# NADS

## National Advanced Driving Simulator

### The Most Sophisticated Research Driving Simulator in the World


U.S. Department of Transportation
National Highway Traffic Safety Administration

National Advanced Driving Simulator

THE UNIVERSITY OF IOWA
Iowa City, Iowa 52242

## Introduction

The National Advanced Driving Simulator (NADS) is the most sophisticated research driving simulator in the world. Developed by the National Highway Traffic Safety Administration (NHTSA), the NADS at The University of Iowa offers the highest fidelity real-time driving simulation experience.

The NADS' primary mission is to conduct research that will lead to a better understanding of the complex driver-vehicle-roadway interaction in critical driving situations. The results of this research will ultimately lead to reductions in the number of traffic-related deaths and injuries on the nation's highways. The NADS can also be used to conduct vehicle system engineering research that will enhance the productivity of the U.S. automotive manufacturing sector.

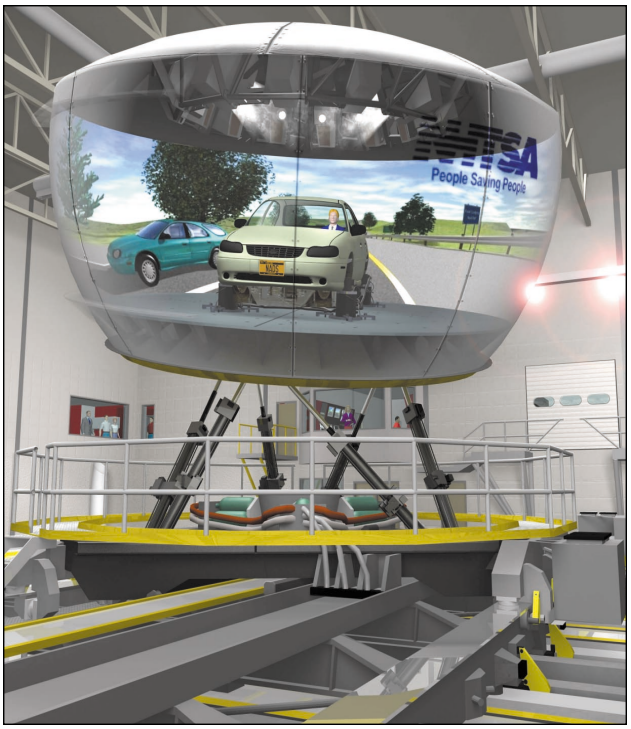
The NADS consists of a large, 24-foot-diameter dome in which entire cars and the cabs of trucks and buses can be mounted. Each vehicle cab is equipped electronically and mechanically using instrumentation specific to its make and model. At the same time, the motion subsystem, on which the dome is mounted, provides 64 feet of horizontal and longitudinal travel and 330 degrees of rotation. The effect is that the driver feels acceleration, braking and steering cues as if he or she were actually driving a real car, SUV, truck, or bus.

The latest in visual display technology, coupled with a high-fidelity audio subsystem, completes the driving experience. The driver is immersed in sight, sound and movement so real that impending crash scenarios can be convincingly presented with no danger to the driver. Vehicle and driver data are collected and stored, and tests can be reproduced. A simulator operator and a researcher control the entire system and provide for the full safety and protection of the driver and equipment during operation.

A world-class team of leaders in simulation technology developed and built the NADS, which is now operated and maintained by a University of Iowa team of highly qualified researchers with a combined total of more than 100 years of simulation and research experience.

**NADS Facility at The University of Iowa**

The NADS is located at The University of Iowa Oakdale Research Park in Iowa City, Iowa. The University of Iowa was selected in a national competition, among major transportation research universities, conducted for NHTSA by the National Science Foundation. The University of Iowa provided $11.58 million in cost sharing to the NADS project, which included the development of software and the design and construction of a $5.7 million building to house the simulator.




**A Look Inside the NADS Dome**

## The NADS Facility

The NADS facility is comprised of a controlled-access, high-bay area that houses the device, the Simulation Development Module (SDM), an operator control room, and a large cab storage and preparation area. These technical resources are within yards of three participant preparation and briefing rooms and a fully equipped medical room used for studies that require examinations, drug administrations or participant monitoring. The entire area is secure to ensure confidentiality and privacy.

Medical-Equipped Participant Room

### *Operator and Research Workstations*

Two main operator and research workstations, for the simulator operator and the guest researcher, are in the NADS control room and overlook the simulator bay through large glass panels. These workstations include multiple large-screen display monitors that can simultaneously present video and digital data. Workstation operators can select, monitor and record numerous experimental parameters. Additional video monitors are used to view a sequence from the driver's perspective. Headphones and speakers allow direct communication between simulator operators and the driver. All data are recorded and up to five data elements may be selected during run-time for display on a workstation. Simulator monitor and control software provide the operator with the control and status information needed for efficient and safe conduct of the simulation.


Operator Control Room

### *Program Planning and General Operations*

As a national resource for carrying out critical highway safety research, The University of Iowa is responsible for operating and maintaining the NADS facility, as well as scheduling government and private sector usage.

Prior to scheduled experiments, NADS researchers team with experienced software, visual display, and hardware engineers to:

- Prepare a detailed experimental plan;
- Define the scenario;
- Plan software model changes, if necessary, or include models supplied by researcher;
- Plan for data collection and reduction; and
- Plan for the recruiting and preparation of study participants.

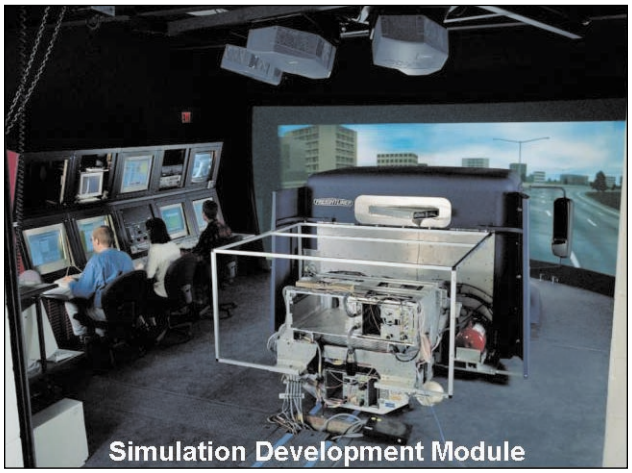
All software and databases developed specifically for an experiment are protected and kept isolated from other researchers. Data security is provided to ensure that proprietary rights are protected to the extent permitted by law.

Before actually conducting an experiment on the NADS, the staff and researchers develop and test scenarios, verify the accuracy of the expected data flow, test any necessary special equipment and obtain approval for use of "human subjects" in a particular study. Next, participants for the study are contacted and scheduled. Finally, a cab is configured in the NADS, and all software files and databases are

loaded and prepared for the experiment. A library of generic scenarios and city/rural databases is maintained for research in areas that do not require unique properties and characteristics. Daily operational readiness tests are conducted to ensure that systems are safe and ready for use prior to conducting experiments.


Vehicle Loading Position

Following an experiment, the NADS staff assists with data reduction and analysis, depending on the researcher's needs.

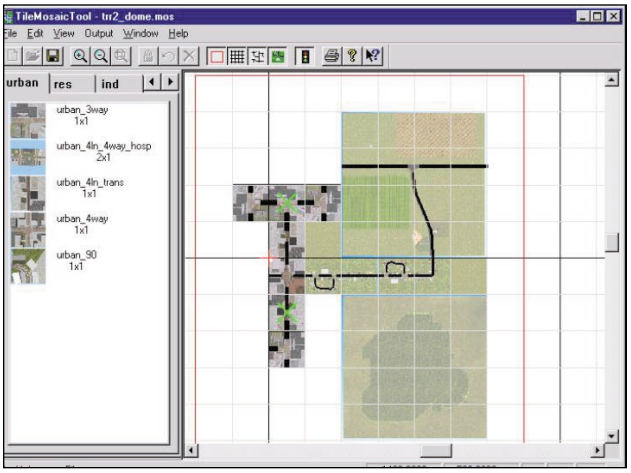

Simulation Development Module

### *Simulation Development Module*

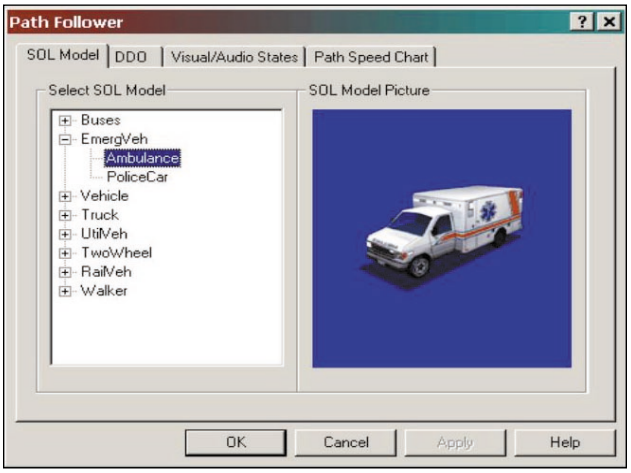
In addition to the NADS, the facility incorporates a Simulation Development Module. The SDM is a fixed-base simulator with a 120-degree field-of-view screen. Each of the available cabs can be installed in the SDM, and the system can replicate the NADS visual environment. The SDM is used to support development and testing of experimental procedures and protocols, including pilot testing of scenarios and training of study participants. This allows for refinement of the scenarios and procedures, and provides a low-cost means of setting up and tuning experiments prior to running experiments on the NADS, thereby greatly reducing development and other experimental costs.

### *Scenario Definition & Control*

The NADS facility includes an extensive, software-based simulation development environment (including tools such as the Tile Mosaic Tool, the Interactive Scenario Authoring Tool, and data reduction workstations) for developing new, or modifying



Tile Mosaic Tool for driving scene databases

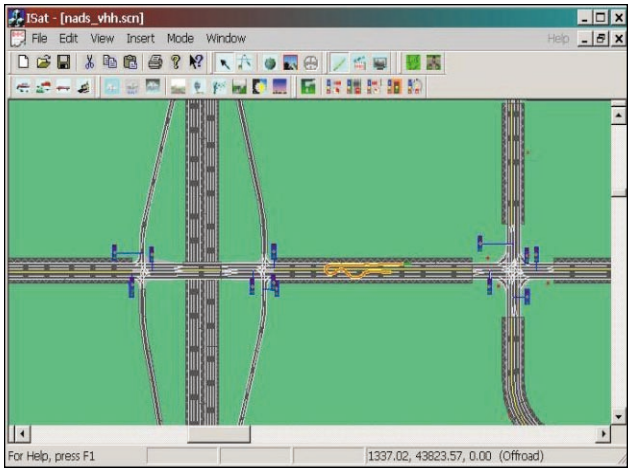


Vehicle Selection Interface

existing, experimental scenarios, special databases (visual, audio, roadways), and data reduction procedures. This software allows a researcher to precisely plan the interactions of the subject vehicle with an elaborate set of scenes and objects. The researcher can also define and control a large set of driving environments - including condition and type of roadway, companion and opposing traffic, traffic control devices and traffic incidents. In addition, the researcher can modify vehicle models populating traffic (e.g., heavy trucks, emergency vehicles) for specific research and develop applications for experimental data collection, reduction and analyses.

### *System Safety*

Ensuring the safety of the study participant is paramount, and the NADS design provides multiple levels of safety controls to protect the driver. During operation, the participant, operator or researcher can halt the simulation at any time. In addition, each motion subsystem contains its own safety monitoring functions to prevent injury to the driver in case of malfunction. The NADS also includes an independent, fully redundant safety monitoring system. This system prevents activation of the simulator, or aborts operation of the simulator, if any potentially hazardous situation exists, or any anomalous system behavior is detected.



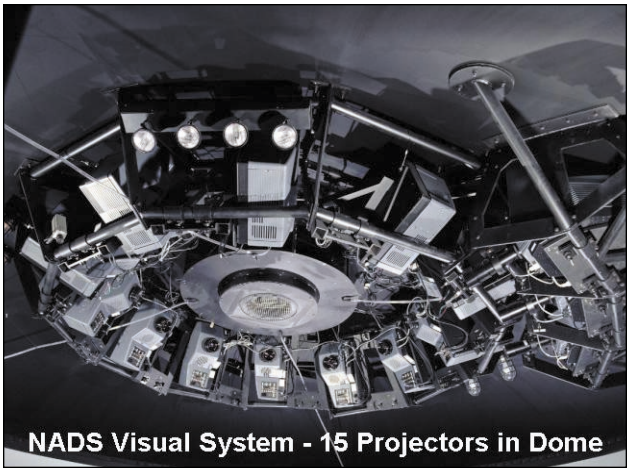
Interactive Scenario Authoring Tool


## NADS Subsystems

The NADS contains a number of subsystems that provide the driver with a realistic representation of the driving environment. These subsystems work in real time to provide repeatable, natural and realistic representations of the visual, motion, auditory and control feel sensory cues associated with the complete driving experience.

### *Visual Subsystem*

The NADS visual subsystem brings together multiple detailed terrain and driving databases with the latest advances in high-resolution imagery. This subsystem incorporates a 24-foot-diameter dome with a high gain screen and utilizes 15 LCD (Liquid Crystal Display) projectors with high resolution that generate the highly realistic images. Other features of the visual subsystem include:

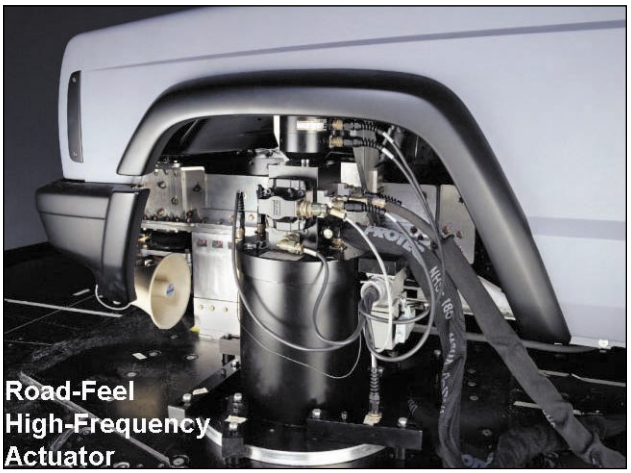


- Multiple-channel projection system that provides complete front and rear field of view, including use of actual vehicle mirrors
- Rapid database generation for scenario development
- Multiple eye points, view points and display channels
- Complex 3-D imagery with full-color, textured buildings, pedestrians, vegetation and other environmental objects
- Complex 3-D imagery fully correlated with other sensory stimuli
- Animation involving numerous objects that create busy traffic situations with:
  - — Independent control rules and logic for animation of other vehicles, pedestrians, scene features and roadways, and
  - — Collision detection for all objects
- Visual subsystem database that includes the full range of:
  - — Current and new highway traffic control devices (signs and signals);
  - — Three-dimensional objects that vehicles encounter (animals, potholes, concrete joints, pillars, etc.);
  - — High-density, multiple-lane traffic interacting with the driver's vehicle;
  - — Common intersection types (including railroad crossings, overpasses, bridge structures, tunnels, etc.); and
  - — Roadway time of day and complete complement of environmental and atmospheric effects


Graphical depiction of typical scene from the forward view.

## Design Specifications of the NADS Visual Subsystem

| Element | Performance |
|---|---|
| Polygons (at 60 Hz) | > 15,000 |
| Total Pixels | > 5 M |
| Transport Delay | ≤ 50 ms (at 60 Hz) |
| Contrast Ratio | 25:1 |
| Luminance | 5 fL |
| Field of View | 360 deg H x 40 deg V |
| With High Resolution Inset | 28 deg H x 7 deg V |
| Forward Inset - High Resolution | 2.2 ArcMin/Line Pair |
| Forward and Side Area Resolution | 7.0 ArcMin/Line Pair |
| Rear Area and Rear-View Mirror Resolution | 15.0 ArcMin/Line Pair |




### *Motion Subsystem*

The motion subsystem provides a combination of translational and angular motion that duplicates vehicle motion kinematics and dynamics within six degrees of freedom. The motion subsystem is coordinated with the vehicle cab subsystem and its high-frequency road feel and control feel subsystem to provide the driver with realistic motion and tactile cues while driving. This subsystem is designed to provide drivers with highly accurate motion cues in all

### Design Specifications of the NADS Motion Subsystem

| Element | Performance |
|---|---|
| **X-Y Platform** | |
| Displacement | ± 32 ft |
| Velocity | ± 20 ft/s |
| Acceleration | ± 20 ft/s$^2$ |
| **Motion Base** | |
| Z (heave) | ± 2.0 ft |
| Z (velocity) | ± 5.0 ft/s |
| Z (acceleration) | ± 25 ft/s$^2$ |
| Pitch | ± 25 deg |
| Pitch rate | ± 45 deg/s |
| Roll | ± 25 deg |
| Roll rate | ± 45 deg/s |
| Yaw (turntable) | ± 330 deg |
| Yaw rate | ± 60 deg/s |
| Pitch, Roll, Yaw accelerations | ± 120 deg/s$^2$ |
| High Frequency Vibration Displacement | ± 0.2 in |
| High Frequency Envelope | 3 Hz - 20 Hz |
| High Frequency Vibration Acceleration | ± 1000 lbf |
| Noise (Multi-axis) | < 0.02 g rms |

axes associated with actual vehicle motions for the full range of driving maneuvers.

Key features of the NADS motion subsystem include:

- Isolated, high-frequency, self-reacting cab vibration actuators that faithfully reproduce road feel
- A turntable allowing ±330 degrees of rotation
- A design that allows for low maintenance costs and minimal staffing requirements

### *Vehicle Cab Subsystem*

The vehicle cab subsystem currently consists of four vehicle cabs, configured to fit within the physical environment of the visual dome on the motion subsystem and provides the driver with realistic vehicle controls. Each cab retains the interior of the actual vehicles with few changes to the internal ergonomics and layout. The four vehicle cabs include a standard sedan (Chevrolet Malibu), a sports/utility vehicle (Jeep Cherokee), a midsize sedan (Ford Taurus), and a commercial truck cab (Freightliner).

Featured in the vehicle cab subsystem are interfaces that allow rapid cab changes to meet desired efficiency standards during NADS operations. The dome can be reconfigured to accommodate and operate a different cab in less than eight hours. The vehicle cab subsystem incorporates a full range of vehicle instrumentation interfaces, including fully functioning controls, dashboard, seating and even an operable radio/entertainment system.

Of particular note is the Eaton truck transmission simulator, incorporated into the Freightliner cab, which can be used to create heavy vehicle scenarios from:

- 140 transmissions,
- 280 engines,
- 33 drive axle ratios, and
- 300 tire sizes.

Additional technology, such as wireless communications, can be incorporated into the vehicle cabs to address specific experimental requirements. In addition, the cab design provides remarkably realistic action and feel for the primary controls (steering, brakes, accelerator) and transmission, and the associated control logic is tunable to allow the simulation of actual or proposed vehicle responses.

### Design Specifications of the NADS Cab Subsystem

| Element | Performance |
|---|---|
| Control Feel Bandwidth | > 50 Hz |
| Weight | < 3,300 lbs |
| Cab Changeout Time | < 8 hrs |


Jeep Cab in the Dome

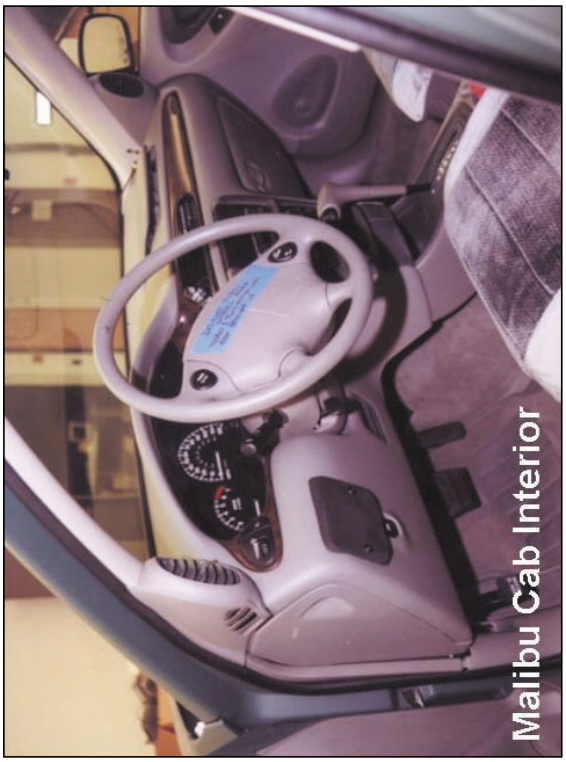

Taurus Cab in Cab Storage


Malibu Cab in Cab Storage


Freightliner Cab in the SDM

**Available Vehicle Cabs**

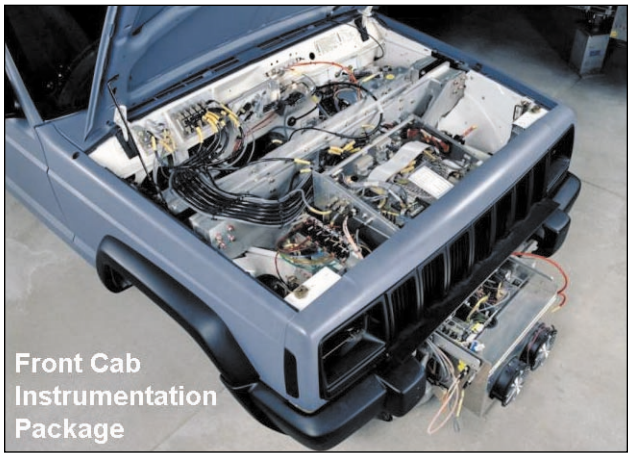


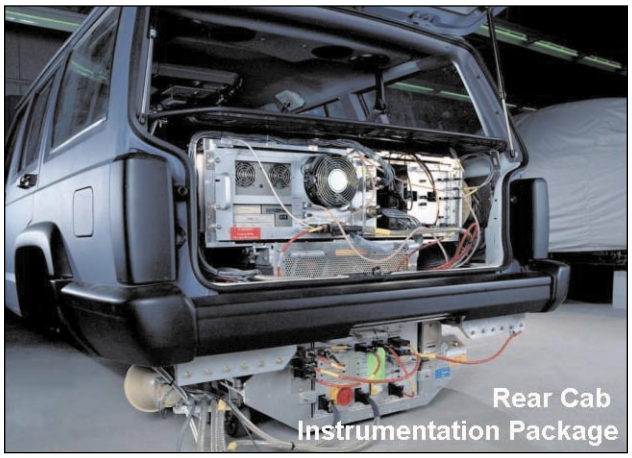




**Vehicle Cab Interiors**

### *Control Feel Subsystem*

The control feel subsystem for steering, brakes, clutch, transmission shift and throttle provide realistic feedback in response to driver inputs, vehicle motions and road/tire interactions. The control feel subsystem is capable of representing automatic and manual control characteristics such as power steering, existing and experimental drive trains, anti-lock braking systems and cruise control. The control feel cuing feedback has high bandwidth and no discernible delay or distortion associated with driver control actions or vehicle dynamics.




### *Auditory Subsystem*

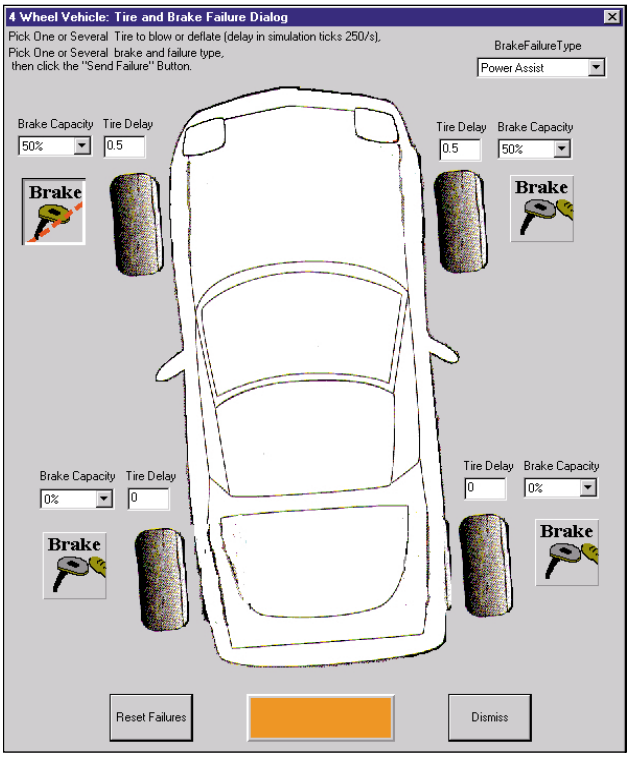
The auditory subsystem provides motion-correlated, directional sound sources via multiple in-cab electrostatic speakers. These sound sources are coordinated with the full range of the visual sensory systems database. The auditory database includes sounds emanating from current and new design highway surfaces, from contact with three-dimensional objects that vehicles encounter (potholes, concrete/tar joints, pillars, etc.), from high-density multiple-lane traffic (including city effects, sirens, tunnel passage), from the vehicle during operation, and sounds that reflect roadway changes due to changes in the weather environments (including wind).

**Design Specifications of the NADS Audio Subsystem**

| Element | Performance |
|---|---|
| Dynamic Range | 100 db |
| Bandwidth | 15 Hz - 20 KHz |
| S/N Ratio | 96 db |
| Distortion | ≤ 1.0 % |
| Dynamic Synch | < 28 ms |

### *Vehicle Dynamics*

The vehicle dynamics software properly represents vehicle motions and control feel conditions in




NADS Vehicle dynamics software - Tire and Brake Failure Dialog Screen.

response to driver control actions, road surface friction conditions and aerodynamic disturbances. The vehicle dynamics software incorporates a multi-body vehicle dynamics model that accurately simulates the motion and feel of vehicle linkages and joints.

All required vehicle responses are computed in real time for driving the visual, motion, cab, control feel and auditory subsystems. The vehicle dynamics models cover light passenger cars and trucks, and heavy trucks and buses. The models encompass normal driving conditions and limit performance and maneuvering that might be encountered during pre-crash avoidance situations, including spinout and incipient rollover.

## NADS Research Uses

The unique capabilities of the NADS lend themselves to studies that could not otherwise be safely carried out on the open road. In particular, the ability of the NADS to create highly complex but realistic scenarios, typical of actual driving situations, in a highly controlled and repeatable experimental setting allows researchers to address a wide range of issues. The ability to impose realistic demands on drivers, including those associated with in-vehicle tasks, traffic conditions, sudden events and environmental conditions (e.g., roadway, visibility), provide research opportunities not possible on test tracks or the open road.

The NADS offers a safe, accurate and repeatable environment for researchers to study human factors issues associated with driver error, which are estimated to be a contributing cause in 90 percent of motor vehicle crashes.

The NADS is a unique research tool that offers the capability to study driver crash avoidance behavior and carry out related crash reconstructions. The complete control of highway environment and traffic scenarios provided by the NADS allows researchers to: 1) set up hazardous driving situations and measure driver response; 2) examine conditions associated with real crash cases; and 3) study driver and vehicle response options and limitations. A clear understanding of driver behavior under these circumstances


Dome-Projected Image

can lead to the development of effective strategies and countermeasures for improved crash avoidance and to reduce injuries and fatalities.

The NADS also provides the capability for safely evaluating advanced in-vehicle systems and control technologies. Important questions regarding the effects of these systems on driver workload, attention, behavior and overall safety are best addressed during the development phase. It is imperative to determine before the production phase if any of these advanced systems will have an unintended or adverse impact on driver performance and highway safety.

The NADS can also be used for conducting highway engineering and design research related to traffic safety. In the NADS' synthetic environments, the driving scene and highway geometry are under the complete control of the simulation programmer. Highway researchers can therefore evaluate


NADS Docking Position

alternative designs for intersections, entrances and exits, tunnel and bridge alignments, traffic control devices and highway signing without incurring the prohibitive expense of actual construction.

The benefits of NADS research extends further to the automotive industry, where the results, in combination with those from simulators developed within the industry, are used in the development and testing of new safety devices.

The NADS is also an ideal tool to study the effects of alcohol, drugs, visual impairments and aging on driving. Medical and pharmaceutical researchers, among others, use the NADS to investigate the safety and efficacy of new medicines and medical devices in the driving environment.

## Summary

As the world's most sophisticated research driving simulator, the National Advanced Driving Simulator offers easy experiment setup, product integration and data collection. The NADS is the first to employ a large motion base, capable of physically moving 64 feet in two directions, and providing users with true, realistic motion experience, whether accelerating, turning or braking. Its computer image generation system features 15 LCD projectors that provide a 360-degree horizontal field of view and incorporates a database of driving scenes spanning more than 2,500 square miles of terrain. Four vehicle cab types are available for use, as well as multiple secure participant briefing rooms and a medically equipped facility for medical studies. In addition, The University of Iowa offers a highly trained and experienced technical and research team to work with researchers on all aspects of research planning, development, execution and analysis efforts.

This highly realistic driving simulator provides a powerful tool for evaluating driver behavior in a wide range of complex situations that would otherwise be difficult, costly and often unsafe to obtain under actual roadway driving conditions. Representative traffic scenarios can be examined safely with experimental repeatability, easy configurability and comprehensive data collection capability. The level of fidelity allows researchers to implement virtually any experiment that they would consider in a real vehicle on any roadway.

The NADS is dedicated primarily to advancing the cause of improved highway safety. As a national research facility, operated and maintained by The University of Iowa, the simulator is accessible to the widest possible spectrum of researchers from both the public and private sectors. NHTSA, as well as researchers from academic and medical institutions and the automotive/transportation industries, uses the NADS to study the total driver-vehicle-traffic environment system with an eye to improving products, highway designs, and reducing the causes of crashes - in addition to reducing fatalities.

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