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Date 29 May 1993

DEVELOPMENT OF A TRACTOR DRIVING SIMULATOR: A TRAINING DEVICE TO AID IN REDUCING ROLLOVER FATALITIES

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Brett C. Asbury

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ABSTRACT

The objectives of this project were to develop a tractor driving simulator that would teach tractor operators the need for ROPS, and serve as a tool for controlled research on operator responses to various system and terrain configurations. A tractor driving simulator was designed and constructed to satisfy these requirements. This thesis focused upon the design, construction, and evaluation of the simulator's operator station, visual feedback system, sound system, and instructor station.

The tractor driving simulator developed was functional and exhibited many characteristics of a real tractor. As a training tool, operators can safely "drive" a simulated tractor through simulated conditions and safely maneuver the simulator through hazardous conditions and occasionally experience tractor rollovers. As a research device, operator actions are both observable and recordable.

The simulator was comprised of two basic components: an operator's station and an instructor's station. The operator's station, where students were positioned during simulation runs, was designed to conform to an actual tractor cab. The instructor's station included electronic system controls and video recorders. It provided control over the visual inputs to the operator's station and provided the hardware necessary to monitor and record the operator's actions during simulation runs. From the recorded data, operator performance in the simulator was analyzed.

From the operator's position, manipulation of the steering, throttle, gear selector, brake, and clutch produced changes in engine sound and apparent position, as seen through a video display mounted in front of the operator's station. "Out-the-window" views from the simulator are very nearly the same as a real tractor. Steering and motor performance closely match what might be expected from a real tractor at low speeds.

The overall evaluation of initial tests conducted on the simulator were positive in that subjects were able to operate the simulator and components functioned properly.

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CHAPTER I

INTRODUCTION

BACKGROUND

Agriculture is consistently rated as one of the most dangerous occupations in the U.S. In 1990, the accidental death rate for agricultural workers was 54.4 per 100,000 workers (Accident Facts, 1991). This death rate is over four times the national average. Although agriculture makes up less than 5% of the nation's population, it accounts for over 17% of occupational accidents (Pfister, 1972). The very nature of the occupation makes it hazardous. Long hours and exposure to the elements typify the work. Constant interaction with powerful equipment often desensitizes the worker to the presence of dangers, and in efforts to save time, safety is often neglected (Job, 1990).

Of the 400+ farm fatalities annually in the U.S., approximately 50% involve tractors or heavy equipment. The leading cause of equipment-related fatalities is overturn (Accident Facts, 1990). Most overturns are the result of operator error. The causes most cited are

- excessive speed,
- improper attachment or position of implements,
- improper traversing of ditches or slippery embankments,
- exceeding the equipments' designed limitations, or
- sudden changes in terrain type.

Mechanical failures are seldom cited as the cause of overturn (Schneider, 1980).

The use of a Rollover Protective Structure (ROPS) and seat belt would greatly reduce the number of such fatalities. In 1974, the Occupational Safety and Health Administration (OSHA) established safety standards that mandate ROPS on tractors (Federal Register, §1928.1). To comply with these standards, new tractors come equipped with ROPS, and kits are available to retrofit most older tractors. These standards require tractors with ROPS be equipped with seat belts. (Future references to ROPS will imply a Rollover Protective Structure and a seat belt.)

While these OSHA standards were passed to ensure a safe and healthful work place, only farms with 11 or more employees need comply. Most farms fall outside OSHA compliance because they employ few people. Compliance on these farms has relied mainly on the movement of new equipment into service. However, the long service life of tractors has slowed the introduction of ROPS-equipped tractors, and many units exist without this safety equipment. Piercy and Turner (1986) estimated only 25% of the tractors in use in the United States were ROPS equipped. Small farm operators often see the expense of ROPS modification as prohibitive. In some cases, the modification cost can nearly match the value of the tractor being modified. Thus, operators who choose to gauge the necessity of ROPS modification on expense alone tend to consider the life-saving benefit only after it is too late.

Education and training has been used by state extension services to combat the apparent apathy toward farm safety. The most successful educational programs involve audience participation. These programs increase interest and retention of the safety message. At recent agricultural field days and 4-H events, the Tennessee Agriculture Extension Service has made effective use of radio-controlled model tractors. Extension Specialists allow audience participants to maneuver an RC tractor through a scaled terrain beset with common overturn hazards. Small crowds are able to watch as various operators make mistakes and overturn the toy tractor. Extension Specialists cite errors and offer advice on proper operating procedures. The one criticism of this program has been that, having a 'toy' appearance, it attracts mainly children as participants.

A preferable training program would reach a larger audience, and more specifically, the actual operators of tractor-powered operations. A tractor driving simulator resembling operational equipment would have less of a toy appearance and would attract an older group of participants.

Development of a tractor driving simulator would enable organizations to screen and teach proper operation of tractor-based agricultural equipment (Schneider, 1980). Actual operational conditions that might otherwise be hazardous to both man and machine could be safely replicated in a simulator. A simulator would provide an educational base for the operator by showing the benefit of protective devices and would allow for controlled research on the operator's response to various tractor system configurations.

Simulator-based training programs used by the automotive industry, the military, and the farm equipment industry were researched, and a task analysis of a tractor rollover training program was performed. From these actions, a requirements list for a tractor driving simulator were developed.

REQUIREMENTS

Simulator Components

A simulator requires two basic components:

1. Operator's station. The operator's station, that place where the student is located during simulator operation, should be similar to the actual operational equipment. Only those components necessary for the training task need to be included. Components not needed can be omitted or statically displayed (Blaiwes and Regan, 1986).
2. Instructor's station. The instructor's station should include system controls, data displays, and malfunction insertion devices. In addition, the station should allow the instructor to monitor the operator and record his performance for later analysis (Blaiwes and Regan, 1986).

Fidelity Requirements

There are three fidelity requirements for the full mission simulator.

1. Visual System. For complete operational training, a full field of view (360 degrees) is

required. For forward-facing tasks only, the horizontal field of view can be reduced to 180-240 degrees. Vertical field of view should be ± 40 degrees from the horizon (Kaminaka, et al., 1983). The wide field of view aids the operator in estimating velocities at low speeds. In the absence of motion, visual scenes influence the operators perceived orientation. Operators tend to believe their eyes.

2. Sound. Engine noise is required so the operator can monitor system condition, response to inputs and for speed estimates. Changing engine RPM noise are an expected response to throttle adjustments. A decrease in engine RPM tends to imply a decrease in speed. In addition, low-frequency sounds can be used to generate some of the vibration encountered in actual operation (Ittelson, 1960).

3. Motion. Because a tractor is a dynamic and unstable piece of equipment, motion should be included in the final design. A tractor simulator requires at least two degrees of motion: pitch, and roll. As visual inputs can be used to enhance these motions, pitch and roll may be limited to ± 40 degrees and yaw to ± 10 to 15 degrees. Yaw motion is also important, but apparent yaw motion can be induced through moving visual scenes (Young, 1967, and Goldberg, et al., 1989).

THESIS OBJECTIVES

The overall objective of this project was to develop a device that would 1) teach tractor operators the need for ROPS and promote their use, and 2) act as a tool to allow controlled research on operator responses to various system and terrain configurations. Due to the magnitude of the overall project objectives, the project was divided in two phases. The first phase comprises the development, construction, and evaluation of the operator's station and visual feedback system, sound system, and instructor's station. The literature reveals that the most important aspect in driving simulation is the visual component. To a lesser extent, motion is required. To reduce costs, some driving simulators have been built without the motion component. Phase I follows this path for the same reason. Additionally, the training will be limited to forward-facing tasks, so only the forward 90 degree field of view was provided. The second phase will provide motion and full field of view to the simulator. Completion of Phase I objectives is the basis for this thesis.

CHAPTER II

BACKGROUND AND REVIEW OF LITERATURE

FARM TRACTOR ACCIDENTS

Tractors Risks

The tractor is the agent most involved in fatal farm accidents. In a summary of Indiana farm fatalities from 1970 to 1979, Field, et al. (1980) found that 53% involved tractors. A summary of fatal Wisconsin farm accidents from 1944 to 1978 by Jensen (1980), concluded that a major percentage involved tractors. Piercy and Stallones (1984) studied farm-related death certificates in Kentucky from 1972 to 1976. Their study found that tractors were involved in 38% of the reported farm fatalities. The Extension Service at the University of Tennessee conducted a review of Tennessee farm accidents from 1980-1990 (Prather, 1992). Their findings indicate that over 50% of the fatalities involved tractors.

Additional studies were conducted by Becker (1982), McKnight and Hetzel (1984), Schneider (1986) and Purschwitz and Field (1987). In these studies, 50 to 76% of farm accident fatalities involved tractors.

Tractor Overturns

Overturn is the leading type of tractor-related accident and accounts for over half the tractor-related fatalities. Figure 1 shows a typical breakdown of fatal tractor accident type. Tractor overturns can be further broken down into three types: forward, rear, and side. The most common tractor overturn is to the side, while forward overturns rarely occur.

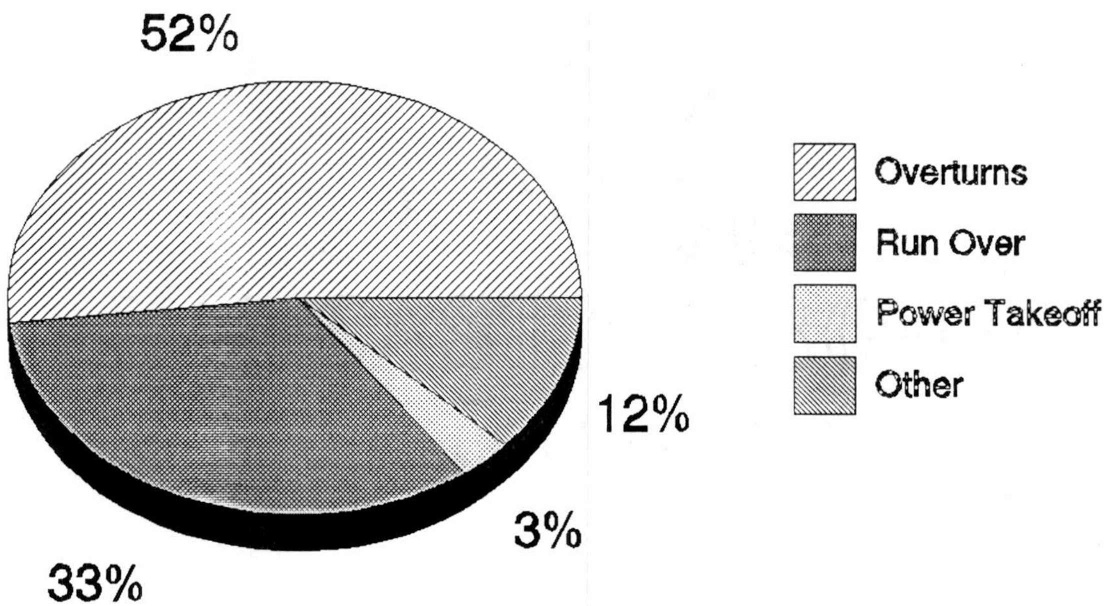

Figure 1. Cause of farm tractor fatalities reported in 1990 (Accident Facts, 1991).

Figure 2 shows a typical frequency breakdown. Forward overturn usually occurs when both front wheels drop into a depression. The front end acts as a pivot, and the forward momentum of the tractor rotates the rear up and over the top. Because the operator is facing forward the majority of the time, this type of accident is least likely to occur.

Rear overturns may be caused when

- a towed load hits a stationary object,
- a load is hitched too high,
- a tractor is steered up a steep incline,
- a clutch is engaged while engine RPM is too high,
- environmental conditions are misjudged,
- or any combination of these.

In rear overturns, the engine supplies the power to create the overturn. Thus, most rear overturns can be controlled or prevented by disengaging power.

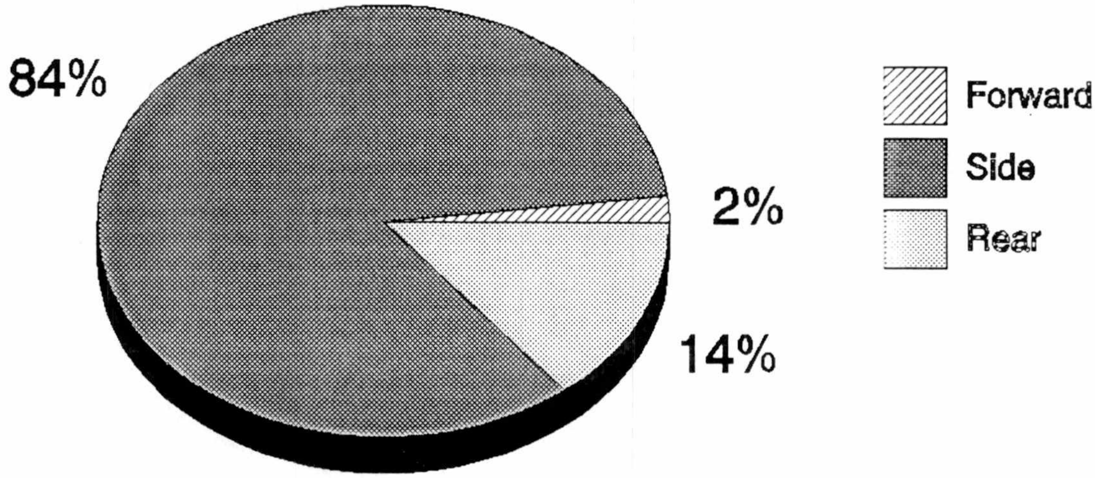

Figure 2. Characteristic frequency distribution of farm tractor overturns by type (Schneider, 1972).

Side overturns are caused by a sudden shift in the center of gravity. They can be caused by such things as

- improper carrying of loads,
- improper height-weight distribution,
- improper traversing of slopes,
- sudden change in terrain type, or
- driving into a hole or drop off.

Side overturns are the most difficult overturn to control. The engine is not always supplying the power necessary to cause the accident.

Rollover Protection System

Tractor overturns have been a problem since the introduction of powered farm equipment. The problem is underscored by a 'preventable' toll of deaths and injuries that result when tractors overturn. The prevention lies in a Rollover Protection System (ROPS). As noted earlier, ROPS comprises a protective structure (or roll bar) and a seat belt. The protective structure provides an envelope of safety in the event of an overturn, and the seat belt prevents operator ejection from within the safety zone. The combined use of these two items almost guarantees operator survival in the case of vehicle upset.

These devices were not developed recently. Rollover protection was developed and used on vehicles in the early 1900's. Seat belts were in use even before this time to prevent ejection from horse-driven carriages (MacCollum, 1988). In a move unrelated to rollover safety, the U.S. Army Corp of Engineers in 1946 mandated 'brush-guards' on earth moving equipment to protect operators from falling objects. An unsuspected benefit was the substantial protection these structures provided during rollover incidents. The Department of Agriculture began testing of ROPS in 1955 (Buchele, 1980).

While it is human nature to attempt an escape when a vehicle turnover is perceived, such a decision is not always the correct one. A study conducted at the University of California at Davis in 1956 found that operators did not have sufficient time to dismount from a tractor during rollover (MacCollum, 1988). The only safe option is a ROPS. Without ROPS, when the operator is ejected or jumps from a tractor, he faces the possibility of being crushed by the tractor even if he manages to survive impacting the ground.

Canada, England, Sweden and New Zealand conducted studies on equipment rollovers. By the mid-1960's, many countries instituted requirements for ROPS on imported tractors. Although U.S. manufacturers complied with these requirements for foreign sales, these devices were not included as standard equipment on units sold in the United States until some manufacturers made ROPS standard equipment in the mid 1980's.

Domestic studies of tractor rollover accidents mirrored the observations overseas. A published report by the National Safety Council, "Resolution on Overturn Protection for Farm Tractor Operators," on January 26, 1969 recommended inclusion of ROPS as standard equipment on heavy equipment manufactured in the United States. Following these recommendations, the Occupational Safety and Health Act of 1972 provided the mandate for ROPS. This act, however, has two major exemptions that prevent it from being fully effective on the farm. These include farms with 10 or fewer employees, and tractors produced before 1969.

Most farms are still family ventures, often with persons under 18 and over 60 conducting the work (Saran, 1988). Few farms employ more than 10 persons. Geographically, farms are widely dispersed and usually far from populated centers.

Many legislators believed (and most farm lobbyists would like it believed) that small farms cannot comply with state and federal laws due to the economic burdens compliance with such laws would entail (Saran, 1988). Thus, many laws that apply to industry often do not apply on the farm. As stated previously, Occupational Safety and Health Administration (OSHA) standards cover only farms with more than 10 employees. While these restrictions on OSHA are meant to help the small farmer, failure to ensure proper safety equipment has resulted in unnecessary deaths and injuries.

To combat the neglect of farm safety, manufacturers are including new or improved safety devices on their equipment to reduce or eliminate hazards. The movement of these new devices into service is, however, limited by the sale of new equipment (Saran, 1988). In compliance with OSHA standards, most new tractors come equipped with ROPS. The long service life of tractors, however, means that many older tractors either are not or cannot be retrofitted with ROPS. In 1986 it was estimated that nearly 75% of the nation's tractors were operated without ROPS (Piercy and Turner, 1986).

Even when retrofit kits are available, farmers are often reluctant to install them (Saran, 1988). On older equipment, the cost of a retrofit can nearly match the value of the equipment. Besides cost, years of operating experience without accidents can give farmers a false sense of security. They may feel that because they are safe operators and accidents are rare events, the odds are they do not need safety equipment (Murphy, 1980).

Accident Victims

Farm fatality statistics describe the most probable accident victim as a young male. The second most frequent descriptor is 'part-time farmer.' Schneider and Baker (1972) found over 40% of farm fatalities involved the under age 20 group. Jensen (1980) found that 35.7% of the farm fatalities involved individuals under the age of 20. Piercy and Stallones (1984) found that over 25% of the accident victims were under the age of 20. In addition, they indicated that fatalities were tied to the high percentage of part-time farmers. The study by Fields. et al. (1980) found that only 30% of the farm fatalities involved full-time farmers. In 1987, Purschwitz and Field found the full-time farmer fatality percentage had dropped to 24%. The gender statistics of these studies showed that males were involved in 93.4 - 95% of fatal farm accidents.

Accident Causes

Operator error is the leading cause of farm fatalities. Farmers perform tasks in periods of constrained time and in varied weather conditions. The combination of these factors result in mental stress and fatigue. Stress causes the farmer to cut corners and engage in unsafe practices. Errors include instances when the operator

- reacts too slowly,
- performs the wrong control move, or
- fails to react.

Ramm (1980) found that operator error or misuse was the cause in 42% of agriculture-related accidents he studied. Jensen (1980) studied 50 fatal accidents in depth. He found 76% were caused by factors other than equipment failure.

Jensen (1980), Tofany (1980), and Kundiev (1991) point out that farmers are more likely to be involved in accidents than their counterparts in industry because 1) they work longer hours, and 2) they often have inadequate training.

Overturn Prevention

Feng and Rehkugler (1986) suggest that there are four ways to prevent tractor overturn casualties:

1). **Provide an automatic control system.** A computer could monitor system parameters and initiate an equipment shutdown in the event of an impending overturn.

2). **Provide a mechanical system to prevent overturn.** Automatic outriggers could be extended during the onset of a rollover to prevent completion.

3). **Provide the operator with information on tractor stability.** Operators could use instruments and audible warnings of turnover conditions to monitor stability and make corrective actions.

4). **Provide training and education.** Operators could be trained to recognize overturn conditions and increase skill.

The swiftness of overturn occurrence has made automatic control devices and mechanical systems difficult to apply. From a legal standpoint, if an overturn is predictable, it is preventable (Murphy, 1982). Because of this implied liability, manufacturers are reluctant to include automatic safety control systems on any equipment unless they are shown to be 100% effective.

Time and sensitivity are impediments to warning devices also. Upon activation of the warning device, the tractor may have already gained enough momentum that preventing the overturn is impossible (Murphy, 1982). The warning light must be within the visual viewing area too and have a signal intensity that will redirect attention (Robinson, 1988). (Humans are limited on the amount of information they can simultaneously process. Therefore, tractor operators can often find themselves in overload situations making the wrong decision.) If the warning device is too sensitive, it may produce what the operator feels are false warnings. When false warnings occur, the device becomes ineffective: all subsequent warnings are likely to be ignored or the devices are likely to be disconnected by the operator.

From the farmer's standpoint, safety devices reduce the efficiency and increase the cost of equipment (Ramm, 1980). For example, the rotary mowing (bush-hog) equipment used by many

Highway Departments is equipped with chain guards to prevent objects from being ejected from beneath the mowing deck. In farming applications, these chain guards limit the size of brush that can be cut. In addition to decreasing the efficiency, chain guards can represent an increase of 30% in purchase price (Ramm, 1980).

Training and education appears to be the only workable solution to preventing tractor overturn casualties. Automatic control systems, mechanical systems, and warning devices have thus far proven unsatisfactory. Operators need to know how to identify and reverse the potentially dangerous conditions they may find themselves in (Davis, 1972). Wisconsin's annual tractor fatality rate was decreased, in part due to such educational programs (Jensen, 1980).

THE TRACTOR OPERATOR

Perceptual Type

Before one can determine the requirements of a tractor operator training program, one must first look at the operator component. A study by Barrett and Thorton (1968) showed that the ability of subjects to react to emergency conditions was significantly related to their perceptual style. Operators can be segregated into two perceptual groups: Field-dependent and Field-independent. Field-independent individuals are more able to respond to emergency situations because their thought processes are more critical and analytical (Barrett and Thorton, 1968). Field-dependent people are easily confused, disoriented, and have difficulty making decisions under stress. Barrett and Thorton's study also showed that although individuals become more field-dependent as they age, it is possible to train and teach people to compensate for this deficit.

Capacity

Human capacity and limits can be divided into four categories (Robinson, 1988)

- Anatomical: The ability to reach and move an object.
- Physiological: The performance decrement due to outside influences.
- Motivational: Whether the task is rewarding or not.
- Computational: Perception, understanding and response.

In operating a tractor, an operator uses sight, sound, and touch to interpret both system and environmental conditions. Based on these interpretations and individual capacity, the operator manipulates physical components to direct and control the tractors performance (Liljedahl, 1984).

Attention is a skill that is learned. In a defensive driving course, subjects are taught "what to attend to and when" (Robinson, 1988). Likewise, an experienced operator knows what is important and what to ignore. However, when an experienced operator ignores inputs that are part of a hazard not frequently encountered, accidents can result. This problem is another reason why it is important to spend time in safety training programs. Even an experienced operator can be a novice if the task is new or operational procedures are changed.

Experienced operators have an inadequate appreciation for their limitations and lack of ability (Robinson, 1988). This belief is the result of three main factors:

1). Accidents are rare events.

2). Accidents are usually the result of many factors all occurring simultaneously.

3). There is a common belief that one's superior skill and care will prevent accidents from occurring.

Farmers often engage in unsafe behaviors, and their experience of "getting away with it" reinforces such action till it becomes a habit (Murphy, 1980). Safe behavior usually means time, extra effort, and inconvenience. For example, it is much easier to leave a tractor running while adjusting an implement rather than turning the machine off.

Most farm equipment operators learn their skill at an early age through hands-on training. Children are not adequately developed either physically or mentally to operate such powerful machinery. They often receive little or inadequate safety training and tend to replicate the unsafe behaviors of the adults teaching them (Murphy, 1980).

Perception of Speed

An operator's perception and estimation of driven vehicle speed is quite complex; much is based on peripheral stimulation (Triggs, 1988). The more detailed and cluttered the peripheral scenery, the higher the estimate of vehicle speed. At high speeds, people have a direct sense of velocity. At slow speeds, velocity is determined by consecutive changes in the visual scene.

In simulators, problems have been experienced with flat screen displays. Flat screen displays lack depth of field and thus cause difficulty in judging distances and estimating velocities (Wheatcliff, 1973). In addition, Evans (1970) found that subject's speed estimations via film were affected by viewing distance.

Sound has a profound impact on speed estimation. In actual road tests, Evans (1970) found that a reduction of audio cues resulted in an underestimation of speed. Speed estimates based solely on sound are closer to the actual vehicle velocity than when only visual stimuli are provided (Triggs, 1988). Mclane and Wierwille (1975), using a motion-based simulator, found that the removal of engine noise resulted in an overestimation of perceived vehicle speed. In addition, they found that visual perception and auditory cues were more important than motion cues in speed estimation. Besides the visual scene, drivers rely upon vestibular and proprioceptive cues to retain control (Sheridan, 1970). Shoup and Becker (1982) pointed out that tractor operators commit increased driving errors as speed and stimuli increase. Goldberg and Stewart (1980) noted that these errors may occur even after the operator reduces the speed or stimuli. Further, Sheridan points out that drivers lose their ability to react after long periods of uneventful or inattentive driving. Bottoms (1983) noted that operators have difficulty judging velocity and position while traversing a narrow course.

Vibration Effects

Vehicle vibration affects an operator's ability to focus on the visual scene and degrades his ability to judge speed and distance (Osborne, 1988). Further, vibration degrades the operator's ability to perform motor tasks and adversely affects operator comfort. These physiological and psychological effects impede the operator's ability to control equipment and increase the probability of accidents (Suggs, 1973). Stephens et al., (1972) showed that operators subject to random vibration in a simulator exhibited a 30% increase in overturn accidents. In cases of sustained low-frequency, high-amplitude vibration, motion sickness often occurs.

Perception of Orientation

To maintain stability, an operator constantly monitors both external and internal cues. These cues include noise, vibration, vision, pressures on the body, limb position and vestibular senses of acceleration and gravity (Goldberg and Parthasarathy, 1989). The most prominent of these cues is the visual input. Operators tend to believe their eyes more than their vestibular senses (Goldberg and Parthasarathy, 1989). These two types of senses often conflict in farming, and hysteresis in orientation may occur. For example, an operator who works on a steep incline for a period of time and follows with work on a flat field may maintain the perception of being on an incline (Witkin, 1959).

With no vision input, operators on a flat surface begin to notice a tilting (roll) position after 10.3 degrees has been reached. On a slope, additional change will be noticed at +/- 5 degrees (Goldberg and Parthasarathy, 1989). Changes in pitch are more easily noticed.

Changes in yaw are not sensed by the vestibular receptors (Stoffregen and Riccio, 1988). Yaw detection is made by changes in the visual scene and movement of the eyes and head.

Visual Field of View

Due to the speed and complexity of equipment, tractor operators need the ability to monitor a wide field of view to operate safely. Kaminaka and Fortis (1983) developed a simulator to evaluate visual monitoring performance of operators. Using a similar structure, Kaminaka, et al., (1981) found that depending upon the task loading, fields of view ranged from 240 degrees for high-task frequency to 180 degrees for low-task frequency. Vertical fields of view remained fairly constant at +/- 40 degrees from the horizon. Kaminaka et al., (1981) recognized changes in the size of an operator's field of view as a function of stress.

Training Effectiveness

Shuster and Guilford's (1970) study on driver education and attitude showed that training improved both knowledge and attitudes toward driver safety. Special courses and programmed instruction can be used effectively to modify unsafe driving behavior. The design of these courses is still important. Documentation and simple presentations that present the alarming problems with unsafe operations are ineffective (Job, 1990). Audiences often invoke the old cliche "It won't happen to me." Further, based on their experience and lack of accidents, they may become over-confident and conclude that they are better than the average driver depicted in the presentations (Job, 1990).

Physical Components in the Driving Task

In an analysis of the complex physical skill of vehicle driving, Herbert (1963) identified five major factors:

1). Multi-limb Coordination: the ability to coordinate simultaneous activity of the extremities.

2). Spatial Orientation: the ability to determine the spatial arrangement of a visual scene.

3). Proprioception: the ability to evaluate and respond to kinesthetic, cutaneous, and vestibular signals, and motion cues.

4). Response orientation: the ability to make rapid decisions about the direction or choice of a movement while in the process of an action.

5). Reaction time: the speed of response to a stimulus.

TRAINING OF TRACTOR OPERATORS

Training Goals

Measuring the effectiveness of present training programs requires establishment of training goals (Blaiwes et al., 1973). Training goals are determined by conducting a task analysis of the operational situation (Blaiwes et al., 1973). Learning depends upon transfer of knowledge and past experiences (Marteniuk, 1976). Thus, effective training consists of practice on tasks that is accompanied by performance enhancement. Performance enhancement occurs when the mental process underlying successful performance is instilled in the student (Blaiwes et al., 1973).

Training Methods

One method most often used in training is 'chunking,' a process in which the task of interest is broken down into smaller sub-tasks (Marteniuk, 1976). Training in the sub-tasks facilitates learning by exposing students to units of the task that do not exceed their short-term memory capacity (Marteniuk, 1976). 'Chunks' also might be referred to as 'Learning sets' (Blaiwes and Regan, 1986). Whatever the name, the goal is to optimize the size of each learning block and thus effect the highest transfer of training (Williges et al., 1973).

A study by Blaiwes (1973) found that in situations where time is limited and the work behavior is complex, performance can be improved through logic-tree methodology. A logic-tree has a "tree" of conditions and possible courses of action. The study found that a group trained in the logic-tree method of problem solving completed tasks with fewer errors, while the control (free-study) group reviewed information that was non-essential to the task at hand and missed the information that was essential.

Whatever the training method, feedback to students should be provided. Knowledge of the results and outcomes of the students' actions result in learning (Marteniuk, 1976). Feedback supplied to the student comes mainly through the senses but can be further enhanced by critiques or evaluations of training sessions (Marteniuk, 1976). Such reports aid the student in gauging his progress and performance.

Training Program

While static displays of full-size overturned tractors have been used for many years, they have met with only limited success in generating greater awareness of tractor safety. They are also costly to prepare and time-consuming to set up. The trend lately has been to use scale tractor models for actual demonstrations of tractor accidents (Piercy, 1986). Scale models are easily transported and can be used to simulate almost any tractor accident. Additionally, scale models are more readily used to study and teach tractor instability (Piercy, 1986). Scale models have been used by 4-H clubs and other youth organizations in both Kentucky and Tennessee to provide tractor safety training (Prather, 1992). Scale models are limited by the fact that some characteristics of the models do not exactly replicate the real tractor (Piercy, 1986). For example, tires on scale models are not as flexible and do not have the same traction characteristics as tires on agricultural tractors.

The Kentucky and Tennessee scale models were created using toy tractor models and radio control (R/C) car components from hobby stores and mail order catalogs (Prather, 1992). Gear changes were made to the R/C racing components so the model more closely replicates the torque and speed of a real tractor. The center of gravity and weight distributions were also matched in a scaled fashion. While the Tennessee model is powered by a self contained battery pack, the Kentucky model is hard wired to a power supply. The Kentucky model has been effectively used in support of 4-H safety programs, fairs, and county exhibitions to demonstrate changes in center of gravity, weight transfer, hitching techniques, and proper towing procedures (Piercy, 1986). The

Tennessee Agricultural Extension Service has documented knowledge gains in groups of youth who participated in their interactive demonstrations (Prather, 1992). The small scale allows a large number of audience members to view and participate. In addition, accident demonstrations can easily be run multiple times. It has been noted however, that adults are hesitant to participate in such demonstrations and often stand back and watch the youth operate the 'toys' (Piercy, 1986).

Training Devices

A training device is defined as an object used to train and is distinguished by both its purpose and the how it is used (Gagne, 1954). A training device is used in two manners:

- To measure performance, and
- To improve performance.

Training devices provide a method of knowledge transfer if they are used so that the skills needed in the operational task are learned (Blaiwes and Regan, 1986).

One type of training device is the scale model, such as the ones used by the Extension Service. Another type is a simulator. A simulator is an apparatus that closely resembles the operational equipment with regard to display, control, and operational interactions. Simulators allow for progressive skill improvement through practice of operational procedures in a simulated and controlled environment (Wheatcliff, 1973). Perfect simulation is not practical because the closer one comes to replicating the operational equipment, the higher the cost (Gagne, 1954). If a simulator duplicates *all* the behaviors of the operational equipment, it is not a simulator; it *is* the operational equipment (Gagne, 1954).

Development of Training Programs/Procedures

Cream et al. (1978) used systematic methodology to match training device features to training requirements during development of the AC-130E Gunship simulator. Systematic models not only provide a method of specifying training objectives, but they also describe the knowledge and behavioral skills required for a given task. Such an approach limits the scope of training three ways:

1). It identifies behaviors required for successful task performance.

2). It reduces training time by specifying task, part-task objectives.

3). It provides simple evaluation of student and program performance based on the specific training statements

(Cream, et al. 1978).

Tasks were broken down into sub-tasks and rated by "criticality, frequency of performance, and difficulty of performance (C/F/D)" (Cream et al., 1978). These rankings provided the answer to the degree of fidelity required of the simulator. Only the elements of tasks ranking high in C/F/D ratings were included in the design requirements. Such a differentiation between essential and nonessential aspects proves cost effective because fidelity can be limited to that which is required in the training task (Cream et al., 1978). Measures of operator performance against specific objectives provided students with a source of feedback against which they could gauge their progress. The results of the study concluded that a simulator developed using systematic methodology provided a better learning platform than traditional training methods.

SIMULATORS

Simulator Development

Once the decision has been made to develop a simulator, several requirements need to be met. First, justification is made by satisfying one or more of the following statements:

1). The simulator can be used in a controlled environment, free from constraints of weather and equipment configuration.

2). Concern for operator safety negates the use of the actual operational equipment in training of dangerous tasks or skills.

3). Multiple scenarios of the same task need to be run to provide adequate training transfer.

4). The cost of simulation is lower than the cost of training on actual operational equipment.

(Williges et al., 1973, Blaiwes and Regan, 1973, Rolfe, 1982).

In the development of a simulator, one must look at what characteristics of the operational equipment are important for effective training (Gagne, 1954) and determine which are required for simulation (Weitz and Adler, 1973). An analysis of these characteristics can be broken down into the following questions:

- What does the student need to know?
- What does the student do?
- How does the student do it?
- Why does he do it?

The goal is to identify the skills that are required and determine the best method to teach these skills (Wheatcliff, 1973). The simulator should be designed to provide for practice of operational activities and should lead to improved performance (Gagne, 1954). It should be remembered however, that the simulator is only part of the training program.

Advanced system simulators usually consist of a student station, an instructor station, and mechanical/electronic hardware (Blaiwes and Regan 1986).

The major hardware components are:

- Control inputs: the signals generated by the operator station in response to control movement and position;

- Visual display: window views and vehicle instruments;

- Motion system: the mechanical system that controls student station orientation (pitch, roll, and yaw);

- Audio system: sound, and low frequency vibration;

- Control system: a computer-based system used to control and monitor system operation.

(Blaiwes and Regan 1986).

Fidelity

Kinkade and Wheaton (1972) divide fidelity into three components: 1) equipment fidelity; 2) environmental fidelity; and 3) psychological fidelity. Equipment fidelity is the amount of similarity to the actual operational equipment (Williges et al., 1973). Environmental fidelity represents the degree to which the simulator replicates the sensory 'feel' of the operational equipment. Psychological fidelity concerns the students perception of similarity between the simulator performance and actual equipment performance.

The desired level of fidelity depends upon the task or skill that is being trained. While high fidelity is often striven for in the belief that it will result in the maximum transfer of training performance (Muckler et al., 1959), it has been found (Blaiwes et al., 1973) that the transfer training effectiveness of simulators does not increase much after achieving a moderate level of physical fidelity. For example, Gagne (1954) cites that some operational instruments can be omitted in an aircraft landing simulator because these instruments provide no useful "stimuli to which the learner must acquire appropriate responses." The simulator need only be operationally faithful to the operational equipment it is to represent (Williges et al., 1973). Design requirements of the simulator should not be based on the degree of fidelity, but on the necessary characteristics and the task that is to be trained (Lee and Bussolari, 1989).

Motion

A big question in equipment simulation is whether or not to incorporate motion systems in the design. Motion provides additional cues that are used in perceptual learning of normal versus abnormal configurations of vehicles (Povenmire et al., 1977). The actual forces of acceleration and gravity that act upon the operational equipment cannot be precisely replicated in a simulator (Ince et al., 1975). Because the replication of motion in a simulator is limited and cannot provide acceleration cues, erroneous motion cues might actually degrade the transfer of training (Williges et al., 1973). The final decision comes down to a question of fidelity versus cost and whether the inclusion of certain characteristics will increase the training effectiveness (Barrett et al. 1969).

An experiment conducted in 1963 by Matheny et al. suggested that motion in an aircraft simulator improved pilot performance. A study conducted by Shirley and Young (1968) suggests that the addition of roll motion cues coupled with visual cues allows an operator to reduce errors in a tracking task. When presented with either a tactile or a visual stimulus, the operator reacted more quickly to the tactile stimulus. In addition, motion cues do not require the same attention as visual cues (Shirley and Young, 1968). In studies conducted by Koonce (1979) and Caro (1979), it was shown that better performance was attained in flight simulators with motion over ones without. Koonce attributes this to the fact that motion cues alerted the operator to the onset of events.

McLane and Wierwille (1975) found that for most applications angular motions were more beneficial than translational motions in the training task. Humans are extremely sensitive to angular acceleration (Stewart, 1971). Cohen (1970) writes that humans are only sensitive to translational acceleration and not to translational position and velocity.

Motion is an essential part of the training when the operational equipment is dynamic and unstable and the operator must operate controls while being bumped around in his seat (Wheatcliff, 1973). However, benefit of motion in the simulator depends upon the type and intensity of response required by the task (Mclane and Wierwille, 1975). Young's study (1967) concluded that marginally stable or unstable vehicles require motion so operators can be properly trained to react to emergency conditions. Caro (1979) confirmed this when he found that motion proved useful only when the vehicle was unstable. However, full scale motion is not required: the most cost effective method of simulation is to include at least two of the following motions: roll, yaw, or lateral translation (McLane and Wierwille, 1975). Bergeron (1970) found that only 25% of the full-motion cue was required to provide the student with the necessary stimuli and feedback. A decrease in the queuing required decreases the cost of the simulator.

Motion systems are usually composed of hydraulically actuated cylinders. The degree of platform deflection and degrees of freedom determine the number of hydraulic components that are required. A low-cost alternative to a motion system was proposed by Barrett et al. (1969). This system is comprised of a seat with six independent inflatable air cushions. The cushions are inflated or deflated to simulate motion of the vehicle. For training of aircraft landing procedures, this device proved to be effective. A simpler four-cell version was developed by Ashworth (1976) for NASA to provide acceleration cues to pilots. Ashworth (1984) found that this 'G-seat' used with a motion system had an additive effect on performance.

Vision & Sound

Visual cues provide the functions of differentiation, identification, and location (Ittelson, 1960). The visual scene provides the individual with a point of reference in, and is our primary contact with, the operational environment (Rose and Wiemer, 1989). When a wide-angle view rotates about a student's line of sight. he feels the sensation of motion and being tilted (Dichgans et al. 1972). While visual space orientation is the most important, auditory space perception also plays a major role (Ittelson, 1960). Both visual and audio cues must be considered together with the other sense modes (Ittelson, 1960). A study by McLane and Wierwille (1975) concluded that performance in a simulator is significantly affected by the combination of motion and audio cues. Neglect of velocity-dependent audio cues degrades the operator's performance in driving tasks (McLane and Wierwille, 1975). Because only selected visual cues are processed by the operator, a determination must be made regarding those that are and are not important (Williges et al., 1973).

Several approaches have been used to generate the visual environment for simulators. Examples range from use of a moving-belt terrain, camera-equipped, scaled remote control (R/C) vehicle to a point-light shadowgram, preprogrammed film, or computer-generated display (Sheridan 1970). In the more dynamic simulators. the outputs from the student station control the apparent movement of the vehicle in the operational environment (Parsons, 1972).

Different vehicles require different fields of view. Aircraft-training simulators that are used by commercial airlines and Military Transport Commands have high-quality visual systems that meet their training needs. Transports operate in a relatively level flight plane at slow speeds and have only a limited front-facing field of view. Fighter aircraft, on the other hand, operate at high speeds, often close to the ground, at any angle, and require a full field of view (Geltmacher, 1988).

The introduction of advanced computer-generated images has greatly enhanced the training capabilities of some simulators (Geltmacher, 1988). However, when finely detailed ground features must be seen, model boards and miniature mockups still provide better resolution than computers (Geltmacher, 1988). The drawbacks of model boards are their reduced flexibility and increased space requirements.

Sound is usually computer-generated in response to the present system's operational condition. Both engine noise and system static can be included.

Simulator Sickness

Perception gives us insight into what probably will happen if we act a certain way (Ittelson, 1960). Illusory perceptions arise when there is a conflict between body sensations and visual stimuli (Johnson and Roscoe, 1969). When experienced operators in motionless simulators experience conflicts between (1) visual scenes showing predictors of acceleration or deceleration, and (2) centrifugal forces that do not occur, simulator sickness often results (Wheatcliff, 1973, Barrett and Thorton, 1968, Guercio and Wall, 1972). Additionally, sickness appears to occur when there are delays in system response time and when the student is enclosed (Casali and Wierwille, 1980). Delays cause the student to become disoriented and the simulator to be difficult to control. The knowledge of being enclosed may cause a claustrophobic reaction, and lack of peripheral reference points may contribute to subject disorientation. Visual delays appear more detrimental to performance and are more likely to produce uneasiness than motion delays (Lawrence, et al., 1988).

Simulator Training

Training situations that are deliberately changed from the operational situation to emphasize a critical task have shown a greater transfer of knowledge than practice in the actual operational environment (Gagne, 1954). Making the training task an exact replication of the real job is contrary to good training procedure (Blaiwes, et al., 1973). Repetition and part-task training are present in most training programs. For example, driver training is often broken down into phases of 'shifting gears' and 'changing lanes.' The important aspect of simulation is that simulator training match the demands that are required of the real task. "Practice makes Perfect," a cliché that bears truth in simulation, is one of the most advantageous aspects of simulator use because it results in optimum learning (Gagne, 1954, Wheatcliff, 1973, Ittelson, 1960).

Simulator Usage

Gagne (1954) points out that the transfer of knowledge reaches a point of diminishing returns. The optimal use of a simulator is until the simulator's peculiarities interfere with the operation of the actual operational equipment (Weitz and Adler, 1973). Simply stated, excessive training in a simulator leads to a reduction of effective transfer to the operational equipment because the operator becomes comfortable with the simulator's operation and responds to expected 'simulator-peculiar' feedbacks. Simple simulators (ones having little physical similarity to the operational equipment) that include tasks similar to the real task provide significant transfer. This suggests that training can be effectively accomplished in devices with somewhat low physical fidelity.

Justification of Simulator Use

Rolfe (1982) writes that deceptive criteria can be used to justify the use of simulation. The most often cited are

- If the operator likes the simulator, it must be an effective training device.
- If the simulator looks like the real thing, it must be an effective training device.
- If the simulator is used at all, it is effective.

The object should be whether or not the student's performance of the training task results in an increased level of performance in the operational environment (Rolfe, 1982). To measure successful achievement of this objective, one must first question the effectiveness of the training.

The ultimate goal of questioning effectiveness is to improve training (Blaiwes, et al., 1973). Effectiveness of simulator training is reflected by the time that is saved in learning a task or skill through practice in a simulator as compared to the time that is required when given only the operational equipment (Gagne, 1954, Roscoe, 1971). This factor is often measured as the amount of time saved in the operational environment by each increment of time spent in the simulator (Povenmire and Roscoe, 1973).

Evaluation

Historically, simulators have been evaluated through the use of a transfer-of-training experiment or by a rating method conducted by either an engineer or an experienced operator. Adams (1979) states that a simulator is a "teaching machine" and can be evaluated on the success of its "predecessors, and the strength of scientific laws." If the basic premises are satisfied, the three major criteria of simulator training will have been met:

- The efficient transfer of knowledge,
- Transfer of knowledge from the simulator to use with the operational equipment, and
- Retention.

(Williges et al., 1973).

TRACTOR SIMULATION

The Overturn Accident

Several causes of overturn accidents have already been cited. To examine the aspects involved, two case types were be reviewed.

Case 1. A tractor operator plows a rectangular field starting on a long edge. The operator brings the tractor up to a comfortable speed on the straights and maintains that speed through the turns. As the operator nears the center of the field, turns get tighter and the high center of gravity produces increased roll. Although the operator feels this increased stimulus, he maintains his speed, thinking he will slow down for the next one. Entering the next turn, still at the same speed, the operator sees his front tire heading for a depression. Since he is already turning it is possible he will turn harder to avoid the obstacle, and since the tractor is traveling too fast for the condition, an overturn occurs.

Case 2. Kelly and Rehkugler (1980) describe the case of a tractor traveling at 8 mph that is working on a side slope with an angle of 35 degrees. The operator, working at this angle for a period of time, has become acclimated to the sideward tilt. Not thinking, he steers the tractor toward the top of the hill. The center of gravity is already near the edge of the operating range, and the tractor tips over. Kelly and Rehkugler (1980) estimate that in such severe overturns, the roll rate will be 75 degrees/second and the tractor will reach a point of no return in 500 ms.

Accidents occur when the tractor is traveling too fast for conditions and the operator makes an incorrect steering decision. Avoidance of the accident requires that the operator

1). Recognize the unstable condition.

2). Make a decision as to what control to initiate.

3). Initiate the control.

There are time delays associated with each of these steps. The avoidance process can be broken down into two steps: reaction time and movement time (Goldberg, Parthasarathy and Murphy, 1989). Reaction time includes the delay in recognizing the unstable condition and the delay associated with determining what to do (i.e., press the clutch, steer away) (Robinson, 1988). Movement time comprises the time from initiation of limb movement till complete activation of the control. Further time delays occur for the machine to respond to any control change. Additionally, reaction time can be affected by surprise, distractions, stress, drugs, age and skill (Robinson, 1988).

Stephens et al., (1972) found that upon recognition of a rollover, operators required approximately 500 ms to initiate a control correction. Marteniuk (1976) has estimated that it takes 100 to 260 ms for an operator to initiate or correct a movement. The reaction time is a function of the amount and intensity of stimuli to which the operator reacts (Marteniuk, 1976). These experiments were conducted with operators sitting stationary, facing forward, and with knowledge of what control to activate. Actual reaction times are degraded in the operational environment by the fact that tractor operators split much of their time between forward- and rear-facing tasks. Once in a rollover situation, a tractor may reach a point of no return before the operator has a chance to react (Goldberg and Parthasarathy, 1989).

Mathematical Models

Several researchers have developed mathematical models to simulate tractor overturns. Goering and Buchele (1967), Smith and Liljedahl (1970), and Mitchell (1972) developed models to predict rear overturns. Goering and Buchele's model was used to predict overturns of unsprung vehicles due to: 1) sudden engagement of the clutch with no hitch load, or 2) slow engagement of the clutch with a large hitch load. While Smith and Liljedahl's model contained five differential equations, Mitchell's model had only one equation and dealt with the moment when the tractor's front wheels leave the ground.

Larson and Liljedahl (1971) were the first to study and develop a mathematical model for side overturns. Their model broke the overturning motion down into eight degrees of freedom. Davis and Rehkugler (1974) developed a model that proved to be valid for simulation of tractor motions on both smooth and irregular surfaces. From their work a computer program, SIMTRAC, was developed to simulate tractor motion. Verification of the Davis and Rehkugler (1974) mathematical model was made with the use of a scale-model.

Feng and Rehkugler (1986) developed a mathematical model for simulation of the sideways tractor overturn on slopes that includes the additional movement of steering and induced movement of irregular terrain. Chen (1976) modified a computer model developed for highway vehicles so it could be applied to tractors and the study of rollovers. The one thing all these mathematical models have in common is the extensive data that is required to describe the tractor and terrain at any instance in time.

Kelly and Rehkugler (1980) have identified twenty-one variables involved in tractor overturns. These are

- center of mass (C.O.M.),
- tread width,
- wheel base,
- tractor mass,
- inertia,
- tire damping ratio,
- spring rate,
- initial velocity of C.O.M.,
- angular velocity,
- acceleration of C.O.M.,
- angular acceleration,
- external forces,
- steering,
- braking,
- engine torque,
- gross coefficient of traction,
- lateral tire force coefficient,
- tire slip angle,

- rolling resistance,
- terrain dimensions, and
- bank angle.

The operator has direct control over only four items from this list: external forces, steering, braking, and engine torque. External forces include the operator's choice of equipment and the terrain on which he operates configuration. Learning the proper control of these variables determines the degree of safety in operations (Kelly and Rehkugler, 1980).

Tractor Simulators

In 1972, Stephens et al. showed that operators could be taught to detect a potential overturn. Since then, tractor simulators have been used mainly as research tools. In 1989, Goldberg, et al., started construction of a tractor simulator with three degrees of freedom. The goal of the project was to study tractor operation and recognition of stability.

Deere & Company Technical Center, IL produced an off-road vehicle simulator as part of their human factors research laboratory in early 1980. This device was built to aid in the testing and development of new off-highway vehicle operator workstations. Unpredictable weather situations made testing in the operational environment difficult and expensive. Simulation allowed for multiple runs of the same configuration in a controlled environment. The simulator is equipped with six degrees of motion and is capable of both visual and sound generation (Duncan and Wegsheild, 1982).

Comparison: Tractor versus Automobile Simulators

While it has been suggested that tractor training could be performed in an automotive driving simulator, there are several differences between the tractors and automobiles that would make this problematic. In comparison, characteristics include

- Tractors have no suspension,
- Front and rear tires are of different sizes,
- Tractors have a higher center of gravity,
- The tractor's rear axle is part of the rigid tractor body,

- Tractors have a greater field of view,
- The front suspension allows some degree of roll,
- Tractors brake using either or both rear wheels,
- Tractor terrain is varied in type and shape (soil is not easily compared to pavement).

(Raney et al., 1961. Chen, 1976)

CHAPTER III

DESIGN OF THE SIMULATOR

GENERAL CONFIGURATION

The tractor driving simulator is a physical representation of an actual tractor. The device enables operators to "drive" a simulated tractor through simulated conditions.

The simulator comprises two major parts: an operator's station and an instructor's station (see Figure 3). The operators station resembles an actual tractor cab and contains the same general equipment in the same location. Equipment includes a seat, instrument console, steering wheel, throttle, gear selector, brake, and clutch. The instructor's station provides control over the visual inputs to the operator's station. It also provides the hardware necessary to monitor and record the operator's actions during a simulation run.

The operator controls the simulator from the operator's station by manipulating the physical controls (gear selection, steering position, throttle position, etc.). Engine sounds and apparent tractor position, as perceived through the video display, changes as the operator drives the simulator. The instructor can however, override operator control of the simulator for various training scenarios. For example, to simulate a system malfunction, braking response could be delayed or rendered inoperative by the instructor's station. Instrument displays and warning lights are controlled from the instructor's station. These features allow an instructor

- to teach operators the proper response to sudden system changes, or
- to experiment with or examine operator responses to various system configurations.

A 1/16th scale Remote Controlled (RC) model tractor provides the operator with a "window to the world". During simulator operation, the operator drives the RC tractor over a scaled

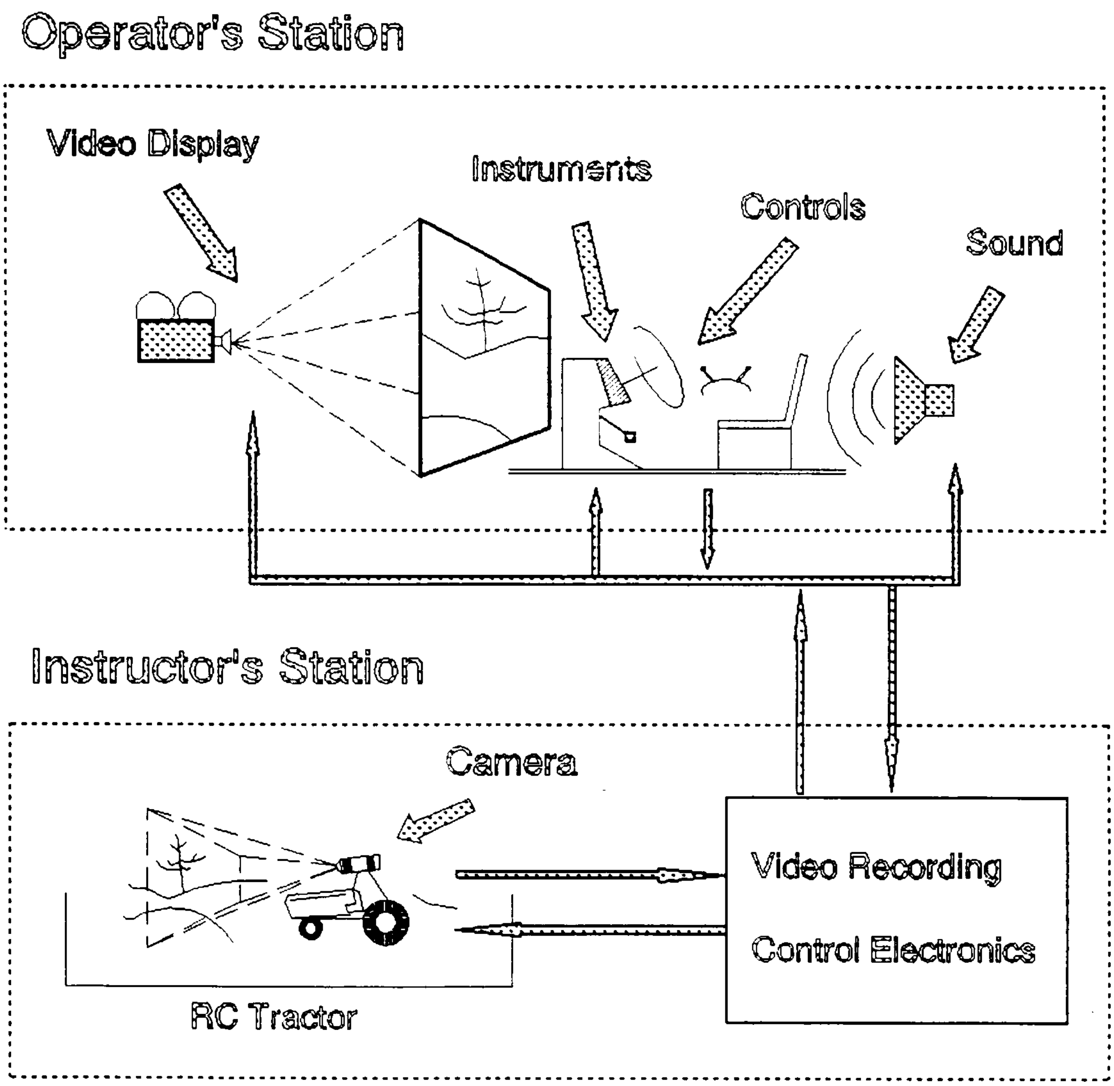

Figure 3. Illustration of tractor driving simulator,

model board landscape. A miniature video camera mounted in the cab of the model tractor captures the "out the window" view and these images are projected in front of the operators station. Video recorders are used to record operator performance.

DETAILED CONFIGURATION

The Operator's Station

The operator's station is where the student is positioned during simulator operation. This station is similar in appearance to an actual tractor cab. Components taken from a John Deere Model 50 "Sound-Guard" cab were installed in the operator's station. Components include a console (which includes the steering wheel, brake, clutch, and instrument cluster), seat, throttle, and gear selector (see Figure 4).

A rectangular steel frame was designed and constructed to provide the base framework for the operator's station. The frame was designed to be rigid and compact while allowing for easy incorporation of a motion component system at a later date. (See Figure 5). Position sensors were mounted on the operator controls (brake, clutch, throttle, and gear selector). These sensors provide the instructor's station with electrical signals that correspond to control positions.

From the operator's position, manipulation of the station controls produces changes in engine sound and apparent position, as seen through the video display. The video display, positioned in front of the operator's station, is comprised of a large rear projection screen and a video projection unit.

Remote Control (RC) Tractor

The purpose of the Remote Control (RC) tractor is to provide a visual "out-the-window" view to the operator's station. Requirements for the RC tractor design were:

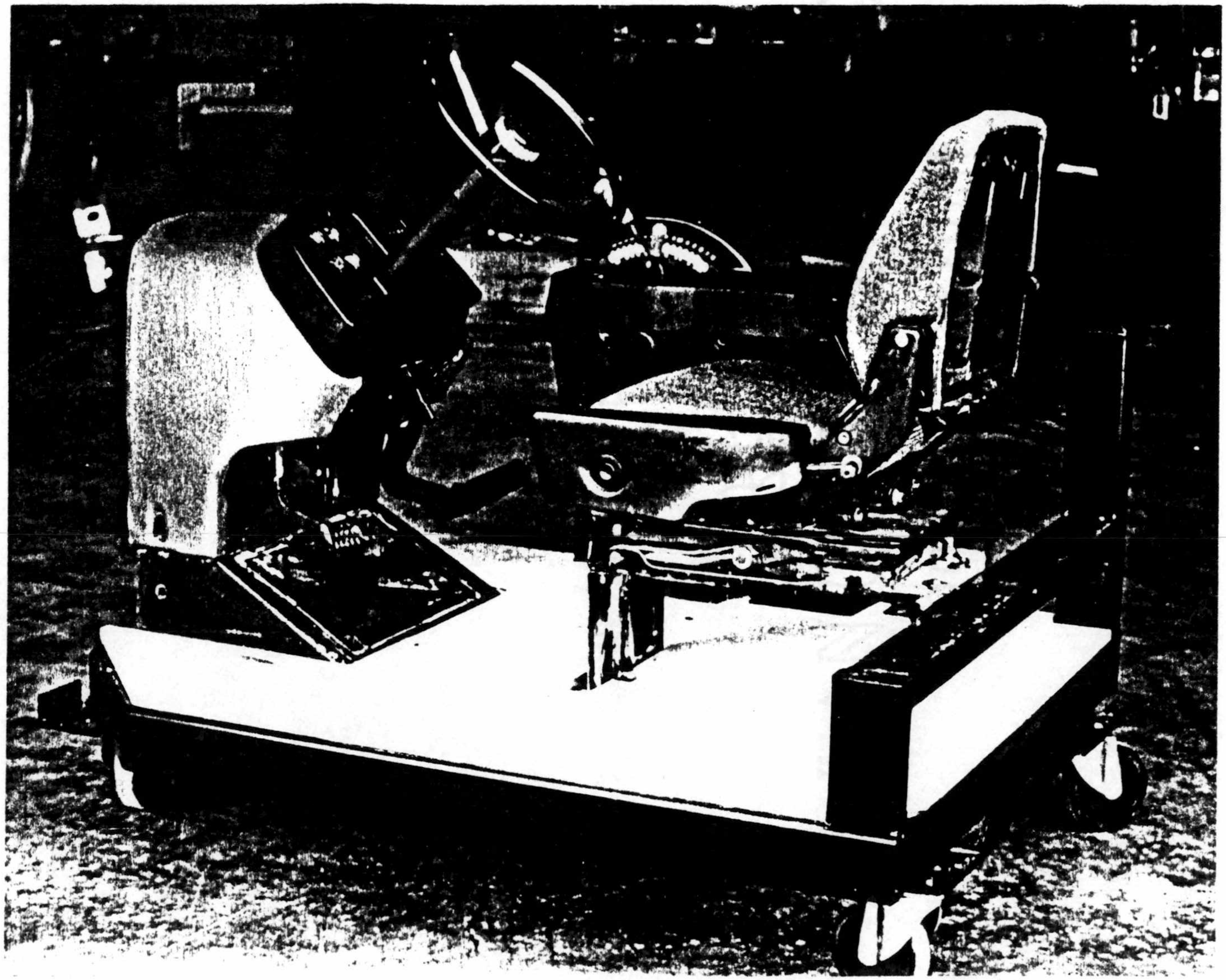

Figure 4. Photograph of operator's station.

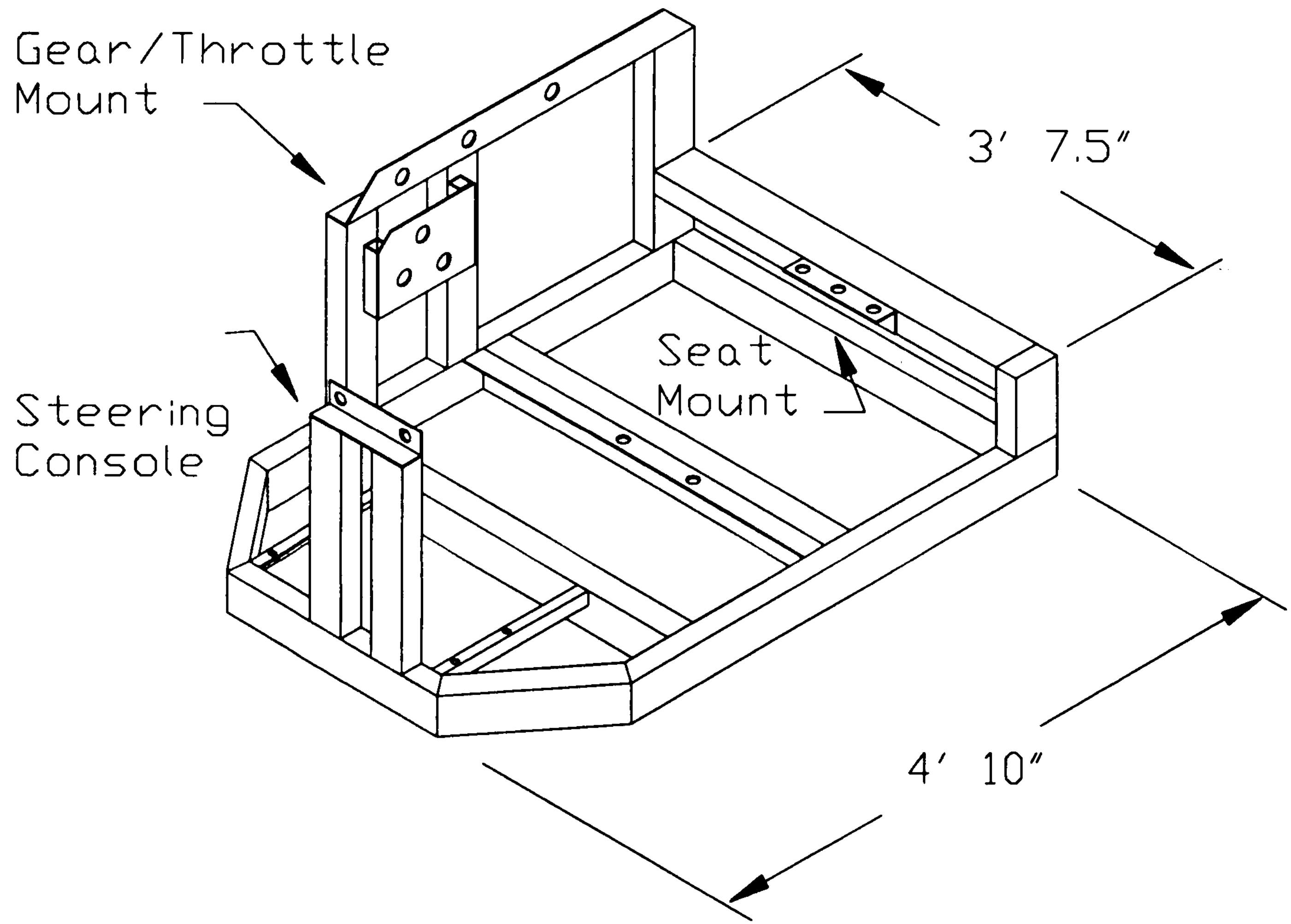

Figure 5. Operators station frame for mounting of steering console, seat, and throttle and gear selectors.

- to produce a "out the window view" on the RC tractor that is similar to that of a real tractor.
- to simulate actual tractor function and performance (speed, engine torque, control response characteristics, etc.); and
- to ensure the entire RC system (RC tractor and Model landscape) is a size practical enough for transport, setup, and display;

The visual scenes come from a 1/16th scale tractor that was constructed to carry a miniature camera over a 1/16th scale model landscape. The 1/16th scale was selected because, 1) model tractor body parts are readily available in this size, and 2) a 1/16th scale model terrain is manageable.

The operator drives this scaled tractor over the model landscape by manipulating the operator station controls. The scene captured by the RC tractor's video camera is then projected in the operator's station. As the RC tractor tilts, the operator's video display responds accordingly. The apparent motion caused by the visual scene causes the operator to perceive actual motion.

Mounted in the cab of the RC tractor is a miniature high-resolution color camera, (Toshiba model no. IK-M40A). The camera uses a 1/2" Charged Coupled Device (CCD) sensor array. With a 4mm lens, this camera has 91.2^{o} horizontal and 69.1^{o} vertical field of view. The entire camera and lens is 1.5" long and 5/8" in diameter. In the initial configuration, only one camera is mounted on the RC tractor (See Figure 6). The RC tractor is however designed to accept additional cameras.

The camera output is connected to a LCD (liquid crystal display) projection unit (Sharp model XG-H400U) for display on a 66" X 87" rear projection screen (Stewart model LF-130) in the operator's station. The screen is mounted for forward facing tasks (See Figure 7). Black walls were erected to the left and right of, and above the operator. During operation of the simulator, the video image projected on the screen is the operator's "window to the world." Video provides the operator both point of reference and orientation information. The addition of a second camera reinforces this information by providing an increased (180^{o}) field of view. (See Figures 8 and 9).

One drawback to the 1/16th scale is that the model is too small to include working brake or

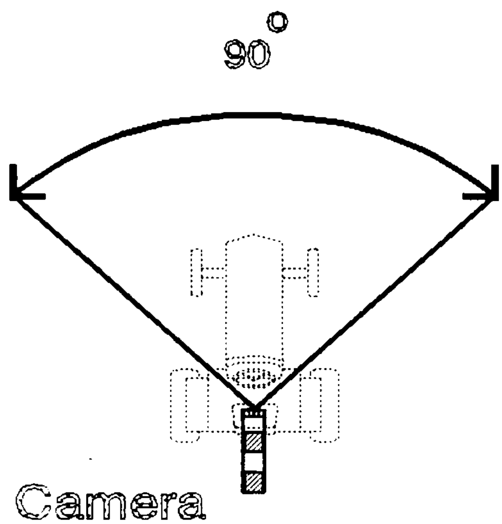

Figure 6. Camera mounting on RC tractor for a 90 degree field-of-view.

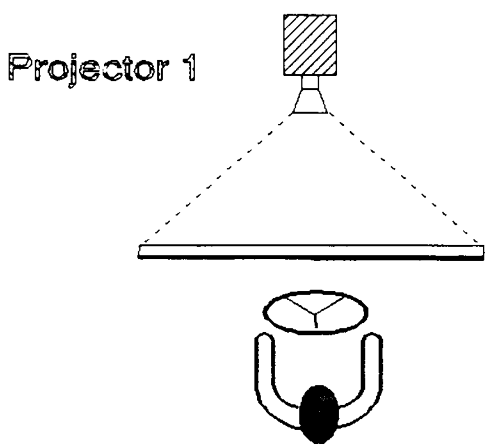

Figure 7. Operator display screen and projection unit for 90 degree field-of-view.

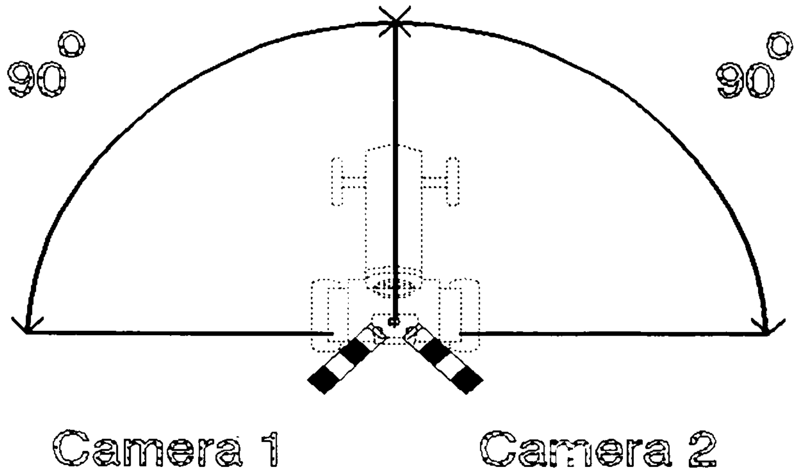

Figure 8. Cameras mounted on RC tractor for 180 degrees field-of-view.

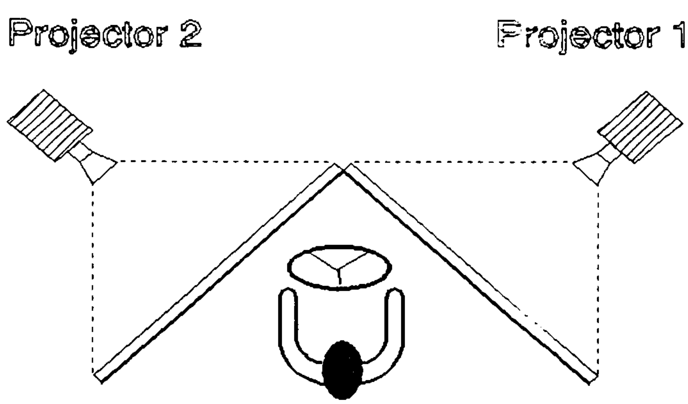

Figure 9. Operator display screens and projection units for 180 degrees field-of-view.

clutch components. Brake and clutch functions in the model were replicated electronically in the motor control circuit. Also, use of a scaled model tractor limits the degree of simulation. For example, scaled components, such as tires, do not have the same dynamic response as real tires.

Motor, transmission, and steering servo components are commercially available parts manufactured for model RC vehicles. The body pieces, wheels, and front suspension were taken from 1/16th scale toy tractors. Mechanical components were either purchased or fabricated in the Agricultural Engineering machine shop.

The motor selected is commonly used in model submarines (Robe part no. 4011). It provides relatively low RPM and high torque (0.45118 inch-pounds @ at 14,000 RPM). A Team Associates "Stealth Transmission" (part no. 6560) was selected. It has a carbide ball differential with an externally adjustable control clutch and a 2.22:1 gear reduction between the input shaft and axle drive. While this gearing would be suitable for a race car, it was not representative of tractor speeds. In the standard motor/transmission configuration with the highest gear reduction attainable (a 12T pinion and 96T spur), the gear reduction is only 17.76:1. Thus, at full power, the drive output is 788 RPM which corresponds to a simulated tractor speed of 159 MPH. Additional gear reduction between the motor and transmission was needed. To simulate true operating speeds, the reduction required between the motor and transmission was approximately 400:1. Fitting the motor, transmission and additional gear reduction into the 1/16th scale tractor was a major design effort. Traditional configuration for RC vehicles is to have the motor parallel to the drive axle. This configuration proved undesirable because the motor restricts the field of view of cameras carried by the RC tractor. (Out the window views from the model must be similar to those of real tractors.) The remedy was the use of a miter and bevel gear set for in-line motor mounting (see Figure 10). In this configuration, it was possible to locate the motor inside the body of the tractor and out of the view of the camera. Also, this allowed the tractor to maintain a more conventional appearance. The bevel gear set provided 3:1 gear reduction. Two additional pinion and spur gear sets (12T pinion and 96T spur gear) each provided 8:1 reduction. The final gear reduction between the motor

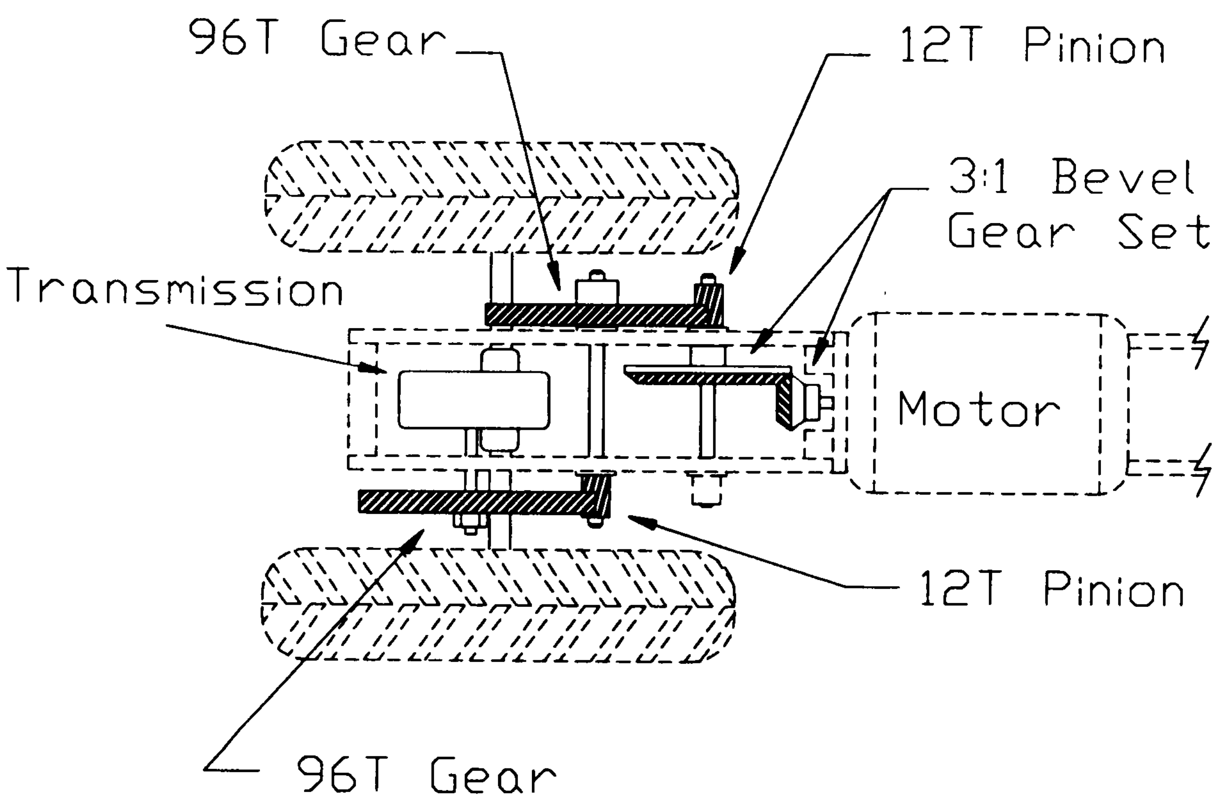

Figure 10. Power train for RC tractor illustrating location of gears, transmission, motor and drive axle.

and drive axle is 426.24:1. At full power, the final drive output is 32.8 RPM which corresponds to a simulated tractor speed of 6.6 MPH. An additional benefit of the low speed gearing is that it provides high drive torque (Drive torque = 0.45118 inch-pounds * 426.24 = 192.31 inch-pounds).

A rigid housing was required to ensure precise alignment of the gear mechanisms. Aluminum plate, 0.125 inches in thickness, was used to fabricate the transmission and gear reduction housing. Gears and hardware were positioned in this housing such that a high center of gravity would be maintained. This vehicle, in a scaled manner, exhibits many characteristics of a real tractor. An exploded diagram of the RC tractor appears in Figure 11 and Figure 12 shows the RC tractor assembled.

RC Tractor Motor Speed Control

Figure 13 shows a simplified operational diagram of the motor control circuitry. Motor speed control is a function of throttle, gear, brake and clutch position. When the gear selector is in the park or neutral position, a micro-switch opens and no power is applied to the motor. Once the gear selector is placed in drive, the park/neutral switch closes and power is applied to the motor based on gear and throttle position settings.

Linear potentiometer (variable resistors) are mounted on the clutch, brake, throttle, and gear selector. By varying these controls, a set-point voltage is produced which corresponds to a set vehicle speed. Note that this set-point voltage is used by the differential amplifier. The differential amplifier controls the current to the motor. Thus, the set-point is used to control motor speed. The gear, throttle, brake and clutch potentiometer that are connected in series. The set-point reference comes from the center tap of the gear selector potentiometer. The gear potentiometer resistance (0 to 500 K Ohms) corresponds to gear selection '1' to '15'. The throttle potentiometer resistance likewise varies from minimum to maximum throttle (150 K Ohms to 0 Ohms). In this configuration, the gear potentiometer provides major control over tractor speed and the throttle is used for finer adjustment. An additional resistor (220K ohms) was added in series with the

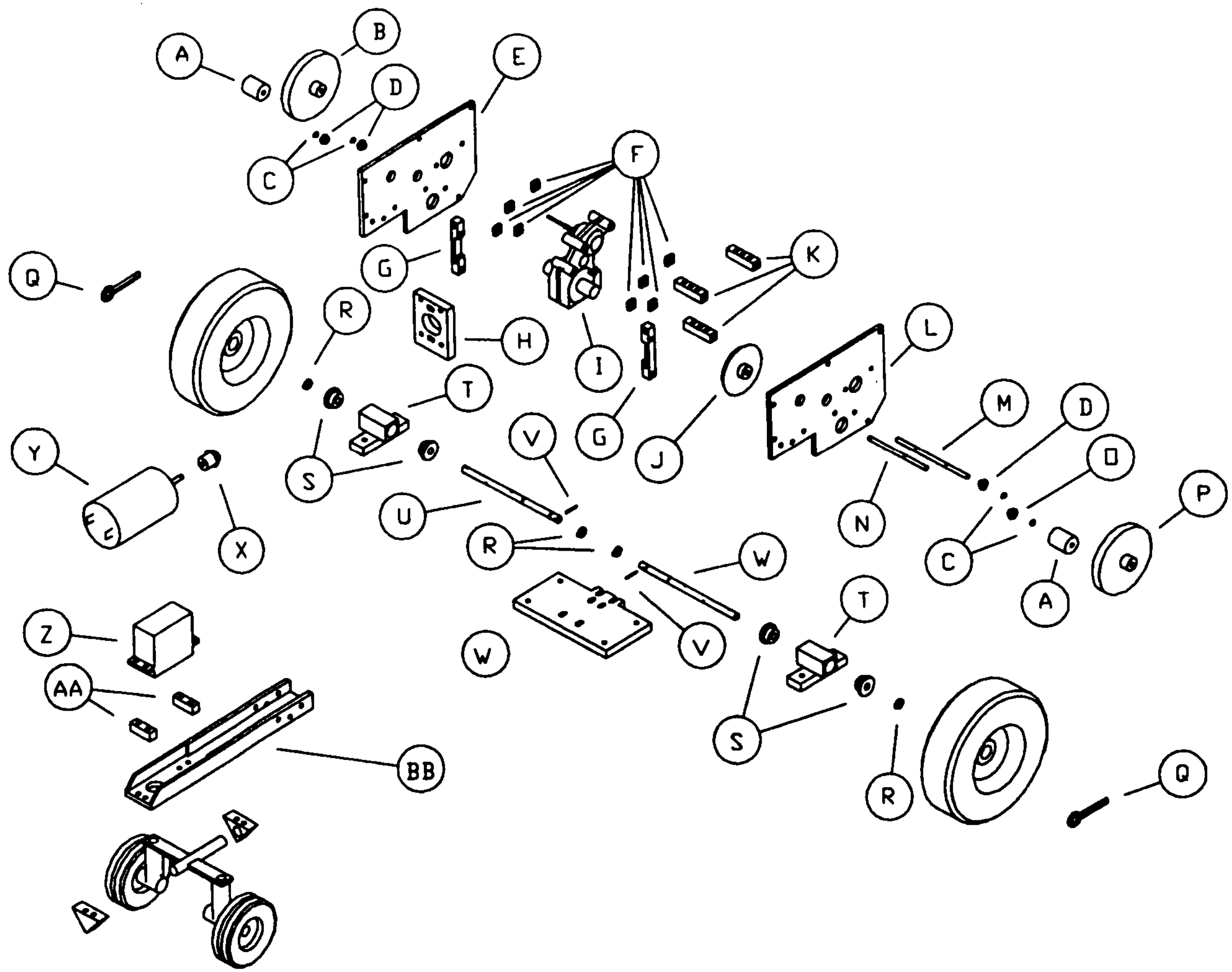

Figure 11. Exploded view of RC tractor. Parts listing in Table 1.

Table 1. RC tractor parts list, with brief description.

Index	Qty.	Description	Part Number
A	2	12 T Pinion Gear	RRP-1012
B	1	96 T Spur Gear	RRP-1896
C	4	1/8" Snap Ring	5100-12
D	3	Bushing	S99BP4-FB082009
E	1	Right Side Plate	*
F	8	Trans Spacer	*
G	2	Motor Plate Support	*
H	1	Motor Plate	*
I	1	Transmission	6560
J	1	Bevel Gear (1.5")	S1343Z-72S36S108
K	3	Spacer	*
L	1	Left Side Plate	*
M	1	Gear Shaft #1	*
N	1	Gear Shaft #2	*
O	1	Bushing	S99BP4-FB081607
P	1	96 T Spur Gear	S1063Z-048S096
Q	2	Cotter Pin	A 9C35-0212
R	4	3/16" Snap Ring	5100-18
S	4	Bushing	S99BP4-FB122408
T	2	Pillow Block	*
U	2	Axle Shaft	*
V	2	Roll Pin	A9C35-02-12
W	1	Rear Support	*
X	1	Bevel Gear (.5")	S1343Z-72S36S108
Y	1	Motor	4011
Z	1	Servo	FP-S148
AA		2 Servo Spacer	*
BB	1	Front End	*
CC	2	Front Supports	*

* fabricated by the University of Tennessee Agricultural Engineering research shop.

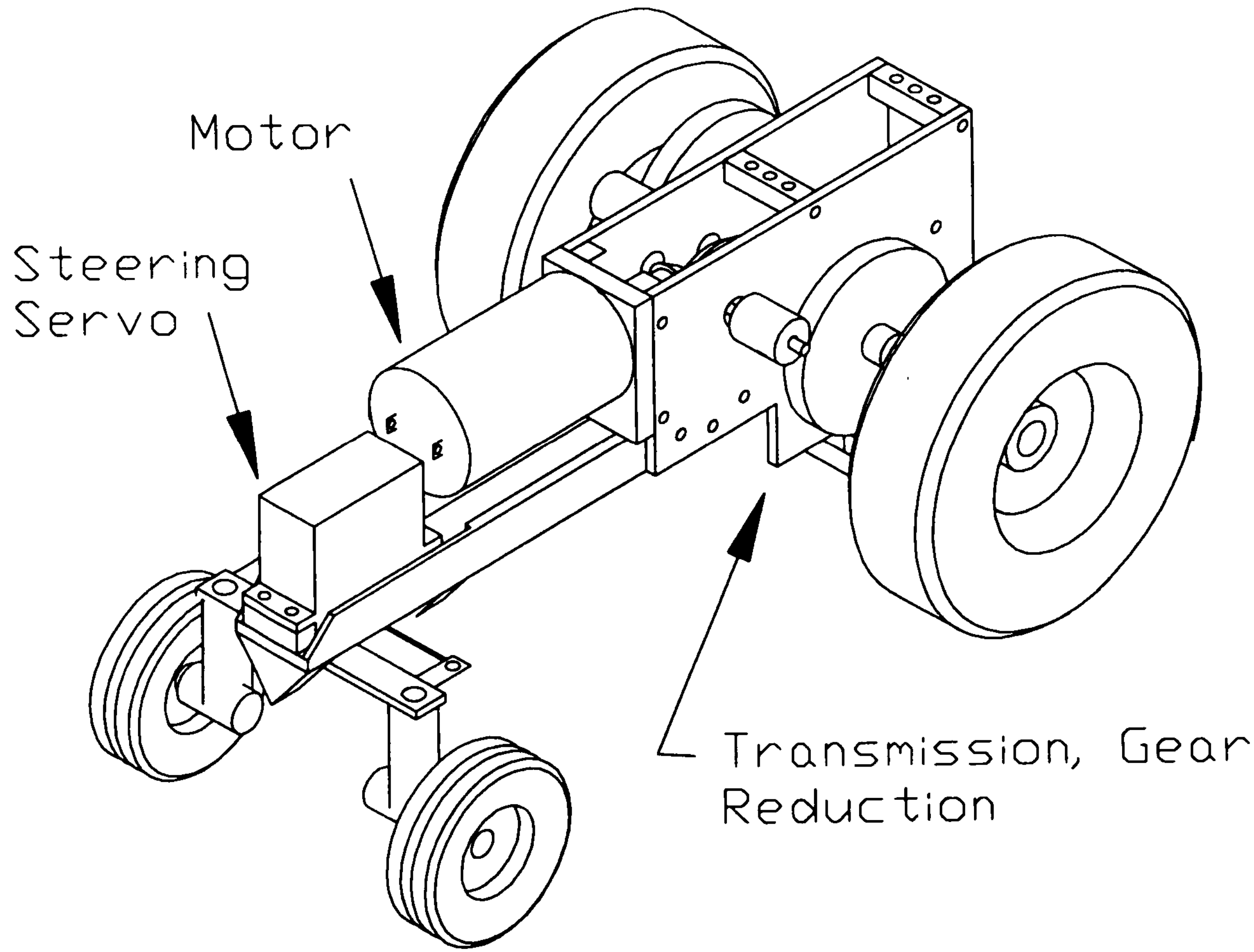

Figure 12. Illustration of assembled RC tractor's drive train.

potentiometer sensors to provide a minimum speed when in first gear and at minimum throttle. The brake and clutch potentiometer in their neutral (not applied) position, have zero ohms resistance. When applied, the resistance rapidly rises to 1 Meg ohms dropping the set-point voltage (tractor speed) to near zero. When the set-point voltage is above zero, the motor runs. Maximum set-point voltage provides maximum speed.

Feedback allows the differential amplifier to govern the speed of the tractor motor. A photoelectric sensor was attached to the RC tractor. The sensor produces an output frequency proportional to motor speed. A frequency-to-voltage (F/V) converter converts the frequency output of the sensor to a voltage level proportional to the motor speed (see Figure 13). The output from the F/V converter is compared to the set-point voltage using a differential amplifier. The output from the amp produces an error signal which is the difference between the set-point and the feedback. The error signal output of the differential amplifier produces the motor control signal that controls a power amplifier in the motor control circuit and thus govern the speed of the RC tractor motor.

The photo-electric sensor is comprised of an IR light emitting diode (LED) and a photo-transistor. A disk with black and white hash marks was mounted on a gear shaft beside the photoelectric sensor (see Figure 14). The light from the LED is reflected off white portions of the disk to turn on the photo-transistor. The black portions turn off the photo-transistor. As the disk rotates, a series of digital signal pulses are generated. Additional electronics were used to buffer and condition the signal. The resulting output is a square wave whose frequency is a function of the actual RPM of the RC tractor motor. The only place suitable to mount the photo-electric device was on the first gear shaft. Figure 14 shows how the disk is mounted on the RC tractor. For reasons that will be noted in the instrument control section, the eight hash marks were placed on a 1.25" disk.

With no load on the RC tractor (driving on a level surface) the circuitry reaches an equilibrium around the set-point voltage. When load is introduced (going up a hill), the motor

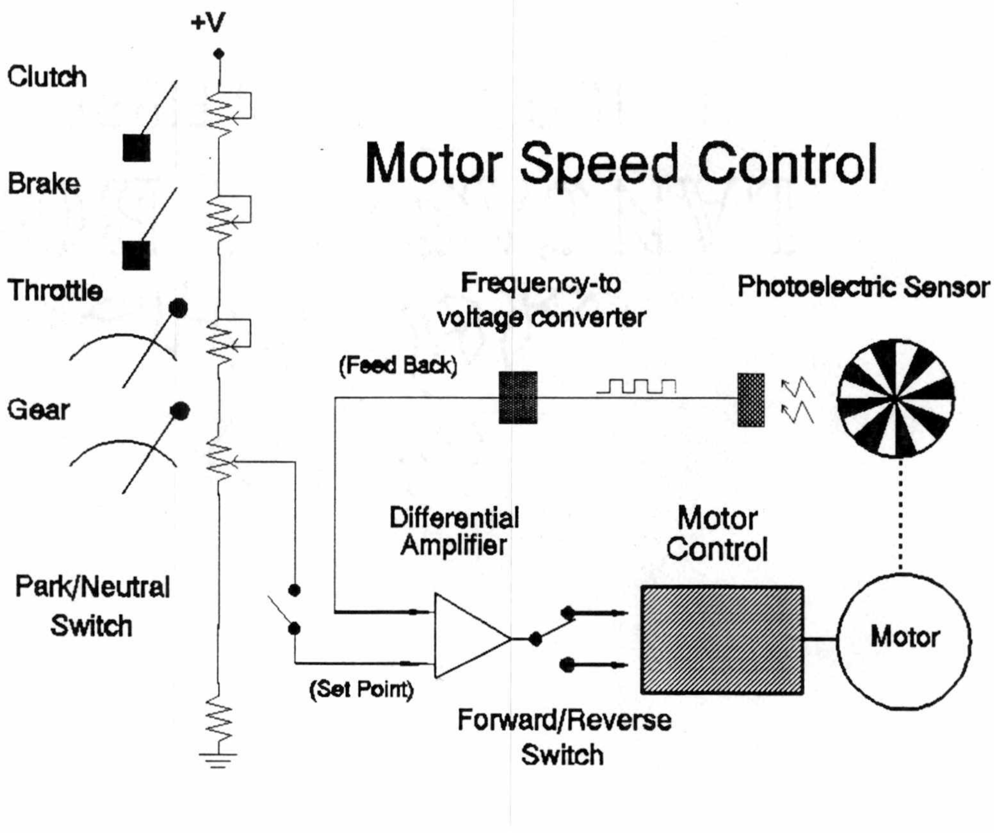

Figure 13. Schematic diagram of RC tractor motor speed control circuit.

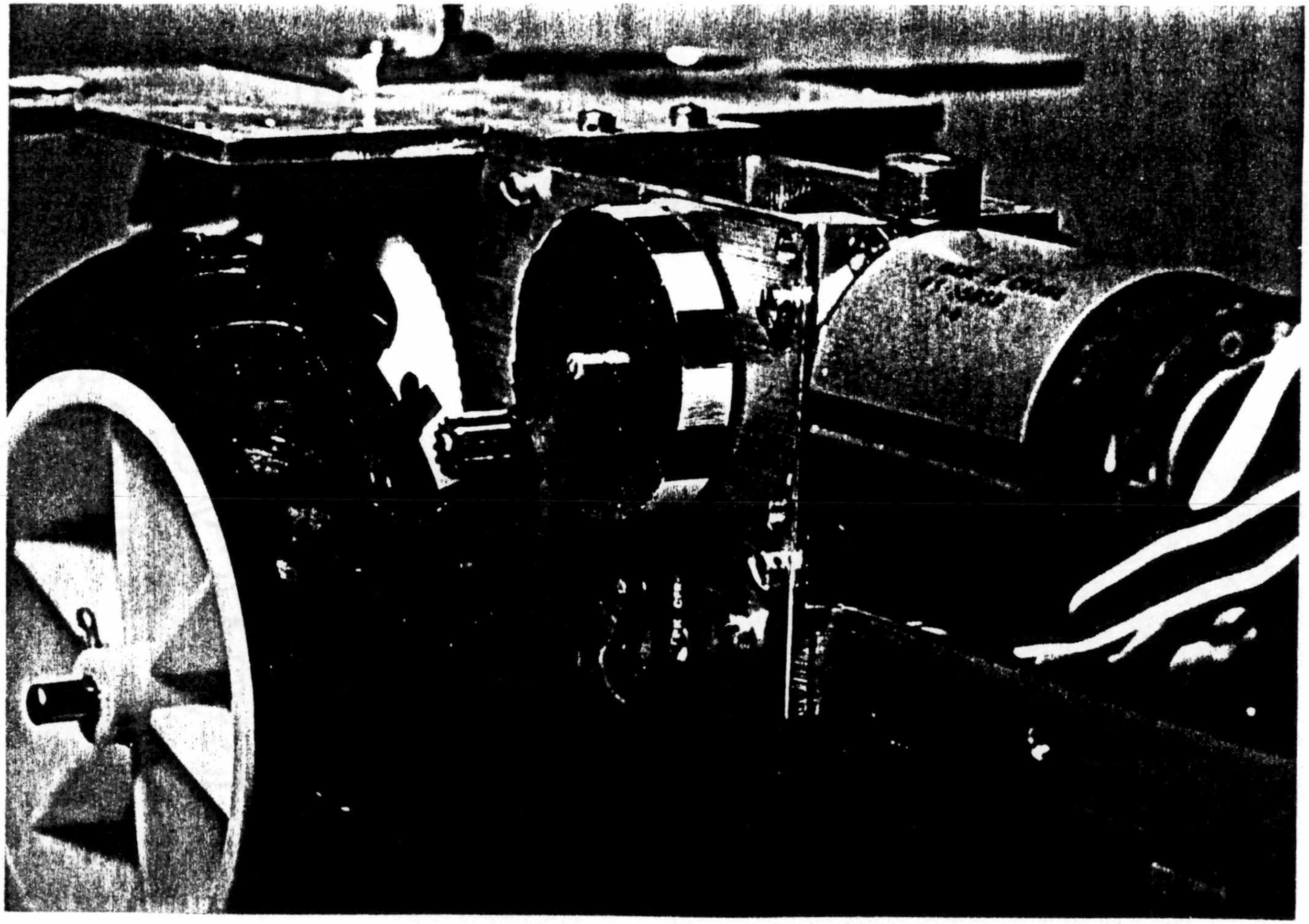

Figure 14. Photograph of photoelectric sensor mounted on the RC tractor.

RPM decrease, and a smaller feedback signal is produced. With a smaller feedback signal, the amplifier output rises increasing motor speed toward equilibrium again reach equilibrium. When load is taken away (going down a hill), just the opposite occurs. An increase in RPM causes the feedback signal to increase. The amplifier output then drops to slow the motor.

The RC tractor is capable of both forward and reverse speeds. A forward/reverse switch attached to the gear selector is used to change the rotation of the motor and RC tractor's direction of travel.

RC Tractor Steering Control

The RC tractor steering mechanism is controlled by an electronic servo (Futaba part no. FP-S148). Control for the servo comes from the operator's station. A steering position sensor interfaces with the RC tractor electronics to drive the steering servo and position the front wheels.

A hydraulic steering pump (spur-gear) is attached to the end of the steering wheel in the operators station (see Figure 15). The bidirectional pump flow is determined by the direction of rotation of the steering wheel. The two output ports are connected to small single acting cylinders. The configuration is such that when the wheel is in the neutral (center) position, both cylinders are at half stroke. As the wheel is turned, fluid is drawn from one cylinder which retracts while extending the other cylinder. A linear potentiometer (sensor) is attached to the rod on one cylinder. The sensor provides a displacement signal proportional to the steering wheel angle. The sensor output is connected to the steering electronics which in turn drives the steering servo and positions the front wheels of the RC tractor.

The basic electronic components include a timer (LM555) and a "one shot" (74LS221). The timer provides a constant 50 Hz square wave. The one shot allows the steering sensor to control the output pulse duration (duty cycle). Output of the circuit produces variable pulse width (1 to 2 ms) depending on steering position (see Figure 16). RC tractor steering movement left or right is a function of pulse width. A 1.5 ms pulse is the neutral position.

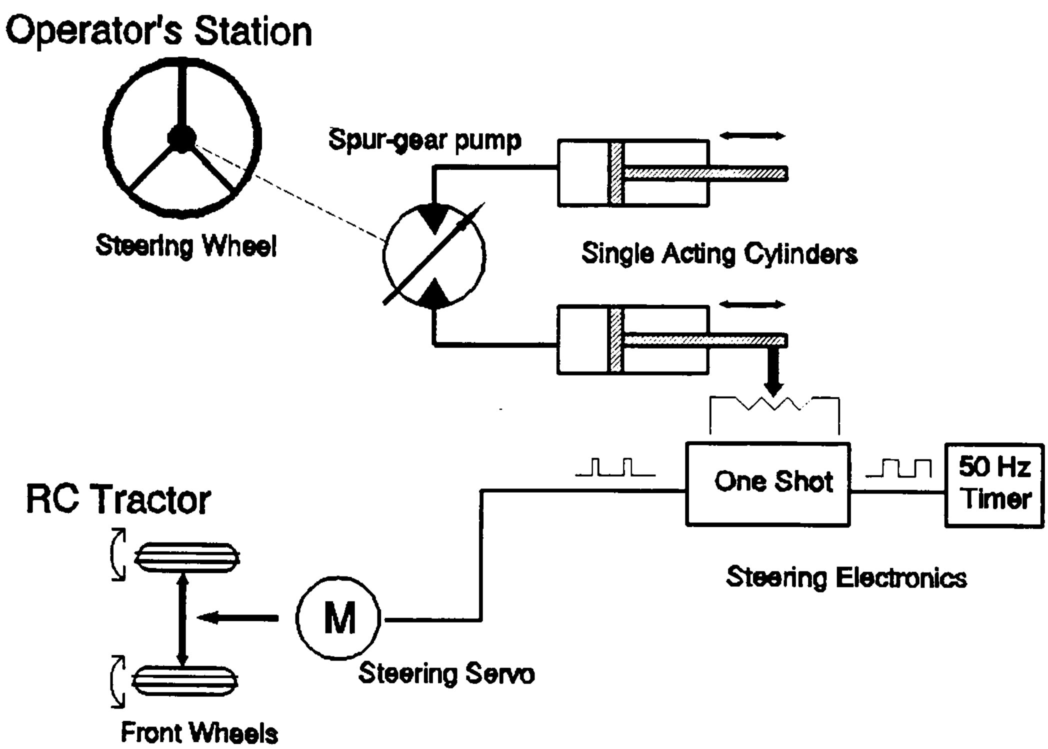

Figure 15. Illustration of how the steering for the RC tractor is controlled from the operator's station.

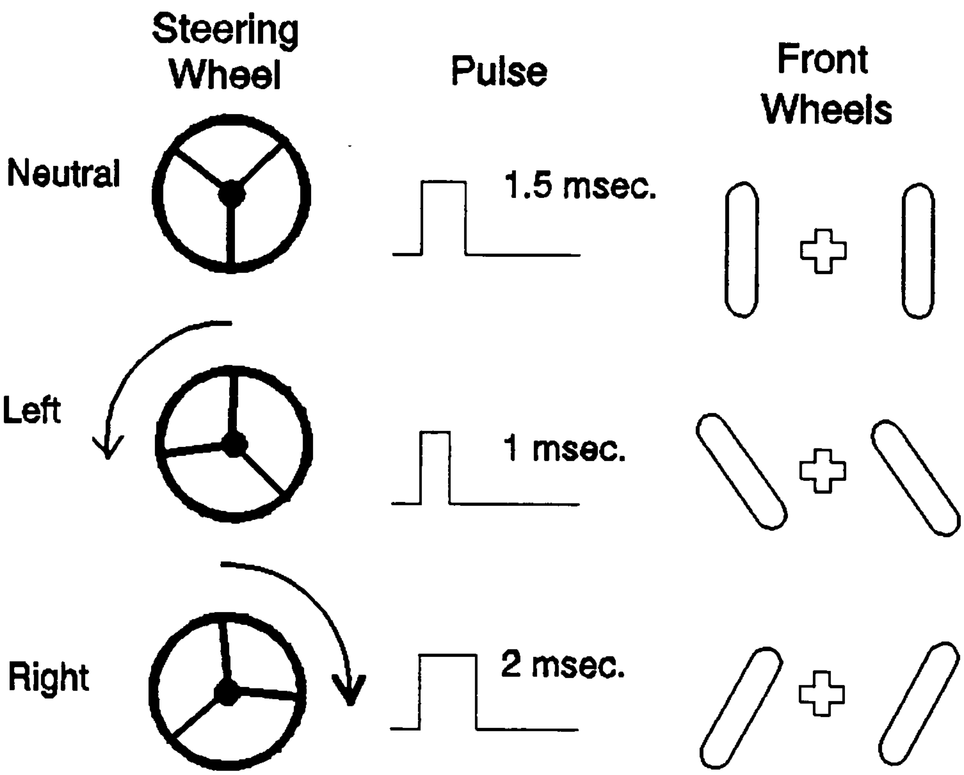

Figure 16. Steering signal pulse width is a function of steering position.

Scaled Model Board Landscape

The RC tractor is driven on the scaled model board landscape. The landscape is visually similar to, and provides many of the same natural obstacles as a real terrain.

The model board landscape was constructed from two 4 ft. x 8 ft. x 1 ft. pieces of polystyrene. Set side by side they provide an 8 ft. square landscape. Construction was conducted in two phases. First, a sample terrain was constructed in 1/64 scale. Once the preliminary design was completed, an 8x 8 grid was drawn over the 1/64 terrain and a corresponding scaled grid of 1 foot squares were then placed on the 1/16th terrain blocks. Using a hot wire, the 1/64th terrain features were replicated on the 1/16th terrain. Once the terrain was roughed out, a wire brush was used to smooth the landscape features. Varied shades of green latex paint was applied to the surface to represent vegetation. Sand was mixed with the paint to increase traction between the RC tractor tires and the model surface. Sand was also used for the road surface. Trees and a barn were added to the terrain to help increase realism.

The RC tractor was placed in one corner of the terrain. The goal of the operator is to traverse to the opposite corner as swiftly as possible. One of two basic directions are possible: 1) a paved road that leads to a dirt road or; 2) a dirt road. On the paved road a sudden obstacle (another vehicle) appears at the cutoff for the dirt road forcing the operator to make some sort of control decision. (See Figure 17). A number of obstacles are present on the dirt road . They include embankments, potholes, and hazardous turns.

A light blue cloth was draped behind two sides of the landscape to simulate a sky background and restrict the RC tractor's view beyond the scaled landscape. The remaining two sides were left exposed so that audiences can view the operator performance.

A support structure was built over the model board to hold the cables that attach to the RC tractor. These cables carry the control signals from the operator's station to the RC tractor, power to the RC tractor, and video signals from the camera to the operator's station.

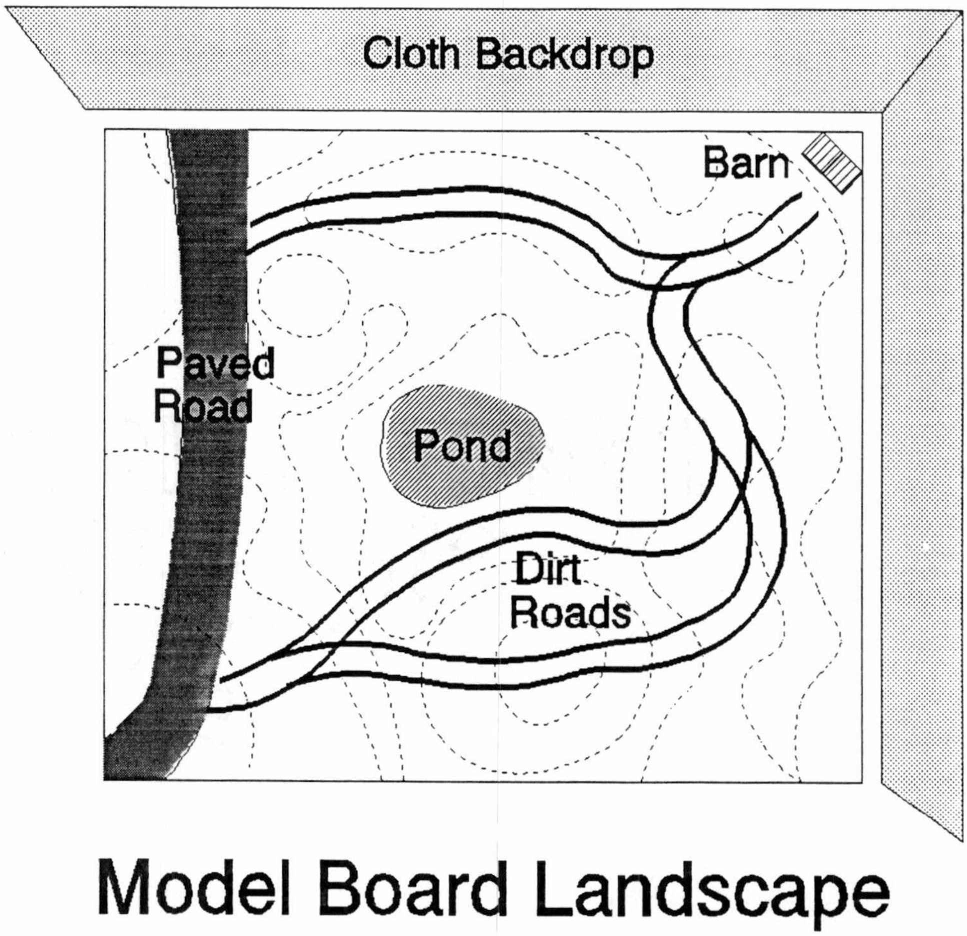

Figure 17. The scaled model landscape configuration.

Instrument Control

Simulator instruments operate in a manner similar to those found on actual tractors. Sensors, mounted on a tractor, send signals to the instrument cluster for display of engine and system information. These indications allow the operator to monitor various system parameters and to initiate corrective actions where necessary. For example, if the engine coolant exceeds operating limits, the operator is alerted by a warning indicator. A glance at the engine coolant gage will show the indicator has moved into the red (over range) zone. When this happens, the operator should stop the equipment.

The simulator does not have sensors to operate the instrument cluster, therefore, they must be simulated. Instrument cluster signals comes from a control panel in the instructor's station which controls the following digital displays, gauges, and warning indicators:

Digital Displays:

- Engine speed in RPM,
- Ground speed in MPH,
- Power Take-off (PTO) in RPM,

Gauges and Indicators:

- fuel gauge,
- transmission pressure gauge,
- engine oil pressure gauge,
- cylinder head temperature gauge,
- engine coolant temperature gauge,
- clutch temperature warning indicator,
- air filter warning indicator,
- hydraulic oil temperature gauge, and
- two transmission filter warning indicators.

Rotary potentiometers located in the instructor's station (Figure 18), control operation of the gages and indicators on the operator station console. Signals for the digital RPM, MPH and PTO displays either come from the RC tractor or are simulated electronically based on operator control settings.

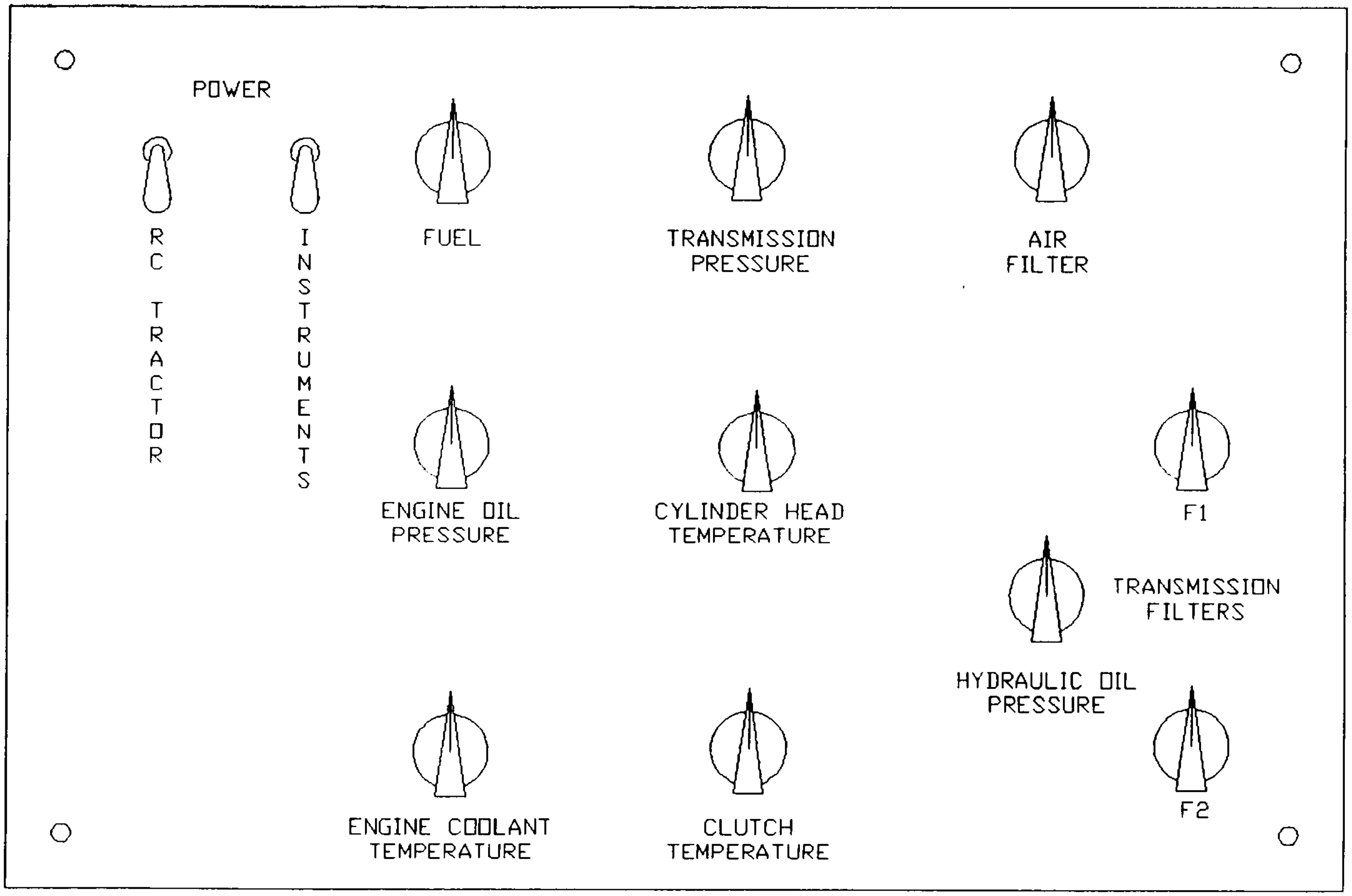

Figure 18. Instructor's control panel.

Instrument Cluster Interface

Inputs to the instrument cluster are frequency-based signals. As input frequencies increase or decrease the displays respond accordingly.

Engine speed is simulated electronically based on throttle position. A variable resistor attached to the throttle in conjunction with a capacitor is used to generate a signal proportional to throttle position. As the throttle position varies, the output frequency changes (The square wave output varies from 8 to 25 KHz). The displayed engine speed (RPM) is a proportional to signal frequency. One RPM is displayed for each 10 Hz of input frequency. Thus, at minimum throttle position the tachometer displays approximately 800 RPM. At full throttle, the tachometer displays approximately 2500 RPM. (See Figure 19).

The digital PTO (RPM) display uses the same signal as the engine speed display. In the display unit, the engine speed signal frequency is divided by three to correspond with the gear reduction between the tractor engine and the PTO drive shaft. Therefore, the PTO display varies from 267 to 800 RPM.

Ground speed (MPH) display operates on the same principle as the engine speed display. The signals for this display however are not simulated. The photo-electric sensor mounted on the remote control tractor monitors the RPM of the motor which is proportional to ground speed. For 1 MPH of ground speed to be displayed on the instrument cluster , an 85 Hz square wave must be applied to the signal input of the digital display. For each additional MPH, the input must increase 85 Hz.

Simulation of ground speed in the RC tractor is a function of tire speed. It was assumed that the if the actual RPM of the RC tractor tires were matched to the RPM of a real tractor tire at a given speed, that the 'out the window view' from the RC tractor would be similar. The rear tire on the RC tractor is approximately 4.375" in diameter. At 1/16th scale this corresponds to an actual tire 70" in diameter. At 1 MPH the tire RPM would be 4.8 revolutions per minute. Converting the required frequency signal to minutes we get 5100 cycles per minute (CPM) to display 1 MPH (85 Hz

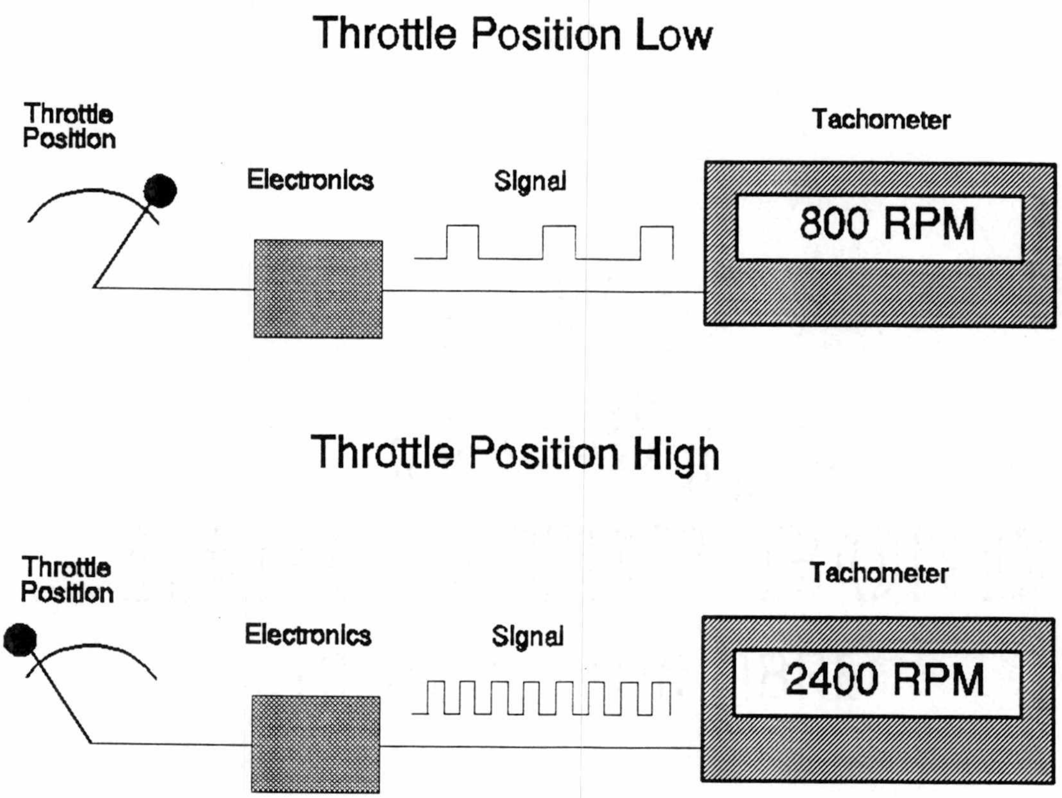

Figure 19. Engine speed display simulation is a function of throttle position.

* 60 seconds). The photo disk is mounted on the first gear shaft. Shaft rotation reduction from this point to the final drive is 142.08 to 1. If the final drive is 4.8 RPM this shaft is only rotating at 682 RPM. To increase the achievable frequency, eight hash marks were placed on a 1.25" disk. (See Figure 20). The resulting signal deviates approximately 7% from the actual signal desired (5456 compared to 5100 @ 4.8 RPM final drive).

Sound Generation

A sound generator is used to simulate engine noise. Sound generation is a function of simulated engine speed and gear selection (See Figure 21). The signal generated for engine speed (RPM) is a square wave with a frequency range of 100 to 400 Hz which corresponds to 800 and 2500 RPM. To generate one sound pulse for each RPM, this signal had to be reduced to approximately 13 - 42 Hz . A decade counter (divide by 10 counter) was used to reduce the tachometer signal by a factor of ten to achieve an effective frequency range of 10 to 40 Hz. An audio amplifier (LM386) was used to power a speaker located beneath the seat in the operator's station. The speaker volume was controlled by the system state, defined as either "no load" and "load". Under a "no load' conditions such as in neutral or park the volume is low. Under a "load" condition such as when driving or just in gear, the volume increases.

Starting the Simulator

Power for the simulator is supplied by a 12 volt deep cycle battery. Power is applied by setting the two power switches at the instructor's control station to ON. (Switch one supplies power to the RC tractor; Switch two supplies power only to the instruments). In the operator's station the simulator is started by opening the fuel cutoff switch (which simulates the fuel cutoff valve on the diesel tractor), and momentarily turning the key to the START position to energizes a self latching power relay (which simulates the starting of a tractor engine). Power to the simulator remains active till either the main power switches at the instructor's station are switched off, or the fuel cutoff switch is closed.

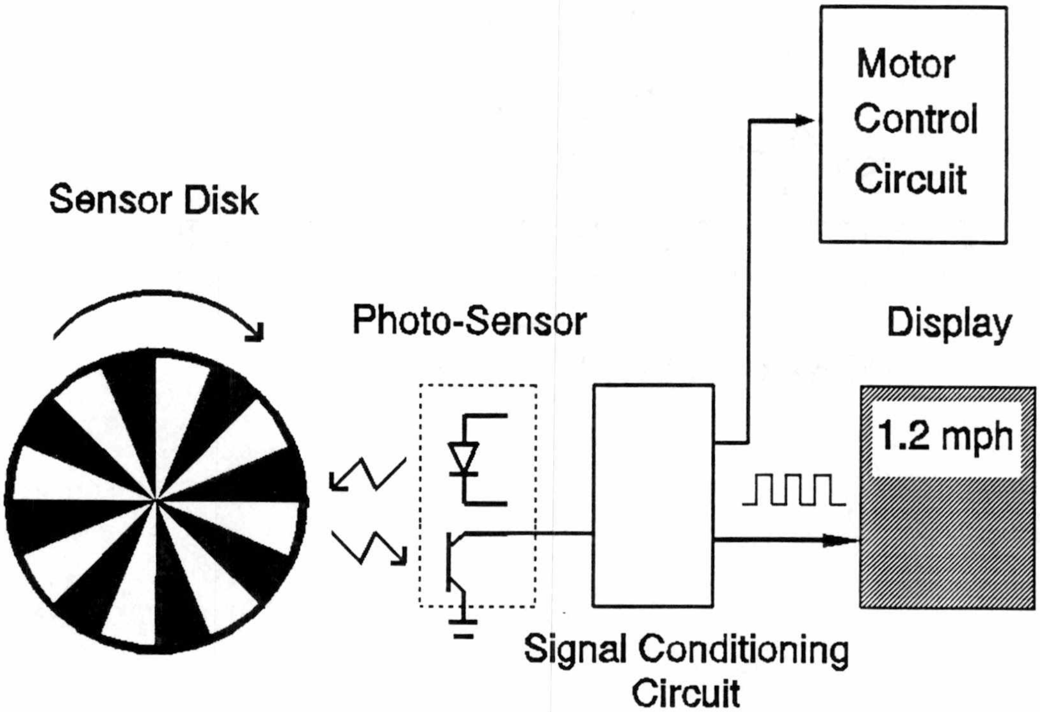

Figure 20. Ground speed display is controlled by the photoelectric sensor.

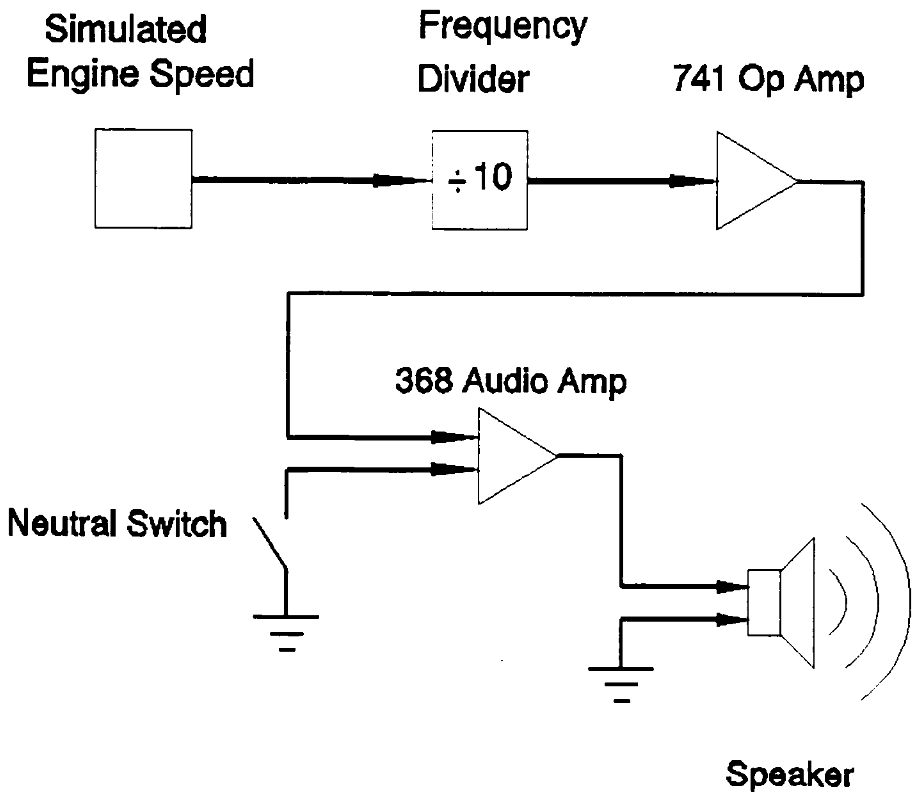

Figure 21. Block diagram of sound generation circuit used in the operator's station.

CHAPTER V

RESULTS AND DISCUSSION

A tractor driving simulator was successfully designed and implemented. Six male test subjects were used to evaluate the simulator. Ages varied from 18 to 33 years. All but one subject had some tractor driving experience. This experience ranged from 2 to 20 years. Four subjects were unfamiliar with the John Deere cab components used in the operator's station.

Evaluations were based on test subject feedback and video recordings. Test subjects provided both verbal feedback and a written appraisal of the simulator. Video from the RC tractor cab was recorded for comparison with video recorded from a camera mounted above the model landscape. Simultaneous replay of the video tapes allowed for analysis of operator response to various system configurations both by watching their view from the cab and by noting their position on the landscape as captured by the overhead camera.

The Operator station controls and the RC tractor performed well in providing visual feedback to the operator. The "out-the-window" view was very similar to that of an actual tractor. The color video camera produced a high resolution picture signal for the video recording monitors. The video image resolution projected on the large screen in front of the operator however lacked detail. The flat screen makes it difficult to discern depth of field in the display (as noted by Wheatcliff, 1973). Test subjects stated that depth of field was worst when traveling down slopes when the horizon moved outside the operators field of view. Also, the limited 90 degree field of view was most disconcerting. Limited depth of field and field of view, made it difficult for operators not familiar with the model landscape layout to operate the simulator.

The operator's station was enclosed in a temporary structure with no visual points of reference other than the video display. The video displayed caused some test subjects to experience some apparent motion. They perceived movement, but did not feel it. The exclusion of motion was the most critical point cited by the test group. One member noted that he used tilt of the tractor or spin of tires to make control decisions when operating a real tractor. In the simulator he could only rely on his eyes. Despite the inadequacies of the video projection system, when tractor rollover occurred, operators felt startled by how swiftly the overturn reached a point of no return. Another test subject reported feeling mildly sick when his body did not feel the rollover his eyes were experiencing.

Test subjects noted that the simulators ground speed appeared limited. However, the maximum speed of the RC tractor was purposely scaled down to reduce the chance of operators driving the RC tractor off the 8 ft. X 8 ft. terrain.

Despite the fact that there was no differentiation between the clutch and brake operation, test subjects reported that the simulator responded very much like a real tractor, especially at low speeds.

Individual braking of the rear wheels was not possible. If the tractor was positioned in a sideward tilt with one drive wheel off the ground, the differential transmission allowed the other wheel to spin. On an actual tractor, the operator has control over the drive wheel by controlling the left or right brakes independently. With the simulator, this is not possible.

Because there was no true clutch on the RC tractor it was not possible to "pop the clutch". This design did not allow free wheeling of the tractor while the clutch was engaged. The drive train was linked to the motor at all times. The rear wheels moved only when the motor is engaged. When not engaged, the effect was as though the brakes were applied.

Test subjects noted that steering control appeared quite similar to an actual tractor. Steering performance degraded however, when going up or down a steep incline. When traveling up steep inclines, the weight transfer of the RC tractor shifted to the rear wheels resulting in reduced front wheel traction. This is a real problem realized by many tractor operators. A less desirable result appeared in the other direction. Traveling down inclines the shifting of weight to the front end loaded the steering servo and steering was sometimes unresponsive.

The Sound generator's frequency was a function of throttle position and the sound level was a function of gear position. Therefore, the sound did not respond to changes in the actual load on the RC tractor. When driving the simulator, sound frequency and sound level remained the same regardless of motor loading conditions. With an actual tractor, the sound frequency and level increases and decreases with engine load.

The model board was more than adequate for providing hazards which resulted in tractor rollover. One drawback was that the terrain was too aggressive in certain areas where the operator was required to operate the simulator. Operators unfamiliar with the model terrain had difficulty negotiating some of the off-road obstacles without rolling the tractor. The model terrain was coated with varied shades of green latex paint and landscape features were highlighted with external lights. However, the lighting washes out the video projection and causes the display to appear flat and uniform. This makes it difficult for operators to discern any physical feature on the landscape. Signs and varying shades of paint were used to help correct this deficit.

The landscape surface was textured with sand to increase traction between the RC tractor tires and the landscape surface. However, the RC tractor would slide or spin at inappropriate points during simulation runs. Changing to a softer rear tires has reduced this problem.

CHAPTER V

SUMMARY AND CONCLUSION

The objectives of this project were to develop a tractor driving simulator that would aid in teaching tractor operators the need for ROPS and serve as a tool for controlled research on operator responses to various system and terrain configurations. A tractor driving simulator was designed and constructed to satisfy these requirements.

The tractor driving simulator was functionally similar to, and exhibited many characteristics of a real tractor. The device enables operators to "drive" a simulated tractor while safely maneuvering through hazardous conditions. As a training tool, operators can safely perform hazardous operations and experience tractor rollovers. As a research device, operator actions are both observable and recordable.

The simulator was comprised of two basic components: an operator's station and an instructor's station. The operator's station, where students were positioned during simulation runs, was designed to conform to an actual tractor cab. Components from a John Deere 50 series "Sound Guard" tractor cab including the seat, instrument console, steering wheel, throttle, gear selector, brake, and clutch were installed to ensure equipment fidelity. The instructor's station included electronic system controls and video recorders. It provided control over the visual inputs to the operator's station and provided the hardware necessary to monitor and record the operator's actions during a simulation run. From the recorded data, operator performance in the simulator was analyzed.

The simulator addressed two fidelity requirements: vision and sound. The operator controls the simulator from the operator's station by manipulating the controls (gear selection, steering position, throttle position, etc.) Engine sounds and apparent tractor position, as perceived from the video display, changes as the operator drives the simulator. A sound generator provided engine sounds. The video display, positioned in front of the operator's station, is comprised of a large rear projection screen and a video projection unit.

A Remote Control (RC) tractor provided the visual "out the window" view to the operator's station. Operators drove this scaled tractor over a model landscape by manipulating the operator station controls. Images captured by a miniature video camera mounted in the RC tractor cab were then projected in the operator's station. As the RC tractor tilted, the operator's video display responded accordingly.

The overall evaluation tests conducted on the simulator were positive in that subjects were able to operate the simulator and components functioned as designed. However, an initial evaluation of the simulator has produced a list of items requiring further development.

- A larger representative sample of operators should be evaluated using the simulator. This group should be representative of people who will be using the equipment (ie., age, background, sex, etc.,)
- Additional cameras will be required to increase the field of view to the operator's station. Increased peripheral vision will increase the visual fidelity of the simulator and make it easier to operate especially with regard to rear facing tasks.
- The sound generation needs to be more responsive to varying RC tractor loading.
- A stronger steering servo is needed in the RC tractor so that steering control will not be adversely effected by weight transfer to the front wheels.

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APPENDICES

Appendix A - Operator Station Mechanical Drawings

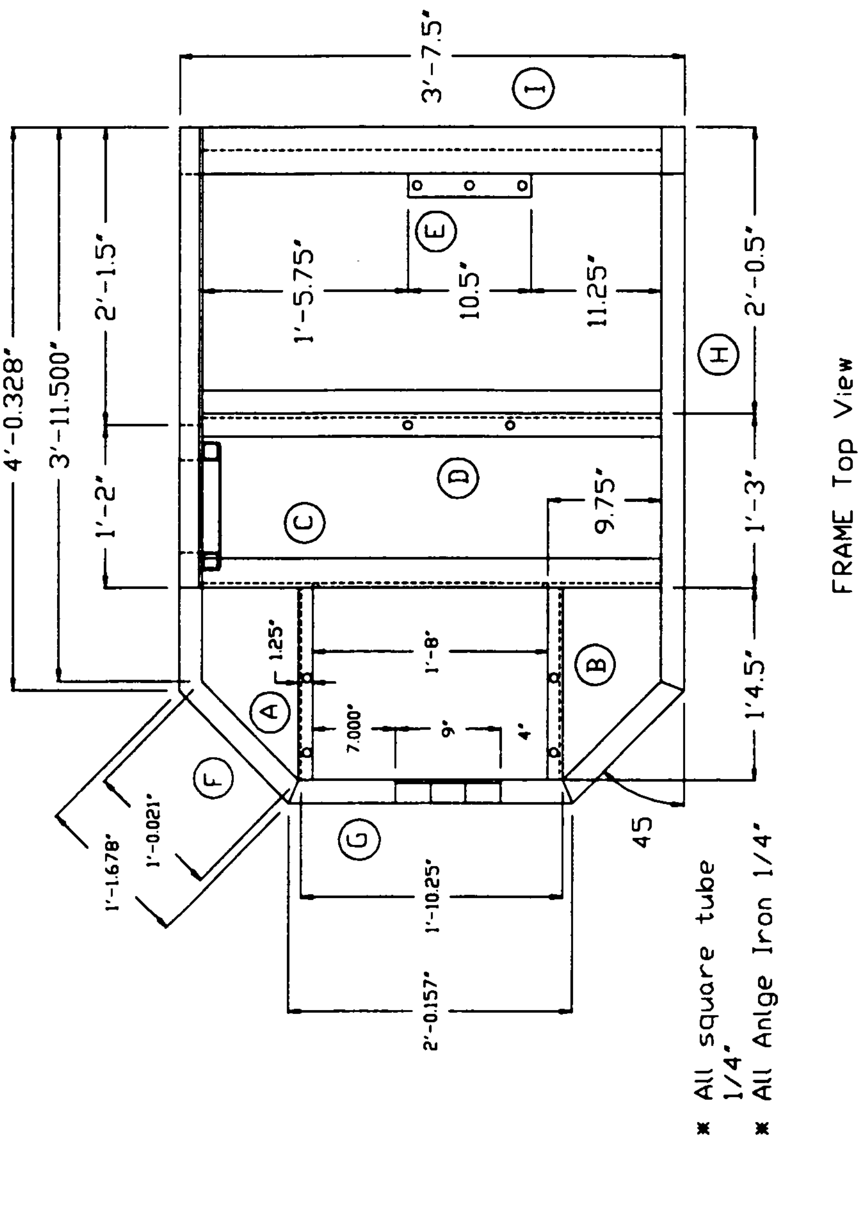

Figure A1. Top view of operator's station steel frame.

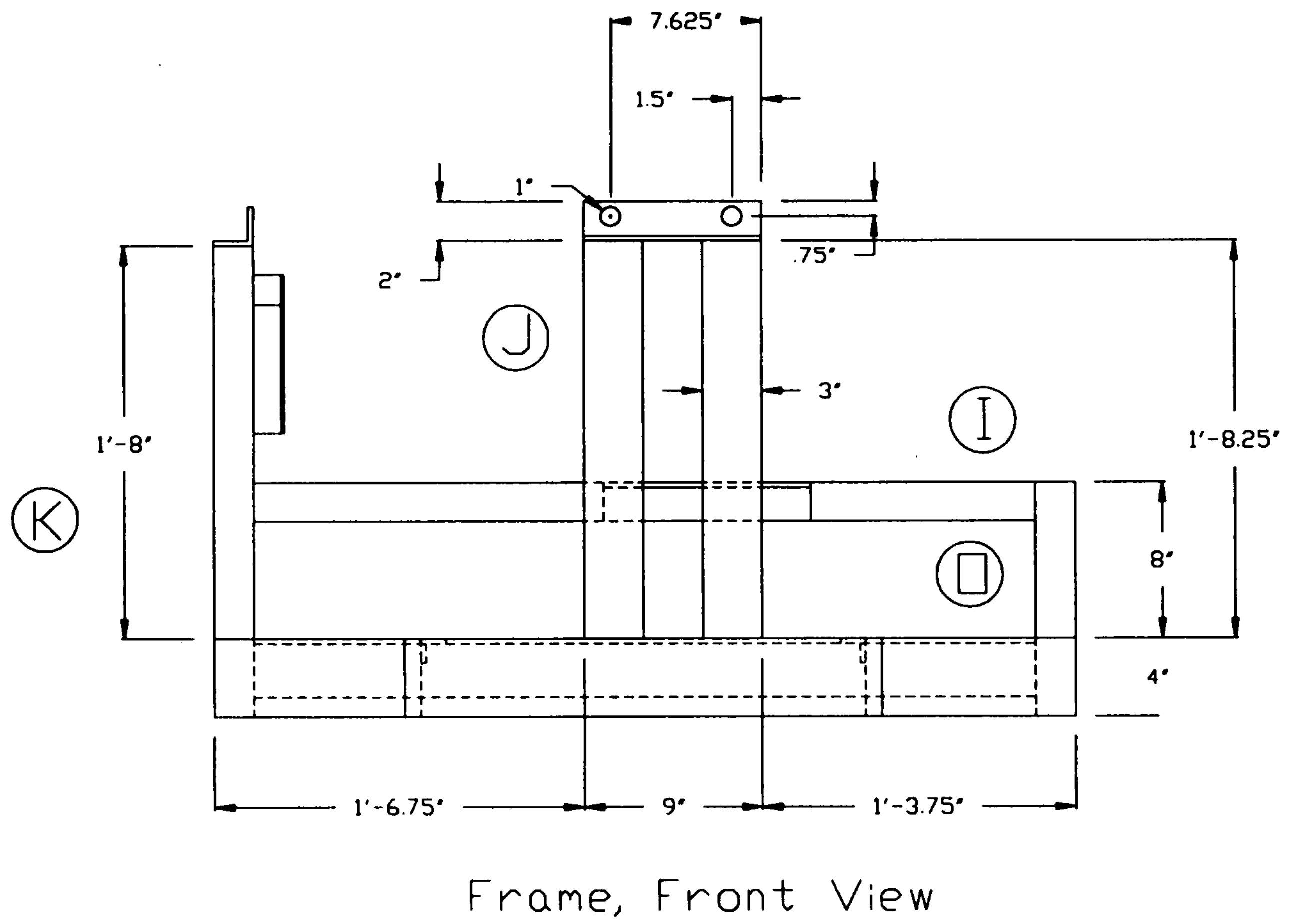

Figure A2. Front view of operator's station steel frame.

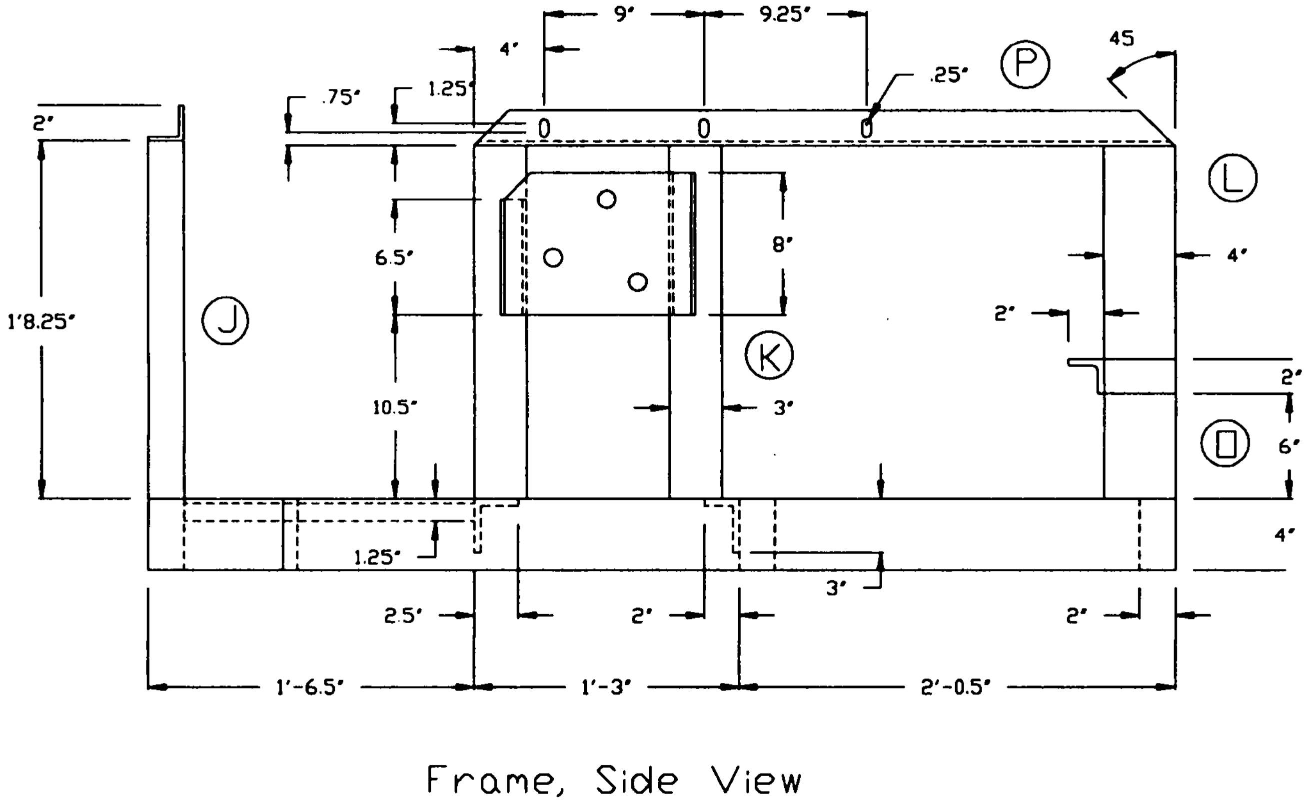

Figure A3. Side view of operator's station steel frame.

Appendix B - Electronic Circuit Diagrams

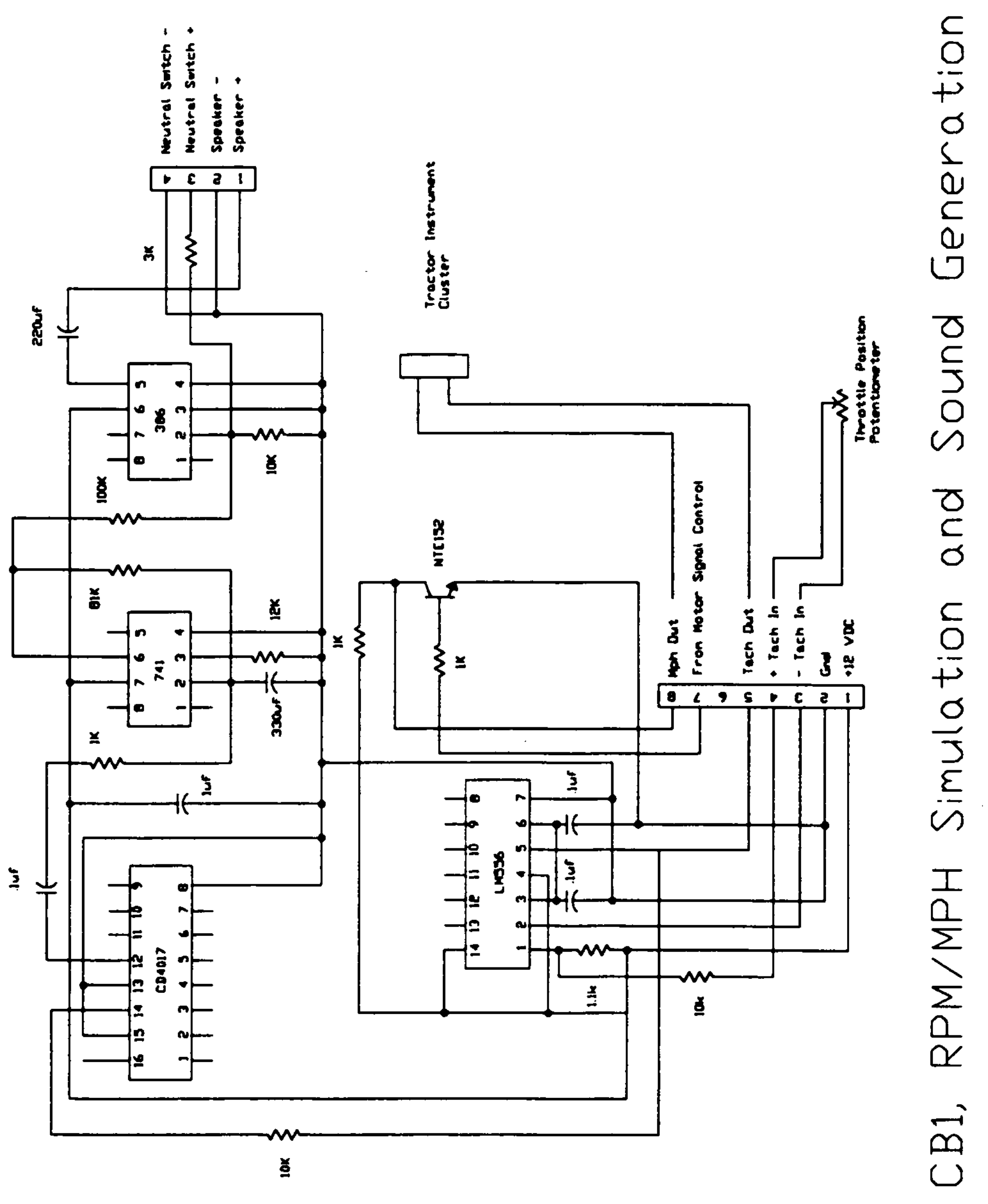

Figure A4. Engine speed, ground speed, and sound generation circuit.

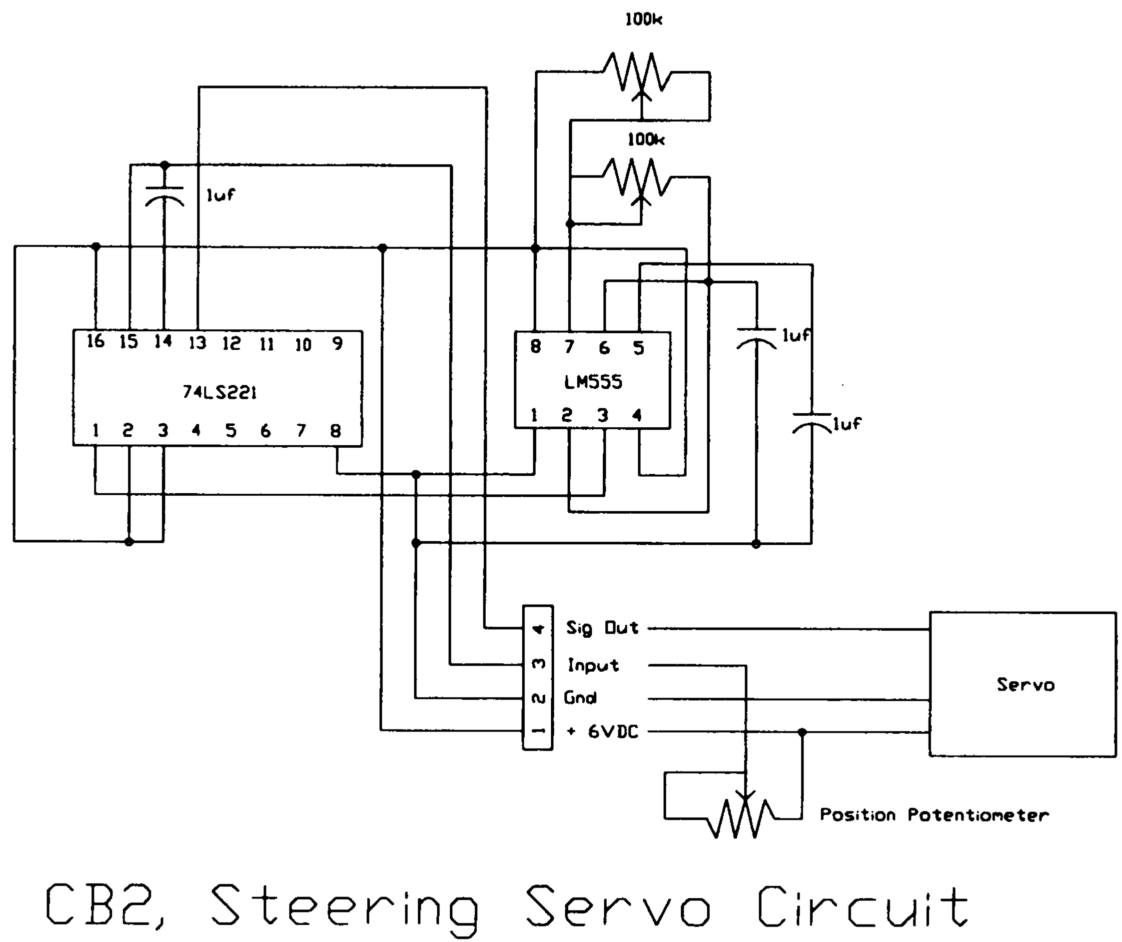

Figure A5. Steering servo control circuit.

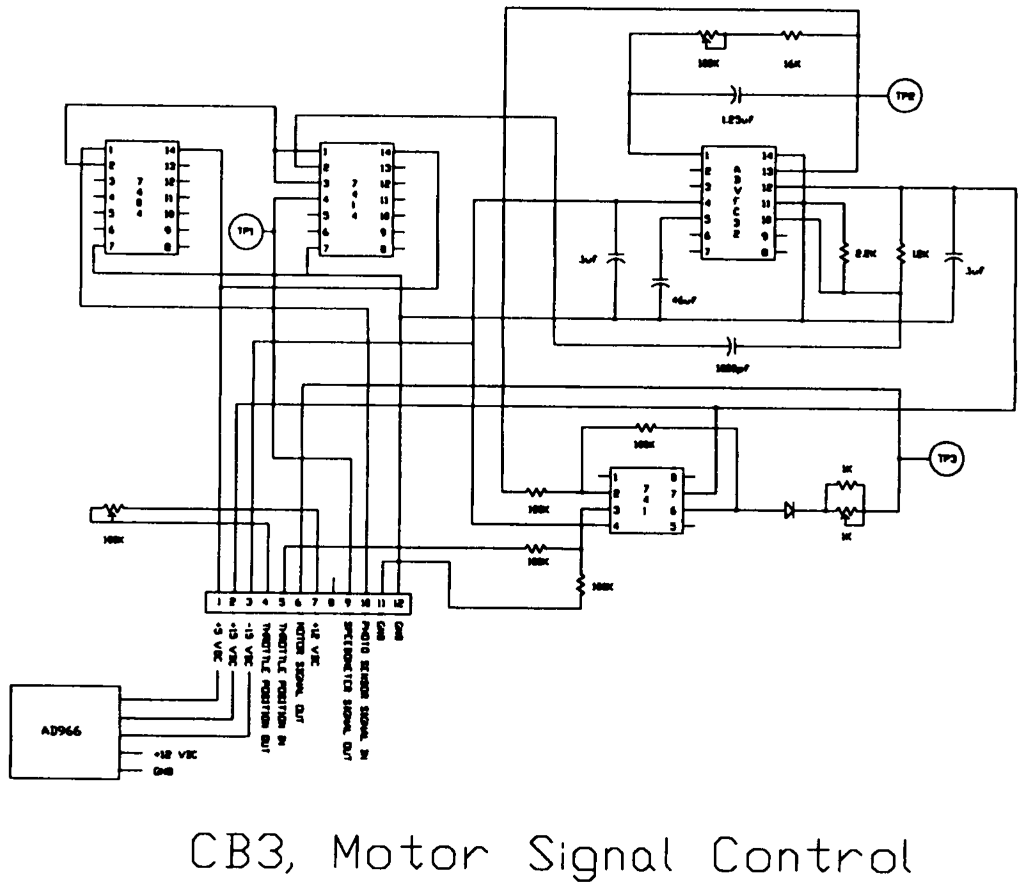

Figure A6. Motor Signal control circuit.

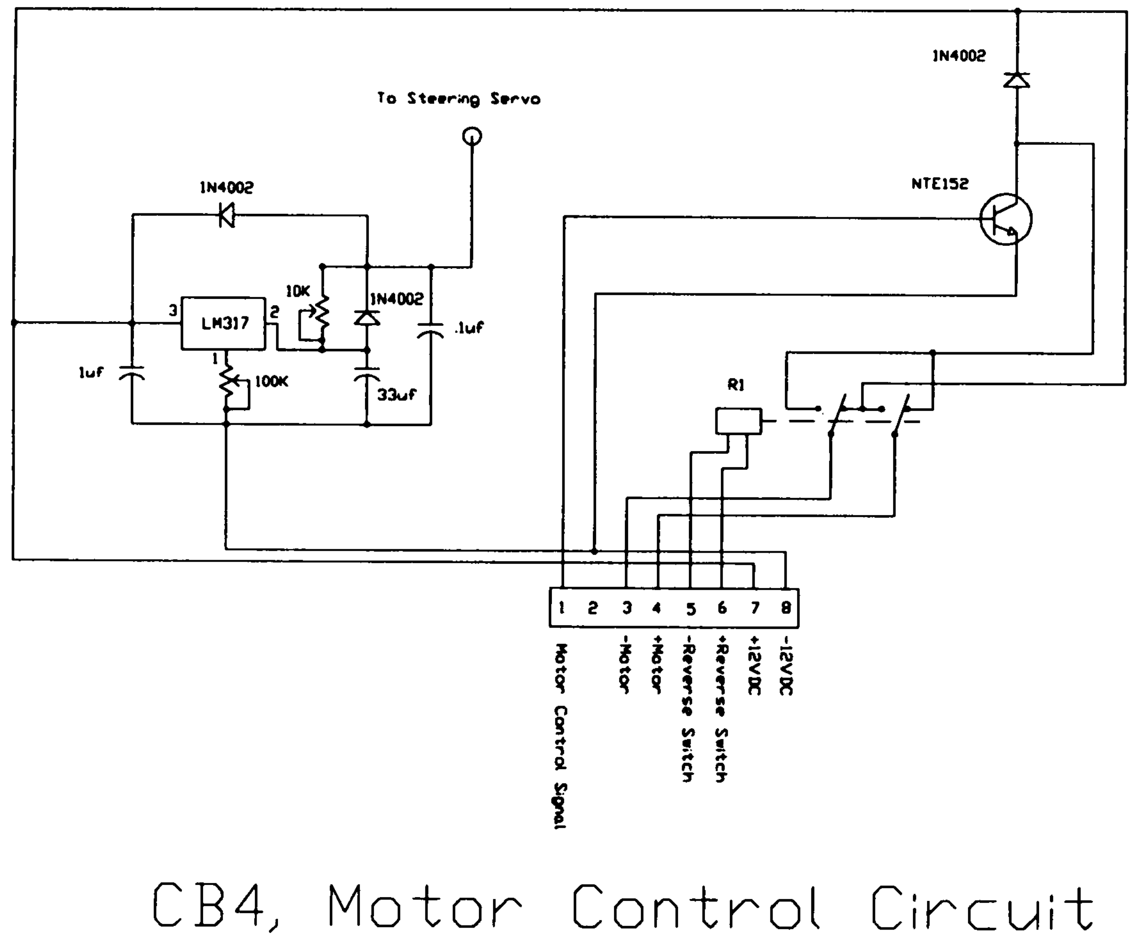

Figure A7. Motor power control circuit.

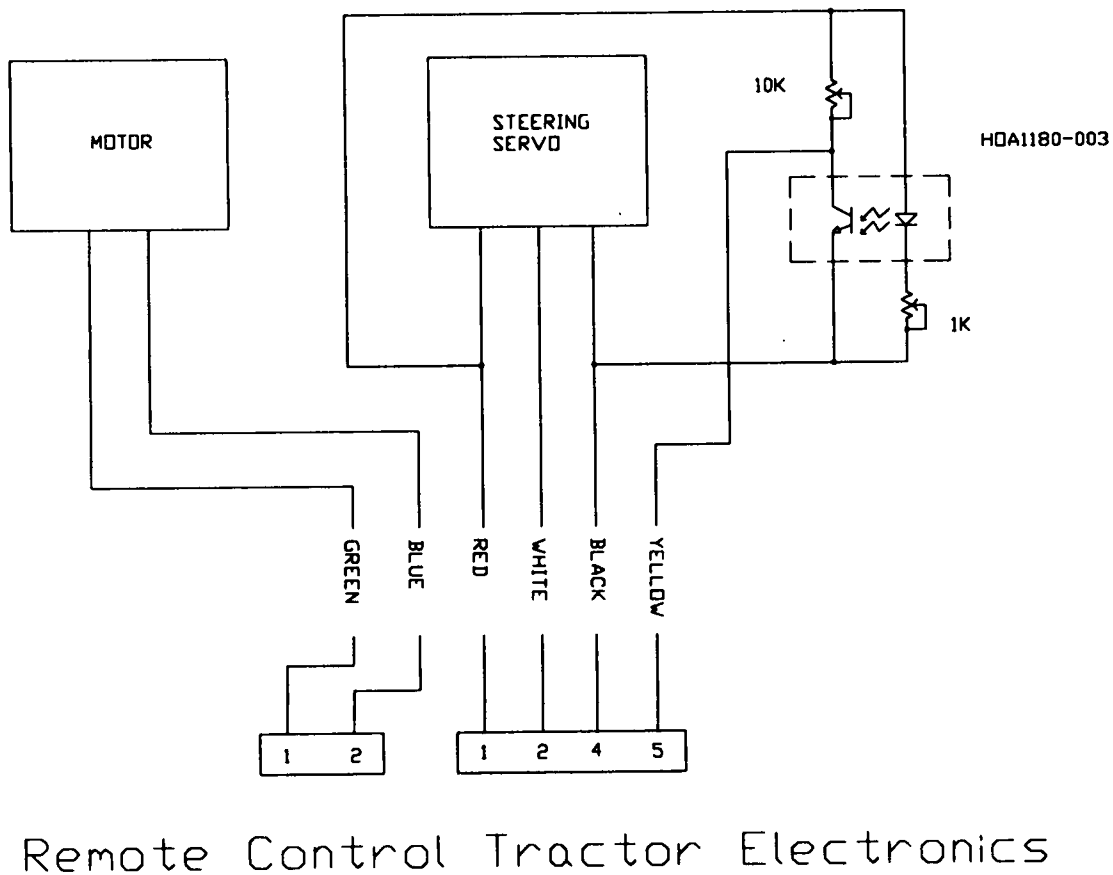

Figure A8. Circuit diagram of electronic components on the RC tractor.

VITA

Brett Clayton Asbury was born in Braintree, Essex, Great Britain on January 15, 1962. The son of an U.S. Air Force NCO, he attended grade schools in South Carolina, Alabama, Alaska, and Delaware. In 1981, he enlisted in the Air Force Reserve and spent a year at Keesler AFB, Mississippi studying aircraft avionic systems. Upon release from active duty, he started work as an industrial repair technician. From 1984 to 1989 he worked for the Richards Corporation, a government contractor in Washington D.C. Within four years he advanced from a position as a technician to a position as supervisor of the field service support group. Further career advancement required additional education. In 1989, he left the Richards Corporation. In January, 1990 he earned an Associate of Applied Science degree in Electronic/Electrical Engineering from Delaware Technical and Community College. In June, 1991 he received a degree of Bachelor of Applied Science in Engineering Technology and Technical Management from the University of Delaware. In August, 1991 he entered the University of Tennessee, Knoxville and in August, 1993 received a Master of Science degree in Agricultural Engineering Technology.