CATSS Final Report

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Systems Engineering Optimization of the UCF Driving Simulator

1.0 UCF Driving Simulator

1.1 Introduction

This research project had two objectives, involving students in research tasks oriented to transportation in general and driving simulation in particular and an investigation of the design and possible improvements to the design of the UCF Driving Simulator. We believe that we have met both of these objectives. This project involved six students working in the following areas;

- Greg Harrigan (Senior, Mechanical Engineering, Carnegie Mellon University), systems and hardware engineering
- Jeff Goodman (Junior, Computer Engineering, University of Central Florida), computer systems design and intercomputer communications
- Smitha Reddy (Masters, Computer Engineering, University of Central Florida), computer systems and software design
- Fritz Feurbacher (Masters, Computer Science, University of Central Florida), software design
- Kapil Bhatia (Masters, Mechanical Engineering, University of Central Florida), simulated vehicle test engineering
- Rebecca Clarke (Senior, Math Education), project support

These students were all exposed to many issues related to simulation and transportation. They applied their individual skills and academic training to the specific systems engineering issues related to the UCF Driving Simulator. All of the students are listed as co-authors of this report. Mr. Goldiez was the Principal Investigator leading this research effort and providing guidance to the students.

The second objective of this project was to analyze and recommend possible enhancements to the UCF Driving Simulator. There are enhancements we believe can be made to the UCF Driving Simulator. In general, we believe that it would be beneficial if a committee was formed to plot a course for enhancements and uses for the UCF Driving Simulator. Specific technical recommendations can be found throughout this report.

1.2 Background and UCF Driving Simulator Overview

The UCF Driving Simulator (DS) is a central component of the Center for Advanced Transportation Systems Simulation (CATSS). The UCF DS grew from a grant made by the State of Florida to UCF's Institute for Simulation and Training (IST) in 1988. The original objective of the research effort was to prototype a driving simulator useful for prescribing devices to assist handicapped drivers. The grant to the Institute for Simulation and Training was transferred to the College of Engineering where additional grants enhanced the simulator. Numerous enhancements have been made by faculty and students over the years.

CATSS Strategic Plan indicates a theme for using simulation in multi-modal transportation studies, cross discipline research between departments, and exposing students to become transportation professionals.

Seeking a flexible and extensible testbed for achieving these goals, CATSS seeks to bring in new subsystems to the UCF DS as well as new uses. A possible re-design, taking advantage of modern object oriented programming and modular design, might make the UCF DS more amenable to upgrades and cost sharing by the transportation community. The system needs to be well documented and redesigned so that the UCF DS can grow with technology and maximize funding and utility.

1.3 Hardware Configuration

The simulator consists of four major parts: the crew station/vehicle; the sensory output devices such as the image generator, force feedback, and sound, and Digital Input Output devices such as signaling and dashboard lights; the computer, which controls processes such as the vehicle dynamics model; and input devices such as the steering wheel, gas pedal, brake, gear selector, and horn. A user sits within the vehicle and provides input to the system such as steering, braking, and acceleration. The computer processes the information from the input devices, and using the vehicle dynamics model periodically updates the current model of the system. This model forms the input stimulus for the image generator, which takes information such as position, velocity, and acceleration, uses it along with the visual database, processes an image, and outputs to the projectors and onto the screens. In addition, the output devices take information from the computer process and output to the sensory output devices such as sound and force feedback.

The UCF Driving Simulator car is a fixed base 1983 Dodge Aries with its driving elements under the hood removed. Within the car the driver has control of braking, acceleration, steering, gear selection, signaling, and use of the horn. Driving input is fed into a Silicon Graphics Onyx Reality Engine 2 and is processed. Refer to figure 1, which is provided on a separate disk upon request. Acceleration (3), gearing (2), and braking (4) are fed through the Analog to Digital converter into the processor. Steering input is fed through the quadrature encoder and into the processor. The on/off (digital) elements such as the horn (14) and signaling (13) are fed through the Digital Input Output. Output consists of four different areas. Steering feedback comes from the processor to a Digital to Analog converter and drives the torque motor (8). Sound comes from stereo jacks located on the processor. These jacks lead to amplifiers (6) located within the car, and finally to speakers (5) located underneath the driver seat. Amplification within the car prevents feedback into the system, which can lead to interference. Dashboard lighting (12) such as signaling outputs through the DIO and into the vehicle. The motion shaker (7) is currently not in use because the speakers provide adequate vibration. Video outputs through the Silicon Graphics Multi-Channel-Option (MCO), which splits the video signal drive four projectors located above the vehicle. Three of them are positioned in an arc directly above the vehicle and project onto the forward screen. The fourth projector is located behind and above the vehicle and projects onto a flat screen from behind. The rear projector is less powerful than the 3 primary Barco projectors and does not provide adequate brightness.

As of July 8, 1999, all of the input/output functions were routed through four terminal blocks located within the car and the control room. Wires within the car connect into these terminal blocks under the hood of the car and then go out into the control room to a set of identical terminal blocks.

This configuration was altered so that input and output devices connect into a computer located in the vehicle instead of through terminal blocks. These functions will then be controlled via Ethernet cable, which will connect to the main computer in the control room. The design alteration was made to minimize cable connections between the host computer and crew station, and input and output systems. One possible drawback of this approach is the eventual incorporation of a motion system, which could cause reliability problems with a standard PC that is probably not designed for an environment created by a motion platform.

1.3.1 Hardware Assessment

Hardware is well documented. There are diagrams describing the locations of wires and their connections. All engineering analyses are available from the principle author. However, under the hood of the car the wiring is very messy and very difficult to understand even with the help of a diagram. It would be very helpful if the wiring were collected and simplified so that in the future upgrades and changes would be simplified.

The upgrades that will be implemented for the simulator in the new engineering building are and will be in the planning phase for a while. In addition, it is impossible to determine what technology will finally be used because technology is rapidly evolving. One can predict a range of technologies that could be added to the UCF DS. It is also known that grants will be used during the next two years to add to the current design before final optimizations are made for the new engineering building. This underscores the need to unify the current simulator, to properly document it, and to make sure that any further additions are thought out with respect to its use, its necessity, and its upgradability.

Before the driving simulator can be fully assessed for upgrade both now and in the future, there needs to be a clear picture of what exists, what can be improved on, and what direction the simulator wants to move. The software first needs to work. When the problems with it are solved, it needs to be fully documented, so that anyone can look at it and be able to make additions, changes, or simply understand its operation.

1.3.2 Technical Assessment of the UCF Driving Simulator

Since its inception, the UCF driving simulator has been continually upgraded by both faculty and students using funds from several grants. During this upgrading process, many of the changes made to the simulator do not appear to be documented. These changes can be broken down into hardware upgrades and software upgrades. In addition, due to the limited scope of many of these research efforts, which concentrated on specific areas like sound, it appears that many of the changes were made without regard to future upgrades nor the impact on the overall design of the simulator. As grants were awarded to the project, purchases were made for additions and upgrades to the system. Unfortunately throughout the process, there seems to have been a lack of a unified direction or over-arching goals for these changes. New computers were bought and new software was added, creating a simulator that while sometimes functional, is not optimized in either use or software/hardware design.

The optimization issues associated with the current simulator are not the responsibility of any one researcher. They are the result of a lack of documentation and a systems engineering and utilization strategy along the way. During an upgrading process or research effort, care needs to be taken to look at the entire scope of the current design, the uses envisioned for the simulator, then implement upgrades that are not only cost-effective and useful, but also do not hinder the overall design in the future. By hindering, we mean that changes should be made in a way that does not compromise the simulator's functionality or ability to accommodate future changes. Without this step by step process, improvements on the simulator are a hit and miss process, which can result in a simulator that is not operational, or it compromise research work. With every undocumented upgrade, the problem is compounded.

Software is the main contributor to this optimization problem on the UCF DS (a more detailed treatment of the software configuration can be found elsewhere in this report). During the software upgrade process the system was never completely stripped down and then brought back up using the new software. This was done because the technicians feared not being able to bring the system back to working order again. We believe that there is currently no researcher involved with the simulator who fully understands the setup of the software running the simulator. Again, this problem is the result of a lack of documentation of software. While a computer-scientist could theoretically be brought in to work on the simulator, it would likely be difficult for him/her to understand the software configuration much less be able to methodically implement changes and improvements.

There are specific problems within the software that have emerged. Software operation is very sporadic. There were extended periods of time during the course of this research project when the simulator would not run. Part of the problem was 'upgrades' to the computer system. Commenting within the code of the C programs that run the simulator would enhance the ability of future researchers to understand and improve the simulator.

1.4 Current Vehicle Dynamics

The UCF automobile simulator uses a software product called "Clarus Drive" which simulates vehicle dynamics. This software consists of two modules, dynamics and audio, each of which can be used separately or together. The Clarus Drive product was made specifically for use with Vega, another software product that is the simulation nerve center, which coordinates the physical simulation with visual feedback. It also gives the user graphical tools to configure the simulation. The audio module requires AudioWorks2 for sound generation.

The Clarus Drive is built up from different classes, each of which represents some aspect of a real world vehicle. Each of these classes can effect the other classes just as a real vehicle's parts would effect one another. Clarus Drive refers to the conglomeration of all the classes that make up a vehicle as a "car." This doesn't mean that the Clarus Drive could not be used to represent other types of vehicles such as a pickup truck, bus, sports car, semi-truck, etc. However there are some limitations because of the granularity of the Clarus Drive representation. New vehicle types would need to consider the Clarus Drive representation and perform a mapping from the alternate vehicle type to the Clarus Drive "car."

The Clarus Drive dynamics is a parameterized model of a 4-wheel vehicle, with 7 exported degrees of freedom (degrees of freedom could not be determined). There is also a driver interface API that is used to input data from the driver interface hardware, such as steering wheel, pedals, and gear stick. The API also makes it possible to extract information to update instrumentation and for other use. General features such as gravitation, rolling friction, wind resistance, centrifugal forces from steering and power train are included. Furthermore the driver interacts with the vehicle through the steering wheel, throttle, brake-pedal, clutch, and gear stick which are some of the input devices that can be connected to the system.

Clarus Drive also supports multiple sound resources, each with a set of sample sounds for the engine, wind noise and from the remaining parts of the power train. The audio uses an ordered sound sample database to playback a continuous sound image of a vehicle. There are three sounds that can be played back, engine, body, and wheel sounds, although eight channels are used to reproduce the sound during runtime. The sound database consists of samples with additional sample state data attached to it. During run time the audio module receives state information from the dynamics of each frame. Based on this data and the tagged sample state data it decides which sounds to play and how to mix them. There are three kinds of sound sources defined within the model. For each model there have to be a number of sounds sampled at different vehicle states to be able to generate a continuous sound scene in real-time.

We can define the granularity of a vehicle by listing all of the classes in Clarus Drive, which represent a "car" and their respective interactions with each other. This will tell us what we can and cannot effectively simulate in terms of different types of vehicles. An intimate knowledge of vehicle dynamics will be required to make the determination of which particular vehicles can be simulated.

First, in Clarus Drive a vehicle is defined in terms of the following four attributes:

1. Power train
2. Wheel assemblies
3. Body
4. Driver interface

Figure 2 shows the main Clarus Drive classes and their relationships.

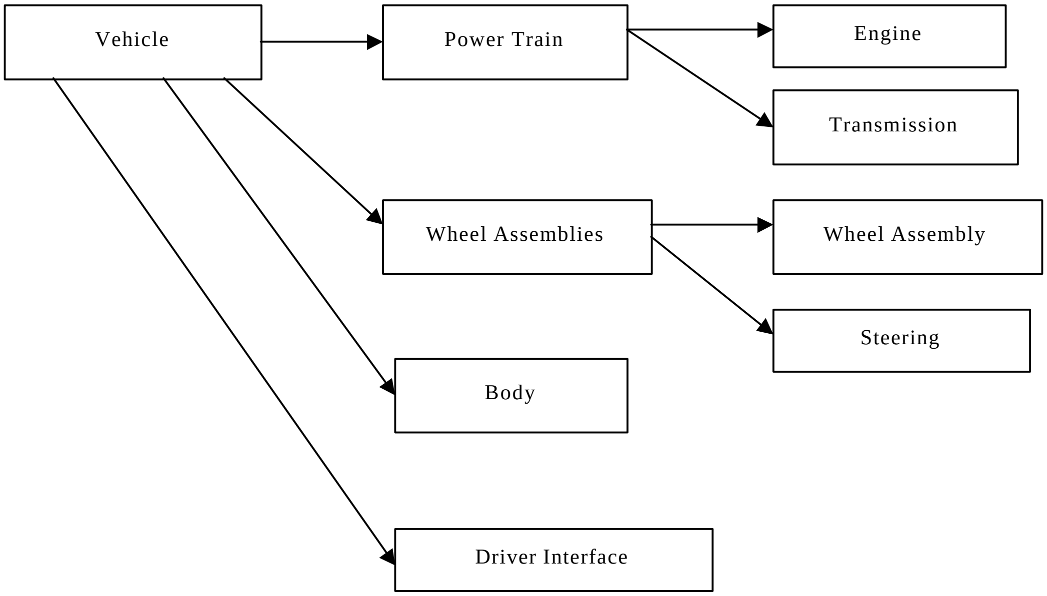


Figure 2 Clarus Drive class diagram. [1]

If a certain type of vehicle cannot be defined using just these four attributes then the designer should probably go no further or work on creating a whole new Vega module. Otherwise, if the designer feels that a particular vehicle he/she wants to simulate can be represented using these attributes, he/she should then take a look at the sub-attributes that represent the previous four attributes. These main attributes and their sub-attributes are listed below:

1.4.1 Power Train

The power train has an engine and a transmission. From the engine a torque is generated which is applied to the wheels through the transmission. The forces of each wheel affect the body. These forces are summed and cause a change in velocity of the body. The angular velocity of the wheel is fed back through the transmission.

The power train attribute is made up of two sub-attributes. These two are:

1. Engine - The engine is represented by the properties:
    - Power
    - Torque
    - Revs

    It interacts with:
    - Transmission

2. Transmission - The transmission is represented by the properties:
    - Clutch
    - Gearbox

    It interacts with:
        - Engine
        - Wheels

1.4.2 Wheel Assemblies

The wheel assembly attribute is made up of four sub-attributes:

1. Brake
2. Wheel
3. Spring
4. Steering

1.4.3 Body

The body attribute is made up of five sub-attributes:

- Mass
- Height
- Width
- Length
- Drag Coefficient

It interacts with:

- Wheels
- Coordinate System

1.4.4 Driver Interface Software

The driver interface is made up of three sub-attributes:

- Clarus Drive dynamics model
- Clarus Drive audio model
- Clarus Drive Sound

Figure 3 below shows the Clarus Drive classes and their feedback relationships.

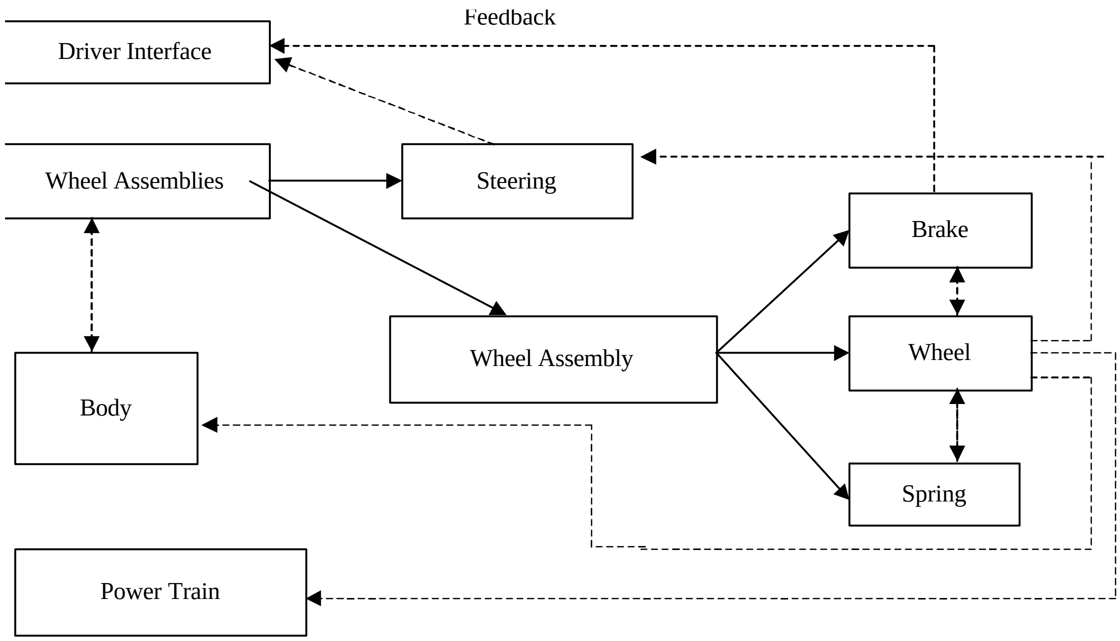


Figure 3 Clarus Drive Class Diagram and feedbacks [1]

Class extensions for the Clarus Drive Dynamics Model, CD Audio Model and CD Sound are provided with the API. The corresponding classes in the API are called cdDynamics, cdAudio and cdSound.

The cdDynamics class instance manages the dynamics of a four-wheeled vehicle in motion. The dynamics is fed with the information on the state of the driver interface, e.g. steering wheel position, clutch position etc, and calculates a new internal state of its different parts based on this information. It also sets the position coordinates of the defined target class instance. Theses actions are performed in a Vega postframe feedback.

Below is the detailed description of all the parameters in Clarus Drive.

1.4.5 Vehicle Attributes Details

Each model attribute has a number of parameters, which can be changed to alter the dynamic behavior of the model. For each attribute, following section describes the parameters and how it effects the behavior of the attribute or model.

1.4.5.1 Power Train Parameters

<u>MaxPower</u>
Unit: [W]
Default: 8200
Description
This parameter represents the maximum power generated from the engine. The engine power generated each frame depends both on the throttle angle and the angular velocity of the engine at the moment.

Max Power Revs
Unit: [RPM]
Default: 4000
Description
The power of the engine reaches its maximum at this value. The accelerating forces of the car will also reach it's maximum, but since the air resistance is vary large at high velocities this will not necessarily mean that the acceleration reaches its maximum velocity.

Max Torque
Unit: [Nm]
Default: 230
Description
The maximum torque generated by the engine.

Max Torque Revs
Unit: [RPM]
Default: 3000
Description
The generated torque from the engine reaches it's maximum at this rev.

Idle Revs
Unit: [RPM]
Default: 800
Description
When the gas pedal is 0 and the clutch is out, the engine angular velocity will converge to the value of this parameter.

1.4.5.2 Clutch Release Position

Unit: [RPM]
Default: 3000
Description
The clutch position is normalized between 0 and 1 where 1 represents a totally depressed clutch pedal and a 0 a fully released. This parameter a fractional position of where there will be no transfer of torque.

Gearbox Type
Default: Manual
The type of gearbox used, either manual or automatic.

Reserve Gear Ratio
Unit: Not Applicable
Default: 11.427
Description:
Ratio for reserve gear.

First Gear Ratio
Unit: Not Applicable
Default: 4.03
Description:
Gear ratio for forward gear1. The ratio of the first forward gear is multiplied with the torque generated by the engine. The result is then multiplied with the Power Shift Gear Ratio before it is applied to the wheels.

Second Gear Ratio
Unit: Not Applicable
Default: 2.16
Description:
Gear ratio for forward gear 2.

Third Gear Ratio
Unit: Not Applicable
Default: 1.37
Description:
Gear ratio for forward gear 3.

Fourth Gear Ratio
Unit: Not Applicable
Default: 1.00
Description
Gear ratio forward gear 4.

Fifth Gear Ratio
Unit: Not Applicable
Description:
Gear ratio for forward gear 5.

Power Shaft Gear Ratio
Unit: Not Applicable
Default: 3.105
Description:
The internal gear ratio of the power shaft.

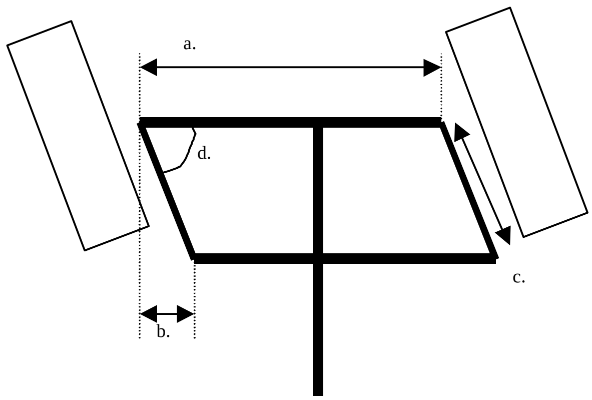
1.4.5.3 Wheel Assemblies

Steering Attachment Radius
Unit: [m]
Default: 0.16
Description:

The distance where the wheel axis (axle) is attached to the wheel rim (at the center) and the attachment of the steering shaft in relation to the wheel axis. This parameter is used to calculate the mean steering angle. See figure 4.

<u>Steering Linear to Angle ratio</u>
Unit: Not Applicable
Default: 0.01
Description:

The ratio between the angle of the steering wheel and the linear displacement of the steering shaft.



a. Wheel distance
b. Steering Linear Offset
c. Steering attachment radius
d. Steering angle

Figure 4. Steering parameters [1]

<u>Spring Normal Length</u>
Unit: [m]
Default: 0.3
Description:
The length of the wheel assembly springs, without any force applied.

<u>Spring Elasticity Constant</u>
Unit: [N/m]
Default: 16350.0
Description:
The normal, first order, spring constant. This parameter is used to calculate the normal forces affecting the car.

<u>Normal Force Damping Constant</u>
Unit: [Ns/m]
Default: 2500.0
Description:
The second order spring constant. This parameter is used to calculate the normal forces affecting the car.

Wheel Radius
Unit: [m]
Default: 1.46
Description:
The distance between the left and the right wheel pairs.

Wheel Base Distance
Unit: [m]
Default: 2.77
Description:
The distance between the front and back wheel pairs.

Brake Maximum Torque
Unit: [Nm]
Default: 1000.00
Description:
The maximum torque the brakes can exert on he wheels (with a fully depressed brake pedal)

Drive System
Unit: Not Applicable
Default: Brake Wheel Drive
Description:
Decides whether torque from the engine is applied to the front wheel pair, back wheel pair or all four wheels.

1.4.5.4 Body

Mass
Unit: [kg]
Default: 1.76
Description:
The mass of the entire car

Length
Unit: [m]
Default: 1.76
Description
The total length of the car.

Width
Unit: [m]
Default: 1.76
Description:
The width of the car.

Height
Unit: [m]
Default: 1.41
Description:
The height of the car

Drag Coefficient
Unit: Not Applicable
Default 0.3
Description:
Defines how the form of the car affects the air resistance force. The wind resistance force is proportional to the square of the velocity.

In addition to the previous vehicle parameters, the following sound characteristics are included.

Body Sound Properties
The body sound depends on the velocity of the vehicle. Typically there should be sounds sampled for the following velocities [km/h]: 20, 30, 35,40, 50, 60, 70, 80, 100, 120, 140.

Engine Sound Properties
The engine sounds depends on both the torque and the Revs of the engine. Typically, this two dimensional sound should be sampled at the following values: for Torque [Nm] 0 at Revs [RPM] 800, 1000, 1250, 2000,2500, 3000, 3500, 4000, 5000, 6000. For torque's of 300 also at the above Revs.

Wheel Sound Properties
The wheel sound depends on the velocity of the car. Typically, there should be sounds sampled for the following velocities, Velocities [km/hr] 20,25,30, 35, 40, 50, 60, 70, 80, 100, 120 and 140.

2.0 Design Considerations for a Driving Simulator

2.1 Crew station/vehicle

The current driving simulator is fixed-base, with the full cabin of a 1983 Dodge Aries. This setup works well because the car is self-supporting and gives drivers the feeling that they are sitting in a real vehicle. In addition, having the entire vehicle allows elements such as sound and steering to easily be based under the hood of the car and easily accessed. Given a fixed-based configuration, it makes sense to leave the shell of the vehicle intact rather than expend effort to remove sections of it.

Adding motion to the system changes the setup of the cabin. "G-seats" would likely require moderate modifications such as removal of interior seats and/or relocating various elements of the interior to accommodate drivers. These modifications are relatively minor. However, motion platforms require that the vehicle be shortened to fit on the platform. Rough calculations have shown that current motion systems under consideration will support a maximum of a 12-15 foot platform base (see Figure 5 which is available on a separate disk upon request). Researchers will likely need to walk around the platform to perform tests or maintenance, and a mid-sized vehicle (with the trunk section removed) measures around 13 feet. This leaves approximately one foot for a person to walk around assuming that the maximum of 15 feet is used as a diameter of the platform and the vehicle has its trunk removed. This amount of walking space is inadequate. Clearly, in any case the shell of the vehicle will need modification.

Structurally, there are three options in modifying the shell of the car. The first involves removing the hood of the car at some point in front of the windshield and masking off the appropriate area of the projection screen to achieve proper visual field of view for the driver. This option forces elements currently located under the hood, such as wiring, sound, and speedometer, to be relocated. In addition, while masking is supported within the simulation program Vega, the need to mask off the projection area would likely detract from the realism of the simulation. This option should be used when the body of the vehicle is clearly too long for the platform.

In the second option, the trunk is removed leaving the rest of the shell intact. This option is plausible, as previously discussed, but might leave insufficient walking room on the platform. In addition, the likely visual scenario will involve a circular platform with a cylindrical or spherical projection screen. Placing the vehicle too close to the periphery of the platform could possibly cause projection problems with things such as shadows and field of view.

The third option involves cutting the vehicle in half midway at some point behind the driver seat, which leaves the front half of the vehicle. This option is more suitable when dealing with smaller platforms and/or larger vehicles. However, removing the entire back portion of the car greatly detracts from the simulation experience. Notably, blind spots, and cabin realism are lessened. In addition, it compromises the structural integrity of the vehicle cabin and necessitates additional support for the cabin to replace the removed rear-wheels. This form of modification would likely be time-consuming and difficult. This option is least preferable to the options of trunk and hood removal, both structurally and practically.

2.2 Motion

One of the major problems with the current UCF simulator is motion sickness. According to the professors in charge, Dr. Bauer, and Dr. Klee, this occurs in 30 percent of females and 10 percent of men. This is caused because the visual scene and lack of motion cause a physiological conflict in human subjects. There are a few options being explored to correct this flaw noted above, such as providing motion to the vehicle in the form of either “G-seats” or a motion platform.

In our preliminary research we posed the question of motion to Robert Schwing, who was formerly associated with the Iowa Driving Simulator. He commented on both G-seats as well as simulator motion in general.

“My experience with these type of devices go back to my Air Force days. Some units were better than others but none were as good as a motion system (even a 3 DOF system). The G-seat and seat belt pulling devices are point-of-contact units that the body figures out relatively fast. A G-suit is a better alternative but is very bulky and prone to rate limitations. Seat rockers and shakers have better frequency response but the body quickly detects the relative motion issue.”

Mr. Schwing continued, “The most important factor that must be identified in your motion system development is the envelop of operation in which the subject vehicle will be studied; e.g., high speed, oval racing, s-turns, stop-and-go, rapid changes in acceleration, etc. Will the use concentrate on human factors or vehicle dynamics? Will the drivers be experts, average, or inexperienced drivers? Are you looking at "transfer of training" or just demonstrating simulator capabilities and proof-of-concept? Our experience here with the Iowa Driving Simulator demonstrates that most drivers use sight and sound as primary cues EXCEPT in certain tasks where motion cue (force) is everything. Examples of these tasks are correlating speed in a turn (drivers hate large lateral forces); gradual deceleration (in a sudden accident, drivers slam on the brakes and don't care about anything except stopping); uniform application of power; driving on the shoulder of the road or uneven pavement; etc.”

A “G-seat” pneumatically provides a feeling of movement for the driver. This option would have to be applied to both the driver and passenger seats in order for both passengers to experience the simulator. Although the simulator is clearly geared toward the driver, a passenger seat would be necessary in the event that a passenger were to use the simulator. The advantages and disadvantages of this option are currently being explored. One possible advantage is the simplicity of the solution, which only requires modification of the vehicle, whereas motion platforms require many of the features of the UCF DS to be abandoned and require a large amount of space. While the option of a G-seat is currently being explored, there are some clear advantages and disadvantages to its use.

- One of the factors involved in design is allowing for modularity of the vehicle, so conceivably different models of cars or vehicles could be implemented for different research purposes. A “G-seat” complicates this in several ways. First, in order to install G-seats the existing vehicle seats would have to be removed. In addition, the seats would have to be sufficiently versatile and compact mechanically and electrically to fit into whatever car may be needed. This could cause problems because seat sizing and configuration varies with each vehicle.
- Using a G-seat in a car instead of the designed seat takes away from the feeling within the vehicle. Car designers spend countless dollars designing car cockpits so that the seat, dashboard, steering well, and other elements are optimally integrated into the cabin. Introducing a new seat with likely a limited amount of adjustability and flexibility would likely decrease the comfort of the driver as well as the ability of the driver to optimally operate the vehicle. This would of course take away from any usage of the vehicle to test new elements of the cabin and make it difficult to assess the differences between different vehicle designs. In fact using a G-seat might render the concept of different vehicles useless.

Motion Platforms are another practical solution for motion. They offer the ability to provide a more realistic simulation while minimizing much of the motion sickness associated with fixed-base simulators. However, motion platforms add complexity to the design, requiring much of the current UCF DS to be abandoned. There are both advantages and disadvantages to the option, which need to be considered.

- With a motion platform both the projectors and the screen(s) must be secured to the platform. The Barco projectors are too heavy and fragile to be placed on a motion platforms. These projectors require tedious adjustments to align them on the screen, and the movement due to the motion platform would pose a serious problem in maintaining their alignment. Therefore, motion necessitates the purchase of a different form of projector that solves weight and vibration constraints. Securing both the screen and projectors to the platform also requires a new screen and the creation of an assembly for both the screen and projectors on the platform.
- The current UCF DS has several other problems when put on a motion platform. The screen is shaped like a torus, thus not spherical, which makes convergence of the different projector images difficult, creates distortion, and takes away from the overall simulator experience.
- As previously stated, another research grant has added a PC to the crew station. The PC is connected to the simulation host computer and is intended to be a distribution point for I/O. An Ethernet cable connects the computers making the hardware interface very clean and simple compared to the original UCF Driving Simulator. However, it is not at all clear that a production PC can withstand the vibration and G environment of a motion platform. These authors envision reliability problems with the on board computer.
- The addition of a motion platform creates many new costs. In addition to the purchase of the platform, there is maintenance cost required, which needs to be assessed. The change to new screens and projectors creates even more new costs.

The greatest advantage to the motion-platform is a more realistic simulation. In addition it will reduce instances of motion sickness if proper steps are taken in synchronizing vehicle modeling for motion drive to the visual system. This increases the usability of the simulator for research. The more realistic the simulation and the less distractions there are while operating it, the better the data researchers will be able to gain from experiments using the UCF DS.

Within the realm of motion platforms there are two different kinds of platforms, hydraulic and electric. Hydraulic platforms hold more weight, but have more problems (e.g., high-pressure hydraulic lines) and maintenance associated with operation and upkeep. Electric platforms are relatively low-maintenance and seem more applicable to this type of usage. Two platforms considered appropriate from Hydradyne are 1000 kg (2200 lb.) and 2500-kg (5510-kg) platforms. A weight and mass distribution analysis was conducted to determine the best platform for the UCF driving simulator. The platform elements were given reasonable weight values and then applied as distributed loads in the likely areas of placement. From this rough analysis a few specific conclusions were reached with regard to choice of platform. First, center of mass does not appear to pose a major problem to the UCF driving simulator given the approximated length of the vehicle and the diameter of the platform. However, this potential problem is increased as the diameter of the platform is increased. Noting the need to give the user the most realistic simulator experience, there is a need to determine how much of the car is actually needed, for instance, should the trunk, the hood, or the entire back half of the car be removed. In other words, choice of platforms affects the limit of possible diameters, which affects the amount of a car that can be placed on the platform, which in turn affects the user's acceptance of the simulator as a real driving experience. A more detailed analysis is therefore necessary. The 2500-kg platform has a wider platform than the 1000-kg model, which provides more stability to the simulator. The 2500-kg allows for more versatility in choosing platform diameter and car length. Second, using approximated weights for the platform elements, the 1000 kg platform appears insufficient for the purposes of the UCF driving simulator. Applying these approximated weights shows that even when steps are taken to minimize these weights, the total weight comes very close to or exceeds the 1000-kg limit. This leaves no room for upgrades that would add weight to the simulator. Noting both the stability and weight advantages of the 2500-kg model our analysis concludes that the 2500-kg Hydradyne motion platform is the better choice for the UCF Driving Simulator.

A final alternative is no motion with a change in visual system. Members of the project team visited Lockheed Martin and noted a military simulator for the HMMV. A drivers compartment had CRT monitors instead of an immersive dome. IST researchers asked Lockheed Martin engineers if motion sickness was a problem. The answer was 'no' because operators have an external stable reference system. This approach should be investigated further by CATSS researchers.

2.3 Sound

In a true driving experience sounds come from many different directions, so there is a need for multiple channels of output. For example, the sound of traffic does not come from the speaker under the seat or hood, which should only output engine rumble. The choice of sound hardware needs to take into account especially the idea of true three-dimensional sound.

Noting the purchase of the NT version of Vega for the UCF DS and the difficulty stated by technicians of working within the Unix platform, it appears that the simulator will shift to NT, whether it is on an SGI or a PC platform. Current sound cards, for NT the based systems support at maximum four separate speakers. Alternatives need to be found such as using multiple sound cards, or using more advanced sound cards that allow for true three-dimensional sound. There is also the possibility of using a crossover circuit to separate sounds within a single channel. This optimization will greatly enhance the driving experience and realism for the user. It should be noted however that although a license for Vega was acquired, as of 7/30/99 we had not been able to successfully run Vega, even with the help of technical support. We have the program running, however the online documentation that explains how the program works currently crashes the entire program when started.

In researching sound card usage under the NT platform the authors found that Vega is limited by the SoundBlaster Live card that currently supports 4 separate speakers, 2 front channels and 2 rear channels. We do not know if more advanced cards will become available in the future, but according to the manufacturer of current sound cards there will likely be models that support additional channels by the time that the simulator is upgraded. There is also the possibility of using the Digital I/O included with the card, which will support up to 8 channels in the future. Vega itself supports up to 8 individual channels. Beyond the scope of Vega there are digital samplers that support more channels which can be amplified to speakers. The Iowa Driving Simulator uses two 20-voice digital samplers that have 8 amplified channels. These samplers are used by the simulation program that Univ. of Iowa has custom written. Unfortunately, this setup does not lend itself to the UCF DS because the current database is written in MultiGen, which is used in Vega. Therefore, using a sound device other than a PC sound card poses significant problems to the current setup, namely having to both rewrite the current database, as well as create a custom visual simulation program. This option does not seem practical considering that Vega already exists. One final option is using a crossover circuit in each separate channels. A crossover circuit splits a signal into low and high frequencies which means in the simulator, that road noise (low) and a horn noise (high) could pass through one channel through a crossover and out to separate speakers.

The likely scenario in this case would involve 8 speakers. The front channel starts with the left and right signals. These signals pass through separate crossovers which results in 4 signals – 2 high signals (left and right) and 2 low signals (left and right) to separate amplifiers, which in turn are connected to speakers. The two front low channels would likely be located underneath the hood of the car, to simulate various low sounds under the hood like engine rumble. The two high front channels would be located in the cabin on the left and the right on the dashboard, providing noise like horns and sirens. The low rear channels would be located underneath the driver and passenger seat, outputting road noise and possibly passing traffic. The high rear channels would be located in the cabin behind the driver and passenger seats, providing similar sounds to the front high channels and giving the feeling of surround sound as created through AudioWorks in Vega.

One further advantage to the SoundBlaster Live card is that it is compliant with IEEE 1394, FireWire, which is further discussed in section 3 of this paper. This will allow things such as real-time sound to be inputted into the system in the future. FireWire is being explored as a possible means for real-time data acquisition and as a general bus architecture for the UCF DS. This sound feature could be coupled with real-time video input as well as other forms of data acquisition.

2.4 Data Acquisition

Both the input and output functions of the simulator require hardware on the computer that can receive information to be processed and then output information to simulator devices. The best cards currently offered are multi-functional, PCI supported which generally have 16 A/D, 2 D/A and either 24 or 32 DIO channels. The current cards all have sampling rates of 200 kHz, and the prices generally are around $600-$900. The main difference between the models found is having the capability of either 12-bit or 16-bit resolution. The price difference between the two is very minimal so it seems to make sense to go with the 16-bit version. The current driving simulator does not require as many channels as are available in these cards, but we anticipate more inputs and outputs with the addition of driver monitoring as well as cameras, and human subject monitoring. The best model found we have found in our research is by a company called Quatech, who makes a 16-bit, 200 kHz card for $895 that has 16 A/D channels, 2 D/A channels, and 32 DIO channels. Assuming that there were enough PCI slots on the computer, we could likely add more cards if needed; though this number of ports will likely be sufficient. More research should be done into anticipating future needs of the simulator before choosing a solution. Current (as of July 99) product information is shown in Figure 6.

Serial Data Acquisition and Control Interfaces

Model #	Price	Sampling Rate	# A/D Inputs	Analog Bits	# DIO Channels	Analog Outputs	bits	ComPorts
ComPorts								
Ontrak Control Systems								
ADR101	$99.00		2	8	8	0	0	RS232
ADR112	$129.00		2	12	8	0	0	RS232
ADR1000	$225.00		8	8	32	0	0	RS232,422,485
ADR2000	$225.00		8	12	8	2	12	RS232,485
ADR2010	$225.00		8	12	8	0	0	RS232,485
ADR2100	$199.00		4	10	32	0	0	RS232,485
ADR7700	$225.00		1	16	4	0	0	RS232,485
ALSO DO CUSTOM								
PCI								
Quatech								
DAQ-1201/1202/PCI	$795.00	200 kHz (12 bit)	16	12	32	2	12	
DAQ-1602/PCI	$895.00	200 kHz (16 bit)	16	12	32	2	12	
Computer Boards Inc.								
PCI-DAS1602/16	$949.00	200 kHz (16 bit)	16	16	24	2	16	
National Instruments								
PCI-6025E	$695.00	200 kS/s (12 bit)	16	12	32	2	12	
PCI-6024E	$595.00	200kS/s (12 bit)	16	12	8	2	12	

Figure 6

2.5 Image Generator

Currently the Silicon Graphics Onyx Reality Engine 2 serves as the graphics processor for the UCF DS. There are two separate paths to be explored in optimizing the simulator. The first involves keeping the SGI platform and taking steps to upgrade and maintain the current machine. The second involves changing to a PC based platform that would possibly use parallel processing with graphics cards like Voodoo 3. The authors believe the increasing maintenance costs for the Onyx, and the improving simulation performance from PC based graphics, will cause the current image generator to be replaced by a unit running NT or BeOS.

Output video is fed through the Silicon Graphics MCO (Multi-Channel Option). More research needs to be done into how the graphics cards will be linked and then routed through a similar device to the projectors. It is likely that each channel will require its own graphics card. There is a system from Evans and Sutherland and MetaVR supporting multiple channels through GenLock circuits.

2.6 Display System

There are three basic options for display systems: CRT LCD/DLP (Digital Light Processing) and custom projection systems. The current projector model used in the UCF DS is the Barco 808, which is a CRT. These projectors are not able to provide more than 800 X 600 resolution, which may be the result of either hardware or software limitations. This projector provides bright 1250 lumens, but it is very bulky. These projectors are clearly unsuitable for a motion platform and are in general, obsolete.

Recently, Texas Instruments came out with a technology called Digital Light Processing (DLP) that they call the next generation in projectors. There are several advantages to this new projector. In comparison to both LCD and CRT projectors, they are lighter, brighter, more clear and precise, and have contrast ratios of around 500:1. Moreover, linearity and convergence is maintained corner to corner. One of key issues in using projectors on motion platforms is its durability and resilience to motion. DLP projectors have compact optics, eliminating convergence issues, and problems due to motion. More detailed information on the technology and its advantages can be seen on the Texas Instruments website, http://www.ti.com/dlp/docs/it/index.html. Comparisons of different DLP models are also shown in Figure 7. DLP technology is clearly the emerging technology in projection. This will likely be the suitable choice in projection when the simulator is ultimately optimized.

Other projector options come from companies like SEOS, who can provide custom, fully integrated projector systems supporting the unique needs of the simulation community (e.g., edge blending and distortion correction). SEOS is the company that provided the projector system currently used by the Iowa Driving Simulator. These projector systems are designed for simulator usage in terms of performance, calibration, and durability. There are several different models, which use CRT as well as LCD systems. Solutions other than those made by companies like SEOS, such as manually implemented configurations of LCD or DLP, require manual configuration of both the software elements such as Vega and hardware elements such as the projectors and projection screens, which will likely be a formidable challenge to designers. Given an unlimited budget the systems by SEOS seem like the best option. However the systems are very expensive. Informal estimates show that the lower-priced systems, which are designed for 180-degree viewing, costs $275,000. The higher priced systems, which allows a 360-degree viewing area, costs around $750,000. These solutions will likely prove too costly to implement for the UCF DS but are worth looking at as possible options because they can be custom designed for the UCF driving simulator.

The newer LCD/DLP projectors are more portable, more reliable, more versatile, and utilize new technology that provides brighter and clearer projections. Changing to LCD projectors as well as a new projector screen would solve many of the problems noted about CRT projectors. LCD and the newer DLP (Digital Light Processing from Texas Instruments) projectors are currently the most viable solution to the aforementioned problems with CRT projectors. They are light (typically under 10 pounds), and they do not require the constant alignment and adjustment of the Barco projector. However, like the Barco projectors, LCD projectors are designed for stationery usage. Manufacturers have said upon questioning that they have no data regarding the stability of LCD projectors with respect to usage in an environment of a motion platform. The newer DLP projectors are designed to be more durable during transport and are also superior in visual quality. This transport durability needs testing to determine its application on a motion platform, which encounters a wide range of motion forces. In an article by SEOS, their researchers have worked with both CRT and LCD systems and have found difficulties in successfully implementing LCD technology in simulators. They compiled a list of the advantages and disadvantages to LCD.

LCD Benefit:

- More light output
- Reduced system maintenance
- Versatile lens option
- Small physical size and weight
- Strong upgrade potential

LCD Drawbacks

- Fixed image matrix – no ability to distort the native (inherent) image
- Residual black level light and associated NVG compatibility issues
- Smearing at high line rate
- Lamp life
- Dead pixels
- Color Balance
- Motion compatibility

Among the drawbacks, the two most pressing issues are use in motion and solution to the problem of fixed matrix projection. According to SEOS, in motion systems LCD projectors are only compatible with motion of approximately +/- 1 g. While motion compatibility is constantly improving with the introduction of technology like DLP, this issue will need to be addressed if either LCD or DLP projectors are used. There is also a problem with distortion correction and smearing of pixels in these projectors because they are fixed matrix. SEOS uses what it calls a Mercator system that provides real-time, hardware based image re-mapping to correct distortion. This process of correction is analogous to what mapmakers use to correct distortion that is caused by translating a spherical surface to a flat surface. There is a similar solution in Vega called non-linear distortion correction. Unfortunately, this solution is only available in the Irix version of Vega. Noting that the optimized simulator will likely use the NT platform, this solution will probably be unfeasible. In any case, steps need to be taken to ensure feasibility of whichever display options are chosen. Currently there are two types of portable projectors that would suit the needs of a motion platform. LCD Projectors are the standard. They typically cost around $6,000, provide XGA quality at around 1000 lumens and have contrast ratios that are generally around 200:1 – 300:1. Statistics on these projectors are shown on Figure 7.

LCD Projectors								
	Cost	Weight (lb)	brightness	True resolution	Contrast ratio	projection distance	Image size	dimensions
Proxima								
Ultralight LS1	$3,995.00	8.4	600 ANSI lumens	SVGA	100:1 ANSI 200:1 full-on	4.3' to 39.3'	20.4"--315.6" diagonal	8.5" x 12.4" x 4.3"
Impression A10	$8,275.00	10.8	1200	XGA	300 to 1	4' to 40'	23"—307"	4.6 x 10.3 x 12.6
Impression A2	$4,499.00	7.7	650	SVGA	300 to 1	3.3' to 50'	19.2—300	4.4 x 8.8 x 12.3
Pro AV DP9310	$11,799.00	38.1	2100	XGA	100:1 ANSI 250:1 full-on	3.6 to 70.8	20—600	15.4 x 22.9 x 9.2
Impression A6+	$6,295.00	11	650	XGA	300 to 1	3 to 32.3	24—300	5.4 x 9.8 x 11.6
DP9250+	$7,899.00	?	1600	XGA	250:1 ANSI	3.3 to 92	20.4--639.6	10.8 x 15.6 x 6.5
DP5950	$5,699.00	?	1250	SVGA	100:1 ANSI	3.3 to 92	20.4--639.6	10.8 x 15.6 x 6.5
Toshiba								
TLP-510A	$4,995.00	14.9	700	XGA	150:1 or greater	3.5 to 39.3	22—300	13.3 x 5.04 x 11.5
TLP-711	$8,945.00	19	1400	XGA	Greater than 200:1	2.5 to 36.2	20—300	15.3 x 4.8 x 14.6
TLP-710U	$7,895.00	15.2	1400	XGA	Greater than 200:1	2.5 to 36.2	20—300	15.3 x 4.8 x 11.7
TLP-511A	$6,495.00	18	700	XGA	150:1 or greater	3.5 to 39.3	22—300	13.39 x 5.04 x 14.25
TLP-411U	$5,295.00	24.5	500	SVGA	100:1 or greater	2 to 27	23.6--326.8	14.3 x 6.7 x 17.9
TLP-410U	$3,895.00	19.6	500	SVGA	Greater than 100:1	2 to 27	22.5—300	
Philips								
ProScreen 4750	$6,899.00	17	750	XGA	170 to 1	3 to 66	(18-27)"-(346-518)	13 X 6.5 X 13
ProScreen 4750/Impact	$7,899.00	17	1000	XGA	170 to 1	3 to 66	(18-27)"-(346-518)	13 X 6.5 X 13
NEC								
NEC MT1030+	$6,698.00	16.1	1100	XGA	300 to 1	3.3 to 39.4	20—300	11.4 X 14.9 X 5.7
NEC MT1035	$8,785.00	16.8	1300	XGA	300 to 1	2.5 to 47.2	25—320	11.4 X 14.9 X 5.7
NEC LT100	$5,430.00	10.8	1000	XGA	200 to 1	3.9 to 40.4	24—300	10 X 13.4 X 5.8
DLP Projectors								
	Cost	Weight	brightness	Resolution	Contrast ratio			dimensions
All Brands								
Boxlight CD-550	$5,699.00	7.4 lbs. (3.4KG)	1000	XGA	> 400:1			3.9" x 9" x 12"
Davis DLX 650	$5,475.00	9.9 lbs. (4.5kg)	800	XGA	450:1 full on			13.2" x 8.86" x 5.122"
PLUS U2-1080		5.7 lbs. (2.6 kg)	800	XGA	500:1(full on/off)			9.2" x 11.6" x 2.3"
PLUS UP-1100	$7,319.00	10.5 lbs. (4.75kg)	1000	XGA	500:1(full on/off)			9.8" x 12.6" x 4.5"
InFocus LP435z	$7,000.00	7.4 lbs. (3.4KG)	1000	XGA	400:1 full on			3.9" x 9" x 12"
Proxima UltraLight™ DX1	$6,830.00	10.6 lbs. (4.8kg)	1000	XGA	500:1 full on			10.0" x 13.46" x 4.6"

Figure 7

2.7 Computers

A Silicon Graphics Onyx Reality Engine 2 is the primary simulation computer system. Modularity is one of the key considerations in a redesign of the UCF DS. SGI currently has a new computer (320) that allows up to four processors in it as well as a gigabyte of random access memory. This computer could provide a low-cost solution to the Onyx Reality Engine 2 as a simulation computer. This computer in itself or linked to another might suffice. However, more research needs to be done into this option to determine viability, and ultimately determine the best computer solution. Source and executable form the UCF DS is required for further research in this area.

Another possibility is the use of a bus such as FireWire (IEEE 1394) and/or Beowulf clusters, which would support parallel processing the elements of the simulator, allowing for the most modularity and upgradability in the future. FireWire was investigated as a separate research task in this project (see following sections 3.2 FireWire IEEE 1394). The results look very promising, but additional research is required to minimize overhead when moving data between machines.

It must be noted that major software and hardware issues must be addressed before distributing the computational tasks. Included for example is time skewing. By separating major simulator functions, such as real time I/O or vehicle appropriate operator activity for post exercise analysis, each computer would feed its data to the appropriate simulator devices. However, there currently exists no commercial products to connect two computers together using FireWire. The use of FireWire and parallel processing versus a single multi-process unit needs further exploration to determine the needs of the system as well as the constraints and advantages to each of these options. Interconnecting separate computers using FireWire adds the ability to add non-time critical components (e.g., a video camera linked to the vehicle performance outputs) as well as adding an opportunity for the UCF simulator to lead the development of new simulator technology by interconnecting computers using this new technology.

2.8 Input Devices

The current input devices are limited to standard items found in automobiles such as braking, acceleration, gear selection, and horn. Moving to modular platform opens up a range of possibilities for input. CATSS sees the UCF driving simulator as being used for many purposes. Other studies could evaluate GPS displays or digital steering, requiring additional input channels. Other studies might require that there are miniature video cameras located within the cabin that track driver response, or human feedback such as pulse or temperature. With a modular design of the system, input devices are limited only by the imagination of the researchers. Devices such as live video or sound could be fed to into a computer on-board the vehicle using FireWire, and then to a monitor located within the control room. Furthermore, this video could be recorded, and then viewed later for study. In addition, FireWire allows real-time data transfer, which could mean that video, sound, pulse, speed, acceleration could all be synchronized and then viewed on a single display in real-time or recorded, and then studied for correlation. For instance, this could be useful in studies that measure driver response time, like the time it takes for a driver to see a sign and then react to it. This response could be viewed in the form of video, and then correlated with acceleration and speed.

3.0 Related Research

3.1 Sound Crossover Circuit

One area for possible growth was simulation of vehicle sounds. The goal was to create a more robust sound simulation than that available from the current UCF DS. The aim was that a more robust sound simulation would allow for a wider range of experimentation and simulation functionality than the current approach. Our research objectives were to extend the functionality of Vega by isolating and reproducing distinct frequency ranges of the vehicle through the use of crossover circuits. The 4 channel sound system currently used on the UCF DS could then be extended to 8 channels by decoupling and isolating sounds based on frequency. Careful speaker placement would then provide appropriate sound placement.

The crossover circuit concept was tested on a small scale using a crossover intended for a car audio system. This crossover was implemented as previously suggested with an amplifier outputting to separate high and low speaker channels. The concept was tested by simultaneously playing different sounds, and then by qualitatively assessing how well the crossover circuit separated them into separate channels. In this test, a low frequency rolling thunder sound was played alongside a high frequency ringing phone, as well as a chiming sound. We found that after adjusting the variable crossover to an appropriate cutoff frequency, the sounds were completely separated and outputted to the appropriate channel as predicted. These results are promising because Vega allows placement of sounds into one of the 4 separate channels. This means that high and low sounds could be placed together and then separated, making it possible to have an 8 channel sound system.

3.2 FireWire (IEEE 1394)

There were several options to make improvements on the driving simulator modularity and performance, which included the use of better computers, software optimization, and better data communications. The original plan that was proposed to IST by the driving simulator staff was to use a wireless Ethernet connection. After doing extensive research of all the available options, we decided that a better way to improve the simulator would be to improve the data communications by distributing simulator processes among a variety of computing devices. The method we used to improve the data communications was by the use of FireWire, which is Apple's name for IEEE-1394.

FireWire is a high speed, low cost serial bus system that provides the same services as modern IEEE-standard parallel busses but at a much lower cost. FireWire is an IEEE standard (IEEE-1394) and is real-time. FireWire includes support for isochronous data transfer, which provides guaranteed bandwidth for real-time video and audio streams. Currently, FireWire boards support speeds of 100, 200, and 400 Mbps. This is as much as four times faster than a fast Ethernet card. FireWire will offer bandwidths up to 3200 Megabits per Second in the near future. FireWire is more cost effective than general and wireless Ethernet and FireWire is a new technology. The technology's intent is to support integrating consumer electronics and computer technology. For example, Fire Wire supports connecting a digital video camera to a computer. FireWire uses a simple tree topology and can connect up to sixty-three devices simultaneously. Some other advantages in using FireWire are that it is auto configuring, which means there is no need for expensive hubs or terminators. FireWire offers true plug-and-play connectivity, which means that the connection can be disconnected and reconnected without having to restart the computer or reconfigure the settings that were previously set.

In summary, the decision of which technology to improve data communications was clear since FireWire is much faster than wireless Ethernet, quite cost effective, and industry supported.

The technical challenge and innovation we face is in using Fire Wire as a means for intercomputer communications. Informal discussions with Apple Computer, the original developer of Fire Wire indicated that using it for intercomputer communications would be the first such application they knew of. We believe that the challenge in utilizing Fire Wire lies in bi-directional communications. As indicated earlier in this paper, Fire Wire's original intent is to allow transfer of data in a single direction, for example, from a DVD player to a computer.

3.2.1 Unibrain's FireBoard 400

When we decided to use FireWire as the method of upgrading the driving simulator, we had to decide on which FireWire card would be the best for our use. Unibrain, a company from Greece, offers two different cards that support speeds of 400 Megabits per Second, the FireBoard 400 and the FireBoard 400 OHCI. We selected the FireBoard 400 because it included FireNet, a software application that offers the ability to connect, disconnect, and reconnect new PC's to the network in the same or different types of topologies.

FireNet is easily upgradable and currently offers a speed of 400 Mbps. In the future, FireNet will offer speeds of 800, 1600, and 3200 Mbps. FireNet offers an application called busview. This allows the user to view the current device's physical id, as well as the physical id of all the other devices in the topology. Each node appears graphically as a box. Using busview, the user can view which of the devices have the drivers installed properly. If a driver is improperly installed, it is easy to see by inspection of the busview graphical display. If the box appears as a solid color, it means that the drivers are installed correctly. If there are stripes through the box, there is something wrong with the drivers that are installed for that card.

FireNet also offers a console application called CMD1394, which allows the user to do several options with the FireWire card. Some of the things that can be done using CMD1394 are:

- Write to registers on your node and all the nodes in the topology
- Read register information from all nodes in the topology
- See what registers are available
- Change your physical id and the physical id of the other devices
- See what errors are occurring when trying to send and receive data
- Reset the bus and see how many times it has been reset
- See the ROM format for all devices connected
- Display the topology, which includes the root node, the parent nodes, and the children nodes

The system requirements for Unibrain's FireWire cards are the following:

- 166 Mhz Pentium MMX or better
- Available PCI slot
- 32 Mb Ram or greater
- Windows 95, 98, or NT
- Fast ATA-2,3,4 or Ultra-ATA, or Ultra SCSI, or Ultra Wide SCSI hard disk
- CD-ROM drive
- Mouse

3.2.2 Sound Research

Sound is a critical component of a simulator experience. Robert Schwing of the Iowa Driving Simulator also commented on what Iowa researchers have found with regard to the importance of sound.

"Our experience here with the Iowa Driving Simulator demonstrates that most drivers use sight and sound as primary cues EXCEPT in certain tasks where motion cue (force) is everything."

The current UCF simulator has minimal sound that is located underneath the driver seat in the form of road noise. In a driving situation drivers experience sound from many different directions. This need for surround-sound is supported within AudioWorks, which is the sound driver in the simulation program Vega. AudioWorks controls every aspect of sound output such as Doppler shift. The UCF driving simulator has the capacity to generate a wide range of sounds. However, only one sound is currently used, namely car noise (engine rumble). There is clearly the opportunity to improve on sound, and in turn provide a more realistic simulation. This feature could be upgraded to provide many additional sounds such as horns, traffic, or rain.

3.3 What has been accomplished

FireWire was originally developed for multimedia applications and we wanted to extend the functionality to distributed computing for human in the loop simulators. Since FireWire is a new technology, the first task was to familiarize ourselves with how it operated. We accomplished this by reading all available documentation including the IEEE Standards specification for IEEE-1394 as well as practical application source code available on the Internet. We installed two FireWire cards in different computers and connected them with a 4.5 meter FireWire cable. By using busview, we were able to see that the two cards were able to communicate with each other and both drivers were installed correctly. The next task was to learn how to use CMD1394 and its command set. After we familiarized ourselves with the commands in CMD1394, we wanted to be able to transfer data from one computer to another and be able to read what was sent back and forth. To accomplish this, we had to differ between which of the known registers can be written to and which ones can only be read from.

After testing all known registers, we decided that there are three types of registers available to the user. The three types of registers are read only register, the read/write registers, and the registers unavailable to the user. An example of the read only register is bandwidth available (0xfffff0000220). The user is able to read from this register but not able to write to this register. If the user tries to write to one of the read only registers, they will receive a cryptic error message. In a read/write register, the user is able to write to the register and then if they read from that register, they will see that the data has been changed. There are very few known registers that are read/write. The registers that are unavailable to users include hardware details that users are not permitted to alter.

3.4 What we hope to accomplish in the future

What we hope to accomplish in the future is real-time human in the loop simulators using FireWire technology as the underlying networking infrastructure for inter-computer communication and for high speed communications between peripherals and a computer. Right now we are able to have basic data transfer between two computers. We can connect up to 63 computers or devices with computing linkages (e.g., digital video cameras) in the future. We will transfer a data stream between two points. We will also get information from the computer directly to the FireWire card. We will compare the latency of small packets versus large packets using speeds of 100, 200, and 400 Mbps.

We will also compare the reliability of data communication between small and large packets. Eventually, we will create standards for in the loop simulations using very fast networking technologies. The FireWire cards are already four times faster than Ethernet and new cards expected to be thirty-two times faster than Ethernet are to be released soon. This technology should be taken advantage of for the UCF DS and the simulation industry, where data transfer is of the utmost importance.

4.0 Simulator Vehicle Performance Testing

4.1 Purpose of the Vehicle Performance Testing

Much like a physical vehicle, there is rarely enough information about a vehicle, such as spring constants to create an accurate vehicle dynamics model. While real vehicles are tested on tracks to determine these parameters, simulators also require testing in a virtual environment. It is critical that future enhancements and changes to the UCF Driving Simulator be evaluated with respect to adding functionality and realism to the simulated driving experience. Accordingly, we suggest some tests to assess the effects of simulator enhancements on simulated performance of the vehicle. Human factors tests are also necessary, but were not part of this study.

4.1.1 Assessment and improvement of dynamics model

It is interesting to test the dynamics model in order to assess both the extent and validity of the model. Oftentimes simulators must be assessed with little provided information beyond the final output of the actual simulator. Performing tests on different simulators can give insight into the inside workings of a simulator, as well as provide a basis for comparing different simulators.

4.1.2 Safe Simulator Design

The hardware on a simulator, such as the motion platform, is subject to the dynamics model that dictates motion. Possible problems must be determined through testing, because much like a vehicle, it is difficult to accurately model possible scenarios without actual testing. It is important that such problems be tested for in order to ensure safe operation if encountered. Steps can then be taken in such a situation to correct the problem, such as shutting down the simulator or simply not allowing for the situation to occur in the software.

It should also be noted that the following procedures make no recommendation as to the method of testing used to obtain results. There are many types of vehicles as well as simulators, and it is therefore impossible to suggest what specific methods for testing are appropriate to a given setup.

4.2 Obtaining Initial Conditions Before Testing Begins

Before testing any element of a simulator it is necessary for consistency that the initial conditions be documented before performing tests. This includes physical elements such as weight, temperature, surface material, and initial elements within the virtual environment such as grade, and type of terrain. These are only examples of initial conditions. The importance of initial conditions are for comparison with subsequent testing and/or determination of changes resulting from change of initial conditions.

4.3 Acceleration and Velocity Parameters

Before testing more complex conditions of the simulator it is first useful to determine the acceleration and velocity ranges and parameters of the simulator on a level surface. These results are useful for further testing both the hardware and software of the simulator.

4.3.1 Determining Range of Vehicle Velocities

A vehicle has a maximum velocity that is usually determined through physical testing over a variety of terrain. In a simulator this limit/range is normally approximated or provided based on testing of the physical model. For the purposes of this testing we will assume that we have no prior knowledge of the physical model. We will therefore assume that the maximum velocity refers to the maximum sustainable velocity over a flat terrain. The range of velocities will be defined as velocities between zero and the maximum speed. In addition it is useful for reference purposes to test the range of velocities over a varied range of terrain.

4.3.2 Determining Range of Vehicle Accelerations

A vehicle has a maximum acceleration from an initial zero velocity. Similar to velocity, the acceleration varies with change in terrain. The range of accelerations should be defined as the accelerations between zero and the maximum velocity. These ranges should be specified with respect to their respective terrain.

4.3.3 Determining Maximum Acceleration from a Given Velocity

In a physical environment, the maximum acceleration of a vehicle is often dependent on the initial velocity of the vehicle at the time of acceleration. Therefore, it is necessary to test the maximum acceleration over the range of velocities. This should be done at constant increments of velocity. The results can then be plotted to determine information such as optimal points of burst speed.

4.4 Deceleration Parameters

Similar to testing acceleration and velocity parameters, it is equally important to understand the stopping capabilities of a vehicle. In a physical environment, stopping distance is highly dependent on the terrain, and frictional surface conditions, as well as vehicle properties such as tires and brake pads. In a simulator, these specific parameters are difficult to determine. Therefore it is more practical to look at the maximum rate of deceleration for various speeds for different terrain and surface conditions. In testing over these surface conditions, braking distance should be tested over the range of velocities at constant increments as previously determined.

4.5 Vehicle Endurance

It is important for any vehicle in either the physical or virtual environment, that the operator understands the range of the vehicle. This measure of fuel consumption rate varies with speed and terrain as well as passenger/cargo load. There are a few important tests that should be performed to gain a clear understanding of the endurance characteristics of the vehicle.

The maximum range of a vehicle is effected by the weight of the vehicle, terrain, and speed. Much like other testing procedures, these factors should be tested simultaneously at incremental values and then compared to find optimal points. It is useful to understand the fuel consumption rate with respect to time given these conditions, so that for instance a larger fuel tank could be used if necessary, or given an applied load on the vehicle an optimal speed could be used to achieve maximum range.

4.6 Vertical Stability in Unaccelerated Motion

During vehicle motion in a physical environment, a vertical excitation results in a frequency response. Each vehicle has what are called natural frequencies, which are the frequencies at which an object naturally tends to oscillate. During continuous excitation at these frequencies the amplitude increases and motion becomes unstable in what is called resonance. Under continuous operation, this motion may lead to vehicle/simulator failure. It is therefore useful to test for and avoid situations that might lead to such a scenario.

In a simulator environment motion can also result in resonance within the hardware, which may be hazardous to simulator operation. These frequencies may be the result of either the vehicle dynamics model or simulator hardware properties. It is therefore useful to test for the presence of this scenario in the virtual environment. Understanding vertical stability allows for improvement of simulator design with respect to both the hardware and dynamics model. It also provides a practical basis for comparing different simulators and dynamics models. In some simulators that have simplified dynamics models, resonance may not exist under any circumstances. However, simulators with more accurate models the resonance might be an issue. Without prior knowledge of a dynamics model, there is often little way to make such a determination without testing. This test is one way to experimentally gain a better understanding of a particular simulator.

The test situation is analogous to a car riding on train-tracks. As the wheels pass over the railroad ties, there is a vertical excitation that occurs at regular intervals. The rate of the excitation is a function of the vehicle velocity as well as the distance between the railroad ties.

4.7 Vehicle Velocities and Excitation Conditions

4.7.1 Determining Range of Vehicle Velocities

As previously stated, a vehicle has a maximum operational velocity limit that is usually determined through physical testing over a range of terrain. In a simulator this limit/range is normally approximated or provided based on testing of the physical model. For the purposes of this testing we will assume that we have no prior knowledge of the physical model. In testing, the constant velocity will be varied between 0 and the maximum velocity over an interval of 5 mph.

4.7.2 Defining Excitation Conditions

As previously discussed, the example of the railroad tie is a form of excitation useful for testing. However, many other possible scenarios are possible such as repeated rolling terrain. The important factor is that the excitation is repeated at a constant interval for the same distance. In testing, the distance between excitations should likely vary between 0 and 10 feet at likely intervals of 1 ft.

During testing, the distance between excitations should be first set at the maximum distance (lowest frequency) and the velocity should first be set at its lowest setting (5 mph). The operator should sustain this velocity for 10 seconds, meanwhile recording the frequency of the vehicle through either visual or mathematical means. It will be useful to graph this data to check for an increase in amplitude or divergence, and thus resonance. After 10 seconds the velocity should then be increased to the next interval and then held constant for another 10 seconds. This process is repeated for each of the velocity intervals within the specified range, over each of the excitation intervals within the specified range. All of these results should be checked for divergence and then plotted to reflect the resulting points of resonance if applicable. It is possible that there are no resonant frequencies in the simulator. This likely means that the dynamics model does not account for this scenario. It is also possible that there is resonance at some point in testing even though the dynamics model does not reflect it. In this case, the simulator hardware is experiencing a frequency response independent of the dynamics model.

4.8 Lateral Vehicle Alignment in Hands-Free Operation

When the operator of a vehicle in a physical environment turns the steering wheel, that person must forcefully maintain the position of the wheel to maintain a change in direction of the vehicle. On a level surface, this means that if the wheel is let go of at a neutral position, the vehicle will continue in that direction until the position of the wheel is changed by the operator. However, on a canted surface the wheel and vehicle often tend toward the cant. This means that if the operator lets go of the wheel while travelling perpendicular to the cant, the car will change direction, unlike the level surface. This condition is the result of the effect that gravity has on the steering and wheel assembly.

In a simulator this effect can provide an important element of realism to the driver in situations where the road is not level. In some simulators this effect may be included in the force feedback part of the steering. In this case, the position of the wheel changes as the vehicle drives on the surface. In some cases like standard rack and pinion steering, the resistance of the wheel to turning away from the cant may increase as the angle of the cant increases. Without this modeling, the driving can let go of the wheel while not on a level surface and still maintain direction.

4.8.1 Testing Procedure

It is easy to determine if the dynamics model includes this scenario. This testing simply involves modeling a canted surface and then driving the vehicle perpendicular to the surface. The operator will quickly notice any resistance to turning and will notice any change in position when letting go of the wheel. If there is change, then the dynamics model accounts for this situation. The accuracy of the alignment change on a canted surface with respect to the physical vehicle is difficult to obtain. It is more practical for most purposes to simply determine if in fact alignment does change.

4.9 Lateral Control Forces (Steering Forces)

In a physical environment, the dynamics of steering is very complex. In a simulator there are a few relevant issues to look at when assessing the model with respect to steering.

4.9.1 Dead-Band:

Steering columns have a range of free motion, through which an operator can rotate the wheel without affecting steering. For example, when an operator is driving a vehicle in a straight direction, the wheel has a few degrees of motion in either direction for which there is no effect on steering. It is interesting to test for the presence of this phenomenon in the force feedback system because in a real vehicle an operator often doesn’t have to hold a wheel perfectly still to maintain direction. Rather, dead-band in effect can allow a driver to more easily maintain a neutral position of the wheel.

4.9.2 Testing Procedure

In designing a simulator to represent a physical vehicle, it may be useful to assess the amount of dead-band in a wheel. One method would be to initially mark the wheel at the neutral position and then measure the allowable change in rotation (dead-band) while driving the simulator on a flat terrain. However, for our purposes we will assume that we have only the simulator and not an actual vehicle. Therefore, in testing the simulator only the presence or absence of dead-band should be assessed. This would again be measured while driving the vehicle at a constant velocity.

4.10 Longitudinal Forces (Brake/Accelerator Pedal)

These test topics are included for completeness. Procedures and tests were not conducted due to limitations in research funding.

1. Dead-band
2. Force Gradient
3. Maximum/Minimum Force
4. Break-Out Force

4.11 Vehicle Performance on an Inclined Surface

The vehicle should be tested to determine performance on differently inclined surfaces. This includes maximum grade, acceleration, and velocity. These test descriptions are listed for completeness. Limitations in project funding precluded complete testing descriptions.

4.11.1 Maximum Grade

In testing, the angle of the incline should be varied from 0 at regular increments and the vehicle motion started from an initial velocity of 0. The maximum grade from a stopped position is the angle at which the vehicle cannot climb the incline.

4.11.2 Acceleration/Deceleration

In testing, the average acceleration over a distance can be measured by specifying the angle of the incline, the distance traveled by the vehicle, and the initial velocity. The acceleration may be tested over the range of incline angles found by testing maximum grade. Initial velocity over these distances may be varied if desired to test for maximum acceleration for different initial velocities. This data shows the range of possible accelerations over a range of initial velocities over a range of incline angles.

For deceleration, tests similar to acceleration can be performed to determine distance and time to reach zero velocity. In this case, these deceleration rates are measured for negative incline angles.

4.11.3 Velocity

Much like acceleration, the maximum velocity at a given inclined grade can be found by accelerating at an inclined angle over a long distance until there is a constant velocity. This data may also show the distance required accelerating to maximum velocity given an initial velocity and incline angle.

4.12 Level Turning Performance

The minimum turning radius at various speeds can be found by modeling a curve at incrementally increasing radii and then maximizing the velocity around the curve until the vehicle will no longer stay within the curve. The radius at this maximum velocity indicates the minimum turning radius for this velocity. By varying the radius of the curve within the model we can determine the minimum turning radius at various speeds.

4.13 Banked Turning Performance

This test is similar to level turning performance, where the radius is varied to find the maximum velocity. In this case, the banked angle is varied along with the radius at increments and tested for maximum velocity. These results show the ability of a vehicle to turn at a given velocity for a specified curve radius and bank angle.

4.14 Other Tests

The following is a list of other tests that should be conducted. Limited resources precluded a complete description of tests and procedures.

1. Force Gradient
2. Maximum/Minimum Force
3. Break-Out Force
4. Hysteresis

5.0 Conclusions

The UCF Driving Simulator is a valuable resource for faculty and students. The authors of this report suggest that a committee be formed to identify or hypothesize future research projects that could utilize the simulator, a research plan be created, and that the simulator design be altered to accommodate the research plan. The research plan should include provisions for engineering related research, human factors research, and anticipated needs of the state and federal DoTs.

We also highly recommend that an effort be conducted to put the UCF DS software in proper order to increase the reliability and future expandability of the system. Experiments to collect and validate the data from the simulator were performed by student Bhatia. Due to various hurdles (software and/or hardware) only the data relating to acceleration time and distance (deceleration time and distance also) could be collected. The data was collected through the main computer of the simulator. In general, the Y-axis represents the distance in meters and the X-axis represents the speed in kilometers per hour. The graphs of these are plotted. The time to reach a particular speed through a particular distance can be calculated from the relation:

$$T = d/v$$

assuming constant acceleration (decceleration)

where T is the time in seconds.

d is the distance in meters

v is the velocity in km per second

A complete set of data is in the attached appendix.