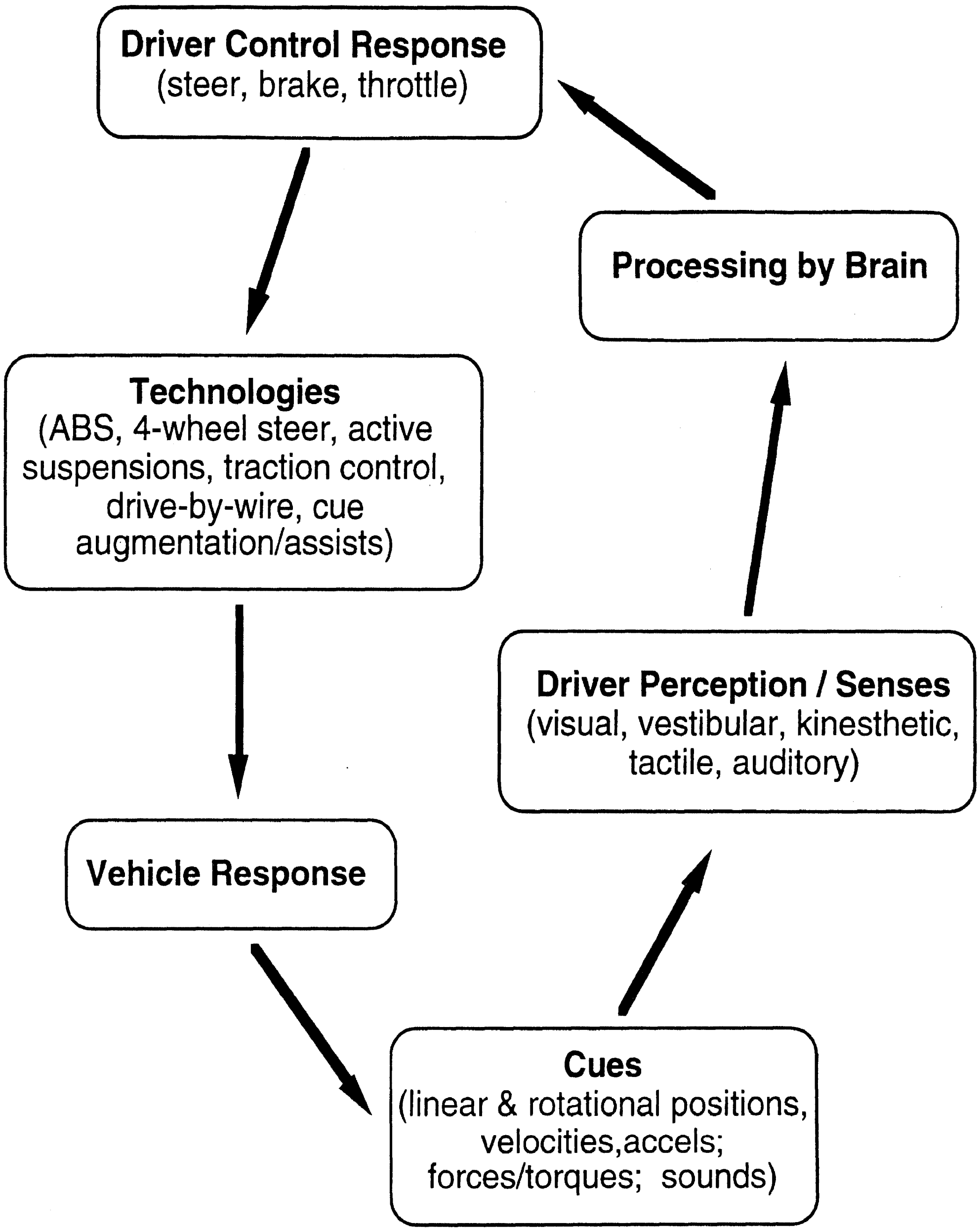
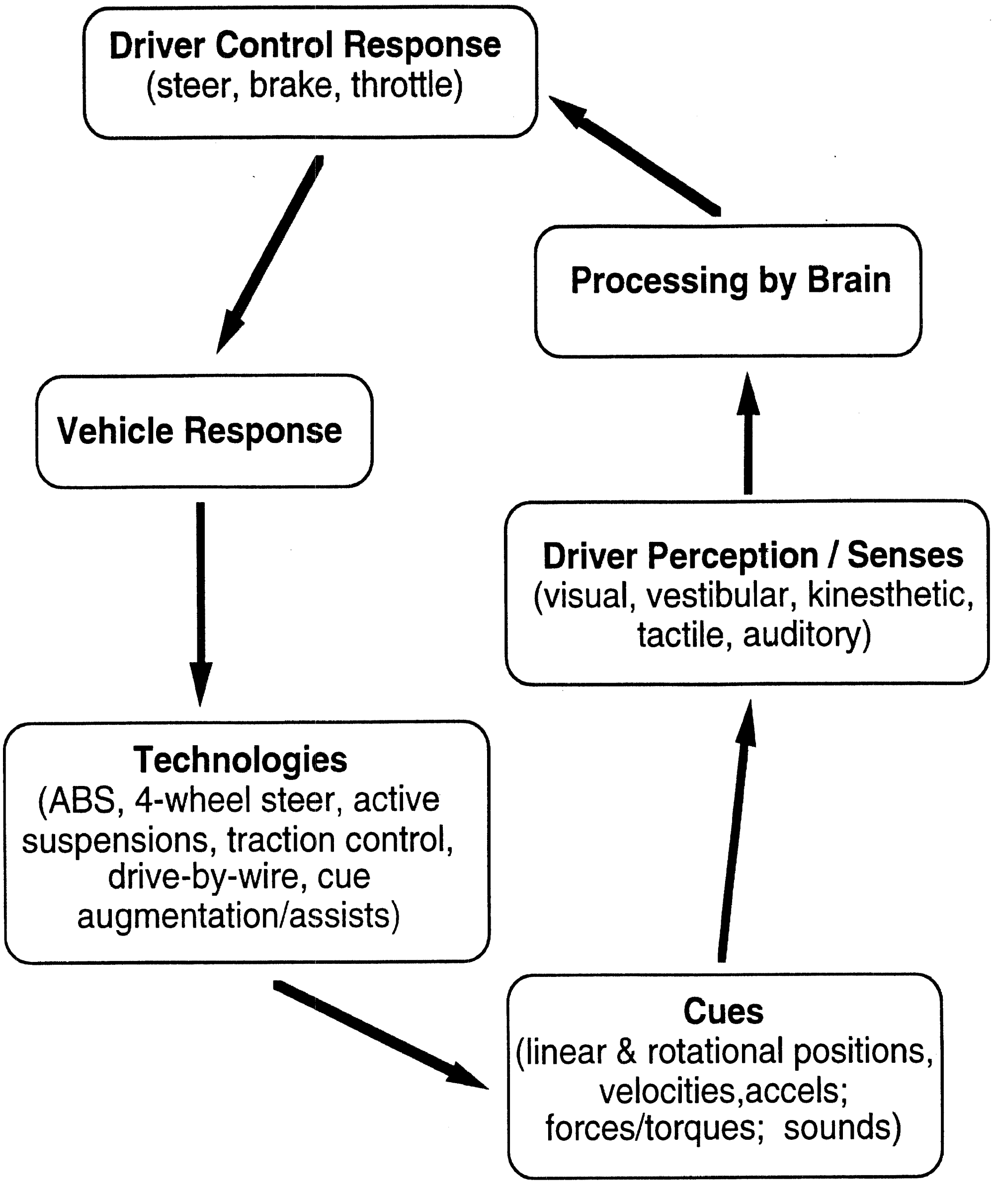


Figure 5. Vehicle Response Modified by Technology



2.1.3 Summary of Selected Human Performance Literature

The relevancy of some materials outlined in the following section may seem at times remote; however, their purpose is to provide a foundation and set of background references. It may be helpful to keep in mind that the topics and observations outlined here (quite broadly) are examples of starting points for further inquiry. So, when topics, such as human time delay limitations, are described or observations about motion influences in simulator studies are offered, these sources can provide initial information about the potential impact of new technologies. For example, knowledge that increased time delays within the control loop are harmful for human driving performance can suggest concerns for any new technology that may be identified as contributing to additional control loop delay because of some characteristic of the technology that incorporates a lag feature. Or, perhaps more subtly, a technology that tends to shift visual usage by drivers away from foveal or central vision areas to increased dependence upon peripheral vision areas may be of concern due to observations that increased usage and reliance upon peripheral vision often leads to degradation in tracking task performance.

A comprehensive collection of materials related to perception and human performance is provided by [Boff et al 1986 / Vols I & II]. These provide a good basic reference and starting point for many of the human factors issues surrounding this project work. The materials cited in Appendix A (General References), are being used as the basis for much of the overview literature discussion that follows. Additional materials related to human-vehicle interactions are provided in Appendices B-J and are organized somewhat informally by topic area (appendix titles). These generally contain abstract information that supplements in more detail the citations and associated discussion that follows. (Appendices K-O apply to the technology areas and are discussed in subsequent sections.)

The multidisciplinary body of knowledge referred to as "human performance" is primarily concerned with characterizing how human beings perform specific tasks — such as driving. It provides the scientific basis of ergonomics (or "human factors engineering" as more commonly used in the U.S.). The general area of "manual control," meant to imply human control, also contains a highly relevant body of information. The basic objective of these disciplines is to provide predictions of human performance in future situations or environments, based upon previously derived principles or theories. Human performance often relies on qualitative terms to describe various measures of performance (e.g., [Kelley 1969]). As well known, humans are not nearly as predictable or well-defined as many other common areas of engineering study. So, issues related to uncertainty and unpredictability are generally given more weight and generally cited as normal and expected characteristics of many human-vehicle interactions.

Human Time Delay and Threshold Limitations

There are certain basic properties of humans that are routinely observed by experimentalists when studying human-machine interactions. Humans are not "linear" elements. They exhibit time delays in reacting to stimuli. Sensed information (motion cues, etc.) must exceed certain thresholds prior to being detected. Other general limitations are:

- required processing times for sensed information
- information transmission time
- requirements to anticipate or predict ahead
- perceptions of higher derivative (or rate) information

Pure time delays are seen to be more harmful to human-vehicle system performance than "exponential" or dynamic lags as associated with first or second order system characteristics [Wallach 1961, Warrick 1949]. Lab experiments involving tracking tasks show that time delays greater than 40 ms produce degradations in performance for zero-order systems (i.e., simple positional control tasks) [Warrick 1949]. The detrimental influence of pure time delays on system stability was also demonstrated in [Pew 1967].

Simple reaction time (the time from stimulus to response with anticipation) experiments show that visual response times under near ideal conditions are about 180 ms. Comparable auditory and tactile response times are about 140 ms [Woodworth & Schlosberg 1954, Young & Stark 1965, Teichner 1954].

It was also demonstrated by [Woodworth & Schlosberg 1954] that auditory delays increase to 300-400 ms as sound amplitudes approach the threshold detection levels. Others have observed that the duration of the stimulus plays a role in reaction times [Teichner & Krebs 1972]. Consequently, reaction time characteristics can display nonlinear properties insofar as they depend upon the amplitude as well as the duration of sensed information.

Some example thresholds (levels that must be exceeded prior to signal detection) for humans are listed below for several sensory channels (assuming long latency detection times in some cases) [Boff et al 1986 / vol I]. Many of these threshold values depend upon exposure time, location, etc. and are considerably more complicated than indicated by these example values:

0.005 g linear accelerations	vestibular saccule
0.1 deg/s/s rotational accelerations	vestibular semicircular canals
5 mg (von Fry hair method)	tactile - female face
355 mg (von Fry hair method)	tactile - male large toe
0.0002 dynes/cm/cm	auditory
(0.63 dynes/cm/cm is ordinary conversation)	

Visual Characteristics

It is known that velocity and position information can be extracted separately from a scene by the human vision system [Miller 1981]. The jump-like saccadic response of the eyeball is primarily triggered by positional errors; the smoother pursuit mode of the eyeball is activated for constant velocity tracking of objects. However, the two modes work together yet independently of one another [Boff et al 1986 / vols I & II]. There is evidence that cells within the human visual system are directly responsive to velocity [Breimeyer 1973, Lappin et al 1975, Pantle & Sekular 1968, Sekular 1979].

The perception of velocity is known to impose costs of increased time delays in the range of 30-200 ms [Levison 1982, McRuer 1980, McRuer & Jex 1967]. Limited abilities to perceive acceleration via the visual channel are observed except in cases where velocity-differencing operations occur by humans for slowly moving targets [Gottsdanker 1952, Boff et al 1986 / vol I].

Velocity information presented to humans in displays as "positions" (e.g., a speedometer gauge) shows improvement in performance for tracking tasks, over cases in which velocity information is presented as a "velocity display" (e.g., nulling of a rotating disk display) [Roscoe 1980]. Velocity information obtained from the peripheral visual areas is generally found to be valuable, particularly as redundant information to positional information obtained from the central foveal vision areas [Moriarty et al 1976, Swartzengruber 1971, Bruel 1981]. It is also observed that basic peripheral velocity information should be compatible with the expectations of humans [Swartzengruber 1971].

Experiments requiring human operators to perform visual tracking tasks on separately located displays (or multi-axis displays) generally show deterioration in performance. Tests engaging the central (foveal) vision and the peripheral vision areas to obtain separate pieces of information also indicate degraded performance [Allen 1970]. Additional reliance on peripheral vision areas further reduces performance. Reference [Moss 1964] shows that increasing angles of display separation results in increases in tracking error. In general, multi-visual display tracking reduces performance on one or more of the channels.

The ability of humans to look ahead and preview information helps to reduce some of the time delay limitations indicated earlier [Reid & Drewell 1972]. In other cases where preview may not be available, such as driving and responding to wind gusts, higher order predictive requirements of humans come into play in order to self-generate rate information for vehicle control purposes.

Motion Influences

As noted above, much of the higher derivative information is obtained from the vestibular (inner ear) and kinesthetic (body distributed) channels. Simulator studies show that the presence of accurate motion information to supplement visual information generally leads to superior flying and driving performance over comparable conditions when no motion is present [Jex et al 1978, Levison & Junker 1977, Levison et al 1979, Roscoe 1980, McRuer 1968].

Conflicts in timing delays from visual displays in roll axis tracking tasks were demonstrated in [Levison et al 1979]. Delays as short as 80 ms indicated reduced tracking performance with roll motion present. Delays of 300 ms produced tracking performance as poor as the same condition with no motion present. (Or, roll motion systems with delayed visual information can be worse than systems containing no motion. And, the presence of some visual delay for such systems involving motion generally exhibits poorer performance than when no visual delay is present.)

Studies such as [McRuer 1968, Levison & Zacharias 1980] show that motion effects help to reduce uncertainties in observed responses and provide for enhanced prediction and gain compensation by the human controller. The importance of accurate and reliable vestibular cue information is noted in simulator studies such as [McRuer 1968]. Cue fidelity issues have also been noted with regard to pilot training and successful transfer to flight conditions. References [Jacobs & Roscoe 1975, Roscoe 1980] provide additional discussions on the importance of motion fidelity and transfer.

Auditory Information

The use of auditory information is generally seen to be most beneficial when acting as a supplementary cue within a multi-channel environment [Vinge 1971, Vinge & Pitkin 1972]. For example, within a multi-channel environment containing several visual channels (central, peripheral, side-task displays, etc.), audio information can be particularly helpful. It is also observed that humans can more easily divide their attention between audio and visual information channels than between two visual channels [Baddeley 1975, Rollins & Hendricks 1980, Treisman & Davis 1973]. In multi-axis control tasks, off-loading some axis control to an audio channel can improve overall performance. However, some studies also note potential conflicts with off-loading to auditory channels [Poulton 1974].

For tracking control tasks, it was noted that human time delay characteristics were as short for auditory as for visual channels [Vinge & Pitkin 1972]. It was also observed that for two-axis tracking task experiments, superior performance was indicated for visual-auditory cases versus visual-visual cases.

Generally, the use of auditory information as redundant and reinforcing information is seen as helpful for improving system performance. Auditory information, though, is most useful under high workload conditions as redundant information supplementing the visual channel [Boff et al 1986 / vol II].

Tactile and Haptic Information

Tactile and haptic cue information is normally conveyed to the driver though the steering wheel and throttle/accelerator pedals. A certain portion of information is also available through such channels by sensing small skin surface vibrations or circulating wind, etc. Steering wheel torque information can be particularly useful to drivers for detecting sudden changes in tire/road friction as well as anticipating control responses for roadway disturbances and wind gusts. Examples of new ideas being advanced in this area are the so-called haptic steering wheel device [Schumann 1994] and new electric steering systems [Murray 1994].

Manual Control

A related and key area of study for this project work is the field of "manual control," or the study of humans interacting with and controlling machines. Closed-loop driver-vehicle systems (or basic driving involving navigation and control) fall into this more general manual control category.

When the human-vehicle system is described as a feedback control system, certain sources of error or limitations are generally described. These include gain errors, time delays, and self-generated noise by the human (or remnant control noise).

In such studies [Levison 1982, McRuer 1968], certain control system qualities are preferred over others. "Better" control behavior is often associated with low control activity. Performance is frequently described in terms of RMS (root mean square) or MSE (mean square error) measures of various system error signals, or levels of stability, or workload, etc. [Kelley 1969].

Basic observations regarding adaptation and gain compensation by human subjects, as well as preferred optimum gain settings, are reported in [Jex & Comwell 1961, McRuer & Jex 1967, Segel & Mortimer 1970]. The well-regarded "cross-over model" experimental observations from laboratory, simulator, and driving experiments also support many of these findings [McRuer 1968].

It is known that as the complexity of the controlled system increases (often referred to or expressed by the term "control order"), the difficulty increases for the human controller. [Poulton 1974] observes that zero-order plants (position control) require one correction by the human; first order systems require two control corrections, etc. RMS system errors increase from about 40 percent to 100 percent as the order of the controlled system increases from first order to second order (i.e., from human control of velocity to control of acceleration). This observation seems to hold across a wide variety of variations in input signal, displays, and task loading.

As task difficulty increases due to system complexity, system performance is decreased, time delays increase, gains are lowered, control remnant is greater, higher estimates of workload by subjects are noted, and greater interference within other tasks is observed [Kelley 1968]. The associated requirements by the human operator to preserve stability under such conditions results in the need to generate longer lead times, which are frequently associated with increased workload [McRuer 1968, Wickens & Derrick 1981]. Perceptually, the need to obtain higher derivative information needed for adequate control burdens the human operator under such circumstances [Wickens et al 1981]. It is also noted that increased usage of bang-bang control strategies by human operators is employed as the order of the controlled system increases [Costello 1968, Hess 1979, Young & Meiry 1965].

Assistance to human operators for controlling higher order systems is usually accomplished through display augmentation or via control dynamics augmentation. Visual augmentation may be in the form of predictive displays or display quickening [Jensen 1981, Kelley 1968]. Control dynamics augmentation usually attempts to alter the system dynamics to a lower or simpler order for improved control [Birmingham & Taylor 1958, Holland & Hanson 1958].

Driving Simulator Studies

A variety of driving simulator studies appear in the literature. A particularly relevant work is that of [McLane & Wierwille 1975] in which systematic cue removal was studied using a fairly comprehensive simulator environment that included motion, visual, and auditory feedback information. It was observed in this study that starting from the complete cue-rich reference condition, removal of cues resulted in degraded driving performance, particularly when two or more cues were withdrawn.

Handling Tests with Normal Drivers

Pertinent handling studies involving more or less ordinary drivers are provided by [Rice & Dell'Amico 1974, Rice et al 1976, Koppa & Hayes 1976]. These studies indicate that normal drivers generally do not elect to utilize the full capability of automobiles under a variety of conditions and test maneuvers, except for longitudinal braking and accelerating.

In [Rice et al 1976] it was observed that drivers will make greater usage of the capabilities of the vehicle and exhibit more aggressive driving behavior when the handling performance capabilities of the vehicle are increased (i.e., more sporty). Opportunities for further safety improvement are suggested for the human element rather than through vehicle advancements.

2.1.4 Ranking of Cue Influences

General review of the overall literature leads to a clear impression that visual aspects of driving are of the highest significance. Quotes referring to the driving process as being 90 percent dependent upon visual information are not uncommon [Peacock & Karwowski 1993, Schieber 1994, Sivak 1995]. There is also a certain common sense aspect to this reasoning process given our own personal experiences and observations, the emphasis that state agencies normally place upon visual acuity tests in registering drivers, and the absence of drivers with severe visual impairments operating motor vehicles. Laboratory simulator studies (and many video games) also demonstrate that most humans can adequately control and navigate vehicles using only vision, even with distorted or inaccurate visual feedback information in many cases. So without rigorously examining numerous studies to prove how important vision is per se as a driving cue, it is simply observed that vision is very important and the exact level of importance can likely vary depending upon the specific driving scenario and task conditions. For example, during straight-line driving in crosswind conditions, drivers are likely to increase their dependence upon yaw motion and lateral accelerations due to wind disturbances. This would tend to activate and increase driver utilization of vestibular rotary motion information, vestibular lateral acceleration cues, and kinesthetic "seat-of-the-pants" (somatosensory) feedback sensations. The percentage of visual cue information, relative to the total cue information, would be reduced under these circumstances due to the increased usage of vestibular and kinesthetic channels. However, the visual channel still remains dominant. Other driving scenarios, such as heavy fog conditions that severely limit driver vision, also provide common evidence of our dependency upon vision for routine driving.

The process of ranking sensory information becomes somewhat less obvious after vision is removed from the list. However, motion cues related to higher derivative information (linear and rotational accelerations as well as rotational velocities) normally sensed by the vestibular and kinesthetic channels tend to show up frequently as topics of importance for most simulator or motion-based studies [Levison et al 1979, McLane & Wierwille 1975]. It is difficult in many cases to identify the separate influences and associated importance of these two sensory channels since most acceleration information is generally detected simultaneously in different ways by both senses. Even under conditions of significant rotation where the vestibular channel could seem to have certain advantages, some form of rotational motion might still be detected by kinesthetic mechanisms that drivers use to locate themselves within a vehicle compartment. Lumping these two sensory capabilities together at a second level of importance seems reasonable given their tendency to provide cooperative and reinforcing information on accelerations. It might further be argued that although the vestibular channel provides additional information, such as rotational rates of change and the sense of gravitational orientation, the kinesthetic sense has certain advantages by being distributed throughout the body. The kinesthetic sense also provides some velocity sensing information via body vibrations and limb movements, as well as control force/torque sensations from the steering wheel and control pedals. Again, as in the case of vision considerations, selected driving scenarios can probably be identified in which drivers depend more on vestibular-sensed information than kinesthetic, and vice versa.

The tactile and auditory channels remain. The tactile sense often is engaged with the kinesthetic sense (haptic) for various task activities during the driving process. Interactions with the steering wheel and foot pedals are good examples. Wind currents passing over the face and hands can also provide additional information on movement and vehicle speed. To the extent that the tactile sense is also distributed across the body and has frequent cooperative interaction with the kinesthetic sensing mechanisms, it would take on a more likely level of importance in the driving process than the auditory channel.

A top to bottom ranking of the primary sensory channels used in driving would then be:

1. Vision
2. Vestibular and Kinesthetic
3. Tactile
4. Auditory

The ranking of specific cues associated with these sensory channels would organize themselves accordingly into several corresponding groups. For example:

- translational/rotary position and velocity information from the visual channel

followed by,

- translational/rotary velocity and acceleration information sensed the vestibular
- linear acceleration, force/torque information from the kinesthetic body senses
- acceleration information derived from visual velocity differencing mechanisms

followed by,

- small amplitude vibratory information sensed by tactile senses
- auditory information regarding velocity, movement, and accelerations

Note that most of the secondary cues also provide redundant/reinforcing cue information during the driving process. This can help drivers to more quickly confirm decisions and better estimate information obtained from the more primary channels. Estimating speed, for example, is often enhanced by the inclusion of auditory information [McLane & Wierwille 1975]. So, even though visual cues would be relied upon primarily, additional auditory sound information and kinesthetic/tactile vibratory information will generally improve the speed estimation process by the driver.

The above discussion is applicable to the conventional driving environment, absent of any special considerations for new technologies that may be introduced into the driving environment. For the purposes of this project, the issue of cue identification and ranking will have further benefit when applied to the analysis of specific technologies and their potential impact for altering driving cues.

For example, the introduction of a new electric steering system may be implemented in such a manner that ordinary feedback steering torques to the driver are sharply reduced or fundamentally changed in some way. Since most drivers have a basic expectation about the general feel of conventional steering systems and depend to varying degree on information received through that channel, a significant departure from this conventional design may be bothersome to many drivers and result in altered driving behavior. Ordinarily, information provided to drivers through steering torque indicates changes in tire/road friction conditions (e.g., snow patches, hydroplaning), road surface irregularities, crosswinds, etc. This frequently permits drivers, used to processing this information, to anticipate and react more quickly to changes in their driving environment. A candidate technology that inadvertently removes this haptic cue path to the driver may unintentionally eliminate this anticipatory cue mechanism that drivers ordinarily employ as part of their steering control behavior (consciously or instinctively). This particular cue diminishment might be characterized in one sense as an effective time delay influence since the anticipatory or quickened information provided from the steering system is now lost. Since the relevant technical literature and associated studies show that increased time delays within the driver-vehicle control loop are generally detrimental to tracking or driving performance, the level of concern assigned to this particular technology would depend, in part, upon time delay findings from those prior studies.

In addition, the loss of torque/force feel as a centering or zeroing mechanism that drivers rely on as a control reference point would also come into play as part of this analysis. These torque/force diminishment effects could be further evaluated using results from prior studies that have examined force versus positional control influences on tracking or driving performance.

Therefore, a ranking procedure that includes such analyses for specific technologies and vehicle design features seems appropriate. The ranking methodology would be included with other items of information (such as expected market penetration) as part of any overall analysis of technologies that are undertaken. Recommendations for subsequent research would then rely on analyses that include technical factors as well as likely future utilization.

2.1.5 Technology Patents

The example patent materials appearing in Appendices K-P are a partial list from 1994. They are organized informally by basic topic: active suspensions, antilock braking, four-wheel steering, cue augmentation devices, drive-by-wire, and traction control. Some patent examples apply to more than one area, but appear only in one appendix, and so may appear misclassified in some cases. However, the primary purpose is to get a broad reading of recent activity occurring in these technology areas and to provide some insight about their basic operating characteristics / features.

As seen from the number of patents alone, a good deal of activity and plans for introducing and applying many of these technologies to automotive vehicles might be indicated. The expected market penetration for some of these technologies by vehicle manufacturers and parts suppliers (next section 2.1.6) is contradictory to the flurry of patent activity also observed. For example, numerous patent applications are seen for four-wheel steering even though expected market penetration forecasts of such systems have been revised sharply downward in recent years [Cole 1994].

In other areas, such as antilock braking systems, the levels of patent activity support expected market forecasts that project heavy usage of such systems over the next decade. Similar, though less aggressive, observations apply to traction control systems. Over time, integration of antilock braking and traction control technologies are logical because of shared and related system componentry and the common purpose of wheel slip control.

Many of the patent applications also offer information about operating principles or features that may be of interest to this work. While basic operating principles are common to technologies within a certain category, the details of implementing certain features are often different and the patent information can reveal many of these differences. Two of the example patents related to traction control/antilock braking [Appendix P: Beck et al 1994, Iwata 1994] and a research study [Sano & Kishimoto 1994] are concerned with suppression of pedal vibrations and noises transmitted to the driver during system operation — one of the primary topic areas initially raised under this task order.

2.1.6 Delphi Forecasts: Expected Market Penetration of Certain Automotive Technologies

The material contained in Appendix Q pertains to Delphi forecasts taken from references [Cole 1994, Underwood 1991]. The basic material is in the form of questions posed to a panel of experts comprised of vehicle manufacturers and automotive parts suppliers. Panel opinions regarding market penetrations of various technologies over the next decade are summarized as charts or tables. Comparisons with previous Delphi forecasts are also included. Selections pertinent to many of the technologies of concern to this project appear in the appendix. A few additional technologies and peripheral items, such as air bags, sensors, or ITS technologies, also appear and provide some information for comparison purposes with the chassis control technologies of primary interest here.

With regard to antilock braking systems, the average consensus is that a 90 percent market penetration is forecast by the year 2003. One comment indicates the suggestion of 100 percent penetration pending a NHTSA requirement. This penetration figure has been consistently revised upward in each of the prior forecasts. However, these estimates may be somewhat high given recent data casting some doubt on the crash reduction benefits of ABS.

Traction control systems are seen as penetrating to a level of about 20 percent by 2003. However, increased linkage to antilock systems is likely to result in higher estimates in future forecasts. Like antilock, prior forecasts of traction control systems have been trending upward.

Estimates of market penetration for active suspensions are 3 percent by the year 2003. Semi-active systems are placed at 8 percent. Cost and power consumption concerns remain.

Electric/electronic power steering systems are estimated to penetrate at levels of 5 percent to 15 percent depending on the specific configuration (all electric vs. electronic/hydraulic, etc.) by 2003. Drive-by-wire throttle control systems are projected to be 7 percent in 2003, down somewhat from the last forecast which projected 10 percent by 2000.

Forecasts for four-wheel steering systems are currently at 1 percent by 2003. Prior forecasts predicted much rosier expectations for these systems. The prior Delphi forecast in 1992 placed their expected market penetration at 8 percent in the year 2000. The sudden drop in forecasted penetration is attributed to higher costs and poor market acceptance of initially equipped vehicles in the last few years by consumers.

ITS collision warning systems are projected currently to be about 8 percent by 2003. Other ITS related technologies such as lane keeping and proposed collision warning systems are down in the 5 percent range in the next decade. Cruise control systems are estimated at 80 percent penetration; adaptive (headway) cruise control at about 5 percent.

2.1.7 Manufacturer Discussions

Only limited interactions with members of the auto industry have occurred during the course of this task order. Paul Fancher, who serves as chairman for an SAE Vehicle Dynamics committee solicited ideas for discussion of cue issues at their last meeting in January. Mr. Fancher made a presentation to aid the committee in understanding how the subject of driving cues might fit into the structure of committee activities. In general, the subject of driver cues was favorably received by the committee, but it was not clear where the forum might go with it. The discussion following the presentation indicated that, although the committee members had an appreciation for the importance of closed-loop control, the committee's work had traditionally emphasized open-loop measures of vehicle performance. Nevertheless, the committee was interested in pursuing the subject of driver cues further.

2.2 Conceptual Model Development

The conceptual model discussed in this section is intended to act as a general framework for examining the basic interactions and mechanisms of the different feedback driving cues. Simple diagrams are used to help review and describe the various interactions between the driver, the vehicle, and sensed information used in the driving process. Certain elementary features that are common to many of the various feedback cues (such as time delays, thresholds, etc.) are also identified. The intent here is to keep the description at a fairly broad conceptual level, utilizing more detailed information only as it supports themes of commonality. Where certain detailed functional characteristics are seen as being common to many of the feedback cues, these may be identified as candidate elements to include within the broader conceptual model being constructed. As more is learned about individual feedback driving cues, either within this work or in follow-on research, suitable locations or "black boxes" within the conceptual model will be made available for containing that information. Consequently, the conceptual model is expected to be flexible and expandable as a resource that can be further refined as new information and research results are acquired. This approach can be viewed as a starting point with a minimal goal of including sufficient numbers of "hooks" or place-holders available to accommodate additional information as it is acquired. In its simplest form the conceptual model should be useful as a basic tool for framing most discussions of feedback cues used in the driving process.

2.2.1 Basic Driving Cue & Technology Interactions

In Section 2.1 a number of diagrams were used to describe the driving process and the influence of different technologies on the feedback flow of information to the driver. A few of these are referred to here again to help bridge this discussion. Figure 6 again depicts the various feedback cues used in the driving task (visual, kinesthetic, vestibular, tactile, and auditory).

The visual channel was identified as being dominant in providing information to the driver, followed by the combination of vestibular and kinesthetic senses. The tactile and the auditory senses follow next in order of importance for most driving tasks.

Figure 6. The Primary Human Sensory Centers Used in Driving

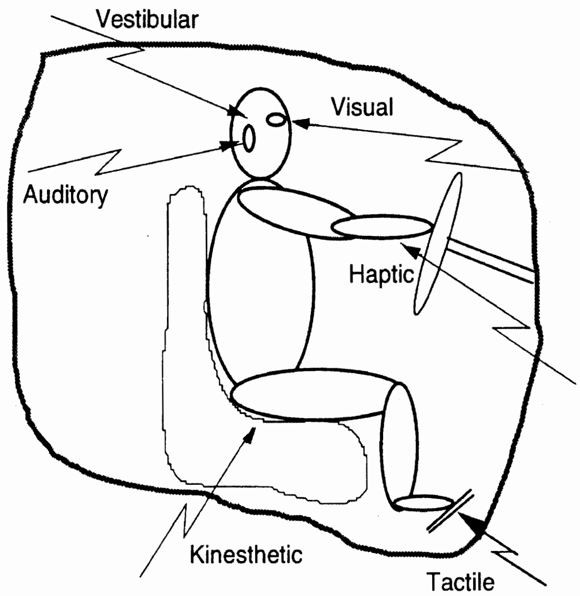
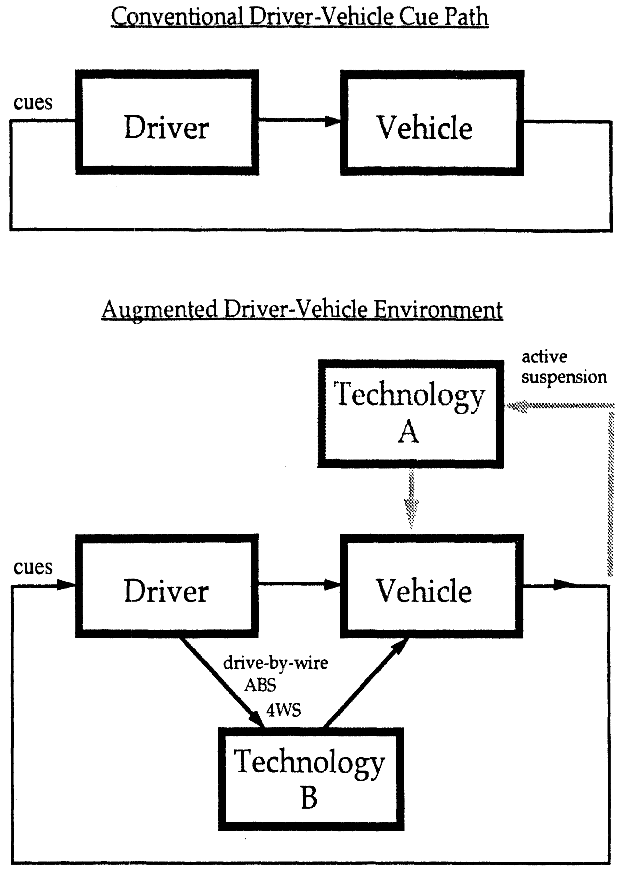
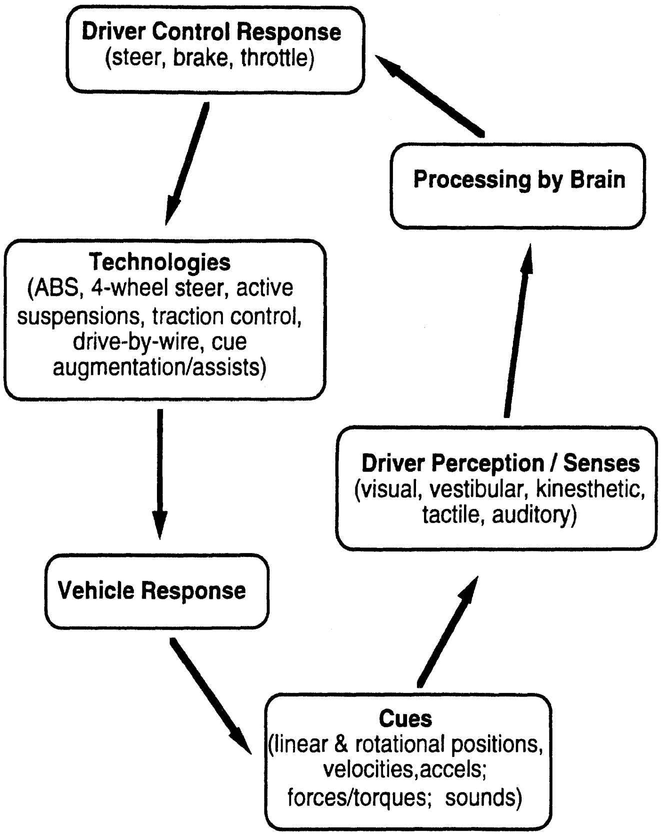


Figure 7. Driver-Vehicle Systems Modified by New Technologies



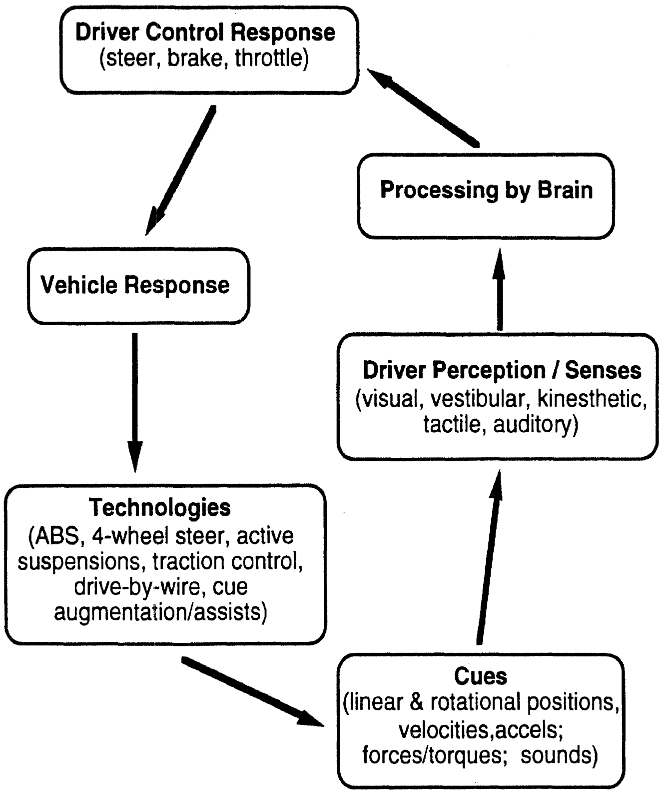
In the top portion of Figure 7, a description of the driving task is shown as a conventional block diagram. As new or advanced chassis control technologies are introduced into the driving environment (ABS, active suspensions, four-wheel steering, etc.) this conventional diagram is altered somewhat insofar as new blocks (A and/or B) now appear and are added to this diagram offering opportunities for feedback cues to the driver to become altered, Figure 7 (bottom). This can be described with further detail by the diagrams of Figures 8 and 9.

Figure 8. Driver Control Response Modified by Technology



In Figure 8, modification of the driver control response is depicted prior to its input to the vehicle chassis. In Figure 9, the technology is shown as intervening further downstream at the output response of the vehicle. In both cases, however, the resulting response of the vehicle and/or associated control feel is altered prior to its transmission back to the driver within the control loop. If significant modifications to these conventional driving cues are introduced by either technology A and/or B, stability and controllability of the vehicle may change from its conventional configuration.

Figure 9. Vehicle Response Modified by Technology



Further, and equally important from a human factors perspective, issues of driver expectations or uncertainty need to be introduced and added to those features already present in the above figures. Conventional vehicles, or vehicles like those a particular person is used to driving, are perceived as responding in some expected way to most steering/braking/throttle inputs used by the driver. If a new vehicle design alters or departs from that "regime of expectation" that a driver normally relies on, some period of adjustment or adaptation would likely be required to allow a driver to become recalibrated to the new features or operating behavior of the new vehicle design.

If this period of adjustment is rapid and easily accomplished, the consequences of any driver adaptation may be insignificant. If, however, the new technology requires more time for adjustment and compensation by drivers, a period of increased risk may be introduced. This increased risk would stem from uncertainties in driver control behavior or decision-making due to the altered or unexpected feedback cues introduced by the new technology or vehicle design. Consequences of additional "thinking time" or decision-making required of drivers in adapting to new vehicle control technologies can be represented in a simple manner as increased time delays in the driver-vehicle control loop. Less reliable or less accurate driver control responses may also accompany such increased time delays.

These considerations may be especially important for new vehicle design features that only appear under special circumstances such as accident avoidance or emergency driving conditions. New design features or feedbacks that are not expected by the driver under these conditions have the potential to complicate matters further. Ideally, drivers should be assisted in a natural manner and not confused by a technology intended to improve a driver's control effort and effectiveness.

Presumably, new technologies that are always "on" or operating under most driving conditions offer the best opportunities for drivers to adapt to any associated changes in the driving environment introduced by the new technology. Exposure to a new or modified driving environment over a long period of time would seem beneficial insofar as permitting drivers to acquire an understanding of the new feedback cues. An increased exposure should allow drivers to experience the operational features of the new technology and to develop a refined sense of expectancy about how the system is likely to respond under different driving conditions.

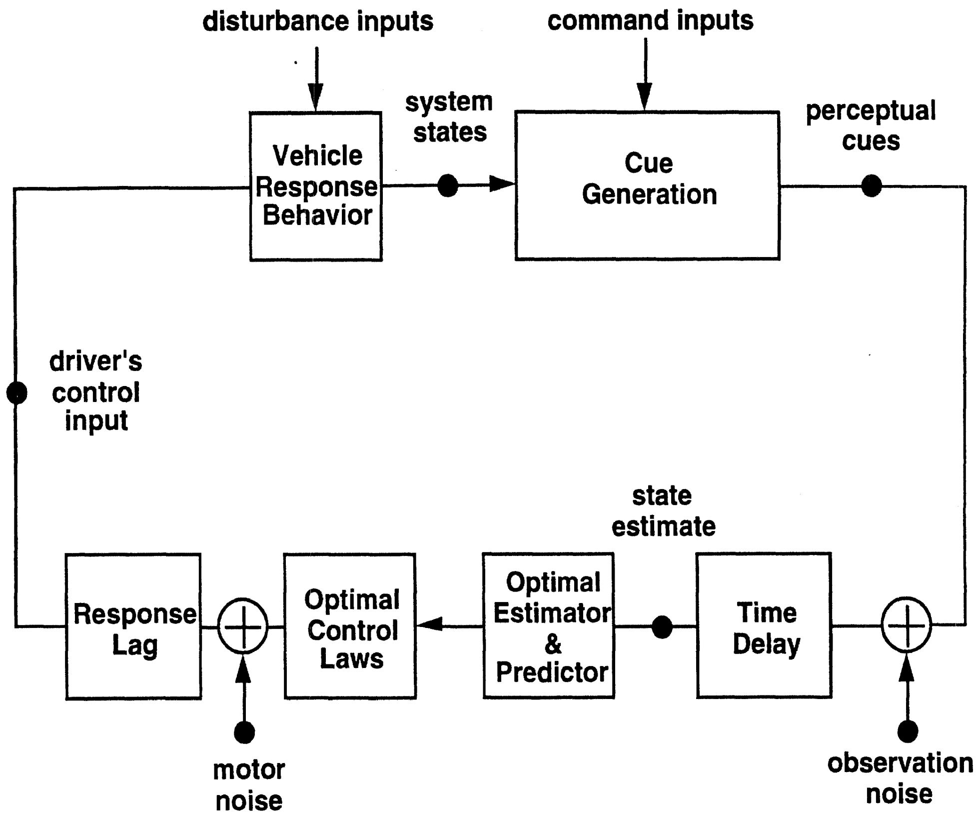
On the other hand, new vehicle technologies designed to become active or intervene only under rare circumstances, such as emergency braking or turning, may have the potential to momentarily confuse drivers if new or unexpected feedback cues are presented to the driver as part of their functional characteristics. It would therefore seem especially critical that such systems designed to operate under rare accident avoidance situations do so in a natural way without surprises or unusual feedback cues.

2.2.2 Conceptual Model

The conceptual model proposed in the following section is intended to provide a broad overview of the basic driving process related to feedback cue issues, but also to permit sufficient detail for describing known interactions. The model should include means for extending or "growing" its descriptive capabilities as more becomes known about specific details of driving cues and their relative influences. The ultimate goal is to provide a descriptive framework understandable at a high level, yet provide ample means for representing greater detail at lower levels within a hierarchical structure or equivalent block diagram.

One way to begin is to look at a representative example of other proposed models in this same general area. One of these is provided by Bill Levison's work at BBN. The driver-vehicle-cues model seen in Figure 10 was proposed by Levison as part of a recent simulator and side-tasking study[2] conducted for the DOT.

Figure 10. Levison Driver-Vehicle Control Diagram.



The key block in this diagram related to our project concerns is the one labeled "Cue Generation." Levison's "Cue Generation" block is a catchall for describing how the various vehicle responses are converted to internal human perceptual cues prior to their corruption by observation noise and time delays further downstream in this control loop diagram.

The Levison diagram is useful for describing the basic elements and certain control-related details for the overall driver-vehicle-cue system. However, it may be preferable for the purposes of this work to have a similar diagram that emphasizes the driver/cue-related aspects <u>and</u> provisions for technology influencing the vehicle response behavior.

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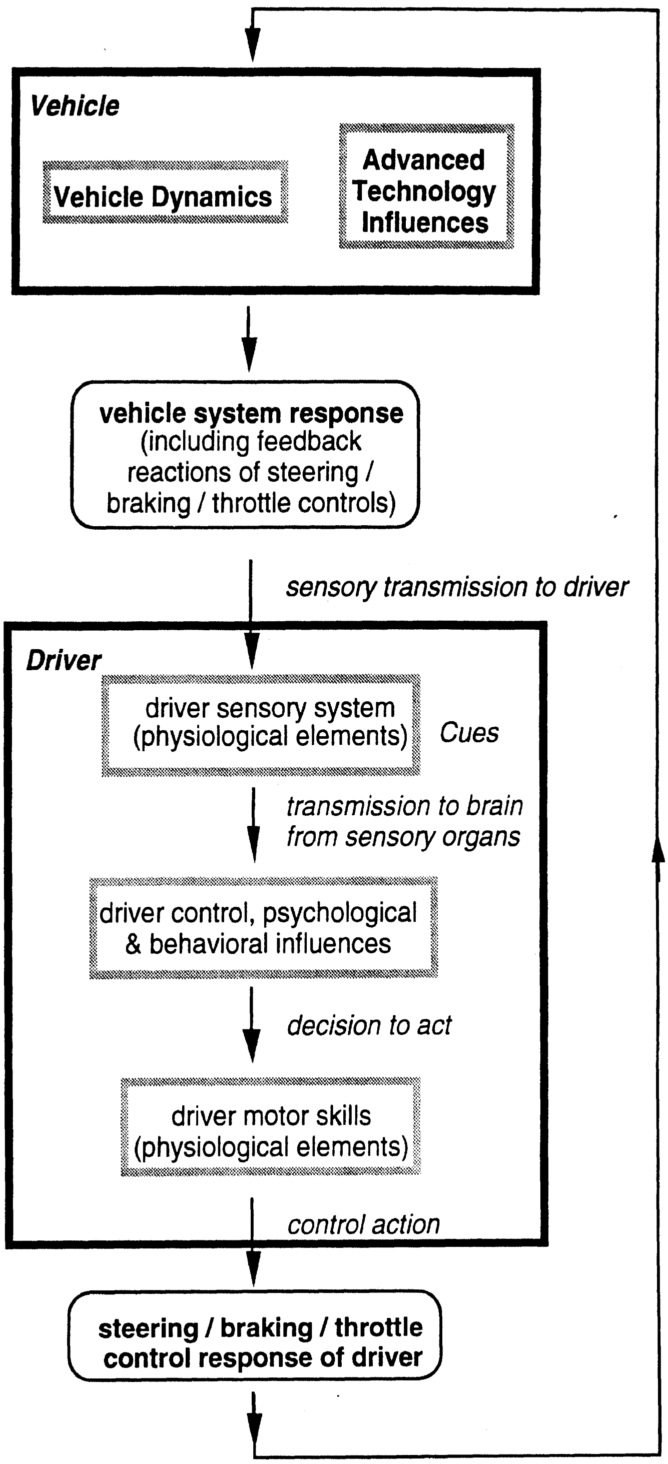
[2] Levison, W. H., "A Simulation Model for Driver's Use of In-Vehicle Information Systems," *Transportation Research Record 1403,* 1993.

The following Figure 11 tries to accomplish this with a block diagram that highlights more of the driver-related elements.

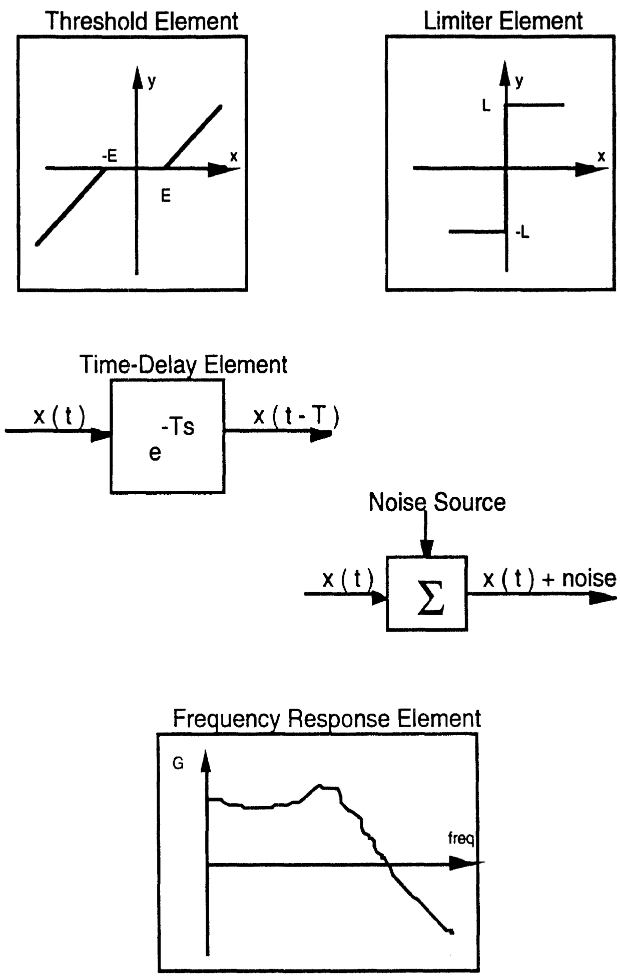
Figure 11. Driver / Vehicle System — Emphasizing Driver Processing Components.



The diagram shows a vehicle block containing the vehicle dynamics and advanced technology influences (vehicle chassis and associated technology componentry), and a somewhat more detailed block describing the driver. Within the driver block are three sub-blocks that represent: 1) the *driver sensory system*, 2) *control/behavioral influences,* and 3) the *driver motor skills* used in ultimately generating steering/braking/throttle control responses. The driver sensory system block within the driver module is intended to cover the physiological mechanisms such as thresholds, transmission delays, signal noise, and frequency dependent features of the human sensory organs.

Many of these basic mechanisms can be more specifically represented as simple elements, such as those seen below in Figure 12.

Figure 12. Simple Elements for Describing Basic Limitations and Characteristics of the Human Sensory System



Thus, this particular block could be broken down further to another level of detail that is described by the specific components in Figure 12. Each sensory channel may have its own set of elements with specific parameter values obtained from the literature or from specific experiments aimed at identifying such values.

The second sub-block within the driver module of Figure 11 is labeled as "driver control, psychological & behavioral influences" and is intended to represent the control decisions and behavioral aspects of individual drivers. Driver control strategies for steering, braking, and accelerating would primarily be defined in this block. Clearly, this is a source of great uncertainty within any such model because of driver personality or behavioral issues. Some of the various driver personality and behavioral issues that might be included here and play a role in affecting driver control skills are listed in the following Table 1.

Table 1. Examples of Behavioral and Decision-Making Issues Affecting Driver Control Skills

• Ability of drivers to deal with increased uncertainty (as may be introduced by a new vehicle design feature or technology). Alternately, the degree of dependency or reliance by drivers upon expected system behavior, (i.e., the consistency of expected vehicle feedback cues)
• Ability / skill of drivers to adapt to new or modified driving cues in an altered driving environment
• Personality likes or dislikes of individual drivers and their willingness to accept the influence of new technology and its potential impact upon their conventional driving experience

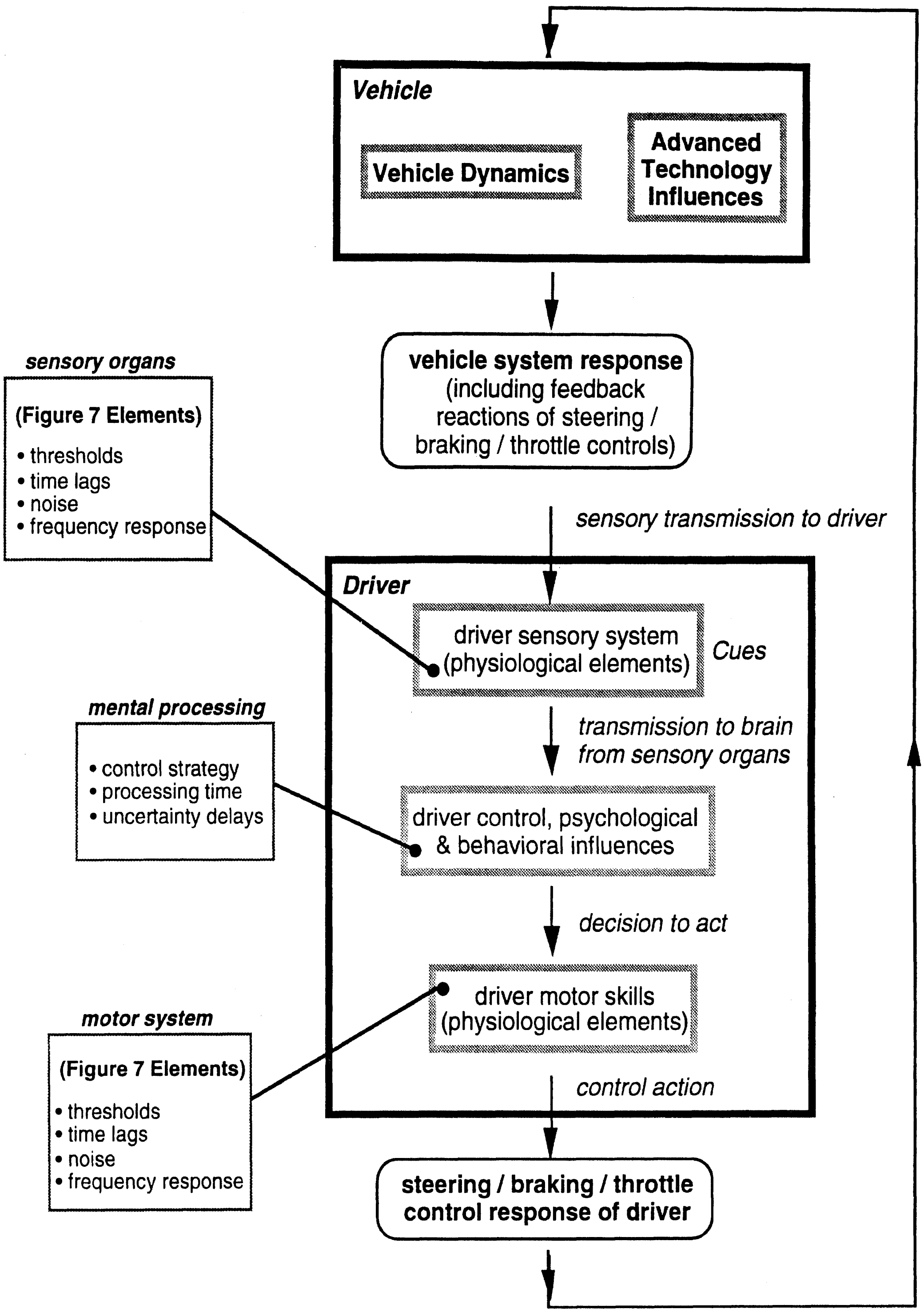
The last driver sub-block in Figure 11 is labeled "driver motor skills" and represents the physiological mechanisms used for physically implementing the driver control decisions as torques and forces applied to the vehicle (steering torque, pedal forces, etc.). Like the front-end sensory system, the motor skill sub-block could be represented by simple elements similar to those seen in Figure 12. However, instead of representing transmission time delays, frequency response limitations, and noise within the sensory system, they would apply to command signals sent to the muscles/tendons responsible for effecting control torques and forces. The transmission lags and frequency response characteristics indicated here would be associated with the muscle groups instead of the sensory organs.

Figure 11 could therefore be expanded somewhat into a form as seen in Figure 13 to more explicitly include such details. Here, the three sub-blocks are defined further and linked to specific elements, such as those described in Figure 12. Other such functions, limitations, or influences can be included as additional information about these blocks is identified. It would seem beneficial to keep diagrams like these initially at a high conceptual level until specific topic areas are identified. This will help to limit the clutter and detail that could easily develop if several types of technology-cue-driver questions were addressed within the context of a single diagram.

Figure 13 thus contains three fundamentally separate sub-blocks for representing the "sensing-processing-action" control behavior of drivers and their cue environment. Sub-blocks for the vehicle dynamics and advanced technology influences are also represented. As studies of specific vehicle technologies and associated driving cue influences are proposed for further examination, diagrams like Figure 13 can be used as a starting point.

One example might be a study examining the importance of steering torque feedback cues using a driving simulator or special test vehicle. (An associated question or topic area here might be *electric steering* systems and their required accuracy in reproducing "conventional/hydraulic" steering torques or feel normally expected by drivers.) A primary focus of such experiments could be on the *level* of feedback torque and its influence on driving performance, the "gain," "threshold," and "limiter" elements (described in Figure 12). The diagram of Figure 13 could therefore be used initially to help plan such experiments and to identify those elements likely to be of primary concern.

Figure 13. Driver / Vehicle / Cue Environment.



Diagrams like Figure 13 or similar ones can be used initially to think about and outline potential problem areas. Specific technology influences and their hypothesized impacts on driving cues and driving performance can then be further developed on a case-by-case basis. For example, possible study of ABS systems and their vibratory pedal feedbacks to drivers during emergency braking conditions might focus on questions of cue alterations and driver expectations of "normal" brake system behavior. A key concern here is that new or altered feedback cues are presumably present (in the form of unexpected brake pedal vibrations). Mental processing issues are also likely involved because of uncertainties about how drivers may react to and deal with such unexpected cues. In this case, mental processing of surprise or unexpected events and the adaptive abilities of drivers may play as large a role as the altered cues themselves (i.e., in addition to any direct physiological reaction that drivers may have to altered pedal vibrations). Issues like these can involve a strong interplay among the technology, the modified cues, and the mental processing abilities of drivers. Several of the elements appearing in Figure 13 help to at least conceptualize these types of interactions. Ultimately, test track or driving simulator measurements of different system responses, combined with appropriate analysis techniques, can be expected to answer many of the questions surrounding altered feedback cues and their net interactive effects upon driving performance and safety.

2.3 Basic Experiments for Future Cues Research

The following section proposes a set of potential follow-on experiments related to the topic of feedback cues and driving. (Several of these are downstream in time and broader in scope than the more immediate track test experiments being recommended in Section 3.) The proposed experiments lie in three basic research areas and are cross-matched with different experimental facilities expected to be available for conducting the proposed tests. Some of these facilities are expected to be available several years from now and are classified as "longer-term." Those facilities that are currently available, or will be very shortly, are classified here as "shorter-term."

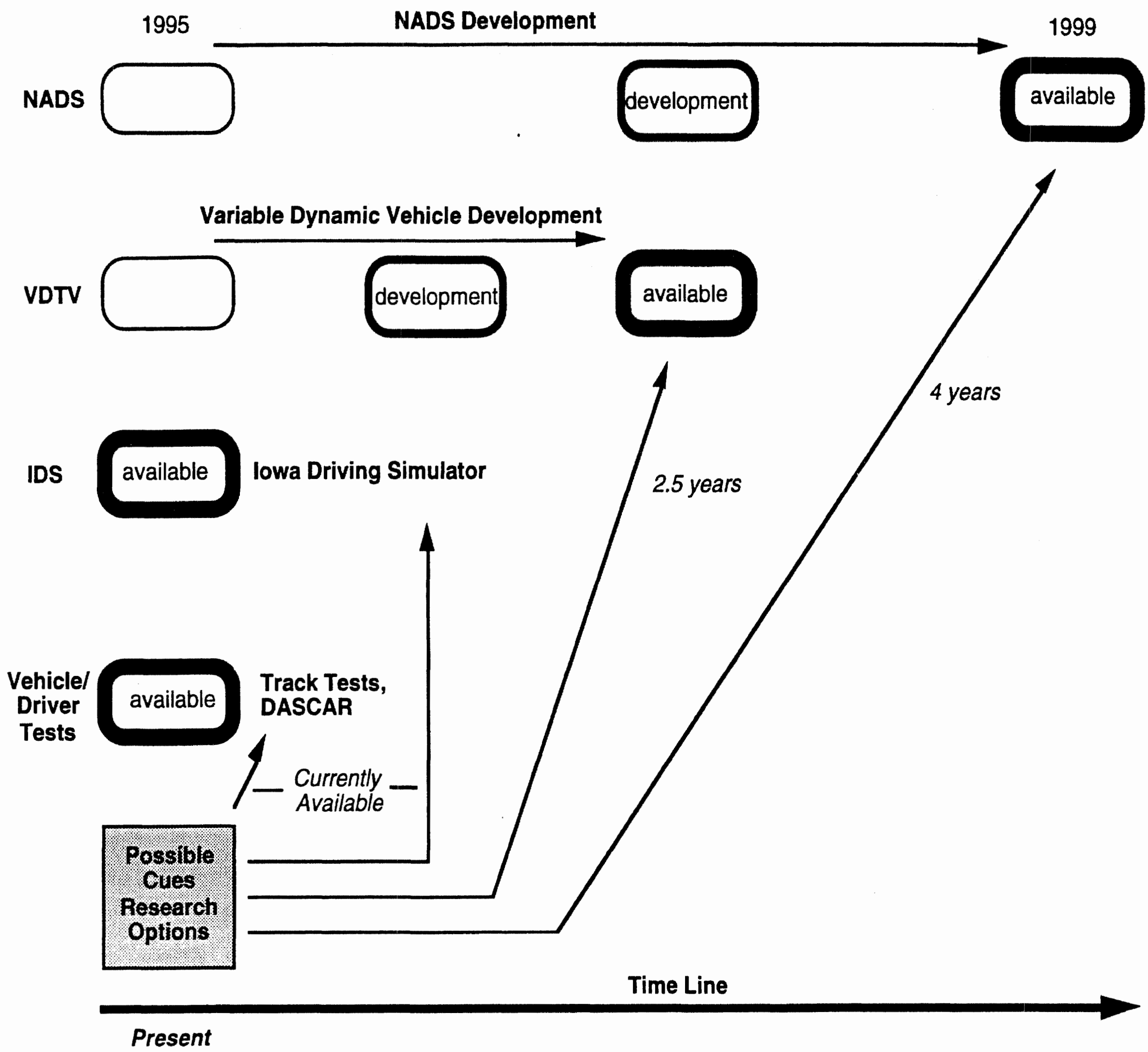
The three basic topic areas coincide more or less with those study areas identified in the current task order as worthy of more in-depth investigation. They are: (1) **diminished or altered feedback driving cues** associated with trends toward drive-by-wire vehicle systems, (2) **proactive or beneficial cue enhancement** ideas for helping drivers better anticipate impending conditions near operating limits, and (3) experiments aimed at **specific technologies**, such as ABS, active/adaptive suspensions, four-wheel steering, electric steering, and traction control. (Antilock brake cycling characteristics and adaptive suspensions/risk homeostasis were initially identified in the task order as two separate areas of study. They are treated here within the "specific technology category" as sub-topics.) Each of these three basic topic areas may contain several sub-topics and associated experimental tests.

Each of the proposed topic areas is then cross-matched with various test facilities that are currently available or are expected to become available over the next four to five years. The longer term test facilities include the national advanced driving simulator (NADS) and the variable dynamics test vehicle (VDTV). The shorter term facilities would include various test tracks (VRTC, Chrysler Proving Grounds, etc.) and driving simulators such as the Iowa Driving Simulator (IDS). The DASCAR equipment package, or a revised version of it based upon current VRTC evaluations, is also envisioned as a desirable option for many of the track testing experiments. (Even though the DASCAR package is envisioned in the long term for *in situ* studies where drivers are not aware of its immediate presence, it possesses data collection capabilities that can be readily employed for conventional track test experiments as well. The data collection protocols and measurements ultimately identified for DASCAR will also likely become standardized by NHTSA for helping to facilitate the exchange of data between different programs.)

Figures 14 and 15 attempt to summarize these proposed plans. Figure 14 shows a time-line of expected availability of the various experimental facilities being considered. Figure 15 then cross-matches the proposed topic areas with each of the facilities. Shaded areas identify perhaps the best match-ups between the proposed research topics and available facilities. For example, under the topic of **diminished or altered feedback driving cues,** the NADS is identified as the most logical facility for these tests since careful control over which (and how) feedback cue signals are being systematically altered is key to much of the success of those experiments. Repeatability and control over the experimental setting is also of importance here. The VDTV and the IDS are also seen as useful facilities in this same topic area, but for a reduced range of operating conditions.

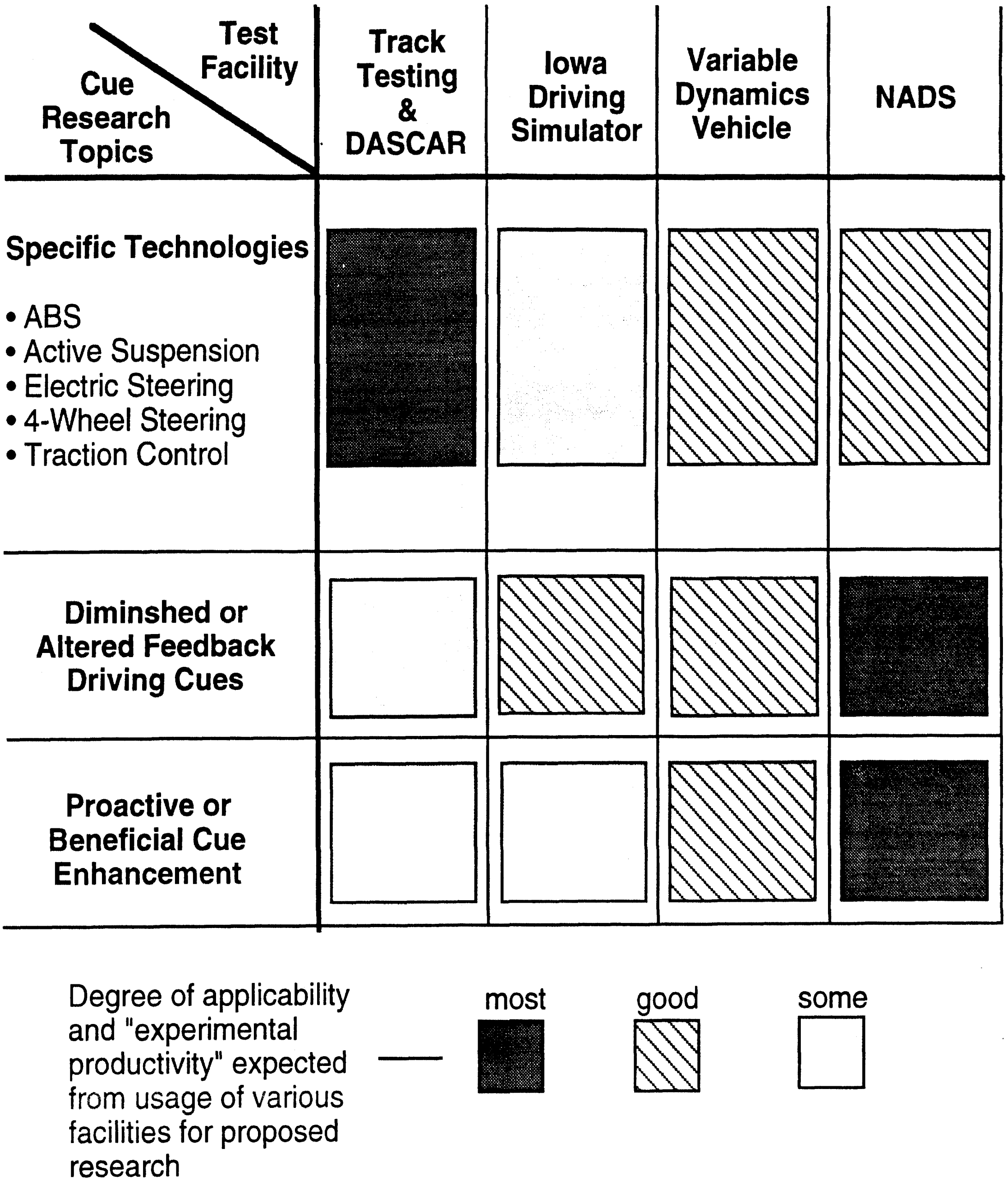
On the other hand, the topic area of **specific technologies** may be best served by experiments conducted on test tracks using current vehicles equipped with specific technologies. An example might be side-by-side comparison tests of an Infiniti Q45 equipped with its fully active suspension option versus the same vehicle absent the active suspension. Handling and braking tests with a small group of test drivers could be conducted with a minimal amount of set-up or vehicle preparation, aside from the normal instrumentation requirements. (Section 3 proposes such a set of tests using a Q45 for follow-on research at VRTC.)

Figure 14. Timeline of Availability for Various Test Facilities



It is currently understood that hardware-in-the-loop experiments involving NADS or IDS simulator facilities could be undertaken, but the level of effort to correctly integrate such equipment (ABS, active suspension, electric steering systems, etc.) may be a significant undertaking. If the level of required effort to implement such hardware-in-the-loop experiments diminishes in the future, such experiments would be attractive and could still be undertaken at that time. The primary advantage here again would lie in the degree of experimental control over operating conditions and repeatability. In the meantime, high fidelity track tests could still be conducted to sort out primary feedback cue interactions with drivers involving such technologies. A set of proposed experiments along these lines appears in Section 3.

Figure 15. Cross-Matching of Cues Research Topics with Available Test Facilities.



2.3.1 Proposed Research Topics

The research experiments proposed in this section are grouped according to the categories appearing in Figure 15. Within each category several proposed studies are presented. Each study is further delineated with respect to the type of facility that might be used to conduct the proposed experiments. For example, under the **Specific Technologies** category, several proposed studies appear, each associated with different technologies (e.g., active suspension, ABS, etc.). Each of these topics may also contain options for conducting the proposed research at different facilities — such as an option for 1) NADS experiments, 2) a version for tests at the IDS, or 3) a version applicable to a track testing scenario. Since the goal of a particular study is often the same, the intent of suggesting different options is to provide NHTSA with a certain flexibility time-wise and also to match up a particular facility's strengths with the basic concerns of a given research topic.

— Specific Technologies —

This group of recommended research studies focuses on evaluating specific examples of existing or anticipated automotive technologies that may be used in newer vehicle designs. The primary test facility envisioned for these experiments is track testing. The first two recommended studies appearing below (human factors tests with ABS and active suspension equipped vehicles) currently are seen as higher priority topics and are presented more fully in Section 3 as recommended follow-on research.

ABS / Brake Pedal Assessment — (see Section 3 for complete discussion)
Test track experiments using a group of current vehicles equipped with antilock braking systems and an identical group of vehicles having no antilock.

> Hypothesis: Brake pedal vibrations experienced by drivers of ABS-equipped vehicles during cycling operation may cause changes in driver braking behavior due to the unexpected or unusual nature of the pedal feedback. This could promote driver pedal modulation techniques, or foot removal altogether, that may result in degraded stopping performance.

Experiments: Conduct braking tests with a group of "off-the-street" drivers in each vehicle to evaluate differences in driver braking control behavior and associated braking performance for the two vehicle configurations.

VDTV / NADS Option: Conduct comparable tests but either include an ABS system as hardware-in-the-loop, or model and simulate the ABS system properties on the NADS or VDTV. Under this option, the same types of braking tests as proposed for the track tests would be performed.

IDS Option: Same as VDTV / NADS option, but braking maneuvers should be restricted to applicable operating regime of the IDS such as for wet surface or low-mu conditions.

Active Suspension Study — (see Section 3 for complete discussion)

Test track experiments using a standard Infiniti Q45 equipped with its fully active suspension and its identical non-active suspension counterpart.

> Hypothesis: Active suspension systems that minimize roll, pitch, and bounce motions of vehicles may cause drivers to alter their control behavior due to reduced feedback information about the response of the vehicle. This may lead to degraded driver control and driving performance and/or altered expectations of vehicle capabilities.

Experiments: Conduct handling and braking tests with a select group of test drivers in each vehicle to evaluate differences in driving performance resulting from the presence of the fully active suspension system.

VDTV / NADS Option: Conduct comparable tests but include either an active suspension system as hardware-in-the-loop, or model and simulate the active suspension system properties on the NADS or VDTV. Under this option, the same types of handling and braking tests can be performed. Emergency-level maneuvers can also be more safely managed under the NADS option.

IDS Option: Same as VDTV / NADS option, but maneuvers should be restricted to applicable operating regime of the IDS. This would include primarily straight-line driving scenarios with some mild turning maneuvers.

Electric Steering System Study

Side-by-side track tests of one or more vehicles equipped with electric steering systems and their otherwise identical counterparts.

> Hypothesis: Steering feel modifications resulting from the introduction of electric steering systems (that may not closely replicate the feel of traditional hydraulic/mechanical steering systems) can cause drivers to alter their steering behavior so as to produce a deterioration in driving performance.

Experiments: Conduct handling tests with two sets of vehicles (equipped with electric and traditional hydraulic/mechanical arrangements) to evaluate differences in driver steering responses and associated vehicle performance. Tests would include on-center straight-line driving scenarios, as well as double lane change or comparable steering maneuvers that fully exercise the electric steering system properties and driver steering control abilities. Of special interest in these tests would be the measurement of driver steering wheel displacement and torque, as well as front-wheel steering displacements or equivalent steering rack motions. In addition, the full complement of vehicle responses would likewise be measured. The recorded data would then be processed and analyzed similarly to that proposed in the active suspension study (above). It is also recommended to include, within the scope of this analysis, a comprehensive model of the principal steering system elements (electric and hydro-mechanical) that provides for steering feel cues to the driver. The steering control model can then be used to compare driver loop closure parameters identified from the electric steering system measurements to those driver loop closure parameters exhibited by comparable data collected with conventional hydraulic/mechanical steering systems.

VDTV / NADS Option: Conduct equivalent tests but either include the electric steering system as hardware-in-the-loop, or accurately model and simulate the electric steering system properties on the NADS or VDTV.

IDS Option: Same as VDTV / NADS option, but restrict maneuvers to applicable operating regime of the IDS.

Four-wheel steering Study

Track tests using a four-wheel steered vehicle and an identical conventional front-steered counterpart.

> Hypothesis: The use of four-wheel steering systems in vehicles requires drivers to modify their steering behavior to varying degree, depending upon the level of "aggressivity" or peculiarities of the rear wheel steering strategy implemented in the particular system. The accompanying alteration of driver steering behavior in some cases may result in degradations of closed-loop steering performance

Experiments: Conduct handling tests for vehicles with and without four-wheel steering using a group of test drivers to assess differences in handling performance. Lane-change or obstacle avoidance maneuvers on both high friction and low friction surfaces should be conducted to distinguish handling performance differences between the two vehicle configurations. Data collection and analyses similar to those proposed in the active suspension study should be followed. (Based upon recent expectations of a declining market for this particular technology [Cole 1994], this topic area may be considered as having a lower research priority than some of the other technologies.)

VDTV / NADS Option: Conduct comparable tests by accurately modelling and simulating various four-wheel steering systems on the NADS or VDTV. As an alternate option, implement the four-wheel steering system hardware on the VDTV.

IDS Option: Same as VDTV / NADS option, but restrict steering maneuvers to the applicable operating regime of the IDS.

Traction Control Study

Track tests using vehicles equipped with traction control systems.

> Hypothesis: Traction control systems that offer improved control of individual wheel slip may also exhibit control system noises or vibrations that in some cases cause drivers to modify their conventional control behavior thereby leading to degradations in acceleration / handling performance.

Experiments: Conduct acceleration tests with a group of lay drivers to evaluate differences in driver acceleration control behavior and any associated acceleration / handling performance for two sets of identical vehicles equipped with and without traction control systems. Proposed tests would include acceleration along curves (similar to a curved freeway on-ramp scenario) under moderate and low friction conditions. Tests would start at low speed and terminate at highway speed conditions. Of particular interest is the initial response of drivers to noise and vibration characteristics of the traction control-equipped vehicles and the manner in which driver acceleration control behavior is possibly altered from conventional practice (in same vehicle / conditions without traction control). The emphasis here, as in the ABS study, is on human factors issues surrounding control behavior of drivers as opposed to characterization of the vehicle acceleration characteristics. However, as in the ABS study, measurements of vehicle acceleration, traction control system noises / vibrations, and driver throttle behavior will be needed to assess differences. Longitudinal acceleration, pitch, and bounce motions would also constitute principal feedback cues that the driver experiences in such tests and should be targeted as examples of primary vehicle response measurements. Directional control of the vehicle and driver steering requirements, due to the enhanced potential for wheel spin under low-mu acceleration tests, will also be of interest.

VDTV / NADS Option: Conduct comparable tests, but either include traction control system as hardware-in-the-loop, or model and simulate the traction control system properties on the NADS or VDTV. Under this option, the same types of acceleration tests as proposed for the track test scenario would be performed.

IDS Option: Same as VDTV / NADS option with maneuvers restricted to the applicable operating regime of the IDS (wet surface or low-mu conditions).

— Diminished or Altered Feedback Driving Cues —

Many of the **specific technologies** studies proposed in the previous section also fall into and overlap this category of **diminished or altered feedback cues**. Consequently, many of those studies may also be included here, but with the use of NADS or the VDTV as the primary test facility. The following topic under this category is suggested as an example of a more comprehensive study of diminished/altered feedback cues that makes use of the particular advantages in experimental control that a NADS or a VDTV offers. It is similar in nature to the test track option (described subsequently) but also includes a matrix of special tests that can be performed only with a high fidelity simulator such as NADS or a fully programmable test vehicle like the proposed VDTV.

Identification and Ranking of Driving Cues from NADS or VDTV Experiments

Use of NADS and/or VDTV to measure, identify, and rank dominant driver feedback cues.

Hypothesis: Identification and ranking of primary feedback cues used by drivers should be measurable from driver-vehicle data collected in the controlled and repeatable test conditions of a NADS facility. A programmable test vehicle (VDTV) that provides many of the same test condition attributes as a driving simulator can also be used to conduct similar experiments on the road.

Experiments: Conduct handling and braking tests on NADS and/or the VDTV for a wide range of vehicle configurations and a single group of test drivers. The vehicle characteristics should be selected to provide distinctly different sets of vehicle dynamic properties and performance capabilities for each of the vehicle configurations. The different vehicle configurations should require drivers to exhibit noticeably different control strategies and behavior, thereby exercising a broad array of feedback cue paths for control purposes.

Further, special tests should be performed with one or more baseline vehicle configurations programmed to remove individual feedback cue paths in repeated experiments. These special experiments (available only with a driving simulator and to a somewhat lesser extent with the variable performance vehicle) may be used to selectively remove one or more feedback cues at a time. The associated test matrix and corresponding test results may then be used to help identify and rank, in a more experimentally direct manner, those specific feedback cues of primary importance in driving tasks. Examples include repeated maneuvers with and without heading angle feedback displayed to the driver and repeated maneuvers with and without roll angle feedback cues presented to the driver. Differences in observed driving performance can then be catalogued and used to identify driver loop closure sensitivities to inclusion/removal of individual feedback cues.

A full complement of vehicle and driver response measurements should be collected for several different driving scenarios and subsequent analyses. Double lane change and closed-loop braking-in-a-turn maneuvers can serve as the primary test procedures. The data analysis should utilize a comprehensive model of the driver/vehicle system to match and correlate with the observed measurements. Based upon the matchings of a comprehensive driver/vehicle model to the experimental measurements, analyses can be performed to rank all identified feedback cues. Comparable but separate analyses using neural network or equivalent methods should also be applied to provide a secondary analysis path and confirmation of findings. Lessons learned from any prior test track experiments (see previous section) and associated data analyses should be applied here in the same manner to maintain consistency, carryover of results, and to provide comparisons of results with comparable on-road experiments.

IDS Option: Same as VDTV / NADS option with maneuvers restricted to the applicable operating regime of the IDS (wet surface or low-mu conditions).

Test Track Option:

Use of test track data to measure, identify, and rank dominant driver feedback cues (in lieu of a driving simulator or variable response test vehicle). Also similar in part to some of the active suspension track tests recommended in Section 3.

> Hypothesis: Identification and ranking of primary feedback cues used by drivers should be measurable from driver-vehicle test data, provided that accurate and sufficient measurements are collected under controlled and repeatable test conditions. While some test track conditions often challenge the latter assumption, careful control and attention paid to the issue of test

track / experimental conditions can produce useful data for cue identification purposes.

Experiments: Conduct handling and braking tests with two vehicles and a single group of test drivers. The two vehicles should be selected to provide distinctly different sets of vehicle dynamic properties and performance capabilities. A full complement of vehicle and driver response measurements (measured with DASCAR or equivalent) should be collected in several different driving scenarios for subsequent analysis. Double lane change and closed-loop braking-in-a-turn maneuvers can be used as the primary test procedures. Maneuvers should be conducted at both low and intermediate g-levels of lateral and longitudinal accelerations to provide test data over a broad range of operating conditions. The data analysis should utilize a comprehensive model of the driver/vehicle system to match and correlate with the observed measurements. Based upon the matchings of the driver/vehicle model to the experimental measurements, conduct analyses to rank all identified feedback cues used for driver control. Separate analyses using neural network methods or equivalent techniques should also be applied to provide a comparable analysis path and secondary confirmation of findings. (While such types of experiments are more ideally conducted within the controlled environment of a driving simulator, the driver-vehicle test data obtained with on-road vehicles will be highly instructive for developing / refining analysis methods and for guiding any subsequent simulator experiments.)

— Proactive or Beneficial Cue Enhancement —

Evaluation of Pitch and Roll Control as Cue Enhancements for Drivers in Near Limit Operating Conditions

Use of NADS to evaluate attitude control system schemes for providing enhanced roll and pitch cues to drivers during near limit emergency maneuvering conditions.

Hypothesis: Driver detection and warning of limit operating conditions may be enhanced or quickened in time through use of additional motion cues applied to the vehicle artificially when approaching near-limit operating conditions.

Experiments: Conduct special near-limit handling and braking tests using NADS and a group of test subjects. Several surprise accident avoidance scenarios should be used to evaluate the performance of drivers in reacting to and contending with each accident avoidance scenario. A test matrix of conventional vehicle configurations without pitch and roll control cue enhancements should be matched against the same vehicle configurations that include some form(s) of roll and pitch enhancement. The roll and pitch enhancement system (activated gradually when approaching near-limit operating conditions) should provide exaggerated (or amplified) roll and pitch motions to the driver in order to trigger a quickened driver response to the impending near-limit operating conditions. Drivers should be exposed to each accident scenario and vehicle configuration in a random sequence designed to minimize learned responses by drivers to the surprise accident scenarios. Sufficient numbers of drivers and tests should be conducted to permit statistically meaningful conclusions to be drawn from the results. An included task to design a "statistically relevant" test matrix should precede the test program.

VDTV Option: Conduct a set of similar experiments with the VDTV, but using accident avoidance maneuvers requiring lower levels of acceleration to provide safe operating conditions for the test drivers. Example tests could include: 1) slalom course maneuvers requiring some arbitrary obstacle avoidance, and 2) braking-in-a-turn maneuvers with driver-controlled, in-lane stops. Both maneuvers should require acceleration maneuvering levels of 0.4 - 0.6 g's to engage nonlinear vehicle properties and operating conditions while still maintaining a safe operating acceleration level for the VDTV. The VDTV would be programmed to represent identical vehicle configurations except for the pitch and roll control cue enhancements in each series of tests. Again, sufficient numbers of drivers and tests should be conducted to permit statistically meaningful conclusions to be drawn from the results. Because of the lower g-levels experienced in the VDTV test, the pitch/roll control system characteristics would also be expected to transition into operation at lower g-levels than those used in the NADS tests.

Haptic Steering Wheel Study

Use of an active steering wheel device to provide supplementary steering torque feedback cues to drivers.

> Hypothesis: Supplementary feedback information delivered through fast-transmitting channels, such as the tactile and kinesthetic senses (haptic) of a steering wheel, may assist drivers in path control and improve driving performance.

Experiments: Implement an active steering wheel device similar to that previously proposed by Schumann[3] and conduct experiments in driving simulators and on the test track to evaluate its potential effectiveness in improving driving performance. Application to the roadway departure accident scenario and/or a "lane-keeping assistant" concept would be likely targets of its use. Preview sensors, such as a forward-looking CCD camera, would be used in such applications to provide roadway location information to the system. Based upon calculated differences between projected vehicle path trajectories and the camera-sensed roadway information, steering torque assists would be provided by the proposed system to the driver.

The focus of this proposed research is to investigate whether or not supplementary feedback cues acting through faster sensory transmission channels, such as the tactile and kinesthetic senses, provide opportunities for improving driver control. The purpose is not necessarily to develop a new technology. If an existing hardware system already exists and is appropriate for use in the proposed study it could be acquired for this proposed work.

In lieu of an existing hardware package, desktop simulators and the IDS may initially be used to test out and develop the required hardware and basic concept. Commonly available steering torque motors can be used for the initial desktop or driving simulator experiments to generate the required steering torque cues. (The CCD camera roadway preview function would be simulated in any initial simulator trials.) If initial results show promise, further development and full-scale testing could be conducted on test tracks, the VDTV, or NADS.

Initial tests could include lane regulation and winding road scenarios to evaluate the haptic steering wheel concept as an effective cueing mechanism for prompting drivers into corrective control responses. At low levels of torque prompting, the system could act as a low-level, lane-keeping assistant to drivers, cueing them into corrective steering responses for lateral path control. Depending upon the torque output capacity available, the initial concept could later be extended into warning and control applications for roadway departure scenarios (e.g., drowsy or impaired drivers).

Auditory Feedback Cue Study

Use of auditory signals to provide supplementary feedback cues to drivers for vehicle

[3] Schumann, J., "The Active Steering Wheel as an Active Display to Support the Driver's Lateral Control Task," *Accident Analysis and Prevention*, 1994.

control applications.

Hypothesis: Supplementary feedback information delivered through the auditory channel may assist drivers in path control and improve driving performance if properly designed.

Experiments: Implement an auditory device to provide feedback cues to drivers for improving closed-loop path control. Steering control applications similar to those proposed for the haptic steering wheel could serve as an initial example. In place of the steering torque device, however, substitute an auditory signal that prompts drivers to provide corrective steering control during path regulation driving tasks.

As above, the focus of this proposed research is to investigate the use of supplementary feedback cues acting through alternate sensory transmission channels, such as hearing, to provide improved driver control. Desktop simulators and the IDS could be used to develop initial designs and perform preliminary tests. Depending on initial results, further calibration, development, and full-scale testing could be conducted on test tracks, the VDTV, and NADS with more complete auditory feedback hardware packages. Like the haptic steering wheel concept, a CCD camera or equivalent preview sensor would be required as part of the final hardware implementation to provide information on roadway location to the system. (The CCD camera roadway preview function would be simulated in any initial simulator trials.)

Driving tests similar to those proposed for the haptic steering wheel study are also proposed here and would include lane regulation and winding road scenarios. Results of these initial tests would be used to judge the effectiveness of supplementary auditory cues as useful mechanisms for prompting drivers into corrective control responses.

2.4 Recommended Driver/Vehicle Measurements for Cue-Related Follow-on Research Studies

The following list of recommended measurements covers: 1) vehicle responses, 2) steering/braking/throttle control feel, and 3) auditory/sound signals. This list is intended to provide a good starting point for research studies aimed at evaluating driver-vehicle systems and associated feedback cue influences.

Many of these measurements are also likely to be common to the DASCAR instrumentation package being developed and reviewed presently by NHTSA. Accordingly, the DASCAR specifications should be reviewed to maintain a consistency (and future ease of interchange) for these recommended measurements with the data formats specified for DASCAR. Likewise, the data processing program Test PAES (Test Planning and Evaluation System), originally designed for aircraft cockpit analyses of aircrews, is also under further development and adaptation to ground vehicle analyses. It should also be reviewed, particularly since it is currently the primary tool for performing post-processing analysis of data collected with the DASCAR system. Test PAES also integrates video tracks into its time history playback capabilities, thereby facilitating the on-board video camera recordings currently present in the DASCAR system. If Test PAES was not available for such test programs, a comparable video and data fusion capability could be developed for existing data processing systems that do not currently handle video tracks. While video information is not imperative to meet many of the goals of the cues experiments, its availability would likely assist in interpreting any unusual vehicle or driver control responses observed in various data samples. It could also be useful subsequently as another source of time history data for lane position and heading angle measurements if video processing algorithms were developed to extract such information from individual frame scenes.

— Vehicle Response Measurements —

Positional Cues

- lateral, longitudinal, and vertical vehicle displacements
- yaw angle (absolute or road-relative), roll angle, sideslip, and pitch angles

Velocity-Related

- lateral, longitudinal, and vertical vehicle velocities
- yaw rate, roll rate, sideslip rate, pitch rates

Acceleration-Based

- lateral, longitudinal, and vertical vehicle acceleration response characteristics
- yaw, roll and pitch accelerations
- head / seat acceleration experiences
- seat belt "harnessing" reactions during braking or cornering
- ride harshness (high frequency characteristics)

— Control Feel Measurements —

- steering wheel torque / force characteristics
- brake pedal forces
- throttle application forces

- vibratory sensations associated with steering/brake/throttle controls
- steering wheel, brake pedal, and throttle displacement and gain characteristics
- frictional and hysteretic properties of the steering, braking, and throttle controls
- time delays in control actuations

— Sound / Auditory Measurements —

- tire squeal; brake squeal; wind noises
- engine noises during steady and transient conditions
- relay and control system noises

Supplementary (optional) information regarding open-loop vehicle properties

The following types of vehicle-alone properties may also be useful in some cases to further document and describe the test vehicle for which the above closed-loop feedback cue measurements are collected:

- steering control sensitivities (inverses of the steady-state steering angle gains plus the steering torque at various levels of lateral acceleration); steady-state steering angle gains (yaw rate, path curvature, side slip angle, and lateral acceleration gains as functions of forward speed and lateral acceleration)
- responses to a ramp-step of steering wheel angle (time histories of yaw rate and lateral acceleration and steering wheel torque); responses to a ramp step of steering wheel torque (time histories of yaw rate, lateral acceleration, and steering wheel and front wheel angle)
- the frequency response of yaw rate and sideslip angle and steering torque to steering wheel oscillations
- steady-state and ramp-step roll response to steering; roll rate or roll angle frequency response to steering wheel oscillations
- fixed control response to a wind gust (sideslip angle, raw rate, lateral acceleration, and steering torque)
- vehicle understeer gradient
- pedal force and displacement gain of the braking system
- braking efficiency on high, low, and medium friction surfaces
- coastdown time history for no brake or accelerator pedal displacement
- vehicle dive during braking; vehicle squat during acceleration
- pedal force and displacement as a function of steady-state velocity

2.5 Recommended Data Processing and Evaluation Methods for Use in Cue-Related Research Studies

The following set of driving performance measures identifies data processing schemes that can be used to evaluate and characterize driving performance. These types of driving performance measures can be used to help evaluate the importance of different feedback cues examined in the various driver/vehicle experiments proposed here. For example, driver/vehicle test data collected from an active suspension-equipped vehicle that consistently shows larger RMS measures of lateral path deviation compared to its non-active suspension counterpart, would be seen as contributing to a reduced level of driving performance (using this example measure alone). Ordinarily, a variety of such measures would be used in combination to draw conclusions about the likely impact of a particular technology on driving performance. In addition, trade-offs in driving performance may also be identified when conflicting indications of driving performance from different measures are observed.

— Data Processing and Evaluation Methods —

- RMS measures of driver/vehicle responses including lateral path deviation, yaw rate, lateral accelerations, and relative heading angle/roadway deviations — primarily relevant to handling maneuvers. (Appendix R contains a driving simulator example and associated recordings of various driver/vehicle response measurements. RMS calculations of path deviation and yaw angle deviation along the example winding road course are also shown in Appendix R to illustrate the nature of these driving performance measures.)
- RMS and DC measures of driver control efforts during various types of handling and braking maneuvers. Similar to above but focused on driver control behavior.
- Stopping distance, lane deviation, average longitudinal acceleration, heading angle deviation, and characterizations of driver brake pedal activity (RMS and DC descriptions of pedal force / displacement) — primarily relevant to "best effort" or emergency condition braking maneuvers (with or without ABS).
- Characterizations of driver/vehicle system latency and crossover frequency during path regulation driving tasks. Applicable primarily to low-level, non-emergency driving maneuvers.
- Subjective ratings and preferences of drivers exposed to alternate vehicle configurations or technologies. A cataloging of driver likes/dislikes associated with a particular

driving configuration or experience and subsequent statistical analysis and interpretation of these preferences.

- Model-matching of experimental measurements using comprehensive models of driver-vehicle systems to identify relative strengths of feedback cue paths used by drivers. Different driver/vehicle closed-loop system properties can be described and documented by the various driver and vehicle parameters identified from such model-matching analyses.

  For example, time history recordings for a particular group of test drivers may exhibit average closed-loop system responses that are notably different for two vehicles that are identical — except for the presence/absence of an active suspension system. Model matching analyses that identify such differences in various driver or vehicle parameters present in a comprehensive driver/vehicle model may then provide explanations of the observed effects of including/excluding the active suspension. If, for example, the primary net effect of the active suspension is to increase the average amount of driver time delay normally observed in the same vehicle tests without an active suspension, driving performance would be adversely affected. These adverse effects should also be observed in traditional RMS measures of test results (increased path deviations, yaw angles, etc.). However, the advantage of using a model-matching approach is that explanations for the observed deterioration in driving performance may also be identified and traced to physical phenomena. The price to be paid is the added complexity of having to exercise a complex model and conduct iterative model-matching calculations to fit the measured data.

- Neural network processing of driver/vehicle experimental measurements to identify and rank relative strengths of feedback cue paths used by drivers in vehicle control tasks. (The MacAdam & Johnson reference, cited in footnote 5 and Appendix A, provides several examples of these types of calculations.)

  Profiles of different driver control behavior can be described and cataloged in terms of the different network weights identified from such neural net analyses. The resulting weight profiles can then be linked to particular characteristics or other performance criteria observed in the test results. A collection of such weight profiles might then be used to document average driver control dependencies upon various feedback signals present in the driver/vehicle closed-loop system test data. Consistent strengthening or weakening of specific feedback weights associated with particular feedback signals, and the presence or absence of a specific technology, would suggest a direct influence by that particular technology (or vehicle modification) on driver control behavior. This type of procedure could then lead to a physical understanding about how specific technologies/design changes can affect specific feedback cue paths used by drivers. Observed changes in driving performance attributable to the presence of certain advanced technologies could then also be directly explained in terms of their modification or restructuring of feedback cues utilized by drivers. Again, like the previous model-matching option, the advantage in using such an approach is that a physical explanation and understanding of the effects of a particular technology is a product of the analysis. That is, we would know not only that a particular technology was or was not associated with a degradation in driving performance, but also know or have good reason to infer how.

3.0 Follow-On Track Testing Recommendations

Two specific test track studies are recommended in this section based upon recent discussions and related work at NHTSA. The first study, "ABS / Brake Pedal Assessment," is designed to examine initial driver control reactions to ABS cycling characteristics under different braking scenarios. Various anecdotal information (and some recent patent-related information) identifies brake pedal feedback vibrations / sounds as bothersome to drivers when such systems are first encountered in certain braking situations. Some of these first encounters may be under slippery conditions in which the ABS is inadvertently triggered by a low friction condition; other encounters may be under more emergency-like maneuvers on high friction surfaces. In either case, the safety concern is that drivers may be surprised by the tactile and kinesthetic feedback vibrations at the foot pedal (as well as possible sound characteristics emitted by the system) and thereby attempt to modulate or "pump" the brake pedal, or remove their foot intermittently during the braking maneuver. The consequences of either of these brake pedal activities may interfere with the normal or optimal operation of the ABS system and could result in degraded braking performance and increased stopping distances. The track tests proposed here are intended to investigate these types of possible driver control behavior patterns using a large group of lay drivers. It is also noted that NHTSA is currently testing seven different ABS systems at VRTC to evaluate their effectiveness under a wide variety of operating conditions. A subset of these seven ABS systems and vehicles would be selected for the proposed tests with the lay drivers.

The second recommended track test study is intended to examine potential influences by an active suspension system on driver control behavior. Currently, only one vehicle (the Infiniti Q45) is commonly marketed with an active suspension option, and so that vehicle and its non-active suspension counterpart are being proposed for a modest series of side-by-side tests with a group of several test drivers. Since this vehicle constitutes a real and representative example of current active suspension technology, it becomes an ideal test bed in which to measure actual driver control responses. Side-by-side testing (with and without the active suspension) can be readily performed to directly assess the influence of the active suspension operation on driver behavior. The initial tests propose using a group of several VRTC test drivers to: 1) examine whether or not there is any evidence to suggest that significant control behavior differences are indeed present, and 2) to develop data processing methods and analyses for extracting useful information regarding feedback cue mechanisms from such test data. A variety of high quality test measurements would be obtained from the proposed tests and those data would support the development of analytical methods focused on feedback cue mechanisms. This also provides a clear opportunity to directly confront, by experimental means, various issues at the center of this cues-related task order. If the data processed for this group of drivers indicate noteworthy differences in driver control response behavior between the two vehicle configurations, a subsequent and more ambitious follow-on study could employ a large group of lay drivers in similar tests to validate and extend these results for the more general driving population. In either event, the data obtained from these initial tests would provide a unique experimental resource with which to further inquire and help explain the nature of feedback cue mechanisms and associated driver control responses.

ABS / Brake Pedal Assessment Study

Test track experiments using a group of current vehicles equipped with antilock braking systems and an identical group of vehicles having no antilock.

> Hypothesis: Brake pedal vibrations experienced by drivers of ABS-equipped vehicles during cycling operation may cause changes in driver braking behavior due to the unexpected or unusual nature of the pedal feedback. This could promote driver pedal modulation techniques, or foot removal altogether, that may result in degraded stopping performance.

Experiments: Conduct braking tests at VRTC with a group of lay drivers in each vehicle to evaluate differences in driver braking control behavior and associated braking performance for the two vehicle configurations. Driver-controlled "best effort" or fixed distance braking maneuvers on moderate and low friction surfaces along curves (braking-in-a-turn) and during lane-changes are recommended. The required stopping distance(s) for fixed distance stops can be set by experimenters to guarantee ABS cycling through most of the stopping maneuver. Of particular interest are the initial responses of drivers to cycling characteristics of the antilock-equipped vehicles and the manner in which their braking behavior is altered. The degree to which drivers are able to adapt to antilock cycling in subsequent tests/exposures is also of interest. The emphasis here is on human factors issues surrounding control behavior of drivers as opposed to characterization of the vehicle braking characteristics per se. Measurements of the vehicle braking characteristics and brake pedal vibrations will be required in order to help assess the degree of exposure to brake pedal forces that each driver experiences in such tests. (Much of this information will be obtained from current ABS test being conducted at VRTC.) In addition, longitudinal accelerations, pitch, and bounce motions would also constitute principal feedback cues that the driver experiences in such tests and should be targeted as examples of primary vehicle response measurements. Other measurements should include interior sound recordings with a microphone (or two) located in the vicinity of the driver's head-rest. ABS system cycling behavior often results in noise levels / characteristics that are reported as being unusual or unexpected to many drivers when first encountering their operation. Accelerometers (longitudinal and lateral) also mounted in the head-rest can provide additional head-related experiences of the test subjects that may be useful in helping to sort out additional pitch and roll motion influences that are normally diminished by more conventionally mounted accelerometers located near the vehicle mass center. Stopping distance, lane position, and orientation of the vehicle within the lane would be used as primary measures of braking performance.

At present, it appears that the DASCAR instrumentation system and a version of the Test PAES post-processing program currently being tailored to ground vehicles could be used to collect and analyze much of these data.

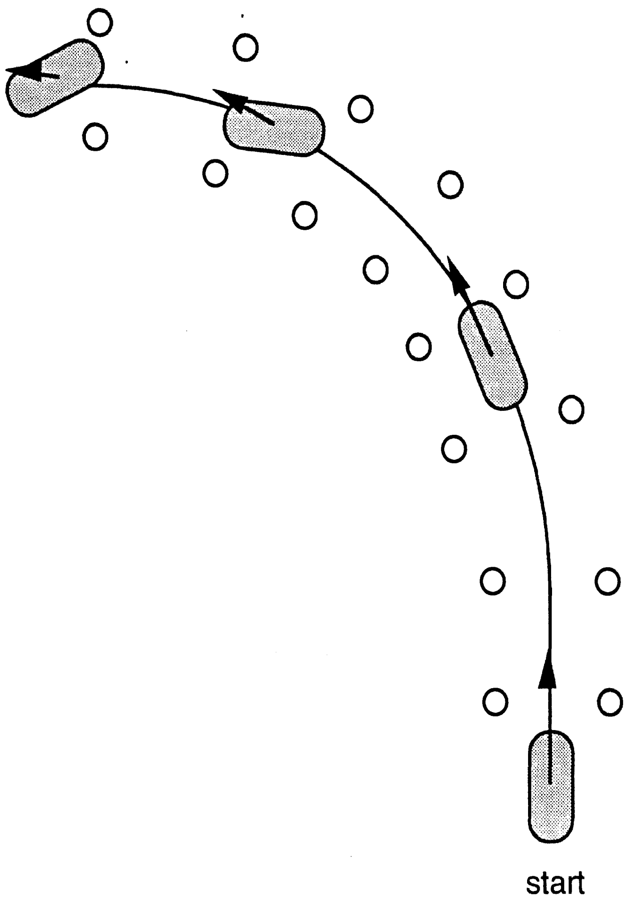
ABS Systems and Test Vehicles:

Of the seven ABS systems currently being evaluated by NHTSA at VRTC, a subset of three ABS systems would be selected based on the outcome of the current VRTC test results. One system having the most vibratory pedal feedback sensation, one system having the least vibratory feedback sensation, and another more "average-like" system (or perhaps the second-most vibratory system) would be selected for testing with the lay drivers. The vehicles currently being tested at VRTC, or duplicates, would be used in the proposed driver-related tests. The same vehicles without ABS systems installed (or equivalently disabled) would constitute the non-ABS vehicle set.

Test Maneuvers:

Two basic test maneuvers are recommended for the ABS driver tests: 1) braking-in-a-turn, and 2) braking during a lane-change. Both tests would require more demanding braking and steering interactions than simpler straight-line braking maneuvers, while also exercising side-to-side load transfer effects that are often more challenging to ABS systems and drivers. Drivers would be asked to perform best effort braking maneuvers. The goal would be to stop the test vehicle in the shortest distance possible while also maintaining directional control of the vehicle and keeping it within the prescribed confines of the coned course. Fixed stopping markers could also be implemented by test personnel, if required, to motivate drivers into exercising sufficient braking effort required to trigger ABS cycling. See Figures 16 and 17.

Figure 16. Braking-in-a-turn Maneuver Along Coned Circular Course.



Both tests would be conducted on a high or moderate friction surface (dry / wet asphalt) and also on a low friction surface such as wet jennite. Initial speeds on the higher friction surface could be 60 mph. Speeds on the low friction surface would be 30-40 mph depending upon the friction levels and turn radii available. Ten repeats of each test condition would be conducted. The ABS test sequences would begin with the non-ABS vehicle. Ten runs would be conducted with that vehicle and then the non-ABS vehicle would be introduced. (The testing sequence could also select each vehicle configuration — with / without ABS — on a random basis. However, arguments about driver adaptation to a "new" vehicle experience becomes clouded because of the back and forth exposure between the non-ABS vehicle and the ABS vehicle. The real world experience in which a driver purchases a new vehicle equipped with an ABS system and then experiences the

ABS operation only with that same vehicle is probably closer to the test sequence scenario being proposed. Questions about whether or not a particular driver should be used to test more than one ABS configuration also arises because of carry-over effects from prior ABS system experiences to the next system tested. A mixed group of drivers might be used to help address this: half would drive only one ABS configuration; the other half would experience all three systems.)

One or two initial practice runs by the test subjects (or perhaps demonstration runs by VRTC personnel) with a non-ABS vehicle would be used to convey the nature of each test procedure to the lay drivers prior to the start of their test runs. Initial speeds and turn radii for the braking-in-a-turn tests would be selected to require approximately 75 percent of the available friction for the initial lateral turning requirement.

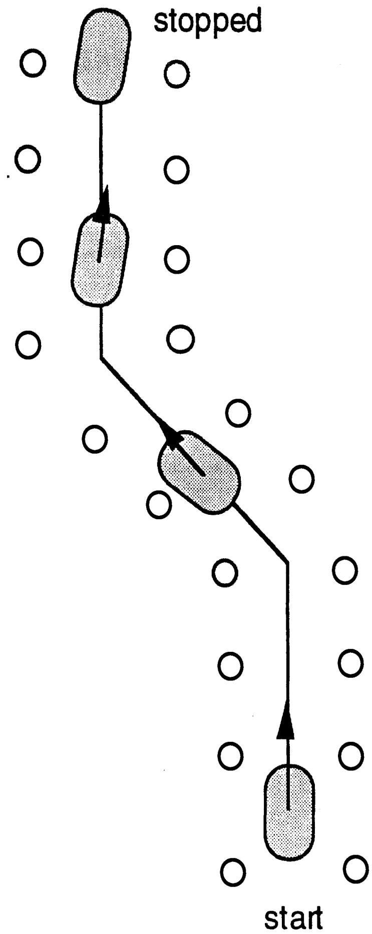
> For example, on a surface with a nominal 0.5 friction coefficient, V^2 / R = 75% x 0.5 g's x 32.2 ft/sec/sec/g = 0.375 x 32.2, where V is the initial vehicle speed and R is the turn radius. If V = 40 mph, R = 285 feet.

Likewise for the braking during a lane-change maneuver, the initial speed could be selected based upon constant-speed test runs through the lane change course that produce peak lateral acceleration levels that are 75 percent of the available friction for that surface.

> As an illustration, for a test surface with a nominal friction level of 0.5, test runs at different constant speeds would be conducted. That speed at which the peak lateral accelerations levels were equal to 75% x 0.5 = 0.375 g's would then be selected as the initial speed for the braking during lane-change maneuvers.

The intent here in both cases is to exercise a good portion of the adhesion capabilities of the vehicle, yet provide some margin of error for recovery given the likely skill levels of most lay drivers. The maneuvers should be closer to "challenging," than to "impossible" for the vast majority of the test subjects. Also, most lay drivers, as noted previously, are not ordinarily willing to make full use of the <u>lateral</u> acceleration capabilities of their vehicle. Consequently, the 75 percent figure is a good starting point but may need to be revised subsequently based upon the initial test runs and observed driver reactions.

Figure 17. Braking During a Lane-Change Maneuver / Coned Course.



Drivers:

Lay drivers having little or no exposure to ABS systems and their cycling behavior would be selected for these tests. A group of 20-100 (depending upon the resources available, statistical reporting needs, and consideration of earlier studies using lay drivers) would be used. Randomly selected male and female test drivers could be selected to cover several age groups, such as 16-20, 21-40, 41-55, and 55-70, with each group being represented appropriately to reflect their respective portion of the driving population. Human factors and statistical specialists should be involved for consultation to help design an appropriate make-up and mixture of the lay drivers selected for the proposed tests.

Data Collection:

A DASCAR (or VRTC equivalent system) having at least 20 channels of recording capability would be recommended. In addition, video recordings of: 1) the driver hand position and instrumentation panel, 2) the driver brake pedal activity, and 3) a forward view out the front windshield would also be useful, if available, to augment the conventional transducer measurements. Such information would help to better document any loss-of-control incidents using the road scene video, and to help describe the variety of pedal modulation actions used by drivers in the braking maneuvers.

The measured data variables would include: longitudinal vehicle position (relative to the lane course or to a global reference), lateral vehicle position (same), yaw angle relative to the lane or a global reference, steering wheel position, driver / master cylinder brake pressure, brake pedal force, interior sound(s), vehicle longitudinal acceleration (near mass center), vehicle lateral acceleration (near mass center), pitch rate or angle, roll rate or angle, four wheel speeds, forward vehicle speed, vehicle yaw rate, vehicle slip angle (if appropriate instrumentation is available), lateral acceleration at head-rest, longitudinal acceleration at head-rest, steering wheel torque, and indicators of ABS operation at each wheel (e.g., brake cylinder pressures). Several of these measurements may also be derived or estimated from post-processing calculations using other measurements (e.g., integration of fifth-wheel speed measurement to estimate longitudinal distance, etc.)

Optional video data (such as available in the DASCAR system) could also be collected: video of hands/dash/instruments, video of brake pedal activity, video of driver view of road scene (out windshield or other location).

Driver comments and subjective ratings would also be recorded for each vehicle configuration driven to help assess driver likes/dislikes of particular features and their general impressions. A numerical rating scale could be used to gauge driver reactions to, for example, the degree of braking control effort necessary to perform the maneuver, pedal feedback sensations, braking system noises, or the degree of steering control effort necessary to perform the maneuver.

Data Processing:

A revised version of the existing Test PAES data processing program currently being evaluated by VRTC (or other existing software packages such as may be available at VRTC or various UMTRI / ERD software routines), would be a preferred software package for processing most of the test data. Test PAES happens to also currently have a post-processing module that interfaces with the DASCAR system and would therefore be a likely candidate if the DASCAR data collection system was used. Other post-processing software packages including various programs from the UMTRI / ERD software library and VRTC could also be used to supplement the Test PAES analysis capabilities. These packages could also substitute if the revised version of Test PAES was not available for the proposed tests.

Performance Measures :

Performance measures applicable to the ABS tests would include:

- stopping distance
- average deceleration of braking maneuver
- various lane position measurements (at the stopping point, maximum lateral lane excursion during run, RMS or variance of lateral vehicle position away from lane centerline)
- yaw orientation of vehicle relative to the lane (at stop, maximum deviation away from lane centerline tangent during run, RMS or variance of heading angle away from lane centerline tangent over entire maneuver)
- approximate description of driver pedal modulation behavior (constant-like, pumping, variable, etc.)
- specific characterization of driver pedal modulation as time history
- approximate description of driver steering wheel behavior (constant-like, severe reversals, variable, etc.) as additional estimate of workload during braking
- specific characterization of driver steering wheel behavior as a time history

Data Analysis:

A summary of each performance measure as a function of the 1st - 10th test repeat experience would be used to illustrate and analyze driver control behavior and adaptation for each ABS-equipped vehicle and its corresponding non-ABS vehicle. Of particular interest would be those test runs representing the first few exposures to the ABS cycling operation and how those resulting driver control responses become altered in subsequent test repeats. Likewise, the stopping performance measures corresponding to these same test sequences (noted above) would also be examined for any changes or trends linked to particular patterns of driver braking control behavior. Driver comments and subjective ratings about each vehicle and ABS system configuration would likewise help to evaluate the degree of required driver control effort and their overall preferences / reactions to each system.

Each test subject would generate data corresponding to a test matrix of: 3 ABS vehicles x 3 non-ABS vehicles x 2 maneuvers x 10 repeats = 180 test runs / driver.

Active Suspension Study

Test track experiments using a standard Infiniti Q45 [4] equipped with its fully active suspension and its identical non-active suspension counterpart.

> Hypothesis: Active suspension systems that minimize roll, pitch, and bounce motions of vehicles may cause drivers to alter their control behavior due to reduced feedback information about the response of the vehicle. This may lead to degraded driver control and driving performance and/or altered expectations of vehicle capabilities.

Experiments: Conduct handling and braking tests at VRTC with a group of test drivers and the two vehicle configurations to evaluate differences in driving performance resulting from the presence of the fully active suspension system. S-curve negotiation, obstacle avoidance, and braking-in-a-turn maneuvers would be used to fully exercise the suspension characteristics of both vehicles and to provide feedback cue measurements needed for analysis. Roll, pitch, and bounce motions and their associated feedback cues will be significantly different between the two vehicle configurations. If available, the DASCAR instrumentation package could be used to collect the necessary driver and vehicle response data. Otherwise, comparable instrumentation packages such as available at VRTC or UMTRI could be used.

Following testing, the collected data should be analyzed to identify differences in handling and braking performance between the two vehicles and the group of test drivers. Additional analyses could be performed with comprehensive driver/vehicle software to match/correlate performance differences between the two vehicle configurations and to identify specific driver feedback dependencies on each of the measured vehicle responses. Neural network or comparable analyses should also be conducted to further assist in identifying the reliance of driver control responses upon each of the various vehicle feedback responses or cues being measured[5]. Significant feedback cues identified as important for driver control activity would be ranked in order of importance based upon its particular contribution to the total measured driver control response. Driving performance

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[4] Only marketed vehicle available with a fully active suspension option.

[5] An example approach is given by MacAdam & Johnson, "The Application of Elementary Neural Networks and Preview Sensors for Representing Driver Steering Control Behavior," *Vehicle System Dynamics*, Vol 24, No, 9/10, 1995.

measures, such as RMS path deviations, yaw rate, or driver control activity, would likewise be included and documented as part of the total analysis.

As noted previously, these recommended tests would help to experimentally address various issues and questions concerning feedback cues raised in this task order. Data obtained from such tests would also provide a resource of experimental data to further analyze and investigate the basic nature of feedback cue mechanisms and associated driver control dependencies.

Active Suspension and Test Vehicles:

The Infiniti Q45 is currently the only commonly marketed vehicle having an active suspension system. Since the active suspension feature is an option on this vehicle it represents an ideal test vehicle for conducting the proposed experiments. Two as-marketed Q45's would be acquired for testing, one with the active suspension option, the other without. These two vehicle configurations would then be used in identical side-by-side tests with the same group of test drivers.

Test Maneuvers:

Three test maneuvers are recommended for the active suspension test series: (1) S-curve negotiation as depicted in Figure 18, (2) an obstacle avoidance (double lane-change) maneuver seen in Figure 19, and (3) braking in-a-turn maneuvers as previously described in Figure 16.

The S-curve tests would be constant-speed tests conducted at 60 mph on a dry surface using a course geometry requiring lateral acceleration levels of approximately 0.25 g's to negotiate each circular curve. These tests would be used to help identify linear operating regime characteristics of both vehicles and to characterize their performance under "normal" or lower g-level operating conditions. Closed-loop driver response data obtained from these tests would also help to construct initial estimates of driver-vehicle models proposed in subsequent data analyses. These data would likewise be used to directly evaluate the impact of active suspension motion suppression effects on the steering control behavior of the test drivers during relatively mild maneuvering conditions.

The obstacle avoidance tests would be conducted at higher g-levels (0.5 g's or so) to evaluate more emergency-like behavioral characteristics and to fully exercise the active suspension systems laterally using more demanding left and right directional changes of the vehicle. These tests would also be conducted on a high friction surface. The data obtained from these tests would permit subsequent analyses of driver-vehicle-suspension interactions while maneuvering under more nonlinear operating conditions.

The braking-in-a-turn tests would be conducted on both high and moderate friction surfaces (e.g., dry and wet asphalt). These tests are intended to exercise the active suspension features for combined longitudinal/lateral and pitch/roll motion compensation. Drivers would be asked to perform closed-loop braking to bring the vehicle to a stop at designated locations. The goal would be to stop the test vehicle in the required distance while also maintaining directional control of the vehicle and keeping it within the prescribed confines of the coned course. Fixed stopping markers would be implemented by test personnel to designate the desired stopping location. See Figure 16.

Figure 18. S-Curve Maneuver / Coned Course.

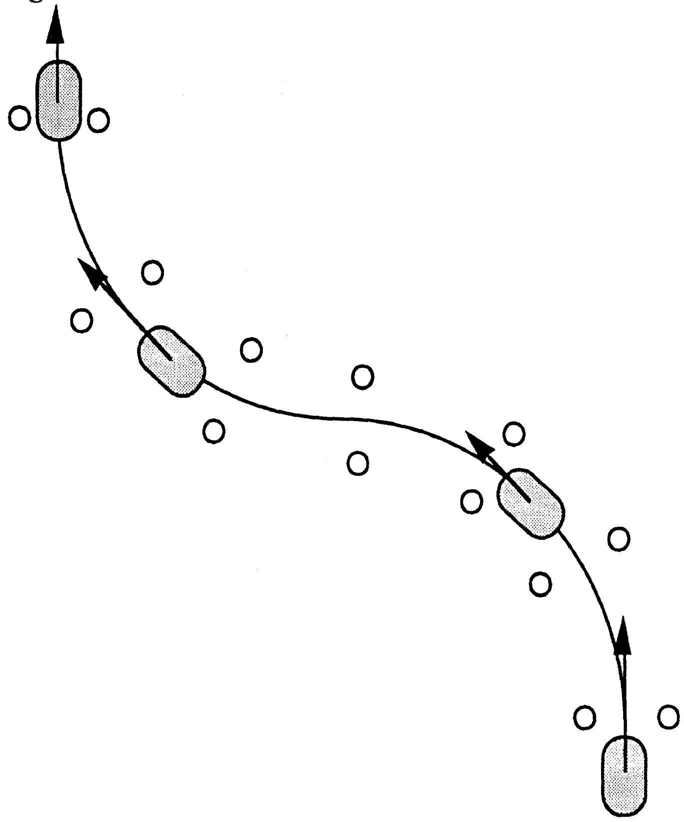
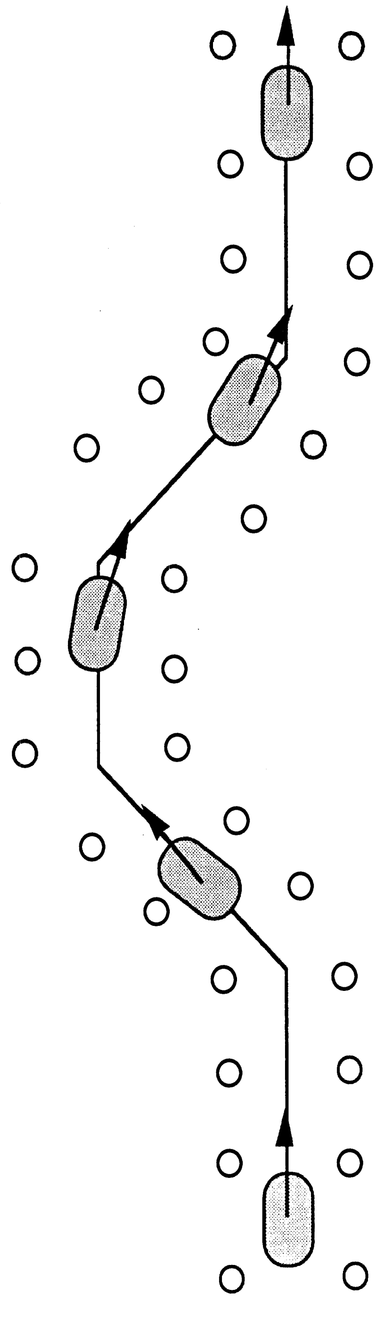


Figure 19. Obstacle Avoidance Maneuver / Coned Course.



The dry surface braking-in-a-turn tests would require *moderate* braking efforts by each driver without triggering activation of the ABS system on the Q45. For example, average longitudinal braking levels of 0.4 g's or so and a dry asphalt surface. Required stopping distances set by the experimenters would control the level of required deceleration. These tests would provide closed-loop braking data for each driver with and without the active suspension system present, while avoiding the added confusion of any ABS system cycling. Data obtained form these tests would be used to analyze the impact of active suspension system effects (pitch, roll, and bounce motion suppression) on the closed-loop braking control behavior of the test drivers.

A more aggressive secondary set of braking-in-a-turn tests would also be conducted on wet asphalt with those tests designed to trigger ABS cycling during similar closed-loop braking stops. The data collected from these secondary tests would provide some additional information on any possible interactive effects between driver control behavior and the presence of two simultaneous technological assists — active suspension activity and ABS activity. Any special interactions that might be observed/hypothesized about active suspension load transfer effects and ABS cycling would have then been be recorded for follow-up review and analysis.

Drivers:

A group of 5 to 10 VRTC / TRC staff test drivers (depending upon available resources) would be used for the initial series of active suspension tests. (Based upon the outcome of this initial study, a larger group of lay drivers could be used in a follow-up project to help establish linkage to the broader driving population.) The data from the VRTC test drivers should permit questions about driver control behavior modification to be addressed in a fairly efficient manner. Further, the initial data set generated from these drivers will permit the development of key data processing algorithms needed for identifying how and to what degree different feedback cue paths are modified by the presence of an active suspension system. (The same or very similar data processing algorithms and analysis methods developed under this proposed work could also be applied in subsequent research projects.)

Data Collection:

As in the proposed ABS tests, the DASCAR (or VRTC equivalent system) having at least 20 channels of recording capability is recommended. Video recordings of the road scene and horizon would be useful for subsequently demonstrating the motion suppression effects of the active suspension system.

The measured data variables would include: longitudinal vehicle position (relative to the lane course or to a global reference), lateral vehicle position (same), yaw angle relative to the lane or a global reference, steering wheel position, driver / master cylinder brake pressure, brake pedal force, interior sound(s), vehicle longitudinal acceleration (near mass center), vehicle lateral acceleration (near mass center), pitch rate or angle, roll rate or angle, four wheel speeds, forward vehicle speed, vehicle yaw rate, vehicle slip angle (if appropriate instrumentation is available), lateral acceleration at head-rest, longitudinal acceleration at head-rest, steering wheel torque, and indicators of ABS operation at each wheel (e.g., brake cylinder pressures). Again, several of these measurements may also be derived or estimate from post-processing calculations using other measurements (e.g., integration of fifth-wheel speed measurement to estimate longitudinal distance, etc.)

Collection of video data of driver view of road scene (out windshield or other location) would be an option.

Driver comments and subjective ratings would also be recorded for each vehicle configuration to help assess driver likes/dislikes of particular features and their general impressions.

Each test driver would generate data corresponding to a test matrix of: 2 vehicles (active / non-active suspension) x 4 maneuvers (s-curve, obstacle avoidance, 2 braking-in-turn tests) x 10 repeats = 80 test runs / driver. Five test drivers would thereby generate a minimum database of 400 test runs to use for the designated analyses.

Data Processing:

As before, a revised version of the existing Test PAES data processing program currently being evaluated by VRTC (or other existing software packages such as may be available at VRTC or from various UMTRI / ERD software routines), would be a primary software package for processing much of the test data. Other post-processing software packages, including various programs from the UMTRI / ERD software library and VRTC, could also be used to supplement the Test PAES analysis capabilities.

In addition, certain analysis code would be needed to: 1) perform model-matching simulations and 2) conduct neural network analyses. Existing computer codes, such as AUTOSIM or the Phase-4 driver/vehicle modelling packages at UMTRI, could be used for the model-matching analyses. Some minor revisions of the driver and vehicle codes present in those programs would be necessary to represent the active suspension features of the test vehicle and possibly some additional refinements to their current driver models.

The initial neural network analyses could be undertaken with MATLAB or similar numerical packages containing neural network computational libraries. Later versions of the neural network architecture and training procedures could be coded in C and transported to the Test PAES or other existing data processing packages used for processing driver/vehicle test data.

Performance Measures :

Performance measures applicable to the active suspension tests would include, depending upon the particular maneuver:

S-curve and obstacle avoidance tests —

- path tracking performance measures during S-curve and obstacle avoidance maneuvers
- RMS path deviations from lane centerline
- steering control behavior and numerical characterizations (dc/RMS levels)
- roll, pitch, and bounce motion summary numerics during cornering maneuvers

Braking-in-a-turn-tests —

- stopping distance and deceleration measures for braking-in-turn tests
- roll, pitch, and bounce motion summary numerics during braking maneuvers
- braking control behavior and numerical characterizations (dc/RMS levels)
- steering control behavior and numerical characterizations (dc/RMS levels)
- various lane position measurements (at the stopping point, maximum lateral lane excursion during run, RMS or variance of lateral vehicle position away from lane centerline)
- yaw orientation of vehicle relative to the lane (at stop, maximum deviation away from lane centerline tangent during run, RMS or variance of heading angle away from lane centerline tangent over entire maneuver)

Data Analysis:

Many of the data analyses techniques noted in Section 2.5 would be recommended for examining the active suspension test data collected here. Of particular interest are questions about whether or not the presence of an active suspension system affects driver control behavior. If it does, what are the primary cue paths or signals being affected/modified. The first question can be addressed by conventional analyses that compare traditional driving performance measures (noted above) with different vehicle configurations being tested (active suspension system / no active suspension).

The second question is more difficult and often requires complex analyses that are not ordinarily undertaken to process most test data. These would include model-matching analyses that attempt to simulate or closely approximate specific instances of test results for various driver/vehicle tests conditions. Differences in driver parameter values used to model the driver component can then be used to help identify which feedback signals have become significantly altered within the driver-vehicle feedback control structure for the two vehicle configurations being compared.

For example, a particular set of test results collected for the active suspension and non-active suspension vehicles may show significant differences in driving performance and associated driver control behavior. Simulation of these two sets of data with appropriate driver/vehicle software tools would then be undertaken to match each test result. Examination of the resulting parameter values used to represent the signal path feedbacks used by the driver model component (heading rate, lateral path displacement, roll angle, etc.) would then provide information about which feedback signals are either strengthened or weakened in the two different vehicle configurations being compared. If sufficient numbers of these types of test result comparisons are then conducted for similar or related tests, conclusions could then be drawn about how an active suspension system likely affects driver control behavior under similar circumstances. The advantage here is that explanations for altered driving behavior become possible based upon a reasonable model of the driver-vehicle system. As long as the model contains sufficient detail about basic mechanisms present in driver-vehicle control interactions (driver time delays, response thresholds, presence of sufficient sensory feedback signals, etc.) the model-matching analysis can be useful for addressing these types of feedback cue questions.

Another approach also noted in Section 2.5 is the proposed use of neural network analyses. In this methodology, a multi-layer architecture of neuron elements is assumed for representing the driver-vehicle system being analyzed. Associated network weights are adjusted by means of an iterative training procedure on each set of test data using measured vehicle and driver control responses as input signals to the network. This approach can be viewed in one sense as a nonlinear regression technique that attempts to match a model (containing nonlinear elements) to the measured test data. In many ways it is similar to the model-matching approach described above but without containing an explicit or detailed model of the driver-vehicle system. If the iterative training or weight adjustment procedure produces a matching of test data results, the resulting weights and architecture can then be used as a model for representing the particular driver-vehicle system in that test. Like the model-matching approach, if repeated neural network analyses corresponding to distinct vehicle configurations consistently show trends in network weights that indicate increased or decreased feedback strengths for specific signal measurements (cues), conclusions can be drawn about the likely effects of an active suspension on driver signal dependencies. Again, as in the case of the model-matching approach, neural network analyses provide the benefit of helping to explain how observed degradations in driving performance (due to the presence of a certain technology) are occurring by identifying which feedback cue path connections (network weights) are being altered and to what extent.

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   The ECCS-II electronic concentrated engine control system is described. The controller has been incorporated in Nissan's CUE-X prototype vehicle. The ECCS-II features a 16-bit microcontroller and successfully realizes many control functions with great precision and high speed. The minicontroller is designed to control such features as: collision avoidance radar, electronically controlled spoilers, drive-by-wire throttle control, four-wheel-drive, four-wheel-steering, and a navigation system that receives information from satellites orbiting the earth. Emphasis is on software and hardware that controls several combustion control features. 8 refs.

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    The main finding is that cockpit motion improves tracking performance due to a faster motion perception process. (Auth)

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    Experience has shown that a vehicle equipped with Active suspension and rear wheel steering can be a very powerful tool for research into vehicle dynamics. Passive or 'adaptive' vehicle suspension systems can be emulated. This has considerable potential for shortening vehicle development times. Active systems provide the ability to separate dynamic modes from one another. This enables detailed examination of each effect without the cross coupling normally experienced with passive vehicles. The driver is an important part of the dynamic loop and ultimately it is he/she who must be able to control the vehicle with confidence, precision, and minimum fatigue. An Active vehicle is a powerful way to investigate the feedback and cues needed by the driver, and to produce objective requirements to achieve them. Thus armed, vehicle design, computer simulation and development functions can be more effective in getting better products more quickly to the market. (Author abstract) 3 Refs.

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A highway driving simulator with a computer-generated visual display, physical motion cues of roll, yaw, and lateral translation, and velocity-dependent sound/vibration cues was used to investigate the influence of these cues on driver performance. Forty-eight student subjects were randomly allocated to six experimental groups. Each group of eight subjects experienced a unique combination of the motion and audio cues. The control group received a full simulation condition while each of the remaining five groups performed with certain combinations of motion and sound deleted. Results indicate that the performance measures of yaw, lateral and velocity deviation are significantly affected by the deletion of cues. In support of the hypothesis that driver performance is augmented by the addition of motion cues, statistically significant negative correlations were obtained between the number of motion cues present and the measures of yaw and lateral deviation. With respect to motion and audio cues, recommendations are made regarding simulator design criteria. 9 refs.

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Since its introduction in 1978, the four wheel ABS system has rapidly come into wide use, particularly in recent years, due to the user's growing concern over safety and cost reduction of the system itself. The three-position type ABS control valve, which has mainly been applied to upper-class vehicles, has the advantages of favorable cost performance and expandability of its functional utility to traction control, etc. During operation, however, this type of valve produces significant vibration and noise which must be controlled so as to improve riding comfort. This report describes the discussion focused on the three position type control valve and presents a control strategy which can effectively suppress the noise and vibration when the valve is in operation. (Auth)

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At the guidance and control level of car driving, the steering wheel as an active control device can be used to transmit relevant, additional proprioceptive-tactile (haptic) information cues for lateral control in the form of perceptible steering wheel torque changes. These information cues can be presented either as discrete signals or in a continuous form. The purpose of a field study, conducted on a 80 km stretch of German freeway, was to determine from a human factors point of view the effectiveness of continuous steering wheel support during driving. (auth)

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Main topics discussed cover multi-task decision making, attention allocation and workload measurement, displays and controls, nonvisual displays, tracking and other psychomotor tasks, automobile driving, handling qualities and pilot ratings, remote manipulation, system identification, control models, and motion and visual cues. Sixty-five papers are included with presentations on results of analytical studies to develop and evaluate human operator models for a range of control task, vehicle dynamics and display situations; results of tests of physiological control systems and applications to medical problems; and on results of simulator and flight tests to determine display, control and dynamics effects on operator performance and workload for aircraft, automobile, and remote control systems. (Author)

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Audio - Appendix B

1. M. K. Apostolos et al., Multisensory feedback in advanced teleoperations: benefits of auditory cues. *Proceedings of SPIE - The International Society for Optical Engineering v 1828. Publ by Int Soc for Optical Engineering, Bellingham, WA, USA. p 98-105,* 1993.

   This paper describes work conducted at the JPL Advanced Teleoperation Laboratory in an experiment that demonstrated the value of auditory cues in teleoperation as part of a simulated Solar Maximum Satellite Repair (SMSR). An experiment was designed to examine a specific teleoperation task of unbolting an electrical connector screw based on the apparent significance of auditory signals. Visual and kinesthetic feedback have usually been the primary modes for cueing operator manual control actions in remote manipulation tasks; however, auditory information may have further beneficial effects on operator performance. In addition to the visual cues available from a pair of stereoscopic cameras and contact force feedback cues from the operator's manual hand controller, we gave the operator an amplified microphonic task presentation. In general, sounds within the robot workspace are not heard in the operator control room. Such auditory cues had not been used in the Advanced Teleoperation Laboratory (ATOP) prior to this experiment. Six subjects participated in the experiment which examined the performance benefits of vision, force, and sound feedback. Our data infers that audio cues can make a significant difference in task completion time. 6 refs.

2. T. J. Doll et al., Development of simulated directional audio for cockpit applications. AD-A175350; AAMRL-TR-86-014, 1986.

   The long-term objective of this work is to develop techniques for conveying accurate spatial information via audio signals delivered to the listener through headphones or earphones. This project included three major activities: (1) an extensive review and synthesis of the research literature on auditory localization, (2) the design, fabrication, and evaluation of an apparatus for demonstrating simulated auditory localization (SAL), and (3) experimental research to determine characteristics of the audio signal, in the time and frequency domains, which enhance localization performance with simulated cues. Previous research is reviewed which describes the cues involved in the perception of sound-source direction, both horizontally and vertically, when the head is stationary. Also reviewed is research on auditory distance perception, the roles of head movement and vision in auditory localization, the perception of auditory motion and volume, and the effects of noise on auditory localization. A feedback control model is presented, which integrates evidence derived from four different theoretical positions concerning the effects of head movement and vision on auditory localization. Possible applications of SAL technology in aircraft cockpits are outlined, and the potential benefits of such applications are discussed. (GRA)

3. C. Giguere and P. C. Woodland, A Computational Model Of the Auditory Periphery For Speech and Hearing Research .2. Descending Paths. *Journal Of the Acoustical Society Of America*, 95, 1, 1994.

   The auditory model described in Giguere and Woodland [J. Acoust. Soc. Am. 94, 331-342 (1993)] is applied to the simulation of the descending Paths to the peripheral ear. An external feedback unit regulates the average firing rate of inner hair cell afferent fibers via a simplified modeling of the dynamics of the acoustic reflex to the middle ear and of the slow efferent innervation of the outer hair cells. The terminal effector of the acoustic reflex system is the stapedial muscle which stiffens the middle ear and reduces vibration of the stapes by up to 15 dB below 1000 Hz. The control function of the efferent system is realized by modulating the coupling gain between the inner hair cell cilia and the surrounding subtectoral fluid over a range of 24 dB. The efferent system has the capability to regulate firing rate over selective tonotopic regions of the auditory nerve. It operates at a lower target rate and has a faster response than the acoustic reflex system. The feedback unit leads to dynamic compression of speech cochleograms along both the time and frequency axes.

4. B. C. Leibrecht, A. J. Lloyd and S. C. Pounder, Auditory feedback and conditioning of the single motor unit. AD-745107; USAMRL-971, 1972.

   The effects of direct auditory feedback of the electromyogram (EMG) on learning to control a single motor unit (SMU) were investigated. Seventeen human subjects were injected with bipolar fine-wire electrodes into the tibialis anterior muscle. A trial light indicated the onset of a trial. If the subject activated an SMU, a correct light appeared. A non-SMU response was followed by an incorrect light. All subjects received an initial training series with auditory EMG feedback followed by a retest at 2 weeks without EMG feedback. Speed of initial learning was substantially improved by direct EMG feedback. The nature and amount of learning, including the ability to use proprioceptive cues in controlling an SMU, were not affected, nor was retention of learning. (Author (GRA))

5. T. M. Nelson and T. H. Nilsson, Comparing headphone and speaker effects on simulated driving. *Accident Analysis and Prevention*, 22, 6, 1990.

Twelve persons drove for three hours in an automobile simulator while listening to music at sound level 63 dB over stereo headphones during one session and from a dashboard speaker during another session. They were required to steer a mountain highway, maintain a certain indicated speed shift gears, and respond to occasional hazards. Steering and speed control were dependent on visual cues. The need to shift and the hazards were indicated by sound and vibration effects. With the headphones, the driver's average reaction time for the most complex task presented - shifting gears - was about one-third second longer than with speaker. The use of headphones did not delay the development of subjective fatigue. (Author abstract) 17 Refs.

6. D. A. Sumikawa et al., Design Guidelines for the Use of Audio Cues in Computer Interfaces. AD-745107; USAMRL-971, 1985.

A logical next step in the evolution of the computer-user interface is the incorporation of sound thereby using our senses of "hearing" in our communication with the computer. This allows our visual and auditory capacities to work in unison leading to a more effective and efficient interpretation of information received from the computer than by sight alone. In this paper we examine earcons, which are audio cues, used in the computer-user interface to provide information and feedback to the user about computer entities (these include messages and functions, as well as states and labels). The material in this paper is part of a larger study that recommends guidelines for the design and use of audio cues in the computer-user interface. The complete work examines the disciplines of music, psychology, communication theory, advertising, and psychoacoustics to discover how sound is utilized and analyzed in those areas. The resulting information is organized according to the theory of semiotics, the theory of signs, into the syntax, semantics, and pragmatics of communication by sound. Here we present design guidelines for the syntax of earcons. Earcons are constructed from motives, short sequences of notes with a specific rhythm and pitch, embellished by timbre, dynamics, and register. Compound earcons and family earcons are introduced. These are related motives that serve to identify a family of related cues. Examples of earcons are given. (ERA citation 11:008164)

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Cue Augmentation - Appendix C

1. W. B. Albery and E. D. Hunter, G-seat component development. AD-A055533; AFHRL-TR-78-18, 1978.

   An effort was conducted to investigate the improved performance of a closed-loop G-seat system. The Air Force and Navy are currently using G-seats in several training and fighter simulators. These devices are all open-loop systems and exhibit excessive time delays. While these seats exhibit good sustained cueing capability, their performance is marginal in producing overall acceleration cues. Because of sluggish response characteristics, virtually none of the seats can give appropriate acceleration onset cues and be in synchronization with current visual systems. Conventional G-seat components were obtained as well as advanced, position feedback metal bellows, and a closed-loop pneumatic control system was designed and developed. The open- and closed-loop performance of this system was evaluated and the contribution of each component in the G-seat hardware was analyzed. Transfer functions were developed for the pneumatic control system.

2. B. R. Ashworth, A. C. Hall and C. E. i. Clark, Helmet weight simulator. 1981.

   A device for providing acceleration cues to the helmet of a simulator pilot is described. Pulleys are attached to both shoulders of the pilot. A cable is attached to both sides of the helmet and extends through the pulleys to a take-up reel that is controlled by a torque motor. Control signals are applied to a servo system including the torque motor, the take-up reel and a force transducer which supplies the feedback signal. In one embodiment of the invention the force transducer is in the cable and in another it is in the take-up reel. (Official Gazette of the U.S. Patent and Trademark Office)

3. S. Balakrishna and A. Santharam, One axis artificial feel system. *Aeronautical Society of India, Journal*, 28, 1976.

   Joy stick feel forces, called proprioceptive cues, provide an important sensory feedback to the pilot. Ideally the stick would possess feel forces governed by maneuvers, aerodynamic and structural forces and manual control requirements. Such ideal systems are not normally incorporated in aircraft, since these forces vary continuously and are difficult to produce artificially. This paper discusses a mechanization technique by which such a goal can be achieved. The technique consists of combining an electro-hydraulic position and load closed loop system which can accept any load-position-time command from an electronic function generator. The closed loop dynamic analysis is made and the system is synthesized. Such a feel system is being used in a ground-based motion simulator.

4. K. S. Berbaum et al., Visual Tasks In Helicopter Shipboard Landing
   Flight Test Experience with Pilot-Induced-Oscillation Suppression Filters. *Applied Ergonomics*, 22, 4, 1991.

   The purpose of this research was to identify visual scene content important in helicopter shipboard landings, particularly in the hover phase, for further study in a research simulator. A second purpose was to illustrate the use of a methodology (Protocol Analysis) which may hold promise for many areas of human factors research. Discussions with pilots, reviews of relevant Naval Aviation Training and Operational Procedures (NATOPS) manuals and observation of simulated helicopter shipboard landings suggested that the visual elements required in helicopter shipboard landings may depend upon whether experienced or inexperienced pilots are flying, a simulator or an aircraft is flown, the environment is day or night, or the pilot seeks to acquire or maintain a skill level. A scenario involving an experienced pilot flying dusk/night approaches in a simulator was intensively studied. As he flew each approach, the pilot dictated real-time verbal protocols of his visual and control activities. These protocols were subsequently partitioned by the authors into nine phases defined in terms of range or altitude from the ship, and the visual tasks required in each segment were described. An outcome of this analysis was a list of visual cue augmentations that may be useful for providing augmented feedback in training.

   Digital flight control systems are popular for their flexibility, reliability, and power; however, their use sometimes results in deficient handling qualities, including pilot-induced oscillation (PIO), which can require extensive redesign of the control system. When redesign is not immediately possible, temporary solutions, such as the PIO suppression (PIOS) filter developed for the Space Shuttle, have been proposed. To determine the effectiveness of such PIOS filters on more conventional, high-performance aircraft, three experiments were performed using the NASA F-8 digital fly-by-wire and

USAF/Calspan NT-33 variable-stability aircraft. Two types of PIOS filters were evaluated, using high-gain, precision tasks (close formation, probe-and-drogue refueling, and precision touch-and-go landing) with a time delay or a first-order lag added to make the aircraft prone to PIO. Various configurations of the PIOS filter were evaluated in the flight programs, and most of the PIOS filter configurations reduced the occurrence of PIOs and improved the handling qualities of the PIO-prone aircraft. These experiments also confirmed the influence of high-gain tasks and excessive control system time delay in evoking pilot-induced oscillations.

5. C. J. Berthe, C. R. Chalk and S. Sarrafian, An in flight investigation of pitch rate flight control systems and application of frequency domain and time domain predictive criteria. *IN: Guidance and Control Conference, Seattle, WA, August 20-22, 1984, Technical Papers (A84-43401 21-63). New York, American Institute of Aeronautics and Astronautics, 1984, p. 731-742.,* 1984.

The degree of attitude control provided by current integral-proportional pitch rate command-type control systems, while a prerequisite for flared landing, is insufficient for 'Level 1' performance. The pilot requires 'surrogate' feedback cues to precisely control flight path in the landing flare. Monotonic stick forces and pilot station vertical acceleration are important cues which can be provided by means of angle-of-attack and pitch rate feedback in order to achieve conventional short period and phugoid characteristics. Integral-proportional pitch rate flight control systems can be upgraded to Level 1 flared landing performance by means of lead/lag and washout prefilters in the command path. Strong pilot station vertical acceleration cues can provide Level 1 flared landing performance even in the absence of monotonic stick forces.

6. M. D. Boardman, 'Shift-Mate' a Fuel Efficiency Monitor. *SAE Special Publications SP-645. Publ by SAE, Warrendale, PA, USA p 31-36,* 1985.

The SHIFT-MATE is a dashboard mounted computer based device that cues a truck driver to shift more efficiently. Through electronic circuitry, key vehicle parameters are monitored, computed, then via graphic display, instructs the driver when to shift for improved fuel economy. The theory of operation is described in the text. The Implementation of specifying heavy trucks based on improved fuel economy requires a particular driving style to fully maximize vehicle fuel efficiency. Truck engine manufacturers and vehicle OEM's recommend operating at lower engine RPM's with progressively higher up-shift RPM's during acceleration to minimize friction and energy losses. This paper describes a simple means of training the truck driver for fuel efficiency - The SHIFT-MATE. (Edited author abstract)

7. B. S. Goldsberry, The effects of feedback and predictability of human judgment. AD-A145744; AD-E001749; TR-84-3, 1984.

Previous research has found that when subjects are given cognitive feedback, they reach higher levels of achievement than when they are given outcome feedback. It was hypothesized that this finding was due in part to the predictability of the task environment since outcome feedback is at a distinct disadvantage as a sole means of conveying such information. A study was conducted to compare response and outcome feedback under three predictability conditions. The design included a control group receiving no feedback at all, two response groups differing in precision of feedback information, and two outcome feedback groups differing on a quantity dimension. The study also attempted to clarify the definition of feedback and to equate the availability of task information in the various feedback conditions that were compared. Contrary to expectations, the utility of outcome feedback was inferior to that of response feedback under all three predictability conditions tested. In fact, an interaction revealed that the effect of increased predictability raised rather than lowered the disparity between outcome and response feedback performance. The results also revealed that a control group receiving no feedback at all performed as well as or better than those with feedback when the availability of task information was equated. Moreover, eliminating the memory requirement inherent in the use of outcome feedback only worsened performance. Similarly, adding precision to the response feedback condition beyond the level of mere directional error information did not improve performance.

8. A. J. Grunwald and S. J. Merhav, Effectiveness of basic display augmentation in vehicular control by visual field cues. *IEEE Transactions on Systems, Man, and Cybernetics*, SMC-8, 1978.

The paper investigates the effectiveness of different basic display augmentation concepts - fixed reticle, velocity vector, and predicted future vehicle path - for RPVs controlled by a vehicle-mounted TV camera. The task is lateral manual control of a low flying RPV along a straight reference line in the presence of random side gusts. The man-machine system and the visual interface are modeled as a linear time-invariant system. Minimization of a quadratic performance criterion is assumed to underlie the control strategy of a well-trained human operator. The solution for the optimal feedback matrix enables the explicit computation of the variances of lateral deviation and directional error of the vehicle and of the control force that are used as performance measures.

9. J. C. Howard, A g-load display for remotely piloted vehicles and other aircraft that are subject to maneuvering constraints. NASA-TN-D-8056; A-6032, 1975.

The absence of kinesthetic cues deprives RPV pilots of essential feedback, particularly during high speed maneuvers. A display was designed to facilitate pilot control of g loads and to permit an immediate indication of g-load constraint violations. The display embodies all the motion vector components that contribute to maneuvering accelerations. In one mode of operation, the device displays the components of angular velocity as variable length pointers emanating from the center of a circle whose radius is determined by the linear velocity of the vehicle. An alternative mode of operation permits the pilot to select a display in which g loads are presented directly as variable length pointers emanating from the center of a circle whose radius is again determined by the linear velocity of the vehicle. Each circle defines a safe region of operation, and penetration of the circumference of the appropriate circle by a pointer implies that the structural design load was exceeded. (Author)

10. G. Lintern and S. N. Roscoe, Visual cue augmentation in contact flight simulation. *In: Aviation psychology.*, 15676, 1980.

Studies on visual cue augmentation are reviewed with regard to simulation of dynamic visual scenes, adaptive simulator training with augmented feedback, and interactions between augmented feedback and intrinsic feedback. Particular attention is given to an experiment performed at the University of Illinois which demonstrated the transfer effectiveness of the automatic presentation and withdrawal of guidance cues in a simple skeletal computer-generated visual landing scene, in lieu of the verbal and manual assistance normally provided by the flight instructor during initial landing training. It is suggested that displays could be more effective for landing training if they were augmented with cues that provide guidance information not present in the real-world visual scene; further improvement might be expected from the adaptive presentation of flight-path prediction symbology.

11. M. Martin, Helicopter night vision system simulation evaluation, Final Report. AD-A110505; OR-16551, 1981.

Simulation experiments demonstrated the ability of the pilot and copilot to fly a night mission at low altitudes, ranging from 50 to 150 feet AGL, in a CH-53D simulation with the night visionics equipment package described previously. Phases I and II HNVS simulation studies indicated that enroute flight profiles over the simulator's rolling terrain can be accomplished at airspeeds ranging from 60 to 80 knots with clearance altitudes averaging 100 feet. This study was conducted with a revised terrain model with improved altitude feedback cues that produced higher clearance altitudes and somewhat lower airspeeds than the prior simulations. The actual speeds and altitudes will be verified in the planned HNVS flight tests. The simulation confirmed the minimum system requirement of a gimbaled FLIR with a navigation system and with ancillary hardware such as a symbol generator. Although this experiment required no data be generated on dead reckoning versus navigation system requirements, both pilot performance and opinion data reiterated the reduced crew station workload with Doppler command steering information. Incorporation of the navigation capability of the Control Display Unit also was instrumental in further reducing the navigation workload.

12. S. N. Roscoe and C. O. Hopkins, Enhancement of Human Effectiveness in System Design,. ARL-75-21/AFOSR-75-10; AFOSR-TR-76-0476, 1975.

This report is part of a study on residual attention, information load, and pilot performance. It has resulted in: (1) General rules and prediction equations for evaluation of task load and operator efficiency; (2) Discrimination of individual differences in attention and assessment of their predictive validity to operational performance; (3) Development of training procedures for timesharing.; and (4) Application of feedback control theory to operator tracking performance in timesharing Investigation of adaptive logic in acquisition of perceptual-motor skills included a review of literature on adaptive training with emphasis on current theoretical models of perceptual motor skills. Experiments were designed to investigate the role of proprioceptive and visual response-produced feedback during motor learning, and the effects of changing response-produced feedback after the same or after different amounts of practice.

13. D. E. Sattler, Helicopter IFR director algorithm development and flight evaluation on the NAE airborne simulator. *AIAA, Guidance, Navigation and Control Conference, Williamsburg, VA, Aug*, 1986.

Attention is given to the development and evaluation of a three cue (i.e., roll, pitch and collective) flight director system, which in combination with a relatively austere stability and control augmentation can provide the small-to-medium sized helicopter with a greatly enhanced IFR capability. The flight director algorithms were designed from first principles and analyzed with root-locus and time-response methods. The analysis provided an in-depth understanding of performance issues and in effect made flight evaluation on the National Aeronautical Establishment Airborne simulator a possibility. Consideration is given to the use of feedback washout versus forward integration, suitable sources for system damping, the equivalence of pilot lead and derivative feedback, the placement and extent of limiting functions, and the general interaction between the flight director system and the flight control system.

14. R. J. Sojourner, *Head-Up Display in the Automobile Environment, Master's thesis.* Air Force Inst. of Tech. Thesis, 1989.

The head-up display (HUD) enables the user to view critical instrumentation without redirecting his or her gaze from the outside environment. With the HUD, instrument-panel symbols appear as virtual images at optical infinity, superimposed upon the external scene. The concept has been so successful within the aerospace industry that automobile manufacturers are beginning to implement HUD technologies in automobiles. The purpose of this thesis was to evaluate HUD effectiveness in a simulated automobile environment using realistic driving tasks. Twenty male and female subjects with a wide age distribution (19-51) participated. A videotape, taken from the driver's perspective, of a car travelling along a route served as the 'scene' that was viewed by each subject. While watching the scene, subjects were required to perform driving tasks related to navigation, speed monitoring, and salient cue detection. Results showed that use of the HUD enabled subjects to respond more quickly to the salient cues, and that more cues were detected when using the HUD. In addition, more speed violations were detected by those subjects using the HUD.

15. R. J. Sojourner and J. F. Antin, Effects of simulated head-up display speedometer on perceptual task performance. *Human Factors*, 32, 3, 1990.

This study compared the effects of simulated head-up display (HUD) and dash-board-mounted digital speedometers on key perceptual driving tasks in a simulated driving environment. Subjects were 20 male and female volunteers ranging in age from 19 to 51 years. A videotape, taken from the driver's perspective, of a car traveling along a memorized route served as the test scene. While viewing the test scene subjects performed tasks related to navigation, speed monitoring, and salient cue detection. The simulated HUD speedometer produced generally superior performance on the experimental tasks; most important, it enabled subjects to respond significantly more quickly to the salient cues. Implications for the effects of HUDs on automobile safety are discussed. (Author abstract) 22 Refs.

16. L. R. Young et al., Three display techniques at the man vehicle laboratory. *NASA Spec Publ*, 215, 1969.

A 3- D display system is described in which a simple computer- generated CRT contact analog system is controlled by movement of the observer's head, as well as by vehicle motion. The prototype VTOL guidance and control display presents attitude and guidance cues on an integrated horizontal situation display, with pitch and roll angles appearing as vehicle axis projections and using a predictive display of attitude and position. An anti-vertigo display is discussed that reduces visual-vestibular conflict by driving a rotating visual field at rates determined by a mathematical model for vestibular function. 5 refs.

Cue Conflicts & Motion Effects - Appendix D

1. S. Balakrishna, J. R. Raol and M. S. Rajamurthy, Contributions of congruent pitch motion cue to human activity in manual control. *Automatica*, 19, 1983.

   The contribution of pitch motion cues to the performance of human pilots in compensatory tracking task are evaluated from pairs of uniquely planned experiments on a motion based research simulator, which allow separation of the visual responses from combined motion-visual responses. Analytical time series human pilot models of the least squares structure are evaluated from the input-output data and the results are discussed in terms of familiar parameters of pilot models and predictor operator. Beneficial contributions of pitch motion cues and subject differences are presented.

2. S. Baron, A pilot/vehicle model analysis of the effects of motion cues on Harrier control tasks, Final Report, Mar. 1981 - Mar. 1982. AD-A136291; NAVTRAEQUIPC-80-D-0014-0019-1, 1983.

   In this study, the results of an analytical investigation of pilot control of a simulated AV-8B (Harrier) aircraft are presented. The analysis was performed using a well-established pilot-vehicle model, namely, the Optimal Control Model. The effects on closed-loop performance of aircraft configuration (SAS-ON or SAS-OFF) and flight condition (hover or cruise) and of simulator motion cueing condition (fixed-base, moving platform or g-seat) were all analyzed. In addition, the interaction between these conditions and the level of pilot attention and/or skill (or training) was investigated by means of a sensitivity analysis in which we systematically varied a parameter of the OCM (the observation noise/signal ratio) which can be related to these pilot factors. The results indicate that motion cues could be very significant in the Harrier hover control task for the augmented (SAS-OFF) vehicle. For hover with the SAS-ON and for cruise flight, motion cues are predicted to be, at best, of marginal utility for improving performance. The model results suggest that motion cues may be provided for these tasks by a g-seat with little loss in performance as compared to using platform motion. However, the assumptions underlying the g-seat analysis have not been verified experimentally.

3. F. C. Belsley, Man-machine system simulation for flight vehicles *Ieee Transactions On Human Factors In Electronics*, 4, 1963.

   Man-machine system simulation for flight vehicles, discussing simulator complexity, realism and interrelation of feedback sensing cues.

4. H. V. Bergeron, Investigation of motion requirements in compensatory control tasks, *IEEE Transactions On Man-Machine Systems, Vol. Mms-11, P. 123-125.*, 1970.

5. G. J. Blaauw, J. Godthelp and P. Milgram, Optimal control model applications and field measurements with respect to car driving. IZF-1983-18; TDCK-78631, 1983.

   Two series of optimal control model predictions are stated for lateral position control in a straight driving scenario with disturbances generated internally by the driver. The first predicts lateral position variations and the time that a driver's vision can be occluded during the observation and control of different combinations of lateral position, lateral speed, yaw rate, lateral acceleration and yaw acceleration. The second series concerns two extreme sets of display variables in relation to driving speed and driving experience. Model predictions for the observation and control of all display variables give occlusion times which correspond with data from instrumented car studies with experienced drivers. However, with exclusive observation and control of the lateral position cue, predicted occlusion times are less than found in experimental results of inexperienced drivers. It is suggested that inexperienced drivers are also controlling yaw rate and/or both acceleration cues.

6. H. W. Case, S. F. Hulbert and J. Beers, Judgment of Vehicle Speeds and Traffic Patterns: Phase I, Interim Rept.. 1971.

   Drivers' speed estimations taken in a driving simulation laboratory indicated large under-accelerations (overestimations) from engine speed alone and no correlation between these and other estimations; medium accuracy and correlation with other estimations from visual cues alone; a high level of accuracy in instructed specific speeds and 'free' driving estimations when driving normally; a positive correlation between specific and 'free' speed estimations; and little accuracy of correlation for proportional estimations.

7. C. R. Chalk, Flying qualities of pitch range command/attitude hold control systems for landing. *Journal of Guidance, Control, and Dynamics*, 9, 1986.

Experience with in-flight simulations has shown that pitch rate command/attitude hold flight control systems exhibit mediocre to poor flying qualities for landing. Pilots report poor control of the flight path and tendencies to balloon and float and to exhibit pilot-induced oscillations. The origin of this flight control concept is traced to analytical models of the pilot/vehicle dynamic system, to such pilot-in-loop design criteria as the crossover model 'law' of manual control, and to sensor redundancy considerations that discourage the use of air data and encourage the use of inertial sensors in flight control systems. Rate command systems reduce the bandwidth of the angle of attack and flight path rate control, alter the control feel for maneuvers, and force pilots to use a pulse control technique and to push to land. For conventional airplane dynamics, the phugoid mode has low residue in the angle of attack and high residue in the pitch attitude and, in this situation, pitch attitude provides the pilot with surrogate cues for control of the angle of attack, flight path angle, and airspeed. Through pole-zero cancellation, the attitude response of a rate command system is made independent of the low-frequency modes of the characteristic equation and these dynamic modes, which must be controlled by the pilot in landing, are rendered unobservable in the pitch response of the rate command system.

8. L. D. Corliss, R. K. Greif and R. M. Gerdes, An in-flight simulation of VTOL hover control concepts. *In: V/STOL Conference, Palo Alto, Calif., June 6-8, 1977, Technical Papers. (A77-34926 15-05) New York, American Institute of Aeronautics and Astronautics, Inc., 1977, p. 276-281.,* 1977.

Results of several parametric ground-based simulations covering a variety of VTOL in-hover control concepts are reviewed. The systems considered are angular acceleration, rate, and attitude control, as well as translational rate control. Since many cues are severely restricted by ground-based simulation (e.g., motion, peripheral vision, and environment), some form of in-flight validation of these results is desired. Such a study has been undertaken utilizing the NASA Ames X-14B VTOL aircraft. This in-flight simulator has been configured with a fly-by-wire capability in the hover mode through an analog-/digital variable stability system. This system permits the implementation of either response-feedback or model-following type of control. A comparison of flight- and ground-based data is shown for the attitude control system with the X-14B being flown in both a tethered hover and a free-flight hover.

9. J. D. Dillow, D. G. Picha and R. O. Anderson, Slushy weightings for the optimal pilot model considering visual tracking task. *In NASA. Ames Res. Center 11th Ann. Conf. on Manual Control p 526-540 (SEE N75-33675 24-54),* 1975.

A pilot model is described which accounts for the effect of motion cues in a well defined visual tracking task. The effect of visual and motion cues are accounted for in the model in two ways. First, the observation matrix in the pilot model is structured to account for the visual and motion inputs presented to the pilot. Secondly, the weightings in the quadratic cost function associated with the pilot model are modified to account for the pilot's perception of the variables he considers important in the task. Analytic results obtained using the pilot model are compared to experimental results and in general good agreement is demonstrated. The analytic model yields small improvements in tracking performance with the addition of motion cues for easily controlled task dynamics and large improvements in tracking performance with the addition of motion cues for difficult task dynamics.

10. R. G. Fuller, *An Evaluation of the Fidelity of Motion Simulators Using a Model of Human Dynamic Orientation Master's thesis.* Thesis, 1977.

A deterministic simulation using a model of human dynamic orientation was written to optimize the parameters of the motion base control system for a six-degree-of-freedom flight simulator. An experiment requiring pilots to rate different levels of motion fidelity during a basic flight task provided a data base for validation of the simulation. Ratings between subjects for linear, rotational, and combined motion cues were inconsistent due, in part, to the subjects' lack of experience in the F-15 aircraft and proficiency in high performance aircraft. The coefficient of concordance among

subjects for the three ratings were .4483, .4835, and .5914, respectively. Comparison of simulation results with experimental data yielded positive correlations as high as .5138. Response of the simulation to changing wash-out filter parameters was investigated and found to be adaptable to experimental optimization methods.

11. R. A. Hess, Model for human use of motion cues in vehicular control. *Journal of Guidance, Control, and Dynamics*, 13, 1990.

A feedback model for human use of motion cues in tracking and regulation tasks is offered. The motion cue model is developed as a simple extension of a structural model of the human pilot, although other equivalent dynamic representations of the pilot could be used in place of the structural model. In the structural model, it is hypothesized that proprioceptive cues and an internal representation of the vehicle dynamics allow the human to create compensation characteristics that are appropriate for the dynamics of the particular vehicle being controlled. It is shown that an additional loop closure involving motion feedback can improve the pilot/vehicle dynamics by decreasing high-frequency phase lags in the effective open-loop system transfer function. Data from a roll-attitude tracking/regulation task conducted on a moving base simulator are used to verify the modeling approach.

12. G. C. Hill, Piloted simulation of hover and transition of a vertical attitude takeoff and landing aircraft. *American Institute of Aeronautics and Astronautics and NASA Ames Research Center, V/STOL Conference, Palo Alto, CA, Dec. 7-9, 1981, AIAA 8 p.,* 1981.

Piloted simulation studies of candidate control systems for VATOL aircraft were conducted on a six degree of freedom simulator. Hover and transitions from wing-born to hovering flight were performed, with and without turbulence, on a representative high performance fighter configuration. Deflection of the rear engine nozzle provided pitch and yaw control moments in concert with reaction controls for roll. Unique motion cues in hover result from the vertical displacement of the cockpit and the thrust vectoring nozzles. Abundant control power available with moderate engine nozzle deflection combined with rate feedback for stability augmentation provided very satisfactory control.

13. A. M. Junker and W. H. Levison, Application of control theory to the investigation of roll motion effects on pilot control behavior. *In: Conference on Decision and Control, and Symposium on Adaptive Processes, 16th, and Special Symposium on Fuzzy Set Theory and Applications, New Orleans, La., December 7-9, 1977, Proceedings. Volume 1. (A79-14957 04-63) Piscataway, N.J., Institute of Electrical and Electronics Engineers, Inc., 1977, p. 247-254.,* 1977.

The application of manual control theory to the investigation of the effects of motion cues on pilot control behavior is presented. Experiments and modeling approaches which have led to the development of a predictive motion sensitive optimal-control pilot-vehicle model for roll axis motion cues are described.

14. A. M. Junker and W. H. Levison, Use of the optimal control model in the design of motion cue experiments. *Presented at the 13th Ann. Conf. on Manual Control, Cambridge, Mass., 15-17 Jun. 1977,* 1977.

An experiment is presented in which effects of roll motions on human operator performance were investigated. The motion cues considered were the result of commanded vehicle motion and vehicle disturbances. An optimal control pilot-vehicle model was used in the design of the experiment and to predict system performance before executing the experiment. The model predictions and experimental results are compared. Seventy-eight percent of the model predictions are compared. The high correlation between model predictions and system performance indicate the usefulness of the predictive model for experimental design and for prediction of pilot performance influenced by motion cues.

15. M. Kirkpatrick and R. G. Brye, Man-systems evaluation of moving base vehicle simulation motion cues human acceleration perception involving visual feedback. NASA-CR-120706, 1974.

A motion cue investigation program is reported that deals with human factor aspects of high fidelity vehicle simulation. General data on non-visual motion thresholds and specific threshold values are established for use as washout parameters in vehicle simulation. A general purpose simulator is used to test the contradictory cue hypothesis that acceleration sensitivity is reduced during a vehicle control task involving visual feedback. The simulator provides varying acceleration levels. The method of forced choice is based on the theory of signal detect ability.

16. G. C. J. Krekeler, D. J. Wilson and D. R. Riley, High angle of attack flying qualities criteria. *AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan,* 1990.

Multiple, manned, fixed-base simulations were conducted to investigate longitudinal and lateral flying qualities for the moderate to high angle of attack flight regime. Pilot evaluations were conducted for tasks which represent point and shoot maneuvering at 30 degrees angle of attack. Simulation pilot comments and pilot rating data are compared with current flying qualities criteria including Control Anticipation Parameter (CAP), frequency response envelope, bandwidth, closed loop, modal parameter, and time history criteria. The comparisons showed that Cooper-Harper pilot ratings and comments at high angle of attack correlate with modifications to some of these current criteria. The potential impact of motion cues during high angle of attack maneuvering and the potential risk of using fixed-base simulation in this dynamic environment are addressed. A comparison of fixed-base data with a limited amount of high angle of attack flight test data shows good correlation.

17. T. Ledin and L. M. Odkvist, Visual Influence On Postural Reactions to Sudden Antero-Posterior Support Surface Movements. 1991.

Visual influence on force reactions to sudden antero-posterior (AP) translations of the support surface in 10 healthy men 23-58 years old (mean 36 years) were studied. Displacements ranged between 13 and 127 mm in both backwards and forwards directions. The experiment was conducted using a modified EquiTest dynamic posturography apparatus. An interactive menu-driven software enabled selection of a suitable translation pattern (i.e. square wave) in the AP direction. Data from four vertical force transducers were acquired and the position of center of pressure (CP) in the AP direction was computed as function of time. The movement of CP in response to AP translation was characterized by the amplitude of the maximum CP displacement relative to the platform and the latency until maximum CP displacement occurred. The experiment unveiled that the latency to maximum CP displacement was larger for conditions with vision present. Furthermore, both the amplitude and latency to maximum CP deflection were increasing functions of translation amplitude. It is proposed that visual feedback influences the neural control on the postural reactions to sudden support surface translations. Absence of visual cues seems to cause a more rapid correction of the body position.

18. W. H. Levison, F-14 modeling study, Final Report. NASA-CR-4164; NAS 1.26:4164; BBN-6579, 1988.

This study explored application of a closed loop pilot/simulator model to the analysis of some simulator fidelity issues. The model was applied to two data bases: (1) a NASA ground based simulation of an air-to-air tracking task in which nonvisual cueing devices were explored, and (2) a ground based and inflight study performed by the Calspan Corporation to explore the effects of simulator delay on attitude tracking performance. The model predicted the major performance trends obtained in both studies. A combined analytical and experimental procedure for exploring simulator fidelity issues is outlined.

19. R. C. McLane and W. W. Wierwille, Influence Of Motion and Audio Cues On Driver Performance In an Automobile Simulator. *Human Factors,* 17, 5, 1975.

A highway driving simulator with a computer-generated visual display, physical motion cues of roll, yaw, and lateral translation, and velocity-dependent sound/vibration cues was used to investigate the influence of these cues on driver performance. Forty-eight student subjects were randomly allocated to six experimental groups. Each group of eight subjects experienced a unique combination

of the motion and audio cues. The control group received a full simulation condition while each of the remaining five groups performed with certain combinations of motion and sound deleted. Results indicate that the performance measures of yaw, lateral and velocity deviation are significantly affected by the deletion of cues. In support of the hypothesis that driver performance is augmented by the addition of motion cues, statistically significant negative correlations were obtained between the number of motion cues present and the measures of yaw and lateral deviation. With respect to motion and audio cues, recommendations are made regarding simulator design criteria. 9 refs.

20. G. K. J. Miller and P. L. Deal, Moving-base visual simulation study of decoupled controls during approach and landing of a STOL transport aircraft. NASA-TN-D-7790; L-9721, 1975.

The simulation employed all six rigid-body degrees of freedom and incorporated aerodynamic characteristics based on wind-tunnel data. The flight instrumentation included a localizer and a flight director which was used to capture and to maintain a two-segment glide slope. A closed-circuit television display of a STOL port provided visual cues during simulations of the approach and landing. The decoupled longitudinal controls used constant prefilter and feedback gains to provide steady-state decoupling of flight-path angle, pitch angle, and forward velocity. The pilots were enthusiastic about the decoupled longitudinal controls and believed that the simulator motion was an aid in evaluating the decoupled controls, although a minimum turbulence level with root-mean-square gust intensity of 0.3 m/sec (1 ft/sec) was required to mask undesirable characteristics of the moving-base simulator.

21. J. A. Neff and A. M. Junker, Effects of motion on the parameters of the human operator engaged in a roll axis tracking task. *In: Conference on Decision and Control, 5th and Symposium on Adaptive Processes, 13th, Phoenix, Ariz., November 20-22, 1974, Proceedings. (A75-37134 17-63) New York, Institute of Electrical and Electronics Engineers, Inc., 1974, p. 167, 168.,* 1974.

A multiple-input single-output linear state variable model is used to determine the extent to which a human controller involved in a compensatory tracking task uses cues other than the visual error signal to improve his tracking performance. The control system used in this study is a roll axis chair designed to simulate roll in a high performance aircraft. The additional cues studied are the angular position and angular velocity of the human controller.

22. R. V. Parrish, B. T. McKissick and B. R. Ashworth, Comparison of simulator fidelity model predictions with in-simulator evaluation data. NASA-TP-2106; L-15519; NAS 1.60:2106, 1983.

A full factorial in simulator experiment of a single axis, multiloop, compensatory pitch tracking task is described. The experiment was conducted to provide data to validate extensions to an analytic, closed loop model of a real time digital simulation facility. The results of the experiment encompassing various simulation fidelity factors, such as visual delay, digital integration algorithms, computer iteration rates, control loading bandwidths and proprioceptive cues, and g-seat kinesthetic cues, are compared with predictions obtained from the analytic model incorporating an optimal control model of the human pilot. The in-simulator results demonstrate more sensitivity to the g-seat and to the control loader conditions than were predicted by the model. However, the model predictions are generally upheld, although the predicted magnitudes of the states and of the error terms are sometimes off considerably. Of particular concern is the large sensitivity difference for one control loader condition, as well as the model/in-simulator mismatch in the magnitude of the plant states when the other states match.

23. R. J. Peterka and F. O. Black, Role of orientation reference selection in motion sickness, Semiannual Status Report. NASA-CR-181393; NAS 1.26:181393, 1987.

Previous experiments with moving platform posturography have shown that different people have varying abilities to resolve conflicts among vestibular, visual, and proprioceptive sensory signals. The conceptual basis of the present proposal hinges on the similarities between the space motion sickness problem and the sensory orientation reference selection problems associated with benign paroxysmal positional vertigo (BPPV) syndrome. These similarities include both etiology related to abnormal vertical canal-otolith function, and motion sickness initiating events provoked by pitch and roll head movements. The objectives are to explore and quantify the orientation reference selection abilities of subjects and the relation of this selection to motion sickness in humans. The overall objectives are to determine: if motion sickness susceptibility is related to sensory orientation reference selection abilities of subjects; if abnormal vertical canal-otolith function is the source of abnormal posture control strategies and if it can be quantified by vestibular and oculomotor reflex measurements, and if it can be quantified by vestibular and oculomotor reflex measurements; and quantifiable measures of perception of vestibular and visual motion cues can be related to motion sickness susceptibility and to orientation reference selection ability.

24. R. J. Peterka and F. O. Black, Role of orientation reference selection in motion sickness, Semiannual Status Report. NASA-CR-191912; NAS 1.26:191912, 1992.

The overall objective of this proposal is to understand the relationship between human orientation control and motion sickness susceptibility. Three areas related to orientation control will be investigated. These three areas are (1) reflexes associated with the control of eye movements and posture, (2) the perception of body rotation and position with respect to gravity, and (3) the strategies used to resolve sensory conflict situations which arise when different sensory systems provide orientation cues which are not consistent with one another or with previous experience. Of particular interest is the possibility that a subject may be able to ignore an inaccurate sensory modality in favor of one or more other sensory modalities which do provide accurate orientation reference information. We refer to this process as sensory selection. This proposal will attempt to quantify subjects' sensory selection abilities and determine if this ability confers some immunity to the development of motion sickness symptoms. Measurements of reflexes, motion perception, sensory selection abilities, and motion sickness susceptibility will concentrate on pitch and roll motions since these seem most relevant to the space motion sickness problem. Vestibulo-ocular (VOR) and oculomotor reflexes will be measured using a unique two-axis rotation device developed in our laboratory over the last seven years. Posture control reflexes will be measured using a movable posture platform capable of independently altering proprioceptive and visual orientation cues. Motion perception will be quantified using closed loop feedback technique developed by Zacharias and Young (Exp Brain Res, 1981). This technique requires a subject to null out motions induced by the experimenter while being exposed to various confounding sensory orientation cues. A subject's sensory selection abilities will be measured by the magnitude and timing of his reactions to changes in sensory environments. Motion sickness susceptibility will be measured by the time required to induce characteristic changes in the pattern of electrogastrogram recordings while exposed to various sensory environments during posture and motion perception tests. The results of this work are relevant to NASA's interest in understanding the etiology of space motion sickness. If any of the reflex, perceptual, or sensory selection abilities of subjects are found to correlate with motion sickness susceptibility, this work may be an important step in suggesting a method of predicting motion sickness susceptibility. If sensory selection can provide a means to avoid sensory conflict, then further work may lead to training programs which could enhance a subject's sensory selection ability and therefore minimize motion sickness susceptibility.

25. B. S. Repa, P. M. Leucht and W. W. Wierwille, The influence of motion cues on driver-vehicle performance in a simulator. *In JPL Proc. of the 17th Ann. Conf. on Manual Control p 157-169 (SEE N82-13665 04-54),* 1981.

Four different motion base configurations were studied on driving simulator. Differently responding vehicles were simulated on each motion configurations and the effects of the vehicle characteristics on driver vehicle system performance, driver control activity, and driver opinion ratings of vehicle performance during driving are compared for different motion configurations. Data show that: (1)) the effects of changes in vehicle characteristics on the different objective and subjective measures of driver vehicle performance are not disguised by the lack of physical motion; (2) fixed base simulator can be used to draw inferences despite the lack of motion; (3) the presence of motion tends to reduce path keeping errors and driver control activity; (4) roll and yaw motions are recommended because of their marked influence on driver vehicle performance (5) the importance of motion increases as the driving maneuvers become more extreme.

26. B. S. Repa, P. M. Leucht and W. W. Wierville, Effect Of Simulator Motion On Driver Performance. *SAE Preprints (Society of Automotive Engineers) Publ by SAE, Warrendale, Pa, USA 820307, 16p,* 1982.

27. R. F. Ringland and R. L. Stapleford, Motion cue effects on pilot tracking Motion cue effects on pilot manual control tracking task. *In NASA, Washington 7th Ann. Conf. on Manual Control p 327-338 (SEE N73-10104 01-05),* 1972.

The results of two successive experimental investigations of the effects of motion cues on manual control tracking tasks are reported. The first of these was an IFR single-axis VTOL roll attitude control task. Describing function data show the dominant motion feedback quantity to be angular velocity. The second experimental task was multiaxis, that of precision hovering of a VTOL using separated instrument displays with reduced motion amplitude scaling. Performance data and pilot opinion show angular position to be the dominant cue when simulator linear motion is absent.

28. R. H. So and M. J. Griffin, Effect of Lags on Human Performance with Head-Coupled Simulators, Final rept. 1 Jul-30 Nov 92. 1993.

This report reviews factors contributing to the effects of lags in head-coupled systems. A model of head tracking behavior is defined with appropriate feedback loops. The relevant lags and their possible effects on operator performance are defined. Twenty-one head-coupled simulators and operational head-coupled airborne systems are listed and grouped according to their feedback loops. Studies of the effects of lags within individual feedback loops are reviewed. The feedback loops investigated were the head-coupled visual loop, the head-slaved weapon control loop, the manual control loop, the eye-coupled visual loop, and the eye-slaved weapon control loop. The effects of relevant task and simulator variables, such as target velocity and motion cues are also discussed.

29. R. L. Stapleford, Multimodality pilot model for visual and motion cues Multimodality model of pilot control behavior using visual and motion cues. *In Nasa, Washington Fourth Ann. Nasa- Univ. Conf. On Manual Control 1969 P 47-57 /See N70-14876 04-05/,* 1969.

30. J. Starke, Overcontrolling, residual oscillations, PIO, a feature of high order, high gain, flight control systems - Pilot Induced Oscillations. *AIAA, AHS, IES, SETP, SFTE, and DGLR, Flight Testing Conference, 2nd, Las Vegas, NV, Nov,* 1983.

Examples are given of pilot-induced oscillation (PIO) observed in recent years with modern high-gain, high-order control systems. These situations were caused by transients and system change-overs or by pilot overreaction upon such transients. They were encountered without any warning in flight regimes thought to be PIO-resistant. Consideration is given to PIO in linear and non-linear systems, PIO due to misleading pilot cue, and PIO due to excessive pilot gain. The importance of checking all flight controls and all pilot cues for possible nonlinearities is stressed. These nonlinearities include freeplay (mechanical or electrical), aerodynamic nonlinearities, feedback limitations, and nonlinearities due to system saturation.

31. J. A. Waterston et al., Influence Of Sensory Manipulation On Postural Control In Parkinsons-Disease. 1993.

Postural control was assessed on a tilting platform system in 20 patients with idiopathic Parkinson's disease and 20 age-matched controls. The amount of information provided by vision and lower limb proprioception was varied during the experiment to investigate the influence of changes in sensory cues on postural control. The patient group with clinical evidence of impaired postural control (Hoehn and Yahr III) had significantly higher sway scores over all sensory conditions than either the Hoehn and Yahr II group or controls. The pattern of sway scores indicated that no obvious deficit in the quality, dr processing, of sensory information was responsible for the postural instability observed in this group. The patients in both Hoehn and Yahr groups were also able to respond appropriately to potentially destabilising sensory conflict situations and significantly improved their sway scores when provided with visual feedback of body sway. The results indicate that in Parkinson's disease, the main site of dysfunction in postural control is likely to be at a central motor level.

32. W. W. Wierwille and P. P. Fung, Comparison Of Computer-Generated and Simulated Motion Picture Displays In a Driving Simulation. *Human Factors*, 17, 6, 1975.

An automotive driving simulator with a computer-generated display system, three axes of physical motion (roll, yaw, and lateral translation), sound, and vibration cues was used to investigate and compare human psychomotor response and vehicle response to different types of displays and motion cues. Subjects drove the simulator under four levels of displays; three being simulated preprogrammed motion picture displays (MPDS), one being the standard computer-generated display (CGDS). Motion and no-motion conditions were instituted at each display level. Each data run included lane-keeping and lane-changing tasks for various simulated highway conditions. During lane changes under MPDS conditions, both preprogrammed and non preprogrammed simulator conditions were examined. Seven dependent variables were used to measure performance. Results of the experiment show that one level of the simulated preprogrammed MPDS produced performance similar to that of a CGDS in all seven measures, whereas the other levels differed significantly. This suggests that using a properly instrumented preprogrammed MPDS will not compromise experimental results for certain research and educational experiments, and that in many cases an economical simulation using an MPDS would be adequate. 10 refs.

33. W. W. Wierwille, J. G. Casali and B. S. Repa, Driver Steering Reaction Time to Abrupt-Onset Crosswinds, As Measured In a Moving-Base Driving Simulator. *Human Factors*, 25, 1, 1983.

Experiment 1 revealed that RT was significantly shorter when physical-motion cues were present. A second variable, vehicle yaw rate rise time, showed no effect. In Experiment 2, design parameters influencing aerodynamic behavior of a vehicle were adjusted. RT increased as the vehicle center of pressure (point of crosswind application) moved rearward from the front axle. However, rearward movement of the center of pressure also produced less disturbance of the vehicle itself. Changes in understeer and steering sensitivity yielded no significant effect. In experiment 3, both uninitiated drivers and drivers with time on task were examined. Neither the first exposure to a step gust nor driving time up to 150 min caused significant changes in RT when performance was compared with that of practiced, fresh drivers. Inter-experiment comparisons using crosswind amplitude and shape as independent variables demonstrated that the amplitude and rise time of the crosswinds were critical determinants of steering RT. 31 refs.

34. C. K. Wojcik, Motion simulation techniques for driving simulators. *ASME Paper*, 1969.

Purpose of motion simulating system in driving simulator is to provide driver with kinesthetic cues that are appropriate for driving simulation presented to him by visual display; these kinesthetic cues are derived from forces acting on driver's body; among these forces, inertia forces are of primary importance here since they signal changes in motion of vehicle; ways of simulating these forces, as well as human ability to perceive them, are discussed here in great detail. 8 refs.

35. L. R. Young, Studies of human dynamic space orientation using techniques of control theory, Final Report, 1964 - 1974. NASA-CR-146858, 1974.

Studies of human orientation and manual control in high order systems are summarized. Data cover techniques for measuring and altering orientation perception, role of non-visual motion sensors, particularly the vestibular and tactile sensors, use of motion cues in closed loop control of simple stable and unstable systems, and advanced computer controlled display systems. For individual titles, see N76-21893 through N76-21897.

Driving Behavior & Cues - Appendix E

1. D. Mahalel and Z. Szternfeld, Safety Improvements and Driver Perception. *Accident Analysis and Prevention*, 18, 1, 1986.

   The argument is advanced that, in certain cases, the common belief that simplification of the driving task increases safety might be misleading. This might be the situation following engineering improvements. Driver confidence in the system may then be increased and driving task difficulties may be underestimated. As a result, decision criteria will be biased and driver attention level decreased. The overall effect is a degradation in driver performance which is due to a poorer detection of relevant cues and to poorer criteria. This degradation ultimately leads to an increase in accidents. The challenge of road engineering, therefore, should be to find the optimal balance between environmental demands (e. g. engineering standards and design levels) and drivers' perception of task difficulties. (Edited author abstract) 16 refs.

2. D. V. McGehee, T. A. Dingus and A. D. Horowitz, Potential value of a front-to-rear-end collision warning system based on factors of driver behavior, visual perception and brake reaction time. *Proceedings of the Human Factors Society v 2. Publ by Human Factors Soc Inc, Santa Monica, CA, USA. p 1003-1005,* 1992.

   The potential value of a front-to-rear-end collision warning system based on factors of driver behavior, visual perception and brake reaction time is examined in this paper. Twenty-four percent of all motor vehicle crashes involving two or more vehicles are front-to-rear-end collisions. These collisions demonstrate that several driver performance factors are common. The literature indicates that drivers use the relative size and the visual angle of the vehicle ahead when making judgments regarding depth. In addition, drivers often have difficulty gauging velocity differences and depth cues between themselves and the vehicle they are following. Finally, drivers often follow at distances that are closer than brake-reaction time permits for accident avoidance. It is apparent that the comfort level of close following behavior increases over time due to the rarity of consequences. Experience also teaches drivers that the vehicle in front does not suddenly slow down very often. On the basis of these driver behavior and human performance issues, a front-to-rear-end collision warning system that provides headway/following distance and velocity change information is considered. Based on the driver performance issues, display design recommendations are outlined. The value of such a device may be demonstrated by the added driver safety and situation awareness provided. The long-term goal would ultimately be the reduction of one of the most frequent type of automobile crashes. (Author abstract) 18 Refs.

3. D. McLean, T. P. Newcomb and R. T. Spurr, Simulation Study Of Effects Of Motion Cues On Braking Performance Of Drivers. *Hum Oper and Simul, Symp, Collect Pap, Loughborough Univ of Technol, Engl, Mar*, 1977.

   A simulation study is described which was conducted to determine the factors which influence the performance of drivers in braking situations and to assess which motion cues result in the best performance. A mathematical model is proposed for the driver in the braking situation and results from the simulation study, based upon that model, are presented and compared with experimental evidence obtained from extensive road tests. 5 refs.

4. R. Rosness, Human Dependability Methods for Control and Safety Systems. STF75-A93060; ISBN-82-595-8562-6, 1994.

   The report describes a suite of methods for task analysis and human reliability analysis which have been selected in order to support prevention of human errors. The methods were selected and described in order to meet the needs associated with human dependability assurance in development and maintenance of offshore control and safety systems. The following methods are described: Goals-Means Task Analysis, which determines which subtasks are required to meet the overall objective of a task; Operations Sequence Diagramming, which identifies the necessary sequencing of task steps and the allocation of the task steps to individuals; Task features descriptions, which identifies cues, feedback and other characteristics of each task step; and Action Error Mode Analysis, which identifies possible human errors, consequences, barriers and preventive measures identified with a task. Appendix A introduces the concepts of Human Dependability and Human Dependability Assurance, and presents selected theories and taxonomies relevant to human reliability.

5. A. Smiley, L. Reid and M. Fraser, Vehicle Steering control: A model of learning. *In NASA. Ames Res. Center The 14th Ann. Conf. on Manual Control p 255-266 (SEE N79-15588 06-54),* 1978.

A hierarchy of strategies were postulated to describe the process of learning steering control. Vehicle motion and steering control data were recorded for twelve novices who drove an instrumented car twice a week during and after a driver training course. Car-driver describing functions were calculated, the probable control structure determined, and the driver-alone transfer function modelled. The data suggested that the largest changes in steering control with learning were in the way the driver used the lateral position cue.

6. A. Smiley, L. Reid and M. Fraser, Changes In Driver Steering Control With Learning. *Proc of the Human Factors Soc, Annu Meet, 22nd, Detroit, Mich, Oct,* 1978.

A hierarchy of strategies were postulated to describe the process of learning steering control. Vehicle motion and steering control data were recorded for twelve novices who drove an instrumented car twice a week during and after a driver training course. Driver describing functions were calculated. The data suggested that the largest changes in steering control with learning were in the way the driver used the lateral position cue. 6 refs.

7. G. L. J. Smith, Effect of stress on driver information seeking. *SAE Pap*, 720143, 1972.

This review suggests that both tired and intoxicated drivers exhibit adaptive behavior on a reduced peripheral sensitivity. The tired driver enlarges his pattern of foveal excursions to secure velocity cues, whereas the intoxicated driver abandons velocity as a task requirement. In both cases, the adaptation results in information seeking behavior which is degraded, in terms of the actual task demands, to the extent that unsafe performance is exhibited. Equipping vehicles with instrumentation which will augment that velocity and positional information which the driver receives may be one way of reducing this source of accidents. 11 refs.

8. D. H. Weir, R. H. Hoh and G. L. Teper, Driver-Vehicle Control and Performance In the Presence Of Aerodynamic Disturbances From Large Vehicles. *Transportation Research Record*, 520, 1974.

Procedures for investigating the effects of disturbances on driver-vehicle systems have been developed. Equations of motion define the lateral-directional dynamics of the vehicle, and multiloop describing functions model the driver's steering response to perceptual cues. The aerodynamic forces and moments can be determined from scale model experiments. The analytical and experimental results are presented. 9 refs.

Kinesthetic - Appendix F

1. J. A. Adams and L. R. Creamer, Proprioception Variables as Determiners of Anticipatory Timing Behavior. AFOSR-1407, 1962.

   Anticipatory timing, where the human operator initiates an accurate response before the actual occurrence of the environmental event, is one of the most striking and least studied aspects of skilled motor performance. An experiment was performed on temporal and control system variables that could influence the timing of responses in a tracking task. Verification was sought for a proprioceptive trace hypothesis that holds the time-varying proprioceptive after-effects of movements to be the internal trace that persists in time and cues the occurrence of a future response. Ninety-six subjects participated. A 2x2x2 randomized factorial design used two values each of movement amplitude, spring loading, and signal duration as a means of manipulating proprioceptive stimuli and their time trace. Results supported the hypothesis. Signal duration and spring loading of the control induced significant effects for the number of beneficial anticipations, but movement amplitude had no significant effect. It was concluded that proprioception has a role in response timing, in addition to its traditional one of informative feedback.

2. J. Fisk, J. R. Lackner and P. Dizio, Gravitoinertial Force Level Influences Arm Movement Control. *Journal Of Neurophysiology*, 69, 2, 1993.

   The ability to move the forearm between remembered elbow joint angles immediately after rapid increases or decreases of the background gravitoinertial force (G) level was measured. The movements had been well-practiced in a normal 1G environment before the measurements in high- (1.8G) and low-force (0G) environments. The forearm and upper arm were always unsupported to maximize the influence of altered G-loading and to minimize extraneous cues about arm position. the effects of varying the G load in the movement plane within a given G background. Rapid and slow movements were studied to assess the role of proprioceptive feedback. indicating that subjects were able to plan and to generate appropriate motor commands for the new G loading of the arm. The amplitude of slow movements was affected by G level, indicating that proprioceptive feedback is influenced by G level. movements, indicating that proprioceptive information from supporting structures, such as the shoulder joint and muscles, had a role in allowing generation of the appropriate motor commands. and for rapid movements. This G-related change in damping suggests a decrease in muscle spindle activity in 0G. A decrease in muscle spindle activity in 0G and an increase in 1.8G are consistent with the results of our prior studies on the tonic vibration reflex, locomotion, and perception of head movement trajectory in varying force backgrounds.

3. J. H. Herzog, *Proprioceptive cues and their influence on operator performance in manual control.* Michigan Univ. Thesis, 1967.

   Proprioceptive cues and their influence on operator performance in manual control

4. R. S. Johansson and K. J. Cole, Grasp Stability During Manipulative Actions. *Canadian Journal Of Physiology and Pharmacology*, 72, 5, 1994.

   The control of adequate contact forces between the skin and an object (grasp stability) is examined for two classes of prehensile actions that employ a precision grip: lifting objects that are "passive" (subject only to inertial forces and gravity) and preventing "active" objects from moving. For manipulating either passive or active objects the relevant fingertip forces are determined by at least two control processes. "Anticipatory parameter control" is a feedforward controller that specifies the values for motor command parameters on the basis of predictions of critical characteristics, such as abject weight and skin-object friction, and initial condition information. Through vision, for instance, common objects can be identified in terms of the fingertip forces necessary for a successful lift according to previous experiences. After contact with the object, sensory information representing discrete mechanical events at the fingertips can (i) automatically modify the motor commands, (ii) update sensorimotor memories supporting the anticipatory parameter control policy, (iii) inform the central nervous system about completion of the goal for each action phase, and (iv) trigger commands for the task's sequential phases. Hence, the central nervous system monitors specific, more or less expected peripheral sensory events to produce control signals that are appropriate for the task at its current phase. The control is based on neural modelling of the entire dynamics of the control process that predicts the appropriate output for several steps ahead. This "discrete-event, sensor-driven control" is distinguished from feedback or other continuous regulation. Using these two control processes, slips are avoided at each digit by independent control mechanisms that specify commands and process sensory information on a local, digit-specific basis. This scheme obviates explicit coordination of the digits and is employed when independent nervous systems lift objects. The force coordination across digits is an emergent property of the local control mechanisms operating over the same time span.

5. C. Kessel and C. D. Wickens, Development and utilization of internal models in dynamic systems: A comparison of monitors and operators as failure detectors, Interim Report. AD-A069730; EPL-78-2/AFOSR-78-5; AFOSR-79-0683TR, 1978.

The development of the internal model as it pertains to the detection of step changes in the order of control dynamics is investigated for two modes of participation: when the subjects are actively controlling those dynamics and when they are monitoring the same dynamics under autopilot control. The experiment used a transfer of training design to evaluate the relative contribution of proprioception and visual information to the overall accuracy of the internal model. The subjects either tracked or monitored the system dynamics of a 2-dimensional pursuit display under single task conditions and concurrently with a sub-critical tracking task at two difficulty levels. Detection performance was faster and more accurate in the manual as opposed to the autopilot mode. The cue utilization strategies of the subjects were analyzed by ensemble averaging technique and it was found that monitors of automatic systems who have had prior manual experience rely upon different perceptual cues in making their detection responses than those who have not. The proprioception channel was found to have an attention focusing role and once incorporated into the internal model this attention focusing mechanism can be used to advantage even when there is no proprioceptive feedback.

6. C. H. Lewis and M. J. Griffin, The effects of vibration on manual control performance. *Ergonomics*, 19, 1976.

A taxonomic model of human operator processes contributing to performance in vibration is used to study coordinated manual tracking during vibration. Experiments are carried out in which twelve subjects were required to perform zero-order pursuit tracking of a quasi-random forcing function in a horizontal axis with free-moving and spring-centered control levers. Performance is measured in terms of information channel capacity and frequency-dependent error. It is found that the subjects were better able to maintain tracking performance when isometric cues were provided in the control. It is suggested that interference with kinesthetic feedback mechanisms may be a major reason why vibration degrades tracking performance.

7. P. L. Noggle, Manual control of unstable vehicles using kinesthetic cues. NASA-CR-106370; MV-69-4, 1969.

Manually operated feedback control stick using kinesthetic cues for human operator of unstable vehicles.

8. S. Salvatore, Effect of removing acceleration cues on sensing vehicular velocity. *Perceptual and Motor Skills*, 28, 1, 1969.

Acceleration cues removal effects on vehicular velocity perception, using movie technique to control visual cues.

9. S. B. Smith, Limited Flight Evaluation of Side Stick Controller Force-Deflection Characteristics on Aircraft Handling Qualities. AFFTC-TR-77-34, 1977.

Air-to-air, air-to-ground, and instrument approach and landing tasks were used in the evaluation. Twenty-three flights were flown in the Calspan NT-33A, variable stability aircraft. Data presented consists of Cooper-Harper pilot ratings and comments on each side stick configuration. The air-to-air tracking test consisted of the AFFTC 'Handling Qualities During Tracking Technique'. For this task, the evaluation pilots preferred the combination of relatively large control stick motion with light control force gradients and, to a lesser degree, the combination of relatively small control stick motion with heavy control force gradients. A fixed stick was not evaluated. The aircraft's lateral-directional characteristics were objectionable during this tracking task (rudder pedal inputs were not used) and detracted from the pilot's ability to evaluate lateral control effectiveness and control harmony. Based upon a limited number of tests, it appeared that varying control force harmony did not improve pilot ratings. Data gathered during air-to-ground tracking or during landings were insufficient and did not lead to any conclusions. The approach tracking task, which was to track the Edwards AFB instrument landing system, did not enable the pilots to finely discriminate between control configurations, and no conclusions could be drawn.

10. J. P. Wann and S. F. Ibrahim, Does Limb Proprioception Drift. *Experimental Brain Research*, 91, 1, 1992.

The hypothesis that proprioceptively perceived limb position drifts during visual occlusion was re-examined by combining some of the protocols used in previous experiments. Sixteen adult subjects made judgments of static limb position during visual occlusion lasting up to 2 min. In addition, the effect of brief 250 ms "glimpses" of the limb, occasional proprioceptive stimulation and directed attention were examined. Despite, conflicting evidence from earlier experiments, there was clear evidence of a drift in perceived limb position, towards the body, during visual occlusion. This drift was halted if brief glimpses of the limb were provided, or minor re-positioning (without vision) was allowed. In neither case, however, did the supplementary cues reset limb position to its originally perceived position. Drift was amplified when subjects attempted to attend to limb position rather than perform a secondary tracking task. The results are not easily accounted for if drift is considered purely as an effect of peripheral sensor adaptation. A notion of central-drift between visual and proprioceptive maps is suggested as an alternative hypothesis.

11. C. K. Wojcik, Motion simulation techniques for driving simulators. *ASME-Paper 69-WA/GHF-10 for meeting Nov 16-20 1969, 8 p,* 1969.

Purpose of motion simulating system in driving simulator is to provide driver with kinesthetic cues that are appropriate for driving simulation presented to him by visual display; these kinesthetic cues are derived from forces acting on driver's body; among these forces, inertia forces are of primary importance here since they signal changes in motion of vehicle; ways of simulating these forces, as well as human ability to perceive them, are discussed here in great detail. 8 refs.

Simulators - Appendix G

1. R. W. Allen, J. R. Hogge and S. H. Schwartz, An interactive driving simulation for driver control and decision-making research. *In NASA. Ames Res. Center 11th Ann. Conf. on Manual Control p 396-407 (SEE N75-33675 24-54),* 1975.

   Display techniques and equations of motion for a relatively simple fixed base car simulation are described. The vehicle dynamics include simplified lateral (steering) and longitudinal (speed) degrees of freedom. Several simulator tasks are described which require a combination of operator control and decision making, including response to wind gust inputs, curved roads, traffic signal lights, and obstacles. Logic circuits are used to detect speeding, running red lights, and crashes. A variety of visual and auditory cues are used to give the driver appropriate performance feedback. The simulated equations of motion are reviewed and the technique for generating the line drawing CRT roadway display is discussed. On-line measurement capabilities and experimenter control features are presented, along with previous and current research results demonstrating simulation capabilities and applications.

2. B. Conrad, S. F. Schmidt and J. G. Douvillier, Washout circuit design for multi-degrees-of-freedom moving base simulators. *American Institute of Aeronautics and Astronautics, Visual and Motion Simulation Conference, Palo Alto, Calif., Sept. 10-12, 1973, 10 p.,* 1973.

   A mathematical framework is presented for designing logic to accept motion-dependent parameters from a simulation, attenuating them ('washing them out'), and generating appropriately limited drive signals. This framework is sufficiently general to encompass six-degree-of-freedom simulators with large motion capability. Emphasis is placed on preserving certain motion cue relations (such as those that would be observed in coordinated flight). Strategies for simulating side forces via tilts are shown. Finally, several specific circuits are shown. These circuits have proven to be readily adaptable to a variety of moving-base simulators.

3. C. S. Ernst and J. B. Sinacori, Methodology for determining motion system requirements for a land vehicle simulator. *Simulation Series v 21 n 3. Publ by Soc for Computer Simulation Int, San Diego, CA, USA. p 5-10,* 1989.

   Presented here is a methodology for defining requirements for a six-degree-of-freedom synergistic motion base system. The system is to be used for simulating the motions of heavy land vehicles, including both tracked and wheeled vehicles, for the purpose of performing human factors testing, developing new design concepts, and conducting other analyses. The following analysis was founded on work presented in (Sinacori, 1973), in which an algorithm for motion cueing was described. The algorithm was intended to be programmed and used for driving a six-degree-of-freedom flight simulator. The adapted version used for this analysis takes angular velocities and specific forces and modifies the inputs in such a way as to recover (reproduce) these quantities as closely as possible within limits of position, velocity, and acceleration imposed by motion system hardware. Three drive algorithm variations were analyzed for their abilities to recover the angular rates and specific forces produced by the vehicle traveling over a variety of terrains. (Edited author abstract) 3 Refs.

4. W. R. Garrott, Sizing the Motion Base of the National Advanced Driving Simulator, Final rept. VRTC-82-0210; DOT-HS-807 979, 1993.

   The National Advanced Driving Simulator (NADS) will move the simulator's cab so that realistic motion cues are provided to the simulator's driver. It is necessary to determine the motion base capabilities that the NADS will need to simulate different severities and types of driving maneuvers with adequate simulated motion fidelity. The objectives of the study were (1) to develop tools, based on existing vehicle dynamics simulations, simulator washout algorithms, and human perceptual models, that allow needed motion base capabilities to be determined and (2) to use these tools to perform analyses that determine the motion base capabilities needed by the NADS.

5. R. Hurdwell and M. J. Pilling, Active suspension and rear wheel steering make powerful research and development tools. *Vehicle Suspension and Steering Systems SAE Special Publications n*, 952, 1993.

Experience has shown that a vehicle equipped with Active suspension and rear wheel steering can be a very powerful tool for research into vehicle dynamics. Passive or 'adaptive' vehicle suspension systems can be emulated. This has considerable potential for shortening vehicle development times. Active systems provide the ability to separate dynamic modes from one another. This enables detailed examination of each effect without the cross coupling normally experienced with passive vehicles. The driver is an important part of the dynamic loop and ultimately it is he/she who must be able to control the vehicle with confidence, precision, and minimum fatigue. An Active vehicle is a powerful way to investigate the feedback and cues needed by the driver, and to produce objective requirements to achieve them. Thus armed, vehicle design, computer simulation and development functions can be more effective in getting better products more quickly to the market. (Author abstract) 3 Refs.

6. R. C. McLane and W. W. Wierwille, Influence Of Motion and Audio Cues On Driver Performance In an Automobile Simulator. *Human Factors*, 17, 5, 1975.

A highway driving simulator with a computer-generated visual display, physical motion cues of roll, yaw, and lateral translation, and velocity-dependent sound/vibration cues was used to investigate the influence of these cues on driver performance. Forty-eight student subjects were randomly allocated to six experimental groups. Each group of eight subjects experienced a unique combination of the motion and audio cues. The control group received a full simulation condition while each of the remaining five groups performed with certain combinations of motion and sound deleted. Results indicate that the performance measures of yaw, lateral and velocity deviation are significantly affected by the deletion of cues. In support of the hypothesis that driver performance is augmented by the addition of motion cues, statistically significant negative correlations were obtained between the number of motion cues present and the measures of yaw and lateral deviation. With respect to motion and audio cues, recommendations are made regarding simulator design criteria. 9 refs.

7. T. Suetomi et al., Driving simulator with large amplitude motion system. *SAE Trans*, 100, 6, 1991.

An advanced driving simulator has been developed at Mazda Yokohama Research Center. The primary use of this simulator is to research future driver-vehicle systems. In an emergency situation, a driver must respond rapidly to perceived motion and visual stimulus to avoid an accident. In such cases, because the time delay associated with the perception of motion cues is shorter than visual and auditory cues, the driver will strongly rely upon perceived motion to control the vehicle. Hence, a driving simulator to be used in the research of driver-vehicle interactions in emergency driving must include a high performance motion system capable of large amplitude lateral motion. The Mazda simulator produces motion cues in four degrees of freedom, provides visual and auditory cues, and generates control feel on the steering wheel. This paper describes the merit of the large amplitude motion system and the features of this newly developed driving simulator. (Author abstract) 6 Refs.

8. J. Svoboda, Development of an automobile simulator for the assessment and training of disabled drivers. PC E07/MF E01, 1989.

Description of the development of a prototype of a relatively low-cost, high-fidelity, microprocessor-based automobile simulator for the assessment and training of disabled and elderly drivers. The system, conceived as a modular one, consists of a cabin module, a computer module, a force-feel module and acoustic module. The cabin module is based on actual car hardware and has all the normal instrumentation and controls. The computer model includes computer hardware, system software and instructor facilities software. The vehicle model software module determines vehicle movements, as well as the engine parameters, in response to the driver control inputs. The fully interactive visual display module, including both hardware and software, generates the car simulator visual cues in response to the vehicle model position outputs. The force-feel and acoustic modules generate realistic control feel forces and acoustic cues in response to the vehicle model outputs.

9. D. H. Weir and C. K. Wojcik, The measurement of driver describing functions in simulated steering control tasks. *In NASA, Washington 7th Ann. Conf. on Manual Control p 209-218 (SEE N73-10104 01-05),* 1972.

Measurements of driver describing functions in steering control tasks have been made using a driving simulator. The task was to regulate against a random crosswind gust input on a straight roadway, in order to stay in the center of the lane. Although driving is a multiloop task in general, the forcing function and situation were configured so that an inner-loop visual cue feedback of heading angle of heading rate would dominate, and the driver's response was interpreted to be primarily single-loop. The driver describing functions were measured using an STI describing function analyzer. Three replications for each subject showed good repeatability within a subject. There were some inter-subject differences as expected, but the crossover frequencies, effective time delays, and stability margins were generally consistent with the prior data and models for similar manual control tasks. The results further confirm the feasibility of measuring human operator response properties in nominal control tasks with full (real-world) visual field displays.

10. W. W. Wierwille, Part-Task Driving Simulator For Teaching and Research. *COED Transactions*, 5, 12, 1973.

It was decided to design and build a simulator for the study of human response in highway driving and to do so with several objectives: as an aid in analog/hybrid computer programming instruction, as a demonstration of man-machine system simulation, as a design problem and as a facility for research. The simulator that was constructed provides a variety of visual, motion, and audio cues to the subject to achieve a good degree of realism. The visual scene is generated by using hybrid computation and by subsequently performing a scan conversion to closed-circuit television format. Physical motion and display modification are controlled by an analog computer, which simulates the vehicle equations of motion. Closed-loop control of the simulation by the human subject is accomplished by electrically sensing the steering wheel, accelerator, and brake inputs, and applying them as inputs to the simulated equations of motion. 12 refs.

Tactile - Appendix H

1. Department of the Navy, Navy Reviews Teletouch Display Development, NTIS Tech Note. 150401/TN, 1991.

This citation summarizes a one-page announcement of technology available for utilization. Human-tactual capabilities and previous efforts in tactile-display development have been reviewed by the Naval Ocean Systems Center (NOSC), San Diego, California, and approaches are recommended for developing teletouch-display systems for telerobotic systems. Teleoperated manipulators currently in use rely mainly upon visual feedback to accomplish simple manipulation tasks. In some cases to enhance manipulative capabilities, force reflection and positional correspondence are provided between slave manipulator and master controller arms, along with simple end-effector proximity and slip sensors. Impressive developments in contact-force transduction have occurred over the past decade. A few experimental devices have demonstrated sensing capabilities exceeding several criteria viewed as ideal not more than a few years ago. However, significant development hurdles still remain to be cleared in transducing and extracting information from tactile-sensor inputs. Present algorithms are efficient only for simple manipulation tasks or when using a highly constrained search space for object identification. Increasing the difficulty of object identification or relying upon multiple tactual cues to complete complex manipulations, demands human intervention to fuse, selectively filter sensor information, construct and test precepts, and to plan and execute control over manipulators.

2. K. B. Shimoga, Survey of perceptual feedback issues in dexterous telemanipulation: part II. finger touch feedback. *IEEE Annual Virtual Reality International Symposium,* 1993.

This paper (Part II of II) surveys the existing touch display technologies in the literature. This survey indicates 5 main approaches to touch feedback, involving visual, pneumatic, vibro-tactile, electro-tactile and Neuromuscular stimulations. A pneumatics approach could use air-jets, air pockets or inflatable bladders to provide touch feedback cues to the operator. Similarly, the vibro-tactile approach could use vibrating pins, voice coils, or piezoelectric crystals to provide tickling sensation to the human operator's skin to signal the touch. The electro-tactile stimulation method can provide electric pulses, of appropriate width and frequency, to the skin while the neuromuscular stimulation approach provides the signals directly to the primary cortex of the operator's brain. With regard to this, seventeen (17) devices, most of whom were built for sensory substitution purposes, have been examined and compared for their suitability as touch feedback devices for dexterous telemanipulation. 6 Refs.

3. S. F. Wiker et al., Comparison of force and tactile feedback for grasp force control in telemanipulation. *In NASA, Lyndon B. Johnson Space Center, Fourth Annual Workshop on Space Operations Applications and Research (SOAR 90) p 104-112 (SEE N91-20641 12-59),* 1991.

The comparative efficacy of using direct force feedback or a simple vibrotactile display to convey changes in the intensity of remote grasp force relayed from a robotic end effector is examined. The findings show that a simple vibrotactile cue, in the absence of direct force feedback, is effective in signaling abrupt changes in remote grasp force regardless of magnitude, and when changes in force are not too slow or protracted in nature (i.e., ramp time less than 2 s). In cases where the operator must dynamically tract and respond to slow but large variations in grasp force, the comparatively crude vibrotactile display would prove helpful; but would not be as effective as that of a direct contact force display. Immediate applications and utility of current generation and near-term prototype tactile displays are discussed.

Vestibular - Appendix I

1. B. R. Ashworth and B. T. McKissick, Effects Of Helmet Loader Cues On Simulator Pilot Performance. *Journal of Aircraft*, 16, 11, 1979.

   In high-performance aircraft, the g forces on the pilot's helmet provide important feedback concerning the aircraft's dynamic state, as well as limiting the pilot's ability to move his head when the g forces are high. A helmet loader has been designed to provide the effects of these forces in aircraft simulators. In order to determine the effect of the helmet loader on a pilot's performance, an experiment was performed in the DMS, consisting of a tracking task using an F-14 aircraft simulation. Pertinent system states were recorded and analyzed using univariate and multivariate statistical algorithms. Analysis of the data indicates that pitch control increases significantly during the transition phases of the task when the helmet loader is activated. Overall, the variation in the performance measures are reduced under the helmet loader activated condition, indicating more precise control of the aircraft simulator for this task. 3 refs.

2. G. L. Zacharias and L. R. Young, Manual control of yaw motion with combined visual and vestibular cues. *In its Proc., 13th Ann. Conf. on Manual Control p 389-402 (SEE N79-17475 08-51),* 1977.

   Measurements are made of manual control performance in the closed-loop task of nulling perceived self-rotation velocity about an earth-vertical axis. Self-velocity estimation was modelled as a function of the simultaneous presentation of vestibular and peripheral visual field motion cues. Based on measured low-frequency operator behavior in three visual field environments, a parallel channel linear model is proposed which has separate visual and vestibular pathways summing in a complementary manner. A correction to the frequency responses is provided by a separate measurement of manual control performance in an analogous visual pursuit nulling task. The resulting dual-input describing function for motion perception dependence on combined cue presentation supports the complementary model, in which vestibular cues dominate sensation at frequencies above 0.05 Hz. The describing function model is extended by the proposal of a non-linear cue conflict model, in which cue weighting depends on the level of agreement between visual and vestibular cues.

Visual - Appendix J

1. J. D. Dillow, D. G. Picha and R. O. Anderson, Slushy weightings for the optimal pilot model considering visual tracking task. *In NASA. Ames Res. Center 11th Ann. Conf. on Manual Control p 526-540 (SEE N75-33675 24-54),* 1975.

   A pilot model is described which accounts for the effect of motion cues in a well defined visual tracking task. The effect of visual and motion cues are accounted for in the model in two ways. First, the observation matrix in the pilot model is structured to account for the visual and motion inputs presented to the pilot. Secondly, the weightings in the quadratic cost function associated with the pilot model are modified to account for the pilot's perception of the variables he considers important in the task. Analytic results obtained using the pilot model are compared to experimental results and in general good agreement is demonstrated. The analytic model yields small improvements in tracking performance with the addition of motion cues for easily controlled task dynamics and large improvements in tracking performance with the addition of motion cues for difficult task dynamics.

2. U. Fligge, M. Soodeen and K. Moebes, Visual system performance for driving simulators. MBB-FE-521-S-PUB-0497; ETN-93-93439, 1992.

   Visual system features which are necessary in providing effective visual cues to a driver are addressed. A selected number of applications for driver simulators are described and associated to a class of visual systems. A medium class visual system is then used to create a basis for a definition between required driver visual cues and visual system performance and features. Driver simulation application is concluded as presenting a great challenge to the visual system because of its complexity. The variation of requirements demand that the visual system be based upon a modular design (multichannel system, varying channel resolution) and support a range of system features (z buffer, texture, three dimensional fixed/moving objects, footprint elevation, and fading algorithm). Other features which enhance the acceptance of a visual system as an information source for a driver are the scene update rate and video output format.

3. S. G. Hart and V. Battiste, The use of visual cues for vehicle control and navigation. *In its Visually Guided Control of Movement p 7-23 (SEE N92-21467 12-53),* 1991.

   At least three levels of control are required to operate most vehicles: (1) inner-loop control to counteract the momentary effects of disturbances on vehicle position; (2) intermittent maneuvers to avoid obstacles, and (3) outer-loop control to maintain a planned route. Operators monitor dynamic optical relationships in their immediate surroundings to estimate momentary changes in forward, lateral, and vertical position, rates of change in speed and direction of motion, and distance from obstacles. The process of searching the external scene to find landmarks (for navigation) is intermittent and deliberate, while monitoring and responding to subtle changes in the visual scene (for vehicle control) is relatively continuous and 'automatic'. However, since operators may perform both tasks simultaneously, the dynamic optical cues available for a vehicle control task may be determined by the operator's direction of gaze for wayfinding. An attempt to relate the visual processes involved in vehicle control and wayfinding is presented. The frames of reference and information used by different operators (e.g., automobile drivers, airline pilots, and helicopter pilots) are reviewed with particular emphasis on the special problems encountered by helicopter pilots flying nap of the earth (NOE). The goal of this overview is to describe the context within which different vehicle control tasks are performed and to suggest ways in which the use of visual cues for geographical orientation might influence visually guided control activities.

4. R. A. Hess and K. K. Chan, A model of the human's use of visual field cues in nap-of-the-earth flight. *IN: Guidance, Navigation and Control Conference, Williamsburg, VA, August 18-20, 1986, Technical Papers (A86-47401 23-63). New York, American Institute of Aeronautics and Astronautics, 1986, p. 875-885.,* 1986.

   A model for the human pilot's use of visual field cues for vehicular control in nap-of-the-earth flight is quantified and combined with a structural model of the human pilot. As such, the model represents a description of preview control for this flight task. Manned simulation and flight test experiments for low altitude lateral-directional maneuvering provide corroborative data for the modeling approach. The model is seen to represent a qualitative as well as quantitative method for analyzing relevant perceptual factors in low altitude vehicular control.

5. R. A. Hess, Simple control-theoretic models of human steering activity in visually guided vehicle control. *In NASA. Ames Research Center, Visually Guided Control of Movement p 115-120 (SEE N92-21467 12-53),* 1991.

A simple control theoretic model of human steering or control activity in the lateral-directional control of vehicles such as automobiles and rotorcraft is discussed. The term 'control theoretic' is used to emphasize the fact that the model is derived from a consideration of well-known control system design principles as opposed to psychological theories regarding egomotion, etc. The model is employed to emphasize the 'closed-loop' nature of tasks involving the visually guided control of vehicles upon, or in close proximity to, the earth and to hypothesize how changes in vehicle dynamics can significantly alter the nature of the visual cues which a human might use in such tasks.

6. J. J. Koenderink and A. J. Van Doorn, Exterospecific component of the motion parallax field. *Optical Society of America, Journal,* 71, 1981.

For the egocentric orientation of observers moving with respect to a plane (e.g., pilots and automobile drivers), the movement parallax field provides the main cue. The parallax field is split into a lamellar and a solenoidal part, and it is shown that the solenoidal part is purely propriospecific. For instance, it can be shown that this component can be completely canceled by an appropriate eye movement. Thus all exterospecific information is contained in the lamellar part, and this part is completely determined by the divergence of the parallax field. Thus the measure of expansion of the visual field as a function of direction of gaze is sufficient to provide all information available for egocentric orientation. It is further shown that the widely used focus of expansion, as introduced by Gibson, is not invariant against eye movements and does not (in general) correspond to extrema of the divergence.

7. D. P. Miller and D. E. McGovern, A laboratory-simulation approach to the evaluation of vision systems for teleoperated vehicles. *Presented at the International Symposium on Teleoperation and Control, Bristol, United Kingdom, 12 Jul. 1988,* 1988.

In order to perform teleoperated missions successfully, a remote vehicle operator must be provided with adequate feedback information. The limited bandwidth of the transmission media, however, forces trade-offs between channel quantity and fidelity. Since conveying vehicle motion cues to the driver in the field is impractical, the primary mode of feedback is visual, via and on-board closed-circuit television system. Intelligent allocation of video bandwidth is predicated on determining which video resolution, field-of-view, color, steering coupling, and the use of multiple cameras. Sandia National Laboratories is conducting mobility testing to study these effects on off-road, remote driving performance. Recent activities included conducting an experiment to investigate the relationships between remote driving performance and laboratory visual performance tasks using videotapes of off-road driving recorded with the vision systems of interest. Subjects participated either in actual remote driving (teleoperation) or in video simulation of remote driving using three different video systems currently being considered for prototype teleoperated vehicle. This paper discusses the results of the experiment. Analysis of the data suggests that the laboratory simulation technique is viable for comparing obstacle detection and identification performance while using different video systems. The establishment of a valid, inexpensive laboratory simulation technique can lead to a cost-effective means of evaluating and comparing numerous combinations of video system parameters for use in teleoperated land vehicles.

8. M. Nagata and H. Kuriyama, Visual Behavior Of Novice and Experienced Drivers. *SAE Preprints (Society of Automotive Engineers) Publ by SAE, Warrendale, Pa, USA 820415, 12p,* 1982.

9. R. A. Olsen, Quantifying the Night Driver's Visual Environment. FHWA/RD-80/096, 1980.

The complexity of a driver's tasks in safely and efficiently utilizing the highway system is largely dependent upon the inputs presented to the visual senses. Visual complexity is determined by road geometry; maneuvering of other traffic; adjacent land uses; pedestrian activity; weather; traffic control devices, lighting, and maintenance of the road features; and many other factors. Darkness changes the visual environment by reducing many cues and by adding a few others. Some of these are added for the driver's benefit, some for other purposes, and some are uncontrolled or uncontrollable at least by highway agencies. In this review of selected literature and research approaches, the objective is to suggest promising next steps toward making decisions on design, selection, and provision of aids to drivers for night driving.

10. J. J. F. Parket, R. R. Gilbert and R. F. Dillon, Effectiveness of Three Visual Cues in the Detection of Rate of Closure at Night. BTI-64-1, 1964.

This study was concerned with an evaluation of the visual cues used by a driver at night as he decides he is overtaking the vehicle in front of him. Three cues were selected for study. These were: (1) Change in apparent area (size) of taillight surfaces. (2) Change in apparent brightness of taillight surfaces. (3) Change in visual angle subtended by taillights. The following conclusions are drawn from the data of this study: (1) The control condition, in which normal taillights were used, is significantly superior to the operation of any single cue. (2) The visual angle cue and the brightness cue each are superior to the area cue. (3) Level of visual angle and level of brightness were found to be significant. Level of area was not. (4) Approach speed does not influence the effectiveness of any of the cue conditions or of the control conditions. (5) Sensitivity to change in the visual angle cue appears to conform to the Weber psychophysical function.

11. M. J. Queijo and D. R. Riley, Fixed-base simulator study of the effect of time delays in visual cues on pilot tracking performance. NASA-TN-D-8001; L-10152, 1975.

Factors were examined which determine the amount of time delay acceptable in the visual feedback loop in flight simulators. Acceptable time delays are defined as delays which significantly affect neither the results nor the manner in which the subject 'flies' the simulator. The subject tracked a target aircraft as it oscillated sinusoidally in a vertical plane only. The pursuing aircraft was permitted five degrees of freedom. Time delays of from 0.047 to 0.297 second were inserted in the visual feedback loop. A side task was employed to maintain the workload constant and to insure that the pilot was fully occupied during the experiment. Tracking results were obtained for 17 aircraft configurations having different longitudinal short-period characteristics. Results show a positive correlation between improved handling qualities and a longer acceptable time delay.

12. N. J. Rackoff and T. H. Rockwell, Driver Search and Scan Patterns In Night Driving. *Special Report National Research Council, Transportation Research Board,* no. 156, 1975.

Because the rates of nighttime accidents are higher than daytime accidents, much research has been directed to the problems of night driving. Many researchers concur that the driver receives most of his or her information through the visual system. During night driving, the visual cues normally available during daytime are reduced. This paper discusses and presents the results of two studies to investigate drivers' visual search patterns in night driving. The first study compares nighttime visual search behavior to daytime behavior on freeways and rural highways. The second study develops methods of using driver visual search data to evaluate illumination at rural highway intersections, which have high rates of nighttime accidents. 29 refs.

13. S. Salvatore, Response Speed As a Function Of Sensory Pattern and Alcohol In a Velocity Judgment Task. *Ergonomics*, 18, 5, 1975.

This research studied the accuracy and rapidity with which judgments of the speed of the vehicle in which the subject travels are formed. Fifteen subjects made velocity judgments in a laboratory setting simulating the visual and auditory cues generated by an automobile moving down the roadway at various speeds. This study analyses the speed of response in the forming of vehicular velocity judgments as the sensory input, upon which such judgment is based, varies. The results indicated the following: (1) The acquisition of velocity information is most rapid with visual information. (2) Within the visual modality peripheral stimulation requires more processing time than frontal information. (3) For all modalities studied reaction time increases as observation time increases from 0. 5 to 1. 0 sec. Decreasing observation time to less than 0. 5 sec does not further reduce processing time. (4) Interactive effects across subjects mask the effects of moderate blood alcohol levels on response speed. (5) Interpretation is modified by field conditions and driving skill. 17 refs.

14. P. Servos, M. A. Goodale and L. S. Jakobson, The Role Of Binocular Vision In Prehension - a Kinematic Analysis. *Vision Research*, 32, 8, 1992.

This study examined the contribution of binocular vision to the control of human prehension. Subjects reached out and grasped oblong blocks under conditions of either monocular or binocular vision. Kinematic analyses revealed that prehensile movements made under monocular viewing differed substantially from those performed under binocular conditions. In particular, grasping movements made under monocular viewing conditions showed longer movement times, lower peak velocities, proportionately longer deceleration phases, and smaller grip apertures than movements made under binocular viewing. In short, subjects appeared to be underestimating the distance of objects (and as a consequence, their size) under monocular viewing. It is argued that the differences in performance between the two viewing conditions were largely a reflection of differences in estimates of the target's size and distance obtained prior to movement onset. This study provides the first clear kinematic evidence that binocular vision (stereopsis and possibly vergence) makes a significant contribution to the accurate programming of prehensile movements in humans.

15. D. Shinar, E. D. McDowell and T. H. Rockwell, Eye Movements In Curve Negotiation. *Human Factors*, 19, 1, 1977.

Eye movements and fixations of five drivers were recorded and superimposed on a videotaped recording of the dynamic visual scene as they drove on a two-lane rural road. The results showed that (1) on curved roads, the fixation pattern follows the road geometry, whereas on straight roads, the search behavior is less active, and most of the fixations are close to the focus of expansion. The results indicate that in driving through curves drivers direct foveal fixations to lateral placement cues rather than rely on peripheral vision; (2) the process of curve scanning begins in the approach zone prior to the curve itself, suggesting that perceptually the curve negotiating process precedes the curve by several seconds; (3) the search patterns on right and left curves are not symmetrical; visual excursions to the right on right curves are greater than eye movements to the left on left curves; and (4) fixation duration statistics may be related to accident rates on curves. Implications of this study for the location of curve warning signs are given. 15 refs.

16. G. L. J. Smith, Effect of stress on driver information seeking. *SAE Pap*, 720143, 1972.

This review suggests that both tired and intoxicated drivers exhibit adaptive behavior on a reduced peripheral sensitivity. The tired driver enlarges his pattern of foveal excursions to secure velocity cues, whereas the intoxicated driver abandons velocity as a task requirement. In both cases, the adaptation results in information seeking behavior which is degraded, in terms of the actual task demands, to the extent that unsafe performance is exhibited. Equipping vehicles with instrumentation which will augment that velocity and positional information which the driver receives may be one way of reducing this source of accidents. 11 refs.

17. L. R. Young et al., Three display techniques at the man vehicle laboratory. *NASA Spec Publ*, 215, 1969.

A 3- D display system is described in which a simple computer- generated CRT contact analog system is controlled by movement of the observer's head, as well as by vehicle motion. The prototype VTOL guidance and control display presents attitude and guidance cues on an integrated horizontal situation display, with pitch and roll angles appearing as vehicle axis projections and using a predictive display of attitude and position. An antivertigo display is discussed that reduces visual-vestibular conflict by driving a rotating visual field at rates determined by a mathematical model for vestibular function. 5 refs.

Active Suspension Patents - Appendix K

1. J. C. Bennett, Single-acting damped hydraulic actuator for active vehicle suspension - has separator tube mounted on end cap which closes inner cylinder to provide duct from reservoir to external fluid source, <BASIC> US 5295563 _A _940322_9411.

<BASIC> US 5295563 A The active suspension hydraulic actuator comprises a reservoir tube closed at a first end and an inner cylinder concentrically mounted in the reservoir tube. A fluid reservoir is formed between the inner cylinder and the reservoir tube. An end cap closes a first end of the inner cylinder. A piston is slidably mounted in the inner cylinder, dividing an interior of the inner cylinder into two chambers. A hollow piston rod is secured at an inner end to the piston and projects through a second end of the inner cylinder. A separator tube is mounted on the end cap and extends through the piston and into the piston rod, providing a fluid conduit from a chamber adjacent the end cap and in communication with the reservoir to the hollow piston rod. A damping control valve is mounted on the actuator providing a selectively controllable fluid passage from the first chamber of the inner cylinder to the reservoir. USE - Automotive vehicle active suspension single-acting hydraulic actuator with damping capabilities. Dwg.1/4

2. T. Bertram and C. Cao, Yaw rate and transverse velocity determn. for vehicle - involves parameter estimation from measurements of transverse acceleration and steering angles of front and rear wheels, <BASIC> DE 4121954 _A1_930107_9302 <EQUIVALENTS> EP 523397 _A2_930120_9303; US 5311431 _A _940510_9418.

<BASIC> DE 4121954 A stochastic or least-squares approximation algorithm (1.1a) estimates a parameter (p) from which the rate of yaw (omega) and transverse velocity (Vy) can be reconstructed (1.1b). The front and rear deviation angles and lateral guidance forces can be deduced from these quantities by simple arithmetical calculation (1.2). The results can be applied directly for adjustments of vehicular dynamics in active four-wheel steering, antilock braking, wheelslip control, and active suspension control by means of operations on adjustable dampers. ADVANTAGE - Relevant data of vehicular movement can be determined continuously from min. number of sensors. Dwg.2/2

<US> 9418 US 5311431 A The method involves obtaining the yawing velocity w and the transverse velocity vy of a vehicle so that these values can be employed, for example, in regulating the vehicle system, with the values being determined with the aid of simple sensors. Measured values are obtained for the transverse acceleration ay and the steering angles d of the two axles, and the yawing velocity w and the vehicle's transverse velocity vy are estimated therefrom in a state estimator. USE - For continuously determining relevant vehicle motion values. Dwg.2/2

3. H. W. Bleckmann et al., Combined control and safety system for motor vehicle - uses same sensors to evaluate safety level allowing for interaction between road irregularities and steering maneuvers, <BASIC> DE 3939292 _A _910529_9123 <EQUIVALENTS> WO 9108120 _A _910613_9126; EP 502846 _A1_920916_9238; EP 502846 _B1_931103_9344; DE 59003375_G _931209_9350; ES 2047338 _T3_940216_9411.

<BASIC> DE 3939292 The processing circuit operates on signals representing road speed (VF), throttle opening (phi) brake pedal movement (SP), steering angle (delta), suspension-levelling pressure (PN), chassis acceleration (aA) and wheel vertical acceleration (aR). The angles (phi, delta) are differentiated and the accelerations (aA,aR) integrated and band-pass filtered for combination with the output of a safety stage. The control circuit incorporating a stored characteristic of damper variation (delta B) vs. modified safety level (S bar) adjusts brake pressure and shock-absorber sensitivity as required. ADVANTAGE - esp. inexpensive and easily mfd. system fulfills all requirements of antilock braking , wheelslip control and chassis adjustment for comfort and safety. @(12pp Dwg.No.30/8)@

<EP> 9344 EP 502846 B A compound control system for automotive vehicles comprising hydraulically operated control members of a vehicle suspension system, comprising an anti-lock control system, an auxiliary-energy source, sensors for gathering measured quantities and electronic circuits for assessing the sensor signals and for generating corrective signals for the suspension control system and for the anti-lock control system, characterized in that the system substantially comprises an active or semi-active suspension control system with controllable shock absorbers (9, 10) and an anti-lock and/or traction slip control system with braking pressure modulators (5) or braking pressure control valves, in that analyzing and controlling circuits (6) are provided for processing signals issued by sensors (11 to 17) which are jointly associated

with the suspension control system and the anti-lock control/traction slip control system, in that the analyzing circuits determine a safety level (S) from sensor signals or, respectively, measured quantities (VF, Sp, pN), which influence the driving stability of the vehicle, and in that corrective signals or actuating signals for the suspension control and anti-lock control/traction slip control are obtained in the controlling circuits in dependence on the determined safety level (S) and the motional behavior of the vehicle and the wheels (VA, VR). Dwg.1/8

4. O. Bode and H. Wallentowitz, Vehicle active suspension system - has gas springs with pressure control chamber whose volume is changed by bellows operated by piston, <BASIC> DE 4211628 _A1_931014_9342
<EQUIVALENTS> DE 4211628 _C2_940421_9414.

<BASIC> DE 4211628 A The active suspension system has gas springs between the vehicle superstructure and the wheel-carrying elements. Each gas spring has a compressible gas chamber connected by a pipe to a control chamber whose volume is adjustable using a control piston. The piston bears on a bellows arrangement on the end of the chamber, the rolling surface of the piston having a concave shape in cross-section and being circularly symmetric. The piston is designed so that the force used to increase or decrease the pressure in the chamber through corresponding volume increase or reduction is always constant. The piston can be displaced mechanically and/or pneumatically and/or hydraulically and/or electrically, esp. electronically. ADVANTAGE - Compact and effective design which can be adapted in many ways. Dwg.1/8
<DE> 9414 DE 4211628 C The suspension system has a pneumatic spring support (1,1') which incorporates a compressible gas space (6,6') which is connected via a bore (7,7') to a pneumatic control chamber (8,8'). The volume of the control chamber can be altered with a piston (9,9'). The control chamber is formed by a bellows (10,10') which is attached at one end to the outside (11,11') of the piston. The section of the piston increases in diameter in the direction of the gas space. USE/ADVANTAGE - Spring suspension for motor vehicles. Only small adjusting forces are required to alter volume of pneumatic control chamber. Dwg.1/8

5. G. Camus and P. Quin, Safety device for servo-controlled hydraulic cylinder for use in vehicle suspension for controlling vehicle roll - uses coupling between piston and controlling distributor valve which is disabled by electromagnet until system fails, <BASIC> EP 608650 _A1_940803_9430
<EQUIVALENTS> FR 2701069 _A1_940805_9433.

<BASIC> EP 608650 A The safety device is for a hydraulic cylinder (1) which is part of a hydraulic circuit (2) and which is controlled by a principal distributor (3), which is itself part of a hydraulic circuit with a controller (31,32). A second distributor (4) has a slider (40) connected to the rod of the piston (10) of the hydraulic cylinder by a mechanical coupling (5). The coupling ensures that displacement of the piston rod (12) as the piston moves away from a preset intermediate position displaces the slider of the second distributor, driving the piston back toward the preset intermediate position. Part of the slider moves inside the core of an electromagnet, which fixes the slider to the core when the electromagnet is excited, disabling the mechanical coupling (5). ADVANTAGE - Ensures hydraulic actuator in active suspension moves to intermediate position if system fails. Dwg.1/7

6. A. Eckert, M. Hoffman and M. Hoffmann, Semi-active suspension adjustment system - employs bodywork accelerometers alone for information on vibration damping for operation of control valves, <BASIC> DE 4036064 _A _920514_9221
<EQUIVALENTS> WO 9208623 _A1_920529_9224; EP 557322 _A1_930901_9335; JP 6501437 _W _940217_9412; EP 557322 _B1_940727_9429; DE 59102387_G _940901_9434.

<BASIC> DE 4036064 A Three bodywork acceleration sensors (S1-S3) are connected to two electronic circuits (2,3,5) which adjusts the vibration-damping force by means of proportional valves (6-9). The first circuit has a section (2) which works out the behavior of the bodywork on all four sides of the vehicle, and filters (3) delivering a signal representative of the actual damper velocity. A linear approximation to discrete Kalman filtering is secured in a band (0.5 to 16 Hz) between the eigen frequencies of bodywork and wheels. USE/ADVANTAGE - Manufacturing costs of vehicle suspension is reduced and quality of adjustment improved by elimination of damper displacement sensors.

<EP> 9429 EP 557322 B A semi-active suspension control system for automotive vehicles which is substantially composed of controllable vibration dampers, chassis acceleration sensors (S1 to S3) with a filter (3) connected downstream thereof for obtaining the information about the chassis performance required for the control, and electronic circuits (2,3,5) for assessing the sensor signals and for generating damper-actuating signals, characterized in that the transmission behavior of the filter (3) in a semi-active suspension control system of the type initially referred to is approximated linearly to the transmission behavior of a filter which covers the entire frequency spectrum occurring and is calculated on the basis of a vehicle model by concentrating on a frequency spectrum, the bottom limit of which corresponds approximately to the 0.1-fold up to the 0.5-fold of the natural chassis frequency of the vehicle chassis, while its top limit corresponds approximately to the 1.2-fold up to the 2-fold of the natural wheel frequency, and in that the output signals (vF) of the filter (3) which correspond to the damper speed or to the signal indicative of the damper speed are assessed to determine the damper-actuating signals. Dwg.1/4

7. P. Girardi and C. Berdah, Active suspension for motor vehicle - uses conventional spring damper system in series with spring and hydraulic actuator controlled in response to measured road conditions, <BASIC> EP 435704 _A _910703_9127 <EQUIVALENTS> FR 2654992 _A _910531_9133; EP 435704 _B1_931215_9350; DE 69005279_E _940127_9405; ES 2047886 _T3_940301_9413.

<BASIC> EP 435704 The active suspension comprises two assemblies mounted in series between the chassis and a wheel. The first assembly (7A) is a conventional passive suspension, comprising spring (8A) and damper (9A) mounted in parallel. The second assembly (7B) forms the active part, and comprises a spring (10) coupled to a hydraulic actuator (11) driven by a controller (12, 14). The controller accepts input on road conditions from a set of transducers (13A, 13B, 13C). ADVANTAGE - Simple to produce. Low cost. Consumes less energy than existing systems. @(9pp Dwg.No.2/4)@
<EP> 9350 EP 435704 B A vehicle suspension comprising between the body of the vehicle and a wheel, a first spring (8) and a damper (9) which are disposed in parallel, the suspension further comprising means for controlling the forces transmitted to the body in dependence on parameters which are linked to the external conditions such as speed, load of the vehicle, state of the ground, etc., characterized in that the means for controlling the forces transmitted to the body comprises a second spring (10) and a controlled jack (11) which are disposed in parallel, the assembly (7B) formed by the second spring and said jack being disposed in series with respect to the assembly (7A) formed by the first spring and the damper.

8. W. Halina and G. Kadlicko, Actuator for active suspension system - has valve responsive to differential pressure across piston of actuator and is controlled by signals indicative of position of and load applied to actuator, <BASIC> US 5299488 _A _940405_9413.

<BASIC> US 5299488 A The actuator comprises a hydraulic actuator having a cylinder and a piston moveable within the cylinder to define a pair of chambers within the cylinder. A control valve controls the flow of fluid between respective chambers and one of a source of pressurized fluid and a reservoir, and a control system controls the valve and movement of the piston within the cylinder. The control system includes a pressure sensing device to determine the pressure differential across the piston and provide a control signal to the valve to allow flow through the valve to reduce the pressure differential. A load sensing device senses loads imposed on the actuator and is operable upon the control valve to regulate flow to maintain a sensed load at a predetermined magnitude. A position sensing device is operable upon the control valve to regulate flow to maintain the piston at a predetermined location within the cylinder. ADVANTAGE - Controls movement of vehicle wheel relative to vehicle body. Dwg.2/15

9. W. Halina and G. Kadlicko, Actuator for use in vehicle active suspension system - uses measurement of differential pressure across control valve connecting two cylinders of actuator in suspension system, to provide control signal, <BASIC> WO 9302880 _A1_930218_9309
<EQUIVALENTS> AU 9224189 _A _930302_9326; EP 597996 _A1_940525_9421.

<BASIC> WO 9302880 A The actuator includes a hydraulic actuator (20) mounted between the body (16) and a suspension arm (12) and includes a hydraulic motor (22) and a suspension spring (24) with the spring counterbalancing part of the body weight and the motor allowing adjustment of the wheel. Fluid is supplied to the motor from an engine driven pump (26) and a reservoir (28). The motor is controlled by a suspension management system (36). The motor has a cylinder (56) with two chambers (58,60)

interconnected through a three-position spool control valve (50) and conduits (64,66) with the pressure differential between the conduits being used to control the position of the control valve to minimize the differential pressure. ADVANTAGE - Provides simple system with sensing of single parameter on basis of which movement of suspension is controlled. Dwg.2/15

10. T. Hamada and M. Tabata, Active suspension of vehicle having system of compensation for cornering force - has control valves each controlling supply and exhaust of working fluid to and from each hydraulic actuator, <BASIC> EP 512396 _A2_921111_9246
<EQUIVALENTS> EP 512396 _A3_930120_9346; US 5294146 _A _940315_9411.

<BASIC> EP 512396 A The active suspension comprises actuators each provided for each of the vehicle wheels so as to generate a suspension force while increasing or decreasing the height of the vehicle body at a portion of it corresponding to each vehicle wheel. A vehicle height detector and a lateral height detector are provided. The actuators are controlled in reference to the detected vehicle body height to obtain a desired attitude of the vehicle body. The controller modifies the control of the actuators according to the lateral acceleration of the vehicle body so as to change the forces generated by the actuators when cornering. ADVANTAGE - Avoids heaving up or driving down of vehicle body due to cornering force during vehicle turning. Dwg.1/16
<US> 9411 US 5294146 A The active suspension comprises actuators each provided for each of the vehicle wheels so as to generate the suspension force while increasing or decreasing the height of the vehicle body at a portion corresponding to each of the vehicle wheels. Vehicles height detection devices each detect the height of the vehicle body relative to each of the vehicle wheels at a portion corresponding to it. A lateral acceleration detection device detects lateral acceleration of the vehicle body. A controller controls the actuators based upon the detected vehicle body heights and the detected lateral acceleration to obtain a desired attitude of the vehicle body with a modification of the suspension force generated by each of the actuators for compensating for a roll of the vehicle body due to the lateral acceleration. The controller further modifies the suspension force generated by each of the actuators according to the lateral acceleration of the vehicle body so as to change the suspension force generated by each of the actuators in compensation for the vertical force exerted to the vehicle body through the suspension mechanism due to the cornering forces. ADVANTAGE - Provides improved active suspension which avoids such heaving up or diving down of vehicle body due to cornering force during turning of vehicle. Dwg.2/16

11. K. Hayase et al., Control system for active suspension of motor vehicle - has automatic adjustment of displacement amplitude threshold dependent on number of times threshold is exceeded or not in given time, <BASIC> DE 4337078 _A1_940505_9419.

<BASIC> DE 4337078 A The active suspension system for a motor vehicle has a fluid suspension unit (1) positioned between each wheel and the vehicle bodywork. A fluid feed (2) and discharge (3) is coupled to each unit (1) controlled by a regulator (4). A vertical acceleration sensor (30) signals an evaluation module (5) and a displacement amplitude threshold is set by the module (6). A counter (7) registers the number of times this threshold is exceeded in a given time and if a preset reference level is reached/exceeded the threshold is raised (8) subject an upper limiting amplitude. The converse is adopted for counts falling below this reference subject to a lower limiting amplitude. ADVANTAGE - Materially reduces number of fluid reversals with advantage to service life of fluid pump and associated controls. Improves reliability of control in conditions of variable terrain. Dwg.1/5

12. K. Hayase et al., Controlling operation of fluid active suspension appts. - selecting required supply-discharge control pattern according to magnitude of detected sprung vertical motion related parameter, <BASIC> GB 2270889 _A _940330_9411
<EQUIVALENTS> DE 4331582 _A1_940407_9415.

<BASIC> GB 2270889 A When a sprung vertical acceleration (ZG), which causes a wafting phenomenon perceptible by a person in a vehicle, occurs during travel of the vehicle, supply/discharge of air/from air spring chambers of suspension units is carried out for a supply/discharge control time determined from the max. value (ZGmax) of the sprung vertical acceleration. The supply/discharge control is started at an advanced time based on the sprung acceleration whose phase is advanced by 90 deg. from that of the sprung velocity to produce a force acting to cancel out the sprung vertical at proper timing. As a result, the operation delay of the suspension appts. compensated for and the sprung vertical motion is

suppressed. USE/ADVANTAGE - Active control based on sky-hook damper theory achieved even where operating fluid used is compressible. Dwg.4/21

13. Y. Hiwatashi, K. Kamimura and A. Mine, Monitoring active suspension of motor vehicle - reducing bodywork height from ground when absolute value of lateral acceleration increases, <BASIC> DE 4132276 _A _920409_9216 <EQUIVALENTS> GB 2248588 _A _920415_9216; GB 2248588 _B _940420_9413.

<BASIC> DE 4132276 A Relative changes between the vehicle bodywork and corresp. wheels in the vertical direction are registered. The supply and recovery of hydraulic fluid into and from suspensions (1a,1c) of corresp. wheels is monitored for expansion or contraction of the suspensions independently from each other. The suspensions are thus held to a stipulated vehicle body height. The lateral acceleration applied to the vehicle is detected and the supply and recovery of the fluid is monitored such that vehicle rolling is kept to a predetermined value. The stipulated height is reduced when the absolute value of the lateral acceleration increases such that the bodywork of the vehicle is lowered while rolling is still held to the predetermined value. ADVANTAGE - Driver given better travel feel when cornering. 1/5
<GB> 9413 GB 2248588 B A method for controlling active suspensions of a vehicle, comprising the steps of detecting vertical relative displacements between a vehicle body and respective wheels of the vehicle, controlling charging and discharging of a fluid into and out of respective fluid suspensions for the respective wheels to extend and contract the suspensions independently so as to maintain the suspensions to have a reference vehicle height, detecting lateral acceleration being applied to the vehicle, and controlling said charging and discharging of the fluid so as to maintain rolling of the vehicle at a predetermined value, said method further comprising the steps of: reducing the reference vehicle height, as the absolute value of the detected lateral acceleration increases; and lowering the vehicle body while the rolling of the vehicle is maintained at said predetermined value.

14. S. Kakizaki, Vehicle active suspension with variable hardness dampers and central control - has motion sensors on sprung mass ends of dampers and with bandpass filtering of signals w.r.t. vehicle speed, <BASIC> DE 4242791 _A1_930701_9327 <EQUIVALENTS> US 5328202 _A _940712_9427.

<BASIC> DE 4242791 A The suspension has a variable characteristic damper on each suspension unit with the hardness controlled by a CPU. Motion sensors on the upper mounting points of each damper provide dynamic data for the CPU via filter circuits. The filters limit the data to the frequencies relevant to the control. The bandwidth of the filter circuits varies with vehicle speed. Each bandpass filter has the upper- and lower-limits varied with the vehicle speed to provide an active suspension control for a wide variety of conditions. Only one frequency band is required. The limiting frequencies are changed in four steps with vehicle speed. ADVANTAGE - Improved response active suspension, simple data processing. Dwg.1/15
<US> 9427 US 5328202 A An apparatus for controlling damping coefficients for vehicular shock absorbers, comprises a number of shock absorbers, each being interposed between a sprung mass and an unsprung mass of a vehicle. A damping coefficient changing device varies the damping coefficients of each shock absorber at least one stroke direction with respect to a piston of the corresponding shock absorber in response to an input control signal. A vehicle body behavior detecting device detects vehicle body vertical accelerations, for deriving vehicle body vertical speeds from the vertical accelerations, and for outputting signals representing the vertical speeds. A filtering device filters the output signals from the vehicle body behavior detecting device so as to pass only signal components which fall in a predetermined frequency band from among the output signals outputted from the vehicle body behavior detecting device. A damping coefficient controlling device produces the control signal to the damping coefficient changing device so as to control the damping coefficients of the respective shock absorbers via the damping coefficient changing device on the basis of the signals passed through the filtering device. A vehicle speed detecting device detects a vehicle speed. A cut-off frequency controlling device variably sets a cut-off frequency of the filtering device to a frequency varied in accordance with the detected vehicle speed. ADVANTAGE - Damping coefficient control is carried out on basis of only a frequency band required to control, even if vehicle speed is varied, neither control lag nor control advance occur, and high control effect may be achieved. Dwg.2b/16

15. R. Kallenbach et al., Active suspension control for motor vehicle - provides variable damping coefft. for strut with uneven damping forces, <BASIC> DE 4112004 _A _921015_9243
<EQUIVALENTS> GB 2255389 _A _921104_9245; DE 4112004 _C2_930909_9336; US 5324067 _A _940628_9425.

<BASIC> DE 4112004 A The suspension strut has a parallel operating damper with variable damping force. The damping characteristic is increased for extrusions of the strut compared with the compression movement. The hardness of the damping is controlled w.r.t. the dynamic deflections of the suspension. The first and second order differential of the suspension movements are computed from the suspension sensors and compared with reference limiting values. A simple strut has a concentric hydraulic construction with a limiting flow by-pass. ADVANTAGE - Optimal stability. Dwg. 2/4
<US> 9425 US 5324067 A An adjustable damper includes at least one adjustable damping valve for adjustment of a damping characteristic of the damper in at least two modes. The damper defines a tension and compression stage. The damper has a difference in damping force between two of the characteristic modes in one of the tension and compression stages, which is smaller than a difference in damping force between two of the damping characteristic modes in the other of the tension and compression stages. The damping valve is actuated only during one of the tension and compression stages having the smaller difference in damping force. The actuator is dependent upon relative movements of opposite ends of the damper. ADVANTAGE - Changeover of damping characteristic will take place in operating phases of slight damping force changes. Dwg.1/4
<DE> 9336 DE 4112004 C The control method for a two-stage adjustable vehicle shock-absorber involves use of at least one adjustable damper valve for setting or adjusting the damping characteristic. Switching over between the damping characteristics in order to optimize the vehicle (handling) properties depends on whether the shock-absorber (damper) is active in the 'pressure' stage or in the 'traction' stage. During spring compression (spring closure) of the wheels, the shock-absorber (damper) piston (47) moves downwards and part of the fluidic medium flows out of the bottom working chamber (B) into the upper working chamber (A). The amount of fluidic medium corresp. to the immersed piston roof volume is thus pressed into an annular space (C). During lowering of the wheels (traction stage) an over pressure is set up in the top working chamber (A), e.g. as caused by the piston speeding up. ADVANTAGE - Switchable 'hard' and 'soft' suspension. Dwg.1/2

16. R. Kallenbach et al., Signal processing in active motor vehicle suspension system - controlling suspension elements using signals representing acceleration of bodywork and relative movement between bodywork and wheels, <BASIC> DE 4116839 _A _920109_9203
<EQUIVALENTS> US 5303155 _A _940412_9414.

<BASIC> DE 4116839 An active suspension system for use in road vehicle systems has a variable spring (6) and dampers (3) located between the body mass (Ma) and the road wheel mass (Mr). The acceleration of the spring mass (Ma) is measured by accelerometer (8) with feedback. Other transducers (7) provide relative position feedback. The signals are conditioned by units with transfer functions (G1, G2) and are received by a controller (14) that generates outputs to adjust the suspension dynamically. USE/ADVANTAGE - Optimum control of car or commercial vehicle suspension using actual acceleration signals. @(10pp Dwg.No.1/3)@
<US> 9414 US 5303155 A The method involves sensing an acceleration of the vehicle body, providing first signals representing the sensed acceleration, sensing relative movements between the vehicle body and wheels and providing second signals representing sensed relative movements. The first signals in a first filter are filtered. The filter has at least a high-pass type transfer performance and provides output signals representing high-frequency portions of the first signals. The second signals are filtered in a second filter. The second filter has a transfer performance dependent on the transfer performance of the first filter and provides output signals representing low-frequency portions of the second signals. The first filter combines output signals and the second filter outputs signals in a linkage circuit providing respective output signals. The control/regulation signals depend on the linkage circuit output signals. USE - For generating control/regulation signals for vehicle chassis. Dwg.1/3

17. K. Kawabata, Active suspension system with working fluid pressure control - suppresses changes in attitude of vehicle by increase and decrease of cylinder pressure in unequal ratios, <BASIC> DE 4117673 _A _911205_9150

<EQUIVALENTS> US 5150917 _A _920929_9242; DE 4117673 _C2_940324_9411.

<BASIC> DE 4117673 The working fluid cylinders (15) of all four wheel suspensions are controlled by valves (17) driven (33) by outputs from a control unit (31) operating on digitized (34) signals from sensors of vertical acceleration (28), longitudinal and lateral accelerations (29) and bounces (30). The pistons are enabled to slide more smoothly by control of fluid pressures in accordance with changes in attitude of the vehicle. Pressure is reduced in one ratio, and increased in another ratio which is smaller. ADVANTAGE - System restricts increase in friction between piston rod and sealing ring when working pressure rises. @(16pp Dwg.No.7/9)@

<US> 9242 US 5150917 A The system includes working fluid cylinders which are respectively disposed between a vehicle body and suspension members which support road wheels rotatably. The working fluid cylinder includes a piston slidably arranged for adjusting a relative distance between the vehicle body and the suspension member to suppress vehicle attitude change. The system includes a pressure control unit which is responsive to vehicle attitude change to control fluid pressure to be supplied to the working fluid cylinders to cause the piston to slide such that an increase in the fluid pressure is provided which is lower than a decrease in the fluid pressure. ADVANTAGE - Restricts friction, caused by fluid pressure elevation in the working fluid cylinder, created between the piston and a seal ring to allow the piston to move smoothly. Dwg.2/9D

<DE> 9411 DE 4117673 C The wheel suspension system for motor vehicles has sensors (28,29,30), in the four wheel positions, which detect alterations in the relative positions between parts of the body and the wheels and which generate a signal representing the position of the vehicle body. The system further incorporates suspension units (11) with adjusting actuators, for the four wheel positions. The suspension units and actuators are mounted between the vehicle body and axles (14) on which the wheels are mounted. The actuators consist of piston-cylinder units (15) which suppress alterations in the position of the vehicle body. Displacement of the piston in the actuator depends on the pressure of the fluid which is fed to it. The fluid pressure is controlled in reaction to the signal from the sensors (28,29,30). The pressure controller reduces the fluid pressure for the piston-cylinder units at a particular rate, when the relevant part of the body moves up. The pressure controller increases the fluid pressure when that part of the body moves down at a second rate which is smaller than the first rate to compensate for friction effects which are generated by the increased pressure in the piston-cylinder units. ADVANTAGE - Smooth damping is achieved during both extending and contracting of suspension units. Dwg.1/9

18. M. Kimura, M. Nakamura and M. Sasaki, Active suspension for vehicle with servo adjustment for damper reaction - has stepping motor drive with fixed stop for reference and self-correcting control program, <BASIC> DE 4226051 _A1_930211_9307
<EQUIVALENTS> US 5310027 _A _940510_9418.

<BASIC> DE 4226051 A The vehicle has shock absorbers on each wheel mounting with a controlled adjustment for the damping reaction. The damping is adjusted via a stepping motor drive and a control circuit. A fixed stop provides a reference point for the stepping motor adjustment, with the damping control computed w.r.t. the fixed point. The vehicle is fitted with inertial sensors to monitor the vertical displacement. The processor control computes the required correction via the number of impulses for the stepping motor, or the time required to reach a particular setting. No external position sensor is required for the motor, with one motor unit on each damper. ADVANTAGE - Compact servo drive, direct control of damping reaction. Dwg.1/15

<US> 9418 US 5310027 A The control system comprises a shock absorber disposed between a vehicle body and a wheel. An adjusting member installed in the shock absorber changes the damping force coefficient of the shock absorber. A stepper motor is connected to the adjusting member to rotatingly drive the adjusting member. A stopper restricting rotation of the adjusting member. Vehicle behavioral information is detected and a signal indicative of the vehicle behavioral information is output. The adjusting member is controlled through the stepper motor into a desired state on the basis of the signal from the information detection. The controlling system includes a corrector which sets the adjusting member at a home position relative to the stopper by outputting predetermined drive signals by installments to the stepper motor to intermittently move the step motor to a stop position restricted by a stopper and to reversely rotate it by a predetermined number of steps. ADVANTAGE - Stepper motor is precisely set at home position without using position detector. Dwg.4,13/1

19. K. Kitamura et al., Semi-active suspension system motor vehicle - has variable damping force damper which is changed over by acceleration sensor mounted in vehicle

body, and controller including integrator and calculation processing circuit, <BASIC> EP 545687 _A2_930609_9323
<EQUIVALENTS> US 5324066 _A _940628_9425.

<BASIC> EP 545687 A The suspension system comprises an acceleration sensor mounted on a vehicle body and a controller including an integrator for converting a signal from the acceleration sensor into a velocity signal and a calculation processing circuit for outputting a changing over signal to a variable damping force damper interposed between the vehicle body and a wheel in accordance with the velocity signal from the integrator. The damper has two change-over modes including a mode in which the compression side damping force is soft when the extension side damping force is hard and another mode in which the compression side damping force is hard when the extension side damping force is soft. ADVANTAGE - Durability of system is enhanced. Vehicle height sensor is not required. Dwg.1/26
<US> 9425 US 5324066 A The vehicle suspension system comprises a vehicle body, a suspension member movably connected to the vehicle body in compression and extension directions, and a damper having one end connected to the vehicle body and another end connected to the suspension member. The damper generates a damping force against compression and extension movements, and has a mode R and a mode C, the damping force against extension being larger in mode R than in mode C, and the damping force against compression being softer in mode R than in mode C. An acceleration sensor is mounted on the vehicle body and generates an acceleration signal proportional to the acceleration of the vehicle body in the compression and extension directions. An integrator integrates the acceleration signal and generates a velocity signal proportional to a velocity of the vehicle body in the compression and extension directions. A data processor receives the velocity signal and switches the damper between the mode R and the mode C depending on whether the velocity signal is larger than zero or less than zero. ADVANTAGE - Variable damping force damper need not be changed over frequently or at high speed, and vehicle height sensor is not required. Dwg.1,2/26

20. N. Kuriki et al., Hydraulic Control Device For Active Suspension Device, 06-001131 -JP 6001131 A-.

PURPOSE: To smooth change in pressure with change in engine rotation by providing a relief valve to hold pump discharge pressure constant. CONSTITUTION: A hydraulic control unit has a relief valve 18 to control and hold the discharge pressure of a hydraulic pump P to a preset pressure, two oil passages L1, L2 parted in the lower course of the relief valve 18 to supply pressure oil to two oil chambers 8, 10 and a pressure reducing valve 9 to control and hold the pressure at the parted portion of two oil passages L1, L2 to a preset pressure. A pressure control valve 11 is also provided in either one of two oil passages L1, L2 to change an inner pressure difference between two oil chambers 8, 10 with the movement of a body or a wheel 1 so that the bi-directional stroke control of a hydraulic actuator 6 is allowed.

21. M. Luger, Active suspension for vehicle - has servo element in track rod controlled by processor w.r.t. driving parameters, <BASIC> DE 4020547 _A _920102_9202
<EQUIVALENTS> WO 9200201 _A _920109_9205; EP 536191 _A1_930414_9315; JP 5508595 _W _931202_9402; US 5292149 _A _940308_9410; EP 536191 _B1_940330_9413; DE 59101289_G _940505_9419; ES 2052381 _T3_940701_9429.

<BASIC> DE 4020547 The track rod (5) of the front- and/or rear wheel suspension incorporates the servo drive (4) to alter the effective length of the rod. This adjustment is in response to control signals from a processor and in relation to the vehicle dynamic situation. The servo drive can alter the wheel setting providing improved stability on cornering. The servo element is a simple double hydraulic cylinder linking both wheels of an axle. The track rod is coupled to the wheel support by angled control levers (13) with one end of the lever pivot mounted on the chassis and the other end to the track rod. The wheel mounting is attached part way along the lever. ADVANTAGE - Improved cornering, can ride with softer tyre pressures. @(12pp Dwg.No.1/8)@
<US> 9410 US 5292149 A An arrangement for the active adjustment of a motor vehicle wheel includes a device which has an adjusting element and in which the suspension links, independently of this device, are linked below and/or above a wheel spin axis to a wheel carrier and are pivotally held on the vehicle body. The device has an adjusting element which is connected with the wheel carrier by means of a tie rod. For forced wheel position adjustments as a function of driving parameters, the adjusting element can be adjusted about a swivel axis formed below the wheel spin axis by a wheel-carrier-side tie rod joint and a wheel-carrier-side link joint. The adjusting element of the device includes at least one hydraulic cylinder

which is constructed so that it can be moved in and out while influencing the wheel adjustment by way of an electronic control unit (40) as a function of driving parameters, such as the suspension travel, the lateral acceleration, the speed, the longitudinal acceleration, the deceleration, the yawing moment, and the steering angle. USE/ADVANTAGE - Wheel adjusting system for vehicle wheel suspension system requiring little space. Has favorable response characteristic and is not subject to excessive forces. Dwg.8/8
<EP> 9413 EP 536191 B A device for the active camber and/or track-width adjustment of a motor-vehicle wheel (12) [sic - recte 2] by way of an adjustment device (3) comprising a control member (4), wherein wheel-guide members (8 and 12) are articulated to a wheel support (6) and are held pivotably on the vehicle body, and the control member (4) is connected by way of an attached intermediate member (13) to the wheel support (6) so as to act upon the said wheel support (6) in an adjusting manner, characterized in that the intermediate member (13) is articulated in a tiltable manner directly to the wheel support (6) by way of a central ball-and-socket joint (14) and is connected by way of a first bearing (18) to a control rod (5) of the adjustment device (3) and by way of a second bearing (16) to a wheel-guide member (12), wherein the adjustment device (3) comprises a control member (4) connected to the control rod (5) and adapted to be movable in and out as a function of travelling parameters such as the wheel springing path (F), the transverse acceleration (Q), the velocity (V), the longitudinal acceleration (B), the retardation (L), the yawing (G) and the steering-lock angle (W) by way of a control unit (40) so as to control the setting of the wheel, and the wheel (12) is adjustable about a pivot axis (X-X) formed below the rotational axis (11) of the wheel by a track-rod joint (9) on the wheel support and a support-arm joint (7) on the wheel support.

22. A. Mine, Vehicle active suspension controller - uses adjustable ultrasonic road surface sensor which together with vehicle speed sensor allows selection of attenuation forces switching signal and controls its output timing against delay, <BASIC> GB 2270050 _A _940302_9407
<EQUIVALENTS> DE 4329161 _A1_940303_9410.

<BASIC> GB 2270050 A The controller operates on suspensions (5,5') between wheel axles (4) of front and rear wheels. An electric motor (7) controls the switching of an attenuation force at an upper end of a shock absorber (20). A road surface sensor detects road roughness and is adjustable linearly and angularly by actuators (12,15). Signals from the surface sensor and a vehicle sensor are input to a control unit (14). The control unit selects an attenuation force switching signal responsive to the road surface and further controls an output timing of the attenuation force signal against a delay of the control system and the road surface detecting position. ADVANTAGE-Optimises road roughness detection and always switches suspension characteristics against delay of whole control system at an optimum timing in whole travel area. Dwg.1/15

23. T. Nezu and M. Uchiyama, Active suspension control system controlling attitude of vehicle - has suspension unit with hydraulic cylinder between axle and body, accumulator serving as spring element and fluid controller, <BASIC> GB 2249764 _A _920520_9221
<EQUIVALENTS> US 5217247 _A _930608_9324; GB 2249764 _B _940615_9421.

<BASIC> GB 2249764 A The control system (1) has an accumulator (5) connected to a hydraulic cylinder (3) and a source of pressurized hydraulic fluid (6). A hydraulic fluid supply and discharge device (7) is controlled to supply and discharge fluid to and from the suspension unit. The control system also has a pressure sensor to detect a pressure level of the hydraulic fluid in the suspension unit. Fluid discharge from the suspension unit is prevented when the pressure level in the suspension unit is lower than a predetermined value. The accumulator (5) is of gas-sealed-in type including a housing with a closed bottom end, a slidable piston defining a gas chamber and a closure member mounted on an open end of the housing. USE/ADVANTAGE - Automobile suspension system. Prevents zero-down phenomenon, preventing noise, deterioration of hydraulic appts. and lowering in driving stability. 3/6
<US> 9324 US 5217247 A The suspension control system for controlling the attitude of a vehicle includes a suspension unit including a hydraulic cylinder disposed between an axle and the body of the vehicle and an accumulator connected to the hydraulic cylinder and a pressurized hydraulic fluid source. A hydraulic fluid supply and discharge valve is operatively connected to the suspension unit and to the hydraulic fluid source. A controller controls the hydraulic fluid supplying and discharging valve to supply or discharge hydraulic fluid to or from the suspension unit. The suspension control system further includes a pressure sensor for detecting the pressure in the suspension unit. The controller also prevents hydraulic fluid from being discharge from the suspension unit when the pressure in the suspension unit is lower than a

predetermined value. USE/ADVANTAGE - Automobile, prevents zero-down phenomenon, and the occurrence of noise, deterioration of hydraulic appts. and a reduction in driving stability. Dwg.6/6
<GB> 9421 GB 2249764 B A suspension control system for controlling the attitude of a vehicle such as an automobile comprising: a suspension unit including a hydraulic cylinder disposed between an axle and the body of the vehicle and an accumulator being designed to serve as a spring element; a source of pressurized hydraulic fluid; a hydraulic fluid supplying and discharging means connected to said suspension unit and said pressurized hydraulic fluid source; and a control means for controlling said hydraulic fluid supplying and discharging means to supply and discharge hydraulic fluid to and from the suspension unit; said suspension control system further comprising a pressure sensor means for detecting a pressure level of the hydraulic fluid in the suspension unit; said control means including a fluid discharge prevention means for preventing discharge of hydraulic fluid from the suspension unit when the pressure level of hydraulic fluid in said suspension unit is lower than a predetermined level. Dwg.1/1

24. R. N. Oakley, Active suspension system for vehicle - uses different sets of preprogrammed constants in algorithms according to sensed vehicle parameters to calculate control signal, <BASIC> WO 9401988 _A2_940120_9404.

<BASIC> WO 9401988 A valve (22) controls the flow of pressurized flow (20) to an actuator (10) along an exhaust (24) sensors (27; 28, 30-35, 41) generate signals corresponding to variable vehicle parameters. These are processed and a control signal output to the valve. In normal operating conditions, the processor uses a set of preprogrammed constants, in algorithms used to calculate the control signal. Different sets of constants are used during different stages/conditions of operation e.g. low vehicle speed and/or low fluid pressure, at start-up. ADVANTAGE - Caters for both high and low vehicle velocities. Dwg.1/11

25. R. Ranzenberger, Transverse acceleration measurement for vehicle active suspension, ABS or ASR control - generating pulses for each rotation of left and right wheels during defined time duration, <BASIC> DE 4229967 _A1_940310_9411.

<BASIC> DE 4229967 A transverse acceleration measuring system uses the detected rotation of each of the vehicle wheels (1, 2) mounted in the same wheel axle within a given time interval, corresponding to the distance travelled by each wheel. The detected values are fed to a processing stage (7), allowing the corresponding transverse acceleration to be calculated. The rotation signals are provided by a pair of sensors (4,5) associated with the left and right non-driven wheels, each providing a signal pulse upon each full rotation of the respective wheel. USE/ADVANTAGE - Eg for anti-lock brake system or anti-slip regulation. Provides high measuring accuracy. Dwg.1/2

26. K. Takahashi, Active suspension for motor vehicle - provides variable flow restriction between supply and dampers, <BASIC> DE 4107181 _A _910912_9138 <EQUIVALENTS> US 5239471 _A _930824_9335; DE 4107181 _C2_940113_9402.

<BASIC> DE 4107181 The vehicle is supported by dampers (19) hinged from the chassis and each supporting a wheel assembly. The dynamics of the suspension are controlled via a set of monitors which measure the static- and dynamic displacements of the vehicle and which regulate the flow of hydraulic fluid to and from the dampers. Variable throttle valves between the pressure reservoirs and the dampers provide the control. The system monitors longitudinal- and transverse displacements as well as the static settings of the suspension. The control is tuned to prevent undue displacements at the resonant points of the suspension. The variable throttle has a fixed bypass and a variable main flow. ADVANTAGE - Improved stability and comfort by simple control. @(19pp Dwg.No.1/10)@
<US> 9335 US 5239471 A The actively controlled automotive suspension system includes a hydraulic cylinder disposed between a vehicle body and a suspension member pivotably mounted on the vehicle body. A pressurized fluid source is connected to the hydraulic cylinder, and a pressure accumulator connected to the hydraulic cylinder for absorbing pressure fluctuation in the hydraulic cylinder. A variable throttling orifice is interposed between the hydraulic cylinder and the accumulator, for variably restoring fluid flow, a pressure control valve for adjusting fluid pressure in the hydraulic cylinder. Sensors monitor the state of a vehicular attitude change, and a controller associated with both of the pressure control valve and the variable throttling orifice controls the magnitude of fluid pressure in the hydraulic and a throttling ratio of the throttling orifice. USE/ADVANTAGE - for vehicle suspension. Actively varies suspension characteristics e.g. body attitude change e.g. rolling, pitching, bouncing etc. Higher driving stability and riding comfort by body attitude control with high responsiveness. Dwg.1/10

<DE> 9402 DE 4107181 C The active suspension system for a vehicle includes a fluid-pressure driven actuating organ, a fluid pressure source (FS), a pressure store (34) joined to a working chamber (20) of the actuating organ as a spring element and for retaining any pressure fluctuations, a pressure control valve (13FL; FR; RL; RR), sensor (40; 41) for monitoring any positional changes of the vehicle chassis, and a control device (42) connected to the pressure control valve and the sensors. A pressure store is joined via a variable throttle opening (31) of the pressure chamber (20) of a hydraulic cylinder (19FL-FR), whereby the pressure store and the throttle aperture absorb any pressure fluctuations in the hydraulic cylinder and damp the piston movement in the cylinder and absorb hf lower-amplitude vibrations caused by road shocks. ADVANTAGE - High level of ride stability and comfort. Dwg.1/10

27. S. Takehara et al., Vibration Reducing Device For Vehicle, 06-092127 -JP 6092127 A-.

PURPOSE: To perform optimum signal reducing action in accordance with a shock absorbing characteristic of a suspension device by changing a reference signal in accordance with changing a transmission characteristic of a vehicle according to changing a spring constant and damping force of the active suspension device, and correcting a vibratory excitation signal output to a suspension mount. CONSTITUTION: In a control means 31, a drive signal is transmitted to an actuator 11 arranged between a suspension device and a car body member, and in the actuator 11, vibration exciting force of reverse phase and equal amplitude to vibration is generated to reduce the vibration transmitted to the car body member. In the case of changing a shock absorbing characteristic of the suspension device 11, the drive signal transmitted to the actuator 11 is corrected by a drive signal correcting means 36, based on the changed shock absorbing characteristic. Further, a vibration sensor 18 for detecting vibration of the car body member is provided, and the control means 31 is provided with a digital filter 27 having a transmission function in accordance with a vibration transmission characteristic of the car body member, to feedback-correct the drive signal.

28. S. Takehara et al., Car Vibration Reducing Device, 06-024231 -JP 6024231 A-.

PURPOSE: To generate optimum vibration reducing motions in accordance with the damping characteristics of a suspension device when the car vibrations are to be reduced by giving the car a vibration of the same amplitude as, and opposite phase to, the car vibration. CONSTITUTION: Optimum vibration excitation control is generated for a car equipped with an active suspension device, through such a procedure that the transfer function of a digital filter 2O is altered in accordance with change in the transmission characteristics of the car associated with changes in the spring constant and damping force of the active suspension device.

29. T. Tanaka et al., Active suspension control motor for vehicle - uses scanner for road contour in-front of vehicle and with correction control, <BASIC> DE 4130877 _A _920319_9213
<EQUIVALENTS> DE 4130877 _C2_930805_9331; US 5347457 _A _940913_9436.

<BASIC> DE 4130877 The active suspension has a scanner to monitor the road contour immediately in front of the vehicle, as well as monitors for the vehicle position and the speed. The processor control computes the time taken for any road bumps, etc. to reach the wheels and adjusts the suspension characteristics accordingly. The control takes into account the attitude of the suspension to correct the timing control. The tilt of the suspension in cornering, or during acceleration and braking, as well as the riding height, all affect the readings from the scanner. A simple scanner uses an ultrasonic detector while the suspension characteristics are altered by a control valve (22). ADVANTAGE - Improved comfort and road holding. @(18pp Dwg.No.1/12)@
<US> 9436 US 5347457 A The vehicular suspension control apparatus includes a selector valve for changing at least one of spring rigidity or damper rigidity of a suspension which is installed between a wheel and a body of a vehicle and extensibly and retractably supports the vehicle body on the wheel. A forward road surface sensor is attached to the vehicle body and adapted to detect an irregularity of a road surface located in front of the vehicle body at a predetermined distance from the mounting position of the sensor when the vehicle body is in a predetermined attitude. A vehicle speed sensor detects a vehicle speed and a controller calculates a point of time when the wheel reaches the irregularity of the road surface, in accordance with the vehicle speed detected by the vehicle speed sensor, when the irregularity of the road surface is detected by the forward road surface sensor, and delivers a command signal for lowering at least one of the spring rigidity and the damper rigidity of the suspension to the selector valve by not later than

the calculated time point. USE - To detect the condition of a road surface in front of the vehicle and properly control the operation of a suspension. Dwg.1/12
<DE> 9331 DE 4130877 C The control unit (30) for the wheel suspensions (12) fits between a wheel (8) and the chassis (7) and actively supports the chassis as they shorten and then lengthen. There is also a device for changing the spring stiffness and the damping and an indicating sensor (33) for detecting an irregularity in the road surface in front of the vehicle. This sensor is fixed to the chassis and it detects any bump as the vehicle comes within a set distance. There is also a sensor (34) for giving the speed of the vehicle. The control unit calculates the time a wheel, at the speed detected, will reach the bump and then gives a control signal for reducing the spring stiffness and the damping to the device (22) for changing these before the bump is reached. The control unit possesses also, to aid in the calculation, sensors (32, 35) to supply the height of the indicating sensor above the road and the inclination of the chassis. USE/ADVANTAGE - Independent of the movement and position of the chassis, the distance away from a bump can be accurately detected. It is suitable for motor vehicles and their suspensions. Dwg.1/12

30. T. Tanaka et al., Active suspension for vehicle - has sensor for road surface contour to vary suspension characteristics, <BASIC> DE 4130713 _A _920319_9213 <EQUIVALENTS> US 5322319 _A _940621_9424.

<BASIC> DE 4130713 The active suspension is controlled by a variety of parameters including height sensors (32), suspension displacement sensors (31), speed sensor (34) and a special sensor (33) which scans the road contour immediately in front of the vehicle. If the road contour is coarser than a preset level, then one mode of suspension is set, while for smooth roads a relative soft suspension provides a smooth ride. The system includes a vibration sensor (7) to monitor the road vibrations and transmission vibrations. The height sensor operates either from the displacement of the suspension of via a scanning sensor. Additional control incorporates a steering sensor (35). ADVANTAGE - Automatic control of suspension characteristics. @(10pp Dwg.No.1/6)@
<US> 9424 US 5322319 A An actuator is extensible and retractable and provided between a vehicle body and a wheel so that the force of the vehicle body to support the wheel is adjustable. A sprung G sensor or a vehicle height sensor detects a vibration input to the vehicle body, and a control valve and a controller control the supporting force of the actuator in accordance with the vibration input detected by the sprung G sensor or the vehicle height sensor, thus restraining the stroke of the actuator. The suspension system further comprises a forward road surface sensor for detecting the size of irregularities of a road surface in front of the vehicle. The control valve and the controller are adapted in execute normal control such that the equivalent spring constant of the actuator is adjusted to a first spring constant when a surface irregularity of a size larger than a predetermined size is detected by the forward road surface sensor. USE/ADVANTAGE - Active suspension system for vehicle. Dwg.3/9

31. Y. Taniguchi et al., Driving Method For Active Suspension, 06-099712 -JP 6099712 A-.

PURPOSE: To supply/discharge actuation medium to/from a front wheel side and a rear wheel side actuators. CONSTITUTION: Under control by a control unit 36 to which vertical acceleration in springing detected by a single vertical acceleration sensor 51 provided on the front wheel side of a car body C is inputted, valves relating to two actuators A on the front wheel side are actuated to joint-control supply/discharge of air to/from both actuators, and control of supply/discharge of air to/from two actuators on the rear wheel side is performed totally after a delay time determined by a car speed V, etc., to this joint-control.

32. Y. Taniguchi et al., Actuation Control Method For Fluid Active Suspension, 06-099711 -JP 6099711 A-.

PURPOSE: To compensate actuation delay of a fluid active suspension, and restrict vertical vibration on spring by detecting vertical acceleration on spring, and controlling supply/discharge of compression fluid to the suspension based on the detected acceleration to offset a vertical speed on spring. CONSTITUTION: Suspension units FS1, FS2, RS1, RS2 provided for four wheels of an automobile respectively, and an air circuit for supply and discharge of air to/from the four suspension units are provided. A supply air solenoid valve 20 and solenoid valves 22, 23, 26, 27 provided in the air circuit are actuated to be opened or closed to control supply/discharge of air to/from four air spring chambers 3 are controlled respectively and separately, and inner pressures in the respective air spring chambers 3 can be thereby changed variously. Four vertical acceleration sensors 51 are provided to detect vertical acceleration on spring for controlling supply/discharge of air. Vertical motion on spring can thus be restricted, thereby generation of floating feeling can be prevented.

33. A. Wiesmeier, Active suspension for cab of commercial vehicle - uses vertical displacement of lower support point of actuating elements as controlled variable, and uses time-synchronous state vector to take into account dynamic time response, <BASIC> EP 579182 _A1_940119_9403
<EQUIVALENTS> DE 4223037 _A1_940120_9404.

<BASIC> EP 579182 A The vehicle suspension (1) for a driver's cab comprises actuating elements (5) of variable length parallel to the driver's cab suspension springs (4). The actuating elements are operated by a control system. The vertical displacement (2) of the lower support point (6) of the actuating element or elements (5) is determined from the acceleration signal (2) by double integration. The dynamic time response is taken into account by a time-synchronous state vector which comprises at least the single-differentiated portion, i.e. the vertical velocity (2), in addition to the displacement (2). The calculation is effected partly by extrapolation of the variation over time of the differentiated variables, and partly by back-calculation of the integrated variables. ADVANTAGE - Minimizes variations in wheel loading, more cost effective than hydraulic systems. Improves driver's comfort. Dwg.1/15

34. W. T. Yopp, Automotive vehicle active suspension system - includes electrically-powered actuator with height sensor and gas supply to pressurize or vent gas spring, <BASIC> US 5322321 _A _940621_9424.

<BASIC> US 5322321 A The system has a height sensor which generates a signal in response to the height between the sprung and unsprung masses of the vehicle. A gas spring supplies a force that assists the electrically powered actuator in supporting the load between the sprung and unsprung masses of the vehicle. A gas supply includes a fill tank for communicating with the gas spring and a reservoir including a low pressure reservoir tank and a high pressure reservoir tank for venting and pressuring the fill tank which is located between the reservoir and the gas spring. The venting and filling of the gas spring by the reservoir is through the fill tank. A compressor pressurizes the reservoir, a valve controlling communication of the fill tank with the gas spring, and the low pressure tank and the high pressure tank of the reservoir means with the fill tank. It also controls the compressor with the low pressure tank and the high pressure tank of the reservoir such that the gas supply pressurizes and vents the gas spring to add a predetermined force or remove a predetermined force, regardless of the momentary ride height of the vehicle. This assists the electrically powered actuator in locating the sprung mass at a desired height w.r.t. the roadway. ADVANTAGE - Allows active suspension system to operate without overcorrecting. Dwg.1/2

Antilock Patents - Appendix L

1. Integrated control algorithm for vehicle antilock braking system - incorporates additional sensor information from steering and suspension systems in controlling brake pressure at each wheel, <BASIC> RD 362017 _A _940610_9434, (Anon)Anonymous.

<BASIC> RD 362017 A The algorithm processes wheel speed sensor signals in step 10, 11, and 12 to come up with the estimated wheel acceleration and wheel slip. Step 21 estimates tyre normal force from suspension sensor signals which include vehicle body corner acceleration and wheel vertical velocity. A normal force index is calculated which indicates the variations in the tyre normal force. A steering index is calculated in step 22 using the steering angle sensor signal and estimated vehicle velocity from step 11. It indicates the desired tyre lateral force. The normal force and steering indices are used as inputs to a fuzzy logic unit (25) to determine the offset values. The offset values are combined with the original and in step 26 to obtain the pre-processed wheel acceleration and wheel slip. The preprocessing step 26 intends to eliminate the disturbance in the wheel acceleration and wheel slip due to the tyre normal force variation and to shift system operating regions to optimally distribute tyre longitudinal and lateral forces according to the steering information. The pre-processed wheel acceleration, and wheel slip, are used as search indices in the control tables (40) instead of the original ones. The output of the control table determines the control action (41) which sends control signals to the brake pressure modulators. ADVANTAGE - Prevents unnecessary ABS activation when braking on uneven road surface. Dwg.1/1

2. J. M. Alcone and J. W. Jeter, Absolute velocity sensor, US 5301130 940405 US 964732 921022 Priority Applic: US 964732 921022, Hughes Aircraft Co Assignee Code: 40312.

A system and method for determining the speed of a vehicle independent of angular wheel rotation rates is provided. The system generates time-varying signals corresponding to the vertical acceleration of the front and rear wheels. The front and rear wheel signals include corresponding perturbations caused by the wheels crossing road disturbances such as bumps. A time lag occurs between perturbations in the rear wheel signal and corresponding perturbations in the front wheel signal. An adaptive algorithm correlates the signals for various time delay values until a time delay value is determined which maximizes the correlation between the two signals. The calculated time delay value corresponds to the actual time lag between the front and rear wheels occurring before the rear wheels encounter a road disturbance previously encountered by the front wheels. Thus, the invention provides a determination of the actual speed of the vehicle determined independently from the angular rotation rates of the wheels.

3. E. Beck and G. Sonnenschein, Anti-lock braking system for road vehicles - has wheel cylinder inlet valve that is driven in pulsed mode when onset of brake lock condition occurs, <BASIC> DE 4236047 _A1_940428_9418 <EQUIVALENTS> WO 9410016 _A1_940511_9420, (Intt)ITT Automotive Euro Gmbh.

<BASIC> DE 4236047 A The antilock braking system for road vehicles has a main foot pressure operated hydraulic valve with a connection (13) to an inlet valve coupled (14) to a wheel brake cylinder. The inlet valve has a stem (11) fixed into the armature (9) of an electromagnetic actuator (15). The flow between the inlet and the outlet is determined by the orifice formed (18) between a ball and seat. In the absence of any brake lock condition the valve is open. When a locking condition is indicated the valve is turned on and off at a suitable frequency together with a variation in the pulse mark-to-space ratio. ADVANTAGE - In anti-lock mode valve noise reduced to non-disturbing level by increasing valve switching speed. Dwg.2/2

4. C. Beyer and P. Dominke, Antilock braking system, US 5277482 940111 US 691013 910614 Priority Applic: DE 3841958 881214, Bosch, Robert GmbH DE Assignee Code: 10560.

A reference speed signal approximating the vehicle speed is generated from the wheel speed signals. Wheel slippage signals are generated from the wheel speed signals and the reference speed signal, and used to produce control signals for brake pressure control devices at the wheels. The ABS is switched off when the vehicle is not braked and a wheel slippage signal exceeds a threshold for a predetermined period of time. In a preferred embodiment, the wheel slippage signal used for generating the control signal is reduced by a specified amount when the slippage signal exceeds a smaller threshold for a predetermined period of time.

5. J. Burgdorf, H. Fennel and M. Latarnik, Antilock braking system with electronic control of force distribution - includes secondary circuit for maintaining constant pressure in rear wheel brakes when master cylinder pressure rises above threshold, <BASIC> DE 4240493 _A1_940609_9424
<EQUIVALENTS> WO 9412377 _A1_940609_9424, (Intt)ITT Automotive Euro Gmbh.

<BASIC> DE 4240493 A The electrohydraulic inlet valve (3) serving the rear wheel brakes is supplied permanently with the battery voltage (+UB) and switched on its earthed side by either of two power transistors (6,8). The other inlet and outlet valves (4,5) are energized via an electronic relay (7) operated by a failure monitor circuit (13). A microprocessor (2) performs a periodic check on the reactions and potential shifts, and if a failure is detected only the rear wheel brake inlet valve (3) remains energized. Combinatorial logic (9) connected to the ignition switch (10) and master cylinder pressure switch (12) closes (A) this valve to prevent instability through overbraking. Another transistor switch (14) operates a warning lamp (15). ADVANTAGE - In the event of a controller failure, the rear wheels can still be braked, without risk of overbraking and skidding. Dwg.1/2

6. J. M. Cheron and G. Kervagoret, Pressure-regulating device for a hydraulic circuit, US 5358316 941025 US 219010 940328 Continuation of: ABANDONED US 909267 920706 Priority Applic: FR 919667 910730, Bendix Europe Services Techniques FR.

The invention relates to a pressure-regulating device for a hydraulic circuit, especially for a brake circuit of a motor vehicle, comprising at least one source of fluid under pressure (10) connected to a reservoir of fluid under low pressure (16) and, in at least one subcircuit (I, II), a second source of fluid under pressure (50) and two pressure receivers (20, 22). According to the invention, a proportional solenoid valve (24, 26) is associated with each pressure receiver (20, 22) and is connected to the source of fluid under pressure (10) and to the second source of fluid under pressure (50), and a differential pressure/vacuum valve (100) closes, at rest, communication between the source of fluid under pressure (10) and the supply of the second source of fluid under pressure (50), this communication being opened when the second source of fluid under pressure is put into operation.

7. S. R. Cikanek, Fuzzy logic electric vehicle regenerative antiskid braking and traction control system, US 5358317 941025 US 1965 930107 Priority Applic: US 1965 930107, Ford Motor Co.

An regenerative antiskid braking and traction control system using fuzzy logic for an electric or hybrid vehicle having a regenerative braking system operatively connected to an electric traction motor, and a separate hydraulic braking system includes sensors for monitoring present vehicle parameters and a processor, responsive to the sensors, for calculating vehicle parameters defining the vehicle behavior not directly measurable by the sensor and determining if regenerative antiskid braking control, requiring hydraulic braking control, and requiring traction control are required. The processor then employs fuzzy logic based on the determined vehicle state and provides command signals to a motor controller to control operation of the electric traction motor and to the brake controller to control fluid pressure applied at each vehicle wheel to provide the appropriate regenerative braking control, hydraulic braking control, and traction control.

8. J. C. Eddy, K. S. Kidston and A. J. Lee, Antilock brake system with closed loop control of hold during release, US 5281009 940125 US 932290 920819 Priority Applic: US 932290 920819, Delco Electronics Corp; General Motors Corp Assignee Code: 17355.

An antilock brake controller provides an adaptive pressure hold period that interrupts the release of brake pressure during the pressure release phase of an antilock braking pressure control cycle of a vehicle wheel by holding the brake pressure constant while the wheel slip rate is below a threshold that is adjusted as a predetermined function of wheel slip for the front wheels and as a predetermined function of wheel acceleration for the rear wheels.

9. T. Fuchida, Anti-skid brake control system for automotive vehicles, US 5358320 941025 US 22222 930225 Priority Applic: JP 929729U 920228, Atsugi Unisia Corp JP.

A brake-fluid reflux type anti-skid brake control system for automotive vehicles, comprises a main brake-fluid supply circuit, a brake-fluid reflux circuit refluxing the brake fluid from the wheel cylinder to the main brake-fluid supply circuit during operation of the anti-skid brake control system, and a brake fluid flow control valve arranged in the supply circuit. The flow control valve employs a throttling device responsive to the pressure difference between the master-cylinder side and the fluid pressure of the wheel-cylinder side, such that when the pressure difference is less than a predetermined threshold the throttling device operates at a fully open mode, and when the pressure difference is greater than or equal to the threshold the throttling device operates at a fully throttling mode. The throttling device is further responsive to a steep positive pressure gradient in the fluid pressure of the master-cylinder side, such that the throttling device operates in the fully open mode even when the pressure difference is greater than or equal to the threshold during quick braking.

10. K. Fukamachi, K. Maekawa and M. Maruo, Apparatus and method of testing anti-lock brake system, US 5339682 940823 US 852960 920317 Priority Applic: JP 9169996 910402, Honda Motor Co Ltd JP Assignee Code: 00623.

An apparatus for testing an anti-lock brake system has rolls and device for detecting rotational changes of the rolls. The test is performed by running a vehicle having mounted thereon the antilock brake system while wheels of the vehicle are placed on the rolls, actuating the anti-lock brake system when a predetermined speed has been attained, and judging operating conditions of the anti-lock brake system from rotational changes of the rolls at the time of braking. In the apparatus, the friction coefficient of each of the rolls is set to such a value that a frictional force to act between each of the rolls and each of the wheels at the time of braking exceeds an inertia force of each of the rolls. Also the inertia weight of each of the rolls is set to such a value that deceleration of each of the wheels at the time of braking can be increased to a predetermined level which is required to start an anti-lock control and that each of the wheels does not stop before the completion of a first braking pressure reduction by the anti-lock control.

11. T. J. Hall, Active compensation system, US 5346292 940913 US 51112 930421 Priority Applic: US 51112 930421, ITT Corp Assignee Code: 41050.

An active compensation system for an anti-locking brake system eliminates undesirable brake fluid pressure buildup and, therefore, brake drag by controlling the normally closed valves within the anti-locking brake system through the anti-locking brake system electronic control module to allow the undesired pressure to be released as the brake fluid passes through the normally closed outlet valves into pressure relieving conduits.

12. K. Hashida, Anti-lock hydraulic control device, US 5320423 940614 US 106712 930816 Priority Applic: JP 92225677 920825, Sumitomo Electric Industries Ltd JP Assignee Code: 81568.

An anti-lock hydraulic control device is composed of a front wheel brake and rear-wheel brake for effecting brake control through a hydraulic system which is connected with a master cylinder and circulates hydraulic fluid; a front-wheel side control valve and rear-wheel side control valve between the master cylinder and front-wheel brake, and master cylinder and rear-wheel brake respectively; a reserve between the front-wheel side control valve and rear-wheel side control valve; a proportioning valve between the master cylinder and rear-wheel side control valve; and a pump connected to the reserve and provided with a discharge opening connected between the proportioning valve and the rear-wheel control valve. When antilock control starts, the pump operates and discharges hydraulic fluid to the rear-wheel side control valve, thus increasing rear wheel brake fluid pressure, and so avoiding the problem of insufficient braking power in the rear-brakes during anti-lock control, and increasing braking efficiency.

13. K. Haupt, Vehicle wheel-slip control system with offset dependent upon engine torque - is brought into operation at higher threshold and with reduced sensitivity of electronic controller as torque is increased, <BASIC> DE 4301676 _A1_940728_9429, (Intt)ITT Automotive Euro Gmbh.

<BASIC> DE 4301676 A The electronic antilock braking and wheel-slip correction system (1) monitors the outputs of tachometers (S1-S4) on individual road wheels, and supplies control commands via electrical

signal lines (4) to hydraulic components of the braking system (BA), electrohydraulic valves (RV) for individual wheel braking, and an engine pump unit (PA) producing auxiliary pressure. The torque of the engine (5) is measured and supplied (7) to the electronic system which adjusts (6) the throttle opening in linear relationship to the threshold offset which is set at zero for a predetermined flap position. ADVANTAGE - Threshold of slip or acceleration is adaptable to any traffic situation to give sensitive and prompt response where coefft. of friction is esp. low. Dwg.1/2

14. K. Haupt, Antilock braking system adaptation to state of road surface - involves evaluation of phase difference between peaks of wheel-slip and deceleration as criterion for relaxation of antilock threshold, <BASIC> DE 4239177 _A1_940526_9422, (Intt)ITT Automotive Euro Gmbh.

<BASIC> DE 4239177 A The curve of vehicular deceleration (aFZ) plotted against time has a waveform exhibiting a slight delay (delta T) in peaking w.r.t. the corresp. average wheel-slip curve (SFZ). The two curves are compared and the thresholds of antilock braking operation are varied in accordance with the delay. Electronic digital signal processing evaluates the delay w.r.t. a reference speed and recognizes presence or absence of a peak in the frictional coefft./slip curve. Where no peak is found, the max. permissible wheel-slip is increased. ADVANTAGE - Braking power is increased where the frictional coefft./slip curve rises continuously without a pronounced max.. Dwg.4/4

15. B. Hauser, H. F. Ohm and G. Roll, Antilock braking control system for motorcycle in motion around curve - restricts front-wheel braking force before attainment of anticipated locking pressure above threshold value of computed tilt, <BASIC> EP 603612 _A1_940629_9425
<EQUIVALENTS> DE 4244112 _A1_940630_9427, (Baym)_Bayerische Motoren Werke Ag; (Kuge)_Fag Kugelfischer Schaefer Kgaa.

<BASIC> EP 603612 A Pressures (PO,P1) in the front and rear wheel brake cylinders are modulated (1) by an electronic control unit (2) in which an antilock braking system controller (3) receives pulse sequences (SO,S1) from respective wheel speed sensors, and exchanges data with an auxiliary circuit (4) determining the strategy for curve negotiation. The angle of tilt is computed from the outputs (SV,SH) of vertical and horizontal accelerometers (7,8), and when a critical angle is exceeded the front-wheel braking pressure is reduced before lock can occur. ADVANTAGE - The tilt of the machine is detected unambiguously and the deg. of control is adapted dynamically to it, preventing over braking while ensuring sufficient retardation. Dwg.1/7

16. M. Inagaki, H. Ogawa and K. Takeda, Combined antiskid and traction control electronic brake system, US 5282676 940201 US 798714 911127 Priority Applic: JP 90334367 901129, Nippon Soken Inc JP Assignee Code: 59967.

A brake system capable of implementing anti-skid and traction control operations has an electromagnetic valve for connecting a master cylinder to a wheel cylinder and for disconnecting the master cylinder from the wheel cylinder when anti-skid or traction control is executed. A piezo-electric hydraulic pump is provided for introducing high-pressure brake oil when anti-skid or traction control is executed. A pressure reduction valve selectively introduces and removes brake oil so that a desired wheel cylinder pressure can be attained when anti-skid or traction control is executed. A hydraulic switching valve is connected to the main oil pressure line parallel to the electromagnetic valve and allows pressure in the master cylinder to be opened to the wheel cylinder during a braking operation. The system also includes a unit for establishing one-way communication from the wheel cylinder to the master cylinder during anti-skid control to prevent pressure in the wheel cylinder from being higher than that in the master cylinder while preventing connection between the master cylinder and the wheel cylinder during traction control.

17. T. Isella, Wheel slip control system, US 5328255 940712 US 846998 920402 Priority Applic: DE 3933653 891009, Bosch, Robert GmbH DE Assignee Code: 10560.

A wheel slip control system (ABS and/or drive slip control and/or engine drag moment control system) is formed so that when vehicle motion along curvilinear path is detected the control system is switched to different permitted wheel slip values on different sides of the vehicle, in such a way that a yawing moment is created which acts counter to the yawing moment produced by the vehicle's tendency to oversteer or understeer.

18. T. Iwata, Automotive brake control system, US 5324103 940628 US 931614 920818 Priority Applic: JP 91207905 910820, Nissan Motor Co Ltd JP Assignee Code: 56116.

An automotive brake control system includes a master cylinder, an external brake fluid pressure source, a wheel-cylinder pressure control actuator applied commonly to a traction control (TCS control) performed for suppressing excessive driving force exerted on driven wheels during quick acceleration and an antiskid brake control (ABS control) performed for preventing brakes from locking vehicle wheels during quick braking, or braking on a low frictional road, and a fluid pump for supplying the brake fluid stored in a fluid reservoir to a pressure accumulator, and a controller for controlling the pump, such that the pump is driven for a first setting time in an ABS pressure reducing mode and drives the pump for a second setting time substantially at a time point where one cycle of the TCS control ends, so as to feed the brake fluid from the reservoir to the accumulator.

19. F. Kageyama, M. Kawamura and K. Nobumoto, Vehicle slip control system, US 5340204 940823 US 137385 931018 Continuation of: ABANDONED US 753439 910830 Priority Applic: JP 90230157 900831, Mazda Motor Corp JP Assignee Code: 11642.

A slip control system for a vehicle having rear right and left drive wheels includes a traction control for controlling a slip rate of a wheel by controlling a braking hydraulic pressure for the wheel under a non-braking condition. The slip rate of a wheel is controlled, by controlling the braking hydraulic pressure for the wheel under a braking condition, so as to provide an antiskid control. A start of the control of the slip rate is restricted by the anti-skid control. The control of the slip rate by the anti-skid control is applied commonly to the right and left drive wheels, while the control of the slip rate by the traction control is applied independently to the right and left drive wheels. The anti-skid control can be always properly carried out without being affected by the traction control.

20. K. S. Kidston, E. E. Krueger and J. J. Queen, II, Antilock brake system with closed loop apply bump, US 5308153 940503 US 932204 920819 Priority Applic: US 932204 920819, Delco Electronics Corp; General Motors Corp Assignee Code: 17355.

A vehicle antilock brake system provides an adaptive apply bump period at the beginning of the apply phase of a antilock brake pressure cycle that provides rapid recovery of the correct amount of pressure for all braking conditions. The apply bump period is established based upon the wheel acceleration and the peak acceleration attained by the wheel during recovery from an incipient wheel lock condition. In particular, the apply bump is initiated when recovery from an incipient wheel lock condition is first sensed and thereafter terminated when the wheel acceleration decreases to below a threshold value that is a predetermined function of the peak acceleration of the wheel during recovery from an incipient wheel lock condition in the ABS pressure cycle.

21. T. Kohno and T. Segawa, Automobile brake system antilock modulator - includes differential pressure responsive unit which can shut off fluid communication between master cylinder and branch line, <BASIC> EP 611687 _A1_940824_9433, (Sume)_Sumitomo Electric Ind Co.

<BASIC> EP 611687 A The modulator comprises a reservoir for storing brake fluid discharged from a wheel brake during antilock control, and a control valve for controlling the brake pressure for the wheel brake by selectively connecting the wheel brake to the reservoir and a main fluid line leading to a master cylinder. A shadoof is provided in the main fluid line between the return point and the master cylinder for checking the fluid flow from the pump toward the master cylinder. The shadoof comprises a differential pressure-responsive which operates to close communication between the master cylinder and the pump when the pressure difference between the pressure at a downstream side of the control valve leading to the wheel brake and the pressure at an upstream side of the control valve leading to the master cylinder exceeds a predetermined value. It allows fluid flow in both directions through the differential pressure-responsive unit while the pressure difference is not higher than the predetermined value. ADVANTAGE - Short brake pedal stroke is maintained during normal braking operations. Dwg.1/5

22. W. C. Lin, Method and apparatus for initializing antilock brake control on split coefficient surface, US 5315518 940524 US 712291 910610 Priority Applic: US 712291 910610, General Motors Corp Assignee Code: 33984.

An antilock brake control system having independently controlled left and right brakes has a control program effective at the onset of antilock operation for sensing when the vehicle is braking on a split coefficient surface and for preventing excessive yaw rate by assessing the yaw rate tendency, and when the tendency is excessive, dumping the pressure on the high coefficient side wheel and forcing that wheel into antilock modulation, thereby initializing the system to contain the yaw rate to an acceptable value.

23. E. Muller and W. Muller, ABS control with rear pressure rate reduction when front pressure and time conditions are met, US 5284385 940208 US 752555 910904 Priority Applic: DE 3910209 890330, Bosch, Robert GmbH DE Assignee Code: 10560.

Antilock control system wherein pressure at the front and rear axles is controlled in cycles which each include a pressure reduction followed by a build-up of the brake pressure in pulses having holding phases there between. When a build-up of brake pressure at the front axle exceeds a predetermined time, the rate of build-up at the rear axle is reduced. The system prevents too much pressure build-up at the rear axle during the dynamic load transfer which occurs when braking a vehicle having a high center of gravity relative to its wheel base.

24. J. Nell and M. Steiner, Road vehicle brake-pressure control device, US 5350225 940927 US 33757 930317 Priority Applic: DE 4208496 920317, Mercedes-Benz AG DE Assignee Code: 26957.

In a brake-pressure control device for a road vehicle, having an antilock braking system whose braking device comprises a vacuum brake power assist unit which has a vacuum chamber connected to the intake stub of the vehicle engine and a working chamber which can be subjected to a higher pressure via a control element operable by the brake pedal, a position sensor is provided which detects the position of the brake pedal and generates output signals. An electronic control unit processes these signals and generates drive signals for a brake-pressure control device making it possible to couple into the wheel brakes a higher brake pressure than would otherwise correspond to the instantaneous pedal position. Such driving of the brake-pressure control device is triggered when the speed Phi at which the brake pedal is operated overshoots a prescribed threshold value Phi s. The brake power assist unit is provided with a solenoid valve arrangement which can be moved from a basic position in which pressure compensation can be performed between the vacuum chamber and the working chamber of the brake power assist unit, whereas the working chamber thereof can be connected only via the control element to the outside atmosphere, into a functional position in which the working chamber is subjected to the ambient pressure but is blocked off from the vacuum chamber.

25. M. Nishii and Y. Nomura, Brake system for rear wheels of motor vehicle - feeds brake pressure to front and rear wheel cylinders equalized upon faulty functioning of anti-locking protection adjustment, <BASIC> DE 4329817 _A1_940310_9411, (Aise)_Aisin Seiki Kk.

<BASIC> DE 4329817 A The hydraulic brake system has a brake pedal (26) for regulating a brake pressure, an antilocking protection device for regulating a brake pressure in order to prevent the rear wheels becoming locked, a judgment device (128) which determines a fault function of the protection regulating device, a front brake device (100,102) for braking the front wheels (96,98), a rear brake device (108,106) for braking the rear wheels (104,106), and a device (10) developing a high pressure which produces a high pressure in relation to an operation of the brake pedal (26). A low pressure developing device (12) produces a low pressure in relation to the operation of the brake pedal, and feed equipment (90,92,94) feeds the high pressure to the rear brake device (106, 108) and the low pressure to the front brake device (100,102). Change-over equipment equalizes the pressures fed to the rear and front wheels when the judgment device (128) determines a fault function. USE/ADVANTAGE - To increase braking force on rear wheels, thus prolonging useful life of brake linings of front wheels. Dwg.3/5

26. M. Sakuma and T. Takayama, Antiskid control apparatus, US 5286100 940215 US 926551 920806 Continuation of: ABANDONED US 574650 900829 Priority Applic: JP 89222728 890829, Tokico Ltd JP Assignee Code: 84985.

The present invention comprises a modulator which controls the brake fluid pressure which is provided to the hydraulic systems which extend from the brake fluid pressure source to each wheel, and a controller which controls said modulator. The controller lowers the rate of the increase in brake fluid pressure in one of the wheels on the opposite right or left side of a wheel which is being antiskid controlled, and by thus operating the modulator and maintaining or decreasing brake fluid pressure, relaxes the conditions for the initiation of antiskid control. Concretely, it lowers the threshold values for the slip ratio and the deceleration in the wheel speed, which are used in the decision to initiate antiskid control.

27. Y. Sano, Control method for an antiskid braking system incorporated in a four-wheel-drive automobile, US 5282138 940125 US 713865 910612 Priority Applic: JP 90158509 900615, Mitsubishi Jidosha Kogyo K JP Assignee Code: 56268.

A control method is intended for controlling an antiskid braking system for a four-wheel-drive automobile in which the front and rear wheel sides are connected by a drive system. The control method includes a step of simultaneously reducing braking pressures on two rear wheels in accordance with the select-low principle when at least one of the rear wheels tends to lock. The step includes a process for reducing the braking pressure on that front wheel which is situated on the same side as the selected rear wheel determined in accordance with the select-low principle at the same time with the braking pressures on the rear wheels.

28. G. Schmidt, Antilock braking system for vehicle - incorporates electromagnetically switchable pressure reducers in each braking circuit and acting on front wheel brakes, <BASIC> DE 4242732 _A1_940623_9426 <EQUIVALENTS> GB 2275515 _A _940831_9432, (Bosc)_Bosch Gmbh Robert.

<BASIC> DE 4242732 A An electromagnetically switchable pressure reducer (26,27) is inserted in each of a pair of braking circuits (1,11). Each pressure reducer has two differently dimensioned working surfaces (d1,d2) for the reduction of pressure at the wheel brake relative to the master cylinder pressure. Such a pressure reduction takes place only at a front wheel (brake cylinders 10 and 11). The pressure reduction function can only come into effect if the antilock protection system is operational. ADVANTAGE - Ensures braking pressure uniformity on the left and right of the vehicle. Dwg.1/6

29. M. Steiner, Anti-lock brake circuit for motor vehicle - has variable volume pressure modulation chamber coupled to brakes by control valves, <BASIC> DE 4003579 _C _910627_9126 <EQUIVALENTS> GB 2241294 _A _910828_9135; FR 2657831 _A _910809_9144; US 5125724 _A _920630_9229; GB 2241294 _B _940105_9401, (Daim)_Mercedes-Benz Ag.

<BASIC> DE 4003579 The hydraulic brake circuit is for a road vehicle with single driving axle, having separate circuits for the front and rear axles. An anti-locking system has a variable volume pressure modulation chamber connected by control valves to the wheel brakes of the driven axle, and also to the brake actuator. A wheel spin controller brakes the spinning wheel. A valve connects the modulation chamber piston control chamber to an auxiliary pressure source or to the un-pressurized tank for the medium used. The modulation chamber is shut off from the actuator. whenever the piston moves to prevent brake locking or wheel spin. The chamber is large enough to accommodate the maximum volume of brake fluid displaced in a single stroke of the piston. A return spring (62) holds the piston (48) in the maximum volume position of the modulator chamber (26) when the brakes are not in use, the chamber connection to the pressure outlet (22) of the actuating unit (16) being shut off immediately on operation of this or the wheel spin controller. ADVANTAGE - Simplicity, reliability, and improved sensitivity. @(10pp Dwg.No.1/2)@

<US> 9229 US 5125724 A The hydraulic brake for a motor vehicle with rear axle drive and front axle/rear axle brake circuit division is equipped with an antilocking brake system, a traction control and an electronic braking force distribution control. In order to effect these regulation and control functions on the rear axle of the vehicle, a pressure modulator is provided which has a modulation chamber connected via brake pressure control valves to the rear wheel brakes. This modulation chamber is separated by a modulator piston from a control pressure space to which the outlet pressure of an auxiliary pressure source can be connected under valve control. The modulator piston is displaced by a return spring into the position corresp. to the max. volume of the modulation chamber, which is the initial position both for normal braking and for traction control operation. ADVANTAGE - Increased brake sensitivity. Dwg.1/2

30. K. Takata, T. Fujimoto and K. Hashida, Antilock brake system for motor vehicle - has solenoid changeover valve for automatic braking such as traction control provided between output circuit and check valves, <BASIC> EP 415389 _A _910306_9110

<EQUIVALENTS> US 5171071 _A _921215_9301; EP 415389 _B1_940406_9414; DE 69007907_E _940511_9420, (Sume)_Sumitomo Elec Ind Kk; (Sume)_Sumitomo Electric Ind Co.

<BASIC> EP 415389 The brake system has a manually controlled brake pressure generator (3), independent controlled brake circuits (4,5,6) each having a wheel brake (12-1,12-2) and a flow control (11-1,11-2) valve for electronically controlling the pressure of the wheel brake, a dynamic pressure source (7) necessary for the pressure control by the flow control valve (11), a reservoir (8), a sensor such as a wheel speed sensor, and an electronic control unit. A pair of check valves (21,22) for introducing and returning fluid are provided in parallel to each other between an output circuit (5) of the brake pressure generator (3) and each controlled brake circuit. A solenoid changeover valve (23,24) for antilock is provided between the output circuit (5) of the brake pressure generator and the check valves (21,22) for introducing fluid to close the line during antilock control. ADVANTAGE - Electronic pressure increase/decrease control can be stopped quickly without need of detecting manual control force. @(8pp Dwg.No.1/2)@
<US> 9301 US 5171071 A The brake system has a manually controlled brake pressure generator, independent controlled brake circuits each having a wheel brake and flow control valve for electronically controlling the pressure of the wheel brake, a dynamic pressure source for the pressure control by the flow control valve, a reservoir, a sensor e.g. a wheel speed sensor, and an electronic control unit. A pair of check valves for introducing and returning fluid are provided in parallel to each other between an output circuit of the brake pressure generator and each controlled brake circuit. A solenoid changeover valve for antilock is provided between the output circuit for the brake pressure generator and the check valves for introducing fluid to close the line during antilock control. ADVANTAGE - Maintains predetermined relationship between pedal stroke and vehicle deceleration. Dwg.1/3

31. B. Topfer, Tractor/trailer brake pressure regulation method and system, US 5333940 940802 US 944324 920914 Priority Applic: DE 4130848 910917, Mercedes-Benz AG DE Assignee Code: 26957.

A brake pressure regulation method and system for a trailer vehicle, which is connected to a tractor vehicle having an electronically controlled pressure-medium brake renders sensing of the forces between the tractor and the trailer vehicle and, to this extent, also a corresponding force-recording apparatus superfluous. The method can be used advantageously in tractor vehicles equipped with an ABS. The method is based on transmission of wheel speed signals from the trailer vehicle to the tractor vehicle and brings about an adjustment of the brake pressure relation between the tractor and the trailer vehicle to the same average speed of the wheels of non-driven axles of the vehicle by correcting the brake pressure for the trailer vehicle adaptively to give braking work which can be distributed in optimum fashion to the tractor vehicle and the trailer vehicle. Since, in this way, the average utilization of adhesion at braked wheels of the trailer vehicle is the same as that at the nondriven, braked wheels of the tractor vehicle, not only is an increase in directional stability during braking achieved but also an advantageous evenness of the brake lining wear on the tractor vehicle and the trailer vehicle. The method can also be carried out very advantageously in conjunction with electronically controlled pressure-medium ABS brake systems for trailer vehicles.

Four Wheel Steering Patents - Appendix M

1. M. Abe et al., Four wheel steering system for motor vehicle - steers rear road wheels according to change in steering angle of front road wheels, <BASIC> GB 2250247 _A _920603_9223
<EQUIVALENTS> GB 2250247 _B·_940907_9433, (Honda)Honda Giken Kogyo Kk.

<BASIC> GB 2250247 A (14) for detecting a front wheel steering angle through which the front road wheels are steered. A vehicle speed sensor (19) detects a vehicle speed of the motor vehicle. A controller (20) controls the rear wheel steering mechanism to steer the rear road wheels based on the detected front wheel steering angle and the detected vehicle speed when the front road wheels are steered. steer the rear road wheels in a direction which is opposite to the front road wheels if the detected vehicle speed is relatively low, and also controls the rear wheel steering mechanism to steer the rear road wheels in a direction which is the same as the front road wheels if the detected vehicle speed is relatively high. behavior at all times irrespective of whether driver's action to steer front wheels is quick or slow.
<GB> 9433 GB 2250247 B front and rear road wheels, comprising: means for detecting a front wheel steering angle through which the front road wheels are steered; means for detecting a vehicle speed of the motor vehicle; a mechanism for steering the rear wheels; and control means for controlling said mechanism to steer the rear road wheels based on the detected front wheel steering angle and the detected vehicle speed when the front road wheels are steered, said control means comprising means for (a) if the detected vehicle speed is relatively low, controlling said mechanism to steer the rear road wheels in a direction which is opposite to the direction of steering of the front road wheels, (b) if the detected vehicle speed is relatively high, controlling said mechanism to change a rear wheel steering angle through which the rear road wheels are steered by a quantity which, when the change in the front wheel steering angle over a predetermined time is relatively small, increases as the change in the front wheel steering angle increases, and controlling said mechanism to change the rear wheel steering angle by a quantity which, when the change in the front wheel steering angle is relatively large, decreases as the change in the front wheel steering angle increases.

2. R. Akita, T. Edahiro and H. Kanazawa, Four-wheel steering system for vehicle, US 5341294 940823 US 748838 910823 Priority Applic: JP 90223937 900824, Mazda Motor Corp JP Assignee Code: 11642.

In a four wheel steering system, the rear wheel turning mechanism is connected to the front wheel turning mechanism by way of a rear wheel turning angle ratio changing mechanism which is mechanically connected to both the front wheel turning mechanism and the rear wheel turning mechanism and transmits the mechanical displacement input there into from the front wheel turning mechanism to the rear wheel turning mechanism to drive the same by an amount the ratio of which to the amount of mechanical displacement input into the rear wheel turning angle ratio changing mechanism gives a predetermined rear wheel turning angle ratio. The rear wheel turning angle ratio changing mechanism is controlled in such a way that, when the front wheels are turned from the neutral position in a middle vehicle speed range, makes the rear wheel turning angle ratio negative for a moment immediately after initiation of turning of the front wheels and thereafter turns the same positive.

3. R. Akita, H. Ohmura and T. Takatani, Four-wheel steering system for road vehicle - has target value for control of steering of rear wheels in answer to steering movement of front wheels by addition and subtraction of operands determined by basic position of signals, <BASIC> DE 4332040 _A1_940331_9414, (Mazda)_Mazda Motor Corp.

<BASIC> DE 4332040 A front-wheel steering mechanism (14) controlled by the steering wheel, and a rear wheel steering mechanism (20). A sensor (26) determines the vehicle speed (V). There is a target value adjustment of the operands on the basic position of at least one vehicle operating condition (V, theta F, theta'F, psi') and the system adjusts a target value for the control of the steering of the rear wheels (18) by addition and subtraction of the operands. The value of the operands is restricted within acceptable ranges. on the basic position of the target value. A target value correction unit, when the adjusted target value is outside a predetermined acceptable range, adjusted in accordance with the vehicle speed (V), corrects the target value to a value within the range. value for control of the steering of the rear wheels by addition and subtraction of the operands.

4. J. Baxter, A. E. Bishop and A. Bishop, Function generator for front and rear steering systems - produces signal to control steer angle of rear steer wheels based upon steer angle of front wheels and vehicle speed, <BASIC> WO 9205062 _A _920402_9216 <EQUIVALENTS> AU 9185411 _A _920415_9230; EP 550579 _A1_930714_9328; JP 6500751 _W _940127_9409; AU 645846 _B _940127_9410, (Bish-)_Bishop & Assoc Pty Ltd a E; (Bish-)_Bishop a E & Assoc.

<BASIC> WO 9205062 A vehicle, and generates a rear steer angle output as a function of the front steer angle and the vehicle speed or speed equivalent inputs, such that for every value of the vehicle speed input there is one value of the front steer angle input for which the value of the rear steer angle output is nonzero. The function generator produces one vehicle speed at which the rear/front steering ratio is zero when a steering wheel controlling the steering of the front wheels is positioned in the on center region and further wherein the ratio becomes negative as the steering wheel is rotated away from the on center region. the rear/front steering ratio is positive when the steering wheel is positioned in the on center region. construction. Contributes little function to control system. Enables optimization of vehicle dynamics under all driving conditions.

5. R. Becker and U. Belzner, Four-wheel steering method for motor vehicle - involves using driving condition variables to effect steering movements of front and rear wheels in same or opposite senses, <BASIC> GB 2256404 _A _921209_9250 <EQUIVALENTS> DE 4118699 _A _921210_9251; DE 4118699 _C2_940331_9412, (Bosc)_Bosch Gmbh Robert.

<BASIC> GB 2256404 A the intention of the driver and/or of variables which represent and/or influence the driving condition. Driving conditions in which a deceleration of a certain, selectable magnitude is present are detected. During these driving conditions, steering movements which are dependent on variables which represent and/or influence the driving condition are at least reduced. In particular, steering movements in the opposite sense during braking maneuvers starting at high speeds are prevented on vehicles with four-wheel steering. movements of the front and rear wheels in the opposite sense, which usually occur below a threshold vehicle speed, are reduced or prevented if the vehicle is decelerating from a higher speed as detected by comparing wheel or vehicle speed. In a modification, opposite steering is reduced only if the vehicle is also cornering as detected by steering angle sensors or by comparison of left and right wheel speeds. least one axle is of steerable design.

<DE> 9412 DE 4118699 C vehicle speed. For fast speeds the rear wheels turn in the same direction as the front wheels, and in the opposite direction for slow speeds. To improve the safety and stability of the vehicle the steering mode is also influenced by the braking- and cornering of the vehicle. This prevents a change in steering mode, during heavy braking and/or cornering from affecting the stability. wheel steering is reduced or set to neutral. The same control is applied when cornering above a set rate and when the ABS system is activated. safety. the intention of the driver and/or variables which represent and/or influence the driving condition. Driving conditions in which a deceleration of a certain, selectable magnitude is present are detected. During these driving conditions, steering movements which are dependent on variables which represent and/or influence the driving condition are at least reduced. In partic., steering movements in the opposite sense during braking maneuvers starting at high speeds are prevented on vehicles with four-wheel steering. movements of the front and rear wheels in the opposite sense, which usually occur below a threshold vehicle speed, are reduced or prevented if the vehicle is decelerating from a higher speed and detected by comparing wheel or vehicle speeds, whether the anti-lock braking system is operating or whether the brake pedal was pressed above the threshold speed. In a modification, opposite steering is reduced only if the vehicle is also cornering as detected by steering angle sensors or by comparison of left and right wheel speeds. which at least one axle is of steerable design.

6. A. E. Bishop, Four wheel steering systems, US 5322308 940621 US 849369 920514 Priority Applic: AU 897201 891103, A E Bishop and Assoc Pty Ltd AU.

A front and rear wheel steering system for a vehicle has a front steer system (23, 25) and a rear steer system (21, 22) with a rear steer controller (12) functioning to set the rear steer angle in dependence upon front steer angle and vehicle speed. A low load capacity feedback device (14) functions to maintain a predetermined relationship between front and rear wheel steer angles with an overload protector (74, 77, 78) protecting the feedback device (14) from damage due to the application of loads above a predetermined level.

7. H. W. Bottesch, Automatic counter-steering system for motor vehicles, US 5276620 940104 US 673982 910325 Priority Applic: US 673982 910325, Unassigned Or Assigned To Individual Assignee Code: 68000.

A counter-steering system is disclosed for a road vehicle including sensors arranged to sense the speed of steerable wheels in response to changes in road surface texture, the lateral movement of the wheels in response to skid movement, and the rotational motion of the steering wheel for the vehicle, and to produce respective signals according therewith. A control system is devised to receive these signals and to produce a control signal in accordance therewith as a corrective routine and to impress this control signal in a force producing mechanism to impart movement of the steerable wheels for corrective purposes. The control system is devised to differentiate time lags between occurrences of repetitive sequences of at least one of the signal in its production of the control signal.

8. D. Burke, D. A. Williams and P. G. Wright, Assisted four-wheel steering system - has microprocessor derived closed loop control, steering angle transducer and four hydraulic actuators, <BASIC> WO 9014980 _A _901213_9101 <EQUIVALENTS> EP 487529 _A1_920603_9223; JP 4505737 _W _921008_9247; EP 487529 _B1_940831_9433, (Genk)_Group Lotus Plc; (Genk)_Group Lotus Ltd.

<BASIC> WO 9014980 providing an input to a microprocessor (18) which is proportional to the angle through which the steering wheel (15) is turned. The microprocessor provides two control outputs, the first is to hydraulic cylinders (19) to steer the front wheels (11,12) in the required direction, and the second control output is to hydraulic cylinders (19) which steer the rear wheels (13,14) as required. A second transducer (20) detects the response of the vehicle to its steering demands and outputs and produces a signal which is the difference of input demand and actual output. @(18pp Dwg.No.2/9)@
<EP> 9433 EP 487529 B input means (15), means (17) for generating a first electrical signal proportional to a demanded input of the steering input means; means (19) for steering a vehicle wheel in response to said first electrical signal; sensing means (20,23) for detecting the response of the vehicle; means (20) for producing a second electrical signal proportional to said detected response; comparator means (18) for comparing said first and second electrical signals and producing a difference signal from the comparison; and means (19) for steering a vehicle wheel in response to said difference signal characterized in that filter means is provided to filter the first electrical signal before the first electrical signal is compared by the comparator means (18) with the second electrical signal.

9. I. Chikuma, Four-wheel steering apparatus, US 5295550 940322 US 754738 910904 Priority Applic: JP 90235553U 900907, NSK Ltd JP Assignee Code: 09033.

A four-wheel steering apparatus operates such that only when the vehicle velocity is lower than a predetermined value, is the provision of the steering angle to the rear wheels electrically controlled by the steering angle sensor for the front wheels and vehicle velocity sensor while at a high-speed traveling, the provision of the steering angle to the rear wheels is performed by the compliance steering mechanism. Hence the control and stability are improved as compared with the case where the steering angle is given to the rear wheels electrically even at a high-speed traveling.

10. I. Chikuma, Four wheel steering for motor vehicle - steers rear wheels by electromotor on steering rack, <BASIC> DE 4129658 _A _920312_9212 <EQUIVALENTS> US 5295550 _A _940322_9411, (Nskl-)_Nsk Ltd.

<BASIC> DE 4129658 motor on the pinion. The motor is controlled w.r.t. the front wheel steering setting and the vehicle speed. Four speeds below a set level the rear wheels are strongly steered to reduce the steering radius of the vehicle, i.e. to assist parking. For higher speeds the rear wheel steering is stabilized. contact with the road to ensure stability. The steering rack has limited movement in either direction and is fitted with a centralizing spring (25). A failure detector blocks the rear wheel steering if a failure occurs. of vehicle. @(17pp Dwg.No.1/8)@
<US> 9411 US 5295550 A angle provided for the front wheel. A rear-wheel output shaft provides the rear wheels with a steering angle by displacement in an axial direction. An electric motor displaces rear-wheel output shaft in the axial direction through a speed-reducing mechanism. A vehicle velocity sensor detecting the velocity of the vehicle. from the steering angle sensor and the vehicle velocity sensor. The rear wheels through the rear-wheel output shaft only when the vehicle velocity detected by the vehicle velocity sensor is lower than a predetermined velocity. neutral position if a steering angle which is not appropriate for the

rear-wheels happens to be provided in travelling at a low speed due to a partial failure of the controller or the like.

11. T. Edaniro et al., Four-wheel steering system for vehicle - controls rear wheel turning angle ratio changing mechanism so that ratio is negative immediately after initiation of front wheel turning, <BASIC> EP 472214 _A _920226_9209 <EQUIVALENTS> EP 472214 _A3_930107_9345; US 5341294 _A _940823_9433, (Mazda-)_Mazda Motor Corp.

<BASIC> EP 472214 which turns front wheels of the vehicle in response to turning of a steering wheel. A rear wheel turning mechanism is connected to the front wheel turning mechanism by way of a rear wheel turning angle ratio changing mechanism and turns rear wheels of the vehicle. mechanically connected to both the front wheel turning mechanism and the rear wheel mechanism and transmits a mechanical displacement input from the front wheel mechanism to the rear wheel mechanism to drive the same. deteriorating driving stability of vehicle. @(20pp Dwg.No.1/3)@
<US> 9433 US 5341294 A turning mechanism by way of a rear wheel turning angle ratio changing mechanism. This is mechanically connected to both the front wheel turning mechanism and the rear wheel turning mechanism. front wheel turning mechanism to the rear wheel turning mechanism to drive the same by an amount. The ratio of this amount to the amount of mechanical displacement input into the rear wheel turning angle ratio changing mechanism gives a predetermined rear wheel turning angle ratio. turning angle ratio changing mechanism is controlled such that when front wheels are turned from neutral position in middle vehicle speed range, rear wheel make turning angle ratio negative for moment immediately after initiation of turning of front wheels, and then turns same positive.

12. T. Fukunaga, A. Ishida and A. Segawa, Rear wheel steering angle controller for four wheel steering vehicle - calculates motor control instruction signal using vehicle speed characteristic estimator, <BASIC> EP 588135 _A1_940323_9412, (Matu)_Matsushita Elec Ind Co Ltd.

<BASIC> EP 588135 A rate of the vehicle. Rotary angle of a handle and rear wheel steering angle are also detected. An electric motor controller steers a rear wheel based on a steering angle instruction signal. A target yaw rate is calculated based on the detected values. A control amount calculator determines the steering angle instruction signal. variation term with a term of unknown portion of the dynamic characteristic variation by vehicle speed change. The steering instruction value is calculated with actual yaw rate becoming target rate. vehicle, where vehicle body side slip angle is smaller even at robust and transient time w.r.t. unknown variation term.

13. P. U. Hansen, Swivelling sub-chassis system for off-road vehicle - includes wheel sets, each having two wheels mounted on sub-chassis swivelling within bearings, with slow acting air or oil shock absorbers located between chassis and wheel supporting ends of sub-chassis, <BASIC> NZ 242929 _A _940726_9430, (Hans/)_Hansen P U.

<BASIC> NZ 242929 A sub-chassis swivelling within bearings fixed along a common longitudinal axis (7) of a rigid chassis (8). Slow acting air or oil shock absorbers (5) are located between the rigid chassis and the wheel supporting ends of the sub-chassis so as to compensate for large movement of the sub-chassis relative to the rigid chassis. (4) are located between the bottom ends of the sub-chassis and the respective stub axle assemblies of the wheels. Wheels are independently hydraulically or electrically hub driven. The left hand front wheel can be at a maximum distance (at position 2) and the right hand front wheel at a minimum distance (at position 3) from the rigid chassis, while the left hand rear wheel can be at a minimum distance (at position 3) and the right hand rear wheel can be at a maximum distance (at position 2). Hydraulic steering allows for two wheel steering at higher speed or four wheel steering at lower speed.

14. T. Hirai, Four-wheel steering control device, 06-092259 -JP 6092259 A-, NISSAN MOTOR CO LTD [000399] (A Japanese Company or Corporation), JP (Japan).

PURPOSE: To make the guarantee of turning round performance at the turning time compatible with the prevention of stability lowering at the lane changing time and the saving time in a four-wheel steering control device for imparting the specified auxiliary steering angle to rear wheels at the steering time. CONSTITUTION: As a first constitution of a four-wheel steering control device, a rear wheel steering angle control means (g) is provided to put an in-phase rear wheel steering angle (c) by an in-phase proportional term (c) back onto the anti-phase side by a return steering term (d) in a region where a steering angle is the specified steering angle or more and to put a delay element (e) in this return steering term (d) to perform rear wheel steering control. A high steering angle region in-phase proportional term (h) left only at the quick steering input time in a steering angle region where the steering angle is the specified steering angle or more is then added as a second constitution.

15. T. Hirai, Four-wheel steering controller, 06-092255 -JP 6092255 A-, NISSAN MOTOR CO LTD [000399] (A Japanese Company or Corporation), JP (Japan).

PURPOSE: To provide a natural response and satisfactory damping feeling in steering input by detecting yaw rate changing rate to alter a time constant according to the detected value for controlling the steering angle of rear wheels.

16. K. Hosoda and S. Kumabe, Vehicle four-wheel steering system - determines target value for controlling turning of rear wheels in response to turning of front wheels based on value representing running state of vehicle other than its speed e.g. turning angle of front wheels or yaw rate, <BASIC> EP 601588 _A1_940615_9423, (Mazda)_Mazda Motor Corp.

<BASIC> EP 601588 A number of correction terms which are determined on the basis of running state values (ThetaF,Psi',ThetaF2) other than the vehicle speed (V) to and from a base term (G4.f4(V)) which is determined according to the speed (V). The base term is set according to the speed so that the rear wheels (3,4) are turned in the reverse phase in a low speed range and in the same phase in a high speed range, and each of the correction terms is a product of a function of the corresp. running state value and a control gain (f1(V),f2(V),f3(V)) determined according to the speed. correction terms are fixed to respective set values and the target value (TGThetaS1) is determined on the basis of the base term and the correction terms thus obtained when it is determined that the vehicle is making a sharp deceleration. stability and heading performance of vehicle harmonized with each other.

17. H. Inoue and O. Takeda, Four-wheel steering system for automotive vehicle, US 5316099 940531 US 898176 920612 Continuation of: ABANDONED US 577654 900904 Priority Applic: JP 89228706 890904, Toyota Jidosha Kogyo K JP Assignee Code: 85331.

In a four-wheel steering system for an automotive vehicle, a travel speed of the vehicle is detected to determine parameter related to the detected vehicle speed, and lateral deviation of the vehicle is further detected to determine a steering angle of rear road wheels on a basis of the detected lateral deviation of the vehicle and the determined parameter. When the detected vehicle speed becomes unreliable due to skid condition of either one of the road wheels, the steering angle of the rear road wheels is determined on a basis of the detected lateral deviation and the fixed parameter.

18. M. Kato, Slip angle measuring method for vehicle having four-wheel steering system - using correction value output from learned neural network for correcting approximate value of slip angle derived on basis of front wheel steering and motion information, <BASIC> EP 615892 _A1_940921_9436, (Mitm)_Mitsubishi Jidosha Kogyo Kk.

<BASIC> EP 615892 A approximate value (A) of vehicle centroid slip angle (beta) by utilizing an approximate expression derived from a linear two-degree-of-freedom vehicle model. The approximate value (A) is derived on basis of outputs from a steering wheel sensor (16), a vehicle velocity sensor (18) and a yaw angular velocity sensor (24). A block (28) is used for pre-processing outputs from the above three sensors, a longitudinal acceleration sensor (20) and a lateral acceleration sensor (22) to create an input information. the input information and outputs a correction value (C) corresponding to a deviation between an actual slip angle and the approximate value. The correction value (C) from the neural network (32) is added to the approximate value (A) from the calculation block (26) to derive a precise centroid slip angle (beta). optical ground speed meter, thus, lowering construction cost and reducing installation space.

19. L. Lundstroem, Two-axled trailer - has four wheel-steering with pair of transmission rods extending in vehicle longitudinal direction, <BASIC> SE 9003011 _A _920322_9221
<EQUIVALENTS> SE 500259 _B _940524_9423, (Lund/)_Lundstroem L.

<BASIC> SE 9003011 A (15a,16a) at right-angles to the vehicle longitudinal center line. Functionally connected to the front axle (3) is a traction device (5) for turn the axle around its rotary axes (15a) dependent upon turning of the traction device in relation to the trailer longitudinal central plane. rods (18,19) transmits the front axle (3) rotation to the rear axle (4) at the same angle but in the opposite direction. The transmission rods are directly or indirectly articulated connected to the rear axle on opposite sides and this via an intermediate link system (20,21). steering.
USE/ADVANTAGE - As a twin-axled trailer with four wheel steering.

20. S. Matsumoto et al., Motion control device for vehicle, 06-032242 -JP 6032242 A-, NISSAN MOTOR CO LTD [000399] (A Japanese Company or Corporation), JP (Japan).

PURPOSE: To control the motion of a vehicle by using 4WS and braking force control and perform effective, efficient and optimum control sharing of each system in response to lateral G and/or longitudinal G in use.

21. Y. Matsuo, Driving force distributing device for four-wheel drive vehicle with, 06-072172 -JP 6072172 A-, TOYOTA MOTOR CORP [000320] (A Japanese Company or Corporation), JP.

PURPOSE: To improve turning performance and stability at the time of

22. M. Matsushita, Four-wheel steering control device, 06-040346 -JP 6040346 A-, SUZUKI MOTOR CORP [000208] (A Japanese Company or Corporation), JP (Japan).

PURPOSE: To carry out optimal rear wheel steering control as usual when constant time passed after electric power supply is inputted by preventing a vehicle from becoming unstable immediately after the electric power supply is inputted when a piezoelectric vibration gyro is used as a yaw rate sensor.

23. T. Mizutani, Radial tire for automobile with four wheel steering, 06-040212 -JP 6040212 A-, TOYO TIRE & RUBBER CO LTD [000314] (A Japanese Company or Corporation), JP (Japan).

PURPOSE: To provide natural and stable sensations from the initial stage of steering to the control limit in a radial tire for an automobile with 4WS, and provide the radial tire with a characteristic easy to foresee the limit.

24. H. Nakai, Rear wheel hunting prevention method for four wheel steering vehicle, 06-099828 -JP 6099828 A-, MITSUBISHI MOTORS CORP [351404] (A Japanese Company or Corporation), JP (Japan).

PURPOSE: To enable rear wheels to be dissolved of their hunting action by steering the rear wheels while constantly comparing a stopping target with the maximum steering angle data of among the rear wheel steering angle data detected by a sensor when the front wheel steering angle exceeds the specified steering angle range.

25. H. Ohmura et al., Control system for rear-wheel steering of motor vehicle - provides antilock braking with device correcting rear-front steering-angle-ratio characteristics, <BASIC> DE 4041404 _A _910704_9128
<EQUIVALENTS> US 5225983 _A _930706_9328; DE 4041404 _C2_940728_9428, (Mazda-)_Mazda Motor Corp.

<BASIC> DE 4041404 A steering-angle control system determines the ratio of the rear wheel's steering angle to that of the front wheels according to given steering ratio characteristics. A device enters the operating state of the antilocking brake system and the control state of each braking device for the wheels in the steering-angle control system. control state of the braking devices during braking. The friction between the right and left wheels and the road surface is measured and the result is used to influence the choice of steering ratio characteristics. system is in operation. @(15pp Dwg.No.1/9)@

<US> 9328 US 5225983 A antiskid braking system which controls a braking force in a brake device in a respective wheel in accordance with a deceleration condition of the respective wheel so as to prevent wheel locking in a braking operation. establishing a ratio of steering amount of the rear wheels to that of the front wheels as a predetermined steering ratio characteristic. An input device inputs an operation condition of the antiskid braking system and an control condition of the brake device for the respective wheel conducted by the antiskid braking system to the rear steering control system. A device is provided in the system for amending the predetermined steering ratio characteristic in accordance with the control condition of the brake device for the respective wheel when the antiskid braking system is in operation. steering vehicle with ABS for improving stability of vehicle Can operate vehicle safely when ABS is operated.
<DE> 9428 DE 4041404 C subordinates rear toe-in angle to front wheel steering and offers ABS-dependent correction. The blocked conditions of front (FR,FL) and rear wheels (RR,RL) are reported and the correction unit switches from pre-imposed steering characteristic to a third characteristic (N to A) giving a wider steering range at low speed in cases where both sets of wheels are identically locked. The correction unit can switch to a fourth characteristics (A1) at still lower speed and offering even wider range when the front wheels lock before those at the rear. A fifth characteristic (A2) is available if the rear wheels lock before the front wheels. The anti-locking system controls right and left wheels and front and rear wheels completely separately. to suit locking sequence between front and rear wheels for maintained road-holding.

26. M. Ota and M. Saito, Four-wheel steering device, 06-099824 -JP 6099824 A-, TOYOTA AUTOM LOOM WORKS LTD [000321] (A Japanese Company or Corporation), JP (Japan).

PURPOSE: To provide a four-wheel steering device that can switch steering systems regardless of the position of front and rear wheel.

27. H. Sasaki, Integrated control device for four-wheel steering and traction, 06-024349 -JP 6024349 A-, NISSAN MOTOR CO LTD [000399] (A Japanese Company or Corporation), JP (Japan).

PURPOSE: To prevent the occurrence of rapid vehicle behavior in a limit turning region by computing a deviation between a target behavior computing value and an actual behavior detecting value by means of the values, limiting a maximum limit amount of a four-wheel steering control system when the deviation exceeds a given value, and facilitating entrance to control of reduction of traction.

28. T. L. Snipes, Vehicle four-wheel steering mechanism - has linkage between front and rear pairs of wheels, including two swing members carried by frame, and three rods, <BASIC> US 5174595 _A _921229_9303
<EQUIVALENTS> EP 523578 _A2_930120_9303; CA 2073103 _A _930118_9314; CA 2073103 _C _940517_9425, (Deere)Deere & Co.

<BASIC> US 5174595 A linkage mechanism operatively couples front and rear pairs of wheels for transmitting pivotal motion between. The linkage mechanism includes a first swing member swingably carried by the frame and coupled with the first rod member for swinging about a vertical axis as the front wheels pivot. swing member that is carried by the frame for pivotal motion about a horizontal axis. other vehicle components located between the mower deck and the vehicle.

29. M. Sugiyama, Electric control apparatus for rear wheel steering mechanism of wheeled, US 5311956 940517 US 974421 921112 Priority Applic: JP 91297479 911113, Toyota Jidosha Kogyo K JP Assignee Code: 85331.

An electric control apparatus for a rear wheel steering mechanism in a four-wheel steering system of a wheeled vehicle is designed to detect a yaw rate of the vehicle body for determining a target steering amount for steering a set of dirigible rear road wheels in accordance with a magnitude of the detected yaw rate in a direction restraining the yaw rate of the vehicle body and to produce a control signal indicative of the target steering amount for applying it to an electrically operated actuator of the rear wheel steering mechanism. The electric control apparatus is further designed to detect a roll angle and/or a roll angle speed of the vehicle body and to determine a correction amount for steering the rear road wheels in accordance with a magnitude of the detected roll angle and/or roll angle speed in an opposite direction relative to the direction restraining the yaw rate of the vehicle body and adding the correction amount to the target steering amount.

30. H. Uemura, K. Tokumaru and A. Doi, Rear wheel steering for four-wheeled vehicles - has auxiliary rod coupled to front steering rod which rotates link shaft driving rear wheel steering box, <BASIC> EP 352656 _A _900131_9005
<EQUIVALENTS> US 4949984 _A _900821_9036; EP 352656 _B1_940209_9406; KR 9208828 _B1_921009_9411; DE 68912985_E _940324_9413, (Mazda)_Mazda Motor Corp; (Mazda)_Mazda Kk.

<BASIC> EP 352656 A rear wheel steering system for a vehicle is actuated by the steering motion of the front wheels. The steering wheel (10) drives a steering rod (18) via a pinion (14) to turn the front wheels. A second rod (22) is coupled to the steering rod and moves axially with it, thus rotating a shaft (24) via its pinion (26). converted in coupler (28), by an arrangement of gear to linear motion to operate steering rods (30L,30R) and hence steer the rear wheels. moments and saves weight. @(30pp Dwg.No.1/24)@
<US> 9036 US 4949984 coupling rear right and left wheels through one shaft. A cam member is rotatable about an axis extending in a direction perpendicular to the output shaft. in rolling contact with opposing portions of the outer peripheral surface of the cam member. An input shaft rotates the cam member in accordance with a turning amount of front wheels.

31. T. Yonekawa et al., Fluid pressure type active suspension in four wheel steer vehicle - has valves which control fluid supply to actuators in response to vehicle operating characteristics and front to rear wheel steering angle, <BASIC> EP 416556 _A _910313_9111
<EQUIVALENTS> US 5069475 _A _911203_9151; EP 416556 _A3_920902_9338; EP 416556 _B1_940803_9430; DE 69011245_E _940908_9435, (Toyota)Toyota Jidosha Kk; (Aise)_Aisin Seiki Kk.

<BASIC> EP 416556 The active suspension is controlled by constantly monitoring the vehicular attitude and supplying a pressurized fluid such as oil from a reserve tank (4) to piston operated actuators (1FR,1FL,1RR,1RL) attached between vehicle body and each wheel. characteristics to a central computer control system which determines the adjustments required to maintain optimum ride height in accordance with the front to rear wheel steering angle ratio. turning is suppressed. @(38pp Dwg.No. 1/20)@
<US> 9151 US 5069475 pressure type actuator provided between the vehicle body and each wheel, working fluid supply and exhaust for supplying and exhausting a working fluid to and from each actuator and a vehicle height detector. The latter detects vehicle height of a portion of the vehicle body corresp to each wheel relative to the wheel. A control unit controls the working fluid supply and exhaust according to control parameters including a vehicle height. fluid supply and exhaust in accordance with whether a front to rear wheel steering angle ratio of the four wheel steering devices is in a same phase region or an opposite phase region so that the vehicle height is controlled to be higher or lower or the rolling control is suppressed less or more according to whether the front to rear wheel steering angle ratio is in the opposite phase region or in the same phase region respectively. @(34pp)@
<EP> 9430 EP 416556 B automobile, comprising fluid pressure type actuators (1FR,1FL,1RR,1LL) each provided between a vehicle body and each wheel, working fluid supply and exhaust means (40,42,44,46) for supplying and exhausting a working fluid to and from each said actuator, vehicle height detection means (144FL,144FR,144RL,144RR) for detecting vehicle height of a portion of the vehicle body corresponding to each said wheel relative to said wheel, and a control means (200) for controlling said working fluid supply and exhaust means according to control parameters including a vehicle height detected by said vehicle height detection means, characterized in that the vehicle has a four wheel steering means and that said control means is adapted to modify the control of said working fluid supply and exhaust means in accordance with whether a front to rear wheel steering angle ratio of said four wheel steering means is in a same phase region or an opposite phase region.

Cue Augmentation Patents - Appendix N

1. B. R. Ashworth, A. C. Hall and C. E. Clark, Simulation appts. providing acceleration cues to simulator pilots has control signals applied to torque motor controlling tension on cable attached to helmet, <BASIC> US 4264310_A_810428_8120, (USA)Nat Aero & Space Admin.

<BASIC> The device is used for providing acceleration cues to the helmet of an aircraft simulator pilot. Pulleys are attached to both shoulders of the simulator pilot. Cables are attached to both sides of the helmet and extend through the pulleys to a take-up reel which is driven by a torque motor. In one embodiment a force transducer is located in the cable and produces a signal proportional to the tension on the cable. the servo and subtracts from the input command signals to the torque motor. In a second embodiment, the force transducer is attached to the take-up reel and produces a signal proportional to the torque on the take-up reel. One complete device is used for each side of the helmet.

2. A. Caine Harold, Collision avoidance device, US 4600913 860715 US 685338 841224 Priority Applic: US 685338 841224, UNASSIGNED OR ASSIGNED TO INDIVIDUAL Assignee Code: 68000.

A collision avoidance device for providing integrated and more standardized visual indications and methods as a system of the degree of safety space cushion following distance conditions between leading and following vehicles. The device is mounted on a central housing placed on the rear of a leading vehicle at approximately center eye level for viewing by the drivers of the following vehicles. A safe distance light is included in the housing as well as a brake light. The safe distance signal light includes a plurality of illuminated areas with opaque spaces there between. The opaque spaces are of sequentially increasing width or thickness. The opaque spaces will progressively disappear to the view of the driver of the following vehicles with greater distance from the leading vehicle. Additional safety lights can be included such as a green safety light as well as directional signals. The green light can be used to indicate acceleration, or may be used to indicate that the set belts are fastened. The lights in the device can be formed to blink with emergency stopping. The integration of all of the various safety illuminated factors provides a basic method of visual stimulation and an increase in the driver' s earlier visual perception and mental awareness of the safety conditions so as to improve the resultant earlier reaction time for stopping as well as based upon an awareness of proper safe spacing between the vehicles indicating visual cues as perceived by the drivers of the following vehicles.

3. J. Kron Gerald, Advanced g cueing system, US 4321044 820323 US 960525 781114 Priority Applic: US 960525 781114, SINGER CO THE Assignee Code: 77120 REASSIGNED.

An improved G-seat system for providing kinesthetic cues to the operator of a vehicle simulator in which the motion sensations associated with the "G" forces are simulated by the motion of a single seat plate (62) having a pair of passive thigh ramps (78) mounted thereon and the variation in the degree of inflation of thin bladders (82A,B) which overlie the seat plate. Raised surfaces (80) may be provided on the plate beneath the ischial tuberosity region of the operator to increase the dynamic range of perceived g-loading effects. A backrest plate (92) may be provided for motion in conjunction with the seat plate and a thin bladder (128) may likewise be provided thereon. Driven radial elements (108,110) may then be positioned on the lower part of the backrest plate to augment pressure cues at selected areas of the operator's back.

4. R. Lowe James, Conformal head-up display, US 4454496 840612 US 202167 801030 Priority Applic: US 202167 801030, MCDONNELL DOUGLAS CORP Assignee Code: 53483.

A system for providing a Head-Up Display (HUD) on board an aircraft to assist a pilot in guiding the aircraft. The display is positioned in the pilot's normal line of sight. In one mode it utilizes a radio beam landing system such as an ILS (Instrument Landing System) to generate symbols that correspond to visual ground cues which, together with an aircraft symbol display, provide the pilot with cues for aligning the aircraft on the appropriate path for approach and landing. The system moves the aircraft symbol in accordance with motion changes of the aircraft. During a landing approach the pilot "flies" the aircraft symbol relative to the simulated and/or real ground cues. By making the HUD correspond with ground cues, the abrupt transition from instrumented to visual flight is eliminated. At altitudes below which available ILS is not acceptable, the system provides a smooth transition to a mode independent of ILS and then to a flare mode. The system also includes a mode that is totally independent of any ground installation. The system also provides an altitude hold mode with a smooth transition to the approach mode.

5. R. Mettig, Brake warning signalling appts. at rear of road vehicle - flashes conventional warning lamp whenever supply of fluid to individual wheel brake is inhibited to prevent locking, <BASIC> DE 4243693 _A1_940623_9426, (Mett/)_Mettig R.

<BASIC> DE 4243693 A signal is sent discontinuously and/or in the form of pulses to the brake warning lamp (10) among the rear cluster (9), via a switch (8) opened and closed by OR logic (7). to any one of the brake valves (3.1 to 3.4) which are operated to inhibit temporarily the supply of fluid to the brake on a locking wheel. equipment already provided on the vehicle, and is inexpensive to mfr. and suitable for retrofitting to existing vehicles.

6. R. D. Murphy and D. H. Cleford, Maneuvering force gradient control system for aircraft uses pitch control signal generated according to roll angle, <BASIC> DE 3406050_A_840823_8435
<EQUIVALENTS> GB 2135479_A_840830_8435; SE 8400953_A_840924_8441; AU 8424511_A_840830_8442; NO 8400608_A_840917_8444; DK 8400803_A_840823_8447; ES 8502652_A_850416_8525; US 4563743_A_860107_8605; GB 2135479_B_870311_8710; SE 450371 _B_870622_8727, (Unac)_United Technologies Corp; (Unac)_United Technologies Corp.

<BASIC> DE 3406050 controller of a vehicle with position-able aerodynamic surface affected by the pitch controller via a position drive responsive to a demand signal. A controller responsive to the outputs of a roll angle sensor is connected to the position drive and forms the demand signal as a function of roll angle. according to a defined relationship w.r.t. the roll. The demand signal is only generated when the roll angle exceeds a defined threshold. workload is reduced and stability improved. @(20pp Dwg.No. 0/2)@
<US> 8605 US 4563743 the roll angle. A command signal is provided as a function of the roll angle to operate the longitudinal trim actuator which automatically moves the cyclic control resiliently forward to push the nose down. The pilot must consequently pull back on the cyclic control (50) to achieve a desired pitch attitude, thereby establishing a longitudinal positive maneuver-force gradient. the roll angle equals or exceeds 30 deg. Both analog and digital versions are provided, and the system may be practiced in association with an automatic flight control system (AFCS) having the longitudinal trim actuator and resilient linkage. @(7pp)@
<GB> 8710 GB 2135479 roll, a maneuver force feedback system causing the aircraft to pitch nose down in the turn, characterized by: actuator means for positioning the pitch axis aerodynamic surfaces of the aircraft in response to a command signal; roll angle sensor means for providing a roll angle signal indicative of the aircraft roll angle as measured from wings-level flight; and control means for causing the aircraft to pitch nose down in the turn as a function of the aircraft roll angle by providing the command signal to the actuator in response to the roll angle signal to give a g-force cue to the pilot.

Drive by Wire Patents - Appendix O

1. K. Hayafune, J. Kawai and M. Shimada, Drive by wire control device for an internal combustion engine and a, US 5305662 940426 US 974812 921116 Continuation of: ABANDONED US 871118 920420 Priority Applic: JP 9188603 910419, Mitsubishi Jidosha Kogyo K JP Assignee Code: 56268.

A control device for an internal combustion engine and a continuous variable transmission which enables well-responsible transmission control to be carried out at a proper transmission rate without increasing the transmission shock. When engine power corresponding to an engine power torque corrected amount is changeable, then an intake air flow adjusting unit is controlled in response to a corrected engine power torque corrected amount. On the contrary, when the corrected engine power torque corrected amount is not changeable, the amount corrected engine power torque corrected is restricted within a range where the engine power can be changed.

2. W. J. Imoehl, Accelerator control apparatus, US RE34574 940405 US 758983 910910 Reissue of: US 4869220 890926 US 157766 880218 Priority Applic: US 758983 910910, Siemens Automotive Assignee Code: 26659.

An accelerator control apparatus for mounting in a motor vehicle for a "drive-by-wire" system. The apparatus provides a bias spring means to generate the "feel" of an accelerator pedal to the vehicle operator, a compression spring means provides frictional forces preventing extraneous pedal actuation and pedal sensor switch means for indicating the rotation position of the accelerator pedal from a first or normal position to any second position.

3. D. C.-H. Shaw and J. Z.-Z. Shaw, Automobile collision avoidance system, US 5314037 940524 US 8367 930122 Priority Applic: US 8367 930122, Unassigned Or Assigned To Individual Assignee Code: 68000.

An automobile collision avoidance system based on laser radars for aiding in avoidance of automobile collisions. The very small beam width, very small angular resolution and the highly directional character of laser radars provide a plurality of advantages as compared with microwave radars. With two sets of laser radars this system can detect the location, the direction of movement, the speed and the size of all obstacles specifically and precisely. This system includes laser radars with transmitters and receivers, a computer, a warning device and an optional automatic braking device. A steering wheel rotation sensor or a laser gyroscope is utilized to give information of system-equipped vehicle's directional change. The system will compare the predicted collision time with the minimal allowable time to determine the imminentcy of a collision. When the system determines that a situation likely to result in an accident exists, it provides a warning. An optional automatic braking device is disclosed to be used when the vehicle user fails to respond to a warning. Furthermore, a wheel skidding detecting system based on a discrepancy between the directional change rate predicted by a steering wheel rotation sensor and the actual directional change rate detected by a laser gyroscope is also disclosed. The detection of wheel skidding can be utilized by various vehicle control designs, including designs to adjust rear wheel steered angle in a four wheel steering vehicle, to alleviate or correct the wheel skidding. Designs to decelerate the engine or to adjust the transmission to lower gears are also disclosed to alleviate wheel skidding.

4. K. Togai et al., Engine output controller for motor vehicle - operates throttle valve, driven by drive-by-wire or similar, on basis of output control quantity, <BASIC> WO 9008888 _A _900809_9034
<EQUIVALENTS> EP 408767 _A _910123_9104; EP 408767 _B1_940720_9428; DE 69010793_E _940825_9433, (Mitm)_Mitsubishi Jidosha.

<BASIC> WO 9008888 A first unit (30A) sets a first target control quantity in accordance with an operation quantity of an artificial operation member (20). A second unit (40A) sets a second target control quantity which can control the slip of wheels (15) and is the same kind of quantity as the first target control quantity. A third target unit (50A) sets a third target control quantity which is necessary for constant speed driving and is the same kind of quantity as the first and second target quantities. with a driving mode of the vehicle. An output setter (70A) sets an engine output control quantity on the basis of the target control quantity selected. The engine output is controlled by the engine output control (7,90) on the basis of this engine output control quantity via an engine output regulator (6). traction control, automatic cruise control

and the like, can be integrally incorporated as single vehicle control without inviting complicated control. @(80pp Dwg.No.1/20)@

<EP> 9428 EP 408767 B said vehicle being equipped with an engine output adjusting means (6) for adjusting an output of an engine and an engine output control means (7,90) for controlling said engine output adjusting means (6) based on at least one of a first target amount of control corresponding to an amount of operation of a mutually-operated member (20), a second target amount of control required to have wheel slippage ceased, and a third target amount of control required to permit constant-speed running of the vehicle, the engine output control apparatus comprises: a first target-amount-of-control setting means (30A,30B,30C,30D) for setting the first target amount of control (theta1,A/Nt1,Tet1,T2t1); a second target-amount-of-control setting means (40A,40B,40C,40D) for setting the second target amount of control (theta2,A/Nt2,Tet2,Twt2); a third target-amount-of-control setting means (50A,50B,50C,50D) for setting the third target amount of control (theta3,A/Nt3,Tet3,Twt3); a target-amount-of-control selecting means (73A,73B,73C,73D) for selecting one of said first, second and third target amounts of control according to an operation mode of the vehicle; and amount-of-control-of-engine-output setting means (70A,70B,70C,70D) for setting an amount of control of engine output (thetat) based on the target amount of control selected by said target-amount-of-control selecting means (73A,73B,73C,73D); wherein said engine output control means (7,90) controls said engine output adjusting means based on the amount of control of engine output (thetat) set by the amount-of-control-of-engine-output setting means (70A,70B,70C,70D), characterized in that the first, second and third target amounts of control are all of the same kind.

Traction Control Patents - Appendix P

1. E. Beck, H. Reinartz and S. Risch, Hydraulic switching valve for vehicle antilock and traction control braking system - has throttle comprising piston and auxiliary piston to prevent reaction effect at brake pedal, <BASIC> WO 9319960 _A1_931014_9342 <EQUIVALENTS> DE 4236045 _A1_931104_9345; EP 586625 _A1_940316_9411; SK 9400036 _A3_940810_9436, (Teve)_Teves Gmbh Alfred; (Intt)ITT Automotive Euro Gmbh.

<BASIC> WO 9319960 A antilock and slip control which is fitted in the aspiration line between the pump and the master cylinder. The valve closes off the line whenever the brake pedal is actuated and opens it at each drive slip control adjustment, and has a throttle consisting of a piston (12) and an auxiliary piston (132) which so delay the through flow of the system medium that the closing time of the switching valve is prolonged. brake pedal.
<DE> DE 4236045 A with antilock and slip control which is fitted in the aspiration line between the pump and the master cylinder. actuated and opens it at each drive slip control adjustment. The valve has a throttle consisting of a piston (12) and an auxiliary piston (132) which so delay the through flow of the system medium that the closing time of the switching valve is prolonged.
ADVANTAGE - Prevents the driver feeling reaction effects at the brake pedal.

2. R. Bodier and H. Schmidt, Motor vehicle with antilocking braking system - uses computer for electronic calculation of road grip and controlled braking sequence, <BASIC> DE 4020505 _A _920109_9203
<EQUIVALENTS> DE 4020505 _C2_940127_9404, (Mesr)_Messerschmitt-Bolkow-Blo; (Daim)_Deut Aerospace Ag.

<BASIC> DE 4020505 Each wheel-brake cylinder has a pressure sensor and each wheel has a wheel-speed monitor. The outputs from the sensors and monitors are linked to a processor to compute the wheel-skid and well as wheel-spin. The processor system calculates the road grip coefficient and determines the onset of aquaplaning by the different reactions on the driven and un-driven wheels. monitoring enables the system to distinguish between aquaplaning and icy roads. A programmed braking/torque control in the processor provides active control of the wheel-brakes. @(6pp Dwg.No.1/3)@
<DE> 9404 DE 4020505 C road vehicle, combines a standard ABS feature for all wheels with control of the permitted propulsive effort and additional software enabling the computer to discriminate between differing road surfaces during braking, constant speed, or acceleration. vehicle speed (18), brake cylinder (9-12) pressures (13-16), pos./neg. acceleration (17), wheel (1-4) r.p.m. (7-10) and outside temp. (19). A separate monitor unit references all of the above variables, whereby an appropriate control characteristic is established relevant to frictional grip enabling optimization of steering response and stopping distance. parameters. Reduced response time and shortening of stopping distances in extreme conditions. Transverse acceleration sensor to system enables prevention of vehicle breakaway/side slip due to over-acceleration or deceleration.

3. H. Fujioka and T. Matsumoto, Wheel behavior detecting system for suppressing wheel slippage - has control variable calculator operating on basis of output values from wheel speed detector, <BASIC> EP 298477 _A _890111_8902
<EQUIVALENTS> US 4924396 _A _900508_9023; EP 298477 _B1_931124_9347; DE 3885802 _G _940105_9402, (Sume)_Sumitomo Elec Ind Kk.

<BASIC> EP 298477 A wheel speed detecting device (1-4) senses the speed of rotation of both front lift and right hand wheels and both rear left and right hand wheels. A second sensor detects the speed of movement of a vehicle. A control variable calculating device (6) operates on the basis of output valves from the wheel speed detecting device (1-4). (f) utilized to detect the occurrence of excessive wheel slippage or excessive wheel spinning. This is represented by the difference on speed rotation of the wheels relative to the speed of moment of the vehicle. A control command determining device responds to an output from the control variable calculating device (6) to detect excessive wheel slippage and than determine command necessary to control braking forces applied to the wheels. braking system designed to suppress any excessive slippage or spinning of automobile wheels. @(13pp Dwg.No. 1/9)@
<US> 9023 US 4924396 comprises a wheel behavior detecting system. The latter comprises a circuit for calculating, on the basis of output values from wheel speed detectors, a bad road coefficient A of

representative of the road surface irregularity upon which the vehicle is moving. A control variable filtering circuit produces a filtered value Lm which exhibits a normal waveform when the bad road coefficient A is small and a filtered waveform when the bad road coefficient is great thus keeping abrupt changes caused by the bad road from erroneously controlling the traction or antilock systems. the filtering circuit, that is, the control variable which has been modified, to determine the command necessary to control braking forces to be applied to the wheels. wheels. @(12pp)@
<EP> 9347 EP 298477 B type which comprises wheel speed detecting means (1-4) for detecting the speed of rotation of front left-hand and right-hand wheels and rear left-hand and right-hand wheels, a vehicle speed detecting means for detecting the speed of movement of a vehicle, a control variable calculating means (6) operable on the basis of output values from the wheel speed detecting means (1-4) and the vehicle speed detecting means to calculate a control variable F utilizable to detect the occurrence of excessive wheel slippage or excessive wheel spinning which is represented by the difference in speed of rotation of the wheels relative to the speed of movement of the vehicle, a control command determining means (8) operable in response to an output from the control variable calculating means (6) to detect the occurrence of the excessive wheel slippage or excessive wheel spinning and then to determine a command necessary to control braking forces to be applied to the wheels, and actuator means (9) operable in response to output values from the determining means (8) to control the braking forces, a wheel behavior detecting system which comprises; a coefficient calculating means (5) for calculating on the basis of the output values from the wheel speed detecting means (1-4), a coefficient A of bad road representative of the surface irregularity of the road on which the vehicle is moving; and which is characterized by a control variable filtering means (7) operable to a filtered value Lm which exhibits a waveform similar to the original waveform of the control variable F when the bad road coefficient A is small, but a waveform in which is component of abrupt charge of the control variable F is removed when the bad road coefficient is great; said control command determining means (8) being operable in response to an output from the filtering means (7) to determine the command necessary to increase or decrease the braking forces.

4. K. Fukuyo and Y. Hoshoya, Pressure controller for vehicle antilock braking circuit - incorporates switching valve circuit to give traction control function, <BASIC> DE 4241913 _A1_930617_9325
<EQUIVALENTS> US 5330258 _A _940719_9428, (Nissan)_Nisshinbo Ind Inc.

<BASIC> DE 4241913 A vehicle having a master cylinder (10), brake pipes (20), wheel cylinders (11), an inlet valve (12), an outlet valve (14), a suction pipe (21) connecting a pump (15) with a reservoir (13), and a pipe (22) between the pump and the main brake line. together with a return pipe (23) containing a switching valve (30), a safety valve (50) and a check valve (40). of a few, cost effective components, can also exercise a reliable traction control function (TCS).
<US> 9428 US 5330258 A master cylinder connected to brake circuits for a number of drive and follower wheels, each brake circuit being connected to a wheel cylinder through a main brake line. The pressure control unit for each of the drive wheels incorporates a selector valve, fitted in the main brake line on a master cylinder side of a connection between the main brake line and the delivery line. The selector valve is formed to switch to a closed state only during traction control operation. and the suction line, and a switching valve installed in the reflux line, the switching valve being formed to switch to a free passage state between a master cylinder reservoir and the suction line during traction control operation. There is a relief valve, fitted across both the main brake line and the reflux line, wherein when the pressure from the delivery line reaches or exceeds a threshold level. The relief valve opens to exhaust excess hydraulic pressure of the delivery line to the reflux line, and at all other times the relief valve remains closed. There is also a check valve connected to the suction line on a working fluid reservoir side of a connection with the reflux line. reliability through the addition only of inexpensive and small number of parts to the basic ABS circuit.

5. R. Holzmann, K. H. Willmann and K. Willmann, Antilock hydraulic braking system having drive slip control - has 2/2-way solenoid valve closed and charging valve opened allowing fluid to be pumped from reservoir, when slip control is needed, <BASIC> GB 2249597 _A _920513_9220
<EQUIVALENTS> DE 4035527 _A _920514_9221; FR 2669595 _A1_920529_9231; US 5205623 _A _930427_9318; GB 2249597 _B _940629_9423, (Bosc)_Bosch Gmbh Robert.

<BASIC> GB 2249597 A multi-way valve (48, 48') is disposed in the connection leading from a master brake cylinder (15) to the wheel brake cylinder of a driving wheel (11, 12) and a charging valve (47, 47') is disposed in a suction line (49, 49') between a pump element (36, 37) and brake fluid reservoir (50). To build up brake pressure for slip control the multi-way valve is closed and the charging valve is opened allowing fluid to be pumped from the reservoir. pressure the charging valve is closed and the multi-way valve is opened. Alternatively, fluid may be drawn directly from a brake fluid reservoir. Pref., the multi-way valve is a 2/2-way solenoid valve. radical heating of return pump and reduced hydraulic noise.
<US> 9318 US 5205623 A traction control (ASR) includes a hydraulic unit with at least one control valve and a return pump having at least one pump element that is embodied as self-aspirating pump element and that is operative in a brake circuit, which contains at least one drive wheel. A valve assembly serves to furnish brake pressure in ASR and each valve assembly comprises a respective charging valve embodied as a 2/2-way magnet valve and an electromagnetic reversing valve. in traction control, only the valve assembly is triggered, and is triggered such that for pressure buildup the electromagnetic reversing valve blocks fluid flow and the charging valve is opened, while for pressure holding both valves block fluid flow, and for pressure reduction the charging valve blocks fluid flow and the electromagnetic reversing valve is opened.
<GB> 9423 GB 2249597 B drive slip control (ASR) for motor vehicles, comprising a master brake cylinder with at least one brake circuit output for supplying a brake pressure upon pedal actuation, a brake fluid reservoir connected to the master brake cylinder, a hydraulic unit which is connected to the at least one brake circuit output and has at least one outlet channel for the connection of a wheel brake cylinder associated with a driving wheel of the vehicle, at least one control valve connected on the one hand by a connection line to the brake circuit output and on the other hand to the outlet channel, and a return pump with at least one self-priming pump element, which is connectable on its input side by the control valve to the outlet channel and is connected on its output side to the connection line, and having at least one valve arrangement for providing a brake supply pressure during drive slip control, the or each valve arrangement having a charging valve, which at least during drive control connects the pump element to the brake fluid reservoir and upon brake pedal actuation shuts off said connection, and an electromagnetic multi-way valve which is disposed in the connection line and shuts off the connection line during drive slip control, the or each charging valve comprises a 2/2-way solenoid valve, wherein, during drive slip control, the valve arrangement or at least one of the valve arrangements is activated exclusively and is activated in such a way that, to build up pressure in the wheel brake cylinder of the at least one driving wheel, the multi-way valve assumes its closed position and the charging valve assumes its open position, to hold pressure, the charging valve and the multi-way valve each assume their closed position, and to reduce pressure, the charging valve assumes its closed position and the multi-way valve assumes its open position.

6. M. Inagaki, H. Ogawa and K. Takeda, Combined antiskid and traction control electronic brake system, US 5282676 940201 US 798714 911127 Priority Applic: JP 90334367 901129, Nippon Soken Inc JP Assignee Code: 59967.

A brake system capable of implementing anti-skid and traction control operations has an electromagnetic valve for connecting a master cylinder to a wheel cylinder and for disconnecting the master cylinder from the wheel cylinder when anti-skid or traction control is executed. A piezo-electric hydraulic pump is provided for introducing high-pressure brake oil when anti-skid or traction control is executed. A pressure reduction valve selectively introduces and removes brake oil so that a desired wheel cylinder pressure can be attained when anti-skid or traction control is executed. A hydraulic switching valve is connected to the main oil pressure line parallel to the electromagnetic valve and allows pressure in the master cylinder to be opened to the wheel cylinder during a braking operation. The system also includes a unit for establishing one-way communication from the wheel cylinder to the master cylinder during anti-skid control to prevent pressure in the wheel cylinder from being higher than that in the master cylinder while preventing connection between the master cylinder and the wheel cylinder during traction control.

7. T. Iwata, Automotive brake control system, US 5324103 940628 US 931614 920818 Priority Applic: JP 91207905 910820, Nissan Motor Co Ltd JP Assignee Code: 56116.

An automotive brake control system includes a master cylinder, an external brake fluid pressure source, a wheel-cylinder pressure control actuator applied commonly to a traction control (TCS control) performed for suppressing excessive driving force exerted on driven wheels during quick acceleration and an antiskid brake control (ABS control) performed for preventing brakes from locking vehicle wheels during quick braking, or braking on a low frictional road, and a fluid pump for supplying the brake fluid stored in a fluid reservoir to a pressure accumulator, and a controller for controlling the pump, such that the pump is driven for a first setting time in an ABS pressure reducing mode and drives the pump for a second setting time substantially at a time point where one cycle of the TCS control ends, so as to feed the brake fluid from the reservoir to the accumulator.

8. T. Iwata, Vehicular hydraulic braking system with wheel-slip control mode - has wheel brake cylinder drain pump operated for two predetermined intervals after implementation of antilock operation, <BASIC> DE 4227440 _A1_930225_9309 <EQUIVALENTS> US 5324103 _A _940628_9425, (Nsmo)_Nissan Motor Co Ltd.

<BASIC> DE 4227440 A pedal operation, and externally by a pump (23), as a basis for antilock braking and wheelslip correction respectively. pressure accumulator (11) after extension from the brake cylinders (14,15) acting on the rear wheels. This pump (12) is restarted after the antilock operation at a point corresponding to the end of the wheelslip regulation cycle for a predetermined duration. unnecessary noise and vibration from pump in wheelslip control mode.
<US> 9425 US 5324103 A pressure source, and a wheel-cylinder pressure control actuator. The actuator is applied commonly to a traction control (TCS control) performed for suppressing excessive driving force exerted on driven wheels during quick acceleration and an anti-skid brake control (ABS control) performed for preventing brakes from locking vehicle wheels during quick braking, or braking on a low frictional road. to a pressure accumulator, with a controller controlling the pump, so that the pump is driven for a first setting time in an ABS pressure reducing mode and drives the pump for a second setting time at a time point where one cycle of the TCS control ends, so as to feed the brake fluid from the reservoir to the accumulator.
ADVANTAGE - Reliable antilock braking is ensured without unnecessary noise and vibration from pump in wheelslip control mode.

9. F. Kageyama, M. Kawamura and K. Nobumoto, Vehicle slip control system, US 5340204 940823 US 137385 931018 Continuation of: ABANDONED US 753439 910830 Priority Applic: JP 90230157 900831, Mazda Motor Corp JP Assignee Code: 11642.

A slip control system for a vehicle having rear right and left drive wheels includes a traction control for controlling a slip rate of a wheel by controlling a braking hydraulic pressure for the wheel under a non-braking condition. The slip rate of a wheel is controlled, by controlling the braking hydraulic pressure for the wheel under a braking condition, so as to provide an antiskid control. A start of the control of the slip rate is restricted by the anti-skid control. The control of the slip rate by the anti-skid control is applied commonly to the right and left drive wheels, while the control of the slip rate by the traction control is applied independently to the right and left drive wheels. The anti-skid control can be always properly carried out without being affected by the traction control.

10. K. Kawase, Brake controller for vehicle, 06-064512 -JP 6064512 A-, AKEBONO BRAKE RES & DEV CENTER LTD [488548] (A Japanese Company or Corporation), JP (Japan).

PURPOSE: To provide a brake controller for vehicle which can perform the antilock control, traction control or automatic brake holding control by a common control piston and a common solenoid valve.

11. H. Nakamura, Antiskid braking control for motor vehicle - has pneumatic primary circuit and throttle valve between control valve and circuit for rapid venting, <BASIC> DE 4223433 _A1_930121_9304
<EQUIVALENTS> US 5297860 _A _940329_9412, (Akeb)_Akebono Brake Ind Co Ltd.

<BASIC> DE 4223433 A brake pressure to the two brake circuits, and pneumatic/hydraulic units to generate the hydraulic wheel-brake pressures. One of the brake circuits has a control valve to reduce the system brake pressure during anti-skid operation. This circuit has a two way release for brake pressure when the brakes are released, using a throttle valve between the control valve and a switching valve. modulated brake pressure or the supply brake pressure. The brake release enables the pneumatic pressure to vent in two directions from the modulating valve.
<US> 9412 US 5297860 A traction control valve and a throttle valve. The shuttle valve selects a higher air pressure either from a brake valve, which operates when the brake is applied, or from a traction control

valve, which opens during traction control to prevent wheel slippage. The shuttle valve allows the higher of the two air pressures to enter the modulator, which converts the entering air pressure to a brake hydraulic pressure to be supplied to the wheel cylinders of the motor vehicle. and the shuttle valve decreases the air pressure from the traction control valve to be transmitted to the modulator when the traction control is activated. The throttle valve and the shuttle valve cooperate to increase the number of discharge air passages so that the brake control device has a greater discharge capacity when the brakes are released. vehicle. Enables stabilized traction control.

12. H. Sasaki, Integrated control device for four-wheel steering and traction, 06-024349 -JP 6024349 A-, NISSAN MOTOR CO LTD [000399] (A Japanese Company or Corporation), JP (Japan).

PURPOSE: To prevent the occurrence of rapid vehicle behavior in a limit turning region by computing a deviation between a target behavior computing value and an actual behavior detecting value by means of the values, limiting a maximum limit amount of a four-wheel steering control system when the deviation exceeds a given value, and facilitating entrance to control of reduction of traction.

13. J. Schaefer et al., Hydraulic dual circuit braking system - uses at least one actively controlled brake filled reservoir for stable antilocking braking, <BASIC> DE 4102864 _A _911121_9148
<EQUIVALENTS> FR 2662129 _A _911122_9206; US 5123716 _A _920623_9228; GB 2252375 _A _920805_9232; US 5211454 _A _930518_9321; US 5275477 _A _940104_9402, (Bosc)_Bosch R Gmbh; (Bosc)_Bosch Gmbh Robert ; (Bosc)_Bosch Gmbh Robert.

<BASIC> DE 4102864 and drive slip regulation using a 4-channel hydraulic unit with braking control valves (31...34) and a brake fluid feedback pump (27) with 2 separate pump elements (28,29) for each braking circuit and respective low press stores (41,42). controlled using a drive (53) e.g. electric motor, electromagnet, etc. to ensure stable anti-locking braking, with a non-return valve (40) associated with the master braking cylinder (15).
<US> 9402 US 5275477 A with two separate pump elements for each brake circuit, and two low-pressure reservoirs connected to the inlets of the pump elements. For supplying brake pressure in the traction control mode, at least one brake fluid reservoir is provided. This communicates with a pump element assigned to a brake circuit having at least one driven wheel. master brake cylinder and the outlet of such a pump element. For the sake of problem-free initiation of braking during the traction control mode without the danger of unstable driving conditions, the brake fluid reservoir is an active, controllable reservoir. In its reversed position a check valve having a blocking direction toward the master brake cylinder is operative. system (ABS) and traction control (ASR) for motor vehicles. hydraulic unit with control valves, a return pump with two separate pump elements for each brake circuit, and two low-pressure reservoirs connected to the inlets of the pump elements. For supplying brake pressure in the traction control mode, at least one brake fluid reservoir is provided, which communicates with a pump element assigned to a brake circuit having at least one driven wheel, and a reversing valve is disposed in each connecting line between the master brake cylinder and the outlet of such a pump element. traction control mode without the danger of unstable driving conditions, the brake fluid reservoir is embodied as an active, controllable reservoir, and the reversing valve is embodied such that in its reversed position a check valve having a blocking direction toward the master brake cylinder is operative. control (ASR). Stable vehicle performance with no rear axle overbraking. (ABS) and traction control (ASR) for motor vehicles having a four-channel hydraulic unit with control valves, a return pump with two separate pump elements for each brake circuit, and two low-pressure reservoirs connected to the inlets of the pump elements. For supplying brake pressure in the traction control mode, at least one brake fluid reservoir is provided, which communicates with a pump element assigned to a brake circuit having at least one driven wheel, and a reversing valve is disposed in each connecting line between the master brake cylinder and the outlet of such a pump element. traction control mode without the danger of unstable driving conditions, the brake fluid reservoir embodied as an active, controllable reservoir, and the reversing valve is embodied such that in its reversed position a check valve having a blocking direction toward the master brake cylinder is operative.

14. S. Tsuchiya, Traction control system for vehicle with driving and follower axle - has traction control valve communicating with air pressure control cut valves so as to

close hydraulic lines of air-over hydraulic type anti-lock brakes, <BASIC> EP 559151 _A1_930908_9336
<EQUIVALENTS> US 5290097 _A _940301_9409, (Akeb)_Akebono Brake Ind Co Ltd.

<BASIC> EP 559151 A opposing pair of driving wheels and an opposing pair of follower wheels which communicate with common master cylinders (5L, 5R). Air pressure from a source (4) is applied to the air master cylinders via a traction control valve (300) and the air pressure is transformed into hydraulic pressure in the air master cylinders so as to prevent the driving wheels held in the excessive running state from slipping. wheel cylinders for both the driving wheels and follower wheels communicate. The air pressure transmitted from the traction control valves is also applied to air pressure control type cut valves (6L,6R) disposed at intermediate positions on the hydraulic lines which closes the lines only when the vehicle is in the traction control state. driving wheels experiencing slippage are controlled.
<US> 9409 US 5290097 A source for jointly supplying an air pressure to each of the air master cylinders. Each air master cylinder transforms the supplied air pressure into the hydraulic braking pressure of two pairs of hydraulic lines. A pair of air pressure control type cut valves are provided, one each being disposed in each of the second hydraulic lines, for opening and closing the second hydraulic lines. third pair of hydraulic lines connecting the traction control valve to one each of the air pressure control type cut valves. The air pressure supplied to the pair of air master cylinders is jointly supplied to the air pressure control type cut valves. with a small number of channels.

15. E. Wehner, Variable rim system for vehicle tyre - uses control rods to move profile sections between outer and inner positions, <BASIC> DE 4328044 _A1_940331_9414, (Wehn/)_Wehner E.

<BASIC> DE 4328044 A profile segment (3) and an elastic profile ring (19). The profile segment is moved outwards and inwards by an actuation rod (2), with a gap (21) between the housing and the tyre. actuation rod is achieved via the antilock braking system controller, and by sensors which give early warning of temp. changes at the road surface.
USE/ADVANTAGE - Variable wheel rim system on vehicle adjusts shape of tyre to match prevailing road surface conditions and is esp. useful with ice and snow.

16. H. Yoshida and K. Yamada, Antilock brake traction control system, 06-048286 -JP 6048286 A-, MITSUBISHI MOTORS CORP [351404] (A Japanese Company or Corporation), JP (Japan).

PURPOSE: To make a hydraulic unit into common use with an automatic braking system and a traction control system with a brake by connecting a wheel cylinder and a first liquid chamber together at the time of operating this ABS, and at the time of operating the TCL system, installing a selector valve which connects the wheel cylinder to a second liquid chamber.

Delphi Forecasts / Automotive Technology - Appendix Q

Material contained in this Appendix is reproduced here primarily from a study[1] conducted periodically by the University of Michigan Office for the Study of Automotive Transportation. A second report[2] provides forecast information applicable to IVHS technologies. The copyrighted material is reproduced here with the permission of the authors.

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[1] D. Cole, Delphi VII Forecast and Analysis of the North American Automotive Industry, Volume 2 - Technology. Office for the Study of Automotive Transportation, University of Michigan, UMTRI 94-4-2, 1994.

[2] S. Underwood, Delphi Forecast and Analysis of IVHS through 1991, Delphi II. University of Michigan, IVHS Technical Rept: #92-17, 1991.

TECH-14 What is the likelihood of federal legislation mandating or regulating the following automotive features by the year 1998, where 1 = Extremely likely and 5 = Not at all likely? Please identify any other features in the comments section.

Automotive Features	Mean Forecast
Onboard emission control diagnostics	
Passenger car	1.8
Light truck	2.1
Antilock braking systems (ABS)	
Passenger car	2.8
Light truck	2.9
Alternate fuel capability	
Passenger car	2.8
Light truck	3.2
Driver impairment interlocks	
Passenger car	3.7
Light truck	3.9

Selected edited comments

- ABS is likely to grow so rapidly that ABS legislation will not be required.
- An insurance break could substitute for legislation on driver impairment. Drunk driving hasn't surfaced in the current debate about health care and costs. Considerable savings could be obtained; yet the resistance to impingement on individual rights could be great.
- California will lead the way again.
- Industry will provide 100 percent ABS because our customers require it. If a law is passed, it will be after-the-fact documentation. On-board emission control diagnostics regulations are in place now, effective with the 1996 model year.
- Onboard emission control diagnostics (and OBD II) are scheduled for implementation starting in 1995.
- Selective use of driver impairment prevention devices will be most likely to apply to specific individuals by court order.
- There will not be legislation on anti-lock brakes per se, but standards will be written that can only be met with ABS.

Discussion

The panelists view as somewhat likely the probability of legislation in the areas of alternate fuel capability and antilock braking systems (ABS). California will lead the way on alternate fuels. Legislation on ABS may be a mute point, since the industry and market demand are mandating the application of ABS.

Legislation regarding driver impairment interlocks is considered unlikely. This is most likely based on the negative public reaction to seat belt interlocks mandated a number of years ago, and new concerns about individual rights versus the public good. Of course, technology could have a significant impact as well.

Onboard emission control diagnostics for light trucks are considered likely, following the lead of passenger cars which will have this requirement beginning in 1995.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement regarding legislation on alternate fuel capability and driver impairment interlocks. Differences in forecasts for antilock braking systems and onboard emission control diagnostics are summarized below.

Automotive Features	Manufacturers	Suppliers
Antilock braking systems (ABS)		
Passenger car	3.1	2.5
Light truck	3.1	2.7
Onboard emission control diagnostics		
Passenger car	1.5	2.2
Light truck	1.8	2.5

Trend from previous Delphi surveys

This question was first asked in the 1992 Delphi VI survey but the responses were in a different form, making the results not directly comparable. The 1992 Delphi VI survey response is shown below regarding the likelihood of federal legislation mandating or regulating the following automotive features by 2000.

Automotive Features	Likely	Not likely
Alternate fuel capability	74%	26%
Antilock braking systems (ABS)	54	46
Driver impairment interlocks	22	78

Responses for antilock braking systems and driver impairment interlock systems were similar between the Delphi studies in 1992 and 1994. Legislation on alternate fuel capability is deemed less likely in the present study.

On-board emission control diagnostics for light trucks was not considered in the 1992 Delphi VI study.

Strategic considerations

With the exception of driver impairment interlocks, panelists consider somewhat likely the probability of application of new or increased regulations on the features selected. It would be to the advantage of manufacturers and suppliers to be pro-active in the development of these regulations with regard to technical feasibility, cost impacts and timing. Legislation developed in a joint manner with industry will result in the best, most cost-effective solutions for the nation as a whole.

TECH-29 Suggest components/systems that are candidates for standardization within the industry.

Summary of Responses	Percent of Responses
Electrical	**25%**
Batteries	4%
Electrical connectors for powertrain, chassis and body	3
Entertainment/message modules; Modular core ECU (Customize software); Navigation	2% each
Communication protocols; Digital satellite phone system; Drive by wire; Driver information systems data entry systems; Electric switch gear; Electronic communication language; Electronic control architecture; High (>12) voltage bus; High levels of computer interaction; In-vehicle message systems format; Message protocols for information exchange; Microprocessors; Phones; Radar systems for adaptive cruise control; RF devices for safety products; Serial bussing	1% each
Safety	**23%**
Airbags	5%
ABS brake systems	3
Lights	3
Tires	3
Brakes	2
Collision warning system operating characteristics	2
Adaptive cruise control; Seatbelts; Software compilers for safety critical software application; Tire pressure warning	1% each
Engine	**7%**
Emissions control components and sensors; Oil filters	2% each
Air cleaners; Engine accessories; Spark plugs	1% each
Electric vehicle	**6%**
Electric vehicle charging interface	4%
Electric vehicle battery module; Electric vehicle user interface	1% each
Processes	**6%**
Advanced quality planning; CAD design systems; Concurrent engineering; Product development process; Simultaneous engineering; Total quality management	1% each
Miscellaneous	**15%**
Diagnostic systems and standards	4%
Modular heating and air conditioning units	2
Active powertrain mounting systems; Bumpers; Catalyst; Defrost glass; Fasteners; Gas caps; Noise control; Rearview mirrors; Wipers	1% each

Discussion

Numerous components/systems have been noted as candidates for cross-company standardization within the industry. A "champion" is needed in order to begin the process. A supplier or manufacturer may start this process through existing forums.

TECH-56 What percentage of North American-produced passenger cars will incorporate the following suspension features in MYs 1998 and 2003?

Suspension Features	Median Response 1998	Median Response 2003	Interquartile Range 1998	Interquartile Range 2003
Front Suspension Configurations				
MacPherson struts	70%	65%	60/80%	50/80%
Twin A-arm	25	30	20/30	20/47
Total	95%	95%		
Rear Suspension Configuration				
Independent	60%	70%	30/75%	40/90%
Non-independent	40	25	25/70	10/55
Total	100%	95%		
Springs				
Air	4%	5%	1/5%	3/10%
Oil/fluid	1	4	0/3	2/5
Composites	5	5	2/6	3/10
Steel	91	85	85/95	70/90
Total	100%	100%		

Other responses include:

Active hydraulics: 1998 - 0 percent; 2003 - 60 percent.

Front Suspension—Active: 2003 - 1 percent.

Rear Suspension—Active: 2003 - 1 percent.

Selected edited comments

- Composites are lighter. The industry is "setting in" on short-long arm front and independent rear.
- Steel springs could go lower, based on weight savings. Air springs will benefit: less weight, height control and improved ride.
- Twin A-arm will see growth. Independent rear suspension configurations will go up, while non-independent configurations will go down. Space, packaging, mass and cost factors will cause non-independent rear suspensions to retrain some market.

Discussion

The trend in suspension systems for the next decade is forecast as follows:

Front Suspensions: MacPherson struts remain the predominant configuration, but with some increasing penetration of twin A-arms.

Rear Suspensions: Independent suspensions will gain in popularity over non-independent systems.

Springs: Steel springs will remain heavily dominant over other alternatives, but lose some ground as oil/fluid springs begin to increase in use.

Large interquartile ranges for both front and rear suspensions indicate uncertainty or differences in opinion throughout the industry with regard to direction.

Manufacturer/supplier comparison

Manufacturers and suppliers are in agreement regarding springs and front suspensions. There is considerable difference between manufacturers and suppliers on rear suspension configurations, however. The results are summarized below.

Suspension Features	1998		2003	
	Manufacturers	Suppliers	Manufacturers	Suppliers
Rear suspension configuration				
Independent	65%	35%	75%	50%
Non-independent	35	60	25	50

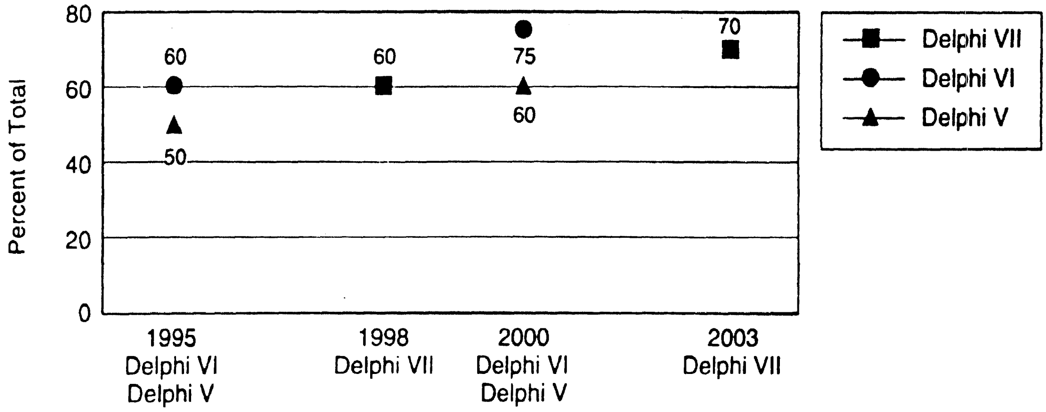
Trend from previous Delphi surveys

Comparisons of the current survey to past surveys are shown in the following table and graph.

Front Suspension Percent Twin A-arm	1995 MY	1998 MY	2000 MY	2003 MY
1994 Delphi VII	—	25%	—	30%
1992 Delphi VI	20	—	20	—
1989 Delphi V	20	—	25	—

The current survey forecasts a greater use of the twin A-arm design than did the 1992 Delphi VI study, and consequently a lesser use of the MacPherson strut. The current survey is similar to the 1989 Delphi V survey.

Independent Rear Suspension Forecasts
North American Car Production



The current survey forecasts independent rear suspension usage to be in line with the previous two surveys. However, there is substantial spread between the forecasts, and a wide interquartile range in this forecast, indicating uncertainty and/or differences of opinion between manufacturers regarding this system. The forecast for springs is similar between this and the previous two Delphi surveys.

Strategic considerations

Because of the many economic, technical and customer satisfaction issues related to suspension designs, trends bear careful watching, particularly in light of value and affordability concerns. It would not surprise us to see long-term use of the lowest cost technologies, particularly since lower cost systems have been refined to the point where they are highly functional and appear to provide value and satisfy a large fraction of consumers. We believe we will see the emergence of two basic chassis designs: up-tech, up-scale (pricey and profitable); and a plain-tech, down-scale version. The customer will define the mix between the two. As in most cases, technological developments should be followed closely by all suspension component suppliers.

TECH-57 What percentage of North American-produced passenger cars will have the following chassis/suspension features in 1998 and 2003?

Chassis/Suspension Features	Est. 1992*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Active four-wheel steering	0%	0%	1%	0/1%	0/5%
Steering					
Power					
Electrical/electronic	0	1%	5%	0/2%	2/10%
Hydraulic with electronic control	0	5	10	2/10	5/25
Traditional hydraulic	96	90	82	86/94	70/88
Non-power	4	3	2	2/4	0/4
Total	100%	100%	100%		
Ride/Handling					
Passive control (present system)	n/a	90%	80%	85/95%	70/91%
Passive-driver selected	n/a	2.9	5	1/6	1/10
Semi-active (damping controls)	n/a	3	8	2/10	5/15
Active (springs & damping control)	n/a	1	3	0/2	1/6
Total		100%	100%		

Selected edited comments

- Active suspension parasitics will restrict market penetration.
- Electric drive will facilitate electrical power steering.
- Height control (load leveling) will grow.
- Limited perceived value will slow movement toward smart ride/handling controls.
- Semi-active will grow. It gives close to the same benefits as active at a fraction of the cost.
- Variable suspensions will remain a sport/luxury item.

Discussion

Traditional hydraulic power steering and passive suspension control (present system) are expected to remain dominant in the next decade according to panelists. However, other concepts such as hydraulic power steering with electronic control and semi-active suspensions are expected to see limited application.

Manufacturer/supplier comparison

Agreement between manufacturers and suppliers is generally good, with the exception of the forecast for active four-wheel steering in 2003. Manufacturers and suppliers forecasts were 0.5 percent and 5 percent respectively.

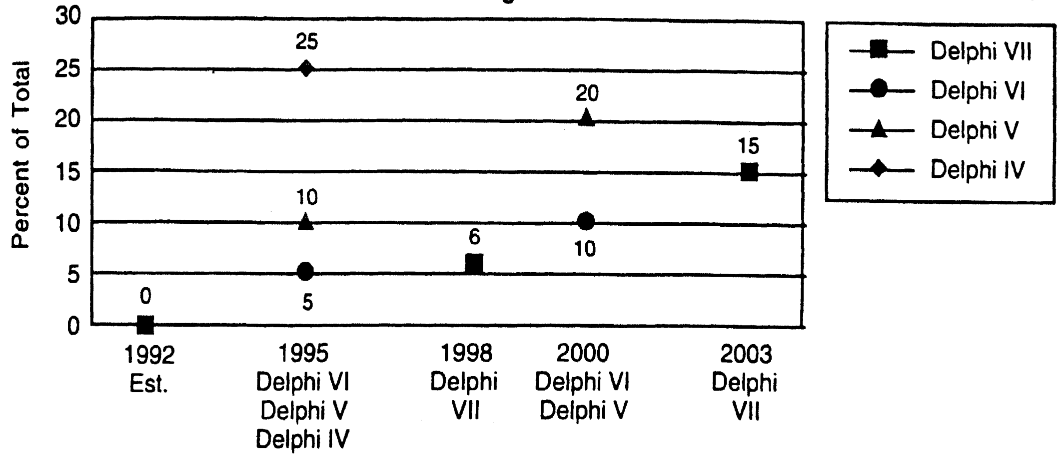
Comparison of Forecast: MKT-40

Active suspensions are also addressed in the Marketing survey. The two surveys are in essential agreement for 1998 and 2003.

Trend from previous Delphi surveys

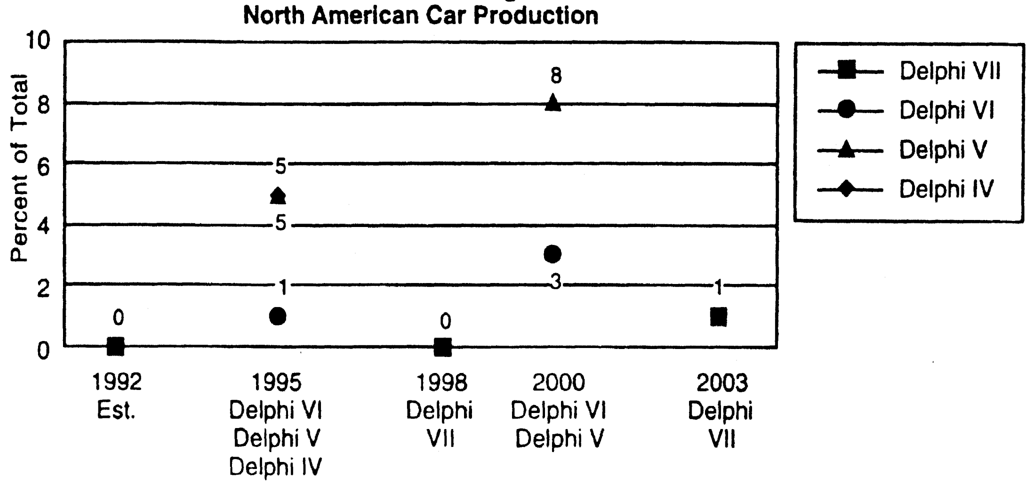
Electrical/electronic power steering was surveyed in 1989 and 1992, but covered all electrical applications to power steering, including hydraulic with electronic control. To compare results, electrical/electronic and hydraulic with electronic control are added together in the graph below.

Electrical/Electronic Power Steering Forecasts
North American Passenger Production



Results for the 1992 and 1994 surveys are similar. Both project lower application rates than the 1989 Delphi V and 1987 Delphi IV studies.

Active Four-Wheel Steering Forecasts
North American Car Production



The forecast for the application of four-wheel steering is negligible, and decreases with each forecast.

1992 Delphi VI Forecast Percent Penetration of Ride/Handling Systems		
	1995 MY	2000 MY
Passive control	88%	78%
Passive-driver selected	5	10
Semi-active (damping control)	5	8
Active (springs & damping)	2	4

Projected application of all ride/handling systems except passive control (present system are generally the same between the 1992 Delphi VI and 1994 Delphi VII surveys.

Strategic considerations

No large-scale application of sophisticated steering or ride and handling systems is expected in the next decade, according to current panelists, though these features will probably remain of interest in high-priced niche market cars. Major breakthroughs in the cost of these systems could change their outlook, but our panelists do not expect this breakthrough. A key consideration for any of these systems is power consumption and therefore impact on fuel economy. Energy consumption will probably be an important characteristic of any future system.

A point of interest particularly with regard to active four-wheel steering (which took the industry by storm several years ago) is that the sizzle is often better than the steak. The customer voted it down, and it languishes with other interesting but expensive ideas waiting for a new generation of affluent customers.

Again we see the importance of balance between affordability and function. Most sophisticated, robust and elegant designs are generally simple and inexpensive. As in most areas of the vehicle there is considerable opportunity for creative and innovative thinking.

TECH-59 What percentage of North American-produced passenger cars will be equipped with antilock brakes and traction control in 1998 and 2003?

Brake and Traction Control Features	Est. 1991*	Median Response 1998	Median Response 2003	Interquartile Range 1998	Interquartile Range 2003
Antilock brakes	19.0%	60%	90%	60/70%	85/100%
Traction control (anti-spin)	0.2%	5	20	2/10	8/40
Powertrain and brakes		5	15	2/10	8/30
Powertrain only		5	20	2/10	10/25

*Source: *Automotive News 1992 Market Data Book.*

Selected edited comments

- It will be 100 percent based upon assumption of NHTSA requirement.
- If costs continue to come down, penetration could be quite high.
- Partial-function traction control (via powertrain controls) could approach 100 percent.
- Potential to become litigation target exists for those few applications where ABS is not standard by 2003.
- Safety and insurance rates will drive adoption.

Discussion

Antilock penetration is forecast to approach 100 percent during the next decade. Traction control is expected to see an application rate of 20 percent in the same time frame.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

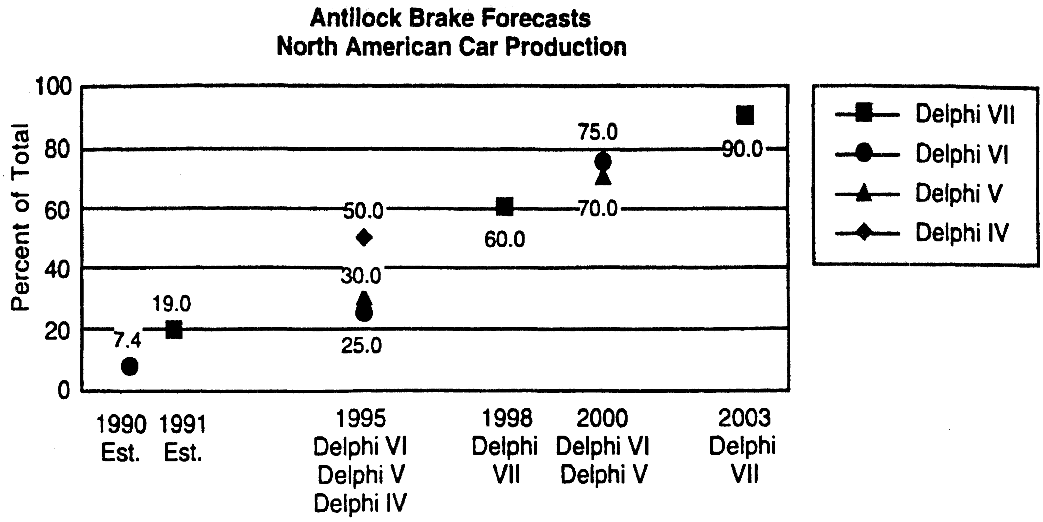
Comparison of forecast: MKT-36

Technology and marketing panels are in agreement with regard to traction control. The results for anti-lock brakes are summarized below.

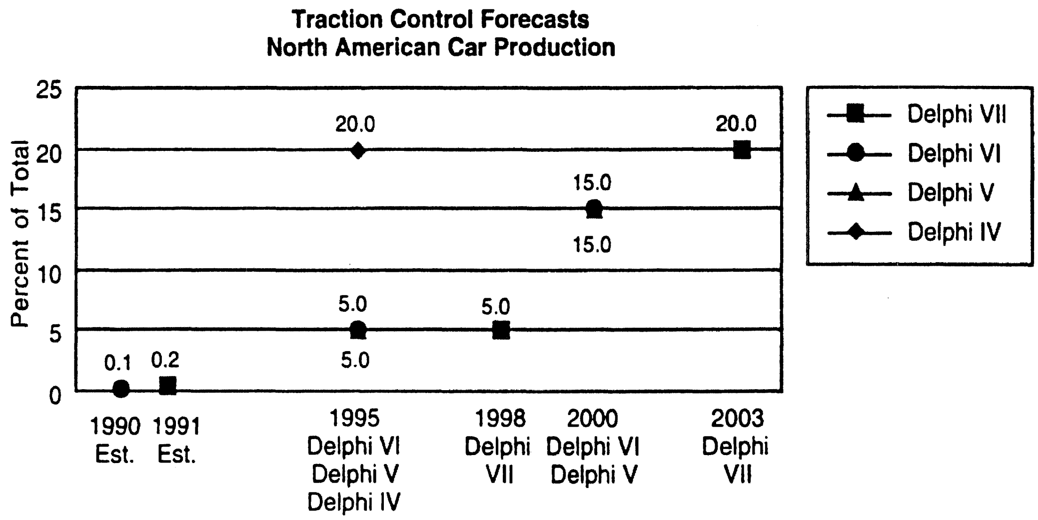
Anti-lock brakes	1998		2003	
	TECH	MKT	TECH	MKT
	60%	40%	90%	75%

Technology panelists forecast higher penetration of anti-lock brakes for 1998 and 2003. Marketing panelists may be more influenced by the cost of this feature.

Trend from previous Delphi surveys



Results of the current survey are in line with previous forecasts.



The current survey is in agreement with the last two surveys. The 1987 Delphi IV forecast is extremely high in its projection for 1995.

Strategic considerations

Delphi forecasts indicate that the application of ABS brakes will approach 100 percent in the next 10-15 years. This is a market-driven move as customers realize the safety benefit of this feature. It is unlikely that legislation will be required to achieve 100 percent application of this system, and legislation, if it comes, may be superfluous. System costs have dropped dramatically in the past few years to further accelerate the application of ABS.

Projected application of traction control lags that of ABS. This system is more a customer convenience than a safety feature, and is probably recognized as such by the customer. Powertrain only control of wheel slip can be achieved at a very low cost, but is also of modest value. This system may see widespread application because of the low cost, however.

Full engine and brake traction control is facilitated with the accelerating application of ABS brakes. It should be noted that some of the key traction control hardware is included with ABS systems and the incremental requirements beyond ABS are modest but still reasonably costly. The value to the customer is greatest in rear drive vehicles, but rear drive vehicles only represent about 13 percent of the passenger car market today, and the penetration is projected to decline. Full engine and brake traction control will probably remain an upscale feature purchased by

TECH-62 What percentage of North American-produced passenger cars and light trucks will incorporate driver, front passenger, and rear seat airbags in 1998 and 2003?

Airbag Applications	Est. 1992*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Passenger Cars					
Driver side	51%	90%	100%	70/100%	95/100%
Passenger side	4	50	90	25/75	50/100
Rear seat occupants	0	2	10	0/5	3/25
Side airbags	0	1	5	0/5	1/10
Light trucks					
Driver side	10%	50%	95%	30/80%	75/100%
Passenger side	0	20	50	5/40	20/100
Rear seat occupants	0	0	0	0/0	0/5
Side airbags	0	0	0	0/2	0/6

* **Source:** *Ward's Automotive Reports,* December, 1993 and various OSAT estimates.

No comments

Discussion

Airbag application rates for the driver side in passenger cars and trucks is expected to be at or near 100 percent by 2003. Passenger side airbags are expected to approach 100 percent in passenger cars and 50 percent in trucks in the same time frame. Rear seat occupant and side airbags are expected to see limited or no application in passenger cars and trucks during this period.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

Light trucks were not addressed in previous surveys. The forecast for passenger cars is in general agreement with past surveys, with the exception of lower projections for side airbags in the current survey. The 1992 Delphi VI survey forecast 10 percent side airbags on the drivers side and 5 percent on the passenger side by 2000.

Strategic considerations

The interquartile range for passenger cars is quite high for passenger side, rear seat occupant, and side airbags, reflecting uncertainty or divergence of opinion within the industry. The significant cost to apply these devices raises questions as to the customers' acceptance of this added cost. It is likely that the customer will accept the cost of passenger side airbags, but less likely side and rear airbags. If legislation forces these devices into the marketplace, the added cost could have a negative impact on total vehicle sales and/or shift the market down-scale. Of course, new low-cost technological developments or other incentives such as insurance premium reduction could alter this concern rather significantly.

There is very good agreement that driver side airbags in passenger cars will be at, or approach, 100 percent by 2000. This is clearly a market-driven trend, even though legislation is in place to require passive restraints. Light truck driver side airbags are also projected to approach 100 percent by 2000.

TECH-63 **What percentage of airbag sensors in North American-produced passenger cars will be either mechanical or electronic by the following years?**

Airbag Sensors	Median Response 1998	Median Response 2003	Interquartile Range 1998	Interquartile Range 2003
Mechanical airbag sensors	50%	10%	20/60%	5/30%
Electronic airbag sensors	50	90	40/80	70/95

Selected edited comment

- I am aware of new and promising mechanical sensor technology.

Discussion

Based on currently known and expected future technology, panelists forecast a shift from mechanical to electronic airbag sensors. Obviously a breakthrough in either technology could alter or accelerate this trend. The single edited comment suggests the potential of such a breakthrough.

Manufacturer/supplier comparison

Manufacturers and suppliers are in close agreement.

Trend from previous Delphi surveys

This question was first asked in the 1992 Delphi VI survey. The results of the two surveys are in close agreement.

Strategic considerations

The industry has gained considerable experience with airbag systems. Any significant change to these systems will come only after extensive testing for reliability. Panelists currently believe that this testing will prove the reliability and cost effectiveness of electronic sensors.

TECH-64 What percentage of vehicles produced in North America will have the following IVHS systems by 2003?

IVHS Technologies	Median Response	Interquartile Range
Adaptive cruise control	5%	2/10%
Collision warning systems	8	5/10
Automatic toll collection	5	1/15
Navigation	5	2/15
In-vehicle message system	10	5/25

Selected edited comments

- Assume that in-vehicle message systems will include voice mail or cellular phones.
- Cost is the reason these systems will not have a significant impact. With wages nearly static, disposable income will take a hit. Higher taxes will do the rest.
- Independent IVHS features like adaptive/radar cruise and collision warning will slowly spread from top end production initial applications.
- Lack of infrastructure will continue to hold back IVHS.
- The dislocation of jobs will cause consumers to be very price conscious.
- These are nice high tech ideas, but they are too costly now. There is little prospect of getting cost down enough that many consumers will buy them.

Discussion

Limited application of IVHS technologies including in-vehicle message systems, collision warning systems and adaptive cruise control is forecast by 2003.

Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi survey

This question was first asked in a similar format in the 1992 Delphi VI survey. The categories were different, however, with the exception of collision avoidance. Results are summarized below.

IVHS Category	By 2000 1992 Delphi VI	By 2003 1994 Delphi VII
Collision warning	0%	8%
Motorist service information	40	—
Cooperative route guidance	15	—
Vehicle location and identification	10	—
Autonomous vehicle navigation	10	—
Speed and highway keeping	10	—
Automated highway chauffeuring	2	—

Comparison of forecast: MKT-37

Questions regarding adaptive cruise control and collision warning systems were asked in the Marketing survey. A comparison between the two surveys is shown below.

IVHS Technology	Median Response	
	TECH	MKT
Adaptive cruise control	5%	7%
Collision warning systems	8	5

Strategic considerations

Panelists forecast limited application of IVHS technologies by 2003. Based on the comments, cost is expected to be the limiting factor. These technologies will likely first appear in upscale vehicles where they can be used as a niche discriminator. Even in an upscale vehicle however, the customer may question the added complexity of these systems, as evidenced by the comments. However, we have learned in the last few years that safety is becoming increasingly attractive to customers, and they will make the final decision assuming, of course, it is a cost-effective technology.

TECH-97 What percentage of North American-produced passenger cars will employ the following electronic/electrical features in 1998 and 2003?

Electronic/Electrical Features	Est. 1991*	Median Response		Interquartile Range	
		1998	2003	1998	2003
Antitheft	9%	15%	25%	12/20%	15/30%
CD player	2	6	15	5/10	10/30
Cellular phones	0.6	5	10	2/10	6/25
Cruise control	72	75	80	75/80	80/90
Digital audio tape (DAT)	0	2	5	1/5	2/10
Drive-by-wire (electronic throttle control)	0	2	7	1/5	2/20
Electronic keyless entry	13	20	25	15/25	20/50
On-board diagnostic via expert systems (AI)	0	2	10	1/10	5/25
Voice activated/interactive controls	0	1	2	0/2	1/10

***Source:** *Ward's Automotive Yearbook*, 1992.

Other responses include:

Electronic Feature	1998	2003
Integrated belts	0.1%	0.5%
Phillips standard	4	40
Satellite mapping	2	5

Selected edited comments

- Antitheft includes "smart" ID of components–embedded chips.
- As the aircraft industry has discovered, electrical is not more reliable than mechanical in many applications. Electrical has difficulty delivering "muscle" and is dependent on a single power source that does not fail softly.
- Electronic keyless entry is tied to antitheft.
- Lack of cellular phone portability will limit market acceptance (monthly cost of car phone service).
- Some OBDII will be artificial intelligence (AI) since the emissions will be inferred.
- The adoption of many features will be accelerated as volume rises and cost and price come down the volume/learning curve.

Discussion

Panelists forecast significant growth in the use of many electronic features, and some application for features not currently used.

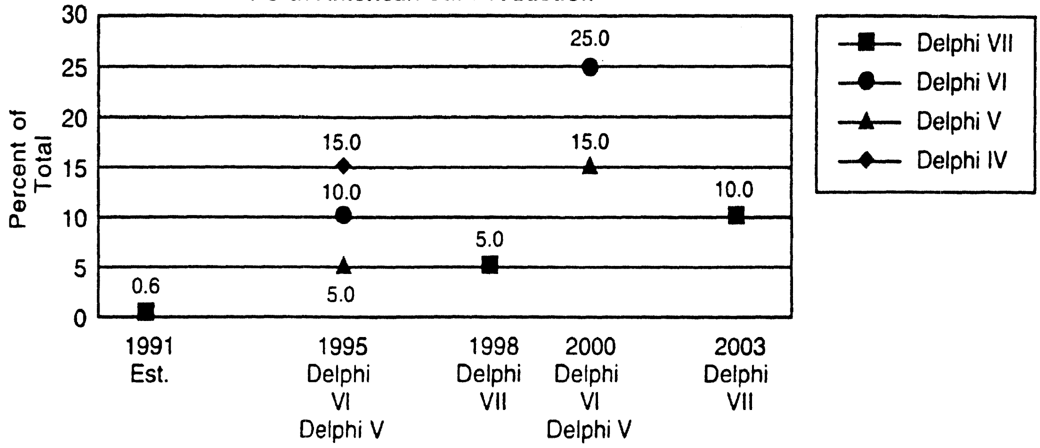
Manufacturer/supplier comparison

Manufacturers and suppliers are in general agreement.

Trend from previous Delphi surveys

Electronic Features	1995			1998	2000		2003
	Delphi IV (1987)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)	Delphi V (1989)	Delphi VI (1992)	Delphi VII (1994)
Cellular phones	15%	5%	10%	5%	15%	25%	10%
Cruise control	—	—	70	75	—	90	80
Drive-by-wire (electronic throttle control)	5	1	2	2	5	10	7
Electronic keyless entry	15	5	10	20	15	25	25
On-board diagnostic via expert systems-AI	—	—	5	2	—	15	10
Voice activated/interactive controls	10	1	1	1	2	2	2

Cellular Phone Installation Forecasts
North American Car Production



Current panelists forecast lower installation rates of cellular phones than did previous panelists. This shift in direction may be a result of the lack of portability of vehicle installed phones and the general popularity of aftermarket systems.

Cruise control: Application rates are expected to continue to increase throughout the next decade, but current panelists do not see as strong an increase as the previous panelists. The 1992 Delphi VI panelists forecast 90 percent application by 2000, whereas current panelists forecast 80 percent by then.

Drive-by-wire: Current panelists are in general agreement with previous panelists.

Electronic keyless entry: Current panelists are in general agreement with previous panelists.

On-board diagnostics via expert systems (AI): Current panelists forecast lower application rates than those of the 1992 Delphi VI survey.

Voice activated/interactive controls: Current forecasts are in line with the previous two forecasts, but significantly below those of the 1987 Delphi IV survey.

Strategic considerations

The increase in the use of electronic features is, in some cases, modestly less than evident in previous forecasts. For example, cruise control, cellular phones and on-board diagnostics via expert systems all have less expected penetration for 2003 than was forecast from previous surveys. The reasons for this decrease may include development or cost reduction delays, a change in the customer acceptance rate of costly options, or a growing perception of a more acceptable option as may be the case with portable aftermarket cellular phones.

Vehicle cost increases as a result of emissions, safety and fuel economy standards will compete with consumer dollars for optional equipment or new technical features. The changing customer definition of value and increased basic vehicle cost will certainly have a profound impact on all nonregulatory driven features.

Collision Warning Systems

System Descriptions

	System	Examples	Description
4.1	Frontal collision warning		Sensors warn driver of possible collision with vehicle or object in frontal location. Signal or message is delivered to a display on the instrument panel warning of collision and indicating braking or steering action. Detection component of the system is typically base on radar, sonar, infrared, or laser technology. Laser, radar, and infrared are generally preferred.
4.2	Back-up and blind spot detection	Near Obstacle Detection System (NODS)	This is similar to frontal collision warning in that sensors detect obstacles and a warning signal is delivered to the vehicle operator. However, in this case the sensors are targeted at the rear and sides of the vehicle where objects cannot be seen.
4.3	Rollover warning (i.e., for trucks on a steep grade)		Tilt and centrifugal sensors transmit information to a computer, which determines likelihood of rollover. Warning is transmitted to display if some threshold is passed.
4.4	Roadway imaging	Infrared	Roadway imaging provides drivers with an enhanced image of the roadway ahead under adverse visibility conditions at night. Systems commonly use infrared imaging technology.

Scenario

Collision warning will have an important place in IVHS. Within 10 years both frontal and back-up warning systems will reach 5% market penetration. The cost will range between $325 and $500. Within 30 years they will be required on all vehicles. Rollover warning will reach 50% market penetration in motor carriers by 2012. Road imaging will reach 50% market penetration in premium vehicles by 2020. Rollover warning and road imaging will be popular only in these specialty markets. Federal government financial support will have little impact on the development of these systems. However, federal regulation will mandate frontal and backup warning systems.

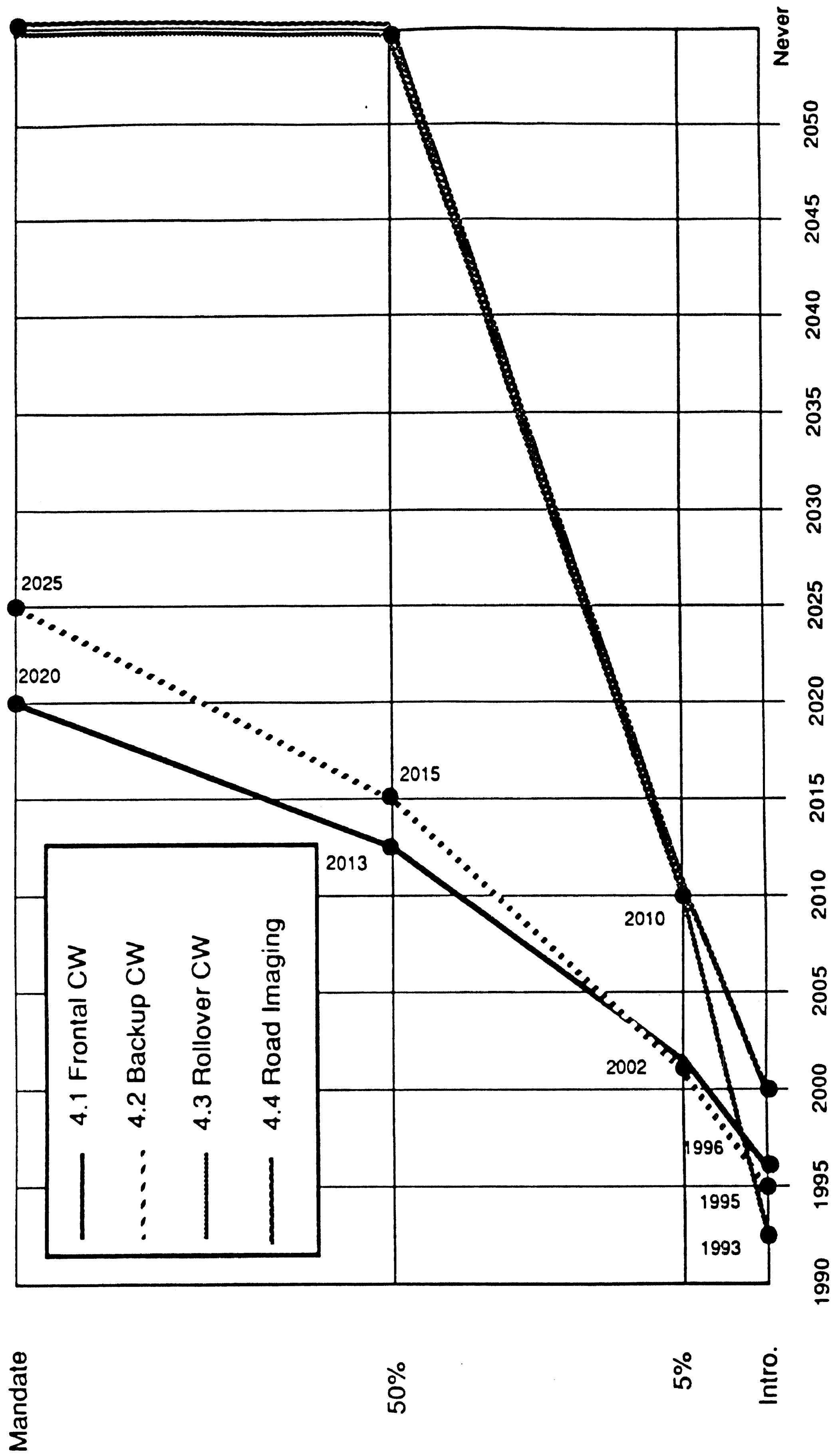
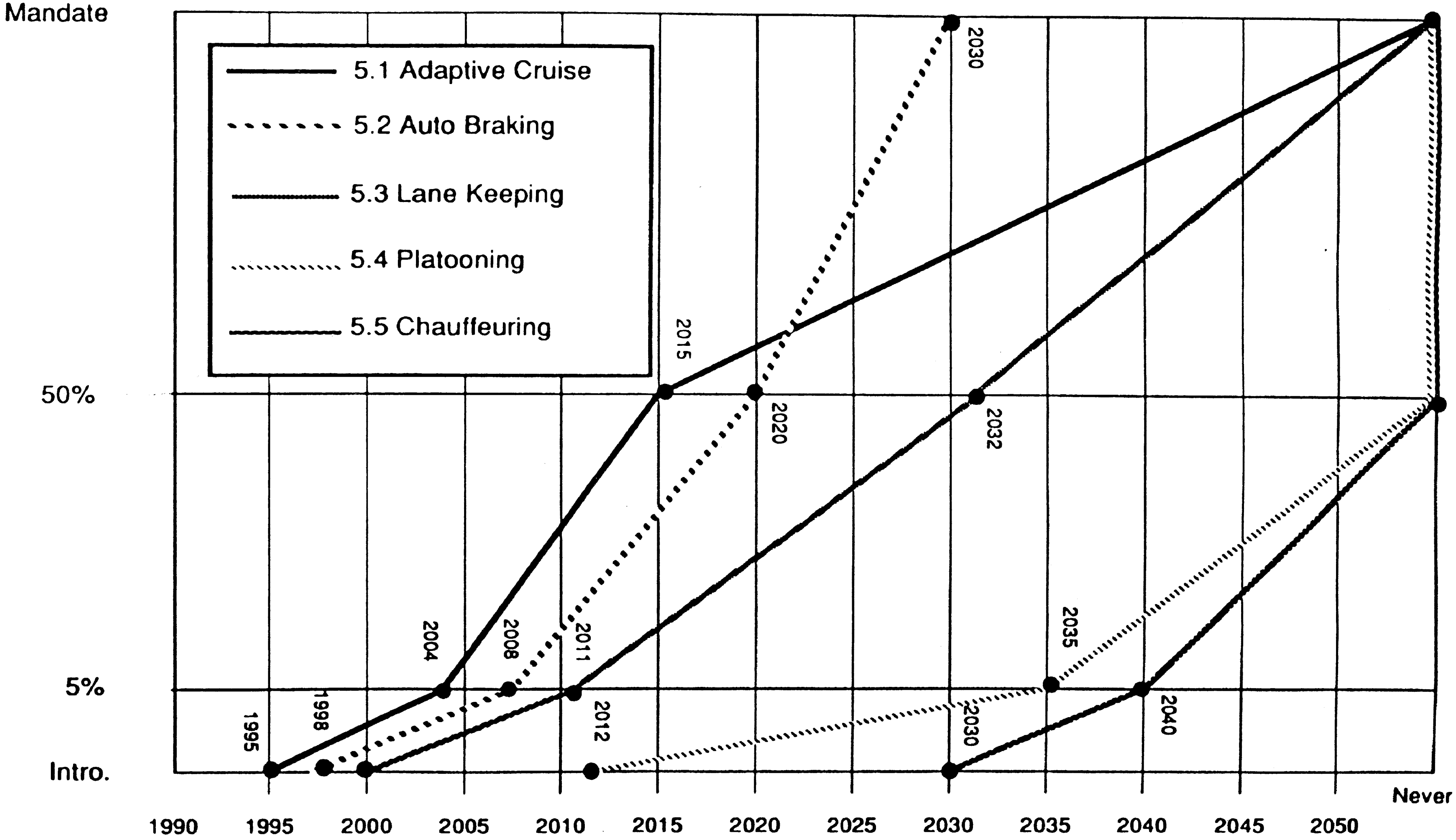


Figure 4. Collision Warning

Figure 5. Collision Avoidance



Collision Avoidance Systems

System Descriptions

	System	Examples	Description
5.1	Adaptive cruise control		Adaptive cruise control is an extension of standard cruise control where the speed of the vehicle adapts automatically to assure minimum headway.
5.2	Automatic back-up braking		Automatic braking links headway sensing to automatic control of braking mechanism. If object is detected and driver does not respond then system automatically activates braking action to avoid obstacle.
5.3	Autonomous lane-keeping to assist driver on long trips		Lane-keeping systems supplement driver control with the capability to automatically maintain land position. The objective is to reduce the frequency and severity of crashes involving failure to maintain position in the lane.
5.4	Automated platooning system to increase throughput		Vehicles are electronically coupled in small groups that follow lead vehicle. The concept is to have vehicles traveling at high speeds and high densities on limited-access highways under control of an automated vehicle-control system. The primary objective is to increase throughput.
5.5	Automatic chauffeuring with auto lane changing and merging		Combines complete lateral and longitudinal control for completely automated travel at high speeds and high densities on limited-access highways.

Analysis

Adaptive cruise control will be the most popular item of the control systems. At a cost of $400, adaptive cruise control will be in 5% of the vehicles by 2004. It will reach 50% market penetration by 2015. Cruise control will not be mandated. Automatic braking will follow on the heels of frontal warning systems with a lag of between 6 to 10 years until the systems are mandated. Automatic braking will cost $750 and will achieve 5% penetration. Lane-keeping will also be accepted, but at a much later date.

There was a lot of disagreement among the respondents regarding platooning and chauffeuring. Most indicated that they would never be adopted without government support. However, if they are eventually adopted, their use will be confined to a small portion of the population. They will never reach 50% penetration, nor will they be mandated. Government investment will be required for these small levels of penetration to be achieved.

Appendix R

Example Data Processing Calculations Using Time Histories Obtained with a Desktop Driving Simulator

Example data seen in this Appendix were obtained from a desktop driving simulator.[1] The simulator uses a Macintosh Quadra as its main processor, a large color monitor for display, and a steering wheel / torque motor assembly for steering control inputs to the simulator. The steering torque motor provides associated feedback of steering wheel torque (or "feel") to the driver.

Figure R-1 shows two scenes from the driving simulator at entrances to the first and third curves (385' and 780' radii curves respectively). The course geometry used for these example calculations is seen in Figure R-2. It takes about 80 seconds to complete one trip through the simulated course at a speed of 45 mph.

Figure R-3 through R-6 show time histories of four driver-vehicle responses measured for this example run. The first two variables are the steering wheel displacement and the corresponding steering wheel torque used by the test subject to steer the vehicle along course. The last two responses are the vehicle lateral error relative to the right lane centerline and the heading angle error of the vehicle relative to the lane edges.

The first two variables (Figures R-3 and R-4) are typical types of driver-related responses that ordinarily would be measured to help evaluate driver workload or steering effort during driving tasks. Computation of the RMS or standard deviations of driver steering wheel angle and torque can be used as indicators of steering effort / workload when comparing the performance of different sets of drivers and/or driver-vehicle combinations. An example calculation is shown on each figure for these particular runs. In comparing different drivers or vehicles, higher standard deviations of steering torque and steering angle would imply larger workload levels for drivers in performing the required steering task. Likewise, higher counts of primary steering reversals used by a driver can also be used as an indicator of higher workload.

The tracking performance of a driver-vehicle system can also be evaluated by comparison of RMS or standard deviation measures of path error and heading angle error (Figures R-5 and R-6). Larger standard deviations for either of these types of signals would ordinarily suggest degraded levels of driving performance when conducting otherwise identical tests with a particular group of drivers and/or vehicles.

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[1] MacAdam, C.C., Green, P.A., and Reed, M.P., "An Overview of Current UMTRI Driving Simulators," *UMTRI Research Review*, Volume 24, Number 1, July-August, 1993.

Consequently, these types of data processing calculations (whether gathered from a driving simulator environment or from test track data) can be used initially to help evaluate and rank the driving performance of different drivers and/or vehicle configurations equipped with specific technologies. Basic evaluations of driving performance and driver control efforts can be summarized in relatively simple terms by means of various numerics (such as RMS or standard deviations). As more detailed information about the driving experience is required, especially as it relates to the interactive nature of driver control responses and specific feedback cue dependencies, more comprehensive analysis tools become necessary. These could include such methods as model-matching techniques that employ more detailed characterizations of the driving process and use of numerical simulations of the driver/vehicle/technology system being examined. Other options include the use of neural networks for conducting signal processing analyses. Several of these alternatives have been described further in Sections 2.5 and 3.0 of this report.

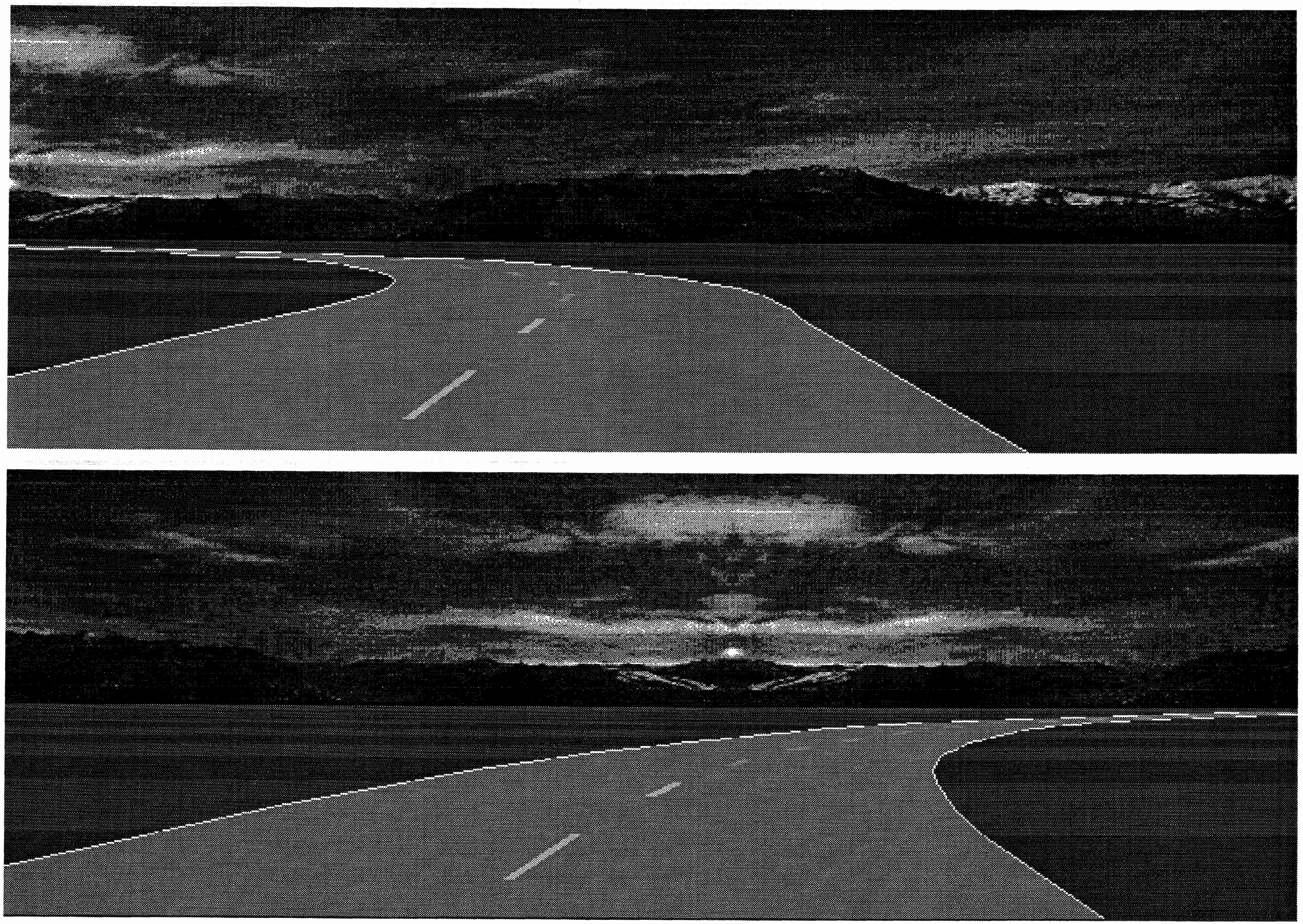

Figure R-1. Scenes of Two Curves Along Driving Simulator Course.

Figure R-2. Simulator Course Geometry.

(not to scale)

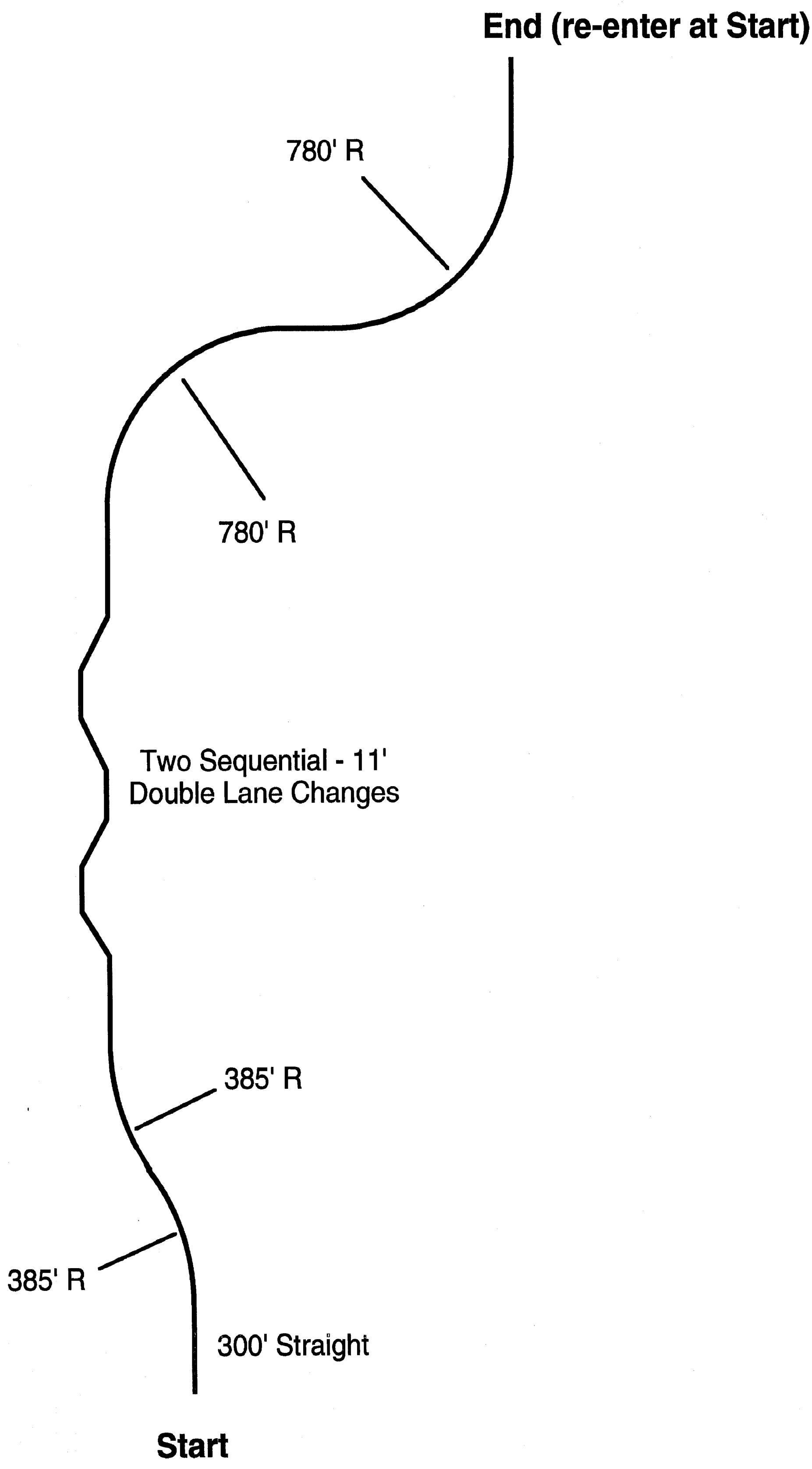

Figure R-3. Time History of Driver Steering Wheel Angle Through Simulator Course.

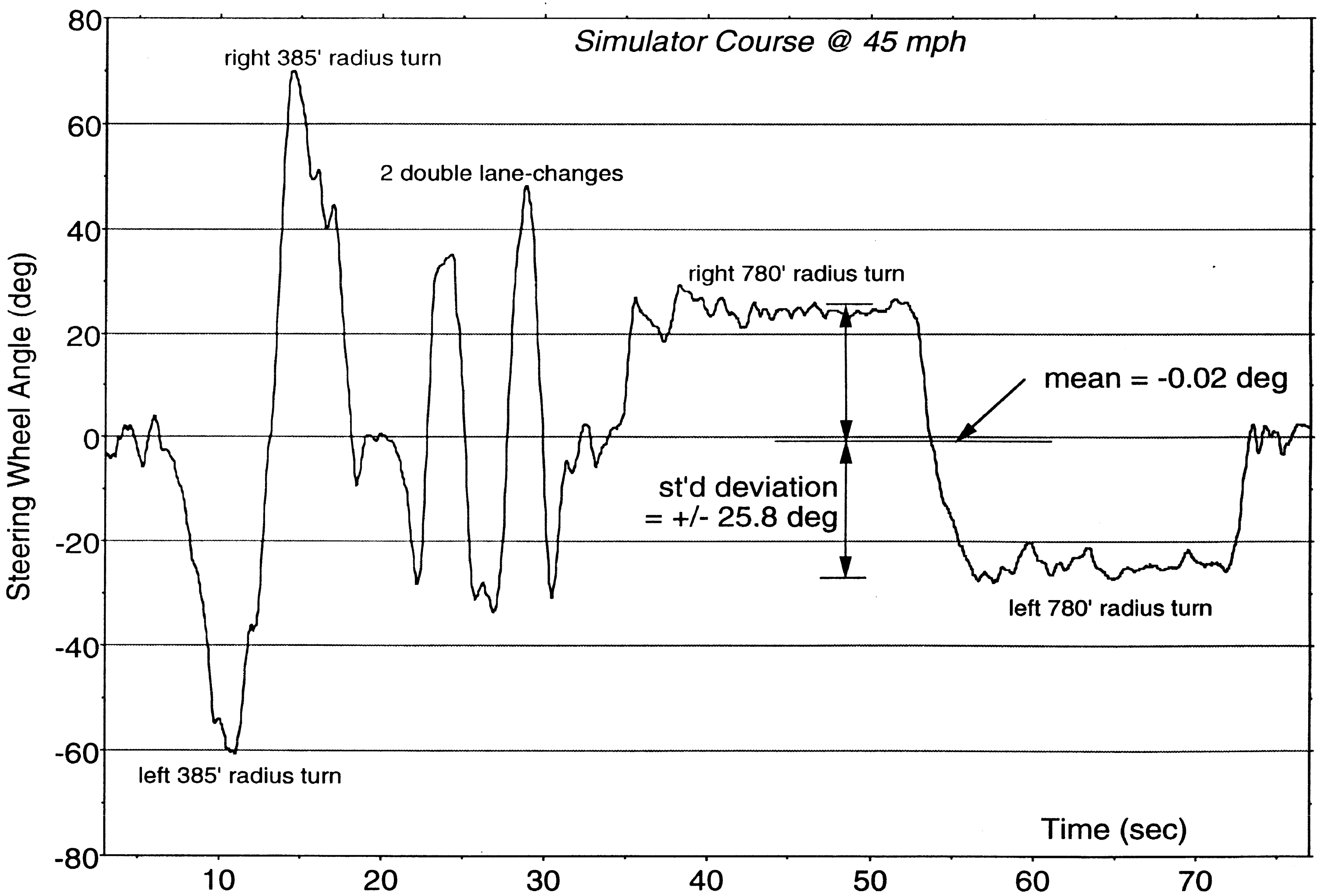

Figure R-4. Time History of Driver Steering Wheel Torque Through Simulator Course.

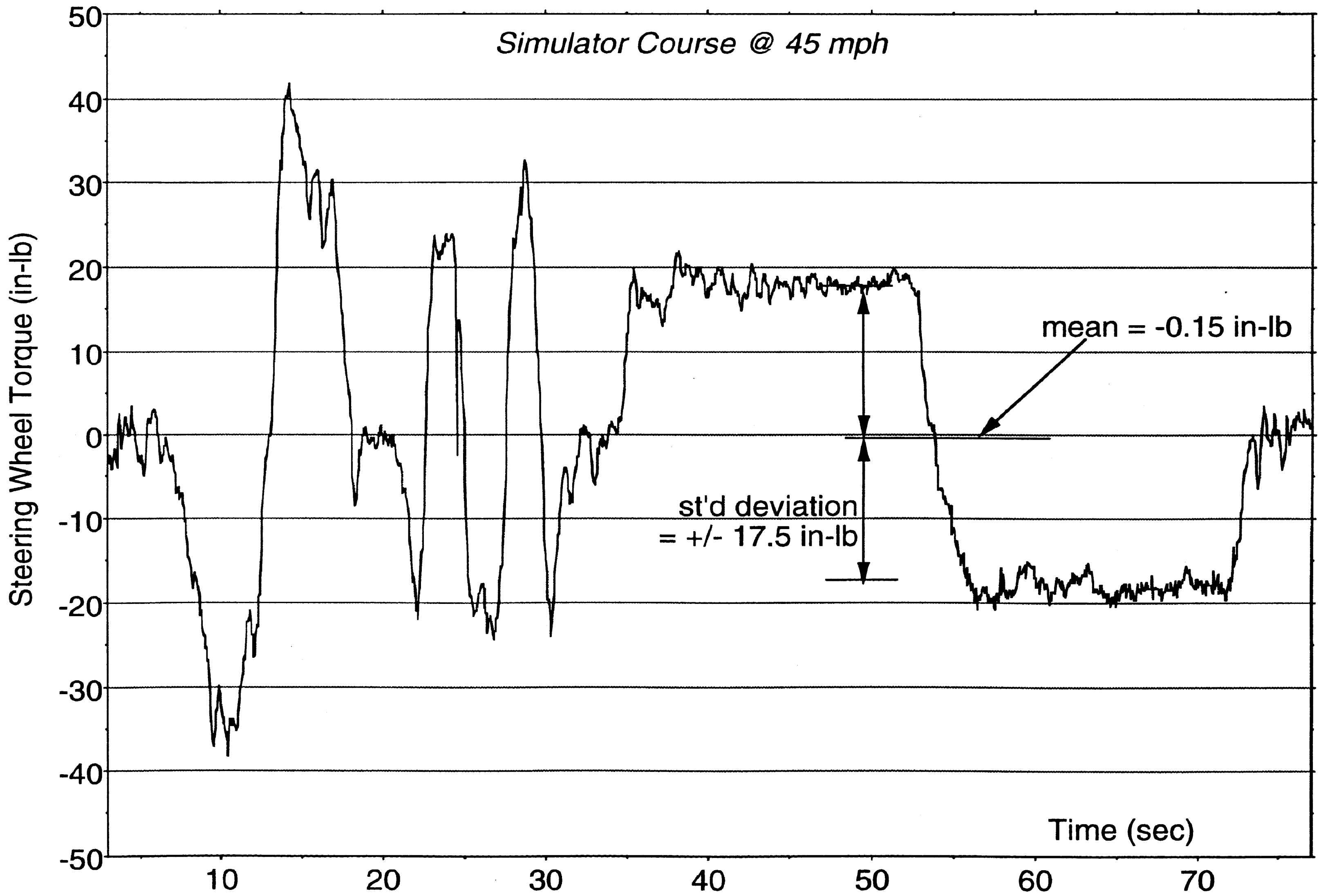

Figure R-5. Time History of Path Error Through Simulator Course.

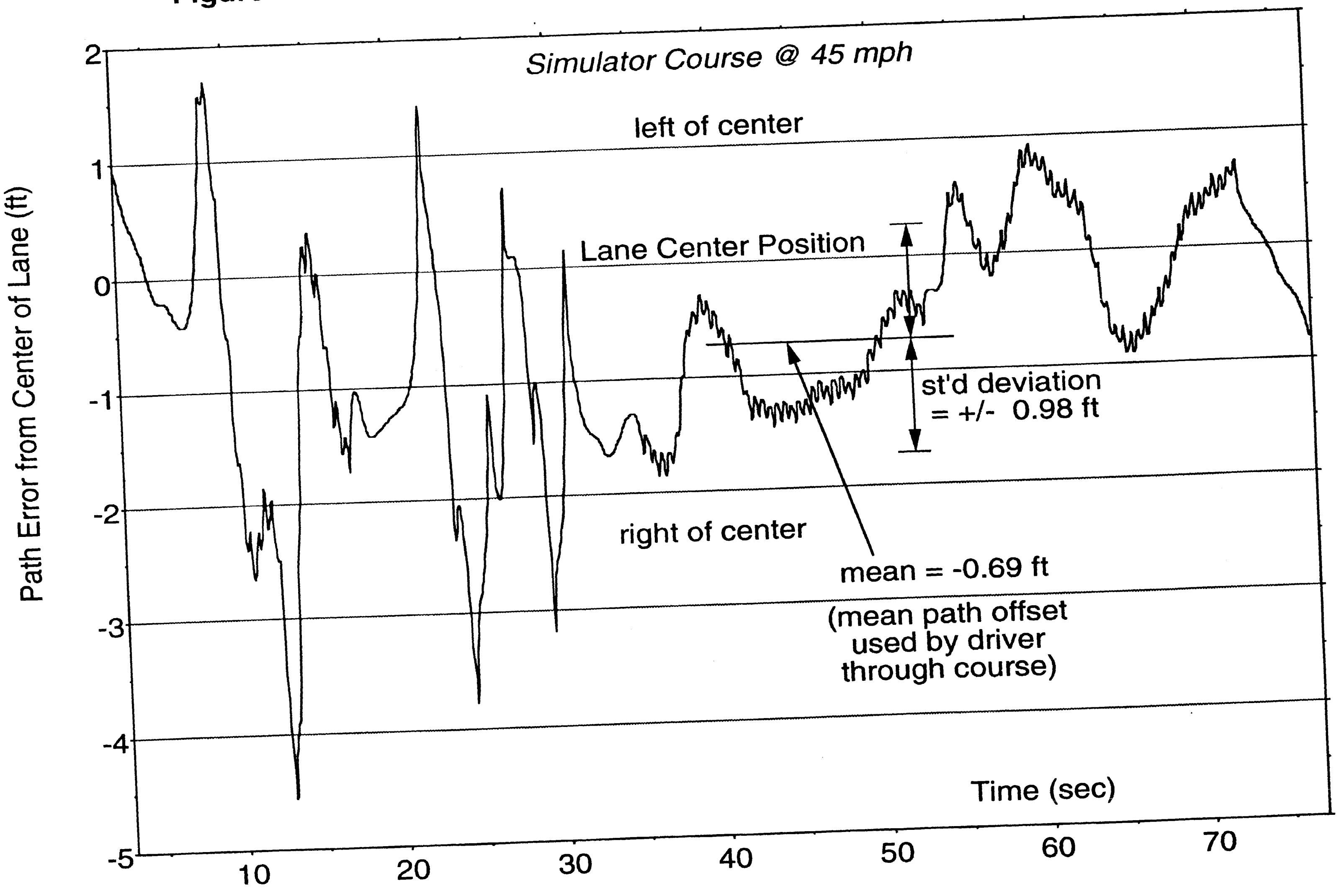

Figure R-6. Time Histroy of Heading Angle Error Through Simulator Course.