THE DESIGN OF A HAND-POWERED VEHICLE FOR THE MOBILITY IMPAIRED

by
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A Masters Degree Project
Submitted to the Faculty of Environmental Design
in partial fulfillment of the requirements for the degree of
Master of Environmental Design
(Industrial Design)

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FACULTY OF ENVIRONMENTAL DESIGN

The undersigned certify that they have read, and recommend to the Faculty of Environmental Design for acceptance, a Master's Degree Project entitled:

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ABSTRACT

The Design of a Hand-Powered Vehicle for the Mobility Impaired

Prepared in partial fulfillment of the requirements for the degree of Master of Environmental Design (Industrial Design) in the Faculty of Environmental Design, The University of Calgary, December 1992.

Supervisor: Professor James O'Grady

This project aims at designing a lever-driven wheelchair that can be used by a disabled individual much the same as the able-bodied might use a bicycle, for exercise and recreation. The name which I have given this vehicle is The Magellan Wheelchair.

My interest in designing an alternative transportation device for the wheelchair rider developed over a period of time during which I was involved at different levels with a variety of groups dedicated to the belief that the disabled population has a viable contribution to make to society. I had numerous opportunities to experience first hand many of the difficulties experienced by the disabled, and one area that caught my attention was that of alternative methods of transportation for the wheelchair bound individual. This led to the decision to design a method of transportation which would allow these people greater accessibility to the outdoor environment and quite possibly the opportunity for increased independence through improved mobility.

The emphasis of this Master's Degree Project is the design of an alternative form of transportation for the mobility impaired. I have aimed at designing a vehicle which could be produced and marketed in today's market place one that utilizes current technologies and takes advantage of the inroads made in wheelchair design.

Key Words: Wheelchair, Mobility-Impaired, Human-Powered Vehicle, Paraplegics, Disabled, Handicapped, Transportation.

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Finally, I would like to thank Corinne who put her life on hold so that I might wander off chasing windmills. I have so much to say. Your support and never ending patience was a great boon to me. It means more to me than you'll ever know. Thanks so much.

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Introduction

Currently, there is very little information available regarding the design of wheelchairs. What information that does exist deals with specific aspects of wheelchair mobility or seating comfort. In 1969 Herman Kamenetz wrote an insightful book that dealt in a small way with the history and design of wheelchairs, but since that time there have been no other major publications which have dealt solely with the design issue.

It is the intent of this Master's Degree Project to design a wheelchair not to replace the user's current chair but to act as an alternative source of mobility allowing them to participate in activities that in the past would not have been available to them.

The written part of this project is divided into two sections. The first includes a description of the user group, a brief historical overview of the evolution of wheelchair design, a look at future trends in wheelchair design and the potential of the Magellan Wheelchair in the current wheelchair market. This first section provides the preliminary research for this project. It also helps to develop a starting point for the design considerations which are looked at in greater detail in Section II.

Chapter 1, **Background** defines the intended user group and provides a description of various physical handicaps as outlined by Huchingson in his book **New Horizons for Human Factors in Design (1980)**. The second chapter; **History**, establishes a historical perspective in terms of the evolution of wheelchair design which leads to Chapter 3, **Future Trends**. This chapter looks at the trends which wheelchair design may follow in the future. It also looks at current materials and components and provides, in some cases, alternatives to present wheelchair design. Chapter 4, **Market Review**, investigates current and other markets and provides a listing of similar and competing vehicles.

Section Two deals with the design process and design solution as presented in this project. Chapter 5 introduces the **Design Brief** which establishes the design parameters. In Chapter 6 the **Final Design**, is presented. In addition, this chapter evaluates the proposed design according to the design criteria, etc. provided in the Design Brief. Finally, Chapter 7, **Conclusion**, sums up the document and provides further recommendations for the Magellan Wheelchair project.

A full scale appearance model was produced. The design presented is intended to be a practical solution to the problem. It utilizes materials and technologies that are currently available. There was a conscious effort to avoid exotic materials and manufacturing techniques for two reasons: first, most disabled individuals feel enough attention is placed on them already and riding in some exotic beast would only increase their already obvious profile when in fact their real desire is to go about their daily business in relative obscurity; secondly, most of the "new" technologies involve high costs. The Magellan Wheelchair is intended to be produced in small quantities because for the most part, as with standard wheelchairs, it is still a prescription item. Details such as seat pan depth and seat back height have to be addressed on an individual basis.

A great deal of time was spent on the up front research for this project. It was felt that this was necessary to provide the designer with the insight and the understanding of the basic needs of the user group. To this end the appendices contain information that proved crucial at times to the design of the model.

The design presented here may not be the only solution, however, I believe that it addresses the problem as outlined in the **Design Brief** (Chapter 5) most successfully.

SECTION I

1. **Background**

In today's society there are hundreds of thousands of men, women and children who, due to various circumstances, face life confined to a wheelchair:

> *"... many people use wheelchairs to have more personal freedom, to improve their physical functions and to live happier lives." (Kamenetz, p: viii)*

Currently we are experiencing an increased awareness of the physically challenged who want to become more involved in "mainstream" society. Today there are over 700,000 North Americans in wheelchairs and the number is increasing by 15,000 each year. (Alger, p: 19)

Many people are now participating in activities that, five or ten years ago, would not have seemed possible. Climber Hugh Herr lost both feet in a climbing accident in 1982, yet continues to climb with the aid of specially designed prostheses (Roberts, p: 41-48, 88-94). Just recently, paraplegic park ranger, Mark Wellman, climbed to the summit of El Capitan in Yosemite National Park in California: a height of 975 meters. This feat required him to do over 9,000 pull-ups on his way to the summit. Who can forget Rick Hansen's "Man in Motion Tour" in 1986-87. In January of 1989, Bill Duff embarked on a cross-country "wheel" to promote a greater understanding and awareness of the potential of disabled persons (Alger, p: 19). Everyday countless others participate in activities that might have been closed to them at one time. The physically challenged are now participating in such sports as skiing, sailing and court sports, not to mention participating in the Boston Marathon and their own Olympic Games.

For many of these people a wheelchair is the most important object in their daily life. In the last twenty years, wheelchairs have advanced significantly in engineering and production. This has resulted in greatly improved quality, design, varieties and uses for today's wheelchair.

Few people would argue with the idea that standard, not special, products should be developed for the disabled. Products which are designed to provide assistance to one group of disabled individuals may actually be an impediment to another. There will, however, be times when a designer will have to design for the disabled person. The industrial designer must:

"... design for the limits of human performance which are generated by the extremes in size, strength, stamina, sensory perception and intelligence" (Faste, 1977).

Designers tend to underestimate the abilities of the disabled. After all, they are only disabled in terms of their specific "handicap" (please see the Glossary for a definition of handicap and disability). Designing with disabled persons in mind, rather than for them, (specifically and after the fact), will prove to be a safer, more economical route to an environment that is easier for everyone to live in.

" Rehabilitation through design and engineering augmentation is much more than a humanitarian goal. By becoming more self-sufficient, the severely handicapped are able to reduce the expense of welfare and individual care." (Huchingson, p: 459)

"In the United States today, it is estimated that 1 out of 10 people has limited mobility due to a temporary or a permanent physical handicap. Improved medical techniques and an expanding population of older people is increasing this number every year. Yet, in general, the physical environment of our nations communities continue to be designed to accommodate the able-bodied, thereby, increasing the isolation and dependence of disabled persons." (Barrier Free Design, p: 14)

We are all handicapped in one way or another. Many people are forced to operate products that weren't designed with their disability in mind, resulting in handicaps. Consequently, they are subject to hazards that non-impaired people are not exposed to, which only highlights the importance of not accepting the "average person" approach to design.

"The inclusion of disabled persons in design consideration is an issue which affects as many as 34 million Americans (23 million with activity limitation plus 11 million who are over 65)." (Faste, 1977)

In recent years, industrial design has been one of the design professions to respond in a positive fashion to the various groups representing the handicapped. Their efforts have dealt mainly with product development but the issue of design for the handicapped also affects other design professions such as architecture and graphic design.

1.1 Description of Users

Many countries throughout the world are becoming increasingly aware of the large number of disabled persons and the problems they face.

> *" This group includes those born with disabilities and those whose abilities diminish during their lifetime as a result of disease, accident or aging." (Vanderheiden, p: 383)*

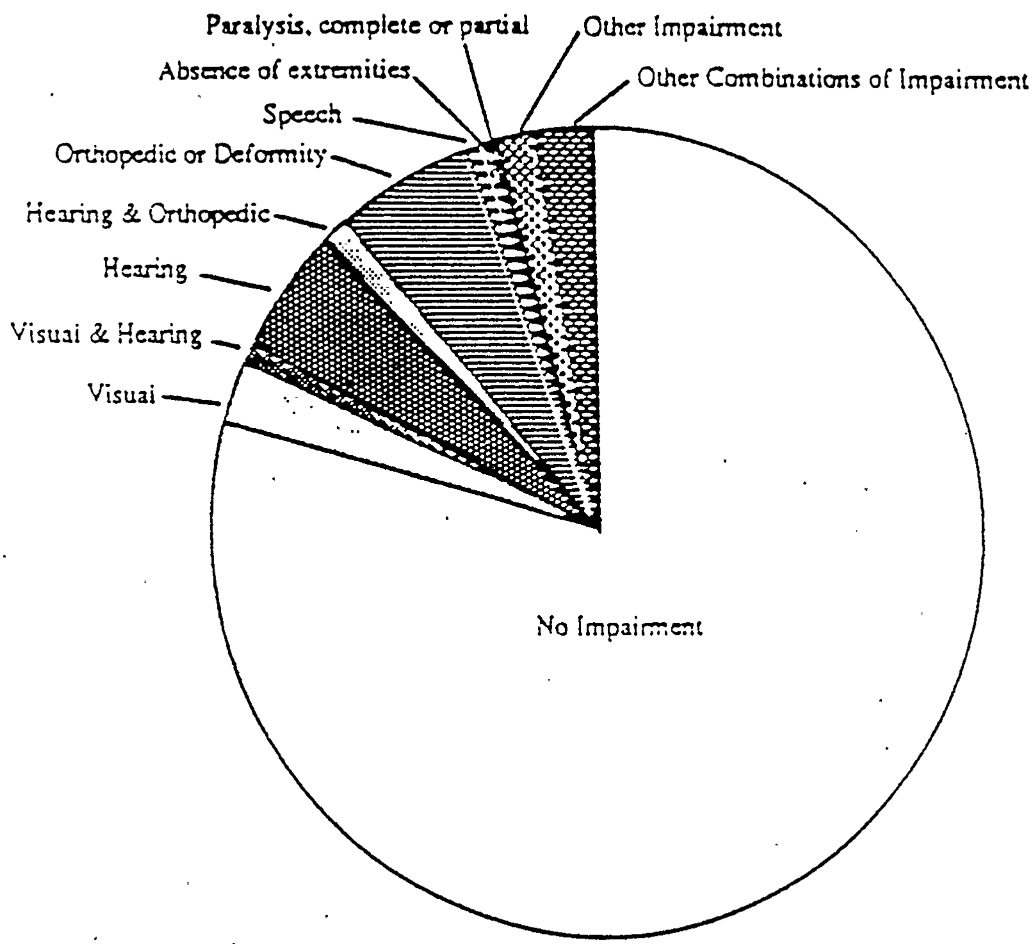


Table 1-1
(Vanderheiden, 1991)

It is important to understand that there is not a clear line differentiating those who are categorized as disabled and those who are not. A large quantity of data has been collected dealing with the handicapped population by the Census Bureau of the United States, by other government departments and by private interest groups representing the disabled. This information provides a broad perspective of the number of people with different disabilities, but it is not always accurate or representative of a certain segment of the disabled population. In a number of cases the individual may have multiple disabilities which would place them in a number of different categories.

In 1990, it was determined that there were approximately 13 million people with;

> *"... physical or motor impairments that interfere with work, of those, about 7 million (approximately 3% of the population) have orthopedic impairments to the back, spine or lower body."* *(Elkind, p: 397)*

Persons with Activity Limitations Resulting from Physical or Motor Handicaps (1990 estimated)

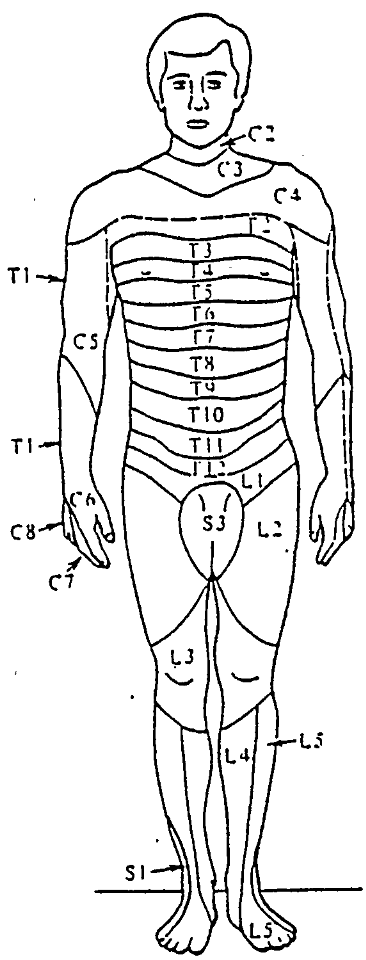
Disability	*Persons (thousands)*	*Percentage of Population*
All persons with activity limits[1]	34 500	13.8
Activity limits in major activity[1]	24 700	9.9
Disability that interferes with work[1]	13 300	5.3
Activity limits caused by orthopedic impairments of:		
Back or spine[1]	3 300	1.3
Hips and lower limbs[1]	4 100	1.6
Deformities or orthopedic impairments[1]	23 400	9.6
Impaired upper limbs[2]	2 900	1.2
Impaired lower limbs[2]	8 600	3.4
Severed spinal cords[2]	580	0.2

Table 1-2
(Elkind, 1991)

1.2 Description of Handicaps

> *" The origin of the disability may be spinal lesion, amputation, diseases such as cerebral palsy, polio, multiple sclerosis, muscular dystrophy and arthritis, or there may be congenital deformations." (Huchingson, p: 461).*

The medical classification of the spinal cord injury is often defined by the location along the spine where the injury occurred.



Parts of the body which become paralyzed following a spinal lesion.
Fracture-dislocation of particular spinal cord segments affects various parts of the body. By and large, paralysis occurs below the lesion, though it not need be total. The following gives an indication of the parts of the body affected by a lesion at a particular segment.

Lesion at C4 affects the diaphragm
Lesion at C5 affects the biceps, arms.
Lesion at C6 affects the wrist, flexion and extension
Lesion at C7 affects the triceps
Lesion at C8 affects the hand

Lesion at T2-T7 affects the chest muscles
Lesion at T9-T12 affects the abdominal muscles
Lesions at L1-L5 affects the leg muscles
Lesions at S2 affects the bowel and bladder

The person with a complete fracture-dislocation at the level of C3 or above usually will not survive.

Figure 1-1 Lesions and affected area
(Huchingson, 1980)

In his book, **New Horizons for Human Factors in Design**, Huchingson (p: 460) states that handicaps are often classified into four areas:

1. Physical or motor handicaps - being without use of one or more limbs. This includes those in wheelchairs and semiambulatory persons with crutches and braces, impaired motor coordination or cardiopulmonary problems.

2. Sensory handicaps - impaired vision or hearing.

3. Intellectual handicaps - being mentally retarded.

4. Emotional handicaps - being psychologically disturbed.

1.3 Physical or Motor Handicaps

For the purposes of this paper only Huchingson's first classification, **Physical and Motor Handicaps**, will be looked at. Within this classification there are four sub-groups:

1. The paraplegic
2. The quadriplegic
3. The amputee
4. The coordination impaired

The first two deal with the spinal cord injured while the last two fall into the "other" category; disabilities that can be the result of any number of causes and which *may* not result in the individual relying on the use of a wheelchair to supplement their mobility.

1.3.1 The Paraplegic

Paraplegics have their lesion in the thoracic region. Persons with lesions below T-6 (see Figure 1-1) can attain a very high degree of physical and psychological independence. They have good trunk stability and may develop great muscular strength in their arms and upper body.

1.3.2 The Quadriplegic

Quadriplegics, or quads as they call themselves, typically sustain their injury as a young adult in an automobile or motorcycle accident or in a sporting event such as football or diving. There are at least 75,000 such persons in North America. Many are capable of productive jobs given proper job design, access and transportation to the workplace.

Designing for quads provides a challenge to bioengineers and human factors specialists. Although much of the voluntary movement of their arms is missing they do have very limited use. Chest and back muscles are paralyzed and wheelchair sitting is somewhat unstable. The C-4 or C-5 quad is the highest level of spinal lesion for which out-patient maintenance is practical (Huchingson, p: 462-464).

1.3.3 The Amputee

This group of physically handicapped typically have lost one or more limbs in industrial or traffic accidents or military service. Those who have lost both lower limbs are functionally similar to some paraplegics and design recommendations offered subsequently regarding wheelchair use are applicable. Those missing one or both upper limbs are traditionally fitted with a grasping device..

1.3.4 The Coordination Impaired

Those with cerebral palsy, multiple sclerosis, Parkinson's disease and many elderly have handicaps characterized by trembling (Huchingson, p: 464-465), making it difficult to perform tasks requiring dexterity such as inserting coins in slots and activating switches (Huchingson, p: 464-465).

1.4 Summary

With the combination of human factors and industrial design, many of the constraints that the disabled individual faces can be overcome. We must recognize, however, that most disabled people would prefer not to have the environment (this being the physical as well as the personal products they might require) designed especially for them. Rather, they would have the environment designed for the participation of all persons.

There are two major reasons for disabled people to feel this way; one is that most "special" products are expensive because of low production runs within that market. However, the single most important reason is that special products often have an unusual appearance which tends to stigmatize the user (Faste, 1977).

> *" Inevitably this 'branding' is valued negatively and thus, simply adds a social problem (prejudice) to what was originally only a physical problem." (Faste, 1977)*

Though we all know design is a compromise, designers are often unaware of whom a particular compromise affects.

2. The Evolution of Wheelchair Design

With the increase in the number of individuals that need a wheelchair it has become a familiar object not only to its user but to everyone. Wheelchair improvements have expanded its use. Intensive rehabilitation of disabled adults and children has brought them from seclusion into greater contact with society in general. Their "mobilization" stimulated further improvements and variations in wheelchairs, which further facilitated the integration of the disabled into all levels of society. (Kamenetz, p: 36)

In a growing population the number of people needing wheelchairs has been growing steadily. In turn the development of the wheelchair has benefited from the increasing number of users and their experiences as well as from the progress being made in the engineering and design fields.

The evolution of wheelchair locomotion from that of the propelled, passive individual to that of the occupant-propelled illustrates the essential principle of rehabilitation: the greatest possible utilization of the individual's capacities which remain after his disease or injury. (Kamenetz, p: 37)

The following two pages provide a graphic representation of some of the more significant developments in the evolution of wheelchair design. The future holds many exciting opportunities. Many builders are experimenting with composite materials and advanced manufacturing processes. The designs are becoming more "user friendly" due to the increase in the amount of time and money being spent on research and development.

HISTORY OF THE WHEELCHAIR
3500 B.C. to 1900 A.D.

Depiction of bicycle like objects found in Middle East in 3000 B.C.

Stone carvings appear dating back to approximately 3500 BC. depicting hand drawn, two-wheeled carts.

Spoked wheels are fitted to chariots about 1300 BC. earliest evidence of chairs with wheels.

Early Roman and Greek physicians recognize the value of movement and transportation for the sick and those who could not walk.

Alternative methods of therapeutic transportation such as: boats, litters , sedan chairs and carts,

Leonardo Da Vinci experiments with bicycle forms.

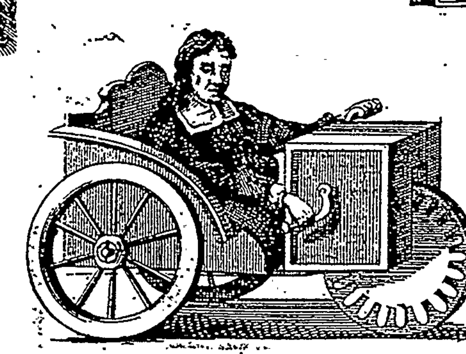
During the renaissance and middle ages there was an increase in the number of wheeled vehicles used for the sick and disabled known as invalid chairs.

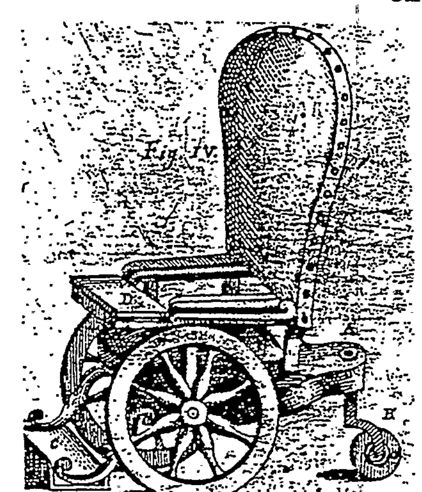
1637-Depiction of a bicycle in a church window in Britain

Significant improvements in wheelchair development - reclining backrests, footrests, armrests and small wheels attached to the bottom of chair legs.

Wheelchairs from the 16th century were large and had to be pushed by more than one individual.

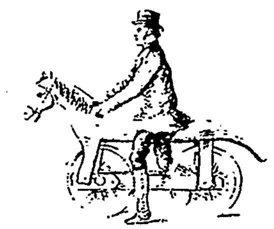
Halfway through the 17th century self-propelled wheelchairs came into existence. These early chairs were operated by cranks and gears.





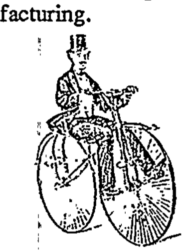
1791-The Comte de Sivrac adds a second wheel and a saddle to a hobby horse. Called celeriferes or velocipedes.

Wheelchairs in the 18th century underwent enormous change. Builders designed the first "wheelable" wheelchair. Castor wheel is developed.



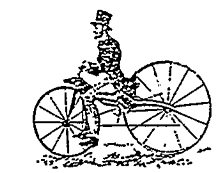
1817-Hobby horse improved upon by Baron van Drais. He added a steerable front wheel. Calls his device a Draisene.

1818-1820-Variations of the Draisene are exported to Great Britain and North America. British become world leaders in design and manufacturing.

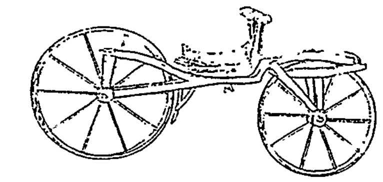


Designs and improvements in the wheelchair develop at an accelerated pace in the 19th century. Noted builders were James Heath and Alfred Carter of London, England.

1839-40- Kirkpatrick Macmillan designs long lever-like arms to propel the rear axle. He also has the first recorded bicycle accident.



1871-76-In England, velocipedes are called bone-shakers. James Starley invents the penny farthing bicycle.



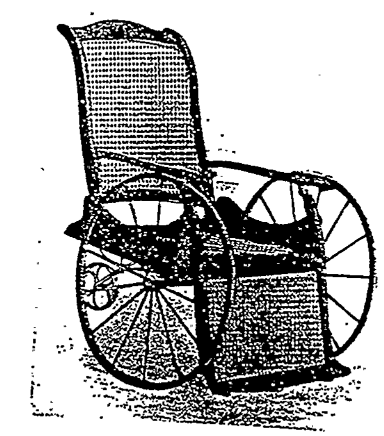
Bicycles introduced in Europe. Wheelchairs adopt wheels from bicycles. First rubber tires are introduced for the bicycle in 1875. Introduction of metal-spoked wheels for the bicycle. Tangential spoking pattern developed.

1885-87-John Kemp Starley improves on the safety. Utilizes the diamond shape frame, curved front forks and handle bars for steering.

1887-John Boyd Dunlop develops the first pneumatic tire. The Michelin brothers of France design a tire which can be removed from the wheel to repair punctures.

Wheelchairs adopt tubular steel frame from bicycle.

1890-Peter Gendron, founder of the oldest wheelchair manufacturing company in the U>S> makes a wheelchair with wire-spoked wheels.



HISTORY OF THE WHEELCHAIR
1900 A.D to PRESENT

1900-The bicycle boom has leveled off and has become more a fact of life in most Western societies.

Early 20th century that wheelchairs are actually called wheelchairs.

Rubber tires first used on wheelchairs.

American wheelchair catalogue shows a three-wheeled chair for self-propulsion with a third wheel in the rear.

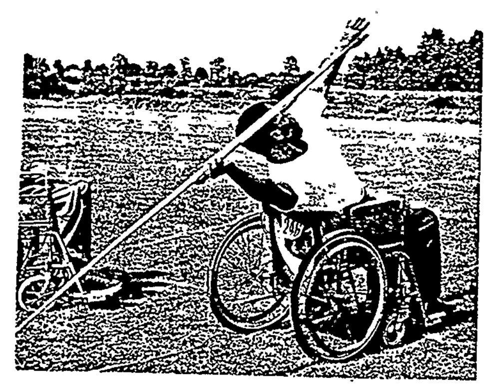
Experiments with folding wheelchair design.

1912-Introduction of the first power chair.

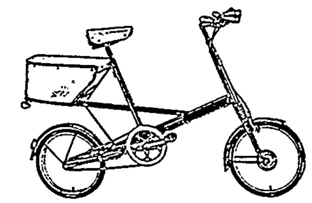
1933-Herbert A. Everest and Harry C. Jennings develop a lightweight, folding wheelchair.

Samuel Duke of Chicago develops a folding wheelchair in 1934. His design uses two small wheels on the front and two large ones in the rear.

Dr. Ludwig Guttman introduces athletics as a method of rehabilitation for disabled war vets. 1941- Spinal injuries unit set up in Stoke Mandeville Hospital in Aylesbury, England. 1944- Centre opens.



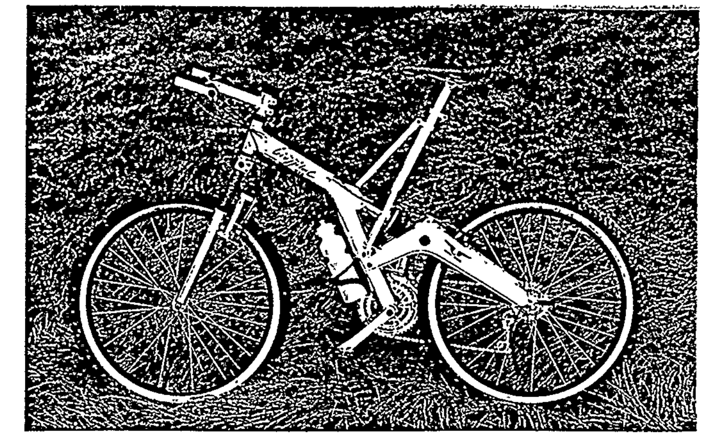
1944-80% of all Chinese citizens use a bicycle for personal travel.



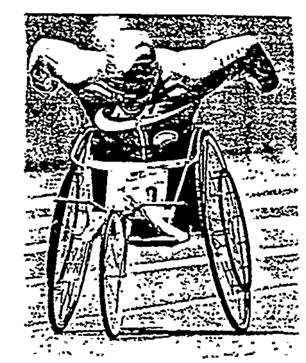
1974- The first Wheelchair marathon is held in Ohio.

1975-Bob Hall
1977- There are 7 wheelchair competitors in the Boston Marathon.

1978-First"ATB" was designed and tested on Mt. Tamalpais in California



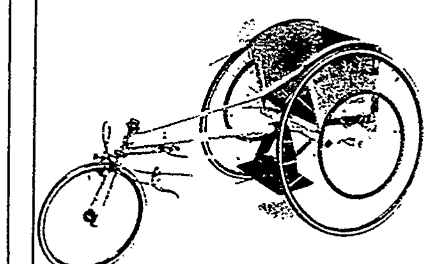
1984-Los Angeles: Wheelchair athletes compete for the first time in an Olympic exhibition event. The time for the 1500 metres is 3 minutes 58.50 seconds.



The U.S. congress passes law guaranteeing the rights of the disabled.

1987-Rick Hansen's "Man In Motion" tour.

Wheelchair designers begin experimenting with exotic materials and manufacturing processes first used in the bicycle industry.



3. Future Developments

3.1 Introduction

Over the past several years, there has been an increased interest in the wheelchair by designers, engineers and the general public. This may be due to the fact that the wheelchair has now come to symbolize the handicapped. A stylized wheelchair is recognized as the international symbol for the handicapped - it is a tangible and recognizable object (Figure 3-1).

Figure 3-1 International Disabled Symbol

With the exception of the sport-type wheelchair (Figure 3-2), which was developed in response to the need for a specialized chair in wheelchair athletics, manufacturers of wheelchairs have been rather conservative in introducing new ideas and have instead concentrated on bringing out minor improvements.

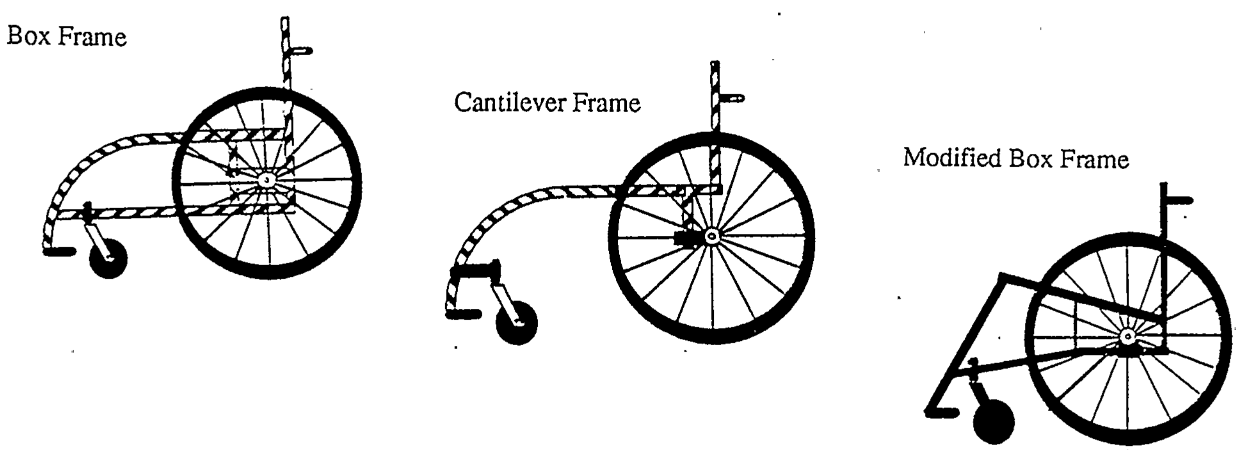


Figure 3-2 Sport Chair Frames
(Cooper, 1991)

Problems of liability and a perceived low overall market demand have contributed to a conservative approach among manufacturers. Although it is difficult to determine how much research is being done by the manufacturers, it is doubtful that much effort is being devoted to improved wheelchair design. (McLaurin, p: 88)

Adaptability and adjustability play key roles in the future of wheelchair design. Adjustability without compromise in performance is the goal (Cooper, 1991).

3.2 Functional Characteristics

The primary purpose behind research is to improve the functional characteristics of the wheelchair. These can be divided into two categories: 1) seating comfort and 2) mobility (McLaurin, p: 89).

3.2.1 Seating

Much has been said about the disadvantages of the sling (or hammock) seat but there is very little documented proof to support these claims.

> *" However, it requires little observation to note that just minor differences in wheelchair seating, usually only width and depth, can hardly accommodate the range of sizes, disability types, personal attributes, and activities that exist in the user population." (McLaurin, p: 89)*

It should be the primary duty of researchers to establish a data resource regarding individual requirements. The most basic work should be a collection of anthropometric data for wheelchair users. McLaurin (1990), points out that both the Universities of Memphis and Virginia have initiated such data collection processes.

3.2.2 Mobility

To some degree, mobility is dependent upon seating as well as on the rolling characteristics of the wheelchair.

One of the most important factors contributing to propulsion efficiency is "mechanical advantage" (McLaurin, 1990), since it determines if muscles perform at their optimum.

Lever or crank drives, or handrim drives that are separate from the drive, (Figure 3-3), wheels, provide a simple means for obtaining an optimum mechanical advantage through a bicycle-type chain and sprocket transmission.

> *" Since levers have been shown to be more efficient than handrims, their use in wheelchairs can be expected to increase in the future. The main disadvantage of levers - the difficulty in achieving the control and maneuverability associated with handrims - appears to have been overcome by recent designs." (McLaurin, p: 89-90)*

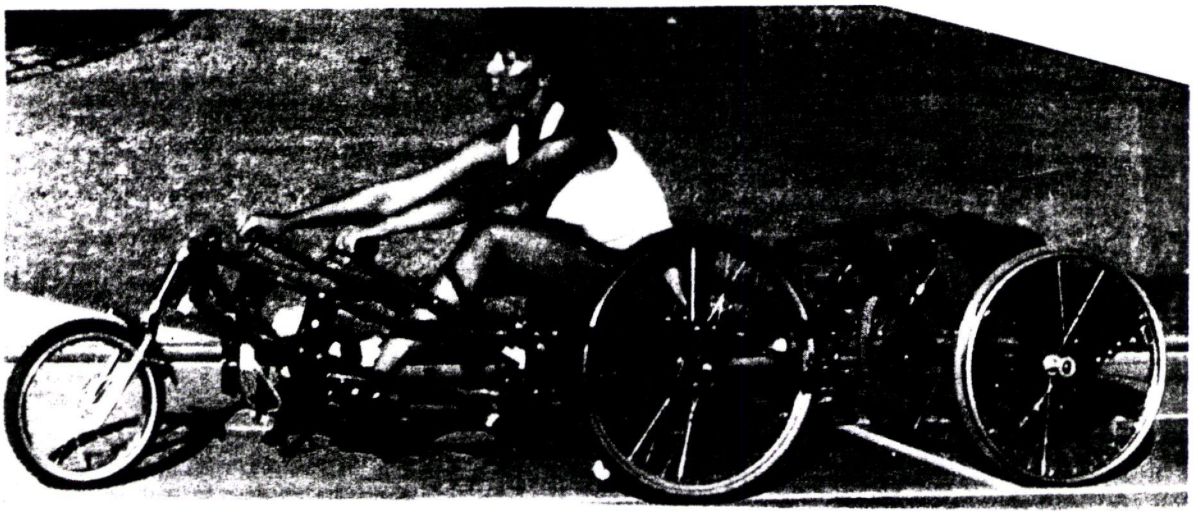
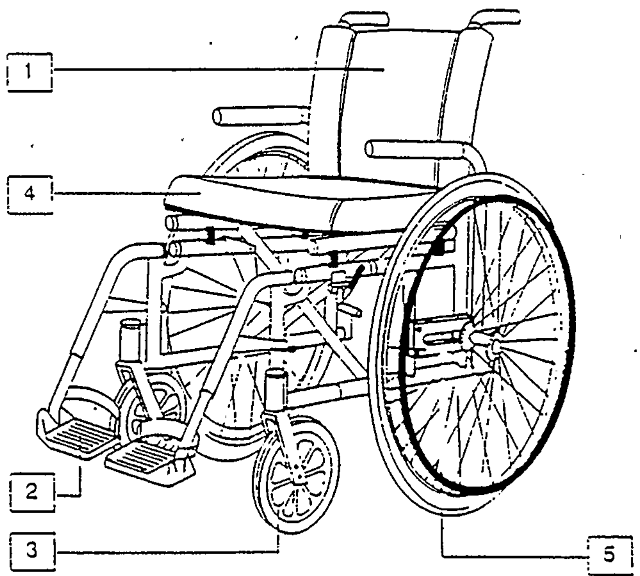


Figure 3-3 Rowcycle with wheelchair towing behind
(Rowcycle, 1990)

Recent research into wheelchair propulsion systems will have significant impact on the future of wheelchair design.

3.3 <u>The Effects of Research on Component Design</u>

Much like bicycles, wheelchairs are an assemblage of components that include a frame, seat, backrest, wheels and drive systems (Figure 3-4).



1. Backrest
2. Frame
3. Front Wheels (castors)
4. Seat & Cushion
5. Rear Wheel & Drive System

Figure 3-4 Wheelchair Components
(Quickie Designs, 1989)

3.3.1 **Frame**

Tubular steel construction will probably be the mainstay for some time to come. Optional materials include aluminum alloys, titanium and composite materials. Regardless of the material, simple stress analysis systems are available to allow the designer to ensure adequate strength where needed. McLaurin in his article, **Current Directions in Wheelchair Research (1990),** cites an example of the tube adjacent to the castor;

> *" ..which has been shown in analysis and testing to be a highly stressed point. By simply replacing the round tubing with square tubing at this point, the strength is increased by about 38%."*

Plastics are also being used more in frame design. Reinforced plastics and composites that can include panels with foam or honeycomb cores are light and strong. Production costs show that side frames can be produced in quantity for as little as $50.00 since these parts are made in a one-step process requiring no further finishing (McLaurin, p: 92).

The frames should adjust to suit the individual. Experimental plastics and composite models have shown how the seat and seat back, and the positioning over the front and rear wheels, can be adjusted with simple tools and little effort. This type of adjustability should become part of routine wheelchair prescriptions (McLaurin, p: 93). Ideally, it should be possible for the user to make these adjustments without leaving the seat.

3.3.2 Seat

For simplicity sake, the sling seat will probably remain the standard for the near future. Increased research conducted on plastics and composites suggests that more consideration be given to rigid seats which provide firm, predictable support.

3.3.3 Lightweight Frames with Adjustable Seat Systems

> *" No wheelchairs are commercially available that reflect the design and development of seats having the optimum support characteristics determined by research, plus the light weight and foldability required for wheelchair use" (McLaurin, p: 94).*

This could be a considerable task if the designer is to remain within the fiscal restrictions of the marketplace.

3.3.4 Wheels

Although the wire-spoke wheel is difficult to improve upon from the standpoint of strength and weight, reinforced plastics are making inroads and use of these materials will increase in the future (Figure 3-5). The main advantages of this type over metal are higher durability and lower maintenance. The main drawback to the use of the plastic wheel is the high cost . Wire-spoked wheels are approximately one-fifth the cost of the reinforced plastic version ($25.00 per wheel as compared to $125.00 or more per reinforced plastic wheel).

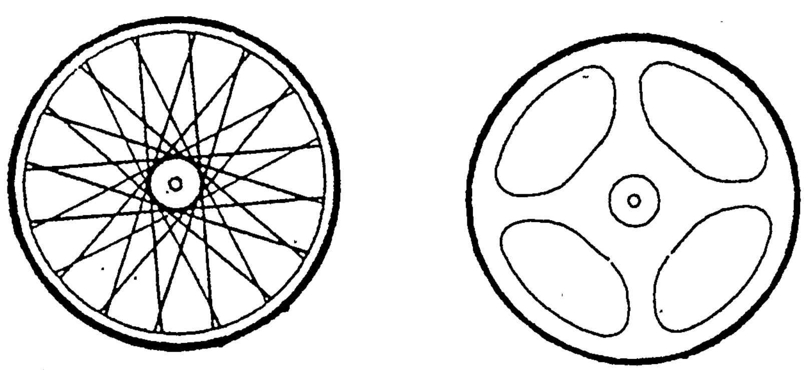


Figure 3-5 Wheel Types

3.3.5 Tires

Non-pneumatic tires made of urethane and other synthetic materials are beginning to appear on some racing and sport chairs. In some cases, they approach the light weight and low rolling resistance of high-pressure pneumatic tires. However, to provide a ride comparable in comfort to pneumatic tires, some type of suspension may be required. Several types of suspension have been undergoing testing but none have been able to provide comfort without bounce, nor have they reduced the stress on the frame (McLaurin, p: 96).

3.3.6 Brakes

Recent surveys conducted by **Paraplegia News, (1985)**, showed that paralyzed veterans would like their wheelchairs to be equipped with running brakes that allow the user to control the speed of the chair on hills and when coming to a stop (McLaurin, 1990). Drum-type brakes, like those used on some wheelchairs and bicycles in Europe, are a satisfactory solution; it is now up to North American manufacturers to respond (McLaurin, 1990).

3.3.7 Drive Systems

Although there are proven functional advantages to alternative drive systems (see Figure 3-6), the inherent simplicity of rim drive still has great appeal to many users, however;

> *" ... The considerable interest in lever drive systems that has generated in the last two years should give rise to one or more commercially available models, either as a complete wheelchair or as an add- on accessory." (McLaurin, p: 96)*

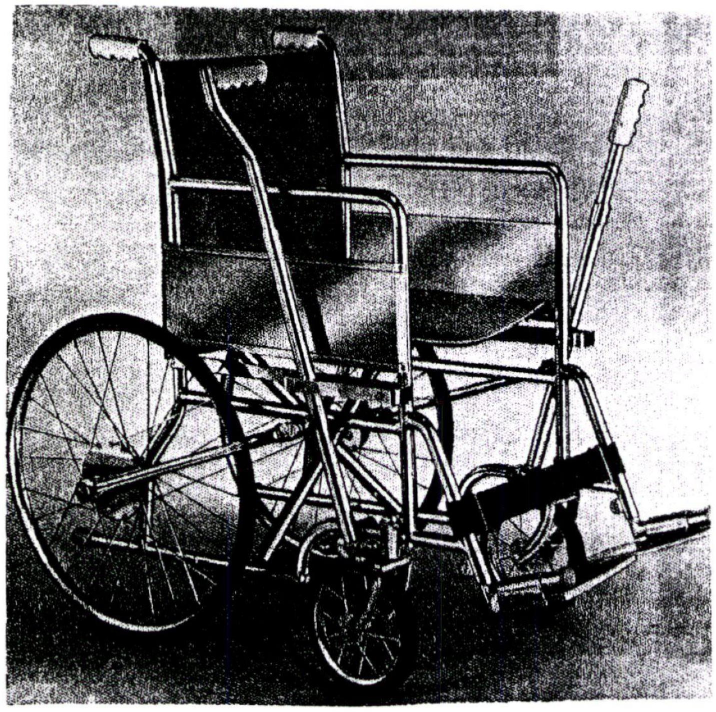


Figure 3-6 Alternative Lever Drive Wheelchair
(Kamenetz, 1969)

3.4 **Summary**

> *" Emerging from the recent advances in wheelchair technology and the availability of inexpensive imported wheelchairs, is a marked distinction between commodity, or occasional use wheelchairs, and prescription-type wheelchairs that serve as an integral part of a user's lifestyle." (McLaurin, p: 98)*

Continued development of the prescription chair is needed. Seating comfort is probably the most important need. Only recently have chairs become available that offer any kind of effective adjustability.

Propulsion systems such as levers are receiving greater attention. Further development in material and structural design can reduce costs and increase the durability of the chair.

Currently, the wheelchair manufacturing industry is undergoing a period of accelerated change with many new designs and concepts surfacing. McLaurin in closing states:

> *" It is hoped that this future includes a marketing system that allows a customer to choose from a variety of components that can be assembled to provide a machine hat suits the size, function, and appearance desired, as well as the*

prospect of immediate delivery. Providing a suitable, reliable product without delay and at a reasonable cost should be the main goal of research in the wheelchair industry." (McLaurin, p: 98)

4. Market Review

4.1 Introduction

The trend towards a growing elderly population and an increase in the number of disabled individuals entering the workforce provides a potential market for products which can be classified as "living aids". Again, most disabled individuals prefer not to have products designed specifically for them, but would rather have the design of existing products enhanced to promote use by both the disabled and the able-bodied. The wheelchair, however, is one item for which the able-bodied individual would have little or no need.

Wheelchairs can be generally classified into two categories - the standard or general wheelchair and the sports chair. The former is a heavy, rigid chair which is used by the more "sedentary" individual and lends itself well to being equipped with external power and drive sources.

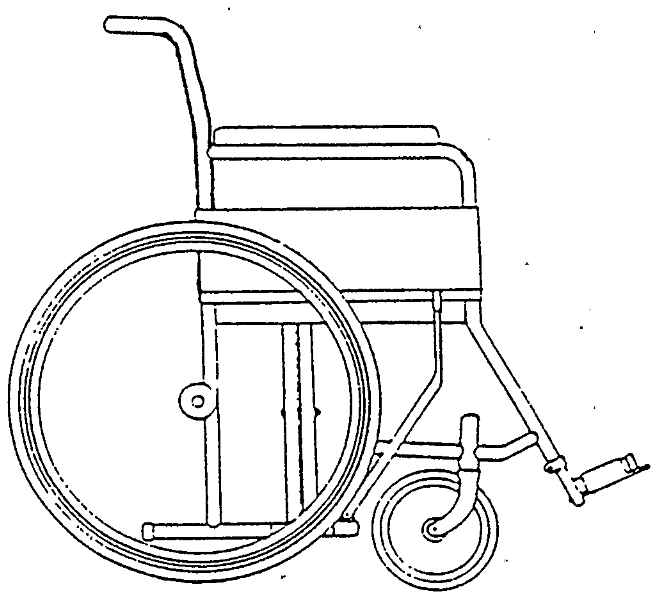


Figure 4-1 Standard or General Wheelchair
(Kamenetz, 1969)

The sport chair is lighter, closer fitting and usually more expensive. Sports chair designs are as varied as there are sports to participate in or individuals to use them. There are chairs for road racing, chairs for tennis and chairs for outings to the beach. The Magellan Wheelchair fits into the recreational sports chair market.

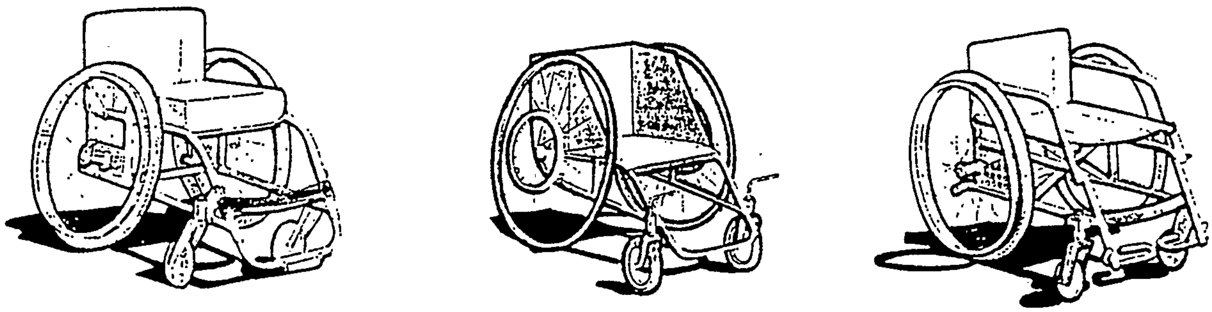


Figure 4-2 Typical Sport Chair styles
(Wilson et al 1990)

4.2 Potential

There are over 700,000 wheelchairs users in North America, of that number 15% to 25% (105,000 to 175,000) participate in some form of physical activity. The Magellan chair is aimed at the active paraplegic with a lesion below T-6 (see Figure 1-1) or individuals with good trunk stability such as lower limb amputees (Huchingson, p: 462). The market for the Magellan chair is one similar to that of the mountain bike. It will not replace the user's regular chair but will act as a supplement or an alternative much like an able-bodied individual might use a bicycle or cross-country skis - for exercise and recreation.

4.3 Competitors

There are 15 competitors identified at this time. Of the fifteen, four are propelled by a rowing motion similar to the Magellan. The other designs use a crank or pedal system similar to a bicycle. The prices range from $1000.00 to over $10,000.00. All but one are manufactured in North America. A partial listing can be found in Appendix III.

4.4 Marketing Strategy

The greatest drawback for all the competitors, save one, is the relatively high cost. Normally a wheelchair is a prescription item with some standard or general chairs available for rent or loan through specialty stores. Each chair should be measured and fit to the specific individual, taking into consideration such things as hip width and leg length. With this in mind, most major manufacturers deal with hospitals, specialty stores and occupational and physical therapists almost exclusively. Another method of marketing for small producers is medical trade shows which take place at various times of the year in a number of different cities. Smaller firms may be involved with mail order practices but this can be risky to the purchaser. Not only is it impossible to get a "feel" for the chair but many manufacturers do not stay in business long, leaving the buyer at risk of losing a portion or all of their down payment. Of 15 small manufacturers surveyed in 1989 only 5 were still in business in 1991 (personal communication (1), 1991).

Since the Magellan chair is designed for the active individual it would be sold through sporting goods and fitness related stores as well as the more traditional methods of trade shows and publications aimed at the disabled. In addition, it could be sold through demonstrations and presentations to hospitals and persons who deal with mobility impaired individuals.

4.5 Other Markets

There is the potential for the Magellan Wheelchair to be adapted slightly in order to be used as a more traditional "Human Powered Vehicle" (HPV) by the able-bodied. The Asian and Middle Eastern markets warrant further investigation. These countries are used to having bicycles on the street (74 million in India, [personal communication (2), 1992]). The major drawbacks are: firstly, in most of these cultures the disabled individual is placed very low in the social class; secondly, the concern or appreciation of the needs of the disabled does not exist as in North America; and thirdly, the costs involved in manufacturing and producing the Magellan Wheelchair might prove to be prohibitive.

4.6 Summary

I have deemed, through market investigation and conversations, with disabled individuals and some small wheelchair manufacturers, that the Magellan chair has the possibility of being a product which could fit nicely into the niche market of specialized sport chairs. The greatest difficulty is the process of initial acceptance. Careful consideration has to be taken in the design of the chair so that both the aesthetic and functional needs are met.

Most of the smaller, independent designers and manufacturers are disabled themselves and seem to have a very tight (yet competitive) "fraternity" that is difficult to approach by the able-bodied.

SECTION II

5. Design Brief

5.1 Purpose of the Design Brief

The design brief is used to aid the designer in establishing the criteria, constraints and critical aims of the project. The design brief also helps the designer to establish goals and objectives as well as to focus on particular areas of the project without becoming bogged down in a myriad of details. It is essential for the designer to look at the project in small pieces with the goal of tying these pieces together to compile the final product.

If the project is being developed for a client, the design brief will also aid in becoming a means of communication between the client and designer. For this project the author is both client and designer and the design brief has provided a means of establishing guidelines which can be followed (to some degree) to the completion of the project.

5.2 Design Objectives

The design objectives are as follows:

1. Provide for greater individual freedom and increased accessibility to a variety of different activities for the mobility impaired.

2. Design a wheelchair that could be used as an exercise device or recreational vehicle much the same as able-bodied individuals use a bicycle.

3. Respond to the biomechanic and ergonomic principles that go into the design of a wheelchair.

4. Design a lever driven wheelchair that could be manufactured locally.
    4.1. Design a wheelchair that can be constructed at a reasonable cost.

5. Increase mainstream society's awareness of the potential of the disabled.

5.3 Assumptions

1. Users will only be in the chair for certain parts of the day.

2. The chair is not intended to replace the users "everyday" chair.

3. The chair is designed to be used on varied terrain; i.e. bicycle paths and mountain bike trails, etc.

4. The fitting of the chair is similar to "standard" or "sport" chairs.

5. Cushions and comfort aids are prescription items and should be dealt with on an individual basis.

5.4 Critical Aims

The critical aims were derived partly from a survey (see Appendix II for a copy of the survey) in which wheelchair users were asked to list the features they thought were most important in a wheelchair.

1. Functional
2. Safe
3. Comfortable and stable
4. Accessible
5. Easy to operate
6. Inexpensive

The terms used above were provided by the tester and approved by the University of Calgary Ethics Committee (please refer to Appendix II).

5.5 Constraints

Inherent in all product design for the disabled, and specifically in wheelchair design, is the consideration of the physical ability of the user. As reported by both Vanderheiden (1991) and Elkind (1991), many disabled individuals have more than one functional disability which makes universal product design next to impossible. The constraints as they apply to the Magellan wheelchair fall into two categories. The first deals with constraints as they apply to the user and the activity. The second category deals with the appropriate technology used in the design and manufacture of the Magellan wheelchair.

5.5.1 User/Activity

Although the use of wheelchairs for athletic and recreational purposes is not new, the use of a wheelchair for long-range commuting and training is.

The constraints as they apply to the user/activity category are as follows:

1. The Magellan Wheelchair will be used by individuals with a wide variety of disabilities and impairments; therefore, it should be adjustable or be designed so that a number of frame sizes, etc. can be offered.

2. The Magellan wheelchair will be used under varying environmental conditions so it should allow for some adaptability (i.e.: individual cushioning requirements, adjustable foot supports, etc.).

3. Ninety percent of those individuals who are dependent on a wheelchair for their mobility earn less than $10,000.00 per year. The Magellan wheelchair should be designed and manufactured so that it is affordable by those who would use it.

4. The Magellan Wheelchair should be easy to maintain. It should also utilize "off-the-shelf" componentry as much as possible to ease repair and maintenance costs.

5. The operational learning curve should be such that little or no time is required to be able to operate the Magellan wheelchair.

6. Most disabled individuals do not like to be seen as different. Most products designed for individuals with physical handicaps look clinical and their appearance sets these people apart from the able-bodied population. With this in mind the Magellan wheelchair should look like an exciting and enjoyable piece of recreational equipment.

7. Even though wheelchair bound individuals may have lesions in similar areas there physical characteristics may not be the same. With this in mind it would be necessary to

design and produce a number of different frame sizes much the same as bicycle manufacturers have.

5.5.2 Appropriate Technology

1. While sports chairs are in high demand, the target market for a wheelchair designed for long-range commuting and training is unknown. The overall target market for a "recreational" vehicle for the mobility impaired is small - approximately 15% to 25% of the population dependent on wheelchairs.

2. Considering the above, the Magellan wheelchair should incorporate materials and manufacturing processes that are applicable to low production runs.

3. There is, however, the potential for increased demand so the above processes should allow for the expansion of production if it is warranted.

4. Design modifications should be considered as a way of keeping production costs down.

5. Allowing for design modifications should not jeopardize the user's safety and comfort.

5.6 Criteria

The criteria for the design of the Magellan chair is divided into the following categories:

1. Safe
    - visible
    - protects the user
    - does not contribute to user discomfort

2. Functional
    - the wheelchair operates as it should
    - reliable
    - frame sizes should fit the individual's anthropometric and biomechanic needs.
        - along with this consideration has to taken in regards to frame size adjustments, options, etc.

3. Aesthetically pleasing

- takes into consideration current and
  future design concerns
- the wheelchair is pleasing to look at and easy to operate

4. Short learning curve

- The operation of the wheelchair is "easy" for all users
- documented instruction is limited and does not require any special skills

5. Easy to adjust and repair

- modification of seat and footrest locations are available and require no special skills or tools to accomplish
- repairs can be done by the user or the user's sporting goods or fitness store

6) Cost effective

- material costs are kept to a minimal by using "off-the-shelf" materials
- production costs will vary depending on the size of the production run

5.7 Design Parameters

Through careful and thorough research, a set of design parameters was established which was used as a set of design guidelines. These initial guidelines were used to establish the basic frame configuration along with a simple set of geometric "rules".

Testing of these rules was carried out using simple test jigs and full scale prototyping of the frame and various other components. Figure 5-1 illustrates the use of sketch models to establish form. In Figure 5-2 a full scale sketch model was developed to "test" the seating and foot placement. This concept was further refined to Figure 5-3 which acted as a testing prototype for the geometry as well as the steering and propulsion system. From the information gathered from these preliminary models along with input from user surveys, questionnaires and conversations with a number of "technical experts" as well as my own insights the following parameters were established.

1, The wheel base should be similar to that of a "standard" wheelchair.

2. The track width should allow for movement between standard door openings.

3. The user sits in a slightly recumbent position.

4. The centre of gravity and ground clearance should be such as to allow the user a feeling of security and comfort.

5. There is an understanding that this is the beginning of an evolutionary process.

5.8 Deliverables

It is the purpose of this MDP to design a wheeled vehicle which can be used for a number of recreational activities. The chair is not intended to replace the users "everyday" chair but to supplement their mobility requirements and to offer them the opportunity to participate in activities that they might otherwise not.

To this end an appearance model was be developed. At the conceptual level it was subjected to a series of modeling stages each designed to test certain aspects of the frame design, propulsion mechanism and seating system. The results of this investigation will lead to a final design proposal which is presented in Chapter 6.

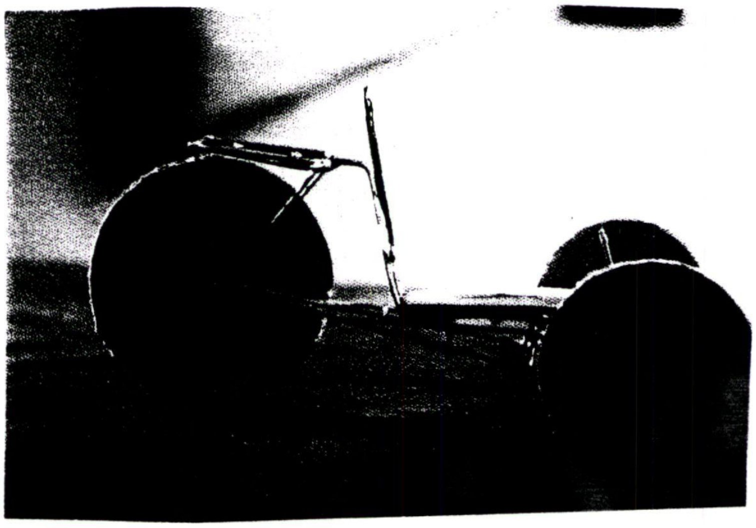


Figure 5-1 Sketch Model

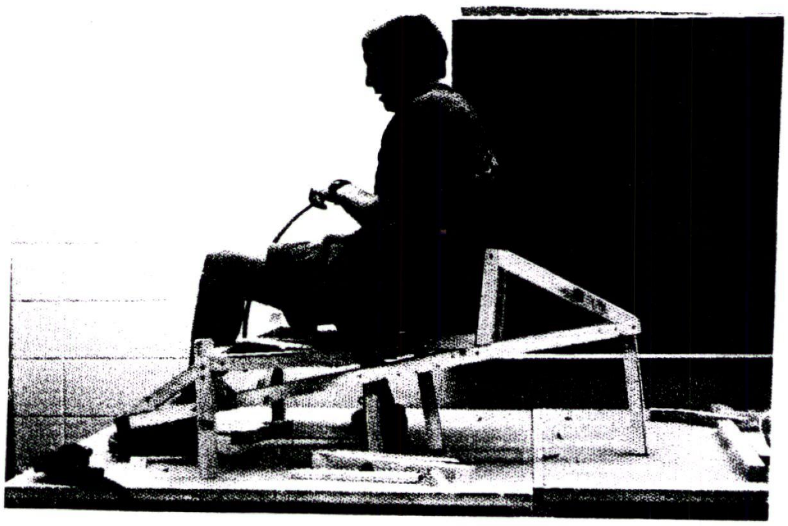


Figure 5-2 Full Scale Sketch Model

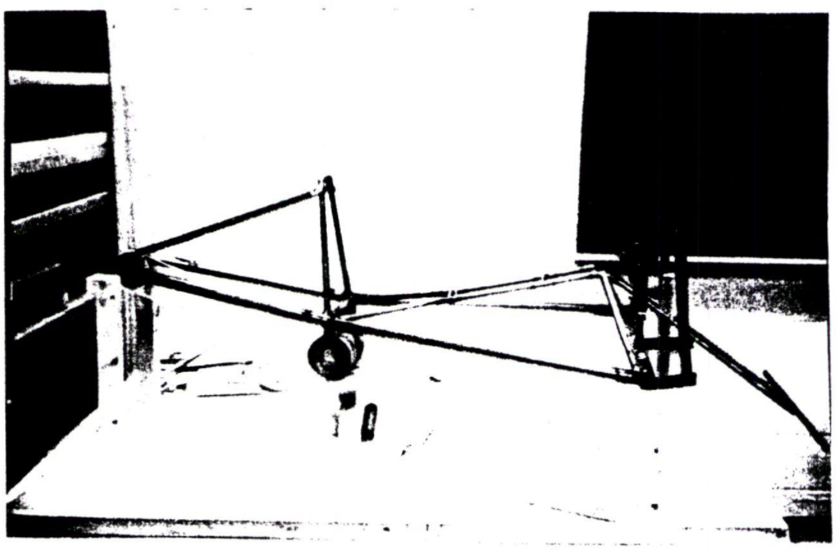


Figure 5-3 Testing Jig

6. **The Design of the Magellan Wheelchair**

6.1 **Introduction**

The emergence of the lightweight, high performance wheelchair has greatly reduced the feeling of encumbrance the wheelchair presents to the user. There is a growing sense of expectation and a heightened potential for sport vehicles to become more an extension of the individual's mobility than a hindrance to it. The design improvements of the sports wheelchair can be applied to the everyday chair and the enhanced performance allows for greater mobility and independence.

Once the recovery and living needs are taken care of, recreation becomes essential for complete rehabilitation. While the traditional wheelchair continues to be upgraded it is necessary to develop alternative design solutions.

As a recreational activity making use of both physical and emotional vitality, "wheeling" is appropriate for an individual trying to overcome difficulties in mobility and participation.

Depending on the interests and specific needs of the individual, the Magellan Wheelchair may be used for a wide variety of therapeutic and recreational purposes ranging from exercise and relaxation to the exploration of the countryside and ones own abilities.

6.2 **User-chair Interface**

The user-chair interface is probably the most critical factor in wheelchair design - and it is usually the least understood. The user and the chair must act as one unit. The wheelchair should be designed to utilize the users maximum potential not limit it.

Even though there is a great deal of variability among users there are some generally followed guidelines which apply to the active sport chair user.

1. The chair must become an extension of the user's body, much like an orthosis.

2. Critical chair dimensions must be matched to the user's body dimensions.

3. The chair must be matched to the user's ability and intended use.

(Cooper, 1991)

6.3 Suggested Design

The final design of the Magellan Wheelchair was developed through the preliminary design brief, a user questionnaire and survey (see Appendix II), the analysis of human factors information, and the construction and testing of several sketch models and test jigs.

6.3.1 Design Form

The form of the Magellan Wheelchair is triangular in shape with a single drive wheel in the rear and two steered wheels in the front. It has an aerodynamic shape which is a very stable configuration as the center of gravity is low and close to the front (Figure 6-1). This configuration is also compact and maneuverable with a small turning radius. In studies it has proven to be a safe and practical solution due to the above mentioned factors (van Engelen, p: 29).

6.3.2 Design Components

The Magellan Wheelchair is made up of the:

1. Frame

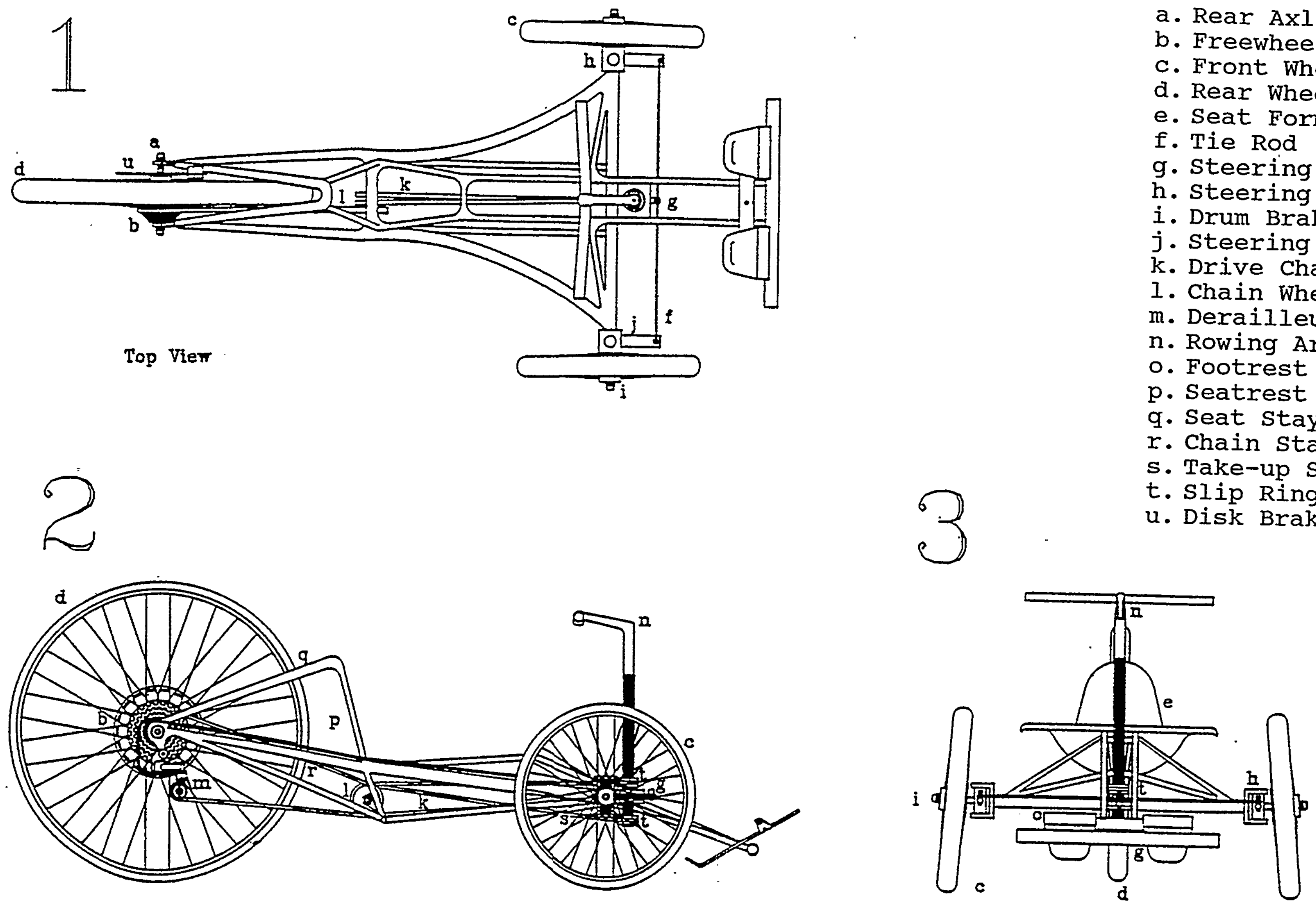
2. Propulsion System

3. Seating System.

The design will be discussed according to a breakdown of these major components and their parts.

6.3.2.1 Frame

The frame is the most important part of the wheelchair. It provides a geometry (by way of seating and propulsion system location) that positions the body for efficient movement.



GENERAL ASSEMBLY

a. Rear Axle and Lock Nut
b. Freewheel Cluster
c. Front Wheel
d. Rear Wheel
e. Seat Form
f. Tie Rod
g. Steering Mechanism
h. Steering Bracket
i. Drum Brake Hub
j. Steering Spindle
k. Drive Chains
l. Chain Wheels
m. Derailleur
n. Rowing Arm
o. Footrest
p. Seatrest
q. Seat Stay
r. Chain Stay
s. Take-up Spring
t. Slip Rings
u. Disk Brake

FIGURE 6-1

The Magellan Wheelchair should be constructed of seamless, chrome-moly tubing - used for strength and comfort. High strength, light-gauge, steel tubing increases comfort in two ways. Firstly, a lighter frame means less unsprung weight. This means that a lighter frame will transmit less road shock to the users body. Second, light-gauge tubing is more resilient, or flexible, which enables it to absorb more of the bumps and smooth out the ride.

The frame is made up of three elements - the main frame, the seat support and footrest and the chain stays, seat stays and back support (see Figure 6-2).

1. Main Frame - constructed of 1 1/8" seamless chrome-moly tubing with a .049 wall thickness.

2. Seat Support, Footrest and Structural Support- constructed of 1/2" and 1 1/8" seamless chrome-moly tubing with a .049 wall thickness (see Figure 6-3).

3. Seat Stays, Chain Stays and Back Support - constructed of seamless 7/8" chrome-moly tubing tapered to 1/2" at the end with drop-forged dropouts.

6.3.2.2 **Propulsion System**

The propulsion system is made up of the following components (see Figure 6-4):

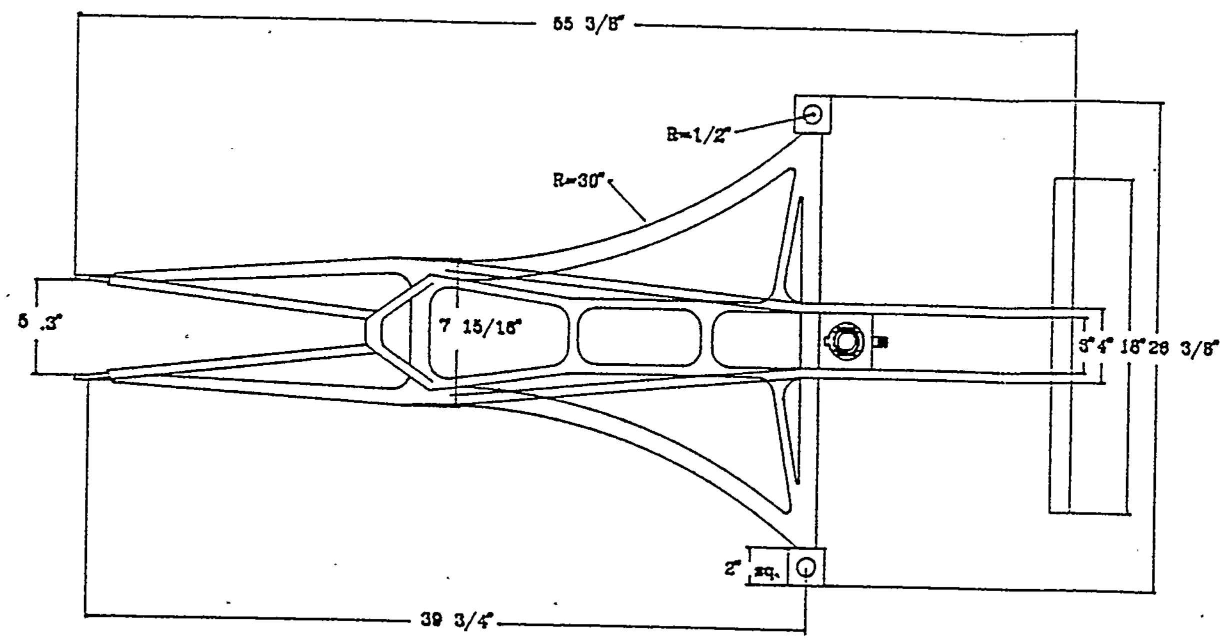
1. Wheels

2. Drive system
   - steering/rowing arm or lever

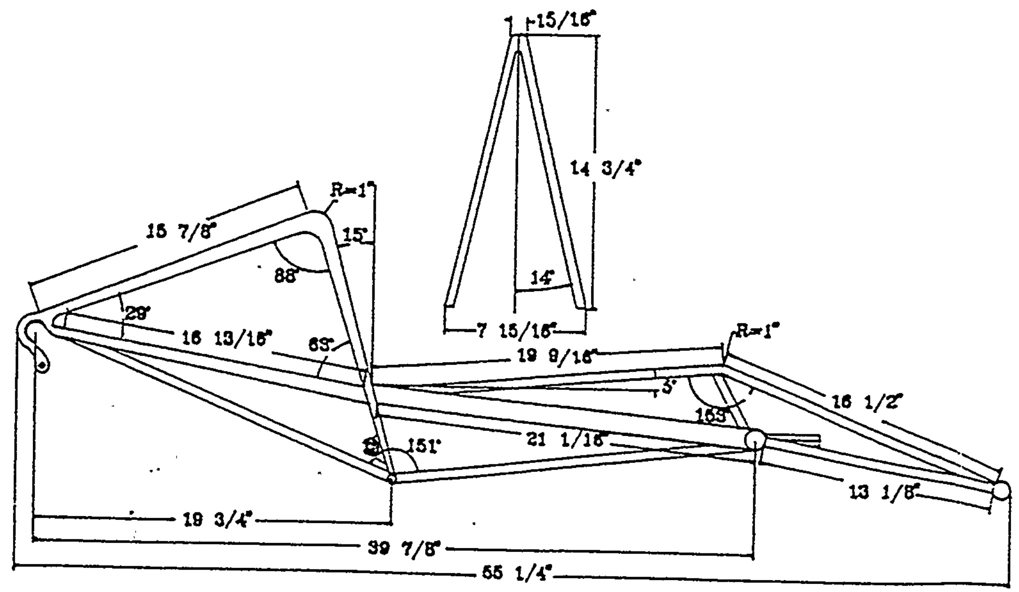
6.3.2.2.1 **Wheels**

Next to the frame nothing has a greater influence on the way the wheelchair rides than the wheels and tires (Figure 6-5).

1. The rear wheel is a 26" x 2.2" ATB type, with stainless steel spokes laced in a 4-cross pattern. (see Figure 6-6)



Top View



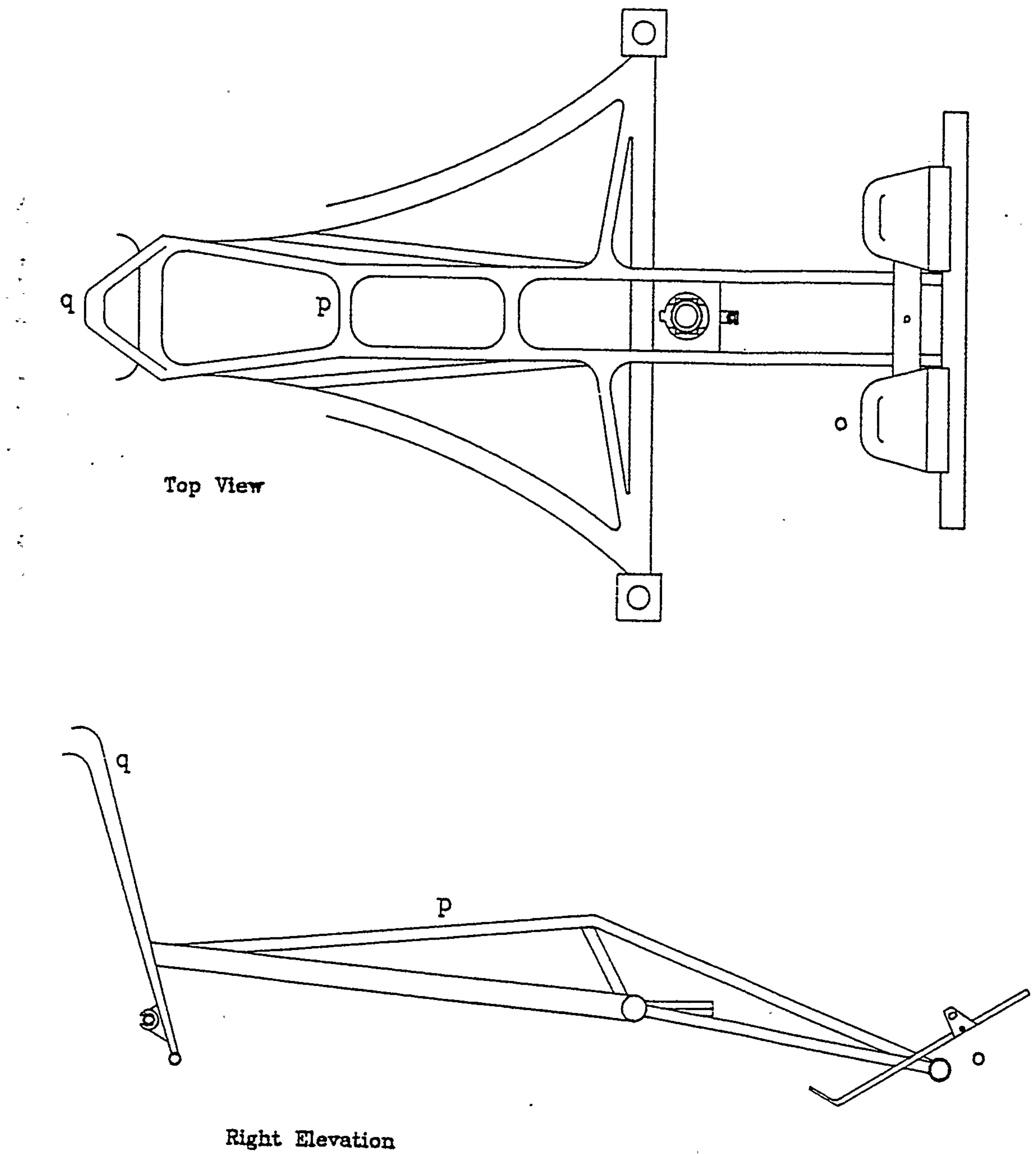
Right Elevation

GENERAL ASSEMBLY

a. Rear Axle and Lock Nut
b. Freewheel Cluster
c. Front Wheel
d. Rear Wheel
e. Seat Form
f. Tie Rod
g. Steering Mechanism
h. Steering Bracket
i. Drum Brake Hub
j. Steering Spindle
k. Drive Chains
l. Chain Wheels
m. Derailleur
n. Rowing Arm
o. Footrest
p. Seatrest
q. Seat Stay
r. Chain Stay
s. Take-up Spring
t. Slip Rings
u. Disk Brake

APPEARANCE MODEL FRAME

Figure 6-2



GENERAL ASSEMBLY

a. Rear Axle and Lock Nut
b. Freewheel Cluster
c. Front Wheel
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h. Steering Bracket
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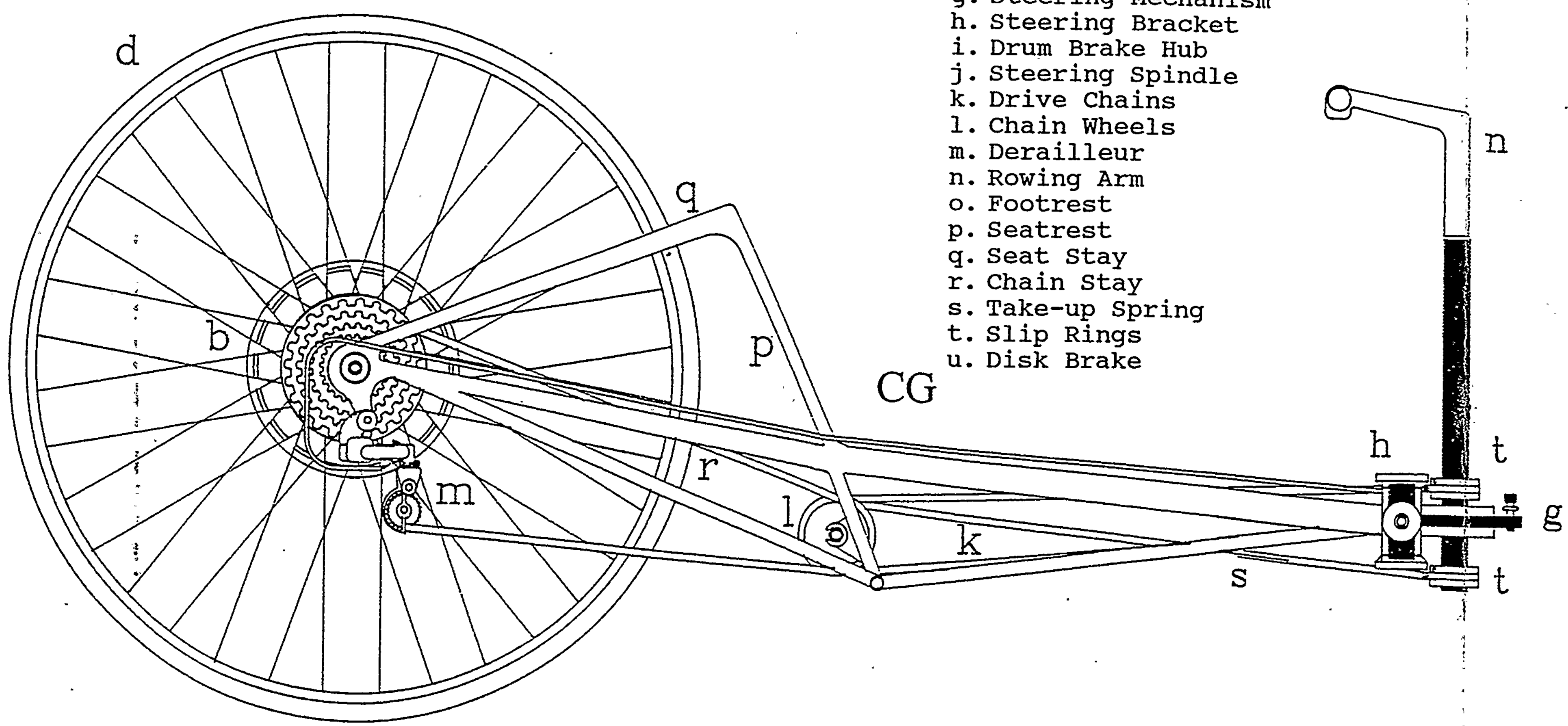
m. Derailleur
n. Rowing Arm
o. Footrest
p. Seatrest
q. Seat Stay
r. Chain Stay
s. Take-up Spring
t. Slip Rings
u. Disk Brake

SUPPORT SYSTEM

Figure 6-3



GENERAL ASSEMBLY

a. Rear Axle and Lock Nut
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l. Chain Wheels
m. Derailleur
n. Rowing Arm
o. Footrest
p. Seatrest
q. Seat Stay
r. Chain Stay
s. Take-up Spring
t. Slip Rings
u. Disk Brake

PROPULSION SYSTEM
Figure 6-4

GENERAL ASSEMBLY

a. Rear Axle and Lock Nut
b. Freewheel Cluster
c. Front Wheel
d. Rear Wheel
e. Seat Form
f. Tie Rod
g. Steering Mechanism
h. Steering Bracket
i. Drum Brake Hub
j. Steering Spindle
k. Drive Chains
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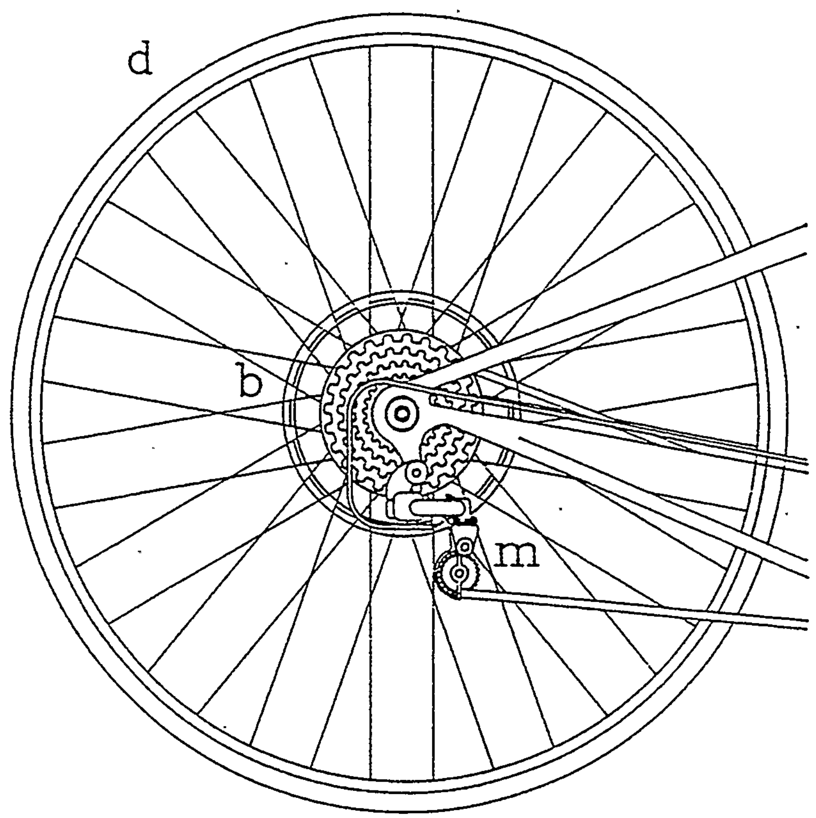
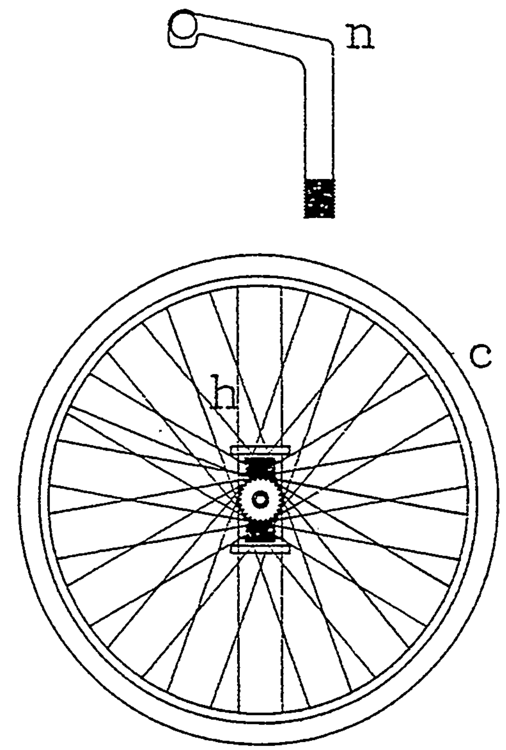




WHEELS
Figure 6-5

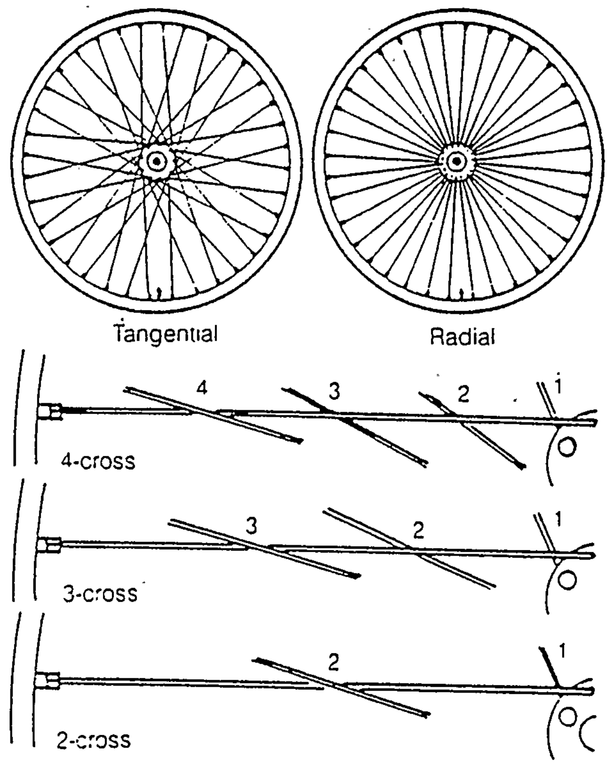


Figure 6-6 Spoking Pattern
(Van der Plas, 1991)

2. The front tires are 16" x 1.75" ATB type, with stainless steel spokes laced in a 3-cross pattern. The front tires are equipped with drum brake and a 5/8" axle for greater strength and durability.

3. The rims are constructed of an alloy which is lighter than steel and more durable than aluminum.

4. Pneumatic tires were used for comfort and shock absorption. It has been suggested that solid tires and tires with hollow cores might provide an alternative, but neither have proven that they can provide the shock absorbency equivalent to pneumatic tires.

6.3.2.2.2 **Drive System**

The drive system is made up of five components (refer to Figure 6-4):

1. The propulsion system of the Magellan Wheelchair is controlled by a single rowing arm. The principle is much the same as a rowing machine or rowing shell. The shape of the rowing arm (**n**) is kept straight to allow for ease of transfer for the user when it is in the neutral or straight up position

2. There are three chainwheels (20 tooth) located beneath the seat tube. Two of the chainwheels are connected to the rowing arm by standard bicycle chains which have been "broken" to allow for greater horizontal travel, using adjustable slip rings (Figure 6-7). The chains are kept in tension by springs attached to the front bar of the frame. These chainrings provide the drive power to the third chainring which is connected to the rear wheel again by a standard bicycle chain.

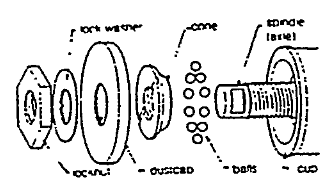
3. The chains are standard bicycle chains. There had been some experimentation on belt systems on the models but they have proven to wear extremely fast when compared to a metal chain. Chains are made from a variety of materials, the most popular being stainless steel.

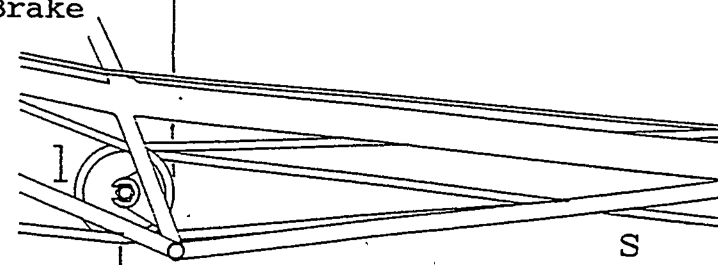
4. There is a six cog (13 -28) freewheel cluster on the rear wheel which acts in conjunction with a deraileur to allow for gearing change. This gearing ratio (from .71 to 1.5) allows the wheelchair to be used under a variety of conditions (refer to Figure 6-4).

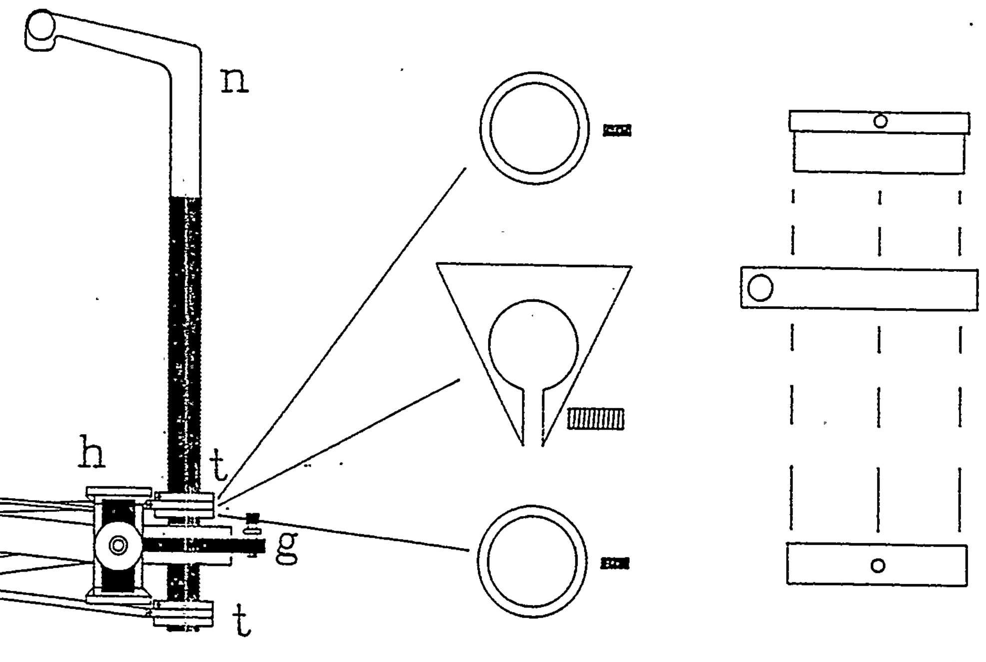
5. The primary braking is accomplished through the use of drum brakes on the front wheels. The drum brake was used because it offers a inexpensive alternative to disk brakes and also because a standard caliper or cantilever system would not work as well. When the brake lever is applied, the cam pushes the brake segments apart against the interior of the drum on the hub shell. The friction absorbs the energy, slowing the bike while the counterlever fixes the interior against the spindle brake arm. In case of emergency, where the drum brakes fail, a disc brake system attached to the rear wheel has been utilized. Disc brakes are used because of the weight and speed potential of the Magellan. The advantage of the disc brake over rim brakes is that it makes use of a greater contact area for braking and has an increased ability to dissipate heat. The rear caliper is attached to a plate that is welded to the left seat stay. The disc brake required

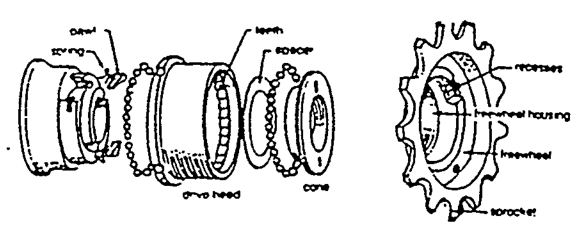
GENERAL ASSEMBLY

a. Rear Axle and Lock Nut
b. Freewheel Cluster
c. Front Wheel
d. Rear Wheel
e. Seat Form
f. Tie Rod
g. Steering Mechanism
h. Steering Bracket
i. Drum Brake Hub
j. Steering Spindle
k. Drive Chains
l. Chain Wheels
m. Derailleur
n. Rowing Arm
o. Footrest
p. Seatrest
q. Seat Stay
r. Chain Stay
s. Take-up Spring
t. Slip Rings
u. Disk Brake

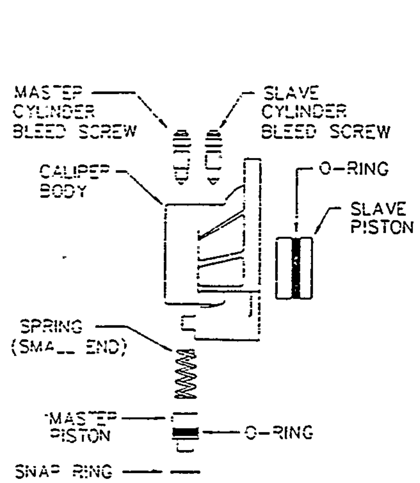




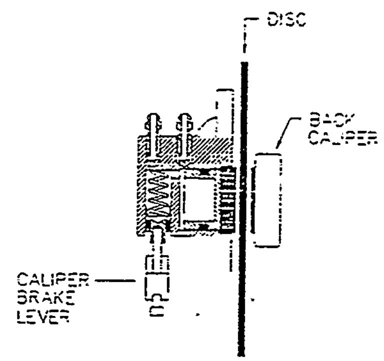




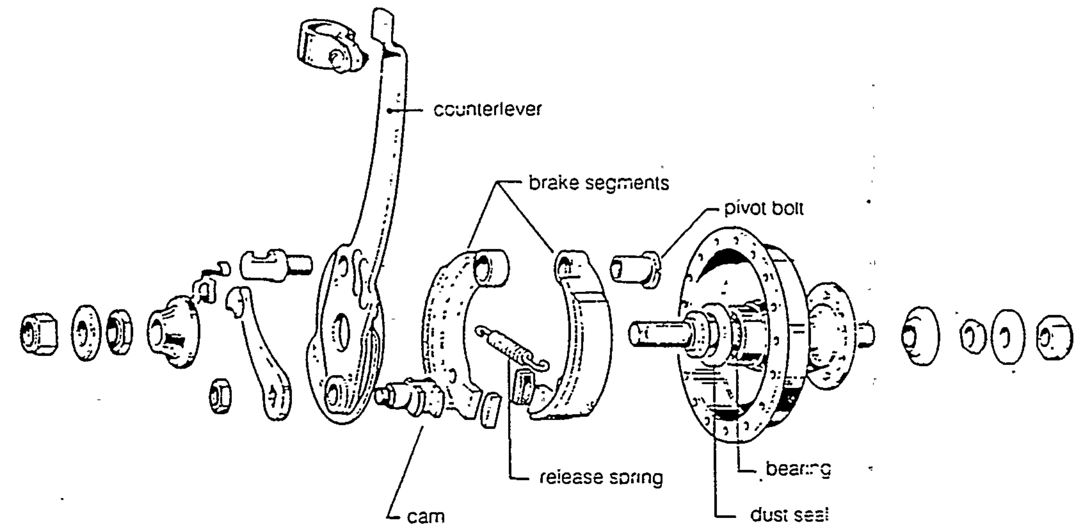
SLIP RINGS
Figure 6-7



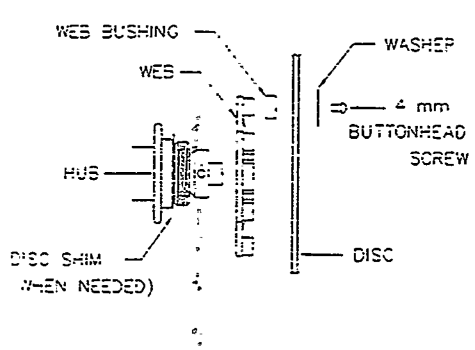
CALIPER COMPONENTS



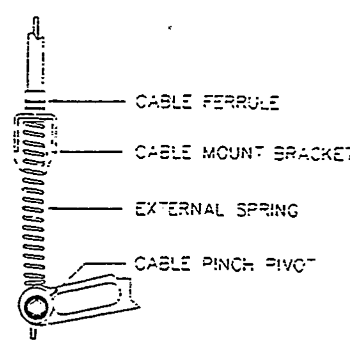
CALIPER CUT-AWAY



(from Van der Plas, 1991)

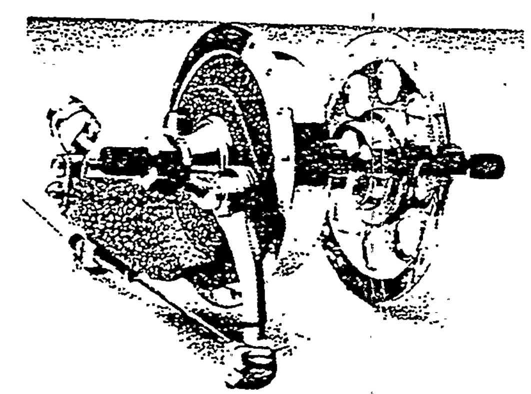


DISC ASSEMBLY



LEVER DETAIL

(from Van der Plas, 1991)



DRUM & DISK BRAKES

Figure 6-8

that the seat stays were larger and stronger than those required if a rim brake system were used (see Figure 6-8).

6.3.2.2.2.1 Steering System

Through testing and the evaluation of previous models it was determined that steering would best be facilitated using a single rowing arm. The rowing arm is attached to a steering mechanism which is welded to the front frame tube (see Figure 6-9).

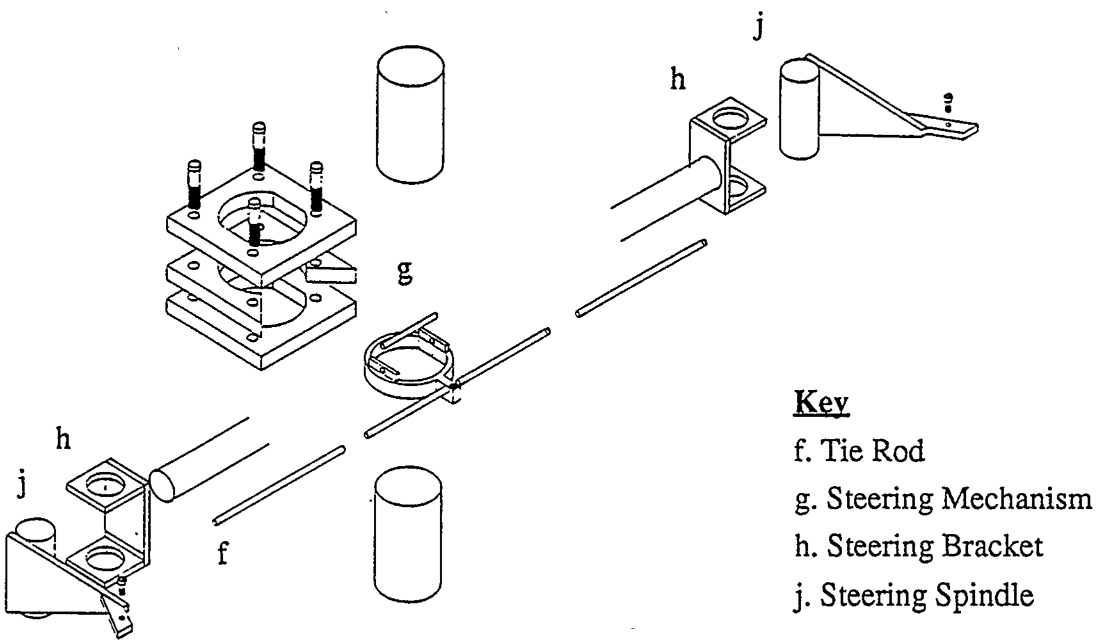
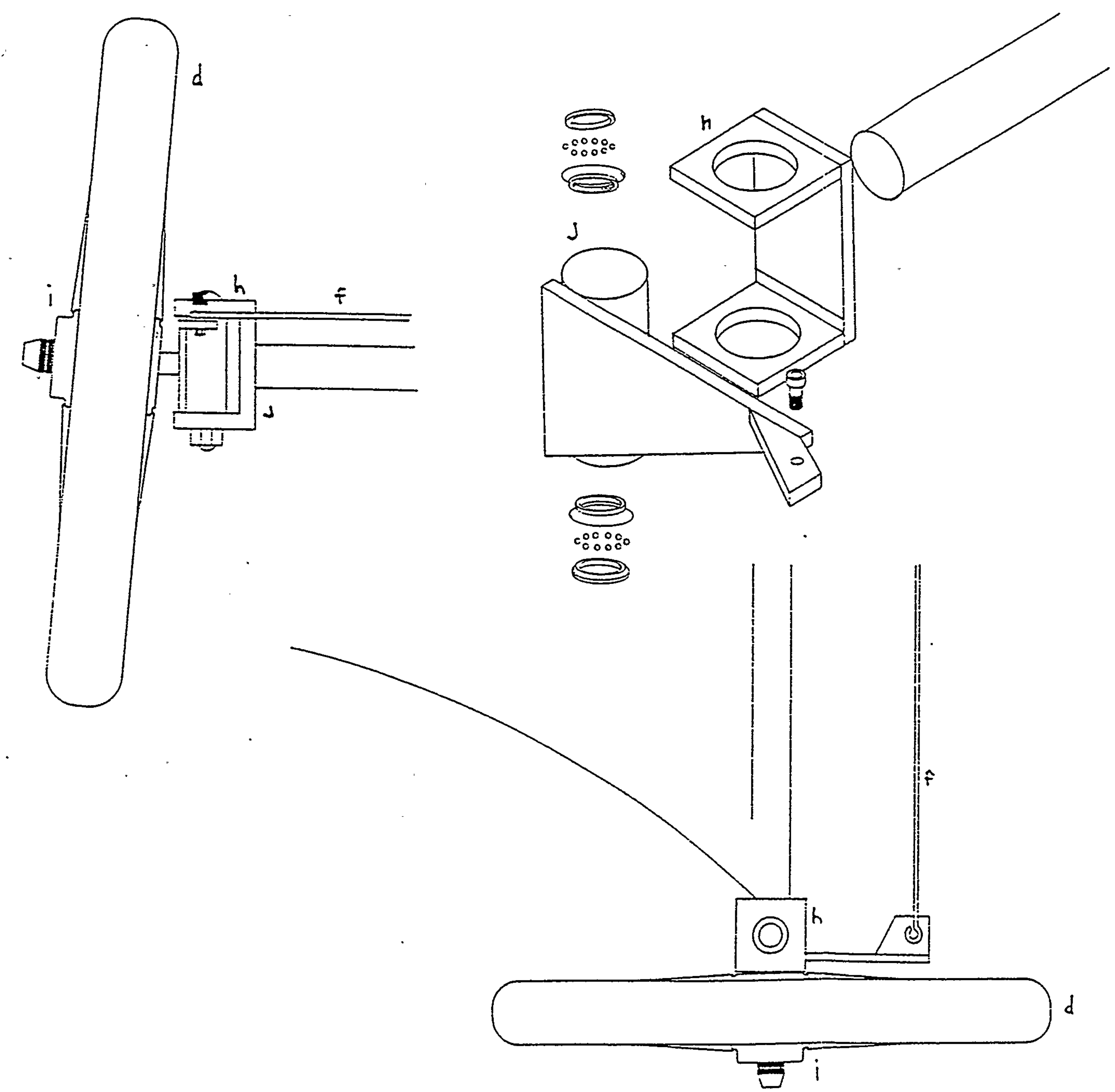


Figure 6-9 Rowing Arm & Steering Mechanism

Two tie rods connect the steering mechanism to the steering knuckles on the front axle spindles. Steering bushings were welded to the front frame tube, these were attached to the axle spindles by modified kingpins (refer to Figure 6-10).

The front wheels have a negative 5^0 camber which would allow the wheels to return to a straight ahead position. Camber refers to when the wheels tilt inward or outward at the top. It is measured in degrees, and represents the amount that the centreline of the wheel is tilted from true vertical (Brown, 1991). Negative camber also increases stability without increasing width.

The wheels also have a slight positive castor which is controlled by the angle of the spindle in relationship to the bushing. Castor refers to the backward or forward tilt of the spindle



GENERAL ASSEMBLY

a. Rear Axle and Lock Nut
b. Freewheel Cluster
c. Front Wheel
d. Rear Wheel
e. Seat Form
f. Tie Rod
g. Steering Mechanism
h. Steering Bracket
i. Drum Brake Hub
j. Steering Spindle
k. Drive Chains
l. Chain Wheels
m. Derailleur
n. Rowing Arm
o. Footrest
p. Seatrest
q. Seat Stay
r. Chain Stay
s. Take-up Spring
t. Slip Rings
u. Disk Brake

STEERING SPINDLE

Figure 6-10

arm at the top of the wheel. Castor is measured in degrees + or - from true vertical. Correct castor allows the wheels to maintain a straight-ahead position and to return to a straight position from a turn (Brown, 1991).

In addition, the wheels had a slight toe-in to facilitate steering the front wheels. Toe-in refers to the shorter distance between the front of the front wheels and the greater distance between the rear of the front wheels.
(Figure 6-11).

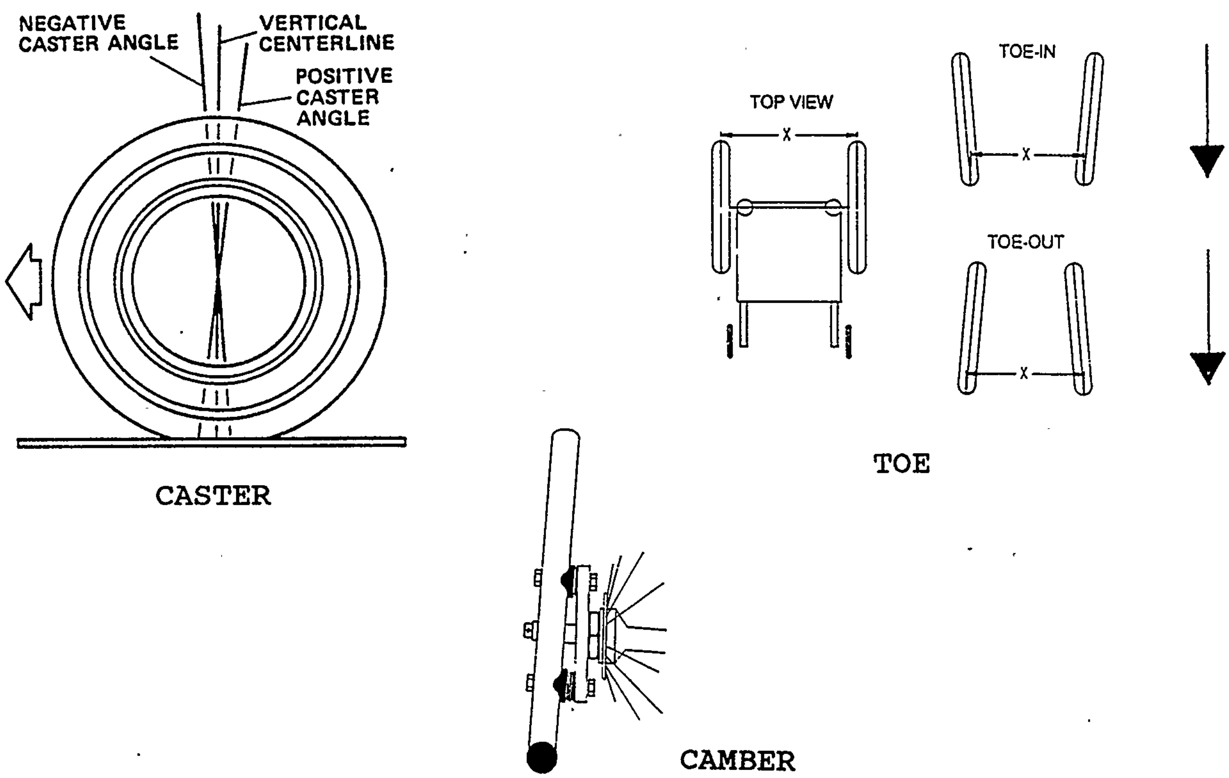


Figure 6-11 Examples of Toe-in, Camber and Caster
(Popular Mechanics, 1989)

6.3.2.3 Seating & Support System

1. The seat of the Magellan Wheelchair is made from a single piece of rigid, molded plastic. The cushioning support of the seat is made up of removable cushions which have been prescribed for the user. The backrest is contoured around the shoulder blades to avoid arm and shoulder restriction during the rowing motion.

2. It has been suggested by a number of authors (Zacharkow (1988), Cooper (1990), and Kamenetz (1969)) that rough or abrasive upholstery materials should be avoided. The user's clothing or skin "sticks" to this fabric causing a shearing motion on the buttocks and posterior thighs. (The health hazards of shearing have been discussed in Appendix I **Ergonomic Considerations.**) Through literature searches and manufacturers suggestions it was determined that vinyl should be used as the covering material. Vinyl is resistant to perspiration and cleans easily. The drawback to vinyl is that it becomes brittle in cold temperatures and sticky to bare skin in high temperatures.

3. The seat support design allows for some adjustability on the horizontal plane. The seat sits on two rails which are attached to the frame. These rails act as guides which direct the horizontal movement. The seat is fixed into the desired position by a pressure clamp which is tightened using an Allen screw and wrench (see Figure 6-3, piece **p**).

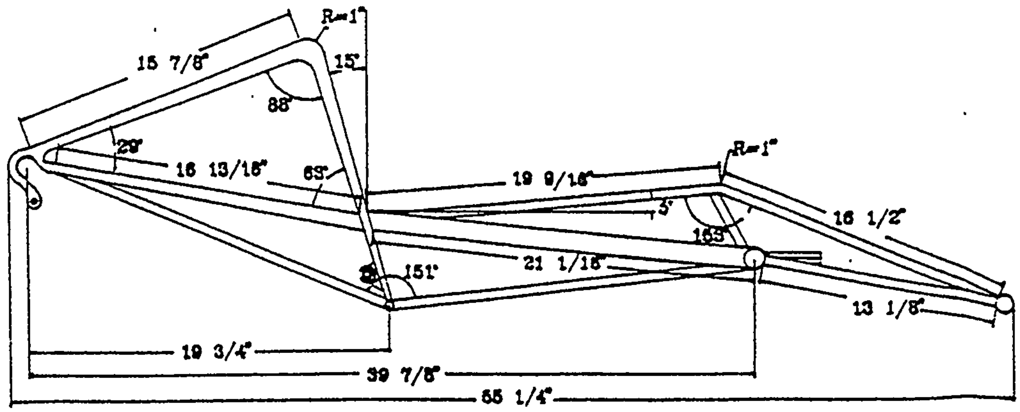
6.3.3 Ergonomic Evaluation

The ergonomic evaluation is based on the three design components: the frame, propulsion system, and the seating system.

6.3.3.1 Frame

The overall length of the appearance model is 76 1/4" (193.75 cm), this is approximately 34 1/4" (87 cm.) longer than the overall length of an Everest & Jennings "Ironsides" wheelchair which is 42" (106.7 cm.). The wheel base of the Magellan is 40" (101.6 cm.) this was determined by the requirement that the center of gravity (CG) be located within the front third of the wheelchair. This also contributes to greater stability and maneuverability due to the smaller turning radius. The track width of the model is 32" (81.3 cm.) which will allow it to fit through most standard doorways.

The seat support and footrest on the appearance model have been designed to accommodate the popliteal height (19 1/4" or 49 cm.) and the buttock popliteal length (21 1/2" or 54.9 cm.) of a 95th percentile, able-bodied adult male (see Figure 6-12). This allows for correct leg extension by the larger user.



Right Elevation

Figure 6-12 Seat Support and Footrest Dimensions

The seat support and the back support have been angled 5° and 105° (relative to horizontal) respectively (Figure 6-13). This is to ensure that the correct seating posture is possible. On a standard wheelchair one of the most persistent problems is the tendency to slide forward and assume a slumped sitting posture (Zacharkow, 1988). This occurs both when sitting in a relaxed position and when propelling the chair. With a horizontal or near horizontal seat and an inclined backrest there is always the force pushing the buttocks forward (Zacharkow, p: 251). This forward thrusting results in an increased upward rotation of the pelvis, an increased rounding of the spine (kyphosis) and more weight being borne by the ischial tuberosities, coccyx, and lower sacrum, along with the potential of shearing over this area. In turn, with increased movement of the wheelchair, vibration and road shock will increase the tendency to slump and the shearing forces on the buttocks (Zacharkow, p: 251). Proper postural stability will assure the optimal spinal posture and pressure distribution for the wheelchair dependent individual, along with minimizing their discomfort, fatigue, and energy expenditure. (Zacharkow, 1988)

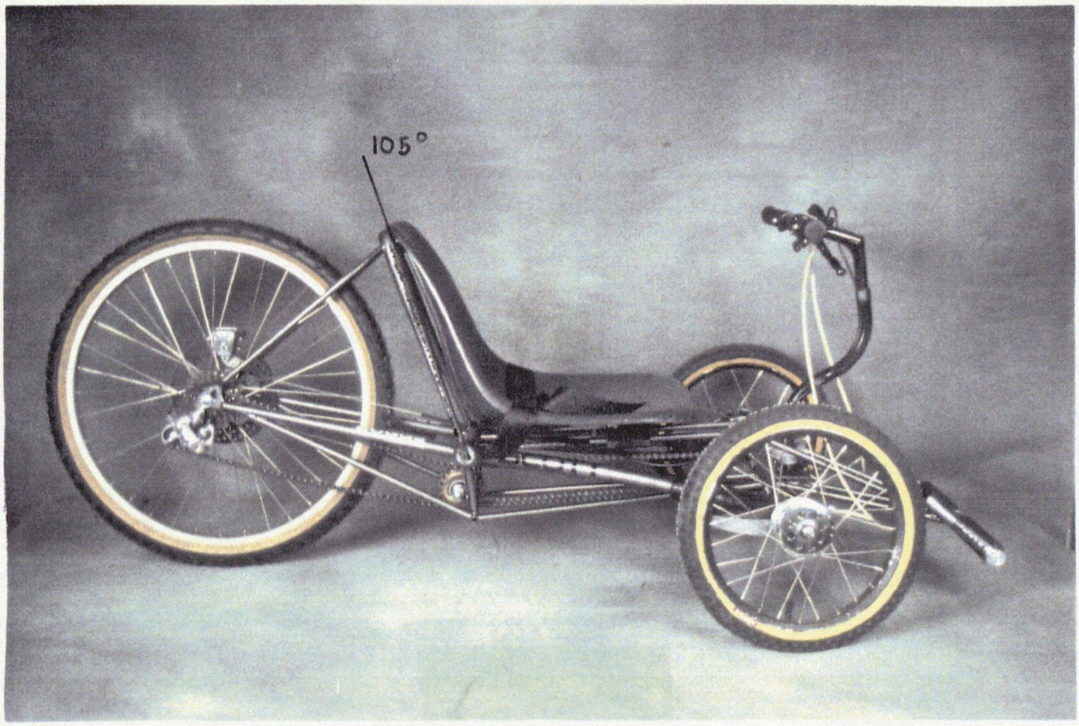


Figure 6-13 Seat and Backrest Position

Because there is very little accurate anthropometric data which deals with the wheelchair bound population (Kamenetz, 1969), the frame of the Magellan was designed to come in a variety of sizes which would accommodate the physical attributes of the user. This would allow the user to match components to frame sizes to achieve the greatest degree of comfort and stability.

6.3.3.2. **Propulsion System**

6.3.3.2.1 **Wheels**

Since rolling resistance decreases with an increase in diameter, it was determined that the rear wheel (the driving wheel) should be as large as possible. The larger diameter wheel produces a higher gear ratio which is more efficient. The two front wheels are smaller for two reasons: (1) They are the steering wheels. With larger wheels more space would be needed to turn and (2) the smaller wheels allowed for better transferability for the user.

6.3.3.2.2 **Drive System**

There are a number of ways to increase the efficiency of wheelchair propulsion. Zacharkow (1988) provides one example:

> *"In regards to future wheelchair designs, a lever drive system has been found to be a more efficient method of propulsion compared to the use of handrims. Compared to the use of handrims, a lever drive system would probably promote a more stable sitting posture with wheelchair propulsion, with the individual obtaining increased support from the backrest and a reduction in shearing forces over the buttocks." (Zacharkow, p: 269)*

The Magellan Wheelchair is powered forward on both the forward and back strokes of the rowing arm with muscle and joint recovery taking place during the opposite stroke motion (Figure 6-14)

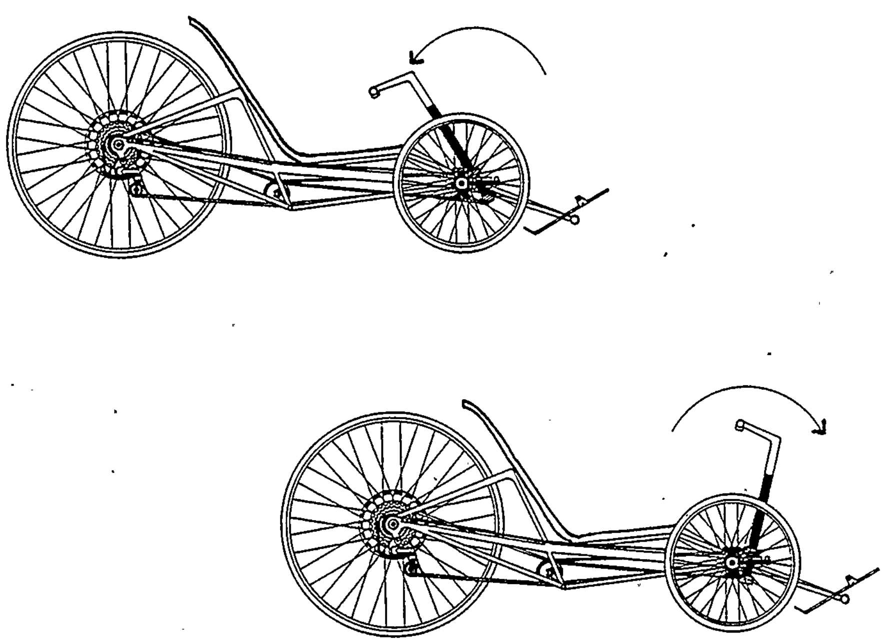


Figure 6-14 Stroke Motion on the Magellan Wheelchair

This motion takes into consideration the use of complimentary activation of opposing muscle groups. For example, extension of the elbow requires contraction of the triceps with concurrent, gradual elongation of the biceps (Milikan et al, p: 35). With a standard wheelchair, muscular imbalance occurs when the opposing muscles are unevenly developed. As a result of this imbalance, the integrity of the joint is compromised. These injuries often involve stretch weakness resulting from the prolonged elongation of the poorly developed opposing muscles. Resulting from this imbalance are forward rounding of the shoulders, varying degrees of discomfort between the shoulder blades, a decreased range of motion, and an increase in the risk of muscle strain, tendinitis, and joint dislocation. The rowing motion alleviates most of these concerns. As well as having superior aerobic and anaerobic qualities, it also opens up the diaphragm which increases oxygen consumption and improves digestion (Grandjean, 1969).

6.3.3.2.3 **Steering**

Steering is accomplished by turning the handle bars either left or right. The steering column has a small tongue welded to it which is attached to the tie rods with a shoulder screw. The tongue also acts as a stop for the steering in either direction. The benefits of this type of steering is that the rowing arm is aligned in centre. The user does not have to swing the rowing arm and handle bars out to the side to steer while maintaining the rowing motion (this type of movement is very unstable) (personal communication: (3) 1992). The major drawback is that while rowing and turning the inside arm may become restricted against the users body. To compensate somewhat for this a small handle bar set-up has been used (Figure 6-15).

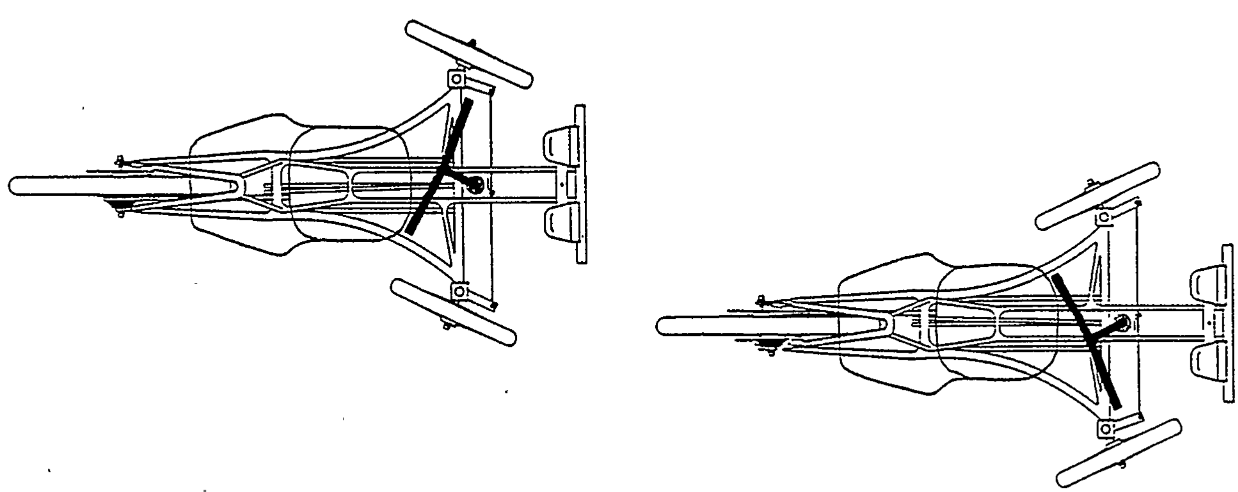


Figure 6-15 Steering Motion of the Magellan Wheelchair

6.3.3.3 **Seating System**

The seat of the Magellan Wheelchair is rigid, molded plastic. The seat pan depth (15" or 38 cm.) has been designed to accommodate a 5% percentile adult female. It has been designed this way so that the smaller user does not experience any discomfort from pressure at the back of the knee (Figure 6-16).

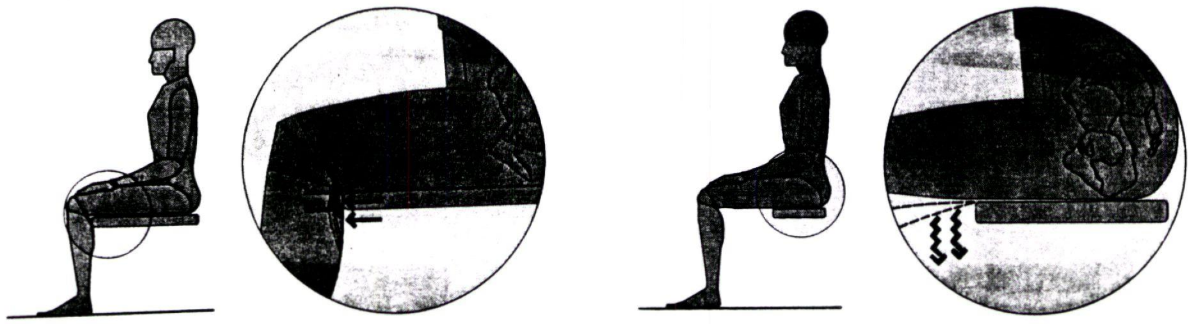


Figure 6-16 Seat Depth
(Pannero & Zelnik, 1979)

According to Brubaker (1990), the proper seat depth should allow for a maximum of 2" (5.08 cm.) of clearance between the front edge of the seat and the back of the knee (Figure 6-17).

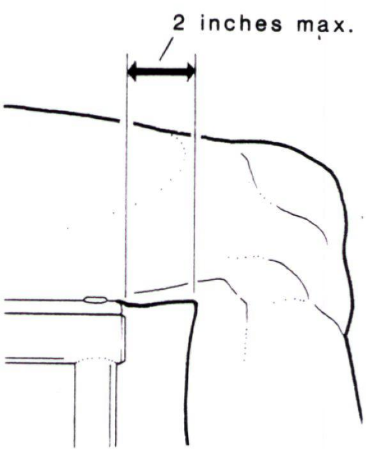


Figure 6-17 Suggested Seat Depth Measurement
(Brubaker, 1990)

The seat width ranges from 11" (27.9 cm.) at the front to approximately 17 1/4" (43.8 cm.) at the intersection of the seat pan and the backrest. This measurement has been used so that it accommodates the hip breadth of a 95th percentile adult female. The width of the seat should be the minimum acceptable for the disabled individual. Zacharkow (1988), recommends a seat width clearance of no more than approximately 1/2" (1.3 cm) to the side of each hip (Figure 6- 18). If the seat width is any wider lateral migration on the seat may occur causing lateral shearing forces on the buttocks and pelvis. This can be compensated for to some degree with cushions.

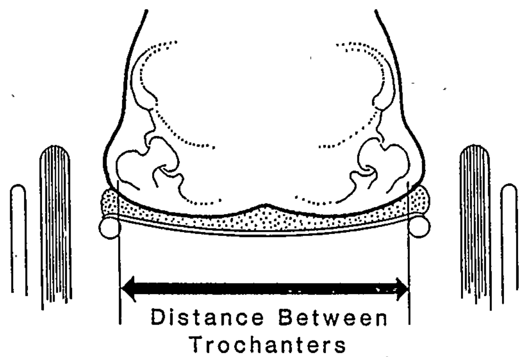


Figure 6-18 Suggested Seat Width Measurement
(Brubaker, 1990)

The backrest height of the seat is 19" (48.3 cm.) from the intersection of the seat pan and the bottom of the backrest to the top of the backrest. The seatback is tapered from the base of the backrest upwards. It provides adequate thoracic support but does not inhibit the shoulders or arms during the rowing motion. Zacharkow (1988), recommends that the back height be approximately 1/2" to 1" (1.3 cm to 2.5 cm) below the inferior angle of the scapulae (Figure 6-19).

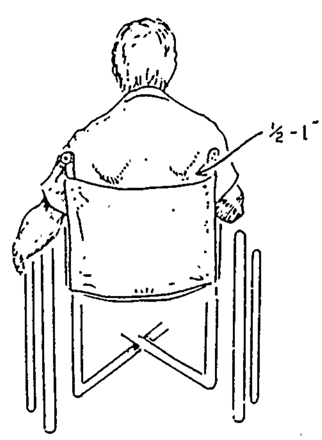
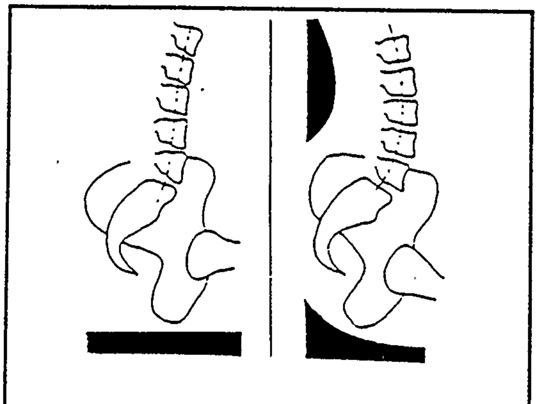


Figure 6-19 Suggested Backrest Height
(Zacharkow, 1988)

In the case of the appearance model of the Magellan Wheelchair a standardized seat was used. If the wheelchair were to go into production it would be wiser to look at having the seat as a prescription item that is fitted more closely to the dimensions of the user.

Acting in conjunction with the seat support and the back support, the seat inclination is such that it alleviates pressure on the buttocks and the posterior thighs. An inclined seat is necessary to prevent the wheelchair user's buttocks from sliding forward on the seat. As was mentioned earlier, this forward sliding motion contributes to a number of serious conditions such as shearing force (a side-to-side sliding motion), backward rotation of the pelvis, poor pressure distribution, and a kyphotic posture (Figure 6-20) of the lumbar region of the spine (Zacharkow, 1988).



Kyphotic posture (A) and Lordotic posture (B)

Figure 6-20 Kyphotic Posture
(Sanders and McCormick, 1982)

The proper seat inclination will also help keep the person's back against the backrest resulting in greater trunk stabilization. Figure 6-21 from Cooper (1991) shows the seat inclination measured from the horizontal plane.

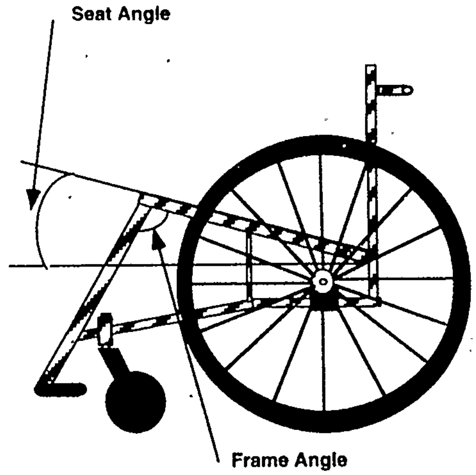


Figure 6-21 Seat Inclination
(Cooper, 1991)

For any given backrest inclination, however, a greater seat inclination will be necessary for the wheelchair individual as compared to an able-bodied person. Zacharkow provides three reasons for this:

1. Due to the lower extremity weakness or paralysis of most wheelchair dependent individuals the pressure of the feet on the wheelchair footrests will not be as effective in counteracting the forward slide on the seat.

2. The use of rough, textured fabrics for cushion covers to help counteract the sliding force on the seat cannot be used with many wheelchair dependent individuals. These fabrics are contraindicated for pressure sore prevention, as they will result in excessive friction or interface shear on the buttocks as a material with a lower surface friction is needed for pressure sore prevention, a greater seat inclination is therefore warranted for the wheelchair.

3. With movement of the wheelchair, a greater seat inclination will help prevent sliding forward on the seat due to road shock and vibration. (Zacharkow, p: 258)

In order for the wheelchair dependent individual to maintain proper trunk stabilization, it is often necessary for them to sit with a trunk inclination between 10^0 to 15^0 from vertical (Zacharkow, 1988, Kamenetz, 1969). The greater the trunk muscle paralysis and sitting instability, the greater the trunk inclination required. (With able-bodied seating, an inclination of 20° is still considered an alert working position (Diffrient et al, 1974)).

As outlined by Zacharkow (1988) tests have been done which showed that a 15° incline in the backrest would reduce body weight on the sitting area by at least 4.4% (Figure 6-22). The Magellan Wheelchair backrest angle is 105° from horizontal (15° from vertical) (see Figure 6-22). As was suggested by Zacharkow and Kamenetz this angle helps to alleviate some of the pressure placed on the ischial tuberosities as well as preventing kyphosis of the spine during the rowing motion.

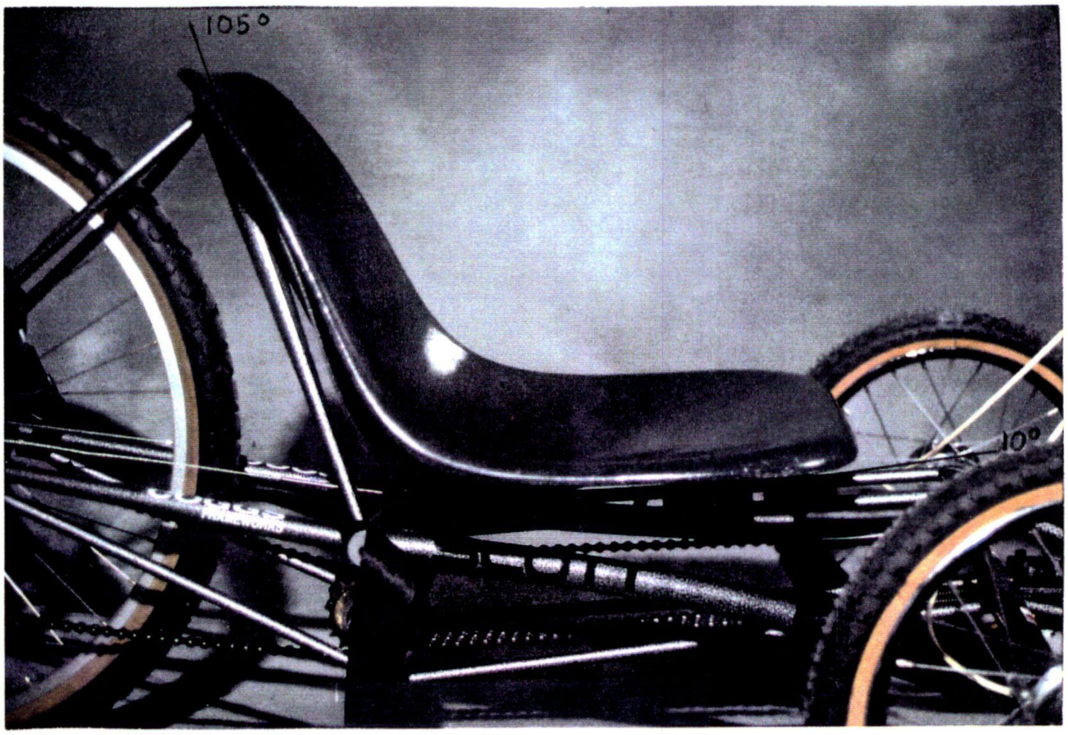


Figure 6-22 Backrest Inclination

The footrest is made of 3/16" stainless steel in the shape of the sole of a foot. The back has a wall which supports the heel. The feet are held in place with Velcro straps across the forefoot. The footrest is attached to the seat/leg support by a pressure clamp which can slide up or down so as to accommodate for a number of different users. For additional lower leg support pads can be added. In the fully extended position the footrest is designed to accommodate the popliteal height of a 90th percentile adult male. The plate length is 10" and the heal width is 4 1/2" (refer to Figure 6-3).

6.3.4 Design Evaluation

The Magellan Wheelchair was designed to improve mobility and meet the recreational needs within a specialized market. In typical product design scenarios, a number of working models and prototypes would be built and tested before they were produced for the commercial market. The prototype of the Magellan Wheelchair should be evaluated or field-tested experiencing a number of environmental conditions and during various recreational activities. The evaluation process should involve users of varying sizes and abilities, keeping in mind the design objectives outlined in the Design Brief.

The results of the evaluation would indicate if any changes should be made to the Magellan as well as providing information for decisions regarding trade-offs to reduce costs, etc.

6.3.4.1 Concerns

There are four areas of concern which were discovered in the preliminary evaluation of the design.

1. There was some concern that the slip rings on the steering column might bind when the rowing arm is extended in either the forward or backward position. This might cause some difficulty in steering and may cause the vehicle to move ahead slightly. To correct this problem the tongue of the slip ring is only 1/4" long so binding would be minimal.

2. There was some concern that the kingpin could show wear caused by turning within the steering spindle. To alleviate this problem the spindle has been constructed like a head set for a bicycle with bearings at either end. It is these bearings that the kingpin rubs against eliminating any friction (see Figure 6-10).

3. Ball joints ends on the tie rods to prevent any flexing of the tie rods when they are engaged in turning. Ball joints aren't required if the wheels are not cambered and the tie rods are parallel to the kingpins, however, if the wheels have been cambered ball joints are required to maintain this parallel relationship and to reduce the stress on the tie rod ends.

4. Front wheel drum brakes- Originally braking was only going to be accommodated on the

back wheel but this provided only about 30% of the braking needed. To alleviate this concern the front wheels were outfitted with a modified drum brake system.

Most of these concerns would warrant further testing and evaluation before changes were implemented. The evaluation might also provide additional information (or problems) which might have some application in the design.

6.3.4.2 **Trade-offs**

Products for the disabled have high costs associated with them for any number of reasons. The products are often highly specialized and the market demand for them is relatively low. This contributes to low production runs which limit the use of high volume, mass production technologies and as a result costs soar.

There are a number of tradeoffs which could be applied to the design and construction of the Magellan Wheelchair.

1. The Magellan is constructed from chrome-moly tubing. In relation to other materials it is relatively expensive ($5.00 per linear foot). The cost of the vehicle could be reduced if it were constructed of ERW (electric resistance welded) steel tubing instead ($1.40 per linear foot). The major drawback to using this steel is that it is not as strong as chrome-moly and the wall thicknesses would have to be increased, resulting in a heavier product.

2. If the Magellan were to go into commercial production frame members could be stocked in quantity by the manufacturer. Any custom manufacturing such as bending could be contracted out.

3. To reduce costs utilization of off-the-shelf components could be increased. This would include mounting brackets, bearings, as well as drive train and propulsion components.

5. To further reduce costs only one frame size could be stocked. Adjustablity using "add-on" components could be utilized.

6. If the cost of the Magellan Wheelchair is still prohibitive to the general user, marketing could be aimed at a narrower target group.

7. The major concern with the drum brakes is that they are sensitive to a phenomenon called fading. During long descents, the brake heats up and causes the drum to expand away from the brake liner. As the diameter increases, the surfaces of the two don't match anymore, leading to a drastically reduced braking effect. The second concern is that the liners wear asymmetrically due to the one-sided pivoted arrangement. However, even with these two concerns the drum brake proved to be a worthwhile choice. The costs were reasonable ($80.00 Cdn. per pair as opposed to $350.00 for the disk brake), and the stopping power good. The Magellan Wheelchair is not designed to obtain and maintain high speeds. With this in mind the front drum brakes and rear disc brake proved to be a very good system.

6.3.5 **Production Costs**

The following provides a rough breakdown of the costs to produce **one** Magellan Wheelchair.

	Appearance Model	Chrome-moly	ERW Steel
1. metals and hardware	$80.00	$275.00	$100.00
2. custom parts (seat)	$10.00	$350.00	$150.00
3. fabrication	$ 0	$600.00	$500.00
4. finishing/painting	$20.00	$150.00	$150.00
5. upholstery	$ 0	$ 75.00	$ 75.00
Total	$110.00	$1450.00	$975.00

The above costs indicate that there is some savings to be made if the production model of the Magellan Wheelchair were to be constructed of mild steel instead of chrome-moly. The factors that have to be taken into consideration are the weight tradeoffs between mild steel and chrome-moly as well as the strength and durability of the two products. In the course of a year a wheelchair bound individual may go through two wheelchairs due to the stress the user puts on the wheelchair and its components. A competitive wheelchair athlete may go through anywhere from five to eight wheelchairs in a year depending on the activity.

Costs may be further reduced if larger production runs were carried out. These costs will vary depending on the volume of production, material costs, etc.

6.5 <u>**Summary**</u>

The design of the Magellan Wheelchair relied on current wheelchair design research as well as a detailed human factors study regarding the design and use of wheelchairs. Research was also conducted into materials, manufacturing processes, as well as future and developing trends in bicycle and wheelchair design.

Every precaution was taken to make the Magellan as safe and functional as possible while making it aesthetically pleasing to the user. The tradeoffs of going to more expensive materials and components are that they require less maintenance and are more reliable. For the wheelchair bound individual any time their wheelchair is in the shop for repairs means a loss of independence due to restricted mobility.

7 Conclusion

During the last ten years there has been a significant change in the attitude toward the design of products to meet the needs of people with physical disabilities. While previously the tendency was to view people with physical limitations as dependent on others, today the emphasis is on designing environments that help integrate people into the community and enable them to live as independent and normal a life as possible. People with physical impairments are a large segment of our population, and the recognition of their specific needs is creating new challenges for industrial designers.

Those with physical limitations often have difficulty living independently because of problems created not by disability or age but by obstacles in their surroundings. The importance of adaptive aids can be appreciated when we understand that a handicap is not a characteristic of a person with a disability, but rather describes a relationship between an individual and the environment. Thus someone with physical limitations may be handicapped in some circumstances but not in others: with the appropriate products a person may be able to perform daily activities, and so is no longer handicapped in those particular situations.

Cumbersome designs reinforce people's feelings of isolation and inadequacy and have contributed to society's stigmatization of people with disabilities. Usually it was the equipment, not the disability, that detracted from the appearance of the person, making the individual seem different, even unapproachable. The equipment formed a psychological barrier to interaction. Traditionally, adaptive aids have been developed by family members, occupational therapists, or medical technicians. Many of these designs appeared clumsy and institutional.

A major factor which has contributed to the recent interest in design of living aids has been the change in society's attitude. Until recently people with physical limitations have been prevented from fully participating in the community; their greatest barrier was society itself. The civil rights movement of the 1960s, which increased our awareness of the rights of all minority groups, provided the initiative to integrate people with physical disabilities into the community. As these groups become more actively engaged they will be less conspicuous as a separate group.

Adaptive aids are designed to supplement a physical impairment, to assist the elderly, and to replace missing parts of the body. The products are essentially tools: although they cannot totally compensate for an impairment, they extend a person's capability, enabling him or her to do more than would be possible without these tools. What makes designing for specific needs challenging is that strict parameters and objective criteria dominate: the functional requirements of the user determine design constraints that must be met in the final product.

The determination of athletes with disabilities has brought about many of the changes that typify the new design movement. Extraordinary advancements in wheelchair design were prompted by change in regulations governing wheelchair sports competitions during the late 1970s. These athletic competitions help focus on a product's strengths and weaknesses and often lead to innovations in equipment design. With competition between equally skilled individuals, excellence in equipment becomes the deciding factor.

Like other industrial designs, wheelchairs are making use of advanced technology. Lightweight materials developed in the aerospace industry are now used to achieve more portable and faster wheelchairs. While the initial benefactors were athletes with disabilities, sports wheelchairs have transformed the design of everyday wheelchairs. In the past a wheelchair was considered a chair, a place to sit. Today it is seen as a tool to enhance mobility. It can be maneuvered with little effort.

The Magellan Wheelchair was designed to take advantage of existing materials and manufacturing processes. It retains some of the characteristics of its predecessors as well as introducing an alternative approach to wheelchair design.

But most of all, it was felt that, even on a conceptual level, the Magellan Wheelchair achieved what was set out in the Master's Degree Project: the design of a wheelchair that would open up other possibilities for the disabled through increased mobility. The intent was to design something that would help to reduce or remove the stigma attached to wheelchairs and their occupants.

However, if this project were to advance beyond this stage more research (e.g.: testing of the prototype) would be required this might include: further investigation into the steering system as well as enlarging the diameter of the freewheels to provide for a greater gear ratio; placement and operation of the front brakes and the emergency brake; colour of the

Magellan Wheelchair because it is so low to the ground it might be wise to incorporate a more visible frame and seat colour or utilize a safety flag system.

GLOSSARY

The following terms have been adapted from Kamenetz (1969).

ABDUCT
Move away from the midline of the of the body. Opposite of adduct.

ABDUCTION
Motion or position of moving away of a limb, a hand or a foot from the midline of the body.

ADDUCT
Move toward midline. Opposite of abduct.

ADDUCTION
Motion toward, or position close to the body. Opposite of abduction.

ANKYLOSIS
State of a joint which cannot be moved actively or passively.

ANTERIOR
Meaning "more forward". Refers to a position in front of another part:

ANTHROPOMETRY
External human measurements.

ARM
The part of the upper limb between the shoulder and the elbow. Term less correctly used for the entire limb.

ARTHRITIDES
Plural of arthritis.

ASTASIA-ABASIA
Inability to stand or to walk due to incoordination or hysteria.

ATROPHIC, ATROPHIED
Pertaining to atrophy.

ATROPHY
Reduction in tissue mass.

BELT, TRANSFER BELT, WALKING BELT
Leather or web strap held by an attendant around the patient's waist during walking or transfers, for support.

CERVICAL
Pertaining to the neck.

COCCYGODYNIA
Pain in the region of the tail bone (coccyx).

CONTRACTURE
Deformity of a joint which cannot be moved to its normal extent, not even passively.

CORD
Spinal Cord.

CUTANEOUS
Pertaining to the skin.

DECUBITIS, PLURAL: DECUBITI
Pressure sore, bed sore.

DISABILITY
Status of diminished function. See also next term.

DISABLED
Physically handicapped. Though disabled and handicapped are not synonyms, these two terms are used interchangeably.

DROPFOOT
A foot that dangles when the leg is lifted, because of weakness or paralysis of the dorsiflexors of the ankle.

EDEMA
Swelling.

FAIR
A grade in manual muscle testing, given to a muscle or a muscle group that can lift the corresponding segment its full range against gravity, but not against resistance.

GOOD
A grade in manual muscle testing, denoting a muscle or muscle group which can move the corresponding segment its full range against moderate resistance, that is, less than normal power.

HANDICAPPED
Disadvantaged. No difference is made between handicapped and disabled. Most often it is a physical handicap or physical disability which is referred to.

HEMI
Prefix meaning half. Refers usually to one symmetric half of the body or part of it. Hemiplegia is a collective name for hemiparesis and hemiparalysis.

HEMIPARESIS
Hemiplegia with incomplete paralysis.

IMPAIRMENT
Medical condition resulting in a diminution of function as evaluated by a physician.

ISCHIA
Plural of ischium, the lowermost bone of the pelvis.

ISCHIAL TUBEROSITY
One of the two bony prominences on which we sit.

KINESTHETIC
Referring to the perception of and skill in motions. Kinesthetic sense: a feeling for balance and motion; motor skill.

KYPHOSIS
Hump in the vertebral column.

LATERAL
Sideward or or away from the midline; at the side.

LEG
The part of the lower limb between the knee and the ankle joint. Term incorrectly used for lower limb.

LIMB
Upper limb is the collective name for arm, forearm, and hand; lower limb, for thigh leg and foot.

LOCOMOTION
Movement from one position or from one place to another. This includes moving about in bed; transfer from bed to wheelchair; traveling in wheelchair; walking, etc.

MUSCULAR DYSTROPHY
A muscle disease most frequently of children and young adults.

MYELOCELE
Abnormal protrusion (bulging) of the spinal cord.

PARAPARESIS
partial paralysis of lower limbs.

PARAPLEGIA
Paralysis of lower limbs. The term does not necessarily imply complete paralysis.

PARESIS
Incomplete paralysis.

PARKINSONISM, PARKINSON'S DISEASE
A chronic disease marked by rigidity. Shaking palsy.

POOR
A grade in manual muscle testing, applied to a muscle or muscle group that cannot move the corresponding segment against gravity.

POSITIONING
The arrangement of a patient-in bed, a chair or elsewhere-in a position which corrects faults and minimizes the dangers of faulty posture.

POSTERIOR
Meaning "more backward." Refers to a position behind another part.

PROTHESIS
Artificial body part, here usually artificial leg.

PROXIMAL
Close to the root of a limb, that is to the shoulder or the hip.

QUADRIPARESIS
Incomplete paralysis of all four limbs.

QUADRIPARETIC
Refers to quadriparesis.

QUADRIPLEGIA
Paralysis or paresis of all four limbs.

RECUMBENCY
The position of lying down.

RECUMBENT
Lying down.

SCOLIOSIS
Lateral deviation of the vertebral column.

SPASTIC
Referring to a certain type of muscle tightness.

SUPINE (POSITION)
Lying on the back.

TETRAPLEGIC
Same as quadriplegic.

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APPENDIX I

- Wheelchair users from Gordon (1989)
- Survey information from McLaurin (1990)
- Disability analysis from Everest & Jennings
- Medical classification from Cooper (1990)
- Seated postures from Colombini et al (1986)

Wheelchair Users

Very little information exists regarding the characteristics and needs of wheelchair users. A study was conducted by Dr Ronald Gordon, of the University of Virginia Rehabilitation Engineering Center. In the study Gordon looked at a total population of 120,000 people in the Charlottesville, Virginia area. Of the total population 200 were wheelchair users (Gordon, 1989).

The information Gordon obtained was from personal interviews; 52% were female; 18.9% considered their disability moderate; 81% considered their disability severe and 64% had an income of less than $10,000 per year (Gordon, p: 121). Those people in hospitals and nursing homes were not interviewed. The information that Gordon obtained is summarized in Tables 1 through 9, Tables 10 and 11 deal with demographic qualifiers.

Table 1

Cause	
Arthritis	11.2%
Stroke	9.7
Amputations	**8.2**
Paraplegia	**8.1**
Polio	6.1
Multiple Sclerosis	**5.6**
Heart	**4.6**
Cerebral Palsy	4.6
Bone & Joint	4.1
Quadriplegia	2
Diabetes	2
Cancer	2
Unknown	30

Table 2

Education	
High School, some	53.6%
High School, graduate	15.3
Some College	13.6
Graduate, College or vocational	15.1
Masters	4.6
Ph.D. or M.D.	3.1

Table 3

Marital Status	
Single	27.7%
Married	38.5
Separated	2.1
Divorced	3.1
Widowed	29.2

Table 4

Happiness	
Very happy	11.2%
Happy	38.3
Neutral	14.3
Unhappy	5.1
Unknown	28

Table 5

Employment Status (16.3% had received vocational rehabilitation)	
Currently employed	15.3%
Employed, not sheltered	10.7
Sheltered workshop	1.0
Unemployed, looking	5.6
Unemployed, not looking	5.6
Retired	32.7
In school	10.7
Housewife	9.7
Other	2.0
Unknown	7

Table 6

Type of Employment	
Never employed	14.5%
Professional	9.8
Managerial	1.6
Clerical	9.8
Sales	0.5
Service	21.2
Farm	3.1
Processing	3.1
Machine Trades	3.6
Bench Work	6.2
Structural	7.3
Other	5.2
No answer	0.5
Housewife	13.5

Table 7

Rehabilitation Training	
Received rehab. training	**62.2%**
Thought rehab very beneficial	**59%**
" " some benefit	**20**
" " very little benefit	11
" " no benefit	9

Table 8

Needs as perceived by Person	
Operation	2.6%
Physical Therapy	**16.3**
Social Activity	**14.8**
Job	5.6
Financial Aid	20.4
Assistant	15.3
Change in Public Attitude	**18.9**
Better Transport Service	**11.2**
Structural Needs in Community	16.8
Home Needs	5.6
Device of Some Sort	**17.9**
Better Social Skills	2.6
Other	9.7
More Education	0.5

Table 9

Limitations as Perceived by Person in Question	
Mobility	**77.0%**
Activity	**62.8**
Diet	20.4
Social	**47.4**
Reading/Writing	19.4
Medication Dependent	45.4
Employment	35.2
Financially Limited Because Of Disabilities	15.3
Caring for Basic Needs	40.8
Reaching	27.6
Lifting	28.6
Communication	6.1
Limited by Pain	19.4

Table 10

Age Distribution

0-17	**9.2%^**
18-22	**3.6**
23-34	**8.7**
35-54	**12.8**
55-64	**16.4**
65+	**49.2**

Table 11

Age at Onset of Disability

1	13.5%
2-5	3.1
6-22	11.5
22-63	42.2
64+	29.7

* Highlighted categories indicate areas that The Magellan Wheelchair would benefit the most.

Anthropometric Survey from McLaurin

In 1990 Colin McLaurin (1990) reported in his paper "**Current Directions in Wheelchair Research**" (1990) that both the Universities of Memphis and Virginia had undergone a series of studies to collect anthropometric data on wheelchair users.

It was hoped that this data would be of use to designers and manufacturers of wheelchairs. Tables 1 and 2 show information collected from 52 respondents for 7 disability groups (McLaurin 1990). Information from these tables were useful in determining wheel base and seat width measurements for the Magellan Wheelchair.

Table 1.
Distribution of Subjects in Anthropometric Survey, 52 Clients

Diagnosis	Number of Clients		Range of Age	Mean Body Weight
	Male	Female	Years	Kg.
Cerebral Palsy	7	11	2-22	58.1 ± 29.9
Muscular Dystrophy	3	2	10-54	88.1 ± 45.3
Spina Bifida	3	3	15-20	104.2 ± 17.8
Paraplegia	9	1	19-53	165.0 ± 46.2
Quadriplegia	4	3	20-45	143.1 ± 37.1
Arthritis	2	2	64-79	142.9 ± 38.7
Other	0	2	28-50	104.0

Statistical Analysis of Anthropometric Survey, 50 Clients

	Dimensions in Centimeters											
	Cerebral Palsy		Muscular Dystrophy		Spina Bifida		Paraplegia		Quadriplegia		Arthritis	
Linear Measurements	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1. Sitting Height	63.5	± 9.9	68.7	± 12.0	68.9	± 6.0	84.0	± 6.0	89.9	± 9.0	77.7	± 6.2
2. Shoulder Height	40.6	± 6.7	46.5	± 8.7	45.9	± 4.9	56.7	± 5.0	61.9	± 8.4	53.2	± 4.2
3. Elbow Height	17.7	± 5.1	17.3	± 7.6	17.0	± 4.8	19.1	± 4.8	25.5	± 7.4	20.0	± 4.9
4. Elbow to Knuckle of Small Finger	26.6	± 6.1	31.0	± 3.9	31.3	± 2.2	36.9	± 1.8	41.1	± 14.0	31.9	± 3.3
5. Back to the Kneecap	44.1	± 11.3	52.1	± 10.8	49.0	± 2.5	58.8	± 4.5	59.7	± 2.7	59.1	± 3.6
6. Back to Underside of Knee	37.6	± 9.6	45.8	± 9.6	42.1	± 1.8	50.3	± 4.3	51.5	± 4.0	50.7	± 3.8
7. Ground to Underside of Knee	58.7	± 5.8	63.6	± 9.0	54.1	± 2.0	54.6	± 3.9	53.1	± 3.5	50.5	± 10.4
8. Ground to top of Knee	66.6	± 6.2	72.4	± 8.3	63.0	± 2.3	65.2	± 4.8	63.9	± 4.0	62.4	± 13.7
9. Ground to heel	26.9	± 11.2	27.4	± 15.1	28.0	± 7.2	7.1	± 4.0	12.2	± 9.4	11.9	± 7.7
10. Shoulder Width	31.2	± 6.9	35.5	± 10.4	42.6	± 7.2	44.2	± 3.2	44.0	± 7.4	37.6	± 4.8
11. Chest Width at Axilla	23.5	± 4.3	26.0	± 8.7	32.0	± 4.6	35.2	± 4.0	34.5	± 5.1	29.9	± 2.9
12. Waist Width	20.0	± 3.6	26.7	± 4.8	30.1	± 7.0	32.5	± 5.6	30.6	± 6.6	32.7	± 6.0
13. Hip Width	24.8	± 5.7	32.6	± 10.7	37.2	± 6.0	41.1	± 6.7	40.3	± 4.8	41.8	± 4.1
14. Width at Knees	26.4	± 5.9	25.2	± 11.6	31.1	± 7.2	31.2	± 10.4	26.0	± 6.8		
15. Foot Length	18.7	± 4.4	22.9	± 1.6	18.8	± 2.0	26.3	± 2.9	26.5	± 1.6	25.4	± 4.0
16. Leg Length	33.3	± 7.9	39.8	± 7.7	34.3	± 1.8	51.4	± 7.1	47.4	± 3.9	45.4	± 6.3
17. Acromian Width	24.1	± 4.4	35.6	± 4.5	34.4	± 4.0	39.5	± 4.4	39.2	± 3.3	34.8	± 3.8

Disability Analysis

The Disability Analysis Chart on the following pages is used to determine the type and extent of the persons disability (disabilities). It acts as an aid in prescribing the proper chair and attachments.

Manufacturers are becoming more aware of the ergonomic and anthropometric characteristics of each user. The user checks the appropriate box concerning the area of concern for them and matches it to the equipment list.

This type of chart is fairly common in hospitals, rehabilitation centres and some mail order companies.

Everest & Jennings Inc.
1803 Pontius Avenue
Los Angeles. California 90025

DISABILITY ANALYSIS

INSTRUCTIONS

1. Check the physical conditions that apply. Obtain medical recommendations.
2. Note any additional conditions at the end of the form.
3. Complete the "Wheelchair Prescription" form.
4. Refer to the "Modification and Accessory Analysis" for uses and limitations of each modification and accessory being considered.

DISABILITY		EQUIPMENT TO CONSIDER
A. PHYSICAL CHARACTERISTICS		
1. Male ☐ Female ☐ Age ________		
2. Attendant ☐		
3. Unusually Tall ☐ Short ☐		Offset or detachable arms · special depth and/or height seat
4. Unusually Heavy ☐ Slender ☐		Special width seat · heavy duty construction
B. LEGS, KNEES, AND HIPS		
1. Ability to stand unassisted on one or both legs	☐	Cane and crutch holder where applicable
2. Not able to stand	☐	
3. Hip fracture or limited flexion	☐	Elevating legrests reclining back · special seat and back cushions
4. One or both knees fused so legs are elevated	☐	Elevating legrests · panel pads · reclining back
5. Knee, leg or foot spasticity	☐	Toe Loops · Heel Loops with or without ankle straps
6. Knee muscles shortening causing knee to be pulled to bent position	☐	Elevating legrests · reclining back · heel loops · fabric legrest pan
7. Tight heel cords	☐	Toe loops · #2 footplates · special angle footplates
8. Shortening of all muscles	☐	Elevating legrests · reclining back · fabric legrest panel
9. Poor circulation in one or both legs	☐	Elevating legrests · panel pads
C. ARMS, ELBOWS AND SHOULDERS		
1. Good strength in both arms	☐	
2. Good strength in one arm, limited strength in other	☐	Brake lever extensions · possibly one arm drive
3. Good strength in one arm, amputation or no strength in other	☐	One arm drive · brake lever extensions
4. Limited strength in both arms	☐	Bilateral arm slings · possibly power drive
5. Limited strength in one arm, no use of other	☐	One arm drive · Power Drive
6. Amputation of both arms	☐	Power Drive with mouth, foot, chin or other control
7. No use of either arm	☐	Power Drive · bilateral arm slings
8. Limited use of fingers in one or both arms	☐	Special handrim projections or knobs (See Catalog)
9. Good strength in one arm and one strong leg	☐	Standard drive and brake lever extensions · possibly one arm dri
10. Shoulder, elbow and hand functions limited	☐	Power Drive · standard drive with special handrim projections · bilateral arm slings
11. Limited power in shoulders	☐	Standard or Power Drive · tray · bilateral arm slings
12. Cannot reach below arm level	☐	Brake lever extensions · 26" wheels
D. RELATED DISABILITIES		
1. Sitting position limited, must sit at an incline	☐	Seat and back cushions · upholstered armrests
2. Skin susceptible to breakdown	☐	Seat and back cushions · upholstered armrests
3. Limited balance or spasticity	☐	Chair must have arms · slack back or semi-reclining back · snaps straps, and rings
4. Unable to enter or exit chair at normal seat height	☐	Elevating seat
5. Bed sores	☐	Seat or back cushions
6. Pain		
Arms, elbows, or fingers	☐	Reclining back · seat and back cushions · pneumatic tires.
Legs, knees and feet	☐	Panel pads if elevating legrests used · pneumatic tires
Back, hips and shoulders	☐	Upholstered armrests · pneumatic tires
7. Limited strength in neck	☐	Hook-on headrest · semi-reclining back · Ortho-back or insert back and insert seat

 Liouy 10T, 1277 FORM No. 39

DISABILITY ANALYSIS (continued)

DISABILITY		EQUIPMENT TO CONSIDER
E. AMPUTEE		
1. Single or double amputation above knee knee with prostheses	☐	Amputee chair - swinging detachable footrests - cane or crutch holder where applicable - insert seat
2. Double amputation below knee or one amputation above and one below the knee with prostheses	☐	Amputee chair - swinging detachable elevating legrests with or without footplates - panel pads - insert seat
3. Single amputation above or below knee or double amputation below knee - without prostheses	☐	Amputee chair - swinging detachable footrests for one or both sides (consider trade-in value) - cane or crutch holder where applicable - insert seat
4. Double amputation above knee - without prostheses	☐	Amputee chair with swinging detachable footrests (for resale value) - solid insert seat with additional foam rubber as required
F. OPERATING AREAS		
1. Eat, read or write in chair	☐	Tray - detachable arms - desk arms
2. Use regular bathroom facilities	☐	Detachable arms - arm locks (chair width is important)
3. Use chair outside	☐	8" Casters - pneumatic tires
4. Chair receives unusually rugged use	☐	8" Casters - heavy duty construction - reinforced back
5. Transport chair in auto, train, plane or boat	☐	Swinging detachable footrests or elevating legrests
6. Smooth operating surfaces only	☐	5" Casters
7. Obstructions such as rugs, rough roads, curbs and thresholds	☐	8" Casters
8. Soft ground	☐	8" Casters - pneumatic tires
9. Doors or auto trunks	☐	Swinging detachable footrests (Chair width and length are important)
0. Elevators	☐	Swinging detachable footrests (Chair width and length are important)

BRAKES ARE STANDARD ON ALL CHAIRS!

NOTES: ____

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____

FOR:

Name ____

Address ____

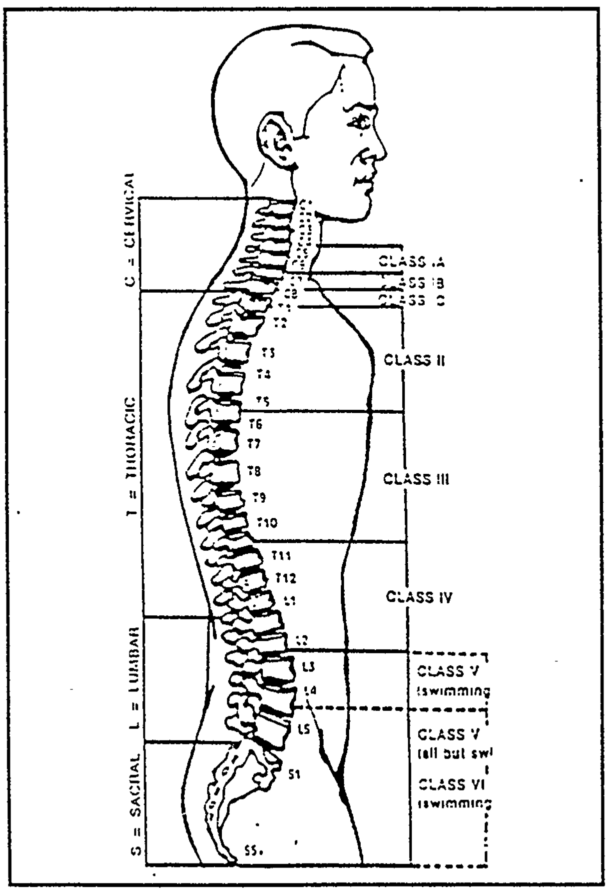
City & State ______________________________ Zip Code ______________

Phone ____

Medical Classification System

The following is the complete Medical Classification chart (Cooper, 1990) which was used to determine the target group(s) for the Magellan Wheelchair (see Figure 6-1).

The Magellan Wheelchair has been designed for the Class III or higher individual. These people generally have good trunk stability and full movement of their upper abdomen, shoulders, and arms (Cooper, 1990). This mobility is necessary to operate the Magellan Wheelchair in its current design form.



A graphic explanation of the classification system used by the National Wheelchair Athletic Association (Cooper 1990).

CLASS IA

All cervical lesions with complète or incomplete quadriplegia who have involvement of both hands, weakness of tricepts (up to and including grade 3 on testing scale) and with severe weakness of the trunk and lower extremities interfering significantly with trunk balance and the ability to walk.

CLASS IB

All cervical lesions with complete or incomplete quadriplegia who have Involvement of upper extremities but less than 1A with preservation of normal or good tricepts (4 or 5 on testing scale) and normal or good finger flexion and extension (grasp and release) but without intrinsic hand function and with a generalized weakness of the trunk and lower extremities interfering significantly with trunk balance and the ability to walk.

CLASS IC

All cervical lesions with complete or incomplete quadriplegia who have involvement of upper extremities but less than 1A with preservation of normal or good tricepts (4 or 5 on testing scale) and normal or good finger flexion and extension (grasp and release) but without intrinsic hand function and with a generalized weakness of the trunk and lower extremities interfering significantly with trunk balance and the ability to walk.

CLASS II

Complete or Incomplete paraplegia below T1 down to and including T5 or comparable disability with total abdominal paralysis or poor abdominal muscle strength (0-2 on testing scale) and no useful trunk sitting balance.

CLASS III

Complete or incomplete paraplegia or comparable disability below T5 down to and incl uding T10 with upper abdominal and spinal extensor musculature sufficient to provide some element of trunk sitting balance but not normal.

CLASS IV

Complete or incomplete paraplegia or comparable disability below T10 to and including L2 without quadricepts or very weak quadricepts with a value up to and including 2 on the testing scale and gluteal paralysis.

CLASS V

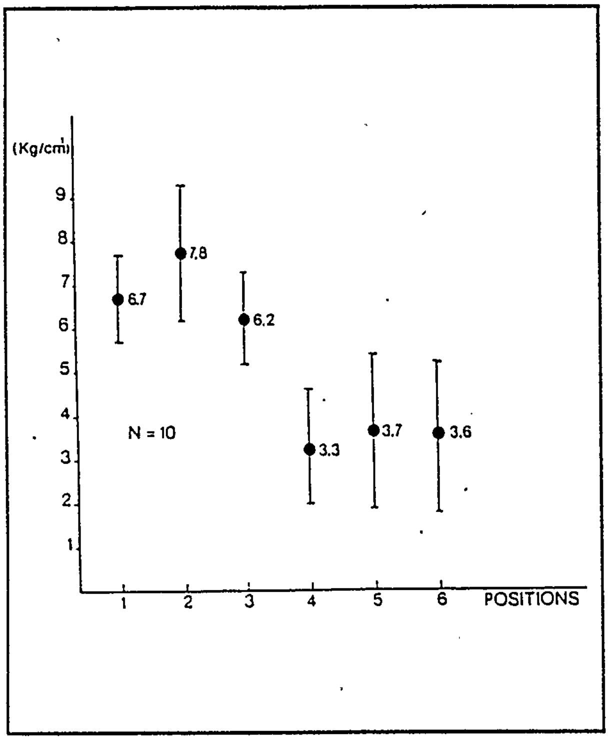
Complete or Incomplete paraplegia or comparable disability below L2 with quadriceps in grades 3-5.

Seated Postures

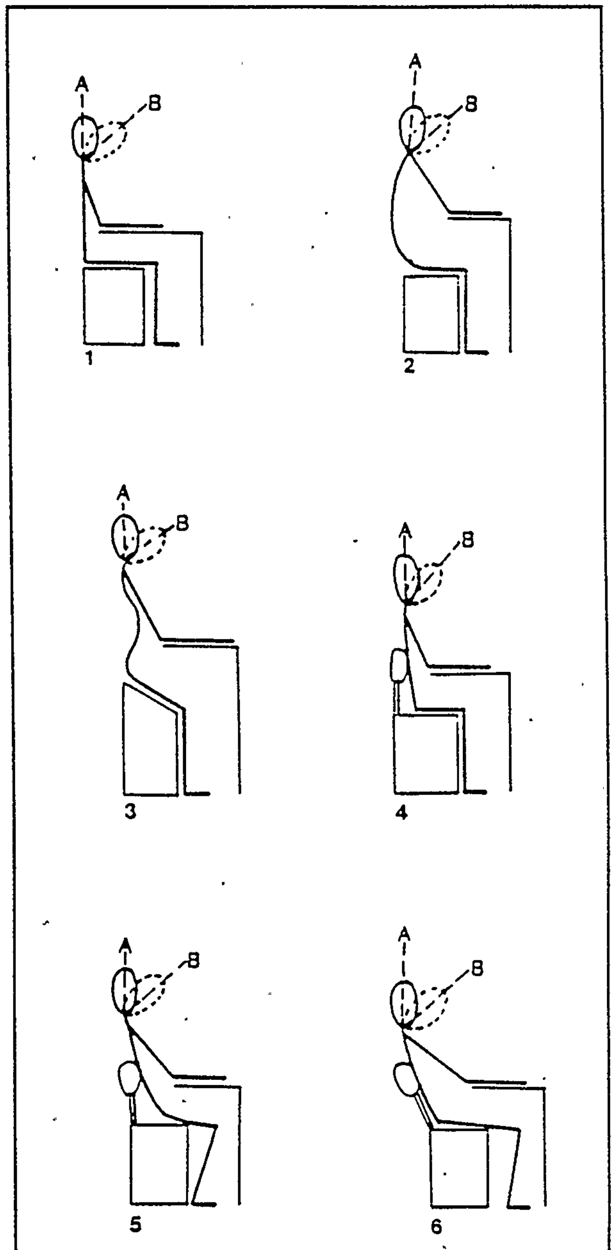
The table illustrates the lumbar load on the L3/L4 area of the spine. Each value corresponds to the position of one of the seated figures.

Figures 1 through 3 illustrate an unsupported lumbar region and this reflects in the higher lumbar load on the table. Positions 4 through 6 show a supported lumbar region with the figures slightly reclined - #4: 10^0, #5: 20^0, #6: 25^0 this reflects in lower lumbar loads with Position 4 being the lowest.

Both Zacharkow (1988) and Kamenetz (1969) recommend a back rest inclination of 10^0 to 15^0.



(Adapted from Colombini et al , 1986)



Ergonomic Considerations of Current Wheelchair Design

All of us are in a very real sense "disabled". How we measure or define disabled is a relative term which must be used in comparison with some kind of "average" or norm established by society. Stephen Pheasant in his book, **Bodyspace: anthropometry, ergonomics, and design**
(1986), states ;

> *"... a disability is the absence of an 'ability' and if we choose to compare ourselves with Olympic athletes or musical virtuosi most of us would find that our 'abilities' were of an exceedingly modest scale." (Pheasant, p: 170)*

Pheasant goes on ;

> *"... any polite person knows that we do not call a person a cripple any more than we call him a 'bastard'. To call someone an invalid', although seemingly less abrasive, is in a sense worse - since it carries with it the implications that the person's existence is in some way less valid than that of other people." (Pheasant, p:170)*

The **World Health Organization** defines healthy as being a state of complete physical, mental, and social well being. Not many of us fill that bill.

It would appear that we are getting caught up in a matter of semantics, however, the distinction between disability and handicapped is of great importance and in many cases dependent upon the design of the environment.

> *" Streets without kerbstones, buildings without staircases and lavatories with adequate turning space do not alter the disability of the paraplegic but they reduce the burden of handicap imposed by the environment upon a person whose mobility is dependent upon a wheelchair." (Pheasant, p: 171)*

The wheelchair user appears to be handicapped three times over. Firstly, whatever the condition that put them in the wheelchair, the disability concern is handicapping. Secondly, they must operate at an eye level which is approximately 400mm lower than standing persons, which is both physically and psychologically disadvantageous. Thirdly, they roll around in an awkward, cumbersome, space consuming and unelegant vehicle (Pheasant, 1986).

From data extrapolated from Pheasant it can be estimated that by the year 2000 8.8% of the western world's population will suffer from physical impairment. (Pheasant, 1986)

Information on Users

Diffrient et al (1982) describes users of wheelchairs as those individuals with:

a. paralysis of various degrees: paraplegics (whose lower limbs are partially or totally affected), and hemiplegics (who have one side of the body affected with partial or total paralysis)

b. spinal injuries and other back problems

c. deformities of the spine, hip or pelvis

d. amputations

e. loss of joint mobility due to rheumatoid arthritis and other musculoskeletal diseases

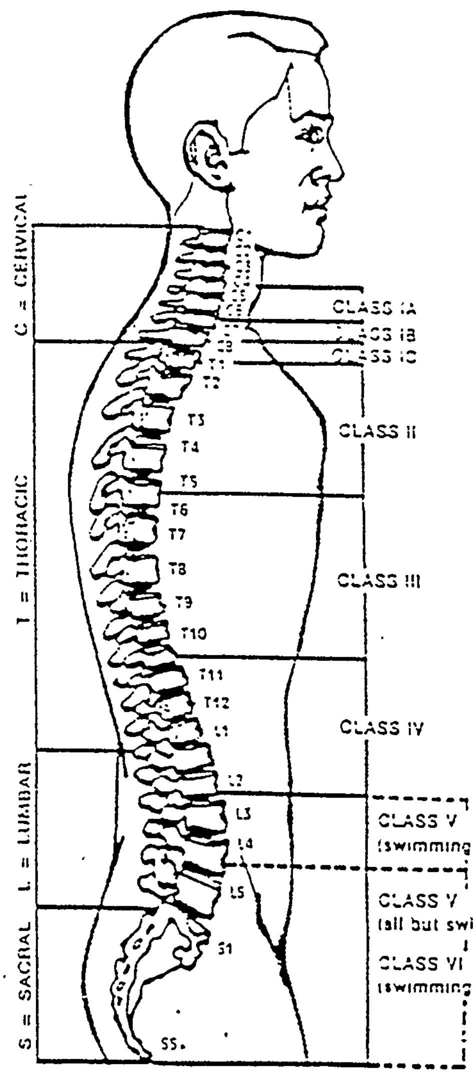
f. loss of muscular strength, muscular dystrophy, and other related diseases

g. loss of controlled movement (like spastics) and those with multiple sclerosis, and and those with multiple sclerosis, and other types of motor incoordination

h. perceptual disorders (those who can move their limbs but cannot direct them)

i. afflictions due to aging (Diffrient et al, p: 26)

For this project, however, the classification system provided by Cooper (Cooper, p: 304) is the most appropriate. This system is based upon where along the spine the lesion or injury occurred and the resulting level of paralysis. Specifically, the project has been developed for the Class III and higher (Class IV and V) individual.



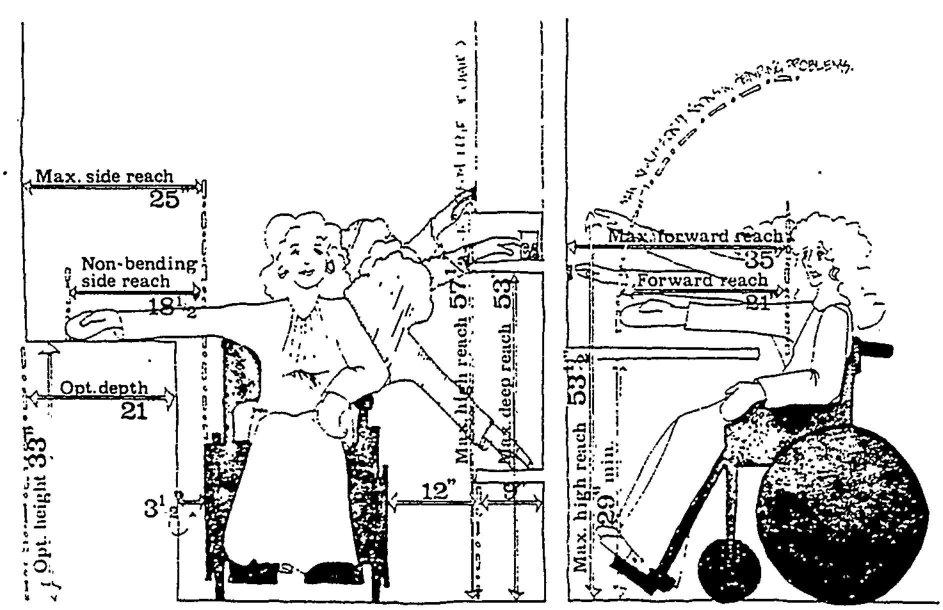
Medical Classification System
(from Cooper, 1990)

Physical Abilities

In his general classification Cooper describes the abilities of Class III individuals as complete or incomplete paraplegia or comparable disability below T5 down to and including T10 with upper abdominal and spinal extensor muscles able to provide some element of sitting balance but not "normal". He describes Class IV as complete or incomplete paraplegia or comparable disability below T10 to and including L2 without quadriceps or very weak quadriceps and gluteal paralysis. Class V is described as individuals with complete or incomplete paraplegia or comparable disability below L2.

Reach

One source of information regarding the physical limitations of individuals confined to a wheelchair comes from Diffrient et al in **Humanscale (1974)**, produced by Henry Dreyfuss and Associates.



Range of Forward & Side Reach
(from Huchingson, 1981)

Pressure Sores

Since pressure sores are a critical factor for many wheelchair bound individuals, (Zacharkow; 1988), this subsection has been entirely devoted to the topic.

In his book, **Posture, Sitting, Standing, Chair Design and Exercise (1988),** Zacharkow claims that over 4% of deaths among spinal cord injured individuals can be directly attributed to pressure sores. (Zacharkow, 1988) Additionally, chronic pressure sores are a major factor in renal amyloidosis. Renal failure, the leading cause of death among the spinal cord injured, is often due to renal amyloidosis. (Zacharkow, 1988)

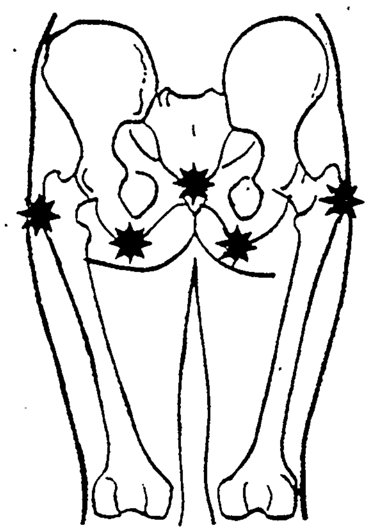
A pressure sore can develop in a few hours and nerve compression in just a few minutes. Similar to the sensation when nerve compression puts the leg "asleep", sensory and motor nerves (peroneal nerves) can be squeezed by the leg pressing against the legrest. (Kamenetz, 1969)

> *"This can happen in normal limbs. The chances are still greater when pressure is prolonged, when the muscle pads surrounding the nerves have diminished, when the nerve has suffered in its substance, when sensation is impaired so that the pressure is not recognized, and when, although aware of pressure, the patient cannot move to correct it because of paralysis" (Kamenetz, p: 137).*

Pressure sores can occur anywhere; the side of the knees, the back of the heal and the worst, often the most painful, the buttocks. The only relief is to discontinue sitting. Simply reclining is not enough as the 'boney prominences' (Kamenetz, 1969), slide forward while the skin remains in contact with the clothing and the seat. This causes a shearing force between the skin and bone stretching and squeezing the vessels and tissue. Little investigation has been done on the relationship between posture, pressure distribution and various wheelchair designs, The most effective way to reduce this pressure is to use a pad which was developed in 1966. It is filled with a gel like substance with consistency similar to that of human fat tissue (Kamenetz, 1969).

Most Common Pressure Sores

The three most common areas for pressure sores are over the ischial tuberosity, the saccrococcygeal region, and the greater tronchanter of the femur. Zacharkow (1988) reported that studies showed 21% of the pressure sores were over the ischial tuberosities, 19% were over the tronchanters, and 15% over the sacrum.

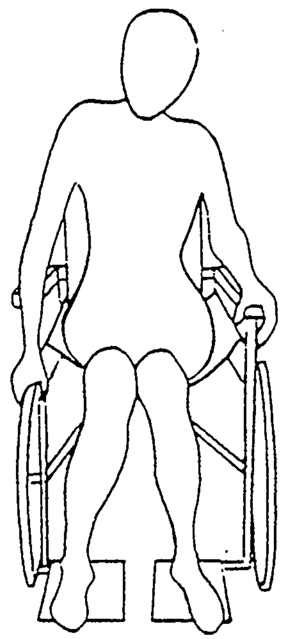


Common pressure sore locations
(from Zacharkow, 1988)

Overall, more pressure sores are due to a sitting position as opposed to a recumbent position.

Problems With Wheelchair Design

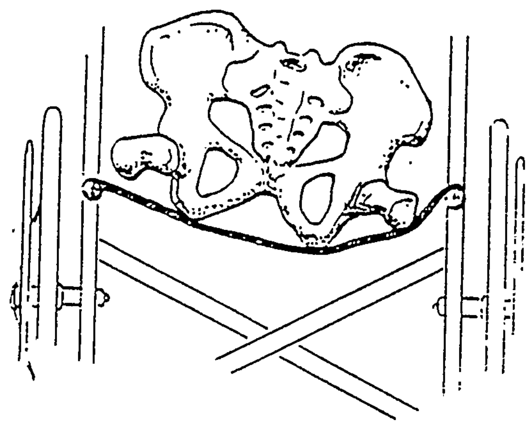
Due to the need to make wheelchairs portable, a hammock or sling seat is often the standard. This type of seat invites tilting of the pelvis which causes the hips to adduct and internally rotate on the hammock seat resulting in a very narrow base of support (Zacharkow, p: 245).



Hip adduction and pelvic tilt
(from Zacharkow, 1988)

This sitting position increases the risk of pressure sores over the ischial tuberosity and tronchanter. Another problem associated with the hammock seat is the increased lateral shearing forcss over the buttocks and tronchanters (Zacharkow, 1988 & Kamenetz, 1969).

A second design concern is the backrest upholstery. As with seating, a hammock backrest provides absolutely no pelvic-sacral support. The individual is forced to sit in a slumped sitting position. This forces the centre of gravity to reside over the ischial tuberosities, with less weight being distributed over the posterior thighs. As the backrest upholstery continues to stretch, both the coccyx and the lower sacrum may become weight bearing.



Weight bearing on the ischial tuberosities due to poor pelvic-sacral support.
(from Zacharkow, 1988)

Leg Position

There is a common misconception that in order to reduce the pressure on the ischial tuberosities the feet of the person should bear little or no weight.

> *"This philosophy on leg position avoids the fact that sitting is not a static activity" (Zacharkow, p: 264).*

Zacharkow (1988) lists five detrimental effects that having the legs hang freely might cause:

1. A very unstable sitting posture as the weight of the unsupported legs will destabilize the trunk.

2. A fatiguing sitting posture, resulting in an increase in back muscle activity in an attempt to stabilize the trunk.

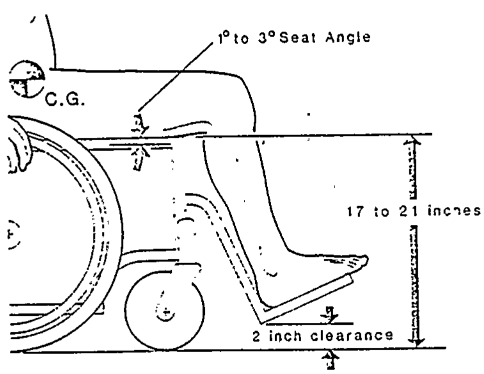
3. The weight of the unsupported legs will result in a force causing the buttocks to slide forward on the seat. The individual will end up in a slumped, kyphotic sitting posture, with an increase in pressure and shearing forces over the posterior to the ishial tuberosities.

4. Without proper foot support, the seated individual will obtain less support from the wheelchair backrest. The combination of foot support and a backrest with a 15^0 inclination resulted in a 31.3% reduction in body weight from the seat.

5. With the feet bearing little if any weight, there will be a very high cut-off pressure at the distal posterior thigh. The compression of the posterior thighs in this posture will obstruct the venous blood flow from the lower legs.

(Zacharkow, p: 264-265)

The footrests should be adjusted to provide foot support, with little or no pressure being exerted over the last distal 1/4 of the posterior thighs.



Leg position
(from Brubaker (b), 1990)

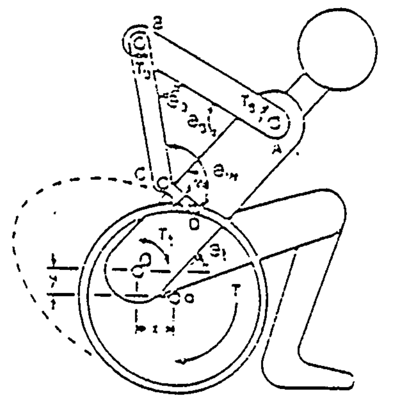
Propulsion

"There are three basic methods of propulsion: (1) motorized propulsion: power is furnished by an electrical battery; the occupant operates a switch by a small movement of some part of the body. (2) Attendant propulsion: the chair is moved by another person by the push handles like a perambulator. (3) Self-propulsion: the user turns the handrims attached to the large wheels. He can also use one or both feet either alone or in combination with one or both handrims." (Kamanetz, p: 138)

There are a number of ways to increase the efficiency of wheelchair propulsion. Some include handrim projections, splints for a paralyzed hand or a harness for an unstable shoulder. For this project another method of propulsion was looked at: lever drive.

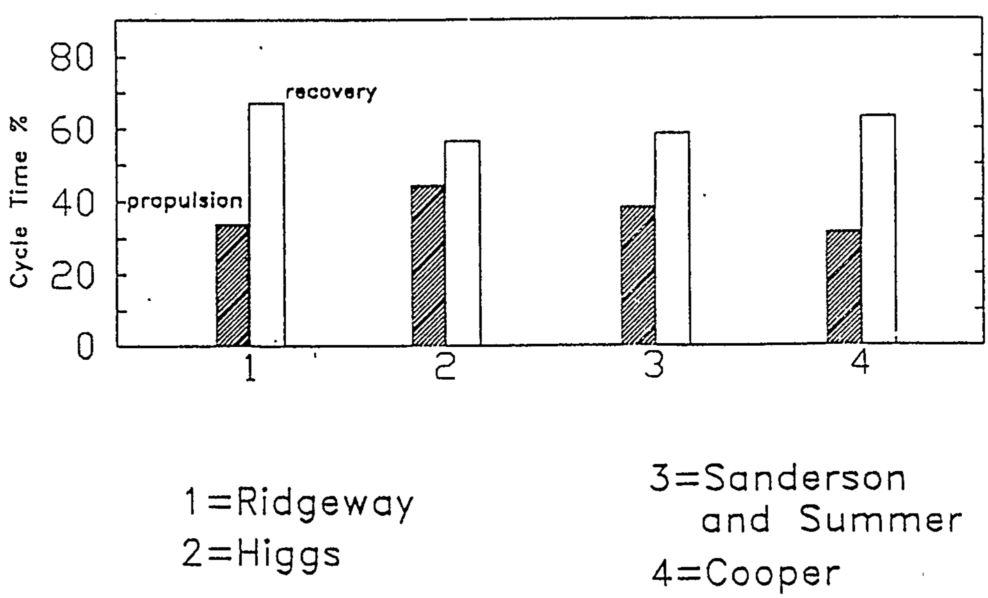
The lever drive system was looked at in greater detail in Chapter 6 which discussed the design solution in greater detail. However, it is necessary to understand the systems of propulsion for the standard wheelchair in order to get a greater appreciation for the various concerns which led to the design of the Magellan wheelchair.

The study of the biomechanics of wheelchair propulsion is fairly recent. Most activity has centred around racing wheelchairs. Much of the published information has appeared after 1980. The figure below shows a typical four-link kinematic model used for biomechanical analysis of wheelchair propulsion.



Four-link kenematic model
(from Cooper, 1990)

Cooper (1990) has investigated the cycle time, (total time for each stroke), spent in propulsion and recovery. His findings produced a mean percent of 36.25% for propulsion and 63.75% in recovery. The table below illustrates these findings along with those of a number of other studies.



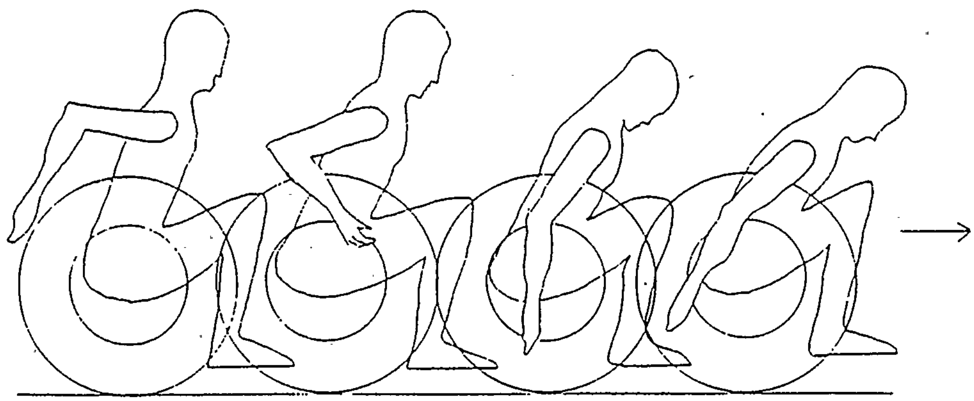
Propulsion and recovery rates
(from Cooper, 1990)

This would indicate that there is a greater need to understand the propulsion biomechanics when designing the wheelchair. As was outlined earlier, the posture of the individual plays an important role in the health and well-being of the wheelchair dependent person.

Another related factor in the study of wheelchair propulsion is that of head and trunk movement during the propulsion stage. Cooper (1990) refers to a study done by Ridgeway et al that showed higher class athletes exhibited less head movement. Class II & III people showed 13.9% movement while those in Class IV & V showed 6.8% of movement. Other studies also done by **Ridgeway** (Cooper, 1990) produced evidence which showed that trunk movement during propulsion was lower with lower class individuals as compared to the higher class individuals.

With greater head and trunk movement comes the increased possibility of developing kyphosis of the spine, greater stress on the joints of the upper limbs and related musculature as well as increased pressure and shearing forces on the buttocks and posterior thighs. The figure below shows typical joint trajectories during steady propulsion.

It is beyond the scope of this paper to delve deeply into all the factors which affect wheelchair performance and propulsion efficiency. Clifford Brubaker, Ph.D., of the University of Virginia Rehabilitation Engineering Center has written a number of highly technical articles on the subject. Most can be obtained through the **Rehabilitation Engineering Society of North America.**



Typical Joint trajectories during propulsion
(from Cooper, 1990)

Cooper (1990) states that;

> *"Evaluating the biomechanics of 'wheelchair propulsion has been limited by available instrumentation and the apparent lack of coordination between nvestigators of different disciplines."*

> *"The Prosthetics Center Bioengineering Laboratory in New York City of the Veterans Administration reported that there was little basic information available about performance factors of wheelchairs. 'Such standards as do exist are descriptive in nature and relate primarily to dimensions and materials of the devices. A meaningful evaluation, however, depends on tests not only of the hardware but also the human factors that enter into efficient use.' The program of the Bioengineering Laboratory consists of specifically designed test procedures to provide information on: 1. analysis of mechanical design, adequacy of materials, and durability; 2. convenience and ease of operation; 3. patient acceptability in relation to appearance, utilization in the home, and the availability of similar devices; 4. stability and safety; 5. force and energy requirements" (Kamenetz, p: 140).*

Wheelchair Selection

The selection of a wheelchair depends not only on the nature of the disability, but also upon the age, height and weight of the individual; where the chair will be used (indoors or outdoors), and method of propulsion (both upper limbs and motorized). Often it is impossible for final selection until the person has reached a plateau in their disease or disability. However, it is often necessary to use a wheelchair to halt the continuance of the disability. In this case, compromises must be made. Most wheelchairs allow for some modification as the person's needs change.

Factors of Selection

A wheelchair should be selected not only according to the measurements and disability of the user but also to their abilities. There is no simple performance for choosing a chair. Cochrane et al lists nine factors for selection:

1. Method of propulsion
2. Positioning
3. Dimensional Compatibility
4. Transfer Method
5. Psychological Factors
6. Environment of Use
6. Transport Considerations
8. Cost
9. After-sales Service

(Cochrane et al, p: 1)

Only Factors 1, 2, 3 and 5 will be looked at in this section.

Method of Propulsion

Propulsion may be independent or assisted by another person. Any method requires that the user has the understanding and vision to use the chair safely.

Positioning

As positions for comfort and different activities vary, certain compromises must be made. There are several independent design features which can influence comfort and functionability (seat cushions, back rests, etc.)

Dimensional Compatibility

Symmetry, if this is possible, is the key to correct sitting posture and comfort. As was stated earlier, the buttocks should bear an equal load and correct anatomical spinal curves should be maintained. Wheelchair seating dimensions should match the body dimensions.

Psychological Factors

The person's reaction to using a wheelchair should not be underestimated.

> *"This is the sum of many values - its appearance, the uncertainty of other people's attitudes, their empathy or perhaps their lack of understanding, the person's confidence, determination to use the chair independently and overcome hindrance and realization that walls and furniture may be damaged and carpets dirtied." (Cochrane et al, p: 2)*

The person's wishes should always be respected when a chair is prescribed by others (Cochrane et al, 1988).

Wheelchair Performance

Wheelchair performance is directly related to the individual's position in the wheelchair. The position (distribution of mass with respect to the wheel axis and shoulder axis relative to the handrim) is related to several ergonomic factors:

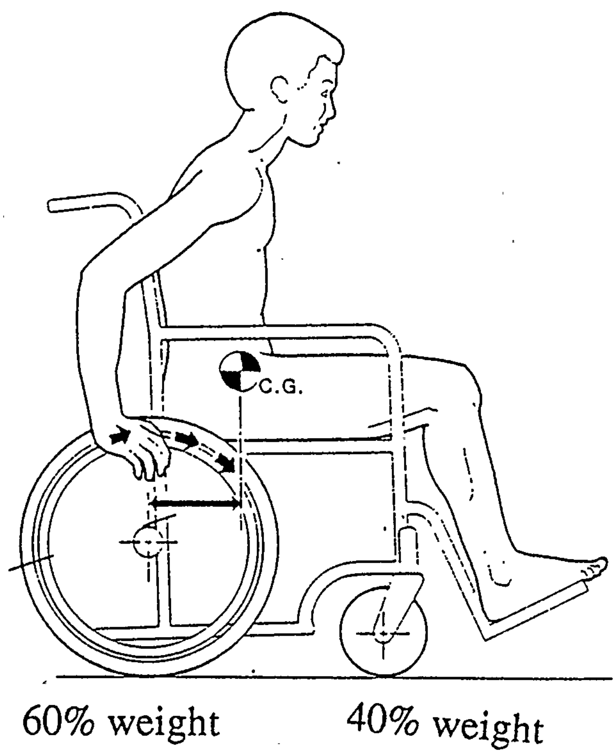
1. Rolling Resistance
2. Downhill Turning Tendency
3. Yaw Axis Control

4. Pitch Axis Control
5. Propulsion Efficiency
6. Static Stability
6. Weight/Portability

(Brubaker[b], p: 37)

Rolling Resistance

The conventional wheelchair configuration results in a weight distribution of approximately 60% over the main wheels and 40% on the castors. By moving the seat slightly rearward so that the weight is redistributed to a 75/25% ratio will decrease rolling resistance by 6%, (Brubaker, 1990[b]). A small amount, yet it could become quite significant over long distances.



Conventional Weight Distribution
(from Brubaker (b), 1990)

Downhill Turning Tendency

This is also known as "side-slope effect". Whenever there is a lateral incline there is downhill turning tendency, and since most outdoor surfaces have a 1^0 to 2^0 slope for drainage, this is a constant condition. A 2^0 slope requires almost twice as much energy to propel a conventional wheelchair (Brubaker, (b), 1990). Again, by moving the seat rearward the centre of gravity shifts and downhill turning tendency is reduced.

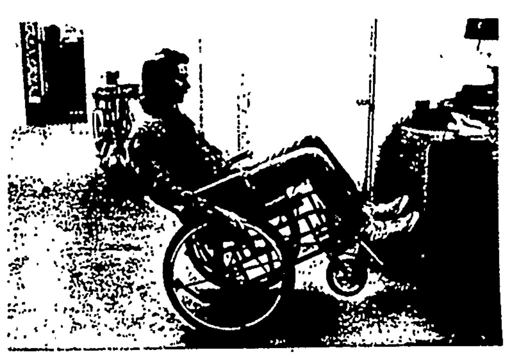
Yaw Axis Control

> "The forces required to manoeuvre the wheelchair are inversely related to the polar movement of inertia of the wheelchair" (Brubaker[b], p: 37).

This moment of inertia can be reduced by moving the seat back towards the main axis.

Pitch Control

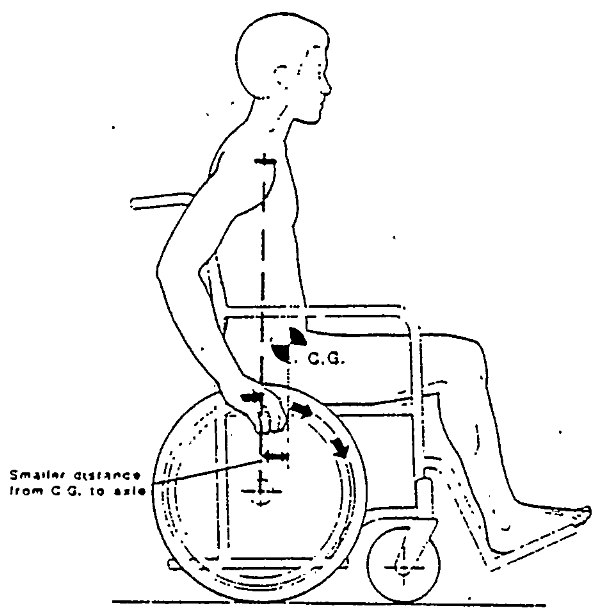
The "wheelie" is an essential ability for all wheelchair dependent individuals because it allows them to climb curbs and provides a greater degree of control and maneuvrability. Trunk movement has a large moment of inertia and is important in pitch control. (A high seat back can limit the effect of trunk motion involved in pitch control). Pitch control can also be improved by a rearward seat position.



"Wheelie"
(from Brubaker (b), 1990)

Propulsion Efficiency

Propulsion efficiency is also consistent with a rearward seat position. The optimum in propulsion efficiency requires minimum energy consumption in the recovery stage. This depends on the position of the seat. The conventional position forces excessive internal rotation, extension, and shoulder elevation in the recovery phase, in order to grip the rim for the stroke (Brubaker [b], p: 2). If the individual is positioned slightly rearward, the recovery phase is initiated by gravity and requires very little muscular effort.



Horizontal propulsion position

If the user is higher or horizontally nearer the wheel axis, shoulder position is more normal and the propulsion stroke is more horizontal.

(from Brubaker(b), 1990)

Static Stability

Brubaker ([b]1990) states that although the static stability of the wheelchair is reduced with a rearward position of the seat it is doubtful if the consequence is well understood. He also feels that static stability is "...probably overestimated by most prescribers." It must also be understood that Brubaker and most of his contemporaries are more interested in the dynamic forces affecting wheelchair propulsion and have spent little time investigating the static stability concern. Static stability is of the greatest concern to those who are confined to a wheelchair. This concern is based on the principle of having a stable and safe method of transportation.

Weight/Portability

Weight and portability have very little to do with propulsion performance on level ground. The additional cost of lightweight chairs is justified only if the individual frequently needs to propel on grades or if the wheelchair is loaded and unloaded from a vehicle by hand.

The ergonomic and biomechanical information contained in this appendix has been instrumental in establishing design guidelines for the Magellan Wheelchair. In addition, the information acted as a catalyst in creating an increased awareness, on the part of the designer, of the particular needs of the disabled. It has also become acutely apparent that there is still a need for increased and improved research in the area of wheelchair design.

A common theme throughout this section of Appendix I has been the apparent lack of established research in the areas of ergonomic and biomechanical analysis of wheelchair design. Cooper (1991) laments about the lack of a coordinated effort on the part of researchers to establish testing and design parameters. Kamenetz (1969) also stated that little information exists beyond simple measurements and discussions about fabrication materials. He was also concerned that the user was not being considered in design evaluation.

Society is just now beginning to realize the potential of the disabled population (Phaesant, 1986). Designers are becoming much more aware of integrating sound ergonomic principles into their designs so that all people regardless of handicap are able to use their products in a safe and reliable fashion.

APPENDIX II

- User Survey
- Questionaire

User Testing Procedure

I. **Introduction**

1. introduction/welcome
2. describe sequence of events for the product evaluation session
3. explain consent form and request signing

II. Product evaluation

1. describe sequence of events
2. show Magellan Wheelchair model or drawings
3. inquire as to the types and experiences with other wheelchairs
4. request that semantic differential rating be completed

III. Demographic information

User Testing Materials

testing package to include

1. participation consent form
2. recording test form
3. production evaluation (semantic differential) sheet
4. demographics data sheet
5. post-product evaluation interview questions

Consent Form

Magellan Wheelchair (HPV) Evaluation Study
Scott Wilkinson, Principal Investigator
Industrial Design Program
Faculty of Environmental Design
The University of Calgary

I voluntarily agree to participate in this product evaluation study of the Magellan Wheelchair (HPV) being conducted by Scott Wilkinson, a graduate student in Industrial Design, Faculty of Environmental Design at the University of Calgary. I understand that the purpose of the product evaluation as explained to me by the investigator is to obtain evaluative responses to the design of the Magellan Wheelchair (HPV). I understand that there will be several different phases to the study as described to me by the investigator and that the responses to the different phases may be audio-taped.

I understand the following:

1) participation in the study will follow the procedure described to me by the investigator,
2) all information I provide will be kept confidential and will not be used to identify me in any way,
3) all study materials will be destroyed upon successful completion of the research project,
4) any recordings of my participation will be erased at once at my request,
5) I am not compelled to answer any question or provide any information requested,
6) danger of physical and psychological risk due to participation in the study is negligible,
7) I have a right to a summary of the results of the study,

8) I am free to withdraw from the study at any time,

9) I will not receive remuneration for my participation in the study.

My willingness to participate in this design evaluation study is indicated by my signature.

Signature:

Date:

Name (please print):

Consent Form
Use of Audio Recordings

I understand that this study is part of a Master's Degree Project (MDP) and as such it may be useful to use excerpts of the audio tapes for the purpose of example in the MDP document and defense presentation. I understand that my permission will be sought and must be granted before any recordings of me will be used. If recordings of me are to be used, I understand the following:

1) I will hear the recording as it is to be used prior to its use in the MDP document or defense presentation,
2) I am under no obligation to agree to the use of any recording,
3) my stated agreement with the conditions of use of recordings stated here is separate from my agreement to participate in the study.

My understanding of the conditions of the use of audio recordings is indicated by my signature below. I understand that if recordings of my participation in the evaluation session are required for inclusion in the MDP document or defense presentation my consent will be sought at that time and must be granted before any recordings of my participation will be used.

Signature:

Date:

Name (please print):

Please look at the Magellan Wheelchair, you may handle the chair if you like. The experimenter will assist you if necessary, please do not attempt to get into or operate the Magellan wheelchair.

After looking at the Magellan wheelchair, please rate the chair on the following scale. Place a mark on the line between the two adjectives to indicate how closely you think the adjective applies to the wheelchair. For example, if the first adjective pair was

light---heavy

and you thought that the chair was light you would place your mark on the half of the line closer to the word"light". How close to the word you put your mark indicates how closely you think the word applies to the Magellan Wheelchair.

You may look and handle the chair as often as you wish.

adequate size------------------------inadequate size

impressive------------------------unimpressive

unappealing------------------------appealing

inviting------------------------repelling

unattractive-------------------------attractive

large------------------------small

ugly-------------------------beautiful

modern-------------------------old-fashioned

multi-purpose-------------------------single-purpose

comfortable-------------------------uncomfortable

complex-------------------------simple

plain-------------------------ornate

contemporary-------------------------traditional

ordinary-------------------------distinctive stylish---------------------------------not stylish

expensive---------------------------------cheap

fashionable---------------------------------unfashionable

uncluttered---------------------------------cluttered

nonfunctional---------------------------------functional

unusual---------------------------------usual

well-scaled---------------------------------poorly scaled

useless---------------------------------useful

good colours---------------------------------bad colours

unbalanced---------------------------------balanced

bad lines---------------------------------good lines

well-planned---------------------------------poorly planned

Now that you have had the opportunity to view and handle the Magellan Wheelchair, please rate it in comparison to the chair that you are currently using. Again you may handle the Magellan as often as you like.

adequate size------------------------inadequate size
impressive------------------------unimpressive
unappealing------------------------appealing
inviting------------------------repelling
unattractive------------------------attractive
large------------------------small
ugly------------------------beautiful
modern------------------------old-fashioned
multi-purpose------------------------single-purpose
comfortable------------------------uncomfortable
complex------------------------simple
plain------------------------ornate
contemporary------------------------traditional
ordinary------------------------distinctive
stylish------------------------not stylish
expensive------------------------cheap
fashionable------------------------unfashionable
uncluttered------------------------cluttered
nonfunctional------------------------functional
unusual------------------------usual
well-scaled------------------------poorly scaled
useless------------------------useful

good colours---------------------------bad colours

unbalanced----------------------------balanced

bad lines---------------------------good lines

well-planned---------------------------poorly planned

Demographics Data Sheet

Please provide the following information:

1. Your age:

   under 20`　　21-35　　36-50　　51-65　　over 65

2. Your gender:

   male　　female

3. Rate in importance the following features with 1 being unimportant and 10 being most important.

   Functional ....

   Safe ....

   Comfortable ....

   Stable ....

   Accessible ....

   Easy to operate ....

   Inexpensive ....

4. Do you or would you like to participate in any of the following: (circle those that apply)

   hiking

   camping

   fitness training

wheelchair athletics

grocery shopping

5. How long have you been confined to your wheelchair:

less than 1 year   2-5 yrs.   6-10 yrs.   over 10 yrs.

Results of the Survey and Questionnaire

Ten subjects were chosen to participate in the User Survey and Questionnaire. Seven of the participants were male and 3 female. The average age of the respondents was 25. The results of the survey and questionnaire are on the following pages. I have used copies of the forms presented to the participants to illustrate the results. Information from this survey was used to develop the Design Brief in Chapter 5. In addition, suggestions made by the participants were studied as to their validity in helping with the design of the Magellan Wheelchair.

The overall impression of the design was that it was unusual and not practical indoors or in confined areas. All thought it would work and all said they would like to try it. Two participants stated that they would buy it if it did not exceed the price of their current wheelchair. Three didn't participate in any outdoor activities and 5 said they would wait for others to try it or they would borrow one to try before buying.

Please look at the Magellan Wheelchair, you may handle the chair if you like. The experimenter will assist you if necessary, please do not attempt to get into or operate the Magellan wheelchair.

After looking at the Magellan wheelchair, please rate the chair on the following scale. Place a mark on the line between the two adjectives to indicate how closely you think the adjective applies to the wheelchair. For example, if the first adjective pair was

light--heavy

and you thought that the chair was light you would place your mark on the half of the line closer to the word"light". How close to the word you put your mark indicates how closely you think the word applies to the Magellan Wheelchair.

You may look and handle the chair as often as you wish.

adequate size-------------------------inadequate size

impressive------------------------unimpressive

unappealing------------------------appealing

inviting-----------------------repelling

unattractive------------------------attractive

large-----------------------small

ugly--------------------------beautiful

modern--------------------------old-fashioned

multi-purpose-------------------------single-purpose

comfortable------------------------uncomfortable

complex--------------------------simple

plain---------------------------ornate

contemporary---------------------------traditional

ordinary---------------------------distinctive stylish---✓-----------------------not stylish

expensive---✓-----------------------cheap

fashionable---✓-----------------------unfashionable

uncluttered--------✓-------------------cluttered

nonfunctional------------✓-------------functional

unusual-----✓-------------------usual

well-scaled-------------✓----------poorly scaled

useless------------------✓--------useful

good colours------------✓-----------bad colours

unbalanced-----------------✓--------balanced

bad lines---------------✓----------good lines

well-planned--------✓-----------------poorly planned

Now that you have had the opportunity to view and handle the Magellan Wheelchair, please rate it in comparison to the chair that you are currently using. Again you may handle the Magellan as often as you like.

adequate size------------√------------inadequate size
impressive---√--------------------unimpressive
unappealing---------------------√------appealing
inviting---√--------------------repelling
unattractive-------------------√-----attractive
large-----------√------------small
ugly-------------√-----------beautiful
modern√-----------------------old-fashioned
multi-purpose--√----------------------single-purpose
comfortable------------√------------uncomfortable
complex--√----------------------simple
plain------------------------√----ornate
contemporary--√------------------------traditional
ordinary------------------------√------distinctive
stylish--√----------------------not stylish
expensive--√----------------------cheap
fashionable--√-----------------------unfashionable
uncluttered-----------------------√---------cluttered
nonfunctional---------------------√-------functional
unusual--√-----------------------usual
well-scaled------------√------------poorly scaled
useless-----------------------√----useful

good colours------------------------------------bad colours

unbalanced--------------------------------------balanced

bad lines---------------------------------------good lines

well-planned------------------------------------poorly planned

Demographics Data Sheet

Please provide the following information:

1. Your age:
   under 20` 21-35 36-50 51-65 over 65

2. Your gender:
   male female

3. Rate in importance the following features with 1 being unimportant and 10 being most important.

   Functional ..9..

   Safe ..10..

   Comfortable ..6..

   Stable ..6..

   Accessible ..4½..

   Easy to operate ..6..

   Inexpensive ..7..

4. Do you or would you like to participate in any of the following: (circle those that apply)

   hiking 5

   camping 5

   fitness training 7

wheelchair athletics 7

grocery shopping 10

5. How long have you been confined to your wheelchair:

less than 1 year   2-5 yrs.   6-10 yrs.   over 10 yrs.

Survey of Powered Wheelchair Problems and Features

Brubaker (1982) has stated that there is a need for more reliable information with respect to design changes and new developments in wheelchair design.

> "Decisions for design changes and new developments have often been arrived at from limited anecdotal information. The fact that these decisions have not been particularly responsive to critical needs in some instances is evidence of the need for better information on wheelchair problems and use patterns." (Brubaker, p.68)

The following figures and tables have been adapted from Brubaker, (1982, pp: 68-74). This information deals specifically with powered wheelchairs but it can be used to provide a general scenario for all types of wheelchairs.

Demographics

Information on the sample population is provided in Table 1. The respective mean and median ages for the population of 428 respondents were 37.6 and 36.6 years. The distribution with respect to sex was 53% male and 47% female. An inspection of Table 1. shows that 53% of the sample population had body weights in the range of 100 to 150 lb.

AGE	
mean = 37.6	median = 36.6
SEX	
53% male	47% female
WEIGHT	
< 100 : 12%	151 - 200: 29%
100- 500: 53%	> 200: 6%

TABLE 1.

The respective educational levels of the different segments of the population is presented in Fig. 1. It can be seen that 69% of this group attended college with 43% obtaining college or university degrees. Only 10% of the group had less than a high school education or equivalent.

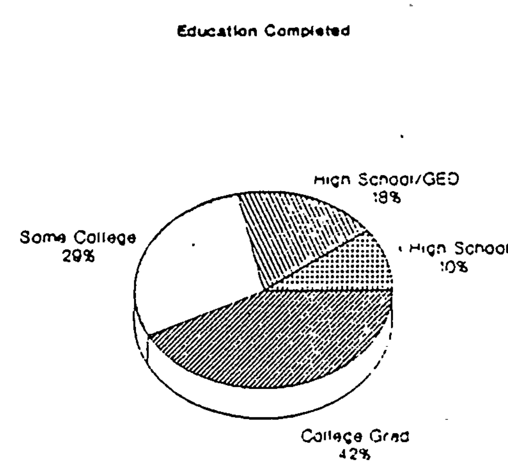


FIGURE 1.

The employment status of the group is presented in Figure 2. Approximately two-thirds of the group were employed full or part time or were engaged in activities that were an alternative to employment (e.g., student, housewife, retired). The remaining one-third (31%) were unemployed. This compares quite unfavorably with the national average - approximately 5% - for unemployment.

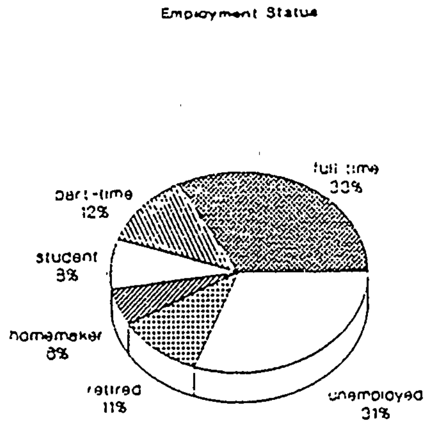


FIGURE 2.

The distribution of disability by type among the total sample population is presented in Figure 3. An examination of this distribution shows spinal cord injury to be the predominant disability accounting for more than 50% with 31% quadriplegics and 22% paraplegics. Cerebral palsy (15%), muscular dystrophy (12%) and polio (6%) were the next most frequent disabilities.

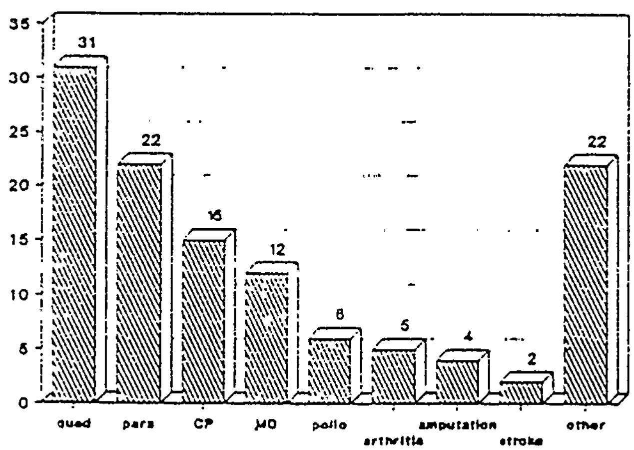


FIGURE 3.

The responses to inquiries on incidence and frequency of pressure sores are included in Table 2. Thirty-four percent had experienced a pressure sore requiring hospitalization with a mean incidence of 3.3 occurrences. The median value of 2.3 occurrences indicates that there was a considerably higher incidence among a relatively small number of individuals.

PRESSURE SORES REQUIRING

HOSPITALIZATION

YES: 34% NO: 66%

OF OCCURRENCES:

mean = 3.3 median = 2.3

TABLE 2.

Wheelchair Use

The history of wheelchair use along with type and number of wheelchairs used/owned by the population are presented in Table 3. The individuals included in the survey were relatively long- time wheelchair users with an average period of use of 16 years. They were nearly evenly split in terms of manual and powered wheelchair use at 53% and 47%, respectively. This appears slightly inconsistent with the figures for average numbers of wheelchairs owned of .6 for powered and 1.1 for manual. This would possibly suggest that some of powered users were in wheelchairs that were borrowed or leased rather than owned.

YEARS OF WHEELCHAIR USE

mean = 16.0 median = 14.4

TYPE OF WHEELCHAIR USED

powered: 43% manual: 57%

NUMBER OF WHEELCHAIRS OWNED

powered: mean = 0.6 manual: mean = 1.1

median = 0.5 median = 1.0

TABLE 3.

The distribution of powered and manual wheelchairs used by respondents to the survey according to manufacturer is included in Table 4. Wheelchairs manufactured by Everest and Jennings were used most frequently in both powered and manual use followed by Motion Designs for manual wheelchairs and by Invacare for powered wheelchairs.

	Powered		Manual	
	%	Adj. %	%	Adj. %
E&J	27.1	57.5	38.1	53.3
Motion Designs			15.2	21.2
Invacare	7.7	16.3	7.5	10.5
Other	12.4	26.2	10.7	15.0
No Response	52.8		28.5	

TABLE 4.

Powered Wheelchair Use - The average years of use of powered wheelchairs and the hours of use per day are included in Table 5.

HOW LONG HAS CURRENT WHEELCHAIR

BEEN USED

mean = 4.4 yrs   median = 3.0 yrs

HOW MANY HOURS IS WHEELCHAIR

USED PER DAY

mean = 11.5 median = 12.1

TABLE 5.

The predominant use of powered wheelchairs in terms of percent respondents according to disability was for those individuals with Cerebral Palsy, Muscular Dystrophy and quadriplegia. The incidence of preferred use of powered wheelchairs was greater than 60% for these disabilities. The responses are included in Table 6.

Disability	% using powered WCs
CP	64
Quadriplegia	61
MD	60
Paraplegia	8
Other disability	37

TABLE 6.

Information on the responses to questions regarding the stability, comfort and kinds of cushions are included in Figures 4, 5 and 6, respectively

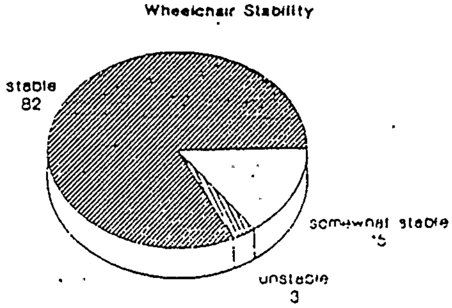


FIGURE 4.

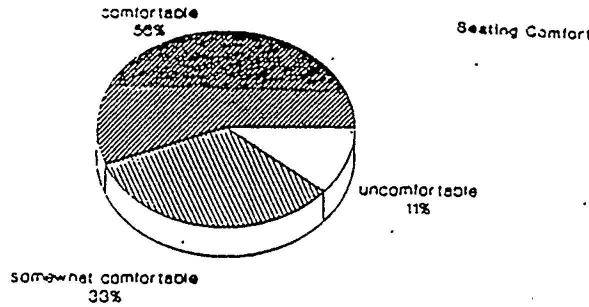


FIGURE 5.

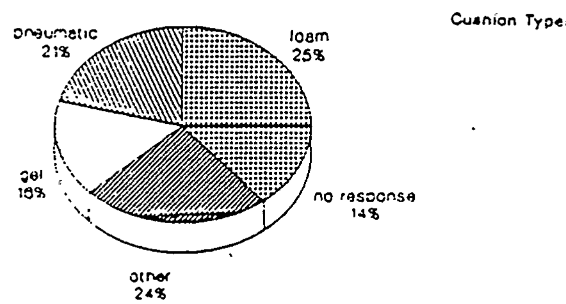


FIGURE 6.

Repairs, Maintenance, Purchase and Associated Costs for Powered Wheelchairs

The distribution of sources for payment of powered wheelchairs used by the respondents is presented in Figure 7. The largest segment of users, 36%, received their wheelchairs from Medicare. The next most frequent methods of payment were with personal funds and personal insurance.

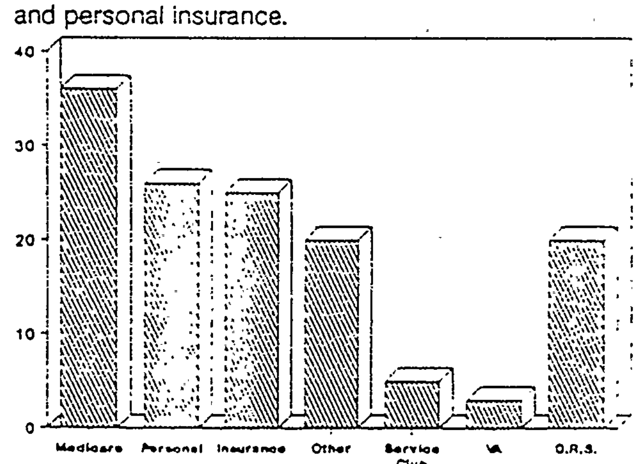


FIGURE 7

Frequency of repairs required for powered wheelchairs and the time the wheelchairs are out of service for repair are included in Table 7. Based on the responses it was determined the mean frequency of repairs for the population under study was 3.9 per year. The average time out of service was 4.8 days per occasion. The respective median values of 2.5 repairs needed per year and 1.5 days out of service indicated that the distributions for these variables are substantially skewed. This would indicate that some of the repairs took a considerable time.

HOW MANY TIMES PER YEAR

ARE REPAIRS NEEDED

mean = 3.9 median = 2.5

HOW LONG IS WHEELCHAIR OUT

OF SERVICE DURING REPAIR

mean = 4.8 days median = 1.5 days

TABLE 7.

The annual costs for repairs and source of funds to pay for these repairs are presented in Figures 8 and 9. Most repair costs, 60%, ranged from $100 to $600. More than 50% of these costs were paid by the individual respondents from personal funds while 39% and 16% were paid by Medicare and personal insurance, respectively.

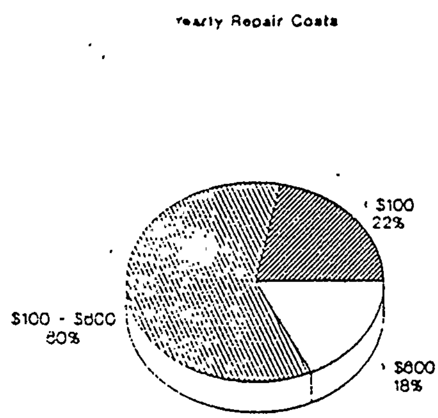


FIGURE 8.

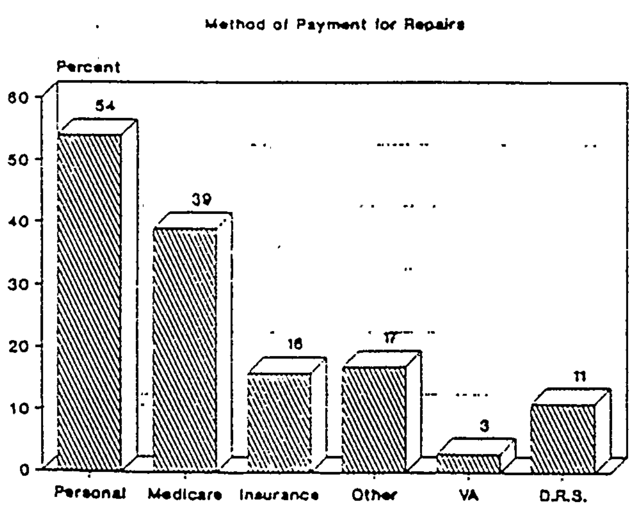


FIGURE 9.

The distribution of problems encountered by the respondents is presented in Figure 10A and 10B. As has been the case in virtually all previous surveys of problems, the most frequent items requiring repair or replacement were batteries and tires

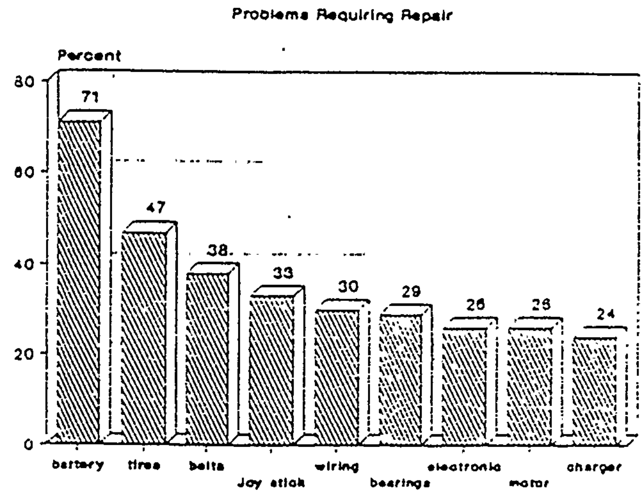


FIGURE 10 A.

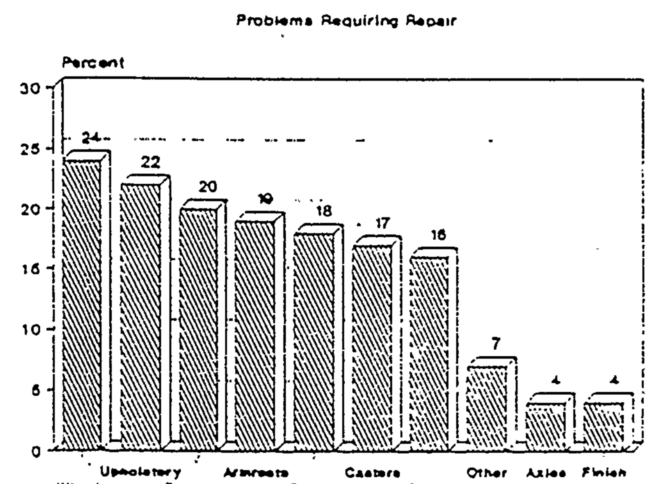


FIGURE 10 B.

The frequency with which various sources were used for repairs by the respondents is presented in Figure 11. It can be seen that a wheelchair repair shop accounted for the largest incidence of repairs, followed by friends and family members, dealers and the users themselves. The high utilization of a repair shop is likely unique to the population surveyed as most ILCs maintain such a facility.

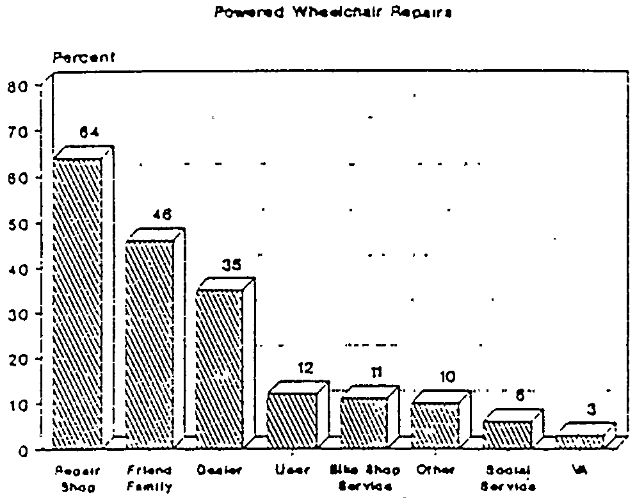


FIGURE 11.

Use Environments and Methods of Travel

The the responses on the relative importance of operation of powered wheelchairs in different environments and terrains is presented in Figure 12. The responses are based on a five point scale in which a rating of "1" indicates that the condition is never encountered while a rating of "5" indicates that the condition is encountered daily. Perhaps the most surprising results are the indications of the high frequency of use in outdoor and, particularly, in off-pavement operation of powered wheelchairs.

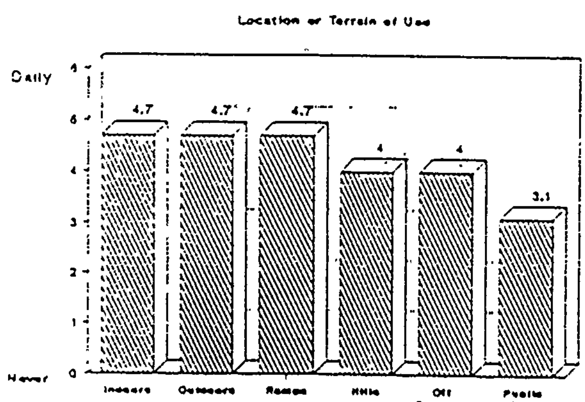


FIGURE 12.

The frequencies for different means of travel and transportation are included by percentage responses in Figure 13. These frequencies are most probably related to the living environments. The use of subways, trains, taxis and buses are obviously dependent on the presence of these services and are in some cases limited to the larger metropolitan areas. The distribution of the sample population was not delineated to reflect the relative importance of different modes of transportation by population density or city size. Clearly the importance of personal transportation is evident in the frequency of travel as passenger and driver.

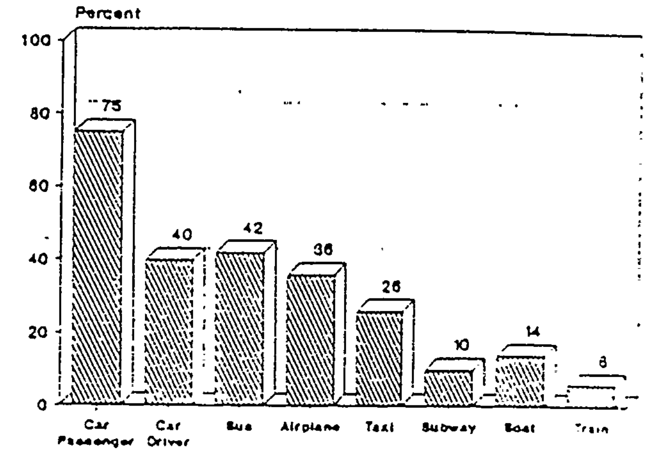


FIGURE 13.

Wheelchair Features

The respondents rated 37 powered wheelchair features on their relative importance using a 5-point scale in which a rating of "1" indicated that the feature was unimportant and "5" indicated that the feature was essential. The mean ratings for these responses are presented in Figure 14 A to H. The highest rated features were "battery life" and "van compatibility" at 4.9. Several features were rated at 4.8. These included: parts availability, ability to climb 1:12 ramp, stability on ramps, outdoor versatility, and sturdy (durable). The next most important features, with mean ratings of 4.7 included: easy service, few repairs, and adequate speed. Features that have commonly been assumed to be important received relatively low ratings. "Light weight" was rated 3.9, ability to "move sideways" was rated 2.5 and ability to "climb a 6-inch curb" was rated 3.4. The latter two ratings cast some doubt on the importance and viability of powered wheelchairs with omni- directional and/or stair-climbing capabilities.

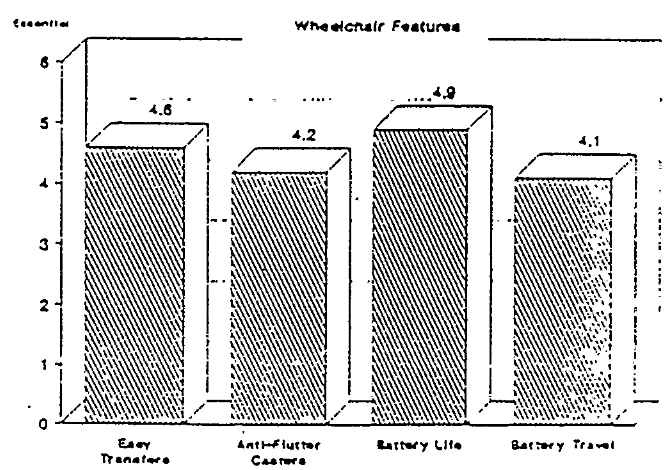


FIGURE 14 A.

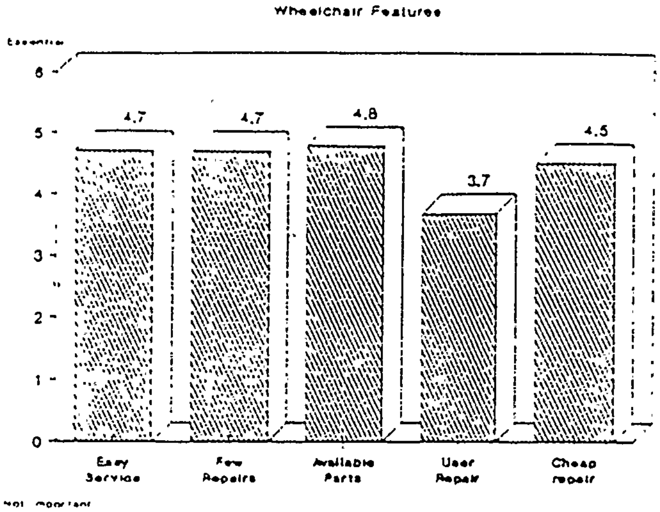


FIGURE 14 B.

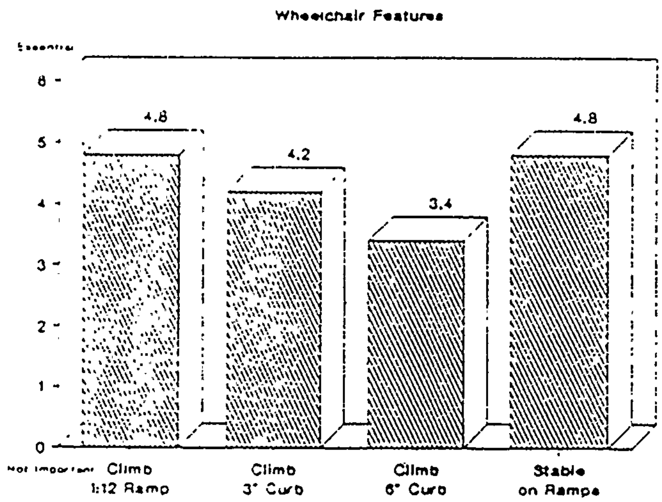


FIGURE 14 C.

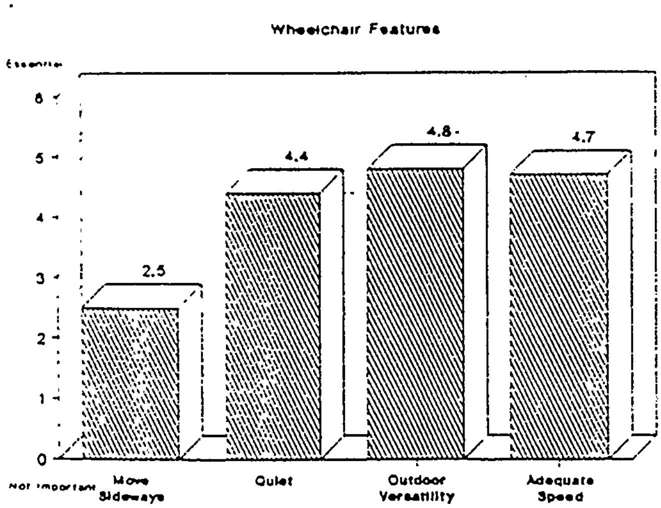


FIGURE 14 D.

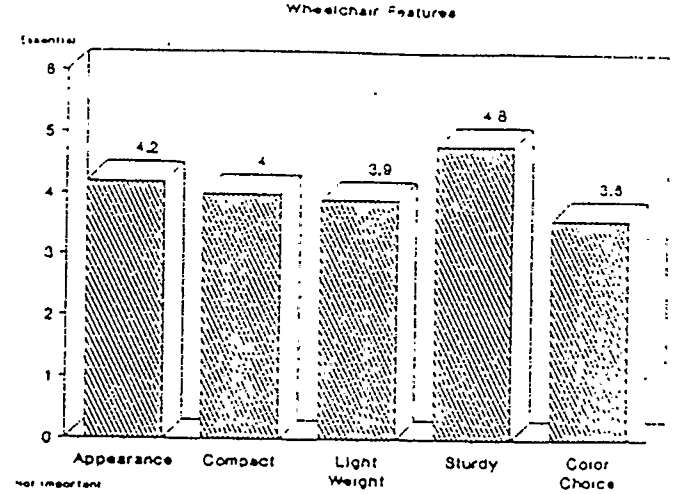


FIGURE 14 E.

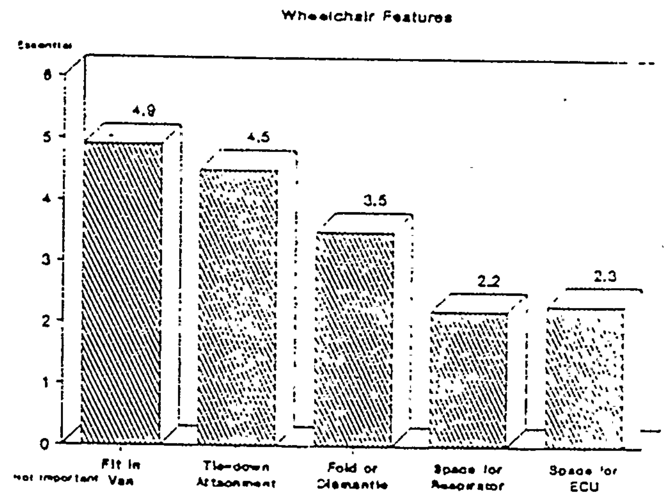


FIGURE 14F.

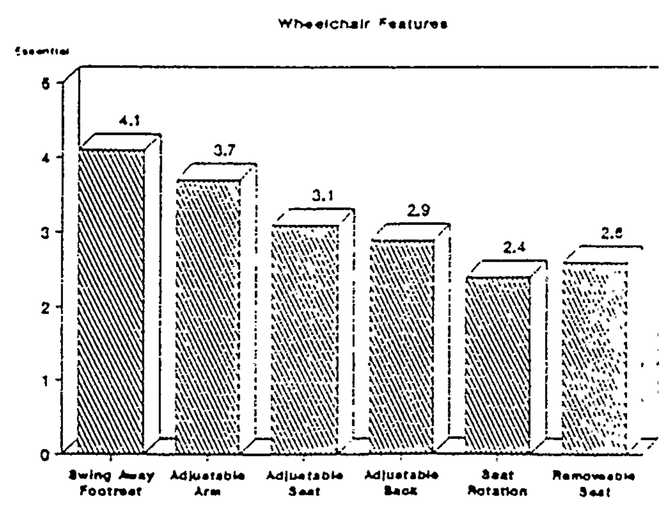


FIGURE 14 G.

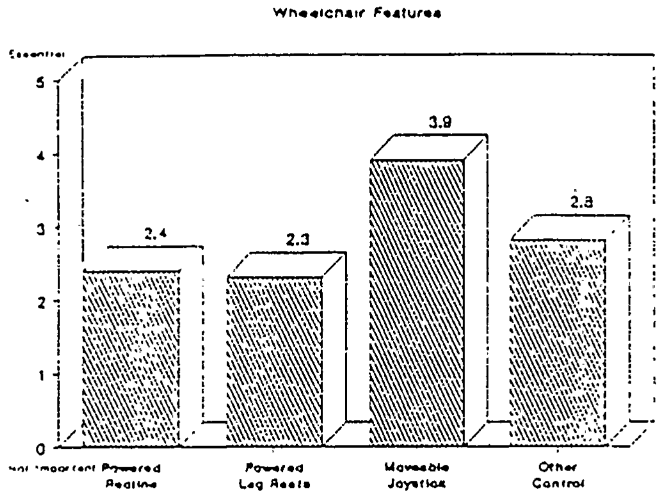


FIGURE 14 H.

Evaluation of Features Relative to Severity of Disability - Responses to questions on the need for assistance with transfers and for outdoor mobility were used to discriminate the severity of disability of the sample population. These responses are included in Figure 15. On the basis of these responses, approximately 20% of the sample could be regarded as being relatively more dependent with respect to mobility.

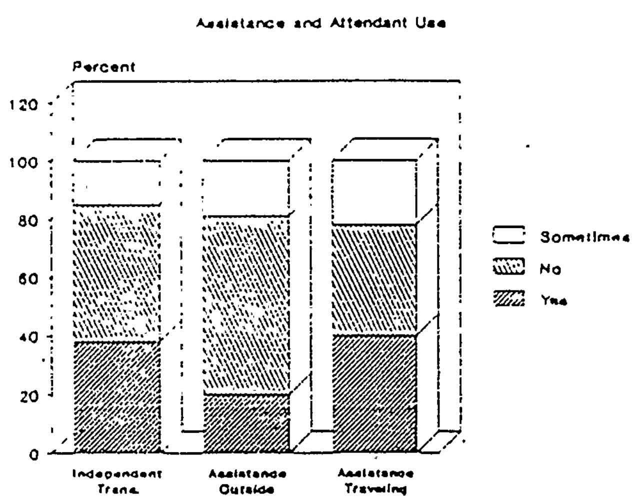


FIGURE 15.

The ratings of wheelchair features judged most important by those respondents that indicated a need for assistance with transfers are presented in Figure 16. Similarly, the ratings by respondents who indicated a need for assistance with outdoor activities (street use) for important features are included in Figure 17. It is of interest to note that these responses are not substantially different than the ratings from the whole sample population. The high rating for "outdoor versatility" in all instances shows that this feature is not influenced by severity of disability - at least for the population under study.

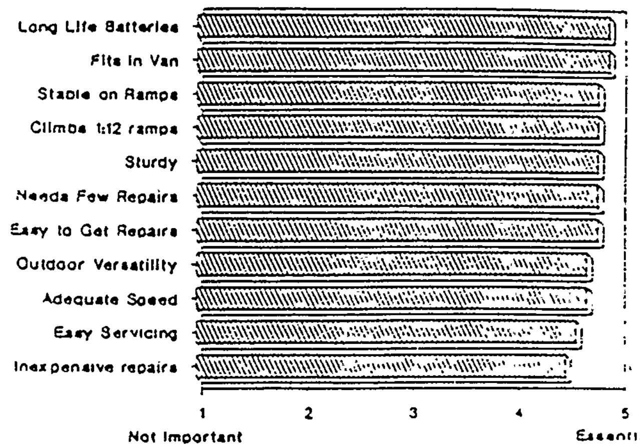


FIGURE 16.

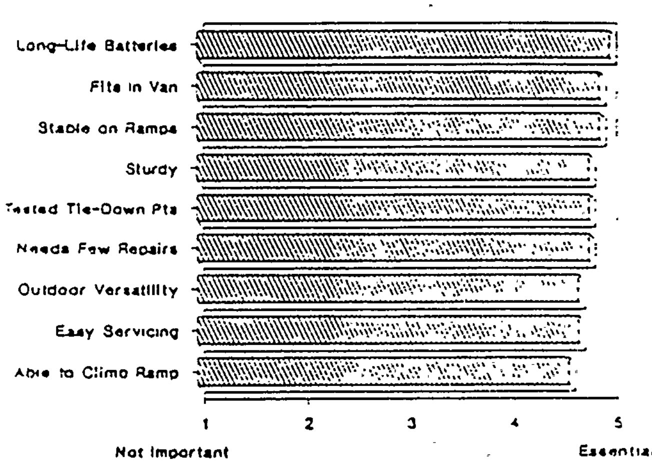


FIGURE 17.

Ratings of some of the features that were not generally perceived as being of great importance were evaluated with respect to the responses by disability groups. The responses were compared using the Chi Square test (P 0.07). The results of these comparisons on these features were as follows:

Rotating seats -- 35% of respondents in the category of "other disabilities" rated this feature as essential (i.e., "5"). This response was significantly different from that of the different disability groups.

Removable seats -- Rated essential ("5") by respondents in "other disabilities" category. Significantly different from other disabilities.

Powered recline -- No difference among disability

APPENDIX III

- Partial list of Dealers and Distributors

Name	Product Name	Cost (*) U.S. $
Access Designs, Inc. 627 Southeast 53rd Avenue Portland, Oregon	Cycl-One	$850.00
Angle Lake Cyclery 20840 Pacific Highway South Seattle, Washington	Counterpoint Opus II	$2,999.99
Crossroads Associates in Rehabilitation, Inc. 1304 Duff Drive, #4 Fort Collins, Colorado	Chinook KT 1000	$1,395.00
Dynamo-Aid MFG., Ltd. 577 Hanley Crescent Windsor, Ontario	Chariot	$850.00-$950.00
Freedom Specialties, Ltd. Box 83 Cleghorn, Indiana	Cycle	$850.00
New England Handcycles 48 Bogle Weston, Massachusetts	Trike 324	$1,900.00
Palmer Industries Inc. P.O. Box 707 Union Station Edicott, New York	The Palmer Handcycle	$799.00
Rehabilitation R&D Center VA Medical Center 3801 Miranda Avenue Palo Alto, California	The Handbike	N/A

Rifton Equipment Route 213 Rifton, New York	The Rifton Large Hand-Driven Tricycle	$495.00**
Rowcycle 3188 North Marks, #120 Fresno, California	The Rowcycle	$1,675.00
Tsam's Things 7124 McComber Street, #5 Sacramento, California	Brike Freedom Rider	N/A

* Base Price

** Only available in a children's model

APPENDIX IV

- Component Considerations from Pang (1989)
- New product considerations from Pang (1989)
- Design conflicts from Pang (1989)
- Product Development Process from Pang (1989)

Advantages and Disadvantages of Shared Components, (from Pang 1989)

Advantages:

- know history of component in similar application
- economies of scale
- lower inventory
- faster product design
- training of service staff not required

Disadvantages:

- no improvement
- component may not be tailored to new application

Off-the-shelf Components

Advantages:

- can obtain history of component but may be under different applications
- possible greater economies of scale if component used for other industries
- minimal effect on product design schedule

Disadvantages:

- modifications to components or revisions to design
- component may not be optimal for application
- training of service staff required

New Developed Components

Advantages:

- general improvement of component over existing
- tailoring of component to specifications

Disadvantages:

- development time adds to product design schedule
- development costs
- lack of component history
- no economies of scale
- production/inventory problems
- training of service staff required

New Product Considerations

The development and design of new products can be a risky venture. Pang (1989) has outlined areas of concern in his paper **Design Process for Powered Mobility Technology** (1989). The various levels of a department or company must make decisions based on a number of different factors. Some of the common considerations are listed below (Pang, 1989):

1. Management/Finance Considerations

- What is the short term and long term profitability?
- What capital investment is required?
- What is the return on investment and pay back period?
- What will be inventory requirements?
- What about cash flow?
- What will be the effect on company size and stability?
- What will be the cost of the product liability insurance?
- Are adequate systems in place - e.g.; order entry, invoice and credit systems?
- Can the product be developed in-house? Consultants?
- What will it cost for research and development?
- Will it qualify for government funded research and development grants?
- How accurate is the information and forecasts?

2. Marketing/Sales Considerations

- Who will buy the product?
- Who are the competition and what is their market share?
- How large is the market? Sales forecasts?
- How stable or competitive is the market?
- What should the selling price be set at? Dealer discounts?
- How much will funding agencies subsidize or reimburse buyers?
- Can existing product be improved to meet needs?
- Will new product cut into sales of existing products?
- What promotions are required?
- When should product be launched for maximum sales effect?
- Where should product be positioned? Deluxe or economy?
- Is the existing distribution network capable of selling and supporting new product?

3. Engineering/Production Considerations

- What features are required? Their relative importance?
- What are the design parameters? Sizes? Variations?
- Can it be done? Technically? Economically?
- Is there expertise available? Suppliers? Government?
- What manufacturing cost is acceptable?

- What is the annual volume anticipated?
- Is there currently enough manufacturing and inventory capacity? Can capacity be increased?
- Are there existing patents to hinder development?
- Are there governing industry standards and codes?

Design Conflicts

Designers must make many decisions as a design progresses and must choose the best compromise between conflicting concerns (Pang 1989). Listed below are common design conflicts that Pang (1989) has identified. Although the conflicts are grouped as pairs often times several conflicts must be dealt with at the same time.

a. **Maneuverability vs. Stability**
b. **Lightweight vs. Strength**
c. **Portability vs. Rigidity**
d. **Aesthetics vs. Function**
e. Power vs. Range
f. Gradeability vs. Speed (ground)
g. **Redundancy (safety) vs. Optimization**
h. **Modularity vs. Customization**
i. **Serviceability vs. Compactness**
j. **Fabrication vs. Tooling**
k. **Comfort vs. Function**
l. **Ground clearance vs. Seat Height**
m. **Adjustability vs. Simplicity**
n. **Outdoor vs. Indoor**
o. **High Quality vs. Low Quality**
p. **Factory Assembled vs. Dealer Assembled**
q. **Optimal Features vs. Standard Features**
r. Factory Installed Options vs. Dealer installed operations
s. **Manufacturing Costs vs. Precision Assembly**
t. Perfection vs. Deadlines
u. **Engineering Achievements vs. Humanitarian concern**

The highlighted design conflicts indicate areas of concern in the design and development of the Magellan Wheelchair. The design process for wheelchairs is not unlike the design process for other products. Large design conflicts are broken down into a smaller more manageable size. Solutions are then found for the smaller concerns and these in turn are combined to create a solution for the larger picture.

Deadlines and manufacturing costs are two of the realities that designers of wheelchairs must face. The wheelchair industry is too competitive to afford longer project development times needed to develop a product that meets 99% of the market need (Pang 1989). Because of this companies develop products that meet 80% of the needs as quickly as possible in order to get a jump on the competition (Pang 1989).

The development time for most large scale products ranges from 12 to 18 months from conception to development.

Innovative and technologically advanced products are hindered by low sales volume, high development and manufacturing costs, and retail price ceilings imposed by funding agencies (Pang 1989).

Successful product designers must have a good understanding of the design process in addition to understanding business principles in order to make the product a success. The designer has to be in constant contact with users, care givers, and therapists.

APPENDIX V

- Solid-frame Wheelchairs from Bair (1982)

Solid Frame Wheelchairs

In the 1930's when Samual Duke and Everest & Jennings were developing their versions of the folding wheelchair their main concern was to develop something that would fit into the automobile, that icon of American society. There were no real health benefits to the folding chair except that it now made it easier for the disabled person to get around. The folding chair has been the centre of some design concern for a number of years, both Zacharkow (1988) and Pheasant (1986) have stated that in fact a number of health problems, directly or indirectly, are caused by the folding chair and its materials of construction. In his article **Advantages of Solid-Frame Wheelchairs** (1982) Lewis Bair discusses the advantages of a solid-frame wheelchair; its advantages over conventional folding wheelchairs and how these advantages affect wheelchair users. The following is a summary of some of the points Bair brings up and how they relate to the Magellan Wheelchair

1. The solid-frame wheelchair is about half the weight of a conventional folding chair - 20 lbs. to 30 lbs. for the solid form as compared to 45 lbs. to 65 lbs. for the folding chair.

   "Moreover the solid-frame chair is much stronger and more desirable because its construction has fewer moving parts and requires less maintenance, which, in turn, results in greater dependability." (Bair, pp. 42)

2. Probably the most important feature in all wheelchairs is the fit. To take advantage of the wheelchair the user must be supported and, above all, comfortable. Factors to be considered include seat width, seat depth, back height, and good pressure distribution (Bair, 1982).

3. In terms of transportability the user's first reaction is that the folding chair is better. However, the releasing front and rear wheels of the Magellan Wheelchair make its transportability competitive with folding models.

(Bair, 1982)

APPENDIX VI

- Wheelchair Standards from McLaurin (1990)

Wheelchair Standards

A series of wheelchair standards is undergoing the final phase of approval by the American Standards Institute (ANSI). These standards have been under development for several years, working closely with the International Standards Organization (ISO) so that the ANSI standards will be comparable and basically the same as other participating countries.

> "The main purpose of these standards is to provide the user and prescriber with the knowledge and assurance that a product measures up in durability and performance. The standards are of value to the manufacturer on an international basis because it enhances their position in foreign markets and restricts the sale of imports that do not meet theses standards." (McLaurin(b), p:100)

ISO standards must undergo rigorous testing procedures and include a majority vote from all participating and observer countries. At a national level the ANSI standards will be adopted as American standards once they have been subjected to public scrutiny and been approved by ANSI's Standards Review Board. The standards, once they are in place are not law but voluntary standards.

Currently there are 17 standards under consideration (McLaurin(b), 1990). Four are general in nature and deal with terms and definitions, overall dimensions, test dummy specifications and procedure for measuring the coefficient of friction of test surfaces (Mclaurin(b), p: 101)

The following has been excerpted from the article **Wheelchair Standards: an Overview** by Colin McLaurin (McLaurin(b) 1990).

1. Static Stability

This applies to manual and powered wheelchairs and refers to the tipping angle of the wheelchair with and without locked brakes when loaded with the appropriate dummy. The tipping in the forward, rearward and lateral directions is determined plus any other direction that may be more critical. The standard will not include acceptance levels, but requires the disclosure of the test results so that the consumer or prescriber may make an informed choice.

The mean value of the test results of other wheelchairs in the same category will be included in the disclosure. Since some wheelchairs have adjustable wheel or seat positions, the maximum and minimum values are recorded.

2. Efficiency of Brakes

This test is concerned with the ability of wheel locks to hold the wheelchair and dummy on a slope. The stopping distance from maximum speed both on the level and on a 5^0 slope is measured on powered wheelchairs. It also applies to wheelchairs with mechanical brakes that are sometimes used on European wheelchairs.

3. Overall Dimensions, Mass and Turning Space

The overall dimensions are self explanatory and include the folded position with and without demountable parts such as footrests. The turning space includes the smallest turning radius and the narrowest corridor in which the wheelchair can reverse direction with a single backing operation.

4. Seating Dimensions

This proposed standard is still under development. It is based on loading the wheelchair with a specified loader gauge to form the upholstery into the shape it would assume in normal use. From this position, 26 measurements are recorded on the dimensions of the seat, backrest, footrests and armrests. For ergonomic reasons, the position of the seat with respect to the handrim or other propulsion device is included. The loader gauge, based on a design used in the European furniture industry, will be available in child and adult sizes.

5. Static Impact and Fatigue Strength

This is one of the few instances where minimum levels of performance are recommended. The actual test values are based on dummy size, and the test results must state which dummy was used, indicating the weight of the person for whom the wheelchair is suitable.

The static test consists of applying a load to various parts of the wheelchair.

The impact testing has several parts. For testing casters, footrests and other parts subject to impact against curbs and potholes, the wheelchair is loaded with the appropriate dummy and crashed into the obstacle at a pre-determined speed. The seat and backrest are tested by dropping a soccer ball fitted with 25 kg of lead shot on specific areas and in specific directions. The wheel and axle assemblies are tested by dropping the wheelchair loaded with the appropriate dummy from a prescribed height so as to land on each wheel separately. The test simulates the stresses incurred when rolling off a curb. The handrims are tested with a weighted pendulum which simulates the accidental striking of the handrims on a door frame.

The fatigue test is conducted using a two-drum test machine. The wheelchair is positioned on the test machine so that the front and rear wheels will run on the drums.

The wheelchair loaded with the appropriate dummy is secured by the axles while the drums are rotated at a speed corresponding to about 1 meter per second. Fastened to each drum are slats, 1/2 x 1 1/2 inches. The number of cycles satisfactorily completed is then disclosed.

The order of testing is specified and one wheelchair must be used for all tests. The disclosed values include the static forces applied, the velocity or drop height of the impact and the number of fatigue cycles completed without structural failure.

6. Test Dummies

This part of the ANSI/RESNA national wheelchair standard outlines the construction of test dummies of nominal mass 25, 50, 75, and 100 kg (55, 110, 165, 220 lbs.). The test dummies are intended for tests in which the wheelchair is required to be loaded.

7. Coefficient of Friction of Test Surfaces

Several test procedures for wheelchairs require that the coefficient of friction of the test surface be within specified limits.

This part of the standard specifies a method of determining the coefficient of friction of a test surface that has a rough texture, such as unfinished concrete.

8. Overall Dimensions

This standard defines the maximum dimensions recommended for manual and powered wheelchairs. This standard serves as a reference for environmental designers to enable wheelchair-accessible hotels, buses, trains, etc., to be designed (28 inches wide, 51 inches long, and 43 inches high).

In summary it must be remembered that these standards are for standard or general wheelchairs and sports chairs. Every effort was taken to make sure that the Magellan Wheelchair fit into the standards which pertained to it. There are two areas where the Magellan Wheelchair did not fit; the wheel base of the chair is 54" and at this point in time the Magellan Wheelchair will not back up easily.

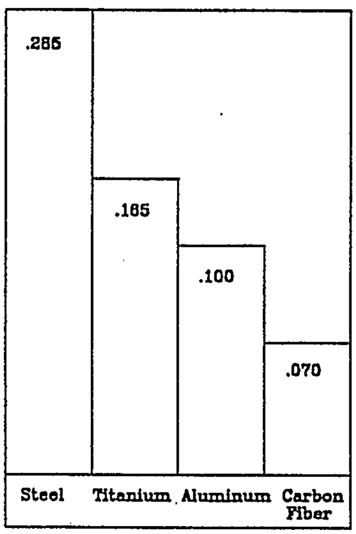
The establishment of standards for manufacturers and designers indicates that there is finally some concern towards the user-chair interface. By creating these standards ANSI and ISO have ensured that the wheelchair user will no longer have to suffer from inadequately designed wheelchairs or chairs constructed of poor quality materials and parts.

APPENDIX VII

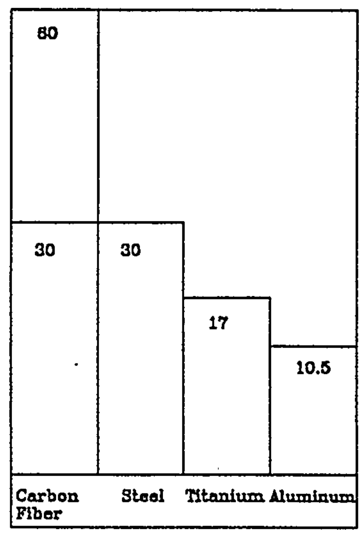
- Frame Materials

Frame Materials

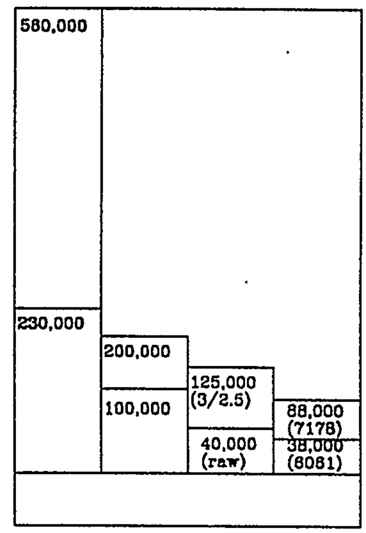
The most common materials used in tubular wheelchair construction are steel, aluminum, titanium, and recently carbon fibre.



WEIGHT
(density in lbs./in.³)



STIFFNESS
(modulus of elasticity in million psi)



STRENGTH
(ultimate tensile strength in psi)

The following is excerpted from Kukuda, 1991.

Steel, aluminum, carbon fibre and titanium differ in strength, stiffness and weight, and each lends itself to different applications. For example, copying the tube dimensions of a traditional steel frame in aluminum or titanium quarantees a limber, flexible ride because neither material is as stiff. That's why aluminum frames typically have larger-diameter tubing than steel ones; the bigger tubes increase rigidity without the added weight of thicker walls.

Another difference is aluminum's lack of a specific endurance limit. Metal frames usually fail not due to a single catastrophic load but because of small, repeated stresses (fatigue). Steel and titanium have defined fatigue limits - if the stresses are smaller than these limits they won't break. Aluminum has no such limit, so each stress cycle, however small, takes the material that much closer to fatigue failure.

Titanium's high strength, light weight, resilience, and resistance to corrosion make it an ideal frame material. Unfortunately, titanium is unlikely to rival the price of steel or aluminum soon. It's costly to refine, requires special building techniques and an oxygen-free welding atmosphere, and suitable tubes are usually only found in defense or nuclear industry waste piles. There is one company in the U.S. which is now attempting to manufacture titanium tubes for recreational uses.

Metal frames are just variations on a theme compared to composites. Unlike metals, which are refined from ores, composites are engineered by combing structural fibres with a non-load-bearing binder - typically an epoxy resin. Until the binder is hardened by exposure to heat or air, the resin-soaked fibres can be molded or formed in virtually any shape.

Because carbon fibre is so strong, stiff and lightweight, standard diameter tubes can work well in epoxy-bonded wheelchair designs.

Even so, there are better ways to use carbon fibre. Metals are equally strong and stiff in all directions (isotrophy), but composites are anisotrophic - their strength and stiffness are only realized along the axis of the fibres. Thus to handle the stresses of a wheelchair frame, composite frames use multiple layers with different fibre angles for each. This method of putting the strength only where it's needed, combined with carbon fibre's light weight, allow building a frame that's significantly lighter than that possible with any metal.

Composites ease of shaping and anisotrophy expand its uses beyond familiar round tubes. They can be molded into load-bearing monocoques (one-piece frames without distinct tubes) or lugs. The following charts provide the "pros" and "cons" of each of the materials mentioned above.

Steel		Titanium	
Pros:	**Cons:**	**Pros:**	**Cons:**
-inexpensive	-heavy	-light	-expensive
-strong	-corrosive	-strong	-designs limited by available tubes
-stiff	-designs limited by available tubes and lugs	-resilient (has lively feel)	-not easily repaired
-resilient (has lively feel)	-assembly produces weaker, heat-affected zones	-shock absorbing	
-easy to work with and repair		-noncorrosive	

Aluminum		Carbon Fibre	
Pros:	**Cons:**	**Pros:**	**Cons:**
-inexpensive	-fatigue risk requires "overbuilding"	-lightest	-expensive
-light	-lacks resilience (has dead feel)	-strongest	-technology still evolving
-adequately strong	-not easily repaired	-best shock absorption	-strength and stiffness are design dependent
-shock absorbing	-bonded joints can fail	-unlimited design applications	-bonded, lugged designs can fail
-noncorrosive		-noncorrosive	-monocoque sizes and designs are limited by molds

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