INTRODUCTION

The concept of a handicapped driver remaining in his wheelchair while at the controls is now a reality. The modification of "van-type" vehicles to permit easy access by an unaided handicapped person has achieved considerable popularity and is very useful to persons whose ability to transfer is marginal or who are unable to transfer unaided. The prospect of independent mobility for the handicapped has opened many opportunities for employment and recreation that did not exist before. The paraplegic has less of a problem than does the moderately severe quadriplegic. Simple hand controls are satisfactory driving aids for the paraplegic. Something more sophisticated is required for the quadriplegic with limited power and range of motions. Control systems have been developed which permit the moderately severe quadriplegic to safely operate a van-type vehicle.

The continuing problem is an adequate and safe wheelchair and driver's seat combination.

CONTROL SYSTEMS

Mobility Engineering has, during the last 8 years, developed a driving system addressed to the quadriplegic who has limited power and range of motion and with reasonable eye-to-hand coordination. This system consists of fully boosted steering and brakes and throttle controls brought to a single lever within easy reach of the patient. The control column is statically balanced to eliminate reaction to acceleration and braking forces. Hand grips of various types are adapted to the patient's particular requirements.

The steering is mechanical hydraulic using an engine-driven pump as a primary source and an electrically driven pump to provide steering control in the event of engine failure. The emergency system is automatic; however, there is a provision for manual control by the driver.

The brake system is vacuum-powered and consists of a dual tandem boost system. Each system has an independent vacuum source.
Forward motion of the control column actuates the throttle, lateral motion of the top of the wheel steers, while motion to the rear applies the brakes. The maximum force required in any direction is 6 oz. The lateral range of motion is a 9 in. diameter semi-circle. Fore and aft motion is 4 in. to 6 in. maximum.

Since the quadriplegic cannot manipulate the instrument panel controls, all electrical driving and environmental controls are brought to a series of touch controls within easy reach of the driver. Provisions are made for duplication of any of the controls on the column as required.

Figure 1 shows the general arrangement of the cockpit controls.
During the development of the control system it was assumed that the patient would remain in his conventional powered wheelchair. Nagging problems with the use of conventional chairs continually occurred:
1. A tall individual in a conventional chair with a typical 5-in. cushion ran out of head room. While the van-type vehicle offers about 50 in. floor to ceiling, it is clearly inadequate in many cases. The first thought is to lower the floor or to raise the roof. Both of these are major structural modifications and require great care, since all current van-type vehicles are integral body and frame construction and removal of sections can seriously weaken the structure.
2. The conventional powered chair is essentially a folding chair with beefed-up wheels to which have been added a battery motor and controls. Even the most cursory analysis indicates a serious structural strength deficit. Add to this the lack of head restraint and lateral trunk restraint and the problem becomes more complex.

Although somewhat ambiguous, the Department of Transportation requirements for the driver’s seat to be able to withstand 20 g and the seat and driver combination to withstand 4 g are considered minimal requirements.

It becomes obvious that a complete new look at a set of special specifications for the wheelchair driver is required.

**DRIVER’S SEAT REQUIREMENTS**

The following is a list of minimum requirements which must be met by a suitable seat:
1. Must maintain the indoor maneuverability of the conventional chair.
2. Must be adjustable in height by the user at will.
3. Must have structural integrity allowing it to meet the minimum Department of Transportation restraint requirements.
4. Must have a headrest.
5. Must provide good hip and torso lateral restraint.
6. Must provide for good patient posture and maximum distribution of weight.
7. Must have improved performance outside the house both in speed and on rough terrain.

While these specifications appear formidable, a careful look shows that we have the technology and most of the hardware on the shelf. It only needs development.

**Seat Design Progress**

Vans with good control systems are on the road now. With this urgent
requirement, it was decided to approach the problem in two phases. The first phase would be a compromise based on utilizing existing commercially available components with the primary objective of safe driver restraint. The second phase was to be a new design to address the total requirements.

**Phase I**

Two chair systems utilizing the principle of height adjustment were under development. One system is by Professor Cunningham of the University of California at Berkeley. This development offered many advantages but was not yet commercially available. The other system was produced by Wheel Chairs, Inc., and developed by Mr. James Allen at Rancho Los Amigos. This unit was commercially available.

The elevating base unit of Mr. Allen’s chair was utilized. A molded, reinforced Fiberglas contour seat was adapted to this base with a special high strength chrome molybdenum tubing interstructure between the molded seat and the base to permit the loads to be taken from the seat directly to the van floor structure (Fig. 2 and 3). A special hold-down structure with rear access and an electrically operated lock completed the system (Fig. 4).

Bilateral shoulder restraints and lap safety belt attached to the interstructure were provided.

Flip-up armrests and an articulated footrest completed the interim seat arrangement.

This seat has been installed in the VA units and several civilian vehicles.

Several problems still exist. However, the basic problems of head room and safe restraint are greatly improved.

**Phase II**

Phase I experience has brought to light a serious problem. While the contour seat appears to have many advantages, the posture of the patient and upholstering to achieve good weight distribution need careful attention. Therefore, the design problem is divided into the base unit and the seating.

**The Base Unit**

1. **Center Section**

   In order to provide a rigid high strength structure to transmit the loads from the seat and patient to the van floor structure, a box center section was designed which provides for engagement and locking with a mating floor structure when in the lowered position.
2. Suspension

A totally rigid wheel attachment to the center structure would have been more easily accomplished but would not have allowed accommodation for uneven terrain.

Therefore, the wheels are attached to the center section by two leading and two trailing arms. The trailing arms incorporate the driving motors and drive train for the rear pneumatic tires and wheels.

The leading arms are a four-bar system to maintain the front wheel
steering system in a vertical position. The front wheels can either be castered or power controlled.

Each of the four arms is attached to the center section by two transverse shafts—one for the two leading arms and one for the two trailing arms. Each arm connects to its shaft through a rubber torsion spring. An antisway torsion bar connects the two leading arms and may be added to the rear arms. In this way each of the suspension arms is independent of others. This should provide a relatively soft ride and excellent “rack” accommodations.

3. Height Adjustment

Two electromechanical actuators will provide rotation of the two transverse suspension shafts. In this way the angle of the suspension arms, relative to the base can be varied by the patient and as a result, the height relative to the ground can be varied. With the arms horizontal,
the seat will be in its lowest position (Fig. 5). Rotating the arms downward approximately 35 deg. will raise the seat 8.5 in. to its highest position (Fig. 6 and 7). Since the front and rear arms can be controlled independently, some limited degree of seat tilt can be obtained. Two torsion springs will be used to offset the static weight.
4. Steering System

The requirements for higher outdoor speeds and rough terrain operation make castered front wheels undesirable. The shimmy characteristic of higher speeds and poor directional stability of caster wheels on rough surfaces would require the use of a rather complicated damping system. The system we have chosen involves powered steering
through a closed loop continuously variable servo mechanism. The front wheels will be steered through 200 deg. or 100 deg. right or left from neutral. Reversal of the power to the inside wheel will occur at approximately 60 deg. from neutral in each direction.
The steering servo system and the power control use a common ramp generator system and are contained in the same control unit.

Steering and power control will be through a single joy stick. The electronic control system has been designed specifically to the chair requirements and involves the use of the latest integrated circuit techniques with resulting miniaturization of the package and greatly improved efficiency.

**Seating Design**

The problem of obtaining an optimum seating arrangement which will meet the requirements of safety, trunk stability, and comfort is being approached in several ways.

It appears that a series of clinical trials with an adjustable seat is the best way to establish the best posture and the range of widths and seat
lengths necessary to accommodate the range of patient dimensions. An adjustable seat is now being prepared. Trials will be made with a series of quadriplegic patients representing a variety of sizes and disabilities. These data will be used to design a range of seat sizes, hopefully narrow, that will accommodate a wide range of patients.

The area of contour molded cushioning incorporated in the basic form is being explored. Prototype seats are planned.

These and other approaches planned will, we believe, result in acceptable compromise which will meet the ultimate requirements.

**SUMMARY**

Although many areas are open to continuing development, the fact is that we can now deliver a safe system by which a large portion of the world's quadriplegics can be given independent mobility. Although imperfect at present, it is hoped that continuing development will bring the systems nearer the ultimate goal.