This program, conceived approximately 3 years ago, was initially directed toward evaluation. Its primary purpose was to clinically evaluate all known commercially available devices, as well as relatively new designs emerging from a number of research and development laboratories. Ultimately, evaluation was to serve as a basis for possible new designs and developments.

At the inception of this program, only conventional electric wheelchairs were used for evaluation. The standard wheelchair was, and presently is, the Everest & Jennings "34" Power Drive, commonly used for indoor and institutional use, but occasionally for outdoor travel. It became apparent, after reviewing the commercial models available from Everest & Jennings, Invacare, and Motorette, that certain performance requirements were evidently lacking from patients' viewpoints. Severe maintenance problems also existed for the professional staff. For instance, many of the younger veterans are highly motivated to return to the university to continue their education. Others are in search of vocational opportunities. Common to both group's needs is the need for a higher performance wheelchair to provide increased speed, improved ramp climbing capability, superior battery performance and greater life expectancy. Relative simplicity in maintenance and repair is absolutely necessary, since qualified technical support is uncommon.

The VA Prosthetics Center considered modular package design in order to reduce the need for electronics and other technical support. Ultimately, the modular package will permit rapid plug and socket electrical connections and the use of basic hand tools, such as screwdriver and wrench, which will permit physical removal and replacement of malfunctioned components.

After approximately 20 months of development effort, one motor package emerged that offered apparent superiority over all other types considered. This new development was based upon the use of printed
motors (Fig. 1) and exhibited exceptional electrical efficiency, excellent performance characteristics, and a high level of reliability.

A proportional joy-stick-operated electronic controller was developed for these motors, which is presently in final development stages. Approximately 35 printed-motor powered wheelchairs (Fig. 2) have been distributed to 12 VA Spinal Cord Injury Services and, from patients' viewpoints, are being extremely well received. The chairs' power packages have performed reasonably well during a trial period and have proved the efficacy of modular design. The modular package facilitates rapid maintenance and repair which has permitted the evaluation to proceed quite simply on a "mail order business" arrangement with participating VA Hospitals.
Our Center has received several requests for improved electric litters. We have introduced electrically powered litters that incorporate the
printed motor design (Fig. 3) with proportional control into a few Spinal Cord Injury Services. These motors, in combination with strategic location on the chair, clearly show that these improved litters provide superior performance. Normally, the steering, achieved by placing a conventional joy-stick control over the main drive wheels, results in a "fish-tailing" phenomenon. Poor performance also results, since conventional wheelchair motor packages are used. The use of printed motors and strategic placement of the direction controlling joy stick over the small swivel casters result in considerably improved performance and steering capability.

Our Center's evaluation and development effort has also led to the opposite end of the performance spectrum in order to meet the continual request for a lightweight, portable, and truly foldable electric wheelchair. We have made use of small torque motors produced by a sister organization of the manufacturer of the printed motors. The VA Prosthetics Center was successful in fabricating a lightweight power package with a miniature joy stick (Fig. 4 and 5). However, performance was markedly reduced and no patient was interested in using the experimental chair over an extended period. Therefore, further evidence was received that additional effort had to be devoted to the development of a higher performing vehicle which retained substantial wheelchair characteristics.
FIGURE 4.—View of lightweight power package for wheelchairs.

FIGURE 5.—Lightweight power package wheelchair showing miniature joystick.
Conventional powered wheelchairs are generally used by paraplegics and low-level quadriplegics. However, high level quadriplegics also enjoy access to these powered wheelchairs, as well as the higher performing printed motor units, via a family of special control devices developed by the VA Prosthetics Center. For those patients who are unable to effectively use their hands and fingers for hand-operated joy sticks, a chin control design is now available. The VAPC Chin Control unit (Fig. 6) is comprised of a rigid bracket providing anterior-posterior, medial-lateral, and vertical adjustment through an assembly of joints and clamps. A swivel joint (Fig. 7) facilitates patient introduction to and removal from the wheelchair.
A chin receptacle is attached to the proximal aspect of a proportional control joy stick. The Motorette or Everest & Jennings "33" Power Drive is readily adapted for use with this bracket. Indeed, both organizations are now producing the VAPC unit. It is interesting to note that many high level quadriplegics are usually able to use the chin control on high performance wheelchairs such as the E & J 24-volt system and the newly developed printed-motor power package.
For those patients who are unable to use either manual or chin control, two VAPC breath-operated systems are available. One has proved to be an extraordinarily reliable and generally useful system. Referred to as the VAPC Pneumatic Wheelchair Control Model II (Fig. 8), it incorporates two air tubes mounted on a small bracket in front of the patient's mouth. Constant blowing or sucking on either or both air tubes activates either or both motors to propel the chair or to change direction. Blowing into the air tube spins the motor in one direction while sucking on the tube reverses the motor's direction. The blowing or sucking generates positive or negative pressure, respectively, so that the occupant of the wheelchair is able to breathe normally. A speed control knob, mounted on top of the control section mounted in back of the wheelchair, may be adjusted for training purposes as well as for normal everyday use.

A second breath control design, the VAPC Pneumatic Wheelchair Control Model III, makes use of four air tubes (Fig. 9) and a unique switching arrangement that precludes the necessity for constant positive air pressure to propel the chair in the forward mode. Generation of a positive pressure pulse into the controlling air tube activates the wheelchair motor into a forward mode, which is maintained until a second puff of air is introduced into the air tube. As with the Model II design, two tubes are used to activate the drive motors. Generating negative pressure on the air tubes reverses the direction of both motors and is concluded when negative pressure ceases. A third tube permits the wheelchair occupant to vary his speed from 0 up to maximum. Generating constant positive pressure into the third air tube increases power to the motor while the chair is stationary or moving, and constant negative pressure reduces power to the motor. When the patient has achieved the desired power level, he ceases blowing into or sucking on the speed control tube and the selected power level is maintained. The fourth air tube activates a main power switch and an automatic reset circuit.

The Center's clinical introduction of these higher performing wheelchairs, especially those that accommodate the chin and breath controls, is generally considered to be contrary to standard and perhaps outdated rehabilitation medicine practice. Thus far, however, evidence is clear that VA patient demands for these devices are readily matched by clinical successes.

Our experiences to date suggest that we should direct our efforts to higher performing mobility aids. The upper limit of performance has not yet been defined, and so we tread forward in a most conservative manner. Our Center is presently engaged in the development of an intermediate or indoor/outdoor wheelchair (Fig. 10). We conceive this unit as being a higher performing vehicle primarily for outdoor use. But it must retain basic wheelchair characteristics and necessary physical size.
and weight limitations to permit the vehicle to operate in the usual indoor environment.

Figure 8.—VAPC pneumatic wheelchair control, Model II.
FIGURE 9.—VAPC pneumatic wheelchair control, Model III.
The VA Prosthetics Center enjoys a record of directing its efforts to apply the most recent technological innovations to the veteran beneficiary and, perhaps as important, is a stimulus to other development and manufacturing organizations to produce improved and less expensive varieties of nonlicensed mobility aids. We, therefore, anticipate that the civilian population will also benefit from our efforts.