A Practical Curb-Climbing Aid for Wheelchair-Bound Paraplegic Persons (A Progress Report)\textsuperscript{a}

ABSTRACT

The article describes in detail an arrangement of trough-shaped wheel ramps and telescoping articulating control rods intended to allow a wheelchair-bound paraplegic to quickly ascend and descend single steps or curbs as high as 8 in. Data on testing of the system with trained and untrained able-bodied male and female subjects is reported; very limited testing with paraplegics suggests that their performance may almost equal that of the able-bodied. Advantages claimed include simplicity, light weight (8 lb), and low cost. Required modification of a standard wheelchair is limited to welding a simple bracket to the outer end of each extended main wheel axle. With ramps and control rods mounted ready for prompt use, chair width is increased by a total of 6 in. When the chair is used indoors or no curbs are expected, a paraplegic occupant, unaided, can dismount the ramps and rods and store them all in a canvas bag hanging from the seat back. In this configuration the chair is only 1 in wider than its original unmodified width. Further testing with handicapped occupants is intended. Good arm, hand, and lower-back strength and movement, plus good coordination, are user requirements.

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INTRODUCTION

A wheelchair-bound person faces many architectural barriers because many buildings were designed to accommodate the general able-bodied population. Doorways which are wide enough for a walking individual are often too narrow for a wheelchair to pass through. Buildings often have single-step or multi-step entrances which limit their accessibility to the handicapped (1,2). Recent efforts to "mainstream" handicapped persons in terms of education and employment have emphasized the problems of such architectural barriers.

Current legislation has mandated elimination of such barriers in public buildings, but full accessibility for wheelchair-bound persons is far from reality. An alternative or interim solution to the elimination of barriers is to make available devices that can overcome such barriers—particularly the frequently encountered curbs and/or single step-ups.

Many designs have been developed for wheelchairs which enable them to overcome certain curb barriers. Most of these designs use some type of cranking mechanism or lever mechanism to lift the wheelchair over the curb (3,4). Use of such devices has proved to be infeasible because of their mechanical complexity, limited capability, slow operation and/or the excessive muscular strength necessary for their operation. Some solutions that involve a complete redesign of commonly used wheelchairs have been judged not cost-effective (4,6).

Helping paraplegic persons in wheelchairs overcome the curb barrier represents an ongoing rehabilitation engineering effort at the Department of Biomedical Engineering at Louisiana Tech University. An examination of various curb-like barriers plus a review of past designs (3-6) have led to the following set of criteria for a practical curb-climbing aid.

1. The aid should be a supplemental device that can be added easily to existing wheelchairs (4).
2. The aid should not interfere with the portability of the wheelchair.
3. The aid should not interfere with the normal operation of the wheelchair on level ground.
4. The aid should weigh less than 10 pounds (4.5 kg.) so that the user will not be excessively burdened (4).
5. The aid should provide for ascent and descent of curbs up to eight inches (20.3 cm) in height.
6. The aid should allow smooth and quick ascent and
descent of curbs, to reduce the time the wheelchair occupant spends in the street or in hazardous situations.

7. The aid should operate with the wheelchair in normal forward position during both curb ascent and descent.

8. The aid should not require extraordinary effort by the wheelchair user or demand extreme motions of his arms or torso (4).

9. The aid should be simple, reliable, easily maintained, and low in cost.

The remainder of this progress report describes what appears to be a very promising design concept which satisfies many of those criteria. The preliminary test results of a prototype based on the design concept are presented, and modifications which might improve the efficiency of the prototype curb-climbing aid are discussed.

DESIGN CONCEPT

The essence of the curb-climbing assistive device is that ramps for overcoming curbs are carried along with the wheelchair to be used by the chair's occupant as needed. Two channel-shaped ramps—one on each side of the wheelchair—are held in alignment with the wheels by telescopic control rods. These rods are used by the occupant to manipulate the ramps into proper positions prior to curb ascent or descent.

The curb-climbing task is performed using the aid in the following manner:

1. The wheelchair is rolled directly toward the curb and stopped about three feet (91.4 cm) from the curb (Fig. 1a);

2. Portable ramps connected to the extendable control rods are then lowered into place by manual rotation and manipulation of ramps and rods;

3. The chair is rolled up the ramps and onto the walkway while the telescopic rods extend and retract, as necessary, to allow the ramps to remain stationary during the wheelchair's ascent (Fig. 1b);

4. After the chair has reached a stable position on the walkway, the ramps are lifted up and over the shoulders of the user and returned to their forward rest positions by rotation of the control rods and ramps. In the rest position, the lower end of the ramp is on the footrest, with the upper portion leaning on the armrest, as shown by the right ramp in Figure 1c.

The curb-descending task is performed in a similar manner.

The curb-climbing aid is composed of left and right
sections which are mirror images of one another. Each section is made up of three components—the portable ramp, the telescoping control rod, and the axle bracket—which are mounted to the axle of a drive wheel.

The portable ramps
Each ramp (Fig. 2) is made from 1/8 in (0.32 cm) aluminum alloy. The center channel is 4 in (10.2 cm) wide by 36 in (91.4 cm) long with 1 in (2.5 cm) high sidewalls. The channel is wide enough to allow simultaneous passage of the drive wheels and front casters.

A ramp length of 36 in (91.4 cm) was chosen to provide a climbing incline of 1:6 when used on a 6 in (15.2 cm) curb. The gradient of 1:6 has been a suggested gradient to be used in architectural “curb cuts” (1). However, a 1980 National Standard calls for a slope no greater than 1:8 in architectural “curb cuts”.

Each ramp is fitted with a rubber curb-stop on the underside. The rubber stop rests against the edge of the curb and helps to hold the ramp in position during use. The rubber stop (4 x 2 x 1/2 inches) is glued approximately 1.5 in (3.8 cm) back from the leading edge of the ramp (Fig. 3). Strips of Scotch “Safety Walk” are used on the upper surface of the ramps to prevent the wheels from slipping during curb ascents and descents.


The telescoping control rods
The telescoping control rods connect the portable ramps to the wheelchair. The rods are used by the occupant in the proper placement of the ramps for use and they assist in the retention of the ramps during rest (Fig. 2). Each control rod is composed of an inner section and an outer sleeve. The inner section is 3/4 in (1.91 cm) square aluminum tubing 31 in (78.7 cm) long, of 1/8-in (0.32 cm) wall thickness. The outer sleeve is made from 1-in (2.5 cm) square aluminum tubing 24 in (60.9 cm) long. The inner section slides freely within the outer sleeve.

A cotter pin placed an inch (2.54 cm) from the upper end of the inner tube slides within a slot in the outer sleeve. The pin prevents the inner tube from sliding completely out of the outer sleeve. When fully ex-
tended, the two control rods place the ramps 42 in (106.7 cm) from the drive wheel axles. The telescoping feature of the rods permits the portable ramps to remain attached to the wheelchair without hindering the wheelchair when it moves along the ramps.

**The axle brackets**

The outer sleeve of each control rod is clamped into a freely turning bracket mounted to the axle of a rear drive wheel, as shown in Figures 4 and 5. The freely turning bracket allows the ramp to remain stationary as the wheelchair moves along it. The bracket's ability to rotate also allows the operator to rotate the ramp over his or her shoulder to place it in its rest position.

A vertical bar 0.5 in (1.3 cm) square and 3 in (7.6 cm) high has been welded to the drive wheel axle (which has been extended 1 in (2.5 cm)). The brackets are bolted to a piece of 3/4-in (1.9 cm) aluminum square tubing 4 in (10.2 cm) long. This tubing slides over the vertical bar and thus provides an easily removable but secure connection between the aid and the wheelchair. One-and-a-half-inch (3.8-cm) aluminum spacers extend the brackets outward to give adequate hand clearance for manipulating the drive wheels and to align the ramps with the front casters and drive wheels. A summary of the overall specifications is

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**FIGURE 4.** Front view and right-side (outboard) view drawings of an axle bracket illustrate the way the curb-climbing aid is attached to a wheelchair. Photographs (Fig. 5 and Fig. 1a) help clarify the nature of the attachment.

**FIGURE 5.** Left-hand axle bracket.
given in Table 1, and the attachment between the extended axle and bracket is seen in Figure 5.

The canvas ramp holder

When the ramps are connected to the wheelchair via the drive wheel axles, the width of the chair is increased by 6 inches. However, when the operator does not expect to encounter curbs, he can easily disconnect the curb-climbing aid from the modified axles and store it out of the way behind the wheelchair in a specially designed ramp holder (Fig. 6). With the aid in its storage position, the overall wheelchair width is increased by just one inch (2.5 cm). Therefore, the problem of narrow passageways often encountered indoors is not greatly aggravated by the needed axle extension.

TABLE 1.
Overall specifications of the curb-climbing wheelchair aid

<table>
<thead>
<tr>
<th>Total device Weight: 8 lb (3.6 kg.)</th>
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<tbody>
<tr>
<td>Materials used: Largely aluminum alloy of medium weight</td>
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<tr>
<td>Ramp size: Two ramps—each 36 in (91.4 cm) long and 4 in (10.2 cm) wide</td>
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<tr>
<td>Ramp gradients:</td>
</tr>
<tr>
<td>Curb Height</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>4 in (10.2 cm)</td>
</tr>
<tr>
<td>6 in (15.2 cm)</td>
</tr>
<tr>
<td>8 in (17.8 cm)</td>
</tr>
<tr>
<td>Total Width of a Standard Wheelchair After Modification—with the aid in its rest position: 31 in (79.7 cm)</td>
</tr>
<tr>
<td>with the aid in its storage position: 27 in (68.6 cm)</td>
</tr>
<tr>
<td>Operator Requirements: good arm, hand, and lower-back strength and movement, and good coordination</td>
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</tbody>
</table>

PRELIMINARY TEST RESULTS

Preliminary field trials of the prototype curb-climbing aid were performed using able-bodied volunteers untrained in the use of a wheelchair. Nine male and four female subjects were given demonstrations and verbal instructions for use of the modified wheelchair and aid, which they then used to surmount a 4-in (10.2 cm) curb. Each subject was afforded one practice effort at ascending and descending the same curb, before being timed on the use of this wheelchair. The total time required to correctly position the ramps, ascend and descend the curb, and return the ramps to their rest positions was recorded. Data were taken for overcoming both 4-in (10.2 cm) and 8-in (20.4 cm) curbs for every subject.

After completing all tasks, the subjects gave their estimates to the following:

1. Using the curb-climbing wheelchair to ascend a 4-in curb required you to exert what percentage of your maximum effort?
   (10% 25% 50% 75% 100%)

2. What percentage of maximum effort was required to descend the 4-in curb?
   (10% 25% 50% 75% 100%)

3. What percentage of maximum effort was required to ascend the 8-in curb?
   (10% 25% 50% 75% 100%)

4. What percentage of maximum effort was required to descend the 8-in curb?
   (10% 25% 50% 75% 100%)

A summary of estimates is shown in Figure 7.
DISCUSSION OF RESULTS

Data from the preliminary field tests show that the majority of the untrained subjects accomplished the curb ascents and curb descents within one minute, despite their minimal familiarity with the curb-climbing aid and without being encouraged to perform these tasks as quickly as possible. Observations made during the tests indicated that, given more practice and encouragement to speed up the effort, a subject can reduce task completion time by as much as 25%.

The usefulness of a curb-climbing aid depends partially on how quickly the aid enables the user to surmount curbs. A paraplegic person must move quickly if he is to negotiate the curbs of a busy street during the time the traffic light is green. To obtain estimates of the speed with which this curb-climbing device could be used to ascend and descend curbs, two well-trained able-bodied operators repeated the same series of tasks that they had performed as novices. Their performance (Table 2) shows that 4-in (10.1 cm) and 8-in (20.3 cm) curbs could be surmounted in as little as 20 seconds and always in less than 30 seconds, including time for deployment and replacement of the ramps.

### TABLE 2
<table>
<thead>
<tr>
<th></th>
<th>4 in-curb</th>
<th></th>
<th></th>
<th>8 in-curb</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ascent</td>
<td>Descent</td>
<td>Ascent</td>
<td>Descent</td>
</tr>
<tr>
<td>Subject 1</td>
<td>0.32 min</td>
<td>0.32 min</td>
<td>0.35 min</td>
<td>0.48 min</td>
</tr>
<tr>
<td>Subject 2</td>
<td>0.41 min</td>
<td>0.42 min</td>
<td>0.44 min</td>
<td>0.41 min</td>
</tr>
</tbody>
</table>

Field tests and past experience indicate that operator fatigue is not a significant problem associated with the operation of this aid. At the recent Second Annual Interagency Conference on Rehabilitation Engineering, held in Atlanta on August 26—31, 1979, the two experienced able-bodied subjects repeatedly demonstrated the curb-climbing aid. Each subject ascended and descended a 5-in (12.7 cm) curb about six times an hour for 3 hours—over 5 days. Neither subject reported any significant fatigue from this much activity.

Because the curb-climbing device is intended for use by wheelchair-bound paraplegic persons, future tests will include more of these individuals. Preliminary data has been gathered on three paraplegic persons: they learned to use the aid very quickly and their task completion times were very similar to those of the able-bodied volunteers.

FIGURE 7
Summary of preliminary test results. Above: recorded elapsed times. Below: percentages of maximum effort, as estimated by subjects, for ascent and descent of 4-in and 8-in curbs. (Presentation indicates means and standard deviations.)

CONCLUSIONS

The hardware and the operating principles of the portable-ramp curb-climbing aid appear to provide the simplest present solution to the curb barrier. The mechanism is inexpensive, light in weight, and can be added to a standard manual wheelchair with only a minor modification. Use of this aid will enable the wheelchair-bound person to safely surmount curbs of greater height than could be negotiated using the conventional "curb jumping" technique.

REFERENCES