A VARIABLE STABILITY TEST VEHICLE FOR ITS APPLICATIONS

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ABSTRACT

A variable stability test bed is under development for the National Highway Traffic Safety Administration (NHTSA). The Variable Dynamic Testbed Vehicle (VDTV) is being designed for research and testing of advanced collision warning and avoidance technologies being developed by industry and most likely being made available to consumers in the near future. The VDTV will also be used by NHTSA in support of the Automated Highway System (AHS) Program and possibly by the AHS program directly.

The VDTV will have advanced dynamic subsystems that can be varied by on on-board programmable computer. Suspension, steering, throttle, and braking will thus be controlled through selected algorithms that may be changed to provide a reasonably broad range of vehicle dynamic characteristics. The vehicle is inherently a drive-by-wire system, is instrumented for both vehicle and human factors measurements, and is therefore ideally suited to many intelligent Transportation Systems (ITS) applications.

This paper describes the intended uses of the VDTV and the vehicle's specifications that were developed by the Jet Propulsion Laboratory (JPL). It also describes the results of dynamic analyses that were conducted by JPL prior to award of a system contract to industry for the detailed design and construction of the vehicle. The analysis shows the dynamic emulation capabilities of the VDTV, as well as expected dynamic performance in limit performance situations that would be encountered in severe crash avoidance maneuvers.

BACKGROUND

JPL conducted a study for NHTSA in 1994 (Reference 1) that examined the need for a test vehicle with features like those of the VDTV. The study also considered the cost and time to acquire such a capability and looked at several configurations that were designed for specific applications. The study found that a VDTV would be beneficial, not only to NHTSA, but potentially to other organizations, as well. NHTSA decided to acquire a single vehicle and awarded JPL the development contract in September 1995. JPL selected a system contractor in June 1996, to develop the VDTV according to JPL's specifications.

DESCRIPTION

The VDTV base vehicle will be in the class of a mid-size passenger car. To this base vehicle will be added the following subsystems or features:

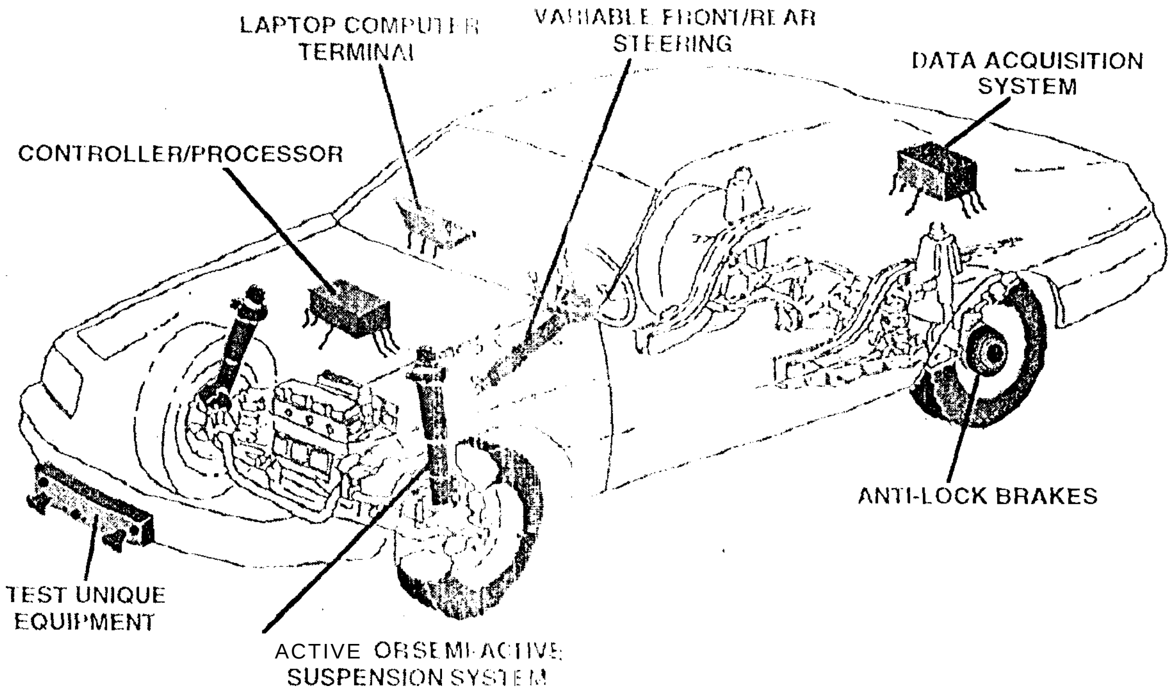
- Steer-by-wire, including programmable steering torque feedback to the driver
- Brake-by-wire, including artificial sensory feedback to the driver
- Throttle-by-wire, including artificial sensory feedback to the driver
- Semiactive or active suspension
- Four-wheel steering
- Mechanically or actively variable antiroll bar stiffness (front and rear)
- Antilock braking system
- Programmable control system
- Data acquisition system
- Interfaces for test unique equipment/sensors

Major capabilities of the VDTV include:

- Lateral dynamics emulation of a range of production vehicles.
- Ability to perform high-g, limit performance maneuvers.
- Programmable controller allowing changes to be made in steering, braking, suspension, and throttle control algorithms.
- Drive-by-wire for lane-following, platooning, obstacle avoidance research.
- Instrumentation for vehicle, subsystem, and driver measurement
- Data acquisition system.

The VDTV is expected to be used by NHTSA for crash avoidance testing, by the National Automated Highway Consortium in various areas of research, and possibly by the National Advanced Driving Simulator Program in the validation of algorithms and in complementary testing.

Figure 1 depicts the concept described above.



- DRIVE-BY-WIRE CAPABILITY
  - THROTTLE
  - STEERING
  - BRAKING
- COMPUTER CONTROLLED SUBSYSTEM
  - POWER TRAIN
  - BRAKING
  - STEERING
  - SUSPENSION

Figure 1. The Variable Dynamic Testbed Vehicle

VEHICLE DYNAMICS

A dynamics analysis was performed to investigate the potential of the VDTV to emulate the lateral performance of a range of production vehicle sizes given the capability to vary the steering algorithms and to change front and rear antiroll bar stiffness. The objective of the study was to provide requirements for the vehicle, in this regard, that were to be included in the procurement package.

The analysis was conducted using the simulation program VDANL (Vehicle Dynamics Analysis, Non-Linear) developed by Systems Technology Incorporated. This program has seventeen degrees of freedom and a comprehensive vehicle and tire data base. The program also has both open and closed loop control options Which were used in conjunction with four wheel steering algorithms and different collision avoidance maneuver analyses. VDANL has been extensively validated by road tests for a variety of production vehicles.

APPROACH - The analysis proceeded in three steps.

1. A number of production vehicles, covering a range from small economy to large luxury cars, were analyzed to determine their lateral performance capabilities.
2. A 1989 Ford Escort was modified to represent a nominal VDTV. Modifications included mass property changes to account for the addition of dynamic subsystems and data acquisition equipment, higher performance tires, increases to the suspension system's spring rates and damping, and addition of variability to the torsional stiffness of the front antiroll bar,
3. A series of sensitivity studies were conducted using the modified Escort to show how well it could emulate the range of performance from the production vehicles of step 1,

The results were analyzed and used to formulate specifications for the Request For Proposal (RFP) that was issued in March 1996. Reference 2 is the complete specification that accompanied the RFP.

SELECTED RESULTS - Reference 3 provides a complete and comprehensive discussion of the analysis conducted by JPL. Representative results are included here to indicate the general expected lateral performance of the VDTV.

EMULATION RANGE REQUIREMENT - Figures 2 and 3 show the results of the analysis of several production vehicles in terms of roll angle and understeer coefficient, respectively - both as a function of lateral acceleration. The range of these parameters was assumed representative of the production fleet for the types of vehicles analyzed. Given this range, the question arises of whether a single vehicle with variable dynamic subsystem characteristics could cover it.

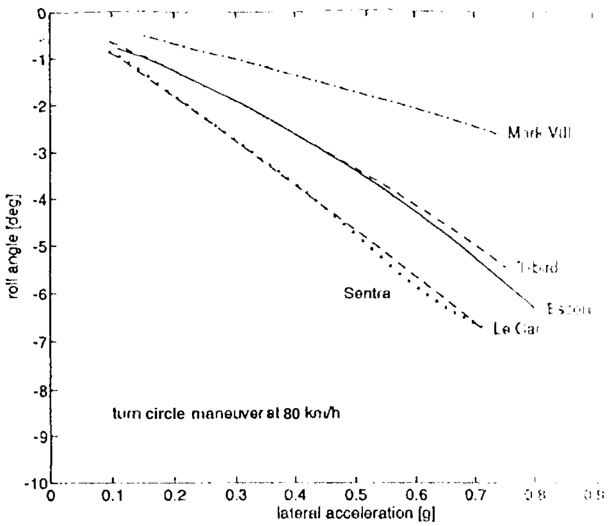


Figure 2. Turn Circle Maneuver: roll angle versus lateral acceleration

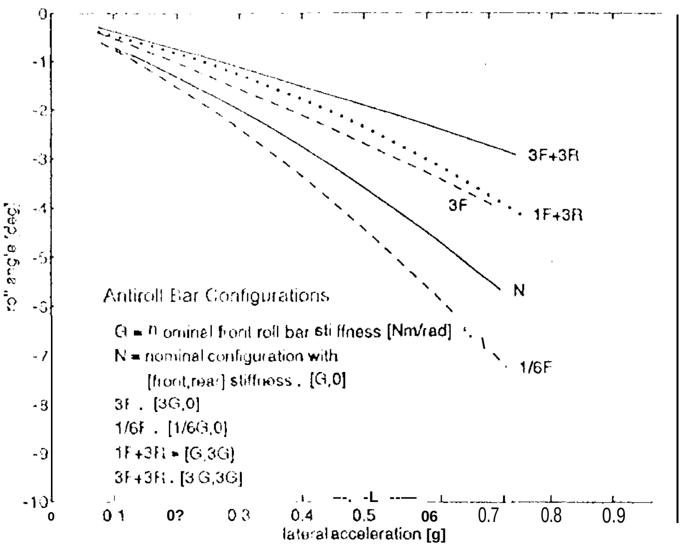


Figure 4. Modified Ford Escort roll gradient results for five antiroll bar configurations

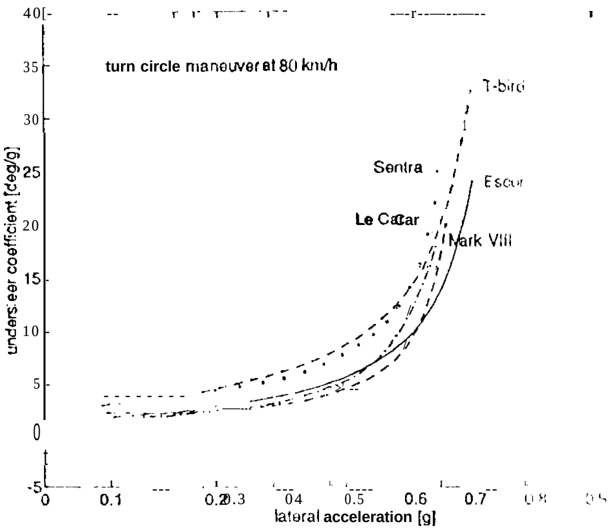


Figure 3. Turn Circle Maneuver: understeer coeff. versus lateral acceleration

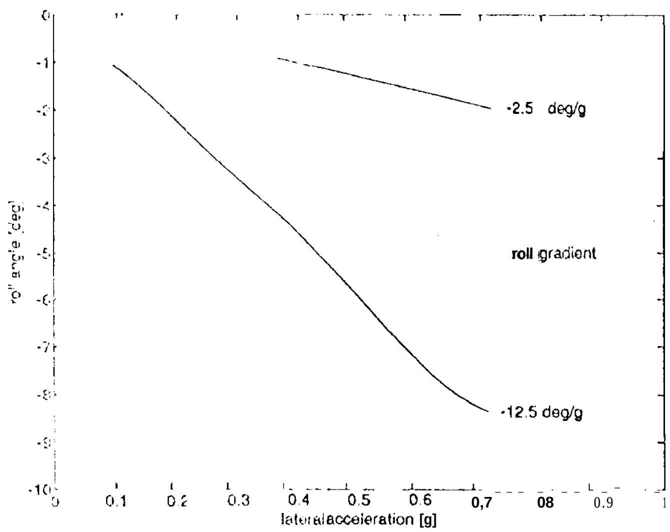


Figure 5. Emulation range requirement for VDTV with an active antiroll bar controlled system

MODIFIED ESCORT RESULTS - Figure 4 through 7 show results in terms of the same parameters of the modified Escort when subjected to a turn circle maneuver in which the vehicle's speed is kept constant and the steering wheel angle is increased at a uniform rate until the limit lateral acceleration level is reached. In Figure 4, different antiroll bar configurations are simulated, including the nominal Escort, which has only a front antiroll bar. Other cases, from one in which the stiffness of this bar is reduced by a factor of six, to one in which the stiffness is increased by a factor of three in conjunction with a rear bar with the same stiffness also are simulated. Figure 5 illustrates similar results for a continuously variable active antiroll bar and which was used as the specification boundaries for the vehicle roll gradient.

Figures 6a and 6b represent ranges of understeer gradient that could be achieved with four-wheel steering (4 WS) and different tire configurations. This handling metric is computed for several 4WS control algorithms: rear wheel angle = K1 • front wheel angle + K2 • yaw rate. K1 is a feed-forward gain that alters the vehicle's steady-state response. K2 is a feedback gain affecting both the steady-state and transient characteristics of the vehicle and results in in-phase rear and front wheel angles when positive (1), and out-of-phase angles when negative (O). Figure 7 shows the specification boundaries selected for this parameter and generally represent the minimum and maximum values with an added approximate 25 percent margin.

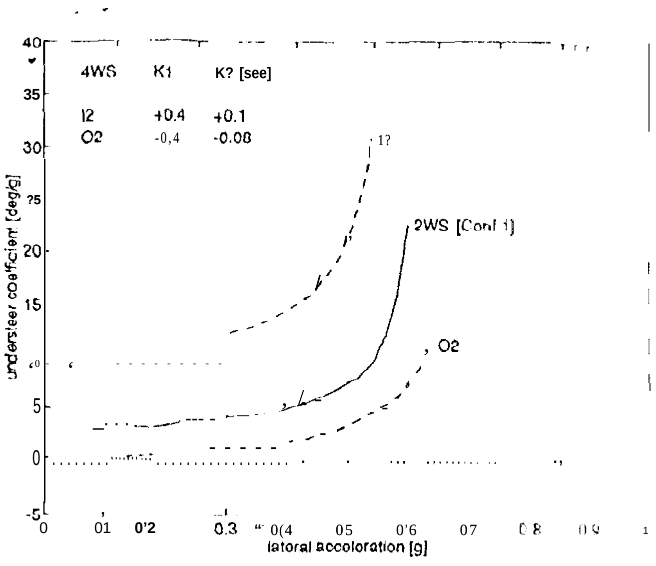


Figure 6a, Understeer coefficient results obtained with 4WS VDI ,

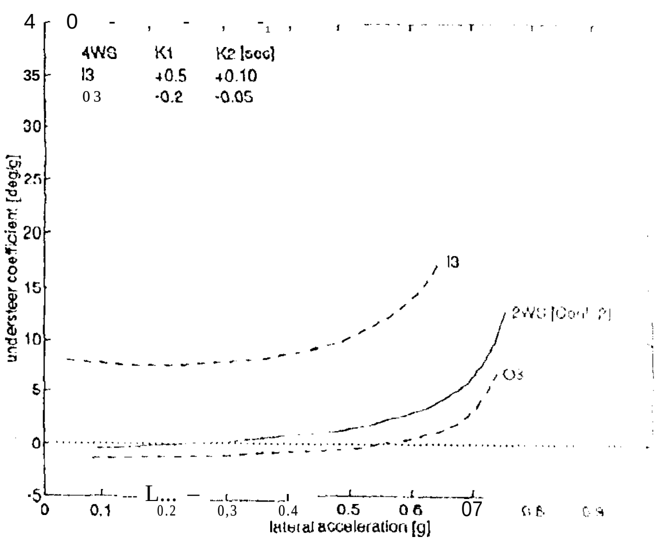


Figure 6b. Understeer coefficient results obtained with WS VDI ,

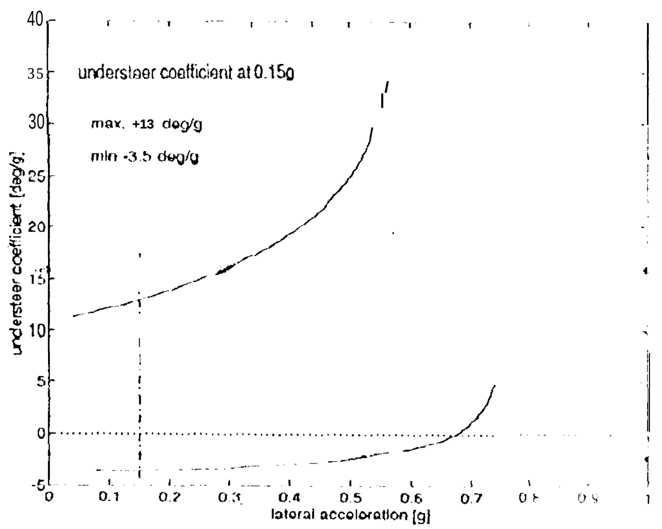


Figure 7. Emulation range specification of the VDTV understeer coefficient

The above results are typical of the analyses performed in support of the VDTV specification development. The analyses also considered transient response characteristics, which are detailed in Reference 3. Similar results obtained with an alternative baseline vehicle are given in Reference 4.

OTHER FUNCTIONAL REQUIREMENTS

In addition to the dynamic performance (lateral and longitudinal) requirements for the VDTV, there arc a number of more general functional requirements imposed on the design in order that the vehicle satisfy the needs of potential users.

SAFETY Safety is of utmost importance in the design and operation of the VDTV. It will be emphasized throughout the program. The system contractor will develop a safety plan in which both hardware and software safety criteria will be specified and used to guide the development of the vehicle. Verification tests will validate the safety aspects of the VDTV before it is accepted for use. one overriding requirement is that the vehicle will not roll over on a flat surface.

SUBSYSTEMS - Requirements for each dynamic subsystem, similar to those of the vehicle-level requirements, were also included. These requirements included deliverable algorithms which would provide a fully functional vehicle when delivered

APPEARANCE 'The VDTV will have the appearance of a typical five.[m<srll~,rt sedan. Because it will be used in human factors research and testing, the interior will be kept as representative of this class of automobiles as possible. Safety considerations may require a roll bar or cage for some types of tests. Instrumentation and data acquisition equipment will be installed in a manner to minimize the modification of the cab

HUMAN FACTORS Much of the testing using the VDTV will involve driver/vehicle interactions. For example, an ideal application is a study of collision avoidance technologies and how drivers will react to varying degrees of autonomy. The VDTV subsystems will be programmable to allow user-supplied collision warning and/or avoidance devices and control algorithms to be tested in a variety of scenarios. To accommodate this and other research, the subsystems will have variable sensory feedback capabilities. An example is the steering "feel" subsystem which will provide a range from full angular motion with little torque to an essentially zero motion, torque-controlled steering.

RELIABILITY Reliability will be stressed in the design of the VDTV. While a complex vehicle, it must be available to users most of the time; an availability requirement' of four operational days a week was specific,!. Three provisions were included to attain this degree of reliability:

- Qualification of dynamic subsystems prior to integration.
- A month-long performance verification test which repeatedly exercises the VDTV in the limit performance regime.
- An optional year-long maintenance contract.

USER INTERFACE - The VDTV will be designed to accommodate a variety of user-supplied equipment. Typically, these devices would include radar, laser, charged couple device camera, and other types of sensors being developed both for collision warning/avoidance and vehicle automation in the AHS' program. It will also permit human factors instrumentation to be easily installed. Accordingly several locations on and within the vehicle will have mechanical, electrical, and data interfaces preinstalled.

OPTIONS -- Recognizing that the complexity and cost of the vehicle are significant factors influencing implementation, JPL asked proposers to provide information (technical and cost) on several options as follows:

- Fully active suspension
- Active antiroll bars
- Continuously variable semi-active suspension
- Dynamically variable tire pressure
- Four-wheel drive
- Changeable dashboard
- Maintenance contract
- Vehicle replication

Proposers were allowed to include any of these options in their base proposal.

IMPLEMENTATION

A twenty-month development contract is planned. JPL will manage the system contract and will design and build the data acquisition subsystem. The latter will include an off-board data processing capability.

The acceptance test will be conducted at a site selected by the system contractor. Delivery of the VDTV is expected to be made to NHTSA at the their Vehicle Research and Test Center East Liberty, Ohio.

ACKNOWLEDGMENTS

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology. It was sponsored by the National Highway Traffic Safety Administration (NHTSA) through an agreement with the National Aeronautics and Space Administration. The authors wish to thank other members of the JPL VDTV team including Robert Norton, Michael Koffman, Larry Combes, and Nhan Le for their contributions to the work described in this paper. This research was conducted under the technical direction of Lloyd Emery of NHTSA. This paper reflects the findings and opinions of the authors and not necessarily those of NHTSA.

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